Ex Libris

From the Gliding Library of

Wally Kahn

THEORY AND TECHNIQUE OF SOARING

THEORY AND TECHNIQUE OF SOARING

BY

JOHN KUKUSKI

LONDON
SIR ISAAC PITMAN & SONS, LTD.

First published 1952

SIR ISAAC PITMAN & SONS, LTD.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE
27 BECKETTS BUILDINGS, PRESIDENT STREET, JOHANNESBURG

ASSOCIATED COMPANIES
PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
SIR ISAAC PITMAN & SONS (CANADA), LTD.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381–383 CHURCH STREET, TORONTO

MADE IN GREAT BRITAIN AT THE PITMAN PRESS, BATH
E2—(A.161)

PREFACE

THIS book has been written to provide a guide and a quick reference for soaring pilots who may feel in need of an explanation of the phenomena and of the unfamiliar terms which they will meet during their flying career. I have tried to keep this explanation as simple as possible and have used mathematical formulae only where they could not be avoided.

I should like to stress the point that it is difficult to formulate exact rules in gliding and soaring. The individual approach to flying technique leaves an open field for research and investigation.

The facts here set down are based on my own personal experience gained in the past while gliding and soaring on the continent of Europe and in Britain.

I should like to acknowledge the invaluable help which I have received from Mr. D. J. Farrar, Mr. M. R. Chantrill, Mr. R. F. Taylor, and Mr. T. R. Young, all of the Bristol Gliding Club, and also to express my thanks to Mr. J. F. Douglas of Sir Isaac Pitman & Sons, Ltd., for the work he has done in the improvement of text and layout.

John [illegible]

CONTENTS

LIST OF SYMBOLS

α alpha—angle of attack, wing chord to wind (L.E.–T.E. chord)
also—radial acceleration

α^1 absolute angle of attack of aerofoil (from no lift line) $= (\alpha - \alpha_0)$

α_0 no lift angle of aerofoil, angle of attack of wing chord at no lift (usually $-$ ve)

α_T angle of attack of tail plane to local air stream

a.c. aerodynamic centre

A area (ft²)

A aerodynamic force

A.R. aspect ratio $\left(\frac{b^2}{S}\right)$

A.S.I. indicated airspeed in m.p.h. (differs from E.A.S. by correction for instrument and position errors)

b span of wing or tail plane in feet

β beta—side slip (angle of)

B.Th.U. British Thermal Unit

C chord of wing or tail plane

$\bar{c}$ mean chord of wing $= \left(\frac{S}{b}\right)$

C_D total drag coefficient

C_{DB} parasite drag coefficient $= \left(\frac{D_B}{q \times S}\right)$

C_{Di} induced drag coefficient (of wing) $= (C_{DP} + C_{Di})$

C_{Do} profile drag coefficient (of wing $= \left(\frac{D_o}{q \times S}\right) = (C_{DW} - C_{Di})$

C_{DP} (parasite + profile) drag coefficient $= \left(\frac{D_P}{q \times S}\right) = (C_D - C_{Di})$
$= (C_{Do} - C_{DB})$

C_{DW} wing drag coefficient $= \left(\frac{D_W}{q \times S}\right)$

C_F skin friction coefficient

C_L total (wing + tail) lift coefficient

C_{LT} tail plane lift coefficient $= \left(\frac{L_T}{q \times S_T}\right)$

C_{LW} wing lift coefficient $= \left(\frac{L}{q \times S}\right)$

C_M pitching moment coefficient $= \left(\dfrac{M}{q \times S \times \bar{c}}\right)$

C_A normal force coefficient $= (C_L \cos\alpha + C_D \sin\alpha)$

C_P centre of pressure coefficient

$= \left(\dfrac{\text{distance of C.P. from aerofoil L.E.}}{\text{chord of aerofoil}}\right)$

C_T tangential (chordwise) force coefficient $= (C_D \cos\alpha - C_L \sin\alpha)$

C.G. centre of gravity

C.P. centre of pressure

γ gamma—ratio of $\dfrac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}}$

$= \dfrac{c_p}{c_v}$; for air $\dfrac{0{\cdot}240}{0{\cdot}1714} = 1{\cdot}403$

also—angle of glide

d diameter

δ delta—deflection or setting of control surface

D total drag of sailplane $= (D_P + D_i) \doteqdot (D_B + D_o + D_i)$

D_B body (plus tail unit) parasite drag $= (D_P - D_o)$

D_F skin friction drag

D_i wing induced drag

D_o wing profile drag = (skin friction—induced drag) $= (D_F - D_i)$

D_P (parasite plus wing profile drag) $= (D - D_i) = (D_B + D_o)$

D_W wing drag (+ve backwards along wind) $= (D_o + D_i)$

ε epsilon—downwash (+ve downwards)

E.A.S. equivalent airspeed = (A.S.I. + correction for instrument and position error)

ft foot or feet

g acceleration due to gravity = 32·2 ft per sec^2

h height above sea-level (ft)

h_T total head of air stream = (p + q) lb per ft^2

H centrifugal force

i setting of wing chord to fuselage datum

I moment of inertia

I.A.S. indicated airspeed (m.p.h.)

θ theta—angle of pitch (+ve looking to starboard, nose rising)

l arm (e.g. C.P. of tail to C.G.)

L lift (+ve up, normal to wind)

L.E. leading edge

m	mass (slugs) $= \dfrac{\text{weight in lb}}{g}$ *also*—metre
max	maximum value
min	minimum value
M	pitching moment (+ve looking to starboard, nose rising)
M_L	rolling moment
M_T	pitching moment due to tailplane = $(M—M_{NO\ TAIL})$
M.A.C.	mean aerodynamic chord
μ	mu—coefficient of friction
ν	nu—coefficient of kinematic viscosity
N	yawing moment (+ve looking down port wing advancing)
n	normal acceleration factor
N.T.S.	normal top speed = 0·87 V max.
ϕ	phi—angle of roll
p	static pressure of air (lb per ft²)
P	tail load
q	dynamic pressure of air stream $= \frac{1}{2}\rho v^2 = \frac{1}{2}\rho_0 v$ (lb per ft²)
r	radius (ft)
ρ	rho—air mass density (slugs per ft³)
s	semispan of wing $= \left(\dfrac{b}{2}\right)$ *also*—second
S	area of wing (ft²)
σ	sigma—air relative density $= \left(\dfrac{\text{density at height}}{\text{density at sea-level}}\right)$
t	time (sec) *also*—maximum thickness of wing
T	temperature (°F) or (°C)
T.A.S.	true airspeed (m.p.h.)
T.E.	trailing edge
u	circumference (ft)
v	velocity (ft/sec)
V_D	design diving speed (m.p.h.)
v_v	vertical velocity (ft/sec)
v_w	velocity of wind
V	velocity (m.p.h.)
V_l	landing speed (m.p.h.)
V_m	minimum speed (m.p.h.)
V_{max}	maximum speed (m.p.h.)

v_S sinking velocity (ft/sec)
V_{ST} stalling speed (m.p.h.)
V_{SS} sideslip speed (m.p.h.)
V_T terminal velocity (m.p.h.)
V_{TS} towing velocity (m.p.h.)
w wing loading (lb/ft^2)
W weight of sailplane
X axis (+ve forwards)
Y axis (+ve to starboard at 90° to X axis)
Z axis (+ ve downwards at 90° to X and Y axis)
$\left.\begin{matrix} x \\ y \\ z \end{matrix}\right\}$ axis of reference fixed in C.G. of the sailplane

CHAPTER I

METEOROLOGY

THE source of the main energy available to the soaring pilot is often an unknown factor to him. The scarcity of really interesting and successful flights is largely due to lack of knowledge of this important subject. This part of the book is not intended as a meteorological treatise, however, and it is limited to the discussion of matters which may be useful to many soaring enthusiasts during thermal and cross-country flights and flights in clouds.

How often the soaring pilot takes off without having the slightest idea of the condition of the air or its behaviour; how often lack of information about the weather is the main thing that spoils a flight which might otherwise be perfect. It is of immense importance for the soaring pilot to know the qualities of the air when he makes a flight, and these can be explained quite easily in terms of thermodynamics, a science in which the soaring pilot will find much fascinating matter to be explored.

THE ATMOSPHERE

The atmosphere is a mixture of a number of gases and vapours which surround the earth and rotate with it. These gases and vapours differ radically from one another in every particular. The chief independent gases in the atmosphere at the surface of the earth are nitrogen (78 per cent), oxygen (21 per cent), argon, carbon dioxide, hydrogen, neon, helium and water vapour which is found in varying quantities. For any given pressure, the higher the temperature the greater the percentage of water vapour which may be present, but this seldom amounts to more than 2·5 per cent of the total gases present. At the surface of the earth the average proportion of water vapour is 1 per cent although of course it is greater over the ocean than over the land. The percentages of all these gases are constant to a height of approximately 7 miles (except for water vapour), and this is the average limit of noticeable vertical movements of the air.

As well as the above constituents the air also contains the following impurities—dust, soot and salts. Dust and soot are most frequently found over industrial regions. The minute particles of salt in the air are formed by the action of the wind in tossing up spray from the sea, and by evaporation. These impurities are of great importance to the soaring pilot, as they change the visibility. If there are no impurities in the air there will be no appreciable condensation of water vapour and visibility will be good.

PRESSURE

The atmospheric pressure is the pressure of a column of air acting on a unit area. The average pressure in the British Isles is 14·7 lb/in.² Mercury placed in a glass tube and turned upside-down in a vessel full of mercury, will show that if the atmospheric pressure is 14·7 lb/in.² the height of mercury in the glass tube, above the level of the mercury in the vessel will be 30 in. If this apparatus is

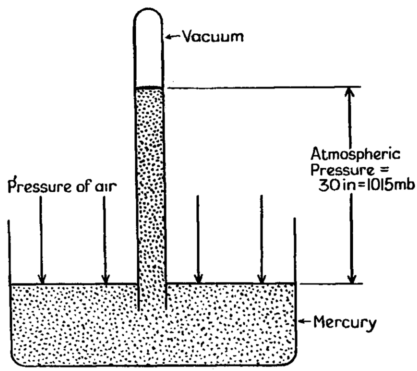


FIG. 1. SIMPLE MERCURY BAROMETER SHOWING A GLASS TUBE FILLED WITH MERCURY AND INSERTED IN A VESSEL

taken up in the air the height of the mercury will decrease with altitude because the smaller pressure of the air will be unable to support it.

This set-up of glass tube and vessel fitted with a millibar scale is called a barometer. 1000 millibars equal 1 bar, which is equivalent to 29·53 in. In the British Isles the average pressure at sea-level is 1013·2 mb. As the changes in the height of mercury with altitude are directly proportionate, the barometer may be used as an altitude indicator and is then called an altimeter. A change of 1 mb is equivalent to 30 ft. Altitude, however, as well as being a function of pressure is also a function of air density and temperature, and normally altimeters are calibrated to give readings based on a standard atmosphere.

To simplify the comparison of performances, the major countries of the world have adopted the International Standard Atmosphere.

STANDARD ATMOSPHERE

This is an arbitrary condition of temperature, pressure and density with altitude which is used for comparing performances, as follows—

Ground temperature $T = 15°C = 59°F$
Isothermal temperature $T' = -55°C = -67°F$
Temperature gradient $a = 0{\cdot}0065°C/m$
$= 0{\cdot}003566°F/ft$

The air—a perfect, dry gas.

The aneroid barometer can be substituted for the mercury type, and as its name implies, this is a non-liquid instrument. The main

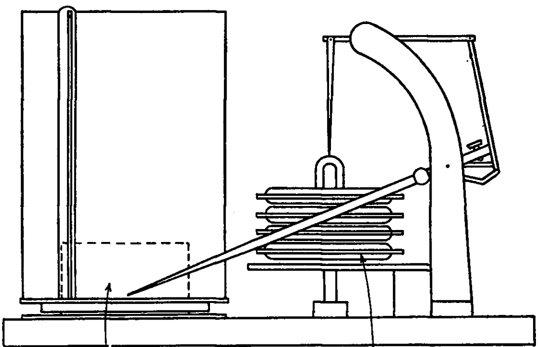


FIG. 2. BAROGRAPH USED FOR ALTITUDE RECORDING DURING SOARING FLIGHT

part of this barometer is a disc-like vacuum cell, the corrugated flexible ends of which are held apart by a short, stiff spring. If the atmospheric pressure changes, there will be corresponding flexure of the spring and the motion of this spring will be indicated by means of a pointer or recording pen. The movements of the pointer or recording pen are usually compensated, by means of a bimetal arm, for temperature changes.

The barograph is an automatically recording instrument which provides a continuous graphic record of the atmospheric pressure. It is usually an aneroid which moves a pen instead of a pointer, and the pen traces the pressure-record on a chart carried by a drum operated by clockwork. It can be seen that this instrument can indicate a change of pressure due to height or due to weather, and in the former case it is called an altimeter and in the latter a barometer.

The difference between an altimeter reading and the standard atmosphere may be as much as 300 ft and for this reason a thermograph is required, as well as a barograph, for the accurate registration of altitude record flying.

TEMPERATURE

The sun is the only source of heat energy that is supplied to the surface of the earth and to the atmosphere. This is of the greatest importance to the soaring pilot because the heating of the earth is responsible for the varying conditions of the troposphere. Any change in the intensity of the radiation absorbed by the earth

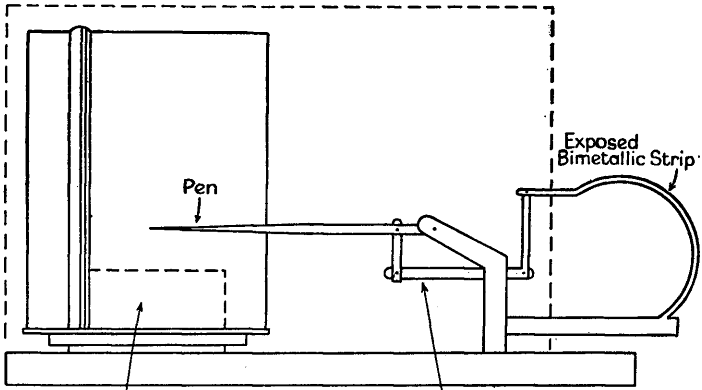


FIG. 3. THERMOGRAPH—TEMPERATURE RECORDER

during a day leads to about the same change in the average intensity of the radiation lost by the earth. Changes in the temperature and temperature-distribution of the atmosphere provide the strength of winds and other weather elements. This subject will be discussed in detail in the chapter on thermo-currents. For the moment the discussion will be limited to temperature only.

Normally, with increase of height the temperature of the atmosphere decreases, and any portion of the atmosphere transferred without loss or gain of heat from one level to another, has at every stage the same temperature and density as the surrounding air. The rate of change of air temperature per unit increase of height above the earth's surface, is called the lapse rate. The lower region of atmosphere, where the temperature fall averages 5·4°F per 1000 ft is called the troposphere. The upper region, where the temperature remains constant with increase in height, is called the stratosphere.

The temperatures of the air are measured by means of a thermograph. This is a self-recording thermometer which provides a continuous graphic record of the temperature. The type most commonly used in meteorology is the bimetallic thermograph. The

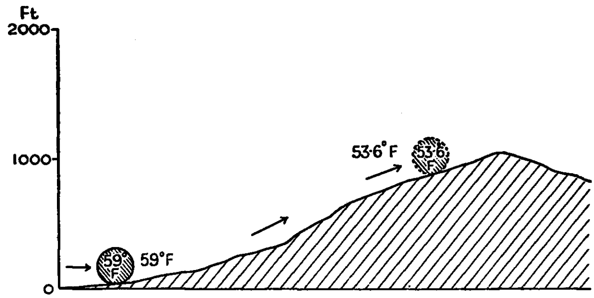


FIG. 4. NEUTRAL CONDITIONS
Bubble of air mechanically forced upwards retains characteristics of surrounding air.

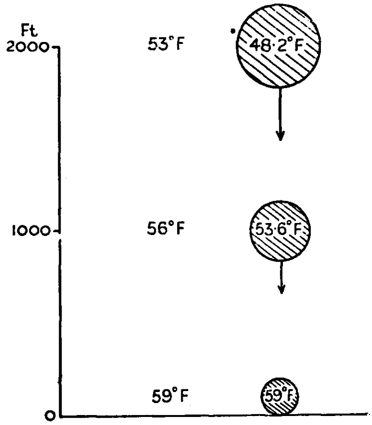


FIG. 5. STABLE CONDITIONS
The atmospheric lapse rate is 3°F per 1000 ft. The bubble of air has a tendency to fall to a lower level.

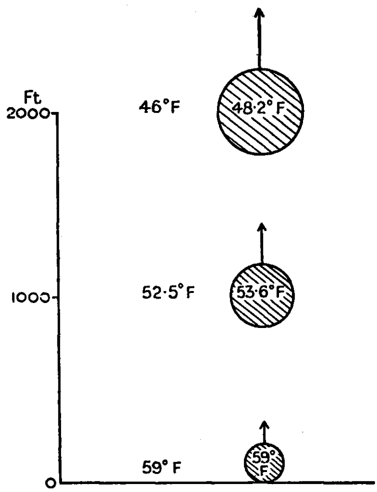


FIG. 6. DRY ADIABATIC LAPSE RATE CONDITION
The bubble of air moves vertically, expands and cools.

bimetallic strip, consisting of two curved thin sheets made from metals of widely different thermal expansions, is fixed to the frame. The rise in temperature changes the curvature of this strip and its free end moves up or down.

A decrease in temperature of the atmosphere of 5·4°F per 1000 ft increase of height is known as the *dry adiabatic lapse rate*—dry because no cloud will develop in such a condition, and adiabatic because no heat is being transferred to or from it. If a bubble of air has moved vertically with altitude (Fig. 4) it will expand and cool at the dry adiabatic lapse rate. The surrounding air has a lapse rate of 5·4°F per 1000 ft. The result of equal temperature between the bubble of air and the surrounding air will be that no change in density, and no vertical motion, will be imposed on the bubble of air. This condition is called neutral.

Should the atmospheric lapse rate be 3°F per 1000 ft, i.e. less than the dry adiabatic lapse rate, then the dry bubble of air which has

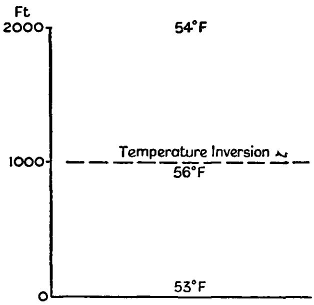


FIG. 7. TEMPERATURE INVERSION

When the temperature of air increases with height up to 1000 ft and then decreases, temperature inversion will be formed at 1000 ft, and the bubble of air moving upwards will be stopped at the inversion level.

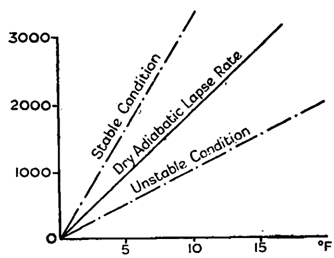


FIG. 8. EFFECT OF CHANGE IN DRY ADIABATIC LAPSE RATE ON ATMOSPHERIC CONDITIONS

It can be said that the dry adiabatic lapse rate drops steadily at the rate of 5·4°F per 1000 ft, which is shown as a continuous line. All lines below this will indicate greater lapse rate—unstable condition.

been moved vertically (mechanically) as shown in Fig. 5, will cool at the dry adiabatic lapse rate which is 5·4°F per 1000 ft and will have a tendency to fall to a lower level. This is because the bubble will be colder and denser than the surrounding air. This condition of the air is called *stable*. On the other hand, if the temperature of the surrounding air is lower than the temperature of the air bubble, and the lapse rate equal to 6·5°F, then it is natural that the bubble of air will have a tendency to rise. It will cool at the dry adiabatic lapse rate and, being warmer and lighter, will move upwards. This condition of the air is called *unstable*. The greater the temperature difference at the beginning of bubble-movement, the higher the bubble will be able to travel before it cools to the same temperature as its surrounding air. Unstable conditions of air do not exist for very long periods, because changes of weather restore the atmosphere to stable conditions.

Sometimes the temperature of the air increases with height, after which it decreases in the usual way. This condition is called temperature inversion. For instance, the surface of the earth, which is a much better radiator than the atmosphere, very often cools to a lower temperature than the air 300 ft or so above it, especially during clear nights. Hence, when the sky is clear and there is a very light wind or none at all, the temperature of the air near the ground increases with increase in height. Even when there is sufficient wind to prevent this inversion, the lower level is still colder than it otherwise would be. The lapse rate of air when inversion takes place is called the *negative lapse rate.*

HUMIDITY

Air which has moved over the ocean contains a quantity of water, and the amount of water present in a given volume of air is known

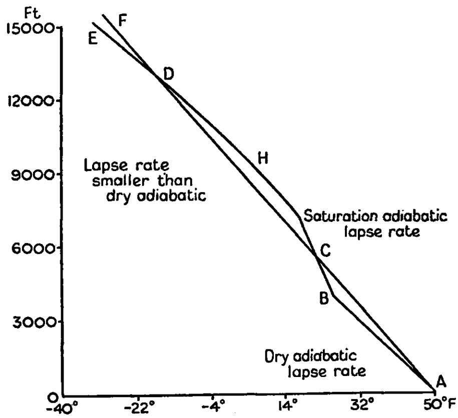


FIG. 9. VARIOUS CONDITIONS OF THE ATMOSPHERE

as its relative humidity. This value is usually given as a percentage. The relative humidity over the British Isles is approximately 70 per cent.

Whenever water is evaporated into the air it takes 318 B.Th.U.s to convert each 0·035 oz of water into vapour, and conversely it can be said that whenever vapour is condensed into water 318 B.Th.U.s are released from 0·035 oz of vapour. When a rising bubble of air becomes saturated due to adiabatic cooling, the actual rate of cooling becomes smaller, as there is a release of heat due to condensation. The value of this new rate is approximately half of the dry adiabatic lapse rate.

The maximum amount of water-vapour which the atmosphere can absorb depends entirely upon the temperature, and the higher the temperature of the air, the more water-vapour it can absorb. When the air can contain no more water, it has a relative humidity equal to 100 per cent and is said to have reached saturation point. When the temperature of saturated water-vapour decreases, the result will be the condensation of the water into small visible drops. If the pressure and temperature are constant, then air which contains say 4 per cent water vapour is less dense than air containing only 0·1 per cent.

If the lapse rate is shown as *AF* (Fig. 9) and is smaller than the dry adiabatic, and *AB* is the dry adiabatic (the lapse rate of the upward

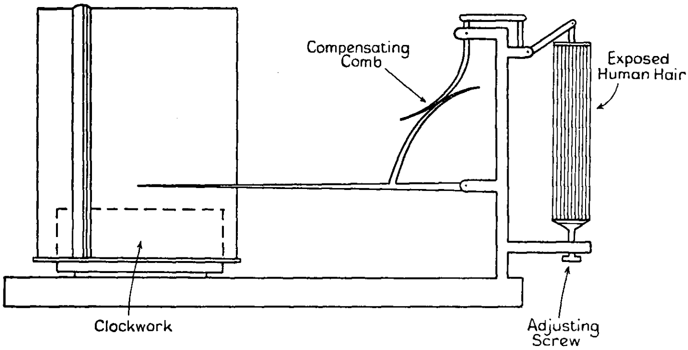


FIG. 10. HYGROGRAPH—HUMIDITY RECORDER

moving unsaturated bubble of air), then the saturation adiabatic lapse rate will be *BCHDE*. This means that the rising air will first cool at the dry adiabatic lapse rate (along line *AB*) then from *B* to *C* the cooling rate will be the saturated adiabatic. The air along *ABC* will be colder than the surrounding air and will be stable. Along *CHDE* the air will be warmer and unstable.

The *relative humidity* is the ratio of the quantity of water-vapour present in the air, to the saturation quantity for a given temperature. The *absolute humidity* is the ratio of the volume of water-vapour present, to the volume of air. *Dew point* is the temperature at which saturation has been reached without change of pressure, and at which condensation of the water-vapour into liquid begins.

The amount of moisture in the air is measured by means of a hair hygrometer, or by a dry bulb and wet bulb thermometer. The hygrometer or hygrograph is a self-recording instrument and gives a continuous graphic record of the relative humidity by means of the measurement of the variation in the length of a bundle of human hair. The length of the human hair varies with the moisture of the air, increasing its length with an increase in relative humidity, and vice versa. Each hair in the bundle is fixed at the ends, and the centre is connected to a pen so that the connecting mechanism keeps the hair in tension.

The dry and wet thermometer consists of two thermometers. The bulb of one is kept wet by a strip of muslin which is tied round the bulb with its ends immersed in a vessel of water. The wet bulb

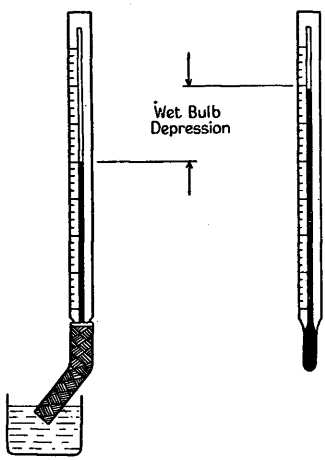


FIG. 11. WET AND DRY BULB HYGROMETER

is cooled by the evaporation from its surface, so that the two thermometers show different readings. The less the air is saturated with water-vapour, the stronger is the evaporation from the surface of the wet bulb, and consequently the greater the difference between the two thermometer readings.

EVAPORATION

If an upward moving bubble of air is moist but unsaturated it will cool, moving from *A* to *B* (Fig. 12), at the dry adiabatic lapse rate. At *B* it will become saturated and form a cloud. From *B* to *C* it will cool at the saturated adiabatic rate and hold all the water condensed. From *C* to *D* the temperature is constant and is equal to 32°F. In travelling from *C* to *D* the water in the air will freeze, and when this happens the temperature will fall at the saturated adiabatic rate until all the vapour condenses at *E*.

Sometimes when the bubble reaches temperature *B*, dew point, it will continue to rise and cool at the saturated adiabatic rate. As its temperature is above freezing point, the water-vapour, which is in a condensed form, will be released as rain. When the curve approaches freezing point, however, there will not, as might be expected, be hail, as there will not be enough water left to freeze and it may only change into snow and precipitation in the form of snow. Hail can form only in thunderstorm conditions.

The water vapour present in the atmosphere comes from the

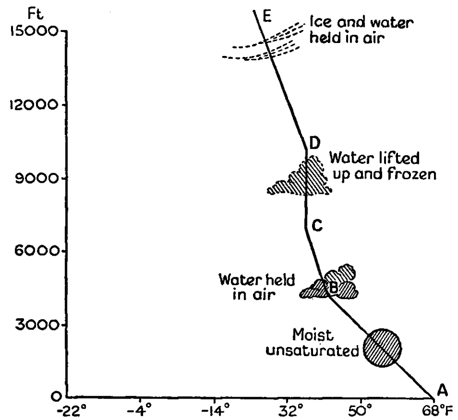


FIG. 12. MOIST UNSATURATED BUBBLE OF AIR MOVING UPWARDS

evaporation of water from oceans, lakes and the active surfaces of vegetation. When the vapour pressure in the air above the water surface is less than the saturation value, water will evaporate from the surface and mix with the air. The speed of evaporation depends on four factors: (*a*) the difference between the saturation vapour pressure at water level, and the actual vapour pressure in the air; (*b*) the velocity of the wind, which means that evaporation increases with wind velocity; (*c*) the area of the surface; and (*d*) the temperature of the water, as an increase in temperature accelerates evaporation.

CONDENSATION

When the water-vapour in the air is saturated, the lowering of the temperature to below dew point results in condensation. When the surface of the earth is cooled during the night to a temperature below dew point, there is a direct condensation of water on the surface. Condensation in the atmosphere is caused by the cooling of the air masses, either by a cold surface below it, or by the expansion of the air when it moves up to regions of lower pressure. A bubble of air may travel in a horizontal direction over seas, lakes or big rivers, when, naturally, it will absorb more moisture. In these circumstances dew point approaches the temperature of the air and may remain constant, and condensation and precipitation may occur without the bubble rising, especially if it moves over cold ground or meets cold air or mountains.

Very often when warm air flows over cold sea or land, it cools from below and the cooling spreads upwards; the relative humidity increases and if it approaches 100 per cent, condensation will start in the form of fog or mist. As the cooling spreads upwards the fog will rise sometimes to several hundred feet. When there is no wind, only that part of the air which is in contact with the ground will be cooled and thus not fog but only dew or frost will form.

The principal forms of condensation are—

Free drops—fog, cloud particle, rain-drop.
Dew—condensed water.
Frost—actually dew formed on surfaces whose temperature is below freezing point.
Glaze—a coating of clear, smooth ice on the ground and trees.
Snow—soft frozen rain.
Hail—formed only in thunderstorms.

At very low temperatures water may be transformed from vapour to ice without passing through the state of liquid water, and vice versa.

PRECIPITATION. When the process of condensation is carried far enough, the water-drops or snow crystals may become so large and heavy that they fall from the cloud and, if they do not evaporate, may reach the surface of the earth.

RADIATION

As stated already, the sun is the only source of heat energy received by the earth's surface and by the atmosphere. This energy is transmitted by means of radiation which is in the form of electromagnetic waves usually called light and heat waves. Part of the sun's radiation consists of visible light, and the rest of heat. A body can be warmed by the absorption of either light or heat. A body which has a tendency to absorb heat energy faster than it radiates it, will become warm. The hotter the body the more intense is its radiation. Because the surface of the earth is a good radiator it is also a good absorber of incoming radiation, but as the atmosphere is a poor absorber of radiation, it takes most of its heat from the earth's surface.

The heat received in one place may be transported to another by means of conduction, radiation, or convection. *Conduction* is the transfer of heat by body contact. The air which is near the ground is heated by conduction. *Radiation* is the transfer of the sun's heat energy by means of waves. *Convection* is the transfer by means of currents or turbulence. The main transfer of heat in the atmosphere is by turbulence and convective currents—convective currents in a vertical direction and large scale air currents in a horizontal direction.

The lower part of the atmosphere is heated from the earth as very little of the sun's energy is absorbed in passing through the atmosphere and most of it is delivered to the surface of the earth. This heat energy is in the form of short wave-length radiation which is not easily absorbed by the air, but is absorbed by the surface of the earth. The air which is in contact with the earth tends to attain the same heat as its surface. The highest radiation is at the time when the sun is high in the sky, and a few hours after the sun has reached its zenith there is a balance between the loss and gain of heat.

The radiation of the earth depends entirely upon the character of the surface, and the specific heat of the particular elements of the surface must be considered; for instance, water has a large capacity for heat and its temperature changes relatively little, but the solid elements of the earth have a small capacity and temperature changes are much greater.

A portion of the heat energy which is absorbed is used to evaporate water, but the majority goes to warm the earth. This heat is accumulated within a few inches of the earth's surface, and naturally the degree of heat varies and depends on the character of the surface and on topographical features. The air which is in contact with the earth's surface becomes heated and the lapse rate in the lowest layer of air increases rapidly. When the lapse rate is greater than the dry adiabatic lapse rate, the layer becomes unstable and vertical currents form which carry the heat, and moisture picked up from the surface, to higher levels. These currents will be stronger over dry land, and weaker over wet ground and water. Bare rock, dry soil and metalled roadways take up relatively high temperatures, while grass-covered land and wooded areas remain cool.

Heat energy is also absorbed by seas and lakes but their temperature remains almost constant day and night. Part of the heat evaporates the water, and part of it is distributed over a deep layer of water, and as there is a frequent mixing of water layers caused by the wind, there will be very little temperature variation on the water surface.

CLOUDS

Clouds are the most useful visual indication of the conditions of the atmosphere. They are very important to the soaring pilot because they not only indicate current conditions, but their types, movements and sequence of change of form also provide a good index to the nature of the coming weather.

As already stated, clouds are formed by the cooling of masses of damp air caused by its upward motion. This water-vapour may be transformed into water or ice. The process of transformation is as follows.

Dry unsaturated air flowing over oceans, lakes, rivers and damp ground, vaporizes the water. Very often this water-vapour moves up in the air with up-currents, and as it does so its temperature decreases. It can move horizontally or vertically, and on its way up may meet conditions which accelerate condensation. The grade of condensation can be seen by the form of clouds. For example, heavy cumulus clouds mean extended condensation, very light or low clouds mean mild condensation, and stratus clouds, stabilization of condensation. The difference between clouds of various forms is due to the ascending motion of the air. The various motions are—

(*a*) Large scale convection.
(*b*) Turbulent motion.
(*c*) Uphill currents.
(*d*) Currents of warm air moving upwards over a wedge of cold air.

Convection currents produce conditions which are very unstable—strong up-currents and gusts. When the wind increases with height the clouds formed by convection currents sometimes take the form of long parallel lines equally spaced, each with a flat base. These are one type of cumulus cloud (see below).

Turbulent motion produces low-level clouds in the form of strato-cumulus. These can form only when the air on the surface of the ground is humid and when turbulence is active, usually when the ground is cold.

Air carried by a strong wind against a range of hills or mountains is forced to rise and, if sufficiently damp, a long bank of more or less continuous cloud forms on or near the high ground.

When warm air flows over a wedge of cold air, the cloud formed has no definite structure. As the ascent continues, the amount of condensed water-vapour increases, and the larger drops fall as rain.

Near the base of a sloping surface of cold air the cloud is called nimbo-stratus. Higher up the slope the cloud is more uniform, but much thinner, and is called alto-stratus.

From the soaring point of view clouds may be classified as lifting

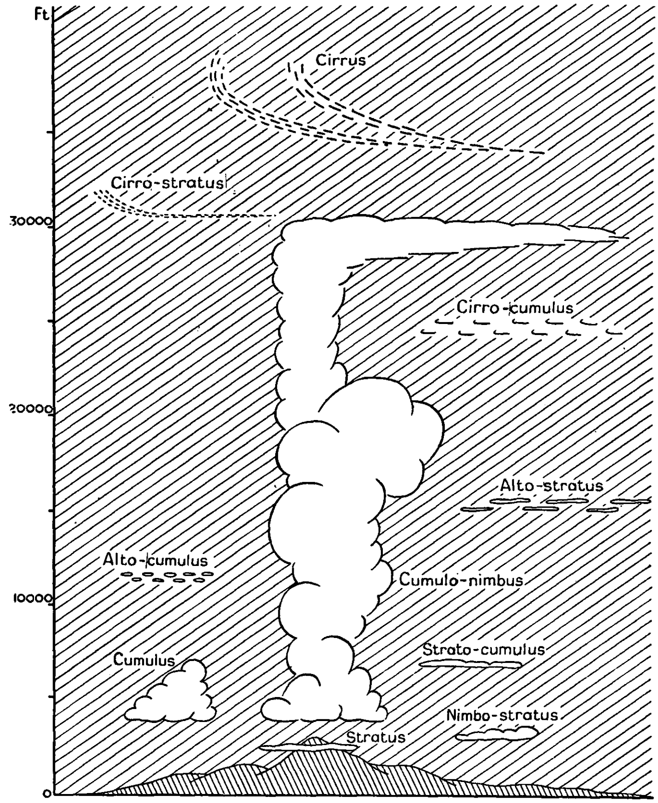


FIG. 13. CLOUDS AND THEIR CHARACTERISTICS

clouds, non-lifting clouds, and clouds which have not yet been explored.

Lifting Clouds

CUMULUS. This cloud is very important to the soaring pilot and it will be necessary to give a detailed description of it. Cumulus clouds are formed on days when there is enough moisture in the air to lead to condensation, when the cold air extends to great heights and the sun is shining. Thermal currents are then formed due to the warming up of the ground surface. Air which begins to rise in such a thermal current is warmer than the surrounding air but becomes cooler as it moves upwards. Then if the temperature reaches dew point, condensation will take place and cloud will form.

The main factor characterizing cumulus development is the instability of the air above the cloud base. If there is an inversion above the cloud base (temperature increasing with height) the cumulus cloud will be very flat, and will very soon disappear. Should the air above the cloud base be very unstable, cumulus

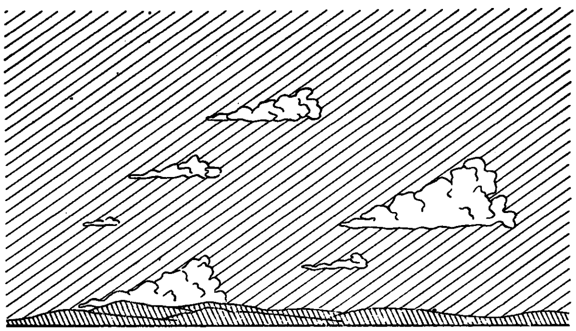


FIG. 14. FORMATION OF CUMULUS CLOUD

cloud may build up to a considerable height. If the air below the cloud base is stable, a milky vapour will form instead of cumulus, and on calm hot days this may cover the sky.

Apart from vertical movement within the cumulus, a slow rotation may be found. This rotational movement is started by thermal up-currents and is in an anti-clockwise direction in the northern hemisphere, when the cloud is viewed from above. The air motions within this cloud are great, and are reflected in the active bulges forming the cloud itself. When this cloud is growing, a great deal of condensation takes place, with the result that a large amount of heat is released. This additional release of heat adds to the air's instability and produces further cloud development.

If a temperature inversion is being formed, then thermal up-currents having a temperature equal to the temperature of the surrounding air cannot move upwards. Their movement is checked and they may even disappear completely. Cumulus clouds may form an inversion when, during unstable conditions of the atmosphere, large amounts of hot air are being carried upwards by means of up-currents. If this inversion is only in the form of a very thin layer, the vigorous cloud formation may penetrate it. In such a case the cloud may produce towers and even thunderstorms. During the day, as the temperature of air increases, the base of cumulus clouds will rise to higher altitudes.

The motion of cumulus cloud may be divided into three categories—

(*a*) Motion due to its formation.
(*b*) Motion due to wind.
(*c*) Rotation.

The main factor of interest to the soaring pilot is the degree of instability of the air above the base of the cumulus, as this controls the development of the cloud. If there is an inversion above the

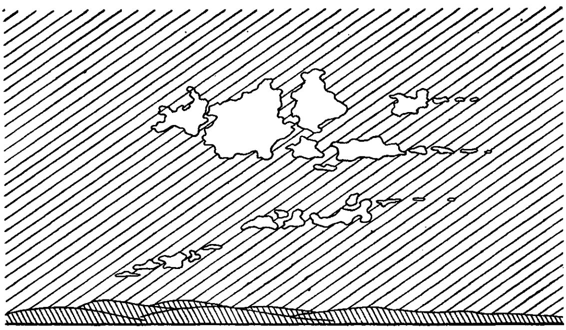


FIG. 15. DISSOLVING OF CUMULUS CLOUD

cloud, the vertical velocity of the thermal up-current will diminish. As cumulus cloud can only rise as far as it has been forced by such an up-current, it will flatten when it meets the inversion and may form strato-cumulus. If there is instability above the base of the cloud, the temperature of the surrounding air will decrease faster than the upward moving air in the thermal up-current, and the cloud may build up to high altitudes.

During its formation the cumulus cloud has fluffy edges and when it is dissolving it has hard and ragged edges. Dissolving cumulus is also characterized by its flat top. The time a cumulus cloud takes to dissolve depends entirely on the size of the cloud, and although a large cloud may take hours dissolving, the life of an average cumulus is fairly short, fifteen to twenty minutes from its birth to its disappearance. Nearly all clouds which form and grow rapidly, disappear with similar rapidity. The life of cumulus depends on heat supplied to the cloud by thermal up-currents. As long as there is such a supply the cloud is in the stage of development, but if this supply ceases the cloud will start to disappear. The dissolution may start from the top of the cloud downwards, or from the bottom upwards.

The formation of cumulus cloud depends entirely on thermal up-currents, and during early morning when the up-currents are weak, only small clouds will be formed. The time of maximum intensity of thermal up-currents is between 1 and 2 p.m. and during that time the maximum growth of cumulus may be expected. In summer, however, a second peak period between 4 and 5 p.m. may be observed. Naturally the base of cumulus will be higher in summer than in winter, as it is strictly associated with air temperature.

When the supply of heat during the growth of a cumulus cloud is stopped, mechanically or thermally, for a short period and then resumed, a second cloud may form and, due to the wind, follow the previous one. In such a way cloud streets are formed.

It must be admitted that it is often difficult to see if a cloud is forming or breaking up, and cumulus cloud looks very different from the air than from the ground. However, with some practice and a knowledge of the fundamental principles of cloud formation, this difficulty can be overcome, and the soaring pilot will learn to rely on his own judgment.

Characteristics. Average altitude 4000 ft, high altitude 12,000 ft, low altitude 1000 ft; approximate altitude of top of cloud—average 7500 ft, highest 12,000–15,000 ft.

CUMULO-NIMBUS. Cumulus cloud quite often grows to enormous size and if it contains water-drops or snow it is still called cumulus, but if it develops above freezing level it is classified as cumulo-nimbus. The main conditions necessary for this development are that there must be a large surface area over which there is an unlimited supply of moist air, a very unstable atmosphere and weak wind, or none at all. When the development takes place the water drops become supercooled and as the vertical currents in cumulo-nimbus are very strong, some parts of it may be pushed to very high levels and the water-drops turn into ice. The cloud then takes the form of an anvil. The cooling at high levels will lead to condensation, which liberates heat and allows convection to continue to a height of perhaps 40,000 ft.

Cumulo-nimbus generally appears as a heavy mass. It may develop far above the ground, and during its horizontal travel it will accumulate moist, cold air which sweeps over ground warmed by the sun. If the up-currents in front of the cumulo-nimbus are very strong, the suction of the moist air may be very great, and as a result a roll of cloud may form which will travel along with the moving cumulo-nimbus. This roll may extend for miles, providing excellent soaring conditions. Strong up-currents may also be found in the frontal part of the cumulo-nimbus. The middle part, however, will be a region of severe turbulence.

Cumulo-nimbus is associated mainly with very hot weather when there is no wind blowing, and with cold fronts where moist, cold air moves over warm ground. It often produces a thunderstorm.

Soaring pilots must remember that in cumulo-nimbus cloud icing conditions are very heavy. There is seldom any precipitation while the cloud is developing, but the rain usually starts when the cloud begins to disintegrate. When this happens the rain from the front of the moving cloud is usually very light, increasing towards the rear.

Characteristics. Average altitude 5000 ft, high altitude 8000 ft, low altitude 1000 ft; approximate altitude of top of cloud—average 18,000 ft, highest 42,000 ft; approximate thickness—average 7000 ft, greatest 30,000 ft.

NIMBUS. The formation of this cloud takes place, as a rule, in a warm front, when warm air moves along the edge of cold air. After the passing of cirro-stratus and alto-stratus cloud, a dark heavy cloud can be seen from which a steady rain falls. This is nimbus cloud.

