No. 1. ONE DOLLAR.

The Aeronautical Annual.

1895.

Edited by JAMES MEANS.

BOSTON, MASS.:
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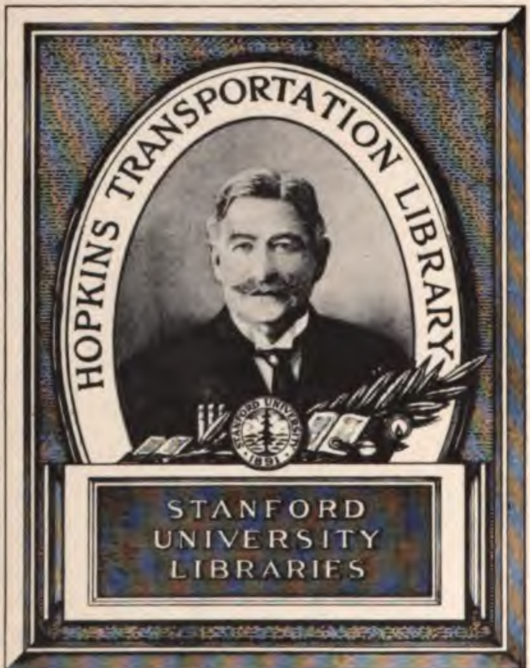
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LEONARDO DA VINCI.

1452–1519.

From a drawing in red chalk by himself. In the Royal Library, Turin.

No. 1.

The Aeronautical Annual.

1895.

DEVOTED TO THE ENCOURAGEMENT OF EXPERIMENT WITH AERIAL MACHINES, AND TO THE ADVANCEMENT OF THE SCIENCE OF AERODYNAMICS.

EDITED BY

JAMES MEANS.

This publication will be sent, postpaid, to any address on receipt of one dollar.

BOSTON, MASS.:
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340 WASHINGTON STREET.

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Rockwell and Churchill
Boston

IF this compilation should happily bring any new workers into the field of aeronautical experiment, the hopes of the editor will be amply fulfilled.

To ask questions of Mother Nature is delectable.

If her answers be often non-committal, even such are lures to lead us into better questioning.

This number of THE ANNUAL contains not much that is new, but divers things which — to use the words of an old compiler — "do now for their Excellency and Scarceness deserve to be Reprinted."

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LIST OF PLATES.

NOTE OF ACKNOWLEDGMENTS.

For the articles by Thomas Walker and F. H. Wenham the editor is indebted to the Reports of the Aeronautical Society of Great Britain, for the years 1877 and 1866 respectively. (See Bibliography, p. 136.) Mr. Wenham's paper was first reprinted in the United States in the Report of the Smithsonian Institution for the year 1890.

Plates II. to VII., inclusive, are photo-engraved from "Saggio Delle Opere di Leonardo da Vinci. Tratti dal Codice Atlantico." Milan, 1872.

The illustration on the cover is made from "Astra Castra." (See Bibliography, p. 135.) The compiler of that work states that his plate is taken from one of Picard's illustrations in "The Temple of the Muses," 1730.

Plate XIV. and the small cuts on pages 134 and 139 are also taken from "Astra Castra."

The Frontispiece is from "The Literary Works of Leonardo da Vinci," by Jean Paul Richter, Ph.D. 2 vols. London, 1883.

LEONARDO DA VINCI.

THE story which tells of the sad fate of Icarus is but one of many which may be found in the pages of antiquity showing that from time immemorial man has longed to fly. Yet, these tales are but traditions, and, search as we may, no written records of the study of the great problem of flight are to be found until we come to the manuscripts of Leonardo da Vinci, who died three hundred and seventy-five years ago.

Within the limits of these pages it is only possible to give a few fragments concerning the life and works of this great man.

He was born in 1452, at the Castle Vinci, which is situated in the vale of the Arno, midway between Pisa and Florence.

Richter says, "He was the natural son of Ser Piero Antonio da Vinci, notary to the Signory of Florence. His mother's name was Caterina. The son was brought up entirely in his father's house. Of his youthful education we are unable to judge; we only know it to have been a varied one. Vasari tells us that 'in arithmetic he made such rapid progress that he often confounded the master who was teaching him by the perpetual doubts he started, and by the difficulty of the questions he proposed. He also commenced the study of music and resolved to acquire the art of playing the lute, when, being by nature of an exalted imagination and full of the most graceful vivacity, he sang to that instrument most divinely, improvising, at the same time, both the verses and the music.'

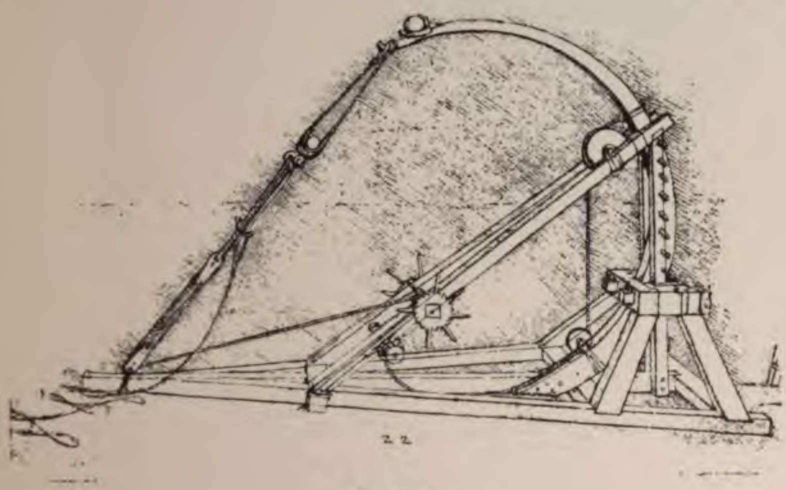
"Yet, of his early pursuits, drawing and modelling in clay had the greatest charm for him. It was this which induced his father to place him with his friend, Andrea del Verrocchio, in whose studio the boy's genius would be developed by a thorough artistic training. No more fitting teacher could at that time have been found in Florence. Verrocchio was one of her greatest geniuses."

Sidney Colvin says, "Considering the range of his speculative as well as that of his practical powers, he seems certainly the man whose genius has the best right to be called universal of any that have ever lived. In the fine arts he was the most accomplished painter of his generation and one of the most accomplished of the world, a distinguished sculptor, architect, and musician, and a luminous and pregnant critic."

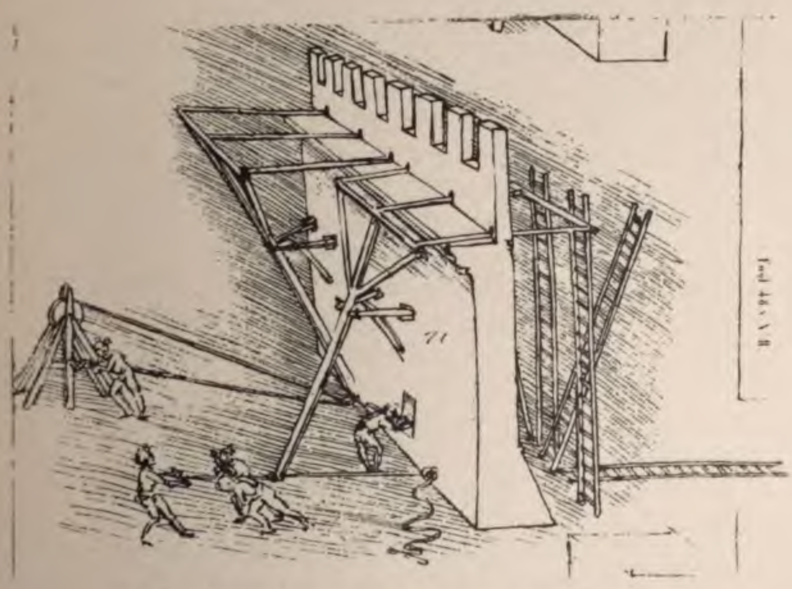
Dr. John William Draper wrote:[1] "Before the heliocentric theory could be developed and made to furnish a clear exposition of the solar system, which is obviously the first step to just views of the universe, it was necessary that the science of mechanics should be greatly improved — indeed, it might be said, created; for during those dreary ages following the establishment of Byzantine power, nothing had been done toward the acquisition of correct views either in statics or dynamics. It was impossible that Europe, in her lower states of life, could produce men capable of commencing where Archimedes had left off. She had to wait for the approach of her Age of Reason for that. The man of capacity at last came. Leonardo da Vinci was born. The historian Hallam, enumerating some of his works, observes, 'His knowledge was almost preternatural.' Many of his writings still remain unpublished. Long before Bacon he laid down the maxim that experience and observation must be the foundation of all reasoning in science; that experiment is the only interpreter of nature, and is essential to the ascertainment of laws. Unlike Bacon, who was ignorant of mathematics and even disparaged them, he points out their supreme advantage.

"Seven years after the voyage of Columbus, this great man — great at once as an artist, mathematician, and engineer — gave a clear exposition of the theory of forces obliquely applied on a lever; a few years later he was well acquainted with the earth's annual motion. He knew the laws of friction, subsequently demonstrated by Amontons, and the principle of virtual veloci-

[1] "The Intellectual Development of Europe." Vol. II. p. 268.



MANGONEL.



DEVICE FOR DISLODGING AN ASSAILANT'S SCALING-LADDERS.

REPRODUCTIONS OF MECHANICAL DRAWINGS BY LEONARDO DA VINCI.

ties; he described the camera obscura before Baptista Porta, understood aerial perspective, the nature of colored shadows, the use of the iris, and the effects of the duration of visible impressions on the eye. He wrote well on fortification, anticipated Cartelli on hydraulics, occupied himself with the fall of bodies on the hypothesis of the earth's rotation, treated of the times of descent along inclined planes and circular arcs, and of the nature of machines. He considered, with singular clearness, respiration and combustion, and foreshadowed one of the great hypotheses of geology, the elevation of continents."

To what these writers have given may be added the statement that Leonardo was a deep student of anatomy, and a designer of flying-machines.

We may read Leonardo's own description of his accomplishments in a letter of which the manuscript is still extant. His allusion to his ability in painting is likely to arrest the attention of the reader. The date of the letter is uncertain. He settled down at Milan about 1482. The letter is addressed to Ludovico Sforza, called Il Moro. Mrs. Heaton, one of the biographers of Leonardo, rightly observes that this letter could only have been written by a genius or by a fool. It reads as follows:

"Having, most illustrious lord, seen and duly considered the experiments of all those who repute themselves masters in the art of inventing instruments of war, and having found that their instruments differ in no way from such as are in common use, I will endeavor, without wishing to injure any one else, to make known to your Excellency certain secrets of my own; as briefly enumerated here below:

"1. I have a way of constructing very light bridges, most easy to carry, by which the enemy may be pursued and put to flight. Others also of a stronger kind, that resist fire or assault, and are easy to place and to remove. I know ways also for burning and destroying those of the enemy.

"2. In case of investing a place, I know how to remove the water from ditches, and to make various scaling ladders, and other such instruments.

"3. Item: If, on account of the height or strength of position, the place cannot be bombarded, I have a way for ruining every fortress which is not on stone foundations.

"4. I can also make a kind of cannon, easy and convenient to transport, that will discharge inflammable matters, causing great injury to the enemy and also great terror from the smoke.

"5. Item: By means of narrow and winding underground passages made without noise, I can contrive a way for passing under ditches or any stream.

"6. Item: I can construct covered carts, secure and indestructible, bearing artillery, which, entering among the enemy, will break the strongest body of men, and which the infantry can follow without any impediment.

"7. I can construct cannon, mortars, and fire-engines of beautiful and useful shape, and different from those in common use.

"8. When the use of cannon is impracticable, I can replace them by catapults, mangonels, and engines for discharging missiles of admirable efficacy, and hitherto unknown; in short, according as the case may be, I can contrive endless means of offence.

"9. And, if the fight should be at sea, I have numerous engines of the utmost activity, both for attack and defence; vessels that will resist the heaviest fire; also powders or vapors.

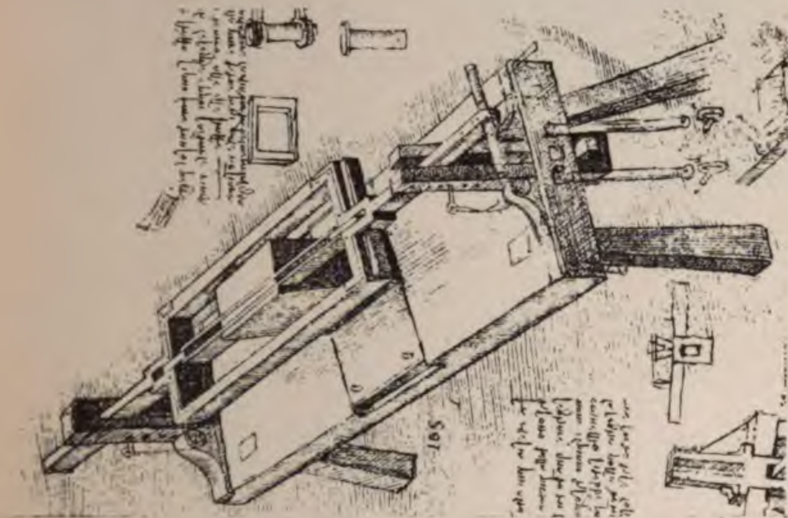
"10. In time of peace, I believe I can equal any one in architecture, and in constructing buildings, public or private, and in conducting water from one place to another.

"Then I can execute sculpture, whether in marble, bronze, or terra-cotta; also in painting I can do as much as any other, be he who he may.

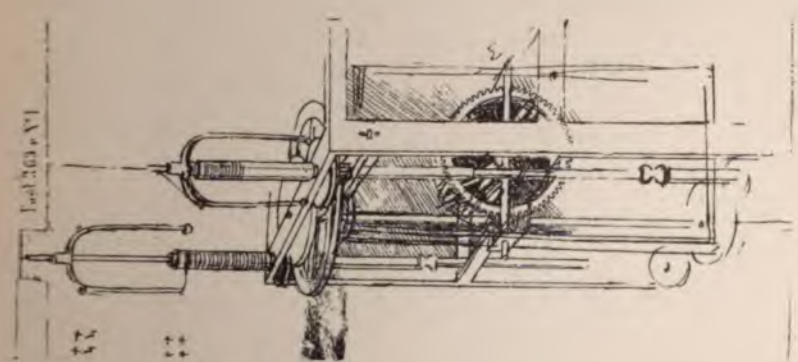
"Further, I could engage to execute the bronze horse in lasting memory of your father, and of the illustrious house of Sforza, and, if any of the above-mentioned things should appear impossible and impracticable to you, I offer to make trial of them in your park, or in any other place that may please your Excellency, to whom I commend myself in utmost humility."

Leonardo left not less than five thousand pages of manu-

Plate III.

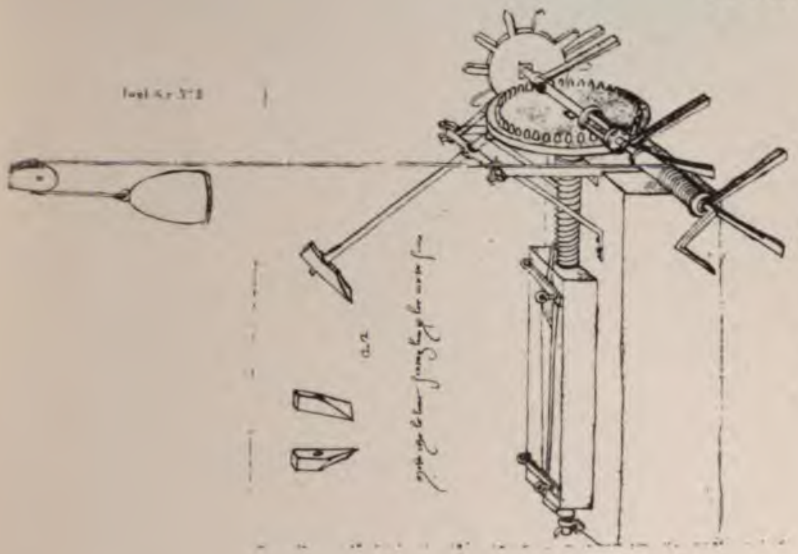


MACHINE FOR SAWING A BLOCK OF MARBLE INTO SLABS.

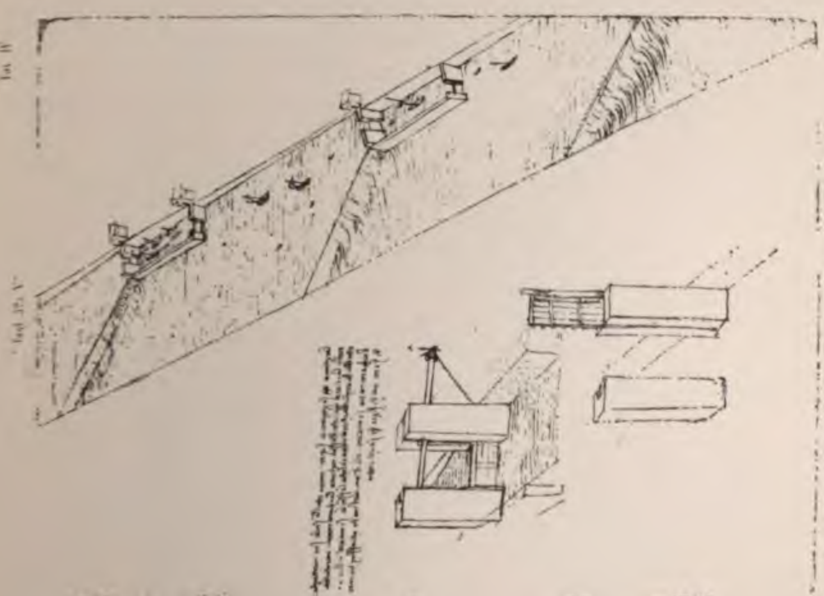


SPINNING MACHINE?

REPRODUCTIONS OF MECHANICAL DRAWINGS BY LEONARDO DA VINCI.



MACHINE FOR CUTTING FILES.



CANAL-LOCKS AND GATES FOR THE SAME.

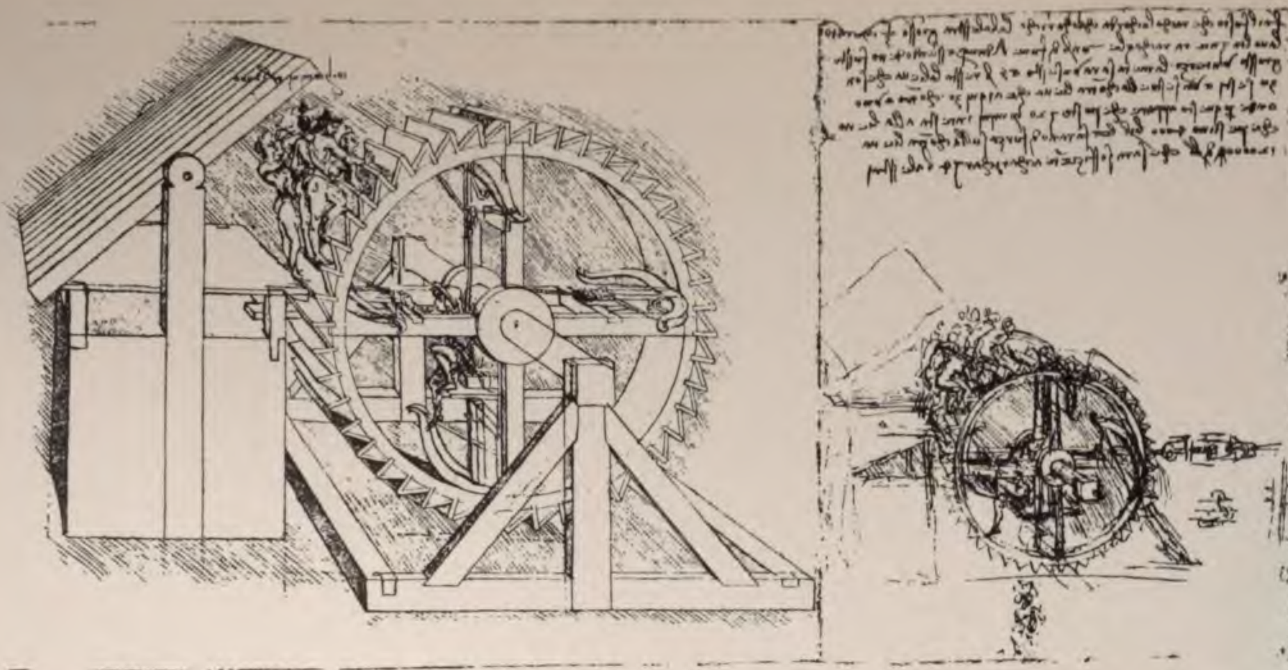
REPRODUCTIONS OF MECHANICAL DRAWINGS BY LEONARDO DA VINCI.

REPRODUCTIONS OF MECHANICAL DRAWINGS BY LEONARDO DA VINCI.

Plate V.

Tav. XI

Foel. 378 r. N°1



This may be one of the machines which Leonardo, in his letter to Sforza, refers to as "engines for discharging missiles of admirable efficacy, and hitherto unknown." Its action seems to be as follows: The men who furnish the motive power are protected from the missiles of the enemy by the sloping barrier; the four cross-bows inside are drawn by the operator, who causes the line attached to each bow-string to bind upon the immovable axle. At the right moment the bow is released, and sends the projectile through the opening under the platform. The drawing at the right seems to give an impression of the engine in the heat of action.

script, which are preserved to this day. The work of editing and publishing these is now going on. One of the most recent publications is entitled "*Codice sul volo degli uccelli.*" ("Treatise upon the Flight of Birds.")[1] Other volumes are shortly to follow. These will contain the unpublished manuscripts preserved in England, some in the British, others in the South Kensington Museum, and the remainder in the Royal Library at Windsor.

Dr. Jean Paul Richter compiled and edited from original manuscripts, "The Literary Works of Leonardo da Vinci." A two-volume edition was published in London in 1883.

The greater part of Leonardo's manuscripts are written with the left hand from right to left, so that a mirror gives the true form of the letters.

Dr. Richter says, "Leonardo's literary labors in various departments, both of art and of science, were those essentially of an enquirer; hence the analytical method is that which he employs in arguing out his investigations and dissertations. The vast structure of his scientific theories is consequently built up of numerous separate researches, and it is much to be lamented that he should never have collated and arranged them. His love for detailed research — as it seems to me — was the reason that in almost all the manuscripts the different paragraphs appear to us to be in utter confusion. On one and the same page, observations on the most dissimilar subjects follow each other without any connection. A page, for instance, will begin with some principles of astronomy, or the motion of the earth; then come the laws of sound, and finally some precepts as to color. Another page will begin with his investigations on the structure of the intestines, and end with philosophical remarks as to the relations of poetry to painting; and so forth.

"Leonardo himself lamented this confusion, and for that reason I do not think that the publication of the texts in the order in which they occur in the originals would at all fulfil his intentions. No reader could find his way through such a labyrinth; Leonardo himself could not have done it.

. . . .

[1] Edoardo Rouveyre, Editore. Paris, 1893.

"The beginning of Leonardo's literary labors dates from about his thirty-seventh year, and he seems to have carried them on without any serious interruption till his death. Thus the manuscripts that remain represent a period of about thirty years. Within this space of time his handwriting altered so little that it is impossible to judge from it of the date of any particular text. The exact dates, indeed, can only be assigned to certain note-books, in which the year is incidentally indicated, and in which the order of the leaves has not been altered since Leonardo used them.

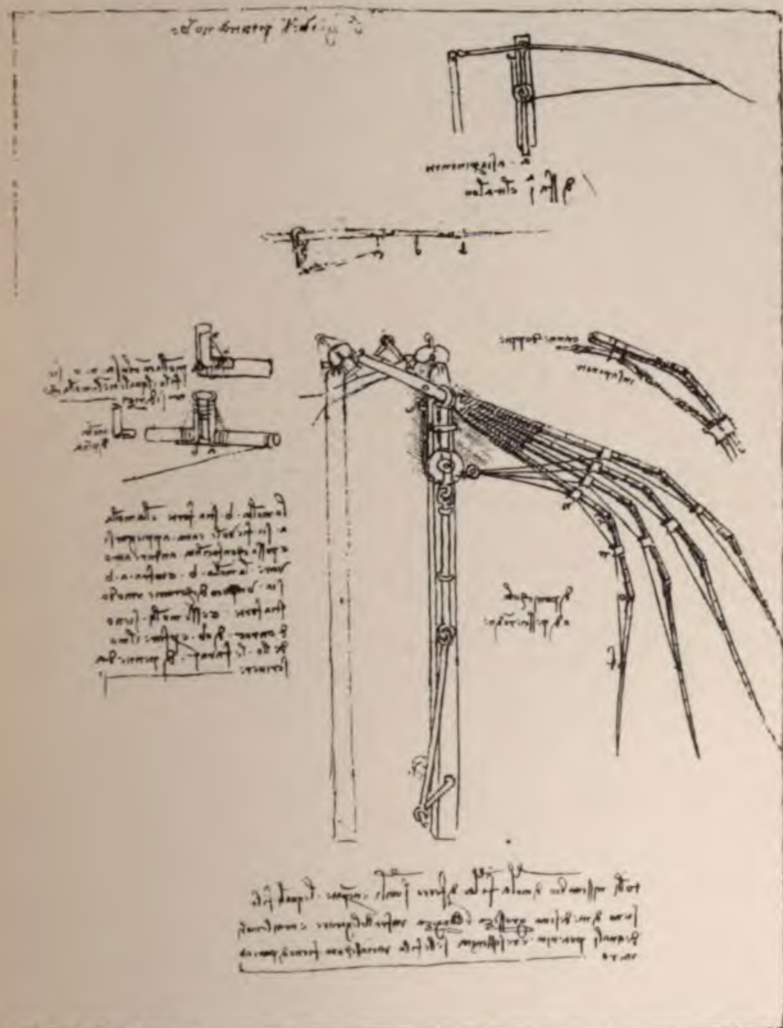
. . . .

"There can be no doubt that in more than one department his principles and discoveries were infinitely more in accord with the teachings of modern science than with the views of his contemporaries. For this reason his extraordinary gifts and merits are far more likely to be appreciated in our own time than they could have been during the preceding centuries. He has been unjustly accused of having squandered his powers, by beginning a variety of studies, and then, having hardly begun, throwing them aside. The truth is, that the labors of three centuries have hardly sufficed for the elucidation of some of the problems which occupied his mighty mind.

"Alexander von Humboldt has borne witness that 'he was the first to start on the road towards the point where all the impressions of our senses converge in the idea of the unity of nature.' Nay, yet more may be said. The very words which are inscribed on the monument of Alexander von Humboldt himself, at Berlin, are perhaps the most appropriate in which we can sum up our estimate of Leonardo's genius: '*Majestati naturae par ingenium.*'"

The master died in France in the year 1519.

Plate VI.



Fogl. 302. r. N°1.

DESIGN FOR MECHANICAL WING.

REPRODUCTIONS OF MECHANICAL DRAWINGS BY LEONARDO DA VINCI.

STUDIES OF VARIOUS PROBLEMS CONCERNING FLIGHT.

REPRODUCTION OF DRAWINGS AND MANUSCRIPT BY LEONARDO DA VINCI

FROM LEONARDO'S "TREATISE UPON THE FLIGHT OF BIRDS."

Those feathers which are farthest from their fastening will be the most flexible; then the tops of the feathers of the wings will be always higher than their origins, so that we may with reason say, that the bones of the wings will be lower in the lowering of the wings than any other part of the wings, and in the raising these bones of the wing will always be higher than any other part of such a wing. Because the heaviest part always makes itself the guide of the movement.

The kite and other birds which beat their wings little, go seeking the course of the wind, and when the wind prevails on high then they will be seen at a great height, and if it prevails low they will hold themselves low.

When the wind does not prevail in the air, then the kite beats its wings several times in its flight in such a way that it raises itself high and acquires a start, with which start, descending afterwards a little, it goes a long way without beating its wings, and when it is descended it does the same thing over again, and so it does successively, and this descent without flapping the wings serves it as a means of resting itself in the air after the aforesaid beating of the wings.

When a bird which is in equilibrium throws the centre of resistance of the wings behind the centre of gravity, then such a bird will descend with its head down.

This bird which finds itself in equilibrium shall have the centre of resistance of the wings more forward than the bird's centre of gravity, then such a bird will fall with its tail turned to the earth.

When the bird is in the position and wishes to rise it will raise its shoulders and the air will press between its sides and the point of the wings so that it will be condensed and will give the bird the movement toward the ascent and will produce a momentum in the air, which momentum of the air will by its condensation push the bird up.

Of four movements performed by birds reflected and incidental to different aspects of the wind.

The slanting descent of birds being made against the wind will be made under the wind, and its reflex movement will be made above the wind. But if such an incidental movement is made to the east, the wind blowing from the north, then the northern wing will remain under the wind; in the reflex movement will do the same, so that, at the end of this reflex the bird will find itself with its face to the north.

And if the bird descends to the south, the northern wind reigning, he will make such a descent above the wind and his reflex movement will be under the wind; but here comes in a long dispute which will be told in its place, because here it seems to happen that he cannot make the reflex movement.

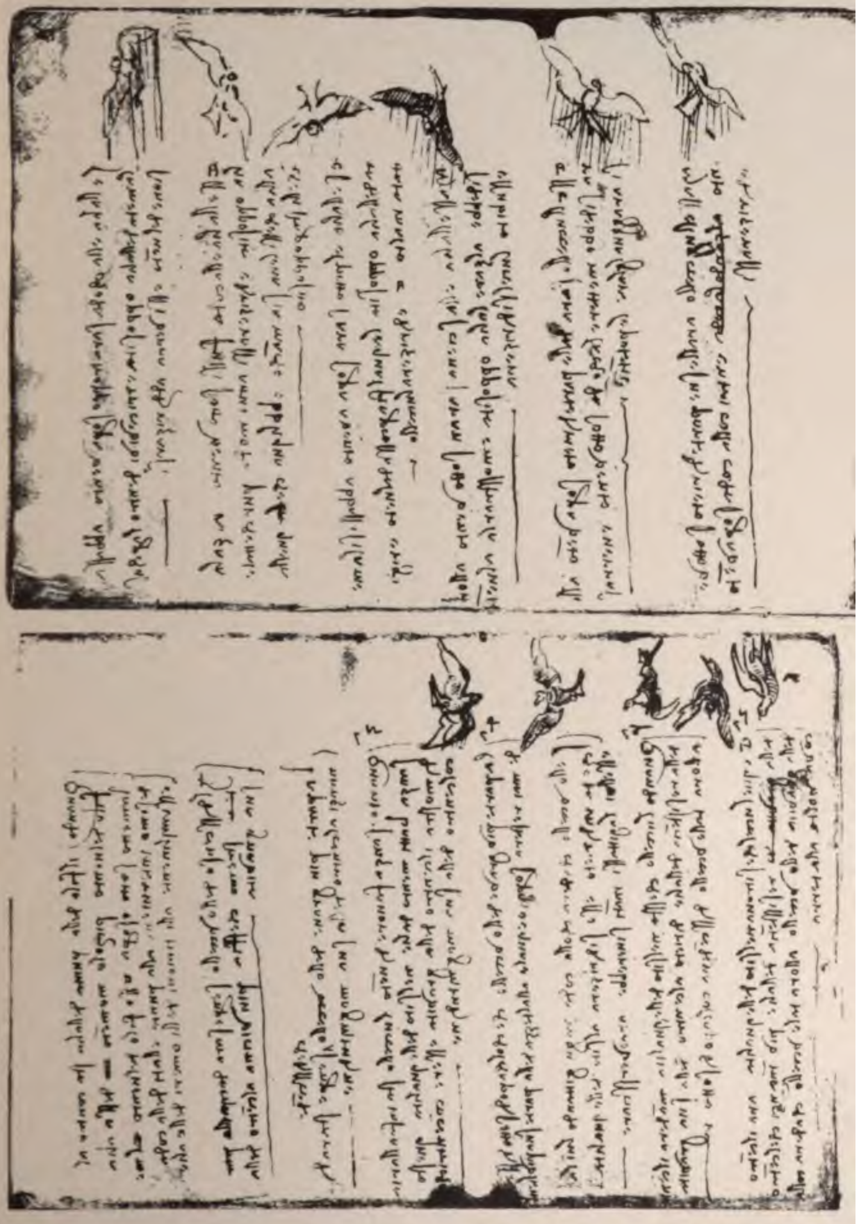
When the bird makes his reflex movement above the wind then he will mount much more than belongs to his natural momentum, seeing that he adds to that the help of the wind which, entering under him, acts as a wedge. But when he has reached the end of the ascent he will have used up his momentum, and he will have remaining only the help of the wind, which would overturn him because he strikes it with his breast, were it not that he lowers the right or left wing, which makes him turn to the right or to the left descending in a semi-circle.

The descent of the bird will always be by that extremity which shall be the nearest to its centre of gravity. The heaviest part of the bird which descends will remain always in front of the centre of its mass.

FROM LEONARDO'S TREATISE ON THE FLIGHT OF BIRDS.

Paris, 1893.

REPRODUCTION OF DRAWINGS AND MANUSCRIPT BY LEONARDO DA VINCI.



REPRODUCTION OF DRAWINGS AND MANUSCRIPT BY LEONARDO DA VINCI.

When without help of the wind the bird remains in the air without flapping its wings, this shows that the centre of its gravity is concentric with the centre of its mass.

The man in the flying-machine to be free from the waist up that he may be able to keep himself in equilibrium as he does in a boat, so that the centre of his gravity and that of the instrument may set itself in equilibrium and change when necessity requires it to the changing of the centre of its resistance.

NOTE. — This paragraph refers to the figure of the man seen in Plate VIII. Of course a supporting surface above the man is presupposed. The interval between Leonardo's writing and Lilienthal's practical work is nearly four hundred years. The former has clearly shown that he understood the supporting power of aerocurves, and in this last paragraph he indicates a knowledge of the fact that the chief difficulty which a soaring man encounters is that of keeping his centre of gravity at all times in the right place. To appreciate Leonardo one must understand Lilienthal. See Mr. Chanute's "Progress in Flying-Machines," p. 285, line 30; and p. 286, line 1. — *Ed.*

ON AERIAL NAVIGATION.

(*From Nicholson's Journal, November, 1809.*)

BY SIR GEORGE CAYLEY, BART.

BROMPTON, Sept. 6, 1809.

SIR, I observed in your Journal for last month, that a watchmaker at Vienna, of the name of Degen, has succeeded in raising himself in the air by mechanical means. I waited to receive your present number, in expectation of seeing some farther account of this experiment, before I commenced transcribing the following essay upon aerial navigation, from a number of memoranda which I have made at various times upon this subject. I am induced to request your publication of this essay, because I conceive, that, in stating the fundamental principles of this art, together with a considerable number of facts and practical observations, that have arisen in the course of much attention to this subject, I may be expediting the attainment of an object, that will in time be found of great importance to mankind; so much so, that a new æra in society will commence, from the moment that aerial navigation is familiarly realized.

It appears to me, and I am more confirmed by the success of the ingenious Mr. Degen, that nothing more is necessary, in order to bring the following principles into common practical use, than the endeavours of skilful artificers, who may vary the means of execution, till those most convenient are attained.

Since the days of Bishop Wilkins the scheme of flying by artificial wings has been much ridiculed; and indeed the idea of attaching wings to the arms of a man is ridiculous enough, as the pectoral muscles of a bird occupy more than two-thirds of its whole muscular strength, whereas in man the muscles, that could operate upon wings thus attached, would probably not exceed one-tenth of his whole mass. There is no proof that, weight for weight, a man is comparatively weaker than a bird; it is therefore probable, if he can be made to exert his whole strength advantageously upon a light surface similarly proportioned to his weight as that of the wing to the bird, that he would fly like the bird, and the ascent of Mr. Degen is a sufficient proof of the truth of this statement.

The flight of a strong man by great muscular exertion, though a curious and interesting circumstance, in as much as it will probably be the first means of ascertaining this power, and supplying the basis whereon to improve it, would be of little use. I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour.

To produce this effect, it is only necessary to have a first mover, which will generate more power in a given time, in proportion to its weight, than the animal system of muscles.

The consumption of coal in a Boulton and Watt's steam engine is only about 5½ lbs. per hour for the power of one horse. The heat produced by the combustion of this portion of inflammable matter is the sole cause of the power generated; but it is applied through the intervention of a weight of water expanded into steam, and a still greater weight of cold water to condense it again. The engine itself likewise must be massy enough to resist the whole external pressure of the atmosphere, and therefore is not applicable to the purpose proposed. Steam engines have lately been made to operate by expansion only, and those might be constructed so as to be light enough for this purpose, provided the usual plan of a large boiler be given up, and the principle of injecting a proper charge of water into a mass of tubes, forming the cavity for the fire, be adopted in lieu of it. The strength of vessels to resist internal pressure being inversely as their diameters, very slight metallic tubes would be abundantly strong, whereas a large boiler must be of great substance to resist a strong pressure. The following estimate will show the probable weight of such an engine with its charge for one hour.

	lb.
The engine itself from 90 to	100
Weight of inflamed cinders in a cavity presenting about 4 feet surface of tube	25
Supply of coal for one hour	6
Water for ditto, allowing steam of one atmosphere to be $\frac{1}{1800}$ the specific gravity of water	32
	163

I do not propose this statement in any other light than as a rude approximation to truth, for as the steam is operating under the disadvantage of atmospheric pressure, it must be raised to a higher temperature than in Messrs. Boulton and Watt's engine; and this will require more fuel; but if it take twice as much, still the engine would be sufficiently light, for it would be exerting a force equal to raising 550 lb. one foot high per second, which is equivalent to the labour of six men, whereas the whole weight does not much exceed that of one man.

It may seem superfluous to inquire farther relative to first movers for aerial navigation; but lightness is of so much value in this instance, that it is proper to notice the probability that exists of using the expansion of air by the sudden combustion of inflammable powders or fluids with great advantage. The French have lately shown the great power produced by igniting inflammable powders in close vessels; and several years ago an engine was made to work in this country in a similar manner, by the inflammation of spirit of tar. I am not acquainted with the name of the person who invented and obtained a patent for this engine, but from some minutes with which I was favoured by Mr. William Chapman, civil engineer in Newcastle, I find that 80 drops of the oil of tar raised eight hundred weight to the height of 22 inches; hence a one horse power many consume from

10 to 12 pounds per hour, and the engine itself need not exceed 50 pounds weight. I am informed by Mr. Chapman, that this engine was exhibited in a working state to Mr. Rennie, Mr. Edmund Cartwright, and several other gentlemen, capable of appreciating its powers; but that it was given up in consequence of the expense attending its consumption being about eight times greater than that of a steam engine of the same force.

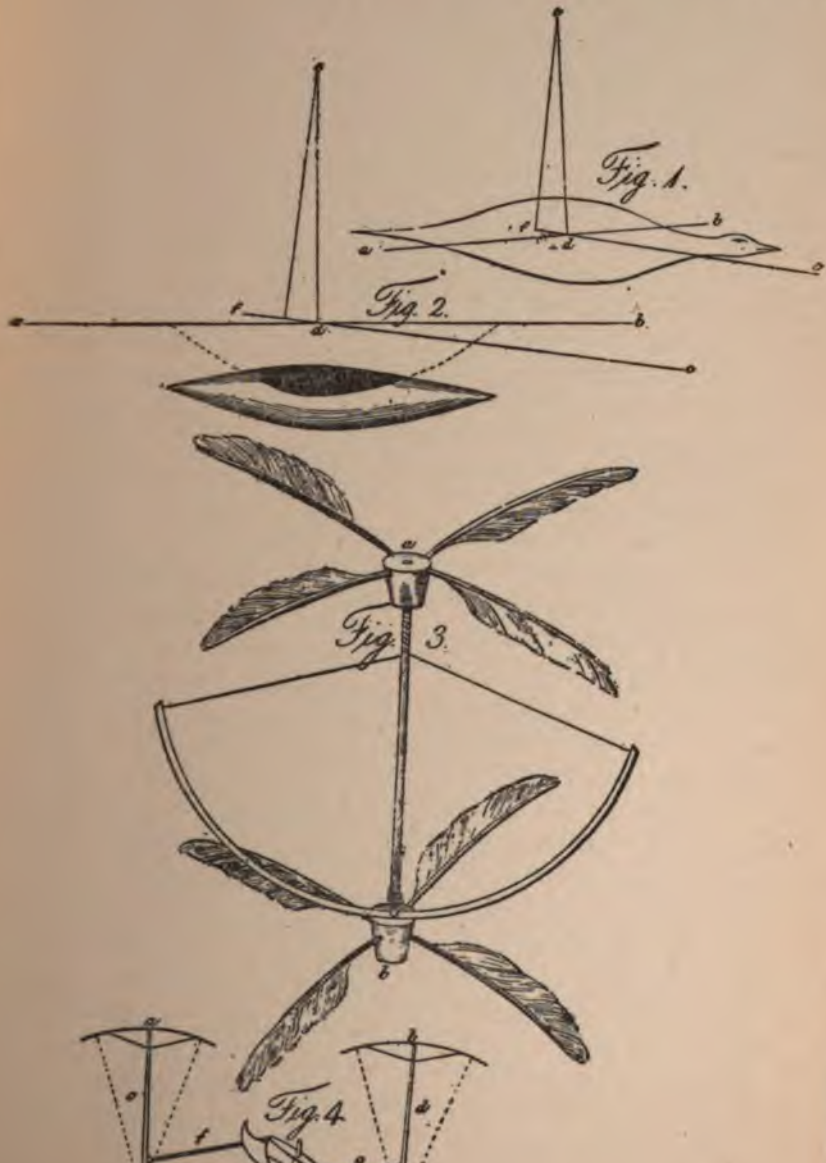
Probably a much cheaper engine of this sort might be produced by a gas-light apparatus, and by firing the inflammable air generated, with a due portion of common air, under a piston. Upon some of these principles it is perfectly clear, that force can be obtained by a much lighter apparatus than the muscles of animals or birds, and therefore in such proportion may aerial vehicles be loaded with inactive matter. Even the expansion steam engine doing the work of six men, and only weighing equal to one, will as readily raise five men into the air, as Mr. Degen can elevate himself by his own exertions; but by increasing the magnitude of the engine, 10, 50, or 500 men may equally well be conveyed; and convenience alone, regulated by the strength and size of materials, will point out the limit for the size of vessels in aerial navigation.

Having rendered the accomplishment of this object probable upon the general view of the subject, I shall proceed to point out the principles of the art itself. For the sake of perspicuity I shall, in the first instance, analyze the most simple action of the wing in birds, although it necessarily supposes many previous steps. When large birds, that have a considerable extent of wing compared with their weight, have acquired their full velocity, it may frequently be observed, that they extend their wings, and without waving them, continue to skim for some time in a horizontal path. Fig. 1, in the Plate, represents a bird in this act.

Let *a b* be a section of the plane of both wings opposing the horizontal current of the air (created by its own motion) which may be represented by the line *c d*, and is the measure of the velocity of the bird. The angle *b d c* can be increased at the will of the bird, and to preserve a perfectly horizontal path, without the wing being waved, must continually be increased in a complete ratio, (useless at present to enter into) till the motion is stopped altogether; but at one given time the position of the wings may be truly represented by the angle *b d c*. Draw *d e* perpendicular to the plane of the wings, produce the line *e d* as far as required, and from the point *e*, assumed at pleasure in the line *d e*, let fall *e f* perpendicular to *d f*. Then *d e* will represent the whole force of the air under the wing; which being resolved into the two forces *e f* and *f d*, the former represents the force that sustains the weight of the bird, the latter the retarding force by which the velocity of the motion, producing the current *c d*, will continually be diminished. *e f* is always a known quantity, being equal to the weight of the bird, and hence *f d* is also known, as it will always bear the same proportion to the weight of the bird, as the sine of the angle *b d e* bears to its cosine, the angles *d e f*, and *b d c*, being equal. In addition to the retarding force thus received is the direct resistance, which the bulk of the bird opposes to the current. This is a matter to be entered into separately from the principle now under consideration; and for the present may be wholly neglected, under the supposition of its being balanced by a force precisely equal and opposite to itself.

Before it is possible to apply this basis of the principle of flying in birds to the purposes of aerial navigation, it will be necessary to encumber it with a few practical observations. The whole problem is confined within these limits, viz. To make a surface support a given weight by the application of power to the resistance of air. Magnitude is the first question respecting the surface. Many experiments have been made upon the direct resistance of air, by Mr. Robins, Mr. Rouse, Mr. Edgeworth, Mr. Smeaton, and others. The result of Mr. Smeaton's experiments and observations was, that a surface of a square foot met with a resistance of one pound, when it travelled perpendicularly to itself through air at a velocity of 21

Nicholson's Philos Journal Vol.XXIV. Pl.6 p.174



feet per second. I have tried many experiments upon a large scale to ascertain this point. The instrument was similar to that used by Mr. Robins, but the surface used was larger, being an exact square foot, moving round upon an arm about five feet long, and turned by weights over a pulley. The time was measured by a stop watch, and the distance travelled over in each experiment was 600 feet. I shall for the present only give the result of many carefully repeated experiments, which is, that a velocity of 11.538 feet per second generated a resistance of 4 ounces; and that a velocity of 17.16 feet per second gave 8 ounces resistance. This delicate instrument would have been strained by the additional weight necessary to have tried the velocity generating a pressure of one pound per square foot; but if the resistance be taken to vary as the square of the velocity, the former will give the velocity necessary for this purpose at 23.1 feet, the latter 24.28 per second. I shall therefore take 23.6 feet as somewhat approaching the truth.

Having ascertained this point, had our tables of angular resistance been complete, the size of the surface necessary for any given weight would easily have been determined. Theory, which gives the resistance of a surface opposed to the same current in different angles, to be as the squares of the sine of the angle of incidence, is of no use in this case; as it appears from the experiments of the French Academy, that in acute angles, the resistance varies much more nearly in the direct ratio of the sines, than as the squares of the sines of the angles of incidence. The flight of birds will prove to an attentive observer, that, with a concavé wing apparently parallel to the horizontal path of the bird, the same support, and of course resistance, is obtained. And hence I am inclined to suspect, that, under extremely acute angles, with concave surfaces, the resistance is nearly similar in them all. I conceive the operation may be of a different nature from what takes place in larger angles, and may partake more of the principle of pressure exhibited in the instrument known by the name of the hydrostatic paradox, a slender filament of the current is constantly received under the anterior edge of the surface, and directed upward into the cavity, by the filament above it, in being obliged to mount along the convexity of the surface, having created a slight vacuity immediately behind the point of separation. The fluid accumulated thus within the cavity has to make its escape at the posterior edge of the surface, where it is directed considerably downward; and therefore has to overcome and displace a portion of the direct current passing with its full velocity immediately below it; hence whatever elasticity this effort requires operates upon the whole concavity of the surface, excepting a small portion of the anterior edge. This may or may not be the true theory, but it appears to me to be the most probable account of a phenomenon, which the flight of birds proves to exist.

Six degrees was the most acute angle, the resistance of which was determined by the valuable experiments of the French Academy; and it gave $\frac{4}{10}$ of the resistance, which the same surface would have received from the same current when perpendicular to itself. Hence then a superficial foot, forming an angle of six degrees with the horizon, would, if carried forward horizontally (as a bird in the act of skimming) with a velocity of 23.6 feet per second, receive a pressure of $\frac{4}{10}$ of a pound perpendicular to itself. And, if we allow the resistance to increase as the square of the velocity, at 27.3 feet per second it would receive a pressure of one pound. I have weighed and measured the surface of a great many birds, but at present shall select the common rook (*corvus frugilegus*) because its surface and weight are as nearly as possible in the ratio of a superficial foot to a pound. The flight of this bird, during any part of which they can skim at pleasure, is (from an average of many observations) about 34.5 feet per second. The concavity of the wing may account for the greater resistance here received, than the experiments upon plain surfaces would indicate. I am convinced, that the angle made use of in the crow's wing is much more acute than six degrees; but in the observations, that will be grounded upon these data, I may safely state, that every foot of such curved surface, as will be used in aerial navigation, will receive a resistance of one pound, perpendicular to itself, when carried through the air in an angle of six degrees with the line of its path, at a velocity of about 34 or 35 feet per second.

Let *a b*, fig. 2, represent such a surface or sail made of thin cloth, and containing about 200 square feet (if of a square form the side will be a little more than 14 feet); and the whole of a firm texture. Let the weight of the man and the machine be 200 pounds. Then if a current of wind blew in the direction *c d*, with a velocity of 35 feet per second, at the same time that a cord represented by *c d* would sustain a tension of 21 pounds, the machine would be suspended in the air, or at least be within a few ounces of it (falling short of such support only in the ratio of the sine of the angle of 94 degrees compared with radius; to balance which defect, suppose a little ballast to be thrown out) for the line *d e* represents a force of 200 pounds, which, as before, being resolved into *d f* and *f e*, the former will represent the resistance in the direction of the current, and the latter that which sustains the weight of the machine. It is perfectly indifferent whether the wind blow against the plane, or the plane be driven with an equal velocity against the air. Hence, if this machine were pulled along by a cord *c d*, with a tension of about 21 pounds, at a velocity of 35 feet per second, it would be suspended in a horizontal path; and if in lieu of this cord any other propelling power were generated in this direction, with a like intensity, a similar effect would be produced. If therefore the waft of surfaces advantageously moved, by any force generated within the machine, took place to the extent required, aerial navigation would be accomplished. As the acuteness of the angle between the plane and current increases, the propelling power required is less and less. The principle is similar to that of the inclined plane, in which theoretically one pound may be made to sustain all but an infinite quantity; for in this case, if the magnitude of the surface be increased ad infinitum, the angle with the current may be diminished, and consequently the propelling force, in the same ratio. In practice, the extra resistance of the car and other parts of the machine, which consume a considerable portion of power, will regulate the limits to which this principle, which is the true basis of aerial navigation, can be carried; and the perfect ease with which some birds are suspended in long horizontal flights, without one waft of their wings, encourages the idea, that a slight power only is necessary.

As there are many other considerations relative to the practical introduction of this machine, which would occupy too much space for any one number of your valuable Journal, I propose, with your approbation, to furnish these in your subsequent numbers; taking this opportunity to observe, that perfect steadiness, safety, and steerage, I have long since accomplished upon a considerable scale of magnitude; and that I am engaged in making some farther experiments upon a machine I constructed last summer, large enough for aerial navigation, but which I have not had an opportunity to try the effect of, excepting as to its proper balance and security. It was very beautiful to see this noble white *bird* sail majestically from the top of a hill to any given point of the plane below it, according to the set of its rudder, merely by its own weight, descending in an angle of about 18 degrees with the horizon. The exertions of an individual, with other avocations, are extremely inadequate to the progress, which this valuable subject requires. Every man acquainted with experiments upon a large scale well knows how leisurely fact follows theory, if ever so well founded. I do therefore hope, that what I have said, and have still to offer, will induce others to give their attention to this subject; and that England may not be backward in rivalling the continent in a more worthy contest than that of arms.

As it may be an amusement to some of your readers to see a machine rise in the air by mechanical means, I will conclude my present communication by describing an instrument of this kind, which any one can construct at the expense of ten minutes labour.

a and *b*, fig. 3, are two corks, into each of which are inserted four wing feathers from any bird, so as to be slightly inclined like the sails of a windmill, but in opposite directions in each set. A round shaft is fixed in the cork *a*, which ends in a sharp point. At the upper part of the cork *b* is fixed a whalebone bow, having a small pivot hole in its centre, to receive the point of the shaft. The bow is then to be strung equally on each side to the upper portion of the shaft, and the little machine is completed. Wind up the string by turning the flyers different ways, so that the spring of the bow may unwind them with their anterior edges ascending; then place the cork with the bow attached to it upon a table, and with a finger on the upper cork press strong enough to prevent the string from unwinding, and taking it away suddenly, the instrument will rise to the ceiling. This was the first experiment I made upon this subject in the year 1796. If in lieu of these small feathers large planes, containing together 200 square feet, were similarly placed, or in any other more convenient position, and were turned by a man, or first mover of adequate power, a similar effect would be the consequence, and for the mere purpose of ascent this is perhaps the best apparatus; but speed is the great object of this invention, and this requires a different structure.

P. S. In lieu of applying the continued action of the inclined plane by means of the rotative motion of flyers, the same principle may be made use of by the alternate motion of surfaces backward and forward; and although the scanty description hitherto published of Mr. Degen's apparatus will scarcely justify any conclusion upon the subject; yet as the principle above described must be the basis of every engine for aerial navigation by mechanical means, I conceive, that the method adopted by him has been nearly as follows. Let A and B, fig. 4, be two surfaces or parachutes, supported upon the long shafts C and D, which are fixed to the ends of the connecting beam E, by hinges. At E, let there be a convenient seat for the aeronaut, and before him a cross bar turning upon a pivot in its centre, which being connected with the shafts of the parachutes by the rods F and G, will enable him to work them alternately backward and forward, as represented by the dotted lines. If the upright shafts be elastic, or have a hinge to give way a little near their tops, the weight and resistance of the parachutes will incline them so, as to make a small angle with the direction of their motion, and hence the machine rises. A slight heeling of the parachutes toward one side, or an alteration in the position of the weight, may enable the aeronaut to steer such an apparatus tolerably well; but many better constructions may be formed, for combining the requisites of speed, convenience and steerage. It is a great point gained, when the first experiments demonstrate the practicability of an art; and Mr. Degen, by whatever means he has effected this purpose, deserves much credit for his ingenuity.

ON AERIAL NAVIGATION.

(From Nicholson's Journal, February, 1810.)

BY SIR GEORGE CAYLEY, BART.

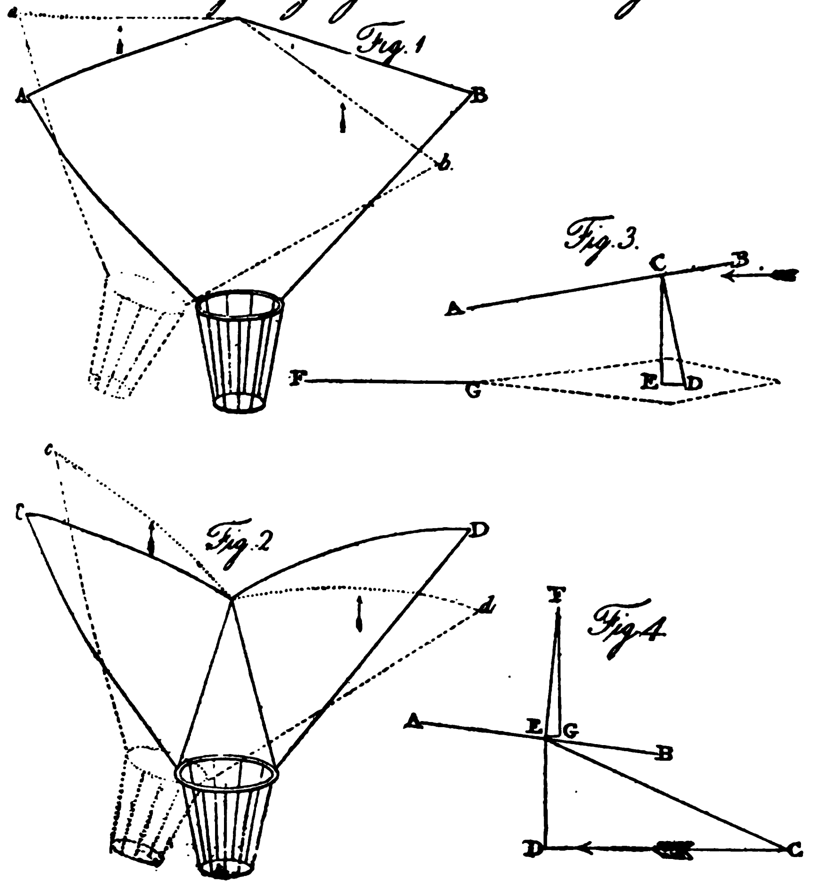
HAVING, in my former communication, described the general principle of support in aerial navigation, I shall proceed to show how this principle must be applied, so as to be steady and manageable.

Several persons have ventured to descend from balloons in what is termed a parachute, which exactly resembles a large umbrella, with a light car suspended by cords underneath it. Mr. Garnerin's descent in one of these machines will be in the recollection of many; and I make the remark for the purpose of alluding to the continued oscillation, or want of steadiness, which is said to have endangered that bold aeronaut. It is very remarkable, that the only machines of this sort, which have been constructed, are nearly of the worst possible form for producing a steady descent, the purpose for which they are intended. To render this subject more familiar, let us recollect, that in a boat, swimming upon water, its stability or stiffness depends, in general terms, upon the *weight* and distance from the centre of the section elevated above the water, by any given heel of the boat, on one side; and on the *bulk*, and its distance from the centre, which is immersed below the water, on the other side; the combined endeavour of the one to fall, and of the other to swim, produces the desired effect in a well-constructed boat. The centre of gravity of the boat being more or less below the centre of suspension is an additional cause of its stability.

Let us now examine the effect of a parachute represented by A B, Fig. 1, Pl. III. When it has heeled into the position *a b*, the side *a* is become perpendicular to the current, created by the descent, and therefore resists with its greatest power; whereas

Nicholson's Philos. Journal. Vol. XXV. pl. III. p. 81.

2 Sir G. Cayley, on Aerial Navigation.



the side *b* is become more oblique, and of course its resistance is much diminished. In the instance here represented, the angle of the parachute itself is 144°, and it is supposed to heel 18°, the comparative resistance of the side *a* to the side *b*, will be as the square of the line *a*, as radius, to the square of the sine of the angle of *b* with the current; which, being 54 degrees, gives the resistances nearly in the ratio of 1 to 0.67; and this will be reduced to only 0.544, when estimated in a direction perpendicular to the horizon. Hence, so far as this form of the sail or plane is regarded, it operates directly in opposition to the principle of stability; for the side that is required to fall resists much more in its new position, and that which is required to rise resists much less; therefore complete inversion would be the consequence, if it were not for the weight being suspended so very much below the surface, which, counteracting this tendency, converts the effort into a violent oscillation.

On the contrary, let the surface be applied in the inverted position, as represented at C D, Fig. 2, and suppose it to be heeled to the same angle as before, represented by the dotted lines *c d*. Here the exact reverse of the former instance takes place; for that side, which is required to rise, has gained resistance by its new position, and that which is required to sink has lost it; so that as much power operates to restore the equilibrium in this case, as tended to destroy it in the other: the operation very much resembling what takes place in the common boat.[1]

This angular form, with the apex downward, is the chief basis of stability in aerial navigation; but as the sheet which is to suspend the weight attached to it, in its horizontal path through the air, must present a slightly concave surface in a small angle with the current, this principle can only be used in the lateral extension of the sheet; and this most effectually prevents any rolling of the machine from side to side. Hence, the section of

[1] A very simple experiment will show the truth of this theory. Take a circular piece of writing paper, and folding up a small portion, in the line of two radii, it will be formed into an obtuse cone. Place a small weight in the apex, and letting it fall from any height, it will steadily preserve that position to the ground. Invert it, and, if the weight be fixed, like the life boat, it rights itself instantly.

the inverted parachute, Fig. 2, may equally well represent the cross section of a sheet for aerial navigation.

The principle of stability in the direction of the path of the machine, must be derived from a different source. Let A B, Fig. 3, be a longitudinal section of a sail, and let C be its centre of resistance, which experiment shows to be considerably more forward than the centre of the sail. Let C D be drawn perpendicular to A B, and let the centre of gravity of the machine be at any point in that line, as at D. Then, if it be projected in a horizontal path with velocity enough to support the weight, the machine will retain its relative position, like a bird in the act of skimming; for, drawing C E perpendicular to the horizon, and D E parallel to it, the line C E will, at some particular moment, represent the supporting power, and likewise its opponent the weight; and the line D E will represent the retarding power, and its equivalent, that portion of the projectile force expended in overcoming it: hence, these various powers being exactly balanced, there is no tendency in the machine but to proceed in its path, with its remaining portion of projectile force.

The stability in this position, arising from the centre of gravity being below the point of suspension, is aided by a remarkable circumstance, that experiment alone could point out. In very acute angles with the current it appears, that the centre of resistance in the sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases, these centres approach, and coincide when the current becomes perpendicular to the sail. Hence any heel of the machine backward or forward removes the centre of support behind or before the point of suspension; and operates to restore the original position, by a power, equal to the whole weight of the machine, acting upon a lever equal in length to the distance the centre has removed.

To render the machine perfectly steady, and likewise to enable it to ascend and descend in its path, it becomes necessary to add a rudder in a similar position to the tail in birds. Let F G be the section of such a surface, parallel to the current; and let it be capable of moving up and down upon G, as a centre, and of being fixed in any position. The powers of the machine being previously balanced, if the least pressure be exerted by the current, either upon the upper or under surface of the rudder, according to the will of the aeronaut, it will cause the machine to rise or fall in its path, so long as the projectile or propelling force is continued with sufficient energy. From a variety of experiments upon this subject I find, that, when the machine is going forward with a superabundant velocity, or that which would induce it to rise in its path, a very steady horizontal course is effected by a considerable depression of the rudder, which has the advantage of making use of this portion of sail in aiding the support of the weight. When the velocity is becoming less, as in the act of alighting, then the rudder must gradually recede from this position, and even become elevated, for the purpose of preventing the machine from sinking too much in front, owing to the combined effect of the want of projectile force sufficient to sustain the centre of gravity in its usual position, and of the centre of support approaching the centre of the sail.

The elevation and depression of the machine are not the only purposes, for which the rudder is designed. This appendage must be furnished with a vertical sail, and be capable of turning from side to side, in addition to its other movements, which effects the complete steerage of the vessel.

All these principles, upon which the support, steadiness, elevation, depression, and steerage, of vessels for aerial navigation, depend, have been abundantly verified by experiments both upon a small and a large scale. Last year I made a machine, having a surface of 300 square feet, which was accidentally broken before there was an opportunity of trying the effect of the propelling apparatus; but its steerage and steadiness were perfectly proved, and it would sail obliquely downward in any direction, according to the set of the rudder. Even in this state, when any person ran forward in it, with his full speed, taking advantage of a gentle breeze in front, it would bear upward so strongly as scarcely to allow him to touch the ground; and would frequently lift him up, and convey him several yards together.

The best mode of producing the propelling power is the only thing, that remains yet untried toward the completion of the invention. I am preparing to resume my experiments upon this subject, and state the following observations, in the hope that others may be induced to give their attention towards expediting the attainment of this art.

The act of flying is continually exhibited to our view; and the principles upon which it is effected are the same as those before stated. If an attentive observer examines the waft of a wing, he will perceive, that about one third part, toward the extreme point, is turned obliquely backward; this being the only portion, that has velocity enough to overtake the current, passing so rapidly beneath it, when in this unfavourable position. Hence this is the only portion that gives any propelling force.

To make this more intelligible, let A B, Fig. 4, be a section of this part of the wing. Let C D represent the velocity of the bird's path, or the current, and E D that of the wing in its waft: then C E will represent the magnitude and direction of the compound or actual current striking the under surface of the wing. Suppose E F, perpendicular to A B, to represent the whole pressure; E G being parallel to the horizon, will represent the propelling force; and G F, perpendicular to it, the supporting power. A bird is supported as effectually during the return as during the beat of its wing; this is chiefly effected by receiving the resistance of the current under that portion of the wing next the body where its receding motion is so slow as to be of scarcely any effect. The extreme portion of the wing, owing to its velocity, receives a pressure downward and obliquely forward, which forms a part of the propelling force; and at the same time, by forcing the hinder part of the middle portion of the wing downward, so increases its angle with the current, as to enable it still to receive nearly its usual pressure from beneath.

As the common rook has its surface and weight in the ratio of a square foot to a pound, it may be considered as a standard for calculations of this sort; and I shall therefore state, from the average of many careful observations, the movements of that bird. Its velocity, represented by C D, Fig. 4, is 34.5 feet per second. It moves its wing up and down once in flying over a space of 12.9 feet. Hence, as the centre of resistance of the extreme portion of the wing moves over a space of 0.75 of a foot each beat or return, its velocity is about 4 feet per second, represented by the line E D. As the wing certainly overtakes the current, it must be inclined from it in an angle something less than 7°, for at this angle it would scarcely be able to keep parallel with it, unless the waft downward were performed with more velocity than the return; which may be and probably is the case, though these movements appear to be of equal duration. The propelling power, represented by E G, under these circumstances, cannot be equal to an eighth part of the supporting power G F, exerted upon this portion of the wing; yet this, together with the aid from the return of the wing, has to overcome all the retarding power of the surface, and the direct resistance occasioned by the bulk of the body.

It has been before suggested, and I believe upon good grounds, that very acute angles vary little in the degree of resistance they make under a similar velocity of current. Hence it is probable, that this propelling part of the wing receives little more than its common proportion of resistance, during the waft downward. If it be taken at one-third of the whole surface, and one-eighth of this be allowed as the propelling power, it will only amount to one twenty-fourth of the weight of the bird; and even this is exerted only half the duration of the flight. The power gained in the return of the wing must be added, to render this statement correct, and it is difficult to estimate this; yet the following statement proves, that a greater degree of propelling force is obtained, upon the whole, than the foregoing observations will justify. Suppose the largest circle that can be described in the breast of a crow, to be 12 inches in area. Such a surface, moving at the velocity of 34.5 feet per second, would meet a resistance of 0.216 of a pound, which, reduced by the proportion of the

ON AERIAL NAVIGATION.

(*From Nicholson's Journal, March, 1810.*)

BY SIR GEORGE CAYLEY, BART.

BROMPTON, Dec. 6, 1809.

NOT having sufficient data to ascertain the exact degree of propelling power exerted by birds in the act of flying, it is uncertain what degree of energy may be required in this respect in vessels for aerial navigation: yet, when we consider the many hundred miles of continued flight exerted by birds of passage, the idea of its being only a small effort is greatly corroborated. To apply the power of the first mover to the greatest advantage in producing this effect, is a very material point. The mode universally adopted by nature is the oblique waft of the wing. We have only to choose between the direct beat overtaking the velocity of the current, like the oar of a boat; or one, applied like the wing, in some assigned degree of obliquity to it. Suppose 35 feet per second to be the velocity of an aerial vehicle, the oar must be moved with this speed previous to its being able to receive any resistance; then, if it be only required to obtain a pressure of $\frac{1}{10}$-th of a pound upon each square foot, it must exceed the velocity of the current 7.5 feet per second. Hence its whole velocity must be 42.5 feet per second. Should the same surface be wafted downward, like a wing, with the hinder edge inclined upward in an angle of about $50^{\circ}\ 40'$ to the current, it will overtake it at a velocity of 3.5 feet per second; and as a slight unknown angle of resistance generates a pound pressure per square foot at this velocity, probably a waft of little more than 4 feet per second would produce this effect; one tenth part of which would be the propelling power. The advantage in favour of this mode of application, compared with the former, is rather more than ten to one.

In combining the general principles of aerial navigation for the practice of the art many mechanical difficulties present themselves, which require a considerable course of skilfully applied experiments, before they can be overcome. But to a certain extent the air has already been made navigable; and no one, who has seen the steadiness with which weights to the amount of ten stone (including four stone, the weight of the machine) hover in the air, can doubt of the ultimate accomplishment of this object.

The first impediment I shall take notice of is the great proportion of power, that must be exerted previous to the machine's acquiring that velocity, which gives support upon the principle of the inclined plane; together with the total want of all support during the return of any surface used like a wing. Many birds, and particularly water fowl, run and flap their wings for several yards before they can gain support from the air. The swift (*hirundo apus Lin.*) is not able to elevate itself from level ground. The inconvenience under consideration arises from very different causes in these two instances. The supporting surface of most swimming birds does not exceed the ratio of $\frac{4}{10}$-ths of a square foot to every pound of their weight: the swift, though it scarcely weighs an ounce, measures eighteen inches in extent of wing. The want of surface in the one case, and the inconvenient length of wing in the other, oblige these birds to aid the *commencement* of their flight by other expedients; yet they can both fly with great power, when they have acquired their full velocity.

A second difficulty in aerial navigation arises from the great extent of lever, which is constantly operating against the first mover, in consequence of the distance of the centre of support in large surfaces, if applied in the manner of wings.

A third and general obstacle is the mechanical skill required to unite great extension of surface with strength and lightness of structure; at the same time having a firm and steady movement in its working parts, without exposing unnecessary obstacles to the resistance of the air. The first of these obstacles, that have been enumerated, operates much more powerfully against aerial navigation upon a large scale, than against birds;

because the small extent of their wings obliges them to employ a very rapid succession of strokes, in order to acquire that velocity which will give support; and during the small interval of the return of the wing, their weight is still rising, as in a leap, by the impulse of one stroke, till it is again aided by another. The large surfaces that aerial navigation will probably require, though necessarily moved with the same velocity, will have a proportionably longer duration both of the beat and return of the wing; and hence a greater descent will take place during the latter action, than can be overcome by the former.

There appears to be several ways of obviating this difficulty. There may be two surfaces, each capable of sustaining the weight, and placed one above the other, having such a construction as to work up and down in opposition when they are moved, so that one is always ready to descend, the moment the other ceases. These surfaces may be so made, by a valvelike structure, as to give no opposition in rising up, and only to resist in descent.

The action may be considered either oblique, as in rotative flyers; alternately so, without any up and down waft, as in the engine I have ascribed to Mr. Degen; by means of a number of small wings in lieu of large ones, upon the principle of the flight of birds, with small intervals of time between each waft; and lastly by making use of light wheels to preserve the propelling power both of the beat and the return of the wings, till it accumulates sufficiently to elevate the machine, upon the principle of those birds which run themselves up. This action might be aided by making choice of a descending ground like the swift.

With regard to another part of the first obstacle I have mentioned, viz. the absolute quantity of power demanded being so much greater at first than when the full velocity has been acquired; it may be observed, that, in the case of human muscular strength being made use of, a man can exert, for a few seconds, a surprising degree of force. He can run up stairs, for instance, with a velocity of from 6 to 8 feet perpendicular height per second, without any dangerous effort; here the muscles of his legs only are in action; but, for the sake of making a moderate statement, suppose that with the activity of his arms and body, in addition to that of his legs, he is equal to raising his weight 8 feet per second; if in this case he weighs 11 stone, or 154 pounds, he will be exerting, for the time, an energy equal to more than the ordinary force of two of Messrs. Boulton and Watt's steam horses; and certainly more than twelve men can bestow upon their constant labour.

If expansive first movers be made use of, they may be so constructed, as to be capable of doing more than their constant work; or their power may be made to accumulate for a few moments by the formation of a vacuum, or the condensation of air, so that these expedients may restore at one time, in addition to the working of the engine, that which they had previously absorbed from it.

With regard to the second obstacle in the way of aerial navigation, viz. the length of leverage to which large wing-like surfaces are exposed, it may be observed, that, being a constant and invariable quality, arising from the degree of support such surfaces give, estimated at their centres of resistance, it may be balanced by any elastic agent, that is so placed as to oppose it. Let A and B, Pl. IV, fig. 1, be two wings of an aerial vehicle in the act of skimming; then half the weight of the vessel is supported from the centre of resistance of each wing; as represented by the arrows under them. If the shorter ends of these levers be connected by cords to the string of a bow C, of sufficient power to balance the weight of the machine at the points A and B, then the moving power will be left at full liberty to produce the waft necessary to bend up the hinder edge of the wing, and gain the propelling power. A bow is not in fact an equable spring, but may be made so by using a spiral fusee. I have made use of it in this place merely as the most simple mode of stating the principle I wished to exhibit. Should a counterbalancing spring of this kind be adopted in the practice of aerial navigation, a small well polished cylinder, furnished with what may be termed a bag piston (upon the principle made use of by nature in preventing the return of the blood to the heart, when it has been driven into the aorta, by the intervention of the semilunar valves) would, by a vacuum being excited each stroke of the wing, produce the desired effect, with scarcely any loss by friction.[1] These elastic agents may likewise be useful in gradually stopping the momentum of large surfaces when used in any alternate motion, and in thus restoring it during their return.

Another principle, that may be applied to obviate this leverage of a wing, is that of using such a construction as will make the supporting power of the air counterbalance itself. It has been before observed, that only about one third of the wing in birds is applied in producing the propelling power; the remainder, not having velocity sufficient for this purpose, is employed in giving support, both in the beat and return of the wing.

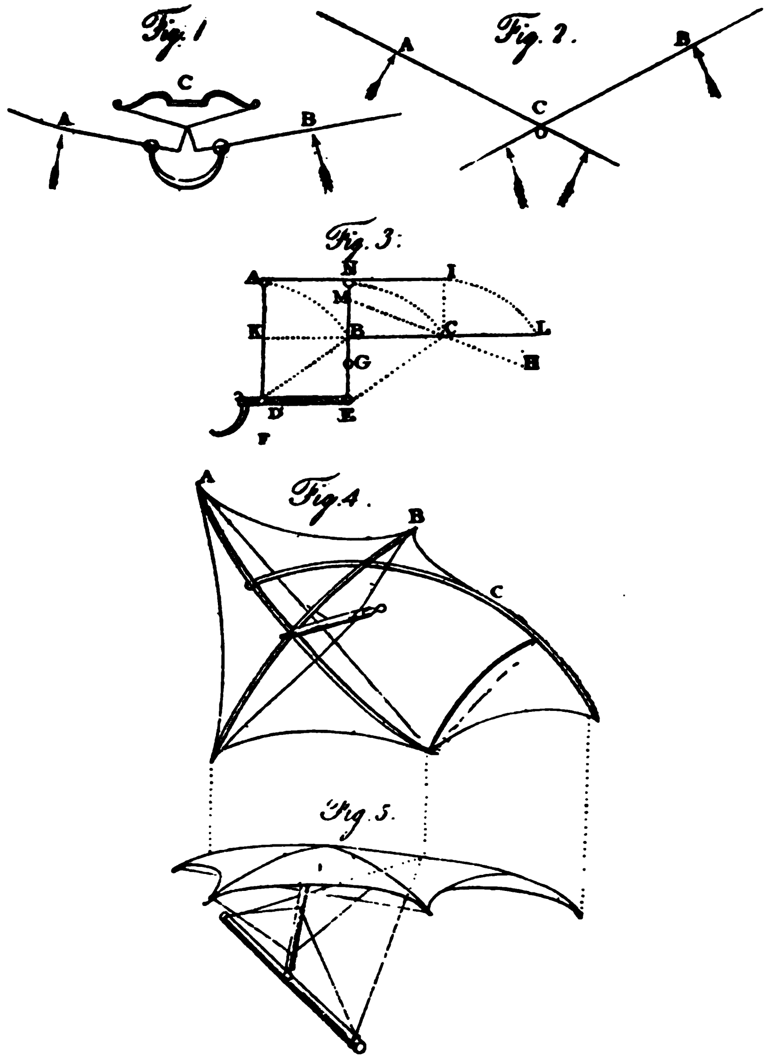
Let A and B, fig. 2, be two wings continued beyond the pole or hinge upon which they turn at C. If the extreme parts at A and B be long and narrow, they may be balanced, when in the act of skimming, by a broad extension of less length on their opposite sides; this broad extension, like the lower part of the wing, will always give nearly the same support, and the propelling part of the surface will be at liberty to act unincumbered by the leverage of its supporting power. This plan may be modified many different ways; but my intention, as in the former case, is still the principle in its simplest form.

A third principle upon which the leverage of a surface may be prevented is by giving it a motion parallel to itself, either directly up and down, or obliquely so. The surface A I, fig. 3, may be moved perpendicularly, by the shaft which supports it,

[1] I have made use of several of these pistons, and have no scruple in asserting, that for all blowing engines, where friction is an evil, and being very nearly airtight is sufficient, there is no other piston at all comparable with them. The most irregular cylinder, with a piston of this kind, will act with surprising effect. To give an instance; a cylinder of sheet tin, 8 inches long and 3½ in diameter, required 4 pounds to force the piston down in 15 minutes; and in other trials became perfectly tight in some positions, and would proceed no farther. The friction, when the cylinder was open at both ends, did not exceed ½ an ounce.

Nicholson's Philos Journal. Vol. XXV pl. IV

Sir G. Cayley on Aerial Navigation.



down to the position K C: or, if it be supported upon two shafts with hinges at D and E, it may be moved obliquely parallel to itself into the position B L.

A fourth principle upon which the leverage may be greatly avoided, where only one hinge is used, is by placing it considerably below the plane of the wing, as at the point D, fig. 3, in respect to the surface A. It may be observed in the heron, which is a weak bird with an extended surface, that its wings curve downward considerably from the hinge to the tip; hence the extreme portion, which receives the chief part of the stroke, is applied obliquely to the current it creates; and thus evades in a similar degree the leverage of that portion of the supporting power, which is connected with the propelling power. These birds seldom carry their waft much below the level of the hinge of the wing, where this principle, so far as respects the supporting power, would vanish.

By making use of two shafts of unequal length, the two last mentioned principles may be blended to any required extent. Suppose one hinge to be at F, and the other at G, fig. 3, then the surface, at the extent of its beat, would be in the position of the line H M. If the surface A I, fig. 3, be supported only upon one shaft, N E, be capable of being forced in some degree from its rectangular position in respect to the shaft, and be concave instead of flat as here represented; then the waft may be used alternately backward and forward, according to the principles of the machine I have ascribed to Mr. Degen. This construction combines the principles of counterpoising the supporting power of one part of the surface, by that of an opposite part, when the machine is in the act of skimming; and likewise the advantages of the low hinge, with the principle of leaving little or no interval without support.

All that has hitherto appeared respecting Mr. Degen's apparatus is, that it consisted of two surfaces, which were worked by a person sitting between them. This statement communicates no real information upon the subject; for scarcely any one would attempt to fly without *two* wings; without these being equally poised by placing the weight *between* them; and also, without these surfaces being capable of receiving motion from his muscular action. I may be altogether mistaken in my conjecture; my only reason for ascribing this structure of mine to Mr. Degen's machine is, that, if it were properly executed upon this principle, it would be attended with success. The drawing, or rather diagram, which is given of this machine in the first part of my essay, is only for the purpose of exhibiting the principle in a form capable of being understood. The necessary bracings, etc., required in the actual execution of such a plan, would have obscured the simple nature of its action; and were therefore omitted. The plan of its movement is also simply to exhibit, in a tangible form, the possibility of effecting the intended alternate motion of the parachutes. The seat is fronted lengthwise for the purpose of accommodating the mode of communicating the movement.

A fifth mode of avoiding leverage is by using the continued action of oblique horizontal flyers, or an alternate action of the same kind, with surfaces so constructed as to accommodate their position to such alternate motion; the hinge or joint being in these cases vertical. In the construction of large vessels for aerial navigation, a considerable portion of fixed sail will probably be used; and no more surface will be allotted, towards gaining the propelling power, than what is barely necessary, with the extreme temporary exertion of the first mover, to elevate the machine and commence the flight. In this case the leverage of the fixed surface is done away.

The general difficulties of structure in aerial vehicles, (arising from the extension, lightness, and strength required in them; together with great firmness in the working parts, and at the same time such an arrangement as exposes no unnecessary obstacles to the current,) I cannot better explain than by describing a wing, which has been constructed with a view to overcome them.

Fig. 4 represents the shape of the cloth, with a perspective view of the poles upon which it is stretched with perfect tightness. Upon the point where the rods A and B intersect is erected an oval shaft; embracing the two cross poles by a slender iron fork; for the purpose of preserving their strength uninjured by boring. To this shaft are braced the ends of the pole B, so as to give this pole any required degree of curvature. The pole A is strung like a common bow to the same curve as the pole B; and is only connected with the upright shaft by what may be called a check brace; which will allow the hinder end of this pole to heel back to a certain extent, but not the fore end. The short brace producing this effect is shown in fig. 4. Fig. 5 exhibits the fellow wing to that represented in fig. 4, erected upon a beam, to which it is so braced, as to convert the whole length of it into a hinge. The four braces coming from the ends of this beam are shown: two of them terminate near the top of the centre of the other shaft; the others are inserted into the point C, fig. 4, of the bending rod. A slight bow, not more than three-eighths of an inch thick, properly curved by its string, and inserted between the hinder end of the pole A, and the curved pole C, completes the wing.

This fabrick contained 54 square feet, and weighed only eleven pounds. Although both these wings together did not compose more than half the surface necessary for the support of a man in the air, yet during their waft they lifted the weight of nine stone. The hinder edge, as is evident from the construction, being capable of giving way to the resistance of the air, any degree of obliquity, for the purpose of a propelling power, may be used.

I am the more particular in describing this wing, because it exemplifies almost all the principles that can be resorted to in the construction of surfaces for aerial navigation. Diagonal bracing is the great principle for producing strength without accumulating weight; and, if performed by thin wires, looped at their ends, so as to receive several laps of cordage, produces but a trifling resistance in the air, and keeps tight in all weathers. When bracings are well applied, they make the poles, to which are attached, bear endwise. The hollow form of the quill in birds is a very admirable structure for lightness combined with strength, where external bracings cannot be had; a tube being the best application of matter to resist as a lever; but the principle of bracing is so effectual, that, if properly applied, it will abundantly make up for the clumsiness of human invention in other respects; and should we combine both these principles, and give diagonal bracing to the tubular bamboo cane, surfaces might be constructed with a greater degree of strength and lightness, than any made use of in the wings of birds.

The surface of a heron's wing is in the ratio of 7 square feet to a pound. Hence, according to this proportion, a wing of 54 square feet would weigh about $7\frac{3}{4}$ pounds: on the contrary the wings of water fowl are so much heavier, that a surface of 54 square feet, according to their structure, will weigh $18\frac{1}{2}$ lb. I have in these instances quoted nearly the extreme cases among British birds; the wing I have described may therefore be considered as nearly of the same weight in proportion to its bulk as that of most birds.

Another principle exhibited in this wing is that of the poles being couched within the cloth, so as to avoid resistance. This is accomplished by the convexity of the frame, and the excessive lightness of the cloth. The poles are not allowed to form the edge of the wing, excepting at the extreme point of the bow, where it is very thin, and also oblique to the current. The thick part of this pole is purposely conveyed considerably within the edge. In birds, a membrane covered with feathers is stretched before the thick part of the bone of the wing, in a similar manner, and for the same purpose. The edge of the surface is thus reduced to the thickness of a small cord, that is sown to the cloth, and gives out loops whenever any fastening is required. The upright shaft is the only part that opposes much direct resistance to the current, and this is obviated in a great degree by a flat oval shape, having its longest axis parallel to the current.

The joint or hinge of this wing acts with great firmness, in consequence of its being supported by bracings to the line of its axis, and at a considerable distance from each other; in fact the bracings form the hinge.

The means of communicating motion to any surfaces must vary so much, according to the general structure of the whole machine, that I shall only observe at present, that where human muscular action is employed, the movement should be similar to the mode of pulling oars; from which any other required motion may be derived; the foot-board in front enables a man to exert his full force in this position. The wings I have described were wafted in this manner; and when they lifted with a power of 9 stone, not half of the blow, which a man's strength could have given, was exerted, in consequence of the velocity required being greater than convenient under the circumstances. Had these wings been intended for elevating the person who worked them, they should have contained from 100 to 150 square feet each; but they were constructed for the purpose of an experiment relative to the propelling power only.

Avoiding direct resistance is the next general principle, that it is necessary to discuss. Let it be remembered as a maxim in the art of aerial navigation, that every pound of direct resistance, that is done away, will support 30 pounds of additional weight without any additional power. The figure of a man seems but ill calculated to pass with ease through the air, yet I hope to prove him to the full as well made in this respect as the crow, which has hitherto been our standard of comparison, paradoxical as it may appear.

The principle, that surfaces of similar bodies increase only as the squares of their homologous lines, while their weights, or rather solid contents, increase as the cubes of those lines, furnishes the solution. This principle is unanimously in favour of large bodies. The largest circle that can be described in a crow's breast is about 12 square inches in area. If a man exposes a direct bulk of 6 square feet, the ratio of their surfaces will be as 1 to 72; but the ratio of their weight is as 1 to 110; which is 1½ to 1 in favour of the man, provided he were within a case as well constructed for evading resistance, as the body of the crow; but even supposing him to be exposed in his natural cylindric shape, in the foreshortened posture of sitting to work his oars, he will probably receive less resistance than the crow.

It is of great importance to this art, to ascertain the real solid of least resistance, when the length or breadth is limited. Sir

Isaac Newton's beautiful theorem upon this subject is of no practical use, as it supposes each particle of the fluid, after having struck the solid, to have free egress; making the angles of incidence and reflection equal; particles of light seem to possess this power, and the theory will be true in that case; but in air the action is more like an accumulation of particles, rushing up against each other, in consequence of those in contact with the body being retarded. The importance of this subject is not less than the difficulties it presents; it affects the present interests of society in its relation to the time occupied in the voyages of ships; it will have still more effect when aerial navigation, now in its cradle, is brought home to the uses of man. I shall state a few crude hints upon this point, to which my subject has so unavoidably led, and on which I am so much interested, and shall be glad if in so doing I may excite the attention of those, who are competent to an undertaking greatly beyond my grasp.

Perhaps some approach toward ascertaining the actual solid of least resistance may be derived from treating the subject in a manner something similar to the following. Admit that such a solid is already attained (the length and width being necessarily taken at pleasure). Conceive the current intercepted or disturbed, by the largest circle that can be drawn within the given spindle, to be divided into concentric tubular laminæ of equal thickness. At whatever distance from this great circle the apex of the spindle commences, on all sides of this point the central lamina will be reflected in diverging pencils, (or rather an expanding ring,) making their angles of incidence and reflection equal. After this reflection they rush against the second lamina and displace it: this second lamina contains three times more fluid than the first; consequently each pencil in the first meets three pencils in the second; and their direction, after the union, will be one fourth of the angle, with respect to the axis, which the first reflection created. In this direction these two laminæ proceed till they are themselves reflected, when they (considered as one lamina of larger dimensions) rush against the third and fourth, which together contain three times the fluid in the two former laminæ, and thus reduce the direction of the combined mass to one fourth of the angle between the axis and the line of the second reflection. This process is constant, whatever be the angles formed between the surface of the actual solid of least resistance at these points of reflection, and the directions of the currents thus reflected.

From this mode of reasoning, which must in some degree resemble what takes place, and which I only propose as a resemblance, it appears, that the fluid keeps creeping along the curved surface of such a solid, meeting it in very acute angles. Hence, as the experiments of the French Academy show, that the difference of resistance between the direct impulse, and that in an angle of six degrees, on the same surface, is only in the ratio of 10 to 4, it is probable, that in the slight difference of angles that occur in this instance, the resistances may be taken as equal upon every part, without any material deviation from truth. If this reasoning be correct, it will reduce the question, so far as utility is concerned, within a strictly abstract mathematical inquiry.

It has been found by experiment, that the shape of the hinder part of the spindle is of as much importance as that of the front, in diminishing resistance. This arises from the partial vacuity created behind the obstructing body. If there be no solid to fill up this space, a deficiency of hydrostatic pressure exists within it, and is transferred to the spindle. This is seen distinctly near the rudder of a ship in full sail, where the water is much below the level of the surrounding sea. The cause here, being more evident, and uniform in its nature, may probably be obviated with better success; in as much as this portion of the spindle may not differ essentially from the simple cone. I fear however, that the whole of this subject is of so dark a nature, as to be more usefully investigated by experiment, than by reasoning; and in the absence of any conclusive evidence from either, the only way that presents itself is to copy nature; accordingly I shall instance the spindles of the trout and woodcock, which, lest the engravings should, in addition to the others, occupy too much valuable space in your Journal, must be reserved to a future opportunity.

A TREATISE

UPON THE

ART OF FLYING,

BY MECHANICAL MEANS,

WITH A

FULL EXPLANATION OF THE NATURAL PRINCIPLES BY WHICH BIRDS ARE ENABLED TO FLY;

LIKEWISE

INSTRUCTIONS AND PLANS,

FOR MAKING A FLYING CAR WITH WINGS, IN WHICH A MAN MAY SIT, AND, BY WORKING A SMALL LEVER, CAUSE HIMSELF TO ASCEND AND SOAR THROUGH THE AIR WITH THE FACILITY OF A BIRD.

BY THOMAS WALKER,
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1810.

To the Right Hon. Earl Stanhope.

My Lord, As far as an obscure individual like myself can judge of exalted characters, I am induced, in unison with public opinion, to hold a belief that your lordship is possessed, in a very superior degree, both of genius and a knowledge of the sciences, as well as a known predilection for every thing that is calculated to improve and extend the mechanic arts, or to meliorate the condition of mankind. To acknowledge also that your lordship is equally preëminent in the senate is but paying a tribute which is *very justly due* to your patriotism, and the great exertions which you have made in advocating the cause of humanity. Every *friend* to his country must hold in grateful remembrance the energetic and manly opposition which your lordship evinced to prevent the commencement of a war more undefined in its object, more inefficient, and more direful and ruinous in its consequences to our country than any war it was ever madly and unjustly plunged into. My countrymen have *now* great cause also to remember, with indignation and deep regret, that, in return for your opposition to the origin of those baneful effects, which your lordship clearly foretold, and are now but too severely felt; in return for your wise counsels and patriotic zeal, your lordship met with every coarse insult and contumely which blind folly and malice could suggest. But your lordship has this inestimable consolation that your life has been most *honourably* engaged not with the savage arts of murder, not with the burning of towns and the destruction of their inoffending and defenceless inhabitants; not with the filling of Europe with miserable widows and orphans; not with the ruin of manufactures and commerce, and the violation of the sacred constitutional rights and liberties of your countrymen; not with the low, base, and contemptible arts of any corrupt and venal faction; not with the arts of tyranny and oppression, or force and fraud; not with the machiavelian arts;

PREFACE.

I AM laying before the public a treatise upon a subject perhaps as extraordinary in its nature as anything that has lately come before them; and after a candid perusal, should it meet with approbation from the friends to arts and sciences, my utmost pride will be gratified. The flight of birds, although so common and familiar to our sight, is certainly as great a phenomenon as any in the creation; and artificial flying, when accomplished, may be considered as one of the greatest wonders of the mechanic arts, which I firmly believe attainable upon the plan I have suggested.

In this little work I have shown that birds' wings do not increase their expansion in exact ratio with the increased specific gravity of their bodies; I have given a demonstration of the cause of the projectile motion of birds, the discovery of a true knowledge of which has bid defiance to philosophers in all ages, which, with other discoveries, I trust will prove that I have given consistency to what henceforth may be denominated the *science* of flying, and which may alone be deemed of considerable importance to science, had nothing more than that been brought forward; but as I have gone much further, and have advanced arguments, and given plans to render the *art of flying practicable*, the importance of this little treatise becomes obvious, more particularly so if we take into consideration the various purposes to which artificial flying may be applied.

When my work was just ready for the press, I was much surprised at the account a friend gave me of what he had seen that day upon flying, in a monthly journal. I immediately procured a sight of it, and found it to be an ingenious paper written by Sir George Cayley, and I own I was astonished at the perusal. I conceived it to be very extraordinary that two persons, not having the least knowledge of each other, should be publishing their thoughts at the same time upon such a subject; nor was I less surprised to find the subject treated of there in a manner so rational and far superior to anything I have ever seen before. From what Sir George has thought, and the calculations he has made upon the subject, he is so sanguine in his belief that flying will be effected as to say, in one part of his paper, as follows: "I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour." — *Vide* Nicholson's Journal for November, 1809.

For my own part, whatever reason I may have to be sanguine of success, I have made a resolution to suppress in my work every thought that confidence could suggest beyond what I could give demonstration of, along with the clearest directions how to attain the end in view; thereby putting it out of the power of critics to say that the principles of my theory have not a good foundation.

Notwithstanding, from the novelty and singularity of the subject, I do expect to meet with a good deal of raillery and sarcasm. The wits will tell me that I am flighty, and the more serious and heavy part of mankind, who are too ponderous for such aerial flights, will express a disapprobation of my scheme; but I do not write for such folks, my sole aim is to deliver my thoughts to the public, in hopes that *men* of *genius* and *science* may turn their attention to a subject that may not before now have attracted their notice, that, by their aid and assistance, the art may be brought into practice; and, as this country stands unrivalled in arts, I hope we shall not be long without a Society for the encouragement of the art of flying. Columbus was laughed at when he talked of a continent beyond the Atlantic; but flighty as he might appear he found it, and *wise* men lost it!

A TREATISE, ETC.

WE learn, from several authors, that, in different ages of the world, the art of flying has been attempted by various means, all of which have hitherto failed of success. When we take into consideration the different methods which are recorded to have been tried, we cannot be surprised that they have all failed, since, compared with what is contained in the following pages, they will obviously appear to be nothing more than mere whims and contrivances, all utterly destitute of the true nature and science of flying.

I am conscious that many of my readers, who have never been led to notice the remarks that many eminently learned men have made upon this art, will be tempted at the first sight of my title page to ridicule a treatise upon artificial flying; for there is not a more common saying, when a person has taken some great difficulty in hand, than that such a thing is as impossible to be done *as for one to fly in the air*. I do assure all such that my treatise is not founded upon a whim of the moment, but from mature deliberation on the display of nature. The study of the works of nature has been to me, during the greatest part of my life, a source of amusement and inexpressible delight. The natural history of birds has particularly occupied my attention, and that enviable faculty which they possess of flying, has greatly excited my curiosity, and led me to that study by which I have obtained *a true knowledge* of the mechanical principles by which they fly, a knowledge which I do not hesitate to declare has hitherto remained undiscovered, although it has been the object of the study and contemplation of many of the most eminent philosophers of past ages.

That great observer of the works of nature, Solomon, did not overlook the subject of flying, but speaks of it in his book of *Proverbs*, xxx, 18, 19 — "There be three things which are too wonderful for me, yea four, which I know not: *the way of an eagle in the air*, the way of a serpent upon a rock." I beg also to remind such of my readers as doubt the possibility of flying that many useful and valuable mechanical inventions, which are now complete and become common, would, a century or two past, have been treated as visionary or impracticable; or had they been accomplished at such periods their effects would have been attributed to witchcraft. I have not the least doubt of being successful in the art of flying, if I had it in my power to give it a fair trial. My invention for attaining the art is founded *entirely upon the principles of nature;* and although these principles are as old as the creation, they have never, until now, been properly attended to. How much are we indebted to the study of nature for discoveries of the greatest importance? and from this delightful study many more are yet to be expected.

The love of pleasure is natural to man, and to gratify this propensity he eagerly attends to every artificial entertainment that is offered to him. He resorts to theatres and operas, to Newmarket, and other haunts of vanity and folly, as if pleasure were nowhere else to be found; at the same time what an inexhaustible fund of entertainment is overlooked by all but a few, although constantly displayed in the wonderful exhibition of the works of nature.

What a pity it is that minds of men are not more generally and forcibly struck with the pure and tranquil delights resulting from the universal study of nature. What riot, confusion, waste of time, loss of money and of health, might be avoided if this pleasing and truly-enlightening study could be made fashionable. What an infinite stock of ideas it would create; how much it would enrich the human mind, and afford matter for social conversation and entertainment far superior to the unimportant subjects which too generally occupy the minds and tongues of men.

I will now present my readers with some account of various schemes which have been tried to accomplish the art of flying, and shall show the cause of their insufficiency. I shall explain the natural mechanical means by which birds are enabled to fly, and my readers will then be able to judge how far my invention for flying corresponds with the natural science, and is thereby calculated to succeed. I shall show likewise the comparative difference between the specific gravity of the humming bird and the condor, also the different expansion of the wings. I shall compare the weight of a man with the weight of the condor, and thereby determine the necessary dimensions of a pair of wings which would enable a man to fly; and, lastly, I will explain an experiment which I have made, in order to demonstrate the principles of artificial flying, and give directions for making a machine wherein a man may sit, and, by working a pair of wings with a lever, be able to ascend into the air, and fly with as much safety and ease as a bird.

During the early part of my life I have dissected a great many birds, and since studied very minutely the mechanism of their wings, tails, and all the parts which they employ in flying.

I have long been accustomed to contemplate a bird as a living machine, formed by the Almighty Creator, either to run upon the earth, to dive in the waters, or to ascend into or fly through the air; and when I examine its various parts, and find such an exquisite display of wisdom in each being formed so perfectly to answer the use it is applied to; when I see the effect of the whole, that such a wonderfully organized animated piece of matter can quit the earth and soar aloft in the air, it appears to me a miracle, and I am struck with admiration.

It is now almost twenty years since I was first led to think, by the study of birds and their means of flying, that if an artificial machine were formed with wings, in exact imitation of the mechanism of one of those beautiful living machines, and applied in the very same way upon the air, there could be no doubt of its being made to fly; for it is an axiom in philosophy that the same cause will ever produce the same effect.

It is easy to demonstrate that a bird is no more able to fly than a man without the mechanical effect of wing;[1] therefore,

[1] The ostrich, in the torrid regions of Africa; the emu, in the extensive plains of Paraguay, in South America, which, standing erect, is about seven feet high, its legs are three

when a man is furnished with a pair of wings large enough, and can apply them in the same manner as a bird does, and with sufficient power, there can be no reason to doubt of a man being able to fly as well as a bird. The machine which I have planned is as close a copy of the natural mechanism of a bird as artificial means will admit of; and when my readers are made thoroughly acquainted with both the natural and artificial means of flying, I flatter myself they will then be willing to acknowledge that my scheme is a very rational one, highly calculated to insure success in the accomplishment of the art of flying, one of the most extraordinary and desirable arts with which we can be acquainted.

Although I have, for many years, been extremely anxious to bring the machine into effect, and am very sanguine in my expectations of success (for I positively assert that flying cannot be accomplished on any other plan than the one I propose), I, unfortunately, have ever found myself unable, from my professional avocations and other circumstances, to put it in practice, or I should long since have made the experiment.

Finding, therefore, that to no purpose I have deferred, for a long time, its execution, which I deeply regret, and the prospect of the future being not more favourable, I am induced to publish my plan, in the hope that the lovers of the arts and sciences, when I have laid before them a scheme so practicable, will readily be induced, for the honour of science and our country, to contribute to the means of bringing it into practice, and demonstrate to their fellow mortals how they may gain a perfect dominion over another element.

In almost every nation where arts and sciences have flourished, persons have manifested a wish to discover the art of flying. In Rome and in Paris particularly different persons, and in ages remote from each other, have tried experiments with wings formed of various materials, which have been fastened to their arms, but none of them succeeded, there not

feet long, its thighs are nearly as thick as the thighs of a man, it runs so swift that the fleetest dogs are foiled by it; the cassowary and the dodo, in the Molucca Islands; and the penguins, in the Straits of Magellan and the South Sea Islands. All these birds are as utterly incapable of flying as a man, none of them being provided with wings for that purpose.

being strength sufficient in a man's arms to enable him to fly with detached wings fastened to him, leaving the whole weight of his body unsupported.

Friar Bacon, who lived nearly five centuries ago, wrote upon the subject, and he affirms that the art of flying is possible; and many others have been of opinion that, by means of artificial wings affixed to the arms or legs, a man might fly as well as a bird.

The philosophers of the reign of King Charles the Second were much engaged with this art. The famous Bishop Wilkin, who, in 1672, published a treatise upon flying, was so confident of its practicability, that he says he does not question but that in future ages it will become as common to hear a man call for wings when going a journey as it is now to call for his boots and spurs.

In the year 1709, as we gather from a letter published in France in 1784, a Portuguese, Friar de Gusman, applied to the king to encourage him in the invention of a flying machine. The principle upon which it was constructed, if indeed it had any principle, seems to have been that of a paper kite. The machine was in the form of a bird, and contained several tubes through which the wind was to pass in order to fill a certain sail, which was to elevate it; and when the wind was deficient the same was to be effected by means of bellows concealed within the body of the machine. The ascent was also to be promoted by the *electric* attraction of pieces of amber placed in the top, and by two *spheres* inclosing *magnets* in the same situation.

These silly inventions show the very low state of science at that time in Portugal, especially as the king, in order to encourage him in his further experiments in such an useful invention, granted him the first vacant place in his College of Barcelos or Santerim, with the first professorship in the University of Coimbra, and an annual pension of 600,000 reis during his life. Of this De Gusman it is also related that, in the year 1736, he made a wicker basket of about seven or eight feet diameter, and covered it with paper, which raised itself about 200 feet in the air, and the effect was generally attributed to witchcraft.

Mr. Willoughby, after observing that the pectoral muscles of a man, in proportion to his weight, are many degrees too weak for flying, recommends to him who would attempt the art with the desire of success to contrive and adapt his wings in such a manner that he may work them with his legs and not with his arms, because the muscles of the legs are much stronger.

The celebrated Lord Bacon wrote on the subject of flying, and believed it practicable, but it seems he could no more direct how it was to be done than any other who had written before him on the same subject.

Thus much, for the satisfaction of my readers, I have thought proper to make mention of what has been attempted in the accomplishment of this wonderful art; but were I to adduce all that has been said and done, at different periods of time, I could compile a large volume of that alone, which would answer no other end than that of curiosity, and to show that no one has ever understood the natural means of flying, which is the only knowledge that can guide us to the completion of artificial flying, and which I hope and trust will be clearly demonstrated in this treatise.

As I shall have occasion to refer to various birds, possessing different powers of flight, in illustration of my design, I here introduce the history of the condor, for the information of such of my readers as may not be acquainted with it.

The condor is a native of America, and hitherto naturalists have been divided whether to refer it to the species of the eagle or to that of the vulture. Its great strength and activity seem to give it a claim to rank among the former, whilst the baldness of its head and neck is thought to degrade it to a rank amongst the latter. It is, however, fully sufficient for our plan to describe its manners, form, weight, expansion, and power; we will therefore leave to nomenclators to decide upon its class. If size (for it is by much the largest bird that flies) and strength, combined with rapidity of flight and rapacity, deserve preëminence, then no bird can be put in competition with it; for the condor possesses, in a higher degree than the eagle, all the qualities that render it formidable not only to the feathered tribe, but to beasts, and even to man himself.

Acosta, Garcilasso, and Desmarchais assert that it measures 18 feet across the wings when expanded; its beak is so strong as to pierce the body of a cow; and it is positively asserted that two of them are capable of devouring that animal. They do not even abstain from attacking man himself; but, fortunately, there are but few of the species. The Indians say that they will carry off a deer or a young calf in their talons as an eagle would a hare or rabbit, that their sight is piercing, and their manners terrific. According to modern authors they only come down to the sea coast at certain seasons, particularly when it is supposed their prey fails them upon the land; that they then feed upon dead fish and such other nutritious substances as the sea throws upon the shore.

Condamine says he has frequently seen them in several parts of the mountains of Quito, and has observed them hovering over a flock of sheep; and he thinks they would, at one particular time, have attempted to carry some of them off had they not been scared away by the shepherds. Labat says that this bird has been described to him, by those who have seen it, as having a body as large as a sheep, and that its flesh is as tough and disagreeable as carrion. The Spaniards residing in that country dread its depredations, there having been *many instances of its carrying off children.* Mr. Strong, the master of a ship, relates that, as he was sailing along the coast of Chili, in the thirty-third degree of South latitude, he observed a bird sitting upon a high cliff near the shore, which one of the ship's company shot with a leaden bullet and killed. They were greatly surprised when they beheld its magnitude, for when the wings were extended they measured 13 feet from one tip to the other; one of the quill feathers was 2 ft. 4¾ in. in length, and 1½ in. in circumference.

Mons. Feuilleé, whose description alone is accurate, has given a still more circumstantial account of this amazing bird.

"In a valley of Illo, in Peru," says he, "I discovered a condor perched on a high rock before me. I approached within gun-shot and fired, but as my piece was only charged with swan-shot the lead was not heavy enough to bring the bird down. I perceived, however, by its manner of flying, that it was wounded, and it was with a good deal of difficulty that it flew to another rock about 500 yards distant on the seashore. I therefore charged again with the ball and hit the bird under the throat, which made it mine. I accordingly ran up to seize it; but even in death it was terrible, and defended itself upon its back with its claws extended against me, so that I scarcely knew how to lay hold of it. Had it not been mortally wounded I should have found it no easy matter to take it, but I at last dragged it down from the rock, and, with the assistance of one of the seamen, I carried it to my tent to make a coloured drawing of it. The wings of this bird, which I measured *very exactly*, were 12 ft. 3 in. (English) from tip to tip. The great feathers, which were of a beautiful shining black, were 2 ft. 4 in. long. The thickness of the beak was proportionable to the rest of the body, the length about 4 in., the point hooked downwards and white at its extremity, and the other part was of a black jet. The thigh bones were 10 in. long, the legs 5 in., the toes and claws were in proportion, and the legs were covered with black scales. The little nourishment which these birds find on the coast, except when a tempest throws up some great fish, obliges the condor to continue there but a short time. They usually come to the coast at the approach of evening, stay there all night, and fly back in the morning."

I now proceed to describe the construction and application of the wings of a bird. How properly are they formed to fulfil the uses they were made for! The first is to expand, and by that means to give the bird a secure hold upon the air below it, which hold is always in proportion to the dimensions of the wings. The tail produces the same effect. We see that by means of a pair of wings and a tail duly expanded, in a perfectly *passive state* and aloft in the air, without any muscular motion, a bird procures a suspending power, which counteracts the specific gravity of its body, and prevents it being precipitated to the ground; such is the effect of the wings and tail when in a *passive state*.

I will next take some notice of the quill feathers, which are replete with proofs of the wisdom of the Almighty artist who made them. As they were intended to swim within so light and subtle a fluid as the air is, it was necessary that they should be formed of the lightest materials imaginable; and as they were intended to strike upon the air with great power and rapidity, it was requisite that they should possess in the shafts great strength with elasticity; it was expedient too that the quill feathers should separate and open to let the upper air pass through the wings, to facilitate their ascent when they are struck upwards; it was also necessary that they should all shut close together, forming each wing into a complete surface or web, when they are, by the muscular power of the bird, forced down in order to give a more secure hold upon the air below, and by that means keep the bird up.

Now if we do but examine the quill feathers we shall find in the shafts astonishing strength with elasticity, and very little specific gravity indeed. The webs of the quill feathers are broader on one side of the shaft than the other, which causes them to open as the wings move up and to shut as they come down, exactly answering the purposes I have already mentioned; therefore, we see how wonderfully-complete the wings are in all their parts, and how effectually they serve all the uses required.

I will now show the application and effect of the wings and tail in *an active* state. When a bird, by the power of its pectoral and deltoid muscles, puts its wings into action and strikes them downwards in a perfectly vertical direction upon the air below, that air being compressed by the stroke of the wings makes a resistance, by its elastic power, against the under side of the wings, in proportion to the rapidity of the stroke and the dimensions of the wings, and forces the bird upwards; at the same time the back edges of the wing being more weak or elastic than the fore-edges, they give way to the resisting power of the compressed air, which rushes upwards *past the same back edges*, acting against them with its elastic power, and thereby *causes a projectile force*, which impels the bird forwards; thus we see that by one act of the wings the bird produces both *buoyancy* and *progression*. When the tail is forced upwards, and the wings are in action, the bird ascends and forced downwards it consequently descends; but the most *important use of the tail is to support the posterior weight of the bird*, and to prevent the vacillation of the whole.

Thus having discovered and explained to my readers the natural machanical means by which birds accomplish flying, they will be able to see that the plan upon which I have formed my scheme for artificial flying is perfectly analogous to the principles of nature, which certainly ought to be clearly understood, and taken as our only guide, before we can ever expect to arrive at success in the art of flying; but with the knowledge of these principles *there cannot remain a doubt of success*.

