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BUILDING AND FLYING AN AEROPLANE

PART I



AMERICAN SCHOOL OF CORRESPONDENCE
CHICAGO ILLINOIS

BUILDING AND FLYING AN AEROPLANE

PART I

INSTRUCTION PAPER

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AMERICAN SCHOOL OF CORRESPONDENCE

CHICAGO

ILLINOIS

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BUILDING AND FLYING AN AEROPLANE

PART I

One of the commonest phases of interest in aviation is the desire to build a flying machine. In fact, this is very frequently the first thing the experimenter undertakes after having gone into the theory of flight to some extent. Only too often, no effort whatever is made to get beyond theory and the machine is an experiment in every sense of the word. An experience of this nature is costly—far more so than is agreeable for the student, and is likely to result in disgusting him with aviation generally. There are hundreds of schemes and principles in the art that have been tried again and again with the same dismal failure in the end. Refer to the story of the Wright Brothers and note how many things they mention having tried and rejected as worse than useless. About once in so often someone “rediscovers” some of these things and, having no facilities for properly investigating what patent attorneys term the “prior art” (everything that has gone before, from the beginning of invention, or at least patented invention) becomes possessed of the idea that he has hit upon something entirely novel and wholly original. There is no desire in the present work to discourage the seeker after new principles—undoubtedly there are many yet to be discovered. The art of flight is in its infancy and there is still a great deal to be learned about it, but there is no more discouraged inventor than he who discovers a principle and, after having experimented with it at great expense, finds that it is only one of many things that numerous others have spent considerable money in proving fallacious, a great many years ago.

If it be your ambition to build a flying machine and you believe that you have discovered something new of value, it will be to your interest to retain a responsible patent attorney to advise you as to the prior art, before expending any money on its construction. You will find it very much more economical in the end. There are prob-

ably not more than half a dozen men alive in this country today who "know all the schemes that won't work." The average seeker after knowledge is assuredly not likely to be one of these few, so that until he knows he is working along new and untried lines that give promise of success, it will pay him to stick to those that have proved successful in actual practice. In other words, to confine his efforts in the building line to a machine that experience has demonstrated will fly if properly constructed and, what is of equal importance, skilfully handled. Build a machine, by all means, if you have the opportunity. It represents the best possible experience. But as is pointed out under the "Art of Flying," take a few lessons from some one who knows how to fly, before risking your neck in what is to you a totally untried element. Even properly designed and constructed machines are not always ready to fly. An aeroplane needs careful inspection of every part and adjustment before it is safe to take to the air in it, and to be of any value this looking-over must be carried out by an experienced eye.

BUILDING AEROPLANE MODELS

The student may enter upon the business of building to any extent that his inclination or his financial resources or his desire to experiment may lead him. The simplest stage, of course, is that of model building and there is a great deal to be learned from the construction and flying of experimental models. This has become quite a popular pastime in the public schools and some very creditable examples of work have been turned out. The apparent limitations of these rubber-band driven models need not discourage the student, as some of the school-boy builders have succeeded in constructing models capable of flying a quarter mile in still air and their action in the air is wonderfully like the full-sized machines.

Models with Rubber-Band Motor. The limitations of the available power at command must be borne in mind, as the rubber-band motor is at best but a poor power plant. It is accordingly not good practice to have the spread of the main planes exceed 24 inches, though larger successful models have been built. In attempting to reproduce any of the well-known models, difficulty is often experienced in accommodating the rubber-band motor to them, as even where the necessary space is available, its weight throws the balance

out entirely, and the result is a model that will not fly. This has led to the production of many original creations, but these, while excellent flyers, would not serve as models for larger machines, as of necessity they have been designed around their power plants. The rubber bands for this purpose may be purchased of any aeronautic supply house. The most practical method of mounting the motor is to attach it to the rear end of the fuselage, usually a single stick, which is accordingly made extra long for that purpose. At the other end it is attached to a bent wire fastened to the propeller in order to revolve the latter. An easy way to wind up the motor is to employ an ordinary egg beater, modified as described below, or a hand

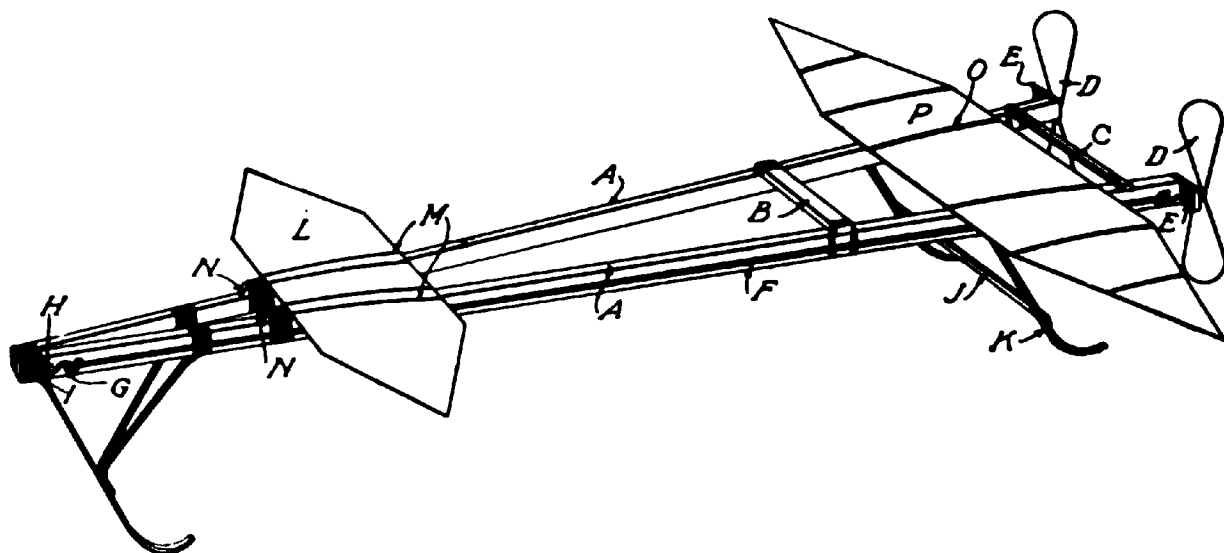


Fig. 1. Details of Main Frame of Rubber-Band Driven Aeroplane Model

drill, inserting a small wire yoke in the jaws in place of the usual drill, or bit. This yoke is placed so as to engage the propeller blades, and the latter is then turned in the opposite direction, storing energy in the rubber band by twisting its strands tightly.

For those students who do not care to undertake an original design at the outset, or who would prefer to have the experience gained by building from a plan that has already been tried, before attempting to originate, the following description of a successful model is given. This model can not only be made for less than the models sold at three to five dollars, but is a much more efficient flyer, having frequently flown 700 feet.

Main Frame. The main frame of the model monoplane consists of two strips *A* of spruce, each 28 inches long, and measuring in cross section $\frac{1}{4}$ by $\frac{3}{8}$ of an inch. As shown in Fig. 1, the two strips are tied together at the front with strong thread and are then

glued, the glue being spread over and between the windings of the thread, Figs. 1 and 2. The rear ends of these strips are spread apart $4\frac{1}{4}$ inches to form a stout triangular frame, and are tied together

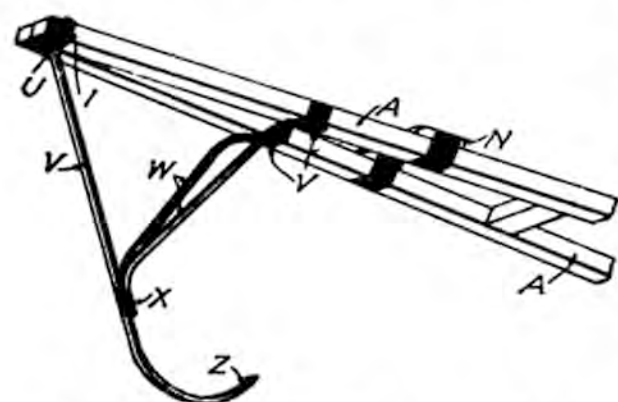


Fig. 2. Details of Forward Skids of Aeroplane Model

by cross bars of bamboo *B* and *C* which are secured to the main strips *A* by strong thread and glue.

Propellers. The propellers *D* are two in number and are carried by the two long strips *A*. Each propeller is 5 inches in diameter, and is whittled out of a single block of white pine. The propellers have a pitch of about 10 inches. After the whittling is done they are sandpapered and coated with varnish. The thickness of the wood at the hub *E*₂, Fig. 3, of the propeller should be about $\frac{5}{8}$ inch. At the rear ends of the strips *A*, bearing blocks *E*₁ are secured. These bearing blocks are simply small pieces of wood projecting about $\frac{5}{8}$ inch laterally from the strips *A*. They are drilled to receive a small metal tube *T*₂ (steel, brass, or copper), through which tube the propeller shaft *T*₁ passes.

The propeller shaft itself consists of a piece of steel wire passing through the propeller hub and bent over the wood, so that it can not turn independently of the propeller. Any other expedient for causing the propeller to turn with the shaft may obviously be

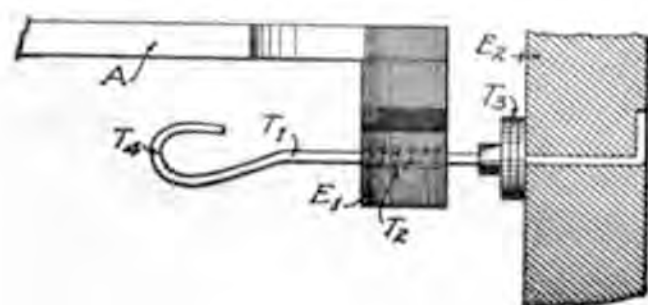


Fig. 3. Details of Propeller and Rudder of Aeroplane Model

employed. Small metal washers *T*₃, at least three in number, are slipped over the propeller shaft so as to lie between the propeller and the bearing block.

That portion of the propeller shaft which projects forwardly through the bearing block *E*₁ is bent to form a hook *T*₄. To the hook *T*₁ rubber strips *T*, by which the propellers are driven, are secured. The rubber strips are nearly as long as the main strips *A*. At their forward ends they are secured to a fastening consisting of a double hook *GII*, the hook *G* lying in a horizontal plane, the hook *H* in a vertical plane. The hook *G* holds

the rubber strips, as shown in Figs. 1 and 4, while the hook *H* engages a hook *T*. This hook is easily made by passing a strip of steel wire through the meeting ends of the main strips *A*, the portions projecting from each side of the strips being bent into the hooks *I*.

Skids. Three skids are provided, on which the model slides, one at the forward end, and two near the rear end. All are made of bamboo. As shown in Fig. 2 the front skid may be of any length that seems desirable. A 6-inch piece of bamboo will probably answer most requirements. This piece *N* is bent in opposite directions at the ends to form arms *Z* and *U*. The arm *Z* is secured to the forward ends of the two strips *A*, constituting the main frame, by means of thread and glue. The strips and skid are not held together by the same thread, but the skid is attached to the two strips after they have

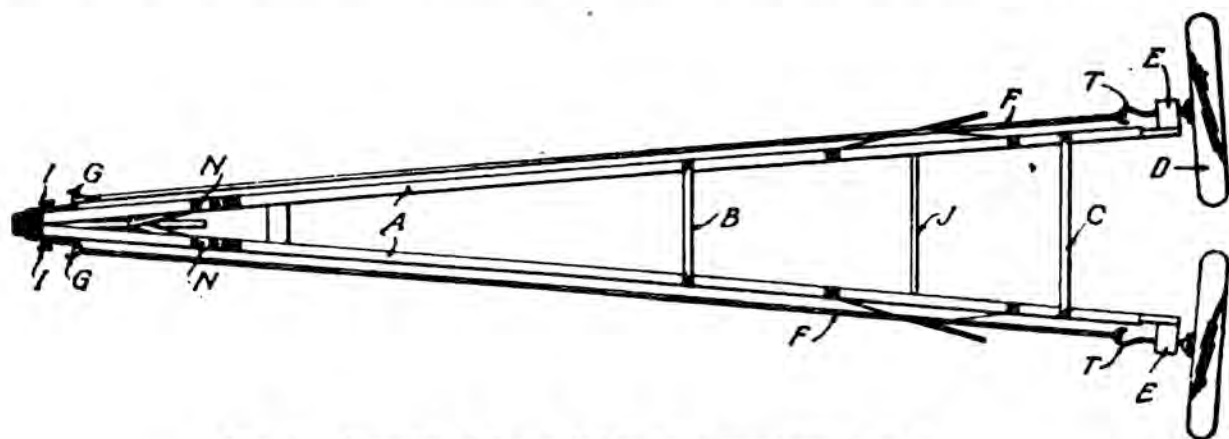


Fig. 4. Details of Rear Skids on Aeroplane Model

been wound. Hence, there are two sets of windings of thread, one for the two strips *A* themselves, and another for the skid and the strips. Strong thread and glue should be used, as before. In order to stiffen the skid, two bamboo struts *W* will be found necessary. These are bent over at the ends to form arms *V*₁, Fig. 2. Each of the arms is secured to the under side of a strip *A* by strong thread and glue. The arms *X* are superimposed and tied to the bamboo skid *V* with strong thread and glue.

The two rear skids, of which one is shown in Fig. 5, consist each of two 5-inch strips of bamboo *S*, likewise bent at either end in opposite directions to form arms *S*₂ and *S*₃. The arms *S*₂ are fastened to the strips *A* by strong thread and glue. To stiffen the skids a strut *C*₁ is provided for each skid. Each strut consists of a 3-inch strip of bamboo bent over so as to form arms *C*₂. Strong thread and glue are employed to fasten each strut in position on the strip and

the skid. In the crotch of the triangular space B_1 , a tie bar J , Figs. 4 and 5, is secured by means of thread and glue. This tie bar connects the two skids, as shown in Figs. 1 and 4, and serves to stiffen

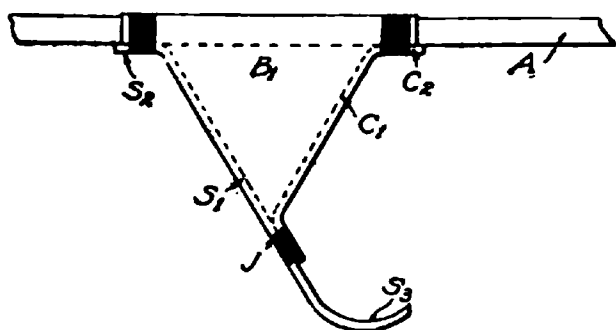


Fig. 5. Enlarged Details of One Rear Skid, Aeroplane Model

them. The triangular space B_1 is covered with paper, preferably bamboo paper. If bamboo paper is not available, parchment or stiff light paper of some kind may be used. It does not need to be waterproof. Thus triangular fins are formed which act as stabilizing surfaces.

Main Planes. The main planes are two in number, but are different in size. Contrary to the practice followed in large man-carrying monoplanes, the front supporting surface is comparatively small in area and the rear supporting surface comparatively large. These supporting surfaces L and P are shown in detail in Figs. 6 and 7. It has been found that a surface of considerable area is required at the rear of the machine to support it, hence, the discrepancy in size. Although the two supporting surfaces differ in size, they are made in exactly the same manner, each consisting of a thin longitudinal piece of spruce R , to which cross pieces of bamboo Q are attached. In the smaller plane, Fig. 7, all the cross pieces are of the same size. In the larger plane, Fig. 6, the outer strips S are somewhat shorter than the others. Their length is $2\frac{1}{2}$ inches, whereas the length of the strips Q is $3\frac{1}{2}$ inches. In order to allow for the more gradual tapering of the plane, around the outer ends of the longitudinal strips R and the ribs Q a strip of bamboo O is tied. The

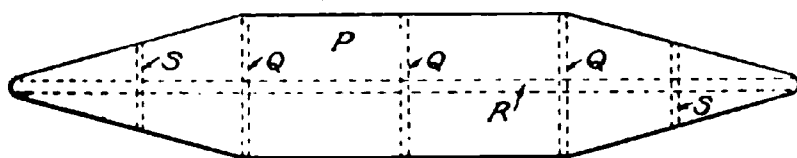


Fig. 6. Details of Main Plane of Aeroplane Model

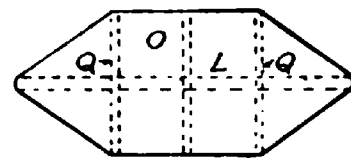


Fig. 7. Details of Smaller Plane of Aeroplane Model

frame, composed of the longitudinal strip and cross strips, is then covered with bamboo paper, parchment paper, or any other stiff light paper, which is glued in place.

The forward or smaller plane has a spread of $8\frac{1}{2}$ inches and a depth of $3\frac{1}{4}$ inches. The main plane has a spread of 20 inches and a depth of $3\frac{1}{2}$ inches at the widest portion. The author has made experiments which lead him to believe that the tapering form given to the outer edge of the plane improves both the stability and endurance of the machine.