The soaring pilot may find weak but steady up-currents in this cloud. They will not be so vigorous and concentrated as in cumulus or cumulo-nimbus, but with very careful manoeuvring it may be possible to soar and even to gain height. This weak lift may be found under the entire cloud base.

Characteristics. Approximate altitude 4000 ft; thickness 2000-4000 ft.

ALTO-CUMULUS. This cloud forms just below the cirrus level, the main difference being that alto-cumulus is formed from water particles instead of ice. These water particles are heated from two sources: directly from the sun and indirectly from the earth. During the day both surfaces of the cloud will have the tendency to evaporate, but during the night only the lower surface will evaporate as there is radiation from the earth and the air may move upwards. The upper part of the cloud will cool, however, and the air may begin to move downwards. This vertical movement of air may last long into the night, until the cloud disappears completely.

Alto-cumulus produces waves and bands, due to the flow of one layer of air over another of different temperature, density and humidity. Waves produced in such a way may have great length and amplitude. Their birth is very similar to the birth of sea waves. The air motion leads to differences in temperature, and as the top of the wave is colder the water-vapour may condense into cloud. The lower part, being warmer, may remain clear. The vertical velocity found in such waves may be of 3–4 ft/sec. The waves can be affected by the wind, and if the wind above the waves is stronger than below they will lie with the wind. If it is not very strong the waves may lie across the wind.

As the conditions within alto-cumulus are very unstable, thunderstorms often develop from them.

Characteristics. Average altitude 13,000 ft, high altitude 36,000 ft, low altitude 5000 ft; average thickness 1000 ft.

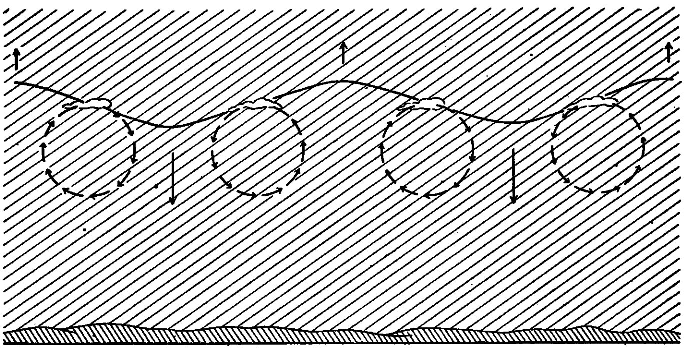


FIG. 16. WAVES PRODUCED IN ALTO-CUMULUS CLOUDS

STRATO-CUMULUS. A heavier and lower variety of alto-cumulus, strato-cumulus as a rule is in the form of dark walls or waves which may lie very close to each other. It appears when upward-moving air is in a state of condensation stopped at a certain level due to inversion. It is most frequent in winter in anti-cyclonic conditions when strato-cumulus may cover the whole sky, with occasional gaps here and there through which the sun may be visible.

Characteristics. Average altitude 7000 ft, high altitude 24,000 ft, low altitude 2000 ft; approximate thickness 1200 ft.

NIMBO-STRATUS. This is a typical frontal cloud and is formed by the over- and under-running of air masses of different temperatures and densities. It forms a low layer of dark grey colour, which is nearly uniform, and usually brings continuous rain and snow. It is associated with stormy conditions over an extensive area. Strong vertical currents may be found under this cloud.

Characteristics. Average altitude 3000 ft, high altitude 6000 ft, low altitude 500 ft; approximate thickness 4000 ft.

Non-lifting Clouds

CIRRUS. This cloud is associated with large movements of air masses and appears at great heights. It is a detached cloud with a feather-like structure, whitish in colour. It is composed of ice crystals with extremely low temperatures, (—30°F to —40°F). It can generally be seen about 1000 miles ahead of a cyclone, and if approaching from the south-west in the northern hemisphere, is an indication of an approaching depression.

As cirrus cloud is associated with strong and changing winds, it will probably produce no lift suitable for soaring.

Characteristics. Average altitude 35,000 ft, low altitude 13,000 ft, high altitude 90,000 ft.

ALTO-STRATUS. The grey or grey-blue veil of alto-stratus usually appears at the same height as alto-cumulus. It is composed of small water-drops with occasional ice crystals, and the sun and the moon are usually hidden by it. It is often found in a cyclone.

Characteristics. Average altitude 15,000 ft, low altitude 6000 ft, high altitude 40,000 ft; approximate thickness 1700 ft.

STRATUS. This is the cloud which appears at the lowest altitudes and may envelop high ground completely. It resembles fog but does not rest on the ground. It is generally very wet.

Characteristics. Average altitude 2500 ft, high altitude 4000 ft.

THERMAL CURRENTS

The distribution of water over the surface of the earth and in the earth is the most important factor in the birth of thermals. A variety of physical effects combine to make water much more conservative of heat than land, and slower to warm up and cool down. This fact has a moderating influence on temperature to a considerable distance inland. Geological formations and their resultant soil types are also important factors in the determination of up-currents. Dark coloured soils and surfaces absorb more of the sun's heat than lighter coloured ones, and are generally warmer by day, causing the adjacent air to be warmer also. Dry soils such as sand have a low specific heat responding rapidly to temperature changes, while wet soils such as clay retain moisture and are therefore conservative of heat and cold. Foundations of chalk and limestone evaporate water fairly quickly, after which they warm up rapidly and are usually good sources of the birth of thermal up-currents. Forests and woods also affect temperature, particularly the maximum temperature, which they moderate by casting shade, offering a large surface for radiation, absorbing heat in the process of evaporation from the foliage, and the production of fog, mist and cloud which ward off the direct rays of the sun.

The sun's rays coming through the troposphere and clear atmosphere lose about 20–30 per cent of their heat energy. The intensity of the earth's radiation depends mainly on temperature, and the hotter the earth the more radiation there will be. For strong thermal currents the temperature difference must be very large over a big range of altitude, or the temperature difference between a thermal current and the atmosphere must be maintained to help to build up strong vertical movement.

A mass of air which is warmer than the surrounding atmosphere may be caused to rise mechanically or thermally, and it will move upwards with increasing speed until it dies out where the atmosphere is stable. When the mass of air has moved upwards, more air will flow in to take its place. This will also become heated and after a while form a new thermal current in the same place. The time taken in the formation of a thermal current varies considerably, and may be from five minutes to periods in excess of an hour. A mild steady wind is a help in the building up of a thermal current, especially when it forms on a hill slope, but a high wind prevents its formation.

As a rule thermal currents are most frequent during calm summer days, when they occur over roads, sand dunes, ploughed fields, wheat fields, beaches and rocks. Isolated hills, especially short or conical ones, have warmer sides than the adjacent atmosphere at the same level and act like chimneys producing up-currents.

For the formation of a thermal current the ground should be warmer than the air, which happens more often during spring and summer than in winter. Clear, sunny days are usually associated with cold polar air, and stronger up-currents are always found in a cold front than in a warm front. The maximum vertical velocity of thermal up-currents is surprisingly great, 1000–1500 ft/min, and they may even exceed these speeds.

After several hours of flying experience, the soaring pilot will find that he can locate the thermal up-currents quite easily; sometimes when the air is dusty it is also possible to see the rotation of the rising air.

THUNDERSTORMS

The thunderstorm most frequently occurs in early spring and early summer. For a thunderstorm to develop there must be sufficient moisture at an altitude of from 5000–10,000 ft, or an unstable condition of the atmosphere up to about 10,000 ft. Thunderstorms most usually occur in regions where there is strong surface heating, especially in regions of light winds, or when one layer of air overruns another of a lower temperature, producing convection, or when a saturated layer is underrun and uplifted by a denser layer. The period of a thunderstorm is very irregular, and its frequency and intensity depend upon the humidity of the air and the rapidity of the local vertical convection.

At the time when the earth reaches its maximum heat, usually between 1 p.m. and 2 p.m., the condition of the atmosphere is most

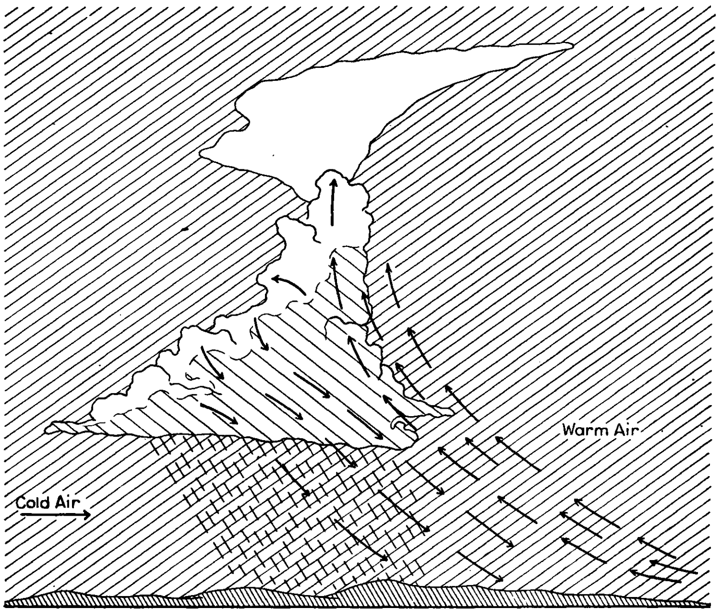


FIG. 17. THE AIR-MASS THUNDERSTORM

favourable to the formation of a thunderstorm because vertical convection of the air over land reaches its greatest altitudes and produces the heaviest condensation and clouds.

There are three main types of thunderstorm, air mass, frontal and orographic.

AIR-MASS THUNDERSTORMS. These occur in regions of high temperature and uniform pressure which are usually associated with light winds and small turbulence. The land in these regions is very strongly heated, causing intense convection. Thunderstorms in these regions take place after two or three days of very warm weather when the air near the ground is so intensely heated that convection reaches very high altitudes. The speed of movement of these thunderstorms is approximately 15–20 m.p.h., their area is 8–40 miles in diameter, and their base may be as low as 1000 ft. The most characteristic feature of this type of thunderstorm is that it takes place only during the day.

FRONTAL THUNDERSTORMS. If convection is caused not by land heating, but by cold air moving under warm air, the temperature lapse rate and the vertical convection itself will be greater, and this may bring high-level thunderstorms. They are caused when the warm air in its climb over the slowly moving cold air, releases its potential instability, which is followed by violent convection within

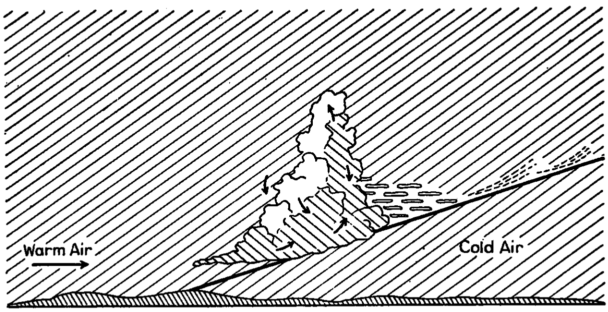


FIG. 18. UP- AND DOWN-CURRENTS IN CUMULUS CLOUD, WHICH IS DEVELOPING INTO A FRONTAL THUNDERSTORM

the cumulus cloud which has formed due to the adiabatic cooling of upward-moving warm air.

Because of higher temperatures, higher moisture content, and a greater degree of potential instability within the air masses, thunderstorms predominate during the warm seasons of the year.

OROGRAPHIC THUNDERSTORMS. These thunderstorms take place when the air is forced up a mountain slope, and are the heaviest type, extending to high altitudes. The average height is 15,000–20,000 ft.

THUNDERSTORM WINDS. Half an hour before a thunderstorm reaches a given place, the wind there begins to die down and to change its direction. As a rule the wind is from the south or south-west, which is always across the path of the coming storm. When the storm is very near, say half a mile away, the wind blows very gently towards the storm, and when the rain of the storm approaches, the wind blows in violent gusts with the direction of the coming storm. These sudden gusts of wind last only for a while, and move with the thunderstorm. Directly in front of the rain there is warm air which is forced upwards with great velocity by the incoming cold air.

When a thunderstorm is approaching there is usually a fall in barometic pressure, sometimes beginning several hours beforehand. The temperature when the thunderstorm arrives is rather high, but falls rapidly with the first gust of wind, sometimes to as low as 14°F.

There are a number of risks involved in flying in a thunderstorm, principal among which are the violently bumpy conditions and rapid changes in the direction of the air movements, which produce unequal loads on the wings of the sailplane, and are strong enough

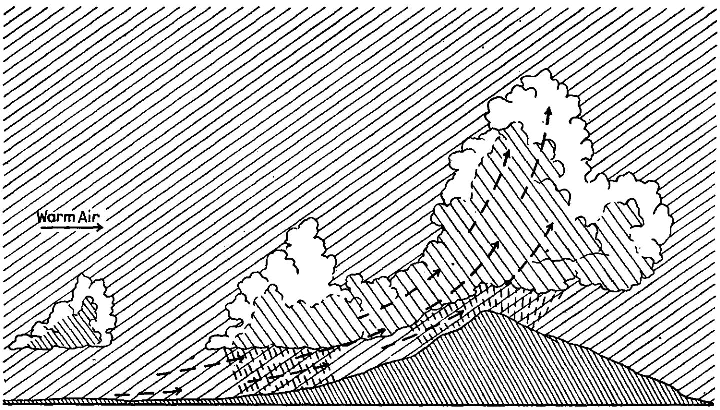


FIG. 19. OROGRAPHIC THUNDERSTORM

to break them. Another risk is that of being struck by lightning. Violent vertical currents lift drops of rain with considerable speed, causing them to break up and take on a positive charge of electricity while the surrounding air takes a negative charge. The charged water-drops, being heavier, collect in the lower part of the cloud, while the negatively charged air forms the top. These conditions give rise to the discharge of electrical energy between the different parts of the cloud, or between the cloud and the earth. When a sailplane enters an electrically-charged region, it may concentrate the charge, raise it above sparking point or, due to conductivity, short circuit it. As a sailplane is built mainly of wood, its electrical resistance is very high, and the discharge may cause it to catch fire.

AIR MASSES

When air of the same temperature and humidity covers a large area of land it is called an air mass. This area may extend to hundreds of square miles. If the underlying surface is uniform and if the air currents are favourable, the air mass will tend to become uniform in a horizontal direction. The areas where such air masses are formed are called air mass sources. The masses are known as tropical or polar.

CHARACTERISTICS OF TROPICAL AIR. Warm, moist, stable clouds, with temperature above surface temperature.

Maritime—very moist, low clouds; fog.

Continental—dry, high clouds.

CHARACTERISTICS OF POLAR AIR. Cold, dry near surface, unstable, thermal currents, broken cumulus clouds.

Maritime—clouds.

Continental—very cold and dry.

Because air travels from high-pressure to low-pressure areas, there will be, in the northern hemisphere, north winds blowing from the equator and south winds from the north pole. The direction of these winds is also affected by the rotation of the earth. The earth rotates from west to east and the air near the equator moves eastwards. Further from the equator the air will have less eastward velocity. The air which moves north in the northern hemisphere, owing to its greater eastward velocity, becomes a south-west wind, whereas the air moving southward is moving into a region which has a greater eastward velocity, so that the north wind becomes a north-east wind. As the two types of air mass are very vital to the soaring pilot, since many flights are affected by them, a more detailed explanation is given below.

The warm tropical air mass is stable as a rule, and the moisture content is high, particularly in the lower layers. When this mass travels towards a colder region, its temperature will be higher than the surface temperature over which it travels. As this warm mass cools from below, the temperature drop will extend over a large area, and may reach dew point, in which case fog will form.

The maritime tropical mass usually flows from the Mediterranean in summer and from the tropical Atlantic in winter. In this air mass there is generally a stable lapse rate, or an inversion in the lower layers, slight turbulence, steady winds, poor visibility, and high relative humidity. Stratus clouds, drizzle, mist, fog and dew may be expected. When a tropical mass invades a warm continent in summer, instability rapidly develops. In winter, however, the stability remains constant and deep layers of fog may cover large areas of continent.

The continental tropical mass comes mainly from North-east Europe in summer, and from North Africa in winter. This air mass is much drier than maritime air, and just average relative humidity may be expected. Visibility within this mass will be fair.

Within the polar air mass we find stable stratification, low specific humidity and low temperature. If this mass moves towards warmer regions, the temperature of the lower layers will be less than the surface temperature over which it travels. The polar air heated from below will develop thermal instability, and the resulting convective currents, after reaching the level of condensation, will form cumulus clouds and sometimes thunderstorms. This mass of air is generally associated with turbulence in lower levels, dry

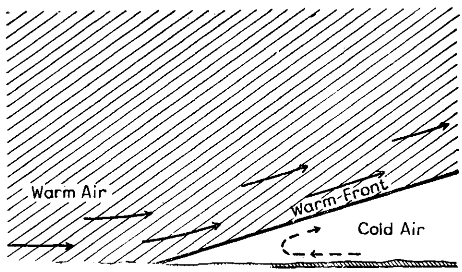


FIG. 20. GENERAL DIAGRAM OF WARM FRONT

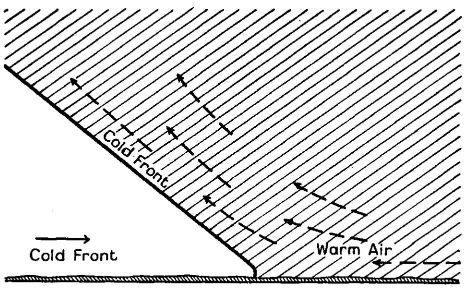


FIG. 21. GENERAL DIAGRAM OF COLD FRONT

adiabatic lapse rate, and good visibility. If it travels over water it will pick up moisture which, by means of convective currents, is brought up to higher levels. The result will be the formation of cumulo-nimbus clouds.

Fronts

When a mass of tropical air moves towards a mass of polar air, the line between these two masses is called a warm front, as the warm air is displacing the cold air on the surface of the earth. Conversely the line which separates a mass of polar air advancing towards tropical air is called a cold front.

A stationary front is that along which one mass does not replace the other. An occluded front is the front resulting from a cold front overtaking a warm front. To characterize the front it is necessary to use the cloud system as it is the only visual indication of the conditions producing a front.

(*a*) *Warm front*. Here the tropical air, having a much smaller density than the polar air, has a tendency to ascend along the frontal surface and to cool adiabatically. As it possesses some humidity this air will condense and a cloud system develop. A general picture of a warm front with typical cloud formation is given in Fig. 22. It can be seen that the warm and moist air moves slowly upwards and produces clouds 100–300 miles wide and as much as

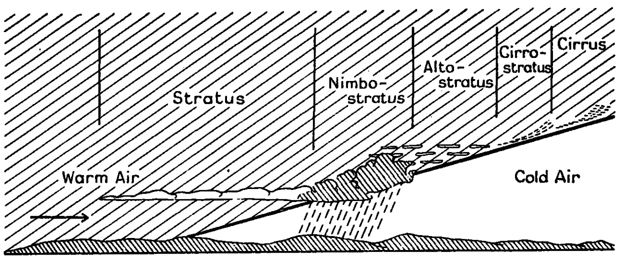


FIG. 22. THE WARM FRONT

1100 miles long. The height of the clouds is between 6000 and 20,000 ft. The upward-moving air cools and is usually associated with a period of complete cloudlessness at first, then cirrus and cirrostratus forms, and lower stratus and fog.

From the ground it is quite easy to recognize an approaching warm front as shown in Fig. 22. Generally a warm front will come from the south-west in England and will be indicated by a decrease of pressure and by thickening of clouds, particularly with altostratus clouds which bring rain in summer and snow in winter. Usually the clouds and precipitation will remain until the warm air covers the ground completely and the cool air becomes so shallow that it will not lift the warm air sufficiently to form clouds. In this warm front the movement of the warm air is so slow that there is not sufficient energy to build up-currents which will be strong enough for soaring. This type of storm is called a stable warm front.

In the unstable warm front, well ahead of it, cirrus and stratus cloud will be seen. Inside the front the air is warm, turbulent and very unstable. The soaring pilot may find strong up-currents and even scattered thunderstorms. These thunderstorms are of a more gentle character than the storms found in cold fronts. Icing conditions may be encountered whilst flying in a warm front as the clouds within it often consist of supercooled water and the temperature is between 15°F and 32°F.

When a warm front approaches London from Cornwall, as shown in Fig. 23, the first indication of the approaching storm in Cornwall will be north-east moving cirrus and cirro-stratus cloud; then rain will cover the area. The indication that a warm front is passing Cornwall will be a decrease of rain, a rise of pressure, a change of wind (in the cold region there was north wind which changes to

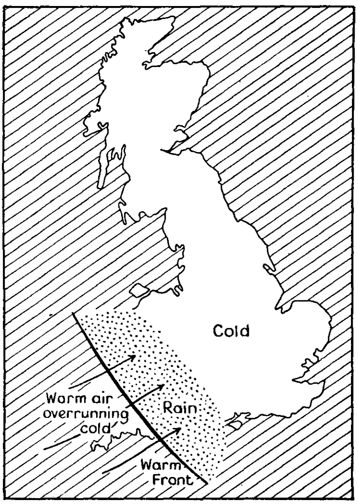


FIG. 23. WARM FRONT MOVING NORTH-EAST

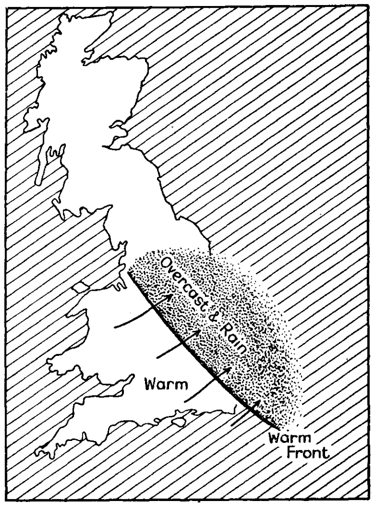


FIG. 24. WARM FRONT PASSING THE MIDLANDS

south-west), and an increase in temperature. Due to convective instability, clouds will form and thunderstorms may occur in this front, and the same front passing the Midlands will produce overcast skies and heavy rain.

(*b*) *Cold front.* A tropical moist air mass originating over regions of considerable heat and moisture becomes very moist up to high levels. When very dry polar air moves in the form of a wedge into a mass of warm air, the warm air is pushed upwards. This causes it to cool adiabatically, generally to such an extent that saturation and cloud formation result. As a rule these clouds are cumulus, and are actually formed by convection or instability within the air mass along the cold front.

When the head of the cold front moves into the area of warm air, a regular line of cumulus and cumulo-nimbus clouds may form. In front of this line, and over it, the warm air will ascend, and as the speed of travel of the cold front is from 25 to 40 m.p.h., the ascent of warm air may provide sufficient vertical velocity to give good soaring conditions. As condensation is taking place in the line of the cold front due to the heat release, strong up-currents may be found, especially during the warmer months of the year when heavy cumulo-nimbus clouds and thunderstorms form.

Cold fronts usually approach from the west and travel in an easterly direction. Their approach is characterized by an increase

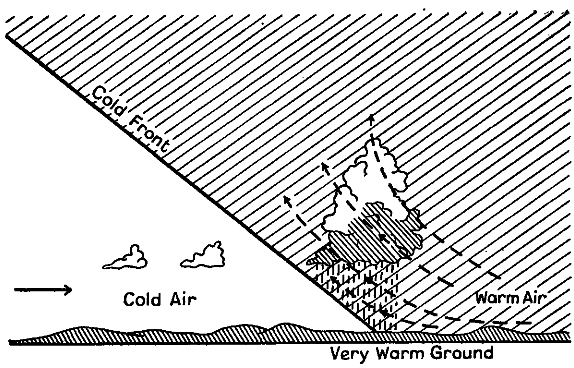


FIG. 25. COLD FRONT
Heavy cumulus and cumulo-nimbus clouds forming in front of it.

in pressure on the ground and by a decrease in temperature. When the main impetus of the storm passes there may be heavy precipitation in the form of rain and hail, as the strong down-currents, which are usually associated with the rear part of cumulo-nimbus, increase the downfall of rain-drops.

When a cold front travels over flat country and there is no disturbance caused by the ground surface, it may take the form of a roll of clouds within which heavy turbulence may be expected. As the cold front travels, the cold mass of air increases in thickness, and if the surface of the ground happens to be warm and wet, thermal convection may develop, producing excellent soaring conditions. Soon after the passage of a cold front, cumulus clouds will very often form and may develop into cumulo-nimbus.

The soaring pilot who attempts to soar in the advance of a cold front should always stay ahead of the thunder-cloud as it is possible to be sucked into the cloud area where very severe up- and down-currents prevail, which may cause the structural failure of the sailplane.

(c) *Occluded front.* As the speed of travel of the cold front is fast it may overtake the slow-moving warm front. When the two fronts

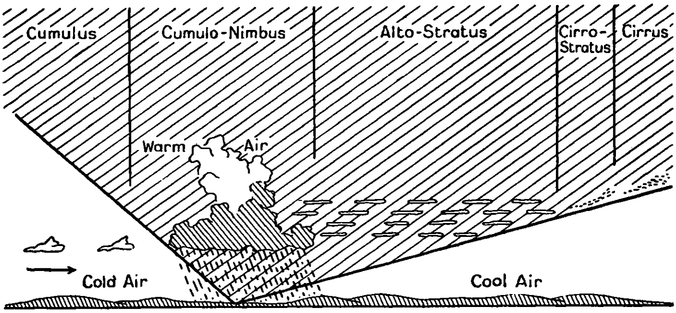


FIG. 26. FAST-MOVING COLD FRONT CATCHES UP WITH SLOW-MOVING WARM FRONT AND FORMS OCCLUDED FRONT

meet, the area of warm air which is between them will be squashed and will move upwards. The warm region is then said to be occluded. When this happens the misty drizzle-belt characteristic of the warm region will be eliminated.

Cold front occlusion occurs when the air in the rear of a cold

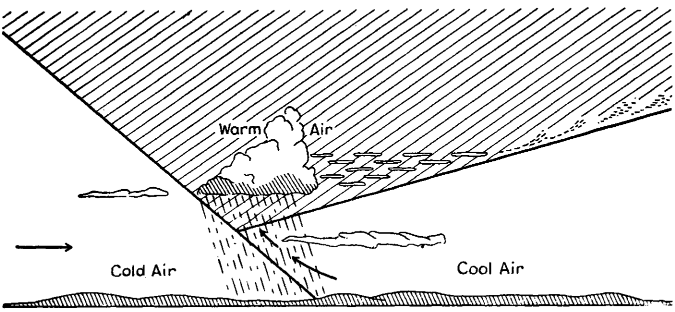


FIG. 27. COLD FRONT OCCLUSION

The cold air displaces the cool air, pushing it up. This cool air will move along the cold front.

front is colder and therefore denser than that in advance of it. This colder air will displace all other air during the cold front travel, pushing it up, and the cool air on the head of the front will start moving up along the slope of the cold front. The weather associated with this will be similar to warm front weather. Precipitation will extend back into the area of colder air, and heavy low clouds may form within this colder air mass.

In a warm front occlusion the air behind the cold front is warmer and less dense than that in advance of it. The cold front will start climbing along the colder air beneath the warm front. This type of occlusion is very common. The weather will be of the cold front type.

(*d*) *Warm front approaching mountains.* When the warm air moves towards a mountain range it will be lifted up by the slope of the mountains. This will cause very intense convection over the

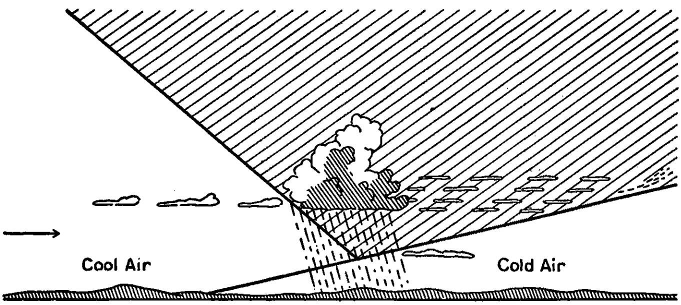


FIG. 28. WARM FRONT OCCLUSION

mountains and precipitation will take place, first in the form of light rain, then steadily growing in intensity. Severe thunderstorms may develop.

A warm front usually breaks up over a mountain range, and part of the warm air may descend along the lee slope while the other part may move upwards. Heavy cumulo-nimbus cloud may develop over the peak of the mountain and remain there for a long time, eventually changing into stratus. As much of the moisture content is lost through precipitation, lasting sometimes several hours, the cloud may disappear and the weather improve until the undercutting cold air arrives.

The part of the warm air which has been lifted over the peak of the mountain moves up along the cold air and may cause vigorous convection and high thunderstorms.

(*e*) *Cold front approaching mountains.* This condition is of great importance to the soaring pilot because heavy up-currents are often associated with it, extending to very high levels. Cold front characteristics change in accordance with the terrain over which it passes. Mountains will slow down the speed of travel of a cold front.

When the cold air is lifted over a mountain range, precipitation

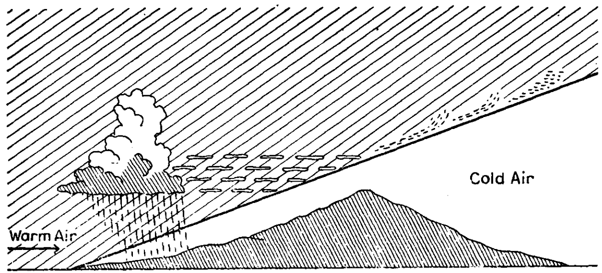


Fig. 29. Warm Air moving towards a Mountain Range

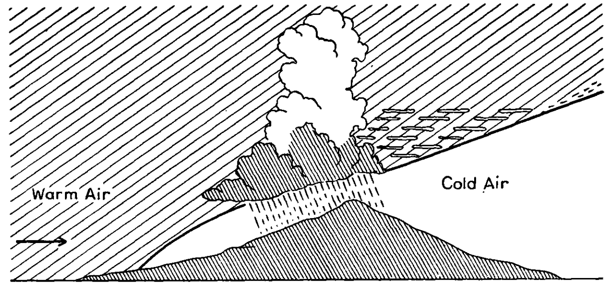


Fig. 30. Development of Warm Front Thunderstorm over Mountain Range

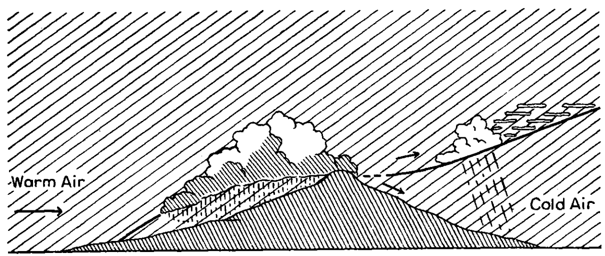


Fig. 31. Breaking up of Warm Front over Mountain Range

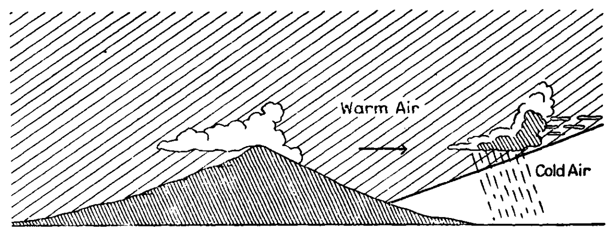


Fig. 32. Warm Air lifted up by Mountain range causes High Thunderstorms

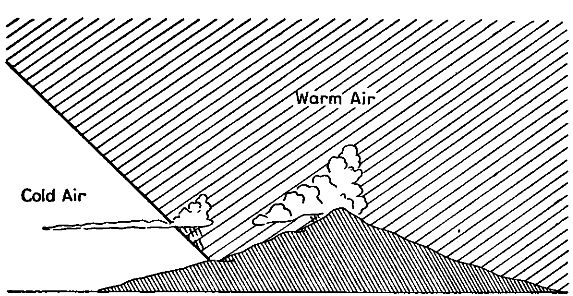


FIG. 33. THE MOUNTAIN RANGE SLOWS DOWN THE SPEED OF TRAVEL OF COLD FRONT

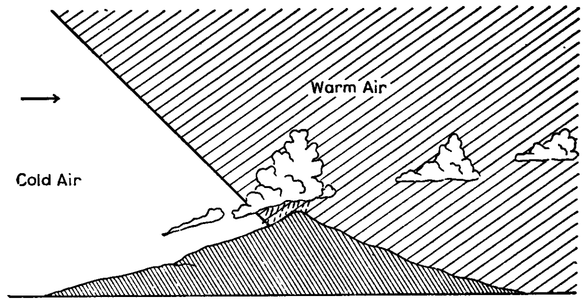


FIG. 34. COLD AIR LIFTED UP BY MOUNTAIN RANGE PRODUCES INSTABILITY WHICH MAY EXTEND TO VERY HIGH LEVEL

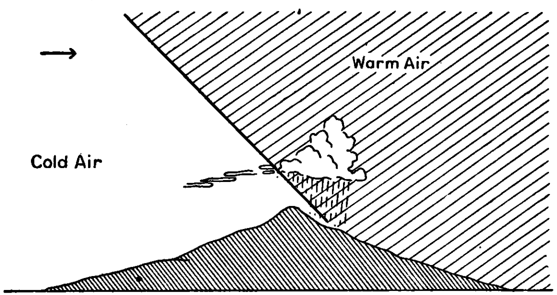


FIG. 35. COLD FRONT PASSING MOUNTAIN RANGE

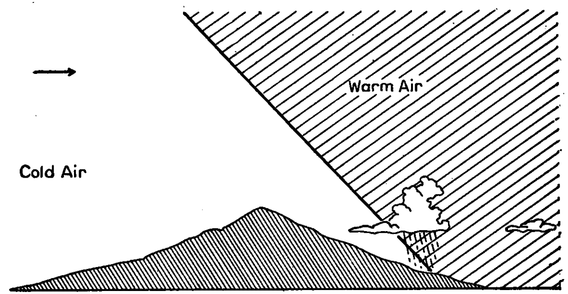


FIG. 36. COLD AIR PASSING THE MOUNTAIN RANGE BECOMES WARMER, CLEARER AND STABLE

will occur, mainly in the form of rain, but sometimes as snow, especially over the higher ridges. When the air starts descending along the lee side of the mountain it is heated adiabatically, and at the bottom of the mountain it will have a much higher temperature than originally, and a much lower specific humidity. On the way down the slope the air will become clear, warm and stable.

CYCLONE

It has been stated before that over the earth's surface there is a continuous circulation of air from one source to another, and at the beginning the various movements owe their characteristics to the source over which they have originated. During progress over land and sea these characteristics will change, and if the air takes a long time to travel over a certain type of area, it will assume local characteristics. Movement of the air is always from high pressure to low, but the path of travel will not follow a straight line. Differences of pressure are due to the differences in temperature which are met over the earth's surface.

The rotation of the earth has a great effect on the direction of air circulation, and in the northern hemisphere the air is constantly deflected to the east. In areas of low pressure there will be a tendency for air to flow outwards in the form of a spiral, and in areas of high pressure, inwards.

Another factor which affects air circulation is the friction between moving air and the earth's surface.

Areas of low pressure, where cold polar air is mixing with warm tropical air, are called cyclones or depressions. These areas are very extensive and usually have a diameter of about 1000 miles. The direction of movement of a cyclone is generally from west to east, and the velocity of travel is greater in winter than in summer. They are also more frequent in winter than in summer.

The winds within the area of a depression will always blow towards its centre. Should there be a cold easterly wind blowing in the northern part of the British Isles and a warm westerly wind in Southern England (*see* Fig. 37), the warm air may be forced into the area of cold air by the rotational movement of the earth or by friction between the two air masses, and form a bulge. As gases of different temperatures and densities do not mix well together, turbulence will result along the line separating the two masses and give rise to waves and bulges.

As a cold air mass travels with a much greater velocity than a warm mass, it will usually overtake the warm air, pushing it upwards.

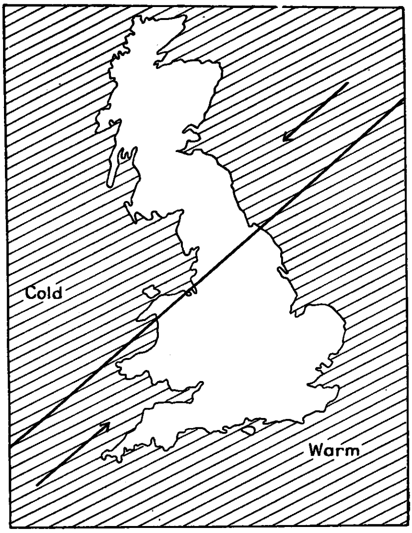


FIG. 37. FIRST STAGE OF CYCLONE DEVELOPMENT
Easterly wind in the north, westerly in south England.

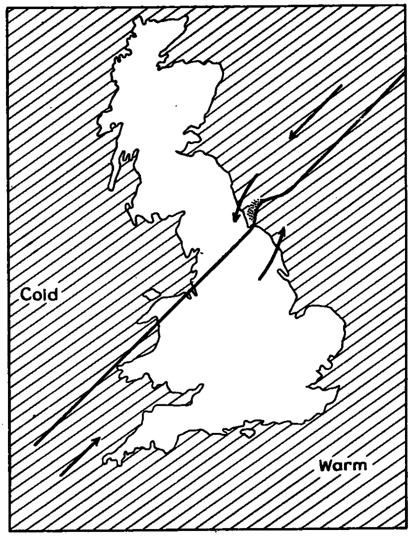


FIG. 38. DUE TO ROTATIONAL MOVEMENT OF THE EARTH AND FRICTION BETWEEN COLD AND WARM MASS, A BULGE MAY FORM

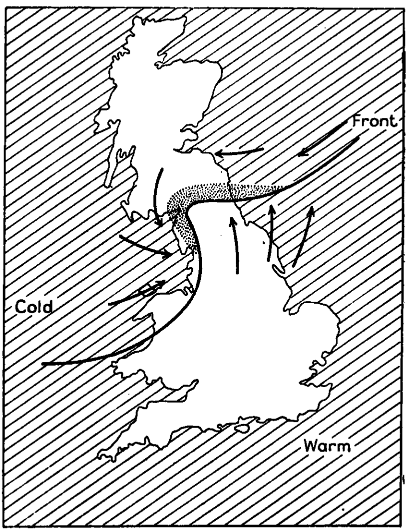


FIG. 39. DEVELOPMENT OF BULGE
Dotted area shows rain.

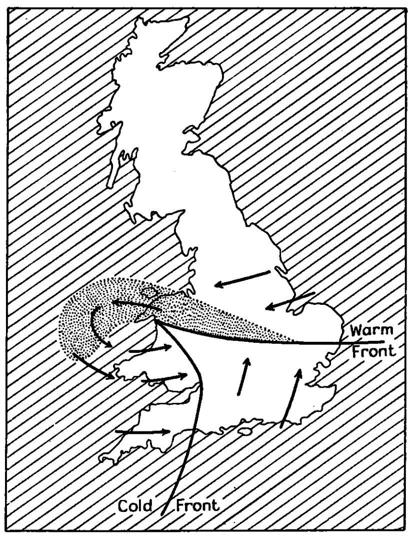


FIG. 40. FULLY DEVELOPED CYCLONE

When the cold air of a cyclone overtakes warm air, and stops the supply of warm air from the ground, the area of warm air will disappear and instead of the original cyclone there will be a huge bubble of relatively warm air at high level. The cyclone has been occluded. This occlusion usually starts in the centre of a fully

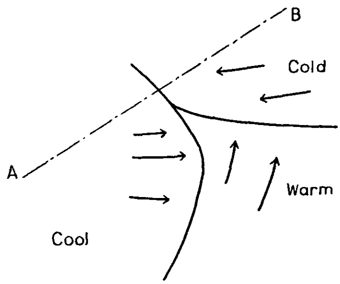


FIG. 41. WARM MASS OCCLUSION IN FULLY DEVELOPED CYCLONE

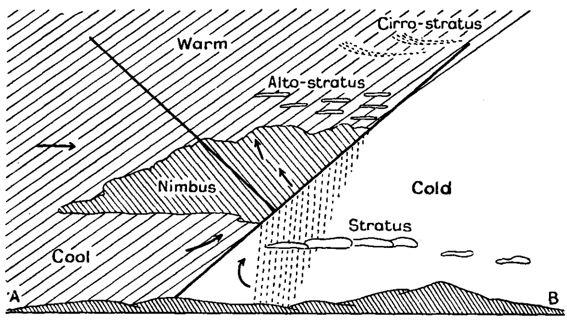


FIG. 42. DISTRIBUTION OF AIR MASSES AND CLOUDS ALONG *A–B* OF FIG. 41

developed cyclone and is shown in Fig. 41. If the air in front of the cold mass happens to be even colder than the mass itself, there will be a warm mass occlusion (*see* Fig. 42). This occlusion seldom lasts longer than one day.

If the air in front of the cold mass is warmer that that of the mass, there will be a cold mass occlusion as shown in Fig. 43, characteristics of which can be seen in Fig. 44.

During the approach of a cyclone, cirrus clouds will be seen first, then cirro-stratus, alto-stratus, nimbo-stratus and eventually rain. The pressure will fall steadily, visibility will be good until the rain comes. This will be followed by a very sudden temperature rise, the rain changing to drizzle, mist or fog, and instead of the nimbo-stratus clouds, stratus and strato-cumulus clouds will form. When a warm front passes there will be no rain, but only drizzle.

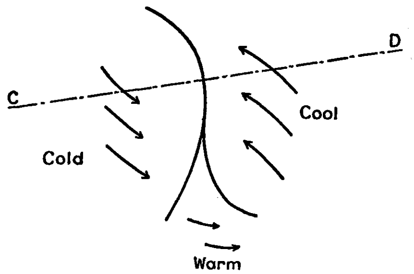


FIG. 43. COLD MASS OCCLUSION IN FULLY DEVELOPED CYCLONE

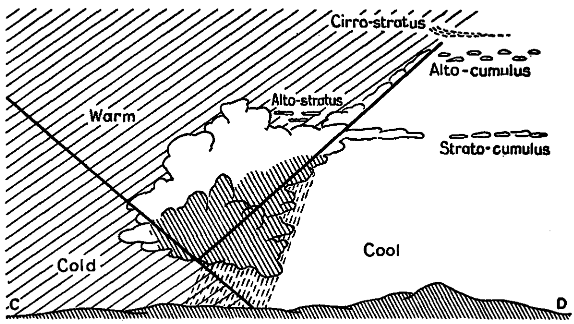


FIG. 44. AIR MASSES AND CLOUDS ALONG *C–D* OF FIG. 43

ANTICYCLONE

Areas of high pressure are called anticyclones and they comprise a region of high pressure with an area of highest pressure in the centre. The air within an anticyclone flows in a clockwise direction around the centre.