When we first think of a man attempting to fly by mechanical means, we are induced, considering his specific gravity to pronounce it impossible; and had we never seen or known of any bird larger than a humming bird, whose weight does not exceed one drachm, and whose diminutive wings measure only three inches from tip to tip; and were to be told by some traveller that he had seen a bird with a body as large as a sheep, that had wings of twelve feet expansion, and that it could quit the earth and ascend into the air with its ponderous body, and there fly about with as much ease as the little humming bird, we should think it too marvellous a tale to be credited. But as we are accustomed to see, almost every day, birds of such various dimensions and specific gravity as are exhibited by nature, from the humming bird to the common wren; from the wren, through a numerous gradation, up to the eagle, we can readily give credit to the history of the wonderful condor in South America, whose existence is so well attested that we can have no reason to doubt of it, more especially as we witness so vast a gradation in the indigenous birds of our own country. I believe that there were two of these prodigious birds in the Leverian Museum.

The following observations upon the wonderful difference in the weight of some birds, with their apparent means of supporting it in their flight, may tend to remove some prejudices against my plan from the minds of some of my readers. The weight of the humming bird is one drachm, that of the condor not less than four stone. Now, if we reduce four stone into drachms, we shall find the condor is 14,336 times as heavy as the humming bird. What an amazing disproportion of weight! Yet by the same mechanical use of its wings, the condor can overcome the specific gravity of its body with as much ease as the little humming bird. But this is not all. We are informed that this enormous bird possesses a power in its wings, so far exceeding what is necessary for its own conveyance through the air, that it can take up and fly away with a whole sheep in its talons, with as much ease as an eagle would carry off, in the same manner, a hare or a rabbit. This we may readily give credit to, from the known fact of our little kestril and the sparrow hawk frequently flying off with a partridge, which is nearly three times the weight of these rapacious little birds.

Let us attend to this subject a little further. Let us consider these wings of the condor, which, with a *mechanical action alone*, produces a power that is capable of carrying through the air both the bird and the sheep, weighing together not less than ten stone, which would then be 204,000 *times the weight of the humming bird!* When this is duly considered, with reference to my plan, what encouragement does it not give to prosecute the art of flying? particularly so when we consider that a man of ten stone weight, in a machine weighing two stone, will only exceed the weight of the condor *one-fifth part;* this is a mere trifle compared with the astonishing difference there is between the humming bird and the condor.

The condor carries ten stone, with wings of twelve feet expansion from tip to tip; the humming bird carries one drachm, with three inches expansion; the common wren is three times as heavy as the humming bird, and has but one inch more of wing; a pigeon weighs 16 ounces, which is 256 times as heavy as it is, and has only ten times more expansion of wing; the goatsucker is forty times as heavy, and has seven times the length of wing. I could here carry the same observations upon other birds to a very great extent, but the above are instances sufficient to prove that birds' wings are not multiplied in their length in the same proportion with the increased weight of their bodies: therefore, as a man weighing ten stone and his machine two, as I have already shown, will only exceed in weight *one-fifth part* of the weight of the condor and his prey; and as the wings of the condor are about twelve feet, suppose we make a pair of wings of silk, one-fifth longer than they are, which will be about fourteen feet and a half, I am thoroughly persuaded they will be found amply sufficient, as they will far exceed the progressive increase of birds' wings.

By attending to the progressive increase of the weight of birds, from the delicate little humming bird up to the huge condor, we clearly discover that the addition of a few ounces, pounds, or stones, is no obstacle to the art of flying; the specific weight of birds *avails nothing*, for by their *possessing wings large enough*, and *sufficient power to work them*, they can accomplish the means of flying equally well upon all the various scales and dimensions which we see in nature.

Such being *a fact*, in the name of reason and philosophy why shall not a man with a pair of artificial wings, *large enough* and with *sufficient power to strike them upon the air*, be able to produce the same effect.

I shall, after a few observations, proceed to describe how a machine may be made with a pair of wings, and a lever to work them with, so that any person will be able to see how far it is calculated to answer the purpose for which it is intended. This machine may be considered as a large artificial bird, and the man placed in the inside as the vital or moving power. All the attempts hitherto made in the art of flying, by different persons, according to historians, have been mere childish whims, not in the least degree calculated to insure success. They each made a pair of detached wings, some of silk, some of leather, and some of sheet iron and various other materials; they fastened them upon their shoulders or arms: thus equipped, they placed themselves upon some eminence, such as a high tower or a church steeple, then took to their wings; but few of them were fortunate enough to escape without some injury.

It is utterly impossible for a man to fly with a pair of wings fixed to his shoulders or arms, with the whole weight of his body hanging down and depending entirely on his pectoral muscles for support. These muscles in a man are many degrees too weak to keep extended a pair of wings of sufficient expansion to effectually counteract the specific gravity of his body. Let a man suspend the weight of his body, with his arms extended, holding to an horizontal beam by his hands and he will very soon find the insufficiency of the strength of his arms to support his weight. On the plan which I have conceived for flying the want of strength in the arms is amply provided for. By furnishing a man with a car to sit in, the whole weight of his body is supported by it, and as he sits much in the same manner as if he were rowing a boat, he is enabled to bring into action his *whole bodily strength, which far exceeds* the strength of his arms only, and by sitting in such a position his strength can be exerted with a far greater force than in any other attitude whatever; he at the same time gains an *additional advantage*, in this plan of mine by exerting his strength upon a lever.

The two greatest requisites for accomplishing the art of flying are these — first, *expansion of wings large enough* to resist, in a sufficient degree, the specific gravity of whatever is attached to them; second, *strength enough* to strike the wings with a sufficient force to complete the buoyancy, and give a projectile motion to the machine. With these two requisites combined *flying must be accomplished;* and, upon my plan there can be no doubt of wings being made as large as ever they may be wanted; neither ought we to doubt of a man's ability, exerting himself in the way I have described to bring into action as great a degree of strength, in proportion to his weight, as the condor is possessed of. Therefore, if we are secure of these two requisites, and I am very confident we are, we may calculate upon the success of flying with as much certainty as upon our walking.

When I first thought of artificial flying, it occurred to me that it would be of some importance to try what effect a pair of wings would have upon the air, without any mechanical power to work them; I thought that if I were to suspend a weight from beneath them, and they should prevent that weight from falling in a perpendicular line to the ground, they would demonstrate that the ideas I had conceived of the cause of the projectile motion of birds were well founded.

I therefore made the following experiment, to which I call the *particular attention of my readers, as it positively demonstrates the cause of the projectile motion.* I made a pair of small wings, of fine paper, and very small slips of wood to keep them extended, and fixed on a tail of the same materials, imitating, as near as I could, the wings and tail of a bird when expanded in a *passive state.* I then suspended a small weight from under them, with a piece of thread, exactly in the centre of gravity; I held them up as high as I could reach, then took away my hand and left them flat upon the air, without giving any impulse to them whatever; and by the weight pressing downwards the air under the wings became, in some degree, compressed, and by its reaction against the under side and the back edges of the wings, *they were projected with an oblique descent from one end of the room to the other, carrying the weight all that distance*, which, without the wings being of this particular construction, could not have been done.

I had cause sufficient to exult in the success of my experiment, which proved to me, in a very satisfactory manner, that what I had conceived to be the cause of the projectile motion of birds *was really the cause*, and that if I could but give a vertical motion to the wings, so that they might strike upon the air with a sufficient force, they would then increase the reaction of the air, and instead of being projected in an oblique descent, totally overcome their specific gravity, and *continue flying in an horizontal direction.*

This is an experiment which any of my readers may make trial of for their own satisfaction and amusement.

Another experiment, serving to shew the different effect of buoyancy obtained by a parachute and by my paper wings may be tried in the following manner: — Take two straight sticks, neatly dressed, about the thickness of a crow-quill and each about sixteen inches long, lay them across each other in the middle, at right angles, and tie them fast with a piece of thread; then tie a piece of thread from the ends of one stick to the other, so as to secure them at right angle: then take a sheet of gauze paper, and fasten all the four corners of it to the four ends of the sticks; but previous to this, paste upon the four corners of the paper four small slips of thin cloth in order to give sufficient strength; then suspend any small weight by a thread from the centre; let the whole fall from a height, and you will see the effect of a parachute in miniature: but this effect is very different from that of the paper wings; the parachute *sinks gradually down in a perpendicular line*, whilst the wings *dart forwards* to the distance of several yards.

I have met with persons who have boldly asserted that it is impossible for a man to exert sufficient strength to raise himself up into the air by mechanical means alone; but the rashness and fallacy of such an assertion is completely refuted and exposed by Mr. Degen, in Vienna, who has very lately actually ascended *into the air*, to a considerable height, by sitting in a machine and giving action to two parachutes; and had he properly understood the principles of birds' wings, and considered the astonishing power in the reaction of the air, which may be *increased in proportion to any force* exerted upon it, *ad infinitum*, and possessed a complete knowledge of the principles upon which it enables birds to fly, he would have chose wings and not parachutes, and might then have accomplished flying in perfection.[1]

There is no doubt that, by large parachutes, worked by a mechanical power, a man may raise himself from the ground to a considerable height; but that cannot be properly called flying, because as the compressed air rushes from underneath the parachutes, to regain its equilibrium *on all sides alike*, there

[1] M. Degen, a watchmaker of Vienna, has invented a machine by which a person may raise himself into the air. It is formed of two parachutes, of taffeta, which may be folded up or extended at pleasure, and the person who moves them is placed in the centre. M. Degen has made several public experiments, and rose to the height of fifty-four feet, flying, in various directions, with the celerity of a bird. A subscription has been opened at Vienna to enable the inventor to prosecute his discoveries. — *Vide* the Monthly Magazine for September, 1809.

can be no *projectile motion* effected, without which *there can be no command or steerage*, and in such case the whole apparatus will be driven which ever way the wind impels it; I therefore cannot give credit to that part of the account of M. Degen's performance which asserts that he flew *in various directions*, although I can readily believe in his having raised himself into the air, and think that great praise is due to him. I do not believe it possible, upon his plan, that he could have gone in any other direction than with the wind; but with a pair of wings constructed and worked according to the natural principles of flying, a projectile motion is obtained in as perfect a manner as buoyancy, *both of which* must be accomplished before we can have the benefit and pleasure of flying with steerage, and that upon the following plan only, viz.:—

Make a car of as light materials as possible, but with sufficient strength to support a man in it; provide a pair of wings of about eight feet each in length, let them be horizontally expanded, and fastened upon the top edge on each side of the car, with two joints each, so as to admit of a vertical motion to the wings, which motion may be effected by a man sitting and working an upright lever in the middle of the car; a tail of about seven or eight feet long, and the same breadth at its extremity, must be fixed to the hinder part of the car, and spread out flat to the horizon in the same manner as we see the tails of birds.

The grebes, by their manner of flying, evince that the most important use of a bird's tail is *to support* the *posterior weight* of the body; for the Creator having left the whole of this class of birds, of which we have five different species indigenous in this country, all totally destitute of any portion of a tail, they are, consequently, always seen when flying to have their bodies hanging down nearly in a perpendicular direction, and appear to fly with great difficulty; but this impediment in flying is of little consequence to them, their organization being perfectly adapted to their mode of living. They find their subsistence in lakes and pools, wherein they are incessantly diving, and, of course, are not obliged to fly until those places are frozen up, when they are compelled to flutter off, as well as they are able, in search of some spring or swamp which is not affected by frost, where they find a temporary subsistence until their favourite lakes are relieved from a surface of ice; they then return to their former haunts, when they again seem quite in their element. Here we find a class of birds, owing to their want of tails, possessing the power of flight in a very imperfect degree, compared with some birds. It also may be observed that birds having extraordinary large tails, as the magpie for instance, do not fly in the best manner; none of these birds possess what seems to constitute the excellence of flying, viz., soaring and reposing upon the air; this can only be effected when the weight of the body is upon an equipoise in the centre of the wings and tail, each bearing up its due proportion, and the expansion altogether so large, as to bring the whole weight nearly in equilibrium with the atmosphere. This must be properly attended to in the construction of a flying machine.

To give a further security to the power of suspension, a sail of an equilateral triangle may be spread horizontally over the man's head, supported by a small light mast or bowsprit, at the height of three or four feet above the car; the sail must be expanded and fixed to the mast by a very light yard, presenting the base of the sail to the head of the car, with the opposite point towards the tail, and there fastened with a cord to another small bowsprit; this sail will be a protection, if large enough, in case of any accident occurring to the machine; it will then prevent the man from being precipitated to the ground in a manner similar to a parachute. I only have mentioned this sail that it may be resorted to if it be found necessary in a long voyage; the first experiment I would try without it.

A coachmaker is accustomed to make strong work with little weight of materials; he, therefore, would be the most proper person to make a machine of this kind. The man must sit in the middle, between the wings and the tail, so as to be a little behind the centre of gravity, for the purpose of causing a little preponderance of weight to act upon the back edge of the wings; for if there be not, in some degree, more weight behind than before, when the compressed air is making a resistance against the underside and back edges of the wings, where it rushes upwards again, causing a great reaction, it would, of course, elevate the hinder part of the car too much.

The wings and the tail should be made of silk, very compactly woven, and as impervious to the air as possible. The silk which the wings are formed of, should be laid on in separate broad slips,[1] and should open to admit the air to pass through as the wings move up, and close together again as they come down, in the same manner as I have described the action of the quill feathers in the wings of birds; although, upon the experiment being tried, this method may not be found so absolutely requisite, for we see flying squirrels, bats, butterflies, beetles, flying fish, etc., with wings formed of compact membranes, all flying exceedingly well. The Madagascar bat has a body the size of a rabbit, with wings four feet long, formed of entire membranes, and, although so large, it can fly as well as our little native bats; therefore it is possible that a pair of artificial wings may be formed without any valves, and yet answer equally well; but this can only be determined by actual trial.

It is necessary to observe that the car in which the man is to sit must be entirely covered on the outside with silk or very thin leather, and along each side of the car the silk or leather must be united to the base of the wings, to prevent as much as possible, the air from escaping anywhere but from the back edges of the wings: should that be neglected, when the air is compressed by the wings being struck downwards, it will rush upwards through the car and thereby fail of giving that resistance against the underside of the wings which is necessary for the purpose of effecting buoyancy and progression.

I think that the shafts of the wings and tail would answer the purpose in the best manner, if they were each of them made of six long slips of thin whalebone, dressed tapering to a point, then wrapped together in a round form with small twine from end to end, and filled with cork along the inside. By making

[1] The tail feathers of turkies laid close and parallel to each other and fast sewed upon eight pieces of strong riband, so as to form the same number of slips, then extended in the wing and well braced, would perhaps answer the purpose much better.

them in this manner they would spring against the air, would be very light, and so strong that it would be impossible to break them with the power or weight of any one person. By forming them as above we shall humbly imitate the shaft of a quill feather, which is composed of a thin horny shell, containing a delicate light pith along the inside.

I here recommend my readers to *particularly observe* that a *main point in this treatise* is that they should not overlook the importance of the knowledge of the reaction of the air against the underside and *back edges of the wings*, for this is what causes the projectile motion, which is indisputably proved by the flying of my paper wings across a room, and which I will further illustrate by the flight of birds, mill sails, &c.

I have frequently conversed with persons about the art of flying by mechanical means, and generally found them disposed to treat the idea with ridicule. I have asked them if they knew how birds were enabled to fly, and they mostly answered me nearly in the following manner: that birds could fly because it was natural to them, that they were covered with feathers, which were such light materials as to help them to fly, and that their wings are properly adapted for flying. This was as far as they could explain, which proved that *all* they knew on this subject amounted to nothing. They generally seemed to indulge an idea that there was something in the flight of birds either supernatural or incomprehensible; but I hope my readers will be convinced, by this little treatise, that the art of flying is as truly *mechanical* as the art of rowing a boat.

I will here further illustrate how flying is effected. The air, when struck upon by wings, produces an effect by its reaction against the underside and back edges, similar to that which is caused by the wind blowing with sufficient force against a mill-sail, when it *rushes off on one side*, and impels the sail to move, with this difference only, that the sail, being fastened at one end to an axis, is made to revolve, whilst the bird, being at full liberty in the air, is caused, by the expansive power of the air acting with a resisting force *against the back edges* of the wings, to glide forward in a right line.

Most of my readers, I think, will acknowledge the great elastic power of the wind, as it is manifested by the sailing of ships and the revolving of mill-sails; these effects are produced by the wind being compressed against the sails from its own natural motion and force; but the effect the air has against the wings or sails of birds is produced by its being compressed, with them striking vertically upon it; and the larger they are made the greater quantity of air is compressed, by which means is caused a more powerful reaction, and consequently a more effectual buoyancy and progression. From this cause all the birds whose wings are *very large* in proportion to their weight are able to fly with the *least exertion* imaginable, whilst birds with very small wings are obliged to use very great labour indeed; this being demonstrated by the examination of the dimensions of birds' wings and their specific gravity, and by observing their different methods of flying.

I have often been delighted with the striking conviction that Supreme wisdom alone could have so nicely adjusted all the various internal and external organization of the vast number of different species of birds, to their diversified wants and modes of living; but it is only necessary to observe here that all those which are under the greatest necessity of flying are provided with the *longest* and *best proportion* of *wings* and *tails*, and are consequently able to fly in the best manner, and those which need them less have them more limited, and are therefore less capable of flying, as if the all-wise Creator had set limits to their powers of flight, that they might not go out of their respective elements.

Although I think that a pair of wings seven or eight feet each in length would be sufficient, still, if I could make it convenient to try the experiment of flying, and were not prevented, as I am, by a chain of untoward and uncontrollable circumstances, I would cause the wings to be made of as large dimensions as I could possibly *move with ease*.

I observe amongst the aquatic birds that the auks, guillemots, divers, etc., have such remarkably small narrow wings that they would be utterly incapable of keeping themselves up in the air if it were not for an exertion which they are obliged to make in the extreme. Their wings are moved with such rapidity as to be with difficulty discerned. In this we see the economy of the all-wise Creator, for according to their habits and appetites they have very little occasion to fly at any time, except during the time of incubation, when they have to ascend the most inaccessible rocks and cliffs they meet with along the sea shore, where they breed and rear their young; all the rest of their time they pass on or in the water, swimming and diving for their food.

All the gallinaceous class of birds have very short concave wings, which they strike with great exertion; they also, in general, have but little occasion to fly; their food, which con sists principally of grain and seeds, being spontaneously scattered over the earth, they are almost constantly upon their legs, running about to pick it up, and seldom fly but to avoid danger.

On the other hand, rapacious birds, whose appetites induce them to be the greatest part of their time upon the wing, in search of a subsistence which is very precarious (as every inferior bird, &c., to which they direct their sanguinary attacks, from that love of existence which God has so strongly implanted in all His creatures, will use its utmost skill and activity to elude its destroyer), are much better accommodated, having wings of large dimensions they can repose upon the air, and project themselves forward with a gentle wafting. This is the class of birds I would copy from in the construction of a machine for artificial flying. The kite or glead, P, B, Z, (or *milvus* from Lin.,) is the best natural specimen that we can find in the British ornithology; this bird has very large flat wings, with a large forked tail, and flies with the least exertion, I believe, of any bird in the creation.

All the hyrundo class of birds are almost constantly flying; they all have bodies of little weight, have large *flat* wings, and fly with great ease. The goat-sucker, which is a species of nocturnal swallow, is admirably constructed for flying with facility.

As I have mentioned aquatic birds, I will here take the opportunity of execrating, with all the indignation of my soul, that savage and brutal amusement which they bring to my mind, and which so many persons frequently practice and take delight in; I mean the shooting these harmless and inoffensive birds. Many are the parties who resort to Flamborough-head, for no other purpose than gratifying their vanity by making a display of their dexterity in shooting, and causing all the havock they possibly can amongst the poor inoffensive birds. Barren must be their minds, and callous their feelings, who can take pleasure in destroying these innocent creatures, which are not in the smallest degree offensive to man when they are living, nor of the least service to him when killed. If these *gentlemen* could eat them when they have done shooting, that would be some excuse; but as their flesh is very rancid these wanton barbarians have no relish for their game. I wish their humanity was as nice as their appetites, they would not find delight in merely shooting them for sport and cruelty, leaving them, some killed and others wounded, floating on the surface of the sea, whilst their helpless young ones must consequently perish with hunger upon the shelvings of the rocks. Such amusements, surely, are not becoming rational beings, but may give pleasure to semi-rationals.

In the months of May and June these birds, which, during the rest of their time are dispersed over various parts of the ocean, are brought by one of the great impulses of nature to assemble at Flamborough-head in myriads, producing a throng, upon a great extent of cliff, similar to what we see in miniature in the front of a bee-hive, on a fine summer's day, when there is a perpetual egress and ingress of thousands.

A person who has never seen such a sight, and is capable of deriving pleasure from contemplating the economy and the works of nature, may find an exquisite gratification in paying a visit, at this season of the year, to Flamborough-head without having recourse to wanton acts of cruelty. Will there ever come upon the earth a generation of men who will despise all pleasures that are either unreasonable or inhuman?

Reason and *humanity* constitute the *only* permanent basis of all human happiness, and *real* honour and true glory of man! without which he is but a compound of folly and madness, and is too often a vile mischievous brute. By a disregard and contempt of these two divine guides families and nations become distracted and are made miserable, as we have too amply witnessed in the deplorable and wretched state in which Europe has been so long afflicted, where the appetite of the cannibal has *only* been wanting to complete the brutality of *civilized* nations. But I am departing too much from my original subject; I will withdraw my pen from this sickening view of poor, frail, erring, human nature!

After having described how to construct a machine to fly in, which, like the swift or great black martin (*apus*, Lin.), cannot fly from the surface of the ground, but must have an elevation to rise from, it becomes necessary that I should give directions how it may be made to ascend. Set two tressels fast upon the ground, one six feet high and the other four and a half, at twelve feet distance from each other; then lay upon them two or three planks, which will form a stage with an oblique plane, upon which the car must be placed, with its head pointing to the higher end of the stage.

A person may then get into the car, and sit a little behind the centre of gravity, which must be adjusted before the car is placed there; being thus elevated he will have depth enough on each side of the car to admit of his wings striking upon the air. He must then push the lever forward about eighteen inches from its perpendicular line, the tips of the wings will then rise three feet and a half above the level of their joints; he must then, with a brisk exertion, pull the lever backwards eighteen inches past the perpendicular line, and the tips of the wings will be struck downwards, passing through an arch of seven feet and suddenly driving down and compressing the air in that arch, part of which will escape past the back edge of the wings (as I have described before), making at the same time a reaction which will push the wings forward: and as the car and the wings are first placed on an oblique plane, they will be impelled forwards, making an oblique ascent. The projectile impulse will naturally force the machine upwards in an angle in which the plane of the wings is laid, somewhat similar to what may be observed in the raising of a common paper kite, except in a right angle, or perpendicular line; but the nearer the angle of ascent inclines to the line of the horizon, the easier will the machine be found to ascend. I believe pigeons can ascend very near in a perpendicular line, but such an ascent would be too incommodious for artificial flying.

When the car is brought to a sufficient altitude to clear the tops of hills, trees, buildings, &c., the man, by sitting a little forward on his seat, will then bring the wings upon an horizontal plane, and by continuing the action of the wings he will be impelled forwards in that direction. To descend, he must desist from striking the wings, and hold them on a level with their joints; the car will then gradually come down, and when it is within five or six feet of the ground, the man must instantly strike the wings downwards, and *sit as far back* as he can; he will by this means check the projectile force, and cause the car to alight very gently with a retrograde motion. The car, when up in the air, may be made to turn to the right or the left, merely by the man inclining the weight of his body to one side.

When I have seen a man sitting in a chair upon a tight rope, with a table before him, spread over with decanters, glasses, &c., &c., and, by his *dexterity alone*, be able to keep himself and all his accommodations exactly balanced there while he sat smoking his pipe, apparently at perfect ease; I have been induced to consider the art of managing a flying machine, compared with such a surprizing display of human dexterity, to be very simple; and see no reason why men should not become as expert in navigating the air as the sea.

As some of my readers, who may have little regard for anything but the *utile*, may be induced to ask, what use will flying be of, when it is attained? I beg leave, in the way of reply, to give the following hints:—I hope it will be granted that flying will be of great use, if by such means we can have our letters, newspapers, &c., conveyed to any part of the kingdom at the rate of forty or fifty miles in an hour, or if that numerous class of mercantile agents who are now denominated riders, henceforth be enabled to glide through the air with great expedition, in flying machines; or if a man, by such means, can take a rope to any mariners in distress along the sea coast, and thereby become the happy instrument of saving their lives; and if the circumnavigator be able to quit his ship, fly and explore the interior parts of a new discovered island, free from the annoyance and hostilities of its rude inhabitants — but it would be tedious to enumerate all the uses to which artificial flying may be applied: it is obvious enough that when one man is enabled to fly, thousands may do the same, either on business or pleasure. It may tend greatly to reduce the vast number of horses kept in this kingdom, and by that means a very great quantity of land which is taken up at present in growing hay, oats, and beans for the support of these quadrupeds, might be then cultivated for the increase of our national stock of subsistence for the population: and I think it is evident that we have great occasion to reduce the superfluous number of those animals, and to employ all the land we possibly can to grow corn, &c., for our own subsistence. It is not improbable, that some persons will ask, if flying and all this can be accomplished: to which I answer, that if my scheme for attaining the art be deemed a rational one, as I hope it will, I think we certainly ought to try the experiment.

After the perusal of this work, I hope my readers will be fully convinced, that all attempts which have been hitherto made in the art of flying have failed, not in consequence of the art being impracticable, but from the natural science of flying having never yet been fully understood. All that has ever been written, and all the experiments that have ever been made towards attaining a knowledge of artificial flying by mechanical means, display a chaos of unsettled thoughts very wide and deficient of the principles of nature; but I hope it will be granted that I have clearly discovered and demonstrated the whole of those principles upon which flying depends, particularly the *cause* of the *projectile motion* of birds. This is a discovery of the greatest importance, for as the air is continually acting, in the manner I have described, against the back edges of the wings, and thereby impelling the bird forwards with great force, *it positively has as much tendency to overcome specific gravity as the expansion of the wings has.* This is a fact demonstrated very clearly by my paper wings and by the manner of flying peculiar to some birds, particularly the woodpeckers. When one of these extraordinary birds has struck its wings once or twice upon the air, and thereby produced a projectile impulse sufficient to force it forward to a considerable distance, it instantly contracts its wings as close to *its sides* as when perched on a bough, and continues flying several yards with its wings kept *close* in that position, until the impulse is abating; it then throws out its wings again, gives another stroke or two to renew the impulse, shuts them up and is again driven forward; thus continuing to fly by distinct and separate projectile impulses alone. Here then we see the great importance of a true knowledge of the cause of the projectile motion of birds, for this surprising bird does not depend upon a continued expansion of wings to keep itself up in the air, but is kept up and carried forward by the projectile force alone!

The green woodpecker is about the size of a pigeon, and, as it is very common in every part of England where wood abounds, many of my readers may have an opportunity of observing its curious method of flying; the same may be observed of the beautiful little goldfinch, and of linnets. Here the physico-theologist, who is accustomed to contemplate the wisdom of God in all His works, might be led to infer that He has caused this deviation from the general method of flying, in order to demonstrate to us the *effect* of the projectile *force*, and that it is one of the *greatest essentials* in the art of flying, and perfectly distinct from and independent of the continued expansion of wings.

When we see pigeons flying *upwards* in the angle of *sixty* or *seventy*, as we do every day, from the streets to the tops of houses, with the plane of their wings parallel to the line of their ascent, I think they prove in a satisfactory manner the great effect of the *projectile force;* for without we admit this to be the cause of their ascending in such angles, how can we possibly account for it in any other way, upon rational principles?

A stone thrown by the hand, and a ball ejected from the mouth of a cannon, are made to overcome specific gravity, and fly to a great distance; we all know that these are not kept up by wings, but entirely by the projectile force. In fact, it is by the air being made continually to push the bird forwards, which constitutes the main cause of flying.

We must attribute to a total ignorance of the fundamental principles, that the art of flying has not been brought hitherto into common practice; for an art, so practicable as it is, must at any period of time have soon succeeded a discovery, such as I have made; and now that the art appears so very attainable, I hope that every friend to arts and sciences will acknowledge that it ought to have a fair trial.

I shall now conclude my treatise on flying with an appeal to the candour and good sense of my readers, whether the arguments I have used, and the principles upon which I have insisted the art of flying may be accomplished, are not such as give it a just claim to their approbation; for I think I may affirm, without being accused of arrogance, that the art of flying has never before been treated of upon such rational and scientific principles.[1]

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[1] I will here take the liberty of communicating a few hints, which I conceive to be of importance to the aërostatic science. Now that we know the true cause of the projectile motion of birds, and I having suggested a plan for producing the same effect by artificial means, we may be able to accomplish what Messrs. Roberts, Blanchard, and others attempted to do, but in vain, entirely from their not possessing a knowledge of this mystery of nature. I am alluding to the steerage of balloons, which they endeavoured, with great labour, to attain, by striking a number of oars *horizontally* against the air; and if we do but take into consideration that the balloon was constantly flying from the air against which they were striking, it does not seem probable that they could, by such means, produce the effect they aimed at.

But if we make a car from the plan which I have laid down in this treatise, and upon a scale large enough to admit of one of Messrs. Mead and Co.'s new invented revolving steam engines, to move the lever with, we then can work, in a *vertical direction*, a pair of

Having now submitted to the good sense of my countrymen the whole of what I intended on the subject of flying, I, for the present, most respectfully take my leave of them, indulging a hope that the prediction of Bishop Wilkins, expressed in a former page, will soon be verified, and trusting that I shall not be disappointed in the opinion I entertain respecting the patronage which they will extend towards the invention now laid before them. Encouraged by the public, I shall not abandon my purpose of making still further exertions to advance and complete an art, the discovery of the *true principles* of which, I trust, I can with verity affirm to be exclusively my own.

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very large wings, which would produce a *projectile force* sufficient to impel the balloon forwards in any point of the compass to which we might incline it; and by having a large tail fixed to the car, in an universal joint, we should be able to give it any inclination whatever; and when we have thus effected a perfect steerage to balloons, we shall be able to convey a number of passengers to any place of destination with accuracy and safety. But for this kind of navigation the balloon must be much smaller than usual, and perfectly spherical, and the gas should be kept in such a degree as not to have too great a tendency to ascend — it should be so regulated as to float in equilibrium with the atmosphere; the aëronauts could then keep the machine at a moderate height — from fifty to a hundred feet would be high enough for ordinary sailing, and if it was found to be inclining too much upwards, it might be counteracted by holding the tail in a descending direction. One of Mr. Mead's patent steam engines can be made with a one-horse power, or equal to the strength of eight or ten men, that will not weigh more than eight stone; and will stand in the small space of four feet by two, with the boiler and all the apparatus belonging to it.

WENHAM ON AERIAL LOCOMOTION.

THE following paper, "On Aerial Locomotion and the Laws by which Heavy Bodies impelled through Air are Sustained," was read by F. H. Wenham, Esq., at the first meeting of the Aeronautical Society of Great Britain, held on the 27th day of June, 1866. His Grace the Duke of Argyll in the Chair.

The resistance against a surface of a defined area, passing rapidly through yielding media, may be divided into two opposing forces. One arising from the cohesion of the separated particles; and the other from their weight and inertia, which, according to well-known laws, will require a constant power to set them in motion.

In plastic substances, the first condition, that of cohesion, will give rise to the greatest resistance. In water this has very little retarding effect, but in air, from its extreme fluidity, the cohesive force becomes inappreciable, and all resistances are caused by its weight alone; therefore, a weight, suspended from a plane surface, descending perpendicularly in air, is limited in its rate of fall by the weight of air that can be set in motion in a given time.

If a weight of 150 lbs. is suspended from a surface of the same number of square feet, the uniform descent will be 1,300 feet per minute, and the force given out and expended on the air, at this rate of fall, will be nearly six horse-power; and, conversely, this same speed and power must be communicated to the surface to keep the weight sustained at a fixed altitude. As the surface is increased, so does the rate of descent and its accompanying power, expended in a given time, decrease. It might, therefore, be inferred that, with a sufficient extent of surface reproduced, or worked up to a higher altitude, a man might by his exertions raise himself for a time, while the surface descends at a less speed.

A man, in raising his own body, can perform 4,250 units of work — that is, this number of pounds raised one foot high per minute — and can raise his own weight — say, 150 lbs. — twenty-two feet per minute. But at this speed the atmospheric resistance is so small that 120,000 square feet would be required to balance his exertions, making no allowance for weight beyond his own body.

We have thus reasons for the failure of the many misdirected attempts that have, from time to time, been made to raise weights perpendicularly in the air by wings or descending surfaces. Though the flight of a bird is maintained by a constant reaction or abutment against an enormous weight of air in comparison with the weight of its own body, yet, as will be subsequently shown, the support upon that weight is not necessarily commanded by great extent of wing-surface, but by the direction of motion.

One of the first birds in the scale of flying magnitude is the pelican. It is seen in the streams and estuaries of warm climates, fish being its only food. On the Nile, after the inundation, it arrives in flocks of many hundreds together, having migrated from long distances. A specimen shot was found to weigh twenty-one pounds, and measured ten feet across the wings, from end to end. The pelican rises with much difficulty, but, once on the wing, appears to fly with very little exertion, notwithstanding its great weight. Their mode of progress is peculiar and graceful. They fly after a leader, in one single train. As he rises or descends, so his followers do the same in succession, imitating his movements precisely. At a distance, this gives them the appearance of a long undulating ribbon, glistening under the cloudless sun of an oriental sky. During their flight they make about seventy strokes per minute with their wings. This uncouth-looking bird is somewhat whimsical in its habits. Groups of them may be seen far above the earth, at a distance from the river-side, *soaring*, apparently for their own pleasure. With outstretched and motionless wings, they float serenely, high in the atmosphere, for more than an hour together, traversing the same locality in circling movements. With head thrown back, and enormous bills resting on their breasts, they almost seem asleep. A few easy strokes of their wings each minute, as their momentum or velocity diminishes, serves to keep them sustained at the same level. The effort required is obviously slight, and not confirmatory of the excessive amount of power said to be requisite for maintaining the flight of a bird of this weight and size. The pelican displays no symptom of being endowed with great strength, for when only slightly wounded it is easily captured, not having adequate power for effective resistance, but heavily flapping the huge wings, that should, as some imagine, give a stroke equal in vigour to the kick of a horse.

During a calm evening, flocks of spoonbills take their flight directly up the river's course; as if linked together in unison, and moved by the same impulse, they alter not their relative positions, but at less than fifteen inches above the water's surface, they speed swiftly by with ease and grace inimitable, a living sheet of spotless white. Let one circumstance be remarked,—though they have fleeted past at a rate of near thirty miles an hour, so little do they disturb the element in which they move, that not a ripple of the placid bosom of the river, which they almost touch, has marked their track. How wonderfully does their progress contrast with that of creatures who are compelled to drag their slow and weary way against the fluid a thousandfold more dense, flowing in strong and eddying current beneath them.

Our pennant droops listlessly, the wished-for north wind cometh not. According to custom we step on shore, gun in hand. A flock of white herons, or "buffalo-birds," almost within our reach, run a short distance from the pathway as we approach them. Others are seen perched in social groups upon the backs of the apathetic and mud-begrimed animals whose name they bear. Beyond the ripening dhourra crops which skirt the river-side, the land is covered with immense numbers of blue pigeons, flying to and fro in shoals, and searching for food with restless diligence. The musical whistle from the pinions of the wood-doves sounds cheerily, as they dart past with the speed of an arrow. Ever and anon are seen a covey of the brilliant, many-coloured partridges of the district, whose *long and pointed wings* give them a strength and duration of flight that seems interminable, alighting at distances beyond the possibility of marking them down, as we are accustomed to do with their plumper brethren at home. But still more remarkable is the spectacle which the sky presents. As far as the eye can reach it is dotted with birds of prey of every size and description. Eagles, vultures, kites and hawks, of manifold species, down to the small, swallow-like, insectivorous hawk common in the Delta, which skims the surface of the ground in pursuit of its insect prey. None seem bent on going forward, but all are soaring leisurely round over the same locality, as if the invisible element which supports them were their medium of rest as well as motion. But mark that object sitting in solitary state in the midst of yon plain: what a magnificent eagle! An approach to within eighty yards arouses the king of birds from his apathy. He partly opens his enormous wings, but stirs not yet from his station. On gaining a few feet more he begins to *walk* away, with half-expanded, but motionless wings. Now for the chance fire! A charge of No. 3 from 11 bore rattles audibly but ineffectively upon his densely feathered body; his walk increases to a run, he gathers speed with his slowly-waving wings, and eventually leaves the ground. Rising at a gradual inclination, he mounts aloft and sails majestically away to his place of refuge in the Lybian range, distant at least five miles from where he rose. Some fragments of feathers denote the spot where the shot had struck him. The marks of his claws are traceable in the sandy soil, as, at first with firm and decided digs, he forced his way, but as he lightened his body and increased his speed with the aid of his wings, the imprints of his talons gradually merged into long scratches. The measured distance from the point where these vanished, to the place where he had stood, proved that with all the stimulus that the shot must have given to his exertions, he had been compelled to run full twenty yards before he could raise himself from the earth.

Again the boat is under weigh, though the wind is but just sufficient to enable us to stem the current. An immense kite is soaring overhead, scarcely higher than the top of our lateen yard, affording a fine opportunity for contemplating his easy and unlaboured movements. The cook has now thrown overboard some offal. With a solemn swoop the bird descends and seizes it in his talons. How easily he rises again with motionless expanded wings, the mere force and momentum of his *descent* serving to raise him again to more than half-mast high. Observe him next, with lazy flapping wings, and head turned under his body; he is placidly devouring the pendant morsel from his foot, and calmly gliding onwards.

The Nile abounds with large aquatic birds of almost every variety. During a residence upon its surface for nine months out of the year, immense numbers have been seen to come and go, for the majority of them are migratory. Egypt being merely a narrow strip of territory, passing through one of the most desert parts of the earth, and rendered fertile only by the periodical rise of the waters of the river, it is probable that these birds make it their grand thoroughfare into the rich districts of Central Africa.

On nearing our own shores, steaming against a moderate head-wind, from a station abaft the wheel the movements of some half-dozen gulls are observed, following in the wake of the ship, in patient expectation of any edibles that may be thrown overboard. One that is more familiar than the rest comes so near at times that the winnowing of his wings can be heard; he has just dropped astern, and now comes on again. With the axis of his body exactly at the level of the eyesight, his every movement can be distinctly marked. He approaches to within ten yards, and utters his wild plaintive note, as he turns his head from side to side, and regards us with his jet black eye. But where is the angle or upward rise of his wings, that should compensate for his descending tendency, in a yielding medium like air? The incline cannot be detected, for, to all appearance, his wings are edgewise, or parallel to his line of motion, and he appears to skim along a *solid* support. No smooth-edged rails, or steel-tired wheels, with polished axles revolving in well oiled brasses, are needed here for the purpose of diminishing friction, for Nature's machinery has surpassed them all. The retarding effects of gravity in the creature under notice, are almost annulled, for he is gliding forward upon a *frictionless* plane. There are various reasons for concluding that the direct flight of many birds is maintained with a much less expenditure of power, for a high speed, than by any mode of progression.

The first subject for consideration is the proportion of surface to weight, and their combined effect in descending perpendicularly through the atmosphere. The datum is here based upon the consideration of *safety*, for it may sometimes be needful for a living being to drop passively, without muscular effort. One square foot of sustaining surface, for every pound of the total weight, will be sufficient for security.

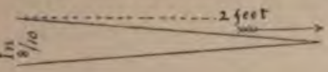
According to Smeaton's table of atmospheric resistances, to produce a force of *one pound* on a square foot, the wind must move against the plane (or, which is the same thing, the plane against the wind), at the rate of twenty-two feet per second, or 1,320 feet per minute, equal to fifteen miles per hour. The resistance of the air will now balance the weight on the descending surface, and, consequently, it cannot exceed that speed. Now, twenty-two feet per second is the velocity acquired at the *end* of a fall of eight feet — a height from which a well-knit man or animal may leap down without much risk of injury. Therefore, if a man with parachute weigh together 143 lbs., spreading the same number of square feet of surface contained in a circle fourteen and a half feet in diameter, he will descend at perhaps an unpleasant velocity, but with safety to life and limb.

It is a remarkable fact how this proportion of wing-surface to weight extends throughout a great variety of the flying portion of the animal kingdom, even down to hornets, bees, and other insects. In some instances, however, as in the gallinaceous tribe, including pheasants, this area is somewhat exceeded, but they are known to be very poor flyers. Residing as they do chiefly on the ground, their wings are only required for short distances, or for raising them or easing their descent from their roosting-places in forest trees, the *shortness* of their wings preventing them from taking extended flights. The wing-surface of the common swallow is rather more than in the ratio of *two* square feet per pound, but having also great length of pinion, it is both swift and enduring in its flight. When on a rapid course this bird is in the habit of furling its wings into a narrow compass. The greater extent of surface is probably needful for the continual variations of speed and instant stoppages requisite for obtaining its insect food.

On the other hand, there are some birds, particularly of the duck tribe, whose wing-surface but little exceeds *half* a square foot, or seventy-two inches per pound, yet they may be classed among the strongest and swiftest of flyers. A weight of one pound, suspended from an area of this extent, would acquire a velocity due to a fall of 16 feet — a height sufficient for the destruction or injury of most animals. But when the plane is urged forward horizontally, in a manner analogous to the wings of a bird during flight, the sustaining power is greatly influenced by *the form and arrangement* of the surface.

In the case of *perpendicular* descent, as a parachute, the sustaining effect will be much the same, whatever the figure of the outline of the superficies may be, and a circle perhaps affords the best resistance of any. Take for example a circle of 20 square feet (as possessed by the pelican) loaded with as many pounds. This, as just stated, will limit the rate of perpendicular descent to 1,320 feet per minute. But instead of a circle 61 inches in diameter, if the area is bounded by a parallelogram 10 feet long by 2 feet broad, and whilst at perfect freedom to descend perpendicularly, let a force be applied exactly in a horizontal direction, so as to carry it edgeways, with the long side foremost, at a forward speed of 30 miles per hour — just double that of its passive descent: the rate of fall under these conditions will be decreased most remarkably, probably to less than $\frac{1}{15}$th part, or 88 feet per minute, or one mile per hour.

The annexed line represents transversely the plane 2 feet wide and 10 feet long, moving in the direction of the arrow



with a forward speed of 30 miles per hour, or 2,640 feet per minute, and descending at 88 feet per minute, the ratio being as 1 to 30. Now, the particles of air, caught by the forward edge of the plane, must be carried down $\frac{8}{10}$ths of an inch before they leave it. This stratum, 10 feet wide and 2,640 long, will weigh not less than 134 lbs.; therefore the weight has continually to be moved downwards, 88 feet per minute, from a state of absolute rest. If the plane, with this weight and an upward rise of $\frac{8}{10}$ths of an inch, be carried forward at a rate of 30 miles per hour, it will be maintained at the same level without descending.

The following illustrations, though referring to the action of surfaces in a denser fluid, are yet exactly analogous to the conditions set forth in air: —

Take a stiff rod of wood, and nail to its end at right angles a thin lath or blade, about two inches wide. Place the rod square across the thwarts of a rowing-boat in motion, letting a foot or more of the blade hang perpendicularly over the side into the water. The direct amount of resistance of the current against the flat side of the blade may thus be felt. Next slide the rod to and fro thwart ship, keeping all square; the resistance will now be found to have increased enormously; indeed, the boat can be entirely stopped by such an appliance. Of course the same experiment may be tried in a running stream.

Another familiar example may be cited in the lee-boards and sliding keels used in vessels of shadow draught, *which act precisely on the same principle as the plane or wing-surface of a bird when moving in air.* These surfaces, though parallel to the line of the vessel's course, enable her to carry a heavy press of sail without giving way under the side pressure, or making lee-way, so great is their resistance against the rapidly passing body of water, which cannot be deflected sideways at a high speed.

The succeeding experiments will serve further to exemplify the action of the same principle. Fix a thin blade, say one inch wide and one foot long, with its plane exactly midway and at right angles, to the end of a spindle or rod. On thrusting this through a body of water, or immersing it in a stream running in the direction of the axis of the spindle, the resistance will be simply that caused by the water against the mere superficies of the blade. Next put the spindle and blade in rapid rotation. The retarding effect against direct motion will now be increased near *tenfold*, and is equal to that due *to the entire area of the circle of revolution*. By trying the effect of blades of various widths, it will be found that, for the purpose of effecting the maximum amount of resistance, the more rapidly the spindle revolves the narrower may be the blade. There is a specific ratio between the *width* of the blade and its *velocity*. It is of some importance that this should be precisely defined, not only for its practical utility in determining the best proportion of width to speed in the blades of screw-propellers, but also for a correct demonstration of the principles involved in the subject now under consideration; for it may be remarked that the swiftest-flying birds possess extremely long and *narrow* wings, and the slow, heavy flyers short and wide ones.

In the early days of the screw-propeller, it was thought requisite, in order to obtain the advantage of the utmost extent of surface, that the end-view of the screw should present no opening, but appear as a complete disc. Accordingly, some were constructed with one or two threads, making an entire or two half-revolutions; but this was subsequently found to be a mistake. In the case of the two blades, the length of the screw was shortened, and consequently the width of the blades reduced, with increased effect, till each was brought down to considerably less than *one-sixth* of the circumference or area of the entire circle; the maximum speed was then obtained. Experiment has also shown that the effective propelling area of the two-bladed screw is tantamount to its entire circle of revolution, and is generally estimated as such.

Many experiments tried by the author, with various forms of screws, applied to a small steam-boat, led to the same conclusion — that the two blades of one-sixth of the circle gave the best result.

All screws reacting on a fluid such as water, must cause it to yield to some extent; this is technically known as "slip," and whatever the ratio or per-centage on the speed of the boat may be, it is tantamount to *just so much loss of propelling power* — this being consumed in giving motion to the water instead of the boat.

On starting the engine of the steam-boat referred to, and grasping a mooring-rope at the stern, it was an easy matter to hold it back with one hand, though the engine was equal in power to five horses, and the screw making more than 500 revolutions per minute. The whole force of the steam was absorbed in "slip," or in giving motion to the column of water; but let her go, and allow the screw to find an abutment on a fresh body of water, not having received a gradual motion, and with its *inertia undisturbed* when running under full way, the screw worked almost as if in a solid nut, the "slip" amounting to only eleven per cent.

The laws which control the action of inclined surfaces, moving either in straight lines or circles in *air*, are identical, and serve to show the inutility of attempting to raise a heavy body in the atmosphere by means of rotating vanes or a screw acting vertically; for unless the ratio of surface compared to weight is exceedingly extensive, the whole power will be consumed in "slip," or in giving a downward motion to the column of air. Even if a sufficient force is obtained to keep a body suspended by such means, yet, after the desired altitude is arrived at, *no further ascension* is required; there the apparatus is to remain stationary as to level, and its position on the constantly yielding support can only be maintained at an enormous expenditure of power, for the screw cannot obtain a hold upon a *fresh and unmoved* portion of air in the same manner as it does upon the body of water when propelling the boat at full speed; its action under these conditions is the same as when the boat is held fast, in which case, although the engine is working up to its usual rate, the tractive power is almost annulled.

Some experiments made with a screw, or pair of inclined vanes acting vertically in air, were tried, in the following manner. To an upright post was fixed a frame, containing a bevil wheel and pinion, multiplying in the ratio of three to one. The axle of the wheel was horizontal, and turned by a handle of five-and-a-half inches radius. The spindle of the pinion rotated vertically, and carried two driving-pins at the end of a cross-piece, so that the top resembled the three prongs of a trident. The upright shaft of the screw was bored hollow to receive the middle prong, while the two outside ones took a bearing against a driving-bar, at right angles to the lower end of the shaft, the top of which ended in a long iron pivot, running in a socket fixed in a beam overhead; it could thus rise and fall about two inches with very little friction. The top of the screw-shaft carried a cross-arm, with a blade of equal size at each extremity, the distance from end to end being six feet. The blades could be adjusted at any angle by clamping-screws. Both their edges, and the arms that carried them, were bevilled away to a sharp edge to diminish the effects of atmospheric resistance. A wire stay was taken from the base of each blade to the bottom of the upright shaft, to give rigidity to the arms, and to prevent them from springing upwards. With this apparatus experiments were made with weights attached to the upright screw-shaft, and the blades set at different pitches, or angles of inclination. When the vanes were rotated rapidly, they rose and floated on the air, carrying the weights with them. Much difficulty was experienced in raising a heavy weight by a comparatively small extent of surface, moving at a high velocity; the "slip" in these cases being so great as to absorb all the power employed. The utmost effect obtained in this way was to raise a weight of six pounds on one square foot of sustaining surface, the planes having been set at a coarse pitch. To keep up the rotation, required about half the power a man could exert.

The ratio of weight to sustaining surface was next arranged in the proportion approximating to that of birds. Two of the experiments are here quoted, which gave the most satisfactory result. Weight of wings and shaft, 17½ oz.; area of two wings, 121 inches — equal to 110 square inches per pound. The annexed figures are given approximately, in order to avoid decimal fractions: —

	No. of revolutions per minute.	Mean sustaining speed. Miles per hour.	Feet per minute.	Pitch or angle of rise in one revolution. Inches.	Ratio of pitch to speed.	Slip per cent.
1st Experiment	210	38	3,360	26	⅛th nearly	12½
2nd Do.	240	44	3,840	15	$\frac{1}{13}$th Do.	8

The power required to drive was nearly the same in both experiments — about equal to one-sixteenth part of a horse-power, or the third part of the strength of a man, as estimated by a constant force on the handle of twelve pounds in the first experiment, and ten in the second, the radius of the handle being five-and-a-half inches, and making seventy revolutions per minute in the first case, and eighty in the other.

These experiments are so far satisfactory in showing the small pitch or angle of rise required for sustaining the weight stated, and demonstrating the principle before alluded to, of the slow descent of planes moving horizontally in the atmosphere at high velocities; but the question remains to be answered, concerning the disposal of the excessive power consumed in raising a weight not exceeding that of a carrier pigeon, for unless this can be satisfactorily accounted for, there is but little prospect of finding an available power, of sufficient energy in its application to the mechanism, for raising apparatus, either experimental or otherwise, in the atmosphere. In the second experiment, the screw-shaft made 240 revolutions, consequently, one vane (there being two) was constantly passing over the *same spot* 480 times each minute, or eight times in a second. This caused a descending current of air, moving at the rate of near four miles per hour, almost sufficient to blow a candle out placed three feet underneath. This is the result of "slip," and the giving both a downward and rotary motion to this column of air, will account for a great part of the power employed, as the whole apparatus performed the work of a blower. If the wings, instead of travelling in a circle, could have been urged continually forward in a straight line in a fresh and unmoved body of air the "slip" would have been so inconsiderable, and the pitch consequently, reduced to such a small angle, as to add but little to the direct forward atmospheric resistance of the edge.

The small flying screws, sold as toys, are well known. It is an easy matter to determine approximately the force expended in raising and maintaining them in the atmosphere. The following is an example of one constructed of tin-plate with three equidistant vanes. This was spun by means of a cord, wound round a wooden spindle, fitted into a forked handle as usual. The outer end of the coiled string was attached to a small spring steelyard, which served as a handle to pull it out by. The weight, or degree at which the index had been drawn, was *afterwards* ascertained by the mark left thereon by a pointed brass wire. It is not necessary to know the *time* occupied in drawing out the string, as this item in the estimate may be taken as the duration of the ascent; for it is evident that if the same force is re-applied at the descent, it would rise again, and a repeated series of these impulses will represent the power required to prolong the flight of the instrument. It is, therefore, requisite to know the length of string, and the force applied in pulling it out. The following are the data: —

Diameter of screw	8½ inches.
Weight of ditto	396 grains.
Length of string drawn out	2 feet.
Force employed	8 lbs.
Duration of flight	16 seconds.

From this it may be computed that, in order to maintain the flight of the instrument, a constant force is required of near sixty foot-pounds per minute — in the ratio of about three horse-power for each hundred pounds raised by such means. The force is perhaps over-estimated for a larger screw, for as the size and weight is increased, the power required would be less than in this ratio. The result would be more satisfactory if tried with a sheet-iron screw, impelled by a descending weight.

Methods analogous to this have been proposed for attempting aerial locomotion; but experiment has shown that a screw rotating in the air is an imperfect principle for obtaining the means of flight, and supporting the needful weight, for the power required is enormous. Suppose a machine to be constructed, having some adequate supply of force, the screw rotating vertically at a certain velocity will raise the whole. When the desired altitude is obtained, nearly the same velocity of revolution, and the same excessive power, must be continued, and consumed *entirely in "slip,"* or in drawing down a rapid current of air.

If the axis of the screw is slightly inclined from the perpendicular, the whole machine will travel forward. The "slip," and consequently the power, is somewhat reduced under these conditions; but a swift forward speed cannot be effected by such means, for the resistance of the inclined disc of the screw will be very great, far exceeding any form assimilating to the edge of the wing of a bird. But, arguing on the supposition that a forward speed of thirty miles an hour might thus be obtained, even then nearly all the power would be expended in giving an unnecessary and rapid revolution to an immense screw, capable of raising a weight, say of 200 pounds. The weight alone of such a machine must cause it to fail, and every revolution of the screw is a subtraction from the much-desired direct forward speed. A simple narrow blade, or inclined plane, propelled in a direct course at *this* speed — which is amply sufficient for sustaining heavy weights — is the best, and, in fact, the only means of giving the maximum amount of supporting power with the least possible degree of "slip," and direct forward resistance. Thousands of examples in Nature testify its success, and show the principle in perfection; — apparently the only one, and therefore beyond the reach of amendment, the wing of a bird, combining a propelling and supporting organ in one, each perfectly efficient in its mechanical action.

This leads to the consideration of the amount of power requisite to maintain the flight of a bird. Anatomists state that the pectoral muscles for giving motion to the wings are excessively large and strong; but this furnishes no proof of the expenditure of a great amount of force in the act of flying. The wings are hinged to the body like two powerful levers, and some counteracting force of a *passive* nature, acting like a spring under tension, must be requisite merely to balance the weight of the bird. It cannot be shown that, while there is no active motion, there is any real exertion of muscular force; for instance, during the time when a bird is soaring with motionless wings. This must be considered as a state of equilibrium, the downward spring and elasticity of the wings serving to support the body; the muscles, in such a case, performing like stretched india-rubber springs would do. The motion or active power required for the performance of flight must be considered exclusive of this.

It is difficult, if not impossible, by any form of dynamometer, to ascertain the precise amount of force given out by the wings of birds; but this is perhaps not requisite in proof of the principle involved, for when the laws governing their movements in air are better understood, it is quite possible to demonstrate, by isolated experiments, the amount of power required to sustain and propel a given weight and surface at any speed.

If the pelican referred to as weighing twenty-one pounds, with near the same amount of wing-area in square feet, were to descend perpendicularly, it would fall at the rate of 1,320 feet per minute, being limited to this speed by the resistance of the atmosphere.

The standard generally employed in estimating power is by the rate of descent of a weight. Therefore, the weight of the bird being 21 pounds, which, falling at the above speed will expend a force on the air set in motion nearly equal to one horse (.84 HP.) or that of 5 men; and conversely, to raise this weight again perpendicularly upon a yielding support like air, would require even more power than this expression, which it is certain that a pelican does not possess; nor does it appear that any *large* bird has the faculty of raising itself on the wing *perpendicularly* in a still atmosphere. A pigeon is able to accomplish this nearly, mounting to the top of a house in a very narrow compass; but the exertion is evidently severe, and can only be maintained for a short period. For its size, this bird has great power of wing; but this is perhaps far exceeded in the humming-bird, which, by the extremely rapid movements of its pinions, sustains itself for more than a minute in still air in one position. The muscular force required for this feat is much greater than for any other performance of flight. The body of the bird at the time is nearly vertical. The wings uphold the weight, not by striking vertically downwards upon the air, but as inclined surfaces reciprocating horizontally like a screw, but wanting in its continuous rotation in one direction, and, in consequence of the loss arising from rapid alternations of motion, the power required for the flight will exceed that specified in the screw experiment before quoted, viz.: three horse-power for every 100 pounds raised.

We have here an example of the exertion of enormous animal force expended in flight, necessary for the peculiar habits of the bird, and for obtaining its food; but in the other extreme, in large heavy birds, whose wings are merely required for the purposes of migration or locomotion, flight is obtained with the least possible degree of power, and this condition can only be commanded by a rapid straightforward course through the air.

The sustaining power obtained in flight must depend upon certain laws of action and reaction between relative weights; the weight of a bird, balanced, or finding an abutment, against the fixed inertia of a far greater weight of air, continuously brought into action in a given time. This condition is secured, not by extensive surface, but by great length of wing, which, in forward motion, takes a support upon a wide stratum of air, extending transversely to the line of direction.

The pelican, for example, has wings extending out 10 feet. If the limits of motion imparted to the substratum of air, acted upon by the incline of the wing, be assumed as one foot in thickness, and the velocity of flight as 30 miles per hour, or 2,640 feet per minute, the stratum of air passed over in this time will weigh nearly one ton, or 100 times the weight of the body of the bird, thus giving such an enormous supporting power, that the comparatively small weight of the bird has but little effect in deflecting the heavy length of stratum downwards, and, therefore, the higher the velocity of flight the less the amount of "slip," or power wasted in compensation for descent.

As noticed at the commencement of this paper, large birds may be observed to skim close above smooth water without ruffling the surface; showing that during rapid flight the air does not give way beneath them, but approximates towards a solid support.

In all inclined surfaces, moving rapidly through air, the whole sustaining power approaches toward the front edge; and in order to exemplify the inutility of surface alone, without proportionate length of wing, take a plane, ten feet long by two broad, impelled with the narrow end forward, the first twelve or fifteen inches will be as efficient at a high speed in supporting a weight as the entire following portion of the plane, which may be cut off, thus reducing the effective wing-area of a pelican, arranged in this direction, to the totally inadequate equivalent of two-and-a-half square feet.

One of the most perfect natural examples of easy and long-sustained flight is the wandering albatross. "A bird for endurance of flight probably unrivalled. Found over all parts of the Southern Ocean, it seldom rests on the water. During storms, even the most terrific, it is seen now dashing through the whirling clouds, and now serenely floating, without the least observable motion of its outstretched pinions." The wings of this bird extend fourteen or fifteen feet from end to end, and measure only eight-and-a-half inches across the broadest part. This conformation gives the bird such an extraordinary sustaining power, that it is said to *sleep* on the wing during stormy weather, when rest on the ocean is impossible. Rising high in the air, it skims slowly down, with absolutely motionless wings, till a near approach to the waves awakens it, when it rises again for another rest.

If the force expended in actually sustaining a long-winged bird upon a wide and unyielding stratum of air, during rapid flight, is but a small fraction of its strength, then nearly the whole is exerted in overcoming direct forward resistance. In the pelican referred to, the area of the body, at its greatest diameter, is about 100 square inches; that of the pinions, eighty. But as the contour of many birds during flight approximates nearly to Newton's solid of least resistance, by reason of this form, acting like the sharp bows of a ship, the opposing force against the wind must be reduced down to one third or fourth part; this gives one-tenth of a horse-power, or about half the strength of a man, expended during a flight of thirty miles per hour. Judging from the action of the living bird when captured, it does not appear to be more powerful than here stated.

The transverse area of a carrier pigeon during flight (including the outstretched wings) a little exceeds the ratio of twelve square inches for each pound, and the wing-surface, or sustaining area, ninety square inches per pound.

Experiments have been made to test the resisting power of conical bodies of various forms, in the following manner: — A thin lath was placed horizontally, so as to move freely on a pivot set midway; at one end of the lath a circular card was attached, at the other end a sliding clip traversed, for holding paper cones, having their bases the exact size of the opposite disc. The instrument acted like a steelyard; and when held against the wind, the paper cones were adjusted at different distances from the centre, according to their forms and angles, in order to balance the resistance of the air against the opposing flat surface. The resistance was found to be diminished nearly in the ratio that the height of the cone exceeded the diameter of base.

It might be expected that the pull of the string of a flying kite should give some indication of the force of inclined surfaces acting against a current of air; but no correct data can be obtained in this way. The incline of the kite is far greater than ever appears in the case of the advancing wing-surface of a bird. The tail is purposely made to give steadiness by a strong pull backwards from the action of the wind, which also exerts considerable force on the suspended cord, which for more than half its length hangs nearly perpendicularly. But the kite, as a means of obtaining unlimited lifting and tractive power, in certain cases where it might be usefully applied, seems to have been somewhat neglected. For its power of raising weights, the following quotation is taken from Vol. XLI. of the *Transactions of the Society of Arts*, relating to Captain Dansey's mode of communicating with a lee-shore. The kite was made of a sheet of holland exactly nine feet square, extended by two spars placed diagonally, and as stretched spread a surface of fifty-five square feet." "The kite, in a strong breeze, extended 1,100 yards of line five-eighths in circumference, and would have extended more had it been at hand. It also extended 360 yards of line, one and three-quarters of an inch in circumference, weighing sixty pounds. The holland weighed three and a half pounds; the spars, one of which was armed at the head with iron spikes, for the purpose of mooring it, six and three-quarter pounds; and the tail was five times its length, composed of eight pounds of rope and fourteen of elm plank, weighing together twenty-two pounds."

We have here the remarkable fact of ninety-two and a quarter pounds carried by a surface of only fifty-five square feet.

As all such experiments bear a very close relation to the subject of this paper, it may be suggested that a form of kite should be employed for reconnoitring and exploring purposes, in lieu of balloons held by ropes. These would be torn to pieces in the very breeze that would render a kite most serviceable and safe. In the arrangement there should be a smaller and upper kite, capable of sustaining the weight of the apparatus. The lower kite should be as nearly as practicable in the form of a circular flat plane, distended with ribs, with a car attached beneath like a parachute. Four guy-ropes leading to the car would be required for altering the angle of the plane — vertically with respect to the horizon, and laterally relative to the direction of the wind. By these means the observer could regulate his altitude, so as to command a view of a country, in a radius of at least twenty miles; he could veer to a great extent from side to side, from the wind's course, or lower himself gently, with the choice of a suitable spot for descent. Should the cord break, or the wind fail, the kite would, in either case, act as a parachute, and as such might be purposely detached from the cord, which then being sustained from the upper kite, could be easily recovered. The direction of descent could be commanded by the guy-ropes, these being hauled taut in the required direction for landing.

The author has good reasons for believing that there would be less risk associated with the employment of this apparatus, than the reconnoitring balloons that have now frequently been made use of in warfare.[1]

[1] The practical application of these suggestions appears to have been anticipated some years previously. In a small work, styled the "History of the Charvolant, or Kite Carriage," published by Longman and Co., appear the following remarks: — "These buoyant sails, possessing immense power, will, as we have before remarked, serve for floating observatories. . . . Elevated in the air, a single sentinel, with a perspective, could watch and report the advance of the most powerful forces, while yet at a great distance. He could mark their line of march, the composition of their force, and their general strength, long before he could be seen by the enemy." Again, at page 53, we have an account of ascents actually made, as follows: — "Nor was less progress made in the experimental department, when large weights were required to be raised or transposed. While on this subject, we must not omit to observe that the first person who soared aloft in the air by this invention was a lady, whose courage would not be denied this test of its strength. An arm-chair was brought on the ground, then lowering the cordage of the kite by slackening the lower brace, the chair was firmly lashed to the mainline, and the lady took her seat. The main-brace being hauled taut, the huge buoyant sail rose aloft with its fair burden, continuing to ascend to the height of 100 yards. On descending, she expressed herself much pleased with the easy motion of the kite, and the delightful prospect she had enjoyed. Soon after this, another experiment of a similar nature took place, when the inventor's son successfully carried out a design not less safe than bold; that of scaling, by this powerful aërial machine, the brow of a cliff 200 feet in perpendicular height. Here, after safely landing, he again took his seat in a chair expressly prepared for the purpose, and, detaching the swivel-line, which kept it at its elevation, glided gently down the cordage to the hand of the director. The buoyant sail employed on this occasion was thirty feet in height, with a proportionate spread of canvas. The rise of the machine was most majestic, and nothing could surpass the steadiness with which it was manœuvred; the certainty with which it answered the action of the braces, and the ease with which its power was lessened or increased. . . . Subsequently to this, an experiment of a very bold and novel character

The wings of all flying creatures, whether of birds, bats, butterflies, or other insects, have this one peculiarity of structure in common. The front, or leading edge, is rendered rigid by bone, cartilage, or a thickening of the membrane; and in most birds of perfect flight, even the individual feathers are formed upon the same condition. In consequence of this, when the wing is waved in air, it gives a persistent force in one direction, caused by the elastic reaction of the following portion of the edge. The fins and tails of fishes act upon the same principle. In the most rapid swimmers these organs are termed "lobated and pointed." The tail extends out very wide transversely to the body, so that a powerful impulse is obtained against a wide stratum of water, on the condition before explained. This action is imitated in Macintosh's screw-propeller, the blade of which is made of thin steel, so as to be elastic. While the vessel is stationary, the blades are in a line with the keel, but during rotation they bend on one side, more or less, according to the speed and degree of propulsion required, and are thus self-compensating; and could practical difficulties be overcome, would prove to be a form of propeller perfect in theory.

In the flying mechanism of beetles there is a difference of arrangement. When the elytra, or wing-cases, are opened, they are checked by a stop, which sets them at a fixed angle. It is probable that these serve as "aeroplanes," for carrying the weight of the insect, while the delicate membrane that folds beneath acts more as a propelling than a supporting organ. A beetle cannot fly with the elytra removed.

The wing of a bird, or bat, is both a supporting and propel-

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was made upon an extensive down, where a wagon with a considerable load was drawn along, whilst this huge machine, at the same time, carried an observer aloft in the air, realising almost the romance of flying."

It may be remarked that the brace-lines here referred to were conveyed down the main-line and managed below; but it is evident that the same lines could be managed with equal facility by the person seated in the car above; and if the main-line were attached to a water-drag instead of a wheeled car, the adventurer could cross rivers, lakes, or bays, with considerable latitude for steering and selecting the point of landing, by hauling on the port or starboard brace-lines as required. And from the uniformity of the resistance offered by the water-drag, this experiment could not be attended with any greater amount of risk than a land flight by the same means.

ling organ, and flight is performed in a rapid course, as follows: — During the down-stroke it can be easily imagined how the bird is sustained; but in the up-stroke, the weight is also equally well supported, for in raising the wing, it is slightly inclined upwards against the rapidly passing air, and as this angle is somewhat in excess of the motion due to the raising of the wing, the bird is sustained as much during the up as the down-stroke — in fact, though the wing may be rising, the bird is still pressing against the air with a force equal to the weight of its body. The faculty of turning up the wing may be easily seen when a large bird alights; for after gliding down its aerial gradient, on its approach to the ground it turns up the plane of its wing against the air; this checks its descent, and it lands gently.

It has before been shown how utterly inadequate the mere perpendicular impulse of a plane is found to be in supporting a weight, when there is no horizontal motion at the time. There is no material weight of air to be acted upon, and it yields to the slightest force, however great the velocity of impulse may be. On the other hand, suppose that a large bird, in full flight, can make forty miles per hour, or 3,520 feet per minute, and performs one stroke per second. Now, during every fractional portion of that stroke, the wing is acting upon and obtaining an impulse from a fresh and undisturbed body of air; and if the vibration of the wing is limited to an arc of two feet, this by no means represents the small force of action that would be obtained when in a stationary position, for the impulse is secured upon a stratum of fifty-eight feet in length of air at each stroke. So that the conditions of weight of air for obtaining support equally well apply to weight of air, and its reaction in producing forward impulse.

So necessary is the acquirement of this horizontal speed, even in commencing flight, that most heavy birds, when possible, rise against the wind, and even run at the top of their speed to make their wings available, as in the example of the eagle, mentioned at the commencement of this paper. It is stated that the Arabs, on horseback, can approach near enough to spear these birds, when on the plain, before they are able to rise: their habit is to perch on an eminence, where possible.

The tail of a bird is not necessary for flight. A pigeon can fly perfectly with this appendage cut short off: it probably performs an important function in steering, for it is to be remarked, that most birds that have either to pursue or evade pursuit are amply provided with this organ.

The foregoing reasoning is based upon facts, which tend to show that the flight of the largest and heaviest of all birds is really performed with but a small amount of force, and that man is endowed with sufficient muscular power to enable him also to take individual and extended flights, and that success is probably only involved in a question of suitable mechanical adaptations. But if the wings are to be modelled in imitation of natural examples, but very little consideration will serve to demonstrate its utter impracticability when applied in these forms. The annexed diagram, Fig. 1, would be about the proportions needed for a man of medium weight. The wings, *a a*, must extend out sixty feet from end to end, and measure four feet across the broadest part. The man, *b*, should be in a horizontal position, encased in a strong framework, to which the wings are hinged at *c c*. The wings must be stiffened by elastic ribs, extending back from the pinions. These must be trussed by a thin band of steel, *e e*, Fig. 2, for the purpose of diminishing the weight and thickness of the spar. At the front, where the pinions are hinged, there are two levers attached, and drawn together by a spiral spring, *d*, Fig. 2, the tension of which is sufficient to balance the weight of the body and machine, and cause the wings to be easily vibrated by the movement of the feet acting on treadles. This spring serves the purpose of the pectoral muscles in birds. But with all such arrangements the apparatus must fail — *length of wing is indispensable!* and a spar thirty feet long must be strong, heavy, and cumbrous; to propel this alone through the air, at a high speed, would require more power than any man could command.

In repudiating all imitations of natural wings, it does not follow that the only channel is closed in which flying mechanism

FIG. 1.

FIG 2.

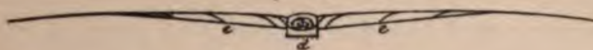

FIG. 3.

FIG. 4.

FIG. 6.

FIG. 5.

may prove successful. Though birds do fly upon definite mechanical principles, and with a moderate exertion of force, yet the wing must necessarily be a vital organ and member of the living body. It must have a marvellous self-acting principle of repair, in case the feathers are broken or torn; it must also fold up in a small compass, and form a covering for the body.

These considerations bear no relation to artificial wings; so in designing a flying-machine, any deviations are admissible, provided the theoretical conditions involved in flight are borne in mind.

Having remarked how thin a stratum of air is displaced beneath the wings of a bird in rapid flight, it follows that in order to obtain the necessary *length* of plane of supporting heavy weights, the surfaces may be superposed, or placed in parallel rows, with an interval between them. A dozen pelicans may fly one above the other without mutual impediment, as if framed together; and it is thus shown how two hundred weight may be supported in a transverse distance of only ten feet.

In order to test this idea, six bands of stiff paper, three feet long and three inches wide, were stretched at a slight upward angle, in a light rectangular frame, with an interval of three inches between them, the arrangement resembling an open Venetian blind. When this was held against a breeze, the lifting power was very great, and even by running with it in a calm it required much force to keep it down. The success of this model led to the construction of one of a sufficient size to carry the weight of a man. Fig. 3 represents the arrangement. *a a* is a thin plank, tapered at the outer ends, and attached at the base to a triangle, *b*, made of similar plank, for the insertion of the body. The boards, *a a*, were trussed with thin bands of iron, *c c*, and at the ends were vertical rods, *d d*. Between these were stretched five bands of holland, fifteen inches broad and sixteen feet long, the total length of the web being eighty feet. This was taken out after dark into a wet piece of meadow land, one November evening, during a strong breeze, wherein it became quite unmanageable. The wind acting upon the already tightly-stretched webs, their united pull caused the central boards to bend considerably, with a twisting, vibratory motion. During a lull, the head and shoulders were inserted in the triangle, with the chest resting on the base board. A sudden gust caught up the experimenter, who was carried some distance from the ground, and the affair falling over sideways, broke up the right-hand set of webs.

In all new machines we gain experience by repeated failures, which frequently form the stepping-stones to ultimate success. The rude contrivance just described (which was but the work of a few hours) had taught, first, that the webs, or aeroplanes, must not be distended in a frame, as this must of necessity be strong and heavy, to withstand their combined tension; second, that the planes must be made so as either to furl or fold up, for the sake of portability.

In order to meet these conditions, the following arrangement was afterwards tried: — *a a*, Figs. 4 and 5, is the main spar, sixteen feet long, half an inch thick at the base, and tapered, both in breadth and thickness, to the end; to this spar was fastened the panels *b b*, having a base-board for the support of the body. Under this, and fastened to the end of the main spar, is a thin steel tie-band, *e e*, with struts starting from the spar. This served as the foundation of the superposed aeroplanes, and, though very light, was found to be exceedingly strong; for when the ends of the spar were placed upon supports, the middle bore the weight of the body without any strain or deflection; and further, by a separation at the base-board, the spars could be folded back, with a hinge, to half their length. Above this were arranged the aeroplanes, consisting of six webs of thin holland, fifteen inches broad; these were kept in parallel planes, by vertical divisions, two feet wide, of the same fabric, so that when distended by a current of air, each two feet of web pulled in opposition to its neighbour; and finally, at the ends (which were each sewn over laths), a pull due to only two feet had to be counteracted, instead of the strain arising from the entire length, as in the former experiment. The end-pull was sustained by vertical rods, sliding through loops on the transverse ones at the ends of the webs, the whole of which could fall flat on the spar, till raised and distended by a breeze. The top was stretched by a lath, *f*, and the system kept vertical by staycords, taken from a bowsprit carried out in front, shown in Fig. 6. All the front edges of the aeroplanes were stiffened by bands of crinoline steel. This series was for the supporting arrangement, being equivalent to a length of wing of ninety-six feet. Exterior to this, two propellers were to be attached, turning on spindles just above the back. They are kept drawn up by a light spring, and pulled down by cords or chains, running over pulleys in the panels *b b*, and fastened to the end of a swivelling cross-yoke, sliding on the base-board. By working this cross-piece with the feet, motion will be communicated to the propellers, and by giving a longer stroke with one foot than the other, a greater extent of motion will be given to the corresponding propeller, thus enabling the machine to turn, just as oars are worked in a rowing boat. The propellers act on the same principle as the wing of a bird or bat: their ends being made of fabric, stretched by elastic ribs, a simple waving motion up and down will give a strong forward impulse. In order to start, the legs are lowered beneath the base-board, and the experimenter must run against the wind.

An experiment recently made with this apparatus developed a cause of failure. The angle required for producing the requisite supporting power was found to be so small, that the crinoline steel would not keep the front edges in tension. Some of them were borne downwards and more on one side than the other, by the operation of the wind, and this also produced a strong fluttering motion in the webs, destroying the integrity of their plane surfaces, and fatal to their proper action.

Another arrangement has since been constructed, having laths sewn in both edges of the webs, which are kept permanently distended by cross-stretchers. All these planes are hinged to a vertical central board, so as to fold back when the bottom ties are released, but the system is much heavier than the former one, and no experiments of any consequence have as yet been tried with it.

It may be remarked that although a principle is here defined, yet considerable difficulty is experienced in carrying the theory into practice. When the wind approaches to fifteen or twenty miles per hour, the lifting power of these arrangements is all that is requisite, and, by additional planes, can be increased to any extent; but the capricious nature of the ground-currents is a perpetual source of trouble.

Great weight does not appear to be of much consequence, *if carried in the body;* but the aeroplanes and their attachments seem as if they were required to be very light, otherwise, they are awkward to carry, and impede the movements in running and making a start. In a dead calm, it is almost impracticable to get sufficient horizontal speed, by *mere running* alone, to raise the weight of the body. Once off the ground, the speed must be an increasing one, if continued by suitable propellers. The small amount of experience as yet gained, appears to indicate that if the aeroplanes could be raised in detail, like a superposed series of kites, they would first carry the weight of the machine itself, and next relieve that of the body.

Until the last few months no substantial attempt has been made to construct a flying-machine, in accordance with the principle involved in this paper, which was written seven years ago. The author trusts that he has contributed something towards the elucidation of a new theory, and shown that the flight of a bird in its performance does not require that enormous amount of force usually supposed, and that in fact birds do not exert more power in flying than quadrupeds in running, but considerably less; for the wing movements of a large bird, travelling at a far higher speed in air, are very much slower; and, where weight is concerned, great velocity of action in the locomotive organs is associated with great force.

It is to be hoped that further experiments will confirm the correctness of these observations, and with a sound working theory upon which to base his operations, man may yet command the air with the same facility that birds now do.

The CHAIRMAN: "I think the paper just read is one of great interest and importance, especially as it points out the true mechanical explanation of the curious problem, as to how and why it is that birds of the most powerful flight always have the longest and narrowest wings. I think it quite certain, that if the air is ever to be navigated, it will not be by individual men flying by means of machinery; but that it is quite possible vessels may be invented, which will carry a number of men, and the motive force of which will not be muscular action. We must first ascertain clearly the mechanical principles upon which flight is achieved; and this is a subject which has scarcely ever been investigated in a scientific spirit. In fact, you will see in our best works of science, by the most distinguished men, the account given of the anatomy of birds is, that a bird flies by inflating itself with warm air, by which it becomes buoyant, like a balloon. The fact is, however, that a bird is never buoyant. A bird is immensely heavier than the air. We all know that the moment a bird is shot it falls to the earth; and it must necessarily do so, because one of the essential mechanical principles of flight is weight, without it there can be no momentum, and no motive force capable of moving through atmospheric currents.

"Until I read Mr. Wenham's paper, a few weeks since, I was puzzled by the fact, that birds with long and very narrow wings seem to be not only as efficient fliers, but much more efficient fliers than birds with very large, broad wings. If you observe the flight of the common heron — which is a bird with a very large wing, disposed rather in breadth than in length — you will notice that it is exceedingly slow, and that it has a very heavy, flapping motion. The common swallow, on the other hand, is provided with a long and narrow wing, and I never understood how it was that long-winged birds, such as these, achieved so rapid a flight, until I read Mr. Wenham's paper. Although I do not profess to be able to follow the elaborate calculations which he has laid before us, I think I now understand the explanation he has given. His explanation of the action of narrow wings upon the air is, that it is precisely like the action of the narrow vanes of the ship's screw in water, and that the resisting power of the screw is the same, or nearly the same, whether you have the total area of revolution covered by solid surface, or traversed by long and narrow vanes in rotation.

"If Mr. Wenham's explanation be nearly correct, that supposing this implement (referring to a model) to be carried forward by some propelling power, the sustaining force of the whole area is simply the sustaining force of the narrow band in front. This, however, is a matter which will have to be decided by experiment. It certainly appears to explain the phenomena of the flight of birds. There are one or two observations in the paper I do not quite agree with. Although I have studied the subject for many years, I have not arrived at Mr. Wenham's conclusion that the upward stroke of a bird's wing has precisely the same effect as a downward stroke in sustaining. An upward stroke has a contrary effect to the downward stroke; it has a propelling power certainly, but I believe that the sustaining power of a bird's flight is due entirely to the downward stroke. I should be glad to hear what Mr. Wenham may have to say upon this. My belief is, that an upward stroke must have, so far as sustaining is concerned, a reverse action to the downward stroke.

"Then with regard to another observation of Mr. Wenham's, that the tails of birds are used as rudders. I believe this to be an entire mistake; for if the tail of a bird could have the slightest effect in guiding, the vane of it must be disposed perpendicularly, and not horizontally, or nearly so, as at present.

"If you cut off the tail of a pigeon, you will find that he can fly and turn perfectly well without it. He may be a little awkward about it at first, but that is because he has lost his balancing power. We all know that it is a common thing to see a sparrow without his tail, therefore, I do not in the least believe that tails have any effect in guiding. They have an important effect in stopping progress, and, undoubtedly, that is one of the necessary elements of turning. If a bird comes close over your head, and is frightened, you will find his claws distended and his tail spread out as a fan, to stop the momentum of his flight. These are the two only observations with which I cannot agree; but as regards the explanation he has given as to the resistance offered by long and narrow wings, he has made an important discovery."

Mr. WENHAM: "With regard to the wing not affording support to the bird during the upward stroke, some of the largest birds move their wings slowly, that is, with a less number than sixty strokes per minute. Now, as a body free to fall must descend fifteen feet in one second, whether in horizontal motion or not, it appears clear to me that there must be some counteracting effect to prevent this fall. When the wing has reached the limit of the down-stroke, it is inclined upwards in the direction of motion, consequently the rush of air caused by the forward speed, weight, and momentum of the bird against the under surface of the wing, supports the weight, even though the wing is rising in the up-stroke at the time. In corroboration of my theory, I will read an extract from Sir George Cayley, who made a large number of experiments. He says, in page 83, of Vol. xxv., 'Nicholson's Journal': —'The stability in this position, arising from the centre of gravity, being below the point of suspension, is aided by a remarkable circumstance that experiment alone could point out. In very acute angles with the current, it appears that the centre of resistance in the sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases, these centres approach and coincide when the current becomes perpendicular to the plane, hence any heel of the machine backwards or forwards removes the centre of support behind or before the point of suspension.'

"From this discovery, it seems remarkable that Sir George Cayley, finding that at high speeds with very oblique incidences the supporting effect became transferred to the front edge, the idea should not have occurred to him that a narrow plane, with its long edge in the direction of motion, would have been equally effective. I may give another illustration. We all know, from our schoolboy experience, that ice which would not be safe to stand upon, is found to be quite strong enough to bear heavy bodies passing over it, so long as rapid motion is kept up, and then it will not even crack. We know, also, that in driving through a marshy part of road, in which you expect the wheels to sink in up to the axles, you may pass over much more easily by increasing the speed. In both these examples there is a greater weight passed over in a given time, and consequently a better support obtained. The ice will not become deflected; neither has the mud time to give way. At a slow speed the same effect may be obtained by extending the breadth of the wheel. Thus, suppose an ordinary wheel to sink ten inches, if you double this width it will sink only five inches; and so on, until by extending the wheel into a long roller you may pass over a quicksand with perfect safety. Now, Nature has carried out this principle in the long wings of birds, and in the albatross it is seen in perfection."

SORCERIES.

A. A Witch.
B. A Spirit raised by the Witch.
C. A Friar raising his Imps.
D. A Fairy Ring.
E. A Witch rideing on the Devill through the Aire.
F. An Inchanted Castle.

Let warlocks grim, an' wither'd hags
Tell how wi' you, on ragweed nags,
They skim the muirs an' dizzy crags
Wi' wicked speed,
And in kirk-yards renew their leagues
Oure howkit dead.

Burns.

FRANKLIN'S AERONAUTICAL CORRESPONDENCE.[1]

(*From Sir Joseph Banks to B. Franklin.*)

BALLOONS.

SOHO SQUARE, 13 Sept., 1783.

DEAR SIR: The having it in my power to answer with precision the numerous questions which are asked me by all sorts of people concerning the aerostatic experiment, which, such as they may be, are suggested by every newspaper now printed here, and considered as a part of my duty to answer, is an obligation for which I am indebted to you, and an obligation of no small extent. I lament that the vacation of the Royal Society will not permit me to lay your paper before them as a body immediately; but it shall be the first thing they see when we meet again, as the conciseness and intelligence with which it is drawn up preclude the hopes of anything more satisfactory being received.

Most agreeable are the hopes you give me of continuing to communicate on this most interesting subject. I consider the present day, which has opened a road into the air, as an epoch from whence a rapid increase of the stock of human knowledge must take its date; and that it will have an immediate effect upon the concerns of mankind, greater than anything since the invention of shipping, which opened our way on the face of the water from land to land.

If the rough effort which has been made admits of the improvement that other sciences have received we shall see it used as a counterpoise to absolute gravity, and a broad wheeled wagon travelling with two only, instead of eight horses, the

[1] From *The Works of Benjamin Franklin*, by Jared Sparks, 10 vols., Boston, 1838.

breed of that rival animal in course being diminished, and the human species increased in proportion.

I have thought, as soon as I return from my present banishment, of constructing one and sending it up for the purpose of an electrical kite, a use to which it seems particularly adapted. Be pleased to direct your favors to Soho Square; they are sent to me without delay wherever I am. Believe me, your obliged, etc.

JOSEPH BANKS.

(*From the Same to the Same.*)

ASCENT OF A BALLOON.

SOHO SQUARE, 28 Nov., 1783.

DEAR SIR: I am in truth much indebted to you for the favor you have done me in transmitting the copy of the *procès verbal* on Montgolfier's experiment, which I have this moment received. The experiment becomes now interesting in no small degree. I laughed when balloons, of scarce more importance than soap bubbles, occupied the attention of France; but when men can with safety pass and do pass more than five miles in the first experiment, I begin to fancy that I espy the hand of the master in the education of the infant of knowledge, which so speedily attains such a degree of maturity, and do not scruple to guess that my old friend, who used to assist me when I was younger, has had some share in the success of this enterprise.

On Tuesday last a miserable taffeta balloon was let loose here under the direction of a Mr. Zambeccari, an Italian nobleman, as I hear. It was ten feet in diameter, and filled with inflammable air made from the filings of iron and vitriolic acid. The silk was oiled, the seams covered with tar, and the outside gilt. It had been shown for several days floating about in a public room, at a shilling for the sight, and half a crown for the admission when it should be let loose.

The day was fine; the wind a gentle breeze from the north. At a few minutes after one o'clock it set out, and before night fell at a small village near Petworth in Sussex, having run over about forty-eight miles of country. The countryman, who first saw it, observed it in its descent. It appeared at first small, and, increasing fast, surprised him so much that he ran away. He returned, however, and found it burst by the expansion of the contained fluid.

I wish I had somewhat more interesting to tell you of, but I am this moment risen from the dinner, which I annually give to the auditors of the treasurer's account. I would not delay my thanks to you, and I trust you will make some allowance for the effects of the festivities of the day, which have, I fear, cramped my accuracy; but I can assure you they have not diminished the real gratitude, with which I declare myself your obliged and faithful servant.

JOSEPH BANKS.

(From B. Franklin to John Ingenhousz.)

ON BALLOONS, AND THEIR PROBABLE IMPORTANCE.

PASSY, 16 Jan., 1784.

DEAR FRIEND: I have this day received your favor of the 2d instant. Every imformation in my power, respecting the balloons, I sent you just before Christmas contained in copies of my letters to Sir Joseph Banks. There is no secret in the affair, and I make no doubt that a person coming from you would easily obtain a sight of the different balloons of Montgolfier and Charles, with all the instructions wanted; and if you undertake to make one, I think it extremely proper and necessary to send an ingenious man here for that purpose; otherwise, for want of attention to some particular circumstance, or of not being acquainted with it, the experiment might miscarry, which, in an affair of so much public expectation, would have bad consequences, draw upon you a great deal of censure, and affect your reputation.

It is a serious thing to draw out from their affairs all the inhabitants of a great city and its environs, and a disappointment makes them angry. At Bordeaux lately a person pretended to send up a balloon, and had received money from many people, but not being able to make it rise, the populace were so exasperated that they pulled down his house, and had like to have killed him.

It appears, as you observe, to be a discovery of great importance and what may possibly give a new turn to human affairs. Convincing sovereigns of the folly of wars may, perhaps, be one effect of it, since it will be impracticable for the most potent of them to guard his dominions. Five thousand balloons, capable of raising two men each, could not cost more than five ships of the line; and where is the prince who can afford so to cover his country with troops for its defence, as that ten thousand men descending from the clouds might not in many places do an infinite deal of mischief before a force could be brought together to repel them? It is a pity that any national jealousy should, as you imagine it may, have prevented the English from prosecuting the experiment, since they are such ingenious mechanicians, that in their hands it might have made a more rapid progress towards perfection, and all the utility it is capable of affording.

The balloon of Messrs. Charles and Robert was really filled with inflammable air. The quantity being great it was expensive and tedious filling, requiring two or three days' and nights' constant labor.

It had a *soupape*, or valve, near the top which they could open by pulling a string and thereby let out some air when they had a mind to descend; and they discharged some of their ballast of sand when they would rise again. A great deal of air must have been let out when they landed so that the loose part might envelop one of them; yet, the car being lightened by that one getting out of it, there was enough left to carry up the other rapidly. They had no fire with them. That is used only in M. Montgolfier's globe which is open at the bottom and straw constantly burnt to keep it up. This kind is sooner and cheaper filled, but must be of much greater dimensions to carry up the same weight, since air rarefied by heat is only twice as light as common air, and inflammable air ten times lighter. M. Mor-

Plate X.

CARICATURE OF THE ASCENT OF THE FIRST AERIAL TRAVELLERS.

See page 124.

veau, a famous chemist at Dijon, has discovered an inflammable air that will cost only a twenty-fifth part of the price of what is made by oil of vitriol poured on iron filings. They say it is made from sea-coal. Its comparative weight is not mentioned.

I am, as ever, my dear friend,

Yours most affectionately,

B. FRANKLIN.

(*From Francis Hopkinson to B. Franklin.*)

AMERICAN PHILOSOPHICAL SOCIETY. — DEFECTS IN THE USUAL METHODS OF TEACHING LANGUAGES. — BALLOONS.

PHILADELPHIA, 24 May, 1784.

DEAR FRIEND: I cannot suffer so good an opportunity to pass without renewing my assurances of the love and respect I have for you, mine and my father's steady friend.

. . . .

We have been diverting ourselves with raising paper balloons by means of burnt straw, to the great astonishment of the populace. This discovery, like electricity, magnetism, and many other important phenomena, serves for amusement at first; its uses and applications will hereafter unfold themselves. There may be many mechanical means of giving the balloon a progressive motion other than what the current of wind would give it. Perhaps this is as simple as any: Let the balloon be constructed of an oblong form, something like the body of a fish, or of a bird, or a wherry, and let there be a large and light wheel in the stern, vertically mounted. This wheel should consist of many vanes or fans of canvas, whose planes should be considerably inclined with respect to the plane of its motion exactly like the wheel of a smoke-jack. If the navigator turns this wheel swiftly around by means of a winch, there is no doubt but it would (in a calm at least), give the machine a progressive motion upon the same principle that a boat is sculled through the water.

But my paper is almost out and perhaps your patience. If you can spare time let me know that I live in your remembrance. Any philosophical communications will highly gratify me, and be thankfully received by our society, who expect their president will now and then favor them with his notice. Are we to hope that you will revisit your native country, or not; that country for which you have done and suffered so much? Whilst there is any virtue left in America, the names of Franklin and Washington will be held in the highest esteem. Adieu, and be assured that there is no one who loves you more than your faithful and affectionate

FRANCIS HOPKINSON.

(*From B. Franklin to Richard Price.*)

BALLOONS.—ENGLISH CONSTITUTION.—STATE OF AMERICA.

PASSY, 16 August, 1784.

DEAR FRIEND: I some time since answered your kind letter of July 12th, returning the proof of Mr. Turgot's letter, with the permission of his friends to print it. I hope it came safe to hand. I had before received yours of April, which gave me great pleasure, as it acquainted me with your welfare and that of Dr. Priestley.

The commencement here of the art of flying will, as you observe, be a new epoch. The construction and manner of filling the balloons improve daily. Some of the artists have lately gone to England. It will be well for your philosophers to obtain from them what they know, or you will be behindhand; which in mechanic operations is unusual for Englishmen.

I hope the disagreements in our Royal Society are composed. Quarrels often disgrace both sides; and disputes, even on small matters, often produce quarrels for want of knowing how to differ decently; an art which it is said scarce anybody possesses but yourself and Dr. Priestley.

I had indeed thoughts of visiting England once more, and of enjoying the great pleasure of seeing again my friends there; but my malady, otherwise tolerable, is I find irritated by the

Plate XI.

THE LANDING.

motion in a carriage, and I fear the consequence of such a journey; yet I am not quite resolved against it. I often think of the agreeable evenings I used to pass with that excellent collection of good men, the club at the *London*, and wish to be again among them. Perhaps I may pop in some Thursday evening when they least expect me. You may well believe it very pleasing to me to have Dr. Priestley associated with me among the foreign members of the Academy of Sciences. I had mentioned him upon every vacancy that has happened since my residence here, and the place has never been bestowed more worthily.

. . . .

Many thanks for your kind wishes respecting my health and happiness, which I return fourfold, being ever with the sincerest esteem, my dear friend, your most affectionate

B. FRANKLIN.

(*From Richard Price to B. Franklin.*)

SINKING FUND. — BALLOONS.

NEWINGTON GREEN, 21 October, 1784.

MY DEAR FRIEND: . . . .

We have at last begun to fly here. Such an ardor prevails that probably we shall soon, in this instance, leave France behind us. Dr. Priestley, in a letter which I have just received from him, tells me that he is eager in pursuing his experiments, and that he has discovered a method of filling the largest balloons with the lighest inflammable air in a very short time and at a very small expense.

. . . .

With the highest regard, I am ever yours,

RICHARD PRICE.

(*To James Bowdoin.*)

DR. JEFFRIES' AERIAL VOYAGE FROM ENGLAND TO FRANCE.

PHILADELPHIA, 1 Jan., 1786.

MY DEAR FRIEND: It gave me great pleasure to receive your kind letter of congratulation as it proved that all my old friends in Boston were not estranged from me by the malevolent misrepresentations of my conduct that had been circulated there, but that one of the most esteemed still retained a regard for me. Indeed, you are now almost the only one left me by nature, death having, since we were last together, deprived me of my dear Cooper, Winthróp, and Quincy.

. . . .

I sent to you by Mr. Gerry, some weeks since, Dr. Jeffries' account of his aerial voyage from England to France which I received from him just before I left that country. In his letter, that came with it, he requests I would not suffer it to be printed, because a copy of it had been put into the hands of Sir Joseph Banks for the Royal Society and was to be read there in November.

. . . .

My acquaintance with Dr. Jeffries began by his bringing me a letter in France, the first through the air, from England. With best wishes of many happy new years to you and good Madam Bowdoin, I have the honor to be, dear Sir, etc.,

B. FRANKLIN.

EXPERIMENT MADE AT VERSAILLES BY M. MONTGOLFIER, ON THE 19TH OF SEPTEMBER, 1783.

From Des Ballons Aerostatiques, Lausanne, 1784.

A FEW WORDS ABOUT A GREAT HOPE.

THE foregoing Franklin letters show the spirit of their time, and tell, better than any words which can be written at this day, of that great hope which in later years gradually gave way to disappointment. We can hardly wonder that when men first saw the balloon they supposed that the aerial ship of the future had been launched. It must have seemed the most marvellous of all human inventions, and it cannot surprise us that in the Montgolfier decade the flights of men's fancies were taken to heights even dizzier than those reached by their "aerostatic machines."

In our minds the balloon is associated with the gazing multitude at a country fair, and the aeronaut is one of the showmen; but, a century ago, many of those who made ascents were among the most learned men of science, and they risked their lives in singleness of purpose, hoping that they might wrest secrets from dear old Mother Nature, and so add to the sum of human knowledge, which is the sum of human good.

As early as 1766 Henry Cavendish, of England, as a result of his experiments with inflated bladders, stated the specific gravity of inflammable air (hydrogen gas) to be about one-eleventh that of common air.

In November, 1782, at Avignon, France, Stephen Montgolfier caused a silken bag filled with hot air to ascend to the ceiling of his room. A short time after at Annonay, in company with his younger brother Joseph, he repeated the experiment and caused the bag to ascend to a height of about seventy feet.

On the 25th of April, 1783, the same experimenters successfully sent a larger balloon, thirty-five feet in diameter, to a height of about one thousand feet. On the 5th of the following

June, at Annonay, this experiment was repeated "in the presence of a respectable assembly, and a great multitude of people." The balloon is said to have reached a height of six thousand feet. Cavallo says: "This public experiment, recorded with all the accuracy it deserves, was immediately announced to the world; accounts of it were sent to the court of France, to several members of the Academy of Sciences, and almost wherever literary and entertaining correspondence could reach."

On the 27th of August, 1783, the first hydrogen gas balloon was successfully sent up. This was constructed by two brothers of the name of Robert, under the superintendence of M. Charles, professor of natural philosophy in Paris, and afterwards a member of the Academy of Sciences.

The first ascent of living creatures was made at Versailles on the 19th of September, 1783, in the presence of the king, the queen, the court, and an immense number of spectators. The "Boston Magazine" of June and September, 1784, gives an account of the experiment and also the caricatures shown here in Plates X. and XI. The imposing spectacle is more accurately represented in Plate XII. Suspended below the balloon was a cage in which the first aerial travellers were placed, a sheep, a cock, and a duck; according to the magazine just mentioned, "Montgolfier's air balloon having ascended to an amazing height above the clouds and being carried in the air forty-five degrees fell down near a cottage where the poor country people were exceedingly frightened and astonished; the cock, the sheep, and the duck came out of the basket which had been tied to it, unhurt."

The following is quoted from the writings of Mr. James Glaisher, F.R.S.: "The first human being who ascended in a balloon was M. François Pilâtre de Rozier, a young naturalist, who two years afterwards was killed in an attempt to cross the English Channel in a balloon. On Oct. 15, 1783, and following days, he made several ascents (generally alone but once with a companion, M. Girond de Villette) in a captive balloon, and demonstrated that there was no difficulty in taking up fuel

AEROSTATIC MACHINE, 70 FEET IN HEIGHT AND 46 FEET IN DIAMETER, WHICH ASCENDED FROM PARIS, WITH TWO MEN, TO A HEIGHT OF 324 FEET, ON THE 19TH OF OCTOBER, 1783.

From Des Ballons Aerostatiques, Lausanne, 1784.

and feeding the fire, which was kindled in a brazier suspended under the balloon, when in the air. The way being thus prepared for aerial navigation, on Nov. 21, 1783, M. Pilâtre de Rozier and the Marquis d'Arlandes first trusted themselves to a free fire balloon. The experiment was made from the Jardin du Chateau de la Muette in the Bois de Boulogne. The machine employed, which was a large fire balloon, was inflated at about two o'clock, and leaving the earth at this time, it rose to a height of about five hundred feet, and passing over the Invalides and the École Militaire, descended beyond the Boulevards, about 9,000 yards from the place of ascent, having been between twenty and twenty-five minutes in the air. The result was completely successful; and it is scarcely necessary to add, the excitement in Paris was very great.

"Only ten days later, viz., on Dec. 1, 1783, MM. Charles and Robert ascended from Paris in a balloon inflated with hydrogen gas."

All this was the beginning of the great hope which has been alluded to. More than a century has gone by, no fulfilment of the hope has come, and now it is the custom to speak of the balloon as a useless thing; *but perhaps we have not yet learned how to use it.* Of course we now know that we cannot drive it against an average wind, yet the ANNUAL ventures the assertion that it is just as unreasonable to speak derisively of the balloon as it would be to comment unfavorably upon a floating dock because of the inability of the latter to win a prize in a yacht race.

Sir John Herschel wrote: "There are epochs in the history of every great operation and in the course of every undertaking to which the coöperations of successive generations of men have contributed (especially such as have received their increments at various and remote periods of history), when it becomes desirable to pause for a while, and, as it were, to take stock; to review the progress made, and estimate the amount of work done; not so much for complacency, as for the purpose of forming a judgment of the efficiency of the methods resorted [illegible] and to what end, is to inquire how they may yet be improved, if such improvement be possible, to accelerate the furtherance of the subject, or to ensure the ultimate perfection of its attainments. In scientific no less than in material and social undertakings, such pauses and *résumés* are eminently useful, and are sometimes forced on our considerations by a conjuncture of circumstances which almost of necessity obliges us to take a *coup d'œil* of the whole subject, and make up our minds not only as to the validity of what is done, but of the manner in which it has been done, the methods employed, and the direction in which we are henceforth to proceed, and probability of further progress."

If in our efforts to solve the great problem of aerial navigation we act in this spirit we are sure to progress, though, perhaps, because of the great difficulty of our task, we must content ourselves with slow advancement.

LANGLEY'S LAW.

THE following is quoted from the third page of Langley's "Experiments in Aerodynamics:"[1]

"To prevent misapprehension, let me state at the outset that I do not undertake to explain any art of mechanical flight, but to demonstrate experimentally certain propositions in aerodynamics which prove that such flight, under proper direction, is practicable. This being understood, I may state that these researches have led to the result that mechanical sustentation of heavy bodies in the air, combined with very great speeds, is not only possible, but within the reach of mechanical means we actually possess, and that while these researches are, as I have said, not meant to demonstrate the art of guiding such heavy bodies in flight, they do show that we now have the power to sustain and propel them.

"Further than this, these new experiments (and theory, also, when reviewed in their light) show that if in such aerial motion, there be given a plane of fixed size and weight, inclined at such an angle, and moved forward at such a speed, that it shall be sustained in horizontal flight, then the more rapid the motion is, the *less* will be the power required to support and advance it. This statement may, I am aware, present an appearance so paradoxical that the reader may ask himself if he has rightly understood it. To make the meaning quite indubitable, let me repeat it in another form, and say that these experiments show that a definite amount of power so expended at any constant rate, will attain more economical results at high speeds than at low ones, *e.g.*, one horse-power thus employed will transport a larger weight at twenty miles an hour than at ten, a still larger

[1] Washington, 1891.

at forty miles than at twenty, and so on, with an increasing economy of power with each higher speed, up to some remote limit not yet attained in experiment, but probably represented by higher speeds than have as yet been reached in any other mode of transport — a statement which demands and will receive the amplest confirmation later in these pages."

Since Samuel Pierpont Langley has, beyond any question, been the first to discover, to state, and to prove this great law of the economy of high speeds, the editor feels justified in naming it *Langley's Law*.

DARWIN'S OBSERVATIONS.

UNDER the date of April 27, 1834, in his journal[1] kept during the voyage of the "Beagle" round the world, Mr. Darwin, after considering the manner in which vultures[2] find their food, writes as follows:

"Often when lying down to rest on the open plains, on looking upwards I have seen carrion-hawks sailing through the air at a great height. Where the country is level I do not believe a space of the heavens of more than fifteen degrees above the horizon is commonly viewed with any attention by a person either walking or on horseback. If such be the case, and the vulture is on the wing at a height of between three and four thousand feet, before it could come within the range of vision, its distance in a straight line from the beholder's eye would be rather more than two British miles. Might it not thus readily be overlooked? When an animal is killed by the sportsman in a lonely valley, may he not all the while be watched from above by the sharp-sighted bird? And will not the manner of its descent proclaim throughout the district to the whole family of carrion-feeders that their prey is at hand?

"When the condors are wheeling in a flock round and round any spot, their flight is beautiful. Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima, I watched several for nearly half an hour without once taking off my eyes. They moved in large curves, sweeping in circles, descending and ascending without giving a single flap. As they glided close over my head, I

[1] A Naturalist's Voyage. Journal of Researches into the Natural History and Geology of the countries visited during the voyage of H.M.S. "Beagle" round the World. By Charles Darwin, M.A., F.R.S. London. 1845.

[2] Concerning vultures see the writings of L. P. Mouillard mentioned in article on Bibliography on pages 137 and 138 of the ANNUAL.

intently watched from an oblique position the outlines of the separate and great terminal feathers of each wing; and these separate feathers, if there had been the least vibratory movement, would have appeared as if blended together; but they were seen distinct against the blue sky.[1]

"The head and neck were moved frequently, and apparently with force; and the extended wings seemed to form the fulcrum on which the movements of the neck, body, and tail acted. If the bird wished to descend, the wings were for a moment collapsed; and when again expanded with an altered inclination, the momentum gained by the rapid descent seemed to urge the bird upwards with the even and steady movement of a paper kite. In the case of any bird *soaring*, its motion must be sufficiently rapid, so that the action of the inclined surface of its body on the atmosphere may counterbalance its gravity. The force to keep up the momentum of a body moving in a horizontal plane in the air (in which there is so little friction) cannot be great, *and this force is all that is wanted*.[2]

"The movement of the neck and body of the condor, we must suppose, is sufficient for this. However this may be, it is truly wonderful and beautiful to see so great a bird, hour after hour, without any apparent exertion, wheeling and gliding over mountain and river."

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[1] *Note by the Editor of the* ANNUAL.—Many writers have expressed the opinion that birds which soar with wings apparently motionless derive support, nevertheless, from a vibratory movement of the feathers, and such writers instance the buzzing of the soaring turkey-buzzard as a fact in favor of their theory. Last summer one of my soaring machines had a slight defect in the textile covering of the aerocurves, and when in rapid motion it gave forth a loud buzzing sound, answering quite well to the description which is given of the buzzard's buzzing. I think that a loose feather in a soaring bird's wing would make a similar sound.

[2] These words are italicized by the editor for the purpose of calling attention to the opinion in regard to flight which Darwin held sixty years ago.

WISE UPON HENSON.

THE machine shown in the accompanying plate was patented by Mr. Henson in England in 1842.

Mr. John Wise, in his book entitled "A System of Aeronautics" (Phila., 1850), writes concerning it as follows:

"The next which is worthy of consideration we find in Henson's idea. Many persons in England were sanguine in the belief that his machine was destined to perfect the art of aerial navigation, and it was seriously contemplated to build one after his model, with which to cross the Atlantic. Indeed, it was well calculated to inspire such a belief in the mere theoretical mind, but to the practical man it at once occurs, What is to keep it from tilting over in losing its balance by a flaw of wind, or any other casualty, and thus tumbling to the ground, admitting that it could raise itself up and move forward?

"The principal feature of the invention is the very great expanse of its sustaining planes, which are larger, in proportion to the weight it has to carry, than those of many birds; but if they had been still greater, they would not have sufficed of themselves to sustain their own weight, to say nothing of their machinery and cargo; surely, though slowly, they would have come to the ground. The machine advances with its front edge a little raised; the effect of which is to present its under surface to the air over which it is passing, the resistance of which, acting on it like a strong wind on the sails of a windmill, prevents the descent of the machine and its burden. The sustaining of the whole, therefore, depends upon the speed at which it is travelling through the air, and the angle at which its under surface impinges on the air in its front; and this is exactly the principle by which birds are upheld in their flight with but slight motion of their wings, and often with none.

"But, then, this result, after the start, depends entirely on keeping up the speed, and there remains beyond that, the still more formidable difficulty of first obtaining that speed. All former attempts of this kind have failed, because no engine existed that was at once light enough and powerful enough to lift even its own weight through the air with the necessary rapidity. Mr. Henson has removed this difficulty, partly by inventing a steam-engine of extreme lightness and efficiency, and partly by another and very singular device, which requires particular notice. The machine, fully prepared for flight, is started from the top of an inclined plane, in descending which it attains a velocity necessary to sustain it in its further progress. That velocity would be gradually destroyed by the resistance of the air to the forward flight; it is, therefore, the office of the steam-engine and the vanes it actuates simply to repair the loss of velocity; it is made, therefore, only of the power and weight necessary for that small effect. Here, we apprehend, is the chief, but not the only merit and originality of Mr. Henson's invention; and to this happy thought we shall probably be indebted for the first successful attempt to traverse at will another domain of nature."