The planes are slightly arched, although it will be found that flat planes will also give good results. The rear edge of the main plane should be placed $4\frac{1}{4}$ inches distant from the forward edge of the propeller block E_1 .

The front plane must have a slight angle of incidence, just how much depends upon the weight of the machine, the manner in which it is made, and various other factors. This angle of incidence is obtained by resting the front portion of the plane on two small blocks N , Figs. 1 and 2, which are fastened to the top of the main strip A by strong thread and glue.

The height of the blocks N should be about $\frac{1}{4}$ inch, although this will necessarily vary with the machine. The blocks should be placed approximately 4 inches from the forward end of the machine. The front end of the forward plane should be elevated about $\frac{1}{4}$ inch above the rear end, which rests directly on the main strips.

Both the front and rear planes L and P are removably lashed to the frame by means of ordinary rubber bands, which may be obtained at any stationery store. These rubber bands are lettered M in Fig. 1.

Winding the Rubber Strips. The rubber strips can be most conveniently wound up by means of an egg beater, slightly changed for the purpose, Fig. 8. The beater and the frame in which it is carried are entirely removed, leaving only the main rod E , which is cut off at the lower end so that the total length is not more than 2 or 3 inches. The two brass strips D on either side of the rod, which are attached to the pinion Q meshing with the large driving wheel H , are likewise retained. A washer F is soldered to the rod

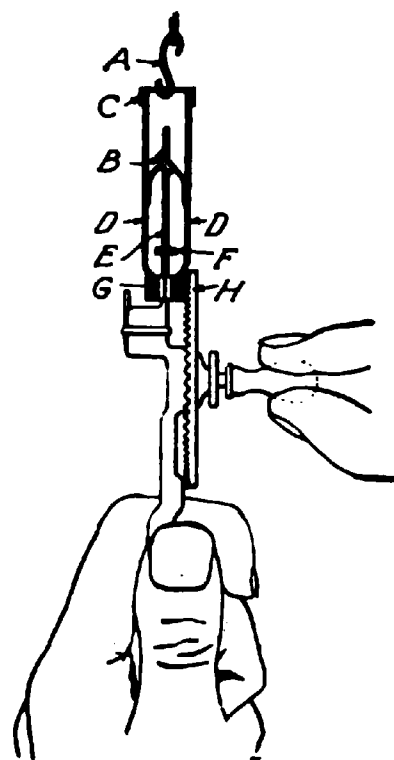


Fig. 8. Device for Winding up Rubber-Band Motors

near its upper end, so as to limit the motion of the small pinion *G* and the brass strips *D* attached to the pinion. Next a wire *B* is bent in the form of a loop, through which loop the central rod passes. The ends of the wire are soldered to the side strips *D*. Lastly, a piece of wire *C* is bent and soldered to the lower ends of the side strips. In order to wind up a rubber strip, the strip is detached from the forward end of the model, and the hook *A* slipped over the wire *C*. The opposite end of the rubber band is held in any convenient manner. Naturally the two strips must be wound in opposite directions, so that the two propellers will turn in opposite directions. By stretching the rubber while it is being wound, more revolutions can be obtained. It is not safe to have the propeller revolve more than 700 times. The ratio of the gears of the egg-beater winder can be figured out so that the requisite number of twists can be given to the rubber bands for that particular number of revolutions.

Model with Gasoline Motor. The next and somewhat more ambitious stage is the building of a power-driven model, which has been made possible by the manufacture of miniature gasoline motors and propellers for this purpose. Motors of this kind, weighing but a few pounds and capable of developing $\frac{1}{4}$ horse-power or more, may be had complete with an 18-inch aluminum propeller and accessories for about \$45. As is the case with the rubber-band driven model, the monoplane is the simplest type to construct, and the dimensions and details of an aeroplane of this type are given here. It will be found that a liberal-sized machine is required to support even such a small motor. The planes, Fig. 9, have a spread of 7 feet 8 inches from tip to tip, each wing measuring $3\frac{1}{2}$ feet by a chord of 15 inches. They are supported on a front and rear wing spar of spruce, $\frac{1}{2}$ by $\frac{3}{8}$ inch in section, while the ribs in both the main plane and the rear stabilizing plane measure $\frac{1}{8}$ by $\frac{1}{2}$ inch in cross section. There are eight of these spruce ribs in the main plane, and they are separately heated and curved over a Bunsen burner, or over a gas stove, which is the same thing. They are then nailed to the wing spars 6 inches apart. The main spars of the fuselage are 7 feet long and they are made of $\frac{1}{2}$ - by $\frac{3}{8}$ -inch spruce, the struts being placed $1\frac{1}{2}$ feet apart, measuring from the rear, with several intermediate struts to brace the engine bed. Instead of using strut sockets for the fuselage, which would increase the cost of construction unnecessarily, a simple com-

bination of a three-way wire fastener and a wire nail may be resorted to. The shape of these fasteners is shown at *A* in Fig. 9. They may be cut out of old cracker boxes or tin cans (sheet iron) with a pair of shears, the holes in the ends being made either with a small drill or by driving a wire nail through the metal placed on a board, and

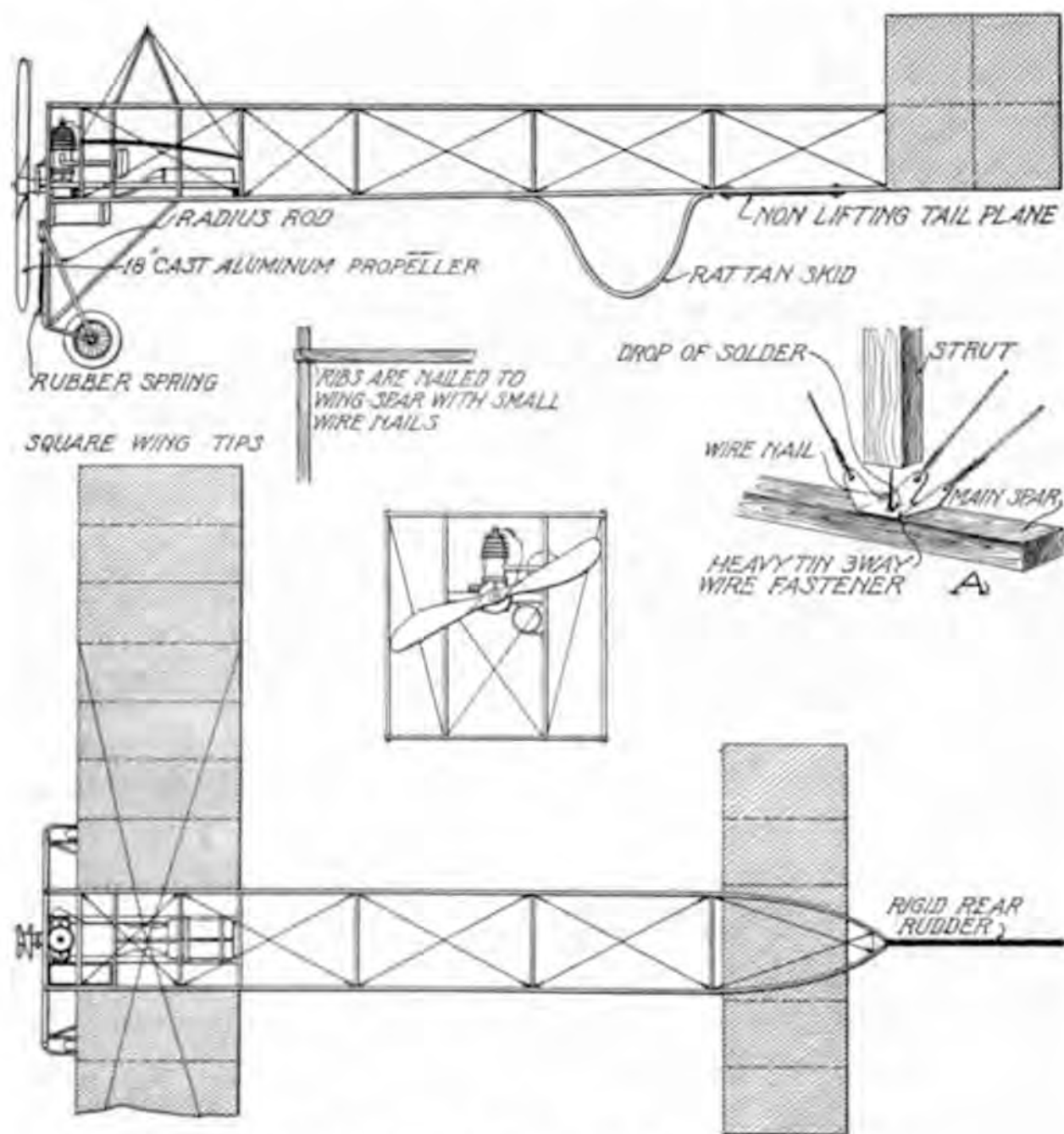


Fig. 9. Details of Power-Driven Aeroplane Model

filing the burrs off smooth. A central hole must also be made for the $1\frac{1}{2}$ -inch wire nail which is driven through the main spar and the fastener then slipped over it. As indicated, this nail also serves to hold the strut. A drop of solder will serve to attach the fastener to the nail. The front of the fuselage is 9 inches square, tapering down to 6 inches at the rear. The height of the camber of the main planes

is $1\frac{1}{2}$ inches and the angle of incidence is 7 degrees, measured with relation to the fuselage. The non-lifting tail plane at the rear which is to give the machine longitudinal stability, measures 4 feet in span by 14 inches in depth.

The running gear or front landing frame is made of $\frac{1}{2}$ -inch square spruce, all joints being made with $\frac{1}{8}$ - by 1-inch bolts. Aluminum sleeves, procurable at an aeronautic supply house, are employed for the attachment of the rubber springs and the radius rods running down to the wheels, which may also be purchased ready to install. Old bicycle wheels will serve the purpose admirably. Light steel tubes $\frac{1}{4}$ inch in diameter are used to run these aluminum sleeves on. Two other steel tubes are joined to the lower corner of the frame by flattening them at the ends and drilling with a small hole for a nail. These are run diagonally up to the fuselage and serve as buffers to take the shocks of landing. For bracing the wings, two similar tubes are fastened to form a pyramid on top of the main plane just back of the engine. From these, guys are run to the wings as shown. The engine bed is made of $\frac{1}{2}$ - by $\frac{3}{4}$ -inch white pine, and to make it solid it is carried as far back as the rear edge of the main plane. The batteries and coil are directly attached to this plane, care being taken in their placing to preserve the balance of the machine. The rudder measures 14 inches square and is made of $\frac{3}{8}$ -inch square spruce, reinforced with tin at the joints, as it is necessary to make the frame perfectly rigid. Both sides are covered with fabric. In this case a 1-horse-power motor furnishes the necessary energy and it is fitted with an 18-inch aluminum propeller which it is capable of turning at 2,400 r. p. m. The carbureter and gas tank are made integral, and the gasoline and oil are both placed in this tank in the proportion of about four parts to one, in order to save the weight of an extra tank for oil.

Flights of half a mile are possible with this model in calm weather, but a great deal of measuring and testing of the fuel is necessary in order to regulate the flight, and "grass-cutting" should be practiced by the builder in order to properly regulate the machine. Trials have shown that the flat non-lifting tail on the fuselage gives excellent longitudinal stability, the machine rising nicely and making its descent very easy angle, so that it is seldom damaged by violent collisions in landing.

BUILDING A GLIDER

The building of hand- or power-driven models does not suffice to give that personal experience that most students are desirous of obtaining. The best method of securing this is to build a glider and practice with it. Any flying machine without a motor is a glider and the latter is the basis of the successful aeroplane. In the building of an aeroplane the first thing constructed is the glider, *i. e.*, the frame, main planes, stabilizing planes, elevators, rudders, etc. It is only by the installation of motive power that it becomes a flying machine. The biplane will be found the most satisfactory type of glider as it is more compact and therefore more easily handled, which is of great importance for practicing in a wind. The generally accepted rule is that 152 square feet of surface will sustain the weight of the average man, about 170 pounds, and it will be apparent that the length of the glider will have to be greater if this surface is to be in the form of a single plane than if the same amount is obtained by incorporating it in two planes—the biplane. A glider with a span of 20 feet and a chord of 4 feet will have a surface of 152 square feet. So far as learning to balance and guide the machine are concerned, this may be mastered more readily in a small glider than in a large one, so that there is no advantage in exceeding these dimensions—in fact, rather the reverse, as the larger construction would be correspondingly more difficult to handle. The materials necessary consist of a supply of spruce, linen shoe thread, metal sockets, piano wire, turnbuckles, glue, and closely-woven, light cotton fabric for the covering of the planes.

Main Frame. The main frame or box cell is made of four horizontal beams of spruce 20 feet long and $1\frac{1}{2}$ by $\frac{3}{4}$ inch in section. They must be straight-grained and perfectly free from knots or other defects. If it be impossible to obtain single pieces of this length, they may be either spliced or the glider may be built in three sections, consisting of a central section 8 feet long, and two end sections each 6 feet in length, this form of construction also making the glider much easier to dismantle and stow in a small space. In this case, the ends of the beams of each end section are made to project beyond the fabric for 10 inches and are slipped into tubes bolted to corresponding projections of the central section. These tubes are drilled

with three holes each and bolts are passed through these holes and corresponding holes in the projecting ends after they have been fitted into the tubes, and drawn up tightly with two nuts on each bolt to prevent shaking loose. Ordinary $\frac{3}{16}$ -inch stove bolts will serve very nicely for this purpose. The upper and lower planes forming the box cell, are held apart by 12 struts, 4 feet long by $\frac{7}{8}$ inch diameter, preferably of rounded or oval form with the small edge forward to minimize the head resistance. It is only necessary to space these equally, starting from both ends; this will bring the splices of the demountable sections in the center of the square on either side of the central section. The main ribs are 3 feet long by $1\frac{1}{4}$ - by $\frac{1}{2}$ -inch section and their placing should coincide with the position of the struts. Between these main ribs are placed 41 small ribs, equally spaced and consisting of pieces 4 feet long by $\frac{1}{2}$ inch square. These, as well as all the other pieces, should have the sharp edges of the square rounded off with sand paper. The ribs should have a camber of 2 inches in their length and the simplest method of giving them this is to take a piece of plank, draw the desired curve on it, and then nail blocks on both sides of this curve, forming a simple mould. The rib pieces should then be steamed, bent into this mould, and allowed to dry, when they will be found to have permanently assumed the desired curvature. Meanwhile, all the other pieces may be shellaced and allowed to dry.

Assembling the Planes. To assemble the glider, the beams are laid out on a floor, spaced the exact distance apart, *i. e.*, 3 feet, and exactly parallel—in the demountable plan, each section is assembled independently. The main ribs are then glued in place and allowed to set, after which they are strongly bound in place with the linen thread, and the various layers of thread given a coating of hot glue as they are put on. This method is not arbitrary, but it is simple and gives the lightest form of construction. If desired, tie-plates, clamps, or any other light method of fastening may be employed. This also applies to the ribs. They are assembled by placing them flush with the front beam and allowing them to extend back a foot beyond the rear beam, arched side up in every case. They may be glued and bound with thread, held by clamps, or nailed or screwed into place, care being taken to first start a hole in the beam with an awl and to dip the nails in soft soap to prevent splitting the

wood. Twenty-one ribs, spaced one foot apart, are used in the upper plane, and 20 in the lower, owing to the space left for the operator in the latter. For fastening the two planes together, whether as a whole or in sectional units, 24 aluminum sockets will be required. These may be purchased either ready to fit, or an effective substitute made by sawing short lengths of steel tubing, slitting them with the hack saw an inch from the bottom, and then flattening out and drilling the right-angle flanges thus formed to take screws for attaching the sockets to the beams. In case these sockets are bought, they will be provided with eye bolts for the guy wires; if homemade, they may have extra holes drilled in the edges of the flanges for this purpose or some simple wire fastener such as that described in connection with the power-driven model may be used, heavier metal, however, being employed to make them. The sockets should all be screwed to the beams at the proper points and then the struts should be forced into them. The next move is to "tie" the frame together with guy wires, No. 12 piano wire being employed for this purpose. Each rectangle is trussed by running diagonal guy wires from each corner to its opposite. To pull these wires taut, a turnbuckle should be inserted in each and after the wire has been pulled as tightly as possible by hand, it should be wound upon itself to make a good strong joint, as shown at *B*, Fig. 6. A fastening as shown at *A* will pull out under comparatively little strain and is not safe. As is the case with most of the other fittings, these turnbuckles may be bought or made at home, the simple bicycle type of turnbuckle mentioned in connection with "Building a Curtiss," being admirably adapted to this purpose. In fact, the construction of the latter will be found to cover the requirements of the glider, except that the ribs are simpler and lighter, as already described, and no provision for the engine or similar details is necessary. All the guy wires must be tightened until they are rigid, and the proper degree of tension for them may be simply determined in the following manner:

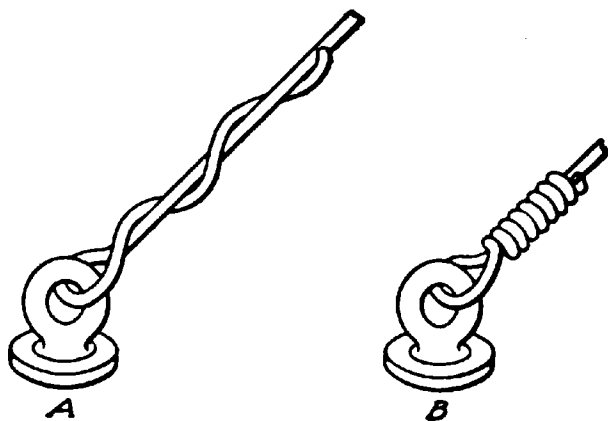


Fig. 10. Wrong and Right Way of Making a Wire Joint

After the entire frame is wired, place each end of it on a saw horse so as to lift it two or three feet clear of the floor. Stand in the opening of the central section, as if about to take a glide, and by grasping the forward central struts, raise yourself from the floor so as to bring your entire weight upon them. If properly put together the frame will be rigid and unyielding, but should it sag even slightly, the guy wires must be uniformly tightened until even the faintest perceptible tendency to give under the weight is overcome.