Two types of anticyclone can be distinguished, cold and warm. The cold anticyclone forms around the poles, where, due to snow-covered ground, the surface conditions are uniform and there is a huge area of intense cold. This anticyclone produces northerly or north-easterly wind in the British Isles. A cold anticyclone moving south will be very dry, cold and stable while in the Arctic region, but on its way over the sea some moisture will be transmitted and produce towering cumulus and cumulo-nimbus clouds. Strong and extensive up-currents reaching very high altitudes are associated with this type of anticyclone. Cold anticyclones form when the cold

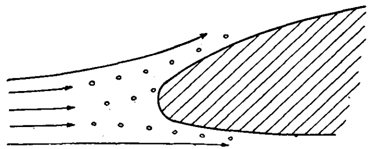


FIG. 45. ICE FORMATION—STAGE 1

The supercooled droplets of icy rain are deflected by the wing and miss it entirely.

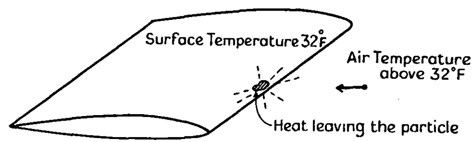


FIG. 46. ICE FORMATION—STAGE 2

Large drops of rain splash on the leading edge of the wing, forming thin water surface.

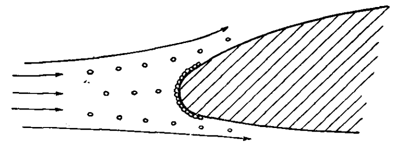


FIG. 47. ICE FORMATION—STAGE 3

The new droplets striking the leading edge will freeze immediately.

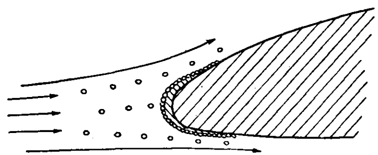


FIG. 48. ICE FORMATION—STAGE 4

Part of the water in the wing evaporates, the water on the leading edge, striking layer of ice already formed, then freezes.

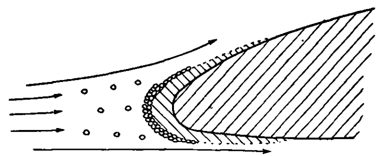


FIG. 49. CHANGE OF PROFILE DUE TO CLEAR ICE FORMATION

air moves south in the rear of a family of depressions, but they do not last more than a few days.

The warm anticyclone develops from a cold anticyclone. The air within it is warm and dry, and it moves very slowly, seldom exceeding 20 m.p.h., although the speed is higher in winter than in summer. Once formed, the warm anticyclone remains for about six days. It forms over the Azores Archipelago and stays there for a considerable time becoming very warm and moist. Should this anticyclone move north, the surface air travels over progressively colder water and becomes cooler, and stability will dominate it to a height of about 2000 ft. By the time it reaches England it will be warm and will be characterized by high clouds and a high percentage of moisture which will have a tendency to precipitation at the slightest provocation.

The direction of travel of anticyclones is the same as that of cyclones, usually from west to east in the northern hemisphere. They generally carry good weather with them.

ICE FORMATION

One of the dangers of flying in clouds is prolongation of flight in icing conditions, especially when the cloud is so thick that not very much can be seen outside the cockpit. During winter, icing will most often be found in the stratus clouds of a cold front. Clear ice will form at temperatures between 32°F and 25°F. If lower temperatures prevail, rime ice will form.

Another common form of icing takes place when flying in cold air through which rain falls, when the temperature of this air is below freezing point.

The alto-stratus clouds of the warm front are the most treacherous, particularly when the temperature of the cloud is between 32°F and 25°F, as the most severe clear ice accumulation will form.

The cumulus clouds with sub-freezing levels which develop within moist air, will also produce icing, owing to the large amount of moisture accumulating in clouds of this type. Thunderstorms appearing in warm weather will also produce icing as a rule.

Ice forms near the stagnation point of the wing profile, in fact a narrow region to either side of the stagnation point serves as the primary water-catching surface. When flying in icy rain the super-cooled droplets approach the leading edge, are deflected by the air stream without being broken, and avoid the wing entirely. Most of the small undeflected droplets strike the leading edge in the vicinity of the stagnation point. The larger drops will not spring off at the time of impact with the leading edge, but will splash, forming a very thin water surface. As the radiating surface of the droplet has increased suddenly to many times its original size, very rapid radiation of the heat contained in the water takes place. The new droplets striking the leading edge will freeze immediately and some of them will fly round the wing.

During the run along the wing surface the water continues to freeze and evaporates on the remaining part of the wing. This ice formation is called *clear ice* (*see* Fig. 49), but when the ice accumulates due to the presence of moisture in small particles, it is called *rime ice* (*see* Fig. 51).

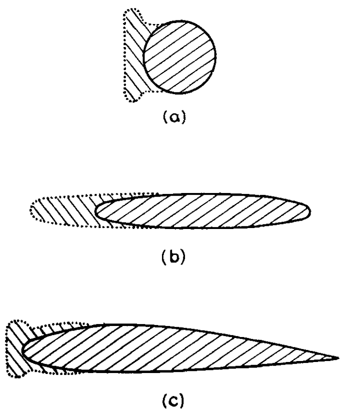


FIG. 50. FINAL STAGE OF CLEAR ICE FORMATION ON—
(*a*) round wire.
(*b*) streamline wire.
(*c*) leading edge of wing.

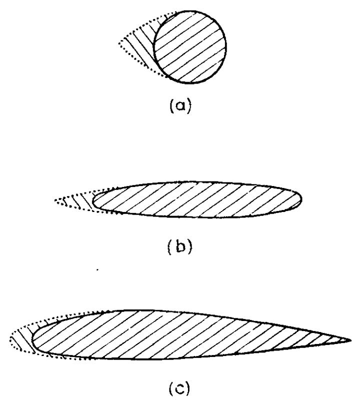


FIG. 51. RIME ICE FORMATION ON—
(*a*) round wire.
(*b*) streamline wire.
(*c*) wing profile.

Ice formation may also occur outside the cloud in completely clear air, under certain conditions. Flying at high altitudes at a temperature below 32°F and rapidly descending, the sailplane may pass a layer of warm damp air, and as the surface of the sailplane structure is still at a low temperature, the air striking it may cool below its dew point.

It should be remembered that *the formation of ice takes place very rapidly* and all pilots should be familiar with icing conditions and know how to avoid them.

The ice formation will change the aerodynamic characteristics of a sailplane completely, and as ice blocks the static and pitot-head tubes, blind flying may be found very difficult. The most dangerous factor, however, is that the total weight of the sailplane will increase and vibration due to unequal loading of wings and tail unit may be imposed on the structure, causing its failure.

Ice may also form on the leading edge of ailerons, elevator and rudder, and may block them completely, making the sailplane uncontrollable.

SLOPE CURRENTS

Soaring by means of slope currents is one of the easiest methods, as it is always possible to tell where lift areas may exist. In the early stages of soaring development these currents were used extensively and formed the only energy available for motorless flight. Even to-day slope soaring forms the main part of soaring training and nearly all pilots go through a slope-soaring course. Its importance, however, has been somewhat neglected owing to the rapid progress of thermal soaring.

In the past a great deal of work has been done in estimating the lifting characteristics of hills and mountains and the results are summarized in the following explanation.

Slope currents form over mountain slopes when there is a horizontal movement of air towards them. The mountain slope deflects the air vertically from its initial horizontal movement, and also increases its speed of travel.

The strength or vertical velocity of slope currents depends upon wind velocity, the height of the mountain, and meteorological conditions existing around the mountain.

FLOW OF AIR OVER MOUNTAINS. When a mountain is not part of a range but stands separately in a region of ground, forming a cone, the air moving towards it will flow in a horizontal and vertical plane. If the base of the mountain is small, the air will have the tendency to pass it in a horizontal plane. Such isolated mountains may produce lift areas extending up to one-third of their height. The lift distribution, however, will depend entirely upon the shape and size of the mountain and the velocity of the wind.

When a mountain is in the form of a continuous ridge, only a small part of the air will flow around it in a horizontal plane, and most of it will have the tendency to flow in a vertical plane, over the ridge. A mountain whose length is four times its height will produce a uniform air flow in a vertical plane. Over such a mountain the lift area may extend to a height four times that of the mountain.

Very steep slopes may produce a turbulent flow over the ridge, and when soaring in such a region pilots should be particularly careful not to fly on the lee side, on account of the prevalence of vicious down-currents which may often exist in the lee areas.

The best lift areas are usually found over the slope where the vertical component of wind velocity caused by the deflection of the slope is the greatest. The vertical velocity is greatest near the slope

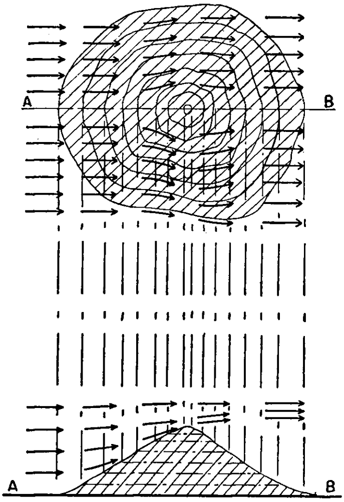


FIG. 52. MOUNTAINS OF CONICAL SHAPE PRODUCE SMALL LIFTING AREAS

The only lift available may be found just behind the top of the mountain.

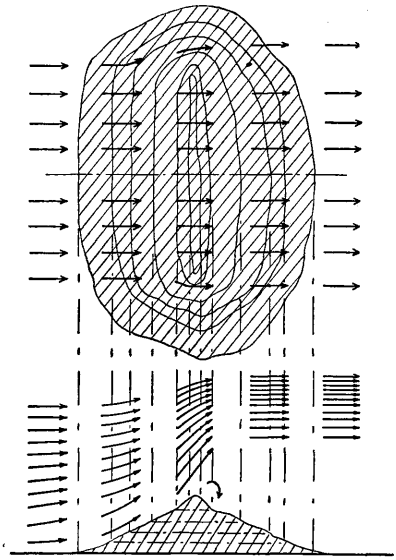


FIG. 53. THE IDEAL SHAPE OF A MOUNTAIN

The lift area extends to four times the height of the mountain.

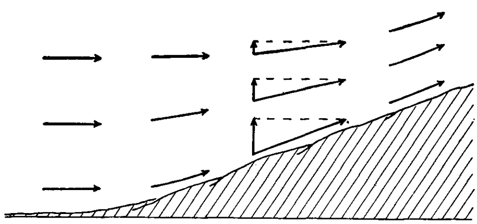


FIG. 54. DISTRIBUTION OF VERTICAL COMPONENT OF WIND VELOCITY DUE TO THE SLOPE

and decreases with height from the slope. Bowls and pockets formed in a slope increase the rate of flow of air, and as the velocity of flow increases also, the vertical component of velocity will provide still stronger lift in such areas.

The influence of the temperature lapse rate plays an important part in the lifting characteristics of a mountain. When the lapse rate is higher than the dry adiabatic lapse rate (5·4°F per 1000 ft) the air which has been deflected by the slope of the mountain and travels

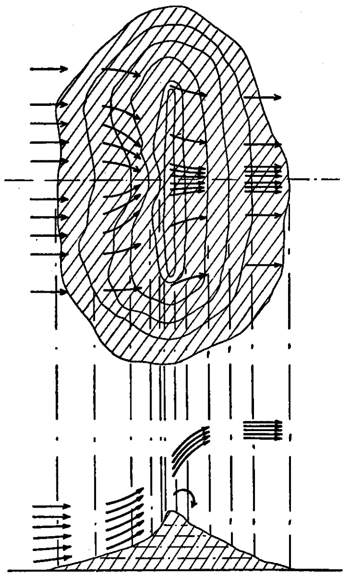


FIG. 55. INCREASE OF VERTICAL VELOCITY DUE TO A BOWL

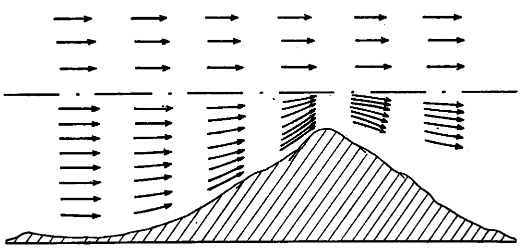


FIG. 56. INVERSION FORMED OVER THE MOUNTAIN REDUCES LIFT AREA CONSIDERABLY

upwards may reach very great heights. In such cases the vertical area of height may be increased to five or six times the normal height, which, it will be remembered, is four times the height of the mountain.

If the lapse rate is lower than the dry adiabatic, and inversion forms over the mountain, the flow of air above the mountain may be stopped. In such a case no lift will be found in spite of the wind.

When cold air covers the valley at the base of the slope, the vertical

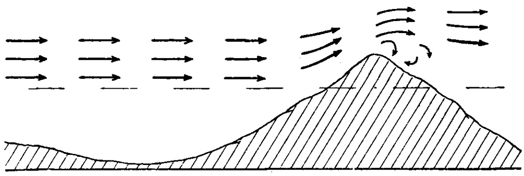


FIG. 57. CONDITION PRODUCING NO LIFT

If cold air covers the valley in front of the mountain, in spite of wind there may be no lift over the ridge.

flow of air may be greatly reduced. This happens very often during autumn and winter mornings. Later in the day, when the cold air has been moved from the valley by the wind, the soaring conditions over the slope may improve.

CHAPTER II

DIRECT SUN THERMAL UP-CURRENTS

THE condition which is essential for the birth of any thermal up-current is that the particular mass of air must be warmer than the air immediately surrounding it. Without this condition there will be no thermal up-current formation.

If there is an area of dry, hot ground surrounded by wet and cold ground, and if the sun shines uninterruptedly, the dry and hot surface will release heat and the layer of air which lies immediately above that surface will become warm. As this air gradually becomes hotter it will expand and decrease in density. The cold, wet air will force its way towards the dry, hot surface in the form of a wedge owing to its greater density, and will push up the warm, dry air, due to the local difference in pressure, $p_1 - dp_1$. This pressure difference is infinitely small but sufficient to start the vertical movement of air. This movement is very slow, and at a certain height h (*see* Fig. 59) the difference in pressures completely disappears as they become equal, i.e. $p_1 - dp_1 = p_2$.

This movement of air in the layer which is very near the ground is independent of the lapse rate within it. Should the adiabatic lapse rate in this layer of air be smaller than the dry adiabatic, as it usually is, the air movement is mainly horizontal and if there is any upward travel it is due to initial velocity, inertia and difference in density. The height to which the warm, dry air may ascend when there is a lapse rate near the dry adiabatic, depends mainly on the velocity of air travel from wet, cold areas to dry, hot areas, and this depends on the intensity of the warming-up of this air along its path of travel.

When the velocity of motion is sufficiently large and the thickness of the layer of air near the ground with a lapse rate near the dry adiabatic is small, the travelling air may break through. As soon as the lapse rate becomes greater than that of the surrounding air, the bubble will gain an upward velocity.

The above discussion is valid only for conditions of no wind. With a wind, however, there is horizontal movement of the whole mass of air, cold and hot. It often happens that the air becomes warm over one stretch of ground, still warmer over the next, and cools again over the next, but the inflow of cold air under warm is continuous. This flow may be of small velocity, and is more intensive from both sides than from the front or back.

The stronger the wind, the greater the turbulence and thickness of the ground layer, and the longer the time needed to warm up the travelling volume of air. This means that the formation of a thermal is more difficult. This is in agreement with experience which shows that the stronger the wind the fewer are direct sun thermals.

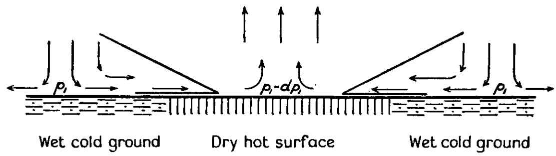


FIG. 58. FIRST STAGE OF FORMATION OF THERMAL UP-CURRENT
Warm air is being pushed upwards by inflowing cold air.

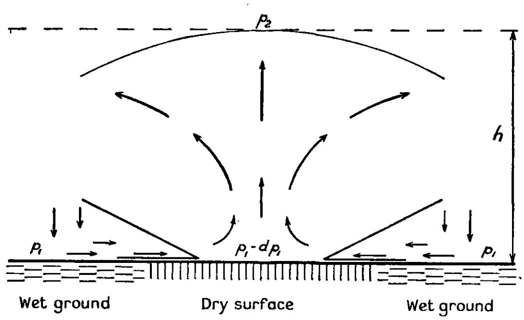


FIG. 59. DEVELOPMENT OF THERMAL UP-CURRENT
At height h, pressures p—dp, and p_2 become equal.

DEVELOPMENT OF A THERMAL BUBBLE

When warm air, having broken through the layer of air near the ground, enters air which possesses a lower temperature than itself, it will move upwards. Having previously travelled in various directions it will now be sucked in and begin its upward travel. Due to the activity of the thermal bubble there will be a horizontal velocity over a large ground area, which must result in vertical movement due to inertia. It must be remembered, however, that such a development is only possible if there is a constant heat supply from area A (*see* Fig. 60). Should there be a slight wind or a cloud between the sun and area A, the heat release from this area will decrease and the warm air break contact with its source.

As a rule such an individual mass is known as a thermal bubble, but it is far from having a perfect spherical shape. When such a thermal bubble is liberated the cold air flowing in from all sides will fill the gap left by the travelling air, and will receive a vertical component due to suction and its own velocity. It may happen that the sucked-in cold air will form a continuation of the thermal bubble, and increase its length considerably.

A thermal bubble may contain some moisture, and when its temperature reaches dew point, the water-vapour will condense and

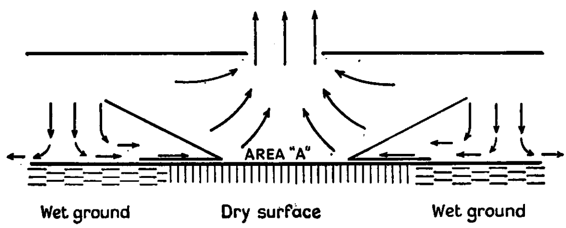


FIG. 60. FIRST STAGE OF FORMATION OF THERMAL BUBBLE

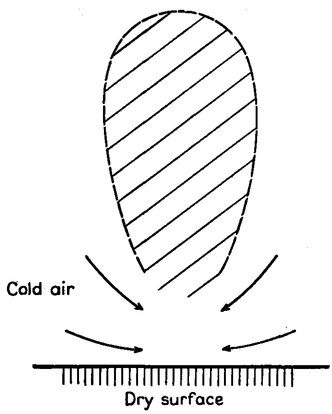


FIG. 61. THE COLD AIR FILLS THE GAP LEFT BY MOVING THERMAL BUBBLE

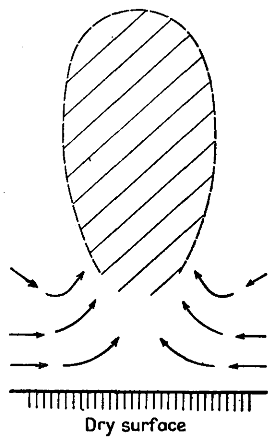


FIG. 62. THE IN-GOING COLD AIR FORMS CONTINUATION OF THERMAL BUBBLE

a cloud will form. Under such a cloud the bubble of warm air may extend to very low altitudes. Naturally such a "long" bubble will decrease its length in a short time.

Immediately under the cloud the life of the thermal up-current may last a long time due to the big vertical velocity contained in the cloud and the large inertia forces superimposed on the surrounding masses of cold air. This explains why, during a day with little wind, a pilot may succeed in staying under a big cumulus cloud for a long time while other pilots trying to get under the same cloud are forced to land.

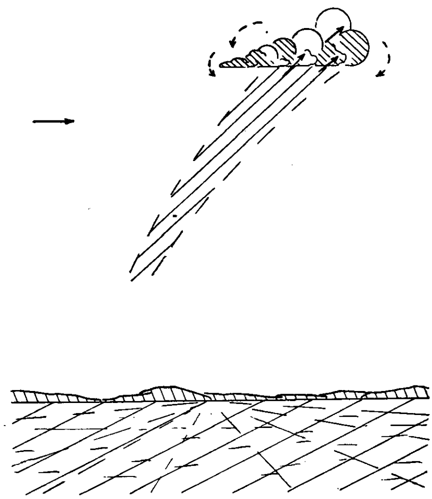


FIG. 63. UNDER THE CLOUD THE THERMAL BUBBLE MAY EXTEND TO VERY LOW ALTITUDES

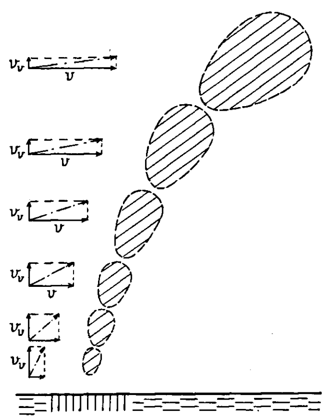


FIG. 64. NEAR THE GROUND THE VERTICAL VELOCITY MAY BE QUITE LARGE; IT DECREASES WITH INCREASING ALTITUDE

THE LIFE OF A THERMAL BUBBLE

The upward travel of a thermal bubble is due to the difference in temperature between it and the surrounding air, or in other words, to the different densities. During its vertical travel the bubble also expands, causing a decrease in vertical velocity. Near the ground the vertical velocity may be quite large and depends upon the temperature difference between the bubble and the surrounding air. Velocity near the ground may be 10 ft/sec but at higher altitudes it may drop to 2 ft/sec or disappear completely.

Upward Velocities in a Thermal Bubble

The most economical method of launching for the majority of schools and clubs is by winch or auto-tow. This kind of launching seldom provides more than 1000 ft of height, so it may be of some interest to discuss a few factors which give a more complete picture of the behaviour of thermal bubbles at such low altitudes.

Much valuable work has been done in this sphere in Germany and Poland, and the following figures are based on the results obtained from these two countries. Taking normal conditions favourable to thermal bubble formation, i.e. ground heated up during the morning, light cumulus clouds, lapse rate greater than dry adiabatic, slight wind, then Fig. 65 can be prepared.

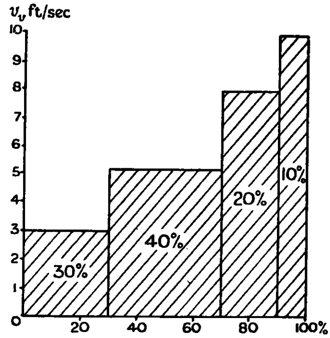


FIG. 65. VERTICAL VELOCITIES IN A THERMAL BUBBLE AT THE HEIGHT 1000 FT

From Fig. 65 it can be seen that at 1000 ft height the most common upward velocities existing in a thermal bubble will be in a range of 3–5 ft/sec (40 per cent of the total). From the soaring point of view these velocities are small but they are sufficient to enable experienced pilots to stay in the air and even gain height. The next group are velocities below 3 ft/sec, which are found in 30 per cent of thermal bubbles. 20 per cent of thermal bubbles, however, possess velocities between 5–8 ft/sec, and only 10 per cent velocities over 8 ft/sec. The most interesting fact is that 70 per cent of thermal bubbles possess velocities below 5 ft/sec.

Naturally a sailplane with a low sinking speed will have the advantage in these particular conditions over a high performance sailplane, which, owing to its greater sinking speed, may be soared only in thermal bubbles of much higher upward velocities. As the average sinking speed of a secondary sailplane is in the range of 3 ft/sec it should not be too difficult for a pilot to stay in the air and gain height, assuming that he adopts the correct circling technique.

The Diameter of a Thermal Bubble

It has been observed that the volume of an upward moving bubble increases with height. This increase in volume due to adiabatic expansion is not, however, very large. It may, therefore, be suggested that if there is any increase in the volume and diameter of the bubble, as has been observed by many soaring pilots, this is due to the inclusion of additional surrounding air.

During vertical movement of a thermal bubble, great velocity exists within it. It may be of some interest to say more about this velocity. If k is the strength of a vortex, v the vertical velocity, and d the diameter of a bubble, then the following formula can be given—

$$v_v = \frac{k}{d}$$

The vortex motion is explained in Fig. 66 and it can be seen that it is due to the inflow of the surrounding air. As the velocity of a bubble usually decreases with its vertical motion, it may be inferred that the decreasing vertical velocity must be associated with a ring vortex which will increase in strength when moving up, so increasing the diameter of the bubble also.

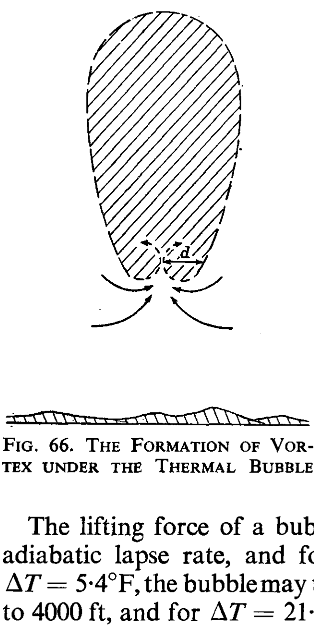


FIG. 66. THE FORMATION OF VORTEX UNDER THE THERMAL BUBBLE

The lifting force of a bubble has been determined using the dry adiabatic lapse rate, and for a ground temperature difference of $\Delta T = 5{\cdot}4$°F, the bubble may travel up to 2000 ft; for $\Delta T = 10{\cdot}8$°F, up to 4000 ft, and for $\Delta T = 21{\cdot}6$°F to 7800 ft for *I.C.A.N.* atmosphere.

The diameter of a thermal bubble can be determined quite simply. If the time taken for a full circle just inside the bubble is measured by means of a stopwatch, say it is 20 sec, and the speed of flight has been kept constant at, say, 37·2 m.p.h. which is 64·7 ft/sec then in 20 sec the path flown by the sailplane will be $64{\cdot}7 \times 20 = 1294$ ft, and is equal to the circumference u.

As $u = \pi \times d$

then
$$d = \frac{u}{\pi}$$
$$= \frac{1294}{3{\cdot}14} = 413 \text{ ft}$$

The height of the bubble can be found in a similar way. Supposing the sinking speed of a sailplane is 4 ft/sec and the time of soaring in a bubble 5 min, then 5 min = 300 sec and 4 ft/sec × 300 = 1200 ft. It can then be said that 1200 ft have been lost during the flight and the thermal bubble must have been at least 1200 ft high. Actually the height would have been greater because it is seldom possible for the soaring pilot to start soaring in the bubble at its lower point.

The Horizontal Movement of a Thermal Bubble

On an absolutely calm day a thermal bubble may be found immediately above the place from which it originated. These conditions very seldom exist, however, as there is usually a slight wind and the bubble will be moved with it. The change of wind with height is shown in Fig. 67. It can be seen that with increasing height the velocity of wind increases, and the horizontal movement or drift of the thermal will increase with height.

At high altitudes there will be a great difference between the actual position of a thermal bubble and its source.

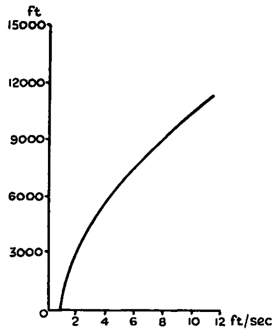


FIG. 67. CHANGE OF WIND VELOCITY WITH HEIGHT

THE BIRTH OF A THERMAL COLUMN

Such a current develops over an area of *constant* heat supply. Assuming that there is an area of land which is dry and hot, and its base is dry also, then the majority of heat supplied to such ground will be used in warming the surface and only a small part of it will

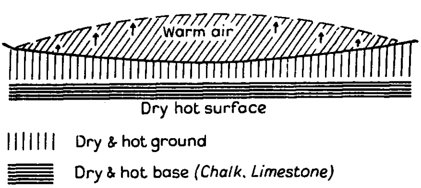


FIG. 68. WHEN THE HEAT SUPPLY REMAINS CONSTANT THE SURFACE BECOMES A SOURCE OF THERMAL COLUMN

penetrate the layers below the surface. If the heat supply remains constant the surface will become a source of constant radiation and the air above it may be warmed to quite high temperatures. An example of this may be found in the valleys of hilly country. As the source of heat supply usually covers a large area, the diameter of the upward moving air will also be fairly large.

During the first stage the layer of air which is warming up will be quite thin, but it will later increase in thickness. Then the middle part of it will rise up and become a sharper shape as the masses of cold air try to stop its movement, but it will continue to push its way upwards, forming a rising column. As the air flows constantly its inertia effect will have the tendency to narrow the column of rising air. Due to the decrease in diameter the rising air will accelerate, and greater vertical velocities will, therefore, be found at some distance away from the earth's surface than near to it. At high

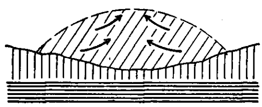


FIG. 69. WARM AIR RISING ABOVE THE AREA OF CONSTANT HEAT SUPPLY

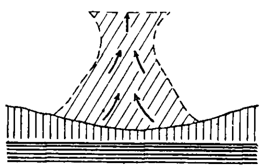


FIG. 70. THE AIR MOVING UPWARDS DUE TO ITS INERTIA HAS THE TENDENCY TO NARROW THE COLUMN

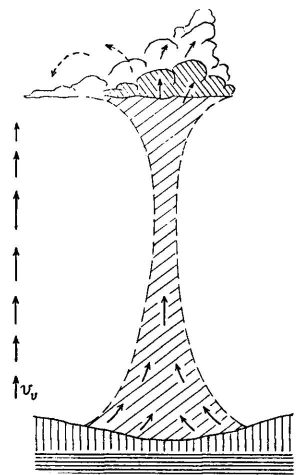


FIG. 71. THERMAL COLUMN AND VERTICAL VELOCITY WITHIN IT

altitudes, however, if the air follows the adiabatic lapse rate, there will be an increase in volume as shown in Fig. 71 and the rising column will have a tendency to splay out.

It is strongly recommended to all soaring pilots to make a very detailed study of thermal currents, their birth, and development. During actual soaring practice there is seldom enough time to study, and this should be done long before any soaring flight is undertaken. A few hours spent in studying the history of thermal currents will be found of infinite value when these currents are actually being used.

Horizontal Rotational Motion of Air in Thermal Currents

The air in a rising thermal bubble or column has a definite rotational motion in a horizontal plane. This rotation may be caused by several factors—friction between air and ground surface, the rotational motion of the earth, friction between different air masses, temperature variation, or high viscosity of the air.

The main element on which the direction of rotation will depend is the earth's rotation. In the northern hemisphere the rotation in a rising mass of air will always be in a clockwise direction, seen from above, at the bottom of a thermal current, diminish to zero near the middle and become anti-clockwise near the top.

The motion of air in a thermal current is the same as that in a cyclone, and it is a known fact that the ground wind in front of a thunderstorm blows from left to right as the observer faces it.

FIG. 72. CYCLONE AND ANTICYCLONE IN NORTHERN HEMISPHERE

(a) Wind directions in areas of depression (cyclone) in northern hemisphere.
(b) Wind directions in area of high pressure (anticyclone) in northern hemisphere.

Another example of this rotation can be seen in everyday life, the water circulation by outflow from bath or sink.

Evening and Night Thermal Currents

It often happens that after sunset at the end of a very warm and sunny day there is still a radiation of heat from those sources which accumulate heat during the day. During the evening the lower layers of air cool and become stable, but in higher layers above 4000 ft great instability may develop. This very often happens in mountains which, by their slopes, will help to move inflowing air so high that it may reach the higher regions of instability. This vertical movement of air up the slope is due to the slight wind against the mountain. Wind, however, is not essential for the birth of evening thermal currents. A wooded slope can radiate some of the heat which has been accumulated, and over such a slope there will be air movement towards it, from the valley and from the ridge.

Thermal currents formed over woods do not produce sufficient vertical velocity to make soaring flight practicable, but they are strong enough to unbalance the unstable layer of air which lies above the hill range, and so start the initial motion of an air mass which will accelerate as it travels. Soaring flights of one to two hours duration after sunset have proved that these currents are strong enough to support a sailplane in the air.

Naturally a wooded slope directed towards the sunrays during the day can accumulate more heat than level wooded areas, but there is no reason why some parts of the level earth, particularly those on a dry base, should not warm sufficiently to provide enough heat release after sunset to make soaring feasible. Large towns should be particularly good sources of heat release during the evening.

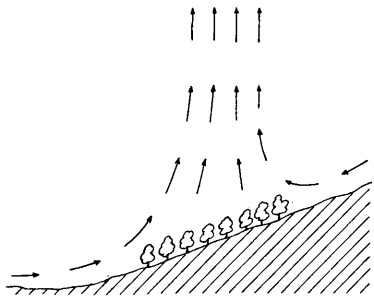


FIG. 73. THE BIRTH OF EVENING THERMAL UP-CURRENTS

Thermal currents may be liberated not only by the heating of the earth, but also by the cooling of the air at high altitudes. This may make high-altitude flights and soaring possible during the night and in winter.

Winter Thermal Currents

The winter period with its short days will not provide long hours of soaring in thermal currents in the lower levels of the atmosphere. The maximum time of radiation seldom exceeds two hours, but even this time is sufficient to build some temperature differences near the ground. In hilly country during a day of slight wind some thermal currents may be liberated. Light cumulus cloud indicates that such currents exist.

There have been quite a number of soaring flights made in Poland and Germany during winter where the temperature of air near the ground was about 14°F and it was possible to stay in the air for more than 2 hours. The bulk of winter thermal currents, however, are products of large horizontal and vertical movements of very unstable air masses, which are very moist. These masses when moved to a higher level soon condense and produce long streets of cumulus cloud.

At present it is the low ceiling prevailing in winter which prevents any real long distance flying, but high-altitude soaring and the development of blind flying still await further exploration, and the future may bring radical advances.

Ocean Thermal Currents

During sunny days it has been observed that there is a formation of well-defined cumulus cloud in the middle of tropical oceans. The birth and development of thermal currents over oceans is different from the thermal currents which exist over the land. They do not depend so much on radiation but rather on temperature differences which exist between the water and the air. When the temperature of the water is higher than that of the air the formation of thermal currents may be possible. In the layer of air which is in contact with the warmer surface of water, there is instability.

CHAPTER III

INSTRUMENTS

THE great progress made in the last fifteen years in the field of soaring flight has developed the technique of flying to a stage where the accuracy and perfection of nearly every flight, soaring or thermal, depends on the proper use of instruments. The genius of man has designed and developed machinery intended to simplify and facilitate his work, especially at those moments when his mind may be engaged on other tasks or when his body and brain may lack proper co-ordination, as often happens during flight. Pilots who in their flying career have brought their "new sense" to a very high standard are often sceptical and independent about instruments, preferring to rely on their senses and sight for aid. Discussion on this subject could be prolonged, but the idea behind this chapter is to explain the function of various instruments, how to use them, whether we can rely on them, and what lies behind the glass of an instrument.

Instruments are part of the equipment of every sailplane and each type will require particular instruments. It would be unwise, however, to fix instruments on a primary glider as they are very sensitive and might be put out of action by the shocks inevitable in the ground slides and low hops of training. Secondary training machines usually possess an airspeed indicator, and machines used on slope soaring, an altimeter. High performance sailplanes require a complete instrument panel if maximum performance is to be secured.

The instruments used on sailplanes can be classified in the following manner—

Visual flying instruments—airspeed indicator, altimeter, rate-of-climb indicator (variometer).

Blind flying instruments—cross-level, fore-and-aft indicator, turn indicator, artificial horizon.

Navigational instruments—compass, clock.

Airspeed Indicator

This instrument can be used on the sailplane for many purposes; it indicates the speed of the sailplane relative to the air and also registers indirectly any changes in the angle of the sailplane (pitch). If the pilot increases the angle of glide—lowering the nose of the sailplane—this will be followed immediately by an increase in speed which is registered on the airspeed indicator. Conversely, decreasing the angle of glide—raising the nose—will result in a decrease of airspeed.

There are three types of airspeed indicator; differential pressure—pitot static, venturi, pitot-venturi; mechanical—rotating element, deflecting element; thermal or hot wire.

The most common is the pitot-static, differential-pressure type, and this consists of a pressure head, usually mounted on the front part of the fuselage, and a sensitive differential-pressure gauge which is connected to the pitot-static tube (pressure head) by means of

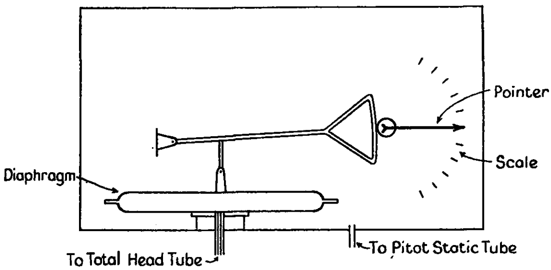


FIG. 74. DIFFERENTIAL PRESSURE AIRSPEED INDICATOR

two tubes. The standard pressure head consists of a static tube and a total-head tube. The static tube is closed at its forward end and pierced at a short distance from the end by a series of very small diameter holes. The total-head tube is open at its forward end. By means of the sensitive differential-pressure gauge the difference between the total head pressure and the static pressure of the surrounding air is measured. The gauge, which is fixed in the instrument panel, consists of an airtight case which is connected to the static pressure tube. The very sensitive diaphragm, usually made of nickel, silver, or phosphor-bronze, is fixed inside the case and connected to the total pressure tube. By means of a lever-quadrant system the movements of this diaphragm are communicated to the pointer. Any change of pressure will be indicated through this mechanism by means of the pointer on the dial. As can be seen, there is a static pressure outside and a total-head pressure inside the diaphragm. The amount which the diaphragm expands is proportional to the difference between these two pressures and therefore proportional to the square of the airspeed of the sailplane. The difference between these two pressures is indicated on the dial of the instrument as miles per hour.

INSTRUMENT ERRORS. The pitot-static tube is subject to two errors. The first is due to inclination of the tube to the direction of the local air flow which will tend to cause a low reading. The second is due to the fact that the velocity of the local air flow is not equal to the airspeed of the machine. Thus in the vicinity of a fuselage the reading will tend to be high, and below a wing at low speeds the reading will tend to be low.

The flow pattern round the aircraft depends on its attitude so that these errors cannot be prevented at all speeds and altitudes. The best position for a pitot-static tube is in the line of the wing chord, in front of the wing, roughly along the streamlines at soaring speed where the disturbance of the air flow is least. The errors should be determined by experiment.

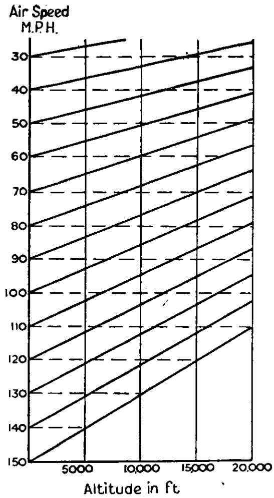


FIG. 75. THE ALTITUDE CORRECTION FACTOR FOR DIFFERENTIAL PRESSURE AIRSPEED INDICATOR

THE INDICATING GAUGE. Airspeed indicators are calibrated for sea-level conditions, where the atmosphere pressure is 29·92 in. and the temperature 59°F. Because the air pressure and density decrease with altitude, this instrument will naturally be subject to an altitude error and the indicated speed will be 2 per cent lower for each 1000 ft of increase in height. Fig. 75 gives the altitude correction.

This diagram may appear somewhat complicated, but it is sufficient to remember that for normal speed range 40–80 m.p.h. the true airspeed is approximately 1 m.p.h. greater for every 1000 ft of height. To find the correct value of an indicated airspeed, follow the horizontal line of indicated airspeed to the altitude shown by the altimeter, and then follow the full line to the airspeed scale. The point where the full line crosses the airspeed scale gives the true airspeed. The true airspeed is always greater than that indicated.

All metal diaphragm airspeed indicators are compensated over a wide range of temperature.

POSSIBLE FAULTS OF INSTRUMENT. The pointer on the dial may not come back to zero, in which case disconnect the rubber pipe from the static and pitot pressure tubes on the back of the gauge case and the pointer should come back to zero. If this does not happen, however, the instrument should be returned for repair.

The instrument may give low readings; this is usually caused by leaks in the rubber pipes connecting the gauge with the static and pitot tubes.

The movements of the pointer may become sluggish due to a stoppage in the pipe system, and in this case make sure that the holes in the static tube are open.

It should be the first duty of a soaring pilot to give the instruments the necessary attention and maintenance, otherwise they will not remain effective. It should be remembered that the metal diaphragm within the case of the gauge is very sensitive and should not be blown or sucked. The pitot-static head should be so adjusted that it points straight forward, parallel to the centre-line of the fuselage. The edge of the pitot pressure tube should be smooth.

All the holes in the static pressure tube should be clear and their edges flush. The joints of rubber pipes should be free from cracks, there should be no bends in the pipes and there should be a good fit where the pipe is connected to the pitot-static head and the body of the gauge. The pipes should be disconnected and blown through from time to time.

Altimeter

This instrument indicates height relative to the take-off point, by means of a measurement of the variation of air pressure with change of altitude. The altimeter is actually an aneroid barometer which has been slightly modified and calibrated so that it gives an indication of height in thousands of feet. It consists of a flexible diaphragm, usually made of nickel-silver, and approximately 2 in. in diameter, its thickness being about 0·006 in. This diaphragm forms one side of a sealed chamber from which the air has been removed. If the pressure outside the sealed chamber increases, the diaphragm will move inwards, and if the pressure decreases, it will try to move outwards, and its movements will be transmitted via arms and shafts to the pointer which moves along the graduated scale on the dial. This pointer is normally returned to zero position on the dial by means of a small coiled hair-spring which is constantly in tension.

The dial can be rotated by means of a pinion meshing in teeth on its outer rim to enable the instrument to be set at zero before take-off, as the atmospheric pressure varies considerably during the day and may affect the indication. This adjustable dial permits the use of any elevation or barometric pressure as zero.

It has already been pointed out in Chapter I on Meteorology, that decrease of pressure for each thousand feet of height is greater near the surface of the earth and decreases gradually as the altitude increases. The mechanism of an altimeter makes allowance for this variation and enables the dial of the instrument to be evenly graduated. The majority of altimeters are compensated for temperature changes at ground pressure only, by means of a small bimetal bar, usually brass-steel. As these two metals have different coefficients of expansion, the brass-steel bar will bend if the temperature changes, but its effective length will remain the same and the reading unaffected.

It will often be found that the altimeter is not properly fixed on the instrument panel. Care should be taken to have the altimeter

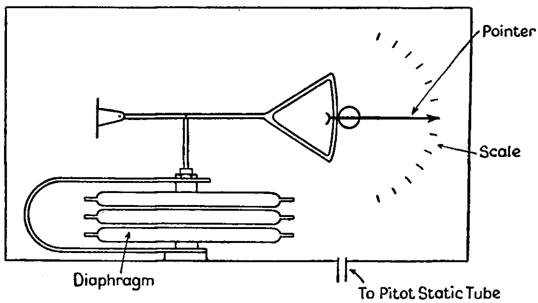


FIG. 76. ANEROID TYPE ALTIMETER

mounted always with the dial in a vertical plane and the dial adjusting knob at the bottom. It should be possible for this knob to be freely rotated, and on no account should it be forced as that might destroy the teeth of the dial completely and make the instrument unserviceable.