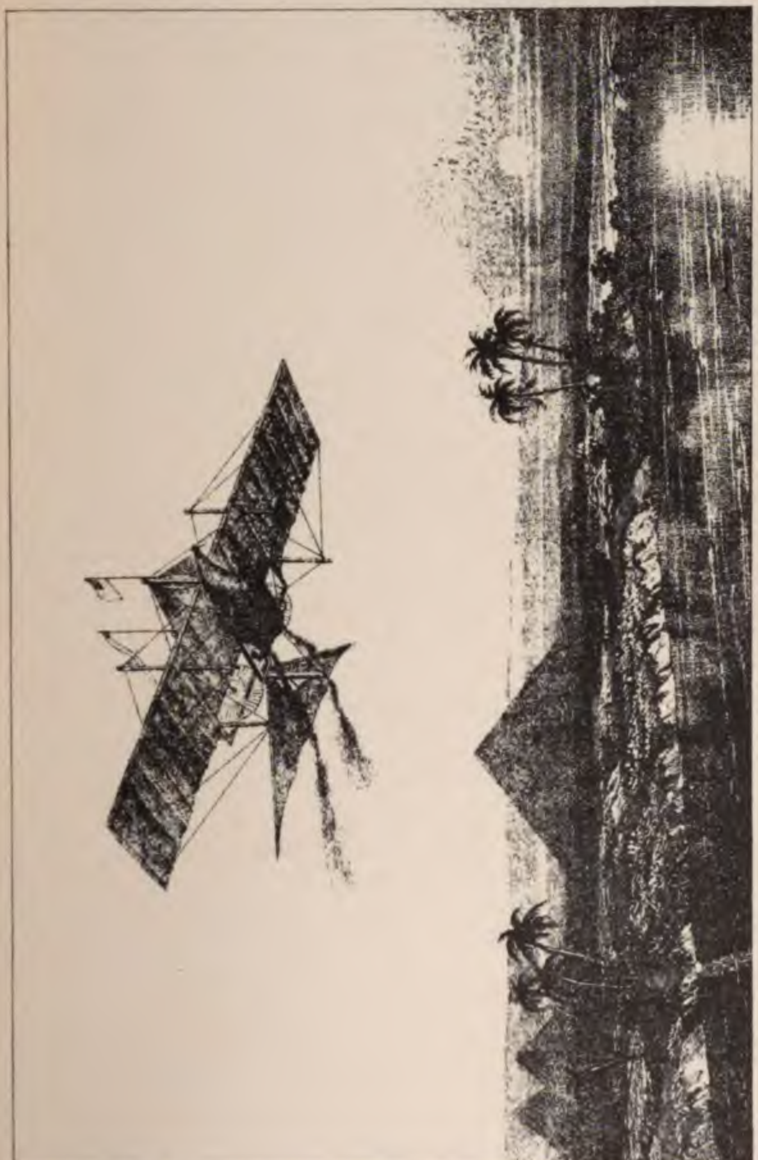
In the "Popular Science Review," 1869, Vol. VIII., p. 1, Mr. F. W. Brearey states that this machine was never constructed.[1]

The account of it is given in this ANNUAL partly because of the interest which attaches to Mr. Henson's plans on account of their date, and partly for the sake of showing what Mr. Wise thought of the combination of an aeroplane with a steam-engine.

Nine years after the publication of his book, Mr. Wise with John La Mountain made one of the most famous balloon voyages on record. They left St. Louis on July 1, 1859; "the States of Illinois and Indiana were passed over in the night and Ohio was reached in the morning. The balloon then passed across Lake Erie into New York, and to Lake Ontario, into

[1] See "Progress in Flying Machines," Chanute, p. 84.

Plate XIV.



HENSON'S PROJECTED FLYING MACHINE. 1842.

which it descended, but rose again, and a landing was made in Henderson, Jefferson County, N.Y. The time occupied in making this journey was nineteen hours and fifty minutes, and the distance traversed 1,150 miles, or 826 in an air line."[1]

Twenty years later, in 1879, Mr. Wise again ascended from St. Louis, this time in the "Pathfinder." He was last seen to pass over Illinois in a northeasterly direction, and is supposed to have perished in Lake Michigan. James Glaisher wrote of him: "In America Mr. Wise is *par excellence* the aeronaut; he has made several hundred ascents, and many of them are distinguished for much skill and daring. He also appears to have pursued his profession with more energy and capacity than has any other aeronaut in recent times, and his 'History of Aerostation' shows him to possess much higher scientific attainments than balloonists usually have. In fact, Mr. Wise stands alone in this respect, as nearly all professional aeronauts are destitute of scientific knowledge."

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[1] Appleton's Cyclopædia of American Biography, Vol. III., p. 602. See also Vol. VI., p. 581.

A TABLE OF WIND VELOCITIES,

FOR THE YEAR 1892.

Compiled from the Report of the Chief of the Weather Bureau, 1891-92.

MAXIMUM VELOCITIES ARE FOR A FIVE-MINUTE PERIOD. A WIND VELOCITY OF 40 MILES PER HOUR IS CONSIDERED A GALE.

	Average for the year. Miles per hour.	Maximum monthly average. Miles per hour.	Minimum monthly average. Miles per hour.	Maximum velocity.	Number of days with gales.
Boston, Mass.	12.0	15.9 in March.	9.6 in July.	48	8
Buffalo, N.Y.	10.9	13.7 in December.	8.4 in August.	55	26
Chattanooga, Tenn.	5.1	7.5 in April.	3.4 in September.	35	0
Chicago, Ill.	16.8	22.2 in April.	13.2 in June.	72	59
Cleveland, O.	11.1	15.6 in November.	8.2 in March.	64	16
Denver, Col.	7.4	9.1 in April.	5.3 in February.	48	3
New Orleans, La.	8.8	12.0 in April.	6.0 in August.	50	5
New York, N.Y.	10.8	14.6 in March.	6.9 in August.	49	6
Pittsburgh, Pa.	6.5	8.4 in November.	4.6 in July.	38	0
Portland, Me.	8.4	10.9 in March.	7.2 in August.	45	4
Portland, Ore.	6.0	9.2 in November.	4.6 in January.	41	2
St. Louis, Mo.	11.0	13.4 in January.	8.1 in August.	48	13
San Francisco, Cal.	8.7	12.0 in July.	4.5 in January.	60	6
Savannah, Ga.	7.8	9.0 in April.	6.2 in August.	32	0

LA MINERVE vaisseau aérien destiné aux decouvertes par le professeur Robertson
Die Minerva, ein Luftschif welches durch Professor Robertson zu einer Entdekung bestimt ist
man sehe die Erklärung nach.

CARICATURE FROM ASTRA CASTRA. LONDON, 1865.

Reference notes not given.

BIBLIOGRAPHY OF AERONAUTICS.

As stated in the opening article, the earliest written records of the study of natural and artificial flight are to be found in the MSS. of Leonardo da Vinci. The following-named work contains all that has so far been published concerning the master's researches in this direction: *I MANOSCRITTI DI LEONARDO DA VINCE. CODICE SUL VOLO DEGLI UCCELLI, e varie altre materie pubblicato da Teodoro Sabachnikoff. Transcrizioni e note di Giovanni Piumati Traduzione in Lingua Francese di Carlo Ravaisson-Mollieu. PARIGI, EDOARDO ROUVEYRE EDITORE.* MDCCCXCIII.

A list containing the names of publications dating from 1627 to 1865, more than seventy-five in number, is to be found on pp. 463–464 of *Astra Castra, Experiments and Adventures in the Atmosphere*, by Hatton Turnor. London, 1865. The compiler designates seventeen of these works by an asterisk, and states in a foot-note that "These books are at the service of the public in the library of the Patent Office, Southampton Buildings, E.C."

Among the seventeen is the following: 1855, *George James Norman: Aeronautica Illustratica, a Complete Cabinet of Aerial Ascents and Descents, from the Earliest Periods to the Present Time.* 10 large folio vols. London.

In a note Mr. Turnor says: "The cost of making this collection exceeded £300. It was twice sold by auction, and bought the second time for the library of the Patent Office for £26. The collector is a young man in somewhat distressed circumstances. To his industry the author owes the greater part of his own collection, as they were the duplicates that necessarily accumulate in so extensive a collection."

Among the rarer works which the editor of the ANNUAL has in his collection are the following:

Des Ballons Aérostatiques,[1] *de la Manière de les Construire, de les faire élever: avec quelques vues pour les vendre utiles.* Lausanne, 1784.

An Account of the First Aerial Voyage in England; with autograph. By Vincent Lunardi, Esq. London, 1784.

The History and Practice of Aerostation. By Tiberius Cavallo, F.R.S. London, 1785.

A Treatise upon Aerostatic Machines. By John Southern. Birmingham, 1785.

An Account of Five Aerial Voyages in Scotland.[1] By Vincent Lunardi, Esq. London, 1786.

A Journal of Natural Philosophy, Chemistry and the Arts. By William Nicholson. 35 vols. London, 1802 to 1813.

A System of Aeronautics, comprehending its earliest investigations, and modern practice and art. Designed as a history for the common reader, and guide to the student of the art. In three parts. Containing an account of the various attempts in the art of flying by artificial means from the earliest period down to the discovery of the aeronautic machine by the Montgolfiers, in 1782, and to a later period.

With a brief history of the author's fifteen years' experience in aerial voyages. Also, full instructions in the art of making balloons, parachutes, etc., etc., as adapted to the practice of aerial navigation, and directions to prepare experimental balloons. By John Wise, Aeronaut. 13 plates, 310 pp. Philadelphia, 1850.

Reports of the Aeronautical Society of Great Britain. One to twenty-three, in twenty-one parts. Eighteenth and nineteenth reports in one part; twentieth and twenty-first reports in one part. London, 1866–1893. See lists of publications given in the above.

The best of the world's knowledge of aeronautics is to be found in the two thousand pages of these reports. The organization has never been a large one, and probably years will pass by before the importance of its twenty-nine years of work will be fully understood and appreciated. Even as the missal

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[1] Kindly given by Dr. J. R. C.

painters kept art alive during the Dark Ages, so has this band of men kept aeronautics alive during the years in which their branch of science has been by the many regarded almost as a pseudo-science. The editor wishes to make the fullest acknowledgment of the debt he owes to this society.

On the Various Modes of Flight in Relation to Aeronautics. By Dr. James Bell Pettigrew. A paper read before the Royal Institution of Great Britain, March 22, 1867. See also *Animal Locomotion; or Walking, Swimming and Flying.* By the same author. No. 8 in the International Scientific Series. 130 illustrations. $1.75. Appleton, New York.

Animal Mechanism. A treatise on terrestrial and aerial locomotion. By E. J. Marey, Professor at the College of France. No. 11 in the International Scientific Series. 117 illustrations. $1.75. Appleton, New York.

Aerial Navigation. By the late Charles Blachford Mansfield, M.A. Edited by his brother, Robert Blachford Mansfield, with a preface by J. M. Ludlow. London, 1877.

Aerial Navigation. By Edmund Clarence Stedman. Century Magazine, New York, 1879.

The Empire of the Air. By L. P. Mouillard. 66 pp. In Annual Report of the Board of Regents of the Smithsonian Institution to July, 1892. Washington, 1893. Original published in Paris in 1881.

Experiments in Aerodynamics. By Samuel Pierpont Langley. This memoir (No. 801, Smithsonian Series) forms part of Volume XXVII., Smithsonian Contributions to Knowledge. Washington, 1891.

This monumental work is so well known that it needs no notice here.

Aerial Navigation. By Octave Chanute, C.E. 36 pp. New York, 1891.

The Possibility of Mechanical Flight. By S. P. Langley. Century Magazine, New York, September, 1891.

Aerial Navigation. The Power Required. By Hiram S. Maxim. Century Magazine, New York, October, 1891.

The Aeroplane. By Hiram S. Maxim. The Cosmopolitan Magazine, New York, June, 1892.

Aerial Navigation. By John P. Holland. The Cosmopolitan Magazine, New York, November, 1892.

Aeronautics. A monthly journal. 12 numbers. October, 1893–September, 1894. Containing papers read at the Chicago Conference on Aerial Navigation, and other valuable matter. M. N. Forney, editor and proprietor, 47 Cedar street, New York.

American Engineer and Railroad Journal. Monthly. This publication devotes several pages of each issue to the subject of aeronautics. The publisher states that Mr. O. Chanute, C.E., of Chicago, has consented to act as associate editor of this department, and will be a frequent contributor to it. Those who are fortunate enough to be familiar with the work which Mr. Chanute has done in the past will need no further words to awaken their interest in this publication. Price, 25 cents per copy, $3.00 annual subscription. M. N. Forney, publisher, 47 Cedar street, New York.

Engineering News. New York. In the columns of this paper the editor, Mr. A. M. Wellington, has printed valuable matter concerning the mechanics of flight. See the issue of Oct. 12, 1893, *et seq.* It is regretted that a lack of complete files of this paper make a more extended notice impossible at this time.

The Internal Work of the Wind. By Samuel Pierpont Langley. Published by the Smithsonian Institution, Washington, 1893.

Zeitschrift für Luftschiffahrt und Physic der Atmosphere. By Otto Lilienthal. Berlin, 1894.

The Maxim Air-Ship. An interview with the inventor. By H. J. W. Dam. McClure's Magazine, New York, January, 1894.

Gliding Flight. By L. P. Mouillard. Cosmopolitan Magazine, New York, February, 1894.

New Lights on the Problem of Flying. By Prof. Joseph LeConte. The Popular Science Monthly, New York, April, 1894.

Progress in Flying Machines. By Octave Chanute, C.E. 308 pp., 85 illustrations. $2.50. Published by the American Engineer and Railroad Journal, 47 Cedar street, New York, 1894. "A history of the efforts that have been made to solve the problem of aerial flight, from the first recorded experiments to the present time." The appendix contains Herr Lilienthal's own account of his 1893 experiments.

This book is one of the most important which has ever been published touching the problem of aerial navigation.

Contents. — General Principles. — Wings and Parachutes. — Screws to Lift and Propel. — Aeroplanes (177 pp.). — Conclusion. — Appendix.

The Development of Aerial Navigation. By Hiram S. Maxim. The North American Review, New York, September, 1894.

The Flying Man. Otto Lilienthal's Flying Machine, by Vernon. Illus. McClure's Magazine, New York, September, 1894.

The Evolution of a Flying Machine. By Hiram S. Maxim. A paper read before the Mechanical Science Section of the British Association, at Oxford, Aug. 10, 1894. Reprinted in the Boston Evening Transcript, Sept. 8, 1894.

Aerial Navigation. By A. F. Zahm, of Johns Hopkins University. Pph., 32 pp. A lecture delivered before the Franklin Institute, Jan. 5, 1894. Philadelphia, 1894.

Aerial Navigation. By J. G. W. Fijnje van Salverda. Translated from the Dutch by George E. Waring, Jr. New York, 1894, Appleton.

Teoria del volo e della navigazione aera. By A. Faccioli. 8vo. Milano, 1894.

THE ROC.

From Lane's Arabian Nights. London, 1853.

A GLIMPSE OF THE FUTURE.

From Astra Castra. London, 1865.

[*Reprint of a pamphlet published in January, 1894.*]

THE
PROBLEM OF MANFLIGHT.

BY

JAMES MEANS

THE FLIGHT OF OTTO LILIENTHAL, OF STEGLITZ, PRUSSIA, AS ACTUALLY ACCOMPLISHED IN 1893. ACCURATELY DRAWN FROM AN INSTANTANEOUS PHOTOGRAPH.

BOSTON, MASS.:
W. B. CLARKE & CO.,
340 WASHINGTON STREET.
1894.

THE PROBLEM OF MANFLIGHT.

As the century draws to its close the interest in the subject of aeronautics steadily increases. There already exists a keen curiosity to know what the aerial machine of the future is likely to resemble, and also to know whether the nineteenth or the twentieth century will claim it for its own.

In the present article the writer wishes to show what inferences may be drawn from the laws of nature as so far ascertained by observation and experiment, and he wishes also to point out a way which may lead to further progress.

The investigators of this subject are now divided into two camps: on the one side there are men who, like Mr. Maxim, are endeavoring to construct machines which will carry motors and therefore be self-propelling; on the other side there are men like Mr. A. M. Wellington, who maintains that a motor is unnecessary and that wind-power is sufficient.

In the New York Engineering News, of Oct. 12, 1893, Mr. Wellington, in a very interesting article entitled "The Mechanics of Flight," makes the following statement: "If the conclusions so far reached in this paper be accepted, it is obvious that they greatly simplify the problem of artificial flight by reducing to a minimum the demand for power, making it chiefly necessary for acquiring the first initial velocity. All attempts at aviation which include any motor for propulsion are, in my judgment, on wrong lines, and predestined to certain failure, since they not only neglect, but destroy, the action of the forces by which true flight may be and is attained. I will not go so far as to say that some (soaring) birds, in the exuberance of power, may not use the wings to accelerate, as they do to retard motion. I think they do, but only in an abnormal way; it is wholly unnecessary, and even destructive of all normal flight. The fish needs a propeller, because it has no gravity in water; the bird does not need it, because it has gravity, and in that gravity has the best and smoothest of all conceivable means of propulsion, if he can make the wind lift him uphill whenever he has slid far enough downhill. If so, man commits an absurdity when he flies in the face of nature and assumes a propelling force where none is needed or exists."

Later on in this article, I wish to describe an instrument, experiments with which can be made to answer for us the question as to whether or not a motor is needed; but just here further quotations should be given to show the trend of the best thought.

Aeronautics (N.Y.) for January contains Professor Langley's remarkable paper entitled "The Internal Work of the Wind." The closing paragraph is as follows:

"The final application of these principles to the art of aerodromics seems, then, to be, that while it is not likely that the perfected aerodrome (air-runner) will ever be able to dispense altogether with the ability to rely at intervals on some internal source of power, it will not be indispensable that this aerodrome of the future shall, in order to go any distance — even to circumnavigate the globe without alighting, — need to carry a weight of fuel which would enable it to perform this journey under conditions analogous to those of a steamship, but that the fuel and weight need only be such as to enable it to take care of itself in exceptional moments of calm."

Mr. Octave Chanute, in his admirable chronicle entitled "Progress in Flying-Machines," which will soon be published, says in one of his closing chapters: "But it is possible to utilize a still lighter power [than that of engines], for we have seen that the wind may be availed of under favorable circumstances, and that it will furnish an extraneous motor which costs nothing and imposes no weight upon the apparatus.

"Just how much power can be thus utilized cannot well be told in advance of experiment; but we have calculated that under certain supposed conditions it may be as much as some six-horse power for an aeroplane with one thousand square feet of sustaining surface; and we have also seen that while but few experimenters have resorted to the wind as a motor, those few have accomplished remarkable results."

The indications seem to be that we must try to construct a machine analogous to the sailing-yacht rather than to the steamship, though perhaps the aerial machine of the future will be, so far as power is concerned, analogous to the yacht Sunbeam with its auxiliary screw.

Before continuing further with this subject, I wish to call attention to certain facts concerning the storage of power and the flight of soaring birds. First, in regard to the storage of power. It is well known that the construction of a useful electric storage-battery presents a most difficult problem. Such a storage device is needed for use upon the surface of the earth; yet, for purposes of aerial navigation, there is a much simpler accumulator which can be used. Take, for example, one hundred pounds of lead and let energy be stored in it by giving it altitude, just as energy is stored in the weight of a clock when it is wound.

What is known as one-horse power is the amount of energy which must be exerted in lifting thirty-three thousand pounds at the rate of one foot per minute, or five hundred and fifty pounds at the rate of one foot per second, or fifty-five pounds at the rate of ten feet per second. To give an illustration, it may be stated that if a man weighing one hundred and sixty-five pounds ascends a flight of steps ten feet high in three seconds, he exerts for the time being just one standard horse-power.

A small balloon which can lift one hundred pounds of lead three hundred and thirty feet high in one minute exerts one-horse power.

The lead when lifted to this height has stored within itself thirty-three thousand foot-pounds of energy.

Now, if weights can be made to slide downhill upon aeroplanes at very gentle grades, then the balloon becomes a valuable motor which stores energy in its load by giving it altitude, and the weight lifted becomes a reservoir of the very power needed for its own transportation, and the name of Montgolfier, the inventor of the under-estimated balloon, takes its place as that of the real founder of the useful art of aerial transportation.

Whether or not it is possible to transport freight by sliding it down long and gentle inclines by means of aeroplanes will be considered further on; just here we must consider the soaring power of birds.

In "The Reign of Law," by the Duke of Argyll (first published in 1867), there is a most notable chapter in which the flight of birds is analyzed. In a note the author makes the following statement: "I owe to my father [John, seventh Duke of Argyll] my knowledge of the theory of flight, which is expounded in this chapter. The retired life he led, and the dislike he had of the work of literary composition, confined the knowledge of his views within a comparatively narrow circle. But his love of mechanical science, and his study of the problem during many years of investigation and experiment, made him thoroughly master of the subject."

Every student of the subject of flight should read the interesting work just mentioned. We may not agree with all the conclusions which are reached, yet the author gives most stimulating food for thought.

The following paragraphs are among the most striking, showing, as they do, advanced ideas:

"In the first place, it is remarkable that the force which seems so adverse — the force of gravitation drawing down all bodies to the earth — is the very force which is the principal one concerned in flight, and without which flight would be impossible. It is curious how completely this has been forgotten in almost all human attempts to navigate the air. Birds are not lighter than the air, but immensely heavier. If they were lighter than the air they might float, but they could not fly. This is the difference between a bird and a balloon." (p. 130, Am. ed.)

. . . .

"No bird is ever for an instant of time lighter than the air in which it flies; but being, on the contrary, always greatly heavier, it keeps possession of a force capable of supplying momentum, and therefore capable of overcoming any lesser force, such as the ordinary resistance of the atmosphere, and even heavy gales of wind. The force of gravitation, therefore, is used in the flight of birds as one of the most essential of the forces which are available for the accomplishment of the end in view." (p. 131.)

. . . .

"The lightness of a bird is a limit to its velocity. The heavier a bird is, the greater is its possible velocity of flight — because the greater is the store of force; or, to use the language of modern physics, the greater is the quantity of 'potential energy' which, with proper implements to act upon aerial resistance, it can always convert into upward, or horizontal, or downward motion, according to its own management and desires." (p. 144.)

. . . .

"When a strong current of air strikes against the wings of a bird, the same sustaining effect is produced as when the wing strikes against the air. Consequently birds with very long wings have this great advantage, that, with pre-acquired momentum, they can often for a long time fly without flapping their wings at all. Under these circumstances a bird is sustained very much as a boy's kite is sustained in the air. The string which the boy holds, and by which he pulls the kite downwards with a certain force, performs for the kite the same offices which its own weight and balance and momentum perform for the bird. The great long-winged oceanic birds often appear to float rather than to fly. The stronger is the gale, their flight, though less rapid, is all the more easy, so easy indeed as to appear buoyant; because the blasts which strike against their wings are enough to sustain the bird with comparatively little exertion of its own, except that of holding the wing vanes stretched and exposed at proper angles to the wind. And whenever the onward force previously acquired by flapping becomes at length exhausted, and the ceaseless, inexorable force of gravity is beginning to overcome it, the bird again rises by a few easy and gentle half-strokes of the wing. Very often the same effect is produced by allowing the force of gravity to act, and when the downward momentum has brought the bird close to the ground or to the sea, that force is again converted into an ascending impetus by a change in the angle at which the wing is exposed to the wind." (p. 152.)

It is to be regretted that the limits of this article prevent more extended quotations from this remarkable book.

Now let us recall what we have seen at sea.

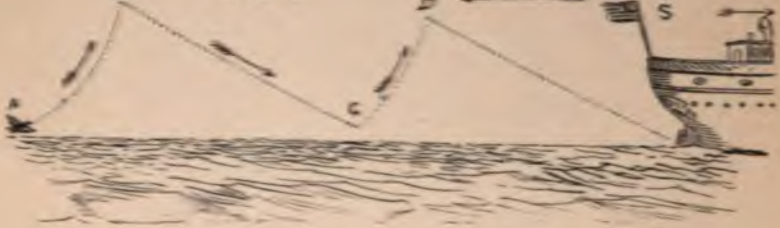
When one stands on the after-deck of a steamer in crossing the ocean, he may watch the soaring gulls to his heart's content. When the ship struggles painfully to force her way into the teeth of a gale, the birds make sport for themselves — they rise and dip, thus conquering the wind. How? Simply by *tacking;* in one sense, just as a yacht tacks to windward. Neither bird nor yacht can sail into the eye of the wind by the wind's power, but either can, by use of that power, reach an objective point lying to windward.

But here the reader may say that the parallelism between the bird and the sailing craft is not correctly drawn, because the yacht has a keel immersed in a dense medium which resists and prevents the making of leeway.

Yet the soaring bird has something which, at necessary times, holds it against the wind just as effectually as the keel holds the yacht: that something is *momentum*, which, while it lasts, holds the bird against the wind as firmly as the kite-string holds the boy's kite.

In Fig. 1, let S represent a steamship going eastward at the rate of twenty miles per hour; W the

Fig. 1



wind blowing westward at the rate of twenty miles per hour; A a gull near the water's surface, with momentum which for the instant gives him an eastward velocity of twenty miles per hour. While the bird's momentum lasts it holds him firmly against the wind. At the point A the bird inclines his wings so that the wind strikes them on the under side, and he is lifted and lifted until, at the point B, his momentum is so reduced that he must tack; then he gives to the wind the thin edge of his wings and slides down to the point C, and then, with velocity regained, he repeats the manœuvre. Altitude sacrificed becomes velocity or momentum, and momentum sacrificed becomes altitude. In this description of the gull's soaring to windward, the movement is reduced to its simplest elements, and it leaves out of account the graceful sinuosity of the bird's airy travels, just as the teacher of dancing leaves grace out of account when she teaches the beginner the elements of the steps.

What has here been said about the storage of energy in weights, and concerning the elements of flight, is all intended to lead up to the important subject of sliding freight downhill upon aeroplanes. It may be asked, How about a calm?

There is no calm for the aeroplane. Give it altitude and it can gain velocity, and velocity gives the *wind of flight*.

The plan for the transportation of freight is simply this: at each shipping-point a power-house (D, Fig. 2)

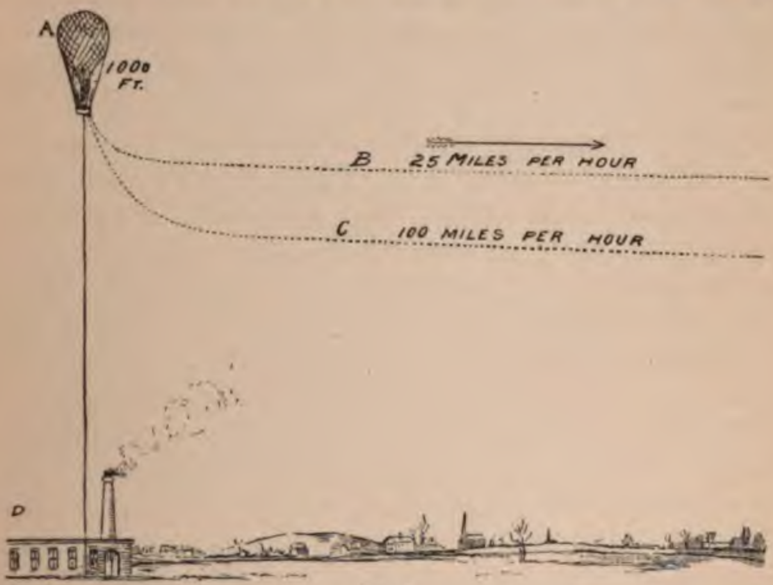


Fig. 2.

may be established to operate captive balloons. These should be cellular, and should be made to hold gas with little waste. In its action the apparatus would be what might be called an inverted elevator; that is, the steam or water-motor in the power-house would not hoist the freight, but, instead, would pull the balloon down after *it* had hoisted the freight and discharged it by means of a soaring machine, which will presently be described.

In Fig. 2 A represents a captive balloon at a height of one thousand feet. B and C represent the courses which would be taken by dirigible aeroplanes or soaring machines bearing loads of freight.

Perhaps this seems fanciful. Then let it be remembered that the feat of safely sliding down a long and gentle incline upon an aeroplane has already been performed by Otto Lilienthal, of Steglitz, Prussia. His experiments were illustrated and described in the Berlin Illustrirte Zeitung of Oct. 7, 1893, and one of the drawings — all of which were correctly made from instantaneous photographs — is here reproduced on the first page of cover. An improvement upon Lilienthal's device may be made by adding a pendulum.*

Now, in order to travel long distances in the air it is only necessary to improve the dirigibility of the aeroplane so that the angle of descent can be brought to a minimum.

How can this be done? By making repeated experiments with very simple and inexpensive mechanical contrivances called soaring machines, these to be dropped from a height.

In Fig. 2 it will be noticed that the course marked B indicates a speed of twenty-five miles per hour, that marked C a speed of one hundred miles per hour.

What speed may we expect of an improved soaring-machine? and upon how gentle a decline can we hope to see it maintain its initial velocity? First, note the fact that with a dirigible aeroplane or soaring machine the rate of speed is practically a matter of choice and depends at the start upon the length of the first swoop. The limit of speed will probably be decided by the

* See U. S. Letters Pat. No. 376937.

strength of the machine and the breathing requirements of the aerial pilot. Let us consider a railroad train. Man has safely travelled at a rate of one hundred and twelve miles per hour. On May 11, 1893, the Empire State express on the N.Y.C. R.R. reached that speed in a mile run in thirty-two seconds, one mile westward from Crittenden. So we know that man can safely breathe when travelling at over one hundred miles per hour; yet for this, of course, he needs the same protection which a cab gives to the locomotive engineer.

We will answer as well as we may the second question, Upon how gentle a decline may we hope to see an aerial machine maintain its initial velocity? When a railway car is at rest upon a smooth steel track having a down grade of one and twenty-three one-hundredths feet in every one hundred feet, it will remain at rest if undisturbed; but let it be once started downward by ever so slight an impulse and it will run down the track, gaining velocity to the end of the grade. It encounters the head resistance of the air and the friction of the track, but an aerial machine would encounter only air-resistance; is it not, therefore, reasonable to suppose that a dirigible aeroplane would in a calm, maintain its initial velocity while running upon a down grade of air of one foot in every one hundred feet? If so, an altitude of ten or twelve hundred feet would send a soaring machine eighteen or twenty miles, and greater altitudes would give longer flights, if, as may be supposed, the rarefaction of the air can be offset by an increase of velocity. These are surmises, but the way to learn is to experiment with soaring machines.

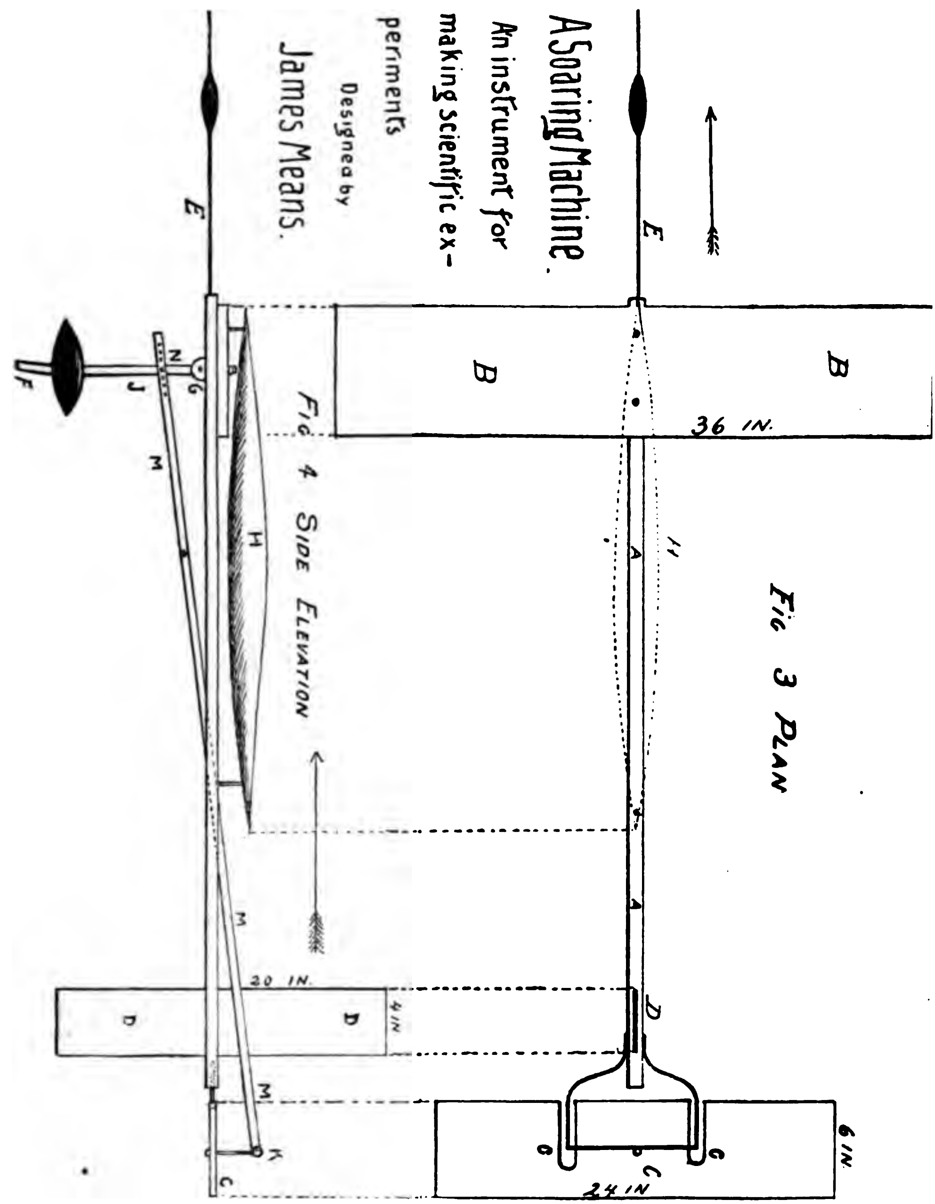
It is above all things important that a soaring machine should, when desired, automatically keep itself in a horizontal or slightly descending course. I have this winter begun a series of experiments with soaring machines, and when these are finished the full details will be reported.

In November, 1893, I launched several of these machines from the balcony of the tower of Boston Light, and more recently I have experimented from the top of the cliffs at Manomet. The former place is an ideal one for the purpose of experiment, being as it is, one hundred and eleven feet above the sea with a straight drop of seventy or eighty feet. Unfortunately, a gale of wind was blowing when I visited the light, and two out of the three machines were total failures, being badly bent by the wind before they were launched. The third machine righted itself before reaching the ground, but the pendulum, which will presently be described, was too light to do efficient work.

The experiments from the cliffs at Manomet were even less successful, owing to the fact that the descent is not sheer. All of the machines failed to gain sufficient velocity to clear the cliff.

Those who wish to experiment with machines weighing only a few pounds will probably find that a height of seventy or eighty feet will be sufficient if the position gives a straight drop. When it comes to experimenting with a soaring machine as large as Lilienthal's and carrying a weight representing that of a man, the summit of Mt. Willard, near the Crawford House, N.H., will be found an excellent place.

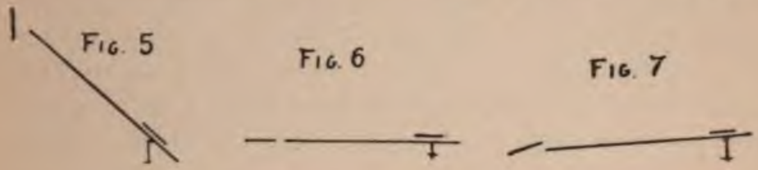
To any one who desires to take up this most fascinating study, Figs. 3 and 4 will give a general idea as to the construction of his first instrument for making experiments. A represents a backbone five-eighths of an inch square and four feet long, made of pine wood; B, the main aeroplane, eight inches wide and three feet



A Soaring Machine.
An instrument for making scientific experiments
Designed by
James Means.
Fig 3 Plan
Fig 4 Side Elevation
36 IN.
20 IN.
24 IN
4 IN
6 IN
B
B
E
E
A
A
D
D
D
C
C
C
C
C
F
G
H
J
K
M
M
M
N

long. This should be made of light tin plate, and bent in the middle so as to form a flattened V; the angle should be about one hundred and seventy degrees. C represents a steering aeroplane six inches by twenty-four inches, pivoted at cc, also made of light tin plate; D, a vertical aeroplane four inches by twenty inches, rigidly fixed in the wooden backbone; E, a rod of steel wire, eighteen or twenty inches long, and carrying an adjustable leaden weight of three ounces; K, a rod two and one-half inches long, soldered in the centre of and vertical to the plane C, with a pivot at the upper end with which the rod MM is connected. This rod should have five or six pivot-holes at its forward end N, so that its working length may be varied for different experiments; J, a rod pivoted at G, free to swing fore and aft; N, a pivot where the rod MM joins the rod J; F, a leaden weight adjustable higher or lower upon the rod J; its proper weight is x, an unknown quantity. Upon ascertaining by repeated experiment the right *weight* for F, the right *position* for the adjustable weight E, and the right *length* for the rod MM, the reaching of the maximum efficiency of a system of aeroplanes largely depends. I think that this sets forth with clearness the problem as it stands to-day. When it is fully solved — and it certainly seems solvable — right and left steering will be a less difficult matter, and alighting will be accomplished by killing the momentum when near the ground by an abrupt upward slant of the main aeroplanes; but this is an anticipation and a digression. Now to return to the instrument we are considering: this soaring machine is intended to gain velocity by a swoop, and then automatically steer itself into a horizontal or very slightly descending course, as indicated by B and C in Fig. 2. It depends upon the principle that the pendulum rod always seeks the perpendicular; for instance, when the machine is launched pointing steeply downward, the positions of the pendulum and aeroplanes are as shown in Fig. 5; therefore the steering aeroplane C will, as soon as velocity is gained, lay

Fig. 5 Fig. 6 Fig. 7



a strong hold upon the wind of flight, and have a tendency to bring the machine into a horizontal course. Now, if the length of the rod MM is made correct by adjustment at the pivot-holes near N, when the desired course, a very gentle decline, is reached, both aeroplanes will be approximately horizontal, as shown in Fig. 6. If, however, the machine deviates either upward or downward from its intended course, the weight at the end of the pendulum causes the steering aeroplane to correct the error. Fig. 7 shows the effect of a slight upward deviation.

H represents a long and very slender air-receptacle made of thin rubber and inflated; this should be pointed at both ends. It may be used to keep the machine afloat when experiments are made near the water. I have not yet used this, but have allowed my machines to go to pieces. The design here given calls for aero*planes* as being more easily made than aero*curves* modelled after the wings of birds, but in all probability the latter will eventually displace the former.

We are brought now, after this consideration of the greatest mechanical problem of the age, to ask, What shall be done to bring to our own century the credit and honor of reaching the solution?

The answer is, encourage experiments with soaring machines. Have regattas and large prizes. Appeal to the people's love of sport, and show what possibilities of recreation have been suggested by the experiments of Otto Lilienthal. Tobogganing on ice we can have only a few weeks in the year: tobogganing on air is possible at all seasons. When we have made our aeroplanes or aerocurves automatic in their steering action, flights like Lilienthal's will be, to say the least, no more dangerous than football and quite as interesting.

In order to encourage the designing and construction of soaring machines, I suggest that a sum of money be raised to be offered as a prize to the constructor of the most successful soaring-machine, the award to be made after a public trial of the same, to take place early in September of the present year (1894).

I will subscribe one hundred dollars if others will subscribe, in any sums they choose, nine hundred dollars more, to make a purse of one thousand dollars, provided that the publisher of some journal of wide influence will be custodian of the fund.

One or two more thoughts in conclusion. We have seen how the soaring bird tacks, first up, then down, then up again, and then down again. That conveys the idea of the perfection of rapid transit for passengers and freight. With the captive balloon we can tack up, with the soaring machine we can tack down. Short tacks up, long tacks down; there is no calm for the aeroplane; give it altitude and it can seize from the calm the wind of flight.

Imagine a bowling alley four hundred feet long, perfectly level, with an athlete at one end and a boy at the other. Let the chute which returns the balls have a drop of fifteen inches in every one hundred feet; imagine the game to be one of rapid transit instead of tenpins. It is a competition between the two ends of the alley to see which end can make the most of what energy it has. Let the athlete exert all his strength to propel the spheres; see them arrive at the end of the alley after their journey of four hundred feet, with sluggish speed; the boy lifts them to a height of five feet to the chute, gives them a gentle push, and they are returned to the athlete's end, arriving, not as sluggards, but as filled with energy. A short tack up and a long tack down is what does it.

There you have the old and the new methods of transit represented. The athlete represents the steam locomotive which, with all its polish and glitter, wastes energy. The boy represents the balloon, the lifter, which stores energy in matter by giving it altitude. The chute represents the free highway which through all the centuries men have supposed to be lacking.

Aerial transit will be accomplished because the air is a solid if you hit it hard enough.

EDITORIAL.

SINCE the foregoing pamphlet was published, about a year ago, I have become more than ever firmly convinced that the soaring-machine is, of all others, the instrument by which we must, for the present, acquire knowledge.

With all due respect to those who are constructing machines to start along the ground with motors, I still express the opinion that such machines are less instructive than are soaring-machines launched from considerable heights. The reason is this. The art of steering machines of the former kind has only been partially acquired, consequently long flights of such do not occur, and their conduct can be studied for a very brief time only. But the soaring-machine, with the potential energy of lead for its motor, when launched from a captive balloon at a considerable height, must, of necessity, declare itself for a considerable length of time and teach the observer new things with every new flight. Every movement is instructive to the designer, and no hasty wreck can occur to deprive him of the opportunity for study. When a soaring-machine which will carry four or five hundred pounds of lead or sand-bags has been satisfactorily designed, then will it be time to consider motors. To trust valuable motors to machines before we have successfully carried sand-bags uses up appropriations faster than is necessary.

After the soaring-machine is sufficiently improved, the adding of a motor — if such be found necessary — will be the adding of a new force which will tend to throw the machine out of equilibrium; yet the power can be applied very gradually so that we may learn to counteract the disturbance of the equilibrium which it causes.

SIR GEORGE CAYLEY made what he called his "noble white bird,"[1] but unfortunately, so far as known, he left no mechanical drawing with dimensions and weights. Had he included such a drawing in his published articles, it would have been a help to later investigators. Since Sir George's day there have been many accounts published of the performances of soaring devices, but most of these fail to give the detailed drawings with weights and dimensions which are needed to give to such accounts their highest value to workers.

On page 163 of Mr. Chanute's "Progress in Flying Machines" there will be seen a cut of a soaring device invented by William Beeson and patented in 1888. Automatic longitudinal stability is intended to be secured by a pendulum, the rod of which always seeks the perpendicular. I quote from Mr. Chanute's book: "Mr. Beeson states in his patent that 'this machine is self-supporting in a light wind, say, of ten miles or more per hour, and that when once raised by a kite or otherwise, and cut loose, it will of itself perform the evolutions of a soaring bird and rise to any altitude.'"

Mr. Chanute continues, "The writer confesses that he has tried the experiment with a small model and has failed; and so, in the hope that some of his readers may be more fortunate, he has given the account of what seems to be a remarkably simple device — if it will work."

I have given several months of study to this pendulum, and have made a large number of experiments with machines working upon this principle. In May, 1894, I went again to Manomet Cliffs provided with six machines of the type shown in Fig. 1.

Owing to the limited height of the place of launching, — less than one hundred feet, — only a short swoop was possible, and the velocity necessary to carry heavy weights could not be obtained.

With wings four feet from tip to tip and six inches wide, the weight of lead used on the pendulum was only twelve ounces. The best flight obtained in this instance was with one instrument

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[1] See page 25.

which, after swooping to within about twenty-five feet of the beach, went to windward in a nearly horizontal course, a distance of about two hundred feet, before alighting. In this case there was no apparent unsteadiness caused by the oscillation of the pendulum. In other trials a tendency of the pendulum to oscil-

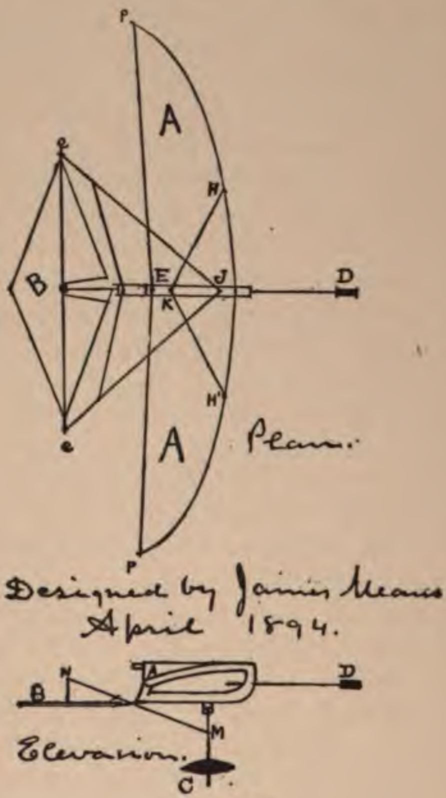

Figure 1.

AA, main aerocurves. *B*, a plane moving upon the axis *ee*. *C*, a weigh movable up or down upon the pendulum rod. *MN*, a connecting rod pivoted at each end and made so that its length is easily varied. *D*, a movable head-weight. *EJ*, wooden support for metal frame.

When this machine is in horizontal flight, if the front tips up or down, the peridulum rod in seeking the perpendicular inclines the plane *B* in a direction which steers the machine back into its horizontal course.

late was shown. I am of the opinion that the best results which can be obtained with a pendulum, when used in a machine of this type, will be when it is so confined by stops that the amplitude of its swing is made small, and perhaps even then a dash-pot may be necessary to give additional steadiness to the pendulum.

During the summer of the present year (1894) I spent the greater part of my time in working at the bench and in the field. I made experiments at York Harbor, Maine, with soaring-machines having rudders acting upon the principle advocated by Alphonse Pénaud in 1872.[1]

These were raised to a height by means of large kites,[2] and were suspended from the kite-string at a distance of 100 to 150 feet from the kite. Fig. 2 shows a very simple device which I used to secure the release of my machines at any desired moment. If my progress during the summer was slow it was largely owing to the fact that calms and light winds were so prevalent that oftentimes I could not get more than three or four days in a month when the wind was sufficient to lift my weights.

In order to launch machines from a greater height than my kites had carried them during the summer I went in September to the summit of Mt. Willard, in the White Mountains. There being at that place a precipitous descent of 800 to 900 feet, I hoped for good results. I went provided with twenty instruments all ready to put together. After trials of seven or eight of these I found that most of them were caught by eddies of wind which turned them in and wrecked them against the face of the cliff. The remaining instruments I still hold, hoping at some future time to launch them from a captive balloon. I believe that to be the most satisfactory way of experimenting with motorless instruments.

The flights of my soaring-machines during the past months have been sometimes downward, sometimes erratic, and some-

[1] See "Progress in Flying Machines," pps. 117, 118, and "Report of Aeronautical Society of Great Britain, 1874.

[2] I wish to express my thanks to Mr. William A. Eddy, of Bayonne, N.J., for his kindness in sending me a working drawing of a tailless kite of his own design.

times approximately horizontal; in watching their conduct I have not learned how to make an entirely satisfactory machine, yet I believe that I have gained some ideas which may have value in determining future methods of experimental work. Knowing of no source of information such as I have needed, my apparatus and methods have been of the crudest kind.

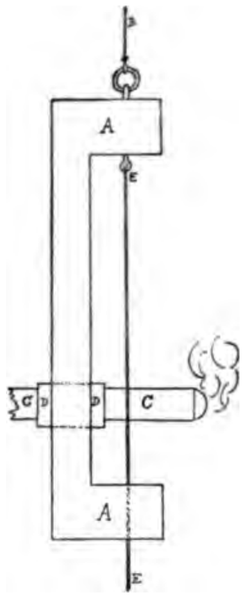

Figure 2.

AA, a block of pine wood 5 in. long ¾ inch thick. *B*, string attached to kite string. *CC*, a slow-match. *DD*, a strip of spring sheet-brass rolled over a pencil into a cylinder which binds the slow-match slightly so that the latter may be moved back and forth. *EE*, the string which sustains a soaring-machine. Small slow-match in ordinary winds burns about ¼ of an inch per minute. By adjusting the length of the match the string will be cut when desired.

Having altered my design after every trial, I can now offer to experimenters the drawing of an instrument which will, I think, be useful to them in beginning a series of investigations. It involves no new principle, but as the result of experiment it is proportioned in such a way that it will soar *instructively*.

Whatever the merits or the faults of the design may be, its dimensions are given, and any one may test it. (See Fig. 3.)

I wish to give to those who are just beginning to experiment, a warning against an error by the commission of which I have been retarded in work. In a series of experiments, slight changes only should be attempted in the design. Frequently a favorable flight will lead one to carry a supposed improvement so far that total failure results. The study cannot be successful unless most careful observations are made to ascertain what causes produce what effects.

The effects of slight changes can be traced to their causes; it is otherwise with the effects of radical changes.

A DEFINITE PLAN. — If I were asked what is the thing to be done which will most help us toward the full solution of the great problem, I should answer, carry out the idea advanced in May, 1890, by Mr. Octave Chanute, and organize an American Aeronautical Society.

Such a society should have for its prime object the encouragement of experimental work. It should offer prizes for the most effective soaring-machines, and every summer it should establish, for a week or two, a camp in some secluded place where competitive trials of soaring or flying machines could be had. An aeronaut should be engaged to keep a captive balloon in the air during the working hours of each day. By a simple hoisting-apparatus attached to the car of the balloon the instruments to be tested could be raised to any desired height and released at will. Thus long flights could be surely attained, and every instrument would necessarily fully declare itself before reaching the ground.

There would at first be many machines which would be failures, but no one need hesitate because of publicity. Each machine could be entered by number, and a working drawing of it placed on file, and the onlookers need not know the name of the designer in case he should wish to remain unknown.

I fully believe that if Mr. Chanute were to carry out his idea (fixing the annual assessment at a sum not exceeding one or two dollars), that a strong and useful working organization could be built up.

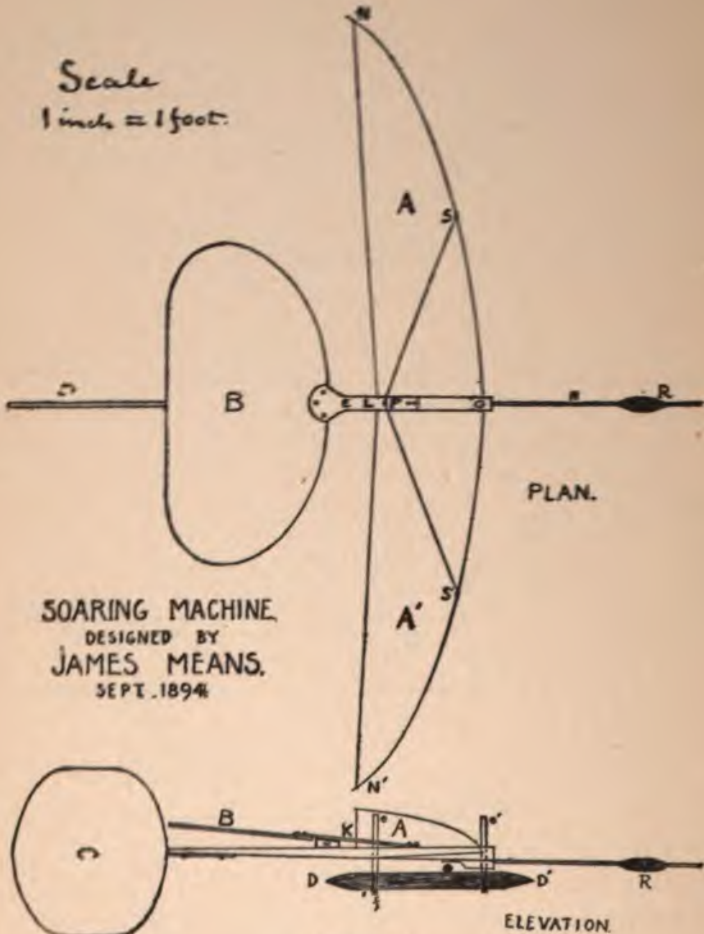

Figure 3.

Materials. — I have found the following excellent: For aeroplanes, the stiffest and flattest Japanese fans that can be had. For aerocurves, varnished silk. For frames, paragon umbrella-ribs. These give remarkable strength for their size and weight. When a wing is made flat, of silk and steel, being elastic, it becomes in action an aerocurve, concaved on the under side. For ballast-carriers, pieces of bamboo, to which are fitted conical plugs of wood. For ballast, lead or sand.

AA', main aerocurves. *B*, aeroplane to keep the machine in a horizontal course. *C*, vertical aeroplane to keep the machine headed into the wind. *DD'*, ballast-carrier, which may be moved forward or aft when the binding screw *f* is loosened; *ee'*, rods sliding up and down in the wooden backbone *FG*, thus raising or lowering the ballast-carrier. *R*, a leaden weight which slides on the rod *H*. *K*, a flat piece of spring steel which carries the aeroplane *B*; this spring is fastened to the wooden backbone by two stout screws. It tends to press very strongly upon the wedge *W*. When the wedge *W* is moved backward or forward it changes the angle of the aeroplane *B* relatively to the aerocurves *AA'*.

The main aerocurves, in order to give lateral stability to the machine, are inclined to each other at an angle of about 165°, according to the principle explained by Sir George Cayley on page 30.

In using umbrella ribs, the braces which run to the umbrella handle should not be detached, as these and their pivots come just where they are needed to give strength to the soaring-machine. *S* and *S'* are the points of junction; you will find holes in the braces at *F*; through these a clinching nail can be driven. From *N* to *L* and from *N'* to *L* are taut cords; these pull in the tips of the ribs and give just the right curve to the forward edges.

Given the positions and areas of surface as per the scale of the drawing, it will be seen that in the adjustment of this machine for the nearest possible approach to automatic horizontal flight there are three factors concerned, namely:

1. The total weight of ballast.
2. The angle of plane *B*[1].
3. The position of the centre of gravity.

This machine is designed for the express purpose of ascertaining the best possible combination of factors. It will make its first flight instructively with two pounds of ballast, with the centre of gravity at the point indicated by the black dot, and with the plane *B* at the angle shown in the drawing. Taking the result of this flight as a starting-point, the machine is capable of improvement to an indefinite extent.

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[1] See description of the Pénaud rudder, on p. 56 of the Ninth Annual Report of Aeronautical Society of Great Britain.

FOR several winters past I have been watching the soaring gulls from my back window, and I have repeatedly observed one phenomenon which leads to the thought that there is some property in air which still remains a profound mystery, and that in the future this very property, whatever it may be, will be found to be one of the most important factors in explaining flight. What I refer to is this: we know that when an aeroplane or an artificial wing is *swiftly* moved against the wind, or the wind against it, there is a strong upward thrust; but I have repeatedly seen the gull over glassy water — indicating a calm — move horizontally, with fixed wings, with *such extreme slowness* that the act seems to be against all the known laws of nature.

SINCE the year 1790 there have been issued by the United States Patent Office one hundred and forty-nine patents for aerial machines or parts of the same. The writer has the drawings and specifications of these bound in a single volume. A study of this inclines one to think that the successful flying-machine of the future will be in its main features, not a new invention, but merely a new design. So many patents have been issued for various combinations of aeroplanes and screws and for wings of different kinds, that in future it will probably be the task of the designer to properly proportion and arrange the parts, and for the inventor to improve the details.

For one example: the aeroplane machine with screw propulsion and with ground wheels for starting was patented in the United States so long ago that the patent has now expired. The invention is public property, but so far as now known a full-sized machine of this sort has never been properly designed, and the problem of securing its dirigibility has not been solved. While undirigible, it is of no practical use, and just as there is no royal road to skating, so there is no method of learning to steer aerial machines save the experimental one.

ONE thing is certain: if the problem of flight had been fully solved by some one unknown to us, and if that person were to present us with a perfect flying-apparatus, that instrument would be of no more immediate use to us than the latest safety bicycle would be to the king of Dahomey, or a pair of skates to a man who had never seen ice. Bicycling, skating, walking, swimming, and flying are all movements which must be learned by practice if at all, and, moreover, the process of learning is, in each case, likely to be attended with some personal discomfort.

MAXIM speaks of Lilienthal as a parachutist, and likens him to a flying-squirrel.[1] He also says that his (Lilienthal's) experiments do not assist us at all in performing actual dynamical flight.

Lilienthal, after alluding to the unwieldiness of Maxim's machine, says, "After all, the result of his labors has only been to show us 'how not to do it.'"[2]

If any two men should be friends rather than foes, these are the two. Each has certain ideas and qualifications which the other lacks, and it is the greatest of pities that they cannot clasp hands over the watery channel.

THE present revival of interest in the subject of aeronautics leads many writers to confidently predict a solution of the great problem at an early date; yet I venture to say that the more one studies the subject the more plainly he sees the enormous difficulties which are still unconquered, and the more inclined he is to think that many years will elapse before any travelling in the air becomes an important feature in the daily life of the human race. Yet these very difficulties are what give the subject its extreme fascination.

IN flying a tandem of ten or twelve kites upon a single string one gets an inkling of the erraticalness of wind passing over land. Wind is the queerest stuff conceivable. Over land,

[1] See Maxim's communication to the Boston "Transcript" of Sept. 8, 1894.

[2] See "The American Engineer," New York, Dec. 1894, p. 576.

especially over broken land, it is absolutely unlike the sailor's wind. Over trees and hillocks it is often broken into billows and eddies great and small, and it often rolls over and over itself as do the great breakers on a long beach.

If some manufacturer of bicycles would cause one such machine to be built with an aerial screw for propulsion he would furnish a valuable instrument for experimental purposes.

Writers frequently express the opinion that aerial machines when they come into use will first be applied to the purposes of warfare. I venture to predict otherwise. It seems likely that the earliest use of aerial machines will be for purposes of sport, and most interesting sport it will be.

The second use will, I think, be to bring ore down from hundreds of mines where it would never pay to run cables. The ore has the energy of position; it is all ready to slide down from the mountains if it is given a smooth road of air upon which to slide. Men who are now earning moderate pay as trapeze performers seem to have the requisite coolness, quickness, and muscular skill to learn the art of steering ore-carrying aeroplanes as Lilienthal steers his machine down a gentle incline. Probably the wages of gold-carrying aerial pilots would be higher than those of trapeze performers.

When we try, by the exercise of our imagination, to peer into the future and see the successful air-ships in their swift action, we probably err if we limit our imaginings to a single type.

The investigator who has given most of his thought to aeroplane machines propelled by screws, naturally in his flights of fancy sees the perfected type of such patrolling the airy spaces. The one who has most carefully watched the soaring birds of prey sees man with wings and the faculty of using them. The advocate of brute force sees no wing-like aeroplanes, but only a machine with whirring steel screws boring into the air in flight or hovering as the colossal pterodactyl might have hovered if he had had the anatomy and the method of the humming-bird. Perhaps in time all of these fancies may be justified by the same multiformity in aerial vessels which now prevails in marine craft. Is the idea far-fetched? We must judge by the past. Let us go back to the simplest forms of water vehicles. The cake of ice upon which the polar bear is carried by a strong and favoring breeze to the shore under his lee; the floating log which sustains the early descendant of the anthropoid apes; the hollowed log, the dug-out, paddled by the savage who has begun to think a little; the dug-out with a bush for a sail used by the savage who begins to take an interest in labor-saving devices; the birch canoe of the American Indian, so wonderful in adaptation to all the needs which brought it into existence — directly from these, what has come? Small boats with oars and sails, galleys with oars, caravels with sails, every kind of paddling, rowing, sailing, electric, and steaming craft, and, leading them all, impressive to the last degree, as she breasts the Atlantic gale of a winter's night, the "Lucania," the *fin-de-siècle* flower.

No one dares to set a limit to man's achievements; we are now only in the earliest stages of the science of aerial navigation; our descendants may see in air-ships the multiformity which we now see in marine craft. There are probably many more ways than one to solve the great problem, if only we can find them out.

SWIFT at the scourge the ethereal coursers fly,
While the smooth chariot cuts the liquid sky.
Heaven's gates spontaneous open to the powers,
Heaven's golden gates, kept by the winged hours;
Commission'd in alternate watch they stand,
The sun's bright portals and the skies command,
Involve in clouds the eternal gates of day,
Or the dark barrier roll with ease away.
The sounding hinges ring: on either side
The gloomy volumes, pierced with light, divide.
The chariot mounts, where deep in ambient skies,
Confused, Olympus' hundred heads arise;
Where far apart the Thunderer fills his throne,
O'er all the gods superior and alone.
There with her snowy hand the queen restrains
The fiery steeds, and thus to Jove complains:

. . . .

To whom assenting, thus the Thunderer said:
"Go! and the great Minerva be thy aid.
To tame the monster-god Minerva knows,
And oft afflicts his brutal breast with woes."
He said; Saturnia, ardent to obey,
Lash'd her white steeds along the aërial way.
Swift down the steep of heaven the chariot rolls,
Between the expanded earth and starry poles.
Far as a shepherd from some point on high,
O'er the wide main extends his boundless eye;
Through such a space of air, with thundering sound,
At every leap the immortal coursers bound:
Troy now they reach'd and touch'd those banks divine,
Where silver Simoïs and Scamander join.
There Juno stopp'd, and (her fair steeds unloosed)
Of air condensed a vapour circumfused:
For these impregnate with celestial dew,
On Simoïs brink ambrosial herbage grew.
Thence to relieve the fainting Argive throng,
Smooth as the sailing doves they glide along.

The Iliad of Homer. Book V. Pope.

FINIS.

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1896.

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THE profits of this edition of THE ANNUAL — if any — will be given to the Boston Aeronautical Society to be added to its Experiment Fund. (See page 86.)

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PRACTICAL EXPERIMENTS FOR THE DEVELOPMENT OF HUMAN FLIGHT.

By Otto Lilienthal.

(Written expressly for the Annual.)

WHOEVER has followed with attention the technical treatises on flying will have become convinced that human flight cannot be brought about by one single invention, but is proceeding towards its perfection by a gradual development; for only those trials have met with success which correspond with such a development.

Formerly men sought to construct flying machines in a complete form, at once capable of solving the problem, but gradually the conviction came that our physical and technical knowledge and our practical experiences were by far insufficient to overcome a mechanical task of such magnitude without more preliminaries.

Those proceeding on this basis therefore applied themselves, not to the problem of flying as a whole, but rather divided it into its elements, and sought first to bring a clear understanding into said elements which should form the basis of final success. For example, take the laws of atmospheric resistance, upon which all flying depends, and regarding which, until very recent years, the greatest uncertainty has existed; these have now been defined to such an extent that the different phases of flight can be treated mathematically. Besides which, the physical processes of the natural flight of the creatures have become the subject of minute investigation, and have in most cases been satisfactorily explained. The nature of the wind also, and its influence on flying bodies, have been carefully studied, thus enabling us to understand several peculiarities of the birds' flight hitherto unexplainable, so that one can apply the results thus obtained in perfecting human flight.

The theoretical apparatus needed for the technics of flying has been enriched so much by all these studies within the last few years that the elements of flying apparatus can now be calculated and constructed with sufficient accuracy. By means of this theoretical knowledge one is enabled to form and construct wing- and sailing-surfaces according as the intended effect renders it desirable.

But with all this, we are not yet capable of constructing and using complete flying machines which answer all requirements. Being desirous of furthering with all speed the solution of the problem of flight, men have repeatedly formed projects in these last few years which represent complete air-ships moved by dynamos; but the constructors are not aware of the difficulties which await us as soon as we approach the realizing of any ideas in flying.

All those, who have occupied themselves to any extent with actual flying experiments, have found that, even if they mastered theoretically the problem of flying, the practical solving of the same can only be brought about by a gradual and wearisome series of experiments based one upon the other.

Also the practical tasks of the technics of flying should be simplified and divided as much as possible instead of steering straight to the final goal.

As these principles have been seldom carried out, the practical results in human flight have remained very scanty up to the present day.

One can get a proper insight into the practice of flying only by actual flying experiments. The journey in the air without the use of the balloon is absolutely necessary in order to gain a judgment as to the actual requirements for an independent flight. It is in the air itself that we have to develop our knowledge of the stability of flight so that a safe and sure passage through the air may be obtained, and that one can finally land without destroying the apparatus. One must gain the knowledge and the capacity needed for these things before he can occupy himself successfully with practical flying experiments.

As a rule the projectors and constructors of flying machines have not gathered this absolutely necessary practical experience, and have therefore wasted their efforts upon complicated and costly projects.

In free flight through the air a great many peculiar phenomena take place which the constructor never meets with elsewhere; in particular, those of the wind must be taken into consideration in the construction and in the employment of flying apparatus. The manner in which we have to meet the irregularities of the wind when soaring in the air can only be learnt by being in the air itself. At the same time it must be considered that one single blast of wind can destroy the apparatus and even the life of the person flying. This danger can only be avoided by becoming acquainted with the wind by constant and regular practice and by perfecting the apparatus so that we may achieve safe flight.

The only way which leads us to a quick development in human flight is a systematic and energetic practice in actual flying experiments. These experiments and exercises in flying must not only be carried out by scientists, but should also be practised by those wishing for an exciting amusement in the open air, so that the apparatus and the way of using it may by means of common use be quickly brought to the highest possible degree of perfection.

The question is therefore to find a method by which experiments in flying may be made without danger, and may at the same time be indulged in as an interesting amusement by sport-loving men.

Another condition is, that simple, easily constructed, and cheap apparatus should be used for such flying exercises, in order to conduce to a still more general participation in this sport.

All these conditions are easily fulfilled. One can fly long distances with quite simple apparatus without taxing one's strength at all, and this kind of free and safe motion through the air affords greater pleasure than any other kind of sport.

From a raised starting point, particularly from the top of a flat hill, one can, after some practice, soar through the air, reaching the earth only after having gone a great distance.

For this purpose I have hitherto employed a sailing apparatus very like the outspread pinions of a soaring bird. The drawings opposite page 22 represent such apparatus. It consists of a wooden frame covered with shirting (cotton-twill). The frame is taken hold of by the hands, the arms resting between cushions, thus supporting the body. The legs remain free for running and jumping. The steering in the air is brought about by changing the centre of gravity. This apparatus I had constructed with supporting surfaces of ten to twenty square metres. The larger sailing surfaces move in an incline of one to eight, so that one is enabled to fly eight times as far as the starting hill is high. The steering is facilitated by the rudder, which is firmly fastened behind in a horizontal and vertical position.

The machines weigh, according to their size, from 15 to 25 kilograms (33 to 55 lbs.).

In order to practise flying with these sailing surfaces one first takes short jumps on a somewhat inclined surface till he has accustomed himself to be borne by the air. Finally, he is able to sail over inclined surfaces as far as he wishes.

The supporting capacity of the air is felt, particularly if there is a breeze. A sudden increase in the wind causes a longer stoppage in the air, or one is raised to a still higher point.

The charm of such flight is indescribable, and there could not be a healthier motion or more exciting sport in the open air.

The rivalry in these exercises cannot but lead to a constant perfecting of the apparatus, the same as, for instance, is the case with bicycles. I speak from experience, for, although the system of my sailing apparatus remains the same, it has gone through numberless changes from year to year.[1]

The apparatus which I now employ for my flying exercises

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[1] See article entitled "Wheeling and Flying."

contains a great many improvements as compared with the first sailing surfaces with which I commenced this kind of experiment five years ago. The first attempts in windy weather taught me that suitable steering surfaces would be needed to enable me to keep my course better against the wind. Repeated changes in the construction led to a kind of apparatus with which one can throw himself without danger from any height, reaching the earth safely after a long distance. The construction of the machine is such that it resembles in all its parts a strut-frame, the joints of which are calculated to stand pull and pressure, in order to combine the greatest strength with the least weight.

An important improvement was to arrange the apparatus for folding which can be seen the most clearly in the figure opposite page 22. All of my recent machines are so arranged that they can be taken through a door 2 metres high. The unfolding and putting together of the flying implements takes about two minutes.

A single grip of the hands is sufficient to attach the apparatus safely to the body, and one gets out of the apparatus just as quickly on landing. In case of a storm the flying-sail is folded up in half a minute and can be laid by anywhere. If one should not care to fold the apparatus, he may await the end of the storm under cover of the wings, which are capable of protecting twenty persons. Even the heaviest rain will not damage the apparatus. The flying apparatus, even if completely drenched, is soon dried by a few sailing flights after the rain stops, as the air passes through the same with great speed.

The latest improvements of the flying apparatus which I use for practical experiments refer to gaining of greater stability in windy weather.

My experiments tend particularly in two directions. On the one side I endeavor to carry my experiments in sailing through the air with immovable wings to this extent; I practise the overcoming of the wind in order to penetrate, if possible, into the secret of continued soaring flight. On the other hand I try to attain the dynamic flight by means of flapping the wings, which are introduced as a simple addition to my sailing flights. The mechanical contrivances necessary for the latter, which can reach a certain perfection only by gradual development, do not allow yet of my making known any definite results. But I may state that since my sailing flights of last summer, I am on much more intimate terms with the wind.

What has prevented me till now from using winds of any strength for my sailing experiments, has been the danger of a violent fall through the air, if I should not succeed in retaining the apparatus in those positions by which one insures a gentle landing. The wildly rushing wind tries to dash about the free-floating body, and if the apparatus take up a position, if only for a short time, in which the wind strikes the flying surfaces from above, the flying body shoots downward like an arrow, and can be smashed to pieces before one succeeds in attaining a more favorable position in which the wind exercises a supporting effect. The stronger the wind blows, the easier this danger occurs, as the gusts of wind are so much the more irregular and violent.

As long as the commotion of the air is but slight, one does not require much practice to go quite long distances without danger. But the practice with strong winds is interesting and instructive, because one is at times supported quite by the wind alone. The size of the apparatus, however, unhappily limits us. We may not span the sailing-surfaces beyond a certain measure, if we do not wish to make it impossible to manage them in gusty weather. If the surfaces of 14 square metres[1] do not measure more than 7 metres[2] from point to point, we can eventually overcome moderate winds of about 7 metres[3] velocity, provided one is well practised. With an apparatus of this size it has happened to me that a sudden increase in the wind has taken me way up out of the usual course of flying, and has sometimes kept me for several seconds at one point of the air. It has happened in such a case, that I have been lifted vertically by a gust of wind from the top of the hill (shown in Fig. 3), floating for a time above the same at a height of about 5 metres, whence I then continued my flight, against the wind.

[1] About 150 sq. feet. [2] About 23 feet. [3] About 22 miles per hour.

Although, while making these experiments I was thrown about by the wind quite violently and was made to execute quite a dance in the air in order to keep my balance, I yet was always enabled to effect a safe landing, but still I came to the conviction, that an increase in the size of the wings or the utilizing of still stronger winds which would lengthen the journey in the air, would necessitate something being done, to perfect the steering and to facilitate the management of the apparatus. This appeared to me to be all the more important as it is very necessary for the development of human flight that all, who take up such experiments, should quickly learn how to use the apparatus safely and understand how to use the same even if the air is disturbed. It is in the wind that this practice becomes so exciting and bears the character of a sport, for all the flights differ from each other and the adroitness of the sailing-man has the largest field for showing itself. Courage also and decision can be here shown in a high degree.

If such exercises are gone through with in a regular and approved method, they are not more dangerous than if one engages in riding, or sailing on the water.

Just as it is in sports on the water, so it is in sports in the air, that the greatest aim will be to reach the most startling results. The machines themselves, as well as the adroitness of their operators, will vie with each other.

He who succeeds in flying the farthest from a certain starting-point, will come forth from the contest as conqueror. This fact will necessarily lead to the production of more and more improved flying apparatus. In a short time we shall have improvements of which to-day we have not the faintest idea.

The foundation for such a development exists already; it only needs a more thorough carrying out to gain perfection. The greater the number is of such persons who have the furthering of flying and the perfecting of the flying apparatus at heart the quicker we shall succeed in reaching a perfect flight. It is therefore of paramount importance that as many physically and technically well-trained men as possible take interest in these affairs, and that an apparatus be constructed which is as convenient and as cheap as possible.

The means by which I sought to facilitate the management of the machines and to increase their use in wind, consisted in the first place in different arrangements for changing the shape of the wings at will. I will, however, pass over the results here obtained as another principle gave surprisingly favorable results.

My experiments in sailing flight have accustomed me to bring about the steering by simply changing the centre of gravity.

The smaller the surface extension of the apparatus is, the better control I have over it, and yet if I employ smaller bearing surfaces in stronger winds, the results are not more favorable. The idea therefore occurred to me to apply two smaller surfaces, one above the other, which both have a lifting effect when sailing through the air. Thus the same result must follow which

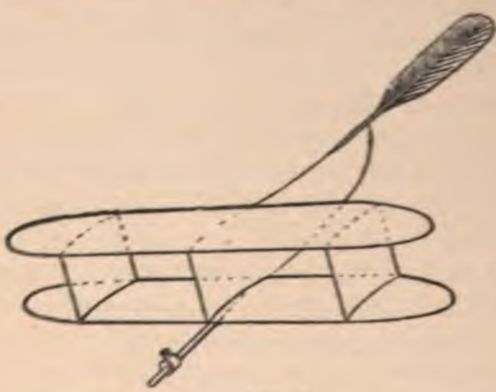


Fig. 1.

would be gained by a single surface of twice the bearing capacity, but on account of its small dimensions this apparatus obeys much better the changes of the centre of gravity.

Before I proceeded to construct these double-sailing machines, I made small models in paper after that system, in order to study the free movements in the air of such flying bodies and then to construct my apparatus on a large scale, depending on

Fig. 3.

Fig. 4.

the results thus obtained. The very first experiments with these small models, the form of which may be seen in Figs. 1

FIG 2.

and 2, surprised me greatly on account of the stability of their flight. It appears as if the arrangement of having one surface over the other had materially increased the safety and uniformity of the flight. As a rule it is rather difficult to produce models resembling birds, which, left to themselves, glide through the air from a higher point in uniformly inclined lines. I need only recall the extensive and expensive experiments made by Messrs. Riedinger, von Sigsfeld, and von Parsefal, of Augsburg, which showed the difficulty of constructing models that would automatically take up a course of stable flight. I myself doubted formerly very much that an inanimate body sailing quickly forward, could be well balanced in the air, and was all the better pleased in succeeding in this with my little double surfaces.

Relying on this experience I constructed first a double apparatus (Fig. 3), in which each surface contains 9 square metres.[1] I thus produced a comparatively large bearing surface of 18 square metres with but 5½ metres[2] span.

The upper surface is separated from the lower by a distance equal to three quarters of the breadth of the lower surface, and it has no disturbing influence whatever, but creates only a vertically acting lifting force. One must consider that with such an apparatus one always cuts the air quickly, so that both surfaces are met by the air-current, and therefore both act as lifters.

The whole management of such an apparatus is just the same as that of a single sailing surface. I could, therefore, use at once the skill I had already obtained.

Fig. 4 shows how I have to change the centre of gravity, and

[1] About 97 sq. feet. [2] About 18 feet.

particularly the position of the legs, to the left, in order to press down the left wing, which is a little raised. In Fig. 5 the opposite movement to the right is shown. I retain the middle position, as shown in the frontispiece, whenever the apparatus floats horizontally.

The flights undertaken with such double sailing surfaces are distinguished by their great height, as is shown in Fig. 6, which gives a side-view of the apparatus.

The landing with this apparatus is brought about in the same way as with the single sailing surfaces by raising the apparatus in front somewhat and by lessening the speed, as shown in Fig. 7.

Fig. 8 shows an exact picture of the construction of the apparatus, as well as of the management of the same.

The energetic effect of the change of the centre of gravity and the safe starting of the apparatus obtained by it gave me courage to trust myself to a wind which at times exceeded a velocity of 10 metres (about 24 miles per hour).

This gave the most interesting results of all my practical flying experiments hitherto. Six or seven metres velocity of wind sufficed to enable the sailing surface of 18 square metres to carry me almost horizontally against the wind from the top of my hill without any starting jump. If the wind is stronger, I allow myself to be simply lifted from the point of the hill and to sail slowly towards the wind. The direction of the flight has, with strong wind, a strong upward tendency. I often reach positions in the air which are much higher than my starting-point. At the climax of such a line of flight I sometimes come to a standstill for some time, so that I am enabled while floating to speak with the gentlemen who wish to photograph me, regarding the best position for the photographing.[1]

At such times I feel plainly that I would remain floating if I leaned a little towards one side, described a circle and proceeded with the wind. The wind itself tends to bring this motion about, for my chief occupation in the air consists in preventing

[1] The photographs were made by Drs. Neuhaus and Fülleborn, who used a camera constructed by Dr. Neuhaus on the Stegemann principle.

Fig. 5.

Fig. 6.

a turn either to right or the left, and I know that the hill from which I started lies behind and underneath me, and that I might come into rough contact with it if I attempted circling. My endeavors tend therefore to remove myself farther from the hill either by increased wind or by flapping with the wings, so that I can follow the strongly lifting air-current in a circle, and so that I can have a sufficient space of air under and beside me to succeed in describing with safety a circling flight and to land finally steering against the wind.

As soon as I or any other experimenter succeeds in describing the first circling flight, one may regard this event as one of the most important conquests on the road to perfect flight. From this moment only, one is enabled to make a thorough use of the *vis viva* of the wind, so that when the wind increases one is able to steer against it, and when it decreases one can fly with it, getting beyond the same. One will feel here a similar effect, as already described by Professor Langley in his celebrated treatise entitled "The Internal Work of the Wind." It is no easy step from the theoretical conviction to the practical execution. The dexterity required to allow one's self to be borne by the wind alone, by describing well-directed circles, is only understood by those who are well acquainted with the difficulties one encounters with the wind. And yet all that may be acquired by practice. When the time comes that athletic associations emulate each other, such results will not be long in following.

Moreover, experimenters will proceed from simple floating and sailing, which in any case form the foundation for practical flight, by degrees to flying with movable implements. As one is enabled to balance himself for some time in the air, the foundations for more extended dynamic effects are easily and safely attained. The different projects may be easily tried by adding the motor work to the simple sailing flight taken as a basis. In this manner one will soon find out the best methods; for practical experience in the air is far better than figuring on paper.

The only thing which may cause difficulties is the procuring of a suitable place for practising.

Just as the starting from the earth is rather difficult for larger birds, the human body, being still heavier, meets with peculiar difficulties at the first flight upward. The larger birds take a running start against the wind or throw themselves into the air from elevated points, in order to obtain free use of their pinions. As soon, however, as they float in the air, their flight, which was begun under special difficulties, is easily continued. The case is similar in human flight. The principal difficulty is the launching into the air, and that will always necessitate special preparations. A man will also have to take a running start against the wind with his flying apparatus, but on a horizontal surface even that will not be sufficient to free himself from the earth. But, on taking a running start from a correspondingly inclined surface, it is easy to begin one's flight even if there is no wind.

According to the example of birds, man will have to start against the wind; but as an inclined surface is necessary for this he needs a hill having the shape of a flat cone, from the top of which he may take starts against the wind in any direction.

Such a place is absolutely necessary, if one wishes to make flying experiments in a convenient way without being dependent on the direction of the wind.

For this purpose I have had an artificial hill, 15 metres high, erected near my house in Gross Lichterfelde, near Berlin, and so have been enabled to make numerous experiments. The drawings show this hill, or part of the same, from the outside. Fig. 9 represents a section of it, showing the cavity in the top intended for keeping the apparatus. At the same time the line of flight taken in calm weather is shown by dotted lines.

If a place for this sport is procured where young persons wishing to indulge in flight can disport themselves in the air, they will then have a chance to make instructive and interesting sailing flights, and I should advise having the hill twice as high, and to form it according to Fig. 10, so that one can commence the flights from a height of 30 metres. The cavity inside should be large enough to hold several complete machines.

Fig. 7.

Fig. 8.

From such a hill one can take flight of 200 metres distance, and the floating through the air on such long distances affords indescribable pleasure. Added to which this highly exciting exercise is not dangerous, as one can effect a safe landing at any time.

Such a place in which young men can practise sailing flights and can at times make motor experiments with the wings would prove to be of great interest, both to those participating and to the public in general.

And when, from time to time, competitive flights were arranged, we should soon have a national amusement in this as in other sports which we have already. One can see even now that the pleasure and interest of the public in such races, when the gymnasts skilled in flights, shoot through the air, would be greater and more intense than, for instance, in horse or boat racing. The air is the freest element; it admits of the most unfettered movement, and the motion through it affords the greatest delight not only to the person flying, but also to those looking on. It is with astonishment and admiration that we follow the air gymnast swinging himself from trapeze to trapeze; but what are these tiny springs as compared to the powerful bound which the sailer in the air is able to take from the top of the hill, and which carries him over the ground for hundreds of yards?

If the atmosphere is undisturbed, the experimenter sails with uniform speed; as soon, however, as even a slight breeze springs up, the course of the flight becomes irregular, as indicated in Fig. 10. The apparatus inclines now to the right, now to the left.

The person flying ascends from the usual line of flight, and, borne by the wind, suddenly remains floating at a point high up in the air; the on-lookers hold their breath; all at once cheers are heard, the sailer proceeds and glides amid the joyful exclamations of the multitude in a graceful curve back again to the earth.

Can any sport be more exciting than flying? Strength and adroitness, courage and decision, can nowhere gain such triumphs as in these gigantic bounds into the air, when the gymnast safely steers his soaring machine house-high over the heads of the spectators.

That the danger here is easily avoided when one practises in a reasonable way, I have sufficiently proved, as I myself have made thousands of experiments within the last five years, and have had no accidents whatever, a few scratches excepted.

But all this is only a means to the end; our aim remains — the developing of human flight to as high a standard as possible. If we can succeed in enticing to the hill the young men who to-day make use of the bicycle and the boat to strengthen their nerves and muscle, so that, borne by their wings, they may glide through the air, we shall then have directed the development of human flight into a course which leads towards perfection.

COPY OF LETTERS-PATENT

GRANTED TO

OTTO LILIENTHAL, OF BERLIN, GERMANY, FOR FLYING MACHINE.

SPECIFICATION forming part of Letters-Patent — No. 544816, dated August 20, 1895.

Application filed February 28, 1894. *Serial No.* 501880. (*No Model.*)

To all whom it may concern:

Be it known that I, OTTO LILIENTHAL, manufacturer, a subject of the German Emperor, and a resident of Berlin, German Empire, have invented certain new and useful Improvements in Flying Machines, of which the following is a specification.

This invention relates to flying machines which resemble in their construction the structure of birds' wings. The object of these flying machines is to imitate the soaring of birds as well as their ordinary flight, which is effected by the flapping of the wings. The improved machine comprises two wings, which, after the manner of birds' wings, are slightly vaulted upward. These wings are fixed by two rods laid crosswise one upon the other and firmly connected together, which rods form a carrying-frame, or part of a carrying-frame, to which the person intending to fly may hold, so as to be suspended between the two wings.

Plate V.

Fig. 9.

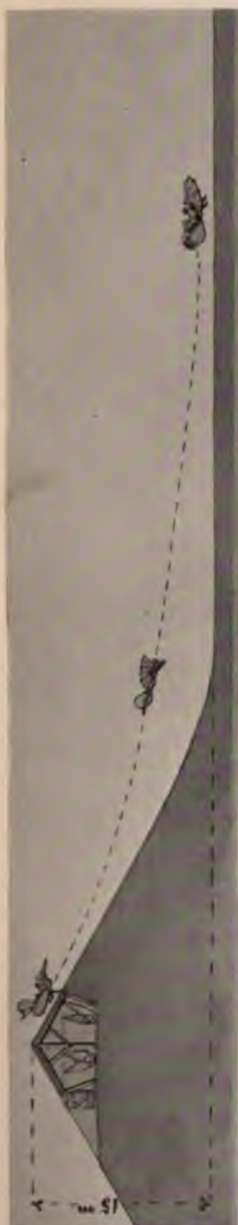
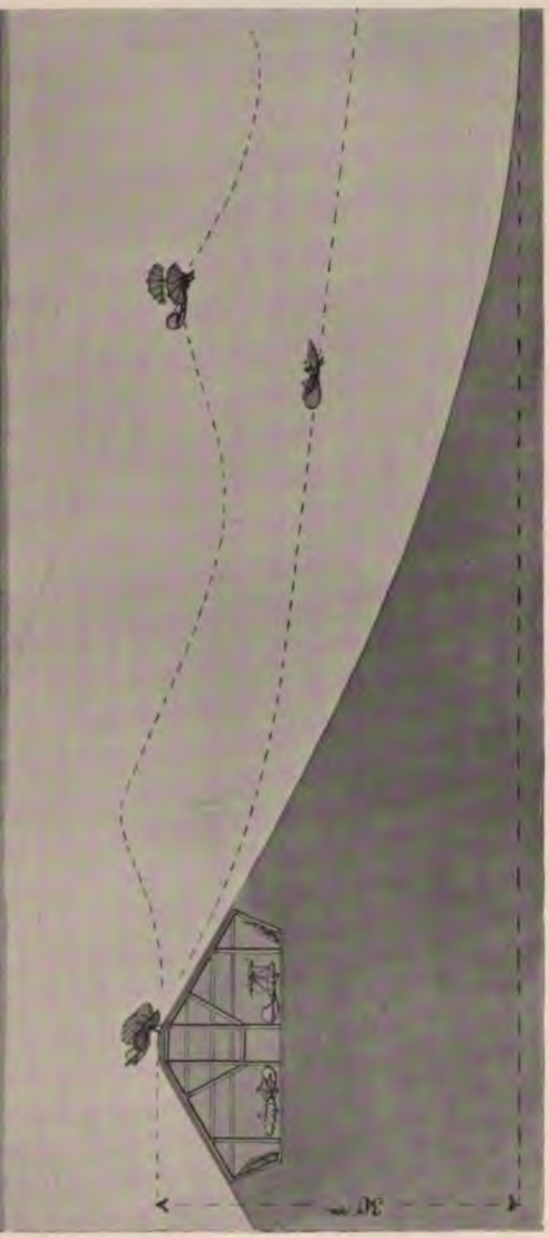


Fig. 10.



In the accompanying drawings the flying machine, constructed according to the present invention, is represented in Figures 1 to 5.

Fig. 1 shows a view from above of this flying machine. Figs. 2, 3, and 4 are sections on the lines A B, C D, and E F of Fig. 1. Fig. 5 shows the flying machine when folded up.

In carrying this invention into practice, two wooden rods *a*, forming an acute-angled cross, are arranged to carry at their upper ends *b* pockets *d*, produced by two small wooden plates. In these pockets are pivoted the wooden ribs *e* of the wings. A string *f*, connecting the points of the ribs, and a wire *g*, fastened to the first rib of the wing and hooked to the hoop *h*, stretch these ribs in the horizontal direction. The tension downward is given to the ribs by wires *i*, which extend from the points *k* of the ribs to the lower ends *c* of the crossed rods *a*. Cushions *l* are fixed between the crossed rods *a*. The said hoop *h* is nailed, glued, or otherwise secured in the pockets *d*. With this hoop are firmly connected the rods *m*, to which are attached in front the wooden bar *n*, with the rods *o o*, and at the rear two diverging rods *p*. On the latter is pivoted the tail *q* in such a manner that it can freely turn upward, but finds downward a point of support on the fixed rudder *r*. This mode of attaching the tail has the advantage that the tail will have no carrying action when the machine is employed like an ordinary parachute, thereby preventing the machine from turning over forward. The rudder *r*, which serves for automatically keeping the machine in the wind's eye, is likewise detachably fastened to the rods *m* and the hoop *h*. The surfaces of the machine over which fabric is stretched are shaded in the right-hand half of Fig. 1.

For using this flying machine, the person inserts his fore-arms between the cushions *l*, fixed to the crossed wooden rods *a*, Fig. 3, and takes hold of the bar *n* with the hands, so that, without changing the upright position of his body, he can carry and properly adjust the machine in a very convenient manner during his run before the flight, while during the flight he can balance and steer the machine, in which he is suspended, by a suitable movement of his body, so as to displace its centre of gravity. In this manner he can imitate the so-called "soaring" of birds, in which the movement takes place merely by a change in the position of the wings with regard to the direction of the wind, there being no rudder movement proper of the wings. As under these circumstances the legs are always freely suspended downward, the landing can safely be effected by putting the feet on the ground.

The folding up of the machine is effected by disengaging the front tension-wires *g* from the hoop *h*, turning the ribs about their centre in the pockets *d* to the rear, and hooking the tension-wires *g* into the eyes on the rods *m*. The apparatus then constitutes a compact whole.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim, and desire to secure by Letters-Patent of the United States of America, is—

1. In a flying machine, the combination of two crossed carrying rods *a*, two wings vaulted upward, and strings or wires *i* extending from the ends of the carrying rods toward the peripheries of the wings, substantially as set forth.

2. In a flying machine, the combination of two crossed carrying rods *a*, two wings vaulted upward, strings or wires *i* connecting the two carrying rods with the wings, and a vertical fixed rudder, substantially as set forth.

3. In a flying machine, the combination of a crossed frame, two wings connected therewith, strings or wires *i*, a vertical fixed rudder *r* and a horizontal tail *q*, adapted to turn upward automatically, substantially as set forth.

4. In a flying machine, the combination with a supporting frame, of a

wing adapted to be folded together and having its ribs diverging from a common support, and suitably hinged thereto a string connecting the outer points of the ribs, and continuous fabric attached to a series of ribs, substantially as set forth.

5. In a flying machine, the combination with a supporting frame, comprising a hoop, of a wing having its ribs diverging from a common support, a string connecting the outer points of the ribs, a wire, as *g*, fastened to the first rib of the wing and attached to the hoop and fabric stretched over the ribs and such wire, substantially as set forth.

6. In a flying machine, the combination with a supporting frame, of a wing having its ribs diverging from a common support, fabric stretched over the ribs and wires, as *i*, extending from the ribs downward to the supporting frame for the purpose of adjusting thereby the tension of the ribs, substantially as set forth.

7. In a flying machine, the combination with a frame, comprising a hoop and crossed bars, connected therewith, of wings supported by said frame, substantially as set forth.

8. In a flying machine, a supporting frame for the wings comprising a hoop *h*, rods extending from it for supporting the operator and a tail and a rudder, and pockets as *d* for receiving the ends of the ribs of the wings, substantially as set forth.

9. In a flying machine, the combination with a supporting frame, of wings with suitable ribs connected therewith, front tension wires *g*, and pockets *d* for receiving the inner ends of the ribs, the ribs being made capable of turning around their centres in such pockets for the purpose of folding up such wings, substantially as set forth.

10. In a flying machine, the combination with a supporting frame, of wings, a fixed rudder and a pivoted tail adjusted to come to rest upon the rudder when swinging downward, substantially as set forth.

Signed at Berlin this 1st day of February, 1894.

OTTO LILIENTHAL.

Witnesses:

HERMAN MULLER,
REINHOLD WEIDNER.

MR. LILIENTHAL DESIRES TO HAVE IT ANNOUNCED THAT HIS AMERICAN PATENT RIGHTS ARE FOR SALE, AND THAT UPON APPLICATION HE WILL BE PLEASED TO GIVE FURTHER INFORMATION CONCERNING THEM. HIS ADDRESS IS OTTO LILIENTHAL, 113 KÖPNICKER-STR., — BERLIN, SO., — GERMANY. — ED.

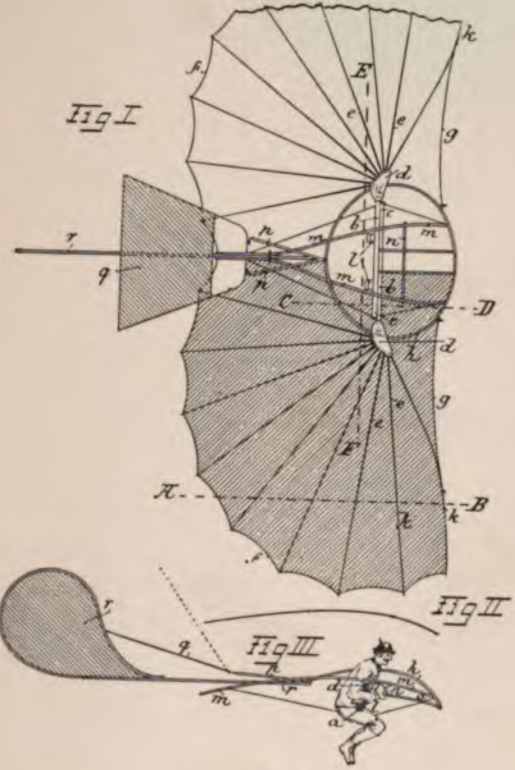


Fig. 4.

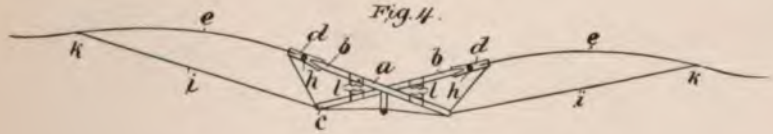
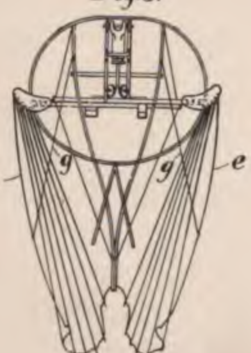


Fig. 5.



WHEELING AND FLYING.

BY THE EDITOR.

THE slow development of the flying machine in its early stages finds its analogue in that of the bicycle. The admirable wheel of to-day is the product of more than eighty years of careful thought and experiment.

The machine has been improved very gradually; most of the modifications have been slight; yet some of the stages have been marked with great distinctness.

The twelve machines here shown in the drawings give a rough outline of the progress made. First, we have the wheel of 1816 (Fig. 1), propelled by striking the feet against the ground. This machine represents the parent form, involving the great principle of two wheels balanced by the act of turning the forward wheel on a pivot. It was used principally for the purposes of sport, and it is easily seen that it was at its best on down grades.

Looking backward, it seems strange to us that a device so simple as a pair of foot cranks attached to the front axle was not soon adopted, yet the discovery of such simple things sometimes takes years of hard thinking. Columbus was doubtless surprised when the superficial people of his day told him on his return that any sailor might have discovered the distant land, "all one had to do was to sail west." His alleged reply, illustrated by the balancing of the egg, was most appropriate. The inventor of the sewing machine informed the world that all through the centuries the sewing needle had been threaded at the wrong end; no one knows how long it took him to think that out. We do know, however, in the case of the wheel, that it took many years to think of putting foot cranks on the front axle.

Mr. Porter says[1] that in 1821 Gompertz invented the "Hobby Horse" shown in Fig. 2, and that in 1840 McMillan made a rear-driving machine as shown in Fig. 3.

He quotes M. de Saunier as saying that the honors of first applying foot cranks to the front axle seem to be evenly divided between Michaux and Lallement, who probably worked independently of each other, the former applying the cranks in 1855, the latter in 1863.

Lallement's machine of 1866 is shown in Fig. 4. This was the machine which immediately preceded the velocipede excitement of the late sixties.

Fig. 5 shows the improvement made from 1866 to 1869.

Mr. Porter says, "In 1871 W. H. J. Grant proposed the use of rubber pedals, . . . and he also vulcanized rubber tires into crescent-shaped metal rims."

"In 1873 there was produced by Starley, 'the Father of the Bicycle,' about the first machine (Fig. 6) embodying most of the features which are found in the modern Ordinary."

The Ordinary was greatly improved in the ten or twelve succeeding years (see Fig. 7), and long distance riding became common, yet the dangers attending the use of the high machine gradually led to the designing of lower wheels, of which types are shown in Figs. 8, 9, 10, and 11.

Later came the safety with cushion tires, which was followed, at last, by the pneumatic Safety of to-day (Fig. 12). This is a mere outline; the intermediate machines were many.

It is not uncommon for the cyclist, in the first flush of enthusiasm which quickly follows the unpleasantness of taming the steel steed, to remark, "Wheeling is just like flying!" This is true in more ways than one. Let us note the points of resemblance. Both modes of travel are riding upon the air, though in one case a small quantity of air is carried in a bag and in the other the air is unbagged. There are many who

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[1] See *Wheels and Wheeling*, by Luther H. Porter. Published by The Wheelman Co., 12 Pearl st., Boston. 387 pp. 75 cents. The editor of The Annual is indebted to the author of the above interesting and valuable work for the principal facts concerning bicycles mentioned in this article. The cuts 1 to 11 are taken from Mr. Porter's book, he having kindly consented to their reproduction.

Fig. 1.
CELERIPEDE.
1816.

Fig. 2
HOBBY-HORSE
1821.

Fig 3.
McCALL'S COPY OF
McMILLAN'S REAR-DRIVER.
1840.

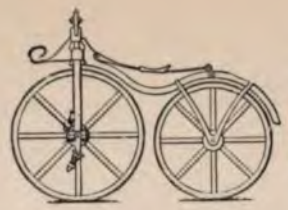

Fig. 4.
LALLEMENT'S VELOCIPEDE.
1866.

Fig. 5.
AMERICAN VELOCIPEDE.
1869.

Fig 6
ARIEL BICYCLE.
1873.

Fig. 7.
"ORDINARY" BICYCLE.
1886.

Fig. 8.
BICYCLETTE.
1880.

Fig. 9.
KANGAROO SAFETY.
1883.

Fig. 10.
MARVEL SAFETY.
1884.

Fig. 11
ORIGINAL ROVER SAFETY.
1884.

Fig. 12.
PNEUMATIC SAFETY.
1896.

THE DEVELOPMENT OF THE WHEEL.

believe that in order to travel upon air it is not necessary to put the air in a bag; they not only believe this but they know it has been done. Lilienthal has done it many times, and the Lilienthal machine is to flying, what the wheel of 1816 was to pneumatic wheeling. The Lilienthal machine seems likely to lead to important things, yet there are men who say of the inventor: "He cannot fly up, he can only fly down, he is a parachutist, a flying squirrel, he has not solved the great problem." True, he has not solved it, but he has given a partial solution which will place his name on the roll of the immortals.

It is not unlikely that men regarded the wheel of 1816 as some now regard the Lilienthal soarer. They probably said, "This machine will do for coasting down hill, but that is not practical travelling. You cannot climb hills with the thing; it is not of much importance anyhow." But after a while, one day a man who thought put cranks on that machine!

Lilienthal flies not only down, but also up. His course as a whole is downward, but when under favoring winds he gets energy from beneath he rises. The only reason that his course as a whole is not upward is that he has not yet completed his apparatus for giving constant energy.

That will take time, and if the world is to make rapid progress in manflight it must have a much greater confidence in the value and importance of the Lilienthal soarer than it had in the wonderful balancing wheel of 1816. It was a balancing wheel, and the great art of balancing began with it. To learn to wheel one must learn to balance; to learn to fly one must learn to balance. Why not begin now, instead of imitating the human race of the first half of the century which took so many years to get its feet off the ground?

NATURAL AND ARTIFICIAL FLIGHT.

By Hiram S. Maxim.

Note.—This article is made up of extracts from an unpublished work and contains the results of Mr. Maxim's latest thought. The author proposes soon to publish the work in full. The whole forms a thesis which was recently sent to the Secretary of the Smithsonian Institution in competition for the Hodgkins prizes. The committee in charge of the Hodgkins Fund awarded to Mr. Maxim honorable mention and a medal for the thesis.

It is speaking quite within bounds to say that this is the most important work which has yet come from this author's pen.—*Ed.*

I.

INTRODUCTORY.

At the time I commenced my experiments in aeronautics it was not generally believed that it would ever be possible to make a large machine heavier than the air that would lift itself from the earth by dynamic energy generated by the machine itself. It is true that a great number of experiments had been made with balloons, but these are in no sense true flying machines. Every one who attempted a solution of the question by machines heavier than the air, was looked upon in very much the same light as the man is now who attempts to construct a perpetual motion machine. Up to within a few years, nearly all experiments in aerial navigation by flying machines have been made by men not versed in science, and who for the most part have been ignorant of the most rudimentary laws of dynamics. It is only quite recently that scientific engineers have

Plate VIII.

MR. MAXIM HOLDING ONE OF HIS ENGINES FOR THE PHOTOGRAPHER.

taken up the question and removed it from the hands of charlatans and mountebanks. A few years ago many engineers would not have dared to face the ridicule which they would be liable to receive if they had asserted that it would be possible to make a machine that would lift itself by mechanical means into the air. However, thanks to the admirable work of Professor Langley, Professor Thurston, Mr. Chanute and others, one may now express his opinion freely on this subject and speculate as to the possibilities of making flying machines, without being relegated to the realm of cranks and fanatics.

During the last five years I have had occasion to write a large number of articles for the public press on this subject, and I have always attempted, as far as it is in my power, to discuss the subject in such a manner as to be easily understood by the unscientific, and I believe that my efforts have done something in the direction of popularizing the idea that it is possible to construct practical flying machines.

In preparing my present work, I have aimed as far as possible to discuss the question in plain and simple language, and to abstain from the use of any formulæ which may not be understood by every one. It has been my experience that if a work abounds in formulæ and tables, even only a few of the scientific will take the trouble to read or understand it. I have therefore confined myself to a plain statement of the actual facts, describing the character of my observations and experiments, and giving the results of the same. All experiments made by others in the same direction have been on a very small scale, and, as a rule, the apparatus employed has been made to travel around a circle, the size of which has not been great enough to prevent the apparatus continually encountering air which had been influenced in some way by the previous revolution.

The first experiments which I conducted were with an apparatus which travelled around a circle 200 feet in circumference, and by mounting some delicate anemometers directly under the path of the apparatus I ascertained that after it had been travelling at a high velocity for a few seconds, there was a well-defined air current blowing downward around the whole circle, so that my planes in passing forward must have been influenced and their lifting effect reduced to some extent by this downward current. My late experiments are the first which have ever been made with an apparatus on a large scale moving in a straight line. In discussing the question of aerial flight with Professor Langley before my large experiments had been made, the Professor suggested that there might be some unknown factor relating to size only which might defeat my experiments, and that none of our experiments had at that time been on a sufficiently large scale to demonstrate what the lifting effect of very large planes would be. A flying machine to be of any value must of necessity be large enough to carry at least one man, and the larger the machine the smaller the factor of the man's weight. Moreover, it is possible to make engines of say from 200 to 400 horse-power, lighter per unit of power than very small engines of from one to two horse-power. On the other hand, it is not advisable to construct a machine on too large a scale, because as the machine becomes larger the relative strength of the material becomes less. In first designing my large machine I intended that it should weigh about 5,000 pounds without men, water, or fuel, that the screw thrust should be 1,500 pounds, and that the total area of the planes should be 5,000 square feet. I expected to lift this machine and drive it through the air at a velocity of 35 miles an hour with an expenditure of about 250 horse-power. However, upon completing the machine I found that many parts were too weak, and these had to be supplanted by thicker and stronger material. This increased the weight of the machine about 2,000 pounds. Upon trying my engines I found that if required they would develop 360 horse-power, and that a screw thrust of over 2,000 pounds could be easily attained, but as an offset against this, the amount of power required for driving the machine through the air was a good deal more than I had anticipated.

NOTE.—For Mr. Maxim's description of this machine see "Century Magazine," N.Y., January, 1895.

II.

NATURAL FLIGHT.

During the last 50 years a great deal has been said and written in regard to the flight of birds. Perhaps no other natural phenomenon has excited so much interest and has been so little understood. Learned treatises have been written to prove that a bird is able to develop from 10 to 100 times as much power for its weight as other animals, while other equally learned treatises have shown most conclusively that no greater amount of energy is exerted by a bird in flying than by land animals in running or jumping.

There is no question but what a bird has a higher physical development, as far as the generation of power is concerned, than any other animal we know of. Nevertheless, I think that every one who has made a study of the question will agree that some animals, such as rabbits, exert quite as much power in running in proportion to their weight as a sea-gull or an eagle exerts in flying.

The amount of power which a land animal has to exert is always a fixed and definite quantity. If an animal weighing 100 pounds has to ascend a hill 100 feet high, it always means the development of 10,000 foot-pounds. With a bird, however, there is no such thing as a fixed quantity, because the medium in which the bird is moving is never stationary. If a bird weighing 100 pounds should raise itself into the air 100 feet during a perfect calm, the amount of energy developed would be 10,000 foot-pounds plus the slip of the wings. But, as a matter of fact, the air in which a bird flies is never stationary, as I propose to show; it is always moving either up or down, and soaring birds, by a very delicate sense of feeling, always take advantage of a rising column of air. If a bird finds itself in a column of air which is descending, it is necessary for it to work its wings very rapidly in order to prevent a descent to the earth.

I have often observed the flight of hawks and eagles. They seem to glide through the air with hardly any movement of their wings. Sometimes, however, they stop and hold themselves in a stationary position directly over a certain spot, carefully watching something on the earth immediately below. In such cases they often work their wings with great rapidity, evidently expending an enormous amount of energy. When, however, they cease to hover and commence to move again through the air, they appear to keep themselves at the same height with an almost imperceptible expenditure of force.

Many unscientific observers of the flight of birds have imagined that a wind or a *horizontal* movement of the air is all that is necessary in order to sustain the weight of a bird in the air after the manner of a kite. If, however, the wind, which is only air in motion, should be blowing everywhere at exactly the same speed and in the same direction (horizontally), it would offer no more sustaining power to a bird than a dead calm, because there is nothing to prevent the body of the bird being blown along with the air, and whenever it had attained the same velocity as the air, no possible arrangement of the wings would prevent it from falling to the earth.

The wind, however, seldom or never blows in a horizontal direction. Some experimenters have lately asserted that if it were possible for us to ascend far enough, we should find the temperature constantly falling until at about 20 or 25 miles above the earth's surface the absolute zero might be reached. Now, as the air near the earth never falls in temperature to anything like the absolute zero, it follows that there is a constant change going on, the relatively warm air near the surface of the earth always ascending, and, in some cases, doing sufficient work in expanding to render a portion of the water it contains visible, forming clouds, rain, or snow, while the very cold air is constantly descending to take the place of the rising column of warm air.

On one occasion while crossing the Atlantic in fine weather, I noticed, some miles directly ahead of the ship, a long line of glassy water. Small waves indicated that the wind was blowing in the exact direction in which the ship was moving, and I observed as we approached the glassy line that the waves became smaller and smaller until they completely disappeared in a mirror-like surface which was about 300 or 400 feet wide and extended both to the port and starboard in approximately a straight line as far as the eye could reach. After passing the centre of this zone, I noticed that small waves began to show themselves, but in the exact opposite direction to those through which we had already passed. I observed that these waves became larger and larger for nearly an hour. Then they began to get gradually smaller, when I observed another glassy line directly ahead of the ship. As we approached it the waves completely disappeared, but after passing through it I noticed that the wind was blowing in the opposite direction and that the waves increased in size exactly in the same manner that they had diminished on the opposite side of the glassy zone.

This would seem to indicate that directly over the centre of the first glassy zone, the air was meeting from both sides and ascending, and that at the other glassy zone the air was descending in practically a straight line to the surface of the water where it spread out and set up a light wind in both directions.

I spent the winter of 1890–91 on the Riviera, between Hyères les Palmiers and Monte Carlo. The weather for the most part was very fine, and I often had opportunities of observing the peculiar phenomena which I had already noticed in the Atlantic, only on a much smaller scale. Whereas, in the Atlantic, the glassy zones were from 5 to 20 miles apart, I often found them not more than 500 feet apart in the bays of the Mediterranean.

At Nice and Monte Carlo this phenomenon was also very marked. On one occasion, while making observations from the highest part of the promontory of Monaco on a perfectly calm day, I noticed that the whole of the sea presented this peculiar effect as far as the eye could reach, and that the lines which marked the descending air were never more than a thousand feet from those which marked the centre of the ascending column. At about 3 o'clock in the afternoon, a large black steamer passed along the coast in a perfectly straight line, and I noticed that its wake was at once marked by a glassy line which indicated the centre of an ascending column. This line remained almost straight for two hours, when finally it became crooked and broken. The heat of the steamer had been sufficient to determine this upward current of air.

In 1893, I spent two weeks in the Mediterranean, going by a slow steamer from Marseilles to Constantinople and returning, and I had many opportunities of observing the peculiar phenomenon which I have before referred to. The steamer passed over thousands of square miles of calm sea, the surface being only disturbed by large batches of small ripples separated from each other by glassy streaks, and I found that in no case was the wind blowing in the same direction on both sides of these streaks, every one of them either indicating the centre of an ascending or a descending column of air.