Stretching the Fabric. The method of attaching the fabric will be determined by whether the glider is to be one piece or sectional, and the expense for this important item of material may be as little or as much as the builder wishes to make it. Some employ rubberized silk, others special aeronautic fabrics, but for the purposes of the amateur, ordinary muslin of good quality, treated with a coat of light varnish after it is in place, will be found to serve all purposes. The cloth should be cut into 4-foot strips, glued to the front horizontal beams, stretched back tightly, and tacked to both the rear horizontal beams and to the ribs. Tacks should also supplement the glue on the forward beams and the upholstery style should be used to prevent tearing through the cloth. In case the glider is built in sections, the abutting edges of the cloth will have to be reinforced by turning it over and stitching down a strip one inch wide, and it will make this edge stronger if an extra strip of loose fabric be inserted under the turn before sewing it down. Eyelets must then be made along these edges and the different sections tightly laced together when assembling the glider. It is also desirable to place a strip of cloth or light felt along the beams under the tacks to prevent the cloth from tearing out under the pressure.

To form a more comfortable support for the operator, two arm pieces of spruce, 3 feet by 1 inch by $1\frac{3}{4}$ inches, should be bolted to the front and rear beams about 14 inches apart over the central opening left in the lower plane. These will be more convenient than holding on to the struts for support, as it will not be necessary to spread the arms so much and there will be more freedom for manipulating the weight to control the glider in flight. In using the struts, it is customary to grasp them with the hands, while with the arm pieces, as the name implies, the operator places his arms over them, one of the strips coming under each armpit. After the fabric has

been given a coat of varnish on the upper side and allowed to dry, the glider is ready for use. The cost of the material should be about \$30 to \$40, depending upon the extent to which the builder has relied upon his own ingenuity in fashioning the necessary fittings—in any case, it will be less than the amount required for the purchase of the engine alone for a power-driven model.

Glider with Rudder and Elevator. It will be noted that this is the simplest possible form of glider in that it is not even provided with a rudder, but for the beginning of his gliding education the novice will not require this, as first attempts should be confined to glides over level ground in moderate, steady wind currents and at a modest elevation. Some of the best gliding flights made by Herring, Chanute's co-worker, were in a rudderless glider. After having mastered the rudiments of the art, the student may go as far as the dictates of his ambition impel him in the direction of improvements in his glider, by adding a rudder, elevator, and warping control. In fact, it is not necessary to confine himself to the simple design of glider here outlined at all. He may take either the Wright or Curtiss machines as a model and build a complete glider, following the dimensions and general methods of construction here given, though these may also be improved upon by the man handy with tools, bearing in mind that the object to be achieved is the minimum weight consistent with the maximum strength.

Learning to Glide. The first trials should be made on level ground and the would-be aviator should be assisted by two companions to help him in getting under way. The operator takes a position in the center rectangle, back far enough to tilt up slightly the forward edges of the planes. A start and run forward is made at a moderate pace, the keepers carrying the weight of the glider and overcoming its head resistance by running forward at the same speed. As the glider cuts into the air, the wind caused by running will catch under the uplifted edges of the curved planes and will buoy it up, causing it to rise in the air taking the operator with it. This rise will be probably only sufficient to lift him clear of the ground a foot or two. Now he projects his legs slightly forward so as to shift the center of gravity a trifle and bring the edges of the glider on an exact level, parallel with the ground. This, with the momentum acquired at the start, will keep the glider moving forward for some

distance. When the weight of the operator is slightly back of the center of gravity, the leading edges of the planes are tilted up somewhat, increasing the angle of incidence and in consequence the pressure under the planes, causing the glider to rise, and if the glide is being made into a wind, as should always be the case, quite a height may be reached as the result of this energy. Once it ceases, the tendency to a forward and upward movement is lost, and it is to prolong this as much as possible that the operator shifts the center of gravity to bring the machine on an even keel, or where at a little height, slightly below this, giving it a negative angle of incidence, which permits him to coast down the air until sufficient speed is acquired to reverse the angle of incidence and again rise so as to provide a "hill" for another coast, thus prolonging the flight considerably. To put it in the simplest language, when the operator moves backward, shifting the center of gravity to the rear, the planes are tilted so that they catch or "scoop up" the advancing air and rise upon it, whereas when he moves forward and the planes tilt downward, this air is "spilled" out behind and no longer acts as a support, and the glider coasts, either until the ground is reached or enough momentum is gained to again mount upon the wind. A comparatively few flights will suffice to make the student proficient in the control of his apparatus by his body movements, not only as concerns the elevating and depressing of the planes to ascend or descend, corresponding to the use of the elevator on a power machine, but also actual steering, which is accomplished by lateral movement to the left or right.

Stable equilibrium is one of the chief essentials to successful flight and this can not be maintained in an uncertain, gusty wind, especially by the novice. The beginner should certainly not attempt a glide unless the conditions are right. These are a clear, level space without obstructions such as trees, and a steady wind not exceeding 12 miles per hour. When a reasonable amount of proficiency has been attained in the handling of the glider over level ground, the field of practice may be changed to some gentle slope. In starting from this, it will be found easier to keep the glider afloat, but the experience at first will prove startling to the amateur, for as the glider sails away from the top of the slope, the distance between him and the ground increases so rapidly that he will imagine himself at

a tremendous height, but by preserving the balance and otherwise manipulating his weight in the manner taught by the practice over the level, a nice flight of much greater distance will be made and the machine will gradually settle down to the ground much farther away from the starting place than was possible in the earlier trials, this being one of the great advantages of starting from an elevation. There is nothing that will fit the beginner so well for the actual handling of a power machine as a thorough course of gliding flights, and it is recommended that those who build gliders become proficient in their use before attempting to pilot an aeroplane, whether of their own make or not.

A further step in advance is the actual building of a full-fledged power machine, and for those who desire a simple and comparatively inexpensive type, requiring very little work that can not be performed in the home workshop, a description of the construction of a Curtiss biplane is given, while for those who are more ambitious and also have greater financial resources, the details of the building of a Bleriot monoplane are given.

BUILDING A CURTISS BIPLANE

Cost. First of all, the prospective builder will want to know the cost. The best answer to this is that the machine will cost all its builder can afford to spend upon it and probably a little more, as the man to whom the expense is not of vital consideration will doubtless not undertake its construction. Speaking generally, and there can be nothing very definite about it, in view of the great difference in the conditions, an expenditure of three to four hundred dollars will cover the complete outlay for everything but the motor. If the builder has the time and facilities for doing all the work himself, this amount may be reduced very materially. On the other hand, if he finds it necessary to purchase most of the material in form ready to assemble, it may exceed this. But it will be a great aid to many to know that there is practically nothing about the modern aeroplane which can not be found in stock at one of the aeronautic supply houses. This makes it possible for many to undertake the construction of a machine to whom it would not be feasible, or at least not an attractive project in view of the time involved, were it necessary to make every part at home. So far

Aeroplane construction doubtless impresses the average observer as being something shrouded in considerable mystery—something about which there is no little secrecy. Quite the contrary is the case in reality. Any man who is fairly proficient as a carpenter and knows how to use the more common machinist's tools, such as taps

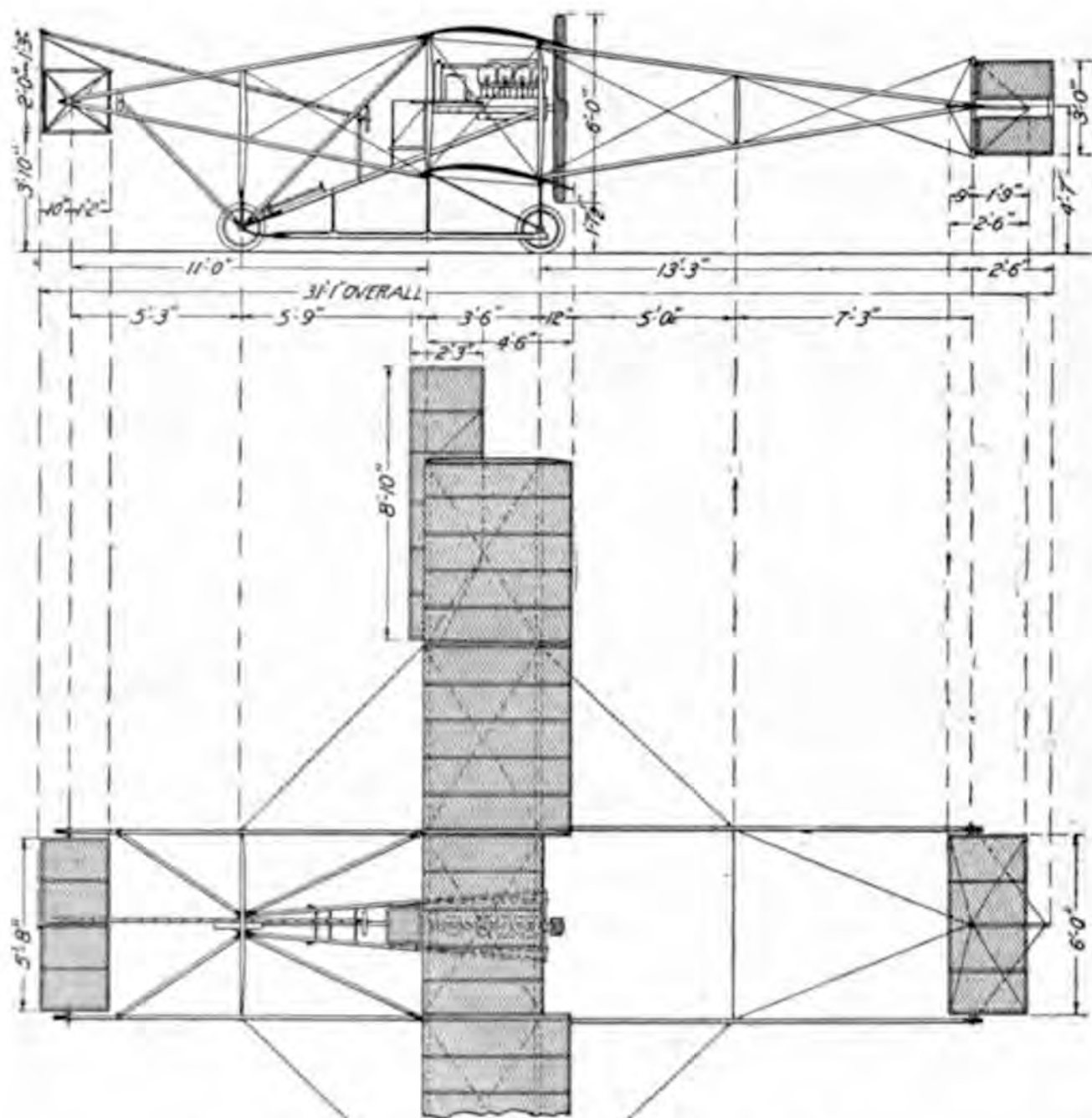


Fig. 12. Plan and Side Elevation of Curtiss Biplane

and dies, drills, hacksaw, and the like, will find no difficulty in constructing the machine of which the details are given here. Having completed its building, he will have to draw upon his capital to supply the motor. One capable of developing 25 to 30 horse-power at 1,000 to 1,200 r. p. m. will give the machine considerable speed, as it will be recalled that Curtiss made a number of his first flights

with a 25-horse-power motor. As to the weight, the lighter the better, but 400 pounds for the complete power plant will not be excessive. The machine can sustain itself in the air with less power than that mentioned, but with a heavy, low-power motor it will be sluggish in action. This is an advantage for the amateur, rather than otherwise, as it will provide him with an aeroplane that will not be apt to get away from him during his first trials, thus making it safer to learn on.

The Curtiss biplane has a spread of 30 feet, the main planes or wings being divided into sections of a length equal to the distance

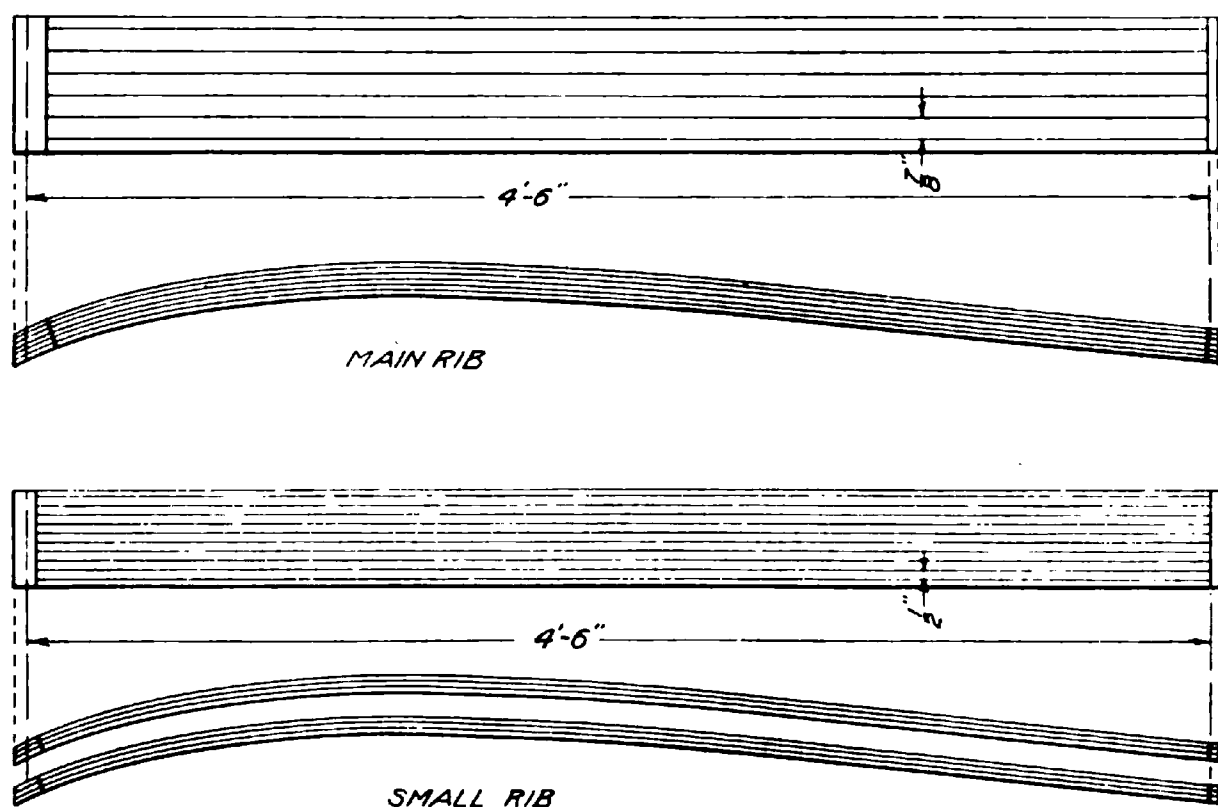


Fig. 13. Details of Main and Small Ribs, Curtiss Biplane

between struts, Figs. 11 and 12. There are five of these sections, each measuring six feet. The struts can be taken out and the sections laid flat on each other for storage. The framework for the front and rear rudders can also be jointed, if desired, making it possible to store the machine in small compass. The longest parts of the machine, when taken apart, are the two diagonal beams running from the front wheel back to the engine bed, and the skid. The horizontal front rudder is packed intact. The vertical rear rudder is unhung and laid flat on the tail. Two men can take the machine apart in a few hours, and can reassemble it in a day. Whether these particular

TABLE I

Relative Strength of Clear Spruce and Elm as Demonstrated by Tests

Material	Size of Pieces (Inches)	Breaking Strain (Pounds)	Weight of Piece (Ounces)
Elm	$1\frac{1}{2} \times 1\frac{1}{8} \times 12$	900	$5\frac{1}{2}$
Spruce	$1\frac{1}{2} \times 1\frac{1}{8} \times 12$	900	$4\frac{1}{2}$
Elm	$1\frac{1}{8} \times 1\frac{1}{8} \times 12$	880	$4\frac{3}{4}$
Spruce	$1\frac{1}{8} \times 1\frac{1}{8} \times 12$	760	$3\frac{7}{8}$
Elm	$1 \times 1 \times 12$	450	4
Spruce	$1 \times 1 \times 12$	600	$3\frac{1}{2}$
Elm	$\frac{1}{2} \times 1\frac{1}{8} \times 12$	390	$3\frac{1}{2}$
Spruce	$\frac{1}{2} \times 1\frac{1}{8} \times 12$	475	3
Elm	$\frac{3}{4} \times \frac{3}{4} \times 12$	275	$2\frac{1}{2}$
Spruce	$\frac{3}{4} \times \frac{3}{4} \times 12$	280	$2\frac{1}{4}$
Elm	$\frac{5}{8} \times \frac{1}{2} \times 12$	175	$2\frac{1}{8}$
Spruce	$\frac{5}{8} \times \frac{1}{2} \times 12$	175	2

features of construction are covered by patents can not be said, as Curtiss has declined to commit himself regarding any rights he may have to them.