If the case of the altimeter is without a connecting tube to the static pressure tube, emerging from the back, a small hole should be drilled in the wall of the cockpit to enable the instrument to receive the static pressure of the surrounding air of the sailplane. To have the cockpit airtight is a great mistake as it is subject to large differences in static pressure.

INSTRUMENT ERRORS. This instrument may undergo considerable changes, sometimes occurring over long periods of time. The most common errors are as follows—

Scale error—The difference between the indicated and true altitude, which is usually due to friction and the functioning of the instrument can be improved by gentle tapping on the glass.

Position error—The mechanism of an altimeter is not statically balanced and the reading may be affected by the varying positions of the sailplane in the air, and by acceleration.

Hysteresis—When climbing the readings will always be lower than the true altitude; when diving the readings will always be higher than true altitude.

Installation error—Faulty connexions in the rubber pipe between the gauge and the static pressure tube.

THE SENSITIVE ALTIMETER. One of the best known altimeters in the gliding world is the K.B.B. Kollsman. The dial possesses three pointers which are of different lengths and are moved by means of a geared mechanism.

The dial of the instrument has 100 ft, 1000 ft, and 10,000 ft scales. The largest pointer, after moving once round the scale gives 1000 ft changes in altitude. The medium sized pointer gives the number of revolutions of the larger one—thousands of feet. The smallest pointer gives tens of thousands of feet.

Owing to these scales the sensitive altimeter enables one to observe heights as low as 5 ft.

Rate-of-climb Indicator (Variometer)

This is a vertical-speed indicator and its principle is similar to that of an altimeter. It consists of a gauge and a thermally insulated container which are inter-connected by means of a rubber pipe.

The gauge is an airtight case in which a metal diaphragm is mounted, the inside of this diaphragm being connected to the container. In a line between the diaphragm and container there is a capillary leak tube. The case of the gauge is connected to the static pressure tube of an airspeed indicator. It can be seen that inside the case and outside the diaphragm there is always the same static pressure as that around the sailplane; inside the diaphragm, in the line and in the thermally insulated container, there is the same pressure.

As the sailplane moves in the air it is subject to up- or down-currents. If the sailplane enters a region of up-current and is moved upwards with it, the static pressure around it changes, and outside the diaphragm there is now less pressure, but the pressure which is inside the diaphragm has to "pass" through the capillary tube. As there is some difference in pressure between the ends of the capillary and therefore between both sides of the diaphragm, the pointer, whose movements are amplified by transmitting mechanism depending entirely on the movements of the diaphragm, will move from its zero position. When the sailplane is held at constant height, the rate of up-going air being equal to the plane's sinking speed, the pointer will indicate zero.

The above-mentioned type of variometer is a very sensitive differential pressure-gauge.

INSTRUMENT ERRORS. THE following errors are common to the types of variometer described above and should be remembered—

Errors due to the fact that these instruments are not in a physically stable state. To avoid these some time should elapse before the instrument is read.

Errors due to changes taking place over a considerable period of time in connexion with the gradual settling of working parts.

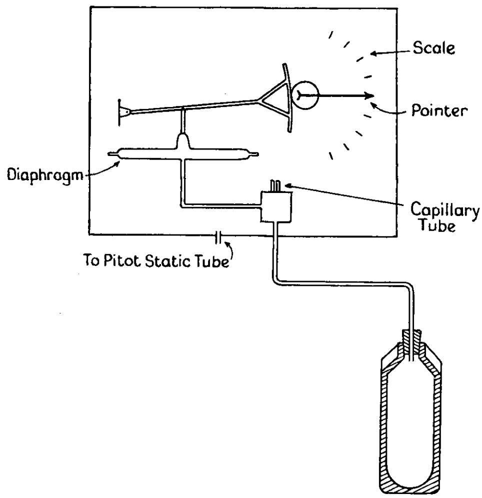


FIG. 77. RATE-OF-CLIMB INDICATOR

Errors due to faulty or imperfect design or construction, or to materials used.

Temperature errors, especially the effect of temperature on the elasticity of the diaphragm and spring.

Mechanical errors due to friction or backlash of moving parts and lack of balance.

Errors due to imperfect elasticity of spring and diaphragm resulting in an increase in reading when the instrument is subject to a prolonged stay in a constant low-pressure region, and hysteresis.

Errors due to frequent flights at high altitudes and in clouds which result in corrosion and strain the diaphragm.

Errors due to failure of the parts because of vibration, heavy landing, or transport of the sailplane in a trailer.

The Cobb-Slater Variometer

This instrument consists of two tapered transparent tubes with a small ball inside each. It works as a flow-meter, measuring the flow

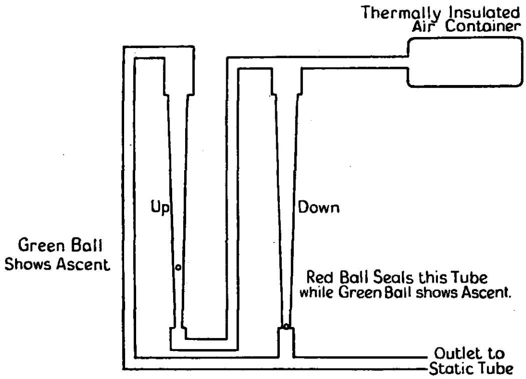


FIG. 78. COBB-SLATER VARIOMETER

from or into a thermally insulated air container. The bottom part of the "up" tube and the top of the "down" tube are connected to

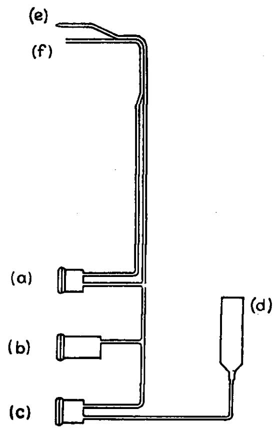


FIG. 79. ARRANGEMENT OF AIRSPEED INDICATOR, ALTIMETER AND RATE-OF-CLIMB INDICATOR AND THEIR PROPER CONNEXION TO PITOT STATIC TUBE

(*a*) Airspeed indicator. (*b*) Altimeter.
(*c*) Rate-of-climb indicator. (*d*) Thermos.
(*e*) Static tube. (*f*) Total head tube.

the air bottle. The top of the "up" tube and the bottom of the "down" tube are connected to the static tube.

During a climb when a change of pressure occurs, the air inside the air bottle will flow out through the "up" tube as the "down" tube is closed by the ball. The ball in the "up" tube will lift and the amount of this movement will indicate the rate of climb in feet per second. When the rate of change of pressure remains constant, the ball will remain at a constant height.

The time lag is almost entirely eliminated on this variometer and very small rates of ascent and descent can be observed.

To check the functioning of this instrument, a portion of the rubber connecting tubing should be squeezed. The air displaced by this pressure will raise one indicator ball off its setting. On release of pressure the other indicator ball will rise.

BLIND FLYING INSTRUMENTS

Fore-and-aft Level

By means of this instrument the inclination of the longitudinal axis of the sailplane to the horizontal can be found. The instrument

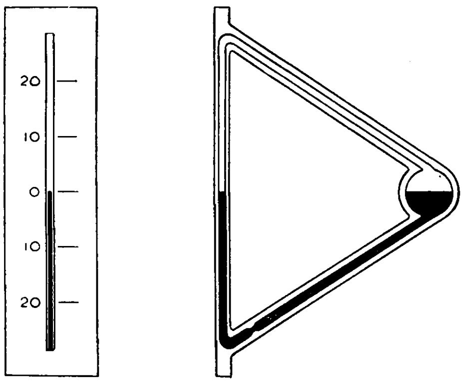


FIG. 80. FORE-AND-AFT LEVEL

consists of a closed glass tube of triangular form which is enclosed in a case and only one side, the vertical, can be seen in the slot of a sealed plate which is fixed to the case of the instrument. The glass tube is filled with coloured alcohol to half its volume, which stands at zero mark on the front plate. The scale is marked in degrees above and below zero mark. During a climb or dive the alcohol will respectively rise or fall, and this movement is visible on the scale.

This instrument gives true readings only during a steady climb or dive. Sudden changes in the angle of glide or accelerated motion give reversed readings.

Bank Indicator

This instrument indicates the balanced or unbalanced lateral forces acting on the sailplane. The principle is the same as in an ordinary spirit-level with the exception that the tube is bent upwards and contains a steel ball. When the lateral forces are in balance the steel ball will be in the centre of the tube but if there is a side force, as in the sideslip, the steel ball will move from the centre.

Turn-and-bank Indicator

This indicates if the pilot is flying straight or if he is turning. It also gives the rate of turn and bank, assuming that the turn indicator has been calibrated for the sailplane in which it is used.

The instrument is based on the gyroscopic movement which occurs when a turn is made. Normally, the gyroscope rotates in a vertical plane and as soon as this plane is deflected, the rotating gyroscope

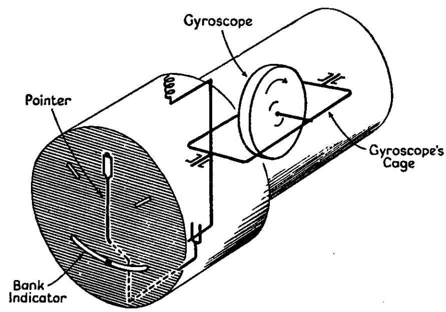


FIG. 81. TURN-AND-BANK INDICATOR

resists this movement and tends to move back to its normal position. This results in the deflection of a pointer.

The gyroscope used in this instrument is fixed with its axis horizontal and crosswise in an airtight cage. It may be driven electrically or by suction produced by a venturi tube and a turbine. Electrically driven gyroscopes are preferable on sailplanes, which do not travel at great speeds, as the suction produced by the venturi may be too small. There is also the risk of the venturi tube being blocked by ice during cloud flying.

In the case of a venturi-driven turn-indicator gyroscope, the cage with the gyroscope is fixed in bearings and is free to move about a longitudinal axis. This cage is held, by means of a spring, to the case of an instrument in a set position, and is connected to the pointer on the dial which has a scale giving the rate of turn, i.e. the length of time in which the sailplane will make a complete circle.

There are different scales on turn indicators; the most common on sailplanes has zero position marked, with two other marks on each side of zero, and when the pointer moves and stays in line with either of these, it shows that the sailplane will complete the circle of turn in two minutes, always assuming that the instrument has been previously calibrated.

During the turn the instrument tries to carry the cage with it, in other words to deflect the plane of rotation of the gyroscope.

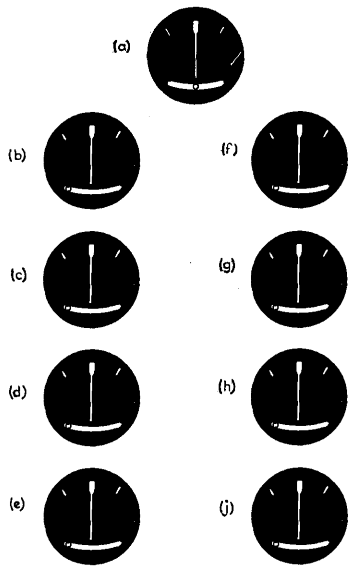


FIG. 82. VARIATION OF TURN-AND-BANK INDICATOR DURING DIFFERENT SAILPLANE MANOEUVRES

(*a*) Straight level flight.
(*b*) Sideslip to port.
(*c*) Correct right turn.
(*d*) Slipping in-right turn.
(*e*) Skidding out-right turn.
(*f*) Sideslip to starboard.
(*g*) Correct left turn.
(*h*) Slipping in-left turn.
(*j*) Skidding out-left turn.

Naturally the gyroscope will try to change its own axis of rotation from horizontal to vertical when this happens, but it is stopped by means of a spring. This phenomenon is called precession. It must be remembered that the pointer of the instrument always moves in the same direction as the nose of the glider.

Most modern turn indicators also incorporate a bank indicator, this usually being of rolling ball type. As the turn indicator is a rate instrument it must be calibrated to read the rate of turn correctly.

Artificial Horizon

This is a gyroscopic fore-and-aft and lateral-level indicator. It enables the pilot to keep the sailplane in any position relative to the ground.

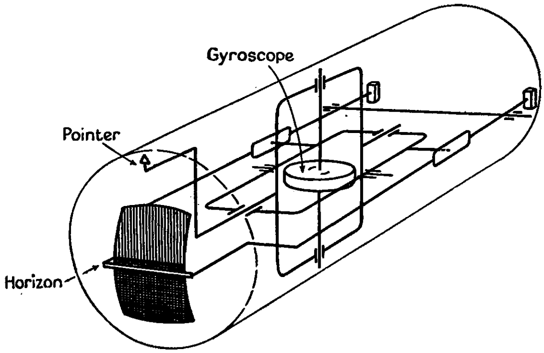


FIG. 83. ARTIFICIAL HORIZON

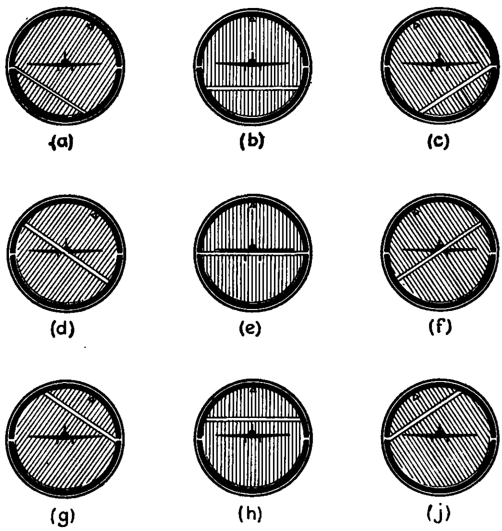


FIG. 84. INDICATION OF ARTIFICIAL HORIZON DURING VARIOUS POSITIONS OF SAILPLANE IN THE AIR

(*a*) Stalled left turn.
(*b*) Climb.
(*c*) Stalled right turn.
(*d*) Correct left turn.
(*e*) Level flight.
(*f*) Correct right turn.
(*g*) Left turn (nose under the horizon).
(*h*) Dive.
(*j*) Right turn (nose under the horizon).

The dial of the instrument has a scale divided in degrees up to 90° on the top section, the lower part shows a small sailplane. On the top part of the dial there is a small pointer attached to the background of the dial, and the background itself carries a horizontal line which is mounted in the centre. This background has freedom of movement. The horizontal line indicates the actual horizon and whatever attitude the sailplane assumes in the air, this line will always be parallel to the real horizon. During a normal flight this line is slightly above the silhouette of the sailplane on the dial, as in the glide the longitudinal axis of a sailplane is not horizontal. The small pointer on the top of the dial rotates with the background along the scale on the rim and gives the degree of bank. The normal artificial horizon will indicate a climb up to 60° and bank up to 90°.

The gyroscope is mounted in a horizontal plane and rotates about a vertical axis, but the cage which encloses it can move about a longitudinal and lateral axis without affecting the gyroscope. The vertical axis remains vertical during flight and the background of the dial will stay stationary with the gyroscope unit.

Compass

In principle a compass is a magnetic needle freely pivoted about its centre. Aircraft compasses usually have a number of magnetic needles which are arranged parallel to each other, to which a horizontal ring or card is attached which shows a scale marked in degrees.

When a magnetic needle is pivoted exactly about its C.G. the north end will dip downwards until it points towards the north magnetic pole in the northern hemisphere. If there is acceleration in a horizontal plane the reading of the compass will be erratic. The C.G. of the needle is usually so arranged that the mass on the south end of the needle is bigger and balances the force imposed on the north end by the north magnetic pole.

On the glass chamber or ring of an aircraft compass there is a lubber line which is parallel to the longitudinal axis of the sailplane. Below the compass case there is usually a small container for compensating magnets which are used to correct the needle deflection. The bowl of the compass contains alcohol which helps to damp out oscillations and vibrations which may be superimposed on the compass during soaring. Alcohol is used because it has a low viscosity which prevents the formation of eddies and swirls.

The normal compass withstands temperatures between −13°F and 122°F, and an expansion chamber is provided to overcome the change in the volume of the alcohol caused by changes in temperature.

The use of the compass is explained in the chapter on blind flying and aeronavigation. Here only the errors and maintenance of this instrument will be discussed.

SPEED ERROR. When the soaring pilot increases speed suddenly, the acceleration forces acting at the C.G. produce a deviation in a clockwise direction, and a decrease in speed produces deviation in an anti-clockwise direction.

NORTHERLY TURNING ERROR. The reading given by the compass needle when making a correct turn on northerly courses may be very small or even reversed. This is due to the fact that although the compass ring or card banks with the sailplane in a correct turn due

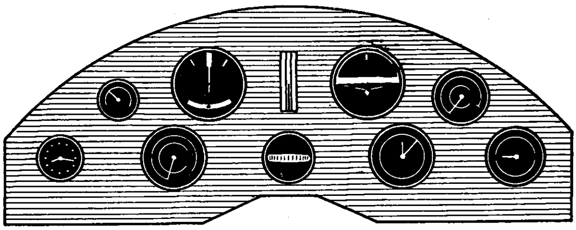


FIG. 85. ARRANGEMENT OF INSTRUMENTS ON THE PANEL

Left to Right, top row: air-temperature indicator, turn-and-bank indicator, fore-and-aft level, artificial horizon, airspeed indicator

Bottom row: clock, altimeter, compass, sensitive altimeter, rate-of-climb indicator

to centrifugal force, the magnetic dip affecting the compass needle will pull its north end downwards, in the northern hemisphere, and the compass ring or card will move in the same direction. The rate of movement of the ring, however, may be much faster than the rate of the sailplane's turn, and it will appear to the soaring pilot as though he made a turn in the opposite direction.

This error has been called the northerly turning error because it is most accentuated on turns from the north or south, but it appears in small magnitude on all turns, or when the wing of a sailplane is tilted by a gust.

OSCILLATION. This may be caused by weather conditions or by the pilot himself when flying north. Oscillation will be in the form of small turns of the compass ring from the north. It is possible for the period of this oscillation to be the same as the natural period of oscillation of the compass, and added together they may result in big compass oscillation.

For damping the oscillations caused in the compass by a turn, filaments (small glass balls) are used which are pulled through the alcohol and which stop its rotational movement.

DEVIATION. The presence of metal parts in the vicinity of the compass causes deviation or deflection of the compass reading from its true magnetic reading. This deviation must be added to the observed reading. This means that if the longitudinal axis of the sailplane is heading towards the magnetic North, and the compass reading is 2°, the deviation will be 2° West or $-2°$, because $-2°$ should be added to the compass reading to get the magnetic North. If the sailplane is heading towards the magnetic South and the compass reading is 175°, the deviation will be 5° East or $+5°$, because $+5°$ should be added to the compass reading to get the magnetic South. The deviation figures are usually arranged in a table and are fixed near the compass.

VARIATION. This is due to the compass needle endeavouring to point the magnetic North instead of the geographic North. The amount and direction of variation is usually given on maps.

Compass error due to variation and deviation is the sum of these two. If both have the same name (for instance "westerly") they are added, if unlike names the smaller is subtracted from the larger and the name stays as the larger, e.g. variation 5°W. deviation 2°W., the error is 7°W., but variation 5°W. deviation 2°E. and the error is 3°W.

COMPENSATION. The standard method of compensating is to fix the longitudinal axis of the sailplane heading towards the magnetic North (0°) and insert compensating magnets into the small container under the compass case until the deviation is zero. Then the longitudinal axis of the sailplane is fixed heading towards the magnetic East (90°) and compensating magnets inserted until the deviation is again zero. The deviation on the 30°, 60°, 120°, 150°, 210°, 270°, 300°, and 330° magnetic courses should be noted on the deviation card. The easterly deviation bears a $+$ sign and the westerly deviation a $-$ sign.

The compass should be fixed in such a position that it can easily be seen by the soaring pilot, and should be attached to the instrument panel by means of brass bolts and nuts as these will not affect the compass reading. It is also very important for the compass to be fixed in a horizontal position.

CHAPTER IV

MECHANICS OF SOARING FLIGHT

THE analysis of the theory and practice of flight necessitates some mathematical investigation without which it would be impossible to explain even the basic ideas of motorless flight. It is sometimes maintained that mathematics and mathematical formulae are an unnecessary complication of the sport of soaring flight, but the soaring pilot who takes a real interest in his subject will find that a study of these things is a necessity if he is to gain a real insight into the reactions of his sailplane in the air.

The following discussion will be limited to the most essential knowledge of flight technique and condensed as much as possible, as the main object of this book is to give the soaring pilot a clear idea of flight as a whole, and to classify some scientific facts and technical terminology.

WEIGHT, LIFT AND DRAG

In a steady, straight glide there are two forces acting on a sailplane, the weight W, which is a vertical force directed towards the centre of the earth, and the aerodynamic reaction A which enables the glider to stay in the air. The weight must be equal to the aerodynamic force to make flight possible,

$$W = A$$

To simplify this discussion the aerodynamic force may be divided into two components, the force which is perpendicular to the path of flight, so-called lift L, and that which is parallel to the path of flight, which is drag D. In a steady glide these two forces are balanced by the weight,

$$\sqrt{L^2 + D^2} = A = W$$

$$L = \cos\gamma$$

$$D = \sin\gamma$$

$$W = L\cos\gamma + D\sin\gamma$$

$$L\sin\gamma = D\cos\gamma$$

or

$$\frac{L}{D} = \cot\gamma$$

Drag is the component of the aerodynamic force on a body parallel to the relative wind and is always directed opposite to the direction of flight and tries to resist it. That is why it is called drag. The other component L, or *lift*, acts upwards.

GLIDING RATIO

Looking at Fig. 86 it can be seen that the angle of glide γ is equal to the angle between lift L and the aerodynamic force A. It is also

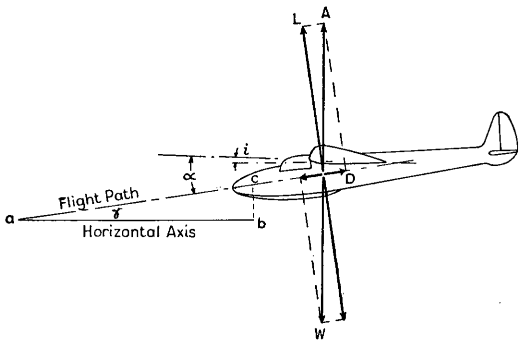


FIG. 86. FORCES ACTING ON A SAILPLANE DURING STEADY GLIDE

the angle between the flight path and the horizontal axis fixed relative to the air. The gliding ratio can be explained as a ratio of ab to bc and

$$\frac{ab}{bc} = \frac{1}{\tan \gamma} = \frac{L}{D}$$

The bigger the lift and the smaller the drag the better the gliding ratio (commonly called gliding angle) which can be obtained. This ratio may be regarded as a measure of the efficiency of a sailplane.

Drag depends on several factors—shape, surface, the position of the moving sailplane in the air in relation to the horizon, the size of the sailplane, the density of the air, and the velocity of travel. The relation between these factors and lift and drag is—

$$L = C_L \times S \times \rho \times V^2 \times \tfrac{1}{2}$$
$$D = C_D \times S \times \rho \times V^2 \times \tfrac{1}{2}$$

Where C_L and C_D = coefficient of lift and drag obtained from wind tunnel test or flight test, the above formula can be written—

$$\frac{L}{D} = \frac{C_L}{C_D}$$

and it can be seen that the gliding ratio of a sailplane depends entirely upon the ratio of lift to drag coefficient. It must be remembered that neither the weight of a sailplane W, nor atmospheric conditions, have anything to do with this ratio. Erroneous ideas sometimes encountered on this point probably arise from the fact that weight and atmospheric conditions have a big influence on sinking speed and the velocity of flight, which will be explained later.

DYNAMIC PRESSURE

This is the product of $\frac{1}{2}\rho v^2$ where ρ is the density of the air and v the relative speed of the air.

Standard density of air at sea-level is $\rho_o = 0{\cdot}002378$ slugs/ft^3.

$$q_o = 0{\cdot}001189\ v^2$$

q in lbs/ft^2 and v in ft/sec and it can be written that

$$q_o = 0{\cdot}002558\ V^2$$

q in lb/ft^2 and V in m.p.h. The value of q at any air density other than standard is

$$q = q_o \frac{\rho}{\rho_o}$$

The relation between a given dynamic pressure and velocity in standard air is

$$v = 29{\cdot}00\ \sqrt{q_o}\ \text{ft/sec}$$
$$V = 19{\cdot}77\ \sqrt{q_o}\ \text{m.p.h.}$$

THE WING

The source of the lift acting on a sailplane is the wing, which also produces the greater part of the drag. A great deal of attention is given to this part of a sailplane by designers and manufacturers with the object of reducing drag to the minimum. The lifting characteristics of a wing depend mainly on the shape of the wing section and very little on its plan form (aerofoil). The aerofoil profile is a cross-section of a wing parallel to the vertical plane of symmetry. Wind tunnel tests on several profiles enable the designer to choose quite a number of efficient profiles of widely differing lifting characteristics. Unfortunately, however, profiles with high lift also usually produce high drag, and those with small drag do not give high lift.

The wing generally has a different aerofoil section along it, moderate high lift profile in the middle and low drag profile at the tip.

The presence of the lift force can be simply explained in the following way, although this is not an entirely accurate description. The air flowing around the wing has a greater distance to cover over the upper part of a profile than under the lower surface. Therefore the speed of air flowing over the wing is greater than that of the air flowing underneath it. This increase in speed results in a decrease of pressure measured vertically to the direction of flow, and the pressure on the bottom surface of the aerofoil increases. The difference in pressure produces the lifting force.

DRAG

When the body or component of a sailplane does not produce lift but only drag, this is called parasite drag.

Parasite drag is that portion of the drag of a glider exclusive of the induced drag of the wings. It is caused not only by skin friction but also by turbulence.

The total drag of a sailplane consists of parasite drag and wing drag, which is divided into induced and profile drag.

Induced drag is that part of the drag which is induced by the lift.

Profile drag is the difference between the total wind drag and the induced drag. The drag of a streamlined body—profile drag—consists of two components: drag due to the shape of the body and drag due to friction. The body with small drag for a low range of speeds will be slim with a rounded nose and sharp end. The body giving the minimum drag will have a maximum thickness of 30–35 per cent of its length from the nose and when $\frac{d}{l} = \frac{1}{3}$.

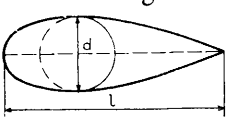


FIG. 87. STREAMLINE BODY

FINESS RATIO

Finess ratio is the ratio of the length to the maximum diameter of a streamlined body. Such a body allows a free passage through the air, creating the minimum number of vortices or eddies immediately behind that body.

When the length of the body shown in Fig. 86 is increased, and its thickness d stays the same, the drag of this body will not decrease, but on the contrary, it will actually increase. This paradox is due to skin friction which depends on the area and smoothness of the surface.

Skin friction plays a very important part in the performance of a sailplane, as the fuselage, wing, tail plane and rudder surfaces are all streamlined, and to reduce skin friction these surfaces should be of a very smooth finish and should be kept polished to a very high degree. The surface finish of a wing has a marked effect on its characteristics. A 10 per cent reduction in C_{Do} (profile drag coefficient) can be obtained with a highly polished surface as compared to a standard doped surface. The importance of high polish on all surfaces of a sailplane is shown by the fact that the weight of dope and paint on a high performance sailplane is in the region of 10 per cent of its total weight.

Apart from drag due to shape and skin friction, there will be another component of drag caused by the force of lift. This is the induced drag already mentioned. The explanation and analysis of

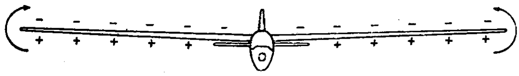


FIG. 88. LATERAL FLOW OF AIR AROUND THE WING ARISING FROM UNEVEN PRESSURE DISTRIBUTION

induced drag is, however, beyond the scope of this book and it is only necessary to state that this drag is closely connected with the downwash of air behind the wing and the vortices formed on the wing tips. Due to the difference in pressure above and below the wing a kind of circulation is produced owing to the fact that air always flows from a region of high pressure to that of a lower one. This circulation flows from under the wing to the top round the tips of the wing.

Fig. 87 shows the high pressure below and the low pressure above the wing which combine to give the lift. At the tips there must be a lateral flow from the high pressure to the low pressure. Induced drag depends on the plan form of the wing and its aspect ratio, and may be reduced by increasing the aspect ratio.

ASPECT RATIO

This is the ratio of span of the wing b to its mean chord $\bar{c}$. By *span* is meant the maximum distance from wing tip to wing tip. The mean chord is the ratio of the area of the wing S to span b.

Aspect ratio $$A.R. = \frac{b}{\bar{c}}$$

Mean chord $$\bar{c} = \frac{S}{b}$$

The wing of high aspect ratio $A.R. = 15$—20 is very common in the design of high performance sailplanes.

DOWNWASH

When air passes over the wings it is deflected downwards, and the angle through which the air is turned is called the *angle of downwash.* This is measured in a plane parallel to the plane of symmetry. Naturally at some distance behind the wings the downwash disappears completely, but in the region of the tail it is still acting and is, therefore, of great importance.

When the chord of the tail plane is parallel to the chord of the wing, the downwash will reduce the angle of incidence of the tail plane. As the tail plane acts as an aerofoil this change in the angle of incidence will affect the lift produced by the tail plane and the pitching moment as well.

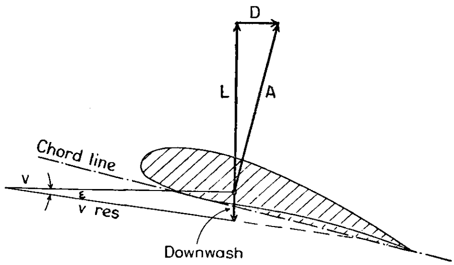


FIG. 89. DOWNWASH AND DOWNWASH ANGLE

The pitching moment of a sailplane is the sum of the pitching moments of the wings and the tail plane.

PROFILES

One of the factors determining the necessary area of a wing is chord length. If a circle is described so that its centre is a singular point *A* and this circle forms a tangent at point *B*, then its radius will be the chord length, and the line which joins *A* and *B* will be a reference line for measuring the angle of attack.

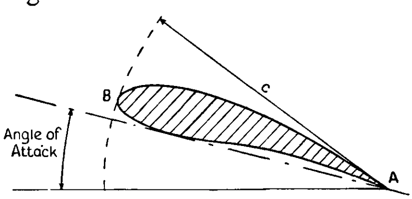


FIG. 90. DETERMINATION OF A PROFILE CHORD

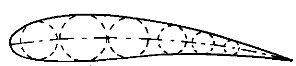


FIG. 91. DETERMINATION OF MEAN CAMBER LINE

The mean camber line is the locus of the centres of the circles inscribed to the profile. The diameter of the largest circle among these defines the thickness of the profile. This is the maximum distance between the upper and lower contours of the profile, measured perpendicularly to the mean line of the profile. The longest distance between line AB and a point on the mean camber line is the camber of the profile.

Twist

Some wings are given a twist so that the angle of incidence is not constant along the span. When the angle of attack decreases at the wing tip (washout) it helps to concentrate lift. As the central part of the wing produces the greatest lift, the bending moment at the wing root will be smaller at the same total lift.

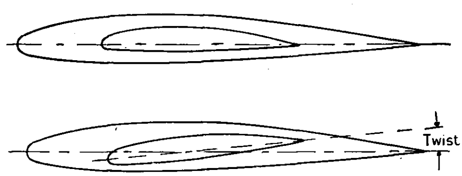


FIG. 92. UNTWISTED AND TWISTED WING

Washout applied to the wing helps its lateral stability. The wing tip stalls first and to prevent this the angle of incidence is reduced.

The *characteristic* of profile is obtained from

$$C_L = \frac{2L}{\rho v^2 S}$$

$$C_D = \frac{2D}{\rho v^2 S}$$

$$C_M = \frac{2M}{\rho v^2 S}$$

and as a rule each factor is plotted against the angle of attack. The form of these curves depends on the shape of the profile.

Lift Coefficient

There is an angle of attack α_0 for each profile at which the lift and lift coefficient = 0.

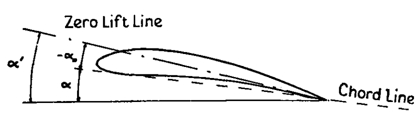


FIG. 93. ANGLE OF ATTACK AND NO-LIFT ANGLE OF AEROFOIL

$\alpha^1 = \alpha - \alpha_0$ this angle is called the effective angle of attack.

The angle α is the angle of attack.

The point where the lift changes is called stalling point.

Drag Coefficient

This curve is usually of parabolic character. Its minimum value is near $\alpha = 0$.

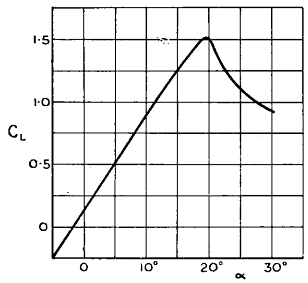


FIG. 94. LIFT COEFFICIENT AGAINST ANGLE OF ATTACK

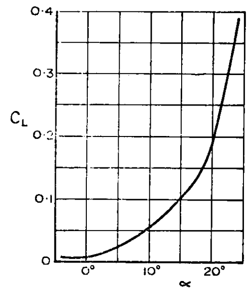


FIG. 95. DRAG COEFFICIENT AGAINST ANGLE OF ATTACK

The polar diagram, Fig. 96, gives comprehensive representation of the relations between C_L and C_D and α^1; C_L is plotted against C_D.

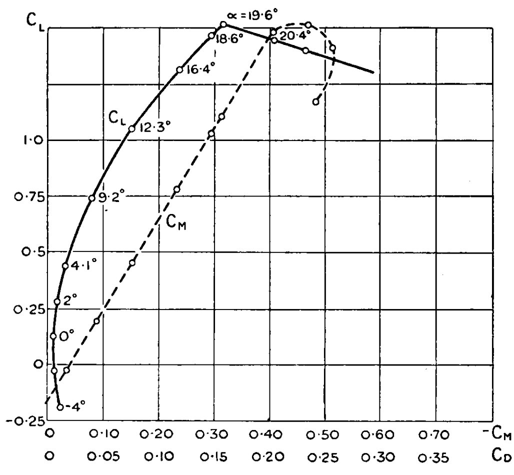


FIG. 96. POLAR DIAGRAM AND PITCHING MOMENT CURVE

CENTRE OF PRESSURE OF AN AEROFOIL SECTION

The point on a profile, prolonged if necessary, which is at the intersection of the chord and the line of action of the aerodynamic force, is the centre of pressure of a profile. The lift which is produced by the profile consists of negative pressure which gives two-thirds of the lift, and positive pressure, one-third of lift. It is unimportant which one of these pressures plays the bigger part in producing the lift, but a very important factor is the location of the aerodynamic force.

The pressure distribution around the profile shows that bigger pressures can be found near the leading edge. The resultant force of all these pressures is located in the centre of gravity of an area enclosed by the pressure distribution curve.

To understand the centre of pressure travel it must be noted that the position of the location of the aerodynamic force varies with the angle of attack. From Fig. 97 it can be seen that the pressures near the leading edge of the profile, in relation to pressures near the

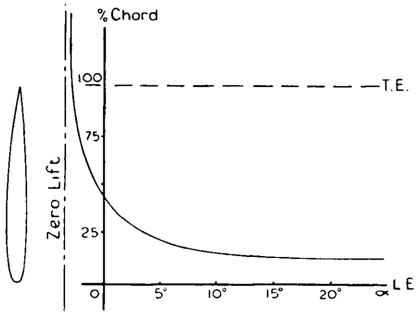


FIG. 97. CENTRE OF PRESSURE TRAVEL AGAINST ANGLE OF ATTACK

trailing edge, increase with increasing angle of attack. When the angle of attack decreases and lift becomes zero, the pressures of the front part of the profile become negative and the total lift force is equal to zero. The positive pressures on the back of the profile and the negative on the front, change, due to the angle of attack, and produce a moment.

Fig. 97 gives the travel of the centre of pressure with the angle of attack. With an increasing angle of attack the centre of pressure will move forward, with a decreasing angle of attack it will move backward. Such a profile is called unstable.

The moment due to the lift force will be—

$$M = L \times l$$

where $l =$ distance of $C.P.$ from $C.G.$

or $M = C_L \times q \times S \times l \times \frac{1}{2}$

and moment coefficient $C_M = \dfrac{C_L \times q \times S \times l \times \frac{1}{2}}{M}$

This moment coefficient has been plotted on the polar curve (Fig. 96) and from it the travel of the centre of pressure can be ascertained.

WING SECTION'S AERODYNAMIC CENTRE

This is a point located on or near the chord of the mean line, approximately a quarter of the chord length aft of the leading edge, and about which the moment coefficient is practically constant. The angle γ between the lift L and resultant aerodynamic force A, is $= \frac{D}{L}$ and is $= \frac{C_D}{C_L}$.

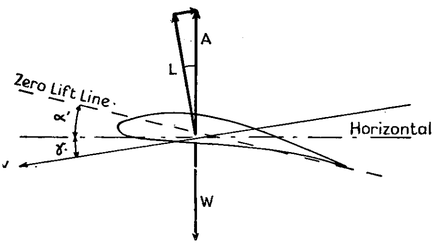


FIG. 98. THE GLIDING ANGLE OF THE PROFILE

The angle γ is very often called the gliding angle of the profile. The minimum value of this angle is found by drawing the tangent from the origin to the polar curve.

Moment coefficient (pitching moment) depends on the position of the point with respect to which the moment is taken. For each profile there exists a point with respect to which the moment M and the moment coefficient C_M have constant values as long as the angle of attack remains in the region of a straight line of the C_L curve. This point is the aerodynamic centre.

CIRCULATION

The air particles in front of the wing move upwards and increase in speed while flowing over the upper profile of the wing, decreasing on the trailing edge, and on the lower profile of the wing the air particles near the leading edge have a tendency to move upwards. This leads to a circular motion around the wing as shown in Fig. 99. The circulation of air particles does not move with the wind but is closely associated with the wing and travels with it during its motion through the air.

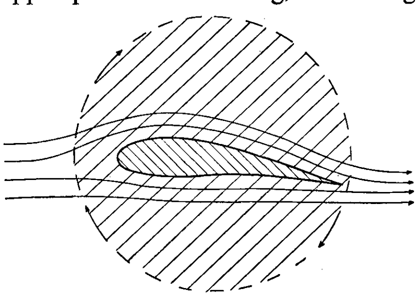


FIG. 99. CIRCULATION AROUND THE PROFILE

Circulation and wing-tip vortices are not only produced by the wing. The tail plane and elevator fin and rudder also produce their own.

POLAR CURVE

The last few pages gave a very brief picture of the relation of the shape and texture of surfaces to the coefficient of lift and drag of a sailplane. There is, however, one more factor upon which the coefficients of lift and drag depend which is of particular interest to the soaring pilot. It is the position of the sailplane in relation to the direction of flight, which, in the case of symmetrical flow, we describe as the angle of attack of the middle section of the wing. Fig. 95 shows that this angle is formed by the path of flight and chord of the wing. For every angle of attack there is an appropriate coefficient of lift and drag. This relation is usually represented in the form of a curve, which is called the polar curve (Fig. 95). This figure gives the polar curve for the average sailplane.

It can be seen that after passing a certain angle of attack the lift C_L will not increase but will gradually decrease, while the drag C_D increases rapidly. This phenomenon is due to the stalling of the wing. The flow of air will not follow the profile of the wing but will break down and cause eddies. In such a case the lift may be very small or may disappear completely, while the drag increases enormously. The negative pressure becomes zero, the positive pressure becomes large and acts as a drag. This angle of attack is often known as "the critical angle" and its consequence is a loss of flying speed. Further increase of the angle of attack increases the breakaway and drag.

SPEED CONTROL

As the performance characteristics are among the most important factors which influence the planning and actual performance of a successful soaring flight, a more detailed explanation must be given to throw a new light on the technique of soaring flight.

It must be remembered that without careful preparation for a flight, and without knowing the correct way to get the utmost efficiency from a sailplane, no flight will be entirely successful. The basis of the technique of flight has been given in previous sections, and the use of the formulae given will be explained below.

The lift force has been expressed in this form—

$$L = C_L \times \rho \times S \times V^2 \times \tfrac{1}{2}$$

and

$$L = W \times \cos \gamma$$

The speed of flight can be found as

$$V = \sqrt{\frac{W}{C_L \times \rho \times S \times \frac{1}{2}}}$$

Cos α may be neglected, as this value, even for a gliding ratio of 1:10 which is difficult to obtain on a high performance sailplane, introduces an error smaller than 0·25 per cent. Once again it can be seen that the speed of a sailplane depends on the value of the coefficients of lift C_L, which again depend on the angle of attack. For example, if flying at a certain angle of attack and holding the control stick so that it cannot move, the cockpit cover were to be jettisoned, the angle of glide would change, as in this case

$$D = W \times \sin \gamma$$

and the new drag D^1 will be given by the equation

$$D^1 = W \times \sin \gamma^1 = C_D{}^1 \times \rho \times S \times V^2 \times \tfrac{1}{2}$$

but the speed of flight will remain unchanged.

SPEED

When the weight of a sailplane and its wing area are constant, the coefficient of lift varies inversely as the square of velocity. Small angles of glide mean high speed; large angles, low speed.

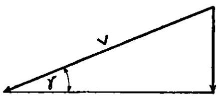


FIG. 100. SINKING SPEED AND ITS RELATION TO HORIZONTAL SPEED AND SPEED OF FLIGHT

Minimum speed is the lowest speed which will be obtained when the lift coefficient is maximum, and this is called the *stalling speed.*

Ground speed is the horizontal component of the velocity of a sailplane relative to the ground.

Landing speed is the minimum speed of a sailplane at the instant of contact with the landing area in a normal landing.

Take-off speed is the speed at which a sailplane becomes entirely airborne.

Sinking speed is a function of the speed of flight along the path of flight, which is the centre of gravity travel with reference to the earth, and is usually given as a vertical component; as in the range of gliding angles γ for high performance sailplanes, sin γ is substantially equal to tan γ

$$\tan \gamma = \frac{v_s}{V}$$

but

$$\tan \gamma = \frac{D}{L}$$

so it can be written that

$$\frac{D}{L} = \frac{v_s}{V} \qquad \text{or} \qquad v_s = V \times \frac{D}{L}$$

The sinking speed is equal to the speed of a sailplane divided by the gliding ratio.