If we should investigate this phenomenon in what might be called a dead calm, we should probably find that the air was rising straight up over the centres of some of these streaks, and descending in a vertical line over the centres of the others. But, as a matter of fact, there is no such thing as a dead calm. The movement of the air is the resultant of more than one force. The air is not only rising in some places and descending in others, but at the same time the whole mass is moving forward with more or less rapidity from one part of the earth to another. So we might consider that, instead of the air ascending directly from the relatively hot surface of the earth and descending vertically in other places, in reality it is moving on an incline.

Suppose that the local influence which causes the up and down motion of the air should be sufficiently great to cause it to rise at the rate of 2 miles an hour, and that the wind at the same time should be blowing at the rate of 10 miles an hour; the motion of the air would then be the resultant of these two velocities. In other words, it would be blowing up an incline of 1 in 5. Suppose now, that a bird should be able to so adjust its wings that it advanced 5 miles in falling 1 mile through a perfectly calm atmosphere; it would be able to sustain itself in an inclined wind, such as I have described, without any movement at all of its wings. If it was able to adjust its wings in such a manner that it could advance 6 miles by falling through 1 mile of air, it would then be able to rise as relates to the earth while in reality falling as relates to the surrounding air.

In conducting a series of experiments with artillery and small guns in a very large and level field just out of Madrid, I often observed the same phenomena as relates to the wind, that I have already spoken of as having observed at sea, except that the lines marking the centre of an ascending or a descending column of air were not so stationary as they were over the water. It was not an uncommon thing when adjusting the sights of a gun to fire at a target at very long range, making due allowances for the wind, to have the wind change and blow in the opposite direction before the word of command was given to fire. While conducting these experiments, I often noticed the flight of eagles. On one occasion a pair of eagles came into sight on one side of the plain, passed directly over our heads and disappeared on the opposite side. They were apparently always at the same height from the earth and soared completely across the plain without once moving their wings. This phenomenon, I think, can only be accounted for on the hypothesis that they were able to feel out with their wings an ascending column of air, that the centre of this column of air was approximately a straight line running completely across the plain, that they found the ascending column to be more than necessary to sustain their weight in the air, and that whereas, as relates to the earth, they were not falling at all, they were really falling some 2 or 3 miles an hour in the air which supported them.

Again, at Cadiz in Spain, when the wind was blowing in very strongly from the sea, I noticed that the sea-gulls always took advantage of an ascending column of air. As the wind blew in from the sea and rose to pass over the fortifications, the sea-gulls selected a place where they could slide down on the ascending current of air, keeping themselves always approximately in the same place without any apparent exertion. When, however, they left this ascending column, I observed that it was necessary for them to work their wings with great vigor until they again found the proper place to encounter the favorable current.

I have often noticed sea-gulls following a ship. I have observed that they are able to follow the ship without any apparent exertion; they simply balance themselves on an ascending column of air and seem to be quite as much at ease as they would be if they were roosting on a solid support. If, however, they are driven out of this position, I find that they generally have to commence at once to work their passage. If anything is thrown overboard which is too heavy for them to lift, the ship soon leaves them, and in order to catch up with it again, they move their wings very much as other birds do; but when once established in the ascending column of air, they manage to keep up with the ship by doing little or no work. In a head wind we find them directly aft of the ship; if the wind is from the port side, they may always be found on the starboard quarter, and *vice versa*.

Every one who has passed a winter on the northern shores of the Mediterranean must have observed the cold wind which is generally called the *mistral*. One may be out driving, the sun may be shining brightly, and the air be warm and balmy, when, suddenly, without any apparent cause, one finds himself in a cold descending wind. This is the much-dreaded mistral, and if at sea, it would be marked by a glassy line on the surface of the water. On land, however, there is nothing to render its presence visible. I have found that the ascending column of air is always very much warmer than the descending column, and that this action is constantly taking place in a greater or less degree.

From the foregoing deductions I think we may draw the following conclusions:

First, that there is a constant interchange of air taking place, the cold air descending, spreading itself out over the surface of the earth, becoming warm, and ascending in other places.

Second that the centres of the two columns are generally separated from each other by a distance which may be from 500 feet to 20 miles.

Third, that the centres of greatest action are not in spots, but in lines which may be approximately straight but generally abound in many sinuosities.

Fourth, that this action is constantly taking place over both the sea and the land, that the soaring of birds, a phenomenon which has heretofore been so little understood, may be accounted for on the hypothesis that the bird seeks out an ascending column of air, and that, while sustaining itself at the same height in the air without any muscular exertion, it is in reality falling at a considerable speed through the air that surrounds it.

It has been supposed by some scientists that the birds may take advantage of some vibratory or rolling action of the air. I find, however, from careful observation and experiment, that the motion of the wind is comparatively steady, and that the short vibratory or rolling action is always very near to the earth and is produced by the air flowing over the tops of hills, high buildings, or trees. If a kite is flown only a few feet above the ground, it will be found that the current of air is very unsteady. If it is allowed to mount to 500 feet, the unsteadiness nearly all disappears, while if it is further allowed to mount to a height of 1,500 or 2,000 feet, the pull on the cord is almost constant, and, if the kite is well made, it remains practically stationary in the air.

I have often noticed in high winds, that light and fleecy clouds come into view, say, about 2,000 feet above the surface of the earth, and that they pass rapidly and steadily by, preserving their shape completely. This would certainly indicate that there is no rapid local disturbance in the air in their immediate vicinity, but that the whole mass of air in which these clouds are formed is practically travelling in the same direction and at the same velocity. Numerous aeronauts have also testified that, no matter how hard the wind may be blowing, the balloon is always practically in a dead calm, and if a piece of gold-leaf is thrown overboard even in a gale, the gold-leaf and the balloon never part company in a horizontal direction, though they may in a vertical direction.

Birds may be divided into two classes: first, the soaring birds, which practically live upon the wing, and which, by some very delicate sense of touch, are able to feel the exact condition of the air. Many fish which live near the top of the water are greatly distressed by sinking too deeply, while others which live at great depths are almost instantly killed by being raised to the surface. The swim bladder of a fish is in reality a delicate barometer provided with sensitive nerves which enable the fish to feel whether it is sinking or rising in the water. With the surface fish, if the pressure becomes too great, the fish involuntarily exerts itself to rise nearer the surface and so diminish the pressure, and I have no doubt that the air-cells, which are known to be very numerous and to abound throughout the bodies of birds, are so sensitive as to enable soaring birds to know at once whether they are in an ascending or a descending column of air.

The other class of birds consists of those which only employ their wings for the purpose of taking them rapidly from one place to another. Such birds may be considered not to expend their power so economically as the soaring birds. They do not spend a very large portion of their time in the air, but what time they are on the wing they exert an immense amount of power and fly very rapidly, generally in a straight line, taking no advantage of air currents. Partridges, pheasants, wild ducks, geese, and some birds of passage may be taken as types of this kind. This class of birds has relatively small wings, and carries about $2\frac{1}{2}$ times as much weight per square foot of surface as soaring birds do.

III.

ARTIFICIAL FLIGHT. — THE ENGINES.

There is no question but what birds — and, for that matter, all animals — when considered as thermo-dynamic machines, are very perfect motors; they develop the full theoretical amount of energy in the carbon consumed. This we are quite unable to do with any artificial machine, but birds for the most part have to content themselves with food which is not very rich in carbon. It is quite true that a bird may develop from 10 to 15 times as much power from the carbon consumed as may be developed by the best steam-engine, but as an offset against this, a steam-engine is able to consume petroleum, which has at least 20 times as many thermal units per pound as the ordinary food of birds. The movement of a bird's wings, from long years of development, has without doubt attained a great degree of perfection. Birds are able to scull themselves through the air with very little loss of energy. To imitate by mechanical means the exact and delicate motion of their wings would certainly be a very difficult task, and I do not believe that we should attempt it in constructing an artificial flying machine. In Nature it is necessary that an animal should be made all in one piece. It is therefore quite out of the question that any part or parts should revolve. For land animals there is no question but what legs are the most perfect system possible, but in terrestrial locomotion by machinery — not necessarily in one piece — the wheel is found to be much more effective and efficient. The swiftest animal can only travel for a minute of time at half the speed of a locomotive, while the locomotive is able to maintain its much greater speed for many hours at a time. The largest land animals only weigh about 5 tons, while the largest locomotives weigh from 60 to 80 tons. In the sea, the largest animal weighs about 75 tons, while the ordinary Atlantic liner weighs from 4,000 to 14,000 tons. The whale no doubt is able to maintain a high speed for several hours at a time, but the modern steamer is able to maintain a still higher speed for many consecutive days.

As artificial machines for terrestrial and aquatic locomotion have been made immensely stronger and larger than land or water animals, so, in a flying machine, it will be necessary to construct it much heavier and stronger than the largest bird. If one should attempt to propel such a machine with wings, it would be quite as difficult a problem to solve as it would be to make a locomotive that would walk on legs. What is required in a flying machine is something to which a very large amount of power can be directly and continuously applied without any intervening levers or joints, and this we find in the screw propeller.

It was about 20 years ago that I first commenced to think of the question of artificial flight. My first idea was to construct a machine with two large screws on vertical shafts. I proposed to run these screws in reverse directions by the use of a caloric or hot-air engine, but after considering the subject for some time, I came to the conclusion that this class of engine would not do. When the Brayton gas engine first made its appearance, I commenced drawings of a machine, using a modification of the Brayton motor which I designed expressly for the purpose; but even this was found to be too heavy, and it was not until after I abandoned the vertical screw system that it was possible for me to design a machine which in theory ought to fly.

The next machine which I considered was on the kite or aeroplane system. This was also to be driven by an oil engine. Oil engines at that time were not so simple as now, and moreover the system of ignition was very heavy, cumbersome, and uncertain. Since that time, however, gas and oil engines have been very much improved, and the ignition tube, which is almost universally used, has greatly simplified the ignition, so that at the present time I am of the opinion that an oil engine might be designed which would be suitable for the purpose.

IV.

THE ADVANTAGES AND DISADVANTAGES OF VERY NARROW PLANES.

My experiments have demonstrated that relatively narrow aeroplanes lift more per square foot than very wide ones, but as an aeroplane, no matter how narrow it may be, must of necessity have some thickness, it is not advantageous to place them too near together. Suppose that aeroplanes should be made ¼ in. thick and be superposed 3 inches apart, that is, at a pitch of 3 inches. One-twelfth part of the whole space through which these planes would have to be driven would be occupied by the planes themselves, and eleven-twelfths would be air space (Fig. 1). If a group of planes thus mounted should be driven through the air at the rate of 36 miles an hour,[1] the air would have to be driven forward at the rate of 3 miles an hour, or else it would have to be compressed, or spun out, and pass between the spaces at a speed of 39 miles an hour. As a matter of fact, however, the difference in pressure is so very small, that practically no atmospheric compression takes place. The air, therefore, is driven forward at the rate of 3 miles an hour, and this consumes a great deal of power, in fact, so much that there is a decided disadvantage in using narrow planes thus arranged.

Fig. 1.

In regard to the curvature of narrow aeroplanes, I have found that if one only desires to lift a large load in proportion to the area, the planes may be made very hollow on the underneath side; but when one considers the lift in terms of screw thrust, I find it advisable that the planes should be as thin as possible and the underneath side nearly flat. I have also found that it is a great advantage to arrange the planes after the manner

[1] The arrows in the accompanying drawings show the direction of the air currents, the experiments having been made with stationary planes and a moving current of air.

shown in Fig. 2. In this manner, the sum of all the spaces between the planes is equal to the whole area occupied by the

Fig. 2.

planes; consequently, the air neither has to be compressed, spun out, or driven forward. I am therefore by this arrangement able to produce a large lifting effect per square foot, and, at the same time, to keep the screw thrust within reasonable limits.

A large number of experiments with very narrow aeroplanes have been conducted by Mr. Horatio Phillips at Harrow, in England. Fig. 3 shows a cross section of one of Mr. Phillips' planes. Mr. Phillips is of the opinion that the air in striking the top side of the plane is thrown upward in the manner shown and a partial vacuum is thereby formed over the central part of the plane, and that the lifting effect of planes made in this form is therefore very much greater than with ordinary narrow planes. I have experimented with these "sustainers" (as Mr. Phillips calls them) myself, and I find it is quite true that they lift in some cases as much as 8 lb. per sq. ft.,[1] but the lifting effect is not

Fig. 3.

[1] In my early experiments I lifted as much as 8 lb. per sq. ft. with aeroplanes which were only slightly curved, but very thin and sharp.

produced in the exact manner that Mr. Phillips seems to suppose. The air does not glance off in the manner shown. As the "sustainer" strikes the air, two currents are formed, one following the exact contour of the top and the other the bottom. These two currents join and are thrown downward as relates to the "sustainer" at an angle which is the resultant of the angles at which the two currents meet. (Fig. 4.) These

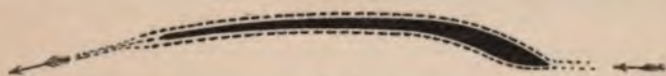

Fig. 4.

"sustainers" may be made to lift when the front edge is lower than the rear edge because they encounter still air, and leave it with a downward motion.

In my experiments with narrow superposed planes, I have always found that with strips of thin metal made sharp at both edges and only slightly curved, the lifting effect, when considered in terms of screw thrust, was always greater than with any arrangement of the wooden aeroplanes used in Phillips' experiments. It would therefore appear that there is no advantage in the peculiar form of "sustainer" employed by this inventor.

If an aeroplane be made perfectly flat on the bottom side and convex on the top, as shown in Fig. 5, and be mounted in the air so that the bottom side is exactly horizontal, it produces a lifting effect no matter in which direction it is run, because as it advances it encounters stationary air which is divided into two streams. The top stream being unable to fly off at a tangent when turning over the top curve, flows down the incline and joins the current which is flowing over the lower horizontal surface. The angle at which the combined stream of air leaves the plane is the resultant of these two angles; consequently, as the plane finds the air in a stationary condition and leaves it with a downward motion, the plane itself must be lifted. It is

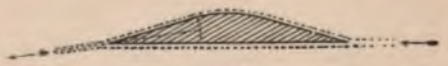

Fig 5.

true that small and narrow aeroplanes may be made to lift considerably more per square foot of surface than very large ones, but they do not offer the same safeguard against a rapid descent to the earth in case of a stoppage or breakdown of the machinery. With a large aeroplane properly adjusted, a rapid and destructive fall to the earth is quite impossible.

In the foregoing experiments with narrow aeroplanes, I employed an apparatus (Fig. 6) which enabled me to mount my planes at any angle in a powerful blast of air, and to weigh the exact lifting effect and also the tendency to drift with the wind. This apparatus also enables me to determine with a great degree of nicety the best form of an atmospheric condenser to employ.

V.

THE EFFICIENCY OF SCREW PROPELLERS. — STEERING, STABILITY, ETC.

Before I commenced my experiments at Baldwyn's Park, I attempted to obtain some information in regard to the action of screw propellers working in the air. I went to Paris and saw the apparatus which the French Government employed for testing the efficiency of screw propellers, but the propellers were so very badly made that the experiments were of no value. Upon consulting an English experimenter who had made a "lifelong study" of the question, he assured me that I should find the screw propeller very inefficient and very wasteful of power. He said that all screw propellers had a powerful fan-blower action, drawing in air at the centre and discharging it with great force at the periphery. I found that no two men were agreed as to the action of screw propellers. All the data or formulæ available were so confusing and contradictory as to be of no value whatsoever. Some experimenters were of the opinion that in computing the thrust of a screw we should only consider the projected area of the blades, and that the thrust would be equal

Plate IX.

K J I

H G F E D

Fig. 13. — A group, showing the various forms of screws which Mr. Maxim has tested. The screw J was found to be the most efficient. A similar screw K, with wider blades, did not do so well. The screw E, although very light and small, did very well. G, a screw made on the French plan, proved the worst screw experimented with. H, the same form as J, except that the blades are much thicker, also did remarkably well.

C B A

Fig. 14.

THE THREE PRINCIPAL FORMS OF SCREW EXPERIMENTED WITH.

A. — Plain screw with flat blades.
B. — Screw with slightly curved blades with increasing pitch.
C. — Screw with curved blades, compound increasing pitch.

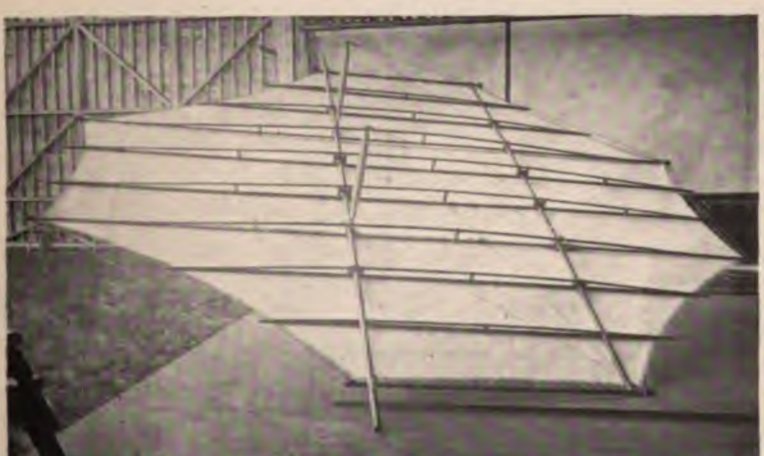

Fig. 15.

THE FORWARD RUDDER FOR STEERING MR. MAXIM'S MACHINE IN A VERTICAL DIRECTION.

This plate is especially interesting as showing the construction of the framing. — Ed.

to a wind blowing against a normal plane of equal area at a velocity equal to the slip. Others were of the opinion that the whole screw disk would have to be considered; that is, that the thrust would be equal to a wind blowing against a normal plane equal to the area of the whole disk at the velocity of the slip. The projected area of the two screw blades of my machine is 94 square feet, and the area of the 2 screw disks is 500 square feet. According to the first system of reasoning, therefore, the screw thrust of my large machine, when running at 40 miles an hour with a slip of 18 miles per hour, would have been, according to the well-known formula, $V^2 \times .005 = P$

$$18^2 \times .005 \times 94 = 152.28 \text{ pounds.}$$

If, however, we should have considered the whole screw disk, it would have been —

$$18^2 \times .005 \times 500 = 810 \text{ pounds.}$$

However, when the machine was run over the track at this rate, the thrust was found to be rather more than 2,000 lbs. When the machine was secured to the track and the screws revolved until the pitch in feet multiplied by the turns per minute was equal to 68 miles an hour, it was found that the screw thrust was 2,164 lbs. In this case it was of course all slip, and when the screws had been making a few turns they had established a well-defined air-current, and the power exerted by the engines was simply to maintain this air-current, and it is interesting to note that if we compute the projected area of these blades by the foregoing formula, the thrust would be —

$$68^2 \times .005 \times 94 = 2173.28 \text{ pounds,}$$

which is almost exactly the observed screw thrust. From this, it would appear when the machine is stationary, and all the power is consumed in slip, that only the projected area of the screw blades should be considered. But whenever the machine is allowed to advance, and to encounter new air, the inertia of which has not been disturbed, the efficiency increases in geometrical progression. The exact rate for all speeds I have not yet ascertained. My experiments have, however, shown that with a speed of 40 miles an hour and a screw slip of 18 miles an hour, a well-made screw propeller is 13.1 times as efficient as early experimenters had supposed and attempted to prove by elaborate formulæ.

When I first commenced my experiments with a large machine, I did not know exactly what form of boiler, gas generator, or burner I should finally adopt; I did not know the exact size that it would be necessary to make my engines; I did not know the size, the pitch, or the diameter of the screws which would be the most advantageous. Neither did I know the form of aeroplane which I should finally adopt. It was therefore necessary for me to make the foundation or platform of my machine of such a character that it would allow me to make the modifications necessary to arrive at the best results. The platform of the machine is therefore rather larger than is necessary, and I find if I were to design a completely new machine, that it would be possible to greatly reduce the weight of the framework, and, what is still more, to greatly reduce the force necessary to drive it through the air.

At the present time, the body of my machine[1] is a large platform, about 8 ft. wide and 40 ft. long. Each side is formed of very strong trusses of steel tubes, braced in every direction by strong steel wires. The trusses which give stiffness to this superstructure are all below the platform. In designing a new machine, I should make the trusses much deeper and at the same time very much lighter, and, instead of having them below the platform on which the boiler is situated, I should have them constructed in such a manner as to completely enclose the boiler and the greater part of the machinery. I should make the cross-section of the framework rectangular, and pointed at each end. I should cover the outside very carefully with balloon material, giving it a perfectly smooth and even surface throughout, so that it might be easily driven through the air.

In regard to the screws, I am at the present time able to mount screws 17 ft. 10 in. in diameter. I find, however, that my machine would be much more efficient if the screws were 24 feet in diameter, and I believe with such very large screws, four blades would be much more efficient than two.

[1] See *A New Flying Machine*, by H. S. Maxim. Century Magazine, N. Y., January, 1895. — *Ed.*

My machine may be steered to the right or to the left by running one of the propellers faster than the other. Very convenient throttle valves have been provided to facilitate this system of steering. An ordinary vertical rudder placed just after the screws may, however, prove more convenient, if not more efficient.

The machine is provided with fore and aft horizontal rudders, both of which are connected with the same windlass. If the forward rudder is placed at an angle considerably greater than that of the main aeroplane, and the rear rudder placed flat so as not to lift at all (Fig. 7), and the machine run over the track at a high speed, the front wheels will be lifted from the steel rails, leaving the rear wheels on the rails.

Fig. 7. — The forward wheels off the track.

If the rudders are placed in the reverse position so that the front rudder is thrown out of action, and the rear rudder lifts to its full extent (Fig. 8), the hind wheels will be lifted from the steel rails, leaving only the forward wheels touching.

Fig. 8. — The rear wheels off the track.

If both rudders are placed at such an angle that they both lift (Fig. 9), and the machine is run at a very high velocity, all four of the wheels will be lifted from the steel rails. This would seem to show that these rudders are efficient as far as vertical steering is concerned. If the machine should break down in the air it would be necessary to tilt the rudders in the position shown in Fig. 10, when it would fall to the ground without pitching or diving.

Fig. 9. — All the wheels off the track.

In regard to the stability of the machine, the centre of weight is much below the centre of lifting effect; moreover, the upper wings are set at such an angle that whenever the machine tilts to the right or to the left, the lifting effect is increased on the lower side and diminished on the higher side (Fig. 11). This simple arrangement makes the machine automatic as far as rolling is concerned. I am of the opinion that whenever flying machines come into use it will be necessary to steer them in a vertical direction by means of an automatic steering gear controlled by a gyroscope. It will certainly not be more difficult to manœuvre and steer such machines than it is to control completely submerged torpedoes.

Fig. 10. — Showing the manner of placing the fore and aft rudders in case of a breakage of the machinery.

Fig. 11.

When the machine is once perfected, it will not require a railway track to enable it to get the necessary velocity to rise. A short run over a moderately level field will suffice. As far as landing is concerned, the aerial navigator will touch the ground while moving forward, and the machine will be brought to a state of rest by sliding on the ground for a short distance. In this manner very little shock will result, whereas if the machine is stopped in the air and allowed to fall directly to the earth without advancing, the shock, although not strong enough to be dangerous to life or limb, might be sufficient to disarrange or injure the machinery.

VI.

THE COMPARATIVE VALUE OF DIFFERENT MOTORS.

So far I have only discussed the navigation of the air by the use of propellers driven by a steam engine. The engines that I employ are what are known as compound engines, that is, they have a large and a small cylinder. Steam at a very high pressure enters the high pressure cylinder, expands and escapes at a lower pressure into a larger cylinder where it again expands and does more work. A compound engine is more economical in steam than a simple engine, and therefore requires a smaller boiler to develop the same horse-power, so that when we consider the weight of water and fuel for a given time, together with the weight of the boiler and the engine, the complete motor with a compound engine is lighter than a simple engine. However, if only the weight of the engine is to be considered, then the simple engine will develop more power per unit of weight than the compound engine. For instance, if instead of allowing the steam to enter the small cylinder, and the exhaust from this cylinder to enter the large or low-pressure cylinder, which necessitates that the high-pressure piston has to work against a back-pressure equal to the full pressure in the low-pressure cylinder, I should connect both cylinders direct with the live steam and allow both to discharge their exhaust directly into the air. I should then have a pair of simple engines, and instead of developing 363 horse-power, they would develop fully 500 horse-power, or nearly 1 horse-power for every pound of their weight. I mention this fact to show that the engines are exceedingly light, and that when compared with simple engines their power should be computed on the same basis. It will therefore be seen that if we do not take into consideration the steam supply or the amount of fuel and water necessary, the simple steam engine is an exceedingly light motor.

But as before stated, great improvements have recently been made in oil engines. I have thought much on this subject, and am of the opinion that if one had an unlimited supply of money, a series of experiments could be very profitably conducted with a view of adapting the oil engine for use on flying machines. If we use a steam engine it is necessary to have a boiler, and at the best a boiler is rather a large and heavy object to drive through the air. If we use an oil engine no boiler is necessary and the amount of heat carried over in the cooling water will only be one-seventh part of what is carried over in the exhaust from a steam engine of the same power. Therefore the condenser need only be one-seventh part of the size, and consequently could be made lighter with the tubes placed at a greater distance apart, and thus reduce the amount of power necessary to drive the machine through the air. Moreover, the supply of water necessary will be greatly reduced and a cheaper and heavier oil may be employed which is not so liable to take fire in case of an accident. It is, then, only a question as to whether an oil engine can be made so light as to keep its weight within that of a steam motor; that is, an oil-engine in order to be available for the purpose must be as light, including its water supply, as a complete steam motor which includes not only the engine, but also the boiler, the feed-pumps, the water supply, the burner, the gas generator, and six-sevenths of the condenser. It requires a very perfect steam-engine and boiler, not using a vacuum, to develop a horse-power with a consumption of $1\frac{1}{2}$ pounds of petroleum per hour; but there are many oil engines which develop a horse-power with rather less than one pound of oil per hour. It will therefore be seen that as far as fuel is concerned the oil engine has a decided advantage over the more complicated steam motor. Moreover, with an oil engine the cooling water is not under pressure, so that the waste of water would be much less than with a steam engine, where the pressure is so high as to cause a considerable amount of waste through joints, valves, and numerous stuffing boxes.

The great advances that have been made of late years in electrical science and engineering have led many to believe that almost any knotty scientific question could be solved by the employment of electrical agencies, and a great deal has been written and said in regard to navigating the air by flying machines driven by electric motors.

Before I commenced my experiments I made inquiries of all the prominent electrical engineering establishments where there was any likelihood of obtaining light and efficient electric motors, and I found that it was impossible to obtain one that would develop a horse-power for any considerable time that would weigh less than 150 lbs. Since that time, notwithstanding that a great deal has appeared in the public prints about the efficiency and lightness of electric motors, I am unable to learn of any concern that is ready to furnish a complete motor, including a primary or secondary battery which would supply the necessary current for two hours at a time, at a weight of less than 150 lbs. per horse-power, and as far as I have been able to ascertain from what I have myself seen, I cannot learn that there are any motors in practical use which do not weigh, including their storage batteries, at least 300 lbs. per horse-power. The last electric motor which I examined was in a boat; it was driven by a primary battery which weighed over 1,000 lbs. to the horse-power. From this I am of the opinion that we can not at present look to electricity with any hope of finding a motor which is suitable for the purpose of aerial navigation.

VII.

CONCLUSION.

My large machine, which was injured in my late experiments, has now been repaired and improved, and is quite ready to be used in any other experiments which I may wish to make on the limited area which I now have at my disposal. The railway track on which my experiments have been made is 1,800 feet long and the land on all sides is thickly studded with large trees. When making experiments about 500 feet of the track is used in getting up the necessary speed and 300 feet is utilized in bringing the machine again to a state of rest. My clear run is therefore limited to 1,000 feet, and the time which the machine takes to pass over this length of rail is at the most only a few seconds. It will therefore be seen that it is not an easy matter to conduct experiments in a satisfactory manner. In addition to these experiments with a large machine, I am also conducting a series of experiments in a blast of air issuing from a trunk 3 feet square. The air is set in motion by the action of screw propellers driven by a steam engine of 60 horse-power, and I am able to obtain any atmospheric velocity that I require, from 5 to 90 miles an hour. This apparatus is shown in Fig. 6, and is constructed in such a manner that it enables me to mount in this current of air any object that I wish to experiment with. For instance, a bar of wood 3 inches square is mounted in the blast of air so that one of its sides forms a normal plane perpendicular to the direction of the blast. The engine is then run until the air is passing through the trunk at a velocity of 50 miles an hour. The tendency of this bar of wood to travel in the direction of the air may then be accurately determined, and this is considered as unity. A cylinder exactly 3 inches in diameter may then be mounted and tested in the same manner. The cylinder will of course have less tendency to travel with the air than the square bar of wood, and whatever this tendency is, will be the coefficient of a cylinder. I have provided oval, elliptical, and various other shaped objects to be experimented with, and when the experiments are finished I shall know the exact coefficient of all shapes that it may be practical to use in the framework of a flying machine, and also what effect is produced by placing two or more bodies in close proximity to each other.

In addition to these experiments, I am also able with the same air blast to ascertain the efficiency of various forms of aeroplanes, superposed or otherwise, and placed at all angles, the apparatus being provided with a scale beam which not only enables me to measure the drift, but also to accurately weigh the lifting effect. The aeroplane, or grouping of aeroplanes, in

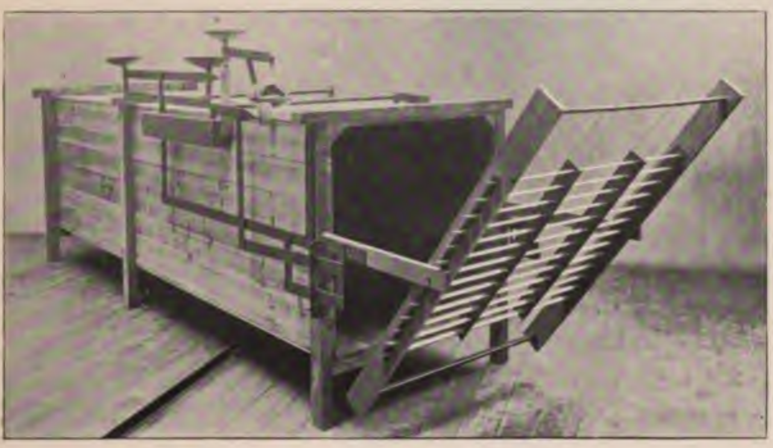

Fig. 6.

AIR-BLAST APPARATUS FOR MEASURING THE LIFT AND DRIFT OF AEROPLANES AND AEROCURVES.

Fig. 12.

THE RESULT OF AN ACCIDENT TO MR. MAXIM'S MACHINE.

This shows one of the wheels which pulled upward on the upper rail. The lifting power of the machine caused the axle to yield as here shown.

which the drift will go the greatest number of times into the lift will be considered the most satisfactory for the purpose.

Experiments are also being made in the same air blast with a view of ascertaining the condensing and lifting power of various forms of tubes, steam in the condition of exhaust being passed through the tubes while the air is driven between them at any velocity required. The experiments are being made with pure steam and also with steam contaminated with oil, with a view of ascertaining to what extent the efficiency of the condenser is reduced by a film of oil such as may be expected from exhaust steam. These experiments will enable me to ascertain very exactly the weight and the efficiency of atmospheric condensers, the amount that their tubes may be made to lift at various speeds and atmospheric conditions, and will also enable me to select the form which I find most suitable for the purpose.

In navigating a boat, it is only necessary that one should be able to turn it to the right or to the left (port or starboard), but with a flying machine it is not only necessary to steer it to the right or left (horizontally), but also in a vertical direction to prevent it from rearing up forward or pitching, and this, if it is accomplished by hand, will require the constant vigilance of a man at the wheel who can make observations, think, and act instantly. In order to prevent a too rapid up and down deviation of the machine I have constructed it of great length, so that the man at the helm will have more time to think and act. As before stated, however, I am of the opinion that the steering in a vertical direction should be automatically controlled by a gyroscope, and I have made an apparatus which consists of a steam piston acting directly upon the fore and aft rudders, the steam valve being controlled by a gyroscope. As the rudders are moved by the steam, their movement shuts the steam off in exactly the same manner that the moving of a rudder shuts off the steam in the well-known steam-steering apparatus now universally in use on all large steamers.

Now that it is definitely known that it is possible to construct a large machine which is light enough and at the same time powerful enough to raise its own weight and that of its engineers into the air, the next question which presents itself for solution is to ascertain how to steer and control such a machine when actually free from the earth. When it is considered that the machine is of great size and that it is necessary that it should move through the air at a velocity of at least 35 miles an hour in order to leave the ground, it will be obvious that manœuvring experiments cannot be conducted in a circumscribed place such as I now have. It is therefore necessary for me to obtain new and much larger premises where I shall have a very large and level field at my disposal. It is not an easy matter to obtain a field of this character in England, and it is almost impossible to find a suitable place near London. Moreover, experiments of this character, which are of little value unless conducted on a large scale, are exceedingly expensive, in fact, too expensive to be conducted by private individuals. Nevertheless, as my experiments have shown most conclusively that flying machines are not only possible but practicable, I think I am justified in continuing my experiments until a comparatively perfect flying machine has been evolved. When I have obtained possession of a suitable field, I propose to erect a large building which will contain the machine with all its wings in position. The building which I have at present, notwithstanding that it cost $15,000, is not large enough for the purpose, as the wings all have to be taken off before the machine can be housed.

There are so many points that may be improved that I have determined to build a new machine on a somewhat smaller scale, using about 200 or 250 horse-power. I shall make the engines of a longer stroke in proportion to their diameter so as to get a greater piston speed.[1] I shall construct my screw propellers with 4 long and narrow blades, very sharp and thin, and shall make them large enough so that the pressure on the projected area of the blades will be about 10 lbs. per square foot instead of over 20 lbs. as now. This will greatly reduce the

[1] The present piston speed does not exceed 800 feet per minute. The piston speed of express locomotives is often more than 1,000 feet per minute.

waste of power which is now lost in screw slip. As the present boiler has been found larger than is necessary, my next boiler will be made lighter and smaller, and instead of carrying a pressure of 320 lbs. to the square inch, I shall only carry 275 lbs. But the greatest improvement will be made in the framework of the machine, which will be constructed with a view of enabling everything to be driven through the air with the least possible resistance. The main aeroplane will be the same form as now, but placed at an angle of 1 in 13 instead of 1 in 8, and will be used principally for preventing the machine from accidentally falling to the earth. The principal lifting effect will be derived from a considerable number of relatively narrow aeroplanes placed on each side of the machine and mounted in such a position that the air can pass freely between them. The fore and aft rudders will be the same form as those now employed. The condenser will consist of a large number of small hollow aeroplanes about 2 inches wide, made of very thin and light metal and placed immediately behind the screw-propellers. They will be placed at such an angle as to lift about 1,000 pounds in addition to their weight and the weight of their contents. Instead of mounting my machine as now on 4 wheels, I propose to mount it on 3, the two hind wheels being about 40 feet apart and the forward wheel placed about 60 feet in front of these. I propose to lay down a track of 3 rails, the sleepers being embedded in the ground so as to produce a comparatively level surface. This railway track should be oval or circular in form so that the machine may be heavily weighed to keep it on the track and be run at a high speed. This will enable me to test the furnace draught, the burner, the steam, the boiler, the engines, the propelling effects of the screws, and the efficiency of the condenser while the machine is on the ground.

When all the machinery has been made to run smoothly I shall remove all the weight except that directly over the front wheel, and shall place a device between the wheel and the machine that will indicate the lift on the front end of the machine. I shall then run the machine over the track at a velocity which will just barely lift the hind wheels off the track, leaving the front wheel on the track. If the rear end of the machine lifts into the air it will change the angle of the planes and the lifting effect will be correspondingly diminished. This will prevent rising too high. Special wheels with a wide face suitable for running on either the rails or the earth will be provided for the purpose, and when I find that I can keep the hind wheels in the air and produce a varying lifting effect above and below the normal weight resting on the front wheel, I shall remove the weight from the forward wheel and attempt free flight by running the machine as near the ground as possible, making the first attempt by running against the wind, and it will only be after I find that I can steer my machine and manage it within a few feet of the earth, ascend and descend again at will, that I shall attempt high flight.

My experiments have certainly demonstrated that a steam engine and boiler may be made which will generate a horse-power for every six pounds of weight, and that the whole motor, including the gas generator, the water supply, the condenser, and the pumps may be all made to come inside of 11 lbs. to the horse-power. They also show that well made screw propellers working in the air are fairly efficient, and that they obtain a sufficient grip upon the air to drive the machine forward at a high velocity; that very large aeroplanes, if well made and placed at a proper angle, will lift as much as 2½ lbs. per square foot at a velocity not greater than 40 miles an hour; also that it is possible for a machine to be made so light and at the same time so powerful that it will lift not only its own weight but a considerable amount besides, with no other energy except that derived from its own engines. Therefore there can be no question but what a flying machine is now possible without the aid of a balloon in any form.

In order to obtain these results it has been necessary for me to make a great number of expensive experiments and to carefully study many of the properties of the air. Both Lord Kelvin and Lord Rayleigh, after witnessing a series of my experiments, expressed themselves as of the opinion that all the mathematical formulæ relating to planes driven through the air at an angle would have to be completely modified. Lord Kelvin himself has written that in some cases my experiments have proved that the conditions were from 20 to 50 times as favorable to the aerial navigator as had heretofore been shown by accepted formulæ, and that the whole mathematical question would require revision.

Experiments of this character unless conducted with great care are exceedingly dangerous. No makeshift or imperfect apparatus should be employed, but the experimenter should have the advantage of the most perfect appliances and apparatus that modern civilization can afford. The necessary plant for conducting experiments in a proper and safe manner is unfortunately much more expensive than the machine itself. If I find that my experiments require more money than I have at my disposal, I feel sure that some future experimenter more fortunate than myself will commence where I leave off, and with the advantages of the knowledge which has been gained by recent experiments will be able to construct a practical flying machine which cannot fail to be a great advantage to mankind.

The numerous and very expensive experiments, conducted on an unprecedented scale, which have made all this possible, and also brought to light new laws relating to the atmosphere, cannot fail to be of the greatest value to mankind, and it is on this basis that I submit the foregoing thesis.

OCTAVE CHANUTE.

(WITH PORTRAIT.)

OCTAVE CHANUTE, ex-President of the American Society of Civil Engineers, was born in Paris, France, Feb. 18, 1832, and came to the United States in the latter part of 1838. He received his education chiefly in New York City, and began the practice of his profession as a civil engineer in 1849, on the construction of the Hudson River Railroad, under JOHN B. JERVIS, Chief Engineer.

He was gradually promoted as the work progressed over the several divisions of the road, and when he left the service of that company, in 1853, he was Division Engineer at Albany, in charge of the completion of terminal facilities and maintenance of way between Hudson and Albany.

In 1853 he went to Illinois with H. A. GARDNER, previously Chief Engineer of the Hudson River Railroad, and was there engaged in building what is now a part of the Chicago & Alton Railroad, between Joliet and Bloomington, in Illinois. Mr. CHANUTE remained upon this work until 1854, when he was made Chief Engineer of the eastern portion of what is now the Toledo, Peoria, & Warsaw Railroad. He built this road from Peoria to the Indiana State line, a distance of about 112 miles, and remained in charge of maintenance of way until 1861. In the latter year he became Division Engineer, with similar duties, on the Pittsburg, Fort Wayne, & Chicago Railroad, between Chicago and Fort Wayne.

In 1862 he was for six months Chief Engineer of Maintenance of Way of the Western Division of the Ohio & Mississippi Railroad, from St. Louis to Vincennes. In 1863 he became Chief Engineer of Maintenance of Way and Construction of the re-

OCTAVE CHANUTE.

organized Chicago & Alton Railroad, and remained upon that line until 1867.

During this connection, having been invited to submit a design for the proposed Union Stock Yards of Chicago, his plan was selected in competition with a number of others and he built these yards as Chief Engineer. He was also awarded a premium for a competitive design for a bridge across the Missouri River at St. Charles, Missouri. In 1867 Mr. CHANUTE went to Kansas City, Mo., as Chief Engineer of the bridge across the Missouri River at that point. This was the pioneer bridge across the Missouri River, and as the river pilots and riparian dwellers had given this stream a bad reputation, the successful completion of this bridge across it in 1868 attracted great attention and interest.

Meanwhile the building of railroads had begun in Kansas, and while yet occupied in the completion of the bridge Mr. CHANUTE was placed in charge as Chief Engineer, first of the construction of the Kansas City, Fort Scott, & Gulf Railroad, from Kansas City to the north line of the Indian Territory, 160 miles; next of a parallel line in the same interest, then known as the Leavenworth, Lawrence, & Galveston Railroad, from Lawrence, Kansas, to the Indian Territory; next of a connecting line between the two, known as the Kansas City & Santa Fé Railroad, and lastly of the Atchison & Nebraska Railroad from Atchison northward.

While simultaneously in charge of the construction of these four railroads, he also designed and built the Union Stock Yards at Kansas City; and in 1871, as the work drew to a close, he became general Superintendent of the Leavenworth, Lawrence, & Galveston Railroad.

In 1873 he was offered and accepted the position of Chief Engineer of the Erie Railway, which, having changed its management, was planning to make extensive improvements. These were to consist of doubling the tracks and narrowing the gauge; building an extension to Chicago and another to Boston, involving the Poughkeepsie bridge since built in another interest; building sundry branches, and improving the property generally at an estimated outlay of some fifty millions of dollars, which it was expected to obtain in England.

The panic of 1873 and the subsequent financial depression prevented the full carrying out of this programme. Mr. CHANUTE, however, remained upon the Erie Railway 10 years, during which time much of the line was double-tracked upon improved grades, the gauge reduced to the standard by laying down a third rail, and the facilities of the line largely improved. In 1875 he was made Assistant General Superintendent, and in 1876 was placed temporarily in charge of the motive power and rolling stock, in addition to his duties as Chief Engineer. This gave him an opportunity of readjusting the locomotives as well as the grades, so that the through freight train, which averaged 18 cars when he first became connected with the line, had grown to 35 cars when he closed his connection with the road in 1883, when he removed from New York to Kansas City, in order to look after his personal interests, and to open an office as Consulting Engineer.

In this latter capacity he took charge of the construction of the iron bridges during the building of the Chicago, Burlington, & Northern Railroad between Chicago and St. Paul in 1885, and of those of the extension of the Atchison, Topeka, & Santa Fé Railroad, from Kansas City to Chicago, in 1887 and 1888; the latter involving, besides a number of minor streams, the Missouri River bridge at Sibley, and the Mississippi River bridge at Fort Madison.

In 1889 Mr. CHANUTE removed his office to Chicago, where he is now principally engaged in promoting the preservation of timber against decay by chemical methods; he being of the opinion that the time has now fully arrived when large economies are to be attained in this country by employing the methods which are in current use abroad.

Mr. CHANUTE became a member of the American Society of Civil Engineers, Feb. 19, 1868, and has contributed a goodly number of papers to its Transactions. Among these may be mentioned, "The Elements of Cost of Railroad Freight Traffic," "Rapid Transit and Terminal Freight Facilities," "The Preservation of Timber," the latter two being reports by committees of which he was chairman; "Engineering Progress in the United States," "Repairs of Masonry," and "Uniformity in Railroad Rolling Stock," besides some contributions to various other societies.

The foregoing biographical sketch is reprinted from *Engineering News*, N.Y., 1891. Since it appeared, Mr. Chanute has rendered to the cause of aeronautical science a service of the greatest value. He has written one of the most important books[1] on flying machines which has ever appeared; he took an active part in the proceedings of the International Conference on Aerial Navigation held in Chicago at the time of the World's Fair; he has also given most generous pecuniary aid to experimenters in need of money.

His high attainments as an engineer enable him to estimate with rare precision the value of the experiments made by others and to show investigators just what bearing their individual work has upon the world's work. — *Ed.*

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[1] "Progress in Flying Machines," N. Y., 1894.

SAILING FLIGHT.

BY O. CHANUTE.

THE soaring, or as the French term it more properly, the sailing flight (vol-à-voile) of certain species of birds, that is to say their power of progressing through the air and of translating themselves at will without any flapping action whatever, has always seemed such a mechanical paradox that its very existence has been questioned by those who have not carefully observed the performance of these birds.[1]

That a bird should float on outstretched wings high in air for hours, with no muscular exertion whatever save the passive one of keeping his wings rigidly extended, seems so preposterous, so much against all our mechanical instincts and experience of the law that expenditure of energy is necessary to produce locomotion, that even when the feat of soaring is first witnessed, the mind doubts the evidence of the eyes and seeks for some undetected movement to account for the forward advance.

Yet there is nothing more certain than that the soaring birds are supported and propelled without flap of wing. It is generally conceded by observers that they extract from the wind the energy necessary to the performance, but the exact way in which this is done is not at all agreed upon.

One principal reason why this extraordinary mode of flight has not attracted more attention, is that the performance is comparatively rare in northern latitudes. It requires a combination of favorable circumstances to entice to the locality the birds which practise it, such as regular diurnal breezes, neither too weak nor too strong, abundant food, and a mild

[1] The principal sailing birds are the vultures, the eagles, kites, hawks, herons, cranes, pelicans, gulls, frigate bird, and albatross.

climate. These circumstances chiefly obtain in subtropical latitudes, and in the vicinity of the sea, and in such regions the soaring birds are plentiful, while in the colder regions, where man's activities are greatest, only the eagles, the hawks, and an occasional visiting vulture are to be seen.

Buzzards and some other soaring birds are, however, abundant in the Southern United States, and much the most convincing evidence would be obtained by personal observation; but for the benefit of those readers who have never seen the performance under favorable circumstances, the following list of authors may be given, who have either described sailing-flight, or advanced theories for its explanation.

LIST OF AUTHORS.

D'Esterno. "Du vol des oiseaux." Chap. VII.
Duke of Argyle. "The reign of law." Chap. III.
L. P. Mouillard. "L'empire de l'air." "Vol des voiliers."
E. J. Marey. "Le vol des oiseaux." Chap. XX.
A. Goupil. "La locomotion aérienne." Chap. IV.
S. Drzewiecki. "Le vol plané." Pamphlet.

A. Pénaud.	"Le vol-à-voile,"	"Aéronaute,"	March, 1875.
C. De Louvrié.	"	"	May, 1884.
J. E. Basté.	"	"	Sept.–Oct.–Nov., 1887.
J. Bretonnière.	"Le vol plané."	"	June–July, 1889.
"	"	"	Apr.–May, 1890.
C. Weyher.	"	"	July, 1884.
"	"	"	March, 1885.
"	"	"	Oct., 1890.

I. Lancaster. "Soaring flight." Letters. "London Engineer," 1882.
J. C. Proctor and others. "Report, Aeronautical Society, Gt. Britain," 1880.
" Various articles in "Knowledge" and newspapers.
S. E. Peal. Aer'l Soc. 1881. P. 10. — "Nature," May 21, 1891.

Thos. Moy. Appendix to "Progress in flying machines." P. 271.
M. Blum. "Soaring." "R.R. and Engineers' Journal," March, 1891.
H. C. Vogt. " "London Engineering," March 23, 1892.
C. Darwin. "Journal on H.M.S. 'Beagle.'" Pp. 223, 224.
E. Liais. "L'espace celeste." P. 335.
Lord Rayleigh. "Soaring." Sundry letters in "Nature," 1883.
A. F. Zahm. " "Notre Dame Scholastic," Dec. 10, 1892.

S. P. Langley. "Internal work of wind." J. Bretonnière. "Sailing flight." W. Kress. "Theory of flight." E. C. Huffaker. "Soaring flight." C. De Louvrié. "Theory of flight." A. M. Wellington. "Mechanics of flight."	} Proceedings Int'l Conference on Aerial Navigation, 1893.

R. Soreau. "Revue Scientifique," March 30 and April 5, 1895.
O. Lilienthal. Reports of experiments. Sundry publications.

Singularly enough, none of the above authors save the last, and perhaps Mr. Goupil, have dwelt upon the particular wing shape of the soaring birds, or explained in their theories why certain species of birds can sail and certain others can only glide[1] (that is to say, slide over the air on fixed wings by utilizing previously acquired momentum or the force of gravity), while the sailing birds can extract from the wind all the energy needed for support or propulsion.

This seems to require a certain mass, say, from a pound's weight upward, to equate the irregularities of the wind, and a particular conformation of bird to extract energy from the

[1] To remove misconstructions it is well to define various modes of flight, the writer proposes the following terms:

Rowing flight.	— Ordinary progression by flapping.	— Examples:	Ducks, Geese, etc.
Hovering "	Remaining over one fixed point.	— "	Humming Birds.
Gliding "	Sliding over the air on fixed wings.	— "	Pigeons, Swallows.
Soaring "	Sailing with occasional flaps.	— "	Hawks, Eagles, etc.
Sailing "	Utilizing the wind alone.	— "	Excelled in by Vultures, Albatross, etc.

wind to the best advantage, so that the main conditions of sailing flight seem to be:

1. There must be wind, although it may be light.
2. No flapping whatever is needed when under way.
3. The bird must have a peculiar conformation.
4. The bird needs a certain mass or weight.

Few of the above-named authors give any precise measurements, so that it is impossible to test their theories by numerical examples and computations. The writer was thereby induced to gather such data for himself. He now proposes, first, to give the results of some of his observations, and then to attempt to reduce the data to the sway of mathematical laws.

PART I. — THE OBSERVATIONS.

In the Southern United States the sailing bird most frequently seen is the turkey-buzzard (Cathartes aura). He is an accomplished soarer, but is somewhat inaccessible, so that it is difficult to watch his manœuvres at close range. The frigate-bird and the pelican are generally still higher up in air or more distant, so that while it is easy to become entirely satisfied that while sailing they obtain all their support and motion without flapping their wings, it is more difficult to observe just how they do it.

After watching many of these birds in Texas, Louisiana, and Florida, the writer found that his desire for exact observations was best gratified by the gulls of California; and omitting herein therefore all the other observations made of other species of birds at longer range, he proposes to confine his relation to the acts of birds which he could watch currently at fifteen to twenty feet distance.

The gulls of San Diego (California) are extraordinarily tame. They are not suffered to be molested, because they act as scavengers of floating refuse food about the harbor, and while the greater number of their kind live out in the open sea, upon fish and the slop of passing vessels, the knowing ones dwell in the bay and feed upon the broken victuals thrown from ships, and upon the garbage of the city. They wait for "Steamer day" with all the eagerness of old Californians before the days of railways, and when a craft comes in they congregate about it on the wing, awaiting the refuse from the kitchen.

They are absolutely fearless of man, and will float or fly within 15 to 30 feet of him while performing their evolutions, so that more may be learned of the minute acts of soaring from them in an hour than from months of observations of other birds which soar comparatively high in the air. Indeed, it is possible to detect their every motion, however slight, to see how they get started underway, how they glide or sail, how they balance themselves in a variable wind, and how they stop their headway to alight. When they sail, there can be no question of there being undetected movements, for the wings are absolutely rigid, the operation being often performed in such close proximity to the observer that the fluttering of a stray bit of down, protruding from below the secondary feathers, can be plainly seen.

By either standing on the lower, or on the middle, or on the upper deck of a steamer, the gulls can be watched either from below, or on a level with the eye, or from above, as may be preferred, so that one observation shall check another concerning the same act of manœuvring.

These acts, for the present purpose (which does not concern itself with rowing flight), may be divided under four heads:

1st. Starting, or getting under way.
2d. Sailing, or soaring on the wind.
3d. Balancing, or maintaining the equilibrium.
4th. Alighting, including stopping the motion.

It may be well to state here, for the benefit of those whose observations have been confined to rowing birds, that while during the first few vigorous strokes, the weight is all sustained by the reaction of the downward blow of the wing on the air, as soon as forward motion is obtained the bird acts as an aeroplane, and the support is mainly or all derived from the air pressure due to the forward speed; that is to say, that the under surface of the wings, whether flapping or extended rigidly, and when progressing as an inclined plane, receives a pressure from the impinging air which acts at right angles to the surface. This pressure is resolved into two components, one vertical which sustains the weight, and the other horizontal which either opposes the motion, if the angle of incidence be above the horizon, or acts as a propelling force if the angle be inclined below the horizon. Thus the flappings of the wings (which the investigations of Professor Marey show to be delivered at a varying angle) chiefly serve as a propelling force when the bird is under full headway, and the bird may also be sustained when gliding or sailing upon rigidly extended wings, provided he have headway enough. In still-air gliding this headway has to be furnished by gravity or from previous momentum, but in sailing the same effect is produced by the passing wind, provided it has sufficient motion with respect to the bird.

Sailing flight depends upon this latter condition, and as the wind constantly varies in intensity, as was well shown by Professor Langley, a certain amount of momentum or mass is required to perform sailing flight properly, and hence it is best exhibited by the larger and heavier birds.

It thus appears that the first important thing for the bird to accomplish in order that he may soar, is to acquire and to retain initial velocity, so that he may at all times, against the wind or with the wind, obtain support from the air by glancing over it at a sufficient speed and angle to produce a sustaining pressure. The first manœuvre to observe, therefore, is how he obtains this initial velocity, and the following comprise the results of the writer's observations of gulls at San Diego.

STARTING.

The gulls take their start either from the surface of the water or from a perch.

If from the former, they first face the wind, paddle a few strokes, spring from the water into the air and flap vigorously for a time, flying directly against the wind and nearly on a level course, some 4 to 6 feet above the water. The flaps at first average 3 per second, and are of great amplitude, or nearly half of a circle, but as headway is gained, say in a distance of 20 to 30 feet, the amplitude is reduced to about 45°, each side of the wing pivot, and the number of strokes gradually diminishes to 2 per second, and eventually to 1 stroke per second, the bird rising meanwhile at an angle rather less than 45°, to a height of 30 or 40 feet above the water, this altitude being gained in a course of 150 to 200 feet, at the end of which the velocity of the bird (measured in still air) is from 26 to 30 feet per second, when, if the wind be sufficient, he is in good condition for soaring flight.

If the gull be on a perch (and the bird seems much to prefer this position), say on the ridge of a building, on the edge of a wharf, or on a pile-head, his exertions to start are much less. He faces the wind as before, launches himself forward and downward, gaining impetus from gravity, and with a very few flaps — sometimes without any — he acquires a velocity of 26 feet per second, then he rises and is prepared to soar upon the wind, which is evidently more rapid at a height of 30 or 40 feet above the water than it is at the surface. The bird may alternately flap and glide for a few seconds, but as soon as he feels himself in a sufficiently strong current, say of 18 to 20 feet per second, he ceases all active exertions and abandons himself wholly to the pleasures of sailing.

If the breeze be steady and strong enough, say 19 to 22 measured feet per second at the surface of the wharf, the gulls occasionally exhibit a third and very remarkabie method of getting under way.

This is sometimes performed from the ridge of a building, or from a ship's spar, but the most satisfactory observations are obtained when the bird is on a pile-head about 10 feet above the water, and therefore on a level with the eye of the observer on the wharf, and some 15 or 20 feet distant. The writer has seen the feat performed many times and will describe the best instances.

The bird stands on the pile-head, and faces the wind. He opens his wing wide, but keeps the front edges depressed, so that the wind glances over them and presses him downward;

then, when the breeze freshens, he changes the plane of his wings by a slight twist, until they present an angle of incidence of about 20° above the horizon. The wind, pressing under the wings, lifts the bird up 2 or 3 feet. The first part of this ascent is quite vertical, but presently the gull, still rising, drifts back about 5 feet, when he comes to a poise for an instant as he changes his angle of incidence, so that it becomes negative and points below the horizon, when his course is reversed. He plunges downward and against the wind until he is within about 4 feet of the water, when, having acquired an initial speed of his own, of about 26 feet per second, he again changes his angle of incidence to some 12° or 15° above the horizon, and he rises again, and is henceforth master of his movements, continuing to sail without flapping, apparently in any direction he desires.

The wind, on the occasions when this performance was exhibited, blew with comparative steadiness at a speed of 14 to 23 feet per second, with an average of 21.12 ft. per second, or 14.4 miles per hour. The sea breeze at San Diego sprang up every morning, being caused by the rarefaction of the air in the sun over the California deserts, and during the writer's visit the wind blew every day from the same quarter and with nearly the same intensity, making this location an ideal one for the performance of sailing flight.

Thus it is seen, that by this last starting manœuvre, it is in the power of a soaring bird, if the wind serves, to rise from his perch without flapping, to remain aloft indefinitely, as will be more particularly described under the head of Sailing, and to return to a perch again, *without furnishing a single stroke of wing*. In point of fact the birds not infrequently give a flap or two, but this seems to be done more as a matter of convenience, to trim the course, or to maintain the velocity.

SAILING.

Once well underway, with their own speed of 26 to 30 feet per second (17.7 to 20.4 miles per hour), the gulls seem to be master of their movements, and, if the breeze blows from 14 to

23 ft. per second (12.92 to 15.64 miles per hour), to be able to translate themselves to any point they choose.

The manœuvre which can be observed at closest range consists in patrolling at lunch time along the water side of a steamer tied to the wharf. The birds then sail back and forth along the side, at a distance of 20 to 30 ft. therefrom and at a height of about 30 ft. above the water. They are attending upon the cook, in hope of garbage.

On the occasion at which the most satisfactory measurements were made the gulls sailed along back and forth a distance of about 100 ft. parallel with the steamer, and some 20 ft. therefrom, so that from the middle deck they could be looked in the eye and the least movement detected. They floated on a horizontal course, turning upon their heel at the end of each lap, and returning over the same path. This was done entirely without beat of wing, or tremor of a feather, save an occasional fluttering of a bit of down projecting from beneath ill-matched feathers, and it entirely set at rest in the mind of the writer any assumption as to support being gained from any minute movements of the feathers or tail.

Whenever a bucket of slops was emptied from the kitchen, the gulls wheeled at once, poised themselves for an instant, and swooped down towards the food. When within 5 ft. of the water they began a curve, throwing their wings at an angle into the attitude of an obtuse angle, and describing nearly a semicircle, they snapped up a mouthful from the water. Then they remounted with a few vigorous flaps, to a soaring attitude on a level with the upper deck of the steamer; thence, a fresh poise having been obtained, and the food swallowed, the operation would be repeated, and when all the slop was eaten up, the sailing along the side would be resumed until the next bucketful.

The wind was blowing at an observed mean velocity (6 measurements) of 18.83 ft. per second, or 12.78 miles per hour, and at an angle of 30° (as near as could be judged) with the line of the ship. The gulls progressed against this side wind at a measured speed of 10 ft. per second, with reference to the ship, and their speed with reference to the wind was therefore equal to its velocity, multiplied by the cosine of the angle of incidence, plus their own apparent motion. Hence the relative speed was $18.83 \times 0.866 + 10 = 26.3$ ft. per second, or 17.88 miles per hour. At this speed the birds were perfectly sustained, and floated back and forth on extended wings slightly arched, wheeling with a short turn at the end of each course, their heads turning from side to side, and their little eyes eagerly watching. Their angle of incidence above the horizon was 5° to 7°, as near as it could be measured when going against the wind, but this angle of incidence is very difficult of measurement, and moreover it constantly varies with the speed, or when the bird rises or falls, or goes with or against the wind. It was estimated by holding a pencil on the line of the water horizon.

During all the time, the birds were constantly balancing themselves, as will be more fully explained hereafter, so that it must not be understood that when they are spoken of as floating on the breeze, they made no movements whatever to regulate their poise or angle of incidence, or to counteract the variations in the direction and intensity of the air currents. Such movements were, however, very slight, about as active as those made by a man to balance himself in walking, and clearly they did not furnish any motive-power for support or propulsion. This power all came from the wind, as will be more fully discussed when the attempt is made to account mathematically for the phenomenon.

There being a question as to the horizontality of the wind, this was tested by liberating bits of tissue paper (such as that placed between visiting cards), from the edge of the steamer. The wind blew them upward at various angles, generally from 10° to 20°; so that it was concluded that the side of the ship produced an ascending trend in the wind; what that trend was at the birds, 20 feet away, there was no mode of ascertaining, but it is believed that it materially assisted them in their evolutions.

Meantime, in other parts of the harbor, other gulls were observed patrolling the sky. They generally soared higher in the air, at a height of 100 to 200 feet, probably to avail of the stronger breeze prevailing at that height, and presumably blowing with exact horizontality. With these latter birds the favorite course seemed to be quartering with the wind, back and forth, for 500 to 800 feet. Their relative speed, after allowing for that of the wind, seemed, by measurement, to be from 22 to 24 feet per second, but the writer believes it to have been somewhat more, as the wind was measured at the surface of a dock, while the birds were aloft. On some mornings, before the sea breeze had fully set in, and when the wind was consequently light, a favorite course seemed to lie just above and to the leeward of a set of "coal pockets" on a dock, which forms a wind-break 650 feet long and about 25 feet high, thus lending additional countenance to the theory that a soaring bird finds assistance from ascending currents of air, deflected from their horizontal course by some obstacle or by rising ground; but when the wind grew stronger, the gulls soared indifferently all over the harbor.

At other times the gulls circled in the air, gradually drifting to leeward. These circlings were seldom long continued, and lacked the majesty of the great sweeps of the buzzard when surveying a township from aloft. The gulls circle rather irregularly, but observation indicated that they dropped earthward while sailing with the wind, thus gaining speed from gravity, and rose more than they had dropped when they reached the quarter circle performed against the wind, thus utilizing the increased velocity to regain the lost altitude. At times, they seemed poised, absolutely fixed in one spot, their own initial velocity at that time being of course exactly equal to that of the wind, and at other times they rose upwards but drifted backward, a little gust of wind having apparently furnished a surplus of sustaining power, but at the expense of forward motion.

In one or two rare instances, the birds were seen both to rise and to advance in a straight line against the wind simultaneously, and this is the hardest manœuvre to explain mathematically. It has, however, been well described and figured by M.

Basté, and his diagrams will be used when an attempt is made to account for this paradox.

The birds having no particular motive to demonstrate that they can sail indefinitely without flapping, occasionally resort to the latter in their manœuvres. When gliding or sailing upon the breeze, they perform an occasional flap, a mere kick, as it were, either to limber up the outstretched wings, or to maintain the speed they require to obtain a sustaining reaction, or to overcome the head resistance without changing their angle of incidence when the wind chances to weaken. Sometimes, also, they glide down some distance and gain speed at the expense of height, to be recovered when the breeze freshens; but there is nothing more certain in the writer's mind than the fact that wind is required for sailing flight, and that the few observers who claim to have seen soaring performed in a dead calm, must in some way have been mistaken.

By a calm, or by a very light breeze of 2 to 4 miles per hour, such as generally prevails in the early morning hours at San Diego, sailing flight does not seem to be performable by the gulls, and if they want to go somewhere they flap exclusively. Their speed when flapping in a calm is from 30 to 33 ft. per second (20.4 to 22.44 miles per hour), this being the result of many measurements along distances of 350 to 500 ft. The harbor gulls are lazy birds, however, and evidently dislike the exertion, for, during a dead calm, most of their time is spent on firm support, the favorite places being the outer ends of piers with little traffic, where there is a chance for the birds to walk about and squawk, apparently in gossip with each other.

When the sea-breeze springs up, generally before noon, the more active or hungry gulls start out upon a cruise, and by rowing flight, continued until they are high in the air, find a wind sufficiently strong for them to sail in, and when this has freshened to 11 or 15 miles an hour at the dock surface, all the gulls leave their perch and float upon the breeze, sailing then seeming to be preferred by them to perching, as involving no more exertion and being a pleasanter mode of passing the time, even when a meal is no longer a desideratum.

If, however, the wind increases to over 30 miles an hour (a rare occurrence), the gulls seem to find sailing unpleasant and generally seek some quiet spot, more or less sheltered, to allow the storm to blow over.

The greatest exertion performed by the gulls is, apparently, during the act of hovering, when beating their wings rapidly so as to remain at a fixed point just above the water, to inspect closely a suspicious morsel. The body is then held at an angle of about 40° with the water, some 18 or 24 inches above it, and the wings are vibrated fast, though without a great amplitude, while the bird remains several seconds in one spot, and cranes his neck forward. If the morsel be deemed acceptable, he sweeps down, snatches it in his beak, and with much flutter, balancing, and effort, he rises again with vigorous flaps to resume his soaring flight, generally preferring, however, to do this at an angle of 30° to 45° to the wind, back and forth, so as to convey to the observer the idea that he is making a series of tacks against the wind.

Almost all observers are agreed (D'Esterno, Mouillard, Pénaud, De Louvrié, Basté, Bretonnière, Proctor, Peal, Langley, etc.) that wind is absolutely necessary for the performance of sailing flight. All of the observations of the writer confirm this, although he has seen the feat performed by buzzards and by hawks, when the breeze measured only 5 or 6 miles an hour at the surface. It may have been more rapid higher up, where the bird was. The gulls do not seem to soar well unless the wind blows at about 10 miles per hour. The difference is probably accounted for by the difference in proportion of carrying surface to the weight, this being, according to the writer's measurements, very nearly 1 lb. to the square foot for the gull, while it is 0.88 lb. per square foot for the buzzard and 0.55 lb. per square foot for the chicken-hawk.

Before making the observations above described a "herring gull" had been shot, weighed, and measured. Its weight was 2.188 lbs., its entire surface, wings, tail, and body projected, measured 2.015 square feet, its cross-section of body at the maximum point was 0.126 square feet, and its cross-section of wings, projected at the point of maximum anterior thickness, was 0.098 square feet. These figures will hereafter be used in computing the support and resistances.

BALANCING.

All sailing birds are accomplished acrobats. It is difficult to detect the more minute movements in the hawks, the buzzards, the frigate-bird, etc., which generally sail at a considerable altitude, but they can be closely studied in the fearless gulls of San Diego, which perform their evolutions right under the observer's nose.

As the wind varies in intensity, or as the birds wish to rise or to fall, they are constantly changing their angle of incidence and their poise. This is done by advancing or moving to the rear the tips of the wings, which are stretched out in a soaring attitude. The movement is slight, and, as the writer suspects, is also automatic. It alters the poise at once fore and aft, and the bird either rises or falls, or he restores the adjustment between his own speed and that of the wind.

If he wants to wheel to one side, a manœuvre which is done very gracefully, he apparently increases the flexion of the wing on the side to which he wants to turn, the body tilts to that side in consequence of its disturbed balance, and the bird wheels to that side. The same result is also thought to follow the advancing of one wing more than the other, but the writer does not feel that his observations are quite conclusive on that point.

But most of the continual balancing is effected with the head and the feet, which, when the wind is at all gusty, are almost constantly in action. The fore and aft balancing is sometimes effected with the head alone, the neck being stretched out or drawn in, or it may be swung from side to side to preserve the transverse equilibrium. Often, however, the legs also come into action. When in full sailing activity in a steady breeze, they are rigidly extended out back under the tail, but when a gust of wind compromises the balance, the legs drop downward, making an angle at the knee, and the feet are adjusted as required to preserve the fore and aft balance, by altering the leverage due to their weight, making thus an adjustable pendule of great efficiency.

As has been said, these movements are slight, and hence difficult to detect except at very close range; nor are they continual, as they are only made as occasion requires, without apparently taking more thought than a man does while walking. They are doubtless due to reflex action as guided by acquired instinct, but they point out the enormous difficulties to be encountered by man if he seeks to imitate the bird, and to sail upon the gusty wind, before he has acquired the science of balancing, or produced an automatic apparatus of his own.

It is difficult to determine accurately the angle of incidence which the bird makes with the horizon when sailing. The general plane of the wings does not seem to be parallel with the lower edge of the body, and the eye becomes confused in estimating the angle. This angle, moreover, constantly varies with the speed, within small limits, but the writer deems it to range between 3° and 15° above the horizon when the bird is on a level course. As he rises or falls the angle of incidence is materially altered, both above and below the horizon, but from the best projections made by the writer against the sky line, he deems that the most usual angle of the wings, when sailing upon a level course, is from 5° to 7° above the horizon, and the latter figure will be used in the mathematical computations.

One peculiarity of the sailing gull consists in his attitude, — the wings are arched downward like a bow. Land-sailing birds generally hold their wings extended either horizontally, or so as to make with each other a slight diedral angle above the horizon, while the gulls and many other sea birds hold their wings when sailing in the singular position described. Why this should be so the writer has been unable to surmise.

ALIGHTING.

While the manœuvres performed in alighting exhibit as many varieties as those for starting, they can be described briefly. The object of the bird is evidently to stop his forward motion so as to avoid a shock upon alighting, and this is very neatly performed in a variety of ways. The method preferred is to arrive at the point selected at a lower level and to rise to the perch, thus destroying speed by the action of gravity. The bird generally rises some 18 inches above the selected perch, this rise being performed at an angle of about 45° or more, and then he poises for an instant and gently drops feet downward on the perch. Sometimes the arriving course is on a level with the point selected; in that case the bird tilts himself to an angle of some 40° to the line of motion and without beat of wing, if he has calculated just right, he finds his headway stopped just above the perch and drops down to it as previously described.

Or the motion may be stopped by backward beat of wing, or by hovering with vibrating wings just above the spot selected, so that the pendant legs soon touch the perch, or the gull's body settles upon the water, but in every case the bird contrives to arrive from such a direction that he faces the wind, if any, when at the perch, and utilizes this as a retarding force.

These are the observations. They were made in March, 1892, and written out in full at the time, substantially as now published, but it took me three years to arrive at a satisfactory explanation of what I had seen, and to compute the forces in action. The chief trouble was that the calculations of weights sustained, at the observed speeds and angles of incidence, were based upon the known pressures of air upon plane surfaces, adding, however, a coefficient obtained, with a pigeon's wing, a non-soaring bird. It was only when Herr Lilienthal's table of air pressures was obtained, in the "Handbook for Aeronauts and Aviators"[1] that I was enabled to figure up satisfactory reactions, with the coefficients obtained by actual experiments with surfaces shaped like the wings of sailing birds.

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[1] "Taschenbuch für Flugtechniker und Luftschiffer." 1895. W. H. Kuhl, 73 Jägerstrasse, Berlin W.

NOTE. — Mr. Chanute not having yet had leisure to prepare the text to accompany his computations, has somewhat reluctantly consented to the present publication of this first part. He intends soon to follow it with the mathematical demonstration, and this may be published in a Supplement to the Annual. — *Editor.*

HOW A BIRD SOARS.

By Professor William H. Pickering, of Harvard Observatory.

By "soaring" is meant the upward spiral progress of a bird, without apparent muscular effort. This action may be observed in this part of the world to particular advantage, in the case of certain large hawks. The following explanation of the principle of soaring is extracted from an article which I published in "Science," 1889, p. 245, and is, I believe, the first description of the process which ascribes to gusts of wind their true influence in the production of the phenomenon:

"Whenever there is a high wind, such as is undoubtedly required by a soaring bird, we know that the air pressure is not uniform, that the wind comes in gusts. Those familiar with mountain summits know that the same phenomena are observed in the upper atmosphere as at the surface of the ground. If we were travelling along with such a wind in a balloon, the gusts would not be so severe, but they would be of longer duration.

*A*____________________*B*

"Imagine, now, a bird travelling from *A* to *B*, in the same direction as the wind, and with its mean velocity. When the wind is uniform, it seems to him that he is in a dead calm. When a gust comes, the wind seems to blow from *A*. It carries him along faster; and when it ceases the wind seems to blow from *B*. It therefore affects him precisely as if he were in an alternating current of wind.

"Suppose, now, that he is drifting towards *B* with a velocity equal to that of the wind, and travelling at right angles to *AB* with such a velocity that he can move along horizontally without falling towards the earth. Suddenly a gust overtakes him from the direction of *A*. He at once turns towards it, and his velocity relative to it is sufficient to raise him in the air. It tends to carry him more rapidly towards *B;* and when his velocity relative to it has sunk to the same value as before, and he again travels horizontally, he turns again at right angles to the line *AB*, but in the opposite direction to that which he had before. Presently the force of the gust diminishes, and the wind seems to blow towards him from the direction *B*. He accordingly turns toward it again, rising from the ground till his velocity relative to the air has assumed its former value, and he moves horizontally, turning again at right angles to the line *AB*, and the cycle is completed. He thus moves along in the direction *AB* with a mean velocity equal to that of the wind, rising when moving parallel to it, and moving horizontally, or perhaps slowly falling, if the gusts do not come with sufficient frequency, when moving at right angles to it.

"In the case of all soaring birds, the spread tail, being an inclined curved surface, presents a large area to the wind. As it is situated at a considerable distance from the bird's centre of gravity, it must convert him into a sort of floating weather-cock, the wings serving as dampers to restrain him from turning too quickly. It therefore appears, if soaring really does depend on the interaction of varying wind-currents, as if the changes of direction involved must be almost automatic, and not a thing which the bird is required to learn; although he may doubtless learn to take advantage of favoring currents by giving proper inclinations to his wings and tail.

"If the question be raised as to the sufficiency of the varying intensity of the wind-currents to maintain the bird's initial velocity against the resistance of the air, we must reply that it is a matter which can only be determined conclusively by experiment. Certain it is, however, that in windy weather the wind does come in gusts. If in the course of his circles the bird happens to be travelling at right angles to the wind, when the gust strikes him he will surely be turned round, almost in spite of himself, so as to face the gust. If the bird does face the gust, it will certainly raise him to a higher level.

"If this explanation proves to be the true one, the reason why small birds cannot soar is probably, that, in those of them that have suitably shaped wings and bodies, their surfaces are so large in proportion to their weights that they rapidly assume the velocity of the surrounding air. In order that they might soar to advantage, the gusts should come more frequently, and be of shorter duration, than we actually find to occur in nature."

Obviously, if the mean velocity of the wind is high, and the gusts comparatively insignificant, the bird may rise without difficulty, but he will drift rapidly along in the direction towards which the wind is blowing. Let us now imagine the conditions reversed; let the mean velocity of the wind be very low, while the gusts are of great intensity. The bird will now rise rapidly, and may then take advantage of his position to soar downwards against the wind, not merely holding his own, but even advancing against it. We thus see how it would be theoretically possible upon a windy day for a bird to travel at will in any desired direction without making the slightest mechanical exertion whatever, and also without taking advantage of any upward currents that might exist. That these currents do exist in certain localities, especially in hilly districts, and that they are often used by the birds almost like stairways there now seems no reason to doubt. That such upward currents are not absolutely necessary, however, for purposes of soaring, it is the object of this article to point out.

SENATE BILL, No. 302.

FIFTY-FOURTH CONGRESS.

BY THE EDITOR.

A BILL, of which the following is a copy, was introduced in the Senate of the United States on the 4th of December, 1895, by Mr. Lodge. It was read twice and referred to the Committee on Interstate Commerce.

A BILL TO SECURE AERIAL NAVIGATION.

"*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled*, That the Secretary of the Treasury is hereby authorized and directed to pay the sum of one hundred thousand dollars to any person, from whatever part of the world, who shall, at any time prior to the first day of January, nineteen hundred and one, construct an apparatus that will, on the verified report of a committee of three members appointed by the Secretary of War, demonstrate, within or near the city of Washington, the practicability of safely navigating the air at a speed of not less than thirty miles an hour, and capable of carrying passengers and freight weighing a total of at least four hundred pounds.

"SECT. 2. That the Secretary of the Treasury is hereby authorized and directed to pay the sum of twenty-five thousand dollars to any person, from whatever part of the world, who shall, at any time prior to the first day of January, nineteen hundred, construct an apparatus that will, on the verified report of a committee of three members appointed by the Secretary of War, demonstrate, within or near the city of Washington, the practicability of safely navigating the air in free flight toward any desired point of the compass for a distance of one mile or more in a descending line; the point of alighting to be not more than sixty-six feet lower than the point of starting. No use shall be made of the buoyant power of any gas lighter than air."

In December, 1893, two years earlier than the introduction of this bill in the Senate, a bill (S. 1344) "to secure Aerial Navigation" was introduced by Mr. Cockrell, and referred to the Committee on Interstate Commerce. The earlier bill having failed to receive a recommendation from the committee to which it was referred, the editor of the Annual has drafted the present bill, and Senator Lodge has kindly complied with the request to present it to the Senate. The bill is now in the hands of the Committee on Interstate Commerce, and our present task is to induce that committee to report favorably upon it.

The earlier bill was so exacting in its requirements that, even if it had passed, there would probably have been few to compete for the prize offered. Moreover, it offered no encouragement to the designers of soaring-machines. For years the present writer has been trying to convince people of the extreme importance of the development of the motorless soaring-machine.

This bill seems likely to bring hundreds of contestants into the field, and it tends to serve the double purpose of advancing the cause of science and of providing recreation for the people.

There are two important points to be considered:

I. The need of the passage of this bill.

II. The probability of its accomplishing the intended result.

I.

It is needless to advert to the fact that a universal highway would be a boon to humanity, for that is generally recognized.

There are many reasons for thinking that the problem of aerial navigation can be solved before the close of the present century, if the United States government encourages investigation and experiment. When we consider the great progress which, during the present century, has been made in other sciences and useful arts, we see plainly how the science and the useful art of aerial navigation have, until recently, been languishing since the days of Cayley, who experimented and wrote well in the early part of the century (1800–1809).

The science of aerial navigation may properly be called *the neglected science.*

Unless the navigation of the air by man be, in the nature of things, impossible, there surely must exist some peculiar set of conditions which will account for man's failure to progress in this direction as he has in others. This will briefly be pointed out.

Until the last decade of our century, there has been a widespread and unreasoning belief in the absurdity of attempts to navigate the air. This has discouraged investigation. In consequence of the lack of educational facilities in this specialty, investigators have been left to work on wrong lines, or by faulty methods. Inventors and investigators are, as a rule, men of limited means; the cost of wreckage obtains as a larger factor in the research we are considering than in almost any other. All these conditions are peculiar, and they account for slow progress.

II.

As to the probability of the bill's accomplishing the intended result: The first section of the bill explains itself. The stipulations are such that neither the whole nor any part of the one hundred thousand dollars would be expended by the United States, save for a full solution of the problem.

The second section of the bill is for the purpose of encouraging experiments which, in the absence of any government award, would probably be comparatively unremunerative, yet which are likely to be very important in the way of leading toward the full solution.

The descent of sixty-six feet in one mile is permitted, in order that men may be encouraged to familiarize themselves with the motions of aerial travel without being put to the great expense of providing motors.

When the useful arts of designing and controlling soaring-machines[1] have been further advanced, the expense entailed by the wreckage of valuable motors will be greatly reduced.

The grade of sixty-six feet to a mile has been fixed upon by assuming that the amount of energy required in a soaring-machine is no greater than that required to keep a railway car in motion upon a gently descending steel track.

If the total weight of a soaring-machine and its operator is two hundred pounds, and if the operator carries his machine to a height of sixty-six feet above a level plain or a sheet of water, he will have stored, within himself and his machine, potential energy amounting to 13,200 foot pounds.

We may have some idea of the transporting power of this energy if we imagine a traveller with a sled upon the glassy surface of a frozen lake tilted to a grade of sixty-six feet to the mile. We cannot yet figure the comparative air-resistances encountered by the travellers upon the ice road and upon the air road, but we have many reasons for thinking that the potential energy of a traveller starting from the summit of an air incline will carry him a surprisingly long distance.

If an experimenter wishes to make use of greater power, there is no stipulation in the bill which prevents his making a start at a high velocity, but, after making this start, the descent to a finish-mark at a distance of a mile must not exceed sixty-six feet. It is expected that the flight will be undulatory, velocity will at times be sacrificed to gain altitude, and altitude will at times be sacrificed to gain velocity, according to the existing conditions of the wind.

Several eminent scientists have expressed the opinion that motors which are now in existence are sufficiently light and powerful to propel flying-machines if the machines can be safely guided; yet as a marine engine would be useless without a properly designed hull and the ability to steer the ship clear of the land, so no motor seems likely to propel a flying-machine in free flight until man has completely mastered the motorless soaring-machine and so provided a ship for the engine.

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[1] Soaring-machine. A motorless machine used for sailing on air.

We have in the achievements of Otto Lilienthal, of Berlin (described elsewhere in this Annual), the best of reasons for thinking that the soaring experiments which will be encouraged by the passage of this bill will lead to the final solution of this great problem, which is to the human race a matter of profound concern.

Lilienthal has made many flights in a slightly descending line, and in some of these has covered a linear distance of several hundred metres. The improvement of machines of the Lilienthal type must result in a continual lessening of the angle of descent in sailing flight. Finally, slow as has been the progress in this line of research during the past eighty years, recognition and encouragement of this science by the United States government would probably establish it in a position where rapid advancement would be possible.

THE BOSTON AERONAUTICAL SOCIETY.

THE Boston Aeronautical Society was organized May 2, 1895. Prof. William H. Pickering, of Harvard Observatory, was chosen president, and Mr. Albert A. Merrill, secretary.

The membership is at present limited to twenty. For several months fortnightly meetings have been held, and at these meetings papers treating of aeronautical subjects have been read and discussed. The members have found these discussions decidedly instructive and helpful.

Preparations are being made for many interesting experiments, which will be tried at the field meetings of the Society, to be held during the coming summer and autumn.

Nearly all of the members are active experimenters; these men feel assured that the Society has a useful work before it, and that the field will be an ever-widening one.

THE BOSTON AERONAUTICAL SOCIETY'S EXPERIMENT FUND.

LIKE many other organizations, the Boston Aeronautical Society must have money, and a good deal of it, too, in order to carry on its work.

It is now gathering a fund to be used in the encouragement of experiment with aerial machines.

The members at present, besides giving their time to the work, are giving what money they can afford. More is needed, and all who are interested in the advancement of science are invited to contribute in sums either large or small.

Any remittances sent to the Treasurer of the Boston Aeronautical Society, Box 344, Boston, Mass., will be gratefully acknowledged. (See blanks at the end of this volume.)

Contributors will desire to know what use is to be made of their money.

The members of the Society will not be satisfied until they have established a country laboratory where well-paid men may be continuously employed in experimenting.

For a building there is needed a barn-like structure near the centre of a level tract, with a large sheet of water not far away. Such a building will answer the twofold purpose of a workshop and a place for the storage of apparatus. A small captive-balloon outfit is needed, so that on any calm day small models of soaring-machines can be launched from a height. A revolving slope, as invented and described[1] by Mr. Merrill, should

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[1] See page 102.

also be provided, so that experiments by athletes on machines of the Lilienthal type may soon be begun.

For the year 1896 a part of the money raised will be paid out to the world's experimenters in the form of cash prizes. These are to be awarded for certain kinds of apparatus which are much needed. Specifications are given below.

The sum of money already guaranteed to the fund is sufficient to provide prizes well worth contending for, but, as it is hoped that the fund will be constantly increased, the definite announcement of the amounts of the prizes will be made public on the first of May, 1896.

The competitive trials will probably take place at a field-meeting of the Society to be held late in the autumn of 1896 in the vicinity of Boston.

Designers unable to attend are invited to send apparatus, which will be tested by a committee of the Society, according to instructions furnished by the designers.

The code of rules governing the trials and awards will be announced later.

It is hoped that experimenters from all parts of the world will enter this competition.

Those who are considering the matter of entering will be in the way of receiving full information concerning details, if they will fill out Blank No. 1 at the end of this volume.

The following prizes, five in number, are offered:

PRIZE A. For the kite showing the maximum of lift to the minimum of drift in a breeze having a velocity of more than fifteen miles per hour.

PRIZE B. For the kite showing the maximum of lift to the minimum of drift in a breeze having a velocity of less than fifteen miles per hour.

PRIZE C. For the kite keeping its equilibrium through the greatest extremes of wind velocity.

PRIZE D. For the soaring-machine in free flight, which, after gaining velocity, shall make the best course. The excellence of the course to be judged by the maximum of length and the minimum of undulation. Energy may be given to the machine by carrying it to a height.

PRIZE E. For the best self-propelled machine.

The rules given are general ones only; the interpretation will rest with the judges. Details will be given later.

The committee in charge reserves the right to postpone the time of the competitive trials.

The foregoing stands approved.

Signed,

WILLIAM H. PICKERING,
ALBERT A. MERRILL,
JAMES MEANS,

Executive Committee of the Boston Aeronautical Society.

DYNAMIC FLIGHT.

By A. M. Herring.

Advance in a new science is generally slow, through lack of sufficient and properly interpreted data upon which to base new experiment. In flying-machine work this is especially true, for not only is there a scarcity of accurately recorded experiments, but even to get at the facts of these, we have, in most cases, to "wade backward," as it were, through a considerable amount of false interpretation of the phenomena observed.

Unfortunately the records of the work which has been done were until quite recently widely scattered; even now they are incomplete, except in a few instances where systematic series of experiments have been made by thoroughly competent physicists.

Starting with a knowledge of what is now known of the action of air on planes, it is quite easy, in a theoretical consideration of the subject, to prove that dynamic flight is not only possible with light and powerful machinery, but that the power required at high speed is so small as nearly to bring flight within the limit of man's unaided strength. But theoretical considerations omit many of the conditions which have to be met in practice. In the actual machine the conditions which arise cause a necessary waste of power many times greater than that originally allowed in even very liberal estimates. It would probably be surprising to a great many to be told that out of perhaps fifty or sixty different kinds of aeroplane and vertical screw models worked by twisted rubber, compressed air, or steam, that have been built and exhibited in flight, not more than two or three have required less than $\frac{1}{20}$ of a horse-power per pound of their weight, and that the majority required nearly twice as much, or over half the energy of a man to sustain a pound.

Yet it is a common thing to find very intelligent men bringing forward plans and projects of machines which practically offer no improvement on what has been done, but who, nevertheless, expect to carry anywhere from 160 to 500 lbs. per horse-power expended, while loading their surfaces so that they have to sustain several pounds to each square foot of area.

Theoretically considered 160 lbs. per horse-power seems a reasonably low figure, and with properly regulated apparatus in calm air it may some day be realized.

For the present, however, it seems certain that we must be content with a great deal less, say with 30 to 50 lbs. per horse-power. All the causes which in practice contribute to this great waste of energy are not definitely known, but a few are, and I will endeavor later on to point them out. The chief losses come from imperfect control of the apparatus, disturbances caused by the wind, and the unexpectedly great resistances offered by the framing, wire-guys, and other necessary parts of the apparatus.

It does not take long to evolve a stick and paper model which will glide beautifully and almost without undulation from one end of quite a large room to the other, while not descending more than one foot in every four that it travels. These models may be simple affairs made of writing-paper stiffened with thin spruce sticks or shavings, the whole being afterwards varnished with a thin coat of shellac to preserve the shape. Tried in a closed room their equilibrium seems perfect, but open one of the windows and direct the course of the model across the draught that blows in or out, and it no longer flies well, — in fact, in most cases, it will not fly at all; likewise when tried out-of-doors in even the faintest breeze it becomes a very poor model indeed.

To make a gliding model which will fly well in the open air, and retain its balance and course relatively free from rocking and undulation, requires a considerably better finished piece of apparatus; greater care must be used to get the shape, size, curvature and inclination of the wings exactly alike, — the edges must be sharp, and lastly, the model must be heavier and the centre of gravity be placed farther forward. The slightest variation in any detail often makes all the difference between a very good "flyer" and a very poor one. It will, of course, be observed that these models fly faster, but on the whole they do not fly so far in proportion to the distance they fall, and if the power be computed it will be found that the weight carried per horse-power is less — generally much less.

This weight carried (per horse-power) diminishes rapidly with increase of load, so much so that with one pound per square foot it is a very good model indeed which will indicate the rate of over forty pounds carried per horse-power; this and a little more, however, has been accomplished by several experimenters.

To obtain such a result uniformly, however, in the open air is very difficult; it requires good workmanship and very carefully finished surfaces; these I have generally made upon light frames of spruce, braced and edged with the finest piano wire. The coverings have been of silk or paper coated with shellac; and for very light and strong wings I have used gold-beaters' skin or ox-gut, which, after stretching on the frame, may be drawn as tight as a drum-head, with a couple of coats of pyroxiline varnish. The latter is a form of dissolved celluloid, or more properly a collodion, to which a number of ingredients, such as castor-oil gum, Canada balsam, etc., have been added in small quantities, rendering the film left by the evaporated varnish tough and flexible. This film has a pronounced tendency to shrink. This tendency in a somewhat less degree is communicated to the material to which the varnish is applied.

With even the best of care and workmanship the ordinary models only reach a certain degree of perfection, such that they will keep their equilibrium in a faint wind, say five or six miles an hour; beyond this it seems impossible to go without devising some sort of arrangement for maintaining a uniform angle of advance. The first thing to suggest itself is to use more than one following surface, and perhaps the next is to employ a pendulum directly or indirectly acting upon the rear surface or upon an auxiliary rudder; both methods, as well as a combination of the two, are undoubtedly good as makeshifts; but though I fell into this error, I am inclined, in the light of more recent developments, to believe that it was a step in the wrong direction.

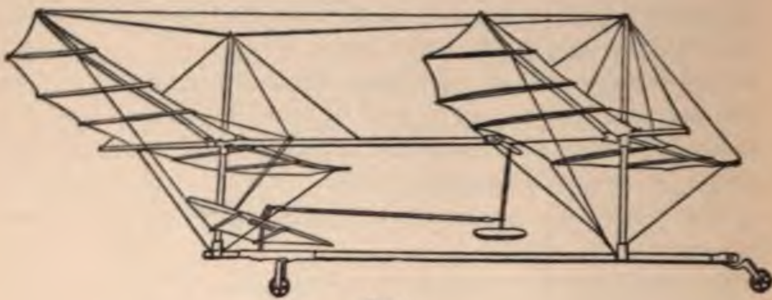


Fig. I.

Figure I represents a double wing pendulum model constructed some time ago. This, when a damper (in the form of thick grease) was applied to the pendulum axle, seemed to promise great results. This model (28 by 28 inches in extreme dimensions, each pair of wings being 28 by 7 inches) flew more successfully than anything I had tried before that time. The fact of its making a number of flights in which the average travel was five and a half times the fall was the reason of its being photographed. The pendulum was afterward replaced by a gyroscope, which, it is needless to say, failed. I mention this model simply because it will give a good illustration of how hard it often is to definitely locate the exact cause of success or of failure in this class of experiment.

As the pendulum regulated the small horizontal rudder (beneath the rear pair of wings) smoothly and gradually for each and every slight variation from the horizontal position of the whole apparatus, it was natural to attribute what success there was to the pendulum and to its connecting mechanism. Nevertheless it occurred to me to test the matter more definitely; accordingly the pendulum was tied in several different positions, and then it was found possible to obtain unmistakably better results than when the pendulum and mechanism were free.

Though I did not appreciate it at the time, I may mention in passing that the chief factors which contributed to the success of the model were, first, the fore and aft position of the centre of gravity (just $1\frac{1}{2}$ in. back of the rear edge of the front wings); second, the vertical position of the centre of gravity, which was by chance so placed that the resistances caused by the wings and framing above were balanced by the resistance of the framing, wheels, etc., below, so that when the model flew at its soaring speed of minimum resistance the efforts were balanced about the centre of gravity.

The expression, "soaring speed of minimum resistance," may not be perfectly clear. If we assume that as the speed increases the model tends to decrease the angle at which the surfaces are presented and thereby to diminish the drift offered by the wings, while at the same time the framing, wires, struts, edges of wings, etc., offer an increasing resistance, it is evident that there must be some speed at which the model will sail on the air while offering the least total resistance.

The velocity thus found, experimentally, is the soaring speed of minimum resistance. In most models it is low, owing to the defective automatic regulation of the angle of advance, and also to the large head resistance offered by the framing, etc.

Although quite a number of steam flying-machines have been constructed, and many of them have been furnished with both light and powerful engines, they have nearly all failed from one or more of three causes: imperfect control of the angle at which the surfaces were presented in flight, improper balancing, or unstable equilibrium.

All three requirements are of the greatest importance; perhaps a complete solution is known for all.

The securing of stable equilibrium is perhaps the hardest problem of all, as the difficulties which it presents are most numerous. If we conceive the wind (and there is never a day that there is not some wind) as a steadily blowing stream of air, — as people generally believe it to be, — a flying-machine would be a very easy thing to construct, and it would have been invented long ago. But the air is never wholly at rest, nor does the wind, as we know, come anywhere near being such an ideally moving stream of air. According to experiments made by Zahm and by Wellner, the air, even in the slightest zephyrs, not only changes the horizontal direction from which it blows, several times in a second, but it changes in its speed and in its up and down trend quite as much and quite as rapidly; not only this, but these relative disturbances are of considerable magnitude, and are more and more pronounced the stronger the wind. Now, the position of the centre of pressure varies very much according to the relative inclination of the wind to the plane, and it also varies with the speed at which the plane travels. But as the centre of the weight of the machine should always be under the centre of support (or centre of pressure), it is easily seen that any changes in the direction or intensity of the wind will cause a corresponding change in the point of support, and consequently derange the equilibrium of the whole apparatus; this is not easily reëstablished in an instant.

The best solution is probably to be found in such surfaces, and their arrangement relative to each other, as will remain undisturbed by the changes in the wind. This, which has been the object of very much of my experimental work, for a long

Fig. 2.

time seemed almost a hopeless task, but I believe it has at last been attained — not perfectly, but nearly so.

In December, 1890, while actively at work on this part of the problem, I constructed a small machine which worked by the power of a twisted rubber spring. The surfaces were in different shapes and arrangements, but finally the model assumed the form shown in the drawings given herewith (Figures 2 and 3). This model, which is still in existence, flies exceedingly well, but it did not do so until the centre of gravity had been properly adjusted beneath the wings and the proper height had been found at which to put the propellers. It is very light, but carries a very great amount of weight in proportion to the power expended. Its flights last from 5 to 7 seconds, during which time it goes from 80 to 135 feet.

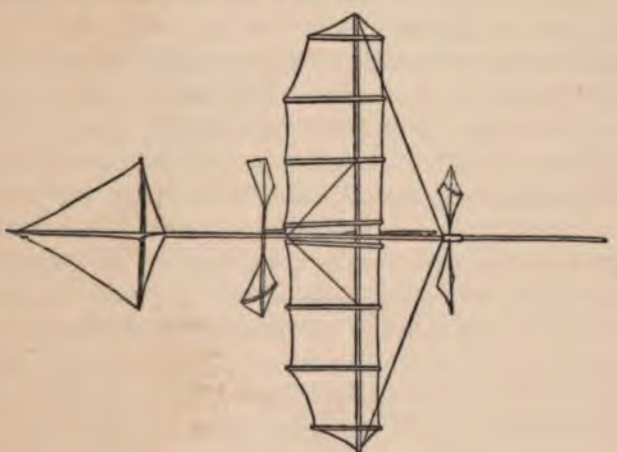


Fig. 3.

To look at the pictures no one would imagine that its conception and construction could have been the work of more than a few days' time at the outside; it represents, nevertheless, the outgrowth of nearly two years' work — one difficulty alone occupying more than four-fifths of the time. I speak of the mechanism which controls its angle of inclination and maintains the model in approximately horizontal flight.

The effect of this regulating mechanism is such as to have decreased the power necessary to propel the model to only one-quarter as much as was necessary without it. A number of trials made in the open air show that it can fly successfully in a wind of over 7 miles an hour. Its velocity is from 12 to 16.3 feet a second with an expenditure of 1.05 to 5 foot-lbs. per second, the former being the least amount it will fly with steadily. The propellers are 16 inches in diameter and make from 11.3 to 24 turns a second per pair. The total weight is 0.30 lbs. and the area of the wings is 258 square inches, or at the rate of 6.0 square feet to the pound; it will, however, fly when loaded with twice its own weight, but requires a greater proportionate expenditure of power.

The model flies well until only about three turns of the spring remain wound. With 15 turns it flies rapidly, while exerting 1.65 foot-lbs. per second.

The slip of the propellers in flight is about 55%, so that at most their efficiency is 45%. This shows that the surfaces carry at the rate of over 200 lbs. (and possibly over 300 lbs.) per "push horse-power." Even the lesser figure is, I believe, considerably higher than has ever been attained by any other free model.

If, however, we were able to bring the rate of loading up to one pound per square foot, instead of one pound to six square feet of surface, we would (theoretically) have to divide the weight carried per horse-power by the square root of six. And if we allow for propellers of 70% efficiency instead of 45%, and also allow for the greater resistance at higher speed, it is probable that instead of carrying 200 to 300 lbs. we could only carry 50 to 60 lbs. per horse-power.

In 1891 I constructed a model similar in design to the above, but provided with a set of compound steam-engines, supplied with an aluminium tubing condenser exposing about nine square feet of surface. The engines, with their pumps, circulator, shafting, boiler, boiler covering, furnace and tanks complete, but not including the condenser, weighed less than one pound, and developed a little over $\frac{2}{10}$ of a horse-power. The condenser, with its joints and connections complete, weighed only $\frac{85}{100}$ of a pound. The total weight of the apparatus was five pounds, and the surface was 14 square feet.

The machine succeeded several times in raising itself from the ground, with its fuel and supplies, and without any outside aid whatever, even in starting, and I succeeded in getting it to fly a little over 240 feet. It sustained a trifle more than 30 pounds per horse-power, and had it not been destroyed by the explosion of its boiler it is believed that a better adjustment of the regulator would have enabled the model to carry at the rate of 50 to 60 pounds per horse-power.

It is a common error to consider the resistances of the framing, guy-wires, edges of wings, etc., as a negligible quantity where a pound or more per square foot may be economically carried. As a matter of fact these resistances, when added together, in some of the very best designs that I have seen, would consume anywhere from 60% to 500% as much power as allowed for the aeroplanes (or rather aerocurves). It is far from correct, however, to assume that such great resistances are absolutely unavoidable; yet with very light construction the resistance offered by the wires alone will always be too great to allow any machine large enough to carry a man to sail economically at such small angles and high speeds as have been usually assumed.

Careful experiments lead me to think that 350 feet is, perhaps, the minimum length of exposed wire which can be used in a light machine to carry a man; this, at 75 miles an hour, would offer a head resistance of over 30 pounds, and would consume over 6 horse-power, nearly 30 times as much power as one man can exert continuously.

It is, perhaps, safe to say that the resistance of the balance of the framing, car, etc., would, under the best possible *light* construction, offer as much as, or more, resistance than the wires at this speed; and both together would consume a total of over 12 horse-power in friction, and yet there are hundreds of well-informed people who believe that if they could regulate their apparatus they would be able to fly 100 miles an hour or more by their own exertion!

As we cannot at present regulate our apparatus with any very great degree of certainty, we cannot sail at small angles; we cannot therefore carry very much per horse-power, and are necessarily limited to lightly-built machines; these, of course, must be braced with almost an innumerable number of small wires to make them sufficiently strong and stiff.

Notwithstanding the great resistance which such a construction offers, it is the best for speed of less than 35 miles an hour, and this is, perhaps, above the speed that will be attained by the first machine that successfully carries (by power) a man in the air.

Perhaps the subject on which there are the least reliable data is the law governing the position of the centre of pressure under the varying conditions of inclination and speed; yet in the design of any model or large apparatus it is probably of more importance than any other single item.

If in a close room the model shown in Figure 1 be launched from the hand, it may be found by repeated trial that the centre of pressure of the combined surfaces can travel so far forward as to come beneath the front wings, instead of remaining about one-third way between the two pair; yet it is apparently not in the same place when the model is flown parallel to and near the floor, as when it is thrown off from about 6 or 7 feet above it. Also, the centre of pressure is apparently farther forward at high velocities than at low, and when the model is balanced for rapid flight it will not sail satisfactorily at slow speed. Similarly a light model made for gliding flight, and consequently for slow speed, is wholly unfit for rapid flight.

The lifting power of planes set at various angles and driven at various speeds seems to be well determined, thanks to the labors of Professor Langley. Concerning curved surfaces, which are far more efficient, there is not so much reliable information.

One very noticeable difference is shown between experiments made in the natural wind and those which are made with a "whirling table" where the surface is driven against an artificial wind produced by motion through still air.

The difference is very largely in favor of the natural wind, which, roughly speaking, gives an average effect very much greater than that produced by moving the same surface through apparently still air.

I have found that in experimenting with small surfaces it is not entirely correct to apply the data thus obtained directly, to similar but very much larger surfaces.

I found a difference in the resistance and lifting power of large surfaces compared with small ones. The larger are generally more efficient. At the same speed they lift more per square foot, and apparently offer slightly less resistance or drift per pound lifted; the centre of pressure is also proportionately slightly farther back.

I have further found that a most striking relation exists between the maximum travel of the centre of pressure of surfaces and the efficiency of those surfaces when compared to some standard (such as a plane).

In general, the less the maximum departure of the centre of pressure from the centre of figure, the greater is the efficiency of the surface, and the greater is the amount which it will lift at a given angle with a given speed; and also the greater is the weight which can be carried by the expenditure of one horse-power.

At almost all angles of inclination the centre of pressure on a square plane is proportionately farther forward than is the centre of pressure on a plane whose advancing edge is five times its breadth. Similarly, at slight angles, the centre of pressure on a properly curved surface (whose vertical projection is square) is farther back than either.

Another variation in the position of the centre of pressure is that produced by speed. If a plane or slightly curved surface be held in a wind and be inclined at a very flat angle, its centre of pressure will be found farther forward at high speed than at low.

The centre of pressure on considerably curved surfaces undergoes a peculiar reversal in its position. In one which the curvature is such that the rise of arc is about ⅛ the chord length, and where the highest point of curvature is ⅓ the way from the front, the maximum forward position of the centre of pressure is found when the surface is tilted at about five degrees; it, however, travels rapidly backward for either a lesser or a greater inclination of the chord.

This peculiar reversal is probably due to the air pressure on the upper side of the front margin, and does not necessarily mean that such a surface is more efficient at an inclination of 1 or 2 degrees than it is at 5 degrees.

The maximum forward position of the centre of pressure in such a surface is about 37 to 39 per cent. of its width; this places it very high in point of efficiency.

In 1894 I built three gliding-machines. The object in the construction of these was twofold: first, to learn, if possible, what the difficulties would be in the management of the machine in the air; and, second, to find approximately the power required to sustain a man and a machine in flight.

The difficulties encountered in gliding flight are almost entirely confined to those introduced by the irregularities of the wind; at least such is the case when you have once learnt how to start; this, perhaps, is the most difficult point of all to master in the beginning, as it is necessary to get up a very considerable speed while running down a fairly steep incline, the speed is so great, — 18 to 20 miles an hour in a calm, — that you invariably feel safer on the machine in the air than you do during the preliminary run.

In trials in a fairly brisk wind, the direction from which the latter blows varies very considerably and irregularly, so much so that the muscular exertion required in shifting the weight so as to always correspond with the centre of pressure on the wings is very great.

The shifting of the latter in the line of flight appears not only to depend on the angle at which the machine is tilted, but also upon the velocity of the air relative to the machine.

At the same inclination the centre of pressure is farther forward at high speed than at low speed, and reaches its maximum forward position in the frequent gusts which one is liable to encounter in flight.

The fore and aft travel is also very great for even small changes in the inclination of the apparatus. This is not so difficult to counteract as is the disturbance produced by variations in the amount of upward and downward trend of the wind; this comes suddenly and unexpectedly, as does also the lateral variation, which causes one wing or the other to lift the more. The last-mentioned difficulty, is, perhaps, the worst of all; it is very great with wings which are long and narrow, but, I believe, it has been very largely overcome by the discovery of a highly efficient surface which possesses the remarkable quality of having little or no travel to its centre of pressure from front to back, and which, furthermore, is almost equally efficient in square shape as when the length is very much greater than the depth. This surface will lift its own weight in a light breeze when the chord of the surface is inclined at so great a negative angle as 15 to 20 degrees.

When properly loaded a model made with this surface was found to glide quite a distance at surprisingly low speed.

Many of the foremost workers on the flying-machine problem are firm believers in the possibility of man learning to soar by utilizing the forces of the wind, as the birds do, but for my own part, if this be ever accomplished, I believe it will be long after the air has been navigated by steam. This, in spite of the difficulties which a few years ago seemed unsurmountable, is not only a probability but is apparently a certainty of the near future. Progress in the "new science" has been very rapid within the past three years, and many of the most formidable barriers to success have disappeared. Much of this advance is due to one man, Mr. Chanute, of Chicago, whose thorough knowledge of the subject and whose acute powers of analysis have been of incalculable benefit to several experimenters, and to myself in particular.

THE REVOLVING SLOPE.

NEW ideas are constantly coming to the mind of Mr. Albert A. Merrill, the secretary of the Boston Aeronautical Society. It was he who originally proposed the formation of the Society, and who awakened the interest of the first members by calling upon them. The accompanying drawing shows one of his inventions.

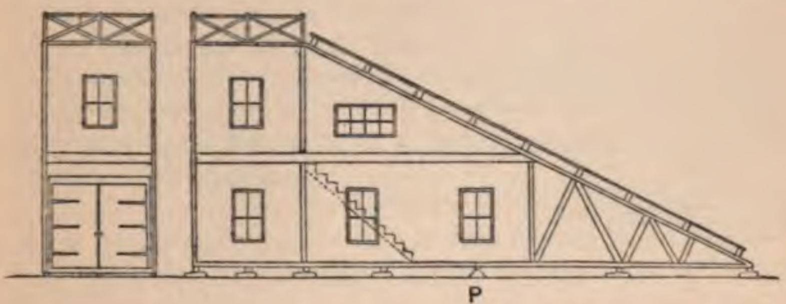
The object is to provide a suitable slope for the starting of any aerial machine. It is desirable to start all flights when facing the wind, as is the habit of all the larger birds. Mr. Lilienthal has usually started from the summit of a hill. In his earlier experiments, the hill which he used did not have the desired slope in all directions; consequently he suffered long delays while the wind held in unfavorable quarters. So he has had a conical hill built which slopes toward all points of the compass, and whenever any wind is blowing he can face it.

Mr. Merrill thinks that artificial hills will be too expensive for common use, and in order to accomplish the desired result more economically and more conveniently he has invented the Revolving Slope.

As indicated in the drawing, this is a building moving upon a pivot, P, and turning upon a circular track similar to that of a locomotive turn-table. The slope can thus be made to face the wind from any quarter. The building serves as a workshop and as a place for the storage of the flying apparatus. When a higher point of starting is needed, for instance, one hundred feet or more, the Revolving Slope can be made of steel trestle-work, which, being open, will not be injured by storms.

Mr. Merrill writes: "For the first structure I would select a large and level plot of soft ground (by soft, I mean free from rocks), within, say, a dozen miles or so of a city, and in a windy locality.

"In the centre of this I would build my workshop, of which the side and end elevations are given. It is seen by the plan that I have made my workshop take the place of Lilienthal's hill. The building is 60 ft. × 12 ft. on the base, by 24 ft. high. It has a flat roof 12 ft. × 12 ft., and the rest of the 60-ft. base is covered by a pitched roof. This roof covers the



entire width of the building. Thirty-six feet of the base of the building are enclosed in walls of matched boards, making a lower room of 36 ft. × 12 ft. × 12 ft., with an upper room 36 ft. × 12 ft. × 12 ft., having a slanting roof. These rooms receive light from the windows as represented, and entrance is effected by the large doors shown in the left-hand view.

"With such a space there would be abundant room for work-bench, tools, models, etc., while the attic could be used for other purposes. In this way the building would be complete in itself, and all kinds of experimental work could go on in its interior, while its roof could be used to test perfected apparatus. The pivot upon which the building turns is seen in the drawing under the right-hand window; and although this is the turning-point, most of the weight is carried by the heavy wooden rollers under the joist, as seen in the plans. The building is turned by a windlass inside; its weight, about five tons, while enough to make it stand firmly, will not interfere with its movement around the pivot. I would advise having steel cables running from the roof to the ground, on each side, to steady the structure, and I think it a good plan to have it built in sections to facilitate transportation. There are many details which perhaps can be worked out by others much better than by myself, and in concluding I can only say that when, some months ago, I suggested this to a body of scientific men, I was assured of the plan being practical by a successful carpenter and builder to whom I went for advice, and who not only believes it possible to carry out the above, but who has now such plans and specifications in his possession as warrant him in saying that the building could be constructed in his shop, transported to the field, and set up in good condition for about $500.