Ribs. Two distinct types of ribs are used, main ribs and small ribs, both of the same curvature, Fig. 13. The main ribs are used between pairs of struts, to hold apart the front and rear beams; they are heavy enough to be quite rigid. Three to four small ribs are laid across each section of the planes, between the pairs of main ribs, to give the cloth the proper curvature, and to maintain it in the form desired. The main ribs are built up of six $\frac{1}{4}$ -inch laminations of wood $\frac{7}{8}$ inch wide and securely glued together. The small ribs are made of three layers $\frac{1}{2}$ inch wide.

The first part of the actual construction will be the making of these laminated ribs, but before describing this detail, the question of suitable material should be well considered. Both weight and strength must be figured on and this limits the choice to a few kinds of wood. Of these *spruce* and *elm* are the best available, with the occasional use of *ash* to give greater rigidity. Spruce is, of course, the first choice. This wood was once considered as having no great strength, but a series of careful tests shows this belief to be unfounded. With the exception of the bed, or support for the

motor and a few other parts, the Wright machines are constructed wholly of spruce.

Table I gives results of tests made with spruce from Washington and Oregon, and with elm from Michigan and Indiana. Testing scales were employed, the pieces being supported at their ends with the load in the center.

These tests were made with clear wood in each case, as knots naturally decrease the strength of a piece greatly, this depending on their size and location.

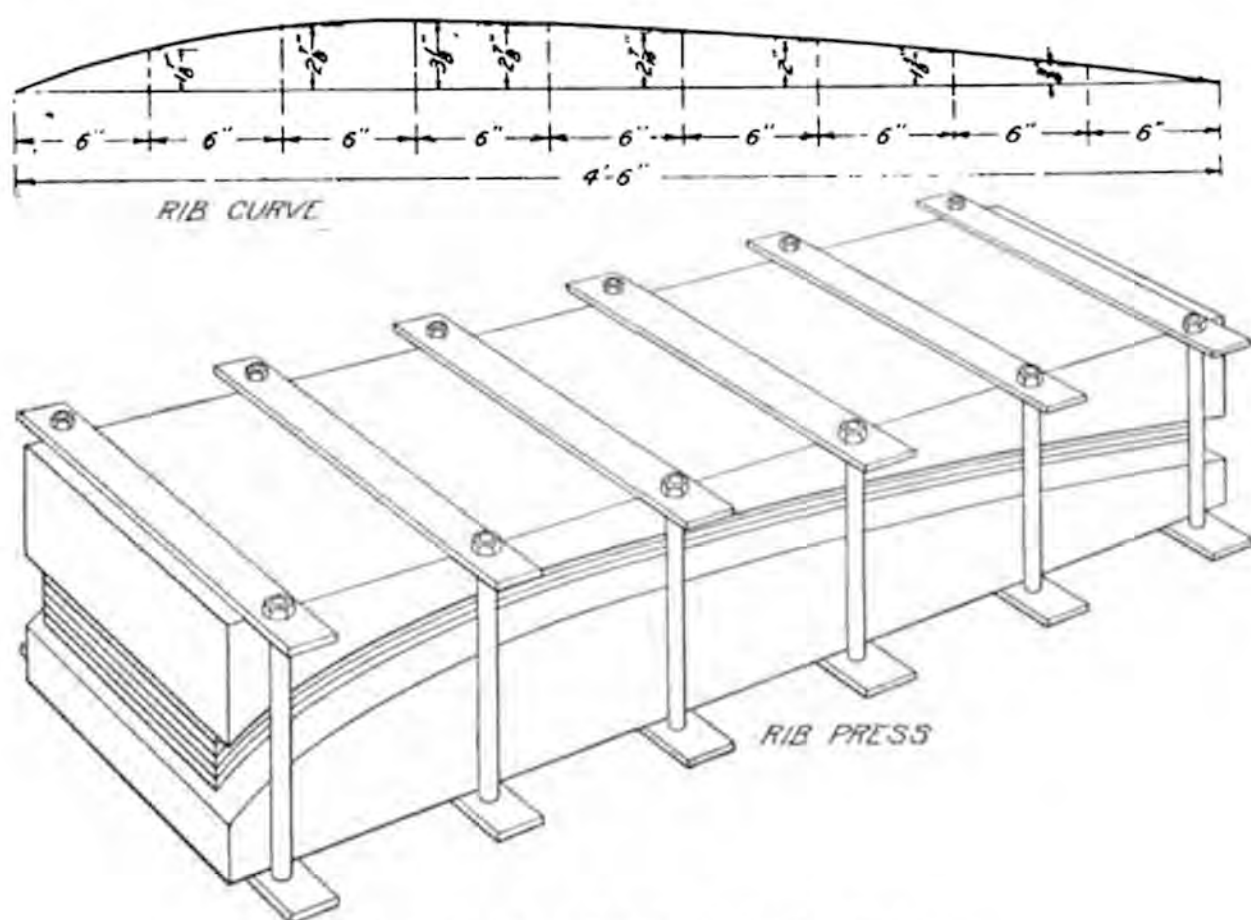


Fig. 14. Details of Rib Press, Curtiss Biplane

Before proceeding with the ribs themselves, the press for giving them the proper curvature must be made. Take a good piece of oak, ash, or other solid wood, 8 inches wide by 5 feet long, and dressed all over. On the side of the piece lay out the curve, the dimensions of which are illustrated in Fig. 14. First, rule the horizontal, or chord line, on it, marking off 4 feet 6 inches on this line, equidistant from each end. Then divide the chord into 6-inch sections and, at the point of each 6-inch section, erect perpendiculars beginning at the rear, $\frac{3}{4}$ inch, $1\frac{3}{8}$ inches, 2 inches, and so on, as indicated on the drawing. The upper ends of these perpendiculars will

form locating points for the curve. Through them draw a smooth curve as shown, continuing it down through the chord at each end. Take the piece with the curve thus marked on it to the local planing, sash and blind, or sawmill—any plant equipped with a band saw—and have it cut apart along the curve. This will cost little or nothing—acquaintance will obtain it as a favor, and acquaintance with any wood-working concern in the aeroplane builder's home town will be of great aid. Failing this aid, the operation may be carried out with a hand saw (rip), but the job will not be as neat and will have to be cleaned up with a draw knife and sand paper, taking care to preserve the outline of the curve as drawn. As the rib press is really a mould or pattern from which all the ribs are to be bent to a uniform curvature, care must be taken in its construction.

To clamp the two halves of the press together, a dozen machine bolts will be required; they should measure $\frac{3}{4} \times 15$ inches. If obtainable, eye bolts will be found more convenient as they may be turned up with but one wrench and a bar. The steel straps are $\frac{3}{8}$ by $1\frac{1}{2}$ by 10 inches long with $\frac{3}{4}$ -inch holes drilled 9 inches apart to centers, to enclose the 8-inch pieces.

Obtain a sufficient supply of boards of reasonably clear spruce, $\frac{1}{4}$ inch thick, 6 to 7 inches wide, and at least 4 feet 9 inches long (dressed both sides), to make all the ribs necessary both small and large. This material should be purchased from the mill as it is out of the question to attempt to cut the ribs from larger sizes by hand. Buy several pounds of good cabinet makers' glue and a water-jacketed gluepot. This glue comes in sheets and in numerous grades—a good quality should be used, costing from 40 to 50 cents a pound if bought in a large city. Laminating the ribs in this manner and gluing them together is not only the quickest and easiest method of giving them the proper curve, being much superior to steam bending, but is also stronger when well done, as the quality of the material can be watched more closely.

Start with the making of the small ribs; apply the glue thin and piping hot in a generous layer to three boards with a good-sized flat paint or varnish brush. Omit on the upper surface of third board and apply between three others, Fig. 13. This will give two series of three each in the press. Tighten up the end bolts first, as the upper part of the press near the top of the curve is likely to be weak

unless liberally proportioned. Then turn down the nuts on the other bolts. Do not attempt to turn any one of them as far as it will go the first time, but tighten each one a little at a time, thus gradually making the compression over the whole surface as nearly uniform as possible. This should be continued until the glue will no longer ooze out from between the boards, indicating that they are in close contact. Twenty-four hours should be allowed for drying, and when taken out the cracks between the boards should be almost invisible in the finished ribs.

Have the laminated boards cut by a power rip saw at the planing mill, to the dimensions shown in the drawing, making an allowance of $\frac{1}{4}$ inch for the width of the saw blade at each cut in calculating the number of ribs which can be cut from each board. In addition, a margin should be allowed at each side, as it is impractical to get all the thin boards squarely in line. For the main ribs, apply the glue between all six boards, clamp and dry in the same manner. Thirty small ribs will be required, if three are used in each section, and forty if four are specified, while twelve main ribs will be needed for standard construction, and sixteen if the quick-demountable plan referred to is followed. It is advisable to make several extra ribs of each kind in addition. If the builder has not sufficient faith in spruce alone, despite the figures given in Table I, one of the laminations, preferably the center, or if two be employed, the outer ones, may be of ash, though this will add considerably to the weight.

To prevent the ribs from splitting open at the ends, they are protected by light steel ferrules, shown in Fig. 15. When received in the rough-sawed condition from the mill, the ribs must be tapered at the ends with a plane or spoke shave to fit these ferrules, and the sharp edges should be rounded off. In doing this, it must be remembered that the upper surface of the small ribs gives the curvature to the cloth surface, so that any tapering must be done on the lower side. The main ribs may be tapered from both sides, as it is the center line, or crack between the third and fourth laminations, that determines the curve. Every inch along this line $\frac{3}{16}$ -inch holes are to be drilled for the lacing, Fig. 15.

The ferrules for the front ends of the small ribs are light $\frac{1}{2}$ -inch seamless steel tubing; they may be flattened to the proper shape in a vise without heating and are drilled with a $\frac{1}{8}$ -inch hole. They

are driven tight on to the tapered ends of the ribs and fastened in place with a small screw. The rear-end ferrules are $\frac{1}{2}$ -inch lengths of $\frac{3}{8}$ -inch tubing, driven on and drilled with a $\frac{3}{32}$ -inch hole for the rear-edge wire. The rear ferrules of the main ribs may be the same $\frac{1}{2}$ -inch tubing used for the front of the small ribs; they should be cut off so that their ends will come in the same line as the holes in the ends of the small ribs. If the quick-demountable plan be followed, the second main rib from each end may be left long and

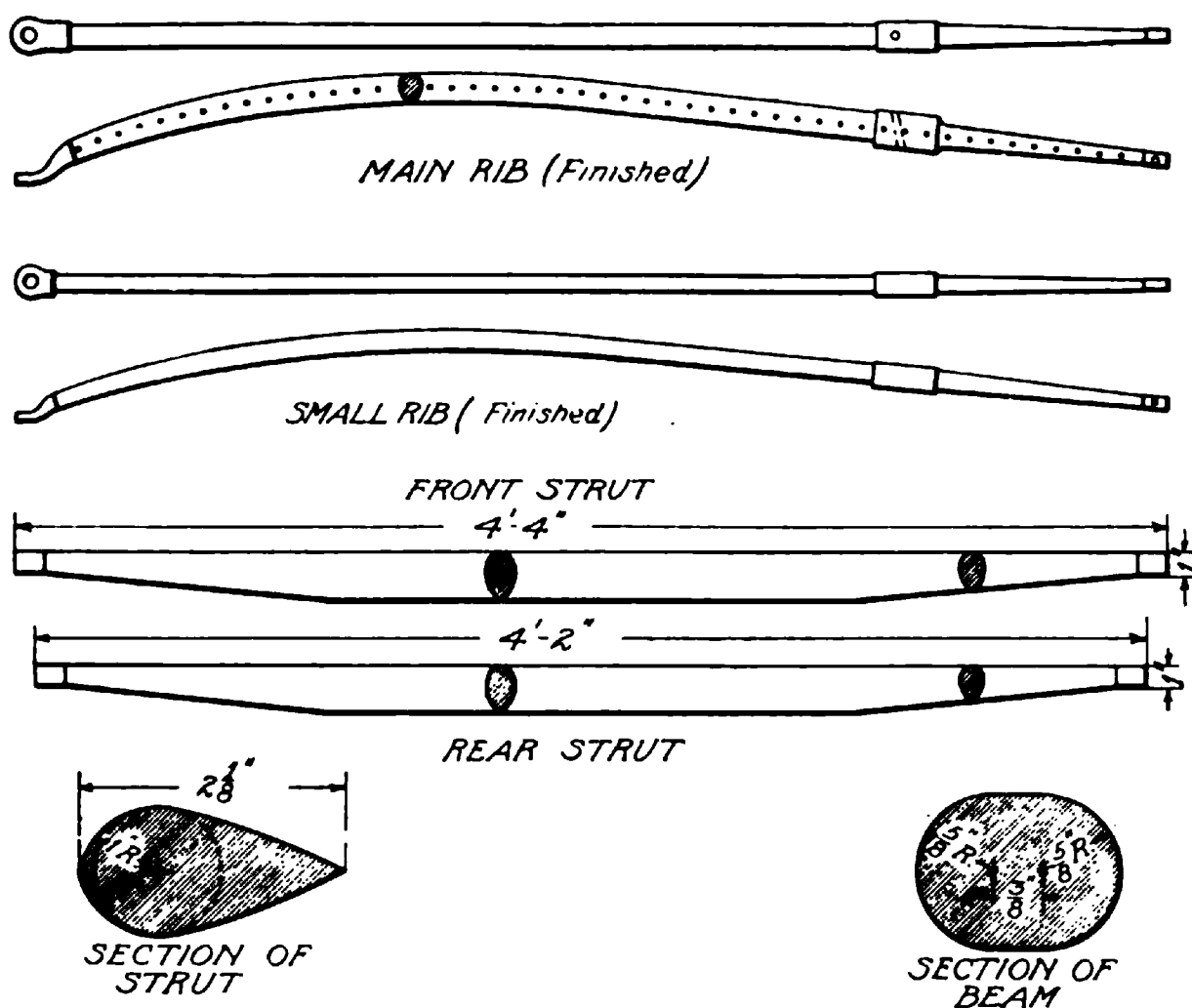


Fig. 15. Details of Ribs and Struts, Curtiss Biplane

drilled with a hole like the small ribs. The front ferrules of the main ribs should be $\frac{3}{4}$ -inch tubing of heavier gauge, drilled with a $\frac{1}{4}$ -inch hole. The finished ribs are sandpapered smooth and shel-laced or coated with spar varnish. The latter is much more expensive and slower in drying but has the great advantage of being weather-proof and will protect the glue cracks from moisture. The ferrules may be painted with black enamel.