In the early years of soaring, sailplanes were characterized by a very low sinking speed so as to improve their performance when soaring in slope currents, which are amongst the weak currents. The sailplane with a very low sinking speed could stay in weak up-currents much longer than the sailplane with a high sinking speed. But as the technique of thermal flight was developed, it was found that the up-currents within a thermal are so strong that the low sinking speed is completely unnecessary.

Cruising speed, in present-day soaring technique, plays an important part. During cross-country flights it is essential to be able to fly as quickly as possible through areas of down-current without much loss of height, in order to fly as far as possible during the relatively short period of thermal activity during the day.

The speed of flight depends on the weight, coefficient of drag and wing area.

$$V = \sqrt{\frac{2}{C_D \times \rho} \times \frac{W}{S}}$$

From this formula it can be seen that the speed of flight will increase with an increase in the ratio of $\frac{W}{S}$. This ratio is called the wing loading (total weight of sailplane divided by wing area).

STALLING

The stall is a condition of the sailplane in which it is operating at an angle of attack larger than the angle of attack of maximum lift. From Fig. 94 it can be seen that the lift coefficient increases in proportion to the angle of attack only up to a certain point where the curve reverses (peak point of the curve). This is the stalling point. For normal profiles stalling occurs between 1·2–1·6 C_L. When the angle of incidence is increased further, C_L will drop nearly to zero.

From formulae at the beginning of this chapter it may be seen that the speed of a sailplane of a given weight in a steady glide is inversely proportional to the square root of C_L. The greatest C_L will therefore determine the lowest possible speed.

During the motion of a wing at small angles of attack the air flow will follow the pattern given in Fig. 101, but at angles which are near the stall, the flow pattern will change, and at a certain point near the nose of the profile the flow may separate and a region of vortices and disturbances will appear. Because the lift of the profile depends to a much greater extent on the negative pressure (suction) on the upper surface of the profile, the lift must decrease rapidly during a stall, as the region of vortices develops.

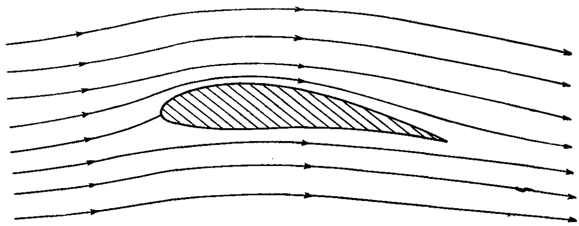


FIG. 101. AIR FLOW AROUND THE WING AT SMALL ANGLES OF ATTACK

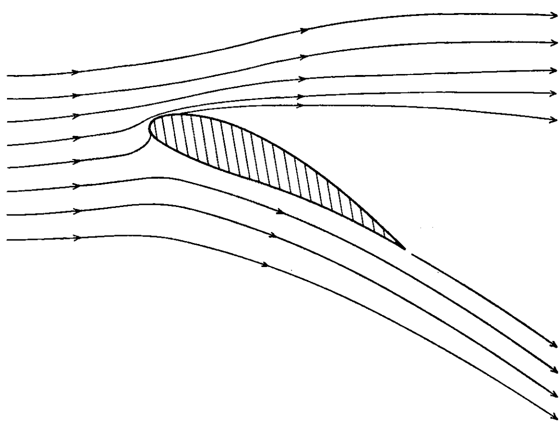


FIG. 102. AIR FLOW AROUND THE WING AT LARGE ANGLE OF ATTACK

PERFORMANCE CURVE

This curve is usually prepared for a sailplane assumed to be moving in still air. The sinking speed is plotted against the speed of travel, and as the sinking speed is a function of the angle of glide, this angle is indicated on the diagram. Analysing this diagram it can be seen that the lowest sinking speed will be obtainable with 38 m.p.h. speed of travel. During those flights where speed is not very important, such as site soaring, flights in the vicinity of the aerodrome, and where the question of the duration of flight is the most important consideration, the most economical flights will be made with 40 m.p.h. speed of travel. When it is a question of covering the maximum possible distance, the ratio of speed of travel to sinking speed must be the maximum. The tangent to this curve crossing point *O* will give the correct answer as to speed of travel, sinking speed and angle of glide. To cover a maximum distance from a certain height this angle should be as small as possible.

From Fig. 103 it can be seen that the most economical cruising

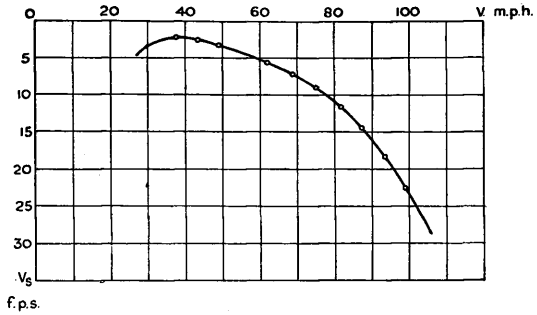


FIG. 103. PERFORMANCE CURVE

speed is 48 m.p.h. Knowing the speed of travel—the speed shown on the airspeed indicator—known as I.A.S. (Indicated Airspeed), and the sinking speed, the distance which can be flown from height *h* can be found.

Now the correction factor should not be forgotten in this discussion. Due to changes in altitude, there will be a different airspeed shown on the airspeed indicator, and the true airspeed should always be taken by estimating the performance of the sailplane at different altitudes. The correction factor due to the change in density of the air is included in the chapter on Instruments, page 58, and the diagram of true airspeed against indicated airspeed, Fig. 75.

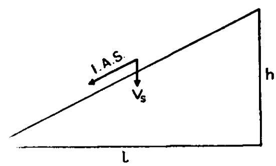


FIG. 104. ESTIMATION OF DISTANCE WHICH CAN BE FLOWN FROM HEIGHT *h*

Axis. Forces and moments acting on a glider are, as a rule, referred to a set of three planes each having specified directions for positive forces and positive moments.

STABILITY

This is the property of a body which, when its equilibrium is disturbed, causes it to develop forces or moments tending to restore the original condition. Dynamic stability is the property of a sailplane which causes such stability, when its state of steady flight is disturbed, to damp the oscillations set up by the restoring forces and moments and gradually return to its original state. The sailplane will be statically stable when, disturbed from the condition of steady glide, it returns to this condition without any help from the pilot. It may, however, oscillate about equilibrium condition without ever remaining in it. In such case the sailplane may be dynamically unstable although statically stable.

The stability of a sailplane depends chiefly on the location of the centre of gravity. The motions of a sailplane can be divided into

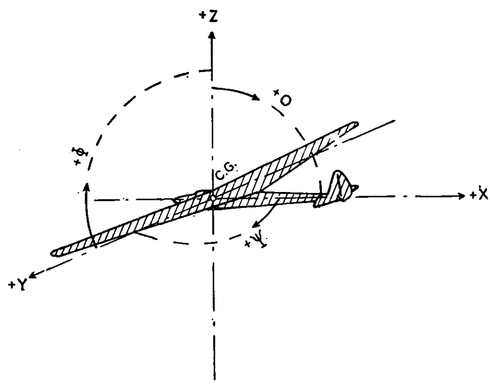


FIG. 105. VERTICAL z–z, LATERAL y–y AND LONGITUDINAL x–x AXIS OF A SAILPLANE

three categories—longitudinal, lateral and directional, and these stabilities will be discussed below.

Longitudinal Stability

This is a stability up or down along the flight path, and it can be determined by calculating the pitching moments of the wing and tail about the centre of gravity.

Pitch is an angular displacement about an axis parallel to the lateral axis of a glider.

Pitching moment is the total air moment acting upon the glider about the lateral axis. The balance and control of the pitching moment is governed by the tail plane.

Balance is a condition of steady flight in which the resultant force and moment on the glider are zero.

The pitching moment M is a product of wing and tail forces about the centre of gravity. The coefficient C_M of this moment is plotted, as a rule, against the angle of attack α or C_L. Naturally the condition of equilibrium or stability will be at $C_M = 0$. When the sailplane is stable and is in a steady glide, all forces are in equilibrium. If the sailplane enters an up-current, the angle of attack will immediately increase, which will result in an increase of C_L too. The negative moment—diving moment, will act on the sailplane, which will move the nose down, decrease the angle of attack and return the sailplane to a stable condition. A down-current will decrease C_L, produce a positive stalling moment, which will tend to increase the angle of attack, and return the glider to a stable condition.

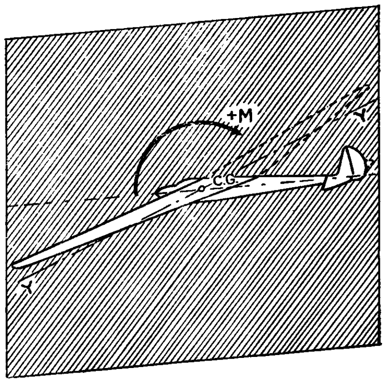


FIG. 106. THE PITCHING MOMENT OF A SAILPLANE TAKES PLACE IN VERTICAL PLANE OF SYMMETRY AROUND y–y AXIS (LATERAL)

In all modern, high-performance sailplanes, a trimming device is fitted, usually a flap on the elevator, which enables the pilot to fly with his hands off the control stick at cruising speed.

Lateral Stability

This is measured with reference to disturbances in the plane of symmetry, disturbances involving pitching and variation of the longitudinal and normal velocities. The sailplane will be laterally stable if an increase in the angle of roll ϕ produces a rolling moment M_L, which will decrease the angle of roll, as in Fig. 136. Forces L and W do not produce any restoring moment when the glider is rolled to an angle ϕ, only a resultant force R which causes a sideslip. The sideslip, however, results in a righting moment as shown in Fig. 143.

Force T acting on the fin and rudder (Fig. 136), and L, acting on the wing, produce a rolling and yawing moment as well. When the tail surfaces are very large for a given dihedral, a sideslip results in a yawing motion which increases the sideslip, and the sailplane will go into a tight spiral dive. When the tail surfaces are too small, the roll will be accompanied by yawing in the opposite direction, which may produce the wallowing motion commonly known as the Dutch roll. To prevent the sailplane from rolling off sideways into a sideslip, dihedral angle is supplied to the wings. The wing has a dihedral when the tips are higher than the centre of the wing.

The sailplane is rolled by means of ailerons which are connected to the control stick. When an aileron is moved the effective camber of the outer portion of the wing is changed. Ailerons do not produce

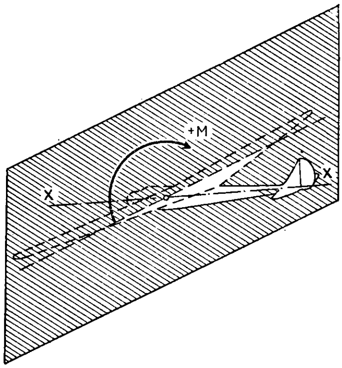


FIG. 107. THE ROLLING MOMENT OF A SAILPLANE TAKES PLACE AROUND LONGITUDINAL AXIS x–x

any rolling moment when the wing is stalled, which makes the sailplane uncontrollable.

Lateral stability also depends upon the characteristics of a wing. It must be remembered that on an ordinary tapered wing the tips stall first, making the ailerons ineffective before the whole wing is stalled. To avoid this the aerodynamic twist (change of the aerofoil section along the span) is used, which enables the central part of the wing to stall first.

Directional Stability

This stability refers to disturbances about the normal axis of an aircraft, disturbances which tend to cause yawing.

Yaw is an angular displacement about an axis parallel to the normal axis of a sailplane.

A sailplane is called directionally stable if an increase in the angle of yaw produces a yawing moment which will decrease the angle of yaw. This yawing moment is the result of a side force acting on the sailplane.

If a sailplane receives a side gust it will have the tendency to move, say, to the left, and the effect of a side wind force F_s is to put the sailplane in a yawed attitude.

The fin always acts at a definite angle of attack, as it consists of a symmetrical aerofoil. During straight flight its angle of attack is 0° and no lift is produced. Due to the yaw, however, the fin experiences a lift, the magnitude of which depends on the angle of yaw, or the angle of fin attack, as it may be called. This lift will provide a restoring moment which will tend to swing the nose into the direction

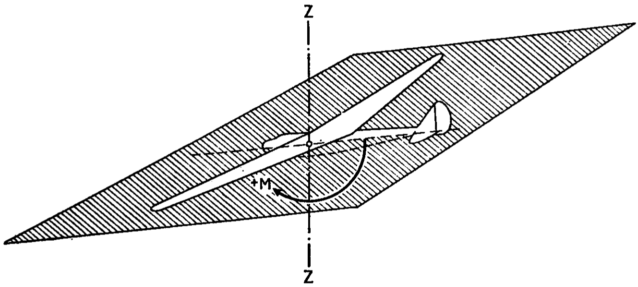


FIG. 108. THE YAWING MOMENT OF A SAILPLANE AROUND VERTICAL AXIS z–z

of the gust. It can be seen from this that a large fin with a high aspect ratio will produce directional stability.

Spiral Stability

The sailplane with a very large fin may produce another form of instability. If an angular yawing velocity is produced due to a gust of wind, then the outer wing travels faster than the inner wing, and, as it also has greater lift, a rolling moment is generated which will try to roll the sailplane in the direction of a turn. The result will be a sideslip inwards. The dihedral angle of the wings tries to lift the inner wing, but due to the action of the fin there will be a moment which will swing the nose of the sailplane into the direction of a sideslip, and the turn of the sailplane will increase.

When the moment due to the fin is greater than that produced by the dihedral angle, the turn, which was originally small, will become greater, and the roll will increase, which again will increase the turn. The sailplane will then lose height in a spiral path.

CHAPTER V

LOADS ACTING ON SAILPLANE

MANY soaring pilots do not realize the importance of the factors upon which the safety and performance of every flight depend. The winch launching of a sailplane, aero-tow, and flight in clouds should be undertaken according to the load factors which have been taken into consideration in the design and construction of the sailplane.

DESIGN AND LOAD

A sailplane which is well designed and built may be taken off, flown and landed economically and safely. The safety factor requires that the sailplane will normally perform such actions without the least risk of the breaking of wings, fuselage or tail plane; the economy factor requires that the wings, fuselage and tail plane should not be heavier than necessary. Most of the accidents which occur can be traced to one of the following causes—forced landing in rough fields, unskilful landing, and cross- or down-wind landing; unnecessary or sudden manoeuvres; gusts of wind.

Soaring pilots should understand that the technique of flying a sailplane is also an engineering problem and involves the estimation of the loads which may be expected to occur during an intended flight, and a knowledge of the strength and safety of the materials of which the sailplane is built.

The forces acting on a sailplane under various conditions are due to air pressure (lift and drag), to ground reactions (landing and take-off) and to weight and inertia forces. The structure of a sailplane must be designed so as to withstand the loads applied under critical conditions.

Before enumerating the various loading conditions it is necessary to have some understanding of the manner in which the structure of the sailplane carries those loads. To do this in a satisfactory manner requires a complete course on the theory of structures and we can do little more here than indicate the various ways of carrying the load.

Consider first of all a cantilever wing (Fig. 109). This wing supports the weight of the fuselage at its mid-point by means of lift force distributed over the wing. It works, in fact, as a beam.

Considering a section near the root, it is evident that the air load carries a bending moment on the beam. This is resisted by compression in the top boom and tension in the bottom boom. However, these booms alone do not make a structure since under a load they would simply slide freely relative to each other (Fig. 110). To

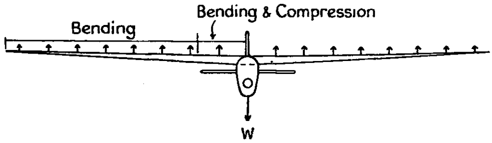


FIG. 109. CANTILEVER WING

prevent this happening, there is a web which resists the sliding or shearing action.

Now, looking at the wing loads from another angle we see that the beam will only carry a load in its own plane (Fig. 111). If the load is shifted on the chord the beam will twist quite easily. In order to prevent serious twisting the beam is made part of a tube

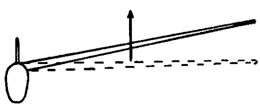


FIG. 110. BOOMS ALONE DO NOT MAKE A STRUCTURE

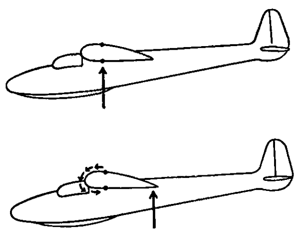


FIG. 111. TWISTING OF THE BEAM

(or torsion box) which resists the twisting action by shear round its walls.

We now have a wing structure which can resist any type of load. It consists of—

Booms to carry tensile and compressive end loads which resist a bending moment.

Web to resist shear.

Torsion box to resist twisting moments.

The fuselage carries loads in much the same way, except that the fuselage skin forms both web and booms, with stringers and longrons as additional boom material.

How the wing carries all the loads to which it can be subjected will now be considered.

Vertical shear is carried by shearing in the spar web.

Vertical bending by end loads in the top and bottom booms.

Fore-and-aft shear bending by the front and rear of the box acting as booms.

Torque by torsion of the box.

A common way of relieving the bending moment on the wing is by use of a strut. In normal flight the strut is in tension and relieves the bending moment (Figs. 112, 113). The strut also carries a compressive load on that portion of the wing between the strut-top fixture and the fuselage. During landing the load on the wing acts downwards and the strut is put into compression; otherwise it would be satisfactory to use wires instead of struts to carry flight loads.

If the load on a sailplane is steadily increased, there will come a stage when there will be an undesirable amount of permanent set

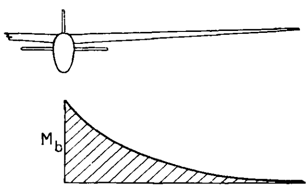


FIG. 112. BENDING MOMENT OF CANTILEVER WING

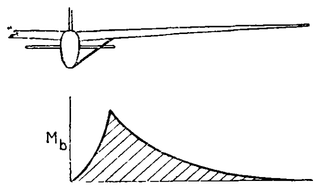


FIG. 113. BENDING MOMENT OF STRUTTED WING

on the removal of the load. If the load is further increased it will lead to failure.

The load on the wing of a sailplane in normal, steady flight is equal to its weight and is called *static load.* During manoeuvres the load is increased in a ratio *n* known as the *normal acceleration factor.*

The design load is defined as the heaviest possible applied load multiplied by a factor of safety (usually $1\frac{1}{2}$). The structure must not fail at this load.

The proof load which is usually two-thirds of the design load, is the load at which there must not be appreciable permanent set on unloading.

Thus, two conditions in the sailplane must be satisfied—

(*a*) It must not fail below the design load.

(*b*) It must not undergo permanent set at the proof load.

DISTRIBUTION OF LOAD

Flight loads may be divided into two groups whose resultant forces are in equilibrium with each other, namely, air loads and inertia loads. The air loads are distributed over the wing, fuselage and tail plane in normal flight, and on the fin and rudder also in manoeuvres. The distribution of air load along the span in two typical cases is shown in Figs. 114 and 115.

When a wing has a washout, the loading on the wing tip may even become negative at high speed. The distribution of load across the chord depends entirely on the angle of attack (Fig. 116). At a large angle of attack the centre of pressure is near 0·2 of the chord, while at small angles of attack it may be behind the trailing edge. It is evident that at high speed, i.e. small angles of attack, there will be a heavy nose-down torque on the wing.

The load on the tail plane is distributed in much the same way as on the wing, and its magnitude is such as to achieve pitching balance of the sailplane. Thus at high speed the nose-down torque on the wing is balanced by a heavy down-load on the tail plane.

The inertia loads are those associated with vertical, and occasionally pitching, accelerations of the sailplane induced by the air loads. In steady flight these inertia loads are due to gravity and are called dead weight load.

STRENGTH GRADES

The British Civil Airworthiness Requirements provide four strength grades for gliders and sailplanes—

Category: *normal*

Grade 1. Primary trainer.
Grade 2. Secondary trainer and large towed transport glider.

Category: *aerobatic*

Grade 3. Intermediate trainer or sailplane with limited aerobatic use.
Grade 4. Sailplane with full aerobatic use.

FLIGHT LIMITATIONS. Normal category Grade 1 gliders are prohibited from being aero-towed. All other gliders may be towed by other aircraft. Normal category gliders are prohibited from making any kind of aerobatic manoeuvres. Aerobatic category Grade 3 sailplanes are prohibited from making aerobatic manoeuvres other than those limited to secondary training. Aerobatic category Grade 4 sailplanes are permitted to make all orthodox aerobatic manoeuvres.

FLIGHT SPEEDS. Excess of the design towing speed V_{TS} when on tow is prohibited, as is excess of 90 per cent of the design diving speed V_D.

The structure of any sailplane has a proof factor not less than 1·0 and ultimate factor 1·5.

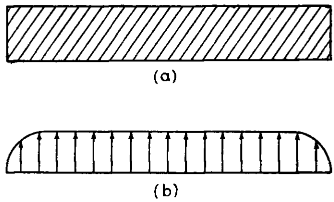


FIG. 114. AIR LOAD DISTRIBUTION ALONG THE SPAN

(*a*) Straight wing.
(*b*) Curve of loading along the span.

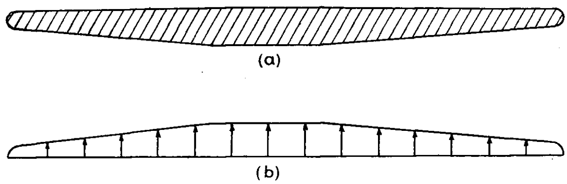


FIG. 115. AIR LOAD DISTRIBUTION ALONG THE SPAN

(*a*) Tapered wing.
(*b*) Curve of loading along the span.

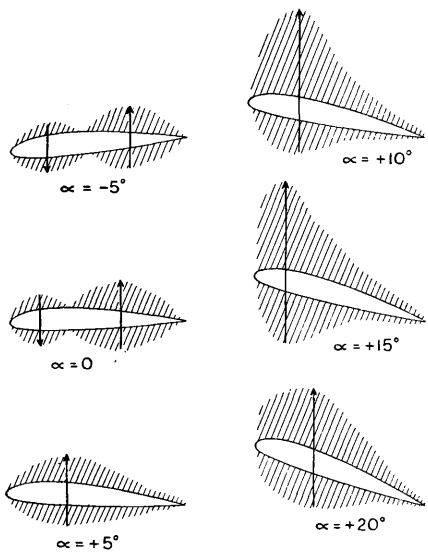


FIG. 116. AIR LOAD DISTRIBUTION AROUND AN AEROFOIL SECTION AT VARIOUS ANGLES OF ATTACK

In the case of a normal category glider in Group 2 (the strength grade which may be towed by another aircraft), the conditions represented by points B and E (Fig. 117) should be investigated. In this diagram the "normal acceleration" is the acceleration of the sailplane at its centre of gravity, normal to the flight path, and the

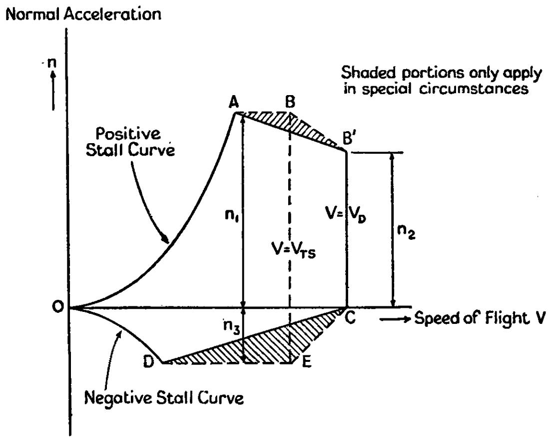


FIG. 117. FLIGHT ENVELOPE

(*a*) Design diving speed.
(*b*) Maximum normal acceleration coefficient.

"speed of flight V" is the speed along the flight path expressed as Equivalent Airspeed (E.A.S.), i.e. true airspeed multiplied by the square root of the relative density.

The values of n_1, n_2, n_3, are chosen from the following table.

TABLE I

	Normal Category		Aerobatic Category	
	Group (I)	Group (II)	Group (III)	Group (IV)
n_1	4·0	$2{\cdot}1 + \dfrac{24{,}000}{W + 10{,}000}$ but not greater than 4·0 nor less than 2·5	5·0	6·5
n_2	3·0	$0{\cdot}75\, n_1$ but not less than 2·0	4·0	5·0
n_3	− 1·0	$- 0{\cdot}4\, n_1$	− 2·5	− 3·0

W is the maximum all-up weight

The design towing speed V_{TS} is important in the case of normal category Group 2 gliders, as the points B and E on the diagram (Fig. 117) are determined by speed V_{TS}. The design diving speed (E.A.S.) V_D should not be less than the value given in Table II, and where appropriate not less than 1·4 V_{TS} if this exceeds the value given in Table II.

TABLE II

	Normal Category		Aerobatic Category	
	Group (I)	Group (II)	Group (III)	Group (IV)
V_D	3·0 V_{ST}	3·5 V_{ST}	4·5	Terminal velocity in vertical dive

V_{ST} is the stalling speed at maximum all-up weight with flaps retracted

When applying the diagram of Fig. 117 it is necessary to consider the corner points only, intermediate points very rarely provide stressing conditions more rigorous than those associated with the corner points.

FLIGHT CASES

The sailplane must be able to stand a range of load factors, or normal acceleration factors, as shown in Fig. 117, at various speeds.

High Angle of Attack

When the angle of attack of a sailplane increases and reaches values which are still below the stall, lift approaches its maximum and the centre of pressure moves forward. This movement of *C.P.* indicates that the load carried by the wing acts on the front part of the wing.

C.P. FORWARD. If the increase in angle of attack is very slow, the maximum load may never exceed the weight of the glider. In such a case the resultant force on the wings is fixed at a point in front of the C.G. There will be a small upward load on the tail. Now, if the sailplane assumes this angle of attack at a high speed, the lift can greatly exceed the weight of the aircraft. In this extreme case we reach the point A on the load-factor diagram (Fig. 117).

This loading condition is one of the most important both in design and flying technique.

PULLING OUT FROM A DIVE. The most severe stresses occur when pulling out from a dive, especially if this pull-out is sudden. The loading changes very rapidly from the diving load to high incidence loading. This rapidity depends upon the speed of dive and length of pull-out. We assume that for any given speed the maximum lift is always at the maximum lift angle, and

$$L_{max} = C_{L_{max}} \times S \times \tfrac{1}{2}\rho V^2$$

The weight $$W = C_{L_{max}} \times S \times \tfrac{1}{2}\rho V_{ST}{}^2$$

where V_{ST} = stalling speed and the ratio of maximum lift to total weight is

$$\frac{L_{max}}{W} = \left(\frac{V}{V_{ST}}\right)^2$$

If $V = V_T$ the terminal velocity, the greatest possible $\frac{L}{W}$ will result; sometimes lift = 15 or 25 W.

If just before pulling out from a dive the velocity is 90 m.p.h. and if this pull-out is executed quickly, so that the wing is stalled, and if $V_{ST} = 30$ m.p.h. the acceleration perpendicular to the wings will be $8g$ and will be balanced by downward inertia force of $8g$. It can be seen that the actual force acting on the sailplane is nine times the weight of the machine, and the structure of the glider must be strong enough to withstand it.

C.P. BACK. The point B corresponds to a pull-out from a dive, but at a very much higher speed than A, and with the wing at a very small angle of attack and maybe still at the same load factor n.

The bending on the wing will now be associated with a nose-down pitching moment due to the characteristics of the aerofoil at small angles of attack.

Low Angle of Attack

When the angle of attack of the sailplane decreases, the speed increases and the centre of pressure tends to move backwards. Since the centre of pressure is at a point 40–60 per cent of the chord behind the leading edge, it is generally behind the C.G. which means that a fairly large down load is required on the tail for balance.

Normal category gliders are restricted from making any aerobatic manoeuvres. This means, in effect, that such a glider can only be used safely for straight flight and gentle turns. Aerobatic category Group 3 provides for limited aerobatic use, and in such a sailplane the strength must be adequate for well executed loops and rolls, sharp turns and small turns; other aerobatic manoeuvres may be safe but this is determined by flight trials of the prototype. Aerobatic category Group 4 provides for all orthodox aerobatics, but certain manoeuvres such as bunts, outside loops, inverted spins, slow and quick rolls and tail slides, could not be made safely even in this class of sailplane.

DIVE. When the sailplane is flown so that the longitudinal axis is vertical or inclined at a small angle to the vertical, the angle of attack is such that very small or zero lift and minimum drag are produced, and the downward acceleration is due to gravity acting on the sailplane. The centre of pressure moves backwards, resulting in forces tending to twist the wings and bring a big down load on the tail. These forces are the down load on the front spar and equal up load on the rear spar in training machines. In high performance sailplanes this condition will be critical for the leading edge.

The nose dive is a critical condition for drag forces on the rear spar and tail surface.

The use of ultimate factors and proof factors as small as 1·5 and 1·0 respectively, carries with it the implication that the proof loads are extremes which will rarely, if ever, be exceeded in flight. For this reason it is necessary to restrict the pilot in normal circumstances to flying at speeds somewhat less than those associated with proof loading. The limiting speeds in dives are, therefore, restricted to 90 per cent of speeds corresponding to proof loading.

A nose dive with negative acceleration (a bunt) corresponds to the point D on the diagram (Fig. 117).

INVERTED FLIGHT. Inverted flight is seldom performed on a normally-stressed sailplane due to the fact that the wings and struts are not designed to withstand heavy reverse loads. Struts are generally designed to take tensional loads and that is why the wings tend to fold up in inverted flight, as they cannot withstand compressional loads.

There may be two cases of inverted flight. Firstly the sailplane may be travelling at high speed and, therefore, at a low angle of attack, and secondly the sailplane may be in a stalled condition on its back. During inverted flight the profile of the wing is in an upside-down position and to gain lift the bottom surface of the profile must be at the positive angle of attack.

LOADS IN TURN

Assuming that a sailplane of weight W travels at a velocity of v and is banked, then the radius of turn is r and the radial acceleration will be

$$\alpha = \frac{v^2}{r} \text{ ft/sec}^2$$

The lift produces two forces, one upward, which is equal to $L \times \sin \alpha$ and one horizontal, equal to $L \times \cos \alpha$.

The centrifugal force will be equal to

$$\frac{W}{g} \times \alpha = \frac{W}{g} \times \frac{v^2}{r}\ \text{lb}$$

If the angle of bank is equal to β then

$$\frac{L \sin \alpha}{L \cos \alpha} = tg\, \beta = \frac{W}{g} \times \frac{v^2}{r} \times \frac{1}{W} = \frac{\alpha}{g} = n$$

The lift on the wings in a turn is greater than in a normal flight and the load factor in a turn can quite easily be calculated, provided that

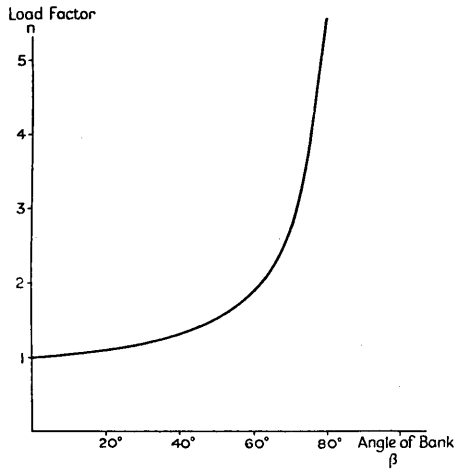


FIG. 118. LOAD FACTOR AGAINST ANGLE OF BANK

the angle of bank is known. From Fig. 118 the load factor for any given angle of bank can be taken.

For example we can see

at 60° of bank $L = 2W$
$70\frac{1}{2}$° of bank $L = 3W$
75° of bank $L = 4W$
84° of bank $L = 10W$

These loads represent those above the loads normally encountered in flight. At these angles of bank the wings must produce a much greater force than usual and it can be done according to this formula

$$L = C_L \times S \times \tfrac{1}{2}\, \rho\, v^2$$

by increasing v or C_L.

LOADS IN GUSTY AIR

When the soaring pilot is flying in gusty air he should remember that gusts increase the dynamic load and impose heavy stress, especially on the wings. These loads increase with increased speed of flight. There are two conditions of gusty air, the standard gust condition, and the rough air gust condition.

Under a given gust, a very light sailplane will encounter less load than a heavy one. This is due to the fact that a light sailplane is better able to accommodate the gust by itself moving normal to the flight path, so that when the gust has reached its maximum intensity,

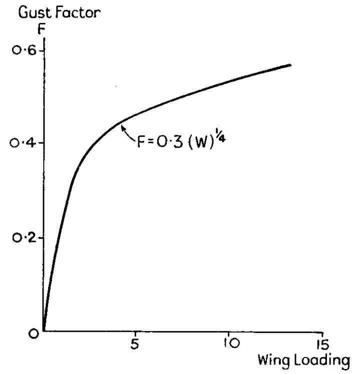


FIG. 119. GUST FACTOR F AGAINST WING LOADING

the sailplane is already moving in the direction of the gust, and therefore the relative gust intensity is not so severe. This is taken account of by the acceleration factor F given in Fig. 119. All sailplanes, with the exception of those in Group 1 of the normal category for which there are no gust requirements, can be used in standard gust conditions, which are up and down gusts normal to the flight path of 50 ft/sec E.A.S. encountered when the glider is in straight, level flight at a speed 2·0 V_{ST}, or at speed V_T if this exceeds 2·0 V_S.

Rough air gust condition consists of up and down gusts normal to the flight path of 65 ft/sec E.A.S. encountered when the sailplane is in straight, level flight at a speed of 3·0 V_{ST}. The factor F is defined in Fig. 119.

The lift coefficient of the wings is increased by a vertical up gust, which, if sudden, may increase the effective incidence of the wing by an angle $tg^{-1}\frac{v_v}{v}$ where v_v is the vertical gust velocity and v is the flight speed (E.A.S.) of the sailplane. This additional angle may be enough to reach $C_{L_{max}}$ at great speed, with a correspondingly high load factor.

The effects of gusts are most severe on sailplanes with high penetration, since the additional lift due to gust is proportional to v_v. It is, therefore, advisable to avoid flying through severe gusts, and should the soaring pilot finds himself in one, he should try to leave it as quickly as possible. The velocity of gust to be considered depends upon whether the aircraft is intended for cloud flying or thunderstorm flying.

The loads sustained by a sailplane when encountering a gust

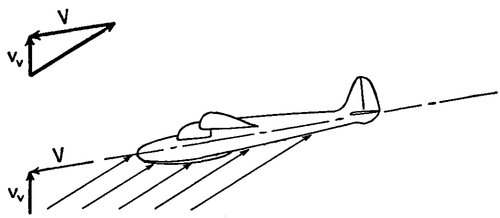


FIG. 120. RESULTANT VELOCITY DUE TO GUST

depend largely on the speed, and pilots should be particularly careful not to exceed the maximum speed.

TOWING LOADS

These loads depend entirely upon the method of towing which is being used. The take-off by means of catapult launching does not impose big loads on the wings and the fuselage takes the whole shock. In this method of launching the load may be as great as 1000 lb and the fuselage must then be very strongly built as this load will be superimposed on its structure from the hook on the nose to the point of hold back.

During take-off by means of a motor winch the loads acting on the sailplane as a whole are very large during normal conditions of the atmosphere. The winch drivers, as well as the pilots, must understand that these loads may very easily exceed the permissible limit when there is strong wind, gusty air or thermals.

The wings of the sailplane, apart from supporting its weight, support the load on the tow cable and the balancing load on the tail. This load may be as high as 700 lb and often exceeds this. The weak link in the tow rope is an essential part of the launching equipment as it will limit the load which may be forced upon the sailplane. For example, if a sailplane with a stalling speed of 30 m.p.h. is being launched at 75 m.p.h. then it can undergo a normal acceleration factor of up to $6\frac{1}{4}$ (under which factor the wing is stalled). In such a case, if the sailplane weighed 500 lb then the load on the tow rope plus the inertia force on the sailplane would be 2625 lb. The bending moment on the wing may be considerably aggravated by dynamic effects when this load is suddenly applied.

Under normal atmospheric conditions the load on the tow line is approximately equal to the total drag of the sailplane. However, the speed of aero-tow in gusty conditions can be the cause of accidents as it is very easy to exceed the permissible limit, and if a

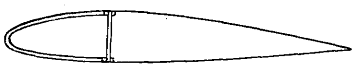


FIG. 121. THE TORSIONAL LOAD IS TAKEN BY THE PLYWOOD COVERING

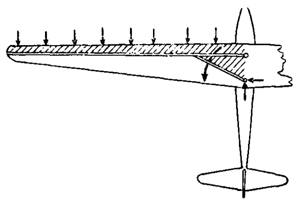


FIG. 122. SECONDARY SPAR RESISTING FORCES IMPOSED ON WING

gust of air hits a sailplane at this high speed the resultant loads may easily go far above the safety limit. The same applies to any rapid manoeuvres executed by the soaring pilot while on tow.

FUSELAGE LOADS

These are loads imposed by the tail unit, skid (by landing) and loads by launching and aero-tow. During steady flight there is always a small down force acting on the tail unit which increases with a decrease in the angle of attack (dive). The other load is a side one due to fin and rudder (twist of fuselage). In landing, the front part of the fuselage takes the load and because the skid is usually fixed under the main bulkhead, the landing loads have very little effect on the whole fuselage. In launching, the pull is taken by the longitudinal members of the fuselage.

SINGLE-SPAR WING. The single spar is normally placed near the centre of pressure forward position, and takes the full load as a direct bending load. For the centre of pressure backward position, the bending load is less. The plywood covering passes from above the spar forward round the leading edge and back to the underside of the spar. If the centre of pressure moves forward a torsional load is imposed on the wing and it is resisted by the plywood covering.

Usually a light secondary spar is employed with single-spar design. The plywood in such case covers this spar and the torsion is transmitted through the spar attachment fittings.

TWO-SPAR WING. The spars are usually placed outside the centre of pressure forward and centre of pressure backward position, to equalize the loads on the spars.

CHAPTER VI

LAUNCHING TECHNIQUE

ONE of the first methods of launching a sailplane was the rubber rope or *bungee catapult.* This method is still used, generally during slope soaring where there is not enough space to place a winch and cable.

The bungee consists of two $\frac{5}{8}$-in diameter ropes made of many elastic rubber strips, which are covered with woven binding. These ropes are connected together at one end, which forms an eye with a steel ring. The steel ring is attached to the open hook on the sailplane. The steel ring will drop off automatically as soon as the bungee loses its energy. The two loose ends of the bungee are 50–60 ft in length.

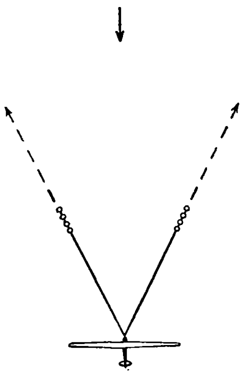


FIG. 123. TYPICAL BUNGEE LAUNCH

The two ropes form V-shape, four men pull the rope along dotted lines. The arrow at the top indicates wind direction.

During bungee launching, these two ropes form a V-shape, with the steel ring at the point of attachment to the sailplane. Four men or more stand holding each free end, in line with the wing tips. This launching crew keep outside the V-shape formed by the bungee. When the pilot signals "O.K." the initial pull applied must be gentle, the launching crew walking the first eight or ten steps along each arm of the V, holding the rope, and then running with it. During this run the sailplane is released from an attachment by means of which it has previously been fixed to the ground, usually by the tail skid. The amount of stretch depends on the weight of the sailplane, and the velocity of the wind. The tail skid should be equipped with a ring or hook to hold a back-rope.

During the stretching of the bungee the crew should continue to run until the bungee drops free from the hook, otherwise they may be injured as the bungee is in tension when it slips off the hook.

AUTO-TOWING

This kind of launching is one of the cheapest methods which can be employed in a gliding centre which operates from an aerodrome.

The runways on the aerodrome improve the smoothness of the actual take-off considerably.

TOWING CAR. For auto-towing a heavy, powerful car is required with good acceleration. For example, the Bristol Gliding Club is successfully using a "Beaverette," an ex-armoured car with balloon type tyres.

The armour plate has been cut away so that the resultant shape gives an excellent view in all directions. On one side of this car a quick release hook has been welded which can be operated by the driver in case of emergency.

TRAINING. Initial training starts with an explanation to the pupil of the action of ailerons, rudder and elevator. First lateral controls should be taught, and then rudder. During initial training spoilers fixed on the top part of the wing above the main spar are very useful. This is a safety precaution as it insures that on the first ground slides the glider does not leave the ground.

When the pupil has mastered the aileron and rudder control, the spoilers are removed and after a brief explanation of elevator action, ground slides and airborne slides are taught. This part of initial training is most important and the instructor should pay particular attention to the behaviour of the pupil in the air. Low hop and high hop stages follow. This method of training requires an exceptionally good instructor, as apart from controlling the pupil, the control of the car must also be absolute.

Auto-towing can also be an excellent first step in training for aero-towing, because the correct speed and height of towing flight can be taught, and the pupil can be accustomed to the different handling technique of the sailplane while on tow. During calm days gentle turns can also be practised on tow. It has been found that such flights improve towing technique and are very useful for aero-towing practice.

WINCH LAUNCHING

Winch launching has been used extensively in the last few years. The main advantage is very rapid acceleration and smooth towing. Because the sailplane and the drum on which the towing cable is wound are the only parts which have to be accelerated, a much smaller load is imposed on the engine than during auto-towing where the towing car also must be accelerated. Very rough ground may be used for winch launching as the only smooth place required is that where the sailplane actually takes off.

Quite a number of winches have been designed and built all over the world. Both petrol and electrical engines are employed. The most essential part, which is sometimes neglected, is the safety device of the cut-off. The safety of towed flight depends on some means of quickly detaching the cable at the towing end in case of the failure of the sailplane's release hook. A well-designed guillotine is one of the best severing devices.

A weak link in the tow cable on the sailplane end is also essential, and for the reduction of wear on the cable a small parachute should be fixed on the sailplane end of the tow cable as this will reduce the speed of fall of the cable to the ground.

Winch launching requires a skilled and technically minded winch operator if it is to be really successful.

AERO-TOW

As the heights which can be reached by winch launch seldom exceed 1000 ft it is sometimes difficult to reach thermal up-currents of such strength as will make soaring flight possible. Aero-tow provides a means of reaching the base of clouds. It can also be an ideal way of transporting a sailplane from one place to another.

On the whole it can be said that aero-towing does not present any more difficulties than winch launching, and as to safety, the loads and stresses imposed on the sailplane during aero-tow are smaller than during winch launching. To make an aero-towed flight safe and successful some experience is needed, of course, and a plan of flight should be properly recorded and discussed with the towing pilot.

The sailplane used for aero-towing must possess a safety factor which will permit such an operation. Normally the safety factor of high-performance sailplanes is sufficient to enable such machines to be aero-towed. One of the most important rules in aero-tow, however, should be that parachute equipment be provided for the pilot of the sailplane as well as for the pilot of the aeroplane.