"It seems to me that with the use of such a building great progress would be made in aerial navigation, at slight expense to the investigators."

THE RELATION OF THE WIND TO AERONAUTICS.

By A. Lawrence Rotch,

Director of Blue Hill Meteorological Observatory.

It is obvious that a knowledge of the velocity and direction of the air currents which may be encountered at moderate elevations above the earth is of great importance to experimenters in aeronautics.

The situation of the Blue Hill Observatory, about 500 feet above the general level of the country around Boston, with a free exposure in all directions, makes the data relating to the wind collected there very valuable, and therefore special attention has been given to such investigations since the establishment of the Observatory in 1885.

Mean Velocity of the Wind at Different Altitudes. — It is well known that there is an increase of wind as we rise above the ground, on account of the retardation caused by the irregularities of the earth's surface. Thus the anemometer on the Blue Hill Observatory records on the average about 60 per cent. more wind than does the instrument on the Boston Post-Office tower, 460 feet lower, but still nearly 200 feet above the city streets. During the past few months kites have been used to extend the range of observation 2,000 feet above Blue Hill, where, by means of a series of especially designed kites, a meteorograph constructed by Mr. S. P. Fergusson, of the Observatory, recorded automatically the temperature and wind velocity at intermediate heights, which were determined by trigonometrical measurements. Excepting certain abnormal cases when the wind decreased aloft, the velocity increased about 25 per cent. at an elevation of from 1,000 to 2,000 feet above the hill. There is, however, reason for believing that slightly above the hill the wind velocity is less, or at least no greater, than on the Observatory tower, the hill acting as an obstacle to the air stream which then flows over it with accelerated speed, like water over a dam. This is certainly the case on Mount Washington, where the observed wind has a greater velocity than have the clouds at the same level.

Since a free balloon takes the motion of the air in which it floats, it is an excellent anemometer, and by noting the times of starting and landing and the places passed over, the velocity and direction of the wind at the average level of the balloon are obtained. This was done by the writer in two ascents from Paris, which serve to confirm the recent kite experiments. In the first voyage, at an average height of about 2,000 feet, the balloon was carried at the rate of 22 miles an hour, while during the same time on the Eiffel Tower, at half that altitude, the wind blew 18 miles an hour. In the second voyage, with an average height of 2,900 feet, the balloon moved 20 miles an hour, while on the Eiffel Tower, 1,900 feet lower, the wind was only 16 miles.

The trigonometrical cloud measurements which were made at the Blue Hill Observatory during 1890 and 1891, by Messrs. Clayton and Fergusson, enable the velocity and direction of the currents carrying clouds at different levels to be calculated. Above the hill the increase of velocity with altitude is regular and uniform, winter and summer, up to the cirrus clouds at an elevation of 8 miles, whose summer velocity averages 79 miles per hour. Starting with a mean summer velocity of 15.3 miles per hour at the top of the hill, the increase in miles per hour for each 330 feet of elevation at various levels up to the greatest height likely to be reached by dirigible and self-propelled aeroplanes is given in the table on page 107.

The slight decrease in velocity between 3,300 and 5,200 feet is probably caused by the slower-moving currents ascending from a lower level, by which the cumulus clouds at that level are formed. The mean of all the increments gives a mean rate of increase of 0.64 mile per hour per 330 feet, the increase in winter being 1.45 miles, or more than twice as rapid.

Height in feet.	1,300 to 2,000	2,000 to 2,600	2,600 to 3,300	3,300 to 3,900	3,900 to 4,600	4,600 to 5,200	5,200 to 5,900	5,900 to 6,600
Increase per 330 ft.	+2.2	+1.6	+2.0	−1.6	−0.2	−0.2	+1.1	+0.7

Height in feet.	6,600 to 7,200	7,200 to 8,200	8,200 to 9,300	9,300 to 10,800
Increase per 330 ft.	+0.2	+1.1	+0.2	+0.9

Maximum Wind Velocity and Pressure. — The greatest velocity or pressure which aeroplanes may encounter is necessary of consideration in order that the motive power may be sufficient to make headway, or at least that the parts may be strong enough to resist the pressure to which they may be subjected.

A balloon moving with the wind experiences but slight resistance, whereas a self-propelled apparatus which might be capable of travelling 10 miles per hour in still air would remain stationary, as regards the earth, when it encountered a contrary wind of 10 miles per hour, and yet there would be actually blowing against it the wind of 10 miles per hour, whose pressure was nearly half a pound upon each square foot of surface normally exposed. If the machine could travel 20 miles per hour and the natural wind blew at half this rate against it, the machine would advance at the rate of 10 miles and would sustain a pressure of about one and a half pounds per square foot, the pressure increasing as the square of the velocity of the impinging air. This factor seems to impose practical limits to the use of air ships against high winds.

The mean velocity of the wind on Blue Hill is about 15 miles per hour in summer and 22 miles in winter, and these may be taken to represent the usual velocities 400 or 500 feet above this part of the country. An extreme velocity of 88 miles per hour during five minutes has been recorded, which, according to the mean of the best formulæ for converting velocity into pressure of normal surface ($P = v^2 \times .0035$) gives a pressure of 28 lbs. per square foot. During the first four years of observation a self-recording pressure-plate was in operation, and on two occasions pressures of over 43 lbs. on the square foot were registered, while the corresponding velocity during five minutes was only 85 miles per hour instead of 110 miles, as the pressure would indicate. This seemed to show that the extreme pressures are of very short duration, perhaps lasting only a few seconds, and the supposition was confirmed by an elaborate series of comparisons of different types of anemometers which has just been completed by Mr. Fergusson. The use of anemometers and pressure-plates recording at short intervals, with large time scales, shows that the wind is exceedingly variable, and that the frequency and intensity of gusts is generally greatest at high velocities. Usually, in a brisk wind, sudden blows or jerks followed by intervals of very slight pressure will succeed each other with great rapidity, often several times a second. It is now demonstrated that the cups of the Robinson anemometer (which is the instrument in general use) do not move one-third as fast as the wind, and that the factor for the pattern used by our Weather Bureau is, at moderate velocities, 2.65 instead of 3. Applying this correction, a recorded velocity of 30 miles per hour is reduced to 26, but recorded velocities below 6 miles per hour require to be slightly increased.

The maximum velocities of clouds at different levels which have been measured at Blue Hill, by the method already mentioned, are as follows:

Height in feet . . .	1,660	5,300	12,650	21,750	29,130
Velocity in miles per hour,	40	69	74	150	230

Inclination and Direction of the Wind. — It is generally assumed that the wind blows horizontally, and our ordinary anemometers measure only the horizontal component. Of late years an instrument for recording the vertical component has been in use at Zi-Ka-Wei, China, and on the Eiffel Tower in Paris, which showed the existence of both upward and downward currents. In 1891 such an instrument was exposed 30 feet above the tower of the Blue Hill Observatory, and observations were made during several months. Upward currents aggregating one thousand feet per day were recorded, due chiefly to the deflection of the horizontal wind on striking the hill, since the vertical wind was roughly proportional to the amount of horizontal wind, but it was also related to the heating of the hill by the sun, being strongest in clear weather. Downward currents were seldom registered, proving that, though they undoubtedly exist, their velocity was too small to affect the fans of the anemometer. That these vertical currents may extend to considerable heights is shown by the production of cumulus clouds, under which the kites have demonstrated the existence of strong ascensional currents. The wave-like appearance of the higher clouds is also evidence of undulatory movements which may extend downwards to the earth, and cause rhythmical oscillations of the barometer. We are not yet prepared to say to what extent these upward currents may be utilized to lift aeroplanes, and the theory that the soaring bird is always sustained by them has not yet been generally accepted.

The wind direction at different levels is important for the aeronaut, and here again the cloud observations at Blue Hill and their discussion by Mr. Clayton have contributed much data. The cyclonic and anticyclonic circulations which control our surface winds are entirely masked above the cumulus region — that is, above the height of a mile — by the general drift from the west-northwest, which deflects the currents to the right in the cyclones and to the left in the anticyclones. Mr. Clayton found that the currents do not all turn to the right as one ascends into the atmosphere, as is usually stated. When the winds have a southerly component, the upper currents come from a direction more and more to the right as one ascends, but when the winds have a northerly component the currents turn to the left as one ascends. In the two balloon voyages already mentioned, the upper winds veered with respect to the lower; that is, they were deflected towards the right hand, and this was the case from the earth's surface up. On these days the surface winds were southerly, and the general circulation was controlled by an area of high barometric pressure in the west.

Diurnal Changes of Velocity and Direction. — If navigating the air ever becomes practicable, the hourly variations of the wind will doubtless have to be considered. There are generally two daily maxima and two daily minima of wind velocity. The chief maximum occurs on Blue Hill during the afternoon, and the chief minimum in the early morning, the hours varying with the seasons. The difference between the chief maximum and chief minimum for the year at Blue Hill is 1.8 miles per hour, but at Boston, nearer sea level, it is 3.3 miles, or more than one-fourth of the mean velocity. In the open sea the diurnal change is very small, but as we rise in the air the time of minimum velocity shifts towards noon, so that on Pike's Peak the low-level conditions are almost completely reversed, the greatest velocity here occurring early in the morning and the least at noon. This appears due to the fact that ascending currents begin near the earth's surface in the early morning and gradually extend higher and higher until the afternoon. The first effect of the ascending air is to retard the more rapidly moving air into which it enters, but as it ascends higher and the more rapidly moving air descends to supply its place, the currents beneath are again accelerated. It therefore results that at low levels the night winds have not only a less average velocity than the day winds, but they are more steady, for the reason that they are not affected by local rising convectional currents. The night, consequently, is the most suitable time to experiment with most aeronautical apparatus.

The diurnal change of wind direction is not so well marked as the change in velocity, but there has been found at Blue Hill and elsewhere a tendency of the wind at all heights to veer around the compass each day. This is independent of the sea breeze, which affects only the surface winds.

THE KITE CONSIDERED AS AN INSTRUMENT OF VALUE.

BY THE EDITOR.

THERE are many reasons for thinking that in the development of the kite we have a study from which useful knowledge may be gained. The equipment necessary for kite-designing and kite-flying being comparatively inexpensive, these occupations are open to many who like to combine open-air exercise with study. Perhaps it can be shown that the kite is worthy of more attention than it has hitherto received.

Three forces act upon a flying kite: (1) the wind, (2) gravity, (3) the string. The pull upon a kite-string is the resultant of two components: (1) lift, (2) drift.[1] It is evident that when a kite is well designed the string may be relieved of a part of the pull which is caused by component number one, the lift. This may be done by making the kite a weight-carrier. It being desirable in the extreme to increase the efficiency of the kite as a weight-carrier, our greatest efforts in designing should be to

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[1] These technical terms are in common use in the discussions of aeronautical matters. Sir George Cayley wrote of these forces in 1809. (See Aero. Annual, 1895, p. 20.) Mentioning the whole force of the air under the wing of the horizontally soaring bird, he says that it may be resolved into two forces, one representing the force that sustains the weight of the bird, the other the retarding force by which the velocity of its motion is constantly diminished. Sir George seems to have been the first student of aeronautics to understand these forces. He applied no names to them. Later writers have used the word *lift* to designate the former and *drift* the latter. Maxim uses the words as follows, in describing a piece of apparatus which he has designed for experiments to ascertain the best possible fabric to be used for sustaining surfaces. He says: "It is constructed in such a manner that a piece of the fabric to be tested can be tightly stretched on a small steel frame, and mounted at an angle in a blast of air, with suitable weighing-apparatus for ascertaining the lift and the drift — 'drift' in this sense meaning the tendency of the object to move in the direction of the wind, while 'lift' means its ascensional force."

The fitness of the chosen words will be seen when they are applied to the kite; *lift* being the weight-carrying power and *drift* the tendency to move to leeward.

obtain the maximum of lift with the minimum of drift, thus bringing the kite nearer to the zenith and decreasing the size and weight of the string which is necessary to control it.

By experiments at York, Me., during the past summer I have tried to learn:

1st. What forms of kite fly with the greatest steadiness.

2d. What is the best way to make the kite a weight-carrier.

In my efforts to secure steadiness of flight I have experimented with kites of many different types, some of which are shown by the drawings on these pages. My first experiments were made with single kites. Fig. 1 shows a Chinese kite.

Fig. 1. — Single Chinese Kite. The segments of circles are loose flaps.

This was copied from one of a large collection which formed a part of the Chinese exhibit at the Centennial Exhibition in Philadelphia.

Having tried this and various other forms of single kite without getting just the results looked for, I was led to make experiments to ascertain to what extent longitudinal stability[1] may be improved by an increase of the long dimension. The results were, on the whole, satisfactory.

Early in the season I visited Mr. C. H. Lamson, of Portland, Me., and I found that he had obtained a decided increase of

[1] The word *stability* is here used to designate steadiness of flight. When firmness of structure is meant, the word *rigidity* will be used.

stability by doubling his kite, *i.e.*, by putting two single Malay kites upon one backbone. Acting upon his suggestion, I doubled my Chinese kite as shown in Fig. 2, and it has

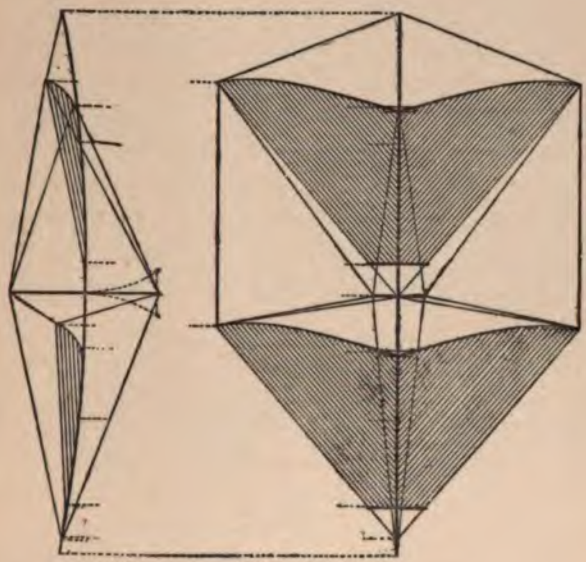

Fig. 2.

proved to be much superior to the single form. It flies at a good angle, all things considered, and, under favorable conditions, with great steadiness. I have seen it maintain its equilibrium in a high wind until its material yielded and it went to tatters.

It will be noticed in Fig. 1 that the single Chinese kite is made with loose flaps. Wishing to ascertain what effect, if any, these had upon the stability of the kite, I had the double Chinese made with the flaps, and one day when the kite was at its best in a strong wind, I lowered it and cut off the flaps. When the kite was immediately raised again, no difference in its flight was perceptible. Every kite-flyer knows that some kites which seem to have stability in ordinary winds are thrown out of equilibrium when the wind strengthens to a certain extent.

My search has been for the steadiest form possible, consequently I have tried everything that time has permitted.

Remarks on page 257 of Mr. Chanute's book[1] led me to have a keel kite constructed. This was tried many times under conditions presumably favorable, yet in every trial it dove to the ground. The keel was placed under the kite something like a boat's keel. The success of Mr. Lamson with another form of keel kite seems to show that my keel was not well placed.

In various lines of experiment it is found that the importance of a principle may be tested by carrying the application of it to an extreme. Therefore, in order to see the effect of further increase in the long dimension, I had a sextuple kite made as shown in Fig. 3. This seemed to be not so good as the double

Fig. 3.

kite. I should state, however, that I have not yet tested the sextuple under many different conditions.

I then had a light triple kite made, about twelve feet long. This was on the general plan of Mr. Lamson's kite, only it had three surfaces instead of two. This proved to be so stable and seemed to adapt itself so readily to unfavorable conditions, such as gusts and eddies, that I immediately made drawings for a larger one of the same proportions and about eighteen feet long. When this kite was finished, its flight was fairly satisfactory.

At this stage of the experiments I began to encounter the difficulty of making things hold together. The first triple kite had broken its backbone two or three times, and in flying this large triple in a strong breeze on the 19th of August, and standing a little to leeward of it when its altitude was low, I noticed

[1] "Progress in Flying Machines," M. N. Forney, 47 Cedar street, N.Y., 1894.

that the irregularities of its flight were caused by distortion under wind pressure. The next day the kite was flown again in a stronger wind, and the backbone broke near the centre.

The following day the kite was repaired and flown again. When 3,166 feet of string were out, the line parted. What became of the kite I have not learned. Boone Island is six miles from shore and ten miles from where the kite left the ground; fishermen near this island last saw the kite and reported it as very high in the air and rapidly travelling seaward. Measurement upon the reel showed that the kite had carried away about 1,400 feet of string, and, as a well-balanced kite with a drag-line of just the right length — as this seemed to be — is self-regulating, I think the kite must have travelled until it came to a calm spot.

I then made drawings for another triple, which was soon completed. The dimensions[1] are the same as those of its predecessor, but, unlike that, it is a very strong kite for its weight of six pounds, the backbone being trussed with steel wire, and it is still in good condition for use next summer. All of the details are given in the explanation of Plate XII. I have seen this kite fly with great steadiness in a strong wind, and I can recommend it as a useful one for the beginner.

The foregoing refers to efforts made to secure steadiness of flight. The second division of the subject relates to the carrying of weights. In the kite-designing of the future this query will often arise when new designs are unsuccessful: *Is a very small factor of drift compatible with the preservation of stability?*

If future experiments give an unmistakable negative answer to this, then the kite may remain of no more importance than it has been; yet I see now no reason to suppose that the answer will be a negative one.

The curves of the surfaces of the kite must be modified and brought more into conformity with the Lilienthal and the Maxim curves, treated of in other articles. The disposition of the surfaces is a most interesting subject, and calls for a series of experiments as endless as the designing of marine vessels.

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[1] See footnote on p. 116 for dimensions.

From what has already been said it will be seen that as kite-designing progresses, designers will not be satisfied with mere stability, but, always taking pains to retain those elements which they find conducive to stability, they will endeavor to increase the lift and to lessen the drift.

Unfavorable conditions of wind near the ground often make it difficult to start weighted kites. If a swivel and pulley block are attached as shown in Fig. 4, and if a double line running through the block be used to fly the kite in lieu of a single line, different weights may be raised to the kite, and after their effect has been ascertained they may be lowered.

The season came to an end before I was able to complete my experiments to determine the weight-carrying power of the triple kite. I hope to make a later report concerning that matter.

The uses of the kite will now be briefly considered. It has been maintained by some experimenters in aeronautics that the

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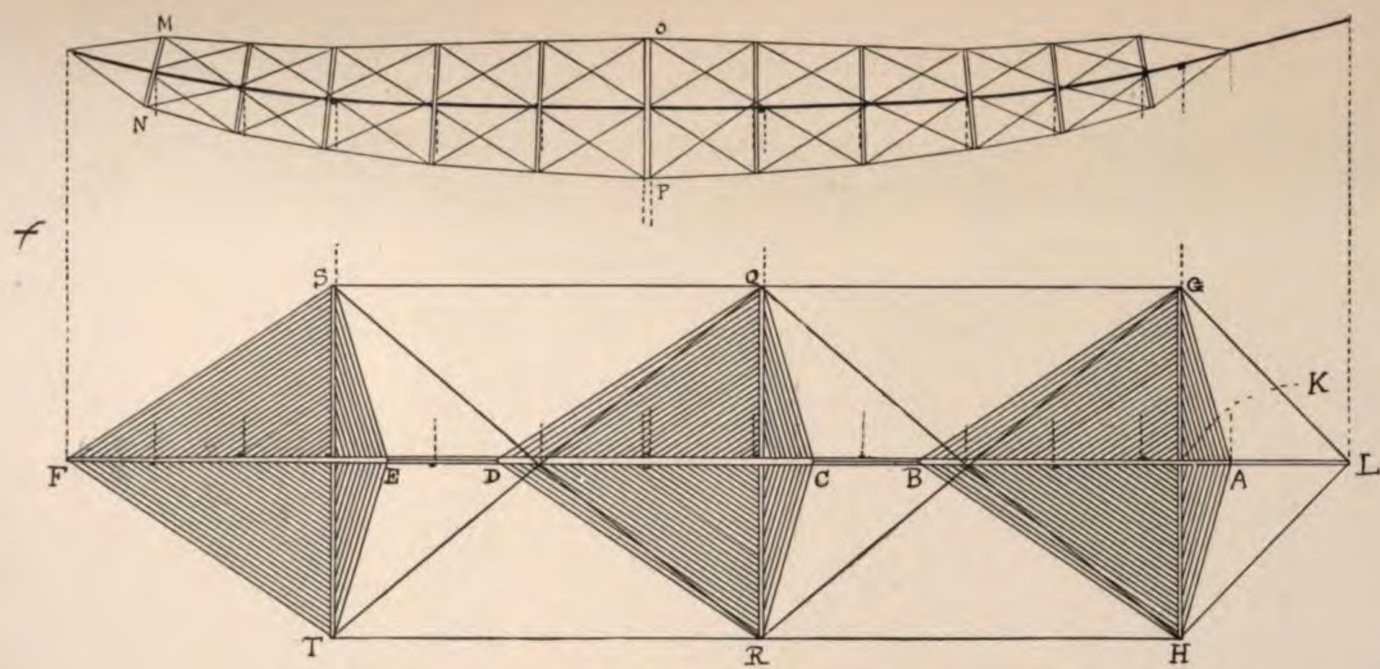
Explanation of Plate XII. Triple Malay Kite, 1895.

Spruce frame. Backbone FL is curved as shown in the upper figure. MN, OP, etc., are spruce uprights ½ in. × ¾ in. and 12 to 20 inches in length, according to position. MO, etc., NP, etc., and also the diagonal lines, are taut steel wires. Backbone is 18 ft. long, ½ in. thick, 1¼ in. wide in the centre, tapering to ⅞ in. wide at the ends. From L to A measured on the stick 1 ft. 6 in. From A to K, 9 in. From K to B, 3 ft. 9 in. From B to C, from D to E, 18 in. each. GH, QR, and ST are bows each 5 ft. long before bending. They are ½ in. × ¾ in. When bows are bent the bow-strings in their centres are about 5 inches from the wood. (See article on the Eddy Kite in Editorial Department.) The surfaces BGAH, DQCR, and FSET are equal.

The curves of the backbone and the three cross-bows have their convex sides toward the wind. This kite is covered with very strong Manila paper. Weight of the whole kite, 6 lbs. Textile fabric made impervious to air and moisture would make a better covering. SR, TQ, QH, RG, SQGL, TRHL, are taut steel-wire stays. The kite is bridled as follows: Find a point on the backbone between D and E 4 inches from D, here attach two cords, each 2 or 3 feet long, drop them so that one will be on one side and the other on the opposite side of the wire NP, unite the ends of the two cords, and rig a chafing-gear on the wire NP so that the cords may not be cut. Attach a long single cord to the cords just united. Pull taut and measure off 16 feet 3 inches from the point of attachment between D and E. Call this point on the cord W. Let the cord fall in a bight and secure W to the backbone at A. Now take four or five galvanized-iron rings and fasten them by marline to the cord, the first one about 7 ft. 4 inches from A, the next about 7 ft. 7 in., and so on at intervals of 3 inches. At the end of the line from the reel place a small snap-hook. When this is snapped into the ring 7 ft. 10 inches from A, the remainder of the bridle measuring 8 ft. 5 in., the kite will be bridled as when last flown. Still, no two kites are alike, and it may be that better results will be obtained from a new kite if the snap-hook is fastened to one of the other rings. Be particular to preserve the symmetry in framing and covering, or your labor will be wasted.



TRIPLE MALAY KITE. 1895.

successful aerial machine of the future will be so designed that it may be raised in the air as a kite and while remaining anchored will act as one. It seems to me that the development of the kite must progress further before the correctness or incorrectness of this view can be determined, for we do not yet know the possibilities of the kite.

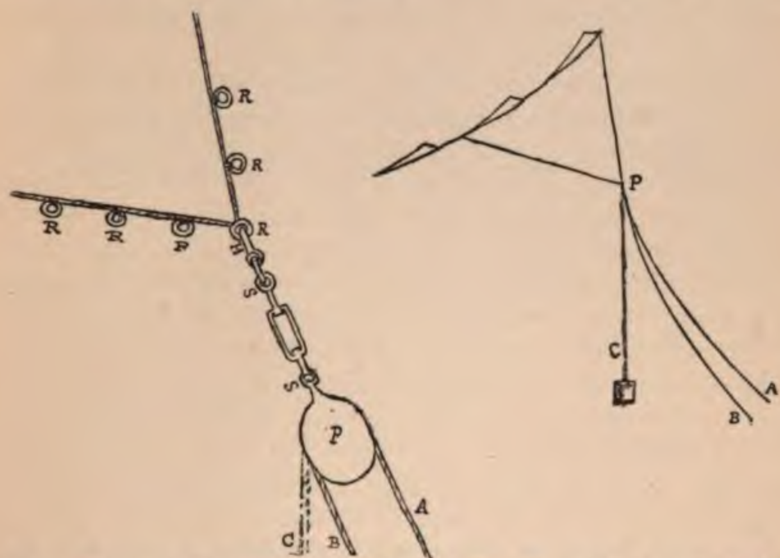


Fig. 4. — H, a snap-hook attachable to any of the rings RRR. SS, a swivel. P, a pulley-block. The kite is raised by the line APB; then weights are attached to B, which is slowly released, the weight swinging free, as shown by the dotted line at C. The weight rises to the kite. Under some conditions it may be necessary to steady the weight by a small guy-line.

It is presumable that the flying-machines of the future will be of various types and various speeds. When we consider the low average velocity of the wind, we are led to think that only low-speed machines will act as kites in ordinary winds. Even if this be so, the practices of kite-designing and kite-flying seem likely to give us useful knowledge.

Mr. A. Lawrence Rotch, the founder of the Blue Hill Meteorological Observatory, shows in another article the great value which kites may have in his line of research.

Still another advantage which may come from the practice of kite-making should be carefully noted. In constructing large kites the difficulties of securing the requisite strength, rigidity, and lightness of framing are precisely the difficulties which, among others, are to confront the designers of flying-machines. Hence it is quite evident that kite men are in a position to give direct aid to flying-machine men by their tests of materials for surfaces, frames, and stays, and of the various methods of light and strong construction.

It is hoped that experimenters, young and old, will be led to compete for the prizes mentioned on another page.[1]

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[1] See article entitled *The Boston Aeronautical Society's Experiment Fund.*

THE MALAY KITE.

By J. B. Millet.

Interest in kite-flying, born a few years ago, grows apace. The printed accounts of elevations reached, or pounds lifted, or wind velocities successfully combated, with comparatively fragile structures, excite the ambitions of many who have formerly looked upon a kite as a child's toy; and with the increasing competition we are sure to get results of great value. Such results will quite as likely be reached by the novice as by the more experienced, provided the former is contented to begin where others have left off in devising a form of kite, rather than pin his faith upon some theoretical structure constructed in an imagination thawed by an open fire on a winter evening. It is this very fact — that the novice may be the more successful kite-flyer — that makes the sport unusually attractive. Once into it he finds it to be a constant fight with the wind, opposing light and fragile forms to wind pressures which are apparently vastly out of proportion. Frequent breakages, inexplicable contortions in the air, eccentric misbehavior under what appear to be the most favorable conditions, all draw heavily upon patience, without which quality in abundance the kite-flyer cannot exist.

After spending a whole day in constructing a tailless kite it is certainly discouraging to see it wrecked in the first strong puff, or dashed to the ground through some mistake in hanging or balance, concerning which there have been until very recently almost no data within reach. Even to-day, after all that has been written on kites within the last two or three years, I should not know where to turn to find, for example, satisfactory answers to these questions:

1. Why does a kite fly without a tail, like the Malay, and what are the best proportions and materials?

2. Why does a Malay kite dart and dive to the ground, and why does it sag slowly to the ground on one side or the other?

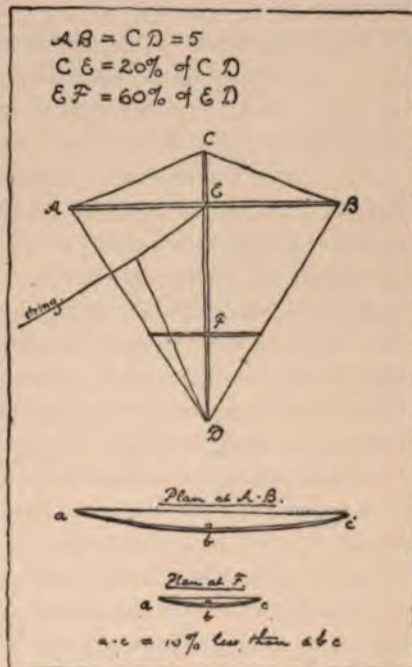
3. Where on the hanger is the proper point to tie on the guy line?

These problems present themselves early in the day, and can only be answered by experience. Theories, in my opinion, seldom "work out" in kite-flying: it is always a question of "try it and see."

Certain facts, however, are now well established by the experience of the many who fly kites, and the purpose of this paper is to set forth some of these facts in order to aid those who wish to make experiments of their own. I expressly disclaim any pretence of being able to solve many of the problems that may arise. An experience of four years has developed a degree of humility in the presence of a well-behaved kite that forbids me to be too sure of anything. There are, however, facts enough relating to structure and probable behavior to give the beginner an excellent start.

To return, therefore, to the three questions above. The Malay, or tailless, kite is selected because it is the best form of flat single plane kite at the present time. There are other tailless forms, but none have been sufficiently tested, and all are in one way or another a deviation from the Malay plan. These deviations waste more time than they are worth, unless the inventor has spent a great deal of time on Malay kites; and beginners are especially cautioned not to waste time and effort on any self-invented or just-heard-of plan, until they have tried a few Malays, and learned from them about what to expect in varying conditions of wind. The beginner not only learns what a kite is, but he gets ideas about the action of the wind, the currents which are affected by the continuity of the land, the position of hills, trees, etc., etc. He will soon realize that the Malay kite is the primer spelling-book and fourth reader in the school of kites. Fortunately its construction is easy, for exact proportions may be had, and if built with ordinary care it flies at once with a degree of success that is almost always improved upon by subsequent trials.

For ordinary use in gentle winds (from four to ten miles an hour), the following measurements will be found trustworthy: The cross-stick AB in the accompanying drawing is bent back (before being tied on the upright at E) until the chord of the arc (in other words, the string to the bow) is 10% shorter than the stick AB. This gives the diedral angle to the kite, which is the first factor in establishing the balance without the use of a tail. The sticks are of straight spruce 5 ft. by $\frac{3}{4}$ in. by $\frac{5}{8}$, or even $\frac{1}{2}$ by $\frac{1}{4}$ for very light winds, up to, say, eight miles. Such kites as these do most excellent work if covered with manila paper of light weight, although I always use thin bond-paper, which is very strong even when damp.



Millet's Modified Malay Kite.

For winds from ten miles up to thirty or thirty-five, the kite must be smaller and the sticks stronger, and the cover cloth instead of paper. Personally I have found that a four-foot kite or a four and a half foot at the outside, is plenty large enough. Kites of this grade must be made much stiffer and of more durable material. The sticks are 4 ft. by $\frac{1}{2}$ by $\frac{3}{4}$, and the covering should be of cloth — any light cloth that is not porous and will not stretch much. Percaline or light cotton-cloth are the best among the inexpensive materials, and so far as my experience goes they give quite as good results as silk. The great advantage in using cloth is that injury to the covering is much less likely to occur, and can be very easily repaired with needle and thread, and the only disadvantage is that it takes longer to sew the cloth on than to paste or glue the paper. The cloth covers invariably fit better, and are efficient for a longer term of life.

The chief strain on the stick CD is backwards at C and D. (We are looking at the face of the kite.) In other words, the stick does not bend back at the point E or *between* E and D, and cannot do so whatever may be the wind pressure, for these reasons: The hanger, as shown, is attached to the upright stick at D and E, and the guy line ties in, as indicated. It will be seen that the upper portion of the hanger is the shorter, and since it is *always more in a direct line with the tension on the kite string*, the main pressure on the sticks comes at E. Sometimes the guy-line tension at D seems to be practically nothing. The pressure at the planes ACB and ADB contributes to this so much that it is wise to make the upright stick a little thicker for six inches above and below E. If AB is so flexible as to bend back in the wind sufficiently to alter the exposed surface much, then tie on an extra piece of the same thickness and about $\frac{3}{5}$ the length of AB.

The second reason why both sticks at the point E should be stronger than elsewhere is that the lower planes AED and BED always form "bags" and at once bring a strain on the side strings AD and BD, which strain bends the upright back from the point E. The attachment of the hanger at the point E makes very little difference to the upright stick.

All this description is necessary in order to arrive intelligently at one of the weak points in kites of this description (single plane), and the one factor which gives so much trouble and is the cause of nine-tenths of the disasters to Malay kites; namely, the side strings *CADB* to which the covering is attached. In my own experience with something like forty kites, I have had only one stick break in the air, and that was the upright at the point E. All other sticks have been broken by carelessness in starting or landing the kite. The side strings, however, have certainly given trouble by stretching or breaking, developing a weakness which no one suspected for a long time. The importance of this weak point, I am ashamed to confess, I did not discover until my third year, although I had ample opportunity. Iron wire, steel wire, and very large cord have all given way under high strain before any other part of the same kite, and nothing has yet been found which brings the strength of this feature up to an equality as the others. It can be approximated sufficiently well for kites to be used in winds up to twenty-five miles by using twisted picture-cord of brass or iron.[1]

Kites of this description will fly without a tail, provided the kite balances along the line CED when held up by the finger at some point on the hanger. If either side is heavier than the other, tie a small piece of wood on the cross-stick until balance is secured; provided, also, that the planes above the cross-bar are properly proportioned (as above described in measurements) to those below. As long as these proportions are maintained, the kite flies; when they are disturbed by the stretching of any side string at any point, there is disaster in store. A very little stretching in a high wind will render the best kite useless, but may be tolerated in winds of low velocity, or even remedied for some time. The common symptom is best described by "sagging" — when the kite slowly sinks to the earth sideways. This is due to one of two causes: Either (1) the slight stretching of a side string in one of the lower planes (which, if considerable, results in diving); or (2) the undue flexibility of the cross-stick on the right or left of E. If due to the first, the kite sags to or towards the ground on the opposite side; if due to the second, it sags to or towards the ground on the same side — the reason being that the uppermost plane, which retains its original efficiency, dominates the other, which has become weaker, and forces it to the ground.

The remedy for stretching is to overhaul the side strings, and, by careful measuring, restore the proportions. The remedy for

([1] In speaking of a kite that will fly in a wind of twenty-five miles I mean one that will continue to do this on various occasions — not one that has been ruined on the trial.)

undue flexibility on either side of E is found in tying on a bracing-stick at the weak point, extending it a little beyond E. In most cases of fairly high winds the disturbance of "balance" of the two sides along the line of the upright may be disregarded, since the resistance to the pressure of the wind has been equalized, and it has been found that slight differences in balance are not noticed in high winds.

Darting about without diving to the ground means simply that the sticks are bending to the puffs, and, if the kite persists, the sticks must be braced by tying on extra pieces.

As regards tying the guy line on to the hanger: I have, in the past, obtained, from several directions, various measurements, and have found that all of them will work under certain conditions peculiar to certain kites. No rule can be given which will apply alike to all Malays. It depends upon the centre of gravity of the kite, which differs in each case, and upon the flexibility of the sticks. It is evident that, since the sticks bend in the wind, some more, some less, and that, since the upright stick bends backward at D, the angle made by the hanger and flying string will change as the point D moves. Therefore, since the angle changes, no rule can be given. The only sure way is to proceed as follows: Place the kite on the floor, face up. Try lifting it by the hanger at some point until you find a place which will raise all four of the ends of the sticks from the ground at the same time. Find ten per cent. of the distance to E from that point, and tie the guy line on at that point. If the kite will not rise, move the tying-point nearer E, one-quarter of an inch at a time, until the kite begins to dive. You are then too high. Moving the tying-point up or down less than one-quarter of an inch will frequently mend or mar matters. Once found, mark it with a colored thread and needle.

After the tying-on point has been once established, no further experiments in that direction will ever be necessary with that kite unless something happens to disturb the proportion between the areas above the cross-stick and those below it. Whenever that occurs (as by stretching of side strings — by far the most common cause) the remedy is to be found in overhauling the edges, measuring and comparing the edges of one side with the other. Once corrected, the kite will fly again. Therefore, do not experiment with the tying-on point, when once satisfactorily fixed, in hopes of remedying any defects which the use of a kite develops.

As to size, the temptation to make larger and larger kites is quite natural, but kites not exceeding five feet are by far the most useful if one wishes to study kites and wind; if, however, flying for sport is paramount, then every one must find for himself the limit of size. It is only necessary to remember that a long stick is more flexible than a short one, and that stiffness rather than flexibility is what is wanted.

Those who wish to have a battle royal between a strong Malay and a small gale will find it advantageous to add another cross-stick as shown in the illustration. This stick stiffens the edges at the point where they are weakest, compels the kite to retain its shape, divides the pressure brought upon the upright stick by the side strings (always a great element of danger), and for these reasons makes the kite much more efficient in high winds. The illustration of the Malay represents a kite with which for nearly an hour I obtained in a wind of 35 miles a very remarkable record, but the kite was so badly stretched in doing it that I abandoned this form for very high winds and adopted the Hargrave. Still the experiment was very useful, and, in my opinion, all Malays intended for winds over 15 miles should be made that way. The cross-sticks and uprights were of spruce, 4 feet by ¾ inch by ½ inch, and lashed to them with small tarred marline were split bamboo sticks, one for each, of the same length. This gave me very heavy, but very stiff sticks. The side lines were of iron wire, No. 20, afterwards abandoned for blocking-cord, which, when shellacked, stretched but very little and broke at 75 pounds. Even this was none too strong. The cover was heavy cotton drill, and the complete structure weighed a little over 3 pounds. At an angle of 40° it pulled from 8 up to 48 pounds repeatedly — wind as above mentioned (35 miles) — and then unexpectedly dove and swooped to the right, carrying away two lightning rods on its way. Upon examination I found every measurement distorted, everything stretched out of shape, and nothing but a complete overhauling could make it fly again. The sticks were intact. It was merely a case of stretching all along the line until all those proportions upon which a good kite depends were lost. If any material can be found which will not stretch when cut on the diagonal, and which will not form too deep "bags" under heavy wind pressure, a kite of this plan could doubtless be made of great service, but it demands a very strong wind.

NOTE. — These experiments were conducted at Sharon, Mass., during the summers of 1892–95. Those described in the following article during August and September, 1895.

SOME EXPERIENCES WITH HARGRAVE KITES.

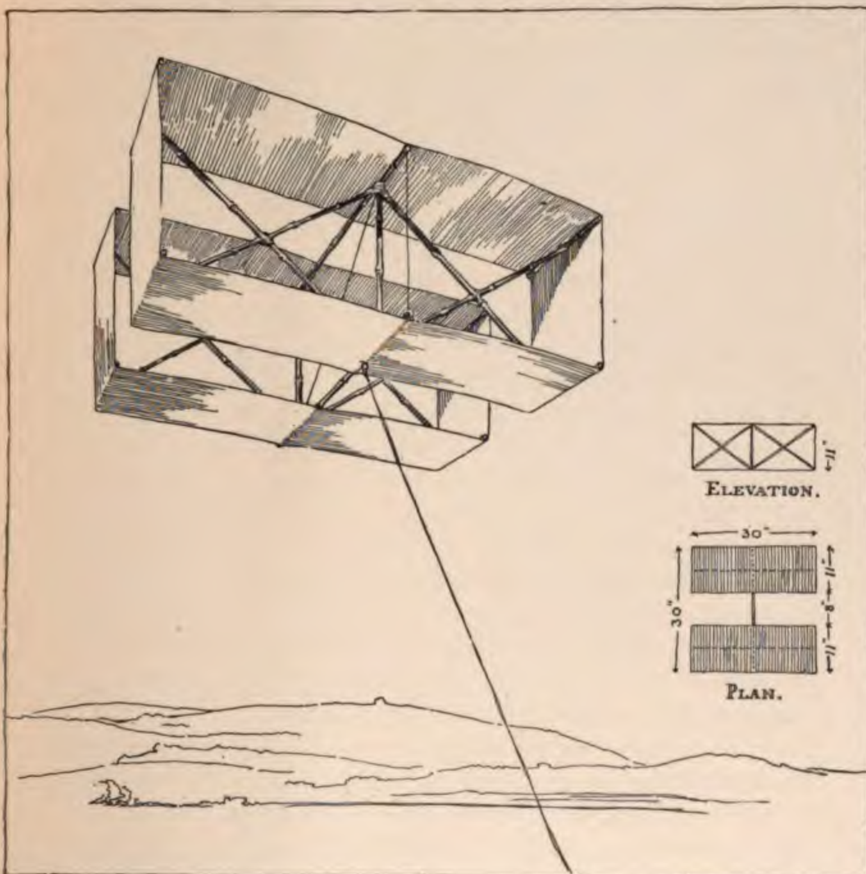
By J. B. Millet.

After spending three summers in making, breaking, mending, and rebuilding Malay kites, always with an increasing enjoyment and accumulation of information, I found myself forced to the conclusion that Malays are not serviceable enough in winds from 15 miles an hour up. To be sure, they will fly in winds of 30 to 35 miles, and will frequently hold together for several severe trials on different occasions, but their efficiency in strong winds (20 to 35 miles) is much less than it should be in proportion to the exposed area. Moreover, this efficiency is rendered less trustworthy for scientific purposes, because, as the wind increases, a Malay nearly always develops eccentricities which are not apparent in a wind of less velocity; as, for example, darting from side to side, or "sagging," or sinking to the ground. Sooner or later, as the wind rises and becomes a small gale, something happens to make the kite practically useless, or which demands tinkering. Either the side strings stretch, or a stick breaks, or some stick bends too much, and so destroys the balance.

It was with considerable reluctance that I abandoned the Malay for use in high winds, and in the face of predictions that I would regret it, from kite-flyers whose knowledge, based on experience, I respect; but after having made and tested Hargraves, of very large and quite small dimensions, I reassert my belief in them with absolute confidence. I tested, on one occasion, a Malay weighing nearly 1 lb., having an area of 8 square feet, against a Hargrave weighing 1½ lbs., having a total area of a little less than 10 square feet, in a wind of 20 to 25 miles. The Malay, at an angle of 45–50 degrees, pulled from four to nine pounds; the Hargrave, at the same angle, pulled from six to seventeen pounds. The lift is easily calculated. The Hargrave was perfectly steady all the time, and required no attention; whereas, the Malay, although in perfect condition, needed more or less looking after nearly all the time.

This test was followed up by others almost daily, until from a mass of results there was no escape from the conclusion that the Hargrave was the steadier, the less likely to break or lose its shape in the air, and — what is more important — lifted much more per square foot of lifting-surface. What is needed is a kite that can be anchored in the wind and left there without fear of disaster from considerable increase in velocity, and that will fly steadily and will not demand constant mending or balancing.

Such a kite I found the Hargrave to be. Its steadiness is most remarkable — provided, of course, the kite is made with care. After reading something of Hargrave's results, and with his measurements in hand, one is tempted, quite naturally, to try and improve on Hargrave's plan, either by altering the shape of the "wings" or the position of the side planes which act as fins to keep the kite in the eye of the wind. Doubtless some improvements on Hargrave's best device will be made by such experimentation, but in my opinion it is better to begin exactly where Hargrave left off, and make your first superimposed plane kite as exactly as possible on the proportions of his measurements. Two kites of whatever plan, made as nearly alike as possible, will no more act exactly alike than two cat-boats made from the same model. Therefore it follows that the disciple of Hargrave may, by using the same measurements, be so fortunate as to excel the best efforts of the inventor himself. Experimenters with kites owe a large and rapidly increasing debt to Hargrave for this invention, and the least we can do is to acknowledge it on all occasions. His kite is an absolute departure from all previous forms, and is by far the most efficient and durable; but it is not for very light winds. It demands winds of twelve to fifteen miles upwards, for although light kites of this form can be made which will fly in winds of lower velocity, they are too fragile to last. The form of the kite demands stiffness both in sticks and covering, which quality deserts us when we endeavor to introduce extreme lightness.



THE HARGRAVE KITE.

Drawn by an Expert.

It will be found upon making a Hargrave that the time and labor spent are far greater than would be required to make several Malays; but in the end there is ample compensation, for the Hargrave does not require constant mending; the parts most frequently broken are very easily replaced; and the whole structure is neither thrown out of balance, nor does it require rebuilding. If the upright or cross stick of a Malay breaks, the repairing practically amounts to making a new kite. There is no breakage in a Hargrave which compares to this.

The thoroughly interested kite-flyer will supply himself with two or three Malays (say 4 or 5 feet tall) for light winds, and the same number of small Hargraves for heavier winds. In flying tandem they may be used together, and it will be found that the Malays are of great assistance in supporting the Hargraves in case the wind suddenly decreases below that velocity which the Hargraves require; whereas, if the wind increases beyond the point of efficiency for the Malays, they simply circle about or sag (as long as they hold together), and the Hargraves pay very little, if any, attention to them. In my opinion, therefore, a combination tandem team is the best one for most purposes, and especially whenever the wind is uncertain or likely to decrease. With the certainty of a heavy wind, a team of small Hargraves will give one or two active men their hands full. By small Hargraves I mean kites of the following dimensions, which I have found to be the most useful, all things considered. All mine were built on the proportions given by Mr. Hargrave in his published accounts, and varied in size from 8 feet spread and depth, down to 30 inches. The largest turned out to be practically useless, unless I had one or two men to assist, on account of its enormous strength. It was very difficult to find the exact point of attachment, because it could not be readily and safely controlled during experiments. The same proved true of all the others, down to what may be called the "three-foot limit." Here I found the most convenient and most useful size, the dimensions of which are given.

It has come to my knowledge that others beside myself were confused by the terms employed by Mr. Hargrave in referring to "height, depth, and width" of his kite. It was difficult to be sure of his meaning without constant reference; therefore I have in correspondence with others recommended the following terms: "Spread" means from tip to tip of the cell (just as in the case of a bird's wings), "depth" means distance from the front to the rear of any cell, while the length of the "main booms" gives the depth of both cells and the distance between added together, or extreme depth of the whole structure; "height" of a cell is, of course, the third and last dimension, and is, in fact, the height of the kite itself as it lies on the ground.

It will be found wise in three-foot cellular kites, or less, to depend entirely on lashings with waxed shoe-thread, and not to make any nail or screw holes. After the frame is put together before sewing in the cover, paint all the lashings with liquid glue, saturating them thoroughly. This adds very much to their strength and stiffness. My smallest kite is made in this way, and although it weighed but 1½ pounds and exposed to the wind four planes (two in each cell) 30 × 11 inches, it safely out-weathered many severe blows (the highest exceeding 35 miles an hour) and is still in good order. The only break was one of the side sticks, which was repaired in a very few minutes. The cover has stretched some, but without affecting the flying qualities to any great extent. This kite, in a wind of 18 miles, up to 35, would easily carry a thermograph weighing three pounds. The best altitude for a period of thirty minutes maintained by this kite was 1,600 feet, with a wind of 18 miles. There was exactly 2,600 feet of large cord out (breaking at 100 pounds — far heavier and stronger than was needed, but no other was convenient), and the angle was greater than 45° for half an hour.

The best material for sticks is small stiff bamboo, while the cover can be made of very thin cotton cloth or percaline. After the cloth is on, and the kite has been found by trial to fly all right, the cloth should be thoroughly saturated with starch made up with benzine so that it will dry quickly. Do not use pressure, as you will be likely to stretch the covering. If put on with a wide brush it will cover evenly enough. It should be dried in the shade. When dry the cloth will be very stiff, and the bending back of the front edges (especially of the fins) will be very largely prevented; while the supporting planes will be much less likely to form pockets and thus increase the drift.

These kites often develop a tendency, especially when first flown, to "sag" down towards the ground to the right. Just why they sag to the right I am unable to say, but the fact is that every one I have made has always sagged to the right and never to the left, which is doubtless a coincidence, but may be due to something unknown to me. This sagging occurs before the cells have been adjusted; in other words, unless the kite flies all right, this sagging is most likely to be the cause. It means that the side of the kite nearest the ground is of weaker efficiency than the other, and is therefore borne down. In a gale which is beyond the strength of one of these kites, it yields to the pressure by "sagging" until it comes to the ground. This may be remedied, up to the limit of the strength of the materials used, by stiffening the weak sides. This is best done by bracing the string — carrying short pieces from one of the diagonals forward to some point on one of the booms. Try the rear cell first, as this particular weakness seems to be developed there oftener than in the front cell. If bracing with string does not remedy the trouble, hunt for a weak point in some diagonal or side stick on the side of the cell.

It will be found sometimes that the side stick bends under pressure, and tying on an extra piece (small, but quite stiff) outside of the cloth will often end the trouble. Once balanced, your troubles are fairly well over; for the kite may be depended upon to behave itself for a long time to come.

The selection of bamboo, the lashing of joints with waxed shoe-thread, and painting on a thick coating of liquid glue afterwards, proved to be most fortunate. The strength of this method of construction far exceeded my expectation, while the rigidity of the kite when flying in a wind of 30 to 35 miles was eminently satisfactory.

It will be noticed by reference to Plate XIII. that the spread and extreme depth (or length of the main booms) are but 30 inches, and the height 11. These dimensions are on so small a scale as to make the kite appear *before trial* to be more of a toy than a useful scientific structure, but my experience proves that this size is by all means the most useful for all purposes except the lifting of heavy weights. In order to try to lift a man we could do no better than follow in Mr. Hargrave's footsteps, but when trying to reach as high an altitude as possible with, say, 3 pounds' weight (representing the thermograph), our problem is quite different. I have on several occasions had this small kite out with 2,640 feet of cord, and it frequently assumed an angle exceeding 55°, with very little "bagging" of the string. In all cases I used string twice as large and heavy as I otherwise would have, had not the position of the kite been over a swamp several miles in extent and I feared some unexpected break. Considering this particular kite as in all respects the best one I had made or seen, I was anxious to save it for a working basis. Regarding it more as an experimental kite which I was quite prepared to see blown to pieces, I did not use that care in the selection of bamboo sticks which I would again. It is not difficult to obtain sticks three feet long that are nearly the same diameter throughout. The side sticks (one in each corner of each cell) should be as stiff, but light, for if heavier than need be they act as weights held out at the end of the diagonal sticks, and bring an unnecessary strain on all the parts.

As regards fastening the guy line to the kite, the proper point is in most cases near the rear edge of the forward cell, but the centre of gravity of the kite determines this, and if this point can be fixed a little forward of the edge the kite will take a better angle. It will be found convenient to lash a small brass ring at this point and fasten a small snap-hook on the end of the guy line. Always hem both edges of the cloth and sew it with a waxed thread wherever it touches the bamboo frame. Measure every distance with care, so as to have right angles at all the corners and no variation in the area of the cells. Special care should be used to secure a balance of area and weight along the line of the main booms, so that the areas on one side will be exactly the same as on the other.

WORK ON THE GREAT DIAMOND.

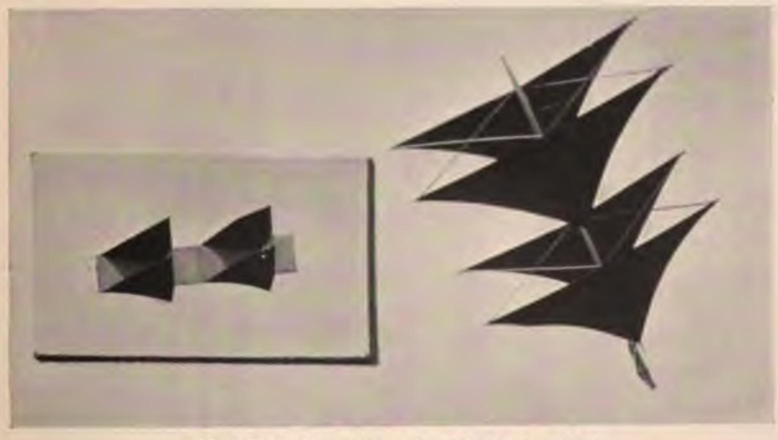
BY CHARLES H. LAMSON.

HAVING an interest of long standing in aerial navigation and also incidentally in kites, when the 1895 April number of the "American Engineer and Railroad Journal" came to hand, describing Mr. Hargrave's latest box or cellular kites, I determined to make one. This kite, with some modifications of my own invention, has been about the most successful of any I have flown this year. The dimensions of my kite were as follows: Length of each cell, fore and aft, 25 inches, which was the full width of the black cambric cloth used for a covering. A narrow hem strengthened the selvage edge. Breadth of each cell, 6 feet, depth, 2 feet, distance between the cells, 4 feet 4 inches, making the full outside dimensions of the kite 6 feet wide and 8 feet 6 inches in length. Material of frame, straight-grained American spruce. The dimensions of the two strips constituting the backbone were $\frac{7}{8}$ by $\frac{1}{2}$ inch. The cross-braces for the cells were made elliptical in section, sharp edges exposed to the wind. Size of section, $\frac{7}{8}$ by $\frac{3}{8}$ inch. The outer corner pieces were tapered from the centre, one inch, to a quarter inch at the points. These were attached to the braces at the required angle by hinges of thin sheet brass. The other ends of the braces were simply notched to press against the corner of the backbone. This method was quite satisfactory. The two under pairs of braces were made four inches shorter than the ones that braced the upper corners, so as to give the cells a slight dihedral angle when placed in position for flight. This seems to me to be of some advantage in preserving the lateral stability of the kite. The cell frames were so made as to give the under sides of the covering a concave surface of $\frac{5}{8}$ of an inch in 25 inches. This kite having so much surface exposed to the wind, 50 square feet, was a very hard puller and uncomfortable to handle in a strong breeze. The writer therefore gave his attention to devising some arrangement whereby undue wind-pressure might be relieved and the kite flown with less danger of breaking away. To effect this purpose the two spars connecting the ends were cut near each cell and jointed so that the angle of the cells, in relation to each other and to the wind, could be changed at will. Two cords were used to limit and adjust this motion. The rear cell was weighted with a half pound of lead and the cells were rigidly fastened with both cells at an angle of about 10 degrees to the backbone. An extension or bowsprit, about 20 inches in length, was added to the lower side of the front cell, and the flying-string was then attached to the extreme point of same. This arrangement proved to be very successful, the pull immediately becoming so light that the cord could be held in the hand even in a high wind. Thus modified, the kite has never shown the slightest tendency to dive or to tip sidewise when flying, or when coming down after it has broken loose, always preserving an even keel and sailing away with a steady, majestic motion like a balloon, and landing softly on the ground without much injury to the kite. A neighbor and friend, Mr. Edward Rogers, becoming interested, was of material assistance in these experiments.

Our kite floating at a good angle with all our available string, we determined at a future trial to see if we could not let out a full mile. For this purpose I ordered from the Pawtucket Braided Line Company 6,000 ft. of No. 2 braided cotton fish-line, which was furnished me without a knot, on a spool. After one or two attempts with insufficient wind, we at last had a perfect day for the test, the wind blowing steadily about 15 miles an hour. The loose edges of the kite shaking badly in the wind, they were stiffened by tacking in 8 thin, light spruce strips which we had provided for the purpose. Then getting our reel into position and bracing the cells in line, everything being in readiness we allowed the kite to go up. It sailed away like a soaring bird, and rose as rapidly as we could let out the

LAMSON'S MODIFIED HARGRAVE KITE.

For working drawings, see Plate XV.



LAMSON'S MULTIPLANE FOLDING KITE.

The larger view shows the Kite being towed by a steamer. The smaller is a side view of the same Kite. Length, 12 feet; Width, 7 feet.

For working drawings, see Plate XVI.

string. The large black boxes of the kite were nearly out of sight when it reached its full limit. After the 6,000 ft. was all reeled off it flew at an angle of about 40 degrees, and probably would have carried up more line if we had possessed it. For added safety a short piece of strong, elastic cord was sandwiched in next the kite. This event was much enjoyed by a large number of spectators, who assisted in winding in the cord. At no time was the pull so strong that the cord could not be easily held in the hand. This experiment took place at Great Diamond Island in Portland harbor, and after drawing in the kite to within about 300 feet of the ground, in order to test its capacity for being towed, we took our apparatus aboard the steamer homeward bound, with the kite still flying in the air. Taking our position on the deck, abaft the smoke-stack, we succeeded in making the roundabout trip to the city without any trouble; the steamer meanwhile turning to all points of the compass in making stops at her landings. We were able to go ashore at the city before hauling down the kite and closing our day's sport.

The Multiplane Folding-Kite. — Finding most kites rather troublesome to pack for transportation, the writer has invented a kite with triangular sails, having the frame jointed so that the sails can be folded back against a central keel. The sails are also adjustable in angle. There are eight of these sails superposed in pairs, two at each end of the keel, or backbone. The arms present sharp edges to the wind. The keel is also jointed at the centre. By folding the sails back, disjointing the keel, and putting the two parts side by side, a large kite can be slipped into a paper or cloth bag, making an unobtrusive package, easily carried under the arm. It is only a minute's work to set the kite up again, and it rises readily from the ground in a fair breeze. Little or no running is necessary to get it up. One of these kites, made of different-colored materials in cloth or paper, presents a most striking appearance in the air.[1]

[1] This kite being so complicated, it is hardly to be expected that many amateurs will care to take the trouble to make one, and, believing that the cause of aviation would be

HINTS TO KITE-FLYERS. — To avoid disaster, kite-flyers should always select a large, level, clear space for their experiments, and away from any houses and trees, which create eddies and currents very dangerous to kites. The seashore with a sea-breeze is the ideal place. There are sometimes downward currents of air which may be avoided by a change of position, so, if there is any wind, do not be discouraged if you do not get the kite up the first time, but select a new spot and try again. Have good cord of ample strength. Beware of hard-twisted line. It winds up and kinks in damp weather. Sometimes the line may be doubled to advantage. It is well to lay out enough string so that the first start will bring the kite well above any elevations in the neighborhood, and into a steady current of air. Be careful to lay your string out exactly against the wind, not across it. If a kite shows a tendency to dive, let out quickly enough string to allow it to take a floating position, and then it may be raised again, or it will come down to the ground gently, when the cause of diving should be investigated. An elastic cord next the kite end of the string is often an advantage to prevent breakages in gusts. Court plaster is very convenient for making quick repairs to the kite fabric.

In the writer's experience, large kites are more satisfactory than small ones. Often a kite which would be very difficult to fly, of the toy size, gives no trouble when made above six or eight feet in diameter. It would seem that the larger surface bridges the small pulsations of the atmosphere, and the added weight tends also to stability. A toy boat tosses about on the least ripple of the water, while a larger vessel would ride steadily.

LILIENTHAL APPARATUS. — After a limited experience in trying one of his soaring-machines, Lilienthal's apparatus seems

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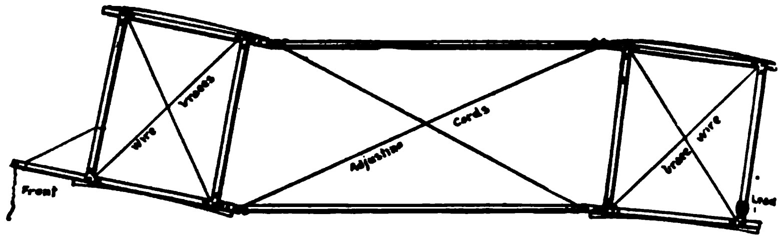
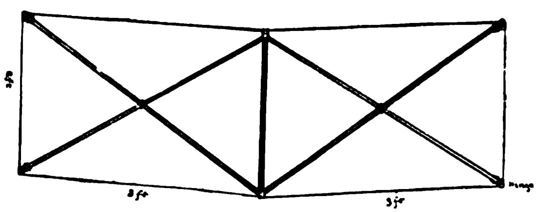
advanced by having them on sale, the writer has applied for a patent, and will have them made for the market for the summer of 1896. It will be called Lamson's Multiplane Kite. The writer has no objection to any experimenter making one of these kites for his own use, should he prefer to do so. Address C. H. Lamson, 203 Middle Street, Portland, Maine, U.S.A.



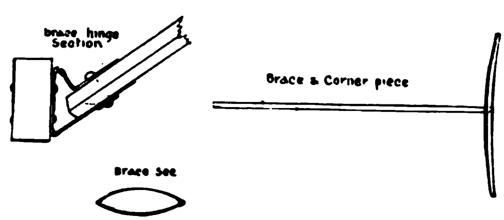
SIDE VIEW OF CENTRAL FRAME OR BACKBONE.

UNDER SIDE OF THE SAME.

CROSS SECTION

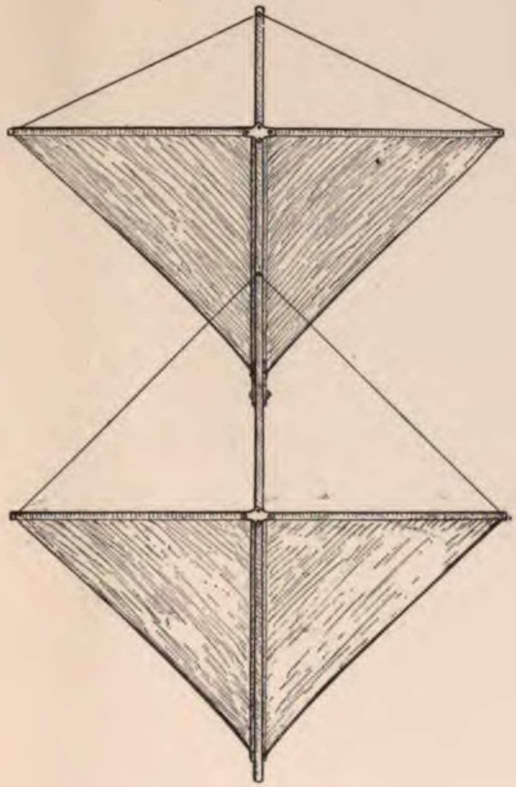


OF EACH CELL.

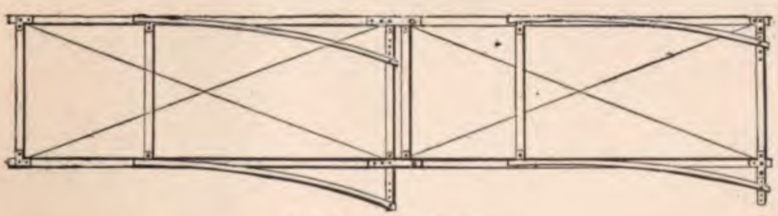


WORKING DRAWINGS OF LAMSON'S MODIFIED HARGRAVE KITE.

See perspective view in Plate XIV.



TOP OF KITE—OPENED.



BACKBONE—SIDE VIEW.

WORKING DRAWINGS OF LAMSON'S MULTIPLANE FOLDING KITE.

See perspective view in Plate XIV.

to the writer to have a number of serious defects.[1] First, it is too difficult of control for the average operator, when in the air. Second, it has no elastic rear edges to assist in forward propulsion. Third, the ribs and frame-work, as well as the body of the operator, present a too large and too rough surface to the air, impeding the necessary forward motion against the wind. (A bicycle rider soon learns by experience what a powerful effect even a moderate wind has in making his progress laborious.) In using the Lilienthal apparatus, the experimenter is soon assured of the ample supporting effect of the air, but the novice feels quite helpless to guide the machine. It is also very difficult to get a good send-off. As Lilienthal says, "Confidence and skill must be acquired by *much* practice."

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[1] At the time of writing, perhaps Mr. Lamson had not seen Lilienthal's latest design. The next will probably be better, and so on. *Sic itur ad astra.* — *Ed.*

MATERIALS USED IN KITE EXPERIMENTS AT BLUE HILL OBSERVATORY.

By S. P. Fergusson.

One season of a few months is hardly sufficient for more than a beginning in the experimental study of kites, and the work at Blue Hill has consisted mainly of practical tests of materials used in the construction of kites. Some experiments have been made with four different types of kites, but the Malay or Eddy kite has so far received the most attention. The object of all the experiments has been to design a kite suitable for elevating meteorological instruments, and most of the kites made have been small and light, since the weight to be lifted is small. Hence, the conclusions set forth should be understood as concerning meteorological work rather more than aeronautical.

The essentials of a good kite are that its frame should be of strong, rigid material that is very light, and that the covering should be light, impervious to air, and smooth, so that the air may slide off the surface with very little friction; also, it should be made of material not liable to stretch while being used.

For frames both wood and metal are recommended, and for ordinary use in fine weather frames made of spruce are very satisfactory. Spruce is used almost exclusively at Blue Hill, care being taken to select straight-grained wood free from knots or other imperfections. Some expeiiments were made with umbrella ribs, but these were found to be less rigid and much heavier than spruce; also, much more time was necessary to construct the frame of umbrella ribs.

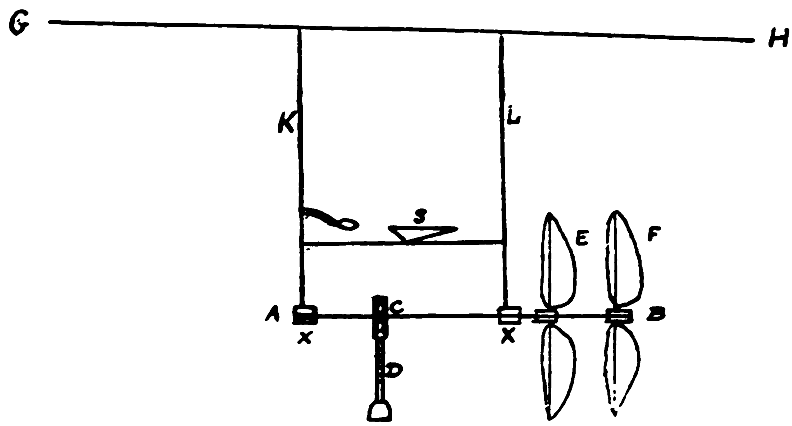
For covering kites both cloth and paper can be recommended. The advantages of paper coverings are their smooth, impervious surface, small liability to stretch, and the ease with which they can be made or repaired. Paper is not very durable, and is very easily torn or punctured. For covering the largest kites, only tough paper, such as heavy manila or bond writing-paper, should be used. The bond paper is almost as strong as manila, and is much lighter, though perhaps more easily punctured. It is perhaps more expensive than other papers, but its advantages more than compensate for this, and it can be recommended as one of the best materials for covering kites. Cloth has the advantage of being very durable, as it is not easily torn or punctured. Its disadvantages are its liability to stretch, its rough surface, and that it is not impervious to air. The first defect could perhaps be overcome by stretching the cloth before use, and the other two defects by varnishing it, which renders the surface both smooth and impervious to air. Cloth is generally heavier, and the best varieties for use, such as silk or nainsook muslin, more than twice as expensive as paper. It also requires more time for perparation than paper. When experiments are made in rainy weather, or kites are sent up into clouds, it is necessary to use cloth, because it is not injured by moisture. As stated, silk and nainsook muslin gave the best results for cloth kites at Blue Hill, though in large-sized kites unbleached sheeting has also worked well. Tracing-cloth appears to have some advantages for covering kites, as it is very smooth, light, and strong; but it is affected by moisture, which dissolves the smooth varnish with which it is coated, and hence renders it untrustworthy in rainy or wet weather. Experience with both paper and cloth coverings shows that with paper coverings the angular height of the kite is much greater, and the lift, or "pull," upon the string also greater than in case of the cloth kites. Kites covered with cloth are usually steadier than those covered with paper.

The best kind of cord for use in kite experiments is a close-twisted linen line. Shoe thread used for stitching soles is much stronger than any other cord in proportion to its weight, but being loosely twisted it is not nearly so durable as the close-twisted cords. Blocking-cord (used in blocking hats) is used almost exclusively at Blue Hill. This cord is of linen, and the sizes range from Nos. 9 to 32, No. 9 being the smallest, with a weight of about 5 oz. per 100 feet, and breaking at 75 to 90 lbs. No. 12 breaks at 120 to 125 lbs. and weighs 6 oz. per 100 ft.; No. 16 weighs 7 oz. per 100 feet, and breaks at 135 lbs.; No. 20 breaks at 155 lbs.; Nos. 28 and 32 did not break at 210 lbs. (the limit of the testing scale). The weight of No. 32 is 13 oz. per 100 feet. The cable-laid twines are also very good, the largest size, No. 48, being about equal to No. 9 blocking-cord in strength and durability. The cords described lose very little of their strength after long use, unless they become abraded; and are recommended as the best for general use. The success with which pianoforte wire has been used in deep-sea sounding indicates that it may be very useful in kite-flying when great altitudes are desired. Single pieces of 5,000 feet or more in length can be obtained, and the weight of wire capable of sustaining 200 lbs. is only one-half that of cord of the same strength. A sample $\frac{3}{64}$ inch in diameter and 25 feet long did not break with a strain of 210 lbs. This sample weighed 6 oz. per 100 feet. The cost varies with different manufacturers, but is generally nearly the same as that of cord of the same length. In the use of wire, great care is necessary to prevent rusting, which soon renders it useless; also, it must always be kept under strain to prevent kinking. The success of experiments depends greatly upon the condition of the line; and whether it is of cord or wire, frequent inspection is necessary. Mr. Eddy recommends, for safety, that all splices in the cord should be replaced by knots, and that the average working-strain of the line should not exceed one-fourth the breaking-strain of the cord used. Experience at Blue Hill tends to confirm this. In joining the ends of two cords the "surgeon's knot" alone should be used, as there is then no danger of the line parting when under variable strains.

SCREW PROPULSION BY FOOT-POWER.

By Samuel Cabot.

THE device I am constructing for propulsion by ariel screws is especially intended for utilizing the force of the legs as in the bicycle, but may be applied to the motion imparted by an explosion or steam motor, utilizing the reciprocating movement of the piston much as the push of the leg is applied to the treadle of a wheel. The machine is shown by a sketch in which GH represents an aeroplane fastened to upright hollow pipes



KL, at the bottoms of which are the ball-bearings XX, which carry in them the shaft AB. Upon the light shaft AB, preferably hollow, which lies in the direction of the propulsion desired, is rigidly fastened a sprocket wheel C, of as small dimensions as is compatible with the size of the shaft. Over this a sprocket chain D is passed, at each end of which a suitable stirrup is provided, into which the operator's foot is placed, the seat being shown at S.

It is now obvious that if the operator's feet are raised alternately straight up and down, the shaft will turn several revolutions to the right, and then an equal number to the left.

The two propellers or screws are placed behind the operator and close to the end of the shaft, but at a distance from each other at least as great as the width of the blades. These propellers are provided with two or more blades, and are of very light construction, but strong and stiff. They are of exactly the same construction except as to pitch, which is left on one and right on the other. They fit upon the shaft with suitable ball-bearings, allowing them to move around it very freely in one direction, but a friction clutch is so contrived that the left one is prevented from moving to the right, and the right one is in a similar manner prevented from moving to the left.

It will now be seen that at each push of one foot the shaft actuates one of these propellers, while the other continues to move in the opposite direction until its momentum from the last stroke of the opposite foot is exhausted. This exhaustion of the momentum, however, need not occur before the next stroke of the same foot comes and again adds to its momentum. The result is thus a constant or nearly constant motion of the propellers in opposite directions. As the pitches of the propellers are also opposed, the action upon the air is therefore constantly in one direction.

The objection to a single propeller, viz., its reaction, tending to turn the whole kite or aeroplane in the opposite direction, is obviated, as the reaction of the two propellers is equal and opposite, thus balancing each other. We thus have a single shaft oscillating by the action of the legs, much as in some of the old forms of bicycle, such as the "Star," and producing an almost constant motion of two propellers in opposite directions.

BIBLIOGRAPHY OF AERONAUTICS.

Continued from The Annual for 1895.

W. H. Kühl (*Jagerstr. 73. Berlin, W.* — Germany) has published a pamphlet of 50 pp., entitled *Aëronautische Bibliographie. 1670–1895.* Price 25 Pf. Important.

Congrès de l'Atmosphère, organisé sous les auspices de la Société royale de Géographie d'Anvers, 1894. Compte-rendu par le Chevalier Le Clément de Saint Marcq, Secrétaire Général. Anvers. Imprimerie Veuve de Backer, Rue Zirk, 35. 1895. Part VIII. of this report contains the following: *Contribution à la Bibliographie de la Locomotion Aërienne par Armand Wouwermans. I. Écrits primordiaux. II. Allemands. III. Anglais. IV. Français. V. Italiens, Espagnols, Portugais. VI. Néerlandais. VII. Scandinaves. VIII. Russes. IX. Collectifs, périodiques, etc. X. Accessoires.*

This is a very valuable contribution to the bibliography of aeronautics. The compiler's search has evidently been most careful and thorough. More than five hundred titles are given. The pamphlet contains 272 pp., of which 36 pp. are devoted to Part VIII. Price not given.

In the *American Engineer and Railroad Journal*, from October, 1894, to August, 1895, inclusive, there will be found under the heading "Recent Aeronautical Publications," a series of valuable lists. M. N. Forney, publisher, 47 Cedar street, New York.

The Annual Reports of The Aeronautical Society of Great Britain (Hamilton & Co., Paternoster row, London) contain lists of "Books, Pamphlets, etc., Received."

Zeitschrift für Luftschiffahrt. Monthly. Mayer and Müller, Berlin.

L'Aëronaute. Monthly. Paris, 91 Rue d'Amsterdam.

L'Aërophile. Monthly. Paris, 113 Boulevard Sébastopol.

Aeronautics. Monthly. Published from October, 1893, to September, 1894, inclusive. Complete sets of 12 nos., $1.00. M. N. Forney, 47 Cedar street, New York.

Taschenbuch zum praktischen Gebrauch für Flugtechniker und Luftschiffer. Edited by Capt. H. W. L. Moedebeck. Published by W. H. Kühl, *Jagerstr. 73. Berlin, W.* — Germany.

Century Magazine, New York, January, 1895. "A New Flying Machine," by Hiram S. Maxim. This article should be read in connection with Mr. Maxim's article in this number of the Annual.

Harper's Young People, New York, January 29, 1895. "The Building of Modern Wonders; the Flying Machine," by Hiram S. Maxim.

See list of works mentioned by Mr. Chanute on page 61 of this Annual.

Within the present limit of space, long lists cannot be given; the student who follows up the lines of search suggested above will find himself in the way of reading a very large amount of material.

There are two books which should be owned by every one who wishes to understand the aeronautical work which is now being carried on; they are:

"Progress in Flying Machines," by Octave Chanute. Published by M. N. Forney, 47 Cedar street, New York, 1894. $2.50.

"Proceedings of the International Conference on Aerial Navigation." Held in Chicago in connection with the World's Fair, Aug. 1, 2, 3, and 4, 1893. pp. 429. Published by M. N. Forney, 47 Cedar street, New York. 1894. $2.50.

TO PUBLISHERS. — Aeronautical publications received will be noticed in future numbers of the Annual.

EDITORIAL.

Please address Communications to

THE EDITOR OF THE AERONAUTICAL ANNUAL,
BACK BAY P. O.,
BOSTON, MASS., U.S.A.

NOTE EXCEPTION. — From June 15 to Oct. 1, 1896, address:
YORK HARBOR,
MAINE, U.S.A.

Cable address: JASMEANS, BOSTON.

The publishers have remaining a few copies of the Annual for 1895. Price, postpaid, One Dollar.

TO ANTIQUARIAN BOOKSELLERS. — *The Editor is making a collection of old books, pamphlets, and prints relating to Aeronautics, and he will be glad to have quotations of prices of any such.*

EXPERIMENTERS IN ALL PARTS OF THE WORLD ARE INVITED TO SEND, FOR PUBLICATION IN THE NEXT NUMBER OF THE ANNUAL, CONCISE ACCOUNTS OF THEIR EXPERIMENTS.

Contributors will kindly note the following:

1. The Editor is not to be held responsible for rejected manuscripts, drawings, or photographs.

2. In describing experiments, contributors are requested to send photographs *and also* working-drawings of those pieces of apparatus which they consider their best.

3. Well-illustrated descriptions of experiments with the following kinds of apparatus are especially desired:

Soaring-machines.
Self-propelled models.
Kites.
Motors.
Screw-propellers.

4. All photographs should be distinct, or they cannot be satisfactorily reproduced. All drawings should be in ink on white paper or tracing-cloth, and they should be sufficiently well-executed to be photo-engraved without re-drawing.

5. Accuracy, explicitness, and conciseness of statement are desirable in the extreme.

6. Please state if any of the text or illustrations have been in print before, and, if so, where? Please give dates of all experiments.

It is expected that The Annual for 1897 will go to press on the first of October, 1896.

THE Editor wishes to express his indebtedness to the following members of the Boston Aeronautical Society, who, complying with his request, have kindly contributed articles to this number of The Annual. Prof. William H. Pickering, Messrs. A. Lawrence Rotch, J. B. Millet, Samuel Cabot, S. P. Fergusson, and Albert A. Merrill.

THE Editor is frequently asked, "What about Dr. Langley's recent experiments?" The only answer now to be made is, that Dr. Langley is not yet ready to give to the public the results of his recent researches.

Those students who are familiar with his memoir entitled "Experiments in Aerodynamics" are aware that it is his custom to complete a series of experiments before publishing results. If fragmentary reports had been made of his work prior to 1891 they would not have been understood.

When Dr. Langley had worked out his conclusions, he gave them all to the public.

The reports of his work which have appeared in the public prints during the past year or two have been unauthorized and misleading.

It is hardly worth while for a student to attach any importance to what is printed concerning the details of Dr. Langley's experiments unless the same is printed over his own signature.

The Master of some Sailing-ship will confer a great favor if he will bring home in good condition the skins of one or two of the very largest albatrosses. The birds should be most carefully weighed as soon as killed, and each skin should bear a tag giving this weight. If measurements are made before the birds are cold, giving the distance from tip to tip of the wings when fully extended, and also of the distance from the ends of the beaks to the ends of the tails, also of the greatest girth of the skinned body, these will be a great aid to the taxidermist who mounts the skins. These specimens are much needed. Perhaps the "Ancient Mariner" would not have come to grief if the albatross had been killed in the cause of science.

Motors. — At the close of an article in the "North American Review" of October, 1895, Mr. Maxim says, "My experiments during the last five years have led me to believe that the flight of man is possible, even with a steam-engine and boiler. I would, however, advise the young engineers who may read this paper, if they wish to do something to advance the science of aviation, to turn their thoughts in the direction of a petroleum motor. These motors have been greatly improved of late years, and I believe it is to the petroleum motor that we must look in the future, as being the engine which will drive our flying-machines. Petroleum is cheap and abundant; it may be obtained in any quarter of the globe, and no other substance that we can obtain on a commercial scale contains such an enormous quantity of latent energy."

When we consider Mr. Maxim's engineering skill, and when we remember how elaborate, we may almost say how exhaustive, have been his experiments with steam motors, we see how weighty are these words of commendation which he gives to the petroleum motor. This advice to young engineers is most generously given; it has cost him large sums of money and years of deep study to qualify himself to give it, and it should be valued accordingly.

For some time past the Editor has been gathering information concerning the gasoline and petroleum motors now on the market. Just at present the market seems to be in a state of preparation.

The interest in automobile vehicles which has recently been awakened bids fair to result in the development of light motors. For this reason the students of aeronautics are likely to take much interest in the development of the horseless carriage.

The recent speed-trials in France and in this country show that the carriage-builders are coming forward promptly with their energy and their money; also that the motor-makers have only partially solved the problem of producing a light motor. The full solution, however, is perhaps not far off.

The Editor wishes to obtain for his own use a motor which can lift 550 lbs. at the rate of 4 feet per second; the four-horse-power motor of commerce cannot always do this. Information concerning the exact weight, size, and price of a motor which can do it will be gladly received.

FLAPPING WINGS *vs.* SCREW PROPELLERS. — There is a difference of opinion as to which is the best method of propelling a flying-machine, — by flapping wings or by screw propellers. The evidence so far gathered seems to show that the latter method is the more rational of the two. The difficulty of preserving the equilibrium is thought by many to be increased by having movable wings.

With sustaining surfaces, which in the course of flight do not change their position relatively to each other, soarers have often been made which are self-righting; that is, they steer themselves into a course which is approximately horizontal.

There are still other reasons why screw propulsion seems to be the best. These were mentioned in an article which the present writer contributed to the "Boston Transcript" of January 12, 1884, and from which the following is an extract:

"Too close an imitation of nature is in many cases more of a hindrance than an aid. To illustrate this point . . . let us suppose the world to have wanted a locomotive. If the inventor had looked to nature for his model, he would probably have chosen, as being the most powerful, the elephant. Then, if he followed the method of those who are trying to solve our difficulty by a study of wing movements, he would have constructed a vast machine with legs and levers!

"Or, again, suppose the inventor who wished to propel a ship by its own motive power should have sought to apply that power in the same manner that nature applies it; he would have gone to the duck, and the product of his thought would have been a web-footed ship!

"It is quite right for us to study nature that we may learn principles; but, as has been said, if we attempt to make the same application of power we do not progress.

"In mechanics we find that the form of power which can be most readily utilized is rotary; . . . but in the animal world revolution is unknown; all propelling power, whether of beast, bird, or fish, is applied by oscillatory movement. The reason for this is not far to seek. Living creatures are dependent upon the circulation of the blood. Revolution necessitates the existence of an independent revolving body."

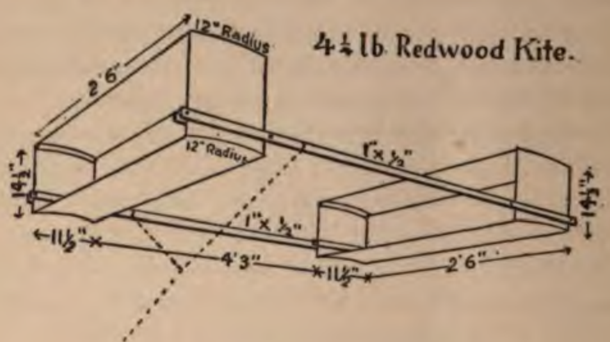
THE AUSTRALIAN KITE-DESIGNER. — For many years Mr. Lawrence Hargrave, of New South Wales, has been experimenting with flying-models and with kites. His work has awakened a great deal of interest among the students of aeronautics, and every new report of his experiments finds eager readers. Those who are unfamiliar with Mr. Hargrave's studies will find interesting accounts in Mr. Chanute's "Progress in Flying Machines," pp. 218–233, and in the "Proceedings of the International Conference on Aerial Navigation," pp. 287–297.

He has read several papers before the Royal Society of New South Wales. These may be found in the Journal of that Society. He says that copies are in the following libraries in Boston: American Academy of Arts and Sciences, Boston

Society of Natural History, State Library of Massachusetts, "and in sixty-five other libraries in the United States."

In one of his later papers, read June 5, 1895, Mr. Hargrave writes:

"The cellular kite is the germ that has been modified and developed, and in all probability it will prove to be the permanent type of the supporting surfaces of flying-machines. A single experiment will show any one that absolute stability and certainty of action may be relied on, and that the careful adjustment and balancing of single planes and affairs with a diedral angle is wasted labor.



"The earlier forms of cellular kites had the planes altogether edged with wood, and they needed much diagonal staying. Pin and eye joints would have been necessary at all the corners if they had been made to collapse, and want of space for storage began to be felt. The distance between the cells has been greatly reduced; the exact distance that they can be apart without impairing the efficiency of the after-cell is not known; but, as far as stability is concerned, a single cell is in stable equilibrium. There is a single-celled kite in the collection, measuring 2 ft. 6 in. long, 2 ft. 6 in. deep, and 6 feet wide, and it flies quite steadily.

"A number of experiments have been made with curved wooden cellular kites."

Mr. Hargrave speaks of the kite shown in the accompanying drawing as one of a variety of stable forms, and he thinks it may be useful to his readers. Of this there can be no doubt.

The experiments which Mr. Millet has made, and which are described in his article, are sure to arouse the enthusiasm of kite-flyers, and to lead many to test the Hargrave kite. Mr. Millet has often said that he considers the Australian a far more advanced kite-designer than any other whose experiments have been reported.

Further light upon the Hargrave kite is thrown by Mr. Lamson, who has experimented with it and modified it as described on preceding pages.

In the last pamphlet which Mr. Hargrave sent to The Annual was the following table, containing the dimensions of five cellular kites similar to those described by Mr. Millet. Although this table has already been published by "The American Engineer and Railroad Journal," it is so sure to be useful that it is here appended:

Kite.	Length of each cell.	Breadth of each cell.	Depth of each cell.	Distance between the cells.	Distance from the forward end of the forward cell to the point of attachment of the kite string.	Weight of the kite.	Lifting surface of the kite.
A . .	1 ft. 11 in.	5 ft. 0 in.	1 ft. 10 1/8 in.	2 ft. 1 in.	1 ft. 7 in.	5 lbs. 7 oz.	38.5 sq. ft.
B . .	1 " 11 "	5 " 0 "	1 " 10 1/8 "	2 " 4 "	1 " 7 "	5 " 14 "	38.5 "
C . .	2 " 3 "	7 " 8 "	1 " 10 1/4 "	4 " 5 "	2 " 8 "	9 " 8 "	69 "
D . .	2 " 6 "	6 " 6 "	2 " 3 1/8 "	3 " 6 "	2 " 3 "	9 " 0 "	65 "
E . .	2 " 6 "	9 " 0 "	2 " 6 "	4 " 0 "	2 " 10 "	14 " 8 "	90 "

THE TAILLESS KITE. — Mr. William A. Eddy, of Bayonne, N.J., was one of the first men in this country to give serious attention to the development of the kite. For several years he has advocated its use for the exploration of the upper air.

For the past two summers Mr. A. Lawrence Rotch, the founder and director of the Blue Hill Observatory, has made it possible for Mr. Eddy to experiment in this direction.

The Blue Hill kite-experiments have awakened much interest.

Mr. Chanute writes of Mr. Eddy as follows: "He has been constantly experimenting with kites during the last few years, and he is recognized as an expert in such matters."

Mr. Eddy had one convex kite in his collection at Blue Hill last summer which he called the "Beard Kite," and which is described in Mr. Daniel C. Beard's "The American Boy's Handy Book" (published by C. Scribner's Sons, N.Y.).

Mr. Beard has given to kite-flyers the earliest working-drawing of a tailless kite, such as is now called the Malay, which the editor has so far found. The description is given in an unsigned letter, dated Rochester, N.Y., Jan. 6, 1882, and is to be found on pp. 384–386 of the 1893 edition of the book just mentioned.

Mr. Eddy's modification of the tailless kite is known as the Eddy kite; it has been tried by many experimenters who have worked from drawings furnished by the designer. The accounts of Mr. Eddy's experiments which have been published from time to time during the past few years have done much to awaken an interest in kite-designing.

Complying with a request made by the Editor, Mr. Eddy writes:

To the Editor of the Aeronautical Annual:

The following is the best Eddy kite for winds above 6 miles per hour, for the season of 1895. Upright and cross sticks of equal length. See Fig. 1.

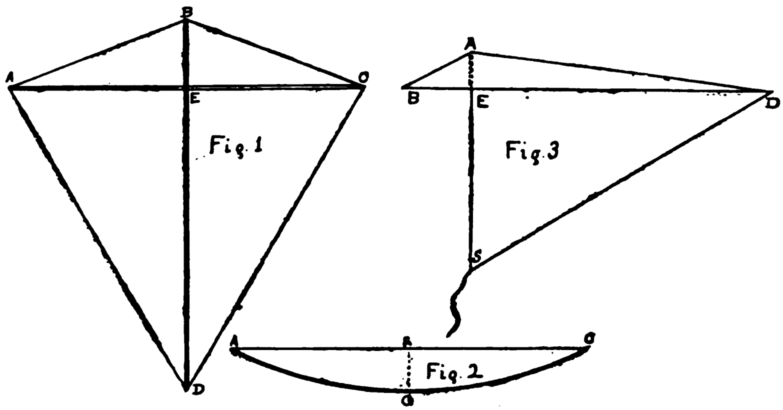
AC = BD.

BD and AC, 60 inches each.

Spruce sticks, $\frac{6}{16} \times \frac{7}{16}$ inch.

BE = 18% of BD.

The cross-stick AC (see Fig. 2) is bowed to a curve in which FG (to the deepest part of the bend) is 10% of AC, or six inches. The string extending from S to E (Fig. 3) is of a length corresponding to the distance around the curved face of the kite from E to A. Therefore, the distance SD corresponds to DA. The distances, however, are never exact, since the point S, or rather the knot at S, should be shifted up and down in the wind to the extent of an inch or two, or until experiment has decided the true position.



For winds of 3 to 6 miles an hour AC should be 14% of BD longer than BD, and spruce sticks $\frac{1}{4} \times \frac{3}{8}$ inch should be used.

Cloth should be used for all kites exceeding six feet in diameter. The best calm-wind flyers are of paper, which is lighter than cloth. Every fraction of an ounce in weight counts heavily in very light winds.

Nine Eddy kites produced a pull of 115 lbs. at Blue Hill Observatory; viz., three kites 9 ft., three 6 ft., one 7 ft., and two 5 ft. in diameter. An altitude of about 3,000 feet was reached by the top kite. Sixty-five mid-air photographs have been taken and printed.

WILLIAM A. EDDY.

THE following is a copy of the earlier bill referred to in the article entitled *Senate Bill No. 302* :

A BILL TO SECURE AERIAL NAVIGATION.

S. 1344. Fifty-third Congress, 3d Session. Introduced in the Senate of the United States by Mr. Cockrell, Dec. 20, 1893. Referred to the Committee on Interstate Commerce. Reported by Mr. Brice without recommendation, Feb. 25, 1895.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Treasury is hereby authorized and directed to pay the sum of one hundred thousand dollars to any inventor, from whatever part of the world, who shall, at any time prior to the first day of January, nineteen hundred, construct a vessel that will, on the verified report of three engineers appointed by the Secretary of War, demonstrate, within or near the city of Washington, the practicability of safely navigating the air at a speed of not less than thirty miles an hour, and capable of carrying passengers and freight weighing a total of at least five tons.

KITE-FLYERS WHO COMPETE FOR PRIZE C, mentioned on page 87, *may* find it necessary to design kites which will spill the wind when gusts come. Here are two hints: (1) See page 196, lines 13–18, of Mr. Chanute's "Progress in Flying Machines." (2) Consider valvular surfaces.

THE WEAKEST PLACE in a kite string is usually found in a knot. Some knots are better than others, but all are bad. There must be some joining. This one is better than any knot: RR, two thimble-rings. M, a link of steel wire. SS, two ends of a kite string served with soft waxed thread. Before passing the string around the rings, protect it with a strip of kid; let the kid run under the serving. Knots are more easily made, and some kite-flyers prefer them until they have lost a few miles of good line.

A SIMPLE instrument for measuring the angle at which a kite flies may be made with the following materials: A piece of pine board 16 in. × 5 in. × ½ in., two screw eyes such as are used in the backs of picture-frames, a weight of two or three ounces, and a piece of string. Screw the eyes into the upper edge of the board near the ends; these are for sights. Near what we may call the muzzle sight, make on the board a graduated quadrant. Drive a small nail at the centre of this quadrant, and attach the string, which is to be weighted at its lower end. Look through the sights at the horizon and see that the string hangs at zero on the quadrant. Cut away enough wood so that the string may hang at 90° when the sights point to the zenith.

When a kite is observed through the sights, the string will show the angular altitude on the quadrant.

A REEL about a foot in diameter, fitted with a brake and screwed to a wheel-barrow, is useful to the flyer of kites.

In high winds he needs a mallet, some stakes, and a lashing, lest the barrow make leeway.

IF you make kites, you will find a constant use for spruce sticks. Clear and straight-grained spruce is surprisingly strong. On no account touch anything but the finest quality. At the beginning of the season you can easily have some boards sawed into strips such as you need, and if you are thus supplied much time will be saved.

SAID Mrs. Lecks to Mrs. Aleshine, "Black stockings for sharks." It's a poor rule that won't work any way you want it to, therefore it may be added, *Black cloth for kites.* You can see a black hawk farther than you can a white swan. Think, too, of the sensitive plate which is the retina of the camera.

DURING the season of 1895 so much time was given to kites that I have not been able to carry my soaring-machine experiments[1] as far as I had hoped to do.

The experiments which I have tried, however, lead me to think that the most successful machine of the future will have its length fore and aft at least double, perhaps treble, that of the width measured from tip to tip of the wings or sustaining surfaces.

One experiment which I intended to make I have not yet found time for. I hope that some one may be interested to try it. It is to set a kite in free flight as a soarer. A long kite like the one in Plate XII. will, perhaps, answer the purpose for the first trial. A weight should be arranged to slide upon a rod or cord underneath the kite and parallel with the backbone. This weight at first should be placed a little forward of the centre of the middle kite; there it should be tied. A strong rubber band should be attached to it and tightly stretched to pull the weight forward when it is released. Before the kite is sent up a lighted slow-match should be placed so that it will release the weight and cut the kite-line at the same time. This sets the kite in free flight, and as the rubber pulls the weight forward the centre of gravity is changed, and the kite may thus be properly ballasted as a soarer.

As improvements are made in kites from year to year, repeated trials of this experiment are likely to be instructive.

IN my experiments at York, Me., last summer, I was fortunate in having the assistance of Mr. Charles W. Bowles, of Canton, Mass. His skill in constructing kites is only equalled by his patience in experimenting with them.

A FLYING kite does not necessarily show the direction of the wind, *i.e.*, a kite does not necessarily fly dead to leeward of the place where the string is held. When several kites are flown from the same point, they will often bear in different direc-

[1] See the Annual for 1895, pp. 152–167 inclusive.

tions. If the divergence is great, it is probably due to lack of bilateral symmetry in some or all of the kites, although variations in wind currents cause some divergence.

IF a kite is unsteady in its flight, it does not *necessarily* follow that it is not well designed and constructed. A study of air currents will help the kite-flyer to understand the movements of his kite.

Most eccentricities of kite-flight are the effects of one of these three causes:

(1) Irregularity of the wind.
(2) Distortion of the kite.
(3) Faulty designing.

SPEEDS IN MILES PER HOUR REDUCED TO FEET AND METERS PER SECOND.

5 miles per hour	=	7⅓ ft. per sec.	=	2.235	meters.
10 " " "	=	14⅔ " " "	=	4.470	"
15 " " "	=	21⅔ " " "	=	6.705	"
20 " " "	=	29⅓ " " "	=	8.941	"
25 " " "	=	36⅔ " " "	=	11.176	"
30 " " "	=	44 " " "	=	13.411	"
35 " " "	=	51⅓ " " "	=	15.646	"
40 " " "	=	58⅔ " " "	=	17.882	"
45 " " "	=	66 " " "	=	20.117	"
50 " " "	=	73⅓ " " "	=	22.352	"
55 " " "	=	80⅔ " " "	=	24.587	"
60 " " "	=	88 " " "	=	26.822	"
70 " " "	=	102⅔ " " "	=	31.293	"
80 " " "	=	117⅓ " " "	=	35.763	"
90 " " "	=	132 " " "	=	40.234	"
100 " " "	=	146⅔ " " "	=	44.704	"

INDEX EXPURGATORIUS.

For the Use of Young Writers.

DÆDALUS.
ICARUS.
PHAETON.
PEGASUS (admissible pictorially).
D. GREEN.
NATIONS' AIRY NAVIES.
PILOTS OF THE PURPLE TWILIGHT.
INTREPID AERONAUT.

(To be continued.)

LILIENTHAL may learn from Maxim that a long fore and aft dimension is desirable.

Maxim may learn from Lilienthal that one must "feel at home with the wind" before he can steer a flying-machine.

Lilienthal may learn from Maxim that propulsion by screws is more rational than propulsion by flaps.

Maxim may learn from Lilienthal that it is better to experiment with machines just large enough to carry the operator than it is to build machines weighing several tons.

What perhaps might be the quickest method of bringing about the full solution of the problem of aerial navigation is one which, under free government, is not workable.

If Lilienthal and Maxim, each of whom possesses qualifications which the other lacks, were together exiled to a lonely island in the South Seas, with a goodly company of artisans, an ample commissariat, and plenty of material, machines, tools, and fuel, and then if their ships were burned and they were told to fly home — but I pause, — the Annual isn't a novel: it is a very serious publication, and prithee remember that it *is* an Annual, and that another number will be asking your kind attention about twelve months hence. Till then, adieu.

The Aeronautical Annual.

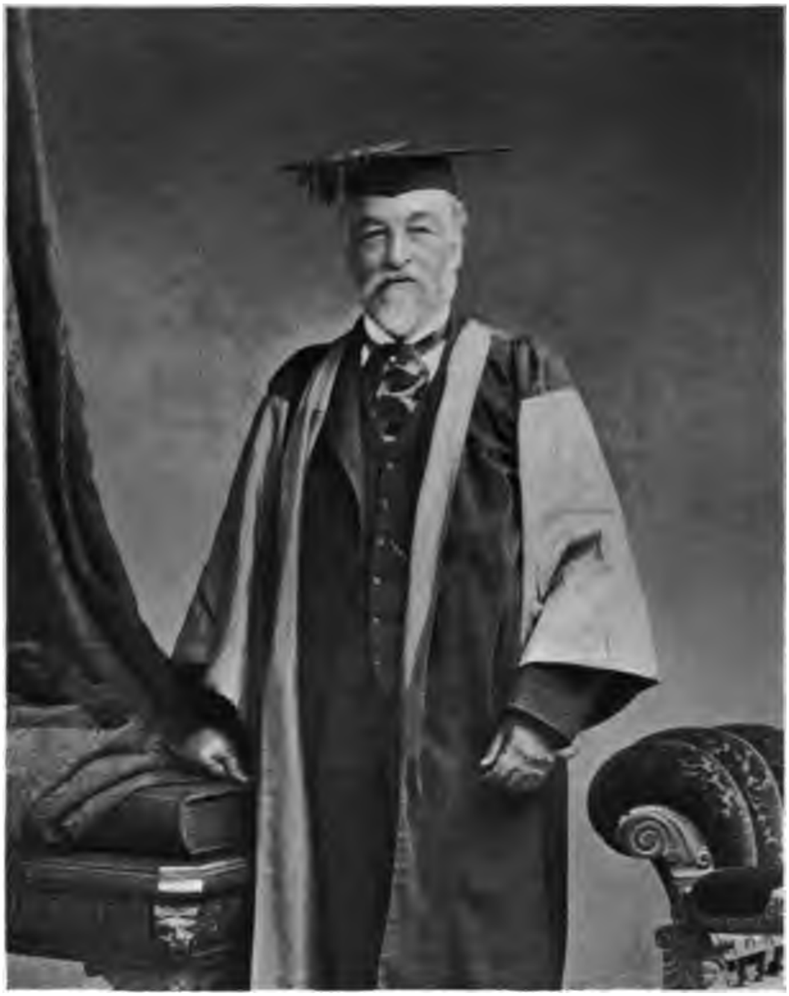
1897.

Edited by JAMES MEANS.

BOSTON, MASS.:
W. B. CLARKE & CO.,
PARK ST., COR. TREMONT ST.

LONDON:
WILLIAM WESLEY & SON,
28 ESSEX STREET, STRAND.

Plate I.



SAMUEL PIERPONT LANGLEY, Ph.D., LL.D., D.C.L.,

Secretary of the Smithsonian Institution.

From a photograph taken at Oxford in 1894

No. 3.

The

Aeronautical Annual.

1897.

DEVOTED TO THE ENCOURAGEMENT OF EXPERIMENT WITH AERIAL MACHINES, AND TO THE ADVANCEMENT OF THE SCIENCE OF AERODYNAMICS.

EDITED BY

JAMES MEANS.

The American publishers will send this number, postpaid, to any address on receipt of one dollar.

BOSTON, MASS.:
W. B. CLARKE & CO.,
PARK ST., COR. TREMONT ST.

LONDON:
WILLIAM WESLEY & SON,
28 ESSEX ST., STRAND.

PRESS OF
Rockwell and Churchill
BOSTON

To the Memory

OF THOSE WHO,

INTELLIGENTLY BELIEVING IN THE POSSIBILITY

OF

MECHANICAL FLIGHT,

HAVE

LIVED DERIDED,

AND

DIED IN SORROW AND OBSCURITY

PROGRESS IN 1896.

THE advance toward the full solution of the problem of manflight which was made in the year 1896 was greater than that of any previous year. Saving the sad death of Lilienthal, the chronicler's pen has only good news to tell.

In times past the extreme difficulty of determining what were the best methods of work was the deterrent which kept investigators from entering the field of aeronautics, and consequently the world's workers were comparatively small in number.

Now, this condition of affairs no longer obtains, for the demonstrations of 1896 were such that the best lines for investigators to follow are very clearly marked out. These lines, three in number, distinct, yet convergent, are as follows:

1. The development of the self-propelled aerodrome.
2. The development of the motorless air-sailer.
3. The development of the motor.

In each of these departments of work there is now a well-defined point of vantage which is accessible to every intelligent experimenter who is inclined to carefully study the ground already traversed, and so to fully understand the results already reached.

Whichever branch of work is seriously undertaken by an individual, he may be sure that, while working upon his own specialty, he is helping those engaged in others toward their common goal.

As stated in the first number of THE ANNUAL, if this compilation should happily bring any new workers into the field of aeronautical experiment, the hopes of the editor will be amply fulfilled.

CONTENTS.

LIST OF PLATES.

SAMUEL PIERPONT LANGLEY.

SAMUEL PIERPONT LANGLEY [1] was born in Roxbury, Mass., on Aug. 22, 1834. At the age of eleven he entered the Boston Latin School, and afterward the English High School, graduating from that excellent institution in 1851, after completing the usual three years' course. As his inclinations tended strongly to mathematical and mechanical pursuits he was not sent to college, and at that time none of the opportunities of higher scientific education now existing at the Massachusetts Institute of Technology and other similar institutions of learning were available for the young student. From his early youth he had been deeply interested in everything pertaining to astronomy, and with the aid of his brother had constructed several small telescopes for the study of the heavens. After leaving the English High School he entered the office of an architect in Boston, and in 1857 commenced the practice of his profession at the West, in Chicago and St. Louis.

The financial and political troubles of the period just before the civil war interfered so seriously with success that he returned to Boston in 1864, occupying the next year with a journey to Europe with his brother. On his return, congenial occupation offered itself in the shape of an appointment as assistant to Prof. Joseph Winlock, then director of the Harvard Observatory.

This opportunity of doing real astronomical work was eagerly seized, and led the next year (1866) to his appointment as assistant professor of mathematics at the U.S. Naval Academy, where in the intervals of arduous work he put in order the small observatory established by Prof. William Chauvenet.

The next year he accepted the appointment of director of

[1] Abridged by Commander Francis M. Green, U.S.N., from the advanced sheets of a memoir of the three secretaries of the Smithsonian Institution.

the observatory and professor of astronomy and physics at the Western University of Pennsylvania, and in connection with this appointment was director of the Alleghany Observatory, then an observatory only in name, consisting of a building in which was a thirteen-inch equatorial without either a clock, transit, or chronograph, and entirely devoid of either a library or endowment.

To raise money for the equipment of the observatory and to enable him to prosecute original research, an admirable scheme was devised by Mr. Langley by which exact time was transmitted by telegraph twice a day to all the principal stations of the Pennsylvania Railway from the observatory. This was the introduction on a large scale of the system of time distribution from observatories which has since become universal. By this means about eight thousand miles of railway were eventually run by these time-signals, affording altogether during the administration of Mr. Langley more than sixty thousand dollars devoted entirely to the uses of the observatory.

The time-service and the resulting income becoming regularly established, the work of research upon the solar atmosphere was commenced and carried on energetically in spite of great difficulties.

The seventeen years from 1870 to 1887 were productive of most excellent and striking work in the study of solar physics. The limits of this sketch only permit this work to be briefly referred to, but astronomers of all nations have united in eulogizing the skill, devotion, and tireless perseverance which have given to the world the intensely interesting and valuable information regarding the heat, light, and chemical action due to the solar radiation.

In his study of the sun's heat he found that the thermopile effectively used for nearly fifty years was not sufficiently sensitive and trustworthy, and this difficulty led Mr. Langley to the invention of the bolometer. By this instrument very small amounts of radiant heat may be measured, changes of temperature of less than $\frac{1}{100000}$ of a degree F. being accurately indicated. Its action is based on the variations of electrical resistance produced by changes of temperature in a metallic conductor, like a minute strip of platinum. This strip forms one arm of an electric balance, the change in the strength of the current flowing through it being measured by a delicate galvanometer.[1] This beautiful instrument has recently been made more effective by the invention of the bolograph, which photographically records the fluctuations of the galvanometer needle. With these instruments Mr. Langley may be said to have opened up a new department of physics.

Mr. Langley's contributions to science have been numerous, and are to be found in the scientific journals of this country and of Europe. Besides these, the "Century Magazine" in 1884 and 1886 contained a series of popular articles on astrophysical research based on lectures delivered by him at the Lowell Institute in 1883. These articles have been since republished in book form under the title of "The New Astronomy," a most fascinating and successful work.

In 1887 he was chosen by the lamented Spencer F. Baird, already in failing health, as his assistant in the secretaryship of the Smithsonian Institution, and in the same year after the death of Professor Baird he was elected secretary of the Smithsonian Institution.

Interested from boyhood in the problems of aerial flight as illustrated by soaring birds, it was not till 1889 that he found opportunity for serious work in this direction. In 1891 he published his now famous memoir entitled "Experiments in Aerodynamics," and in 1893 the equally celebrated one on "The Internal Work of the Wind." The importance of the views thus advanced was universally admitted as shown by able articles by various experts, notably Mr. O. Chanute, of Chicago, Dr. von Salverda, of Holland, and Lt.-Col. Elsdale, of the Royal Engineers. Satisfied that important results would be derived from continued experimental work, Mr. Langley diligently prosecuted his investigations, and in May, 1896, he had the intense satisfaction of seeing an aerodrome constructed by him-

[1] "The Bolometer and Radiant Energy." Proceedings of the American Academy of Arts and Sciences, 1880–1881.

[illegible]

[illegible] was made [illegible] [illegible] steam-engine [illegible]

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[illegible] and this [illegible] are more [illegible] possible [illegible] insoluble as theretofore affirmed by many of the most eminent scientific men.

Whether Doctor Langley's scientific labors in this department of physics will soon result, like those of the preceding secretaries, in the practical application of his discoveries to the use of mankind, it is perhaps too early to assert positively. I think, myself, that they will so result before many years, but there are so many intricate questions to be solved before commercial success can be achieved that another generation may pass before the problem of flight is fully solved.

Moreover, Doctor Langley's labors and discoveries are by no means over. He has thus far published only the result of his investigations on planes, while saying in the penultimate paragraph of his summary that it is not asserted that planes are the best forms to use. Lilienthal and Phillips have since shown that concave-convex surfaces are more efficient forms, and it is very much to be desired that Doctor Langley shall next publish some data concerning such forms.

The practical development of a scientific truth is somewhat like the growth from a new seed. We recognize the existence of the plant, we ascertain some of its virtues, but we cannot tell its full uses, how soon it will mature, nor how large the tree will be.