Struts. Before going into the detail of the construction of the remainder of the *main cell* and its attached framing, a brief descrip-

tion of its parts and their relation to one another will make matters clearer. The upright struts, Fig. 15, which hold the two planes apart, fit at each end into sockets, which are simply metal cups with bolts projecting through their ends, Fig. 16. Those at the bottom of the front row of struts pass through the eyes of the turnbuckles and connections for the wire trussing, then through the flattened ferrules of the main ribs, and finally through the beam, all being clamped together with a nut. Those at the top go through the turnbuckles first, then through the beam, and finally the rib ferrule. The bolts at the back row of struts must go through the full thick-

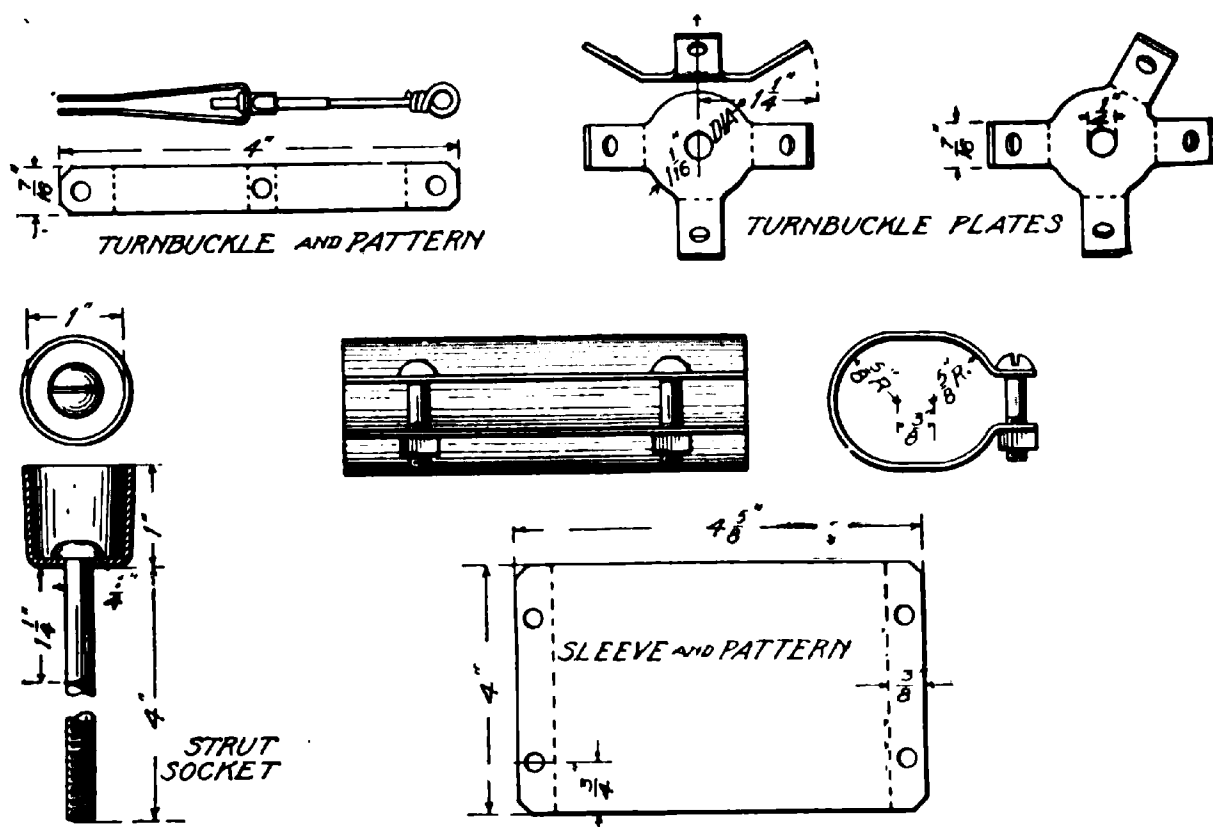


Fig. 16. Details of Metal Parts of Curtiss Biplane

ness of the main ribs, and so must be longer. The drawings, Figs. 15 and 16, show the method of attachment of both the main and the small ribs and illustrate a neat method of attaching the turnbuckles—instead of being strung on the socket bolt one after another, they are riveted to the corners of a steel plate which alone is clamped under the socket.

Beams. The beams are jointed at each strut connection, the ends being cut square and united by a sheet-steel sleeve, a pattern of which is shown in Fig. 16, clamped on by two small bolts. The hole for the socket bolt is drilled half in each of the two abutting beams. As it is very difficult to obtain long pieces of wood suf-

ficiently straight grained and free from knots for the purpose, this jointed system considerably cheapens the construction. Both beams and struts are of spruce, but to give additional strength, the beams of the middle section may be ash. Special aero cloth, rubberized fabrics, or light, closely-woven duck (racing yacht sail cloth of fine quality, this being employed at first by the Wright Brothers in their machines) forms the surfaces of the wings. The front edge of each section of the surface is tacked to the beam and the rear edge is laced over the rear wire already referred to, this wire being stretched taut through the holes in the rear tips of the ribs, both main and small. After the cloth is stretched tight, it is tacked to the small ribs, a strip of tape being laid under the tack heads to prevent the cloth from pulling away from under them. If the aeroplane is intended to be taken apart very often, the standard design as shown by the large drawings, Figs. 11 and 12, may be modified so as to make it unnecessary to unlace the cloth each time. This is arranged by regarding the two outer sections at each end of the plane as one, and never separating them. Additional main ribs are then provided at the inner ends of these sections, and are attached directly to the beams, instead of being clamped under the strut sockets. In taking the machine apart, the struts are pulled from the sockets, leaving the latter in place. It will then be an advantage to shorten the main planes somewhat, say 3 inches on each section, so that the outer double sections will come under the "12-foot rule" of the Express Companies.

Running Gear. Three wheels are provided—one in front under the outrigger and two under the main cell for starting and landing. Two beams extend from the front wheel to the engine bed and serve to carry the pilot's seat, as will be seen from the elevator, Fig. 12. A third beam runs back horizontally from the front wheel and on rough ground acts as a skid. The rest of the running gear is made of steel tubing, the pieces being joined simply by flattening the ends, drilling and clamping with bolts; no sockets or special connections of any kind are necessary here. If desired, the wheels may be carried in bicycle forks and may be fitted with shock absorbers, some idea of the various expedients adopted by different builders for this purpose being obtainable from the sketches, Fig. 40 in "Types of Aeroplanes." Two separate tubes, one on each side of the wheel

make a simple construction and will probably serve just as well. The details of the running gear will be given later.

Outrigging and Rudders. For the outriggers and the frames carrying the front horizontal or elevating rudder and the rear vertical rudder and tail, or horizontal keel, either spruce or bamboo may be employed. Bamboo will be found on machines turned out by the Curtiss factory, and while it is the lighter of the two, it is not generally favored, as spruce is easier to obtain in good quality and is far easier to work. At their ends, these outriggers are fitted with ferrules of steel tubing, flattened and drilled through. The outriggers are attached to the main framework of the machine by slipping the ferrules over the socket bolts of the middle section struts, above and below the beams. It is preferable, however, to attach the rear outriggers to extra bolts running through the beams, so that when the machine is to be housed the tail and rudder can be unshipped and the triangular frames swung around against the main frame, considerably reducing the space required.

The tail, horizontal and vertical rudders, and the ailerons are light frames of wood, covered on both sides with the same kind of cloth as the main planes or wings. These frames are braced with piano wire in such a manner that no twisting strains can be put on them. The front horizontal rudder, which is of biplane construction like the main cell, is built up with struts in the same way. Instead of being fitted with sockets, however, the struts are held by long screws run through the planes and into their ends, passing through the eyes of the turnbuckles.

DETAILS OF CONSTRUCTION

Main Planes and Struts. It is preferable to begin with the construction of the main planes and their struts and truss wires, the ribs already described being the first step.

The main beams offer no special difficulties. They are ovals $1\frac{1}{4}$ by $1\frac{5}{8}$ inches, all 6 feet long except the eight end ones, which are 6 feet 2 inches. The beams of the central section should be of ash, or should be thicker than the others. In the latter case, they must be tapered at the ends so that the clamping sleeves will fit and the additional wood must be all on the lower side, so that the rib will not be thrown out of alignment. The spruce used for the other beams

should be reasonably clear and straight grained, but a small knot or two does not matter, provided it does not come near the ends of the beam. The beams may be cut to the oval shape by the sawmill or planed down by hand.

"Fish-shaped" or "stream-line" section, as it is more commonly termed, is used for the struts, Fig. 15. It is questionable whether this makes any material difference in the wind resistance, but it is common practice to follow it in order to minimize this factor. It is more important that the struts be larger at their centers than at the ends, as this strengthens them considerably. At their ends the struts have ferrules of the 1-inch brass or steel tubing, and fit into the sockets which clamp the ribs and beams together. The material is spruce but the four central struts which carry the engine bed should either be ash or of larger size, say $1\frac{1}{4}$ by 3 inches.

Care Necessary to Get Planes Parallel. The front struts must be longer than the rear ones by the thickness of a main rib at the point where the rear strut bolt passes through it, less the thickness of the rib ferrule through which the bolt of the front strut must pass. However, the first distance is not really the actual thickness of the rib, but the distance between the top of the rear beam and the bottom of the strut socket. In the drawings the difference in length between the front and rear struts is given as 2 inches, but it is preferable for the builder to leave the rear struts rather long and then measure the actual distance when assembling, cutting the struts to fit. The ends of the struts should also be countersunk enough to clear the head of the socket bolt.

One of the items which the builder can not well escape buying in finished form is the strut sockets. These are cup-shaped affairs of pressed steel which sell at 20 cents each. Sixteen of them will be required for the main frame, and a dozen more can advantageously be used in the front and rear controls, though for this purpose they are not absolutely necessary. They can also be obtained in a larger oval size suitable for the four central struts that carry the engine bed, as well as in the standard 1-inch size. The bolts which project through the bottom of the sockets are ordinary $\frac{1}{4}$ -inch stove bolts, with their heads brazed to the sockets.

For the rear struts, where the bolt must pass through the slanting main rib, it is advisable to make angle washers to put under the

socket and also between the beam and rib. These washers are made by sawing up a piece of heavy brass tubing, or a bar with a $\frac{1}{4}$ -inch hole drilled in its center, the saw cuts being taken alternately at right angles and at 60 degrees to the axis of the tube.

The sleeves which clamp together the ends of the beams are made of sheet steel of about 20 gauge. The steel is cut out on the pattern given in the drawing, Fig. 16, and the $\frac{3}{16}$ -inch bolt holes drilled in the flanges. The flanges are bent over by clamping the sheet in a vise along the bending line and then beating down with a hammer. Then the sleeves can be bent into shape around a stray end of the beam wood. The holes for the strut socket bolts should not be drilled until ready to assemble. Ordinarily, $\frac{3}{16}$ -inch stove bolts will do to clamp the flanges together.

Having reached this stage, the amateur builder must now supply himself with turnbuckles. As already mentioned, these may either be purchased or made by hand. It is permissible to use either one or two turnbuckles on each wire. One is really sufficient, but two—one at each end—add but little weight and give greater leeway in making adjustments. As there are about 115 wires in the machine which need turnbuckles, the number required will be either 115 or 230, depending upon the plan which is followed. Those of the turnbuckles to be used on the front and rear controls and the ailerons, about one-fifth of the total number, may be of lighter stock than those employed on wires which carry part of the weight of the machine.

Making Turnbuckles for the Truss Wires. On the supposition that the builder will make his own turnbuckles, a simple form is described here. As will be seen from Fig. 16, the turnbuckles are simply bicycle spokes, with the nipple caught in a loop of sheet steel and the end of the spoke itself twisted into an eye to which the truss wire can be attached. The sheet steel used should be 18 or 16 gauge, and may be cut to pattern with a heavy pair of tin snips. The spokes should be $\frac{3}{16}$ inch over the threaded portion. The eye should be twisted up tight and brazed so that it can not come apart. The hole in the middle of each strip is, of course, drilled the same size as the spoke nipple. The holes in the ends are $\frac{3}{16}$ inch.

In the original Curtiss machines, the turnbuckles were strung on the socket bolts one after another, sometimes making a pack of them half an inch thick. A much neater construction is shown in

the drawings, in which the bolt pierces a single plate with lugs to which to make the turnbuckles fast by riveting. The plates are of different shapes, with two, three, or four lugs, according to the places where they are to be used. They are cut from steel stock $\frac{3}{8}$ inch thick, with $\frac{1}{4}$ -inch holes for the socket bolts and $\frac{3}{8}$ inch, or other convenient size, for the rivets that fasten on the turnbuckles.

The relative merits of cable and piano wire for trussing have not been thoroughly threshed out. Each has its advantages and disadvantages. Most of the well-known builders use cable; yet if the difference between 1,000 feet of cable at $2\frac{1}{4}$ cents per foot (the price for 500-foot spools), and 8 pounds of piano wire at 70 cents a pound, looks considerable to the amateur builder, let him by all means use the wire. The cable, if used, should be the $\frac{3}{8}$ -inch size, which will stand a load of 800 pounds; piano wire should be 24 gauge, tested to 745 pounds. It should be noted that there is a special series of gauges for piano wire, known as the music wire gauge, in which the size of the wire increases with the gauge numbers, instead of the contrary, as is usual with machinery wire gauges.

One by no means unimportant advantage of the piano wire is that it is much easier to fasten into the turnbuckles. A small sleeve or ferrule, a $\frac{1}{4}$ -inch length of $\frac{1}{8}$ -inch tubing, is first strung on the wire. The end of the wire is then passed through the turnbuckle eye, bent up, thrust through the sleeve, and again bent down. When the machine is taken apart, the wire is not disconnected from the eye, but instead the turnbuckle spoke is unscrewed from the nipple. The shape of the sheet-steel loop should be such as to hold the latter in place. Cable, on the other hand, must be cut with about 2 inches to spare. After being threaded through the turnbuckle eye, the end is wound back tightly on itself and then soldered, to make certain that it can not loosen.

With a supply of turnbuckles and cable or piano wire at hand, the builder may go ahead with the main box-like structure or cell, which should be completed except for the cloth covering, and in proper alignment, before taking up the construction of the running gear and controls.

Running Gear. The running gear of the machine is built of seamless steel tubing, those parts which carry the weight of the machine direct being of $\frac{3}{4}$ -inch outside diameter, 16-gauge tubing,

while the others are $\frac{5}{8}$ -inch outside diameter, either 18 or 20 gauge. About 25 feet of the heavy and 45 feet of the light tubing will be required, in lengths as follows: Heavy, four 3-foot, three 4-foot; light, one 6-foot, two 4-foot 6-inch, and seven 4-foot pieces. Referring to Fig. 17, two diagonal braces from the rear beam to the engine bed, the V-shaped piece under the front engine bed struts and all of the rear frame except the horizontal piece from wheel to wheel, are of heavy tubing. The horizontal in the rear frame, diagonals from the rear wheels and the rear end of the skid to the front beam, the two horizontals between the front and rear beam, and the forward V are of light tubing.

Three ash beams are used in the running gear. Two of these run diagonally from the rear end of the engine bed to the front wheel.

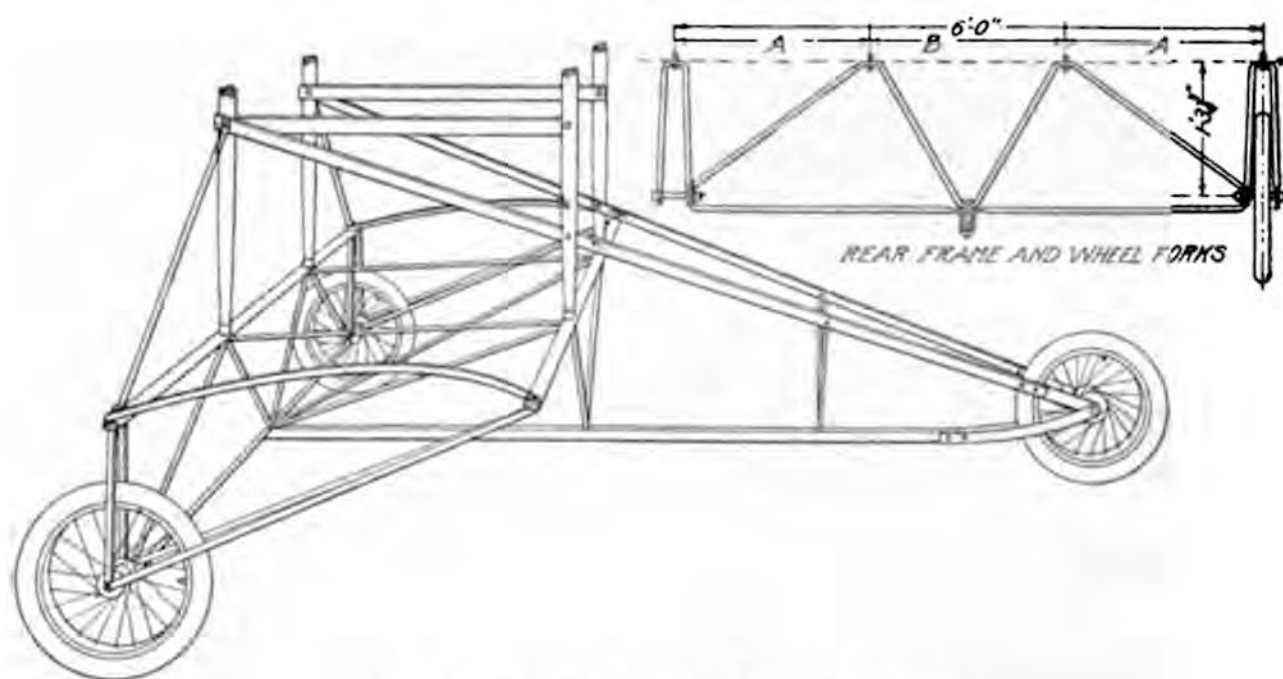


Fig. 17. Details of Curtiss Running Gear

These are about 10 feet long and 1 by $1\frac{3}{4}$ inches section. The third, which on rough ground acts as a skid, is $8\frac{1}{2}$ feet long and about 2 inches square. Between the points where the tubing frames are attached to it, the upper corners may be beveled off with a spoke shave an inch or more down each side. The beams are attached to the front wheel with strips of steel stock $1\frac{1}{2}$ inches wide and $\frac{1}{8}$ inch thick. The engine bed beams are also ash about 1 by $1\frac{3}{4}$ inches section. Their rear ends are bolted to the middle of the rear engine bed struts and the front ends may be $\frac{1}{2}$ inch higher.