As the speed of flight plays a rather important role in aero-towing, an airspeed indicator should be included on the instrument panel of the sailplane. Both sailplane and aeroplane must be fitted with quick release apparatus.

The towing cable is usually attached to the aeroplane by a point on or near the tail skid, but a special rig built on the fuselage to take up the towing cable was frequently used before the Second World War in continental countries. The cable can be of steel, but a manilla rope is preferable. Its length may vary from 300–450 ft. For instructing in aero-tow it is much better to use a longer cable. This will produce smaller shocks than a short cable, due to the higher degree of stretching. When a steel cable is used a rope of at least

25 ft in length and $\frac{1}{4}$ in. diameter must also be used as this will provide a weak link as well as an elastic shock absorber.

Technique of Aero-tow

To avoid unnecessary misunderstanding occurring during flight it is advisable to fix certain rules for any aero-towed flight. The pilot of the aeroplane and the soaring pilot should form a tuned crew and respond to each other's manoeuvres automatically. The soaring pilot should not try to work out why the aeroplane pilot performs any manoeuvre but should concentrate on following his lead.

The rules of take-off, climb and ascent should be known by both pilots before they start, and intercom. or telephone can be of great assistance.

The following procedure can be recommended.

TAKE-OFF. The soaring pilot should inspect the sailplane he is going to fly, check rigidity, controls, and inspect the machine for airworthiness. Before entering the cockpit the parachute should be put on and inspected, especially the harness and the locking device. Considerable time can be wasted in looking for the cable after it has been released by the aeroplane pilot, and a few pieces of different coloured fabric firmly fixed to it at intervals of about 20 ft will make this task much easier.

Soaring pilots should make sure that the towing cable is not attached to the sailplane when there is no pilot in the cockpit. When the soaring pilot is ready to take off he should test the release device both with tension applied to the cable and without, to see if the cable drops off easily.

During these preparations the pilot of the aeroplane should keep his machine at 90° to the direction of the wind as this will enable him to see what is happening on the field. When the signal for the take-off is received from the soaring pilot, the cable should be attached to the aeroplane and then taxying can begin. The gentle taking-up of the slack in the cable is an art, and correctly done does not strain the aeroplane, cable or sailplane.

There is no need to exceed the permissible flying speed of the sailplane either during take-off or whilst on tow. As soon as the sailplane is airborne and has 10–15 ft height, if the airspeed indicator shows the correct towing speed, the soaring pilot may help the aeroplane pilot to take off by easing the control stick forward very gently (diving) which will slacken the cable and take some load off the tail of the aeroplane.

During the take-off the soaring pilot should fly well above the towing aeroplane so as not to be involved in the slipstream produced by the airscrew. A height of 12–20 ft above the aeroplane is quite safe, but skilled pilots usually fly somewhat lower, as this is a greater help to the tug pilot and avoids any risk of raising the tug aircraft's tail.

TURNS. The difficulty in aero-towing is that to make it really perfect the soaring pilot should follow every manoeuvre performed by the pilot of the aeroplane. In the case of a turn it can be expected that the towing cable may slacken, so the soaring pilot should keep it in

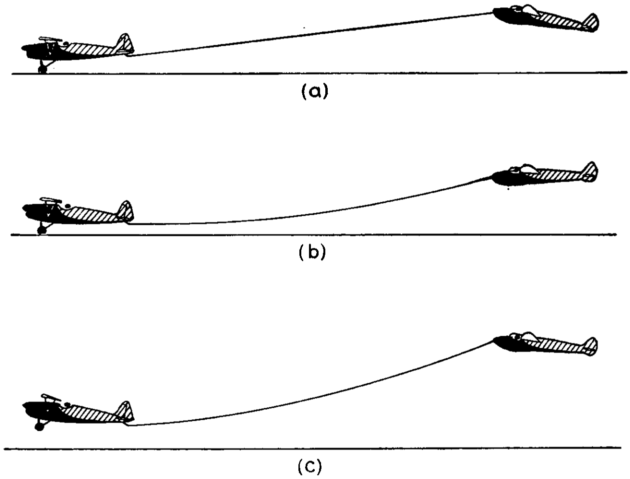


FIG. 124. TAKE-OFF BY MEANS OF AERO-TOW

(a) The sailplane takes off first.
(b) When the height of 20 ft has been reached, the soaring pilot dives gently.
(c) When the aeroplane becomes airborne the soaring pilot climbs at exactly the same angle as the aeroplane.

tension by applying enough rudder opposite to the direction of turn. This means that the sailplane should be directed not towards the centre of the circle but slightly outside it. To keep the sailplane at the radius of the circle which is being performed by the aeroplane during steep turns, sufficient bank should be applied, but remembering to keep the towing cable stretched. This may be a little difficult at first, but with practice will be found quite easy.

DESCENDING. This is one of the easiest manoeuvres and to know how to perform it may be very useful during cross-country flights as it is sometimes easier to overtake a front or a storm while flying near the ground than to continue at 5000 ft.

When the pilot of the aeroplane closes the throttle, the speed of the aeroplane will drop before that of the sailplane which may compel the soaring pilot to come too near the aeroplane; this is dangerous, particularly as the cable will hang loose from the sailplane. It is avoided, however, if, after closing the throttle, the pilot of the aeroplane maintains the normal towing speed and the soaring pilot starts a sideslip in the direction of flight. The speed of this sideslip should correspond to the speed of the aeroplane. The difficulty here

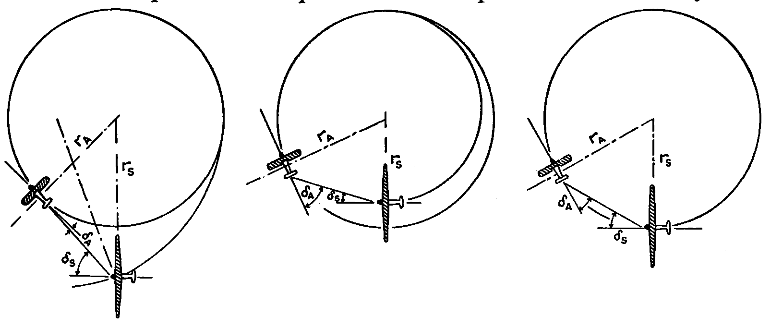


FIG. 125. RADIUS OF TURN—AERO-TOW

(a) Sailplane slipping out, radius of turn r_S too big, angle δ_S between longitudinal axis of sailplane and cable bigger than δ_A.
(b) Sailplane slipping in, radius of turn too small.
(c) Correct turn—radius of turn of aircraft the same as that of sailplane, $\delta_A = \delta_S$.

lies in keeping the sideslip constant and in following the aeroplane in its descent.

COCKPIT DRILL

After entering the cockpit the pilot should study his surroundings, and if the sailplane is a new one to him he should study the layout of the cockpit carefully.

First the instrument panel must be checked and the position of each instrument noted.

Secondly the flying controls should be inspected, and their movements and peculiarities noted, and the flap and dive brakes control tried out.

All controls must be tested for freedom of movement before every flight, the pilot looking at the rudder, elevator and aileron and checking their correct movement. If there are brakes on the landing wheel their action should be examined.

The pilot should also look around the cockpit for any loose articles.

HARNESS. When putting on the harness the highest possible eye hole in the shoulder straps and end holes in the up-coming straps should be used as this will bring the straps tightly to the body and prevent them slipping off the shoulders. Any discomfort felt at first will quickly disappear.

CHAPTER VII

LANDING TECHNIQUE

NORMALLY approaches are made at a speed from 30 to 40 per cent higher than stalling speed. When the soaring pilot has to pass over high obstacles just before landing, the very flat gliding angle sometimes necessitates a long landing run. When the speed of approach is too great, this must be dissipated somehow before touch-down, and the result is the over-running of a large area of landing space. On the other hand, if the speed of approach is too low the consequence may be a stall, and slow speed is the main cause of landing accidents. Excess height can always be reduced by sideslipping or by the use of flaps or spoilers if fitted.

Some inexperienced pilots find difficulty with the rudder, as even a small amount of applied rudder will result in a drift and skid, which may feel like being out of the wind.

The *wind speed* should be carefully checked when approaching to land. The wind sometimes lulls suddenly and if the soaring pilot has insufficient speed to maintain the glide a stall will result. By watching trees or grass the wind may be roughly estimated and the correct speed of approach chosen. The wind very near the ground has a much lower speed, due to surface friction, so that the speed of approach when nearing the ground should always be increased.

One of the easiest ways of landing, on the home aerodrome site or in a strange field, is landing against the wind. This will shorten the landing run and make it much safer as the speed of approach may be considerably reduced. The correct estimation of wind direction is essential and can be done from the air by observing smoke, the drift of the sailplane, waves on water, the movement of flags, or ripples on corn.

The Selection of a Landing Ground

This should be made in relation to the amount of space required for the particular sailplane to float before touch-down. It is a good habit to observe fields from trains, buses or during country walks, and to try and work out the best way of landing on those fields. In this way the eye soon becomes used to assessing the configuration of the ground and this will subsequently help the pilot to pick out the conditions required for a good landing. To be able to land "on the spot" should be one of the main ambitions of the good soaring pilot, as this will indicate that he has mastered the sailplane, and can put it down exactly where he wishes and under perfect control. The pilot should also practise the recognition of various types of field-covering from the air, such as grass, stubble, cultivated and ploughed land.

If it is necessary to land on a strange field, this should be chosen as near as possible to a convenient road and buildings, as this will usually mean that help will be available. It is better to select a long cross-wind field with a good approach than a small head-wind field if the latter is otherwise difficult.

If possible the pilot should circle the field before landing, as this will enable him to assess the approach and look for obstacles. The approach should be made with excess height rather than too little, as it can always be slipped off. It is better to aim to overshoot the field than to undershoot.

Cross-wind Landing

This should not usually present any difficulties when there is a steady wind blowing. The approach to land is made as for an into-wind landing, but when the drift is noticeable the pilot should slip into and against the wind.

As the wings are rather low on the sailplane there is a danger of hitting the ground with the wing tip when a slip is performed near the ground. The best precaution is to increase the slip before coming near the ground so as to drift against the wind, then, when the wings are levelled, the sailplane will have a momentum against the wind which has to be absorbed before it can reproduce drift. By this time the sailplane will land without drift either way.

Down-wind Landing

Opinions are divided on this subject and some instructors do not allow their pupils even to attempt a down-wind landing. It is, however, the conviction of the writer that in certain circumstances a down-wind landing is safer than any other. This is born out by accidents which have taken place in attempts to land into the wind from a very low height due to the final turn into-wind being attempted too late and too near the ground. Such accidents can be serious and it is, therefore, important to go into the matter in more detail.

The mass of air in which the sailplane soars very seldom remains stationary, which means that seldom is there no horizontal movement of air over the ground, or no wind. However, if the air is stationary, the normal landing speed of, say 45 m.p.h., remains 45 m.p.h. in relation to the ground or landing field, irrespective of the direction in which the pilot lands.

If the air is in motion as shown in Fig. 126 (*b*) with a velocity V_W = 18 m.p.h., a vector diagram of speed can be made which

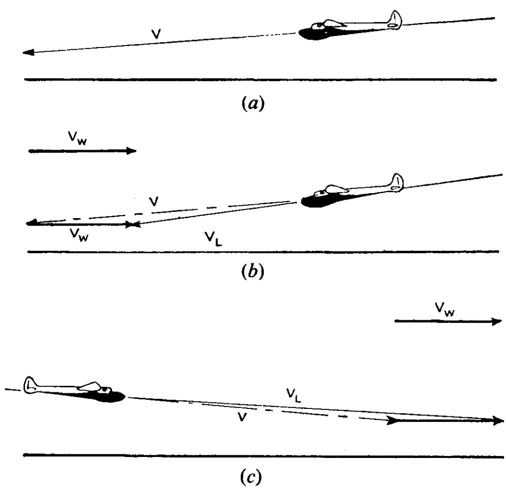


FIG. 126. LANDING SPEED (V_L)
(*a*) Landing with no wind.
(*b*) Landing into wind, landing speed decreases.
(*c*) Down-wind landing.

indicates that the actual landing speed (relative to the landing field) decreases considerably and in this particular case is equal to 30 m.p.h. This decrease in landing speed produces a reduction in landing distance also. The bigger the air motion (the stronger the wind), the

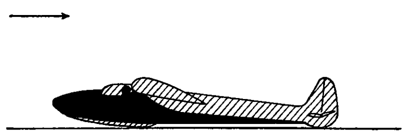


FIG. 127. THE PERFECT LANDING

smaller the landing distance. This type of landing is the most common and the easiest.

Supposing, however, that the landing is made down-wind in the same moving mass of air, as shown in Fig. 126 (*c*) the vector diagram of speed shows that the actual landing speed increases to 60 m.p.h. in relation to the landing field. It follows that the landing distance will be increased, and if the wind speed is about 18 m.p.h. the landing distance will be increased to about twice that which would be normal in stationary air.

Here it must be emphasized that if the landing distance in stationary air is 300 yds, from the same height landing into the wind

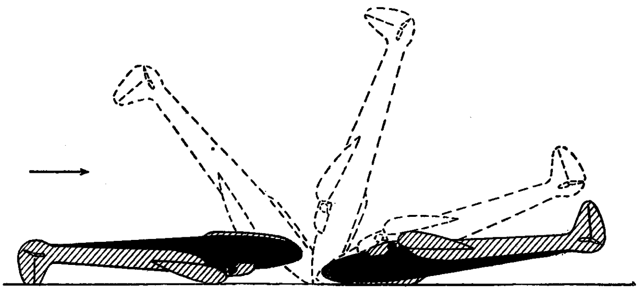


FIG. 128. THE RESULT OF MOVING CONTROL STICK FORWARD WHEN LANDING

it will be 200 yds and down-wind 600 yds. There is, however, one point worth mentioning. The landing technique of a down-wind landing is slightly different from an into-wind landing. In the latter, when the landing distance needs greatly reducing, after the sailplane touches the ground and during the ground run, some pilots move the control stick right back, and some go as far as constantly to move the rudder in full symmetrical, steady deflections. The full deflection

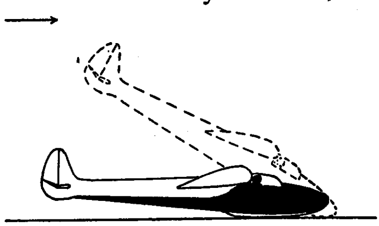


FIG. 129. DURING DOWN-WIND LANDING BACKWARD MOVEMENT OF CONTROL STICK SHOULD BE AVOIDED

Upwards deflected elevator produces additional area which is easily affected by wind.

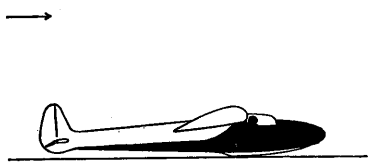


FIG. 130. DOWNWARDS DEFLECTED ELEVATOR HELPS TO HOLD THE TAIL TO THE GROUND

of the elevator and rudder produces an additional area of resistance to the air which slows the motion on the sailplane along the ground. Forward movement of the control stick is dangerous as it strains the fuselage and generally results in the sailplane turning over on its nose.

During a down-wind landing neither of the manoeuvres described for an into-wind landing should be performed. When the sailplane is on the ground the rudder should stay in the neutral position, but the control stick should be moved hard forward, as the downward deflected elevator will produce an additional area for the wind to press upon and so hold the sailplane to the ground.

Landing on Soaring Sites

This section should perhaps be entitled "Landing in Mountainous Country" as it can be assumed that the soaring sites are in close relation to hills or mountains. There are three different types of landing which can be used on most soaring sites: up-hill landing, landing on top of the hill and landing on the lee side. The most common is the up-hill landing because, due to the lack of a proper

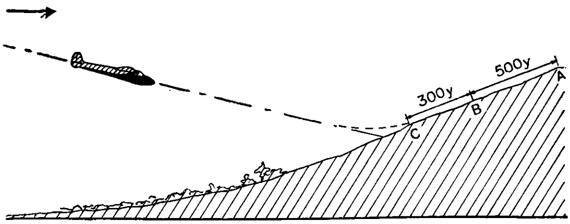


FIG. 131. UP-HILL LANDING ON WINDWARD SLOPE

landing field, and for reasons of transport economy, the landing should take place in the vicinity of the take-off point.

Naturally, before any up-hill landing is attempted the terrain should be studied very carefully and chosen so that no obstacles such as stones, tree roots, bushes, are in the way and a 300-yd length of the slope is unobstructed below the landing strip.

Training for up-hill landing should be started on a calm day. Having fixed the position of the landing strip, which should be at least 500 yds in length (*see* Fig. 131), the soaring pilot should fly well away from the slope so that after making an 180° turn the sailplane is at the height of point *B* on the slope. Then the speed should be increased about 10–15 m.p.h., diving gently, taking as the object of dive an area below the landing strip, *C*. When in the near vicinity of the slope the pilot should pull out so as to fix the flight path parallel to the slope. The actual landing is the same as on a horizontal field, remembering that the increased speed of approach will normally result in a longer landing distance, but which in this case is counteracted by the fact that the sailplane is travelling up the slope.

The most common mistake is an excessive increase in diving speed, which brings the sailplane too near the top of the hill. The correct speed of approach (diving speed) depends on the wind-speed. With a strong wind a higher speed of approach should be used, and as the lifting characteristics of a slope increase with a strong wind, the object of dive should be moved below point *C*. Should he overshoot the top of the soaring site the pilot should regain his speed of flight as soon as possible. If the wind is strong this speed should be at least 20–25 m.p.h. higher than normal flying speed because the strong down-currents near the slope on the lee side may otherwise cause disaster. Therefore, after passing the top of the hill the pilot should fly away from the slope at the increased speed and not until he is well away from the soaring site should he turn the sailplane back towards the slope.

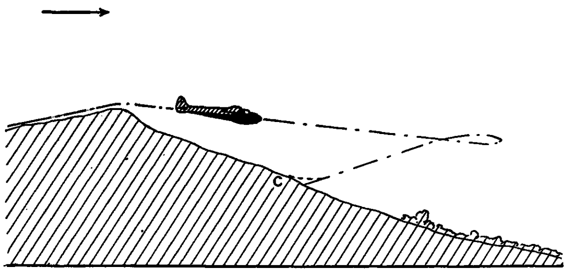


FIG. 132. UP-HILL LANDING ON LEE SLOPE

The approach to land on the lee side should be made at an even higher speed than when landing up the hill on the windward side. The down-currents on the lee side will have the tendency to force the sailplane to the ground and the landing distance will be much shorter than during a windward side landing. The object of dive will depend upon the configuration of the slope and wind speed down the slope. This type of landing needs a high degree of skill and can only be recommended to very experienced pilots.

If a suitable landing field is available, landing on top of the hill during calm days should not present any difficulties if it is remembered that it is always safer to overshoot than undershoot the landing field. During windy days some lift over the top of the hill may be expected, and a strong wind makes it difficult to put the sailplane down. When soaring over the top of a hill the pilot should on no account fly away from it towards the lee side.

If the machine is at a considerable height this should be reduced by sideslipping, the last sideslip being as near the ground as is safely possible, and with the direction of the sideslip always towards the wind. Just before touching the ground the wing on the windward side should be lowered and kept in such a position during the whole landing run. When the machine stops this wing should rest on the ground.

Spoilers

Basically spoilers were developed to replace ailerons in giving lateral control, but they have not been developed satisfactorily for this purpose and their main use now is as dive brakes. The spoiler is a flap-like device, usually in the form of a small metal plate located on the top of the wing above the front spar, hinged at the front edge so as to project above the upper surface of the wing. It can be fitted on the top and bottom surface of the wing, and sometimes is only on the bottom. The function of the spoilers is to disturb the smooth flow along the upper surface of the wing, and to produce a turbulent flow with consequent loss of lift and increase in drag.

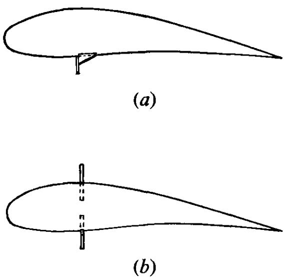


FIG. 133. SPOILERS
(a) Fixed on the bottom surface of wing.
(b) Spoilers projecting from top and bottom surface of wing.

When flying in clouds it is easy to exceed the safe maximum speed of the sailplane accidentally, and this may happen very rapidly. The sailplane is not designed to withstand the heavy loads which may be superimposed on its structure during certain dives, but if the spoilers are open during the dive the resistance of the sailplane will increase and its diving speed decrease. Spoilers do not generally affect the lift and pitching moment very much.

Flaps

All modern sailplanes are equipped with flaps or spoilers, both of which are used for the same purpose, to steepen the angle of glide without increase in speed. When the rear part of the wing is hinged so that it can be swung downward, this part is called a flap. In the sailplane the flaps do not usually extend from fuselage to ailerons, but are located only in a small portion of the wing.

The normal glide takes place at rather small angles, making the approach path when landing very long. An increase in the angle of glide will also increase the speed, which may make the landing run dangerously long. When the flaps are moved down the negative pressure on the whole of the upper surface of the wings will increase, the pressure on the bottom surface will also increase. The negative pressure will give rise to a large drag which will increase with the flap angle. A good profile may give as much as 1·6 C_L maximum and this may be increased by means of a flap to something between 1·8 and 2·3.

The centre of pressure will travel rearward when the flap is deflected, and the soaring pilot must remember to stabilize the sailplane when he moves the flaps down. The centre of pressure may move as much as 10 per cent of the wing chord.

On some sailplanes the flaps increase the downwash on the tail, and it is possible for the longitudinal stability and balance to be

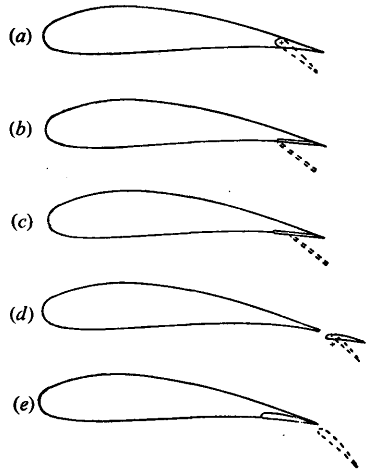


FIG. 134. VARIOUS ARRANGEMENTS OF FLAPS

(a) Plain flap.
(b) Plain split flap.
(c) Zap flap.
(d) Airfoil flap.
(e) Variable-area fowler flap.

maintained when lowering the flaps in spite of the increase in pitching moment.

The main advantages of the flap are increase of maximum lift which reduces the stalling speed, increase of drag which gives a steeper gliding angle, reduces the landing speed and the length of the landing run. There are various types of flap, some of which are illustrated in Fig. 134.

CHAPTER VIII

CIRCLING TECHNIQUE

THIS subject is one of great importance to the soaring pilot, as a turn made without sufficient speed during a training flight may result in a spin. Later on, during soaring flights in thermal up-currents, the correctly made turn is one of the main factors which enable the pilot to remain in such currents. Even experienced pilots should constantly practise turns to obtain the best results from the sailplane flown. The plane of rotation due to control movements was discussed in the section dealing with stability, but to give a clearer picture of the effects of controls Fig. 135 has been prepared.

The effect of the three controls—aileron, rudder and elevator, will always be the same, each in its own plane, i.e. aileron—lateral, rudder—directional, elevator—longitudinal, irrespective of the sail-plane's attitude. These three planes should be visualized as permanently fixed in relation to each other and to the sailplane.

PRIMARY EFFECT OF CONTROLS

AILERONS. The object of the ailerons is to balance or deflect a sail-plane around the X–X axis (lateral plane). When the control stick is moved sideways, say to the left, the left aileron moves upwards and the right aileron downwards. Due to this aileron movement the shape of the wing section will change along the distance covered by the ailerons. Assuming that the ailerons on the sailplane are of normal type, the result of control stick movement to the left is shown in Fig. 136.

The lift of the starboard wing L_S will be much bigger than the lift of port wing L_P. Due to the difference in lift and moment M_L resulting from this difference, the sailplane will bank into the direction of the control stick movement. The horizontal component of lift force will swing the sailplane in the direction of bank in spite of the fact that no rudder is applied.

The drag of the starboard wing D_S will become bigger than the port wing drag D_P, and due to a moment M_D resulting from this difference, the sailplane will tend to swing to the right, around axis Z–Z. To swing the nose of a sailplane in the direction of the required turn, in this case to the left, an additional moment must be applied, and this moment M_T can be obtained by deflecting the rudder to the left.

Rudder. The object of the rudder is to balance or deflect the sailplane around the Z–Z axis (Fig. 136). When the left foot is pressed forward the left rudder will be applied, which will swing

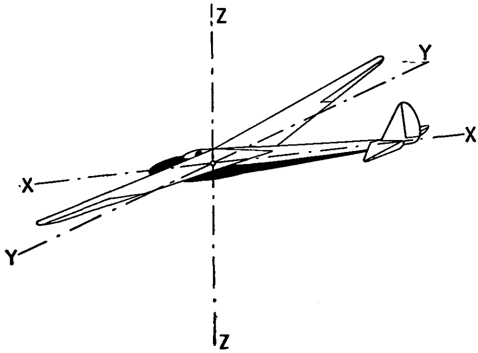


FIG. 135. AXIS OF ROTATION OF THE SAILPLANE

x–x longitudinal axis.
y–y lateral axis.
z–z vertical axis.

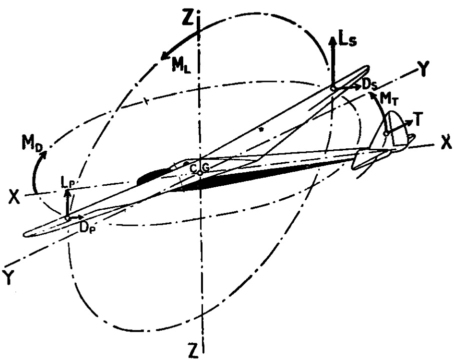


FIG. 136. FORCES AND MOMENTS ACTING ON SAILPLANE DURING A TURN

the nose of the sailplane towards the port wing. This is because the air-stream on the left rudder surface will meet more resistance, and a moment will result which will swing the tail unit to the right. The amount of rudder applied produces the rate of swing, and the more rudder applied the faster the nose moves. But the sailplane itself may skid out to the right as it swings around a point B on the left, due to a force H being exerted on the sailplane which tends to move it away from the centre. As this turn continues the sailplane will bank, in spite of the control stick being in central position, as the starboard wing travels faster, and due to this increase of speed it gets more lift.

Apart from the tendency to skid outwards, the depressed rudder will also bank the sailplane in the direction of turn.

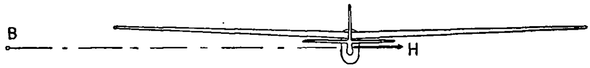


FIG. 137. SKIDDING DURING A TURN
Sailplane swings around point *B*; force *H* tends to move sailplane away from point *B*.

Soaring pilots should remember that rudder always swings the nose of the sailplane towards the wing tip irrespective of the wing tip's position.

ELEVATOR. This balances and deflects the sail plane around the *Y–Y* axis. When the control stick is pressed forward the elevator will move down, the section of the tail plane and elevator will change, the lift will increase and the nose of the sailplane will move downwards. The result of control stick movement is always a change in the path of flight. The more the control stick is moved backwards or forwards the more will be the upward or downward movement of the elevator and the bigger the rate of pitch.

When the path of flight is changed the sailplane travels along a curve which is similar to part of a circle. The inertia force is exaggerated and is known as centripetal force. When pulling out from a dive this force adds to the force of gravity, and when the sailplane is put into a dive it subtracts from the force of gravity.

THE TURN

In a correctly made turn the sailplane has a much better aerodynamical performance than in a turn with slipping in or skidding out, and the safety and economy of flight is higher.

THEORY OF THE TURN. Fig. 138 shows the forces acting on the sailplane in normal flight. Aerodynamic force *A* balances the weight of the sailplane *W*.

When coming from straight flight into a turn, the sailplane, or rather its centre of gravity, will describe a horizontal circle. If the radius of this circle is r and the speed of travel v, then there will be radial acceleration α acting on the sailplane (Fig. 139) and radial acceleration

$$\alpha = \frac{v^2}{r}$$

To maintain this acceleration a resultant horizontal force H will be required. This force

$$H = \frac{W}{g} \times \alpha = \frac{W}{g} \times \frac{v_t^2}{r}$$

and is the centrifugal force which in a turn is equal in magnitude

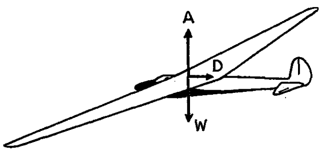


FIG. 138. FORCES ACTING ON SAILPLANE IN NORMAL FLIGHT

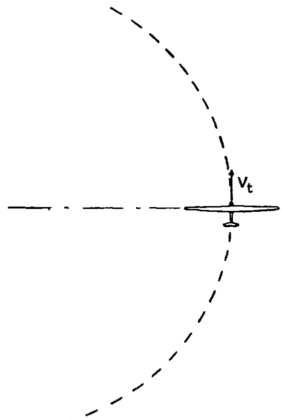


FIG. 139. TURN AT CONSTANT FORWARD SPEED V AND CONSTANT RADIUS r

and opposite in direction to the accelerating inward (centripetal) force.

In a turn the weight must be balanced by the vertical component of lift and the centrifrugal force must be balanced by the horizontal component of lift.

$$W = L \times \cos \alpha$$

Centrifugal force $= \dfrac{W}{g} \times \dfrac{v_t^2}{r} = L \times \sin \alpha$

from which—

$$\tan \alpha = \frac{v_t^2}{g \times r}$$

As W is constant L must vary as sec α and the acceleration in turn is—

$$\frac{\alpha}{g} = \frac{L}{W} = \sec \alpha$$

and as L varies as v_t^2, then the ratio of speed in horizontal flight and speed in turn at constant angle of attack—

$$\left(\frac{v_t}{v}\right)^2 = \sec \alpha$$

and the radius of turn will be—

$$r = \frac{v_t^2}{g} \times \cot \alpha$$

Angle of attack	Speed in m.p.h.		Angle of bank	Radius in ft
	Horizontal	In turn		
α	v	v_t	β	r

The steeper the turn the greater the centripetal force. This force is not produced by elevator or rudder movement but by the wings,

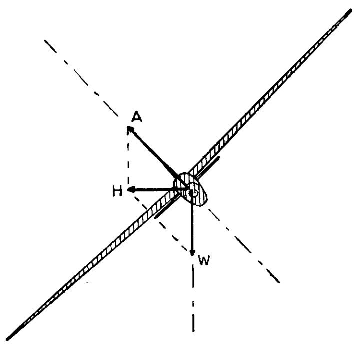


FIG. 140. DISTRIBUTION OF FORCES IN A TURN

as it is a horizontal component of lift. It can be seen from Fig. 140 that to obtain force H the sailplane must be banked. There is no turn without a bank.

In a turn where no sideslip is involved, the vertical component of lift L must be equal to the weight W. As the lift is perpendicular to the wings it must also increase with the bank, and force H also.

The distribution of lift along the span of the wing in a turn differs from that in straight flight because the outer wing moves faster than the inner wing. The moments so introduced will, however, be balanced by the action of ailerons and rudder.

From Fig. 140 the angle of bank β can be found.

$$\tan \beta = \frac{H}{W} = \frac{\frac{W}{g} \times \frac{v^2}{r}}{W} = \frac{v^2}{g \times r}$$

Bank is the position of the sailplane when its lateral axis is inclined to the horizontal. In a right bank the lateral axis is inclined downward to the right. The angle of bank β is independent of weight and also independent of wing area and wing section.

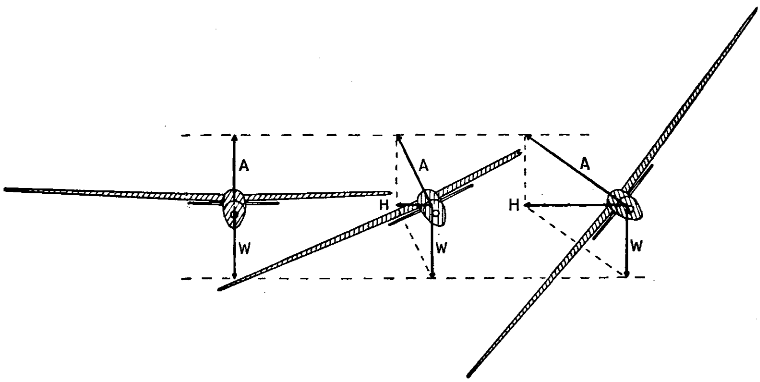


FIG. 141. DIAGRAM SHOWING FORCES IN TURNS

The term "a flat turn" is sometimes used, but this is incorrect. There may be a turn of large radius r, or small-banked turn, and a turn of small radius, or steep-banked turn. Only when the correct bank is used for the corresponding radius, or vice versa, can the turn be called correct.

THE CROSS-LEVEL AND THE TURN

As it is difficult for the soaring pilot to make a correct turn by means of sense alone, a cross-level is usually mounted on the instrument panel of the sailplane, and this indicates the degree of accuracy of the performed turn.

Several forces act on the steel ball of the cross-level, e.g. W, and the inertia force I which is equal to the centrifugal force H but is directed the opposite way. This inertia force I is called the centripetal force, as already explained. The resultant of these two forces W and I is equal to the aerodynamic force A but is directed the opposite way. In a correctly banked turn this resultant force is perpendicular to the wings. In such a turn the steel ball of the cross-level will be in the middle of the curved glass tube of the instrument.

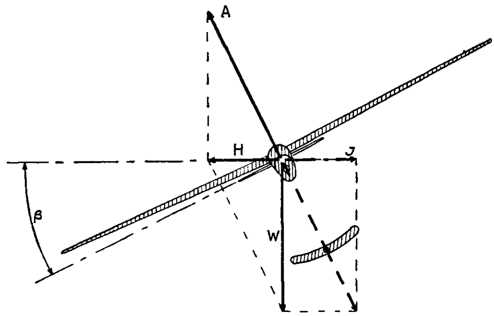


FIG. 142. CORRECT POSITION OF STEEL BALL IN A TURN

The aerodynamic force A can be calculated from the equation—

$$A = \frac{W}{\cos\beta} = \frac{\frac{W}{g} \times \frac{v^2}{r}}{\sin\beta}$$

If the aerodynamic force decreases so that $A = A_1$, the centrifugal force $H = H_1$.

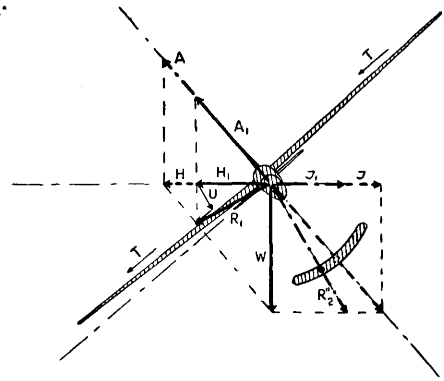


FIG. 143. "SLIPPING IN" IN A TURN

The resultant of A_1 and H_1 will be R_1. There will be a force U perpendicular to the wings which will produce loss of height, and force T parallel to the wings which will produce slipping in. In such a case the steel ball of the cross-level will move down to resultant force R_2 of I_1 and W.

If the aerodynamic force increases and $A = A_2$, the force U_2 will lift the sailplane up and force T_2 will produce skidding out. The steel ball will move up and stay on the resultant force R_4 of I_2 and W.

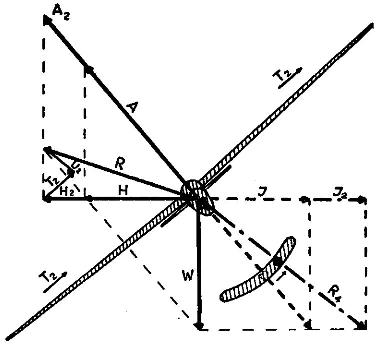


FIG. 144. "SKIDDING OUT" IN A TURN

In steeply banked turns there may be an additional lift L_F acting, which is due to the fuselage. This force will depend on the shape and size of the fuselage. It is generally very small compared with the lift produced by the wings. In such turns the steel ball will not

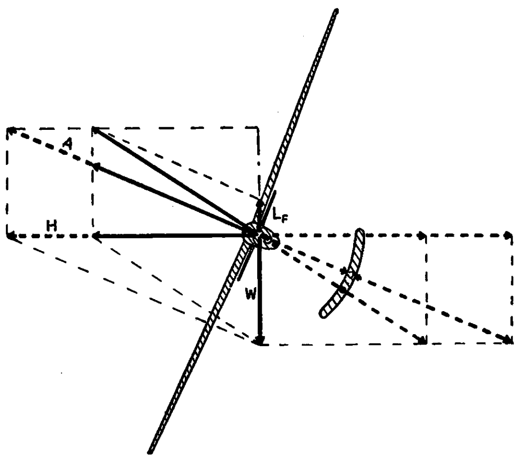


FIG. 145. IN STEEPLY BANKED TURN THE STEEL BALL MOVES TOWARDS THE CENTRE OF TURN DUE TO FUSELAGE LIFT L_f

stay in the centre of the cross-level although the turn may be correct. It will move towards the centre of the turn. However, if the steel ball moves outwards there will be skidding out.

TECHNIQUE OF THE TURN

AILERONS. The main factor in the turn is the centrifugal force H, as it is due to this that the lift of the wings changes. The correct bank in a turn depends upon this force.

The turn should be started by moving the control stick to the side. The sailplane will then start banking and will continue to do so as long as the control stick is in the sideways position. During the bank the wing which moves upwards travels at a higher speed than the wing which is deflected downwards. Due to these different velocities there is a different lift acting on each wing. When the control stick is moved back to its neutral position (ailerons not deflected) the sailplane will still increase the bank, and if the pilot wishes to hold the sailplane at a constant bank the control stick must be moved the opposite way. This movement of the control stick must be such as to bring the steel ball to the centre of the cross-level.

Sailplanes with a large span, which therefore produce big differences in the speed on the wings, will require quite a lot of "opposite way" movement of the control stick, whereas those with a small span will need only small movement, or may not require it at all.

RUDDER. The amount of rudder deflection in a turn depends on the bank, direction and type of ailerons. It is possible for the ailerons to be designed in such a way that no rudder movement is necessary in a turn.

The air flow around a sailplane in a shallow banked turn will be as given in Fig. 146. The steeper the turn, the more rudder deflection is necessary, but at about 30° bank the effect of control reversing begins to be noticeable and the rudder raises or lowers the nose of the sailplane and acts as an elevator. The tighter the turn, the more the rudder controls the position of the nose in relation to the horizon.

ELEVATOR. The correct lift force of the wings which is needed for a certain bank is set by means of the elevator. As in a banked turn more lift, which is a function of wing incidence, is necessary and the control stick must be moved backwards. The amount of control stick movement depends upon the degree of bank. Naturally this explanation should not be interpreted as a rule of turn, but merely as an indication.

Turns should be practised first of all with gentle bank and rudder applied just to find out how much rudder a particular sailplane requires in the turn. The soaring pilot should make every turn so that any time he looks at the cross-level he will find the steel ball in the centre, and the correct speed on the airspeed indicator. In every turn the wind must come directly from in front of the sailplane, that is into the face of the soaring pilot if it is an open cockpit sailplane. The angular velocity in the turn must be constant, so must the bank and speed.

Steeply banked turns should not be practised until the technique of shallow banked turns is completely mastered and the pilot has considerable experience.

The turn should be started with the ailerons, which will effect the directional stability of the sailplane, and then the rudder should be

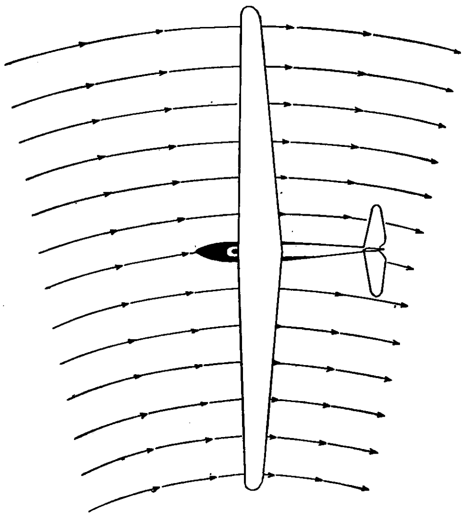


FIG. 146. AIR FLOW AROUND SAILPLANE IN SHALLOW BANKED TURN

deflected into the direction of the turn. Then the effect of the elevator should be checked. The control stick should be moved gently backwards and the sailplane will turn faster. The steeper the turn the more backward movement of the control stick required. When the sailplane is banked sufficiently and the correct amount of rudder applied, to keep the turn constant the bank should be held off by bringing the control stick in the opposite direction to the bank. When the ailerons are brought to normal position the directional stability will change and the rudder will have to be withdrawn too. The rudder should be taken off at the same time as the control stick is pulled backwards, because if the rudder is not withdrawn it assumes a function of the elevator and results in excess speed.

If the speed in a turn increases due to the rudder being deflected, it should not be reduced by applying opposite rudder as that may result in heavy loading on the fuselage. However, if the speed decreases it can be corrected by a small deflection of the rudder in the direction of turn.

In very steep turns when the sailplane is near the stall, application of bottom rudder will bring back the circling speed. Such action is often practised when flying in thermal currents as, due to the turbulent air in such conditions, the sailplane is liable to lose speed and stall.

When practising turns, one or two complete circles should be made as this will give sufficient time for the pilot to observe the instruments and bank and apply correction if necessary.

If the pointer of the turn indicator or the ball of the cross-level has moved outside the turn, the sailplane is skidding out and this should be corrected by decreasing the centrifugal force by moving the control stick forward and by moving the rudder towards its neutral position if the bank is correct. When the bank is shallower it should be increased by moving the control stick into the direction of turn. If the steel ball moves towards the turn the sailplane is slipping in and the turn can be corrected by moving the control stick backwards and moving the rudder towards the turn. When the bank is too steep it should be decreased by moving the control stick sideways, in the opposite direction to the turn.

It must be remembered that the cause of skidding out in a turn is usually too much rudder applied in the direction of turn. The cause of slipping in is too much applied aileron.

The sailplane should be taken out of the turn by decreasing the bank by moving the control stick in the opposite way to the turn. The rudder should be in the normal position, the control stick pushed forward. This forward movement of the control stick must be bigger than usual, as in this case the elevator must be deflected below its neutral position. If this movement is too small the aileron which should bring the wing of the sailplane to the horizontal, may produce such drag that when it reaches normal position the sailplane will lose speed and stall.

CHAPTER IX

TECHNIQUE OF SOARING

THE characteristics of thermal currents have been described in previous chapters. Now the question arises as to how these currents can be used to bring flight to the maximum efficiency, and what technique should be adopted to this end.