It is significant, however, that, prior to the publication of Doctor Langley's work, it was the rare exception to find engineers and scientists of recognized ability who would fully admit *the possibility* of man being able to solve the twenty-century-old problem of aviation. Prof. Joseph Le Conte, in the "Popular Science Monthly," of November, 1888, has very recently taken the ground, flatly, "that a pure flying-machine is impossible." This was probably based on the fact that the then accepted formula of Newton, and the calculation of Napier and other scientists, if correct, rendered the solution practically impossible. Since the publication of "Experiments in Aerodynamics," however, it is the exception to find an intelligent engineer who disputes the *probability* of the eventual solution of the problem of man-flight. Such has been the change in five years. Incredulity has given way, interest has been aroused in the scientific question, a sound basis has been furnished for experiment, and practical results are being evolved by many workers. Much remains to be discovered concerning curved surfaces, with which alone practical flight is likely to be achieved, but when this is accomplished it is probable, in my edgment that the beginning of the solution will be acknowledged to date back to the publication of Doctor Langley's book, and that he will be distinguished as Secretary Henry is now with regard to the development of electrical appliances.

The administration of the Smithsonian Institution under the direction of Mr. Langley has been most satisfactory. Among the notable features of it have been the establishment of the National Zoological Park and the Smithsonian Astrophysical Observatory. The latter is at present the only direct endowment by an institution established to encourage research in physical science, especially as at the U.S. Naval Observatory at Washington none of the appropriated funds for its support are permitted to be used for physical research.

Mr. Langley's contributions to science have been numerous and have been largely published in the "Comptes Rendus" of the French Academy and in the "American Journal of Science."

Mr. Langley is a member of the National Academy of Sciences, a fellow of the Royal Astronomical Society, of the Royal Society of London, is an official correspondent of the French Academy and a member of numerous other American and foreign scientific societies. In [illegible] he was elected president of the American Association for the Advancement of Science. He has received the following honorary degrees: LL.D. from University of Wisconsin in [illegible], University of Michigan in [illegible], Harvard University in [illegible], and Princeton University [illegible]; D.C.L. from the University of Oxford in [illegible]. He was the first to receive from the National Academy of Sciences the Henry Draper medal for work in astronomical physics, and in [illegible] was awarded the Rumford medal by the Royal Society of London, the Rumford gold and silver medals by the American Academy of Arts and Sciences.

More than all these formal honors to him is the world-wide recognition of his achievements in the discovery of so much of the solar spectrum and in the formulation of the principles of aerodynamics.

STORY OF EXPERIMENTS IN MECHANICAL FLIGHT.

By Samuel Pierpont Langley.

The Editor of "The Annual" has asked me to give matter of a somewhat personal nature for a narrative account of my work in aerodromics.

The subject of flight interested me as long ago as I can remember anything, but it was a communication from Mr. Lancaster, read at the Buffalo meeting of the American Association for the Advancement of Science, in 1886, which aroused my then dormant attention to the subject. What he said contained some remarkable but apparently mainly veracious observations on the soaring bird, and some more or less paradoxical assertions, which caused his communication to be treated with less consideration than it might otherwise have deserved. Among these latter was a statement that a model, somewhat resembling a soaring bird, wholly inert, and without any internal power, could, nevertheless, under some circumstances advance against the wind without falling; which seemed to me then, as it did to members of the Association, an utter impossibility, but which I have since seen reason to believe is, within limited conditions, theoretically possible.

I was then engaged in the study of astro-physics at the Observatory in Allegheny, Pennsylvania. The subject of mechanical flight could not be said at that time to possess any literature, unless it were the publications of the French and English aeronautical societies, but in these, as in everything then accessible, fact had not yet always been discriminated from fancy. Outside of these, almost everything was even less trustworthy; but though after I had experimentally demonstrated certain facts, anticipations of them were found by others on historical research, and though we can now distinguish in retrospective examination what would have been useful to the investigator if he had known it to be true, there was no test of the kind to apply at the time. I went to work, then, to find out for myself, and in my own way, what amount of mechanical power was requisite to sustain a given weight in the air, and make it advance at a given speed, for this seemed to be an inquiry which must necessarily precede any attempt at mechanical flight, which was the very remote aim of my efforts.

The work was commenced in the beginning of 1887 by the construction, at Allegheny, of a turn-table of exceptional size, driven by a steam-engine, and this was used during three years in making the "Experiments in Aerodynamics," which were published by the Smithsonian Institution, under that title, in 1891. Nearly all the conclusions reached were the result of direct experiment in an investigation which aimed to take nothing on trust. Few of them were then familiar, though they have since become so, and in this respect knowledge has advanced so rapidly that statements which were treated as paradoxical on my first enunciation of them are now admitted truisms.

It has taken me, indeed, but a few years to pass through the period when the observer hears that his alleged observation was a mistake; the period when he is told that if it were true, it would be useless; and the period when he is told that it is undoubtedly true, but that it has always been known.

May I quote from the introduction to this book what was said in 1891?

"I have now been engaged since the beginning of the year 1887 in experiments on an extended scale for determining the possibilities of, and the conditions for, transporting in the air a body whose specific gravity is greater than that of the air, and I desire to repeat my conviction that the obstacles in its way are not such as have been thought; that they lie more in such apparently secondary difficulties as those of guiding the body so that it may move in the direction desired, and ascend or descend with safety, than in what may appear to be the primary difficulties due to the nature of the air itself," and, I added, that in this field of research I thought that we were, at that time (only six years since), "in a relatively less advanced condition than the study of steam was before the time of Newcomen." It was also stated that the most important inference from those experiments as a whole was that mechanical flight was possible with engines we could then build, as one-horse power rightly applied could sustain over 200 pounds in the air at a horizontal velocity of somewhat over 60 feet a second.

As this statement has been misconstrued, let me point out that it refers to surfaces, used without guys, or other adjuncts, which would create friction; that the horse-power in question is that actually expended in the thrust, and that it is predicated only on a rigorously horizontal flight. This implies a large deduction from the power in the actual machine, where the brake horse-power of the engine, after a requisite allowance for loss in transmission to the propellers, and for their slip on the air, will probably be reduced to from one-half to one-quarter of its nominal amount; where there is great friction from the enforced use of guys and other adjuncts; but above all where there is no way to insure absolutely horizonal flight in free air. All these things allowed for, however, since it seemed to me possible to provide an engine which should give a horse-power for something like 10 pounds of weight, there was still enough to justify the statement that we possessed in the steam-engine, as then constructed, or in other heat engines, more than the indispensable power, though it was added that this was not asserting that a system of supporting surfaces could be securely guided through the air or safely brought to the ground, and that these and like considerations were of quite another order, and belonged to some inchoate art which I might provisionally call *aerodromics*.

These important conclusions were reached before the actual publication of the volume, and a little later others on the nature of the movements of air, which were published under the title of "The Internal Work of the Wind" (Smithsonian Contributions to Knowledge, Volume XXVII., 1893, No. 884). The latter were founded on experiments independent of the former, and which led to certain theoretical conclusions unverified in practice. Among the most striking and perhaps paradoxical of these, was that a suitably disposed free body might under certain conditions be sustained in an ordinary wind, and even advance against it without the expenditure of any energy from within.

The first stage of the investigation was now over, so far as that I had satisfied myself that mechanical flight was possible with the power we could hope to command, if only the art of directing that power could be acquired.

The second stage (that of the acquisition of this art) I now decided to take up. It may not be out of place to recall that at this time, only six years ago, a great many scientific men treated the whole subject with entire indifference as unworthy of attention or as outside of legitimate research, the proper field for the charlatan, and one on which it was scarcely prudent for a man with a reputation to lose, to enter.

The record of my attempts to acquire the art of flight may commence with the year 1889, when I procured a stuffed frigate bird, a California condor, and an albatross, and attempted to move them upon the whirling table at Allegheny. The experiments were very imperfect and the records are unfortunately lost, but the important conclusion to which they led was that a stuffed bird could not be made to soar except at speeds which were unquestionably very much greater than what served to sustain the living one, and the earliest experiments and all subsequent ones with actually flying models have shown that thus far we cannot carry nearly the weights which Nature does to a given sustaining surface, without a power much greater than she employs. At the time these experiments were begun, Penaud's ingenious but toy-like model was the only thing which could sustain itself in the air for even a few seconds, and calculations founded upon its performance sustained the conclusion that the amount of power required in actual free flight was far greater than that demanded by the theoretical enunciation. In order to learn under what conditions the aerodrome should be balanced for horizontal flight, I constructed over 30 modifications of the rubber-driven model, and spent many months in endeavoring from these to ascertain the laws of "balancing"; that is, of stability leading to horizontal flight. Most of these models had two propellers, and it was extremely difficult to build them light and strong enough. Some of them had superposed wings; some of them curved and some plane wings; in some the propellers were side by side, in others one propeller was at the front and the other at the rear, and so every variety of treatment was employed, but all were at first too heavy, and only those flew successfully which had from 3 to 4 feet of sustaining surface to a pound of weight, a proportion which is far greater than Nature employs in the soaring bird, where in some cases less than half a foot of sustaining surface is used to a pound. It had been shown in the "Experiments in Aerodynamics" that the centre of pressure on an inclined plane advancing was not at the centre of figure, but much in front of it, and this knowledge was at first nearly all I possessed in balancing these early aerodromes. Even in the beginning, also, I met remarkable difficulty in throwing them into the air, and devised numerous forms of launching apparatus which were all failures, and it was necessary to keep the construction on so small a scale that they could be cast from the hand.

The earliest actual flights with these were extremely irregular and brief, lasting only from three to four seconds. They were made at Allegheny in March, 1891, but these and all subsequent ones were so erratic and so short that it was possible to learn very little from them. Penaud states that he once obtained a flight of 13 seconds. I never got as much as this, but ordinarily little more than half as much, and came to the conclusion that in order to learn the art of mechanical flight it was necessary to have a model which would keep in the air for at any rate a longer period than these, and move more steadily. Rubber twisted in the way that Penaud used it, will practically give about 300 foot-pounds to a pound of weight, and at least as much must be allowed for the weight of the frame on which the rubber is strained. Twenty pounds of rubber and frame, then, would give 3,000 foot-pounds, or one-horse power for less than six seconds. A steam-engine, having apparatus for condensing its steam, weighing in all 10 pounds and carrying 10 pounds of fuel, would possess in this fuel, supposing that but one-tenth of its theoretical capacity is utilized, many thousand times the power of an equal weight of rubber, or at least one-horse power for some hours. Provided the steam could be condensed and the water re-used, then, the advantage of the steam over the spring motor was enormous, even in a model constructed only for the purpose of study. But the construction of a steam-driven aerodrome was too formidable a task to be undertaken lightly, and I examined the capacities of condensed air, carbonic acid gas, of various applications of electricity, whether in the primary or storage battery, of hot-water engines, of inertia motors, of the gas engine, and of still other material. The gas engine promised best of all in theory, but it was not yet developed in a suitable form. The steam-engine, as being an apparently familiar construction, promised best in practice, but in taking it up, I, to my cost, learned that in the special application to be made of it, little was really familiar and everything had to be learned by experiment. I had myself no previous knowledge of steam engineering, nor any assistants other than the very capable workmen employed. I well remember my difficulties over the first aerodrome (No. 0), when everything, not only the engine, but the boilers which were to supply it, the furnaces which were to heat it, the propellers which were to advance it, the hull which was to hold all these, — were all things to be originated, in a construction which, as far as I knew, had never yet been undertaken by any one.

It was necessary to make a beginning, however, and a compound engine was planned which, when completed, weighed about 4 pounds, and which could develop rather over a horse-power with 60 pounds of steam, which it was expected could be furnished by a series of tubular boilers arranged in "bee-hive" form, and the whole was to be contained in a hull about 5 feet in length and 10 inches in diameter. This hull was, as in the construction of a ship, to carry all adjuncts. In front of it projected a steel rod, or bowsprit, about its own length, and one still longer behind. The engines rotated two propellers, each about 30 inches in diameter, which were on the end of long shafts disposed at an acute angle to each other and actuated by a single gear driven from the engine. A single pair of large wings contained about 50 square feet, and a smaller one in the rear about half as much, or in all some 75 feet, of sustaining surface, for a weight which it was expected would not exceed 25 pounds.

Although this aerodrome was in every way a disappointment, its failure taught a great many useful lessons. It had been built on the large scale described, with very little knowledge of how it was to be launched into the air, but the construction developed the fact that it was not likely to be launched at all, since there was a constant gain in weight over the estimate at each step, and when the boilers were completed, it was found that they gave less than one-half the necessary steam, owing chiefly to the inability to keep up a proper fire. The wings yielded so as to be entirely deformed under a slight pressure of the air, and it was impossible to make them stronger without making them heavier, where the weight was already prohibitory. The engines could not transmit even what feeble power they furnished, without dangerous tremor in the long shafts, and there were other difficulties. When the whole approached completion, it was found to weigh nearer 50 pounds than 25, to develop only about one-half the estimated horse-power at the brake, to be radically weak in construction, owing to the yielding of the hull, and to be, in short, clearly a hopeless case.

The first steam-driven aerodrome had, then, proved a failure, and I reverted during the remainder of the year to simpler plans, among them one of an elementary gasolene engine.

I may mention that I was favored with an invitation from Mr. Maxim to see his great flying-machine at Bexley, in Kent, where I was greatly impressed with the engineering skill shown in its construction, but I found the general design in-compatible with the conclusions that I had reached by experiments with small models, particularly as to what seemed to me advisable in the carrying of the centre of gravity as high as was possible with safety.

In 1892 another aerodrome (No. 1), which was to be used with carbonic acid gas, or with compressed air, was commenced. The weight of this aerodrome was a little over 4½ pounds, and the area of the supporting surfaces 6½ square feet. The engines developed but a small fraction of a horse-power, and they were able to give a dead lift of only about one-tenth of the weight of the aerodrome, giving relatively less power to weight than that obtained in the large aerodrome already condemned.

Toward the close of this year was taken up the more careful study of the position of the centre of gravity with reference to the line of thrust from the propellers, and to the centre of pressure. The centre of gravity was carried as high as was consistent with safety, the propellers being placed so high, with reference to the supporting wings, that the intake of air was partly from above and partly from below these latter. The lifting power (*i.e.*, the dead-lift) of the aerodromes was determined in the shop by a very useful contrivance which I have called the "pendulum," which consists of a large pendulum which rests on knife edges, but is prolonged above the points of support, and counterbalanced so as to present a condition of indifferent equilibrium. Near the lower end of this pendulum the aerodrome is suspended, and when power is applied to it, the reaction of the propellers lifts the pendulum through a certain angle. If the line of thrust passes through the centre of gravity, it will be seen that the sine of this angle will be the fraction of the weight lifted, and thus the dead-lift power of the engines becomes known. Another aerodrome was built, but both, however constructed, were shown by this pendulum test to have insufficient power, and the year closed with disappointment.

Aerodrome No. 3 was of stronger and better construction, and the propellers, which before this had been mounted on shafts inclined to each other in a **V**-like form, were replaced by parallel ones. Boilers of the Serpolet type (that is, composed of tubes of nearly capillary section) were experimented with at great cost of labor and no results; and they were replaced with coil boilers. For these I introduced, in April, 1893, a modification of the ælopile blast, which enormously increased the heat-giving power of the fuel (which was then still alcohol), and with this blast for the first time the boilers began to give steam enough for the engines. It had been very difficult to introduce force pumps which would work effectively on the small scale involved, and after many attempts to dispense with their use by other devices, the acquisition of a sufficiently strong pump was found to be necessary in spite of its weight, but was only secured after long experiment. It may be added that all the aerodromes from the very nature of their construction were wasteful of heat, the industrial efficiency little exceeding half of one per cent., or from one-tenth to one-twentieth that of a stationary engine constructed under favorable conditions. This last aerodrome lifted nearly 30 per cent. of its weight upon the pendulum, which implied that it could lift much more than its weight when running on a horizontal track, and its engines were capable of running its 50-centimetre propellers at something over 700 turns per minute. There was, however, so much that was unsatisfactory about it, that it was deemed best to proceed to another construction before an actual trial was made in the field, and a new aerodrome, designated as No. 4, was begun. This last was an attempt, guided by the weary experience of preceding failures, to construct one whose engines should run at a much higher pressure than heretofore, and be much more economical in weight. The experiments with the Serpolet boilers having been discontinued, the boiler was made with a continuous helix of copper tubing, which as first employed was about three millimetres internal diameter; and it may be here observed that a great deal of time was subsequently lost in attempts to construct a more advantageous form of boiler for the actual purposes than this simple one, which with a larger coil tube eventually proved to be the best; so that later constructions have gone back to this earlier type. A great deal of time was lost in these experiments from my own unfamiliarity with steam engineering, but it may also be said that there was little help either from books or from counsel, for everything was here *sui generis*, and had to be worked out from the beginning. In the construction which had been reached by the middle of the third year of experiment, and which has not been greatly differed from since, the boiler was composed of a coil of copper in the shape of a hollow helix, through the centre of which the blast from the ælopile was driven, the steam and water passing into a vessel I called the "separator," whence the steam was led into the engines at a pressure of from 70 to 100 pounds (a pressure which has since been considerably exceeded).

From the very commencement of this long investigation the great difficulty was in keeping down the weight, for any of the aerodromes could probably have flown had they been built light enough, and in every case before the construction was completed the weight had so increased beyond the estimate, that the aerodrome was too heavy to fly, and nothing but the most persistent resolution kept me in continuing attempts to reduce it after further reduction seemed impossible. Toward the close of the year (1893) I had, however, finally obtained an aerodrome with mechanical power, as it seemed to me, to fly, and I procured, after much thought as to where this flight should take place, a small house-boat, to be moored somewhere in the Potomac; but the vicinity of Washington was out of the question, and no desirable place was found nearer than thirty miles below the city. It was because it was known that the aerodrome might have to be set off in the face of a wind, which might blow in any direction, and because it evidently was at first desirable that it should light in the water rather than on the land, that the house-boat was selected as the place for the launch. The aerodrome (No. 4) weighed between 9 and 10 pounds, and lifted 40 per cent. of this on the pendulum with 60 pounds of steam pressure, a much more considerable amount than was theoretically necessary for horizontal flight. And now the construction of a launching apparatus, dismissed for some years, was resumed. Nearly every form seemed to have been experimented with unsuccessfully in the smaller aerodromes. Most of the difficulties were connected with the fact that it is necessary for an aerodrome, as it is for a soaring bird, to have a certain considerable initial velocity before it can advantageously use its own mechanism for flight, and the difficulties of imparting this initial velocity with safety are surprisingly great, and in the open air are beyond all anticipation.

Here, then, commences another long story of delay and disappointment in these efforts to obtain a successful launch. To convey to the reader an idea of its difficulties, a few extracts from the diary of the period are given. (It will be remembered that each attempt involved a journey of thirty miles each way.)

Nov. 18, 1893. Having gone down to the house-boat, preparatory to the first launch, in which the aerodrome was to be cast from a springing piece beneath, it was found impossible to hold it in place on this before launching, without its being prematurely torn from its support, although there was no wind except a moderate breeze; and the party returned after a day's fruitless effort.

Two days later a relative calm occurred in the afternoon of a second visit, when the aerodrome was mounted again, but, though the wind was almost imperceptible, it was sufficient to wrench it about so that at first nothing could be done, and when steam was gotten up, the burning alcohol blew about so as to seriously injure the inflammable parts. Finally, the engines being under full steam, the launch was attempted, but, owing to the difficulties alluded to and to a failure in the construction of the launching piece, the aerodrome was thrown down upon the boat, fortunately with little damage.

Whatever form of launch was used it became evident at this time that the aerodrome must at any rate be firmly held, up to the very instant of release, and a device was arranged for clamping it to the launching apparatus.

On November 24th another attempt was made to launch, which was rendered impossible by a very moderate wind indeed.

On November 27th a new apparatus was arranged to merely drop the aerodrome over the water, with the hope that it would get up sufficient speed before reaching the surface to soar, but it was found that a very gentle intermittent breeze (probably not more than three or four miles an hour) was sufficient to make it impossible even to prepare to *drop* the aerodrome toward the water with safety.

It is difficult to give an idea in few words of the nature of the trouble, but unless one stands with the machine in the open air he can form no conception of what the difficulties are which are peculiar to practice in the open, and which do not present themselves to the constructor in the shop, nor probably to the mind of the reader.

December 1st, another failure; December 7th, another; December 11th, another; December 20th, another; December 21st, another. These do not all involve a separate journey, but five separate trips were made of a round distance of 60 miles each before the close of the season. It may be remembered that these attempts were in a site far from the conveniences of the workshop, and under circumstances which took up a great deal of time, for some hours were spent on mounting the aerodrome on each occasion, and the year closed without a single cast of it into the air. It was not known how it would have behaved there, for there had not been a launch, even, in nine trials, each one representing an amount of trouble and difficulty which this narrative gives no adequate idea of.

I pass over a long period of subsequent baffled effort, with the statement that numerous devices for launching were tried in vain, and that nearly a year passed before one was effected.

Six trips and trials were made in the first six months of 1894, without securing a launch. On the 24th of October a new launching piece was tried for the first time, which embodied all the requisites whose necessity was taught by previous experience, and, saving occasional accidents, the launching was from this time forward accomplished with comparatively little difficulty.

The aerodromes were now for the first time put fairly in the air, and a new class of difficulties arose, due to a cause which was at first obscure, — for two successive launches of the same aerodrome, under conditions as near alike as possible, would be followed by entirely different results. For example, in the first case it might be found rushing, not falling, forward and downward into the water under the impulse of its own engines; in the second case, with every condition from observation apparently the same, it might be found soaring upward until its wings made an angle of 60 degrees with the horizon, and, unable to sustain itself at such a slope, sliding backward into the water.

After much embarrassment the trouble was discovered to be due to the fact that the wings, though originally set at precisely the same position and same angle in the two cases, were irregularly deflected by the upward pressure of the air, so that they no longer had the form which they appeared to possess but a moment before they were upborne by it, and so that a very minute difference, too small to be certainly noted, exaggerated by this pressure, might cause the wind of advance to strike either below or above the wing and to produce the salient difference alluded to. When this was noticed all aerodromes were inverted, and sand was dredged uniformly over the wings until its weight represented that of the machine. The flexure of the wings under these circumstances must be nearly that in free air, and it was found to distort them beyond all anticipation. Here commences another series of trials in which the wings were strengthened in various ways, but in none of which, without incurring a prohibitive weight, was it possible to make them strong enough. Various methods of guying them were tried, and they were rebuilt on different designs, — a slow and expensive process. Finally, it may be said, in anticipation (and largely through the skill of Mr. Reed, the foreman of the work), the wings were rendered strong enough without excessive weight, but a year or more passed in these and other experiments.

In the latter part of 1894 two steel aerodromes had already been built which sustained from 40 to 50 per cent. of their dead-lift weight on the pendulum, and each of which was apparently supplied with much more than sufficient power for horizontal flight (the engine and all the moving parts furnishing over one-horse power at the brake weighed in one of these but 26 ounces); but it may be remarked that the boilers and engines in lifting this per cent. of the weight did so only at the best performance in the shop, and that nothing like this could be counted upon for regular performance in the open. Every experiment with the launch, when the aerodrome descended into the water, not gently, but impelled by the misdirected power of its own engines, resulted at this stage in severe strains and local injury, so that repairing, which was almost rebuilding, constantly went on, — a hard but necessary condition attendant on the necessity of trial in the free air. It was gradually found that it was indispensable to make the frame stronger than had hitherto been done, though the absolute limit of strength consistent with weight seemed to have been already reached, and the year 1895 was chiefly devoted to the labor on the wings and what seemed at first the hopeless task of improving the construction so that it might be stronger without additional weight, when every gramme of weight had already been scrupulously economized. With this went on attempts to carry the effective power of the burners, boilers, and engines further, and modification of the internal arrangement and a general disposition of the parts such that the wings could be placed further forward or backward at pleasure, to more readily meet the conditions necessary for bringing the centre of gravity under the centre of pressure. So little had even now been learned about the system of balancing in the open air that at this late day recourse was again had to rubber models, of a different character, however, from those previously used, for in the latter the rubber was strained, not twisted. These experiments took up an inordinate time, though the flight obtained from the models thus made was somewhat longer and much steadier than that obtained with the Penaud form, and from them a good deal of valuable information was gained as to the number and position of the wings, and as to the effectiveness of different forms and dispositions of them. By the middle of the year a launch took place with a brief flight, where the aerodrome shot down into the water after a little over 50 yards. It was immediately followed by one in which the same aerodrome rose at a considerable incline and fell backward, with scarcely any advance after sustaining itself rather less than ten seconds, and these and subsequent attempts showed that the problem of disposing of the wings so that they would not yield, and of obtaining a proper "balance," was not yet solved.

Briefly it may be said that the year 1895 gave small results for the labor with which it was filled, and that at its close the outlook for further substantial improvement seemed to be almost hopeless, but it was at this time that final success was drawing near. Shortly after its close I became convinced that substantial rigidity had been secured for the wings; that the frame had been made stronger without prohibitive weight, and that a degree of accuracy in the balance had been obtained which had not been hoped for. Still there had been such a long succession of disasters and accidents in the launching that hope was low when success finally came.

I have not spoken here of the aid which I received from others, and particularly from Doctor Carl Barus and Mr. J. E. Watkins, who have been at different times associated with me in the work. Mr. R. L. Reed's mechanical skill has helped me everywhere, and the lightness and efficiency of the engines are in a large part due to Mr. L. C. Maltby.

THE AERODROMES IN FLIGHT.

THE successful flights of Dr. Langley's aerodrome were witnessed by Dr. Bell and described by him as follows:[1]

Through the courtesy of Dr. S. P. Langley, Secretary of the Smithsonian Institution, I have had, on various occasions, the privilege of witnessing his experiments with aerodromes, and especially the remarkable success attained by him in experiments made upon the Potomac river on Wednesday, May 6, 1896, which led me to urge him to make public some of these results.

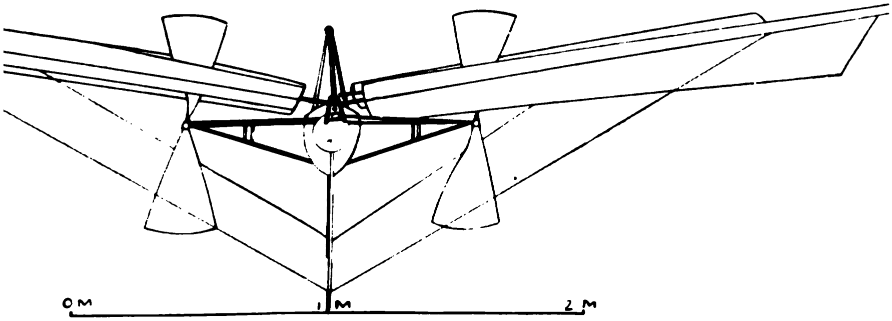
I had the pleasure of witnessing the successful flight of some of these aerodromes more than a year ago, but Dr. Langley's reluctance to make the results public at that time prevented me from asking him, as I have done since, to let me give an account of what I saw.

On the date named two ascensions were made by the aerodrome, or so-called "flying-machine," which I will not describe here further than to say that it appeared to me to be built almost entirely of metal, and driven by a steam-engine which I have understood was carrying fuel and a water supply for a very brief period, and which was of extraordinary lightness.

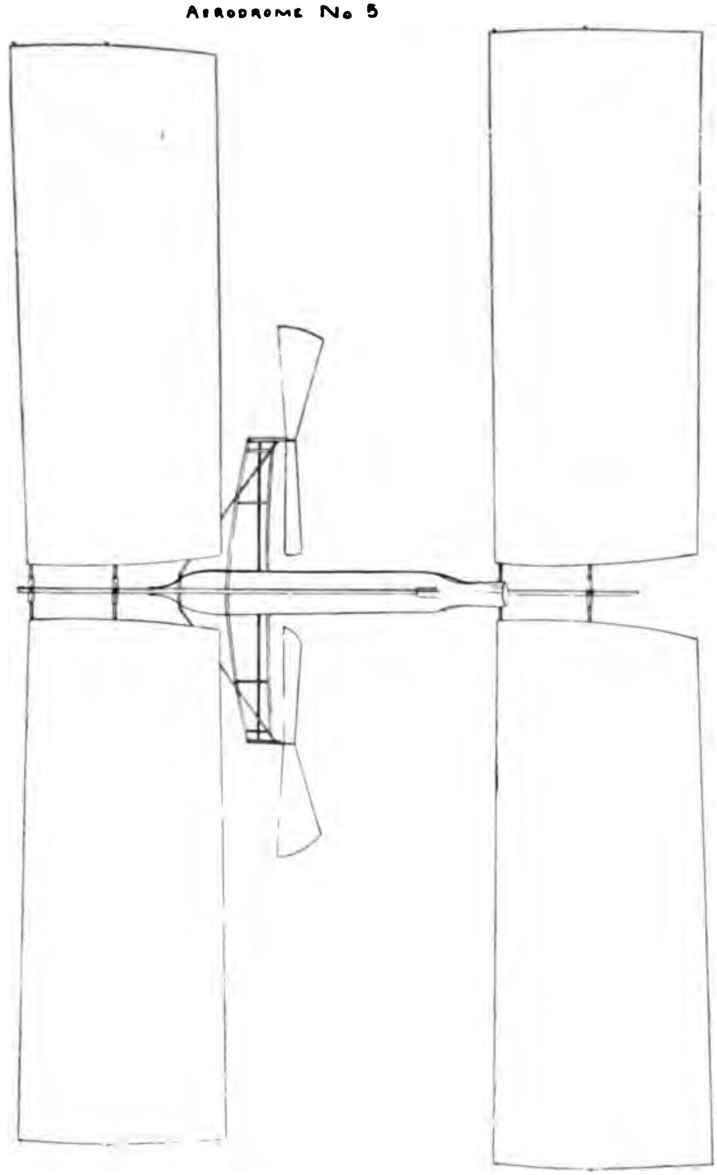
The absolute weight of the aerodrome, including that of the engine and all appurtenances, was, as I was told, about 25 pounds, and the distance from tip to tip of the supporting surfaces was, as I observed, about 12 or 14 feet. The method of propulsion was by aerial screw-propellers, and there was no gas or other aid for lifting it in the air except its own internal energy.

On the occasion referred to, the aerodrome, at a given signal, started from a platform about 20 feet above the water, and rose at first directly in the face of the wind, moving at all times with remarkable steadiness, and subsequently swinging around in large curves of, perhaps, a hundred yards in diameter, and continually ascending until its steam was exhausted, when, at a lapse of about a minute and a half, and at a height which I

[1] "Nature," London, May 28, 1896.



AERODROME No 5



AERODROME No. 5

SCALE DRAWINGS OF LANGLEY'S AERODROME No. 5.

judged to be between 80 and 100 feet in the air, the wheels ceased turning, and the machine, deprived of the aid of its propellers, to my surprise did not fall, but settled down so softly and gently that it touched the water without the least shock, and was in fact immediately ready for another trial.

In the second trial, which followed directly, it repeated in nearly every respect the actions of the first, except that the direction of its course was different. It ascended again in the face of the wind, afterwards moving steadily and continually in large curves accompanied with a rising motion and a lateral advance. Its motion was, in fact, so steady, that I think a glass of water on its surface would have remained unspilled. When the steam gave out again, it repeated for a second time the experience of the first trial when the steam had ceased, and settled gently and easily down. What height it reached at this trial I cannot say, as I was not so favorably placed as in the first; but I had occasion to notice that this time its course took it over a wooded promontory, and I was relieved of some apprehension in seeing that it was already so high as to pass the tree-tops by 20 or 30 feet. It reached the water 1 minute and 31 seconds from the time it started, at a measured distance of over 900 feet from the point at which it rose.

This, however, was by no means the length of its flight. I estimated from the diameter of the curve described, from the number of turns of the propellers as given by the automatic counter, after due allowance for slip, and from other measures, that the actual length of flight on each occasion was slightly over 3,000 feet. It is at least safe to say that each exceeded half an English mile.

From the time and distance it will be noticed that the velocity was between 20 and 25 miles an hour, in a course which was taking it constantly "up hill." I may add that on a previous occasion I have seen a far higher velocity attained by the same aerodrome when its course was horizontal.

I have no desire to enter into detail further than I have done, but I cannot but add that it seems to me that no one who was present on this interesting occasion could have failed to recognize that the practicability of mechanical flight had been demonstrated.

ALEXANDER GRAHAM BELL.

Not long after the May experiments Dr. Langley went abroad for needed rest and recreation, and in the autumn, after his return, further experiments were tried. On the 28th of November a flight was made which was more than three-quarters of a mile in length, the time occupied being precisely one minute and three-quarters. Mr. Frank G. Carpenter was a fortunate witness of this, the longest flight ever made, and with Dr. Langley's approval he wrote a detailed account of it for the "Washington Star" of Dec. 12, 1896. His article is interesting from beginning to end.

LANGLEY'S AERODROME IN FLIGHT.
May 6, 1896.

AERODROME No. 5, '96.

DR. LANGLEY has two successful aerodromes, No. 5 and No. 6; the former made the flights of May 6th and the latter that of November 28th. Plate II. gives scale drawings of No. 5, and Plate III. shows a perspective view of the same in flight. The weight of this, with fuel and water sufficient for the flights described, is about 30 pounds. The weight of the engine and boiler together is about 7 pounds. The power of the engine under full steam is rather more than one-horse power. There are two cylinders, each having a diameter of 1¼ inches. The piston stroke is 2 inches. The two screws are 39 inches from tip to tip, and are made to revolve in opposite directions; the pitch is 1¼; they are connected to the engines by bevel gears most carefully made; the shafts and gears are so arranged that the synchronous movement of the two screws is secured. The boiler is a coil of copper tubing; the diameter of the coil externally is 3 inches; the diameter of the tubing externally is ⅜ inch; the pressure of steam when the aerodrome is in flight varies from 110 to 150 pounds to the square inch. The flame is produced by the ælopile, which is a modification of the naphtha "blow-torch" used by plumbers; the heat of this flame is about 2,000 degrees Fahrenheit. Four pounds of water are carried at starting, and about ten ounces of naphtha. In action the boiler evaporates about one pound of water per minute. Flights could be greatly lengthened by adding a condenser and using the water over and over again, but, as Dr. Langley says, the time for that will come later.

RECENT EXPERIMENTS IN GLIDING FLIGHT.

By O. Chanute.

Having for a number of years studied the physical principles underlying flight, and having passed in review the experiments of others in a series of articles which eventually swelled into a book,[1] I ultimately reached the conclusion that the contingent compassing of artificial flight by man involved the study of at least ten separate problems, or the devising of means for observing and mastering the conditions enumerated as follows:

1. The resistance and supporting power of air.
2. The motor, its character and its energy.
3. The instrument for obtaining propulsion.
4. The form and kind of the apparatus.
5. The extent of the sustaining surfaces.
6. The material and texture of the apparatus.
7. The maintenance of the equilibrium.
8. The guidance in any desired direction.
9. The starting up under all conditions.
10. The alighting safely anywhere.

It is probable that some of these problems can be solved in more ways than one, and these solutions must then be harmoniously combined in a design which shall deal with the general problem as a whole, before the best possible result is attained.

I further reached the conclusion that the seventh problem, the maintenance of the equilibrium under all circumstances, was by far the most important, and the first which should be solved; that until automatic stability, at all angles of flight and conditions of wind, was evolved, and safety thereby secured, it

[1] "Progress in the Flying Machines," M. N. Forney, N.Y., Editor, 1894.

would be premature to seek to apply a motor or a propelling instrument in a full-sized machine, as these additions would introduce complications which might be avoided at the beginning.

I seriously doubted, at first, whether automatic stability could be secured with an artificial machine; whether such combinations could be devised, for an inanimate apparatus, as to perform the complicated functions of the life and instinct of the birds, who probably preserve their balance through almost unconscious reflex action of their nerves and muscles. Observation, however, indicated that this might be automatic, requiring no thought under ordinary conditions, and the final conclusion was reached that it might be possible to evolve an artificial apparatus which should afford automatic stability and safety most of the time; that the variations of the wind were the great difficulties to be encountered, that they must be met and overcome, and that perhaps they might be utilized in obtaining propulsion and support, as is daily done by the soaring birds.

I therefore published an article in the "Engineering Magazine" for April, 1896, in which I advised those seeking a solution of the problem of flight to turn their attention to experiments in soaring flight, with full-sized apparatus carrying a man, as the quickest, cheapest, and surest way of ascertaining the exact conditions which must be met in practical flight.

This mode of procedure doubtless involves a certain amount of personal danger of accident. It might be pointed out that the advice is easy to give, but hazardous to follow, and so I further determined to try such experiments myself, so far as my limited personal means would allow.

For this purpose I secured the services of Mr. A. M. Herring, who had tried some experiments of his own. He rebuilt for me his Lilienthal apparatus, with which he had made some gliding flights in 1894, and he also built another full-sized gliding apparatus after a design of my own.

These were completed in June, 1896, and on the 22d of that month we, a party of four persons, went into camp in the desert sand hills on the south shore of Lake Michigan, just north of the station of Miller, Ind., 30 miles east of Chicago.

These sand hills have been piled up by the wind blowing the sand from the beach. They gradually increase in altitude, from a point about 10 miles east of Chicago to the vicinity of St. Joseph, Mich., on the east shore of the lake, where they attain a height of 200 or 300 feet. They occupy a strip two to five miles wide around the south and south-eastern turns of Lake Michigan, and are bleak, bare, and deserted, being entirely incapable of cultivation. North of Miller, Ind., these hills rise about 70 feet above the lake. They are of soft yellow sand, almost bare of vegetation, and face in every direction of the compass, so that almost all directions of wind can be utilized in gliding experiments.

The method of carrying on these adventures is for the operator to place himself within and under the apparatus, which should, preferably, be light enough to be easily carried on the shoulders or by the hands, and to face the wind on a hillside. The operator should in no wise be attached to the machine. He may be suspended by his arms, or sit upon a seat, or stand on a dependent running board, but he must be able to disengage himself instantly from the machine should anything go wrong, and be able to come down upon his legs in landing.

Facing dead into the wind, and keeping the front edge of the supporting surfaces depressed, so that the wind shall blow upon their backs and press them downward, the operator first adjusts his apparatus and himself to the veering wind. He has to struggle to obtain a poise, and in a moment of relative steadiness he runs forward a few steps as fast as he may, and launches himself upon the breeze, by raising up the front edge of the sustaining surfaces, so as to receive the wind from beneath at a very small angle (2 to 4 degrees) of incidence. If the surfaces and wind be adequate, he finds himself thoroughly sustained, and then sails forward on a descending or undulating course, under the combined effects of gravity and of the opposing wind. By shifting either his body or his wings, or both, he can direct his descent, either sideways or up or down, within certain limits;

he can cause the apparatus to sweep upward so as to clear an obstacle, and he is not infrequently lifted up several feet by a swelling of the wind. The course of the glide eventually brings the apparatus within a few feet of the ground (6 to 10 feet), when the operator, by throwing his weight backward, or his wings forward if they be movable, causes the front of the supporting surfaces to tilt up to a greater angle of incidence, thus increasing the wind resistance, slowing the forward motion, and enabling him, by a slight oscillation, to drop to the ground as gently as if he had fallen only one or two feet.

These manœuvres require considerable quickness and dexterity, yet they are easily learned in a few days, the principal rule to be learned being that the movements to be bodily made are the reverse of those instinctive motions which would occur to catch one's self from falling if walking on the ground. In point of fact, we found that a week's practice sufficed for a young, active man to become reasonably expert in these manœuvres, and hundreds of glides were made with the several machines, experimented in 1896 under variable conditions of wind, without the slightest personal accident.

As before stated, we went into camp on the 22d of June, 1896. The party consisted of Mr. A. M. Herring, already mentioned, Mr. W. Avery, an electrician and carpenter, Mr. William Paul Butusov, a former sailor, and myself. The tent was large enough to shelter the machines, but we learned in a few days that this precaution was unnecessary, and that they could be safely left exposed to the wind, outside, by tying them down to pegs or to bushes, or even by loading them down with sand. There was a fishing station of two houses within a mile of the tent, from which outside aid might have been obtained in the improbable case of an accident. Miller Station was two miles inland, and, having come through that station with our suspicious baggage, we soon had more visitors than was altogether pleasant in preliminary experiments.

The Lilienthal machine was first set up. It is shown, poised for a flight, in Plate IV., Fig. 1. The wings were 20 feet from tip to tip, 7 feet 6 inches in maximum breadth, and measured

168 square feet in surface, with a weight of 36 pounds. Mr. Herring, who had used it before, took the lead in gliding with it.

It was realized from the first that the machine was difficult to handle and to poise in the wind. The variable puffs pelted the apparatus; they occasionally lifted one wing more than the other, or rocked the machine fore and aft, so that a struggle was necessary before a poise could be obtained. Once under way the same action continued, and the operator was compelled to shift his weight constantly, like a tight-rope dancer without a pole, in order to bring the centre of gravity directly under the centre of pressure and to avoid being upset. This, in fact, is the principle of the Lilienthal apparatus. The equilibrium depends upon the constant readjustment of the weight, so as to coincide with the variable position of the centre of pressure due to the shifting direction and force of the wind. Lilienthal, who evolved this machine, so superior to any that had preceded it, was an expert in its use. He made thousands of flights without serious accident; but it is due to those who may desire to repeat such experiments to state here plainly that we found it cranky and uncertain in its action and requiring great practice. If strongly built it was not, however, nearly so hazardous to life and limb as the above statement would seem to imply. The radiating ribs forming the frame of the wings extend downward about as low as the waist of the operator when in flight, and whenever an awkward landing is made, by reason of the apparatus tilting to one side or the other, the ribs on that side are the first to strike the ground. Acting as springs, breaking or not as the case might be, they save the operator from bodily harm even in a descent of 20 feet. These breakages were easily repaired by wiring on wooden splints to the ribs, so that practice could be resumed in a few minutes.

About 100 glides were made with this machine, the longest being 116 feet, and the heights started from were 20 to 30 feet in winds of 12 to 17 miles per hour. Mr. Avery proved an apt pupil, and in the course of a week learned to manage the machine nearly as well as Mr. Herring. Mr. Butusov did not do so well and was upset, but not harmed. I did not venture

Fig. I. — GLIDING MACHINE. p. 33.

Fig. 2. — See p. 35.

myself, feeling that I was no longer young and active enough to perform such acrobatic exercises without breaking the apparatus. After it had been broken, mended, tried again, and overhauled a goodly number of times, it was finally decided, on the 29th of June, to discard it, and it was accordingly broken up.

This decision was most unfortunately justified on the 10th of the succeeding August, when Herr Lilienthal met his death while experimenting with a machine based on the same principle, but with two superposed sets of wings. This deplorable accident removed the man who has hitherto done most to show that human flight is probably possible, who was the first in modern times to endeavor to imitate the soaring birds with full-sized apparatus, and who was so well equipped in every way that he probably would have accomplished final success if he had lived.

Having discarded the Lilienthal machine, we next turned our attention to the apparatus after my own design. This was based upon just the reverse of the principle involved in the Lilienthal apparatus.[1] Instead of the man moving about, to bring the centre of gravity under the centre of pressure, it was intended that the wings should move automatically so as to bring the movable centre of pressure back over the centre of gravity, which latter should remain fixed. That is to say, that the wings should move instead of the man.

The apparatus consisted in 12 wings, each 6 feet long by 3 feet wide, measuring 14¾ square feet in area, each pivoted at its root to a central frame, so that it could move fore and aft, this action being restrained by springs. The main frame was so constructed that the wings could be grouped in various ways, so as to ascertain the best arrangement for maximum support and for counterbalancing the effects of wind gusts, if possible. The total wing surface was 177 square feet, and the weight was 37 pounds. Fig. 2, Plate IV., shows the first grouping tested, which was found at once to be reasonably steady, but deficient in lifting power. It was recognized that the wings interfered

[1] To establish priority of invention a patent has been applied for.

with each other's efficiency; that the wind was deflected downward by the front wings, so that the middle and rear wings did not afford the same sustaining power as at the front. After making a few glides with this arrangement, a series of changes was tried to ascertain what was the best grouping and the best distance between the wings in order to obtain the maximum lift and the greatest steadiness. The paths of the wind currents in each arrangement of the wings were indicated by liberating bits of down in front of the machine, and, under their guidance, six permutations were made, each of which was found to produce an improvement in actual gliding flight over its predecessors.

The final arrangement to which this series of experiments led is shown on page 53. Five of the pairs of wings had gradually accumulated at the front, and the operator was directly under them, while the sixth pair of wings formed a tail at the rear, and being mounted so as to flex upward behind in flight, preserved the fore and aft balance. It was at once demonstrated that this apparatus was steady, safe, and manageable in winds up to 20 miles an hour. With it about 100 glides were made. The longest of these was 82 feet, in a descending course of about 1 in 4, against a wind of 13 miles an hour; the object constantly in view being not to make long glides, but to study the equilibrium of the machine and the principles which should govern in developing it further. These were found to be that the supporting surfaces should be concentrated at the front and the man placed directly under them; that the lowest wings should be at least 2½ feet above the ground; that they should be about two-thirds of their breadth apart vertically, and not less than their breadth apart horizontally, being set so as to present an angle of incidence of 3 to 7 degrees above the horizon when in flight, and that the wings should be pivoted so as to move very easily, the friction upon this first set of pivots having been found entirely too great to permit the wings adjusting themselves easily to the variations of the wind, and the man having had to move his body.

Having ascertained these facts, the experiments were termi-

CHANUTE'S 1896 GLIDING MACHINE IN FLIGHT.

Working drawings of this machine are given in Plate VII. Another view of the same machine is shown in Fig. I, Plate VI.

nated on the 4th of July, and the equipment was sent back to Chicago in order to rebuild the machine.

It may safely be asserted that more was learned concerning the practical requirements of flight during the two weeks occupied by these experiments than I had gathered during many previous years of study of the principles involved, and of experiments with models. The latter are instructive, it is true, but they do not reveal all the causes for the vicissitudes which occur in the wind. They do not explain why models seldom pursue exactly the same course, why they swerve to the right or left, why they oscillate, or why they upset. When a man is riding on a machine, however, and his safety depends upon the observance of all the conditions, he keenly heeds what is happening to him, and he gets entirely new and more accurate conceptions of the character of the element which he is seeking to master.

The fact which most strongly impressed itself upon us was the inconstancy of the wind. It is incessantly changing in direction and in strength. This fact is not new, it has been well shown experimentally by Mr. A. F. Zahm, by Professor Langley, and probably by others, but its effects upon a man-ridden machine must be seen and felt to realize that this is the great obstacle to be overcome in compassing artificial flight. It cannot be avoided, it cannot be temporized with, and it must be coped with and conquered before we can hope to have a practical flying-machine.

One remarkable feature of the wind, however, struck us as hitherto unknown, or at least unmentioned. *The wind gusts seem to come in as rolling waves*, rotating at a higher speed than the general forward movement. The buffetings which the apparatus received from the wind, while the operator was endeavoring to steady it, preparatory to a flight, seemed to indicate that he was struggling with a rotary billow which produced the fluctuations. Professor Langley has termed these fluctuations "the internal work of the wind," and it is quite conceivable that they should be produced by a revolving motion, striking the surfaces with velocities varying with the distance from the centre of rotation, and producing all the pulsations which have been revealed by the instrumental measurements.

Mr. Herring first called my attention to this feature of the wind, and I have ever since been wondering how I could, for so many years, have been watching smoke curling away from chimneys, steam convolving from trains, or dust and leaves whirling in wind gusts, without realizing that the elastic tenuity of air must perforce produce rotary motions much more active than those which occur in water.

This observation, if confirmed by further investigation, promises to give us a better understanding of the forces to be mastered. There are indications that there is a certain synchronism about these air waves, and that arrangements can be devised, not only to encounter them, but to avail of them in securing propulsion and automatic stability.

Be this as it may, we returned to Chicago much encouraged by the result of these preliminary experiments, with much clearer ideas as to the difficulties to be surmounted, and with good hopes that by reconstructing the machine we could obtain still better performances.

The original twelve-winged machine was reconstructed by pivoting the wings upon ball-bearings placed at the top and bottom of wooden uprights fastened to the main frame. The wings at the front were reduced to ten in number, in order to space them further apart without increasing their total height, but one pair was soon taken off, and the required supporting surface was restored by placing a concave aeroplane over the top of the wings. Two pairs of wings, superposed, were placed at the rear, but one pair was taken off after the first few trials, and the apparatus, provided with a rear keel or rudder, assumed the shape shown in Plate VI., Fig. 1. The total supporting surface at the front was then 143.5 square feet, the wings at the back measured 29.5 square feet, and the weight was 33½ pounds. The ball-bearings are at the level of the lower and of the third pair of wings from the bottom in the figure, and each set of moving wings, four in number, is connected rigidly by vertical wooden rods and diagonal wire ties so as to move

Fig. I.—CHANUTE'S 1896 GLIDING MACHINE. p. 38.

Fig. 2.—CHANUTE'S TWO-SURFACE GLIDING MACHINE. p. 39.

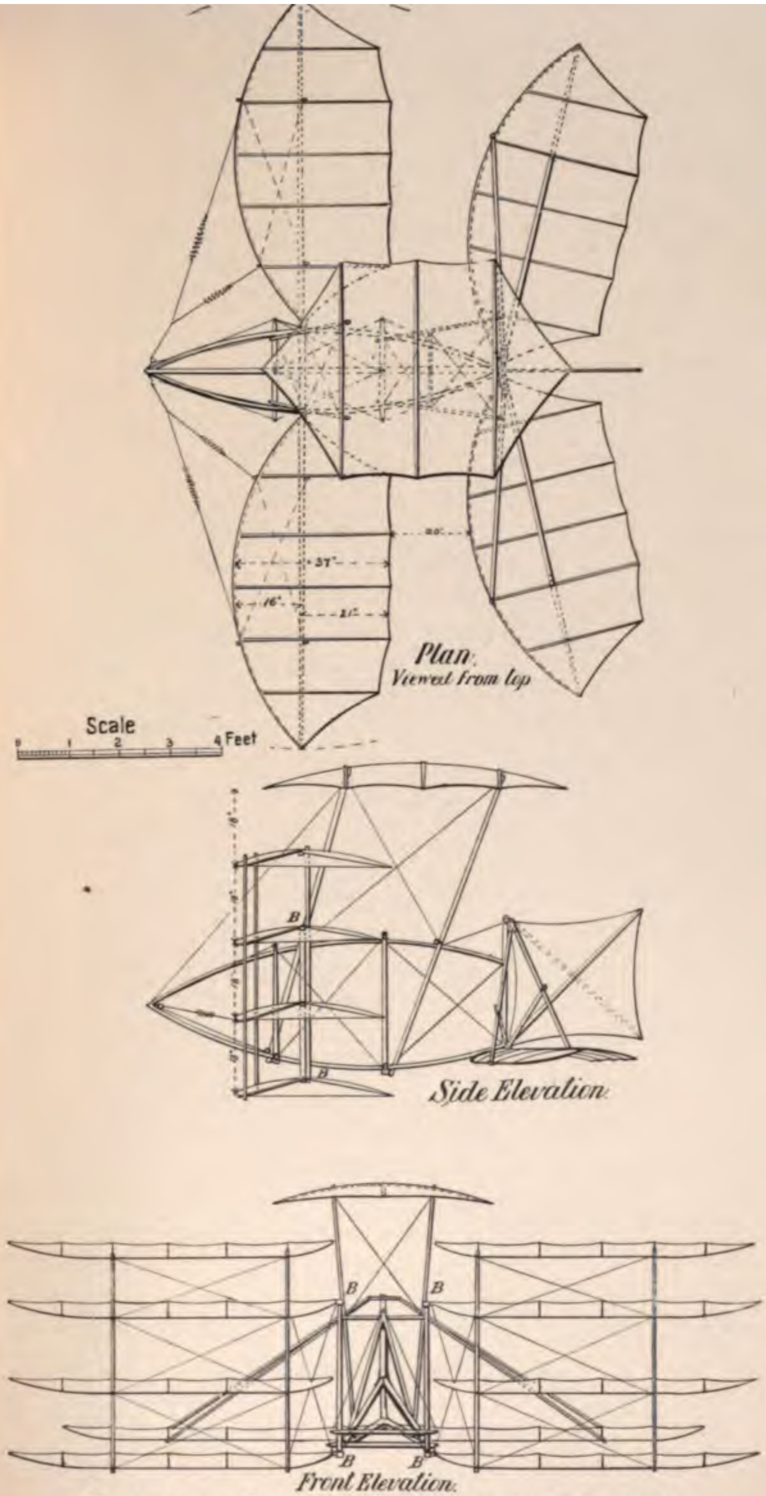
together. Elastic rubber springs at front and rear connect them with the frame and restrain the movements produced by the fluctuations of the wind and relative speed. The detailed construction of the apparatus is shown on Plate VII. It had been originally intended to erect the machine with five pairs of superposed wings at the front, and they were in fact put on, but the first few trials in the wind showed that the height and leverage were too great for easy control, and the top pair was accordingly taken off.

There was built simultaneously another full-sized machine, based upon a different principle. Instead of having pivoted wings, this consisted of three superposed concave surfaces, stretching 16 feet across the line of motion, by a breadth of 4 feet 3 inches, these surfaces measuring an aggregate of 191 square feet. The lower surface was cut away at the centre to admit the body of the operator. The machine was provided with a combined horizontal and vertical rudder, and its total weight was 31 pounds. The first few trials developed the fact that the sustaining power was in excess, and that the bottom surface was too near the ground. It was removed, leaving the apparatus in the condition shown on Plate VI., Fig. 2. The sustaining surfaces and the rudder were connected by an automatic device, designed by Mr. Herring, for the purpose of securing stability. The curvature of the wings (versed sine) was about one-tenth of the chord. Estimates were made in advance of head resistance due to the framing and to the drift of this machine. It was computed that it required a relative speed of 22 miles an hour and an angle of incidence of 3 degrees for support, and that its angle of gliding descent would be 10 degrees, or 1 in 5.6, which computations were fully verified in the experiments, as will be seen hereafter.

Still a third full-sized machine was constructed at my expense at the same time. This was designed by Mr. William Paul Butusov, who has already been mentioned as being present at the preliminary trials in June, and who stated that he had already tested with success a similar construction some seven years previously. This closely resembled the apparatus experimented by Le Bris in 1855 and 1867. It consisted in a boat-like frame of ribs and stanchions, which might be covered with stout oil-cloth and thus transformed into a boat. Above this were four longitudinal keels of balloon cloth, stretched on a frame, each 8 feet long and 3 feet deep. The central space was left open, but the two side spaces were roofed over. This occupied 8 feet in width, and immediately above were placed the wings, each 16 feet long, by a maximum width of 7 feet, tapering to the tips. The total spread was, therefore, 40 feet from tip to tip, and above this again a square aeroplane or kite was placed, hung on trunnions at its centre, so that its angle of incidence might be varied at will by lines carried to the hands of the operator. The latter stood upright in the boat on a running board 8 feet long, and might therefore shift his weight to that extent by walking forward or backward, and he might also shift it about 3 feet sideways by leaning to one side or the other. The whole arrangement is shown in Plate VIII., Fig. 1, except the rudder and tail, which are partly hidden by the man, and which are moved by light lines passing over pulleys and carried to his hands. In addition to this a pair of parallel bars (curtain-poles) were fastened to the frame, to which the man might cling or brace himself.

When finally completed the apparatus spread 266 square feet of sustaining surface and weighed 160 pounds. The various parts (wings, keel-roofs, top aeroplane, and tail) were then tested by suspending them inverted, and loading them with sand to the maximum load they might be called upon to carry, and as some of them showed signs of crippling, or did cripple, they were strengthened with additional material until they were safe to stand the strains. This brought the total weight up to 190 pounds.

These three machines being ready, we again went to the sand hills on the 20th of August, 1896. Having on the previous occasion found the vicinity of Miller too accessible to the public, we went, this time, five miles further down the beach, where the hills were higher, the solitude greater, and the path more obscure to the railroad, which it reached at a sand-pit



MULTIPLE-WING GLIDING MACHINE, Invented by O. CHANUTE, C.E.

station consisting of a single house, and called Dune Park. The distance from our camp was about two miles, through a series of swamps, woods, and hills, so that intending visitors not infrequently got lost.

We went from Chicago by a sailing vessel in order to avoid arousing gossip at the railroad station, and in the afternoon of August 21st we got the material unloaded and the tent pitched at the experimental hill. We hoped to begin setting up the machines on the morrow.

Unfortunately, that very night a fearful storm and whirling wind came up from the south-west at 3 A.M. It blew the tent to ribbons, blew away and wrecked such wings as were not boxed, while all of the party and the provisions were drenched, the camp equipage being moreover scattered and damaged.[1] It became necessary to send at once to Chicago for another tent, which arrived at Dune Park by express in the afternoon of the twenty-second, but this disclosed our presence to the people at the sand pit, and some ten days later brought down the newspaper reporters to see what we were about.

Our party consisted of five persons, Mr. Herring, Mr. Avery, Mr. Butusov, already mentioned, Dr. Ricketts, — a young surgeon who found that function such an entire sinecure that he could only exhibit to us his talents in cooking,— and myself. In addition to this there was, for a time, a carpenter to erect the trestle work from which to launch the Butusov machine. The hill selected faced the north and rose 100 feet above the lake, there being an intervening beach of about 350 feet between its base and the water. It was of soft yellow sand with many bare slopes, but with occasional clumps of trees and bushes. To the south it sloped to a bare wilderness of sand.

The first machine which was repaired and set up after the tornado was the aerocurve, with three superposed fixed surfaces and automatic tail attachment. It was first tested on the 29th of August, with tentative glides from a height of 15 to 20 feet above the bottom of the hill, but it was found to rock so that the lower surface struck the ground, hard to manage, and to lift

[1] The frying-pan was blown 200 yards away.

more than required. The lower aerocurve was therefore taken off, thus reducing the sustaining surface to 135 square feet, and the weight to 23 pounds. This was thereafter found ample to sustain an aggregate weight of 178 pounds (23 pounds of machine and 155 pounds of operator), and all the subsequent experiments were made with this arrangement. During the next 14 days scores and scores of glides were made with this machine, whenever the wind served. It was found steady, easy to handle before starting, and under good control when under way, — a motion of the operator's body of not over 2 inches proving as effective as a motion of 5 or more inches in the Lilienthal machine. It was experimented in all sorts of winds, from 10 to 31 miles an hour, the latter being believed to be a higher wind than any gliding machine had been tried in theretofore, and yet the equilibrium was not compromised, the machine gliding steadily at speeds of about 17 miles per hour with reference to the ground, and of about 20 to 40 miles an hour with reference to the air, or relative wind. On one occasion a relative speed of 52 miles an hour was acquired in a descent. Some of the best glides made were as follows:

Operator.	Length in feet.	Time in seconds.	Angle of descent.	Height fallen, feet.	Speed, feet per second.	Descent of
Avery..........	199	8.	10°	34.6	24.9	1 in 5.75
Herring........	234	8.7	7½°	30.4	26.9	1 " 7.69
Avery..........	253	....	10½°	46.	....	1 " 5.50
Herring........	239	....	11°	46.3	....	1 " 5.24
"	220	9.	....	....	24.4	
"	235	10.3	....	....	22.8	
Avery..........	256	10.2	8°	25.5	25.1	1 in 7.18
Herring........	359	14.	10°	62.1	25.6	1 " 5.75

One of these flights is shown by Fig. 2, Plate VIII.

The varying flatness of the angle of descent was undoubtedly due to the varying strength of the wind, and also to its ascend-

Fig. 1. — See p. 40.

Fig. 2. — A GOOD START.

ing trends as it struck the slope of the hill. The latter were exhibited by liberating bits of down at the foot of the hill, whence they would ascend parallel with the surface and pass over the top to the plain beyond. On many occasions the machine and man were raised higher than the starting point by increasing wind velocity, but this action was found to be much too irregular to be availed of as a source of power.

It was found that by moving the operator's body backward or forward, an undulatory course could be imparted to the apparatus. It could be made to rise several feet to clear an obstacle, or the flight might be prolonged, when approaching the ground, by causing the machine to rise somewhat steeply and then continuing the glide at a flatter angle. It was very interesting to see the aviator on the hillside adjust his machine and himself to the veering wind, then, when poised, take a few running steps forward, sometimes but one step, and raising slightly the front of his apparatus, sail off at once horizontally against the wind; to see him pass with steady motion and ample support 40 or 50 feet above the observer, and then, having struck the zone of comparative calm produced by eddies from the hill, gradually descend to land on the beach several hundred feet away.

A few hidden defects were gradually evolved, such as lack of adjustment in the automatic device, and occasional swerving out of the course in sudden gusts of wind; but safe landings were made in every case, by simply throwing the body back and causing the front edge of the aerocurve to rise so as to diminish the speed; and the machine was not once broken. It was kept out of doors moored to pegs driven in the sand, and was injured by storms on but three occasions. It was concluded, however; that a permanent machine of this kind should be arranged to fold up (as this was not) so as to admit of carrying it about and of sheltering it from the weather.

The movable winged machine (12 wings) was not set up till the 4th of September, 1896. Upon being tested, it was found at once that a mistake had been made in not providing entirely new wings for it. The old wings were so racked, twisted, and distorted by their prior service that they did not lift alike, and that it was difficult to poise the machine and to balance it in the wind. Nothing is so important in such experiments as to keep the sustaining surfaces in perfect shape and to prevent any racking when under strains. This is inculcated to us by the birds, who are constantly "pluming" themselves when on the perch. They pass each flying feather through their beaks, repair those barbs which have become separated, rearrange the lap of the feathers, and beat their wings up and down to limber up the muscles. I have reason to believe that it was in consequence of the failure to keep his apparatus in constant rigid good order that Herr Lilienthal so unhappily lost his life. A correspondent in Germany, who had witnessed his exercises two weeks before the fatal fall, wrote me that he had found that in the particular machine with which the accident occurred "the connections of the wings and of the steering arrangements were very bad and unreliable," that he had remonstrated with Herr Lilienthal very seriously, and the latter had promised that he would put the apparatus in order, but, with that contempt of danger which long familiarity and thousands of successful flights is sure to create, it is much to be feared that he did not attend to it immediately, especially as he was about to discard that particular machine for a new one from which he expected great results.

It was also found that in spacing the wings of the twelve-winged machine further apart, it had been made too high. The top was 10 feet 6 inches above the ground, and the leverage of the wind made it difficult for the operator to control the machine. The top pair of wings was accordingly taken off, and the experiments thereafter made with the apparatus as cut down. In this shape it proved steady and manageable, the flights being over twice as long, with the same fall as with the original machine in June. The following are some of the glides made on the 11th of September against a wind of 22.3 miles per hour:

Operator.	Length in feet.	Time in seconds.	Speed, feet per second.	Remarks.
Herring	148	7.	21.1	Angle not measured.
Avery	174	7.6	22.9	" " "
Herring	166	7.5	22.1	" " "
Avery	183	7.9	23.1	" " "
Herring	172	7.8	22.	" " "

The angles were approximately 10 or 11 degrees, or 1 in 5.

This machine had been provided with a swinging seat, consisting of network with a narrow board at its front, and with a pair of swinging bars and stirrups against which the legs could be braced, so as to move the wings fore and aft by means of light lines running through pulleys. The heights started from being only 30 to 35 feet above the base of the hill, and the glides being accordingly very brief, these attachments could not be brought into action, but their efficacy was tested by suspending the apparatus between two trees and facing the wind with a man in the seat. It was found, as was expected, that by thrusting the wings forward the machine was tossed up, and *vice versa* that by thrusting one wing forward the machine turned towards the opposite side, and that these would be effective ways of directing the apparatus when under flight, either up or down, or in a circling sweep. The automatic regulation, however, did not work as well as was hoped, perhaps in consequence of inaccurate adjustment of the springs. The man still had to move about one inch to preserve the equilibrium when under way. The machine made steady flights and easy landings, and was not once broken in action. It is certainly considered safer and more manageable than the Lilienthal apparatus which we tested. No photographs were taken of this machine in flight, as it was not tested nearly so often as would have been desirable, and whenever it was, something always interfered to prevent getting the camera.

It must be confessed that the results with this apparatus were rather disappointing, and yet the principle is believed to be sound. As the variations of the wind are constantly changing the position of the centre of pressure, it is necessary that either the wings or the weight shall move, or that the angle of incidence relative to the air shall be absolutely maintained in order to keep the centre of pressure and the centre of gravity upon the same vertical line. These are the two principles which are involved in the two machines which have herein been described. Which of the two shall hereafter prove to be most effective in practical use, or whether the two can be combined, cannot be determined at present, but it is my judgment that one or two more seasons should be devoted to perfecting the automatic equilibrium, to eliminating hidden defects, and to adjusting the strength of the springs and moving parts, before it will be prudent to apply a motor, or to try to imitate the soaring of the sailing birds.

Towards the last we gathered such confidence in the safety of the machines that we allowed anybody to try them who wanted to. A number of amateurs took short flights, awkwardly of course, but safely. One of them was raised about 40 feet vertically and came down again so gently that he felt no jar upon alighting. Others glided from 70 to 150 feet, and all agreed that the sensation of coasting on the air was delightful, although they were somewhat timid about tempting fate too many times. Any young, active man can become expert in a week with either of these machines.

We performed nothing like continuous soaring with any of the machines. The fluctuations of the wind were entirely too irregular to be availed of; for a wind gust, which tossed a machine up, was almost immediately succeeded by a lull which let it down again. If we had had a long, straight ridge, bare of trees at its summit, and a suitable wind blowing at right angles thereto, we would have attempted to have sailed horizontally along the top of the ridge, transversely to the resulting ascending current. This manœuvre is frequently and easily performed by the soaring birds over the edge of a belt of trees. They ride across the face of the ascending aerial billow, decomposing its upward trend into propulsion as well as support. The feat should be performable by man, and should, in my judgment, be attempted before circling flight is tried. It requires, of course, that the equilibrium shall be first mastered, and also that the angle of flight shall be flatter than with our machines. This was, as has been seen, from 8 degrees to 11 degrees, or a descent of 1 in 7 or 1 in 5. Now, the soaring birds generally sail at angles of 4 degrees to 6 degrees, or a descent of 1 in 15 to 1 in 9, and hence they lose very much less elevation. This disadvantage in the machines resulted from the increased head resistance due to the framing and spars as compared with the wing edges of the birds, and especially from the fact that in order to give the man easy command over his movements and to let him land on his feet, he has to be in the natural erect position. This produces a body resistance due to about 5 square feet of surface, while it would be that due to only about 1 square foot if the man were placed horizontally, as is the body of the bird. It is probable, however, that the machines can be improved in this respect, and that flatter angles of flight will be obtained than those recorded herein.

The apparatus of Mr. Butusov, like that of Le Bris, had been inspired by watching the sailing of the albatross in southern latitudes. He stated that having begun by experimenting with the main wings, he had been led to add various adjuncts, such as the keels and the top aeroplane in order to improve the stability. It was no part of the original programme to test such a machine, but in view of the degree of success said to have been attained both by Le Bris and by Mr. Butusov, it was determined to give the apparatus a trial.

As it weighed 190 pounds, and the operator's own weight was 130 pounds, a total of 320 pounds, it was necessary to furnish special appliances for launching the machine. This was provided for by building an inclined trestle work, which consisted in a pair of tallowed guides or ways, 8 feet apart, descending at an angle of 23 degrees down the slope of the sand hill selected, the top being 94 feet and the bottom 67 feet above the lake. The last 10 feet of these launching ways was horizontal, and connected with the sloping portion by a curve of 5 feet radius. The ways stood about 11 feet above the side of the hill, the central space between them being entirely unobstructed, the supports being braced by raking posts and braces. The trestle faced due north, so as to avail of the north wind, which, blowing down the whole length of Lake Michigan, arrived with fewer of the whirls and eddies than prevailed with the winds coming from the south, south-east, or south-west. These had been disturbed by blowing over the sand hills, and it is a peculiarity well worthy of note by other experimenters that they will find it much preferable to avail of winds which have traversed across a sheet of water or a level plain than of those which have come over hills, trees, or other obstacles.

This fixed position of the launching ways, however, unfortunately required the waiting for a north wind to blow before experiments could be conducted with this apparatus. The prevailing winds in September were from the south, and there were many storms, so that the instances were rare indeed, during the three weeks which elapsed after the trestle and apparatus were completed, when the wind came from the right direction, and with just the velocity (18 to 25 miles per hour) which was desired. Hence the machine was not given that complete and thorough test which it would have received had the inventor accepted my proposal to launch from ways rigged up on a floating barge, which might have been anchored or towed against any wind of suitable velocity.

Before proceeding with the tests, the whole apparatus was carefully measured. It was ascertained that the whole sectional area of the framing, spars, wing edges, ribs, stanchions, guys, cords, etc., including 5 square feet for the body of the operator, was 44.92 square feet, reduced, however, by reason of the rounding of the parts to an equivalent of 33.28 square feet, which area, multiplied by the pressure, would give the head resistance; that the apparatus would require a relative speed of 25 miles an hour (3.06 pounds per square foot pressure) in order to float it at an angle of incidence of +2 degrees, and

Fig. I. — CHANUTE'S LAUNCHING WAYS.

Fig. 2. — See p. 58.

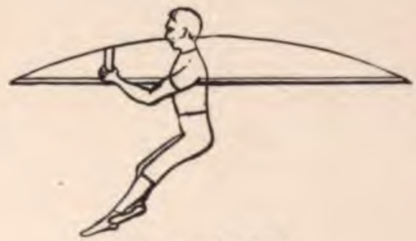


Fig. 3. — See p. 58.

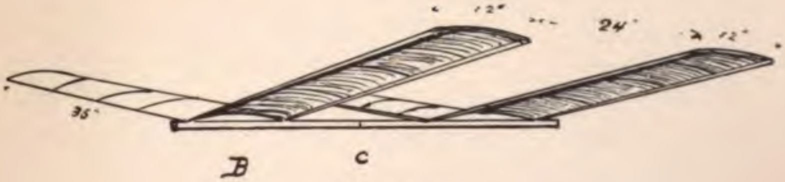


Fig. 4. — See p. 62.

that, therefore, if Lilienthal's coefficients were used, the total resistances would be:

Head resistance, 33.28 sq. ft. × 3.06 lbs.	= 101.83 lbs.
Tangential component, 266 sq. ft. × 3.06 lbs. × 0.008	= 6.51 "
Retarding component, 320 lbs. × (sin 2° = 0.035)	= 11.20 "
Total,	119.54 "

So that the angle of descent might be expected to be:

$$\frac{320 \text{ lbs.}}{120 \text{ lbs.}} = 1 \text{ in } 2.67 \text{ or } 22 \text{ degrees.}$$

These calculations were closely verified, as in the case of the other two machines.

It was the 15th of September (1896) before a proper wind served. It then set in from the north about noon and blew 28 miles an hour. The apparatus was accordingly placed in the ways, tested as to fit by running it up and down restrained by head and tail ropes, and then it was placed upon the level portion of the ways facing the wind. Additional guy lines were fastened to the wings, and Mr. Butusov got into the machine. The guy lines were manned, and the apparatus was suffered to rise 2½ to 3 feet above the ways, in order to test its balancing and the degree of control of the operator over its movements.

This appeared to be complete. A very slight step to the front or rear sufficed to depress or to raise the head of the machine, and the side motions were equally sensitive. The support was found to be ample from a 28-mile wind, and it was apparent that the great range of motion provided for the operator would give him command of the machine at all angles of incidence. The apparatus was then hauled down by the guy lines and settled back upon the ways squarely, resting thereon by means of four sliding shoes projecting from the machine on a line with the top of the boat-like body. It is shown in that position by Fig. 1, Plate IX.

It was desired next to launch it in ballast, and also to test it as a kite, and preparations were begun for that purpose; but a small rip having been discovered in one of the wing coverings, and a buckling in one of the braces, it was thought more prudent to repair these before proceeding further, and the machine was removed from the ways.

The wind changed to the south-west in the night, but on the 17th it again blew from the north, with a speed, however, of but 12 miles per hour. In the hope of its freshening, the machine was got into the ways, loaded with 130 pounds of sand in bags, and rigged as a kite, by fastening a bridle to the keel of the boat and leading therefrom a long rope passing through a pulley fastened to a post in the sand, 250 feet away on the beach. This rope was handled by four men, with instructions to run with it so as to take up the slack as soon as the apparatus left the ways. Four guy lines, hanging down from the front and rear, and from each wing of the machine, were likewise manned, in order to control the movements of the kite in case of need.

All being ready, the restraining line was cut and the machine slid down the tallowed ways and took the air fair and level. It went horizontally some 20 feet, but its motion was then checked by the friction on the sand of the kite line, which the crew, gazing open-mouthed at the sight, failed to haul in as the machine flew forward. This check was sufficient to overcome the initial velocity proper to the machine, and the wind (12 miles an hour) was insufficient to sustain it. The apparatus glided downward and landed squarely on its keel about 100 feet from the end of the ways, a descent of about 1 in 2. The tip of one wing struck the hillside, but no harm was done as it flexed. Some three or four of the stanchions of the boat frame were, however, broken. These were replaced in two hours, but the wind had fallen so light by that time that the experiment could not be repeated.

To test the apparatus properly a north wind of about 25 miles per hour was required. This did not set in again till just before the advancing season compelled the breaking up of camp and returning to the city. On the 19th of September the equinoctial storm set in and blew from the north-west 56 to 60 miles an hour. Another gale of 60 miles an hour blew on the 22d, ac-

CAMP CHANUTE, 1896, SOUTHERN SHORE OF LAKE MICHIGAN.

BLUE HILL OBSERVATORY, MILTON, MASS.

Founded by A. Lawrence Rotch, Esq.

See pp. 149 to 153, 157, and 170 to 172.

companied by heavy rains. These were followed by southerly winds, so that it was the 26th before the machine could be tested again. A wind then set in from the north-east, with a speed of 18 miles an hour, and although this was quartering, instead of dead ahead as was desired, it was determined to launch the apparatus. This was first attempted with the operator in the machine, but as the quartering wind greatly increased the friction of the launching ways and diminished the required initial speed, the operator was replaced by 90 pounds of sand in bags, and a rope was fastened to the front of the machine in order to increase its velocity by pulling thereon. The apparatus went off, but as soon as it had fairly left the end of the ways, the quartering wind swerved the head of the machine around, and it took a descending north-westerly course, describing a curved path. The tip of the left wing then struck the top of a tree, swinging the machine around further, and then this same wing struck the hillside and was broken. The machine then fell to the ground, landing upon its keel about 75 feet from the end of the ways, and a number of ribs and stanchions were broken, so that the repairs, if made, would probably have occupied a day or two.

It was evident that the machine was moderately stable; that on neither this nor on the previous trial would the operator have been hurt if he had been in the machine; but it was also evident that the apparatus, as then proportioned, glided at too steep an angle to perform soaring flight; that it would lose so much altitude when going with the wind that the loss would not be recuperated when turned to face the wind. It was recognized that this, as well as the other two machines, could be modified so as to materially reduce the head resistance and thereby flatten the angle of descent, but the season was so far advanced, the weather so inclement, that it was decided to break up camp and to return to the city. This was done on the 27th of September.

Such were the experiments. They occupied an aggregate of seven or eight weeks in the field, they were carried on without the slightest accident to the operators, and they made manifest several important conclusions. The first is that it is reasonably safe to experiment with full-sized machines, if the methods and writings of Lilienthal be previously studied. The second is that experiments with full-sized machines, carrying a man, are likely to be more instructive and fruitful of eventual progress than experiments with models. The third is the inference that it is probably possible to evolve an apparatus with automatic stability in the wind, but that in order to do so, there must be some moving parts, apart from the man, in order to restore the balance as often as it is compromised. The fourth conclusion is that the problem of automatic stability will be most easily worked out with a light apparatus, so light as to enable the operator to carry it with ease, and so arranged as to enable him to use his legs in landing. The fifth conclusion is that it will require a good deal of experimenting to adjust the working parts, to regulate the springs, and to discover hidden defects, before it will be quite safe to try to perform soaring feats in the wind. The sixth is that the incessant fluctuations of the wind, which so very greatly complicate the problem of maintaining automatic stability, probably result from the rotary action of its billows, and future experimenters are urgently advised to study this action and to endeavor to meet it.

A word or two of caution may also be given. It is best to begin experimenting with a new machine in short and low gliding flights over bare and soft sand hills, but more ambitious flights and soaring feats should be attempted first over a sheet of water to mitigate the fall should anything go wrong. Experiments should not be tried in high or gusty winds, and the apparatus should be frequently examined and kept in constantly perfect order. Wire stays should be employed as sparingly as possible. Not only do they vibrate when the machine is under way, and so increase the resistance, but they get loose and allow the apparatus to become distorted. It is well to fly a model of a projected apparatus as a kite, but it does not follow that a satisfactory kite will make a good flying-machine, because the required angles of incidence are so different. A good kite will fly steadily at an angle of 20 or 30 degrees with the wind, but a good flying-machine needs to fly at an angle of 2 to 5 degrees to reduce the drift to the lowest possible.

I do not know how much further I shall carry on these experiments. They were made wholly at my own expense, in the hope of gaining scientific knowledge and without the expectation of pecuniary profit. I believe the latter to be still afar off, for it seems unlikely that a commercial machine will be perfected very soon. It will, in my judgment, be worked out by a process of evolution: one experimenter finding his way a certain distance into the labyrinth, the next penetrating further, and so on, until the very centre is reached and success is won. In the hope, therefore, of making the way easier to others, I have set down the relation of these experiments, perhaps at tedious length, so that other searchers may carry the work of exploration further.

One of Mr. Chanute's Gliders: see p. 36.

RECENT ADVANCES TOWARD A SOLUTION OF THE PROBLEM OF THE CENTURY.

BY A. M. HERRING.

PERHAPS no subject offers more scope to the imagination than the benefits and changes for mankind which would result from a practical solution of the problem of manflight. At the same time there is probably no problem which the inventive skill of man has ever attacked which apparently offers, at first sight, more numerous and easy ways of unravelment, and yet which, on careful investigation, develops greater or more unexpected difficulties. In the beginning of experiment the methods apparently open might be roughly divided into four classes.

The first of these would comprise all those machines in which the whole or part of the weight was lifted by a balloon or gas-bag; the second, all those forms of apparatus which were intended to sustain or lift their weight with screw propellers revolving on vertical axes; the third, those machines which were intended to sustain their weight (and that of the operator) on flapping or beating wings; the fourth, and last, class would contain the aeroplane, or more properly the *aero-curve* machines; for the aeroplane may now safely be said to have disappeared from competition with the more efficient form of surface.

The limitations of the navigable balloon are now pretty well recognized. To obtain a speed of even 20 miles per hour, a spindle-shaped envelope of very large size is necessary, and the result at its best is an exceedingly frail and bulky machine, whose ultimate speed capacity is insufficient for wind velocities which frequently occur even near the ground. Its chief defects are great bulk and extreme frailty; for the envelope, in proportion to its relative size, is not many times stronger than a soap bubble. An instance may be cited in support of this in the large navigable balloon built for the Antwerp exposition, which became tilted up during a trial, when the rush of gas to the higher end burst the balloon.

The future utility of the navigable balloon is still the subject of differences of opinion; it is, however, certain that whatever may be its ultimate practical advantages as a flying machine, the drawbacks of enormous size and frailty are sure to offer a considerable offset to them.

The vertical screw machines have much to recommend them, but there are far greater difficulties offered to their production than would be supposed. The ability to rise directly into the air from any given spot would be an exceedingly desirable quality. And hence we find that the great majority of experimenters who attack the problem of dynamic flight begin here, starting with a plan of some modification of this type of machine. The stumbling-blocks, however, are soon met. Not least among them is the fact that when the surfaces which form the blades of the screws are revolved over one spot (as they must be to rise directly into the air) they do not give any considerable lifting effect in proportion to the power consumed; for where one might from the theory even of the aeroplane expect a lift of possibly 100 pounds per horse-power, the best result the inventor can produce on a practical scale is pretty sure to be less than one-seventh of that figure. In fact, the lift with the lightest engines we can build is likely to be but little, if any, more than the weight of the machine itself. With engines weighing much more than 4 or 5 pounds per horse-power (250 times as powerful weight for weight as a man), practical success with this type of apparatus is not possible.

The third class, or the beating wing machines, are subject to the same disadvantages in regard to the enormous power required as those of the vertical screw type. In addition to this, the question of maintaining a stable equilibrium in windy weather still further greatly complicates them, so much so, in fact, that there is but small hope of practical machines operated on this principle ever being produced.

It is unnecessary to point out that any combination in a machine of the principles involved in either of the above three classes would still subject it to the fundamental objections of at least one of the classes. These objections are so formidable that to the great majority of the foremost workers in this field, there now appears but one main principle left, and upon this there is an ever-increasing hope, if not certainty, that flight will be accomplished. This principle is the one which underlies the aeroplane and aerocurve; namely, that when a thin surface is driven rapidly through the air, and is slightly inclined to its path, the equivalent of a pressure is developed on the side which is exposed to the air current — *i.e.*, the under side — which is much greater than the driving force necessary to produce it. If an arched surface (arched in the line of motion) with the hollow side undermost be substituted for a plane, we have an aerocurve. Its chief advantage is that it possesses a higher efficiency. Another but minor difference is that it is not necessary to incline an aerocurve in order to develop a pressure on the hollow side when it is moved through the air. [What is spoken of here as a pressure on the under side is chiefly a partial vacuum over the upper surface.]

The one advantage which the dynamic or power machine of the aerocurve type has over the vertical screw is the fact that it can, through the agency of the surfaces, convert the relatively small push of the screw propellers into a much larger lifting effect.

It is interesting to note that the first approach to human flight of modern times was attained only by the use of the aerocurve, when early in 1894 the late Otto Lilienthal, of Berlin, Germany, built a huge bat-like machine, with curved rigid wings, on which he was able to "slide" downhill on the air, 150 feet or so at a time.

Practice with this machine soon enabled him to start from very high places, and his flights became correspondingly longer. Early in the beginning of these trials, he became aware, as his writings show, of the enormous power and disturbing effect which those ever-present irregularities in the wind produce, and which, in a large measure, were the cause of his losing his life—a sad accident which has taken from the field of aerodynamics one of, if not, *the* ablest of its workers; for both the practical and theoretical work of Lilienthal in the new science is of the greatest value, and will be so recognized when more generally understood.

In his first articles Lilienthal repeatedly cautioned others against attempting to glide in winds which exceeded 7 metres a second (about 15½ miles an hour), as being excessively dangerous. However, when he made the improvement on his machine of superimposing two smaller surfaces and thereby reduced the "tip to tip" measurement from about 24 feet to 18 feet, the diminished leverage upon which the gusts could act enabled him to sail in stronger winds, so that he even experimented in winds of 22 miles an hour. This, without further improvement in the automatic stability of his machine, was an unwise thing to do, and the accident which occasioned his death, on the 9th of last August, is, more or less correctly, attributed to it; nevertheless, the immediate cause was undoubtedly the result of defects in the machine itself, which had been allowed to deteriorate and get out of repair. In his double-deck machine the upper surface was joined to the lower one by two or three small vertical posts and numerous wires. Probably some of these wires had become rusted or so weakened that they broke when the machine was struck by a heavy puff, and so allowed the upper surface to tilt back and suddenly stop the headway of the machine, but not that of the unfortunate operator, who swung round and round over the apparatus as it pitched to the ground. This tendency to revolve over backward is frequently set up by a very strong sudden gust striking the machine squarely in front; it can, however, be counteracted by a quick movement of the operator's body and legs toward the front. A serious defect in the design of the Lilienthal apparatus is here seen, for on it the operator's position is somewhat strained, and his movement very limited, owing to the fact that he is obliged to hold to a small bar with both hands, while his weight is carried on his elbows, which rest, a little farther back, on a portion of the main frame. (See Plate IX., Fig. 2.)

These defects suggested themselves to the writer when, in the summer of 1894, he built a machine similar in many respects to that of Lilienthal. It differed from his in two important particulars: first, the upward movement of the horizontal tail was limited; second, the range through which the operator could shift his weight was nearly three feet instead of about eight inches. To obtain this range of movement the weight of the body, when in flight, rested upon two horizontal bars fitting under the armpits. (See Plate IX., Fig. 3.)

No very startling results, however, were obtained with this machine or with the three subsequent ones, the longest flight attained being only 187 feet in length; experiment with these machines, nevertheless, furnished a great deal of valuable information. No one who has not experimented with a machine of the Lilienthal type can form any accurate conception of the tremendous power and lifting effect which 130 to 150 square feet of concave surface can exert. It is with an apparatus of this kind that a novice first becomes fully aware that no wind is anything like constant, and that the power of those much-talked-of "gusts" is real, and not imaginary.

Any one wishing to begin experiment with a gliding machine cannot be too cautious in the selection of an experimental station. Nothing could be more dangerous than to start from a flat roof or a precipitous cliff, or to begin experiment in a locality where surrounding objects, such as hills, buildings, or even large neighboring trees, are likely to break up the wind into swirls and eddies. What is most desirable — in the beginning, at least — is a hill surrounded by country that is as level as possible. Both the starting and landing points should be on comparatively soft earth, free from stones, bushes, and snags. Perhaps the best station of all is to be had where there are high, bare sand-hills or dunes, facing a large body of water. The slope of such a hill (to a beginner) is of as much importance as anything else; it must be steep at the top and run off gradually as it nears the bottom so that when he has gained proficiency enough he may start from near the top in calm weather and yet have his flights always close to the hill-side. If this be so and the soil be comparatively soft, the operator can easily save himself from a dangerous fall which might result from a poor start or a breakage of the machine.

In first experiment with a full-sized gliding machine, a man's natural instincts irresistibly impel him to move in the wrong direction when the balance of the apparatus is disturbed. It is, therefore, at first, impossible to distinguish between effects produced by one's own errors and those produced by wind changes, but in time three separate causes of unsteady flying become easily distinguishable from each other; namely, improper adjustment of the machine, errors of the operator, and changes in the trend, velocity, or direction of the wind.

When the mastery of the machine becomes about as perfect as possible very much of this unsteadiness disappears; nevertheless, with a wind as steady as winds ever are, — even after having blown for hundreds of miles over absolutely level prairie, or, as in the case of our later experiments, having come in an unobstructed path for several hundred miles over the waters of Lake Michigan, — we found that the effect was by no means a steady one, but was such as to indicate that they were broken up into an inconceivable number of irregularities in pressure, velocity, and direction, in spite of the fact that a light anemometer showed fluctuations in velocity of seldom more than 10 or 12 per cent. in readings of 5 seconds' duration, taken 10 to 20 seconds apart.

In a wind of 9 to 10 miles per hour with a simple machine of the Lilienthal type the disturbances of the wind are barely noticeable, but at 12 miles they are quite apparent, at 14 miles they require considerable practice to combat, at 16½ miles, even with best skill at command, a flight is more or less risky; and when the wind blows above 18 miles per hour it is dangerous, even with a total load of 182 pounds (machine, 27 pounds, operator, 155 pounds) on 130 square feet of surface.

Nothing, perhaps, is more surprising than the power which a gust in even a 14 or 15 mile wind will occasionally exhibit, such, for instance, as sometimes happens to an inexperienced or careless operator, who, in facing the wind with the machine preparatory to making a start, suddenly finds himself lifted anywhere from 2 to 10 feet above his starting place. These flights are invariably backward, and are due to mismanagement in allowing the wind to catch under the surface of the machine while the operator is too far back on it to exert a proper control. In the hands of a skilled person, the flights, in mild winds, generally appear to an on-looker as remarkably smooth, and even in spite of the fact that the operator is seen to frequently shift his position on the machine with considerable rapidity; yet in slightly stronger winds — those of 15 to 16½ miles per hour (mean velocity) — the irregularities become very perceptible to the spectator, who may sometimes see the apparatus rock and toss not unlike a ship in a rough sea.

To appreciate the causes which render a gliding machine, or in fact any machine of the aerocurve type, unstable, it is necessary to understand, in a measure, both the peculiarities of the wind and the effect they have on the position of the centre of pressure of the surfaces.

In order for any apparatus in free air to be in equilibrium it is necessary, of course, that the centre of pressure should be in the same vertical line as the centre of gravity. It is not, as many believe, absolutely necessary that the centre of weight should be beneath the sustaining surfaces; this may be demonstrated by trying the small paper model shown in Plate XII., Fig. 1, which, if not weighted too heavily, will always fly with the "fin" side up, even if dropped with the weight and fin side undermost.

When a surface is inclined to the air through which it is moving, the lifting pressure is not uniform, but is very much greater toward that edge which is first struck by the current. On a square *plane* 100 inches on a side, the centre of all the lifting pressures may be anywhere between the centre of figure and as far forward (apparently) as 14 inches from the front edge, according to the angle and speed at which the surface is presented to the air. The travel sidewise might be even more, granting that gusts may come from either side. With an aerocurve the travel is probably seldom more than $\frac{1}{5}$ as much as it would be with a plane. In practice with any ordinary gliding machine of large surface it is found that the gusts come from any quarter: in front of the apparatus, from the extreme left to the extreme right, and in a wind of over 22 miles per hour they follow each other with such suddenness and with such extreme changes that it is absolutely impossible to shift one's weight in time to counteract them. These conditions, which had to be met, made it imperative to seek for automatic stability along very different lines from any that had heretofore been tried.

The changes or gusts which have the most influence in disturbing the machine are seldom of more than half a second duration, and oftentimes they last less than half that time; yet in so short an interval, it has frequently happened to me, in my experiments with my first three gliding machines, that in less than half a second the lateral equilibrium was so far disturbed that the lateral axis of the machine would make an angle of 35 to 40 degrees with the horizontal. At other times, the angle of advance (the angle at which the surfaces are presented to the air) was so much increased that nearly every bit of the headway was destroyed. On two occasions, the change in direction, both vertically and to the side, was so violent and sudden as to shake my hold loose of the machine.

During my last flight on a Lilienthal type of machine, while experimenting in a wind of about 18 miles an hour, the machine was struck twice in quick succession by a gust from the right. The first impulse raised that side until the apparatus stood at an angle of about 40 degrees; the second impulse, which came between $\frac{1}{4}$ and $\frac{3}{4}$ of a second later, increased the inclination to nearly a vertical one, so that one wing pointed to the ground and the other to the zenith. Anticipating a complete overturning of the machine (as did happen) I let go my hold and dropped to the sand below, a distance of not more than 12 or 14 feet, where I landed on my feet, but on the left wing of the overturned machine, which had drifted under me as

I fell. This accident damaged the machine so much that it was not rebuilt. We recognized from these experiments that the disturbances increased much more rapidly than the mean velocity of the wind; also that in winds of 18 miles or over, it was impossible for a man to shift his weight far enough and rapidly enough on a single surface machine to keep it in proper equilibrium under all circumstances.

In addition, the conclusions were reached, first, that the angle of advance *must* be automatically maintained, with almost absolute certainty, at a very small angle; second, that the lateral equilibrium should also be largely, if not wholly, automatic, and be maintained by some more effective method than a dihedral angle between the surfaces, or by placing the operator far beneath the apparatus. The first of these is considerably the most important, as disturbances of the angle of advance generally entail disturbances of the lateral equilibrium as well.

In the beginning of experiment to obtain longitudinal stability, three clearly defined methods (each with its own limitations developed by experiment) appeared open.

The first and simplest method is to find such a surface, or grouping of surfaces that the displacement of the centre of pressure is very great for very small changes of the angle of incidence; the second method is to find such a form of surface that its centre of pressure remains in one spot, no matter from what angle the relative wind may come; the third method is to provide a separate mechanism to either take up or counteract the disturbing effects of the wind changes.

The first method may be said to have been practically attained (as far as it is attainable by such an arrangement) in the various modifications of the Hargrave kite, and also in its predecessor, the Brown biplane, or, a little better still, in what might be called a "bicurve," — that is, a biplane machine on which slightly arched surfaces have been substituted for planes. Such a model is shown in Plate IX., Fig. 4, B being the front aerocurve. This model will maintain a very good equilibrium for gliding flight so long as the centre of gravity is anywhere between C and the rear edge of B; but each change in the position of the centre of gravity corresponds, of course, to a different angle of flight, *i.e.*, to an angle at which the centre of pressure of the combined surfaces coincides with the vertical line through the centre of gravity of the whole apparatus.

The centre of pressure travels toward B as the angle of flight is diminished, and in the reverse direction when it is increased. This great range in the possible position of the centre of pressure is a measure of the corresponding change in efficiency which the rear surface undergoes at various angles of flight. This efficiency diminishes very rapidly as the angle of flight is diminished; at very flat angles its useful effect disappears altogether. Not only this, but at small angles of incidence, those under 8 degrees, the longitudinal stability of the arrangement disappears as well. From many experiments with gliding models of this type I found it impossible to obtain glides which represented a travel of over 4 lineal feet for each foot of height lost, unless the model was so weighted that no part of the weight rested on the rear surface. Also, that the power required to support any given weight at an angle of 15 degrees or less is about *twice* as much as would be needed on superimposed surfaces of the same size held at the same angles of inclination.

When the model shown in Plate IX., Fig. 4 (or any similar one) is so loaded that each surface must carry about half the total weight, the apparatus will take up an angle of about 26 degrees with the relative wind. Under this condition a dynamic model would require between 40 and 46 per cent. of its weight in thrust to keep it "afloat," or if liberated as a gliding model it will travel forward a little over twice as far as it descends vertically. At the flattest angle, about 15 degrees, at which it maintains a good equilibrium, it will glide only 3 to 3¼ times as far as it falls.

As the rear surfaces in an apparatus with following surfaces come more and more in the "wake" of the front elements, the relative supporting effect of the rear becomes less and less as the angle of flight is diminished. Thus, through the phenomena of "interference," the relative efficiency (as a lifting factor) of the rear surfaces becomes greater or less (as the angle of flight is increased or diminished) — a corresponding travel of the centre of pressure results which maintains the longitudinal equilibrium, but at the expense of extra weight of apparatus and considerable additional power.

This fundamental principle — that of interference — underlies the stability of the Malay, Eddy, Bazin, Lamson, Chanute, and Hargrave kites. It is still further applied in the three last named, in which the vertical keels form pairs of Brown's "biplanes," which maintain the lateral equilibrium as well.

It would seem that one might be able to avail of the wonderful stability which a system of following surfaces exhibits, by so grouping the surfaces *vertically* as well as horizontally that they could not interfere. It is comparatively easy to so space them that interference is practically avoided, but from several hundred experiments in this direction I have invariably found *that the automatic equilibrium is always impaired in direct proportion as the front and rear surfaces cease to interfere.* The further conclusion arrived at from these experiments was that in following surface machines, a low efficiency is essential to insure safe equilibrium. Quantitively this efficiency is so low that probably less than 30 pounds can be carried per horse-power when the surfaces are loaded to a greater extent than one pound per square foot of area. Consequently, though dynamic models might be made that would work satisfactorily on this plan, a full-sized machine to carry even one man would offer no such encouragement to its projector, chiefly because the weight of a machine increases much more rapidly than its surface or supporting power. Following surfaces therefore are not available.

Just as experiment and careful measurement made this fact clear, a new prospective method of obtaining automatic equilibrium began to open up. A study of the peculiarities in the travel of the centre of pressure of variously arched surfaces indicated the possibility of evolving such a form that the centre of the lifting pressures would remain in the same spot for all angles of inclination. The result of much investigation in this line is shown in Plate XI., Fig. 1. Strictly speaking, this piece

Fig. I.—See p. 65.

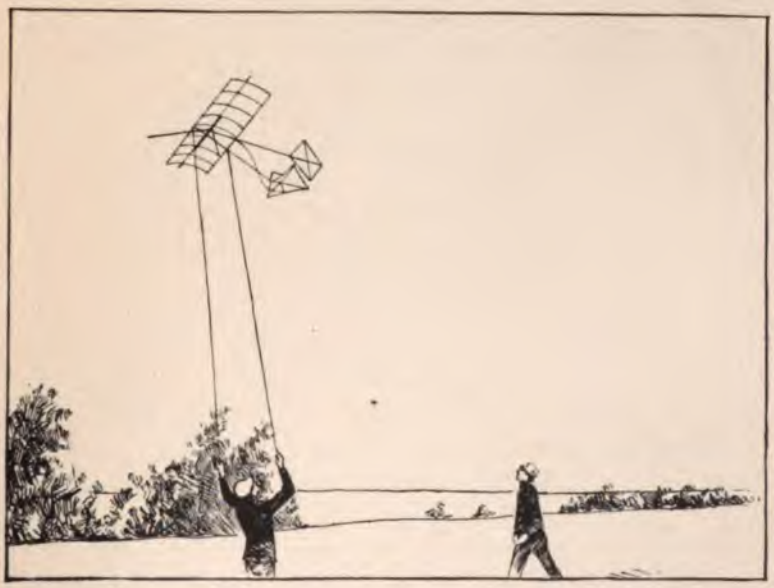


Fig. 2.—See p. 67.

of apparatus is a gliding model, and as such in a wind of 30 miles an hour or less it possesses a perfect equilibrium, owing to the fact that the position of its centre of pressure is almost absolutely constant for all angles of incidence between plus 90 degrees and minus 20 degrees; the same is also approximately true whether the wind strikes from in front or "abeam." It will also fly as a tailless kite, but as such is somewhat inferior to the Hargrave, both in steadiness and in the "angle of the string," yet the lifting effect is probably four times as great per square foot of surface. The projected area of the dome[1] is not quite 6 square feet, yet in some experiments it has registered a pull of over 40 pounds on a spring-balance, and on one occasion repeatedly broke a cord tested to 69 pounds.

As a flying machine it would have the advantages of being able to sustain great weight on a very small surface, and would require but a slow speed to do so. A dome machine of only 9½ feet in diameter would be of sufficient size to carry a man in gliding flight at a speed (relative to the air) of only 20 to 21 miles per hour. But its drift is so great that it would not carry the operator horizontally more than 2¼ to 2¾ times the height from which it started. As a great thrust of the screw is far more costly in power than great speed, such a machine could hardly be a practical success. However, owing to the very low sailing-speed a dynamic machine to carry one man might be built which would fly; but it would be of little practical value, owing to the excessive power required, and its limited speed capacity. This line of experiment was therefore laid aside in the spring of 1896.

By way of explanation I may here add that from a great number of previous experiments with various devices — such as modifications of the drag rudder, gyrostat, and pendulum regulators — I had come to the belief (which all my more recent experiments have only served to strengthen) that *the action of any device to maintain a machine in safe equilibrium must be*

[1] The plan of the dome is nearly circular, being only about one-eighth longer across the wind than with it. The curvatures of the front to rear sections are (as near as possible) all similar, each having a rise of 24-100 of the chord length, and having its highest point 42-100 of the same distance from the front.

such that it prepares the machine for each impending wind-change before that change actually occurs, and that any device which tends to forcibly right the flying machine *after* it has departed from an even keel more often produces (in the open air) greater *unsteadiness* than the reverse. The reason for this is not far to seek. It lies chiefly in the fact that the most formidable, as well as the most frequent, disturbances met with in the natural wind are cycloid gusts or rotating masses of air which frequently give a machine (or model) powerful double impulses. These impulses are generally opposite in their effect, and succeed each other by irregular intervals varying from about one-fourth to one second apart; and, therefore, a regulator, such as a pendulum or gyrostat mechanism, which begins to act on the machine after it is disturbed, and continues to do so until it regains an even keel, is often the means of greatly augmenting the second impulse of the pair, or the first of a new gust which may strike the apparatus from a different quarter. I do not mean to say that such devices will not work at all; on the contrary, they can be made to give very good results in fairly mild weather, but they all fail in winds of much less velocity than those which any practical machine must be able to contend with.

This conclusion reached, it would appear that the methods left would be found only through a careful study of the wind-changes themselves. As before stated, I had become aware almost from the beginning of my gliding experiments of several distinct kinds of disturbances, the most formidable being very sharp, well-defined changes in the velocity and direction of the wind, which last but a fraction of a second and appear to come in pairs. Their distinguishing characteristic (besides their much greater suddenness and power) is, that in practically all cases they are preceded by a perceptible warning which generally consists of a slight strengthening of the wind followed by a momentary calm, which in turn is followed immediately by the "gust" in its fullest force. During the momentary freshening, the wind either comes from or veers in the direction from which the gust proper will strike. These changes can easily be

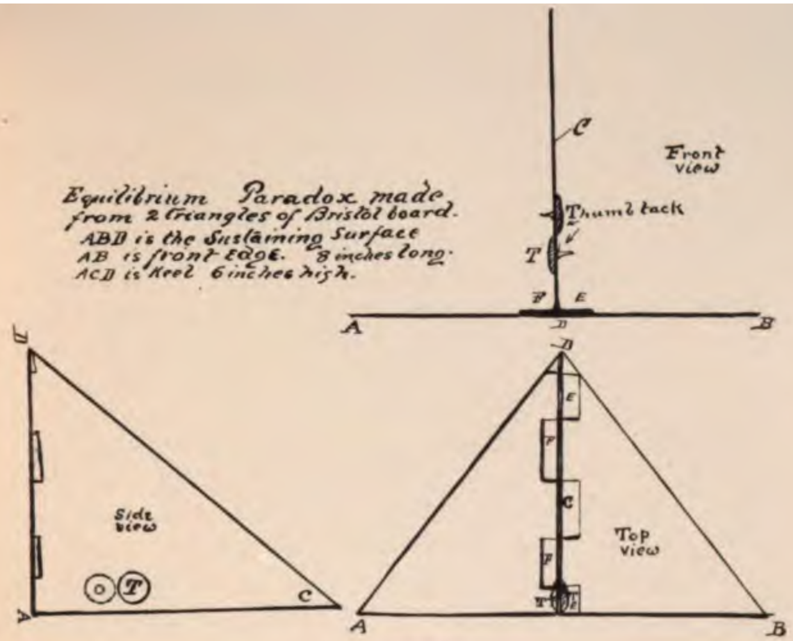


Fig. 1.— See p. 60.

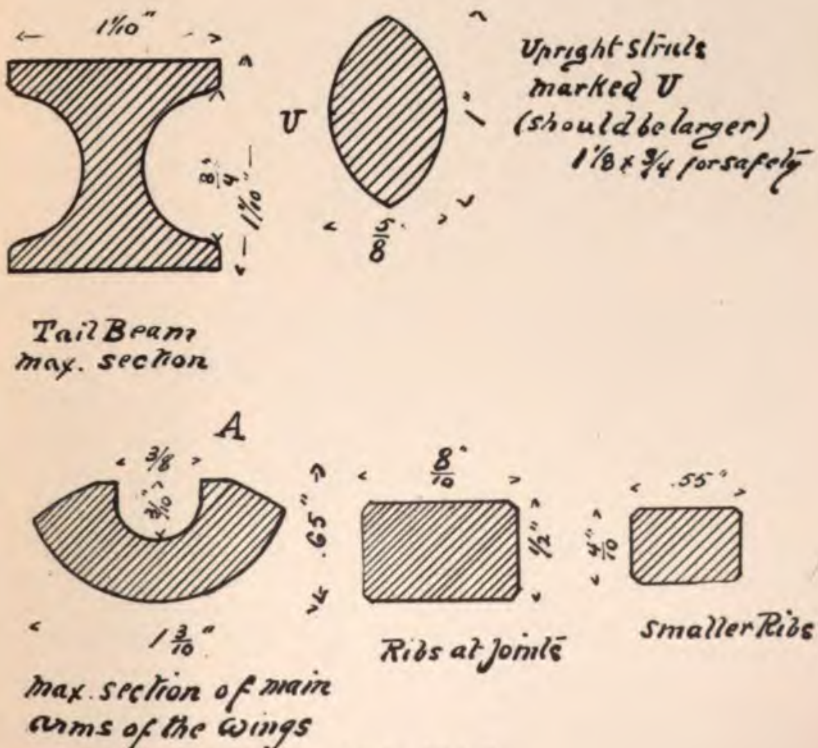


Fig. 2.— See p. 72.

verified by an observer in a strong wind by noting the effects as he feels them on his face.

There are many observations which might be given to corroborate the theory that practically all the gusts which have any material effect in disturbing the angle of advance or the lateral equilibrium of an apparatus are of a rotary character; they are, in fact, nothing more or less than diminutive tornadoes; which travel, however, much more rarely on vertical axes than on diagonal or horizontal ones. In a few cases the axis of a gust is found to be horizontal and parallel with the wind. In the majority they are nearly horizontal, but across the direction of the mean wind. The direction of rotation is usually backward, *i.e.*, in the reverse direction that a wheel would have in rolling over the ground. In what may be called steady winds the swirls are of much greater diameter, and the out-flowing eddies, or the momentary freshening of the wind, precede them by a longer interval.

The observations which led to a recognition of the rotary character of the wind-changes also were the means which furnished an explanation of the action of certain simple devices previously found to work with success as far back as 1890 on a small dynamic model which has been illustrated in a previous issue of this Annual.[1] I was, therefore, not wholly in the dark in commencing experiments to produce a regulator which should prepare the apparatus to meet each particular "gust" before it arrived.

The horizontal regulator of the dynamic model was slightly modified to adapt it more closely to the new theory, and in May, 1896, applied to the kite shown in Plate XI., Fig. 2. This kite, which is here shown in a 28-mile wind, possessed such perfect power in maintaining the surfaces at a small angle with the wind, through changes which would otherwise prevent it from flying at all, that, in momentary freshening or changes, it would rise until the strings passed the zenith and made an angle of 6 to 8 degrees beyond the vertical. The average angle maintained by the surfaces with the horizontal varied between such narrow

[1] Aeronautical Annual, No. 2, pp. 94 and 95.

limits that it could not be easily detected by the eye. From a number of observations it was found possible to set the regulator to maintain an angle of between 2 and 3 degrees (above the horizontal), and calculations from the weight and surface of the kite, the pull on the string, and its angle above the horizontal show that the lift and drift of the kite correspond very closely indeed with the theoretical ones computed from the annexed tables.[1]

Later in the summer this regulating device was improved and its use extended so as to counteract the rotating columns whose axes were more or less vertical, and thus preserve the lateral equilibrium of the apparatus. With this change it was applied to the gliding machine shown in Plate XIII., Fig. 1. By its use the safe limit of wind in which experiments could be carried on was raised from 16½ miles per hour (with the simple Lilienthal, or 20 miles with the Lilienthal double deck) to over 30 miles, and with it the maximum length of flight was increased from 187 feet to 359 feet; at the same time the rocking and tossing of the apparatus was reduced to such an extent that an on-looker could not in any of the 150 to 200 flights detect that the apparatus in flight ever departed from an even keel, either laterally or longitudinally, — *i.e.*, the angle of advance was maintained perfectly at the very flattest angle. It is evident from repeated measurements that this angle never exceeded 4 degrees with the relative wind.

The difference in the amount of ascending trend of the wind at different times and at various points in front of the hill made great differences in the length of flights. The results of an average flight in calm air are here given:

Net projected area of 2 supporting surfaces, 134 square feet; size, 16 feet 2 inches × 4 feet 4 inches.

Net area of horizontal tail (which receives a pressure on its upper side), 19 square feet.

Weight of machine, 23 pounds.

Weight of operator, 155 pounds.

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[1] See page 178. [These tables were computed in English measures from data and fundamental formulæ given by the late Otto Lilienthal.]