The wheels are usually 20 by 2 inches, and of the bicycle type,

but heavier and wider in the hub; the tires are single tube. These wheels, complete with tires, cost about \$10 each. This size is used on the standard Curtiss machines, but novice operators, whose landings are not quite as gentle as they might be, find them easily broken. Therefore, it may be more economical in the end to pay a little more and get heavier tires—at least to start with.

For working the tubing into shape, a plumber's blow torch is almost indispensable—most automobilists will already possess one of these. The oval, flat variety, holding about one pint, is very handy and packs away easily, but on steady work requires filling somewhat too frequently. With a dozen bricks a shield can be built in front of the torch to protect the flame and concentrate the heat. Whenever it is to be flattened and bent, the tubing should be brought to a bright red or yellow heat. Screwing the vise down on it will then flatten it quickly without hammer marks. Where the bend is to be made in the middle of the piece, however, it may be necessary to resort to the hammer and anvil.

It is convenient to start with the framework under the rear beam. This may be drawn accurately to full size on the workshop floor, and the tubes bent to fit the drawing. With this framework once in place, a definite starting point for the remainder of the running gear is established. Here and in all other places, when boring through wood, the holes should be drilled out full, and larger washers should be placed under the bolt head and nut. All nuts should be provided with some sort of locking device. The perspective drawing, Fig. 17, should show the general arrangement clearly enough to enable the builder to finish the running gear.

Outriggers. Both the front and rear control members, or "outriggers" as they are termed, Fig. 12, may be conveniently built up on the central section of the main frame, which, it is assumed, has now been fitted with the running gear.

The horizontal rudder, or "elevator," is a biplane structure like the main cell of the machine, but with fewer struts; it is carried in front of the main planes on two A-shaped frames. The vertical rudder, at the rear, is split along the middle and straddles a fixed horizontal plane, or *tail*. This also is carried on two A-shaped frames. Lateral stability is controlled by two auxiliary planes or ailerons, one at each side of the machine and carried on the two outer

front struts. These three control units—*elevator*, *tail* and *rudder*, and *ailerons*—will now be taken up separately and their construction, location on the machine, and operation will be described.

Horizontal Rudder or Elevator. The two planes of the elevator are 2 feet wide by 5 feet 8 inches long and are spaced 2 feet apart,

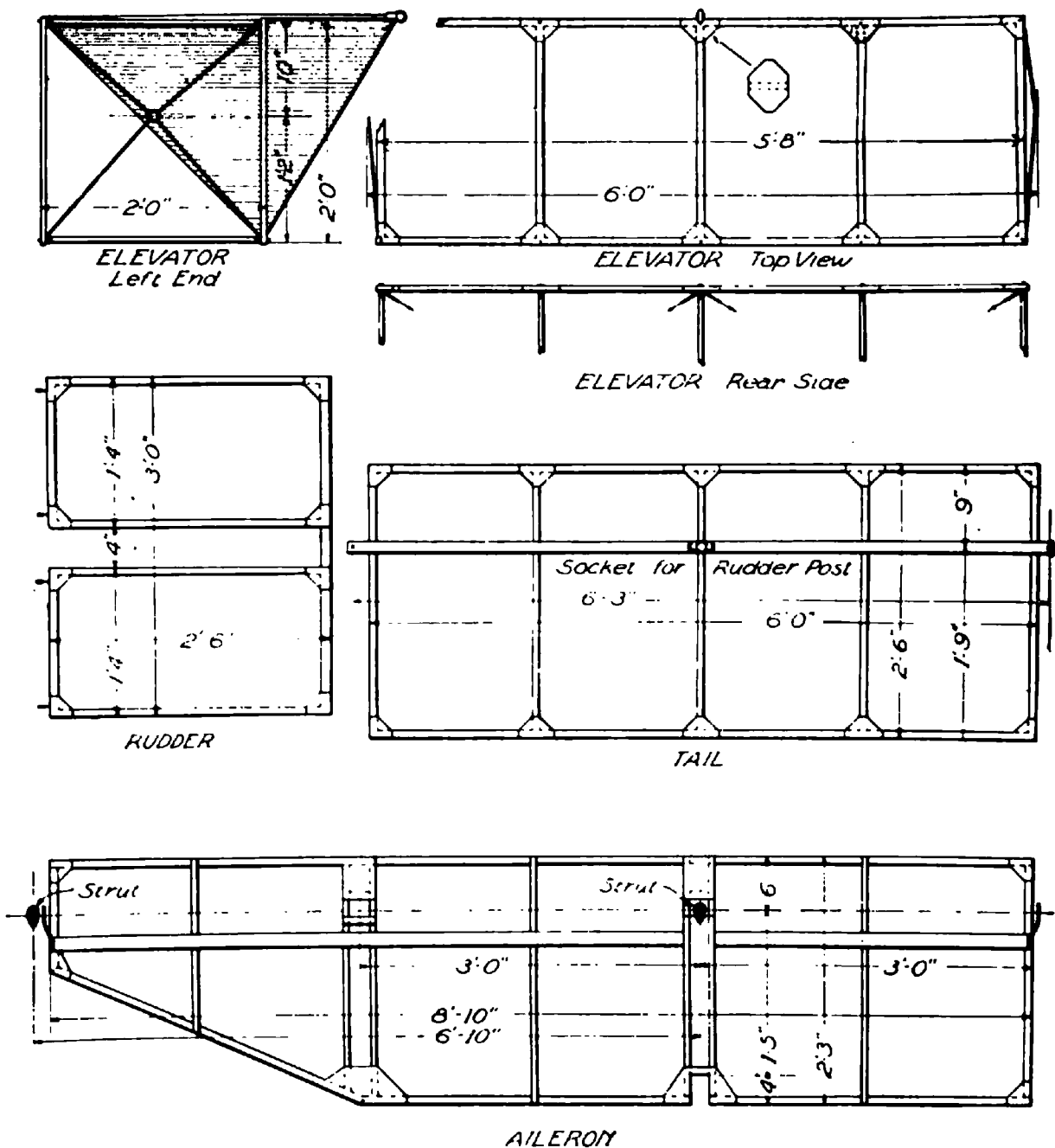


Fig. 18. Details of Rudders and Ailerons, Curtiss Biplane

being held in this position by ten struts. The frames of the planes are built of spruce sticks $\frac{1}{2}$ by 1 inch, each plane having two sticks the full length and five evenly spaced crosspieces or ribs. These are joined together with squares of X-sheet tin, as shown in the detailed drawing, Fig. 18. With a little experimenting, paper patterns can be made from which the tin pieces can be cut out. The sticks are then nailed through the tin with $\frac{3}{4}$ -inch brads.

It is convenient to draw the frames out accurately on a smooth wood floor and then work over this drawing. The first few brads will hold the sticks in place. When all the brads have been driven, a little drop of solder should be run in around the head of each one. This is a tedious job. One must be careful to use no more solder than necessary as it increases the weight very rapidly. Two pounds of wire solder should be sufficient for all the control members which are built in this way. When the top side is soldered, pry the frame loose from the floor with a screwdriver and turn it over. Then the projecting points of the brads must be clinched and the soldering repeated.

At this stage, the two frames should be covered on both sides with the prepared cloth used for covering the main planes. The method of preparing this cloth is detailed a little farther along.

The struts, so-called, to continue the analogy with the main planes, are turned sticks of spruce $\frac{3}{8}$ inch in diameter. They are fitted at each end with ferrules of thin $\frac{3}{8}$ -inch brass, or steel tubing, driven on tight. Instead of using sockets, the struts are held at each end, simply by a long wood screw driven through the tin and wood of the plane frame and into the strut. These screws also hold the turnbuckles for the truss wires. For trussing purposes, the elevator is regarded as consisting of two sections only, the intermediate struts being disregarded.

The turnbuckles and wire used here and in the other control members may well be of lighter stock than those used in the main planes. Piano wire, No. 18, or $\frac{1}{16}$ -inch cable is amply strong. The sheet steel may be about 22 gauge, instead of 16, and the bicycle spokes smaller in proportion. No turnbuckle plates are necessary. The screws running into the struts may be passed directly through the eyes of the turnbuckles, where they would have been attached to the turnbuckle plate. In order to secure a square and neat structure, those struts which have turnbuckles at their ends should be made a trifle shorter than the others.

At each end, the elevator has an **X**-shaped frame of $\frac{1}{4}$ -inch steel tubing; at the intersection of the **X**'s are pivots on which the elevator is supported. Each **X** is made of two tubes, bent into a **V** and flattened and brazed together at the points. The ends of the **X**'s are flattened and bent over so that the screws which hold the struts in place may pass through them.



Fig. 19. Curtiss Biplane Ready for Flight

To the front middle strut is attached an extension which acts as a lever for operating the elevator. This is a stick of spruce $\frac{3}{4}$ inch in diameter and 3 feet 3 inches long. At its upper end it has a ferrule of steel tubing, flattened at the end. The lower part of the stick may be fastened to the strut by wrapping the tube with friction tape, or by improvising a couple of sheet steel clamps. The upper end of the stick is braced by a $\frac{1}{4}$ -inch steel tube, extending to the top of the rear middle strut, and held by the same screw as the strut. This extension lever is connected to the steering column by a bamboo rod, 1 inch in diameter and about 10 feet long, provided with flattened ferrules of steel tubing at each end. Each ferrule should be held on by a $\frac{1}{8}$ -inch stove bolt passing through it.

Front and Rear Outrigger Frames. Both the front elevator and the tail and rudder at the rear, are carried, as mentioned above, each on a pair of **A**-shaped frames, similar to one an-

other, except that those in the rear are longer than those in the front. Both are made of spruce of about the same section as used for the struts of the main frame. These pieces may either be full length, or they may be jointed at the intersection of the crosspieces, the ends being clamped in a sheet-steel sleeve, just like that used on the beams of the main frame. In this case, it is advisable to run a $\frac{1}{8}$ -inch stove bolt through each of the ends.

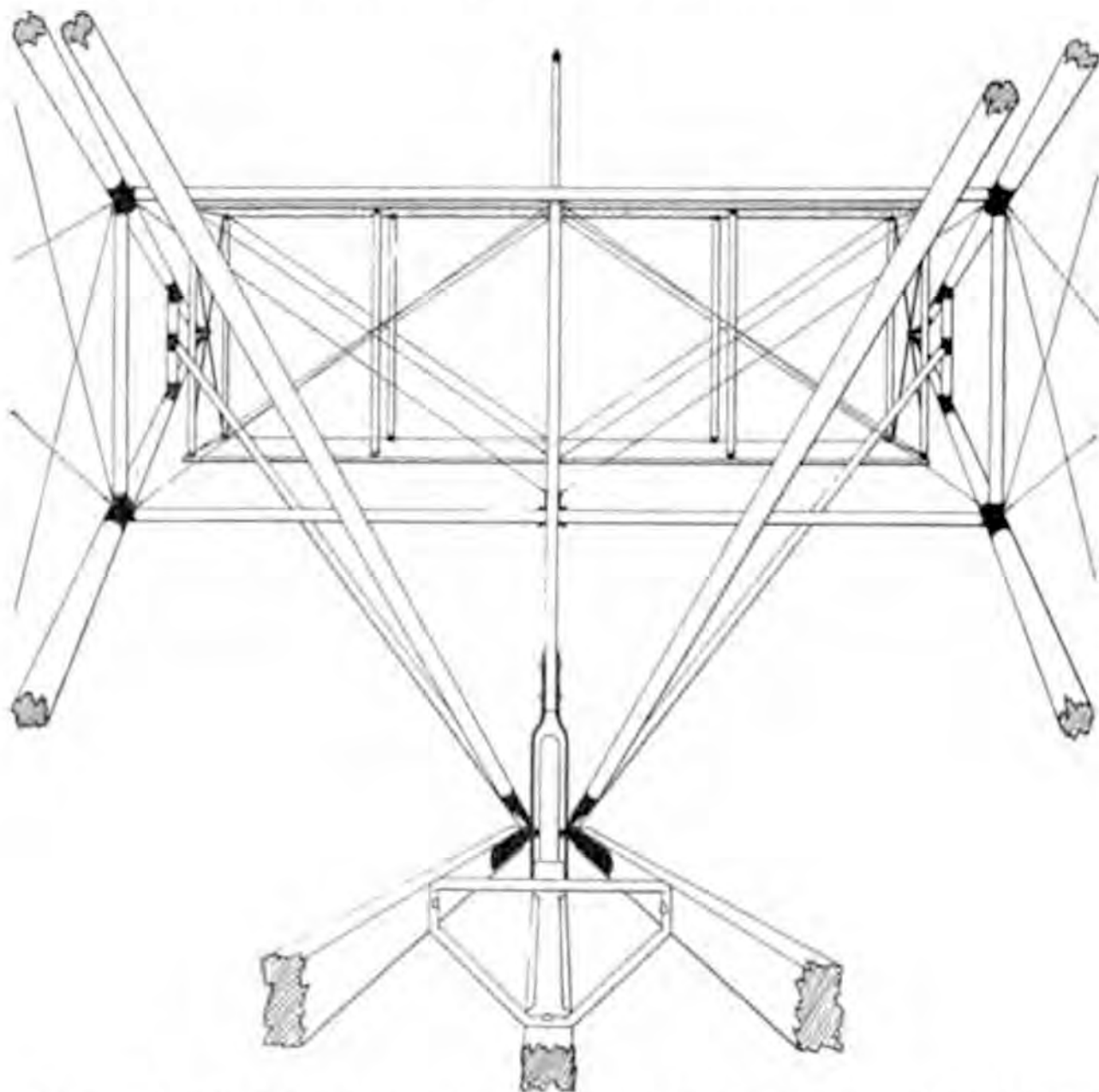


Fig. 20. Details of Outriggers and Front Elevating Planes as Seen from Driver's Seat

The crosspieces of the **A**-frames are spruce of the same section, or a little smaller. At their ends may be used strut sockets like those of the main frame; or, if it is desired to save this expense, they may be fastened by strips of $\frac{1}{8}$ -inch steel stock with through bolts.

The front outrigger has, besides the two **A**-frames, a rather complicated arrangement of struts designed to brace the front wheel

against the shocks of landing. This arrangement does not appear very plain in a plan or elevation, and may best be understood by reference to the photograph, Fig. 19, and the perspective drawing, Fig. 20. Fig. 20 is a view from the driver's seat. The elevator is seen in front, the **A**-frames at each side, and at the bottom the two diagonal beams to the engine bed and the skid.

Reference to this drawing will show the two diagonals run from the front wheel up and back to the top of the main frame, and two more from the wheel forward to the short crosspieces near the apexes of the **A**-frame: there is also a vertical strut which intersects two horizontal pieces running between the ends of the longer crosspieces of the **A**-frames. Altogether, there are five attachments on each side of the front wheel, through which the axle bolt must pass, viz, the connections to the skid, to one of the diagonals to the engine bed, to one of the rear diagonals, to one of the front diagonals, and to one side of the fork carrying the vertical strut. Of these the skid attachments should be on the inside closest to the wheel, and the engine bed diagonals next.

The four additional diagonals running to the front wheel may be spruce of the same section used in the **A**-frames, or turned one inch round. At each end they have flattened ferrules of steel tubing. The beams of the **A**-frames have similar ferrules at the ends where they attach to the main frames. These attachments should be made on the socket bolts of the struts on either side of the middle 6-foot section and on the outer side of the main beams—not between the beam and the socket itself.

It is possible, of course, to make all the **A**-frames and diagonal braces of bamboo, if desired, the qualities of this material already having been referred to. Bamboo rods for this purpose should be between 1 and $1\frac{1}{4}$ inches in diameter. Where ferrules are fitted on the ends, the hole of the bamboo should be plugged with wood glued in place.