SOARING IN THERMAL CURRENTS

Two methods have been successfully used during initial training in thermal current soaring. The first is soaring by means of "feel" in which, from the beginning of his training, the soaring pilot relies on his senses and learns to detect the size and velocity of thermal currents from the behaviour of his sailplane, such as the rapid movement of wing or the whole sailplane when it enters the rising current, changes in the "air note" of the soaring sailplane or its vibration.

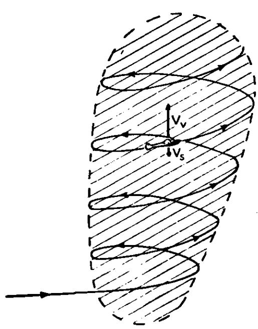


FIG. 147. RATE OF VERTICAL TRAVEL OF SAILPLANE IN THERMAL BUBBLE IS EQUAL TO THE DIFFERENCE BETWEEN VERTICAL VELOCITY OF BUBBLE (V_v) and SINKING VELOCITY OF SAILPLANE (V_s)

The other method is training by means of the rate-of-climb indicator (see Instruments) which indicates the lifting area of the thermal currents. Much can be said in support of both these methods of training, and it would be better to leave the choice to the individual soaring pilot as the adoption of the right method depends on his particular ability.

Velocity of Vertical Travel

Every sailplane has a certain sinking velocity which varies according to the aerodynamical characteristic of the machine. Let us assume that this speed is equal to 2 ft/sec. If the vertical velocity of the thermal up-current is equal to the sinking velocity of the sailplane, with careful handling the sailplane will not change the altitude at which it is flying, neither losing nor gaining height.

When the vertical velocity of the thermal current is greater than 2 ft/sec then the rate of the vertical travel of the sailplane will be equal to the difference between the vertical velocity of the thermal up-current and the sinking velocity of the sailplane.

The Search for Thermal Currents

On a day when the sky contains cumulus clouds it is quite easy to find the thermal up-currents. There are hot days, however, when there may not be a single cloud in the sky and then the soaring pilot must rely on his own knowledge acquired during intensive training.

The most critical moment usually comes when the cable from the winch, auto- or aero-tow is released. It must be remembered that every search for thermal currents should be made in relation to a suitable landing place. Then the pilot should look for the area of land where there is the greatest contrast in colour. When the wind drift is known he can fly straight to this area, and when approaching should concentrate on watching the rate-of-climb indicator and the behaviour of the sailplane.

During sunny days, areas of ground on which the sun is shining can be the source of thermal currents. Birds, butterflies, and smoke in the vicinity of factories can be very helpful in the search for thermals. Birds and smoke, particularly, can be seen from a great distance, and then it is only a question of sufficient height to reach those areas where they can be seen ascending.

Sandy valleys are usually associated with good thermal currents, but it may happen that on a very calm day there is insufficient air movement to upset the balance of the layer of air near the ground. It has been observed that by flying through such areas the movement of the sailplane in the air can sometimes liberate thermal currents.

The Sailplane in Thermal Currents

When a sailplane strikes a thermal current its behaviour is completely different from that during a normal steady glide. If it flies straight into the thermal current, and the nose of the sailplane enters the middle of the current first, the first noticeable thing will be a change of pitch stability. The angle of attack of the sailplane will increase and a change of horizontal speed will follow immediately. When one of the wings of the sailplane enters the region of rising air a rapid change of bank will be experienced.

There are, however, several things which may indicate the nearby existence of a thermal current to the pilot. These things cause unlimited discussion in every soaring centre and it will be of some interest to point them out and explain their conditions.

Around a thermal current there is usually an area of strong vortices due to the vertical movement of the air (friction and suction of the upward moving thermal bubble). This area is characterized by light vibrations which are superimposed on the structure of the sailplane. As there is vertical velocity, with the addition of normal horizontal velocity this will produce a resultant velocity which will be indicated by the airspeed indicator. Inside the thermal current the vibrations of the sailplane become more noticeable. These vibrations are followed by a change in the sound of the soaring sailplane. For those pilots who still think of the rate-of-climb

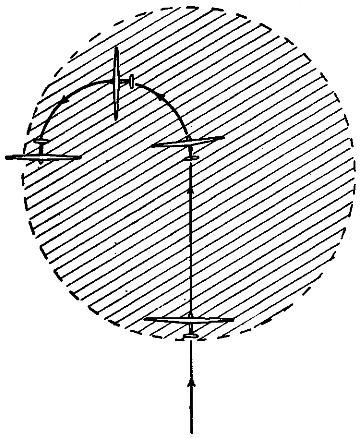


FIG. 148. CORRECT WAY OF REMAINING IN THE BUBBLE

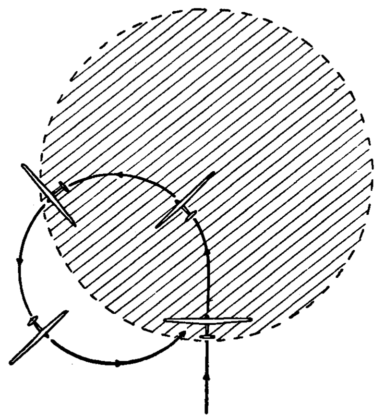


FIG. 149. VARIOMETER READING (SAILPLANE INSIDE DOTTED CIRCLE—BUBBLE) WILL BE HIGH, OUTSIDE THE BUBBLE—LOW

indicator with reserve, this sound is the main indication of the strength of the thermal current in which they fly.

A sensitive ear may also distinguish the completely different noise of the sailplane when flying in up- and down-currents. There is no doubt that the human ear is the most sensitive instrument for detecting changes of pressure. It is therefore, recommended that it should be trained on every possible occasion.

The main thing for the pilot to ascertain when entering the area of rising air, is the size of this area. Assuming that the sailplane is flying at 40 m.p.h. which is equivalent to 58 ft/sec, and the thermal current has been located on the left due to the port wing being lifted, the pilot should fly straight forward for about 5 sec, in which time the distance covered will be $58 \times 5 = 290$ ft. The pilot should then start circling to the left with a bank which will produce a circular path of travel of 400 ft diameter.

If two rate-of-climb indicators are fitted both of them should be watched all the time. The first circle may bring the sailplane into the maximum lifting area, and this will be indicated by the constant reading of the rate-of-climb indicator.

Circling should be performed with as low a bank as possible as steep turns increase the sinking velocity, and circling with a bank of more than 45° is not economical. Steeply banked turns are sometimes made, especially near the ground, as it is better to sacrifice some lift

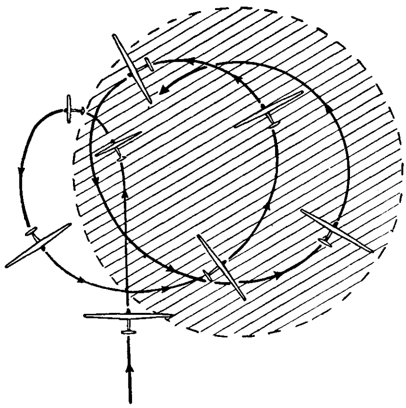


FIG. 150. METHOD OF ENTERING CENTRE OF LIFT

and be sure that the sailplane remains in the thermal current, than to circle with mildly banked turns and lose the thermal.

It can be said that normally when circling below 1500 ft the bank should be about 30° and the radius of the circle in the range of 100–120 ft, depending on the sinking velocity of the sailplane.

After entering the thermal current, the pilot may keep the rate of turn constant, or if he wants to get a better rate of climb he can widen the circle by taking off some bank, and so explore the diameter of the best lifting area.

The reading of the rate of climb during the first circle is often not steady because the sailplane may not stay all the time in the rising air.

When the rate of climb is watched very closely the best lift area can be found. Where the reading is small an increase in bank may be necessary so as to bring the sailplane in the shortest time into the area of best lift. Where the reading is high the bank should be decreased as this will enable the sailplane to stay longer in the best lift area.

During the circling and exploring of the thermal up-current it is advisable not to change the direction of turn. By careful manoeuvring, steepening and lessening the bank, the sailplane can be brought into the maximum lift. Of course it is possible for the pilot to take the wrong turn after entering the thermal current, due to misleading feel or wrongly judged position of the current. He may then alter the direction of circling, but a warning should be given that this is very difficult and not always successful.

The Drift

The theory of drift has been explained in the chapter on thermals, and it can only be added that the drift should always be remembered

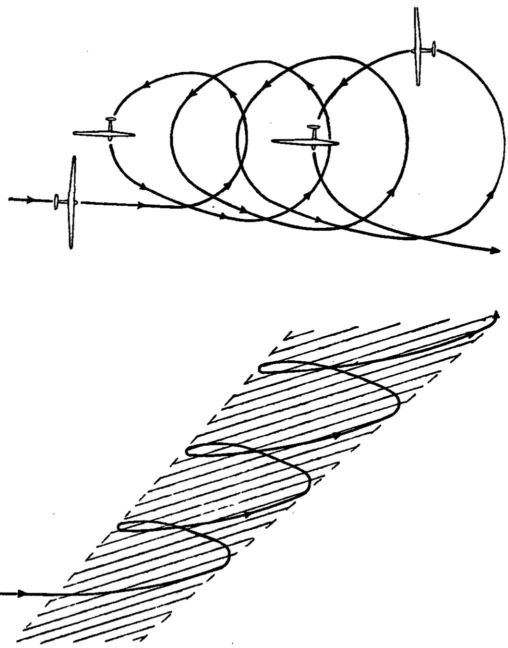


FIG. 151. THE DRIFT OF THERMAL CURRENT

when circling in a thermal bubble or column. The circling technique should be performed in such a way as to remain in the thermal current all the time. The sailplane should be allowed to drift with the thermal current, and in this way the possibility of staying within it is increased.

This short discussion on soaring in thermal currents should not be taken as representing hard and fast rules. Circling technique depends on the individual outlook, feel and ability of the soaring pilot, and it has been put in this form to give a picture of what occurs in a thermal current and what may be expected from the sailplane. The best school for soaring is intensive and intelligent training. The pilot should think over every possibility that can be met in rising air and be prepared to react correctly. In this way success may be achieved.

SOARING IN CLOUDS

When a pilot is fully trained in flying in thermal currents and blind flying, the actual soaring in clouds should not bring any particular difficulties. Naturally a knowledge of cloud formation and development is essential before starting any cloud soaring.

Two types of cloud soaring must be distinguished, that in cumulus and in cumulo-nimbus. The pilot must know the state of a cloud before entering it. Whether it is in a state of development or dissipation. He must also know the direction in which it is moving.

SOARING IN CUMULUS. Training should start with practice in flying straight through small cumulus clouds which are in a state of development. Before entering the cloud it is advisable to note the indication of the compass. If there is another cloud behind the first the same procedure can be repeated, if not a turn should be made so that the same cloud can be flown through again.

The unpleasant part of this manoeuvre will be flying through the area of down-currents which surrounds each cloud. The pilot should be prepared for this as the turbulence found around the cloud may be very heavy.

The vertical velocities in a cloud are generally much bigger than in a thermal up-current, so that some height will be gained while flying through it. This makes the matter of looking for another cloud or returning to the first one quite easy. The approach should be made against the sun if possible as this will simplify navigation inside the cloud, and the pilot should choose the middle of the cloud to traverse. The lifting part of the cloud base is usually in front, or on the sunlit side.

To judge the distance between the sailplane and the cloud is often rather difficult, and to begin with the pilot may find that his estimate of distance is far from being correct. So also with the shape of the cloud. After a few flights when the pilot becomes familiar with the mist enveloping him, and the greyness, circling in clouds may be started.

The base of a small cumulus cloud is generally at the level where condensation takes place, and on a particular day at a certain time the bases of all the cumulus clouds in the sky will be at the same height. The top of the cloud usually extends up to inversion level.

When circling has been started in a thermal current with an indicated rate of climb of, say, 6 ft/sec, and this circling brings the sailplane under a cloud base, and the pilot then enters the cloud, the rate of climb inside the cloud will often increase in a very short time and the pilot can soon read 7·5 ft/sec and 9 ft/sec rise.

When a cumulus cloud is not entered from a thermal up-current, but the pilot has just flown under it, it may take some time and flying before the area of rising air is reached and the possibility of cloud flying found. The usual practice is to fly down-wind and steer into the direction of maximum cloud thickness, or begin a systematic exploration of cloud base. Once in a cloud rapid movements of the control stick or rudder bar should be avoided.

If the air is very turbulent and speed becomes too high during circling, the soaring pilot should straighten the sailplane first and then ease off speed. He can then go into the turn again.

SOARING IN CUMULO-NIMBUS. In this cloud, soaring may bring the pilot to great heights, and it must be remembered that the conditions associated with cumulo-nimbus differ from those which can be met within cumulus. Very heavy turbulence, rain and icing can make soaring very unpleasant.

The actual technique of soaring is the same as for flying in cumulus clouds. Before entering the cloud the pilot must study it and find out which part of the cumulo-nimbus is likely to develop, and should part of it be in a state of development already, he must locate this area. It is difficult to discover whether the cumulo-nimbus is forming or breaking up and sometimes strong lift may be found in spite of a heavy shower of rain.

The pilot should always fly straight to the biggest tower of the cloud, and as soon as the area of lift is reached, circling should be started. The lift which can be found under the base of such a cloud is usually of the order of 9–12 ft/sec. The lower part of the cloud may provide lift of 18 ft/sec or more, and this will increase with increase of height in the cloud.

When the base looks quite flat it is a sign that cumulo-nimbus is active. A dark slate-grey area denotes a great depth of vapour above and is usually bordered by a hanging ragged fringe which constantly moves into the cloud. Circling in cumulo-nimbus is very trying, and to attempt it the pilot should be in his best physical and mental condition. When he feels any symptom of exhaustion it is better to leave the cloud as soon as possible, steering out on a compass course, or in the case of heavy turbulence, coming out in a spin or opening the dive brakes and diving out.

If possible an electrically-operated turn indicator should be used when circling in cumulo-nimbus cloud. The disadvantage of a venturi-driven turn indicator is that it ices up at the slightest provocation.

When the cumulo-nimbus is composed of several towers it is possible to fly straight through them and in this way to avoid circling. Of course the compass must be used when flying through and a reading taken before entering the cloud. For the inexperienced pilot this is a satisfactory way in which to commence training for flying in cumulo-nimbus cloud.

There is one thing which must be remembered when flying in this cloud. Cumulo-nimbus may develop to great heights, and due to the reduction of pressure when climbing the physical and mental state of the pilot will be affected. The lack of oxygen affects the brain and body like a narcotic, and at one stage the pilot may begin to feel very comfortable, merry and joyful. Headache and loss of memory may follow this condition. The only advice which can be given here is that the pilot should watch the altimeter and watch himself. The safe limit for flight without oxygen is 15,000 ft–17,000 ft above sea-level.

CROSS-COUNTRY SOARING

Good cross-country flights bring great rewards to the soaring pilot. The time spent during the flight in various atmospheric conditions met on his track give the finest training in soaring, meteorology and navigation. But one of the main advantages is the development of self confidence, a clear way of thinking, and the ability, through necessity, to use the knowledge and experience gained in his previous training.

A cross-country flight is seldom a success without careful planning, and the correct approach to the problem is very important. Cross-country flying may be accomplished by four different means—pure thermal soaring, cloud soaring, flying in thunderstorm or moving front, and slope soaring.

Pure Thermal Soaring

Training for cross-country flying should start from hill soaring, or if the soaring centre happens to be in flat country, from circling in thermal up-currents. In hill soaring, when there is a chance of finding thermal up-currents, the pilot may leave the slope when he has enough height, to search for thermals. In the case of flat country the flight should be initiated from the vicinity of the aerodrome, as in the case of failure there will always be a chance of coming back, regaining height on another thermal near the aerodrome, and starting the departure again. The path of flight should be kept in the form of a circle the centre of which will be the slope or aerodrome. The radius of the circle may be steadily increased when the pilot feels sufficiently confident in his new soaring technique. The main thing in such training is to get used to the lie of the land and obtain some practice in locating thermal up-currents over fresh areas. Many long distance flights have been made under a cloudless sky by soaring in pure thermal up-currents. The technique of such flights will be described below.

When setting off for cross-country flying the lift of the thermal

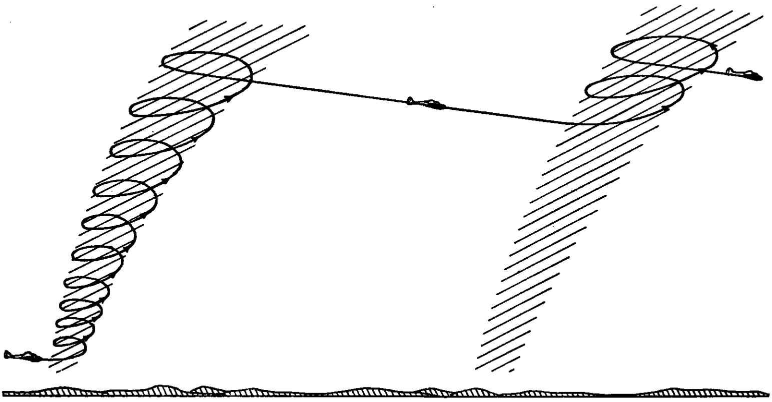


FIG. 152. THERMAL UP-CURRENTS PROVIDE GOOD CONDITIONS FOR CROSS-COUNTRY FLIGHTS

currents must be checked first. These currents may be found as early as 9 a.m. and remain until 4 p.m. in the summer. Starting the flight in early morning the pilot must investigate conditions existing in the air. A good way of doing this is to start circling in a thermal current near the slope or aerodrome, and watch for its size and vertical velocity. No cross-country flight should be attempted by a beginner until at least 3000 ft is reached. When this is difficult to attain it is better to come back to the slope and wait some time hill-soaring, or to land on the aerodrome, rather than fly into the unknown.

The best conditions for cross-country flight in pure thermals are light wind near the ground and strong wind at high altitudes which may be reached by the thermal up-currents. Only when the pilot is satisfied with the diameter and strength of the thermal up-currents should cross-country flying be commenced.

When an altitude of 3000 ft is reached the first cross-country flight should be started down-wind at the normal cruising speed of the sailplane. At this speed it would be easier to detect any thermal up-currents by feel or by the rate-of-climb indicator. The maximum height should be reached in every up-current which is met on the way down-wind.

When the pilot gains some experience in cross-country flying he can adopt a different method of cruising if long distance is his chief objective. In non-lift areas the speed should be increased to 1·5 of normal cruising speed, and circling performed only in up-currents of 9–12 ft/sec as this will save valuable time. Very weak thermal

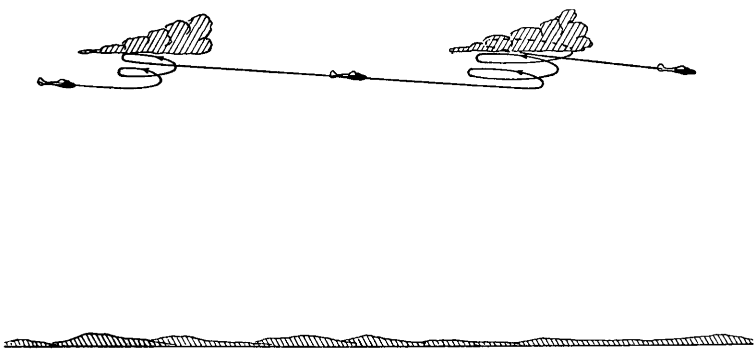


FIG. 153. CROSS-COUNTRY SOARING BY MEANS OF CUMULUS CLOUDS

up-currents may be found on the track giving only 2–3 ft/sec and flying straight through them, without circling, at the lowest possible speed, will give a better result and save energy, as the pilot will gain height without being delayed by circling at low rates of climb. In down-currents, however, the sailplane must be flown much faster, so as to traverse them in the shortest possible time.

The pilot may find he is forced down to about 1000 ft. At this height it is recommended to look for a landing place, while not forgetting to look for possible areas of thermal up-current. Areas of strong down-currents should not discourage or alarm the pilot as up-currents exist close to these regions.

Cross-country Flying by Means of Cumulus Clouds

This kind of cross-country soaring is usually associated with good thermal up-currents and high wind speed. Two ways of flying can be adopted, from one cloud base to another, or by entering each cloud and circling to the top before flying on to the next one.

On a day when cumulus clouds are small and the inversion layer is low, the main object will be to gain height in thermal up-currents and circle until the cloud base is reached. Here again it must be remembered that not every cloud provides lift underneath it as condensation may cease, and there will then be down-currents. The time spent at the cloud base should be as short as possible, and the soaring pilot should immediately head for the next thermal up-current which will be easy to find on such a day as it is indicated by visible cloud.

In a newly formed cloud there will always be lift, but if a more distinct, fully developed cloud is seen on the track, by the time the pilot arrives under it he may find down-currents. When flying from one cloud to another a constant look out should be kept for possible thermal up-currents which may not be indicated by cumulus cloud.

A range of hills or mountains may be useful when the sailplane's height becomes very low. By means of slope currents it is possible to stay for some time at the same height and wait for a cloud to come along.

The ideal condition for cross-country soaring will be when cumulus streets exist. It will then be only a question of reaching the cloud base to be able to cover a great distance along the street of cloud. A day of highly developed cumulus clouds with domed tops may provide very interesting cross-country soaring, as the pilot must spend some time circling in thermal up-currents and, after reaching the cloud, do some blind flying too.

When inside a cloud the pilot should try to make regular circles as this will keep the sailplane within the area of uplift, and the top of the cloud may then be reached. During flight from one cumulus to another the maximum cruising speed should be flown, and if the altitude is high enough the farthest cloud which can be reached should be aimed at.

Cross-country Soaring in Thunderstorm

This kind of soaring demands great skill from the pilot because there is always some risk when flying within a thunderstorm. Sound knowledge of the history of thunderstorms would be of great help, and the pilot should study the thunderstorms which develop in his neighbourhood as this will teach him a great deal, particularly about the movements and divisions in a thunderstorm. The experience gained on the ground may find application in the air. It is an accepted fact that to find the way to a thunderstorm is very difficult. It needs a great deal of patience and determination to bring the sailplane into the area of lift.

When the soaring centre is situated on a slope and the normal bungee launching used, the pilot must wait to take off before the approach of the thunderstorm until the first breath of wind reaches the lower part of the slope. This can be determined by observing trees, corn, and smoke. Only when this wind is seen should the pilot take off and fly straight towards the centre, usually the darkest part of the thunderstorm.

When operating from an aerodrome or flat country, and using winch or auto-tow, the launch must be timed so that at the moment

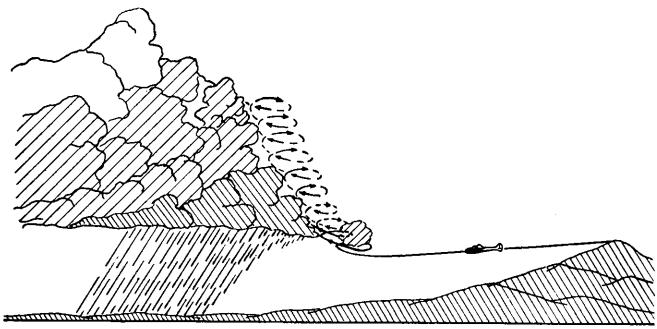


FIG. 154. THUNDERSTORM AND THE WAY OF APPROACHING IT

of releasing the cable the sailplane will be near the area of lift. It is important to know the exact moment to take off as if it is too early valuable height may be lost waiting for the thunderstorm to arrive, or if too late the pilot may find himself in a region of heavy rain or great turbulence.

Some thunderstorms have a tendency to separate when approaching, especially when a hill or mountain range is in their way, and then the whole energy of the storm is directed in one way only. Only by careful study and observation can it be determined which part of a thunderstorm will remain or develop.

Usually the middle part of the thunderstorm may be distinguished by the white cumulus cloud in the form of a roll which moves ahead of the storm. Its circular motion can be seen well ahead. The part of the thunderstorm which indicates such motion is the part in which to fly. A small and stationary roll may soon disappear. The pilot should always avoid rounded and motionless cloud and head for the heavy, sharp, dark cloud.

When soaring ahead of the main cloud of the storm, very smooth flight can be expected as the air which the pilot meets is the warm air which is being pushed up by the incoming cold air. Very turbulent air is usually met in the cumulus-rolls or in the thunderstorm cloud itself. The advantage of flying ahead of the thunderstorm is that when the pilot is once on the level of the storm it becomes much easier for him to judge the size and development of it.

Thunderstorms usually approach from the west and these are the most severe and the biggest. Some approach from the east, but these do not last very long. As the duration of a thunderstorm is not very long, the distances covered when soaring in one are not very great. Assuming that a storm lasts about 3 hr and its horizontal velocity is between 30–40 m.p.h., the distance which can be flown will not be more than 120 miles. If a thunderstorm is met when cross-country flying it may help the pilot to cover a long distance, especially as these storms usually occur in the afternoon when a number of miles have already been flown.

BLIND FLYING

One of the most fascinating flights in a sailplane is that made purely on instruments. The technique of such flight will be analysed in detail in this chapter as the correct approach to the training for such flight is one of the factors which result in the efficiency and perfection of blind flight.

When flying in a sailplane through cloud, rain or snow, the pilot's own senses become unreliable, and he is liable to make most unorthodox control movements because he cannot see the horizon. If, however, the instruments which form blind-flying equipment are fitted they will indicate the true position of the sailplane in the air.

Before attempting any training in blind flying there are four conditions which must be fulfilled—

(*a*) The pilot must be fully trained in soaring and gliding, and must be able to fly correctly in conditions of full visibility.

(*b*) The theory and technique of basic aerobatics must be known and practised.

(*c*) The pilot must possess a theoretical and practical knowledge of instruments.

(*d*) The machine must possess first-class stability and handling characteristics.

The first step in blind-flying training should be taken in conditions of full visibility, and the following points practised.

The Compass

A young pilot often finds difficulty in reading the compass and becoming mystified by its indication forgets which way to turn from one course to another. It will be of help if he imagines himself at the centre of a compass, facing the direction of flight. The needle of a compass always points to the north, whatever the direction of flight. In the case of an ordinary flat compass this needle can always be seen. In the spherical compass with a scale attached to the needle, it must be remembered that the unseen needle still continues to point to the north (*see* Instruments). In a turn our imaginary compass remains stationary in spite of the fact that it looks as though it moves. It is the pilot, whom we have assumed is at its centre, who swings round. If the indication of the compass is as shown in Fig.

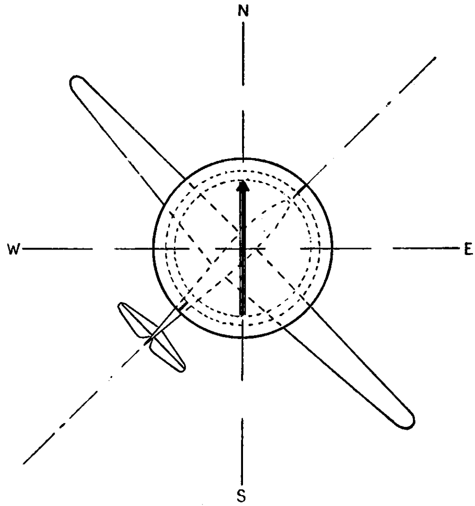


FIG. 155. TO BRING SAILPLANE TO "NORTH," PILOT TURNS TO THE LEFT (PORT)

155, the pilot should turn the sailplane to the left if flight in a northerly direction is required. If he wants to fly west he should perform a left turn.

When bringing the sailplane "on course" which should always be done by a banked turn, particular attention should be given to the cross-level. The steel ball must be in the middle of the instrument, as any side slipping or skidding will produce a swinging effect on the compass and some time will elapse before it becomes resettled.

When the sailplane is in a steady glide and the wings are parallel to the horizon, the pilot should select an object on the horizon, in, say, S. direction, and note the compass reading. Keeping his eyes on the compass the pilot should then make a steeply banked turn, trying to get on N. course. The sailplane will most probably turn through N. It should then be brought back into the direction of the previously selected object. The pilot can then start a turn again in the same direction as before, keeping his eyes on the compass, and using less bank. When about 20° from N. the turn should be stopped and the sailplane flown straight and level. This phenomenon is called the northerly turning error and when turning on course anywhere between north-east and north-west the turn should be levelled at 20° before the required course is reached.

To understand this error pilots should practise the same, setting N. course. In this case the needle will have a tendency to swing back about 20° after levelling from the turn. When turning on course anywhere between south-east and south-west the required course should be passed by about 20° before levelling the turn.

Fore-and-aft Control

The control of a sailplane in the horizontal plane is by means of the fore-and-aft level, artificial horizon, and airspeed indicator. The first two instruments are closely associated with airspeed indicator readings.

For his second lesson in blind flying the soaring pilot should chose the study of the fore-and-aft level. If the sailplane is equipped with a tail trim, the pilot, holding the control stick lightly, should adjust the tail trim to the best gliding speed. The fore-and-aft level as well as the airspeed indicator should be watched simultaneously.

When slowly moving the control stick forward the angle of glide will increase, which will result in a decrease in the height of the fluid column in the fore-and-aft level. The speed of travel will increase. Moving the control stick backwards, the column of fluid will increase in height, and speed will decrease. The fore-and-aft level, as well as the airspeed indicator, will not follow the control stick movement immediately. A certain time will elapse before these instruments will indicate the correct angle of glide, and speed. There is always a tendency to over-correct the movements of the sailplane, but when control stick movements are gentle the instrument readings will follow more promptly.

The Tail Trim

Although there are various types of tail trim the effect is always the same, the lifting or depressing of the tail. The most common form in sailplanes is the adjustment of tabs on the elevator. The rule in trimming is that when the handle of the trim is moved forward the nose of the sailplane will go down, when moved backwards it will go up. When trimming, the speed of the sailplane should be set and the handle of the trim then moved so that when taking the hand off the control stick the sailplane should proceed at the set speed.

Artificial Horizon

This instrument gives a more sensitive indication of the attitude of a sailplane in the air than the fore-and-aft level and the cross-level. When the technique of movements with the fore-and-aft level has been sufficiently mastered, the pilot may rest his eyes on the artificial horizon. The amount of movement of the silhouette of an aircraft on the shield of the artificial horizon is equal to the fluid column travel of the fore-and-aft indicator.

Various positions of the sailplane in the air are shown in Fig. 84. During early practice in controlling the sailplane by means of the artificial horizon, the pilot can look at the true horizon from time to time, making the intervals longer and finally flying for a few minutes by means of the artificial horizon alone. One of the main rules in blind flying is that whatever training is being undertaken the pilot must watch the airspeed indicator and altimeter constantly.

The best method of practising blind flying is to attempt a flight on a day when small cumulus clouds cover the sky. This will provide the pilot with some lift without the danger of being sucked inside the cloud. If possible the pilot should use the same sailplane throughout his blind-flying training because sailplanes differ greatly one from another, and until the pilot has fully mastered blind-flying technique the same sailplane will enable him to become more easily accustomed to the instruments and their indications.

Soaring pilots generally distrust the instruments at first and their reaction is to correct the sailplane's position by "feel." This is a very dangerous temptation as the sense of feel often gives a wrong impression. The soaring pilot must rely on his instruments.

Turn Control

The turn indicator is one of the most useful instruments in blind flying. It can even be said that accurate flying without it is impossible when flying in cloud. The turn indicator shows the rate of turn around its vertical axis, and usually the cross-level is incorporated in it, which shows the centrifugal force acting on the sailplane in a turn.

When flying straight, with the sailplane laterally level, the pilot should apply left rudder. The pointer of the turn indicator will move to the left. The ball of the cross-level will move to the right which means that the sailplane is sliding out (skidding). To bring the ball back to the centre the control stick should be moved to the left. When the ball of the cross-level is in the centre and the pointer of the turn indicator deflected, the soaring pilot has made a correctly banked turn. It should be remembered that the pointer always follows the rudder, whether the sailplane is banked or not.

If the speed in a turn starts to build up, the rudder should be moved back until the turn needle is central again, the speed should be eased off on the elevator, then circling begun again. The speed should never be eased off whilst still in the turn as that would probably cause a high speed spiral dive.

Speed Control

To control the speed of the sailplane the pilot should concentrate on watching the airspeed indicator and fore-and-aft level (or artificial horizon). Holding the control stick lightly, the tail trim should be adjusted so that the sailplane flies "hands off." The trim should remain unchanged during blind flying.

Now, after making a note of the flying speed the control stick can be moved forwards and backwards, and the change in indication of the fore-and-aft level noted, together with the airspeed change. When the eye is used to the indication of these two instruments the pilot will notice that it is enough to look at the fore-and-aft indicator to keep the best flying speed, as this instrument shows the angle of glide. For this reason the fore-and-aft level is most useful in the case of failure of the airspeed indicator.

SOARING IN A STANDING WAVE

Although the first attempts at soaring and altitude record breaking were made in Germany, and the theory of the standing wave developed there, quite a lot of good work has been done in England and theoretical investigation carried out by W. E. Filmer and T. Horsley. Unfortunately the standing wave has not been explored in detail for various reasons, and the subject is still open for soaring pilots to investigate and study.

The standing wave is the result of wind striking a mountain or range of hills. When the air flows over a mountain it may behave in three different ways, it may flow horizontally over the mountain ridge (Fig. 156), it may be deflected upwards over the mountain (Fig. 157) or it may flow close to the mountain (Fig. 158). The character of the flow will depend upon the velocity of wind, temperature lapse rate, the character of the slope particularly on the lee side, and the land behind the mountain.

If the air flows horizontally over the mountain, or is deflected upwards, there will be a calm area over the lee side. When the air follows the mountain shape closely it will be deflected by it, ascend on the windward side, and descend on the lee side. This descent may be accelerated by the fact that the air on the windward side cools adiabatically while ascending, due to expansion. When this rising air cools sufficiently at high levels, it will fall down as it reaches the lee side, since it will then be heavier than its surrounding air.

Naturally, the falling and rising of air behind the peak of a mountain is closely associated with the lapse rate of the mass of air. Only

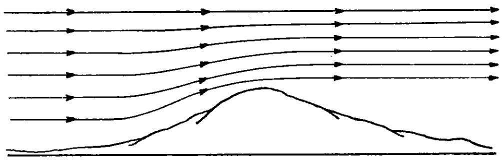


FIG. 156. UNSTABLE AIR
Flow over mountain range horizontal.

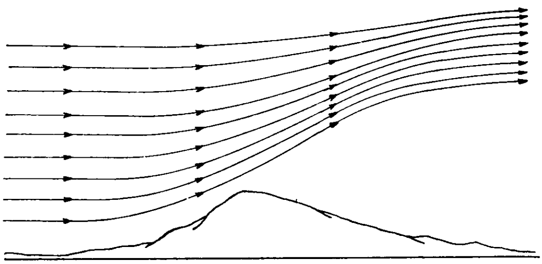


FIG. 157. VERY UNSTABLE AIR
Deflection of flow due to mountain extends to great heights.

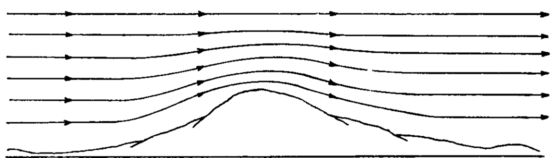


FIG. 158. AIR FLOWING CLOSE TO MOUNTAIN

the air which has an adiabatic lapse rate lower than the normal will fall down along the lee side. Air with an adiabatic lapse rate higher than normal will rise when passing the top of the mountain. A high adiabatic lapse rate is associated with cold, unstable, polar air mass, and during such conditions the formation of the standing wave cannot take place.

The stable air of a warm front may provide conditions suitable for the birth of a standing wave, assuming that there is a sufficiently strong wind blowing towards the mountain range. The standing wave most often occurs when there is a wind velocity of 20–40 m.p.h. but here again it depends upon the character of the slope of the mountain range.

At a certain wind velocity there will be no eddy formation on the lee side of the mountain but only a very strong down-current. Due to acceleration the velocity of this down-current may increase at the bottom of the lee slope. Due to the unsteadiness of wind velocity there will be a change in lift in areas of rising air. With strong wind the diameter of the rolling column will decrease, while with weak wind it will increase.

The vertical character of the ground which lies behind the mountain is closely associated with standing wave form. Hills and valleys behind the mountain will not improve the standing wave.

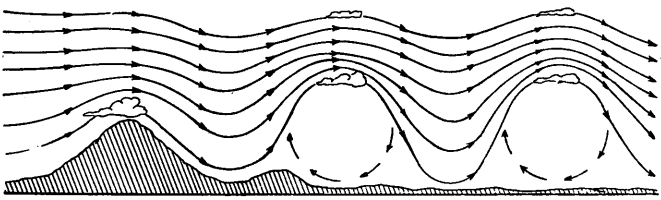


FIG. 159. STANDING WAVE AND ITS FORMATION

Clouds are the best indication of a standing wave as when watching them from the ground the lifting portion and height of the wave can be detected. These clouds form along the standing wave. Their front part is usually strongly marked while the rear is loose and hangs down. Quite often the distance between the individual clouds remains the same for long periods, and they indicate the highest positions of the wave.

The turbulence of air near the ground behind a mountain may be very heavy. Aero-towing should be undertaken with particular care in such areas as the turbulent region may extend to great heights.

The technique of flying in the standing wave differs completely from thermal up-current soaring. The pilot should keep to straight flying in lift areas as long as the lift is acting. Only when there is no more lift, and the highest altitude has been reached can circling be commenced, as the greatest height can only be reached in the top part of the wave. In this way the sailplane can be kept in the area. If the wind is very strong a crab soaring technique (similar to slope soaring) should be adopted.

If the object of the flight is duration, then the best method is to stay in the rising part of the wave, soaring along it from one end to the other. If it is desired to cover the maximum distance the pilot must first reach the highest point in the first wave which forms behind the mountain. He should then fly straight to the next wave, and although the sailplane will thereby lose some height, it will arrive in the rising part of the next wave, where height can be regained by circling or flying along it. As soon as the maximum height is again reached, the pilot can proceed to the next wave.

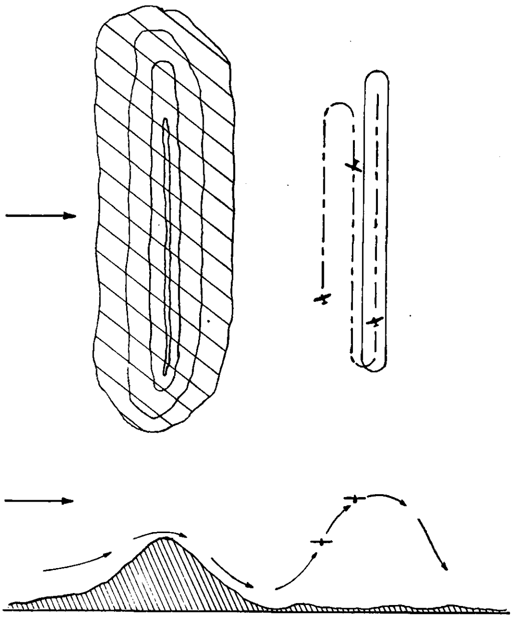


FIG. 160. SOARING IN STANDING WAVE

If the waves become flatter circling may become useless, and the pilot should then turn back in the wave against the wind and fly in the rising part to the maximum height. The last part of the distance flight will be a normal glide with the wind. The standing wave may be found behind any mountain where conditions are favourable. It has been observed all over the world.

CHAPTER X

SAILPLANE AEROBATICS

THE main object of aerobatics is to provide a basis for soaring pilots which will give them security and safety even when the sailplane is in abnormal positions, and to teach them how to bring it back to the normal position correctly, avoiding faults and dangerous movements of the controls. Quick and sure reaction may save the life of the pilot and his sailplane.

On the other hand aerobatics provide a great experience for the pilot in the air, and only when fully trained in aerobatics can he appreciate the real beauty of flight. If the soaring pilot wishes to bring his flying to a high standard he must know the mechanics of aerobatics as well as how to make the various figures in the air.

There are many types of sailplane flown in different parts of the world, and each of them requires a different handling technique. It would be impossible to discuss how aerobatics should be performed with each type, and the following explanation is limited to basic rules only. The pilot himself must find his own way to bring the aerobatic figures to perfection.

The use of the normal sailplane is limited to certain conditions, such as initial training, secondary training, slope soaring, thermal-current soaring, cloud flying, aero-towing or aerobatics. Not every sailplane can be used for aerobatics as the design and construction does not always take into account the heavy loads which are thereby superimposed on the sailplane. Soaring pilots should ascertain the technical data on their sailplanes and should check the category of the particular type flown.

The altimeter and airspeed indicator are essential equipment, and so is a parachute, without which no aerobatics should be performed. The minimum safe height for aerobatics is 1500 ft as this is about the minimum height from which a parachute jump can safely be made. No aerobatics should be allowed below this height.

SIDESLIP

The sideslip is often used to lose height quickly, without gaining speed. It is the motion of a sailplane relative to the air in which the lateral axis is inclined and the sailplane has a velocity component along the lateral axis. When it occurs in connexion with a turn it is the opposite of skidding.

To go into a sideslip, bank in the desired direction of the sideslip should be applied. To maintain direction only the elevator and top rudder should be used. During the sideslip normal gliding speed should be maintained. When coming out from a sideslip the rudder should be brought to neutral position, helping with the opposite aileron.

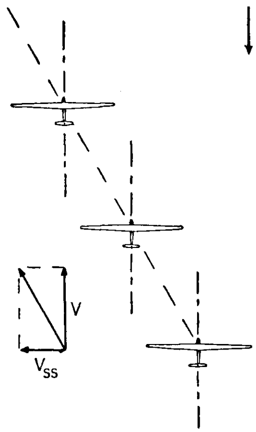


FIG. 161. SIDESLIP WITH NOSE INTO WIND
Flight path indicated by dotted line.

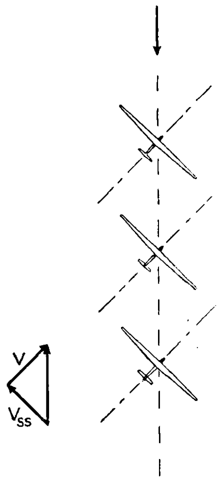


FIG. 162. SIDESLIP
Flight path parallel to wind.

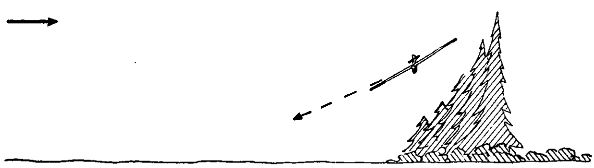


FIG. 163. SIDESLIP BRINGING SAILPLANE INTO TURN AND INTO-WIND LANDING

There are three ways of sideslipping—

(*a*) Keeping the nose into the wind. When sideslipping the sailplane will drift to the left, or right, and before landing the sailplane must be on the level and head into the wind.