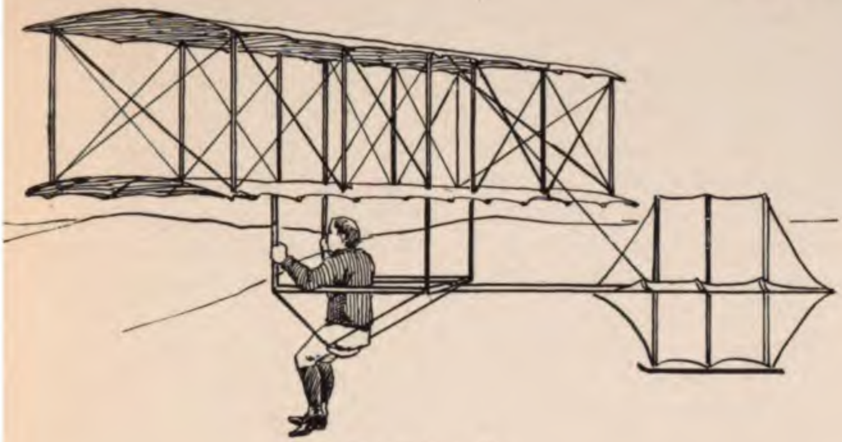


Fig. 1. — See p. 68.

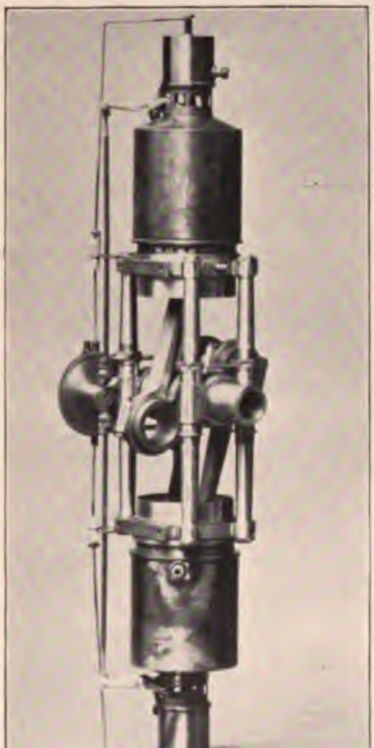


Fig. 2. — HERRING'S MOTOR. See p. 72.

Pressure on upper side of tail (acting as weight), about 7 pounds.

Total weight carried by 134 square feet, 185 pounds.

Total weight carried per square foot area, 1.37 pounds.

At the time of the following experiment the air was nearly calm, the only trace of wind was from the north-east; the flight was made by running downhill toward the north. Length of flight, 242 feet from last foot-print to first at landing; time of flight, 7.4 seconds (in the air); difference in level between points was 42½ feet. Speed of machine was therefore practically 22 miles an hour. The wind pressure is $22 \times 22 \times .005 = 2.42$ pounds per square foot. The proportion of this as a sustaining factor was $\frac{1.37}{2.42}$, or 57 per cent. By referring to the tables (see p. 178) hereto appended it will appear (see second column, opposite positive angle of 3 degrees and 4 degrees) that this amount of lift (57 per cent. of the normal pressure) corresponds to a positive angle of the surfaces of between 3 and 4 degrees, and by referring to the third column we find that the drift of the surfaces is (.0525 for 3 degrees and .0582 for 4 degrees) about .056 times the total weight of machine and operator and negative pressure on the tail, or $.056 \times 185 = 10.36$ pounds, which is drift of the surfaces alone; to it we must add the head resistance offered by the framing of the machine and that offered by the operator's body. The framing consists of 64 lineal feet of timber which forms the main arms of the wings; this has a thickness of ⅝ of an inch across the wind, and therefore exposes a cross-section surface of about 3.3 square feet. The upright posts are 64 feet in collective length, being on an average $\frac{6}{10}$ of an inch in width (across the wind). Their area is therefore practically 3.2 square feet. But as they are sharpened more or less to lessen the resistance they offer to the wind, the total area offered by the woodwork, instead of being $3.3 + 3.2 = 6\frac{1}{2}$ square feet, is equivalent to only 2½ square feet. Besides this the framings of the tail and vertical rudder expose an equivalent of half a square foot of surface. The regulator and its cords, bands, etc., expose .52 of a square foot, and 160 lineal feet of wire .05 of an inch in diameter expose the equivalent of .5 square foot more, making the total equivalent area exposed equal to 4.02 square feet. This at 22 miles an hour would offer a resistance of $4.02 \times 2.42 = 9.73$ pounds; to this must be added the resistance offered by the 5 square feet of the operator's body, arms, and legs. This brings the total resistance to: Resistance of surfaces, or drift, 10.36 pounds; head resistance of machine, 9.73 pounds; and resistance offered by operator, 12.1 pounds; total = 32.19 pounds. This moved over a distance of 242 feet would consume $242 \times 32.19 = 7,790$ foot-pounds, which would be furnished by the weight of the machine and operator (178 pounds), descending through a vertical distance of $7,790 \div 178 = 43$ feet 9 inches, against an actual measured height of only 42½ feet. The difference in energy can easily be accounted for in either of three ways: First, a slight overestimate of the resistance offered by the operator's body; second, the presence of a slight ascending current of air; or, lastly, that the speed gained in running down the hill at the start was greater than 22 miles an hour. (It is possible to gain a speed of 26 miles if the weight is about half supported on the machine.) It may be interesting to point out in passing that the energy (7,790 foot-pounds) absorbed in keeping the machine and operator afloat during 7.4 seconds represents barely 2-horse power, but less than one-third of this is drift of the surfaces. It is, however, now pretty well known that it would take at least 3-horse power to produce a thrust of 32 pounds, even with as large screws as could be conveniently carried on a machine of this size.

The details of the regulating mechanism of neither this nor the "three-deck" machine have been here given, as they are now the subject of applications for patents; nevertheless, to any one wishing to repeat the experiments I shall be pleased to give all the information necessary.[1]

During October I constructed a new machine of the same general design as the "double deck," but provided with three superimposed surfaces instead of two. In this a considerable

[1] The author's address is, A. M. Herring, 372 East Ontario street, Chicago, Ill., U.S.A.

change was made in the mechanism which governed the lateral equilibrium. Instead of depending upon the power in the small eddies which precede a rotating gust to operate the machine, their power was used only to work the valves of a mechanism operated by compressed air; in this way the regulation (which is accomplished through a reflex action) became much more powerful and prompt. The tests of the new gliding machine showed that a considerable advance had been made, in that the limit of wind velocity in which flights were safe was raised from 31½ miles an hour to over 48, and the maximum length of flight increased from 359 feet to 927 feet (best) and 893 feet (second best); at the same time it was found quite safe to turn the apparatus and fly at a considerable angle with the wind. It was by this means chiefly that the length of flight was increased, as the longer flights were made while "quartering" on the wind; that is, the apparatus after starting (the start must always be made dead against the wind) was kept pointing at an angle from 15 to 35 degrees with the wind, according to the strength of the latter, while the apparatus itself moved along a course nearly, but not quite, at right angles to the wind. This enabled me to keep close to the hill-side and take advantage of the rising current of air flowing over the slope. In a few of the flights it would have been possible to have landed on a higher point than the starting one, owing to irregularity of the wind which occasionally raised me, after having gone several hundred feet, to a level above my starting place; these rises were only momentary, and all the flights as a whole were on a descending grade. As the slope both to the right and left had several clumps of small trees which it was necessary to steer over or around (according to the height at which the machine happened to be while it passed near them), these "quartering" flights were not made to any great extent.

With a machine on which the angle of advance is automatically controlled with a fair degree of accuracy, the steering requires but little more effort than a bicycle, and at the same speed, *i.e.*, above 20 miles an hour, I have much doubt in my mind whether a bicycle (on a level road) could be turned on a much shorter radius than a flying machine. It is possible to land within less than 5 feet of any predetermined spot if it be selected well within the range of flight of the starting place.

In a few of the glides with the last machine I attempted to carry an additional weight, in the shape of a bag partially filled with sand. This bag was fastened between the middle and bottom surfaces, and beginning with about 12 pounds, the weight was gradually increased until 41 lbs. were carried without materially shortening the length of flight. The heavier weight considerably increased the difficulty in landing in light wind, owing to the greater speed relative to the ground. In high winds it was of very little hinderance either in starting or landing. The object in view in experimenting with the weight was to ascertain the power required on a dynamic machine and to test the manageability of the apparatus with a weight equivalent to the necessary engines and supplies. The result was so very encouraging that I have since then commenced constructing the engines. One of the pair is shown in Plate XIII., Fig. 2. It develops (alone) about two-thirds of the total thrust-power needed; its weight is only twelve pounds; its action is, however, a little irregular, and on that account is still the subject of experiment; it is a gasolene engine of the Otto cycle type.

Not least among the interesting results brought out by these gliding experiments is the fact, which becomes more and more evident from repeated experiment, that there is a very great difference in the supporting power of the air, whether one faces the natural wind or advances through still air; for while a natural wind of 18 to 19 miles per hour is sufficient (over level ground) to support the double-deck machine and operator, and will even momentarily raise them directly in the air for a foot or two, the same machine requires a minimum speed of 22 miles to support the same weight at the same angle in still air.

On Plate XIV. are given drawings of the three-deck machine; another drawing will be found on Plate XII., Fig. 2, giving exact sizes of struts, etc., in cross-section. If built to scale the

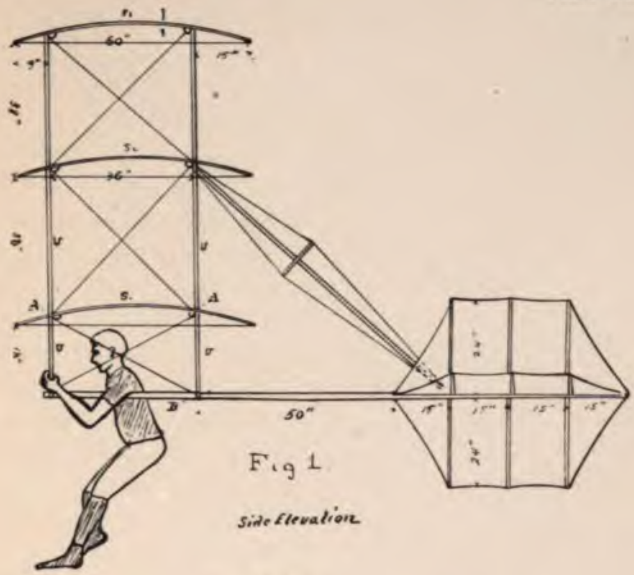
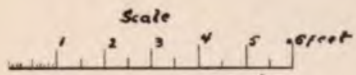


Fig 1

Side Elevation



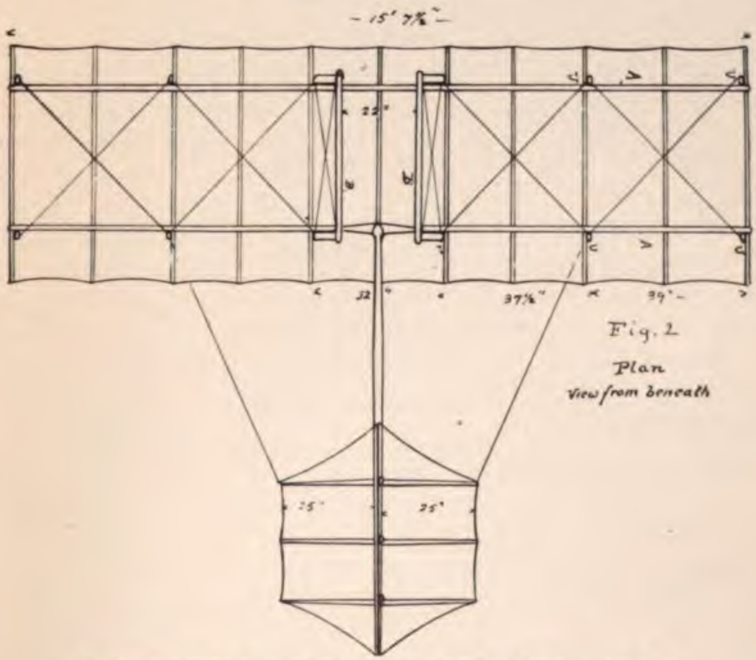


Fig. 2

Plan
View from beneath

WORKING DRAWINGS OF HERRING'S GLIDING MACHINE. See p. 72.

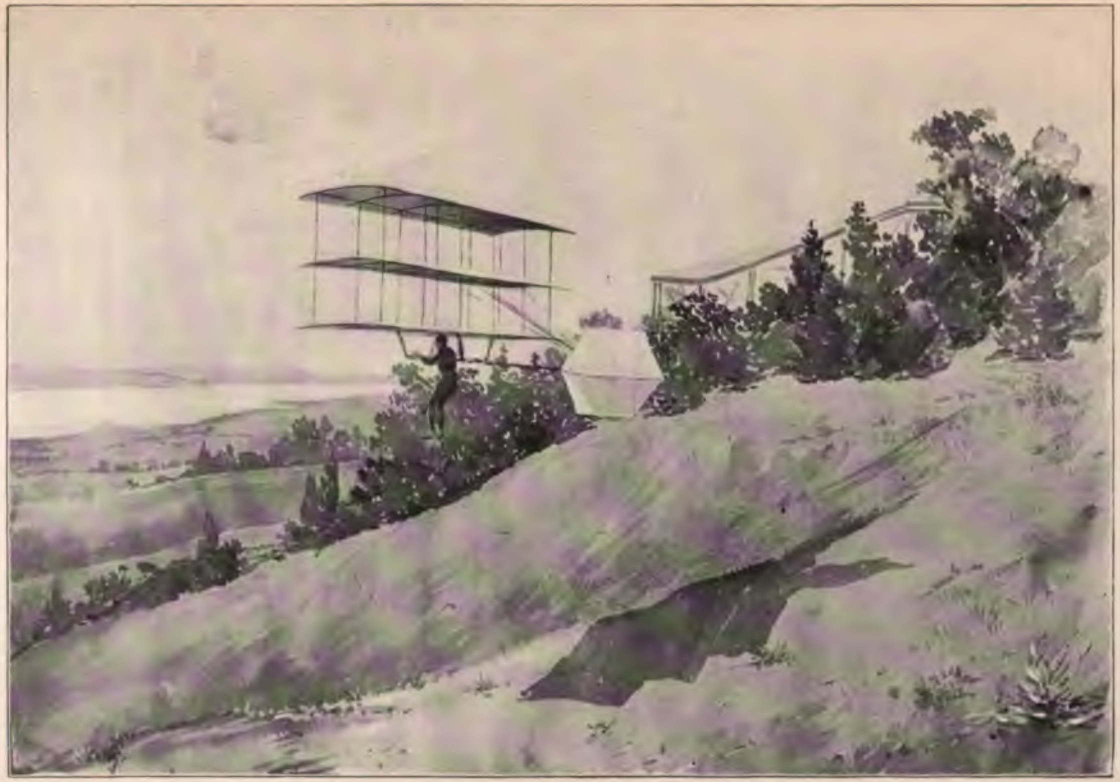
machine will have 227 square feet (net) surface. This is, however, 40 per cent. more than a man of average weight ever requires except in a calm or in winds of less than 10 miles an hour. In winds over 12 miles an hour a beginner will get along better with the upper surface removed. If this machine is built on such a scale that the dimensions are only two-thirds of those given, it will be of ample size (103 square feet surface) for the average operator in any wind of over 25 miles an hour. It is better not to reduce the size of main spars and struts at all from the sizes given for the larger machine when constructing the surfaces on a smaller scale. The sizes given are for the best grade of black or silk spruce *only;* this wood will stand at least 16,000 pounds to the square inch; it must be straight grain and entirely free from flaws.

There is, perhaps, no better sport imaginable than coasting through the air, especially so where the flights are comparatively long. In moderate winds, of 18 to 25 miles per hour, the path of the machine is often quite horizontal for a hundred feet or so after leaving the hill-side, until, in fact, the rising current which flows over the hill has been cleared. If during the first part of the flight an operator wishes to keep near the ground he may do so by moving an inch or two forward on the machine; he will find, however, that in thus sailing downward through an ascending wind the speed increases at a tremendous rate.

Perhaps the most trying ordeal is experienced when the machine unexpectedly encounters a strongly ascending current of air which may raise the operator, in some instances, 40 or 50 feet above his line of flight. Such occurrences are comparatively frequent in a wind of 30 miles or over, but are not dangerous so long as the regulating mechanism remains in working order, as the machine then retains an absolutely level keel. I have twice been raised as much as 40 feet above my *starting* point without either myself or those who were on the ground being able to detect any change whatever in the inclination of either axis of the machine. Considering the fact that the rise through even such a distance seldom takes more than 1¼ to 1½ seconds, the automatic stability of the machine would seem to be well attained.

After having adjusted the regulators, and repeatedly tested them in a number of short flights, and at the same time having found the correct position for his weight, all the beginner need do, after starting, is to keep as still as possible and he will make a very creditable flight. If it be necessary to steer to the right or left, moving the body over to that side and a little forward will accomplish the result. For ordinary steering it is seldom necessary to do more than stick out one leg toward the side to which you wish to turn. If you meet a very strongly ascending trend of wind it is manifested by an increase in the weight which appears to rest on your arms; in such a case the vertical rise may be greatly diminished by moving 2 or 3 inches forward of the normal position as long as the rise continues; it is better, though, to simply stick the legs out in front.

Descending currents of air diminish the weight on the arms and give one the sensation experienced in a quick-starting elevator on a down trip. So far, out of, possibly, over 300 trials with the regulated machines, a descending current has never brought the machine quite down but once, but even then the dropping speed was not too great to make a comparatively easy landing possible. On the other hand, the machines have been momentarily raised above their line of flight in probably 2 flights out of every 5. And in winds above 25 miles an hour the machines have risen above the starting point in as many as 75 per cent. of the flights. The highest rise was probably little short of 60 feet. The most difficult thing a beginner has to learn is how to land, *i.e.*, when to move back on the machine in order to check its headway; this knowledge can only be gained by actual experiment.



GLIDING MACHINE IN FLIGHT.

Mr. Chanute's launching ways are seen in the distance.

OTTO LILIENTHAL.

A MEMORIAL ADDRESS DELIVERED BEFORE THE
DEUTSCHEN VEREIN ZUR FÖRDERUNG DER LUFTSCHIFFAHRT,
NOVEMBER 26, 1896.

BY KARL MÜLLENHOFF.

[Translated from *Zeitschrift für Luftschiffahrt.*]

THE irreparable loss which our Society has sustained in the death of Otto Lilienthal is still fresh in our memories. We all remember distinctly the untiring character of him who united the definiteness of aim which characterizes manhood with all the ardor and enthusiasm of youth.

For a long time, more than ten years in fact, Lilienthal was a member of our Society, and only a few of our oldest members can remember the whole of the energy which he devoted to our work. This is why I, who introduced Lilienthal into the Society, will endeavor to show what his membership really meant; all the more so, as it was I especially who was fortunate enough during the many years of mutual intercourse to really know the depths of this noble character and to learn to appreciate it. During this long period I had the good fortune to be initiated into all the phases of his studies of the problem of manflight.

Otto Lilienthal was born May 24th, 1848, at Anclam in Pomerania. Up to his sixteenth year he went to the Latin High School of his native city; in 1864 he entered the Potsdam Technical School; after graduation from this institution in 1866 he began the study of civil engineering by a one year's practical course in Schwartzkopf's machine shops. From 1867 to 1870 he was a student at the Berlin Technical Academy, and he had just been graduated from that academy when, in the summer of 1870, the beginning of the Franco-Prussian war called him into the service.

He served as volunteer in the Fusileer Infantry Regiment of the Guards, and was with that regiment at the siege of Paris. After the campaign was over he took a place as civil engineer in Weber's machine shops at Berlin, and was afterwards, from 1872 to 1880, engaged in the large machine shops of C. Hoppe, of Berlin.

In 1880 he started a machine factory of his own, and succeeded, in the course of time, in bringing it to a flourishing condition by his energy and inventive powers.

The products of his machine shops were of great variety. One of his inventions was the construction of light steam motors with serpentine pipes. He also made a specialty of marine signals. His achievements in these procured for him the silver State medal. The fog-horn which could be heard during the time of the Berlin trade exhibition near the Imperial ship was constructed and exhibited by him.

From his earliest youth he had been much interested in the subject of manflight, and as early as 1861, being only thirteen years of age, he began to make practical flying experiments, together with his younger brother Gustavus. The first wings made by the two brothers consisted of light flaps which were fastened to the arms; with these they attempted running downhill. The experiments were mostly made at night by moonlight, the young flying artists being naturally afraid of the teasing of their school-fellows.

The experiments which had been started in Anclam were continued in Potsdam. The two brothers constructed wings which were fastened to the back, and which moved up and down by throwing out the legs as in swimming. In 1867 and 1868 while in college, Lilienthal constructed a more complicated apparatus. In these experiments also his brother Gustavus took an active part.

The experiments interrupted in consequence of the campaign were taken up again as early as the autumn of 1871.

Lilienthal had seen that the negative results of previous flying experiments could be traced to the fact that it had been the custom to attempt the solution of the problem of birds'

Plate XVI.

OTTO LILIENTHAL.

Born 1848. Died 1896

"For thousands of years we human beings have racked our brains to unravel the mysteries of flight and we feel happy when we drink mere drops from the Fount of Knowledge, and here the storks seem to run riot in the art of flying, as if nothing in the world were easier." – See p. 89.

flight trusting only to incomplete and even sometimes erroneous observations; or else to undertake the task of deriving the laws of the mechanics of flight purely theoretically without resorting to any observations at all.

Both methods would naturally lead to erroneous results. Lilienthal concluded to investigate the whole subject by means of exact experiment, examining scrupulously all the phenomena to be seen in the flight of birds. He began by measuring — by means of a long series of systematic measurements — the amount of the resistance of the air which the bird's wing has to overcome when in motion.

These experiments and measurements were for a long period made only by Otto Lilienthal, with the help of his brother. They showed the important and new result, that the curved wings, which nature, as we know, provides exclusively for her subjects, have a much more effective form than the flat surface hitherto so often constructed by men.

Besides this, Lilienthal was the first to point out the phenomenon which he thought was the probable explanation of the action of birds in sailing flight; that is, the existence of air-currents with upward tendency.

According to the observations made by Lilienthal these currents form on the average an angle of 3½ degrees with the line of the horizon.

Otto Lilienthal described the results of his numerous experiments in his pamphlet of the year 1889, entitled "The Flight of Birds as a Basis for the Art of Flying."

Shortly afterwards with the greatest zeal he again took up the practical attempts at flying which he had begun so long before. He had come to the conclusion that he could scarcely attain the solution of the problem of flight in his study, but that he must take the knowledge he had gained by observation and calculation out into the open air, to test with the wind, and in the element for which it was made, the apparatus constructed according to the theories he had developed. Theorizing alone would never bring about success. Brooding over and calculating about it would not bring one to the desired goal. One must draw up plans, build a machine, and then experiment with it. Lilienthal was right in pointing to the example of the bicycle to show how important practical experiments are in contrast to pure theory. Without doubt, our ancestors would have shaken their heads incredulously over the problem of the bicycle; it was first solved practically and now has come the theoretical solution. Of all the various methods of flying which nature shows us, sailing flight seemed the most worthy of imitation. It allows, as observation shows, the swiftest and most uninterrupted motion forward with a minimum of physical exertion. The solving of the mystery of this sailing-flight must therefore be the most important task of the flight technician.

The apparatus used by the experimenter in resuming his attempts in the spring of 1891 had the shape of birds' wings when spread out. The cross-section through the wing lying in the plane of the direction of flight was curved parabolically; the surfaces of the wings comprised in the beginning 10 square metres; they decreased gradually on account of various changes and repairs to 8 square metres. [The width comprised at its greatest 7 m. by 2 m.] The framework of the wings was formed of willow-wood; the covering was made of sheeting covered with wax. The weight of the apparatus was about 18 kilos.

In order to hold the apparatus the arms are placed in two cushioned openings in the frame, the hands at the same time grasping two corresponding handles. In this way the wings are perfectly under control, and may be safely leaned on in the air.

At first, of course, the flying experiments were made only from a low height and when there was no wind. Lilienthal made a spring-board on a large lawn in his garden in Lichtefelde which could be made higher by degrees; when first experimenting the board was but one metre high, later it was raised to two metres. On the spring-board he could take a run of eight metres in length. In spite of the jump the landing on the soft earth was gentle, so that a jump like this could be repeated many times without resulting in the least weariness or danger.

On having practised sufficiently the jumping off in this manner without wind, he selected another practising ground between Werder and Gross-Kreutz where several mounds of larger size, standing alone, made the experiments possible. Here it was found at once that in these experiments particular attention must be given to the wind then blowing. It is necessary when floating to move against the wind, for if one falls away from the wind, the pressure of the wind is felt, and the experimenter is not able to resist the one-sided effect. A vertical steering surface therefore had to be put on, thus enabling the apparatus to go against the wind.

On the grounds between Werder and Gross-Kreutz the jumping was done very frequently from greater heights and with winds of different force; a great deal of new experience was thus obtained. The final result was, that jumps of 20–25 metres' length could be made from the highest jumping point there, from a height of 5 to 6 metres. This was done when there was no wind as well as with winds of different force.

The difference showed itself particularly in the duration of the flight; the stronger the winds, the longer the journey in the air. The fact that landing when there is no wind is often a rather violent affair corresponds to what has been said, and it is therefore necessary to raise the wings a little in front shortly before landing, in order to mitigate the harshness of the shock and to prevent tilting over. This, however, refers only to flight when there is no wind; if the flight is against the wind, the landing on the ground is of an absolutely gentle nature.

The practising places not offering enough space to cover longer distances from greater heights, another spot, suitable for continuing the experiments, had to be chosen in the following year, 1892.

Such a place was found between Steglitz and Südende. The slopes here have a height of about 10 metres.

The experiments were made with an enlarged apparatus with a surface of 16 square metres and 24 kilos' weight, at a velocity of the wind up to 7 metres. He could take a start up to the jumping place, thereby obtaining a relative velocity of the air of 10 metres per second. Under these circumstances the first part of the sailing flight was almost horizontal; in its further course the line of flight sank considerably and declined rather suddenly at the end, as the wind loses a part of its force in the lower strata. In the most favorable case the length of the jump would be equal to 8 times the height of the jumping place above the landing point.

The surroundings of Berlin having a great dearth of good places for trying such flying experiments, Lilienthal constructed at Maihöhe near Steglitz a flying station of his own in the spring of 1893. A small declivity on this hill was arranged for a station for sailing flights. A tower-like shed was built, from the roof of which the flights were made, and which thus afforded a jumping place of 10 metres' height. The interior of the shed was used for storing the apparatus. The roof, which for the sake of a more secure start was covered with turf, sloped down, as did the declivity round the shed, towards south-west, west, and north-west. The apparatus showed a change as compared with that of previous years; it could be folded together, like the wings of the bat. It could, in consequence of this arrangement, be removed more easily and stored at almost any place.

It was only seldom, however, that the wind was favorable on the Maihöhe, and it was thus most important for the energetic continuing of the flying experiments that — in 1893 — Lilienthal succeeded in finding grounds which were suitable for his purposes in every respect. These are on the Rhinow mountains near Rathenow. Out of surrounding flat plough-lands there rises a chain of hills covered only with grass and heath, of up to 60 or even — as at the Gollenberg — up to 80 metres' height above the plain. The hills offer on every side descents, at an angle of from 10 to 20 degrees; and it is possible here to select a suitable position in whatever direction the winds make desirable, in order to glide above them through the air. The grounds really appear to be made for such flying experiments. The wind does not produce such gusts as at the flying tower at Steglitz, where one would always receive an irregular gust of wind from below, when passing the edge of the jumping place. Often enough this gust threatened to be fatal. Besides, this uniform acclivity permitted landing anywhere.

The wings which were used showed some changes as compared with those used previously. Their weight is 20 kilos, the complete weight just 100 kilos, the width from tip to tip 7 metres, the greatest breadth 2½ metres, the complete surface 14 square metres, a size which appears to be fully sufficient.

The wings are lowered when the experimenter runs downhill against the wind; at the proper moment he raises the supporting surfaces a little, so that they are about horizontal; then while poising in the air he endeavors by suitably changing the point of gravity to give to the apparatus such a position that it shoots quickly forward while lowering itself as little as possible. After a short time a great progress in the safe management of the apparatus could be observed. Very often sailing flights of 200 to 300 metre length were made from a height of 30 metres; a great additional progress consisted in the fact that he succeeded in directing the course of flight to the right and left. Changing of the point of gravity is effected by stretching the legs in one or the other direction; even a slight change of the centre of gravity brings about at once a decline of the supporting surfaces towards the direction desired, the pressure of the air also increasing on this side. The direction of the course of flight then deviates to that side. Several times during the experiments the deviation from the straight line of flight was carried so far that Lilienthal would at times return to the starting place.

A place which was very well suited for his experiments, and much more conveniently situated, was procured by Lilienthal in the spring of 1894, in Gross-Lichterfelde near Berlin; he caused a conic hill to be thrown up, which, having a height of 15 metres and at the basis a diameter of 70 metres, should admit of flying experiments in whatever direction the wind blew.

On this place he tried with good success his new flying apparatus, consisting of two surfaces arranged one above the other.

He had come to the point already that the experiments regarding sailing flight could be considered as being completed, and he proposed to take up the second task, viz., the imitating of the rowing flight of birds. A light machine, weighing in all only 40 kilos and supplying 2½ horse-power for a short time (4 minutes), was constructed and tested several times. Lilienthal was therefore certainly justified in his words, when he declared in a lecture given in July, '96, in the Berlin trade exhibition buildings, that he had strong hopes of being able to further still more the development of the flying sport; but an accident put an untimely end to his endeavors on the 9th of August.

He had made, on that fatal day, a very extensive sailing flight on the Rhinow mountains, and thereby the special steering of the movable horizontal tail had proved to be very satisfactory; he then wanted to undertake a second flight of as long a duration as possible, and wanted to define the duration of the flight.

As a rule, such flights would last from 12 to 15 seconds. He gave the timing-piece to his assistant. According to the statement of the latter, the flight was — up to half of the course of flight — almost horizontal; then the apparatus had suddenly tilted over in front, and had shot down rapidly from a height of 15 metres, being completely tilted over on the ground. The daring sportsman was dragged from the *débris*. His spine being broken, he died twenty-four hours later. . . .

At present one cannot foresee what development may be in store for the principles laid down by Lilienthal in the art of flying: one thing however is certain, that not one of the numerous explorers and experimenters who have busied themselves with the problem of flying has done so much as Lilienthal to bring the difficult problem nearer its solution. It has therefore been justly emphasized, in the many accounts and debates which Lilienthal's experiments have called forth over the whole world, that he possessed three qualities in happiest union: He was first a thorough mathematician and physicist, and had given important contributions to the theory of flight by reason of his untiring observations and measurements of the resistance of the air to curved surfaces. Second, being a clever constructor, and especially as mechanical engineer, he was able to build the apparatus himself as he thought best fitted for imitating the flight of birds. Third, he possessed great daring and physical dexterity, so that he was in himself fitted for making experiments in flying.

Therefore his memory will be faithfully cherished by all those who have decided to labor on in the field of work which he made his own.

OUR TEACHERS IN SAILING FLIGHT.

By Otto Lilienthal.

Translated from Prometheus.

I have recently seen such wondrous feats performed in sailing flight that, as I now sit at my table to write, I do so with more enthusiasm than ever before; for the things which I have seen prove clearly and definitely that flight must be much easier than it is generally believed to be, if we only, with suitable wings, boldly trust ourselves to the wind. All perplexities concerning light motors, and speculations on the amount of power required for flying, are relegated to the background by the fact that the power of the wind alone is sufficient to effect any kind of independent flight.

If we had not those magnificent models in flying, those large and heavy birds which, without a flap of the wing, allow themselves to be borne by the wind, doubters would be justified, and we should lack the courage to attempt the solution of the problem with the perseverance which is necessary; but, as it is, the tangible results cannot be denied, there is a flight which does not require any effort, where only the shape and position of the wings must be right in order to float, circle, or sail in the air at any height or in any direction desired; therefore our confidence, notwithstanding many vain attempts, is always renewed.

But which are the birds best fitted as models in soaring flight? How can we best find a position for making fruitful observations?

If we go through the fields in summer, we see now and then a bird of prey circling about; then a swamp bird, of the larger kind, passing along arrests our attention: yet if one goes out on purpose for such observations, it may be that he will lie in wait for days in vain, or if a sailing bird comes in sight, it is very likely high up in the heavens and far away, so that little can be learned from it.

The Americans are proud of their buzzard which gives them such exhibitions in the art of soaring, but in order to observe this near at hand and to be able to study the effect of soaring, places of concealment must be arranged in the tops of trees and in rocks from which the observer may watch the motions of flight.

Things are easier for people living on the coast; the graceful soaring flight of the gulls can be frequently observed near at hand, as these birds are not very timid, from their being so seldom hunted. But the best opportunity for studying soaring flight is to be had in the lowlands of Northern Germany, in the villages, where the stork lives his family life on the low roofs, unconcernedly showing off his art close above the heads of observers, and by his size giving the observer the clearest impressions of the shape and position of the wings.

But even at these stork nests it is tedious to wait for the moment when the old birds return with food for their young; it is generally only for a short moment, in the quick coming and going, that one can observe closely the flying or the soaring stork.

Observation is more productive when the young birds are fledging. As soon, however, as they have learned to soar, which soon happens in windy weather, they do not remain in the vicinity of the nest, and one can look for them a long time in vain.

Being convinced that Father Longlegs is just made for our instructor in flying, I kept a great many young storks some years ago, whose attempts at flying have given me many explanations in flying technics. As soon, however, as their proficiency extended to soaring, when rising above the tree-tops, they felt the magnificent bearing-effect of the wind, and ventured into higher regions, they joined other wild storks, and so ended all further observation.

While on a journey to procure these young storks a friendly man told me that there could be no better place for observing

wise. They circled in order to ascend quickly to higher air strata.

When instructing their young the storks fly mostly in smaller or larger companies, at different heights, flying over the village alternately with or against the wind. In some of the nests young birds were standing, which did not yet take part in the exercises. As soon as these latter saw their relatives fly away above them they would greet them in their own peculiar language, by laying their heads on their backs and rattling with their beaks. Generally some of those flying would descend from the rest to their young ones in the nest. If the flight in doing this had to be made from a great, windy height, it gave the impression that the stork found the descent more trying than the ascent.

To descend more rapidly the stork employs various manœuvres. The simplest is that of letting the legs hang, thus lessening the soaring effect by a resistance to the air. With a good sailing-wind, however, these means are insufficient, and head and neck have to be lowered, at the same time the wings are bent so low down as to form the perfect shape of a bell. This position, however, appears to cause the stork an effort, as it soon changes again to the outspread position. On attaining this, however, it again commences to ascend, and then it is seen, after a few vain efforts to come down quickly from the height, to employ a radical means for rapid descent. This consists of placing itself in a vertical plane; that is, with the point of one wing underneath, the point of the other above. In this manner it can, of course, shoot downwards like an arrow. In its downward rush, however, it changes several times from the right position to the left. Finally it takes once more the position of the bell, till it lands on the nests, where it is always received, after such feats of prowess, with a joyful rattle.

A good deal could be said about these drops, often from a height of several hundred metres, but we have less interest in the descent from the height than in the art of balancing in the air simply by means of outspread wings.

In order to observe this proficiency frequently close to, we chose a point of observation on a farm which was blest with five stork-nests, and from where we could oversee a dozen others.

The only means of lifting the last veil from the mystery of soaring is to be able to frequently observe large birds at a near distance in their soaring flight.

Three things are essential for soaring: a correct shape of wing, the right position of wing, and a suitable wind. In order to judge of these three factors and their changeable effect, we have nothing but our practised eye to depend upon.

Just how much the cross-section of the wing is arched when the stork is resting on the wind can be determined only by eye measurement; similarly the position of the wing to the direction of the wind and to the horizon. But when hundreds of storks give one the opportunity to observe the same in clear weather close at hand, what is seen is impressed so indelibly on the mind that it enables one to draw correct conclusions as to the existing laws.

In general, one can say that when the stork flies with wings spread horizontally and allows itself to be borne by the wind alone, it is but seldom that a stronger gust of wind causes the stork to draw in its wings.

The parabolic profile of the wings has a depth which I consider to be about $\frac{1}{20}$ of the breadth of the wing. The pinions are mostly spread out, but do not lie in one plane; but the more they are to the front, the higher are the points, certainly because they would otherwise hinder one another in their bearing capacity.

When in this position the stork passes slowly against the wind above the observer, the head and neck are, as a rule, stretched straight out; but if one imagines that soaring is possible in this position, that it causes little resistance, he will be surprised to see a stork, sailing in this manner, suddenly, without changing its position, lay its head back and rattle joyously. While we human beings are striving to find the proper shape for the wings, building theory on theory, flying takes place in nature in a wondrously simple way, quite as a matter of course.

It is ever with a large surplus of flying capacity that nature has equipped her subjects. A stork which has lost some of its largest pinions does not for that reason sail less gracefully than its comrades.

Storks are not particular in the way they hold their pointed beaks and long necks, as has been observed already. One after the other sailed over our heads; one held itself to one side, the other kept to the other side, without any change in their flight. Here comes another one very slowly against the wind; just as it stands over our heads it bends its head to the left to take a minute survey of its wings, on which it puts its head quite to one side and begins in a most leisurely way to put the feathers on its left wing in order with its beak; meanwhile its graceful sailing-flight does not suffer the slightest interruption. We looked at one another surprised by this sight, as if we would say, "That is beyond everything! For thousands of years we human beings have racked our brains to unravel the mysteries of flight, and we feel happy when we drink mere drops from the Fount of Knowledge, and here the storks seem to run riot in the art of flying, as if nothing in the world were easier." [1]

Afterwards I found out that a stork, putting beak, head, and neck back quite to the left, certainly changes the left wing a good deal more, but that, in this position, wherein head and neck are directly in front of the arm of the wing, to a certain extent a broadening of the left wing and therefore an increase in the bearing capacity of the same takes place.

One might therefore not be at all surprised if the balance in soaring be not disturbed. The young storks, which are known by their gray legs, betray themselves also in the air by their less sure flight; in soaring they are sometimes thrown here and there by the wind, and therefore take more frequently to flapping their wings than their red-legged parents, which understand in a masterly way how to meet every gust of wind.

[1] Wir Menschen quälen uns seit Jahrtausenden, hinter die Räthsel des Fluges zu kommen und sind schon froh, wenn wir tropfenweise aus dem Born der Erkenntniss schöpfen können, und hier wird von den Störchen in einer Weise mit dem Flugvermögen gewuchert, als gäbe es in aller Welt nichts Leichteres als das Fliegen.

Whoever observes minutely a stork, which is proficient in flying, sailing along at a moderate height, will notice a limited but almost uninterrupted turning and moving of the wings which apparently serve to exactly meet the pressure of the wind. Our eyes are riveted with admiration and wonder on each of these birds as they pass along. They skim and sail in the air, and their bodies, weighing four to five kilograms, appear to be borne by a magic power. Their whole behavior indicates that a flight like this is no labor, but rather akin to resting; their tameness lets them pass close to us; we can recognize each feather of their outspread wings. All deception as to the real cause of sailing flight appears excluded. That which is possible to these storks must also be possible to any other similarly formed flying body.

As the little swallow, which just now sails over the farm-yard through the broken window into the cow-shed, understands soaring on the same principles as the stork, so must, on the other hand, a larger apparatus, capable of bearing up a man, be able to sail on the wind, if it be of the right shape.

Of course such an apparatus alone cannot equip us for flying; the capability of using it, which is inborn with the stork, must be gained by us by laborious training, but even in this we can trust ourselves fully to our long-legged instructor. It shows us with what facility one can change the irregular blowing of the wind into bearing-power, provided we have the necessary practice. When the stork sails over the roofs of the houses one can see how it applies every gust in the air to its advantage. The higher it circles, the more tranquil and certain its flight becomes in proportion to the increasing uniformity of the wind.

A particularly fine spectacle is a stork remaining for a great length of time floating (remaining stationary) at one point in the air. This feat also, where all the forces are equally balanced, I saw performed by older storks only. These masters in the art of flying understand how to keep their position at one point even in high winds, as well as to shoot along with high velocity, all of which they perform by careful adjustment of their outspread wings.

The simplicity of the instruments with which nature obtains these wonderful effects in flying gives us hope that we shall come to a satisfactory solution of the problem.

Whoever needs incentive to labor with zeal ought to look up the little village of Vehlin in Ostprignitz in mid-summer, when the magnificent birds in their fine black and white garments sail majestically overhead, and are seen against the blue of heaven like emblems of liberty.

AT RHINOW.

[The following is a translation of an extract from an article by Lilienthal in *Zeitschrift für Luftschiffahrt*, March, 1895.]

LILIENTHAL writes thus of the extreme care needed in making changes in an air-sailing machine:

My neglect of this circumstance I once came near paying dearly for. The winter before last I constructed several machines, the sustaining surfaces of which had an exact parabolic profile which almost coincided with the arc of a circle. The holding point for the hands and arms I placed in such a manner that the centre of gravity of the body was, on the average, situated one-tenth of the width of the wing in front of the centre of the surface. In my experiments made before Easter from the still higher mountains near Rhinow, I perceived that I had to bear with the upper part of my body a good deal towards the back to prevent my shooting forward in the air with the apparatus. During a gliding flight taken from a great height this was the cause of my coming into a position with my arms outstretched, in which the centre of gravity lay too much to the back; at the same time I was unable — owing to fatigue — to draw the upper part of my body again towards the front. As I was then sailing at the height of about 65 feet with a velocity of about 35 miles per hour, the apparatus, overloaded in the rear, rose more and more, and finally shot, by means of its *vis viva*, vertically upwards. I gripped tight hold, seeing nothing but the blue sky and little white clouds above me, and so awaited the moment when the apparatus would capsize backwards, possibly ending my sailing attempts forever. Suddenly, however, the apparatus stopped in its ascent, and, going backward again in a downward direction, described a short circle and steered with the rear part again upwards, owing to the horizontal tail which had an upward slant; then the machine turned bottom upwards and rushed with me vertically towards the earth from a height of about 65 feet. With my senses quite clear, my arms and my head forward, still holding the apparatus firmly with my hands, I fell towards a greensward; a shock, a crash, and I lay with the apparatus on the ground.

A flesh wound at the left side of the head, caused by my striking the frame of the apparatus, and a spraining of the left hand, were the only bad effects of this accident. The apparatus was, strange to say, quite uninjured. I myself, as well as my sailing implements, had been saved by means of the elastic recoil-bar, which, as good luck would have it, I had attached for the first time at the front part of the apparatus. This recoil-bar, made of willow wood, was broken to splinters; it had penetrated a foot deep into the earth, so that it could only be removed with difficulty. I describe this accident so minutely because it is probably the worst which could happen in sailing flight; I wish to say that this is not the accident which gained publicity through the press, and which was the cause of a correspondence from all countries. The only outside spectators of this fall were the little girls and boys of the Stöllner schools, who had had vacation, and were looking on with their teachers at my experiments from the ridge of the mountain.

My brother, who also took part in these experiments and had been able to get a perfect side-view of my unsuccessful flight, said it had looked as if a piece of paper had been sailing about in the air at random. In my thousands of experiments this is the only fall of that kind, and this I could have avoided if I had been more careful.

If one uses the necessary precautions when making the experiments, any great danger is, strictly speaking, excluded. The use of a recoil-bar is, of course, always advisable.

In the very slight accident which a reporter who happened to be present brought into the papers in a greatly exaggerated and incorrect way, the elastic impact of the recoil-bar proved to be excellent. In this experiment a change in the curve of the surfaces came into account. I was occupied in testing wings of the strongest possible curves to make comparative experiments regarding the influence of the amount of concavity on the bearing capacity. I had already taken several successful flights with an apparatus the concavity of which was a little over $\frac{1}{12}$ of the breadth of the wing; then while sailing, the apparatus was pressed down in front by a wind from above, in the middle of the course of flight, by means of which it was run to the ground.

With these strongly curved profiles the danger is, that the surface being strongly inclined, the front receives some pressure of the air from above in consequence of sudden changes in the wind, and this would, of course, greatly diminish the stability of the flight. As has already been observed, it is not advisable to extend the height of the profile beyond $\frac{1}{12}$ of the breadth of the wings, in spite of the excellent sustaining qualities which may so be obtained.

One can produce very safe working qualities with strong power of sustentation with a height of profile between $\frac{1}{18}$ and $\frac{1}{15}$ of the breadth of the wing.

As a matter of course, the more one penetrates into the details of the technics of flight the more varied the points of view will become. This is the case even with simple sailing flights which demand only a simple sustaining surface. How much more this will be the case in dynamic flight! I have had already enough impressions as to that. But of this some other time.

THE BEST SHAPES FOR WINGS.

By Otto Lilienthal.

[Abridged translation from *Zeitschrift für Luftschiffahrt*, XIV. Jahrgang, Heft 10.]

THE results which we reach by practical flying experiments will depend most of all upon the shapes which we give to the wings used in experimenting.

Therefore there is probably no more important subject in the technics of flying than that which refers to wing formation.

The primitive idea that the desired effects could be produced by means of flat wings has now been abandoned, for we know that the curvature of birds' wings gives extraordinary advantages in flying.

The experiments on the resistance of air to curved surfaces have shown that even very slight curvatures of the wing-profile increase considerably the sustaining power, and thereby diminish the amount of power required in flight.

The wing of a bird is excellent not only because of the curvature of its cross-section, but the rest of its structure and formation also has influence upon the flight. Therefore the outline of the wing is certainly of importance.

It is probable that the form of the cross-section of the wing and flight-feathers (*Schwungfedern*) has a favorable influence upon the flight.

Experiments have not yet been made to show conclusively whether or not the feather structure of a wing endows it with a special quality whereby the sustaining power is increased. With investigators this has been a subject of conjecture. Therefore it is questionable (*auch fraglich*) whether we are wrong if, in constructing flying apparatus, we keep to the bat's wing, which is easier to construct.

Bats fly much better than is generally thought. Two early bats, which I saw flying this summer in broad sunshine and in somewhat windy weather, sailed along so well without flapping their wings that I thought, at first, they were swallows. Of course on evenings when there is no wind, the bat must flutter continually. The early-flying bat is also called evening-sailer (*Abendsegler*) which indicates that its sailing flight has been marked.

The most important point as regards the form of the wing will always be the curvature of its profile. If we examine any bird's wing we find that the enclosed bones cause a decided thickening at the forward edge. The question now is, What part does this thickening play in the action of the curved surface? The thickening is quite considerable, particularly in birds which have long, narrow wings. An albatross in my possession has a breadth of wing 16 centimetres, the thickened part of which measures 2 centimetres; the thickness is therefore $\frac{1}{8}$ of the breadth of the wing. As the albatross is one of the best sailers, we can scarcely assume that the comparatively great thickness of the wing at its outer edge has a detrimental effect upon the bird's flight.

For a long time I have assumed that the thickening which all birds' wings have at the front edge produces a favorable effect in sailing flight.

. . . .

By means of free-sailing models I have now learned that nature makes a virtue of necessity, that the thickened front edge is not only harmless, but in sailing flight is helpful (*sondern den Schwebe-effect nicht unerheblich erhöht*).

The experiments are easily tried. It is only necessary to make a number of models of equal size and weight, each one having a different curve in its sustaining surfaces. These models I make of strong drawing paper, the size of the surfaces being about 4 inches in width by 20 inches in length.[1]

The experimenter can let these models sail from any tower or roof in front of which there is an open space. Each model must be made to glide through the air many times until it

[1] Drawings of these models will be found on pp. 14 and 15, Aeronautical Annual, No. 2.

reaches the ground. Experiments must be made in the stillest possible air.

The lengths of flights are all noted down, and from a long series of experiments the arithmetical mean for each design is computed. The models having the best profiles will make the longest flights. In this way a reliable table can be made which will show the relative merits of the profiles, and will also show quite plainly in which direction the most useful form will have to be developed.

Until now I have endeavored to find out the best proportions for wings by constructing different kinds of sailing apparatus. In this way, of course, many important facts have been ascertained. The construction of full-sized apparatus requires a great deal of time and is expensive, therefore we must welcome a method which permits inquiry into the forms of wings in models which fly automatically. Besides that, it is not every one's business to throw himself into space in a sailing apparatus, although he who would succeed in practical flying can scarcely avoid this way.

Considering the fact that the most important thing is to ascertain what are the best qualities of the natural wing,— which is in every respect perfect,— these steadily sailing models offer every one an opportunity of engaging in experiments of this kind. Further, any one who takes up this kind of experiment will find great pleasure in watching the manœuvres of his small flyers, which often vie with the best sailers among birds. I can therefore recommend this occupation not only for the furthering of the science of mechanical flight, but also because it affords a most interesting pastime.

The few measurements made so far by this method are too incomplete to be fit, as yet, for publication. I am preparing, however, a systematic series of experiments, the results of which will be stated when the experiments are finished.

Meanwhile, I cherish the hope that this paper may be an incentive to others to make similar experiments, so that we may sooner reach the desired end.

NOTE.— This is a part of Lilienthal's unfinished work, which it is to be hoped will be taken up by many. The fact that he thought it well worth doing is significant.— ED.

SAILING FLIGHT.

By O. Chanute.

[Begun in Aeronautical Annual No. 2.]

PART II. — THE EXPLANATIONS.

Many theories have heretofore been advanced to account for the paradox of sailing flight. The writer knows of some twenty-three different explanations, more or less complete; but most of them are fragmentary — rough casts, as it were, as to how the feat is accomplished, without qualitative or quantitative considerations. Indeed, all of them except Basté's and Vogt's lack the latter, and no one, so far as the writer knows, has published full mathematical computations showing just how the sailing bird is supported and propelled, at the actual measured speeds of wind and bird, and at the angles of incidence observed.

Before submitting some computations of my own, it seems desirable to first review the theories which have been advanced. These may be grouped under eight different heads, as follows:

1. Assimilates sailing flight to kite action.
2. Assumes rising trends in the winds.
3. Supposes different coefficients on front and rear of birds.
4. Surmises propulsion to be obtained by tacking and circling.
5. Believes energy to be derived from combination gravity and wind.
6. Believes energy to be drawn from the different speeds of wind strata.
7. Believes energy to be drawn from intermittency of wind force.
8. Believes energy to be drawn from variations in wind direction.

I. KITE ACTION.

Count d'Esterno in his book[1] and writings assimilated the sailing bird to a kite, in which the weight replaced the action of the string. He held that inasmuch as the area of the sus-

[1] "*Du Vol des Oiseaux.*" *Librairie Nouvelle.* 1864.

taining surfaces was greatly in excess of that of the edge surfaces (body and wings) which the wind acted upon, it was possible for the bird to transform into forward propulsion whatever surplus lifting effect he received from the wind. He illustrated his views and the action of the bird in this way:

"Suppose the bird is gliding downward, without any flapping, in calm air, and transforming a descent of 1 metre into 8 metres of forward progress. Now let us suppose the bird to have an initial velocity of 1 kilometre per minute, say, 8 metres in one half second; let the bird be immersed in a wind of 8 metres per half second, and blowing at right angles to its path. Let us suppose, further, that this wind can elevate the bird 2 metres while it drifts it back 8 metres. Now the bird does not want to rise, and must therefore expend the 2 metres of altitude. What does he do with it? He then transforms 1 metre of potential altitude into 8 metres of progress against the wind to overcome the drift which would otherwise result, and he transforms also the remaining 1 metre of potential altitude into 8 metres of forward progress, with which he translates himself in whatever direction he likes. Thus, as a final result, sailing flight will afford him, after deducting all losses, a speed of 1 kilometre per minute."

It will be observed that the statement is not very clear, and that there is no exact explanation as to how the feat is accomplished. Most commentators have dismissed this explanation, together with a somewhat similar statement made by the *Duke of Argyll* in "The Reign of Law," with the remark that if it is meant to imply that the bird alternately transforms altitude into speed, part of which is lost in overcoming resistance, and transmutes the reduced speed into a recovery of the original altitude, that then this involves perpetual motion, and that the latter is an absurdity.

Mr. V. Tatin is more specific in his criticism. In the course of an article in the "*Revue Scientifique*" of Nov. 7, 1891, he says:

"It seems to me that the error is apparent. If the bird first progresses 8 metres by descending 1 metre, there is no reason why the descent should not continue, and it is quite gratuitously that *d'Esterno* adds: 'Suppose that the wind elevates the bird 2 metres.' This was easy to write, but why should the wind elevate it 2 metres? We see clearly enough that it will be drifted back 8 metres, because it must gradually acquire the speed and direction of the surrounding medium, on which it rests, but we see also that during this drift of 8 metres there will be descent, and not elevation. This first prop being knocked away, all the remainder tumbles down."

This criticism is not quite fair, because it assumes that the bird will in the long run part with all his inertia. He will not do so if he manages to extract energy from the wind, but the puzzle is to explain how he does it. Almost all the observers have stated that it is accomplished by a skilful interchange of elevation for velocity and of velocity for elevation, but they are not agreed as to the explanation.

One of the most eminent of such observers was *M. Basté.* He published a carefully prepared paper (in French) in "*L'Aéronaute*" for September, October, and November, 1887, containing an excellent account of 40 selected typical observations made by himself from 1871 to 1885 upon the numerous sailing birds in Uruguay, the Argentine Republic, and Brazil. This paper is well worth studying by persons interested in the subject, and some of his diagrams of bird evolutions will be given herein farther on.

In his attempt at theoretical demonstration he assimilates the soaring bird to a kite, in which the string is replaced by weight, and he carries this theory farther than his predecessors, by showing that the uplift is quite sufficient to sustain the weight at the angles of incidence observed by himself, of 2° to 8°; but he fails to show how the forward propulsion is obtained, save by the inference that altitude and speed can be interchanged without loss.

For the uplift he adopts the formula, for angles of incidence between 1° and 7°, of:

$P = SP' \sin a$ in which ——:

P = The lift on the bird.
P' = The air pressure due to the speed.
S = The sustaining surface of the bird.
$\sin a$ = The sine of the angle of incidence.

This formula gives materially less results than that of *Duchemin*, shown by *Professor Langley* to agree best with experiment in which the uplift is:

$$P = SP' \frac{2 \operatorname{sine} a \cos a}{1 \quad \operatorname{sine}^2 a}$$

Basté applies his formula to two cases: the first, that of a gull weighing 0.64 pounds, and with 1.03 square feet surface (1.61 square feet per pound) exposed at an angle of 5° to a wind blowing at 44 miles per hour, and he calculates that the uplift is 0.99 pounds, or 50 per cent. more than the weight of the bird, so that it must rise. (This uplift would be 1.72 pounds by the Duchemin formula.) In the second case, he selects a falcon weighing 0.46 pound, with a surface of 1.28 square feet (2.78 square feet per pound) exposed at an angle of 12° to a wind of 20 miles per hour. His uplift amounts to 0.54 pounds, while it would be 0.99 pounds by the Duchemin formula.

Basté does not seem to have measured the wind when making his observations. The weak feature in his demonstration is that he has assumed winds of undue intensity, but this is offset by the fact that he has employed a formula which gives less than the real results. He says that with wing surfaces in the proportion of 2.69 to 2.93 square feet per pound birds can sail in winds of 4½ to 11 miles per hour; that birds with 1.46 to 1.71 square feet per pound require winds of 20 to 27 miles per hour, while birds with 1.37 to 1.46 square feet of wing surface per pound maintain and transport themselves in sailing flight in winds of 44 to 56 miles per hour.

This agrees fairly well with the observations of the present writer, which indicate that sailing flight is practicable to the buzzard weighing 0.88 pounds per square foot, in a 5 or 6 mile breeze, and to the gull weighing 1 pound per square foot, in a wind of 12 to 18 miles an hour.

Basté, however, does not show how the resistance of the body and wings is overcome, nor how the bird obtains forward motion. As a deduction he says:

"To resume the preceding observations and demonstrations I simply conclude: that sailing flight is the immediate result of a skilful combination of two forces possessing different intensity and direction, *i.e.*, the force of gravity and the pressure of an aerial current. But that, by reason of the faculty possessed by the bird, of changing the position of his body, of folding or inclining his wings, and of thereby displacing his centre of gravity, there results such a great diversity in the application of these two forces that the resulting movements become so complex as to constitute an entire system of aerial locomotion."

2. RISING TRENDS OF WIND.

Pénaud, in an unfinished essay upon sailing flight in "*L'Aéronaute*" for March and April, 1875, accounted for the phenomenon by assuming ascending currents of wind to prevail, and he adduced terrestrial slopes and obstacles, the impinging of wind currents upon each other, eddies and solar action, as abundant and adequate causes to produce such rising winds.

Mathematically, this theory is quite satisfactory, even if we base our calculations upon plane surfaces. If we assume, for instance, an ascending trend inclined but 15° upward, and a plane surface loaded to 1 pound to the square foot, and if we suppose that surface to be inclined forwards, so that its front edge shall point 5° *below* the horizon, then the wind will still make an angle of 10° with the surface, at which angle the normal pressure will be, by Duchemin's formula, 0.337 of what it would be if the plane were at right angles to the wind. Now, this normal pressure is decomposed into two resultants, the "lift" and the "drift," which are as the cosine and the sine of 10° or angle of incidence. If next we suppose the wind to be blowing at the rate of 25 miles per hour, at which the rectangular pressure, by ordinary wind tables, is 3.125 pounds per square foot, we will then have for the lifting force:

Lift $= 1 \times 3.125 \times 0.337 \times \cos 10°$, or $0.985 = 1.03$ pounds, which will a little more than sustain the weight. But the plane is making an angle of 5° *below* the horizon, and the horizontal component or "drift" is directed towards the front and acting as a propelling force; we therefore have, with the same wind pressure:

Drift $= 1 \times 3.125 \times 0.337 \times$ sine $5°$, or $0.087 = 0.0916$ pounds, this being the propelling traction per square foot, so that if the surface measures 1,000 square feet, it will be dragged forward by a constant horizontal force of 91.6 pounds, and this, inasmuch as the speed of the wind is 25 miles per hour, amounts to:

$$\text{Power} = \frac{91.6 \times 25}{375} = 6.10 \text{ horse-power},$$

which would enable the plane to advance horizontally against this ascending wind, and to overcome the resistance of such spars and body as might be requisite.

It will be seen hereafter that still better results can be figured out by basing calculations upon the concave surfaces of birds' wings.

This theory has been concurred in or separately advanced by *De Louvrié*, *Moy*, "*Close Hauled*," several other writers in the technical press, and by *Lilienthal*, the latter stating that the wind blowing over a level plain generally has an upward trend of 3° or 4°, and that this is the principal reason for the sailing flight of birds. It is very much to be regretted that he did not publish his theory with full calculations.

The existence of ascending trends of wind is fully confirmed by *Mr. Maxim* in an article entitled "Natural and Artificial Flight," in the Aeronautical Annual for 1896. In this he describes his many observations at sea and on land, and deduces the conclusion that the wind seldom or never blows in a horizontal direction, that there are ascending and descending columns of air, generally separated from each other by distances varying from 500 feet to 20 miles, and that the soaring birds seek out and utilize the ascending columns, being enabled to recognize them through the sensitive air-cells which abound throughout their bodies, and which act much as aneroid barometers.

This theory assimilates the soaring bird to a ship sailing close-hauled upon the wind, the force of gravity replacing the effect of the keel. Its defect is that it is not complete, for careful observation shows that while local ascending trends of wind are not uncommon, are indeed very frequent, yet the sailing birds are sometimes seen to perform their feats perfectly when every test shows the mean wind to be horizontal. I saw, for instance, at Tampa, Florida, in February, 1893, three buzzards advance half a mile dead against the wind, on a level course, without one single flap, while the smoke from the tall chimney of the adjoining hotel laundry, the top of which was about at the same level as the birds, indicated that the wind was quite horizontal.

3. DIFFERENT COEFFICIENTS FRONT AND REAR OF BIRDS.

This theory approximates a bird circling in the sky to a set of Robinson anemometer cups, which spin round and round by reason of the difference in coefficient of their concave and convex sides. It was first advanced by *Mouillard* in "*L'Empire de l'Air*," without, however, great insistance upon it. He held that when the sailing bird went with the wind, the current exerted pressure against the fluffy rear, so as to impart a speed which was subsequently used in gaining height, when the bird presented his smooth front to the wind.

This conjecture was independently presented in 1894 by *Mr. Winston*. It had also been advanced in 1884 by *M. Weyher* in "*L'Aëronaute*," but the latter took it back in 1890, for the very sound reason that the wind can in no case impart more than its own speed to the bird, and that therefore the latter cannot, by turning around, then progress against the same wind.

M. Mouillard now holds the opinion that the soaring bird, having first acquired an initial speed of his own, either by flapping or by gliding downward, next receives impulse by heading into the wind, and is raised up, just as a car on a "roller coaster" would be lifted higher than its point of departure were the whole roadway to be set into motion in a contrary direction to the car, after the latter has begun running down the first incline. His article setting forth this view will be found in the "Cosmopolitan Magazine" for February, 1894.

We next come to the fourth group of theories, which hold that energy is obtained by going over courses of differing lengths in:

4. TACKING AND CIRCLING.

Mr. S. E. Peal has been carefully observing the soaring birds in Upper Assam, India, for many years. He has repeatedly (much too briefly) published his observations, and in an article in "Nature," of May 21, 1891, which will well repay perusal, he brings out a number of important facts. He states that Upper Assam is a dead level, some 60 miles wide by 200 long, that the prevailing wind is a steady breeze of about 5 to 10 miles an hour, that there are no up rushes of air, and that large birds like the cyrus, adjutant, pelican, and vulture can rise from 300 to 3,000 feet in a *steady* breeze without flapping their wings. He says:

"Firstly, these large birds do not soar in a dead calm or a storm, or during high winds. They prefer a steady breeze.

"Secondly, they rise from the ground by flapping the wings, and continue this till they are 100 or 200 feet up, and then begin to soar, in right or left hand spirals 100 or 200 yards across. At each lap they rise 10 or 20 feet, and make as many yards leeway, drifting slowly *with the wind*, and continue thus to rise until out of sight above. . . . The speed of the bird is always greater than the breeze, and the resistance is unequal on opposite sides of the loop of the spiral; least when it travels with the breeze, and greatest when on the opposite half, meeting it.

"It seems to me the solution is that when going with the wind the bird gathers momentum by going down a slight incline, and when it turns and meets the breeze, this extra momentum is used in lifting the bird and carrying it over a *shorter* course.

Thus it starts the next lap at a *slightly* higher level, but some 20 yards to leeward. Variation of the speed of the wind at different levels is here quite out of the question; the bird, too, keeps to its steady spiral, and as steadily ascends at each lap."

Mr. Magnus Blum, in a letter to "Nature," in February, 1891, modifies this theory by observing that when the bird, with an initial speed of its own, is sailing at right angles to the wind, he is also drifted sideways by the current; that hence he passes over the diagonal between those two courses, and does this in the same time that would otherwise be occupied by his own course in calm air; that as the diagonal is longer, the speed must be greater, the increment of velocity being gained from the wind, thus constituting the method by which the bird gathers the energy required to overcome the head resistance and to maintain the altitude, with, however, some oscillations in level when going with the wind or against it. Hence he infers that the fundamental evolution for the bird to perform consists in a series of zigzags, with loops at the turning points, and that spiral sailing is but a modification of this fundamental manœuvre. He gives no quantitative calculations to show that the impulse received is sufficient to overcome the head resistance and to maintain the velocity. We shall again find this zigzag or tacking idea, differently applied, in M. Bretonnière's paper, and it would seem worthy of closer investigation than it has yet received.

Mr. Goupil, in his book "*La Locomotion Aérienne*," advances substantially the same idea (page 69), that the bird gathers energy from the wind when sailing quartering, or at right angles thereto; but he gives no calculations to show that the effect is sufficient to account for the phenomenon.

Professor Proctor evidently inclined to the general explanation offered by Peal, but did not exactly formulate a theory. He wrote quite a number of interesting short articles on the subject. One of them, a letter to the "English Mechanic," occasioned a lively controversy by a dozen writers, which was republished in the report of the Aeronautical Society of Great Britain for 1880. Although somewhat inconclusive, it is worth perusal by the curious.

Prince Mikounine made some interesting observations upon the soaring flight of vultures in the mountains of the Caucasus, which he published in "*L'Aéronaute*" for September, 1878. He endeavored to place himself on the same level as the birds, and carefully noted the direction of the wind. He alone, of all the various observers, thought that the birds rose when going with the wind, and descended when facing it.

5. COMBINATION OF GRAVITY AND WIND.

M. S. Drzewiecki, a Russian engineer, who presented a very able paper in French at the Aeronautical Congress at Paris in 1889, upon "Birds considered as Animated Aeroplanes," followed this up in 1891 with an essay upon "Soaring Flight," which was printed for private circulation.

In the exposition of his theory he supposes a bird, on a perch and facing the wind, to glide downward and forward against the breeze, so that the two velocities shall combine. He shows that by bringing his centre of gravity forward the bird will descend, and, calling V his potential speed, g the factor for gravity, and h the height, then the velocity due to the fall will be: $V=\sqrt{2\,gh}$. He then goes on to say: "Hence the bird, at the lowest point in its course, will possess this absolute speed V (as regards the earth); then by a fresh displacement of his centre of gravity, the inverse of that at starting, he will alter his angle of incidence so as to transform his descent, first into horizontal translation and then into a progressive rise, against the wind as before. At the time of the transformation of the descent into a horizontal movement, the absolute speed V, that due to the fall, being combined against the velocity —V' of the wind, which is blowing adversely, will give the bird a relative velocity against the air of $V+V'$.

"Hence, like a child's marble rolled against an inclined plane which is made to travel in a contrary direction, the bird will rise to a greater height than its starting point, or to an altitude depending upon his relative speed of $V+V'$ of:

$$\frac{(V+V')^2}{2g}.$$

"But if, instead of availing of all this potential lift the bird, through a new change in his angle of incidence, ceases to rise at a point where the remaining speed will still be equal to V', and hence be sufficient to uplift him to the height

$$\frac{V'^2}{2g},$$

it is evident that the difference in altitude between the lowest point reached and that last mentioned will be:

$$h' = \frac{(V+V')^2}{2g} - \frac{V'^2}{2g},$$

and, in consequence thereof, the bird will have arisen from the lowest point:

$$h' = \frac{V^2+2\,VV'}{2g},$$

and will still possess a speed of V′ relative to the air. This velocity being equal to that of the wind, it follows that the bird is then under precisely the same conditions (except that he is free in air) as when he was on the perch before starting, and is ready for another descent.

"In the first descent the bird lost in altitude

$$h = \frac{V^2}{2g};$$

he regained, as we have already seen,

$$h' = \frac{V^2+2VV'}{2g},$$

and hence the altitude gained by the evolution was

$$H = h' - h = \frac{2VV'}{2g}.$$

"Upon the next evolution the soaring bird will continue to gain altitude, and can thus rise indefinitely without muscular effort, by profiting exclusively of the speed of the wind."

M. Drzewiecki then describes the two methods which may be practised by the bird in effecting this recuperative descent; 1st, by progressively changing his angle of incidence, so as to keep his longitudinal axis always tangent to his trajectory, and 2d, by maintaining constantly his aeroplane at the angle of least resistance, which *M. Drzewiecki* finds to be 1° 50′ 45″. He holds that the first method is adopted when the wind's speed is greater than that of the bird, and the second method obtains when it is less.

He then applies these principles to helical circling in the air, which he considers as the fundamental manœuvre, and he estimates that once altitude is gained, the bird can glide downward in the same direction as the wind at an angle of 2° 31′ 10″, or in the ratio of 45 horizontal feet for every foot of descent.

The objection to this theory, as expounded, is that the speed due to gravity v is a *vertical* speed, and that the speed of the wind v′ being a *horizontal* speed they should not be added together. The true *relative* speed would seem to be the diagonal of the parallelogram of velocities, or $\sqrt{v^2 + v'^2}$, instead of $v + v'$; but, on the other hand, this "relative wind" will not be horizontal, as assumed by *M. Drzewiecki*; it will be inclined upward as regards the course of the bird, and thus perform the office of a rising trend of wind.

Some loss would seem to be involved in the supposing the bird to leave the perch dead against the wind, and accordingly *M. Bretonnière*, in a paper on "Sailing Flight" presented to the International Conference on Aerial Navigation at Chicago in 1893, modifies the theory by considering the bird as leaving the perch on a course at right angles to the wind, and then drifting a little, descending so as to gain speed from gravity, which speed is thereafter transformed into elevation by heading into the wind. The mathematical demonstration is practically the same as that of *M. Drzewiecki*, the vertical and horizontal speeds being added together; but, according to *M. Bretonnière*, the fundamental manœuvre is a zigzag instead of a circular sweep, and he holds that this would be the proper manœuvre for a man to perform if he were attempting to imitate the soaring birds.

Unfortunately neither of these writers has explained how the bird extracts energy from the wind, and *Mr. Soreau*, a French engineer, in an article in the "*Revue Scientifique*" for March 30 and April 6, 1895, criticises them as follows:

"The conclusion in M. Bretonnière's theory is quite erroneous. . . . A uniform wind is impotent in the mechanics of flight; its variations alone can benefit the birds. . . . In the theory of *M. Drzewiecki* the author says naught concerning ascending currents or wind squalls, and yet he talks of work obtained from the wind. He attempts to demonstrate that the bird, by gathering increased speed through gravity, can then rise higher than he fell. In such case, the transformation into height of the kinetic energy due to the fall would be greater than the original unit! It is just the reverse of what really occurs."

Mr. A. M. Wellington, in a paper on "Mechanics of Flight" presented at the same conference, held that the soaring bird gathered speed from the wind by plunging downward in the same direction in which it blows, and he likens the action to that of a spherical mass rolling down an inclined plane on a floating hulk which travels in the same direction as the rolling ball. As in this case the ball would be travelling faster than the hulk, it is difficult to see how it could gather energy therefrom, although it would doubtless gather speed and energy from gravity, which would send it up again, barring losses, to the same height it started from.

It will be noted that all these theories are based upon the assumption that what we call the "wind" blows as a practically uniform current of air, regular both in velocity and direction.

Many eminent scientists hold, however, that for the sailing bird a uniform current is equivalent to a calm, and they brush aside all the above theories except Pénaud's, upon the ground that it is not physically possible for sailing flight to occur in a uniform current.

Lord Rayleigh, the highest scientific authority in Great Britain, says in an interesting letter published in "Nature," April 5, 1883:

"I premise that if we know anything about mechanics, it is certain that a bird, without working his wings, cannot, either in still air or in a uniform horizontal wind, maintain his level indefinitely. For a short time such maintenance is possible at the expense of an initial relative velocity, but this must soon be exhausted. Whenever, therefore, a bird pursues his course for some time without working his wings, we must conclude either (1) that the course is not horizontal, (2) that the wind is not horizontal, or (3) that the wind is not uniform. It is probable that the truth is usually represented by (1) or (2); but the question I wish to raise is whether the cause suggested by (3) may not sometimes come into operation."

Lord Rayleigh then states that circular sailing is possible without flapping if the wind be stratified into two layers of different velocities, for by keeping near the plane of separation, the bird can gain relative velocity without work in passing from one stratum to the other; but he adds that, *à priori*, he would not have supposed that the variation of velocity of the wind, as the height increases, would be adequate for the purpose of sailing flight.

This brings us to the three groups of theories which suppose energy to be derived by the bird from irregularities in the wind.

6. DIFFERENT SPEEDS OF WIND STRATA.

One of the best expositions of this theory is that of *Mr. Wm. Kress* in a paper entitled "A Theory of Sailing Flight," read before the Conference on Aerial Navigation of 1893. He supposes the moving sea of air to be composed of strata of wind of different speeds, vertically superposed. He shows by a table that a circling bird in passing from a current blowing 5 metres per second (11 miles per hour) into another of 10 metres per second (22 miles per hour) can be at all times supported without beating his wings, and can then return into the original current with a velocity increased by 3 metres per second.

It is well known that winds do almost invariably increase in speed with altitude, but the cases must be rare indeed in which the increase is as great as *Mr. Kress* has assumed within the limits of one of the bird's circlings; so that although the theory itself is sound, it remains to be proved that the exact variations assumed exist in nature.

Mr. H. C. Vogt, of Copenhagen, in a letter to London "Engineering," published March 25, 1892, gave a series of elaborate computations to show that an albatross weighing 20 pounds, with 11 square feet of sustaining surface, derives from a stratified wind all the necessary energy to sustain his weight and to advance against that wind. For this purpose he supposes the gale to blow at the rate of 60 feet per second (41 miles an hour) at a height of 65 feet over the sea level, and of 30 feet per second just over the wave tops. The bird is assumed to commence his manœuvres at a height of 65 feet over the sea, to descend to the calmer region at the sea level, gathering 1,410 foot-pounds of energy, and to reascend against the wind to his original altitude of 65 feet, having advanced against the wind a distance of 250 feet in 6.25 seconds, and being then ready to repeat the operation. This letter should be carefully read by all interested in the question. The calculations are correct, and it is not impossible that in a 40-mile gale and a rolling sea there should be as great differences as those assumed in the speed of the wind aloft and at the sea level, but the computations only apply to this special case, and do not explain how a hawk or a buzzard can sail indefinitely on pulseless wings in a breeze of 5 or 6 miles per hour.

7. INTERMITTENCY OF WIND FORCE.

The difficulty in conceiving how a bird could extract energy from a uniform current of wind led *Professor Marey*, in his masterly book "*Le Vol des Oiseaux*," published in 1889, to suggest that sailing flight might be accounted for by the intermittency in wind velocities which are known to exist. He showed that it was quite possible for a bird to be sustained, to advance against the wind, and to rise, without flapping, if it could avail of a series of wind gusts and relative calms occurring at appropriate intervals. This he illustrated by a figure (page 316) somewhat similar to that which will be hereinafter given in discussing the manœuvre of the gull rising from a pile-head, but he did not elaborate this theory, nor show just what fluctuations occurred in the wind.

It was reserved for *Professor Langley* to set forth this theory fully in his now celebrated essay on "The Internal Work of the Wind." He showed by records of instrumental measurements, ingeniously made so as to give the actual facts, that the wind is very far from being a uniform current, such, for instance, as a stream of water; that, in fact, the wind is constantly fluctuating in velocity and force, not only in those gusts and comparative calms which are apparent to our senses, but in numberless minor fluctuations which had not previously been revealed, in consequence of the inertia of the measuring instruments employed. *Professor Langley* then showed that it is quite possible to conceive how a sailing bird can maintain himself in the air, and also advance against the wind without work, by taking advantage of these fluctuations. This it can do by merely altering its balance and consequent angle of incidence. By increasing this angle during a wind gust the bird can gain altitude, and by diminishing this angle during a lull he can glide downward and gather velocity, to be subsequently expended in regaining altitude. This is illustrated by a figure drawn from theoretical considerations alone, which is almost identical with the figure to be hereinafter given from actual measurements of the gull starting from the pile-head.

This paper will, of course, be read in full by all interested in the subject. It has been published by the Smithsonian Institution and in the "Proceedings of the International Conference on Aerial Navigation," and need not therefore be further epitomized here.

The theory is entirely sound, but not quite complete. There is no question in my own mind but that sailing birds do utilize prolonged wind gusts in gaining altitude, and do gain velocity during relative calms by gliding downward, but I question whether they can utilize the minor fluctuations of the wind, especially in light breezes, and whether the wind gusts and relative calms are sufficiently timely and strong to account for spiral soaring. The author of this theory has yet to show by quantitative calculations that the fluctuations of the wind, as actually observed, are sufficient to produce the required support and advance of a sailing bird weighing, say, 1 pound per square foot of sustaining surface, and how the various manœuvres and feats of soaring flight which have been observed are to be accounted for.

It may be mentioned here as a curious illustration how similar conclusions are simultaneously reached by able thinkers, that only a few months prior to the presentation of Professor Langley's essay, the same identical theory was briefly propounded by *Mr. W. H. Dines*, the eminent British meteorologist, in a private letter to myself, and that I subsequently found a somewhat similar theory, evidently quite original, in an Italian book, "*Teoria del Volo*," by A. Faccioli, published by U. Hoepli, Milan, in 1895.

8. CHANGES IN WIND DIRECTION.

The suggestion of *Lord Rayleigh*, that among the three inferences which may be drawn in accounting for sailing flight is "that the wind is not uniform," covers, of course, changes in direction as well as in velocity. *Professor Langley* mentions that changes in direction of wind occurred during his experiments, although they were not recorded by his instruments. By such changes in direction, both vertical and horizontal, *Prof. A. L. Zahm*, then of Notre Dame University, accounted for what he termed "Naval Soaring," in an article published in the "*Notre Dame Scholastic*" of Dec. 10, 1892.

This theory assimilates sailing flight to the tacking of a ship, gravity and inertia answering for keel resistance. It explains the zigzags and the circlings which soaring birds so frequently exhibit, and is a sound explanation provided the changes in direction can be shown to obtain with sufficient force and frequency to produce the observed manœuvres. To determine this, *Professor Zahm* subsequently constructed an experimental apparatus to record simultaneously the changes in vertical and horizontal direction which occur in the wind. He has published the results in a paper entitled "Atmospheric Gusts and their Relation to Flight," which will be found in the "Proceedings of the International Conference in Aerial Navigation." The experimental apparatus not proving quite satisfactory, he has not attempted to apply its records to quantitative calculations in support of his theory, but it is to be hoped that he shall soon find time to resume this interesting investigation, as it showed greater variations in wind direction than is generally realized by our unaided senses.

From my recent experiments with full-sized gliding machines, carrying a man, I am now inclined to attribute the fluctuations in wind velocities observed by *Professor Langley*, and those in wind direction observed by *Professor Zahm*, largely to one and the same cause. This is the apparently rotary or oscillating character of wind currents. To the man in the machine, buffeted by the wind, the current seemed to arrive as a series of revolving billows, and to veer in direction and in velocity according to the position which the apparatus might occupy at any one time with reference to the centre of rotation of the aerial wave. This observation was originally due to *Mr. A. M. Herring*, who most frequently used the various machines experimented with, and once the fact was pointed out all the subsequent observations seemed to confirm the idea that all wind waves have a more or less rolling character. The reader needs but to watch smoke issuing from a chimney, to gain an impression as to the shape of these wind waves, and to conceive the changes in velocity and direction which will be experienced by a stationary object exposed thereto, or by a sailing bird passing through them. It is believed that, as it has practically no inertia, the smoke immediately partakes in a large measure of the motion of the air, and that its curlings represent the conditions which must be met in free flight. This observation is of important promise, as furnishing a better understanding of the character of the wind, and as suggesting what to investigate in further attempts to imitate the birds.

Having now passed in review all the theories of sailing flight of which the writer hereof has knowledge, the reader will note that none of them takes into account the shape of the birds themselves, and that no mention seems to have been made of the cross-sections of the wings of sailing or other birds. If these various theories were true and complete it would follow *that all birds could soar*, and yet it is well known that the great majority of birds, even those of considerable mass, such as the geese, the ducks, the wild turkeys, etc., can glide a limited distance, but that they cannot sail upon the wind like the eagles, the vultures, the gulls, or the albatrosses. In fact, sailing flight is confined to a few species, and the performance is chiefly seen in particular localities.

This led the writer hereof to question whether there might not be some important difference in the cross-section of the wings of soaring and non-soaring birds, and a brief investigation revealed such divergences as to lead to the inference that this difference in shape may alone account for the fact that one class of birds can extract energy from the wind while other classes cannot.

These differences are fairly shown in Fig. 1, which represents the cross-section of the wings of the frigate, the buzzard, the gray pelican, the gull, and the hawk, all of them soaring birds, and of the duck, the pigeon, and the wild turkey, which are non-soarers. These sections are all taken just forward of the first joint in the arm, and exhibit a marked difference between the sailing and the non-sailing birds. It will be noticed that the former have all a downward projecting lobe at the front, and that the radius of curvature at about one-quarter of the distance back from the front edge is considerably sharper on the under side than on the upper side of the wing, while the non-soarers have not only thinner wings, but the curvature is nearly the same on the upper and the lower surfaces. It is probable that all these wings are somewhat flatter than here shown when in full action carrying weight, but all the sailing and non-sailing birds which I have examined exhibit the same kind of difference in shape, and I believe that it will be found universal. The inference which I have drawn therefrom will be stated when we come to discuss what has been called "aspiration."

One other matter of observation has also greatly impressed me. It is the fact that sailing flight seems to be most frequently and easily performed in the regions of more uniform air currents: in the steady trade winds, in the regular sea breezes, and in those southern zephyrs in which it is hard to detect sufficient fluctuations in velocity to produce the effects which have been theoretically ascribed to them.

And yet there is nothing more certain than that the sailing birds extract energy from such winds; that buzzards, for instance, maintain themselves in the air at speeds of 15 to 20 miles per hour without a flap of wing, in breezes of 6 to 8 miles an hour; that gulls can keep up indefinitely at speeds of 17 to 22 miles per hour, in winds of 13 to 16 miles per hour, and that the fluctuations of these winds, either in velocity or direction, do not seem to be great. Indeed, it has not infrequently occurred to me that the sailing birds seemed to dislike gusty winds, and that they aided themselves by flapping more often in such winds than they did in steady breezes.

These facts led me to question whether it was not possible that sailing flight might take place in a nearly uniform wind; but, as previously stated, it was only when I obtained Herr Lilienthal's table of air pressures, published in Moedebeck's "Handbook for Aeronauts and Aviators," that I was enabled to figure out satisfactory reactions at the angles and speeds which I had observed.

This table is understood to have been obtained from actual experiments with surfaces arched upward (in section) about $\frac{1}{12}$ of their width, and in presenting it *Herr Lilienthal* (using metric units) says:

"When a wing with an arched profile is struck by the wind at an angle α with a velocity V, there will be generated an air pressure R which generally is not normal to the chord, but is the resultant of a force N normal to the chord, and of another force T tangential to the chord. If we call F the area of the wing, then:

* The normal pressure $N = \eta \times 0.13 \times F \times V^2$.
* The tangential pressure $T = \vartheta \times 0.13 \times F \times V^2$.

"The table on the following page, giving values of η and ϑ, show that arched surfaces still possess supporting powers when they are struck by the air at an acute angle *from above*, that is to say when α becomes negative. The resisting components of the air pressure T change, with angles exceeding 3°, into propelling components, which, at an angle of 15°, become equal to $\frac{1}{12}$ of the lift, and do not disappear entirely until 30° is reached."

This does not mean, as *Lilienthal* subsequently makes clear by an example, that there is no horizontal component of the *normal pressure* N, or "drift," when the angle of incidence is above the horizon, but that, at certain angles, the *tangential pressure* T, which would be parallel with the surface if applied to a plane, and therefore produce no effect but friction, acts on a curved surface as a propelling force.

This table, which will be used in the calculations hereinafter given, is as follows:

* $0.13 \times F \times V^2$ in metric units $= 0.005 \times S \times V^2$ in miles per hour.

TABLE OF NORMAL AND TANGENTIAL PRESSURES

Deduced by Lilienthal from the diagrams on Plate VI., in his book "Bird-flight as the Basis of the Flying Art."

α Angle.	η Normal.	ϑ Tangential.	α Angle.	η Normal.	ϑ Tangential.
− 9°	0.000	+ 0.070	16°	0.909	− 0.075
− 8°	0.040	+ 0.067	17°	0.915	− 0.073
− 7°	0.080	+ 0.064	18°	0.919	− 0.070
− 6°	0.120	+ 0.060	19°	0.921	− 0.065
− 5°	0.160	+ 0.055	20°	0.922	− 0.059
− 4°	0.200	+ 0.049	21°	0.923	− 0.053
− 3°	0.242	+ 0.043	22°	0.924	− 0.047
− 2°	0.286	+ 0.037	23°	0.924	− 0.041
− 1°	0.332	+ 0.031	24°	0.923	− 0.036
0°	0.381	+ 0.024	25°	0.922	− 0.031
+ 1°	0.434	+ 0.016	26°	0.920	− 0.026
+ 2°	0.489	+ 0.008	27°	0.918	− 0.021
+ 3°	0.546	0.000	28°	0.915	− 0.016
+ 4°	0.600	− 0.007	29°	0.912	− 0.012
+ 5°	0.650	− 0.014	30°	0.910	− 0.008
+ 6°	0.696	− 0.021	32°	0.906	0.000
+ 7°	0.737	− 0.028	35°	0.896	+ 0.010
+ 8°	0.771	− 0.035	40°	0.890	+ 0.016
+ 9°	0.800	− 0.042	45°	0.888	+ 0.020
10°	0.825	− 0.050	50°	0.888	+ 0.023
11°	0.846	− 0.058	55°	0.890	+ 0.026
12°	0.864	− 0.064	60°	0.900	+ 0.028
13°	0.879	− 0.070	70°	0.930	+ 0.030
14°	0.891	− 0.074	80°	0.960	+ 0.015
15°	0.901	− 0.076	90°	1.000	0.000

While I feel quite certain that most of the sailing feats which have so puzzled observers are performed in consequence of ascending trends of wind, or by the aid of wind gusts, lulls, and changes of direction, — that, in fact, sailing birds do constantly utilize such trends and fluctuations, — I am also constrained to believe, from many personal observations, that the theories above reviewed are not complete, and that birds of certain types do extract energy from a wind which all visible tests show to be horizontal, and blowing with such slight fluctuations that the required reactions cannot, with our present knowledge, be figured out from the observed facts.

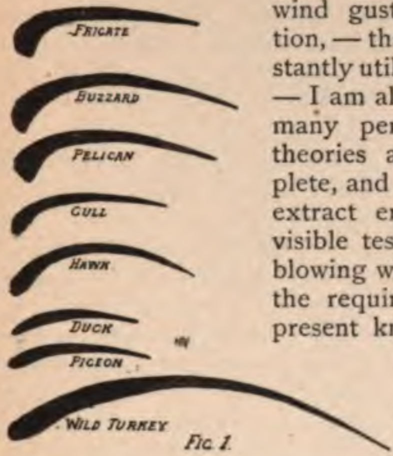


FIG. 1.

I believe that this possible obtaining of energy in such cases is due to the section of wing peculiar to sailing birds, as shown in figure 1; but before attempting the consideration of this, it seems best to consider more obvious cases, and to begin with the manœuvre of the gulls patrolling along the weather side of a steamer tied to the wharf.

The average measured velocity of the wind on that occasion was 12.78 miles per hour, it had an ascending trend of 10° to 20° at the side of the steamer, and the relative speed of the birds was 26.3 feet per second, or 17.88 miles per hour. They presented an angle of incidence of 5° to 7° *above the horizon.*

I found it impossible to compute the forces in action with the Duchemin formula for pressures on planes, even with a coefficient of 1.30 for the concavity of the supporting surfaces (obtained from some rough experiments with a pigeon — a non-soaring bird). An inadequate *sustaining* reaction could be figured out, but the *propulsion* could not be accounted for. If the angle of incidence had been negative a propelling force could have been calculated even for a plane, but as the observations showed that the angle was positive the whole case was dropped. Three years later, however, the Lilienthal coefficients rendered the matter easy of explanation.

As the relative speed of the bird was 17.88 miles an hour, it corresponded to a rectangular pressure of 1.60 pounds per square foot. Taking the lowest observed angles of incidence or 5° above the horizon for the bird, and 10° of ascending trend for the wind, the two would make an angle of 15° with each other, for which the Lilienthal coefficient for normal pressure is 0.901. The supporting surface of the gull measured was 2.015 square feet, and we therefore have:

$$\text{Normal} = 2.015 \times 1.60 \times 0.901 = 2.90 \text{ pounds.}$$

But as the angle of application is 15°, we have:

$$\text{Lift} = 2.90 \times \cos 15°, \text{ or } 0.966 = 2.80 \text{ pounds,}$$

which more than sustains the weight of 2.188 pounds.

The resistances consist in the "drift" and the resistance offered by the body and wing edges. The body measures 0.126 square feet in cross-section, and the most probable coefficient for its "fair" shape is 1/10. The wing edges measure 0.098 square feet in section, and their coefficient for roundness is probably 1/4. The course being horizontal, the "drift" is that due to an angle of +5°, for which the Lilienthal normal coefficient is 0.650. This factor must be multiplied by the sine of +5°; that is, by 0.087. We then have:

Drift = 2.015 × 1.60 × 0.65 × 0.087 =	0.182	pounds.
Body resistance = 0.126 × 1.60 ÷ 10 =	0.020	"
Wing resistance = 0.098 × 1.60 ÷ 4 =	0.039	"
Total resistance,	0.241	"

But the tangential pressure is that due to 15°, the angle between the bird and the ascending wind, and for this the Lilienthal coefficient is −0.076, so that the propelling factor is:

$$\text{Tangential pressure} = 2.015 \times 1.60 \times -0.076 = -0.245 \text{ pounds;}$$

whence it appears that the resistances and the propulsion are practically equal, and that the bird can continue his patrol indefinitely without beat of wing, as he derives all the energy needed for this purpose from the ascending wind. As the speed is 26.3 feet per second the work so done is:

$$\text{Energy} = 0.245 \times 26.3 = 6.44 \text{ foot-pounds per second.}$$

This amounts to 0.0053 horse-power per pound of bird, equivalent to 188 pounds sustained per horse-power. It well illustrates the superiority of arched surfaces over planes, for it will be recollected that in figuring out the propulsion of 1,000 pounds on as many square feet, 6.10 horse-power was required to overcome the "drift" of the plane alone, without allowing for body or wing edge resistance, and we had to assume in sailing flight a negative angle of 5° for the plane and an ascending wind of 15°, blowing at 25 miles per hour, as against an ascending trend of 10°, blowing at 12.78 miles an hour on an arched surface, as just above calculated.

The sailing of the gulls just above and to the leeward of the coal pockets is probably to be accounted for in the same way, *i.e.*, by an ascending local current in a breeze too light to furnish support and propulsion if horizontal, for when the breeze grew stronger the birds soared all over the harbor in apparently horizontal winds. Unfortunately they were then at so great a height that the angle of incidence could not be seen. This angle was, however, fairly well observed during flapping flight in calm air, and was judged to be from 3° to 5° above the horizon. Assuming the first figure, and the lowest observed speed of 30 feet per second, or 20.4 miles an hour, for which the rectangular pressure is 2.08 pounds per square foot, we have, using the Lilienthal coefficients:

Normal = 2.015 × 2.08 × 0.546 = 2.288 pounds,
And lift = 2.288 × cos 3°, or 0.998 = 2.283 pounds,

which is seen to sustain the weight; while we have:

Drift = 2.288 × sin. 3°, or 0.052 =	0.119	pounds.
Body = 0.126 × 2.08 ÷ 10 =	0.026	"
Wings = 0.098 × 2.08 ÷ 4 =	0.051	"
Total resistance,	0.196	"
Tangential pressure at 3°,	0.000	"

Work = 0.196 × 30 = 5.88 foot-pounds per second, or 0.0049 horse-power per pound of bird, which power, however, is furnished by the bird instead of being derived from the wind.

A manœuvre much more difficult to account for is that of the gull starting from a pile head (described under the head of "Starting"), and gaining a limited increase of altitude while advancing against the wind. There is no question as to the accuracy of the observation. The feat, although rare, was repeatedly witnessed by myself as well as by others. The bird, after rising without beat of wing 2 or 3 feet, descended about 8½ or 9 feet, then rose again some 12 feet, or say 3 to 3½ feet above the point at which he came to a poise, as shown in figure 2.

FIG. 2.

The bird was 10 feet above the water, facing a wind which I am sure was horizontal and varying from 14 to 23 feet per second, or 9.52 to 15.64 miles per hour. These speeds were measured by a "Richards" anemometer, but as the observations lasted from 10 to 20 seconds each, it is probable that neither the maximum nor the minimum was recorded. A detailed analysis of the subsequent performance will show that it can be accounted for by a variety of suppositions.

The gull first opened his wings wide, but as he kept the front edge depressed, the wind blew on his back and pressed him downward. Then, when a wind gust arrived, he raised the front edges to an angle of incidence estimated at 20° above the horizon, and rose upward. Let us assume that the gust blew at the rate of 18 miles an hour, or a very little more than the average maximum observed. According to ordinary tables of wind pressures, the speed assumed corresponds to a pressure of 1.62 pounds per square foot. Then, as the bird's sustaining area was 2.015 square feet and the Lilienthal coefficient is 0.922 for 20°, we have:

$$\text{Normal} = 2.015 \times 1.62 \times 0.922 = 3.01 \text{ pounds.}$$

And as the angle is 20°, cosine 0.939, therefore:

$$\text{Lift} = 3.01 \times 0.939 = 2.826 \text{ pounds.}$$

As the bird's weight was 2.188 pounds, he needs must rise; but as the angle is above the horizon, the "drift" is positive, and the negative tangential pressure being small in comparison, he must needs also drift backward, thus losing relative speed and inertia. He will, theoretically, come to a poise when the lift just equals his weight. At 20° of incidence this will occur when the relative velocity becomes 15.87 miles per hour, corresponding to a rectangular pressure of 1.26 pounds per square foot. We then have:

$$\text{Lift} = 2.015 \times 1.26 \times 0.922 \times 0.939 = 2.188 \text{ pounds.}$$

It will appear by examination of theoretical tables of potential lifts against gravity, due to a given velocity of motion, that a speed of 18 miles per hour corresponds to a fall (or lift) of 10.84 feet, while a speed of 15.87 miles per hour corresponds to a fall of 8.63 feet; so that the gull could theoretically rise 10.84 —8.63 or 2.22 feet without the aid of the upward jump which he usually makes, but would lose 2.13 miles per hour of his relative speed. This agrees closely with the observed rise of 2 to 3 feet.

He could, however, go no higher with the wind then prevailing. He therefore altered his angle of incidence, by simply thrusting his wings back, thereby causing the weight of his body to tilt him to a negative angle of incidence as he plunged downward.

The problem to solve is how he subsequently gathers energy from the horizontal wind.

It is clear that if at the precise moment that the bird came to a poise the wind lulled materially, although this might be less than to the observed minimum of 9.52 miles per hour, the gull would acquire vertical speed more quickly than otherwise, and that if a fresh gust occurred just as he reached the lowest point of his course, he would again have been benefited by an increased relative velocity. This is the theory set forth by *Professor Langley*.

It is also clear that if the wind arrives as a billow revolving on a horizontal axis, and the bird starts up from the pile head on its ascending trend, and comes to a poise on its crest, he will be benefited by being able to gain speed upon the downward trend. The wind, upon the occasions when this performance was exhibited, blew at a speed varying from 14 to 23 feet per second, so that if those extremes had occurred during any single wave, they would have indicated a speed of rotation of

4.5 feet per second, this being one-half of the difference between the extremes recorded, while the mean velocity is 18.5 feet per second. If the speed of rotation be 4.5 feet, and the horizontal velocity 18.5 feet per second, then we have an ascending trend of $\frac{4.5}{18.5} = 0.243 = 14^{\circ}$, which we have already seen to be ample to furnish the required propelling power.

As many times, however, as I watched this manœuvre, the course gone over seemed to be identically the same: the gulls never failed to rise some 2 or 3 feet, to descend to within about 4 feet of the water, nor to rise thence about 12 feet, and, although there is a certain synchronism about the rotating billows, it seems difficult to believe, in the absence of actual measurements which I have not taken, that the rolling aerial waves, or the gusts and the lulls, occurred with such absolute exactness as to serve the bird at the very instant when he came to a poise because the relative velocity no longer sufficed to keep him up, so as to enable him to descend in a comparative calm, and to meet with another wave or gust at the exact time when he arrived at the bottom of his course.

There is another way in which the bird may gather energy from the wind during his descent at a negative angle to the horizon. When he first plunges downward, *the wind blows on his back,* and thus accelerates his fall to a greater speed than that due to gravity alone, and this increased speed can thereafter be transformed into greater elevation. This action, however, can continue but a very brief period, because it will drift the bird still further back, and because, as soon as he begins to fall, pressure accumulates under his wings, and he gradually flattens his angle of incidence. I have made a number of computations of the foot-pounds which can be so gained, based upon a number of assumptions of the coefficient of air pressure due to the convexity of the bird's back, the varying angle of incidence, and the length of time of the action, but they do not fully account for the subsequent rise of 3.5 feet above the point where he came to his first poise, and I freely confess that I am unable to show how the bird gathers energy from the wind, save on the assumption of an opportune gust.

Moreover, this only applies to one particular manœuvre, which is rarely seen, and which may be accounted for by the existence of exceptional circumstances, like some of the soaring feats described by *Basté*. One of these he terms the "Planement sur place," which may be rendered as soaring on a vertical stand, as shown in section in figure 3. The bird was high in air, facing a strong wind at M, with an angle of incidence above the horizon. He was then seen to ascend on rigid wings, drifting backward through positions 2 and 3, until he arrived at M′, position 4, whence he descended and advanced through positions 5, 6, and 7, until he once more reached the point M.

FIG. 3.

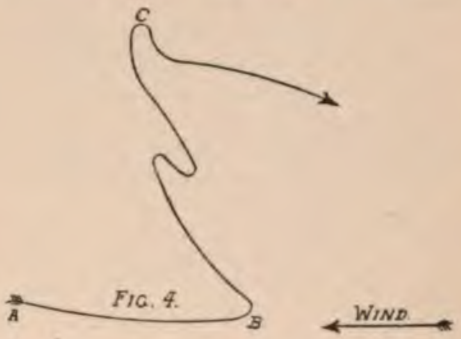


FIG. 4.

It seems reasonable to believe that in this case the bird simply utilized a wind gust to rise, coming to a poise at M′ when the lull began, and thence descended by gravity. The gust may or may not have had an ascending trend. There does not seem to be much doubt that there was an ascending trend, however, during another feat described by *Basté*, which was also performed during a very high wind, and which is shown in vertical section in figure 4. The bird was at A, about 10 feet above the sea, and first glided against the wind to B, whence he rose some 150 feet to C, with a poise and a short downward plunge about the middle of the course. *Basté* draws the wind as horizontal, but the manœuvre indicates an intermittent gust with a rising trend, during which the bird gained much altitude which might be subsequently utilized in gliding.

Such feats, although very interesting in themselves, are easily accounted for by the exceptional circumstances under which they are performed; but the explanation does not account for the continuous sailing of birds on set wings in breezes so light that some observers have claimed that the evolutions take place in a dead calm. I have myself seen a buzzard sailing 75 feet overhead in a breeze which measured 1½ miles per hour at a height of 5 feet above the ground, and which was to all appearance horizontal. *Peal* describes the performance in steady breezes of 5 to 10 miles an hour, when small tufts of cotton from the *Bombyx malabaricum* are shown by the telescope to float beautifully horizontal at elevations from 200 to 2,000 feet, and *Basté* says, as indeed all observers will agree, that the manœuvre most frequently employed by the birds is that of spiral soaring, that it takes place in light steady breezes, and that it is represented in plan by figure 5. The bird starting from the point A descends with the wind to about the point B, whence, facing the wind, he rises to the point C, which is higher than A, and thence repeats the evolution, his circlings overlapping each other and the bird meanwhile drifting slightly down the wind. The dotted lines on the diagram indicate the descents, and the full lines the ascents, as figured by *Basté*. He also states that occasionally, instead of drifting

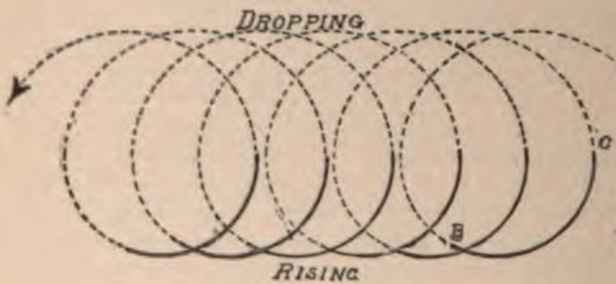


FIG. 5.

with the wind, the bird performs a manœuvre which brings him back to the original point A, describing in that case a closed ellipse instead of a circle, and that this is done by descending down the wind and by reascending on an undulatory course when coming back against the wind.

Now, this spiral soaring, performed on rigid wings in steady breezes of 5 to 10 miles per hour which are apparently horizontal, and through which the bird maintains an average speed of about 20 miles an hour, is the mystery to be explained. It is not accounted for, quantitatively, by any of the theories which have been advanced, and it is the one which has led some observers to claim that it was done through "aspiration," *i.e.*, that a bird acted upon by a current actually drew forward into that current against its direction of motion.

Aspiration really exists under some circumstances. I have seen, hundreds of times, buzzards advancing against winds of 10 to 15 miles an hour, without losing altitude, for distances which precluded the idea that this was done at the expense of previously acquired momentum. On several such occasions I liberated bits of down which went off quite horizontally, but I am not prepared to admit that the wind was also horizontal at the bird. There are, to be sure, some curious phenomena which have been termed "aspirating currents." *Dr. Thomas Young*, the great physicist, showed in 1800 that a curved S-like surface suspended horizontally by a thread advanced against an air jet impinging upon its upper surface. *Professor Willis*, of Cambridge, demonstrated that a light disk, placed parallel to and very close to another disk in which a tube was inserted, rose up against the blast when air was blown through the tube, and we now have the modern "ball nozzle," in which a ball is aspirated to and held suspended in a conical adjutage through which a stream of water or of air is issuing; but in every such case we can show that the force exerted is greater than the reaction produced through rarefaction, and these phenomena do not help us to explain the possibility of "aspiration" for a bird immersed in a current.

The simplest and most satisfactory explanation is to admit that there is an ascending trend of wind at the bird, and then propulsion can be accounted for, as has been done for the gull patrolling along the steamer; but even this could not be figured out without the Lilienthal coefficients based upon experiments with arched surfaces. An inspection of these will show that between angles of $+6°$ and $0°$ the lift is from 3 to 12 times what it would be with planes of equal area, while at angles between $+3°$ and $+32°$ the tangential pressure, producing only friction on a plane, becomes a propelling factor, and thus, if the angle of incidence with the course be, say, $+3°$ and the angle with the wind be, say, $+9°$, sufficient reactions can be computed under a bird to support his weight and to propel him against the current.

I have inferred that these coefficients result from the peculiar shapes of sailing wings which have been shown in figure 1, in connection, probably, with the rolling or oscillating action which I have noticed in the wind; that the current passing over the upper surface produces a certain rarefaction which increases the pressure upon the lower surface by a certain amount due to an unbalanced pressure of the atmosphere,[1] while a part of the aerial waves encountered is reflected back under the lower sur-

[1] As the weight of the atmosphere presses in all directions 2,160 pounds per square foot, a rarefaction of $\frac{1}{1080}$ would result in an unbalanced pressure of 2 pounds per square foot.

face, just as a sea-wave is reflected by a wall and would tend to drag it forward if its top were suitably shaped. That this action does not occur, or occurs in lesser degree, with other forms of wings seems to be established by the fact that the flapping birds do not sail, but only glide.

This is advanced simply as conjecture because I have made no instrumental measurements, but it may possibly serve to explain hereafter how the bird obtains energy from the wind. I now believe that this action could not take place if the wind consisted of uniform horizontal films or layers, such as we generally conceive. There is an analogous case for water. A vessel adrift upon a smoothly flowing current cannot by any method be made to extract energy therefrom, but the same vessel adrift upon sea-waves can be made to propel itself against the wind and waves by a plane attached some distance ahead below the keel, which plane shall act on the water in the trough of the sea where the particles are oscillating towards the wind, and so drag the vessel forward. It is conceivable that by a descent through waving horizontal wind, enough energy and speed should be gathered to rise in a light breeze higher than the initial point, but this is, as yet, speculative.

Direct aspiration against a horizontal wind cannot be figured by the Lilienthal coefficients. It is my opinion that this is an exceptional performance, which requires an ascending trend, and that, besides, the wind must be stronger than for spiral sailing. Aspiration therefore leaves unexplained the mystery of spiral sailing flight in light breezes if the latter be really horizontal.

The mystery vanishes if we suppose the wind to have a sufficient ascending trend; but the objection has been advanced that we cannot assume ascending trends to occur all over the sky (especially in cloudy weather), and that in point of fact spiral sailing is observed to occur promiscuously and continuously all over the sky. *Mr. Maxim* presents the most reasonable hypothesis to account for this, *i.e.*, that there are ascending and descending columns of air, and that the birds seek out the former; but this hypothesis requires evidence that the sailing birds invariably keep over such ascending columns in their wandering spirals; that a thousand buzzards, patrolling a township by circling, find columns enough to support them; or that the frigate bird, going out one hundred miles to sea and back again in a day, performs his journeyings by the aid of ascending columns.

I am not prepared to advance any other theory of spiral sailing in light breezes. My own observations of the rotary action in wind currents are confined to a short distance above the surface, and *Mr. Maxim* gives good reasons for doubting whether this action extends to any great height in the air. It is worth investigating, but until this is done it would be speculative to base a new theory upon anything but ascertained facts.

Upon the whole, sailing flight cannot yet be said to be accounted for in all its phases. Its full explanation requires that it shall be shown how the bird extracts energy from the wind, that the conditions assumed actually exist at the time of the particular evolution considered, and that the manœuvres of the bird will produce the observed result. This must be supported by quantitative calculations based upon actual observations of the speeds of the wind and of the bird, the angles of incidence with their coefficients, and the distances traversed horizontally and vertically, so that a good deal more is required than has yet been presented, in order to carry conviction.

It may be added that the simplest and most satisfactory explanation thus far is that which assumes ascending columns or trends of wind to exist at opportune times and places, but that it does not account for the cases in which all observers are agreed that the wind is horizontal.

THE WAY OF AN EAGLE IN THE AIR.

BY E. C. HUFFAKER.

I HAVE seen the bird soar many times when, close at hand, there was no evidence whatever of any movement in the air.

But the senses cannot readily detect a warm current of air having a velocity of much less than four feet per second, and an ascending current having such a velocity would amply suffice to sustain the bird.

Of aerial currents he can only avail himself of those to which he can offer some sort of resistance, and the power which he extracts from the air is directly proportional to the resistance which he offers to its movements. From ascending currents he is able to extract energy through the resistance of his own weight, which, being a constant quantity and incapable of destruction by the winds, may be used continuously as long as the bird remains in the ascending current.

He may also oppose the winds with the inertia of his body. But this inertia, unlike gravity, cannot be indefinitely opposed to the resistance of winds moving in a fixed direction; so that it becomes an available source of power only when their direction is variable. But this variability in direction must be understood to include variations in velocity, since with regard to the mean velocity the variations may be regarded as opposite in direction.

Two classes of theories may therefore be advanced to account for soaring flight: the one based upon the inertia of the body, the other upon its weight.

The simplest theory is that the bird soars by means of ascending currents. But it is difficult to account for the existence of such currents under many of the circumstances of actual flight.

The vultures soar as often as they find a dead body, and will continue to do so for days, not only in the vicinity, but over the immediate locality in which the body is found, at least whenever even a light wind is blowing. Nor does the character of the surrounding region of country seemingly affect their ability to soar. And as ascending currents cannot exist at all times and in all places, but are more often absent than present in any given locality, it is difficult to understand why they should at all times be found in the neighborhood of a dead body.

This difficulty, however, will disappear if we suppose that the soaring bird is capable of producing ascending currents.

The immediate effect of the action of the wings upon the air is to drive it downward, as Maxim found to be the case with his whirling table. But under certain conditions of the atmosphere it is theoretically possible for these descending currents to give rise to ascending currents, which may increase in volume until the bird himself is carried up by them.

This may occur whenever the lower strata of air become superheated, or whenever the temperature in ascending decreases more rapidly than 1° F. for each 183 feet of ascent. Under such circumstances, if a bird begins soaring in circles, say 100 feet above the earth, the masses of air sent downward by his wings will continue to descend until they reach the surface.

Other masses of warm air must rise to take their place, and in this way channels are made through which an interchange is effected between the warm air below and the cold air above. This circulation once set up will speedily involve masses of air vastly greater than those first set in motion by the bird. The bird, as it were, taps the great reservoirs of energy stored in the lower strata of the air by the rays of the sun on every warm day. And it is noticeable that it is on warm days when there is little wind that the bird soars best.