Generally, in the construction of the outrigger frames, the builder can use his own discretion to a considerable extent. There are innumerable details which can be varied—far too many to consider even a part of the possibilities in this connection. If the builder runs across any detail which he does not see mentioned here, he may safely assume that any workmanlike job will suffice. Often, the

method may be adapted to the materials on hand. The diagonal wires from the crosspieces of the A-frames to the struts should be crossed.

Rudder and Tail Construction. The frame for the rudder and tail are constructed in much the same way as those for the elevator, Fig. 18. Spruce sticks 1 by $\frac{1}{2}$ inch are used throughout, except for the piece at the back edge of the rudder and the long middle piece across the tail; these should be $1\frac{1}{2}$ by $\frac{1}{2}$ inch. This long middle piece of the tail is laid across on top of the rest of the framework. When the cloth is put on, this makes the upper surface slightly convex while the lower surface remains flat. The ends of this piece should be reinforced with sheet steel, fairly heavy and drilled for $\frac{1}{4}$ -inch bolts, attaching the tail to the A-frames.

The rudder is hung from two posts extending above and below the tail. These posts may be set in cast aluminum sockets, such as may be obtained from any supply house for 20 cents apiece. The posts need not be more than $\frac{3}{4}$ inch in diameter. At their outer ends, they should have ferrules of steel tubing, and the turnbuckles or other attachments for the truss wires should be attached by a wood screw running into the end of each. From these posts the rudder may be hung on any light hinges the builder may find convenient, or on hinges improvised from screw eyes or eye bolts, with a bolt passing through the eyes of each.

In steering, the rudder is controlled by a steering wheel carried on a hinged post in front of the pilot. This post should be ash about 1 by $1\frac{1}{4}$ inches. It hinges at the bottom on a steel tube of $\frac{1}{2}$ -inch diameter which passes through it and is supported at the ends on diagonal beams to the engine bed. Two diagonals of lighter tubing may be put in to hold the posts centered between the two beams.

The post is, of course, upright, and the hub of the wheel is horizontal. The wheel may be conveniently mounted on a piece of tubing of the same size as the hub hole, run through the post and held by a comparatively small bolt, which passes through it and has a big washer on either end. The wheel is preferably of the motor-boat variety with a groove around the rim for the steering cable.

The rear edge of the tail should be about 1 inch lower than the front. To make the rudder post stand approximately vertical, wedge-shaped pieces of wood may be set under the sockets.

The steering connections should be of flexible cables of steel such as are made for this purpose. There should be a double pulley on the post just under the wheel, and the cables should be led off the post just at the hinge at the bottom, so that swinging the post will not affect them. The cable is then carried under the lower main plane and out the lower beams of the A-frames. It is attached to the rudder at the back edge; snap hooks should be used for easy disconnection in packing. Perhaps the best way of guiding the cable, instead of using pulleys, is to run it through short pieces of tubing lashed to the beams with friction tape. The tubing can be bent without flattening by first filling it with melted lead, which, after the bending, can be melted out again.

Ailerons for Lateral Stability. The framework of the ailerons is made in the same way as that for the elevator, tail, and rudder, Fig. 18. The pieces around the edges should be $1\frac{1}{2}$ by $\frac{1}{2}$ inch, as also the long strip laid over the top of the ribs. The ribs should be $\frac{1}{2}$ by $\frac{3}{4}$ inch. Each aileron has two holes, one for the strut to pass through, and the other for the diagonal truss wires at their intersection. The back edge also has a notch in it to clear the fore and aft wires. Each aileron is hung on four strips of soft steel about $\frac{1}{2}$ by $\frac{1}{16}$ inch, twisted so that one end is at right angles to the other. These are arranged one on each side of the strut which passes through the aileron, and one at each end. Bolts through the struts carry three of them and the outer one is trussed by wires to each end of the outer strut.

A frame of $\frac{1}{4}$ -inch steel tubing fits around the aviator's shoulders and is hinged to the seat, so that he can move it by leaning from one side to the other. This is connected by flexible cable to the rear edges of the ailerons, so that when the aviator leans to the left, he will raise the left and lower the right aileron. The upper edges of the ailerons are directly connected to each other by a cable running along the upper front beam, so that they must always move together.

Covering of the Planes. Mention has already been made of the fact, in the general description of the machine, that light sail cloth, as employed on the Wright machines, may be used for the planes or wings. As a matter of fact, many different materials may be successfully employed, the selection depending upon the builder himself and his financial resources. About 55 square yards of material

will be required, and in comparing prices always compare the width as this may vary from 28 to 55 inches. Rubberized silk which is used on the standard Curtiss machines is the most expensive covering, its cost running up to something like two hundred dollars. There are also several good aero fabrics on the market which sell at 60 cents a square yard, as well as a number of brands of varnish for the cloth—most of them, however, quite expensive. The most economical method is to employ a strong linen cloth coated with shellac, which will be found very satisfactory.

The covering of the frames with the cloth may well be postponed until after the engine has been installed and tested, thus avoiding the splashing of oil and dirt which the fabric is apt to receive during this operation. The wire to which the cloth is laced, must be strung along the rear ends of the ribs of each plane. The wires pass through holes in the ends of the small ribs and are attached to the main ribs with turnbuckles. At the ends of the planes the main ribs must be braced against the pull of the wire by a piece of $\frac{1}{4}$ -inch tubing running from the end of the rib diagonally up to the rear beam. Both turnbuckles and tube are fastened with one wood screw running into the end of the rib.

The cloth should be cut to fit the panels between the main ribs and hemmed up, allowing at least an inch in each direction for stretch. Small eyelets should be put along the sides and rear edges an inch apart for the lacing. At the front edge, the cloth is tacked directly to the beam, the edge being taken well under and around to the back. Strong fish line is good material for the lacing.

After the cloth is laced on, it must be tacked down to the small ribs. For this purpose, use upholstery tacks as they have big cup-shaped heads which grip the cloth and do not tear out. As an extra precaution a strip of heavy tape must be run over each rib under the tack heads. All the control members are covered on both sides, the edges being folded under and held by tacks.

Making the Propeller. If the completed biplane is to fly properly and also have sufficient speed to make it safe, considerable care must be devoted to the design and making of the propeller. Every aeroplane has a safe speed, usually referred to in technical parlance as its *critical speed*. In the case of the Curtiss biplane under consideration, this speed is about 40 miles an hour.

By speeding up the motor considerably, it may be able to make 42 to 43 miles an hour in a calm, such a condition representing the only true measure of an aeroplane's ability in this direction, while on the other hand, it would not be safe to let its speed with relation to the wind (not to the ground) fall much below 35 miles an hour. At any slower rate of travel, its dynamic stability would be precarious and the machine would be likely to dive to the ground unexpectedly. The reasons for this have been explained more in detail under the heading of "The Internal Work of the Wind."

The necessity of making the propeller need not discourage the ambitious builder—if he can spare the time to do it right, it will be excellent experience. If not, propellers designed for driving a machine of this size can be purchased ready to mount from any one of quite a number of manufacturers. But as the outlay required will be at least \$50, doubtless most experimenters will prefer to undertake this part of the work as well as that of building the framework and main cell, particularly as more than 90 per cent of the sum mentioned is represented by labor. The cost of the material required is insignificant by comparison.

True-Screw Design. First it will be necessary to design the propeller to meet the requirements of the biplane itself. As this is a matter that has already been gone into in considerable detail under the appropriate heading, no further explanation of propeller characteristics or of the technical terms employed, should be needed here. We will assume that the biplane is to have a speed of 40 miles per hour in still air with the motor running at 1,200 r. p. m. With this data, it will not be difficult to calculate the correct pitch of the propeller to give that result. Thus

$$\frac{40 \times 5280 \times 100}{60 \times 1200 \times 85} = 3.45$$

or in round numbers a pitch of $3\frac{1}{2}$ feet. 40 (the speed in miles per hour) times 5,280 (feet per mile) divided by 60 (minutes in an hour) gives the speed of the aeroplane in feet per minute. Dividing this by 1,200 (revolutions per minute) gives the number of feet the aeroplane is to advance per revolution of the propeller. The " $\frac{100}{85}$ " part of the equation represents the efficiency of the propeller which can safely be figured on, *i. e.*, 85 per cent, or an allowance for slip of 15

per cent. Forty miles an hour is the maximum speed to be expected, while the r. p. m. rate of the engine should be that at which it operates to the best advantage.

The merits of the *true-screw* and *variable-pitch* propellers have already been dwelt upon. The former is not only more simple to build, but experience has shown that, as generally employed, it gives better efficiency. Hence, the propeller under consideration will be of the true-screw type. Its pitch has already been calculated as $3\frac{1}{2}$ feet. For a machine of this size and power, it should be 6 feet in diameter. Having worked out the pitch and decided upon the diameter, the next and most important thing is to calculate the pitch angle. It will be evident that no two points on the blade will travel through the air at the same speed. Obviously, a point near the tip of the propeller moves faster than one near the hub, just as in rounding a curve, the outer wheel of an automobile has to travel faster than the inner, because it has to travel farther to cover the same ground. For instance, taking the dimensions of the propeller in question it will be seen that its tips will be traveling through the air at close to 4.3 miles per minute, that is,

$$\frac{6 \times \pi \times 1200}{5280} = 4.28$$

in which 6, the diameter of the propeller in feet, times π gives the circumference of the circle which is traveled by the blade tips 1,200 times per minute; this divided by the number of feet per mile gives the miles per minute covered. On the other hand, a point on the blade but 6 inches from the hub will turn at only approximately 3,500 feet per minute. Therefore, if every part of the blade is to advance through the air equally, the inner part must be set at a greater angle than the outer part. Each part of the blade must be set at such an angle that at each revolution it will move forward through the air a distance equal to the pitch. This is known as the pitch angle. The pitch divided by the circumference of the circle described by any part of the blade, will give a quantity known as the *tangent* of an angle for that particular part. The angle corresponding to that tangent may most easily be found by referring to a book of trigonometric tables.

For example, take that part of the blade of a $3\frac{1}{2}$ -foot pitch pro-

TABLE II
Propeller Blade Data

Radius in Inches	Tangent	Pitch Angle	Add	Final Angle
6	1.1141	48° 5'	48°
9	.7427	36° 36'	37°
12	.5571	29° 7'	3° 13'	32° 20'
15	.4457	24° 1'	3° 9'	27° 10'
18	.3719	20° 24'	3° 6'	23° 30'
21	.3183	17° 40'	3°	20° 40'
24	.2785	15° 40'	2° 50'	18° 30'
27	.2476	13° 54'	2° 46'	16° 40'
30	.2228	12° 40'	2° 45'	15° 25'
33	.2025	11° 27'	2° 43'	14° 10'

PELLER which is 6 inches from the center of the hub. Then

$$\frac{3.5 \times 12}{6 \times 2\pi} = 1.1141$$

tangent of 48 degrees 5 minutes

in which 3.5×12 reduces the pitch to inches, while $6 \times 2\pi$ is the circumference of the circle described by the point 6 inches from the hub. However, in order to give the propeller blade a proper hold on the air, it must be set at a greater angle than these figures would indicate. That is, it must be given an angle of incidence similar to that given to every one of the supporting planes of the machine. This additional angle ranges from 2 degrees 30 minutes, to 4 degrees, depending upon the speed at which the particular part of the blade travels; the greater the speed, the less the angle. This does not apply to that part of the blade near the hub as the latter is depended upon solely for strength and is not expected to add to the effective thrust of the propeller.

Table II shows the complete set of figures for a blade of $3\frac{1}{2}$ -foot pitch, the angles being worked out for sections of the blade 3 inches apart.

These angles are employed in Fig. 21, which shows one blade of the propeller and its cross sections.

It should be understood that these calculations apply only to the type of propeller known as the *true screw*, as distinguished from the *variable pitch*. The design of the latter is a matter of personal skill and experience in its making which is hardly capable of

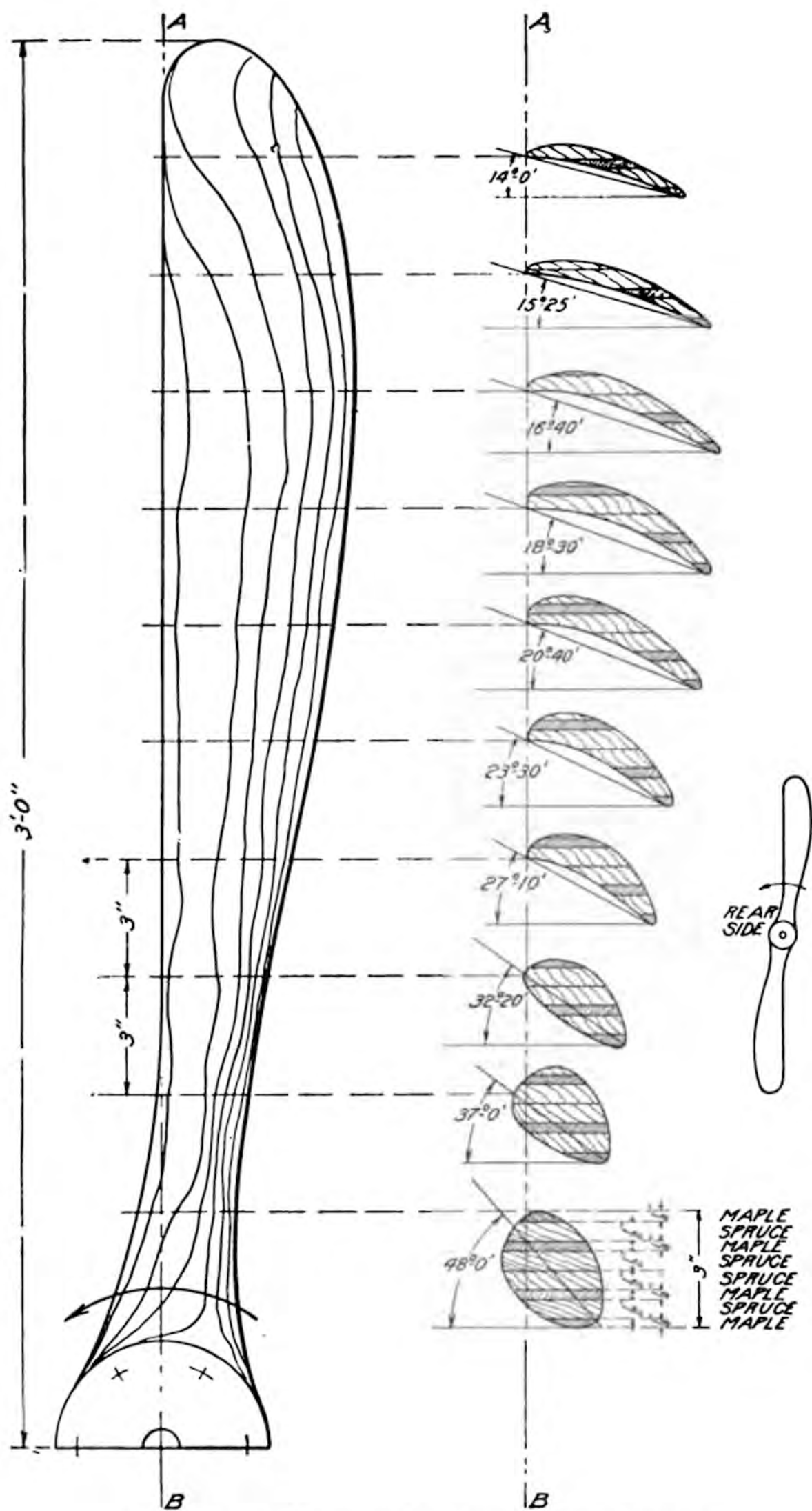


Fig. 21. Details of Propeller Construction, Curtiss Biplane

expression in any mathematical formula. There are said to be only about three men in this country who know how to make a proper variable-pitch propeller, and it naturally is without advantage when made otherwise.

Shaping the Blades. Like the ribs, the propeller is made up of a number of laminations of boards finished true and securely glued, afterward being cut to the proper shape, though this process, of course, involves far more skill than in the former case. Spruce is the strongest wood for its weight, but it is soft and cracks easily. Maple, on the other hand, is tough and hard, so that it will be an advantage to alternate the layers of these woods with an extra maple board, in order to make both outside strips of the harder wood, so as to form a good backing for the steel flanges at the hub, the rear layer extending the full length of the thin rear edges of the blades. Other woods may be employed and frequently are used by propeller manufacturers, such as mahogany (not the grained wood used for furniture, but a cheaper grade which is much stronger), walnut, alternate spruce and whitewood, and others.