Certain facts, not otherwise easily explained, give color to the theory. The bird usually soars for some time, often for several minutes, before he begins rising, where the ground beneath is manifestly destitute of prey. A current already in existence would carry him upward as soon as he entered it.

Hawks and vultures soar in companies when rising in circles and separate as soon as they reach a desired altitude. Acting in concert they could generate a rising current more speedily than when acting singly. Two will often be seen rising together to great heights, following each other on the opposite sides of a circle. I once saw two large hawks, at which I was trying to get a shot, rise from a dead tree in a wide river bottom, and after some vigorous flapping begin ascending almost perpendicularly in circles, until they were entirely lost to view in the blue sky above. The day was calm, and if a current rising to so great a height already existed near the spot from which they were frightened, it seems singular that they s readily found it. But if the heated air over th condition to rise, great masses might have fo outlet through an opening made in the overlyin hawks, and this opening the birds could as easi at any other spot upon the plain.

But even if this theory could be shown t would by no means offer a full solution of the p ing flight.

It would not account for those flights in maintains his altitude without turning upon his often does when the winds are high. This feat, as "aspiration," is, I think, seldom or neve except in strong winds; nor — except in the breaks — is the bird's rise very rapid for long Mississippi I have seen scores of black vulture tudes so soaring in a strong steady wind fr Mexico over an almost level country. In th case these birds would encounter as many de cending currents, and if they derived support rents, it must have been because the ascendin more effective than the descending, which is not supposition when we consider the constructio wing, with elastic quills and concave lower an surfaces. In the anemometer the instrument is through the greater pressure upon the concave cups. The same principle applies, perhaps e ively, to wings. Besides, we know that by beati a still air the bird is supported and borne for suppose the wings stationary and the air bea upon their upper and lower surfaces, the resu same, provided, of course, that the wind beats with sufficient rapidity.

Professor Langley has shown that a horizont fall, descends far more slowly when driven ed the air than when allowed to drop vertically. true of a fleece of cotton exposed to a horizo releasing two pieces of cotton from the hand, in to be a strong horizontal wind, I found t carried more than 300 yards before coming to th fell within 50 feet; still others rose until lost released in companies soon drifted widely apart cotton must have soon acquired a velocity equal velocity of the wind; yet in some way they were kept from falling as they would have done in still air.

If we suppose that the direction of aerial currents is continually changing, and that these changes at a given point occur at intervals of two or three seconds, "aspiration" may be accounted for.

Air ascending and descending in large masses might also be made available, since by descending through the falling and ascending through the rising masses, the bird would remain a longer time in the latter than in the former, even in direct flight.

The variations in the velocity of the winds can be made available by a bird having in general the mean velocity of the wind, by the resistance due to inertia, which may be alternately overcome in opposite directions. But it is not altogether clear how a steady advance into the winds may thus be made. No theory yet advanced, however, has found general acceptance, and a certain degree of mystery still surrounds the majestic flight of the great soaring birds.

In some way they accomplish the feat of remaining in the air for hours without flapping, maintaining their elevation, taking long journeys, rising, falling, moving with the wind or against it, gathering strength from the storm, and all with a grace and sublimity of movement unapproachable.

What may be termed the mechanism of flight is also little understood. We are ignorant of the form of the wing in flight, of its movements, and of the function of its several parts, as well as of the manner in which it penetrates the air and maintains its equilibrium through all the vicissitudes of flight.

The wing from which we take our measurements is not the wing with which the bird soars, either in general form, curvature, or detail of construction.

Our studies must usually be carried on from a distance, and when on rare occasions the vulture hovers for a few seconds overhead, with his great hollow wings outstretched to the wind, we are in danger of learning nothing, through our eagerness to learn everything. It is only when we come to search for the details of construction that we are able to make progress.

In this way, however, we may arrive at certain definite conclusions: that the fundamental form of the wing is a concavo-convex surface, with rigid front margin bevelled above to a sharp edge, and set in the rear and at the outer ends with a row of elastic quills, curved in all directions, each overlapping the next outer quill, and together under pressure forming a firm elastic surface; that the locus of greatest curvature lies near the front margin, and that the elasticity is greatest along the rear and outer margins; that the primaries are stronger and more firmly set than the secondary and tertiary quills.

As a rule the wings of the soaring birds are not placed at right angles to the body, but point forward, the front line often forming a cupid's bow, as in the hawks. Considering only the broad expanse of the wing and neglecting the small front portion which slopes in an opposite direction, the angle of elevation of the wing is greatest across the primaries.

The wing, therefore, taken as a whole presents upon its under surface a channel extending from tip to body, and so formed as to deflect the currents inward and backward. These currents which cannot pass the stiff outer quills find an exit among the more flexible secondaries. In this way a pressure is produced upon the forward portion of the under surface. At the same time the air above the wing tends to cross the wing, somewhat at right angles, and to be drawn in by expansion from above. This crossing of the upper and lower current produces a pressure much greater than would result if they moved parallel across the wing.

The lifting power of planes, as determined by experiments with whirling tables, is known to be far less than that of the bird's wing. This may be due to the crossing of the upper and lower currents described above, resulting in a slight degree of compression and expansion. Usually the wind passes an obstacle in its path as the water does, with little change in density, the resulting pressure upon the obstacle being due to the inertia of the displaced masses of air. It is not to be supposed that a plane with front edge elevated simply presses down the air underneath.

If we allow that the air is thus pressed downward one inch by a plane having a width of one foot, and that the disturbance extends to a distance of ten inches below the plane, and that a corresponding rarefaction takes place upon the upper surface, then the resulting lift along the rear margin would amount to the enormous pressure of more than 400 pounds to the square foot, whereas we are fortunate if we secure a pressure of 1 pound per square foot. In order to secure such a pressure it is only necessary to alter the volume of the air involved by

$\frac{1}{4000}$ part of its original volume. This results from the fact that the normal pressure of the air, both above and below the plane, is over 2,000 pounds to the square foot, and a change of volume amounting to only $\frac{1}{4000}$ would give a change of pressure both above and below of one-half pound, by a well-known law of the pressure of gases.

If we could readily compress the air in a free atmosphere artificial flight would be easily accomplished. This is prevented in part by the rapid transmission of pressure, amounting in a direct line to perhaps more than 1,000 feet per second, and in part to the formation of compensating currents, by which the rarefied areas are relieved by a flow of air from the compressed areas.

Every one has noticed how loose windows rattle when a door is opened or closed. If the door of a large church be suddenly opened the effect may be detected at the remotest part of the building, if a sash is loosened and all other openings closed. So far as the ear can detect, this transmission of pressure is instantaneous, and it must have extended to every nook and corner of the building. If, however, the door be held ajar and swung violently back and forth, no sound from the window will be heard, as the air has now formed a circuit for the transmission of pressure from one side of the door to the other. A small opening in one window will also prevent the others from rattling when the door is opened or closed, the pressure finding relief in the outer air.

It will also be found that if the windows be closed and the door but slightly ajar, a perceptible pressure is required to close it quickly, and the windows will rattle again. Here the air cannot complete the circuit from one side of the door to the other, and we have a rarefaction.

It seems possible that the deflection of currents in passing the wing may also result in compression and rarefaction, with a consequent increased pressure.

The form of the wing when pointed forwards adds to the stability of the flight, acting somewhat upon the principle of the Pénaud tail. For the angle of elevation being least upon the following portions of the wing, those portions will be subject to greater changes of pressure than the leading portions, and so tend to maintain an even course of flight. But a more important purpose is served in offering a path to the winds across the surface.

The imprisoned air within the concave surface must escape along the lines of least resistance, and these are found along the rear margin of the secondary quills.

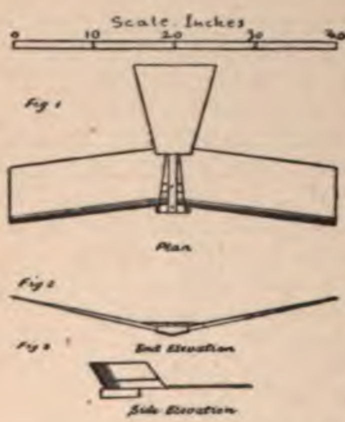
The result is therefore a uniformity of pressure upon the two wings and their several parts, which could not be obtained with a plane wing or one of cylindrical section.

The wings may lie in a horizontal plane, be elevated above it or depressed below it. Usually the tips are upturned, but the rule is not invariable.

Birds which usually fly by flapping, as the crow and dove, sail with the wings depressed.

The centre of gravity seems to lie very near the centre of magnitude of the wing surfaces in ordinary flight, and slightly below the root of the wing and the plane of the tail. The latter serves as a supporting organ in some of the soaring birds, and in perhaps all of the flapping birds.

In order to investigate experimentally the principles of soaring flight and the laws of equilibrium, I have constructed a number of artificial birds, or gliding models, which, on being released from the top of a hill or other elevation glide forward under the influence of gravity in a manner similar to that of the living birds.



Figures 1, 2, and 3 show the form of one of these models. It consists essentially of a body to which are rigidly attached a pair of wings and a tail. The body and central tail-piece are made of oak, the frame of the wings and tail of some wood which is light, fine-grained, elastic, not easily broken or split. The arm of the wing placed in front is bevelled above and hollowed out beneath like the wing of the bird. The rear margin, unlike that of the natural wing, is rigid, while the front and rear strips are joined by three ribs. I have made the rear margin rigid because of the simplicity of construction which it allows. The rear piece, however, is loosely attached to the ribs.

A cord does not answer the purpose so well as a strip of wood, since the yielding of the cord alters the entire surface of the wing, at the same time that it puts the main arm under a strain to which it must, to a certain extent, yield. Both wings and tail are covered by stretching cambric over the upper surfaces, fastening it in place with mucilage. The model has a wing-area of two square feet, including the body, and when complete weighs about eleven ounces. Eleven ounces of lead are added in the form of plates nailed to the body. The model, therefore, carries eleven ounces to the square foot of wing-surface.

The main arm of the wing tapers from one-half inch at the base to one-eighth at the tip.

As to whether this makes a flight of 20 feet or 2,000 feet depends largely upon relative adjustment of its several parts. The angle of elevation of the chord of the wing, regulated by means of wedges of wood driven between the ribs and the main arm, should be greatest at the tips and least near the body. The tail should next be placed parallel to the middle rib of the wing. It should be fastened to the upper part of the body by means of wire nails. Finally the centre of gravity is to be fixed by shifting the plates of lead. It should be slightly in front of the centre of figure of the wings. The model should be thrust lightly forward from the hand. If upon trial it mounts rapidly upward, the resultant of pressure passes in front of the centre of gravity. A new adjustment may now be made in four ways: by moving the centre of gravity forward; by decreasing the angle of the tips; by increasing the angle at the base; or by altering the setting of the tail. If, on the contrary, the model plunges downward, the reverse of these alterations may be made. If the model flies well but descends too rapidly, the angle of the middle or outer ribs should be increased. If the flight is undulating, the tail may be depressed or the centre of gravity moved forward.

If the model turns to the right or left while maintaining a horizontal position, the angles on one of the wings may be altered. If at the same time it descends rapidly in a curve and comes down, no simple rule for rectifying the adjustment can be given. This is the most serious difficulty I have encountered.

The fore-and-aft stability has given me but little trouble. Out of thousands of experiments I have not made twenty in which the model came down on its tail, and perhaps less than one hundred in which it came down on its head. Where the model has either risen too rapidly or fallen too rapidly, I have known what course to pursue to secure a better flight.

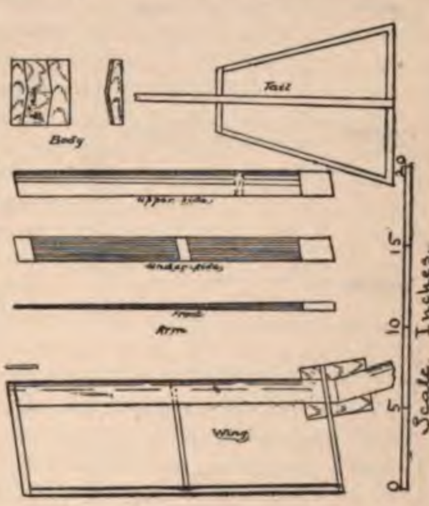
I have also succeeded in so adjusting it that without a vertical rudder, and solely through the action of the air upon the wings, it would always turn into the wind.

It also gives a fair promise of soaring.

For the benefit of any who may be disposed to repeat these experiments, I subjoin working drawings showing the construction of the model in detail.

The construction is not difficult, but it is important that the work should be accurately done.

The body should be strong and the wings firmly attached by means of wire nails. The ribs should be fastened to the arm with springs and binding wire. It is not necessary that the cloth should be stretched very tightly, as a certain amount of curvature is desirable. The cloth may pass either under or over the end and rear pieces, which should be bevelled to fine edges. If desired, the inner portions of the rear margin may be made flexible by means of strips of cloth stiffened with mucilage.



But the disadvantages arising from the change of form resulting from the use of flexible margins are not offset by any marked advantage attending their use.

I have not found that the rigidity of the frame is objectionable. The elasticity of the air is more perfect than that of any frame that can be constructed, and if proper provision be made for its escape when compressed, its pressure will remain very nearly constant.

Besides, the elasticity obtained by means of an elastic cord along the rear margin is not the elasticity of the bird's wing, which pertains to the entire structure, including the arm.

An artificial wing, in which the torsion of the arm could be called into play, would be much more efficient than one with an elastic rear margin; for the pressure along the rear margin is but slight, and the yielding of a cord under increased pressure upon the entire surface would cause the wing to bag, and so make matters worse instead of better.

A concave surface properly constructed possesses great lifting power. In the bird the chord of any fore-and-aft section is but little inclined to the line of flight.

But its efficiency seems to depend upon the manner in which the currents pass it. They must follow the surface, as the formation of dead areas is fatal. Nature has provided the bird with a covering of soft feathers upon the under forward portion of the wing where the curvature is greatest, which by their elasticity insure a constant current across the surface of the wing. The accompanying figure shows some of the wing profiles which I use.

A current of air passing near a surface very nearly in line with it will be deflected by it, whereas it might break away from one greatly inclined to its course. This is true both of convex and concave surfaces.

A current of air blown through a pipe-stem against a lamp chimney will follow the surface through a quadrant.

Smoke so blown against a card will not rebound, but spread out in a plane over the surface. But a current passing an inclined knife-edge is liable to leave the rear surface altogether. The coverts referred to prevent this in the bird, for their elasticity keeps them pressed all the while against the current. The most effectual means I have found for preventing this in artificial wings consist in increasing the angle at the tips and compensating this by decreasing the angle near the body, for a steady movement can only be obtained when the general angle of elevation is small.

After a few changes the position of the centre of gravity may be left undisturbed and the subsequent adjustments applied to the wings and tail, more especially to the proper apportionment of the relative angle of elevation of the several parts. The angle at the tips must be sufficiently great to insure the requisite lift, and the reverse inclination near the body sufficient to accommodate the air from primary portions. It is chiefly upon this adjustment that the lateral stability depends. A vertical rudder may keep a model headed into a wind, but it offers no resistance to a tendency to turn upon a fore-and-aft axis, and it is in overcoming this tendency that I have found my chief difficulty. I have accordingly discarded the vertical rudder altogether, and depend wholly upon the setting of the wings for lateral stability.

When the angles are properly adjusted the model may turn through half a quadrant upon a vertical axis, while still maintaining its horizontal position.

All that is now necessary is to increase the resistance of the advancing wing. This may be done by increasing the angle of elevation at the tip. This should increase the lifting power of the wing as well, and so elevate it; but it appears that the resistance increases more rapidly than the lift. At any rate a wing is held back by increasing its outer angles.

I have met with a singular result in altering the angle of elevation of the tail. It often happens that depressing the tail causes the model to rise or descend more slowly than before. The explanation seems to be that while in this way the general angle of elevation is increased, the effect is most marked on the parts nearest the body, the centre of pressure being thereby lowered and moved backward.

A model properly balanced should maintain at all times a position approximately horizontal, under varying wind velocities. This is a matter of great importance and marks the difference between success and failure in a variable wind. If properly balanced a model may be carried upward to a great height by a strong wind upon a hillside, and will rise and fall without careening or plunging.

I have repeatedly secured such flights, and I do not doubt that it is possible to construct a model which would remain in the air an indefinitely long time.

The hill on which my experiments have been conducted has an elevation of about 175 feet above the valley at its base. About the summit and slopes of this hill vultures and hawks are daily to be seen soaring. Occasionally my models fly for a short time as well as the birds. On one occasion while standing on the summit in what appeared to be a dead calm, a model on being thrust lightly forward mounted upward several feet and sailed away horizontally.

In winds I have many times secured such flights, many of them being several hundred feet in extent. *The birds but do continually what my models do occasionally.* From this hill the birds make journeys to the neighboring hills, usually by a descent, often without it, and seldom by flapping. Then they repeat the manœuvre of ascending in spirals, sail away to other points, and so continue for hours uninterruptedly. It is not alone upon the hills and their slopes, however, that they soar. They may be seen near the earth, over meadows, and in sheltered curves, wherever chance carries them. But their predilection is for the hills.

I once witnessed a large hawk ascending the slope of a hill with the utmost difficulty, being scarcely able by repeatedly flapping to keep clear of the earth. On the summit the land spread out in a level platoon over which the wind was blowing, and into which the hawk mounted and advanced with all imaginable ease, not once flapping again. Such flights as this are liable to mislead us. We are ready to underrate the bird's powers of flight in the absence of winds. In this instance the hawk not only flew up hill, but he did so in the face of a wind blowing down the hill. It has not yet been demonstrated that the bird cannot maintain his altitude in a still air without flapping. Writers have been ready enough to explain soaring flight through the agency of ascending currents. But it is equally certain that the bird would be borne down by descending currents, which are equally numerous, and with which he can contend only by flapping. On the other hand it cannot be demonstrated by observation that the bird can soar in a calm. But we may safely assert that in fair weather with light breeezes, and in stormy weather with heavy winds, he may at all times soar.

It is not for lack of power that man fails to fly. The winds supply it in lavish abundance, and if he is unable to make some sort of a flight with the power at his disposal, maintaining his elevation so long as the winds are favorable, he is not likely to fly by the use of engines. The problem is one of equilibrium, not power. Nor does flight require any delicate adjustment of the parts. I have usually obtained my best results with models that were torn and battered by repeated falls. The birds, also, soar with broken quills. I once witnessed the flight of a buzzard that had lost all the secondary quills from one wing and half from the other, yet his soaring was perfect, and he rose 500 feet without flapping.

When the bird wishes to soar in circles, one wing is depressed by increasing the weight upon it, while the tail is set approximately parallel to the elevated wing. The angle of elevation of the latter is then diminished so that it penetrates the air more readily than the inner wing, and so travels with a greater velocity.

I have succeeded in adjusting a model so that it would fly in a curve and maintain a satisfactory rate of fall, but I have not been able to reproduce soaring flight proper, in which the bird, by moving in small circles, maintains his elevation in a wind.

Experiments with models in a wind blowing across a meadow seem to indicate that a horizontal wind has greater supporting power than still air, as the model will advance farther into the wind and advance more slowly than in a calm. I have not found that elevated wings offer any marked advantage over horizontal wings with upturned tips, and the adjustments are more difficult. Nor have I found any advantage in greatly lowering the centre of gravity. In the bird the wings are usually elevated, though there are exceptions to the rule. In one respect the bird has a great advantage over us, in being able to adjust his wings according to the varying circumstances of flight.

Models such as I have been using must encounter all kinds of winds with no change in their adjustments. However, a model which flies well in a calm will usually fly well in a wind of moderate velocity, often better.

In considering the results of these and similar experiments, it is well to bear in mind the relative importance of success and failure. A hundred failures through imperfect adjustment are offset by a single success. The successful experiment demonstrates the possibilities of an undertaking. I have thus been able to demonstrate that an artificial bird may glide through still air with a fall of three feet per second, so that a single-horse power would serve to maintain in horizontal flight a similar machine weighing 183 pounds; that it may be borne upward by light winds; that it may contend successfully with strong ones; that it may be made to automatically turn into a wind without the use of a rudder; that it may be made to come down safely; and that in almost every respect at least a distant approach may be made to the more perfect flight of the birds.

SCREW-PROPELLERS WORKING IN AIR.

By Hiram S. Maxim.

A great English marine engineer in lecturing on the screw-propeller stated that recent experiments had shown that a piece of common boiler-plate riveted to the hub of a propeller was only five per cent. more wasteful in power than the most perfect screw that could be made, of course it being understood that in both cases the diameter and mean pitch were correct. I think, however, that if this same engineer had made his experiments with screws running in the air, he would have found a much greater difference.

The first screws that I experimented with were about 18 inches in diameter, and were attached to an apparatus in which the screw shaft could be moved in a longitudinal direction, its travel forward being opposed by a suitable spring, — in fact, this spring was part of the dynamometer that indicated the screw thrust. I remember on one occasion, while experimenting with screws, I found that, with a certain number of revolutions per minute, the screw thrust would suddenly mount on starting to, say, 21 pounds, and then fall back to 14 pounds. It occurred to me that this might be due to the momentum of the moving parts; that is, the weight of the moving parts, having been set in motion while there was little tension on the spring, might carry the screw shaft forward farther than was actually due to the thrust. I therefore limited the travel of the screw shaft in such a manner that it required 15 pounds thrust to move it forward. This of course would completely eliminate the factor of momentum. However, upon starting up the screw suddenly the dynamometer needle passed over to 21, the same as before, and then fell back to 15, the limit. These experiments went to prove that the screw, when started suddenly in still air, produced a thrust of 21 pounds, but when the current of air had become established, the screw would then be running in a rapidly moving current of air, and the thrust would only amount to 14 pounds, the speed in both cases being the same. Several other experiments were made which proved this to be true.

The screw-propellers employed in these experiments were made of light American pine, with a great degree of accuracy, coated with very hard glue, dried, varnished with shellac, and painted so as to keep their form.

At the beginning of the experiments, upon multiplying the thrust of the screw in pounds by the pitch of the screw in feet and by the number of turns that it made in a minute, I found that the foot-pounds represented were exactly like the readings of the dynamometer. At first I thought that some mistake had been made, because it appeared to me that the readings of the dynamometer ought to be more. However, upon attaching a pair of blades of the exact area and thickness of those of the screw, but without any pitch at all, I found that, notwithstanding the dynamometer was so sensitive that the touch of the finger tip to the shaft would move the needle, the power required for moving the blades in the air was not sufficient to be indicated. This demonstrated that there was no skin friction. Since that time I have found that a well-made screw is an excellent dynamometer for testing an engine. But all screws are not suitable for the purpose. A screw made exactly like those exhibited by the French government at the last International Exhibition in Paris, when tested in the same manner, showed that the useful effect of the screw in thrust was very much less than the readings of the dynamometer, while with any sort or kind of a screw that we were able to produce, consisting of a frame covered with a woven fabric, the useful energy in thrust never amounted to more than half the readings of the dynamometer, but when a perfectly made screw was employed, — that is, perfect on the face side, but very much rounded on the back in order to give great stiffness and rigidity, — it was found that the action was almost as good as with a thin screw. These experiments appeared to me to show that a well-made screw works very efficiently in the atmosphere.

I will mention another interesting point which will be useful to experimenters; namely, suppose that a small screw-propeller is making 2,000 turns a minute and, we will say, produces a thrust of 20 pounds without moving forward. Suppose that we now allow it to move forward, still maintaining the same number of revolutions per minute. Of course, as the velocity increases, the slip of the screw diminishes, but it is a curious fact that up to 50 or 60 miles an hour the actual thrust remains almost constant. What is lost in thrust by diminished slip in the air seems to be exactly compensated for by the advantages of running into new air the inertia of which has not been disturbed.

Another fact I would point out is that the thrust is greatly increased by a strong side wind, it being understood that the number of turns is kept constant. A side wind also had a great effect upon the flying machine on which I experimented. I often found that when the machine was running along the track at the rate of about 40 miles an hour, a side wind having a velocity of not more than 4 to 5 miles an hour would often produce a lifting effect of fully a ton on the upper rail, while the wheels on the opposite side would not be lifted off the track. The slightest movement of air across the track would always make the machine lift much more on one side than the other.

In regard to future experiments, I would say that the gun business has been very lively during the last year, that I have had much new experimental work to do, and that I have had very little time to devote to flying machines. I, however, have obtained very large premises with plenty of room, where I hope to resume experimental work as soon as I have the time.

GLIDING EXPERIMENTS.

By Percy S. Pilcher.

Experimental Department of Hiram S. Maxim.

I made my first trials with a soaring machine in the summer of '95, having constructed the machine during the spring.

I had seen photographs of Lilienthal's apparatus, but I purposely made mine before going to see his so that I should not copy his details. I, however, went to see him fly before I commenced to experiment myself. My first machine had 150 square feet of surface and the wing tips were considerably raised above the body. At first I had a vertical rudder only, but I soon discovered that I could do absolutely nothing without a horizontal rudder. I found that it was quite impossible to control the pitching motions of the machine, and it was not until I had put on the horizontal rudder that I was able to leave the ground at all. This point is very clearly illustrated by experiments with model gliders. It is exceedingly difficult to make a glider with one surface only which will sail properly, but with two surfaces nothing is easier.

Although a machine in which the wing tips are considerably raised would always tend to right itself when falling, it is almost impossible to use such a machine for practising soaring out of doors, because although the machine is stable enough when the wind is right ahead, if the wind shifts and gets a little on the side it will press the weather wing up and depress the lee one so as to turn the machine over. But when I altered the shape of the wings so that they rose in the centre, but turned down again towards the tips, that is, so that the tips were scarcely higher than the middle of the machine, the machine became comparatively easy to handle, and I was able for a beginner to make some very good jumps. On one occasion when a man towed the machine by a string attached to the front of the machine I spent seventeen seconds in the air, and this is the longest time I have ever been off the ground.

During the summer I made a second machine which was straight transversely, although curved in the fore and aft direction. All the wing surface was considerably raised so that it was just above my head when I was in the machine, but with this machine I could not get along at all. When the weather became too cold I had to stop experimenting, and during the winter I built a new machine, which has 170 square feet of surface and weighs 50 pounds.

During the last summer I had to be very busy about other things, so that I have only had the machine out about ten times and have not been able to choose my days. In this machine I did away with the vertical rudder altogether. For days when there is not much wind the machine is quite manageable as it is, but for squally days I think that a vertical rudder should be added. With this machine I have twice cleared nearly 100 yards, once with a slight side wind and once in a dead calm. Most unfortunately I have never had the machine out when there has been a breeze blowing up the best hill for experimenting, or I should be able to give a much better account of its performances. Once when sailing fast I saw I was going to land in a big bush, so getting back a little in the machine I was able to rise a little and pass quite clear of the bush, although it was quite calm at the time; and I have also been able to steer sideways to a limited extent by moving the weight of my body towards the side to which I wanted the machine to turn. This is the first machine in which I have had any wheels, which are a great convenience for moving the machine about, and often save the framework from getting broken if one lands clumsily. The wheels are backed by stiff springs which can absorb a considerable blow.

A new machine is being built which will have an oil engine to drive a screw-propeller. With this machine, without the engine, I drop 50 feet in 10 seconds; that is at the rate of 300 feet per minute; taking my weight and the weight of the machine at 220 pounds the work lost per minute will be about 66,000 foot-pounds or 2-horse power. When I have been flown as a kite it seems that about 30 pounds pull will keep me floating at a speed of about 2,200 feet per minute, or 25 miles an hour. $30 \times 2,200 = 66,000$ foot-pounds = 2-horse power, which comes to just the same thing.

An engine is now being made which will, I hope, exert enough power to overcome the losses arising from friction and slip, and keep the new machine floating horizontally. Of course for the same wing-surface the machine will have to sail faster in order to keep afloat with the extra weight of the engine, and more power than the 2-horse power will therefore have to be used.

About 170 square feet seems to be the best area for a machine of this class for a man of average weight; if it is made larger the machine becomes heavier, and is much more difficult to handle because of its increased size and weight, and if it is smaller its sailing speed becomes unpleasantly great.

Last June I happened to be in Berlin again, and Herr Lilienthal very kindly allowed me to fly off his hill with one of his double surface machines. A light steady breeze was blowing, and after the practice I had had with my own I had no difficulty in handling his machine, but I was very much afraid that with the superposed wings high above the machine, as shown in Lilienthal's latest machine, they would prove very dangerous machines, especially in squally weather.

I hope with the new machine with the engine that I shall be able to obtain results worth reporting in your next ANNUAL, but "we shall see what we shall see."

MISCELLANY.

Principal Contents: — Carbonic Acid or Air? — Professor Zahm's Experiments. — Blue Hill Aerial Explorations. — A Keel Kite. — A Rubber-propelled Model. — Methods of launching Aerial Machines. — The Albatross. — Plates XVII. and XVIII. — The Secret. — Blue Hill Measurements of the Velocity of Flying Ducks.

CARBONIC ACID OR AIR?

By Prof. C. H. Peabody, Mass. Institute of Technology.

Now that liquid carbonic acid is a regular article of commerce it has been suggested that it may be a convenient medium for supplying power to flying models. A statement of some of the properties of this material and of some results of calculations concerning it, together with a comparison with compressed air, may be of interest. It should be remarked that the properties of the liquid, and of the gas or vapor near saturation, are not very well known, and further that the calculations depending on thermodynamic relations are subject to a considerable unknown error, especially near the critical temperature, which is about 85 degrees Fahrenheit.

One pound of liquid carbonic acid at freezing point occupies a volume of about 31.8 cubic inches. Its expansion with rise of temperature is very notable; thus, at 60 degrees Fahrenheit it occupies 50.1 cubic inches, and at 80 degrees Fahrenheit it occupies 90.8 cubic inches.

One pound of gaseous carbonic acid at freezing point and at atmospheric pressure occupies 14,000 cubic inches. At 60 degrees Fahrenheit the volume becomes 14,800 cubic inches.

The pressure of the saturated vapor, or of the liquid, is 520 pounds per square inch at freezing point; at 60 degrees Fahrenheit the pressure is 777 pounds, and at 80 degrees Fahrenheit it is 1,008 pounds, absolute.

The problem of interest for the experimenter is to determine the amount of energy that can be derived from one pound of the fluid. In dealing with this problem it must be considered that in the short time of flight of a model, little if any heat can be derived by the fluid from without, and consequently the vapor formed must be vaporized at the expense of the liquid remaining, which liquid will consequently be cooled to a low temperature. An approximate calculation shows that if we start with one pound of liquid at 60 degrees Fahrenheit, and continually withdraw dry saturated vapor till the temperature of the remaining liquid is reduced to 15 degrees Fahrenheit, about .28 of a pound of vapor will be formed and .72 of a pound of liquid will remain. The primary reason why I limited the calculation to this temperature is that the properties of the substance for lower temperatures are unknown; it may be admitted that 15 degrees Fahrenheit is a sufficiently low temperature for the experimenter, although the pressure of the fluid is then still very high, amounting to 243 pounds to the square inch.

Let it be assumed that the vapor as formed is drawn through a reducing value and is used at a pressure of 60 pounds above the atmosphere. Now, a perfect gas under such circumstances does not change its temperature appreciably when its pressure is reduced by passing it through a partially opened valve, but an imperfect gas does. What the change may be for carbonic acid cannot be readily determined from its known properties; there will not be a very large error if the change is neglected. The average temperature will be assumed to be 22½ degrees, beginning at 60 degrees and falling as low as 15 degrees Fahrenheit.

One .28 of a pound of carbonic acid at 22½ degrees Fahrenheit, and at 60 pounds above the atmosphere, will occupy about 756 cubic inches. Suppose that we decide to use it in a simple engine exhausting against the pressure of the atmosphere and with the valve set to cut off at three-fourths of the stroke. Assume further that this engine is to run two minutes and to make a thousand revolutions per minute. Such an engine will have a piston displacement of 0.2521 of a cubic inch, and may be given a stroke of one inch and a diameter of $\frac{9}{16}$ of an inch.

A calculation for the horse-power of the engine gives 0.073 horse-power, not allowing for defects or losses. It may be safe to assume that 0.06 of an indicated horse-power will be realized, and that 0.05 of a horse-power will be transmitted to the propeller.

Should the experimenter be content to fly the model one minute only, then the engine may be made twice as large and the power for the time chosen will be twice as great. Again, if he wants to run the engine at half the speed he may make it twice as large and get from it the same power.

Considerable more power may be obtained if the gas is used at a higher pressure and with more expansion. Suppose, for example, that the pressure is made 150 pounds above the atmosphere, and that a compound engine is used which has the large cylinder three times as large as the small cylinder; suppose that the cut-off is still kept at three-fourths of the stroke. In such case the piston displacement may be made 0.1143 of an inch, and the engine may have a stroke of $\frac{7}{8}$ of an inch, while the diameters of the cylinders will be $\frac{13}{32}$ of an inch and $\frac{23}{32}$ of an inch.

The calculated horse-power for such an engine is about 0.12; the indicated power may be assumed to be 0.085, and the power transmitted to the propeller 0.07.

At first sight it appears as though there will be an advantage in flying the model where the temperature is higher, as then the pressure of the fluid is higher and more will be vaporized before the lower limit of temperature is reached. There is also a gain of about two per cent. from using the fluid at a higher temperature at the engine. Unfortunately the entire gain is much more than offset by the fact that the reservoir will hold a less weight at a higher temperature.

Let us now make a comparison with compressed air, and assume that we must have the same volume at 60 pounds pressure at the engine in order to generate the same power, air being very nearly a perfect gas will experience little change of temperature in passing through the reducing valve from the reservoir to the engine. Let it be assumed that the air is used at 60 degrees Fahrenheit and at 60 pounds above the atmosphere. Under such conditions 756 cubic inches will weigh 0.17 of a pound, and this weight will occupy about 70 cubic inches at an absolute pressure of 800 pounds per square inch. Considering that some space must be allowed above the liquid in the carbonic acid reservoir for proper separation of liquid from the vapor, it appears that compressed air for developing a given power will occupy little, if any, more space, and will weigh only one-sixth as much. If, then, compressed air is readily obtainable, it will be found preferable for work on models.

PROFESSOR ZAHM'S EXPERIMENTS.

PROFESSOR ZAHM, of the Catholic University of America, is determining experimentally the resistance of the air for speeds of one hundred feet a second and upwards,[1] by a newly devised method which promises unusual

[1] Man has travelled at the rate of 165 feet per second on the N.Y.C. R.R. See Aeronautical Annual, No. 1, p. 153.

accuracy of measurement. Bodies of various shapes, spheres, spheroids, cylinders, etc., are shot horizontally through a long room and caught in a barrel of cotton. During the body's flight its time of transit past three points in its path is recorded, and from this the velocity, retardation, and resistance are deduced. Thus in principle Professor Zahm's method is like the others known to the science of ballistics; but it differs from the others in three important details: (1) the measurements are made in still air at a uniform temperature; (2) the projectiles are made of wood which is from ten to twenty times as light as the projectiles commonly employed in gunnery, this making the resistance ten to twenty times more manifest, and hence the same number of times more precisely measurable; (3) the transits are recorded by the breaking of "screens" which have neither elasticity nor inertia.

The device for recording the transits is, perhaps, the most interesting feature of Professor Zahm's method. Three parallel streams of sunlight run squarely across the path of the projectile, and then are made to fall side by side on a photographic plate which moves at a known speed. Thus the uninterrupted streams trace three sharp parallel lines on the plate, and as the projectile crosses the streams in turn, short interruptions appear in the record whose consecutive distances apart serve to determine the time of the projectile's passage from stream to stream. With streams ten feet apart, for example, and a projectile moving five hundred feet a second, the duration of passage from one stream to the other would be one-fiftieth of a second. As the streams used are about one-hundredth of an inch thick, the time required merely to cut one so as to stop the light is, for such projectile velocity, one six-hundred-thousandth of a second; and it is found that, by use of the dividing engine, the records can be read with this degree of accuracy if, during the tracing of the record, the photographic plate moves at a speed of ten feet a second. By increasing the speed of the plate it would be possible to record the instant of the projectile's transit by a point accurately to a millionth of a second or less; but it is found that the above measurement of the duration of passage from stream to stream, together with the mass of the projectile and the distance between the streams, are all that is required to compute the resistance accurately to one per cent.

This research was begun at the Johns Hopkins University, and is still in progress in one of the private laboratories of the Catholic University of America. Professor Zahm hopes to publish in the next issue of THE ANNUAL the results of his investigations, and to express approximately the law of the resistance of the air within the proposed limits of speed.

BLUE HILL AERIAL EXPLORATIONS.

BY H. HELM CLAYTON.

ON August 4, 1894, a Richard thermograph, remodelled and lightened by Mr. S. P. Fergusson for the purpose, was lifted 1,440 feet above the ground with kites, by Mr. Wm. A. Eddy at Blue Hill.

This method of investigation seemed promising, and has been adopted by Mr. Rotch as a part of the work of the Blue Hill Meteorological Observatory, with the object of thoroughly exploring the air up to as great altitude as is possible. Active work was begun in July, 1895, since which date ascents have been made with considerable regularity and on an average twice a week, in all kinds of weather.

The first instrument used was a thermograph to which was soon added a barograph. In November a meteorograph was finished by Mr. Fergusson, which recorded temperature and wind velocity. This was used until May, 1896, when a meteorograph was received from Richard, of Paris, which records temperature, humidity, and altitudes by the barometer. This has, since then, been in regular use.

Cord was at first used for the kite-line, but this was re
vantage by steel piano wire in January, 1896. At first, o
were purchased, but a month later a mile more was ad
July a second and in September a third mile was added
new reels had to be devised and strengthened to withstan
strain of the successive layers of wire, clamps devised for
kites to the line, a recording reel and dial made for indic
line run out at any time, instruments prepared to read th
and kites, screens invented and tested for protecting the
graph from heating by the sun's rays, formulas found
height of the kites with corrections for the sag of the li
worked out, all of which were necessary for accurate wor

A partial description of the apparatus is given by
"United States Weather Review" for September, 1896.

The development of instruments and methods require
but resulted in successively higher and higher flights, as
table:

Date.	Altitude reached.	Date.
August 4, 1894	2,070 feet.	July 23, 1896
August 28, 1895	2,536 "	August 1, 1896
January 26, 1896	2,454 "	August 31, "
March 11, "	3,230 "	September 20, 18
April 13, "	4,593 "	October 8, "
July 20, "	6,591 "	February 10, 189
July 22, "	5,600 "	

These altitudes are above the level of the ocean, which
miles from Blue Hill. To find the altitudes above the
Blue Hill, subtract 630 feet from these figures.

The records obtained during most of the flights are c
and promise to add many interesting facts to the existin
atmosphere. We have found that, as a rule, changes
countered aloft before they are perceived at the ground.
the decrease of temperature as the instrument rises a
found to be very rapid, until at a height of a mile or n
may pass through the top of the cold wave, as happened
January 19 the instrument was sent up in the midst of
height of 4,050 feet the temperature was found to be 16.5° F
while at the same time at the ground it was 7.9° Fahrenh
ing the air to be more than 24 degrees colder at a height
the ground.

Preceding warm waves the fall of temperature is usuall
air is sometimes much warmer aloft than at the ground
when, at a height of 2,800 feet, the air had a temperature
same time at the ground its temperature was only 36.8°,
like temperature above and a winter temperature below.
portant fact which these kite ascents have shown is
between the overflowing warm currents and the colde
The recording instrument reaches the top of the cold cur
very quickly into the warm current above, so that the tem
rises 20 to 30 degrees within a vertical distance of only
This condition, which has hitherto received no adequa
frequent occurrence, and plays a very important role in
sequences. When the warm upper layer is damp its low
by contact with the lower current either through conduct
a thick layer of cloud is formed which overhangs the
When the warm upper current is dry no clouds are for
the colder current, but the warmer current acts like a wa

ascending currents caused by the heating of the air near the ground during the daytime cannot pass. In consequence no summer clouds, such as are ordinarily seen during the daytime of fair days, can form, and the sky remains clear throughout the day. If the warm current is found at the height of a mile, cumulus clouds may form, but the height of their tops is limited to the lower surface of the warm current and no thunder-showers can form. Ascending and descending currents are the chief factors in causing the gustiness of the air, so that in the warm current into which they do not penetrate the motion of the air is usually very steady. As a rule our records indicate a decrease of the gustiness of the air as the kites ascend, even when there is no change from warmer to colder currents, and at altitudes exceeding a mile the motion of the air is probably always very steady.

Sudden changes in the directions of the currents at different altitudes are very common and sometimes very great. Sudden shifts from south to west, or from north to east, are frequent, and in a few cases the kites have come into currents exactly opposite to those at the ground. On November 18 the kites were sent up in a north-east current, and when the height of about 1,000 feet above the hill was reached they quickly shifted around in a sort of spiral, and came into a strong south-west current above, so that kites on the lower part of the line were pulling in one direction and kites on the upper part of the line in another. The velocity of the wind usually increases with height, and not uncommonly becomes too strong for the kites.

The humidity generally increases until the level of the clouds is reached, when suddenly, as the tops of the clouds are passed, the air becomes extremely dry.

The diurnal changes in weather at the height of a mile are very different from those at the earth's surface. In our greatest ascents the recording instruments have been at a height of a mile or more for several hours, embracing in one case a large part of the afternoon and evening. The records indicate that the large daily change in temperature which takes place at the earth's surface is not found at the height of a mile or more. At this height the air is approximately as warm at night as during the day, and the only changes are those due to the passage of warm and cold waves. The daily change in humidity is, however, very large, and exactly opposite to that found at the ground. The nights aloft are very dry during fair weather, and the days extremely damp.

Up to the present time all the work of the ascent, including the winding in of the kites, has been done by hand by Mr. S. P. Fergusson, Mr. Arthur Sweetland, and myself, occasionally assisted by Mr. Rotch or some friendly visitor. The winding was done with a windlass, and the wire was wound on a strong reel. At present the cranks of the windlass are replaced by wheels, and a two-horse power engine winds in the line. This is expected to make high flights much easier to attain

A KEEL KITE.[1]

BY H. HELM CLAYTON.

SINCE the beginning of the experiments at Blue Hill, in lifting meteorological instruments into the air by means of kites, we have felt the need of kites which can fly through a large range of wind velocity. The Eddy and the Hargrave kites which we have tried, if made light enough for light winds, are wrecked or disabled by strong winds or gales. In 1894 I tried the device of an elastic cord in the lower part of the bridle of the Eddy kite to lessen the pressure on the kite in strong winds, but the sensitiveness of the kite to changes in position of the point of attachment of the line rendered the device useless because the kite became unstable when the cord in the bridle

[1] From a paper read before the Boston Scientific Society on Feb. 23, 1897.

stretched. In 1895 I tried the device of having the extreme parts of the side-planes hinged and held by India-rubber bands so that they could fold back in high winds. This acted fairly well, but because the kite lost angular altitude when the planes folded back the experiments were not considered entirely satisfactory. Finally, in February, 1897, profiting by the experiments of Mr. Lamson and some suggestions in Mr. Chanute's book on "Progress in Flying Machines," I tried the device of introducing a keel in the ordinary diamond-shaped kite. This gave stability without the use of a tail, and enabled the kite to fly through a larger range of wind velocity than any kite we have yet tried. The experimental kite I have made is not sensitive to the position of attachment of the kite-line to the bridle, so that the point of attachment can be moved through a considerable range without destroying the equilibrium of the kite. For high winds the point of attachment can be brought well forward, so that the kite presents a slight angle to the horizon and hence a diminished surface to the wind. In consequence the kite can withstand strong gales without too great a strain on its parts. The experimental kite was flown in a wind averaging 12 miles an hour, and also in a gale averaging 45 miles with gusts exceeding 50 miles (indicated velocity). The slight inclination of the plane of the kite gives a great vertical thrust in proportion to the drift by the wind, so that the kite continues to fly at a good angle in gales, notwithstanding the increased friction on the edges and surfaces of the kite in proportion to area presented to the wind. By introducing a spring or elastic band in the lower part of the bridle, the points of attachment may be so adjusted that the kite will present the best angle for flight (20° to 30° from horizontal) for light winds. When the wind increases the stretching of the spring will cause it to present a smaller and smaller angle to the wind, thus preventing the great increase of pressure found on the usual

Fig. 1

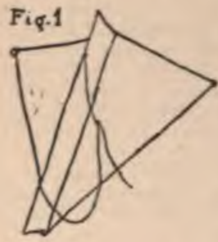


Fig. 2

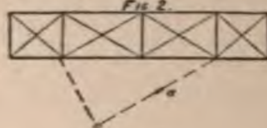


Fig. 4

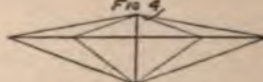


Fig. 3

form of kites. In this way it is possible to make the pull of the kite on the line much more nearly uniform through a large range of wind velocity than is possible with the usual forms of kites. This is a very important point in sending up valuable instruments when safety demands that the strain on the line shall not exceed a certain limit which is somewhere between one-fourth and one-half of the breaking strain of the cord or wire, the factor of safety being higher with the wire than with the cord.

In brief, the points in its favor, many but not all of which are shared by the other kites which we have used, are: It is tailless; it is stable; it is comparatively simple in construction; it flies at a good angle and through a large range of wind velocity. With a spring in the lower portion of the bridle it is partly automatic to changes of wind pressure, thus giving a more uniform pull than the ordinary kites. However, the extent of this last advantage has not yet been fully determined.

A picture of the kite is shown in Fig. 1.

The method of construction is as follows:

A truss shown in Fig. 2, which corresponds with the vertical line in Fig. 3, is made for the keel out of some light and strong wood, as, for example, spruce. In my experimental kite this truss is 7 feet long and 15 inches deep. The sticks are $\frac{3}{8} \times \frac{5}{8}$ inch, and there are four sections in the truss. The short sticks used for braces are fastened to the main sticks by strips of aluminium bent at right angles like angle-irons, and these are held in place by wrapping with twine. The truss is then guyed by a light wire (phospor-bronze was used in my kite). The wood is represented by heavy lines and the wires by light lines in the diagrams.

Next a stick of the same length as the truss, but somewhat stronger than any of the individual sticks used in the truss, is secured at its middle to the top of the truss at right angles to the frame and at about 20 to 25 per cent. of the length of the truss from the top, as represented in Fig. 3. In this figure the vertical heavy line in the centre represents the keel, which is seen edge on. The best position for the cross-stick has not been determined. When it is less than 10 per cent. of the distance from the top, the kite becomes less stable and more sensitive to the hanging, though it was found possible to fly the kite without any covering in front of the cross-stick. The covering (nainsook in my kite) is made large enough to fold over the keel and extend about an inch beyond the edges of the frame where it is folded over and pasted. It may be made to fit the keel smoothly by two strings passing from the front to the rear of the keel on either side outside of the covering and along the surface of the kite. Finally, two guys carried from the ends of the cross-stick to the lower ends of the keel, front and back, aid in holding the keel and cross-sticks in place. Though it is not necessary except for the strongest winds, a short stick may be erected above the keel and the cross-stick guyed as shown in Fig. 4. The places for tying the bridle are shown by the broken line under the keel truss in Fig. 2. The position of the spring is shown at *a*. It is necessary in this kite, as in others of this type, to take great care to have the centre of the cross-stick over the keel and the cross-stick as nearly at right angles to the keel as possible, so that there shall be the same amount of surface on each side of the keel below the cross-stick. Otherwise the kite will fly to one side and not directly into the wind. If the cover over the rear end of the keel is drawn tight at the bottom so as to form a V the stability is increased, but this is usually not necessary.

A RUBBER-PROPELLED MODEL.

COMPLYING with a request, Dr. Langley has kindly sent the following description of one of the early models referred to in his article:

Model No. 26. — This model was constructed anterior to May, 1891. Its motive power is twisted India-rubber, carried in tubes of paper stiffened by shellac, these tubes serving at the same time to form a part of the frame and give strength to the construction.

There are two pairs of wings, one over the other, spreading 83 cm. The upper wing is 14, and the lower 19 cm., from front to rear. The area of the upper is 1,148, and of the lower 1,634 cm. Each wing makes a large diedral angle (about 165 degrees) with the others. They are nearly flat, with a very slight curvature toward the tips, where they are strengthened in each case by three light, very thin strips of wood, which are only indicated in the drawing. The ribs of the wings are of hickory, and their surfaces of silk, strengthened with these thin pieces of wood toward the extremities. They are guyed with fine wires, and both pairs can be slid forward or back to obtain the requisite balance.

The area of the horizontal tail is 144 cm. This tail, it is important to notice, is carried on the end of a long and *elastic* rod, and is intended to be set at an angle with the plane of the wing as in the Pénaud original design.[1]

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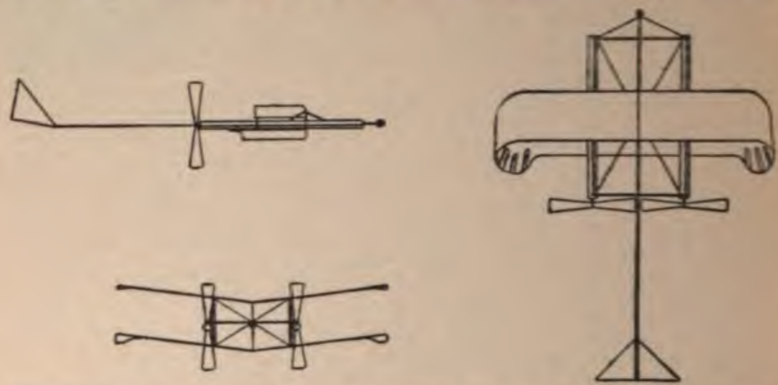
[1] The importance of the elastic feature in the Pénaud aeroplane tail is insisted on in the article on Flight in the 9th ed., Encyclo. Brit., quoted on pp. 164 and 165 of this number of THE ANNUAL.

There are two propellers. These are made of a central rib of wood, with blades of paper stiffened with glue. Their diameter is 23 cm., and width of blade about 5 cm. There are 100 turns of rubber within each paper tube, the

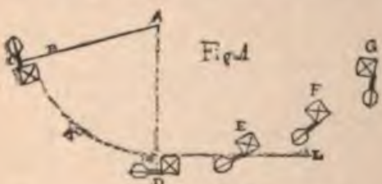


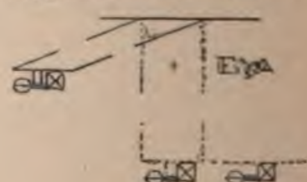
tension from which is applied directly to the propellers, each of which revolves on a journal passing through a piece of cork, which can be withdrawn from the tube.

The total weight of No. 26, including frame, rubber, wings, and tail, is 156 grammes. (In this model the area of the wings bears a much larger proportion to the weight than is usual, being at the rate of nearly 8 feet of surface to the pound of weight.) There is no record of the length of flight attained by this model. None of the flights of the other models exceeded 100 feet.

METHODS OF LAUNCHING AERIAL MACHINES.

Large soaring birds commonly begin their flights by running toward the wind upon land or water, or by dropping from an elevated perch. No aerial machine sustained by aerocurves is under the conditions requisite for free flight until, relatively to the wind, it has a certain velocity. Dr. Langley has told[1] of the difficulties which he has encountered and overcome in launching his aerodrome. In conversation recently, he suggested another method of





launching which will commend itself to experimenters with models. This consists in using an apparatus which he calls the *double pendulum*. The problem is to hold an aerodrome firmly in its place while velocity is being given to it, and to effect its release at just the instant when its velocity and direction are those requisite for satisfactory free flight. Before the double pendulum is described the defects of the single pendulum must be indicated.

[1] See p. 21 *et seq.*

In Fig. 1, AB is a pendulum supported at A; C is an aerodrome clamped to a frame at the free end of the pendulum in such a manner that automatic release is given to it when it has just passed the position D. Now, if the backbone of the aerodrome is horizontal at D, the aerodrome, instead of going in the desired course toward L, takes an upward course DEFG, and soon it is pointed toward the zenith. The cause of this is as follows: the aerodrome, when clamped to the pendulum, partakes of the rotary motion of the latter round the point A, its upper side is toward A as the face of the moon is toward the earth, yet the release of the aerodrome in nowise deprives it of its rotary motion, and thus the positions seen at EFG are accounted for. Turning now to Fig. 2 we see how the double pendulum remedies the defect, and how, by its use, an aerodrome may be launched unhandicapped. One important merit of this double pendulum apparatus, as mentioned by Dr. Langley, is that it contains no elements which unfit it for use on a large scale for a man-carrying machine. Dr. Langley further suggests that the pendulum be made as light as is compatible with strength, and that a powerful spring be used to give it motion, this being much quicker in its action than the force of gravity.

THE ALBATROSS.

THE contour of the albatross, shown in Figure 2, Plate XVIII., is taken from Alfred Newton's "Dictionary of Birds," and the following quotation comes from the same source: "In process of time the name has become definitely limited to the larger species of *Diomedeidæ*, a family of the group *Tubinares*, and especially to the largest species of the genus *Diomedea exulans*, the 'Man-of-war bird' or wandering albatross of many authors. Of this, though it has been so long the observed of all observers among voyagers to the Southern Ocean, no one seems to have given, from the life, its finished portrait on the wing, and hardly such a description as would enable those who have not seen it to form an idea of its look.

"The diagrammatic sketch by Captain (now Professor) Hutton, here introduced, is probably a more correct representation of it than can be found in the conventional figures which abound in books. The ease with which this bird maintains itself in the air, 'sailing' for a long while without any perceptible motion of its wings, whether gliding over the billows, or boldly shooting aloft again to descend and possibly alight on the surface, has been dwelt upon often enough, as has its capacity to perform these feats equally in a seeming calm or in the face of a gale; but more than this is wanted, and one must hope that a series of instantaneous photographs may soon be obtained which will show the feathered aeronaut with becoming dignity.

"The most vivid description is perhaps that given by Mr. Froude in his 'Oceana,' of which a part may here be quoted. 'The albatross wheels in circles round and round, and forever round the ship, now far behind, now sweeping past in a long rapid curve, like a perfect skater on an untouched field of ice. There is no effort; watch as closely as you will, you rarely or never see a stroke of the mighty pinion. The flight is generally near the water, often close to it. You lose sight of the bird as he disappears in the hollow between the waves, and catch him again as he rises over the crest; but how he rises and whence comes the propelling force is to the eye inexplicable; he alters merely the angle at which the wings are inclined; usually they are parallel to the water and horizontal, but when he turns to ascend, or makes a change in his direction, the wings then point at an angle, one to the sky, the other to the water.'

"The mode in which the 'sailing' of the albatross is effected has been much discussed, but there can be little doubt that Professor Hutton is right in declaring ("Ibis," 1865, p. 296) that it is only 'by combining, according to the laws of mechanics, this pressure of the air against his wings with the force of gravity, and by using his head and tail as bow and stern rudders, that the albatross is enabled to sail in any direction he pleases, so long as his momentum lasts.'

"Much discrepancy, at present inexplicable, exists in the accounts given by various writers of the expanse of wing in this species. We may set aside as a gross exaggeration the assertion that examples have been obtained measuring 20 feet, but Dr. George Bennett, of Sydney, states that he has 'never seen the spread of the wings greater than 14 feet.' Recently Mr. J. F. Green says that, out of more than one hundred which he had caught and measured, the largest was 11 feet 4 inches from tip to tip, a statement exactly confirmed, he adds, by the forty years' experience of a ship-captain who had always made a point of measuring these birds, and had never found one over that length.

"In the adult bird the plumage of the body is white, more or less mottled above by fine wavy bars, and the quill feathers of the wings are brownish-black. The young are suffused with slaty brown, the tint becoming lighter as the bird grows older. It is found throughout the Southern Ocean, seldom occurring northward of latitude 30° S., and is invariably met with by ships that round the Cape of Good Hope or pass the Strait of Magellan."

The "London and Edinburgh Philosophical Magazine" (1869) contains a paper by Professor Hutton, in which the air resistances encountered by the albatross are mathematically discussed. Professor Hutton estimates the weight of an albatross at 16 pounds and the area of contour as 8 square feet. He dissents from the view expressed by the Duke of Argyll and Dr. Pettigrew, that the extremely long and narrow wings of the albatross are the best for flight, and says that the vulture and the condor sustain him in this opinion. Compare the contours of the vulture and the albatross in plate XVIII.

PLATES XVII. AND XVIII.

One who intends to study the phenomena of soaring flight must first familiarize himself with the instrument by which the feat is accomplished. The qualities of the wing, which are evidently provisions in regard to flexing and flapping, are probably of less importance to us than those qualities which conduce to sustentation and steering.

The bird's wing, in its construction and action, is one of the most exquisite of nature's works.

Plates XVII. and XVIII. are introduced here, not because the illustrations are needed for any special article, but because students who discuss aeronautical problems are in constant need of such drawings as these to illustrate their points, and they will probably here find them convenient for reference.

Dr. Pettigrew in writing of the albatross wing shown in Fig. 5, Plate XVII., said that he had the original wing in his possession and that it measured over six feet in length.

The following is taken, with permission of the publishers, from Coues' "Key to North American Birds": — Fig. 6, Plate XVII., "shows the bones of the right wing of a duck, *Clangula islandica ;* A, shoulder, *omos ;* B, elbow, *ancon ;* C, wrist, *carpus ;* D, end of principal finger; E, end of hand proper, *metacarpus ;* AB, upper arm, *brachium ;* BC, forearm, *antibrachium ;* CD, whole hand or pinion, *manus;* composed of CE, hand proper or *metacarpus*, excepting d^2 ; ED, or d^2, d^3, d^4, fingers, digits, *digiti ;* AB, *humerus ; rd, radius ; ul, ulna ; sc*, outer carpal, *scapholunare* or *radiale ; cu*, inner carpal, *cuneiforme* or *ulnare*, these two composing wrist or *carpus ; mc* the compound hand-bone, or *metacarpus*, composed of three metacarpal bones, bearing as many digits — the outer digit seated upon a protuberance at the head of the metacarpal, the other two situated at the end of the bone; d^2 the outer or radial digit, commonly called the thumb or *pollex*, composed of two *phalanges ;* d^3, the middle digit, of two phalanges; d^4, the inner or ulnar digit, of one phalanx; d^2 is the seat of the feathers of the *bastard wing* or *alula :* D to C (whole pinion), seat of

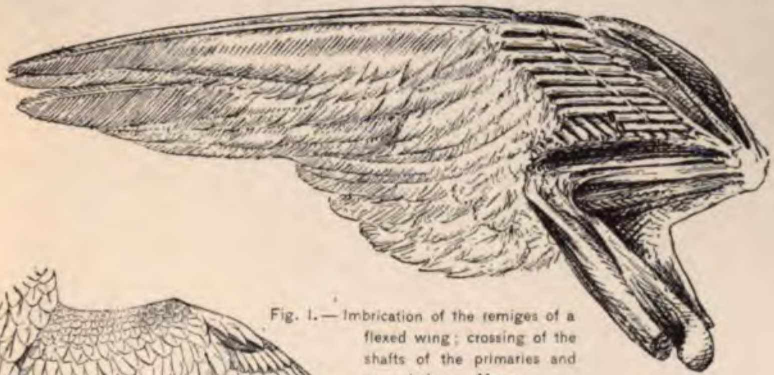


Fig. 1.— Imbrication of the remiges of a flexed wing; crossing of the shafts of the primaries and secondaries.— Marey.
— *"Le Vol des Oiseaux."*

Fig. 2.— Wing of Golden Plover. From "The Reign of Law," by the Duke of Argyll.

Fig. 3.— Wing of Gannet. From "The Reign of Law," by the Duke of Argyll.

Fig. 4.— Right wing of the Kestrel. From Pettigrew.

Fig. 5.— Left wing of the Albatross. From Pettigrew.

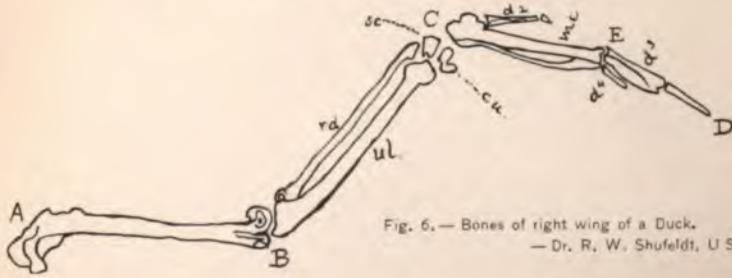


Fig. 6.— Bones of right wing of a Duck.
— Dr. R. W. Shufeldt, U.S.A.

Fig. 1.—The Bat. From Pettigrew.

Fig. 2.—Contour of Albatross. —Prof. Hutton.

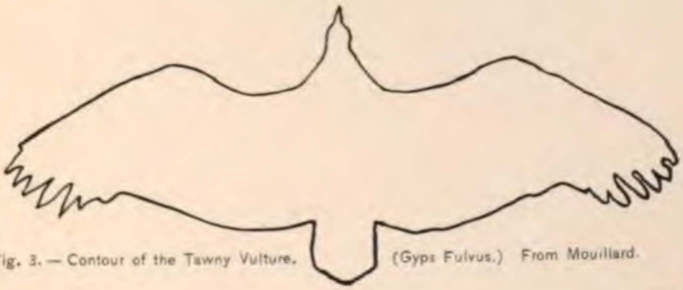


Fig. 3.—Contour of the Tawny Vulture. (Gyps Fulvus.) From Mouillard.

Fig. 4.—Posterior muscles of the wing of the Falcon.

Fig. 5.—Anterior muscles of the wing of the Falcon. This and Fig. 4 are from Marey's *"Le Vol des Oiseaux."*

the flight feathers called *primaries;* C to B (fore-arm), seat of the *secondaries;* at B and above it in direction of A, seat of *tertiaries* proper; below A, in direction of B, seat of scapularies (upon *pteryla humeralis*), often called *tertiaries*. The wing is shown partly spread; complete extension would bring ABCD into a right line; in complete folding C goes to A, and D to B; all these motions *nearly* in the plane of the paper. The elbow-joint and wrist are such perfect hinges that, in opening or closing the wing, C cannot sink below the paper, nor D fly up above the paper, as would otherwise be the effect of the pressure of the air upon the flight feathers. Observe also, *rd* and *ul* are two rods connecting B and C; the construction of their jointing at B and C, and with each other, is such that they can *slide lengthwise* a little upon each other. Now, when the point C, revolving about B, approaches A in the arc of a circle, *rd* pushes upon *sc*, while *ul* pulls back *cu;* the motion is transmitted to D, and makes this point approach B. Conversely, in opening the wing, *rd* pulls back *sc*, and *ul* pushes on *cu*, making D recede from B. In other words, the angle ABC cannot be increased or diminished without similarly increasing or diminishing the angle BCD; so that no part of the wing can be opened or shut without automatically opening or shutting the rest — an interesting mechanism by which muscular power is correlated and economized."

THE SECRET.

Albert Ross has the following in "Marine News" concerning "The Mystery of Soaring Flight:"

"If a bird can soar (*i.e.*, gain altitude without expending energy from within) in a uniformly moving horizontal wind, then he can also soar in a calm, for when he is in flight in the wind referred to, he is in a relative calm as soon as the resistance of the wind has overcome his inertia. There must be air *resistance* against his wings if he is to derive energy from the air, and when his inertia has been overcome (*if we understand the properties of air*) there can be no resistance against his wings, excepting that which is caused by the gravity of the bird, and gravity has never been found to give back to a body any more energy than that of which it deprives it.

"The question is, *Do we now understand the properties of air?* Many careful observers have stated that they have seen gains of altitude made by soaring birds in cases where the influence of moving air seemed to be negligible. Some scientists reply, 'The observers were mistaken, the air currents were more potent than they thought.' That reply is distinctly unscientific.

"There is a use for the elastic rear part of the bird's wing which has not yet been discovered. It does not contradict the laws of thought to assume, for the purposes of experiment, that the constant action of the sunlight upon the air is such that when the air is agitated by the swift passage of the wing-bone, a molecular action is caused in the air which causes an expansion, and that the expansion, acting upon the rear feathers, upward bent, gives a forward thrust. The way to ascertain whether or not this theory is correct is to take air and churn it in a glass receiver under various conditions of light, temperature and humidity. I have suggested this to several physicists, and have been told that if the experiment were tried the results would probably be negative. Some physicists say that 'if there had been anything in this theory of expansion some one would probably have found it out before now.'"

MEASUREMENTS OF THE VELOCITY OF FLYING DUCKS.

Contributed to "Science," of Jan. 1, 1897, by H. Helm Clayton: "Measurements of the heights and velocities of clouds are now being made at the Blue Hill Meteorological Observatory by Mr. Rotch as a part of an international scheme for such work. The measurements are made with specially constructed theodolites in which a large conical tube, with crossed wires at one end and an eyepiece at the other, replaces the ordinary telescope.

"On the morning of December 8, while Mr. S. P. Fergusson and I were engaged in measuring clouds, a flock of ducks passed across our base-line, which is 2,590.3 metres (8,496 feet) in length. We succeeded in getting one simultaneous set of measurements on the apex of the flock, from which its height was calculated, and one or two independent subsequent observations, from which the velocity was calculated. The height was 958 feet above the lower station, which is situated in the valley of the Neponset river, above which the ducks were flying.

"The velocity of flight calculated from this measurement of height, and from the angular velocity measured at one end of the base-line, is 47.9 miles in an hour, and from the angular measurements made at the other end of the base-line is 47.7 miles an hour, making a mean of 47.8 miles. The wind was very light, having a velocity of only two miles an hour according to the automatic record made at Blue Hill Observatory, 615 feet above the valley station. The direction of the wind was from the north, and the ducks were flying from the north-east. These observations were not in our programme, but they may prove of interest to ornithologists and students of aeronautics."

A PRACTICAL illustration may perhaps make clearer the mutual action of the bird and the wind. The reader doubtless knows the "roller coasters" in which a car runs down one slope and ascends another, but never quite so high as the starting-point, because of friction and resistance of the air. Now let him fancy that, as the vehicle starts down a slope, the whole roadway moves in the contrary direction, gliding under the vehicle like the wind beneath the bird; his own mechanical instinct will at once indicate that the vehicle will then rise higher than the starting-point (if the route admits of this), the increased rise being produced by the action of the roadway gliding past. This may be verified by constructing a little apparatus, in which the roadway shall consist of an undulating, smooth groove, either straight or circular, and the vehicle shall be a steel ball, turned perfectly true and smooth. If the groove be straight in plan (undulating in side view), and mounted upon wheels, then two phases of bird ascension may be simulated:

1. The ball may be started down the slope, and at the same time the grooved roadway may be briskly moved in the contrary direction. The ball will be found to rise on the upward slope higher than the point it started from. This parallels the case of the bird which, already under way, breasts the blowing wind and rises on it.

2. Or we may place the ball at rest at the bottom of one of the curves, and by simply imparting quick motion to the roadway, the ball will be seen to ascend upon the opposing slope. This parallels the case of the bird rising above his perch by simply unfolding his plumage to the breeze. This, indeed, he may do without springing up; but in this case he generally drifts back a little, while, if he gains some initial velocity, he can rise and advance simultaneously, thus exhibiting a notable case of "aspiration."

To rise in circling flight lighter breezes suffice. This action may be simulated by making the groove circular in plan, and rotating the whole apparatus on a pivot. Its path may be made to conform to the bird's orbit by making a series of long, gentle descents, and of short and sharp ascents, the combination of the two occupying one round. Then, by rotating the pathway in one direction and starting the ball in the other, the latter will be found to ascend upon an irregular helical path; just as the bird drops a little when he is going with the wind and rises again, and higher up, when he sweeps against the current again. This last illustration is imperfect, inasmuch as the whole pathway has been made to revolve, while the wind utilized by the bird blows on as a current. It, moreover, takes no account of the irregular wind gusts which the bird utilizes. It also exhibits much more friction than the actual performance which we have tried to simulate.

What the bird does in a wind, man can do. Our muscular strength is much too small to progress by direct action like the flapping denizens of the air; but our brain is sufficient to supply simple guidance when we shall have acquired the necessary skill. So, if we add life to the aeroplane and a moderate muscular power to supply the guidance, to perform in the right way and at the right time those evolutions produced by birds in gliding flight, the author believes that man may succeed in riding on the wind. To compass this, to achieve simple journeying flight in elementary form, experiment, practice, acquired skill, are doubtless requisite; but of great daring or of fresh invention there is little, if any, need. The principles are known, the path is pointed out by observers of birds, and now success awaits the skilful, prudent man who will thoroughly understand what he has to perform. — ***Mouillard, 1894.*** (*Cosmopolitan.*)

FROM "L'Empire de l'Air," by Mouillard, 1881 (see Smithsonian Report, 1892):

"The most stirring, exciting sight (the word is not too strong) is to stand in the vulture roost on the Mokatan ridge, near Cairo, and to look upon the *Gyps fulvus* (tawny vulture) passing within five yards in full flight. . . . All my life I shall remember the first flight of these birds which I saw, the great tawny vultures of Africa. I was so impressed that all day long I could think of nothing else; and indeed there was good cause, for it was a practical perfect demonstration of all my preconceived theories concerning the possibilities of artificial flight in a wind. Since then I have observed thousands of vultures. I have disturbed many of the vast flocks of these birds, and yet, even now, I cannot see one individual passing through the air without following him with my eyes until he disappears in the distant horizon. . . .

"The vulture's needs are few, and his strength is moderate. To earn his living he but needs to sight the dead animal from afar. And so, what does he know? He knows how to rise, how to float aloft, to sweep the field with keen vision, to sail upon the wind without effort, till the carcass is seen, and then to descend slowly after careful reconnaissance and assurance that he may alight without danger, that he will not be surprised and compelled to precipitous and painful departure. And so he has evolved a peculiar mode of flight; he sails and spends no force, he never hurries, he uses the wind instead of his muscles, and the wing-flap occasionally seen is meant to limber up rather than to hasten through the air. And so the true model to study is the vulture — the great vulture. Beside him the stork is as a wren, the kite a mere butterfly, the falcon a pin-feather. Whoso has for five minutes had the fortune to see the Nubian vulture in full sail through the air, and has not perceived the possibility of his imitation by man, is — I will not say of dull understanding, but certainly inapt to analyze and to appreciate." [1]

As to sailing flight, none of the old-time falconers doubted in the least its existence. They observed it every day, and they knew that the wind was a necessary condition. Nobody troubled himself about an explanation in those days; but later on, when physicists attempted to explain the mechanics of flight and succeeded in conceiving the action of the wing stroke and the effects of air resistances, sailing flight appeared to them as a physical impos-

[1] Mouillard in his tables gives the following figures concerning the Nubian vulture: Weight of bird, 8152 grams; surface within contour, 1.11295 sq. meters; spread of wings, 2.66 meters; mean width of wing, .46 meters. One square meter sustains 7323 grams. Relative surface required to sustain 80 kilos., or 176.4 lbs. avoirdupois, 10.88 sq. meters, or 117 sq. feet, 16 sq. inches.

sibility. They said that it was impossible to admit that a bird, suspended at a fixed point in the sky, should find in the action of the wind sufficient power to advance against that wind. As well, said they, might we throw an inert mass into a flowing river, and expect the current to cause the body to advance up-stream. And yet, modern observers have contested this verdict. M. d'Esterno and M. Mouillard demonstrated that, unless we absolutely disbelieve ocular evidence, we must accept the actual fact that sailing flight is possible, even if we have to admit that our present mechanical knowledge is insufficient to explain it. — *Marey. Inst. of France.*

LILIENTHAL wrote as follows under date of April 17, 1896: "I am now engaged in constructing an apparatus in which the position of the wings can be changed during flight in such a way that the balancing is not effected by changing the position of the centre of gravity of the body. In my opinion this means considerable progress, as it will increase the safety. This will probably cause me to give up again the double sailing surfaces as it will do away with the necessity which led me to adopt them."

FLAPPING wings may be imitated, but only with small models; the increased strength and weight of material necessary for larger apparatus, and the great motive power required for alternative action, have proved to be obstacles not yet overcome. — *Mouillard, 1894.*

WE must not allow ourselves to be deceived as to the form of the bird's wing. It is always more curved when not spread than when the bird is resting its weight upon it in the air. Besides which, the curve, which in the beginning appears to be considerably stronger towards the front edge, becomes somewhat more uniform as soon as the quills are bent straighter at their roots by the pressure of the air from beneath. — *Lilienthal, March, 1895.*

MY investigations concerning the effects of curved wings had one result which was quite unexpected, namely, that the air resistance is not perpendicular to the chord of the profile curve, but that in certain impact angles of the air its direction inclines forward, with a perceptible drawing component.[1] — *Lilienthal, March, 1895.*

LILIENTHAL wrote, May 28, 1896: "I would finally remark that bodily strength and dexterity are of less consequence than the general intelligence and the gift of perception in technical matters when selecting the men [for gliding experiments]."

OBSERVATIONS OF THE FLIGHT OF BIRDS, by Leonardo da Vinci, Darwin, Sir George Cayley, the Duke of Argyll, Chanute, Lilienthal, Maxim, and others may be found in Nos. 1 and 2 of the Aeronautical Annual.

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[1] *Mit nicht unerheblich ziehender Componente.*
For Lilienthal's mathematical treatment of this subject see "Zeitschrift für Luftschiffahrt," February and March, 1895, and also the very interesting manual entitled "Taschenbuch für Flugtechniker und Luftschiffer," by Captain H. W. L. Moedebeck, published by W. H. Kühl, Berlin, 1895.

EDITORIAL.

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THE SCIENTIFIC VALUE OF FLYING MODELS.

THE ultimate object of aeronautical study and experiment is, of course, to hasten the time when it shall be possible to construct a *practical* flying machine.

There are some experimenters who think that the day of the great achievement will come sooner if in the immediate future we give the most of our time and thought to the development of the motorless air-sailer. Others think that more rapid progress will be made through the development of the self-propelled aerodrome.

It is quite needless to attempt at this time to say who is right; time will show us all that. Moreover, as stated in the introductory note, whichever branch of work is seriously undertaken by an individual, he may be sure that while working upon his own specialty he is helping those engaged in the others toward their common goal.

The supreme importance which attaches to the flying model comes from the fact that experiments with it may be made to lessen the number of risks of human life and limb. We have now reached the stage of experiment where it is necessary to use all possible persuasion to keep reasonably near *terra firma* those persons who have nothing but the courage of ignorance to equip them for ventures in the air. A part of the glory of the work of '96 at Camp Chanute comes from the fact that no one of the experimenters was injured, all being under the control of an accomplished scientist, firm and clear-headed. If the lamented Lilienthal, with his great knowledge of engineering, his long experience, and his superb self-control, could come to his untimely end, is Fate likely to be kind to the novice?

Remembering that Lilienthal said, "It is not every man's business to launch himself into space," and knowing that there are some men who are so situated that experiments with models are the only ones which they can undertake, let us consider the possible value of the results of such experiments.

We can readily see that many models otherwise excellent will have limitations to their usefulness because of the laws governing the strength of materials. In designing a model it is advisable to keep in mind, so far as possible, the probability of the retention of its good qualities in case its enlarged counterpart is constructed. We know that the elements of strength contained in the model, which will also appear in a full-sized machine, are those which have come from the engineering skill shown in the structure, and that these elements must be so far in excess of the actual needs of the model that they will offset the great loss in the proportional strength of materials which occurs when the size of machines is increased.

I once knew of an imposing piece of experimental apparatus, having several hundred square feet of surface, which was withered by the wind because the designer had forgotten the simple point just mentioned.

It is not necessary to immediately settle the question as to how far the performance of a model is a *demonstration* of what can be done with its enlarged counterpart; it is enough for the present to know that experiments with models can throw much light upon several subjects that are now imperfectly understood. The following are some of these:

1. Automatic devices for preserving equilibrium.
2. Disposition of surfaces.
3. Placing of screws.

4. Curves of surfaces.
5. Relation of weight to area.
6. Relation of power to weight.
7. Effects of elasticity in sustaining surfaces.

Any one of these subjects is enough to occupy an experimenter for a long time.

In regard to the first subject it will be noticed that the contributors to THE ANNUAL have given no detailed descriptions of the automatic devices which they have tried. This is because of the conservatism which leads every rational experimenter to withhold details from the public until his own tests have satisfied him that the proper time has come to make an announcement.

Mr. Chanute in his book[1] describes many attempts which have been made to secure automatic equilibrium, and it goes without saying that no one will begin any kind of aeronautical experiment until he has given to that book the most thorough study. It may here be said that rolling balls, shifting mercury ballast, and pendulum devices to move rudders have been tried, but none of these have so far given satisfactory results.

If there is one man whose name is mentioned oftener than that of any other in connection with the subject of automatic equilibrium it is that of Alphonse Pénaud,[2] whose flying models attracted much attention twenty years ago and recently have attracted still more.

In 1874 Mr. T. J. Bennett, of Oxford, brought Pénaud's automatic rudder to the notice of the Aeronautical Society of Great Britain, in the following words:

> But all the above models flew by accident, there being no special means provided for maintaining the equilibrium fore and aft. This problem M. Pénaud has solved by means of his automatic rudder. . . .
>
> At last the idea occurred to him of placing a small horizontal rudder behind the sustaining planes, and inclined at a small angle to them. It succeeded perfectly. Its mode of action is as follows:
>
> The centre of gravity of the machine is placed a little in front of the centre of pressure of the aeroplane, so that it tends to make the model descend an

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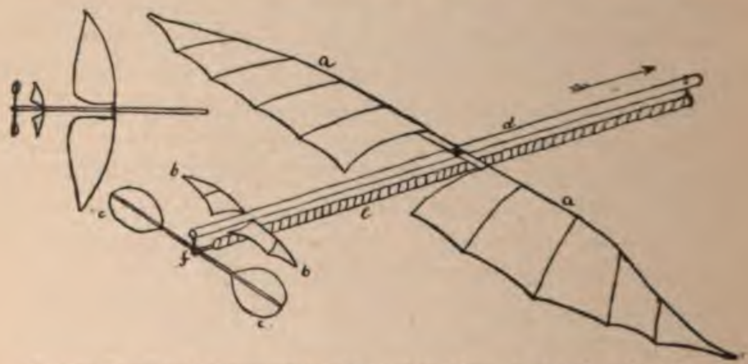
[1] "Progress in Flying Machines." Published by M. N. Forney, N.Y., 1894.

[2] A Frenchman, now of honored memory, who died in sorrow and disappointment in 1880, before reaching the age of thirty years. See "Progress in Flying Machines," pp. 117-122.

incline; but in so doing it lessens the angle of inclination of the aeroplane, and the speed is increased. At the same time the angle of the horizontal rudder is increased, and the pressure of air on its upper surface causes it to descend; but as the machine tends to turn round its centre of gravity, the front part is raised and brought back to the horizontal position. If owing to the momentum gained during the descent the machine still tends upwards, the angle of the plane is increased and the speed decreased. The angle of the rudder from the horizontal being reduced, it no longer receives the pressure of the air on its superior surface, the weight in front reasserts its power, and the machine descends. Thus by the alternate action of the weight in front and the rudder behind the plane, the equilibrium is maintained. The machine during flight, owing to the above causes, describes a series of ascents and descents, after the manner of a sparrow.[1]



aa, elastic aeroplane; *bb*, automatic rudder; *cc*, aerial screw centred at *f*; *d*, frame supporting aeroplane, rudder, and screw; *e*, India-rubber in a state of torsion, attached to hook or crank at *f*. By holding the aeroplane (*aa*) and turning the screw (*cc*) the necessary power is obtained by torsion. — *M. Pénaud, 1872.*

There was one very important element contained in the Pénaud model shown in accompanying cut, and that was the *elasticity of the sustaining surfaces*, which probably had much to do with the success of its flights. Even at the risk of some repetition, another paragraph[2] is here quoted:

As *rigid* aeroplanes and screws were employed in the construction of these models (previously described) they flew in a hap-hazard sort of a way.

[1] It will occur to the reader that the flight of a sparrow is not conspicuous for its horizontality. Any one who experiments with motorless gliders (see AERONAUTICAL ANNUAL, No. 1, p. 166) made on the Pénaud principle will find the first flights decidedly sparrow-like, but he will also find that by varying the amount of weight carried, the position of the centre of gravity, and the size and angle of the rudder, the undulation of the flights can be made less and less. — *Ed.*

[2] See Encyclopædia Britannica, 9th edition, N.Y., 1879, Vol. IX., p. 321. The italics used in the quotation are in the original.

it being found exceedingly difficult to confer on them the necessary degree of stability fore and aft and laterally. M. Pénaud succeeded in overcoming the difficulty in question by the invention of what he designates his automatic rudder. This consists of a small *elastic* aeroplane piaced aft or behind the principal aeroplane, which is also *elastic*. The two elastic aeroplanes extend horizontally and make a slight upward angle with the horizon, the angle made by the smaller aeroplane (the rudder) being slightly in excess of that made by the larger.

As there are several more subjects to be considered in this editorial, more space must not be given to this matter of automatic stability. To say that experiments with models can instruct us concerning it, is almost like stating an axiom.

We come now to the second subject: the disposition of surfaces. The nature of the questions which arise in this connection can best be explained by referring the reader to the previous pages of this number of THE ANNUAL, where Mr. Chanute has described the permutations of his surfaces,[1] and where Mr. Herring has discussed the matter of "interference."[2]

Very much of what is now known concerning the disposition of surfaces has been learned from the flights of models. I think that no experimenter will doubt that there is still more to be learned.

When we consider the third subject, the placing of screws, we shall see how models may instruct us in such a manner that undue risks of life and limb may be greatly lessened. The motorless gliding model is acted upon by two forces — gravity and the pressure of the air upon its surfaces. When a motor and propellers are used there is a third force, the thrust of the screws, which has to be considered in all calculations. We are justified in assuming that any self-propelled flying machine must have the excellence of equilibrium of the best gliding machine when at any time its engines are stopped; therefore it is possible to gain knowledge as to the best way of placing the *motor*, by using, in place of the motor, ballast having the weight and general form of the motor which is later to be used.

Where the line of screw-thrust is to come, so that, when this third force is applied, the equilibrium of the machine will not be

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[1] See p. 35 *et seq.*

[2] See p. 63 *et seq.*

seriously compromised, is a matter upon which engineers are not fully agreed, and therefore an amateur may well refrain from expressing an opinion. The difficulty comes in the travel of the centre of air pressure, which is now imperfectly understood.

This much seems probable, that if engineers will furnish working hypotheses, careful laymen may test these in placing the screws on their models, and in that way do useful work.

The air-sailer who in flight first adds the thrust of a screw to the forces he is accustomed to deal with will stand in need of all the knowledge which can be gained from self-propelled models.

The fourth subject is, the curves of surfaces. Lilienthal's article entitled "The Best Shapes for Wings," which is given on previous pages, leaves at present little to say under this head.

The fifth and sixth subjects may be considered together.

The relation of the whole weight of a model to the area of its sustaining surfaces and the relation of the power used to the whole weight sustained are very important matters, and it may be assumed that when model-flying becomes common, many models will be made with removable motors, so that with one motor comparative tests of different forms of models can be made, and useful if not precise data be obtained.

The value of comparative tests made with steam motors would perhaps be impaired by the variations of the power coming from different conditions of the flame in different flights, but with compressed air or liquid carbonic acid the comparative tests would be useful, to say the least.

The seventh subject — the effects of elasticity in sustaining surfaces — gives great scope to experimenters. Those who devote themselves to it can surely help to answer the still unanswered question, Does the feather structure of a bird's wing give to it a certain quality which makes it a better model for us to follow than the featherless wing of the bat? To Lilienthal this seemed to be an open question.

I have tried to make a strong plea in behalf of the flying model. It seems to me that, whatever its limitations may be, it can lessen the risks to life and limb. We are fortunate that we live in a time of peace, when such things are the first to be thought of. If we were at war it would be necessary to call for recruits who would risk their lives in making glides from captive balloons, for if we did not do that some other nation would, and when bags of explosives are dropped into the smoke-stacks of multi-million-dollar battle-ships, it will cause a revision of opinions concerning the balance of power of the world.

MOTIVE POWER FOR FLYING MODELS.

THE designer of a motor for a flying model must begin by choosing his type. There are not more than eight from which he is likely to choose. These are as follows: Motors actuated by (1) steam, (2) explosion of gas or vapor mixed with air, (3) electricity, (4) compressed air, (5) liquid carbonic acid, (6) rubber under torsion or tension, (7) steel springs, (8) inertia of a revolving body.

In choosing the type the designer will naturally, at the start, consider this question: What are the qualities most to be desired in the motor of a flying model? It goes without saying that it is desirable to have a maximum of power with a minimum of weight, and to have the motor safe to use. The other points to be considered are:

1. Probable usefulness of an enlarged counterpart.
2. Uniformity of motion.
3. Duration of action in flight.
4. Durability.
5. Economy.
6. Simplicity.

In considering types we may narrow the subject by a process of elimination.

Rubber under torsion or tension has the advantage of being extremely simple and cheap. It has the disadvantage of requiring the use of a fusee or something equally clumsy and wasteful of power if it is to give a uniform motion to a propeller. Pénaud, who died seventeen years ago, did excellent work with rubber-propelled models without using the fusee, yet it is probable that those who read what Dr. Langley says of rubber on pages 15 and 16 of this ANNUAL will conclude that while rubber may be useful for preliminary experiments, it is not likely to be so beyond these.

Makers of models who have experimented both with rubber and steel springs pronounce the latter to be inferior to the former.

Coming now to electricity, it is safe to say that the weight of any battery, primary or secondary, at present known, is too great to be carried by any flying machine. It has been suggested that experiments with models propelled by electric motors and furnished with energy through trailed conducting wires would be useful, but even a slack wire would be a disturbing element, and the phenomena observed would not be those of free flight.

The principle of inertia propulsion has been used to some extent in marine torpedoes. The highest velocity compatible with the strength of materials is given to a revolving wheel with a heavy rim; this wheel is like that of the gyroscope of the physical laboratories; in torpedoes it gives its energy to the propelling screws. Some experimenters have suggested the use of the gyroscope for giving stability to flying machines in horizontal flight. If this principle were applied in a flying model the wheel would serve a double purpose, if revolved in a horizontal plane and geared to propellers; that is, it would act to preserve the equilibrium of the model and also as a reservoir of energy. It seems to me that this method of propulsion offers less to the experimenter than those which are now to be considered.

In trying to accurately estimate the relative values of steam and explosion engines for our purpose, we must bear in mind the fact that during two centuries of experiment, the former have received much more attention from inventors than the latter. It is not necessary now to consider the reasons for this; it must suffice to say that the steam-engine is given into our hands in a comparatively well-matured condition, while the explosion-engine comes to us less fully developed. I think it will be generally admitted that the explosion-engine has at the present time greater possibilities of improvement than the steam-engine has.

It is speaking within bounds to say that as an authority on light-weight motors, Mr. Hiram S. Maxim stands second to no man in the world. His commendation of petroleum motors on p. 147 of No. 2 of THE ANNUAL should therefore be read with interest by students. In this connection, however, it is well to remember that the greatest successes ever made with light-weight motors have been made by Langley and Maxim respectively with steam-engines.[1]

In coming now to the consideration of motors moved by compressed air and liquid carbonic acid, it is necessary for a moment to refer to steam-motors as forming with them a group, and to note the fact that between these three types of motors there is such a strong similarity that in case we are compelled to abandon one form of energy and adopt another in its place, we can do so without making very radical changes in the motors. This would seem to be an advantage to experimenters.

If compressed air or liquid carbonic acid have any advantages over steam, I think that these would hold only in the case of the motor of a flying model, and that they would not be found in its enlarged counterpart. The reason for this opinion will be seen when we consider the relative length of flight of a flying model and that of a practical flying machine of man-carrying size. In the former a two-minute flight is ample, for at the end of that time the flying model will be at such a distance from the experimenter that observation and study of its conduct will be of little use. Of the latter a long flight is required.

With a small tubular holder for the air or carbonic acid it is possible to get a considerable amount of power for a short time, and this will suffice for very instructive flights of models. As to the comparative merits of liquid carbonic acid and compressed air, the reader is referred to the article which Pro-

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[1] See p. 20 of this ANNUAL, p. 36 of No. 2 ANNUAL, and p. 444 *et seq.* "Century Magazine," N.Y., Jan., 1895.

fessor Peabody has kindly contributed to this number of THE ANNUAL. (See p. 147.)

As to a holder for the liquid carbonic acid or compressed air, it seems to me that it will be well to begin with one which will have about forty cubic inches of space. The only way that I know of to get a suitable holder is to have several made by a maker of the best shot-gun barrels, and then carry them to the hydraulic testers and have one-half of the lot tested to destruction; the other half should be tested to a sufficient degree to make them safe to transport when charged with liquid carbonic acid.

In conclusion it may be said that to the experimenter with flying models there are four types of motors which are likely to be useful; namely, the steam, explosion, compressed air, and carbonic acid motors. Each has advantages. As for immediate needs it seems to me that the air or carbonic acid motors are likely to be the most satisfactory, because they are comparatively simple and are sufficient for short flights.

AN IMPORTANT WORK.

JUST as knowledge of the ocean currents is requisite in marine navigation, so knowledge of aerial currents is indispensable to those who would come to a right understanding of the problems of aeronautics.

Langley, in his "Internal Work of the Wind," has shown the importance of the pulsation of wind currents as a factor in explaining the phenomena of soaring flight; Chanute, Lilienthal, Maxim, Pénaud, and others have alluded to the ascending air currents which are now known to exist; Chanute and Herring on previous pages of this number of THE ANNUAL write of the rolling billows of air which they have encountered, and the result of all is, that we thirst for more knowledge concerning the mysterious aerial ocean.

The value of the data which have been gathered at Blue Hill Observatory in the past twelve years is known and appreciated by meteorologists in all parts of the world; yet now no longer content even with his summit station, the founder and director is making observations at altitudes of over 9,000 feet. The methods of work and the results so far reached are described elsewhere in this number of THE ANNUAL. The work is now well under way, and the knowledge which will be gained in the next few years is likely to prove of great value.

The Blue Hill Meteorological Observatory was built in 1885, by A. Lawrence Rotch, Esq., who has since directed its work and defrayed the cost of maintenance. This amounts now to over $4,000 a year. The observations and investigations have been published annually since 1887 in the "Annals of the Astronomical Observatory of Harvard College."

The situation of Mr. Rotch's observatory on the summit of the highest hill[1] in the vicinity of Boston, with a free exposure in all directions, especially adapts it to the needs of meteorologists.

The observations were first made in coöperation with the New England Meteorological Society. Among the methods and investigations which, proving successful at Blue Hill, were afterwards adopted by the United States Signal Service, and by its successor the United States Weather Bureau, there may be mentioned simple self-recording instruments with which the observatory was equipped in 1885 and 1886, the issue of local weather predictions, the international form of publishing meteorological data, observations of the height and velocity of clouds. Kites for elevating self-recording instruments which have been in use at Blue Hill since 1894 are about to be applied to this purpose by the United States Weather Bureau.

Since 1886 observations of the direction of motion and relative velocity of clouds have been made several times a day at Blue Hill, this being the longest series of the kind in the United States. Trigonometrical measurements of cloud heights and absolute velocities had been made in Sweden, and in 1890 and 1891 these were repeated at Blue Hill by Messrs. Clayton and Fergusson. The publication of the results obtained attracted

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[1] The summit is 635 feet above sea level. It is 10.4 miles S.S.W. from the State House in Boston. Travellers from New York to Boston via Providence may see the observatory on the right about 15 minutes before reaching Boston. See illustration, Plate X.

much attention and facilitated the internationa observation now being carried out, in which th methods employed six years previously at Bl being used there. It will be seen that such c known the direction and velocity of the air cu altitudes.

Of special interest to students of aeronau gusson's researches on the methods of measur and vertical components of the wind. Kites important method of continuing these investig air at considerable heights above the earth's s researches are carried farther, and as more bec cerning the vertical component measured abo turbed surface stratum, the ascending currents almost unknown quantities which they now are is to undertake a very difficult task; special be invented and constructed; yet from what far by Mr. Rotch and his able assistants, we a even more.

KOCH'S APPARATUS.

THE accompanying drawings are reproduc dated November, 1889, and included in a pa Koch, published in Munich in 1891. The title Flight as a Prerequisite of Dynamic Aeronau

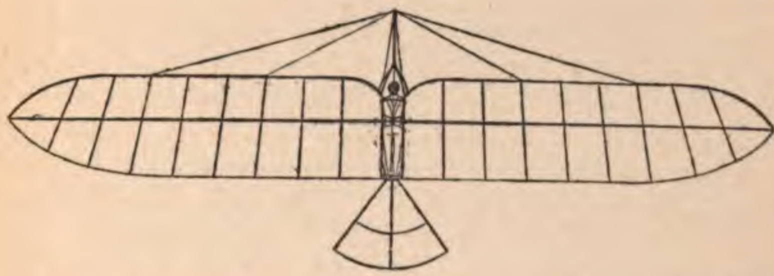
Koch's drawings are given here solely becau which attaches to them on account of his ope

Not only was Koch ahead of his time w suggested this horizontal position, but any now advocate its immediate adoption would The control of the gliding machine, although every year, is not yet sufficient to make it re an air-sailer to assume this position.

All this, however, need not prevent us fron great economy of power[1] which will result wh

[1] See AERONAUTICAL ANNUAL, No. 1, pp. 151-153. See also in Aerodynamics," p. 106, lines 33-40.

man shall acquire such control over the gliding machine that he can properly direct one of a very compact design while he occupies the position shown in the drawings.



In the original drawing there are dotted lines to show how the position of the wings may be changed by swinging them backward and forward, thus changing the position of centre of pressure relatively to the centre of gravity. These lines do not appear in this cut. Mr. Chanute discusses Koch's device on pp. 215–217 of "Progress in Flying Machines."

THE length of time which it will take to reach a complete solution of the problem of mechanical flight will depend largely upon the amount of money contributed to pay the expenses of experimenters.

Money so contributed may easily be wasted, and there are never wanting men who eagerly affirm that a certain amount of money placed in their hands will surely bring the solution of the problem.

If some Lorenzo di Medici should now appear near the close of this nineteenth century, his first thought concerning this subject would be, "If I give a large sum of money for the purpose of bringing to the nineteenth century the credit of achieving mechanical flight, how can I assure myself that the money will be wisely used?"

The Editor suggests this answer to the question: Let any donor make his gift to science with one condition; namely, that the faculties of the four leading technological institutes of the United States shall consent to choose a board of five trustees who shall control all the expenditures of the fund. This would be a sure safeguard against incompetent claimants.

WHEN a model glider with a Pénaud rudder is heavily weighted it ordinarily requires a high starting point to give it velocity sufficient to sustain the weight; the large angle at which the rudder is set makes a long swoop necessary before the model steers itself into a horizontal course. Sometimes a sufficiently high launching place is not attainable. Query: Can good glides be made from a comparatively low starting point by setting the tail at a smaller angle with the main sustaining surfaces, and arranging it to snap back into the large angle position two or three seconds after launching? A spring released by the unwinding of a rubber cord might answer the purpose.

MR. R. W. WOOD was one of the last Americans to visit Lilienthal and to witness his flights. On Sunday, Aug. 2, 1896, just one week before the fatal accident, he was at Rhinow hills with the dauntless engineer. In the "Boston Evening Transcript" of Saturday, Oct. 31, 1896 (page 20), will be found a very interesting article of two columns' length in which Mr. Wood tells the story.

IT having been stated in the public prints that THE AERONAUTICAL ANNUAL is published under the auspices of the Boston Aeronautical Society, the Editor wishes to say that it never was so published, and, further, that he has ceased to be a member of the society referred to, and knows nothing of its proceedings. None of the resident members of that society are now contributors to the pages of THE ANNUAL.

THE illustrations on Plates III., V., and XV. are made from drawings kindly contributed by Robert D. Andrews, Esq.

"McCLURE'S MAGAZINE" states that in a future number it will publish "the first authentic account" of Professor Langley's flying machine. The readers of THE ANNUAL will perceive that the statement is erroneous.

FLYERS of models may make progress by taking the best gliding machine of the previous season and reproducing it in a convenient working model size and applying motor and screws to it.

THE records of the Aeronautical Society of Great Britain show that Otto Lilienthal was a member as early as 1873.

AERONAUTICAL PERIODICALS.

Zeitschrift für Luftschiffahrt und Physik der Atmosphäre. — Edited by Dr. A. Berson. Published monthly by Mayer & Müller, Berlin. Subscription price (in Postal Union), 13 M. 50 Pf. per annum. Established 16 years.

The Aeronautical Journal. — Published quarterly at 2 s. per copy, by King, Sell & Railton, Ltd., 4, Bolt Court, Fleet St., London, E.C.

L'Aéronaute. — Edited by M. Hureau de Villeneuve. Monthly. Office of publication, 91 Rue d'Amsterdam, Paris. Subscription price (in Postal Union), 9 francs per annum. Established 30 years.

L'Aérophile. — Edited by M. George Besançon. Monthly. Office of publication, 14 Rue des Grandes-Carrières, Paris. Subscription price (in Postal Union), 12 francs per annum. Established 5 years.

Revue de l'Aéronautique. — Edited by M. Henri Hervé. Quarterly. Published by Masson et Cie., 120 B'd Saint Germain, Paris. Subscription price (in Postal Union), 10 francs per annum. Established 7 years.

STUDENTS who give especial attention to
resistances will be interested in the followin
widerstandsgesetze, der Fall durch die Luft
(304 pp., 67 illus.), by Friedrich Ritter
lished by A. Hölder, Vienna, 1895. A cop
been received by THE ANNUAL; it was first l
ologist, next to a professor of engineering
hands of a physicist in Washington, and wh
be given to the Boston Public Library. The
lishers of scientific books and pamphlets
when copies are sent to THE ANNUAL they w
use.

THE date of issue of this, the third number
is May 25, 1897. It was necessary this yea
lication in order to give the leading contribut
complete their articles. Last year THE ANN
in February, and it is hoped that future nu
in that month, so that experimenters may h
study the previous season's work before arr
mer plans. Contributors will please send i
No. 4 some time during November, 1897.
communications to THE EDITOR OF TH
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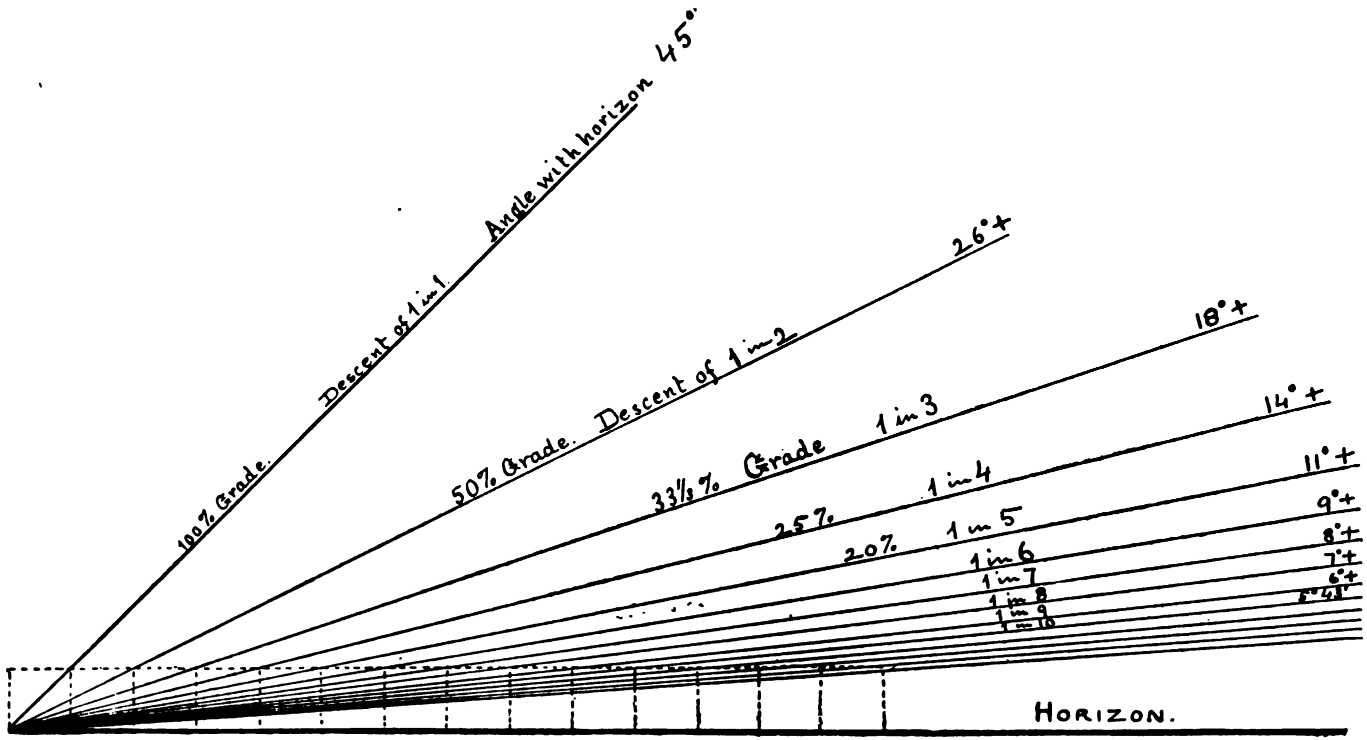
EXPERIMENTERS in all parts of the world are in
cation in the next number of The Annual, concise
ments. Contributors will kindly note the followi
not to be held responsible for rejected manuscripts, dra
2. In describing experiments, contributors are requested t
also working-drawings of those pieces of apparatus which
3. Well-illustrated descriptions of experiments with the fo
ratus are especially desired: Gliding machines; Self-pro
Screw propellers. 4. All photographs should be distinct,
factorily reproduced. All drawings should be in very b
or tracing-cloth, and they should be sufficiently well execut
without re-drawing. 5. Accuracy, explicitness, and conc
desirable in the extreme. 6. Please state if any of the t
been in print before, and, if so, where. Please give dates



The above diagram is intended to assist the eye in judging the angle of descent of an air-sailing machine or gliding model.

HERRING'S TABLE.

Properties of a curved surface, curved to arc of a circle having a rise of arc equal to 1/12 the breadth of wing, deduced from Lilienthal's tables and Smeaton's coefficient (.005 v^2).

Angle of incidence.	*Lift*, per cent. of normal plane.	*Drift*, as a per cent. of lift.	Max. travel horizontally for one foot fall.	Miles per hour for one lb. per sq. ft.	Mile pounds per lb. supported with loading of one lb. per sq. ft.	Pounds per horse-power.
−9	.000	inf.	0	inf.	inf.	0
−8	.0396	1.54	.65	71.	109.34	3.43
−7	.0792	.655	1.525	50.2	32.75	11.4
−6	.119	.396	2.53	40.9	16.2	23.15
−5	.160	.257	3.89	35.3	9.07	41.3
−4	.200	.175	5.72	31.75	5.53	67.8
−3	.242	.125	8.00	28.85	3.6[illegible]	103.6
−2	.286	.091	10.9	26.45	2.41	155.6
−1	.332	.076	13.1	24.55	1.87	200.5
0	.381	.063	15.8	22.9	1.45	251.7
+1	.434	.0544	18.4	21.5	1.17	320.6
2	.489	.0513	19.5	20.2	1.04	360.6
3	.546	.0525	19.0	19.1	.993	377.6
4	.600	.0582	17.1	18.3	1.07	350.5
5	.650	.0655	15.2	17.54	1.14	329.
6	.689	.0708	14.1	17.03	1.25	300.
7	.730	.0850	15.2	16.55	1.41	266.
8	.764	.0862	11.7	16.18	1.48	268.
9	.792	.105	11.6	15.9	1.67	224.6
10	.808	.116	9.5	15.7	1.82	206.05
11	.829	.125	8.0	15.5	1.84	204.
12	.847	.137	7.3	15.4	2.11	177.7
13	.852	.151	6.6	15.3	2.31	162.3
14	.864	.165	6.0	15.2	2.51	149.4
15	.870	.18	5.55	15.15	2.73	137.4
16	.873	.20	5.	15.1	3.02	124.2
17	.875	.223	4.48	15.1	3.37	113.3
18	.874	.244	4.10	15.1	3.68	102.0
19	.880	.27	3.70	15.15	4.08	91.9
20	.866	.30	3.3	15.2	4.56	82.2
21	.862	.32	3.13	15.25	4.88	79.0
22	.856	.35	2.86	15.3	5.36	70.1
23	.850	.37	2.71	15.3	5.66	66.3
24	.843	.40	2.5	15.4	6.16	60.8
25	.825	.434	2.30	15.55	6.71	55.9
26	.827	.458	2.18	15.56	7.12	52.6
27	.818	.484	2.07	15.6	7.55	49.6
28	.808	.50	2.0	15.5	7.75	48.4
29	.797	.54	1.85	15.9	8.59	43.6
30	.788	.57	1.75	15.9	9.06	41.4
32	.768	.62	1.61	16.1	9.98	37.5
35	.733	.76	1.32	16.55	12.58	30.
40	.681	.86	1.16	17.15	14.75	25.0
45	.628	1.03	.97	17.8	18.33	20.4
50	.570	1.20	.83	18.7	22.44	12.3
55	.510	1.48	.68	19.8	29.30	12.0
60	.450	1.79	.56	21.1	37.77	9.7
70	.318	2.87	.348	25.1	72.3	5.2
80	.167	5.79	.173	34.6	200.33	1.85
90	0	inf.	0	inf.	inf.	0

In the accompanying tables the first column is the angle of inclination of the chord in reference to the horizontal when the surface is moved through still air.

The second column is the proportion of (.005 v^2) the normal pressure which acts as a lifting force at the velocity V in miles per hour. The result would be given in pounds per square foot of area. Thus one square foot of curved surface having a rise of arc of about one-twelfth of its chord length, if exposed at a positive angle of eight degrees in a wind of twenty miles an hour, would exert a lifting effect of .005 × 20 × 20 × .764 = 1.528 pounds = say one and a half pounds per square foot.

The third column is the driving force necessary to overcome the resistance of the surface, it is expressed as a fraction of the weight resting on the surface. If this weight be (as before found) 1.528 pounds, then the driving force necessary is 1.528 × .0862 = .1317 pounds for every square foot of surface of the machine. If, however, the weight of a machine complete is known, and is, say, 200 pounds, and it is desired to find the push of the screws necessary to drive it at an angle of, say, 8 degrees, we can find the necessary thrust directly by multiplying the weight 200 pounds by the factor in the third column opposite 8 degrees, thus 200 × .0862 = 17.24 pounds, which is, however, probably not more than one-third the total resistance which should be allowed on any practical machine. The fourth column is the reciprocal of the third-column figures. It shows how far a surface would travel (theoretically), given in terms of the height lost. Thus a surface would travel 19.5 feet horizontally for every foot fallen through — if the surface be maintained at an angle of 2 degrees with the relative wind. The fifth column is the speed necessary to support one pound per square foot at the given angle. Thus at a positive angle of 2 degrees it would require a speed of 20.2 miles per hour to sustain an apparatus when the total load on it was just one pound for every square foot of sustaining surface. The other columns scarcely need explanation. In computing the normal pressure of the wind, it is better in a full-sized machine to compute the natural wind as .005 v^2, and with the apparatus moved in still air to use the formula .004 v^2, as the effect in moving through still air is much less than that produced by the natural wind of the same velocity. The greater pressure of the natural wind is the logical effect of its irregularity, for the *mean of the squares* of several different velocities is easily proven to be greater than *the square* of their mean velocity.

NOTE. The lift and drift and mile pounds for 1°, 3°, 4°, 11°, 16°, 19°, and 20° have been very closely verified by experiments of A. M. Herring with a small regulated kite of 3 square feet.

DATE DUE			