The boards should be selected with the greatest care so as to insure their being perfectly *clear*, *i.e.*, absolutely free of knots, cross-grained streaks, or similar flaws, which would impair their strength and render them difficult to work smoothly. They should measure 6 inches wide by 6 feet 1 inch in length. Their surfaces must be finished perfectly true, so that they will come together uniformly all over the area on which they bear on one another, and the various pieces must be glued together with the most painstaking care. Have the glue hot, so that it will spread evenly, and see that it is of a uniform consistency, in order that it may be smoothly applied to every bit of the surface. They must then be clamped together under as much pressure as it is possible to apply to them with the means at hand, the rib press already described in detail forming an excellent tool for this purpose. Tighten up the nuts evenly a little at a time, avoiding the application of excessive or uneven pressure at one point, continuing the gradual tightening up process until it can not be carried any farther. This is to prevent the boards from assuming a curve in drying fast. Allow at least twenty-four hours for drying, during which period the laminated block should be kept in a cool, dry place at as even a temperature as possible.

Before undertaking the remainder of the work, all of which must be carried out by hand, with the exception of cutting the block to the outline of the propeller, which may be done with a band saw, a set of templates or gauges should be made from the drawings. These will be necessary as guides for finishing the propeller accurately. Draw the sections out full size on sheets of cardboard or tin and cut out along the curves, finally dividing each sheet into two parts, one for the upper side and one for the lower. Care must be taken to get the sides of the template square, and when they are used, the propeller should be laid on a perfectly true and flat block. Each template should be marked as it is finished, to indicate what part of the blade it is a gauge for. The work of cutting the laminated block down to the lines represented by the templates is carried out with the aid of the plane, spoke shave, and gouge. After the first *roughing out* to approximate the curvature of the finished propeller is completed, the cuts taken should be very fine, as it will be an easy matter to go too deep, thus spoiling the block and necessitating a new start with fresh material. For finishing, pieces of broken glass are employed to scrape the wood to a smooth surface, followed by coarse and finally by fine sandpaper.

Mounting. The hub should be of the same diameter as the flange on the engine crank shaft to which the flywheel was bolted, and should have its bolt holes drilled to correspond. To strengthen the hub, light steel plates of the same diameter are screwed to it, front and back, and the bolt holes drilled right through the metal and wood. This method of fastening is recommended where it is possible to substitute the propeller for the flywheel formerly on the engine, it being common practice to omit the use of the flywheel altogether. The writer does not recommend this, however, as the advantages of smoother running and more reliable operation gained by the use of a flywheel in addition to the propeller far more than offset any disadvantage represented by its weight. It will be noted that the Wright motors have always been equipped with a flywheel of ample size and weight and this is undoubtedly responsible, in some measure at least, for the fact that the Wright biplanes fly with considerably less power than is ordinarily employed for machines of the same size. If the motor selected be equipped with an unusually heavy flywheel, and particularly where the wheel is of comparatively

small diameter, making it less effective as a balancer, it may be replaced with one of lighter weight and larger diameter. It may be possible to attach it by keying to the forward end of the crank shaft, thus leaving the flange from which the flywheel was taken free for mounting the propeller. An ordinary belt pulley will serve excellently as the new flywheel, as most of its weight is centered in its rim, but as the common cast-iron belt pulley of commerce is seldom intended to run at any such speed as that of an automobile motor, it should be examined carefully for flaws. Otherwise, there will be danger of its bursting with disastrous results under the influence of centrifugal force. Its diameter should not exceed 16 inches in order to keep its peripheral speed within reasonable limits. Where the mounting of the motor permits of its use, a wood pulley 18 to 20 inches in diameter with a steel band about $\frac{1}{8}$ - to $\frac{1}{4}$ -inch thick, shrunk on its periphery, may be employed. Most builders will ridicule the idea of a flywheel other than the propeller itself. "You do not need it; so why carry the extra weight?" will be their query. It is not absolutely necessary, but it is an advantage.

In case the flywheel of the engine selected is keyed to the crank shaft, or in case it is not possible to mount both the flywheel and the propeller on different ends of the crank shaft, some other expedient rather than that of bolting to the flange must be adopted. In such a case, the original flywheel, where practical to retain it, may be drilled and tapped and the propeller attached directly to it. Where the flywheel can not be kept, it will usually be found practical to cut off its rim and bolt the propeller either to the web or spokes, or to the flywheel hub, if it be cut down to the latter.

The drawing, Fig. 21, shows the rear or concave side of the propeller. From the viewpoint of a man standing in its wind and facing forward, it turns to the left, or anti-clockwise. On many of the propellers now on the market, the curved edge is designed to go first. This type may have greater advantages over that described, but the straight front edge propeller is easier for the amateur to make.

Mounting the Engine. Having completed the propeller, the next step is the mounting of the engine. Reference to the types available to the amateur aeroplane builder has already been made. There are a number of motors now on the market that have been

designed specially for this purpose and not a few of them are of considerable merit. Their cost ranges from about \$250 up to \$2,500, but it may be possible to pick up a comparatively light-weight automobile motor second hand which will serve all purposes and which will cost far less than the cheapest aeronautic motor on the market. It must be capable of developing 30 actual horse-power at 1,000 to 1,200 r. p. m. and must not exceed 400 pounds complete with all accessories, such as the radiator and piping, magneto, water, oil, etc. Considerable weight may be saved on an automobile motor by removing the exhaust manifold and substituting a lighter flywheel for the one originally on the engine—or omitting it altogether, as just mentioned. A light-weight aeronautic radiator should be used in preference to the usual automobile radiator.

When placing the engine in position on the ash beams forming its bed or support, it must be borne in mind that the complete machine, with the operator in the aviator's seat, is designed to balance on a point about $1\frac{1}{2}$ feet back of the front edge of the main planes. As the operator and the motor represent much the larger part of the total weight, the balance may easily be regulated by moving them slightly forward or backward, as may be required. It will be necessary, of course, to place the engine far enough back in any case to permit the propeller blades to clear the planes. The actual installation of the engine itself will be an easy matter for anyone who has had any experience in either automobile or marine gasoline motor work. It is designed to be bolted to the two engine beams in the same manner as on the side members of the frame of an automobile, or the engine bed in a boat. Just in front of the engine is the best place for the gasoline tank, which should be cylindrical with tapering ends, to cut down its wind resistance. If the designer is not anxious to carry out points as fine as this, a light copper cylindrical tank may be purchased from stock. It should hold at least ten gallons of gasoline. In front of the tank is the radiator.

Controls. The controls may be located to conform to the builder's own ideas of accessibility and convenience. Usually the switch is placed on the steering column, and it may be of the ordinary *knife* variety, or one of the special switches made for this purpose, as taste may dictate. The throttle control and spark advance may

either be in the form of pedals, working against springs, or of small levers working on a notched sector, at the side of the seat. The complete control, levers, and sector may be purchased ready to mount whenever desired, as they are made in this form for both automobile and marine work. This likewise applies to the wheel, which it would not pay the amateur to attempt to make.

Another pedal should work a brake on the front wheel, the brake shoe consisting of a strip of sheet steel, fastened at one end to the fore part of the skid and pressed against the wheel by a bamboo rod directly connected with the brake pedal. An emergency brake can also be made by loosely bolting a stout bar of steel on the skid



Fig. 22. Method of Starting the Engine of an Aeroplane

near its rear end; one end of this bar is connected to a lever near the seat, so that when this lever is pulled back the other end of the bar tends to dig into the ground. As making a landing is one of the most difficult feats for the amateur aviator to master and sufficient space for a long run after alighting is not always available, these brakes will be found a very important feature of the machine.

The engine is started by swinging the propeller, and this is an operation requiring far more caution than cranking an automobile motor. Both hands should be placed on the same blade, Fig. 22, and the latter should always be pulled downward—never upward.

With the switch off, first turn the propeller over several times to fill the cylinders with gas, leaving it just ahead of dead center of one of the cylinders, and with one blade extending upward and to the left at a 45-degree angle. After closing the switch, take the left blade with both hands and swing it downward sharply, getting out of the way of the following blade as quickly as possible.

Tests. The first thing to be done after the propeller is finished and mounted on the engine is to test the combination, or power plant of the biplane, for speed and thrust, or pulling power. From these two quantities it will be easy to figure the power that the engine is delivering. The only instruments necessary are a spring balance reading to 300 pounds or over; a revolution counter, such as may be procured at any machinist's supply house for a dollar or two; and a watch. One end of the spring balance is fastened to the front end of the skid and the other to a heavy stake firmly driven in the ground a few feet back. The wheels of the biplane should be set on smooth boards so that they will not offer any resistance to the forward thrust. When the engine is started the spring balance will give a direct reading of the pull of the propeller.

With one observer noting the thrust, another should check the number of revolutions the engine is turning per minute. To do this, a small hole should previously have been countersunk in the hub of the propeller to receive the conical rubber tip of the revolution counter. The observer stands behind the propeller, watch in one hand and revolution counter in the other. At the beginning of the minute period, the counter is pressed firmly against the hub, and quickly withdrawn at the end of the minute. A stop watch is naturally an advantage for the purpose. The horse-power is figured as follows, assuming, for example, a thrust of 250 pounds at 1,200 r. p. m.

$$\frac{250 \times 1200 \times 3.5 \times 100}{33,000 \times 85} = 37 \text{ h. p.}$$

As before, the " $\frac{100}{85}$ " allows for the slip and represents the efficiency of the propeller; 33,000 is the number of foot pounds per minute or the equivalent of one horse-power, and 3.5 is the pitch of the propeller.

Assembling the Biplane. Assembling the machine complete requires more space than is available in the average workshop.

However, it is possible to assemble the sections of the planes in a comparatively small room, carrying the work far enough to make sure that everything will go together properly when the time comes for complete assembly at the testing ground. In this case, it is preferable to assemble the end sections first, standing them away when complete to make room for the central section, on which the running gear and outriggers are to be built up.

The builder will have decided by this time whether he will make his machine on the regular plan, with one main rib between each section, or on the quick-detachable plan, which has two main ribs on either side of the central section, as previously explained.

It is desirable to be able to assemble two sections at once and this should be possible anywhere as it requires a space only about 6 by 13 feet. Two wood 2×4's, about 12 feet long, should be nailed down on the blocks on the floor; make these level and parallel to each other at a distance of 3 feet 6 inches on centers, one being 3 inches higher than the other. Strips of wood should be nailed on them, so as to hold the main beams of the frame in place while assembling.

The two front and two rear beam sections are laid in place and joined with the sheet-steel sleeves, the flanges of the sleeves on the inner side of the beams. Then through the sleeves in the front beams, which are, of course, those on the higher bed, drill the holes for the strut socket bolts ($\frac{1}{4}$ inch). The holes for the outer ones go through the projecting ends of the beams; those for the inner ones are half in each of the two abutting beams. At the end where the central section joins on, a short length of wood of the same section may be inserted in the sleeve while drilling the hole. An assistant should hold the beams firmly together while the holes are being drilled.

Now lay in place the three main ribs belonging to the two sections under construction and fasten them at the front ends by putting in place the strut sockets for which the holes have been drilled, with a turnbuckle plate under each socket, Fig. 16. The strut socket bolt passes through the main rib and the beam. The bed on which the assembling is being done, should be cut when sufficiently under the joints to leave room for the projecting bolt ends. Set the ribs square with the front beams, then arrange the rear beams so that

their joints come exactly under the ribs; clamp the ribs down and drill a true, vertical hole through the rib beam, holding the two sections of the beam together as before. Then put the rear strut sockets in place, using the angle washers previously described, above and below the rib.

When the quick-detachable plan is followed, the ribs at the inner ends of the double section, where they join the central section, should be bolted on an inch from the ends of the beam, using $\frac{1}{4}$ -inch stove bolts instead of the socket bolts. The sleeves should be slotted, so that they can slide off without removing these bolts, as the sleeves and ribs which occupy the position over the joints of the beams, belong to the central section.

The sections should now be strung up with the diagonal truss wires which will make them rigid enough to stand handling. The wires are attached at each end to the flange bolts of the sleeves. Either one or two turnbuckles may be used on each wire, as already explained; if but one turnbuckle be used, the other end of the wire may be conveniently attached to a strip of sheet steel bent double and drilled for the bolt, like the sheet-steel slip of a turnbuckle. The attachment, of whatever nature, should be put between the end and the flange of the sleeve, not between the two flanges.

Three or four ribs can be used on each section; four are preferable on sections of full 6-foot length. They are, of course, evenly spaced on centers. At the front ends, they are attached to the beam by wood screws through their flattened ferrules. The attachment to the rear beam is made with a slip of sheet steel measuring $\frac{1}{2}$ by 3 inches, bent over the rib and fastened to the beam at each side with a wood screw. A long wire nail is driven through the rib itself on the beam.

Four double sections should be built up in this manner, the right and left upper and the right and left lower sections. Uppers and lowers are alike except for the inversion of the sockets in the upper sections. Rights and lefts differ in that the outer beams are long enough to fill up the sleeves, not leaving room for another beam to join on.

Inserting the struts in their sockets between the upper and lower sections of the same side will now form either of the two sides of the machine complete. Care should be taken to get the rear struts the

proper length with respect to the front ones to bring the upper and lower planes parallel. The distance from the top of the lower front beam to the top of the upper front beam should be the same as the distance between the rows of bracing holes in the upper and lower main ribs just above and below the rear struts—about 4 feet 6 inches. It should hardly be necessary to mention that the thick edges of the struts come to the front—they are fish-shaped and a fish is thicker at the head than at the tail.

The truss wires may now be strung on in each square of the struts, beams, and main ribs, using turnbuckles as previously described. The wires should be taut enough to sing a low note when plucked between the thumb and forefinger. If the construction is carried out properly, the framework will stand square and true with an even tension on all the wires. It is permissible for the struts to slant backward a little as seen from the side, but all should be perfectly in line.

For adjusting the turnbuckles, the builder should make for himself a handy little tool usually termed a nipple wrench. It is simply a strip of steel $1\frac{1}{2}$ by $\frac{1}{2}$ by $\frac{3}{32}$ inches, with a notch cut in the middle of the long sides to fit the flattened ends of the turnbuckle nipples. This is much handier than the pliers and does not burr up the nipples.

It has been assumed in this description of the assembling that the builder is working in a limited space; if, on the contrary, he has room enough to set up the whole frame at once, the work will be much simpler. In this case, the construction bed should be 30 feet long. First build up the upper plane complete, standing it against the wall when finished; then build the lower plane, put the struts in their sockets, and lay on the upper plane complete.

Returning to the plan of assembly by sections, after the side sections or wings of the machine have been completed, the struts may be taken out and the sections laid aside. The middle section, to which the running gear and outriggers will be attached, is now to be built up in the same way. If the builder is following the plan in which there is one main rib between each section, it will be necessary to take off the four inner main ribs from the sections already completed, to be used at the ends of the central section. The plan drawing of the complete machine shows that the ribs of the central

section are cut off just back of the rear beam to make room for the propeller. This is necessary in order to set the motor far enough forward to balance the machine properly. The small ribs in this section have the same curve but are cut off 10 inches shorter at their rear ends, and the stumps are smoothed down for ferrules like those for the other small ribs. In the plan which has one main rib between each section, the main rib on each side of the central section must be left full length. In the quick-detachable plan with two main ribs on each side of the central section, the inner ones, which really belong to this section, are cut off short like the small ribs.

In the drawing of the complete machine, the distance between the struts which carry the engine bed is shown as 2 feet. This is only approximate, as the distance must be varied to suit the motor employed. By this time, the builder will have decided what engine he is going to use—or can get—and should drill the holes for the sockets of these struts with due respect to the width of the engine's supporting feet or lugs, remembering that the engine bed beams go on the inside of the struts. In the drawing of the running gear, Fig. 17, the distance between the engine-bed struts has been designated $.4$. The distances, B , on each side are, of course, approximately $(6' - 2.4)$, whatever $.4$ may be.

EXAMINATION PAPER

BUILDING AND FLYING AN AEROPLANE

PART I

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure that you understand the subject.*

1. What type of machine, biplane or monoplane, makes the best glider and why?
2. Give the dimensions of a glider which will support a man's weight.
3. In a glider which has no rudder, how is the machine controlled?
4. Give carefully the details of the start in making a glide.
5. In what direction relative to the wind should a glide be made? Justify your answer.
6. How must the stability and balance of a glider in flight be controlled?
7. State the proper conditions for a successful glide.
8. Give the essential characteristics of a Curtiss aeroplane, defining the various parts.
9. Describe briefly the details of construction of the main supporting surfaces of a Curtiss.
10. Draw a diagram of the assembled planes showing how the struts and cross wires are placed to give the required rigidity.
11. Give the details of the running gear of the Curtiss.
12. What is the office of the Curtiss ailerons and how are they controlled from the operator's seat? Draw sketch.
13. Describe the details of the front and rear outriggers.
14. What type of propeller is advised for the Curtiss? Give the details of its construction.

BUILDING AND FLYING AN AEROPLANE

15. Describe carefully the manner in which a propeller should move through the air in order to give the maximum propulsion.
16. What determines the exact location of the motor in the aeroplane?
17. Give correct method of starting the motor when ready for a flight.
18. What tests should be conducted before a flight is undertaken?

**After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.**

(Signed)

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