(*b*) Keeping the nose across the wind. The sailplane will slip down the landing path sideways without any drift.

(*c*) Sometimes when the approach is difficult, due to obstacles, a sideslip may be performed in a turn.

In the sideslip the resultant direction is always built by the direction of sideslip and direction of glide. Of course if the bank of the sailplane increases a drift from the landing path will result. To correct this, more rudder and elevator will be required so as to turn the sailplane out of the wind. The pilot should be very careful with the rudder, as applying too much without moving the control stick forward may result in a spin.

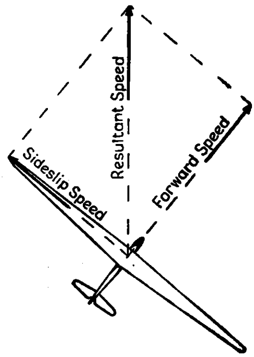


FIG. 164. DISTRIBUTION OF SPEEDS IN SIDESLIP

There is one variety of sideslip which is much more effective than the normal, but it requires great skill and a good knowledge of the use of the sailplane. It is the sideslip at a speed very near stalling speed. In this particular sideslip direction cannot usually be maintained and the sailplane turns. The pilot has to know his sailplane well as a stall near the ground means a certain crash. The pilot must make sure that when the sideslip is completed his sailplane is facing into the wind. This sideslip is dangerous and is not recommended to young pilots.

SPIRAL

This is a manoeuvre in which the sailplane descends in a very tight and steeply banked turn. It should be started from a position of normal turn, and special attention should be paid to rudder movements, control of which may be a difficult matter at first. During a properly performed spiral the ball of the cross-level should be in the middle. The tighter the spiral and the more nose drop, the more speed will be required. In the past some instructors have mistakenly taught their pupils that the nose of the sailplane should always be in the same position relative to the horizon, forgetting that the radius of turn is a function of speed. It must always be kept in mind that for each angle of bank there is only one corresponding speed, and the greater the bank the higher the speed.

It is easy to see from this description that a vertical spiral cannot be performed as it would require an infinite speed. The 60° spiral looks like a vertical one from the pilot's cockpit. The control of rudder must be very gentle and smooth as it replaces the elevator in the spiral, and by a false movement the sailplane may be brought into a steep dive and unnecessary and dangerous strain superimposed on the fuselage and wings. The torsion on the fuselage might even be so great as to break the sailplane.

The sailplane should be brought out from a spiral by means of the elevator and ailerons, moving the control stick gently forward and taking off the bank with the ailerons. Here the soaring pilot must be particularly careful to perform these actions in a very gentle manner, and help the movement with rudder in the opposite way to the direction of turn. A correctly finished spiral directs the sailplane in the same course at which it has been started. The spiral should therefore be finished at about a quarter of a complete turn.

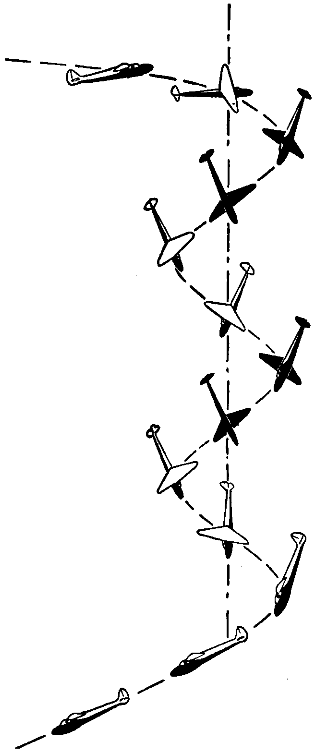


FIG. 165. SPIN

It may happen that the sailplane will not come out from a very steep spiral by means of the ailerons, then the elevator should be moved to its neutral position and rudder applied in the direction of turn. This will result in a dive from which the sailplane can be brought out very gently.

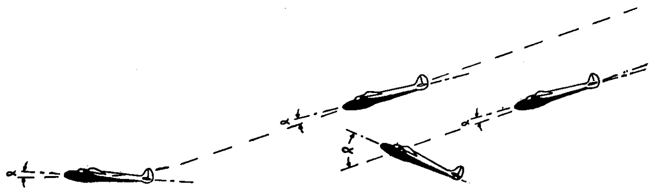
SPIN

One of the first figures which should be practised is the spin. The soaring pilot must remember that there is no need to hold the control stick stiffly. It should be held gently and the feet rested lightly on the rudder bar. The pilot must also get used to the strange feeling that the earth is rotating. He must learn to feel a part of his sailplane, and watching the earth he must realize that he is in motion with the sailplane. The spin does not involve any unpleasant reaction on the human body, and after a few trials it is easy to get used to it.

The spin is not the result of "lost speed" as is sometimes thought, but rather of an increase in the angle of attack. It would, therefore, be wrong to try to stop the spinning by moving the control stick backwards to bring the machine out of the steep nose position, although this would be the first reaction of the pilot.

To put the sailplane into a spin it should be brought to a stalled attitude by gentle movement of the control stick backwards, when the nose of the sailplane will move upwards, and the angle of attack will increase. A break of flow around the wings will occur, which will produce a decrease in lift. When this decrease in lift is the same on both wings the nose of the sailplane will drop down in a vertical plane, and the sailplane will start regaining speed.

When at the moment of complete stall, the rudder should be deflected by energetic quick movement, say to the left, then the sailplane will swing—partly turn. The starboard wing will have to describe a longer arc of travel than the port wing. The air flow on the port wing will decrease, that on the starboard wing increase. The port wing will drop and the starboard wing move up, the drag of the port wing will increase due to the increase in angle of attack. A rolling



(a) (b)

FIG. 166. THE STALL

(a) By gentle movement of the control stick backwards.
(b) By sharp movement of the control stick backwards when flying at speeds near landing speeds.

moment will develop and as the yawing moment due to rudder movement to the left is already acting, the sailplane will swing down to the left. The spin has now started.

When the rudder and control stick are held deflected the machine will perform a perfect spin. After two or three turns the speed of downward travel and speed of rotational movement will become steady.

Bringing the Sailplane into the Spin

When in a steady glide the speed should be noted and by a very gentle back movement of the control stick this speed should be decreased to the minimum. The wings should remain parallel to the last moment of stall. The position of full stall will be indicated by the drop of the nose of the sailplane. During this period the pilot can observe how long it takes to bring the sailplane to the stall, and how long it takes, after the nose has dropped, to restore the previous attitude.

When the minimum speed is reached, an energetic quick movement of the rudder will bring the machine into the spin. Some sailplanes, however, require some opposite aileron, and in this case the control stick will have to be moved to the right. The sailplane will turn to the left around the port wing and start spinning to the left. The use of aileron, however, depends on aileron design. In sailplanes with differential ailerons, the pilot should not wait until the sailplane is fully stalled, but as soon as the speed is reduced, he should apply full rudder and help to initiate the rotary movement with aileron given in the same direction. The downward deflected aileron will increase the angle of attack of the wing and stall it.

FIG. 167. WHEN THE DROP OF LIFT IS THE SAME ON BOTH WINGS THE SAILPLANE WILL DROP ITS NOSE AND START REGAINING SPEED AS SHOWN IN THE PICTURE

The Sailplane in a Spin

The spinning of the sailplane normally occurs when both rudder and elevator are fully deflected, which means the left foot pressing firmly to full extent, and the control stick pulled backwards as far as the pilot's body. It is also possible for the sailplane to stall without any help from rudder or elevator when flying in very rough conditions from an area of rising thermal current to an area of down-current, or when performing a spiral if a sudden or too harsh movement of controls has been applied.

If during a spin the rudder remains fully deflected but the control stick is moved gently forward, the machine may still spin but the path of descent will increase. When the rudder has been withdrawn to neutral, after some time the rotational speed will decrease and if the control stick is moved forward sufficiently, the spin may stop completely. When in a spin if the control stick is in its maximum rearward position, and the rudder is brought gently to its neutral position, the speed of rotation will decrease and usually stop completely.

There is a certain position of elevator and rudder which will stop the spin completely, and if they are both held very near this position the spinning effect will remain the same but a very small movement will be sufficient to arrest it. Such a spin is called a controllable spin.

Bringing the Sailplane out of the Spin

When the rudder and elevator are brought to the neutral position the sailplane should stop spinning after a quarter or a full turn. Some machines may require more forward movement of the control stick, and some others may even require opposite movement of rudder. The best method is to see how the particular sailplane

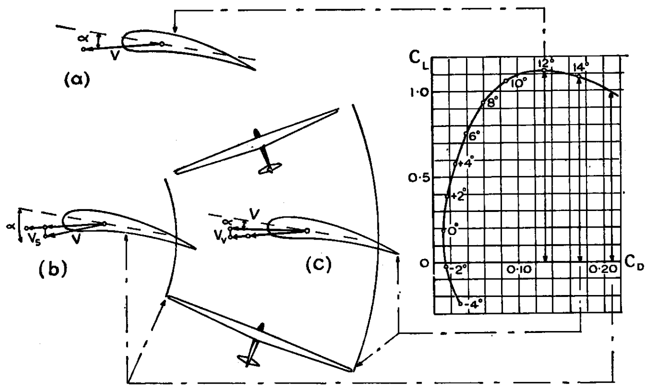


FIG. 168. DISTRIBUTION OF LIFT AND SPEEDS IN SPIN

(*a*) Angle of attack and speed—normal flight.
(*b*) Speed decreases on inside wing tip in a turn (sinking speed of the wing tip shown by V_s).
(*c*) Speed increases on outside wing tip in a turn (upward speed of the wing tip shown by V_v).

behaves, first withdrawing the rudder to neutral position. The control stick should then be moved forward gently until the spinning stops completely. If the spinning does not stop opposite rudder should be applied, with more forward movement of the control stick.

The soaring pilot must keep a constant check on his actions as the impressions he receives of them during a spin may not be true. Sometimes not enough forward movement of the control stick delays recovery from a spin, or the movement of the foot is so pronounced and the leg muscles so stiff, that it is difficult for the other foot to bring the rudder back.

LOOP

This is a manoeuvre executed in such a way that the sailplane follows a circle in the vertical plane. It is one of the easiest figures in aerobatics.

The necessary anti-centrifugal force required for turning over is produced by the wings. This force A must be big enough to withhold the weight of the sailplane *W* and centrifugal force *H*. The force *H* is acting in the opposite direction to *A*, the force *W* always vertically.

Pulling out from a shallow dive, at (*a*) the weight *W* will add to force *H*. Maximum lift is necessary here. At (*b*) it will add to drag *D* and decrease the speed. At (*c*) it will add to the aerodynamic force *A*. Minimum lift is necessary here. At (*d*) it will act opposite to drag *D* and increase the speed.

Before starting the loop the speed of flight should be increased about 50 per cent. The sailplane must be flown in a straight line

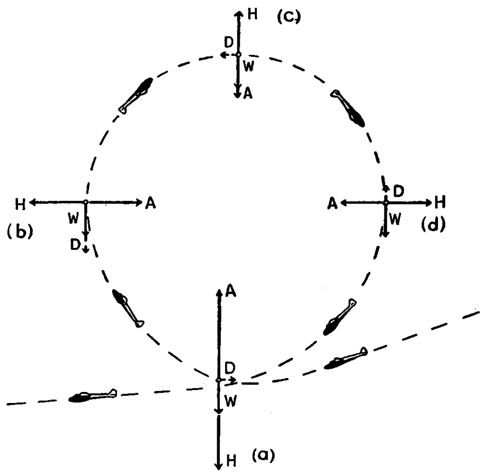


FIG. 169. DISTRIBUTION OF FORCES ACTING DURING A LOOP

with the wings laterally level, and this should be checked before pulling out. When the required speed has been reached, the control stick should be moved backwards with smooth, slow and gentle movement. The only indications of correct movement of the control stick are that the body of the pilot is being forced down into the seat, and the particular sound of the moving sailplane. With the decreasing speed shown on the airspeed indicator, the control stick must be moved more and more backwards. This movement is very important and should produce the same acceleration on the pilot's body all through the loop.

When the horizon is seen, the pilot being on his back, the control stick must be moved forward very gently. This will result in smoothing the top of the loop. Otherwise the loop will have the shape of an ellipse and not a circle.

The pilot's sense of feel is the main factor in the efficiency of a loop. When in an inverted position, the wings must be maintained parallel to the horizon to ensure that the loop remains in one plane.

After passing the inverted position the sailplane will assume a diving attitude in which, for a very short moment, the control stick should be moved more forward to gain speed. When this is achieved the sailplane can be brought out from the dive by a gentle pull out so as to close the circle which the sailplane has made in the air. It is better to perform one's first loops with slightly more acceleration than is really necessary, and concentrate on the position of the wings in relation to the horizon, and the smoothness of the curvature of the flight path.

The most common mistake during the loop is rapid and harsh movement of the control stick, which results in a very small diameter loop and over-acceleration, which may be unpleasant for the pilot. When the initial speed is too low, or control stick movement too slow, the sailplane may stall at the top of the loop and start to spin.

When, being at the top of the loop, the pilot notices that the wings of his sailplane are not horizontal, some aileron can be applied and the position corrected, but this is difficult and it is easier to make the correction by applying opposite aileron when coming into the last phase of the loop. This figure should be practised over a straight piece of ground, road or railway line, and the nose of the sailplane kept along it all the time.

The control stick must be held firmly during the loop, especially if a large drop in speed has been observed during the top part of the loop, because the sailplane might then slip down on the tail, causing heavy loads on the elevator.

STALL TURN

This is one of the most difficult manoeuvres in aerobatics. The sailplane is put into a dive, the speed of which is twice the normal flying speed. The pilot should then observe the horizon, looking at it along that wing in the direction of which he wants to perform the turn, and move the control stick backwards. The path of flight being anything between 70–90° the control stick should be moved gently, and the angle of flight observed by the wing in relation to the horizon all the time. Then the control stick should be moved forward so as to keep the sailplane along a straight path, and the sailplane will move upwards. When the speed drops to minimum and the sound of the sailplane disappears, full rudder should be given, with the help of opposite aileron if necessary, and the sailplane will turn through 180°.

The soaring pilot should first practise the rudder movement. Doing so the wing will drop, due to the greater velocity on the outside wing. The complete drop of speed must occur when the sailplane is deflected nose downwards. The moment when the sailplane turns is the most important in this figure, and it can only be performed correctly after long practice. When the machine is

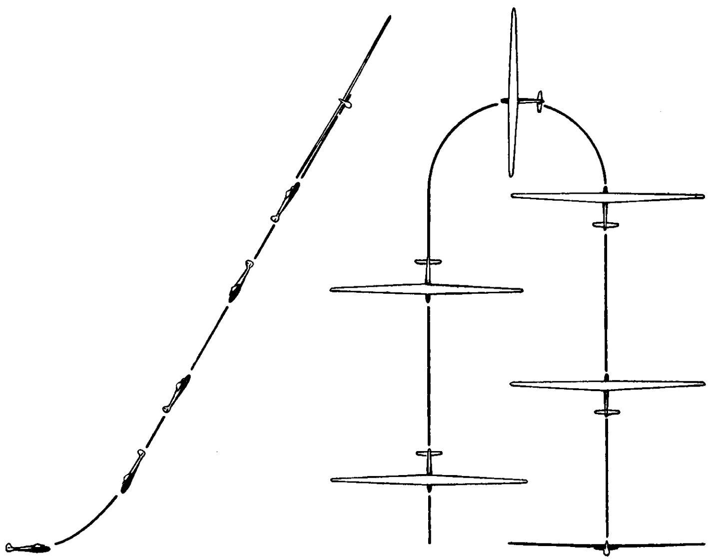


FIG. 170. STALL TURN

brought to turn at too high a speed skidding out will follow. When the speed is too low it may side or tail slip.

When full rudder and aileron has been applied and the turn has been completed, it is often necessary to apply opposite aileron and so prevent the sailplane coming into the inverted position. This should be done soon after the sailplane starts the turn. When the 180° turn has been made the rudder and aileron must be brought to the neutral position, and the angle of dive kept equal to the angle of climb (70°–90°) by means of the control stick.

The direction of flight when coming out from a stall turn must be exactly opposite to the previous direction, and the speed the same as before pulling out.

The stall turn should be practised over a straight road or railway line, which can be seen clearly from the height at which the pilot flies, as in the loop.

SLIDE ON TAIL

This figure is performed when the sailplane is being pulled out from a dive, as in the first part of the loop. Instead of pulling the control

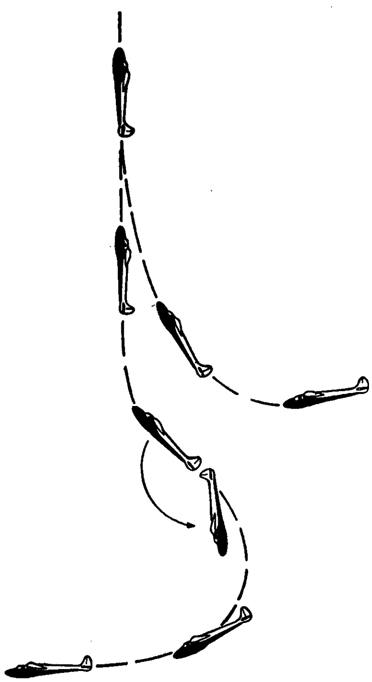


FIG. 171. SLIDE ON TAIL

The sailplane turns around the C.G., with its nose down (forwards).

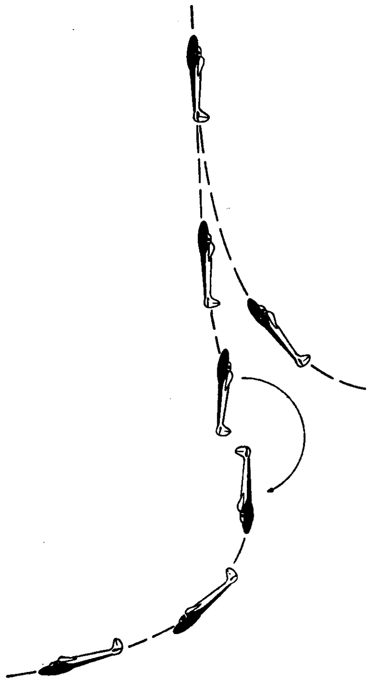


FIG. 172. SLIDE ON TAIL

The sailplane turns around the C.G., with its tail down (backwards).

stick backwards, it is moved forwards so much that vertical flight will result, bringing the sailplane to the minimum speed. When the speed has dropped completely the sailplane will stall very rapidly, or move down through the nose or tail. It should be emphasized that this slide on tail can only be performed on sailplanes designed and constructed for such a manoeuvre, as heavy loads are imposed on the structure which could easily approach the limiting values.

The speed of the sailplane should be increased by about 1·5 times the normal speed, and the control stick moved backwards, as in the loop. When the sailplane approaches the vertical position, forward movement of the control stick will keep it vertical. The control stick must be held very firmly to withstand eventual elevator movement. When the sailplane starts moving backwards the control stick should be pulled gently until it rests against the pilot's body. As the sailplane is sliding backwards the action of the elevator is reversed and the machine turns around its centre of gravity, ending with its nose down. Slight forward movement of the control stick will increase the speed, and then the sailplane can be pulled out of the dive.

When the sailplane is in the vertical position and begins to slide tail down, and the control stick is moved forwards, not backwards, a tail slide will result, but the machine will turn over backwards and not forwards as in the previous case.

During the tail slide the control stick or rudder may slip from the pilot's grasp. Then excessive loads on the elevator may result, and the forces acting on the tail may become bigger than the structure can withstand, and the hinges may be pulled out. Every movement of the elevator and rudder must be under control all the time to prevent dangerous deflections occurring.

INVERTED FLIGHT

During inverted flight the wings of the sailplane are at a negative angle of attack. The lift produced at such an angle will be small, and break-away of flow, and stall, occur more easily at greater speed than in normal flight. The pilot must remember that in inverted flight the action of the control stick concerning speed is opposite to that in normal flight. This means that if a decrease in speed is required the control stick should be moved forwards, and pulled back to increase the speed. The nose of the sailplane should be kept just above the horizon, and if speed increases the control stick should be moved forwards.

If the nose of the sailplane drops down because the speed is too low and the angle of attack too great, the control stick should be moved backwards until the speed increases, and then moved forwards again if necessary.

The easiest way to bring the sailplane out from inverted flight is by means of a half loop. First the speed in the inverted flight must be reduced by moving the control stick forwards, then it should be moved backwards, quickly and energetically. This will result in a tight half loop. If the control stick is moved too slowly, high speeds may be reached and the sailplane will go into an inverted dive, which may end disastrously.

SLOW ROLL

This is a manoeuvre in which a complete revolution about the longitudinal axis of the sailplane is made, the movement having a horizontal axis. The first roll should be made only when the pilot has thought over every action of the elevator, rudder and ailerons which will be necessary to perform this figure.

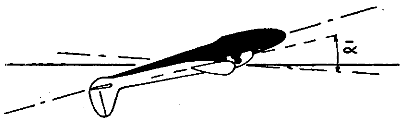


FIG. 173. INVERTED FLIGHT
(Notice wing at negative angle of attack.)

The actions of the pilot can be divided into three periods—bringing the sailplane into the roll, the roll itself, and bringing it out. These periods must be well understood.

The speed necessary for a roll is about $1\frac{1}{2}$ times that of normal flight, and if the speed is not well chosen and is too low the roll may develop into a spin. It is better to commence the training with a

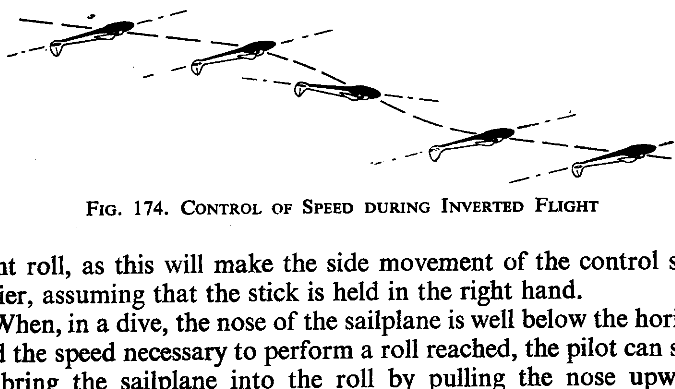


FIG. 174. CONTROL OF SPEED DURING INVERTED FLIGHT

right roll, as this will make the side movement of the control stick easier, assuming that the stick is held in the right hand.

When, in a dive, the nose of the sailplane is well below the horizon and the speed necessary to perform a roll reached, the pilot can start to bring the sailplane into the roll by pulling the nose upward, above the horizon, and at the same time banking the sailplane with full aileron, and keeping the nose up with the top rudder. This is the first stage of the slow roll. As soon as these actions have been performed the sailplane will have the tendency to turn in the direction of bank, which should be prevented by smooth movement of the control stick forward. After reaching vertical position, the rudder must be slowly and smoothly withdrawn until, while arriving at an inverted horizontal position, it reaches its normal position. The control stick will still be forward and the ailerons deflected.

During the next part of the roll opposite movement of controls takes place. The rudder begins to deflect in the direction of the roll, and as the last phase of the roll is reached the control stick goes back to its neutral position.

To stop further rotation in the desired horizontal position, opposite aileron should be applied. Some pilots try to keep the sailplane in the required position by early withdrawal of the ailerons, but this results in considerable slowing down of the rolling motion of the sailplane, and probable sideslip. At the end of a correctly performed slow roll the speed of the sailplane should be normal flying speed, and the direction the same as when starting the roll.

Generally it can be said that aileron starts the rotation of the sailplane along its longitudinal axis and the rate of aileron movement produces the speed of rotation. Rudder and elevator are used for maintaining correct speed and direction.

The most frequent faults made during the roll are, firstly, the loss of orientation when in an inverted position. The pilot's first reaction is to withdraw the ailerons to neutral position, which results in inverted flight, or to keep the control stick in a backward position, resulting in an inverted dive. In such case the next action should be to move the control stick farther backwards and to come back to normal flight through a half loop. This may result in high acceleration and heavy loads on the sailplane, which may be very dangerous for the pilot and the sailplane.

The second common fault is that when in the inverted position speed is being lost, the pilot may bring the sailplane to normal flying speed of inverted flight by moving the control stick backwards. Then the sailplane may start a spin in the inverted position.

QUICK ROLL

This is really a dynamic spin with its axis horizontal instead of vertical. In inexperienced hands it often ends with a normal spin. The figure requires greater speed than the slow roll, almost twice the speed of normal flight. This speed reached, the pilot should do three movements together, and do them quickly, almost brutally, although smoothly. He should pull the control stick fully back, deflect the ailerons fully, and apply rudder in the opposite direction. This will result in a quick movement of the sailplane around a horizontal axis. When the turn is almost completed the pilot should as quickly withdraw the controls and move them in the opposite direction. It is impossible to state how much the controls should be deflected, as every type of sailplane has different characteristics. One can only say that if the sailplane falls into a spin before completing its full turn it means that too much rudder was applied. If it falls into a spin after arriving at its normal horizontal position, it means that the control stick was pulled back too far, or not moved forward enough, or early enough, at the end of the roll. So the pilot must discover for himself which of the controls were used incorrectly.

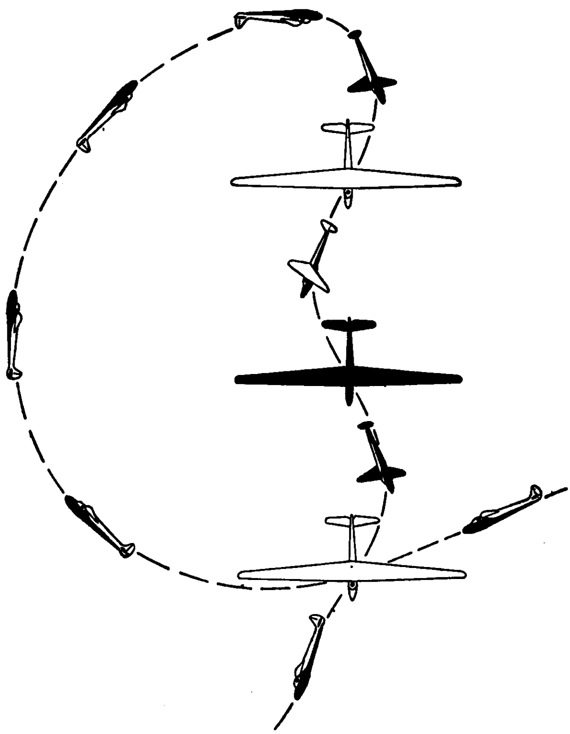


FIG. 175. INVERTED SPIN

The pilot can control the movement of the sailplane during the actual roll very little, if at all, as it is a very quick and forceful figure. It requires a sailplane especially built for aerobatics.

INVERTED SPIN

This figure is most unpleasant for the pilot, and is very seldom performed. When in the spin the body of the pilot is pressed against the side and into or out of his seat.

One of the methods of starting an inverted spin is to bring the sailplane into a half loop, and as soon as the horizon is seen, the control stick should be moved forward gently, so as to stop the loop. At the moment when the speed drops completely the control stick is moved fully forward and rudder and ailerons applied. The sailplane then starts an inverted spin.

The airspeed indicator must be watched all the time, and as soon as excessive speed is being reached and there is a feeling that an inverted dive instead of inverted spin is being performed, the machine should be brought out of the spin immediately, by moving rudder and aileron to neutral position and moving the control stick backwards. Sometimes opposite rudder and aileron are necessary to stop the rotation.

The other, and much easier, method of bringing the sailplane into an inverted spin is to start a roll, and when the machine is in the inverted position, move the control stick more forward. It may sometimes be necessary also to change the ailerons.

Orientation in the inverted spin is more difficult to retain than in all other aerobatic figures, and if lost may result in disaster. For this reason no pilot should attempt it until he is really at home in slow and quick rolls and in inverted flight, including inverted turns.

FORWARD LOOP

This can be done from normal flight downwards, or from inverted flight upwards. The latter is more difficult and requires a very strong sailplane. The forward loop should not be attempted unless the pilot is very proficient in all other aerobatic figures, nor unless the sailplane was designed for it. One of the pioneers of gliding and soaring in Great Britain was killed while trying it in a very strong sailplane which was still not strong enough.

If the sailplane is especially designed for inverted flight, this manoeuvre can be tried, but the pilot must remember that the human body cannot withstand negative accelerations so well as positive. An acceleration of $-3{\cdot}5\,g$ is the maximum.

Doing a forward loop from normal flight, the pilot has to move the control stick forward fairly smartly, otherwise the first quarter of the loop will be very extended. The stick must also be moved far enough forward, to prevent the second quarter being the same, resulting in an inverted spin from the third quarter of the loop. The pilot must be careful to have enough speed at the bottom of the loop as it is most difficult to make the second part of the loop similar in radius to the first.

The most unpleasant parts of the loop for the pilot are the second and third quarters when the negative acceleration makes the blood

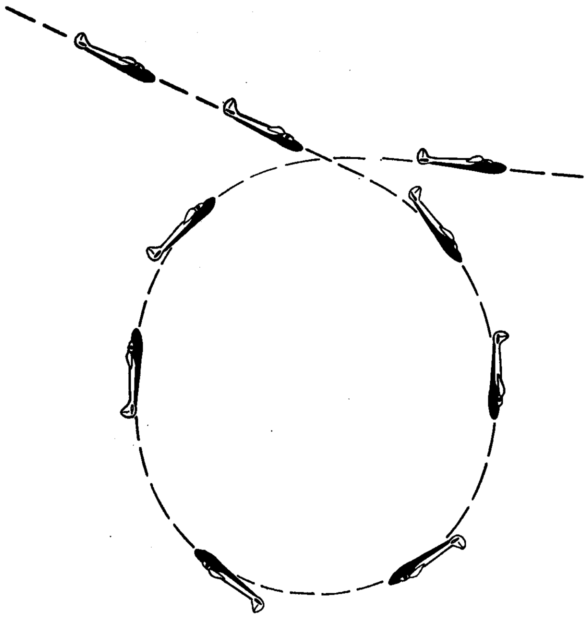


FIG. 176. FORWARD LOOP STARTING FROM NORMAL DIVE

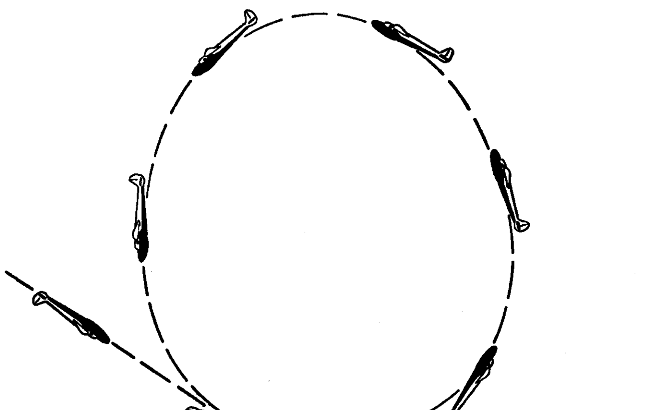


FIG. 177. FORWARD LOOP STARTING FROM INVERTED DIVE

rush to his head, and he is hanging on his harness. For this reason the figure should not be attempted unless the pilot is very fit, and the harness is quite safe, and can be pulled very tight. This may be uncomfortable in normal flight but is necessary for this figure, which demands special precautions.

The second method of performing a forward loop is as follows. When diving in inverted flight, and when the speed of dive is at least twice the normal, the control stick is moved forward with smooth and gentle movement. As the acceleration is negative the pilot's body will be pulled off the seat and rest on the harness. The control stick should be pressed forward long and far. When arriving at the top of the loop the control stick must be moved back.

At first soaring pilots usually move the control stick too hard and too quickly, which results in over-acceleration. Here the pilot must be particularly careful because excessive acceleration may break the harness, or cause him to experience a black-out.

CHAPTER XI

AIR NAVIGATION

A GREAT many of the successful cross-country flights made during the last few years indicate that the soaring pilot must possess some information on navigation, as well as having a knowledge of meteorology and the technique of cross-country flying. During cross-country flights, as well as when going into or coming out of a cloud, finding one's position in relation to the earth is of vital importance.

Most cross-country flights are made within the moving air masses, so it is very important to know how these air masses may affect flight in altering direction, speed of travel, etc. A goal flight without basic information on air navigation is almost impossible to achieve. Such a flight is seldom made in the form of a straight line as the pilot may be forced to fly around areas of down-current or other unfavourable areas.

Every soaring flight should be made with the idea of improving the pilot's powers of navigation, and the correct planning of every flight should be his main object. Only by constant practice will success be achieved. It is through navigation that the soaring pilot is enabled to determine the position of his sailplane in the air in relation to known points on the earth. The time will come, and it is hoped it may come soon, when flight in the stratosphere will be possible. Then the soaring pilot will have to be an experienced navigator in addition to being an expert on soaring.

Navigation is the science of conducting the sailplane from one point on earth to another. Correct and speedy travel from place to place means economy in time, which is very important in soaring. The pilot should always use the simplest possible methods in checking his position in the air. In clear weather and during short flight, when distinctive landmarks can be seen for a long distance ahead, it is easy to find one's position. The reliability of such a method depends more upon the human element than upon science and technical knowledge.

Cross-country flight under difficult conditions, such as in clouds, demands a knowledge of dead reckoning navigation, however. This involves the use of the compass and the calculation of the courses and distances flown.

Direction

There are three basic directions used in air navigation—

(*a*) the North geographic pole is called the ***true north.***
(*b*) the North magnetic pole is called the *magnetic north.*
(*c*) the North compass pole is called the *compass north.*

The difference between the true north and the magnetic north is called variation, and this may be westerly (— sign), or easterly (+ sign). The difference between the magnetic north and the compass north is called deviation, and this may be westerly (— sign) or easterly (+ sign).

The direction in which the sailplane is moving is called the course,

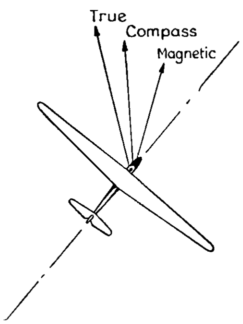


FIG. 178. THE COURSE

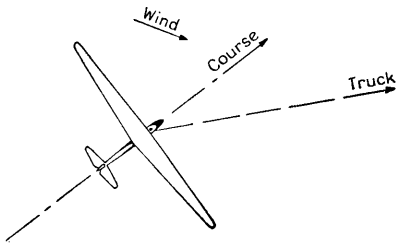


FIG. 179. THE DRIFT

and similarly there will be three expressions for this—true course, magnetic course, and compass course. Supposing that the compass of a sailplane shows course 300°, deviation is west 3°, and variation west 10°, then the true course will be—

Compass course . . .	. 300°
Deviation	. −3°
Variation . . .	. − 10°
True course. . . .	. 287°

The direction of sailplane travel in relation to earth is called track, and similarly there will be—true track, magnetic track, and compass track. The difference between course and track is called drift (port or starboard). The drift is caused by the wind carrying the sailplane off its track.

Wind direction is the direction *from which* the wind is blowing.

Ground position is the position on the earth directly beneath the sailplane.

Distance is measured in

statute miles = 5280 ft
nautical miles = 6080 ft
kilometres = 3280 ft

Speed is the rate of change of position and is usually given in

statute miles per hour (m.p.h.)
nautical miles per hour (knots)
kilometres per hour.

Air speed is the speed at which the sailplane travels in the air (m.p.h.).

Ground speed is the speed of the sailplane in relation to the ground (m.p.h.).

Wind speed is usually given in m.p.h.

Height is given above sea-level (ft) and above the ground.

MAPS AND MAP READING

A map is a conventional representation of the surface of the earth, and exact knowledge and reading of it is essential to the soaring pilot. Every opportunity should be taken for the study of maps, so as to discover the meaning of everything shown upon them.

The main differences between a map and a chart are—

(1) the difference in units of measurement. (On charts the units of distance are given as nautical miles, on maps as statute miles. Relief is given in feet on charts and in feet and metres on maps.)

(2) the main area shown on a map is land-area, and that shown on a chart is sea-area.

Scale is the ratio between a given length on the map and the actual distance on the ground.

Relief is represented by—

spot heights or depths,
contours and form lines,
layer tints.

All heights on 1-million scale maps are measured from mean sea-level at Newlyn, Cornwall, and are given in feet. All lines connecting places of the same height are called contours. The difference between two contours is called the vertical interval. Layer tints give an easy picture of relief which helps considerably in estimating heights from the ground.

The legend of a map consists of conventional signs to give a physical picture of the earth including those things listed below.

Landmarks—The pilot may look for the following—

(*a*) railways, which help in estimating the wind near the ground,
(*b*) roads, which are rather difficult to identify in England due to their number and the problem of distinguishing the main from country roads,
(*c*) water, rivers and lakes which are easy to identify,
(*d*) woods, mountains, hills, towns and villages.

Every soaring pilot would do well to spend some time at home learning how to read a map. As the majority of flights are made within sight of the ground it should not be difficult to fix the position of the sailplane in relation to the earth by the use of a map. The main thing is to know how to recognize on the map those things which are visible from the air, at various heights. The pilot should look at the ground from time to time and make a mental note of the main features. The use of the map will enable him to know what to expect.

PLANNING A FLIGHT

Even the simplest flight should be made with some plan. Leaving the soaring site or aerodrome for even short intervals can be used for improving navigation. Taking off hastily and without preparation should be avoided.

A good choice of landmarks is very necessary, especially when cross-country flight is undertaken. The pilot should also keep to his compass, bearing in mind the track which he has previously marked out on the map. The meteorological forecast must be known, and if possible discussed or thought over on the ground. The wind should be checked as to speed and direction at various heights. When in the air it should be checked by observing smoke or the shadows of clouds on the ground. From these indications the drift can be calculated and compass course corrected accordingly.

The temperature of the air should be read off quite often as this will give an idea of air mass travel and change of wind.

The altimeter should be set to the pressure of take-off point (zero height), but shortly before take-off it should be set so that it gives the height of the take-off point.

From his compass, his observation of drift and course, and from the clock, the soaring pilot could pin point his position on the map, were it not for unknown factors such as changes of wind. Also, as the pilot studies one place on the ground in an attempt to recognize it on the map, the sailplane may go off course. Constant circling in thermal currents or clouds is also very misleading to navigation.

In map reading the first essential is orientation. When in the air the map should always be held with the magnetic north in the direction of the magnetic north as indicated by the compass.

One last word of advice to the soaring pilot is to always try to fit the ground seen from the air to the map, and not vice versa.

CHAPTER XII

THE PARACHUTE AND ITS USE

As this book is addressed to the soaring pilot with the idea of giving him a brief encyclopaedia of soaring, it is necessary to include a few lines on the subject of safety during soaring flight. In spite of the fact that sailplanes built to-day are stressed and designed to withstand heavy loads, accidents may occur during cloud-soaring, aerobatics or aero-towing, and if there are several machines flying under cloud there is the danger of collision. The possession of a parachute gives the pilot a high measure of personal safety.

To enable the soaring pilot to have the absolute and implicit confidence in his parachute which is so desirable, it is necessary for him to understand the design, maintenance, function and technique of its use. Any neglect in the care and maintenance of his parachute may cost the pilot his life, and he should give it regular attention and inspection.

There are two types of parachute now being used on sailplanes, the automatic and the manually operated. The automatic type opens itself during the jump whereas the manual has to be operated by the pilot. In appearance the two parachutes are very similar either packed or open. The manually operated parachute is more generally used on sailplanes, and is attached to the pilot's body. After the pilot has made his jump, and during the fall, he pulls the rip cord and the parachute leaves its pack and opens. This parachute may either be carried on the pilot's back, or form a seat. As the seat in a sailplane is situated very low, the seat type of parachute is difficult to fit and brings the pilot's body up too high. The back type fits into the back of a specially shaped compartment and forms a back rest for him.

One of the best types of parachute is the Irving, in which the silk canopy and rigging lines are in separate packs in a cover which is attached by means of harness to the pilot's body. This harness has a quick release enabling the pilot to free himself at any time from both harness and parachute. The parachute consists of a vented canopy and rigging lines.

Canopy

The umbrella part of the parachute is called the canopy and is made of silk cut in a number of gores of triangular shape and sewn together so that the finished canopy forms a circle. The standard type of parachute has a canopy 24 ft in diameter.

Ventage

In the centre of the canopy a small opening is provided to enable the air which is trapped under the canopy to pass out. The flow of air through this vent reduces the swinging of the parachute and pilot during descent.

Rigging Lines

These are the silk cords by means of which the pilot is suspended from the canopy during descent. These cords are continuous from their point of attachment on one side of the harness, over the top of the canopy and back to the other side of the harness. There are no knots or splices along their length. These lines can withstand heavy loads during the opening of the parachute and a single line can actually take 400 lb. As the 24-ft diameter canopy has 24 rigging lines, they can withstand a 9600-lb load.

The Auxiliary Parachute

A parachute about 3 ft in diameter is attached to the top of the canopy by a multiple silk cord. Its frame is made of steel ribs and it is placed under tension in the pack cover of the main parachute so that as soon as the rip cord is pulled and the flaps of the pack open, the auxiliary parachute springs out, fills with air and pulls out the canopy from the pack.

When open this auxiliary parachute will pull the canopy out regardless of the pilot's position in the air and so eliminate the possibility of the pilot being entangled with the canopy. It also enables the canopy to open much quicker and permits jumps from the sailplane even at low altitudes.

The Harness

The part of the parachute which is attached to the pilot's body, and is permanently connected to the rigging lines is called the harness. The webbing used in the harness is especially woven from pure linen yarns and all the stitches are done by machine and are tight and locked within the webbing.

Metal Parts

Nickel steel, either chromium or cadmium plated is generally used for these parts. The quick-release box is made from duralumin bar, with a press button on which is inscribed "Turn to unlock" and

"Press to release," and an arrow indicating the direction of turning for unlocking.

When fitting on the four connecting lugs of the harness, the press button must be in the locked position with the locking plungers fully visible in the slot of the quick-release box. When the connecting lugs are pushed into the slot the locking plungers should spring into the holes of the connecting lugs. To unlock the harness the press button is turned clockwise, and to remove the harness from the pilot's body the press button is struck with a sharp blow towards the pilot's body.

The Pack Cover

This is made of plain weave khaki duck, with a stiff base. Four flaps enclose the ripping lines and canopy and are retained in a closed position by brass locking cones which are locked by pins attached to one end of the rip cord. The other end of the rip cord forms a handle which is stowed in a pocket in the harness on the left side of the body. When the pilot pulls the rip cord the locking pins are withdrawn from the locking cones and the flaps open by the action of elastic cords. These elastic cords should be renewed every six months.

Maintenance

The packing of a parachute can only be done by a well-trained and reliable person with proper tools and accommodation. As these facilities are not usually available at gliding centres, the parachute should be sent to the manufacturers or a parachute depot for repacking, and this should be done at least once every two months.

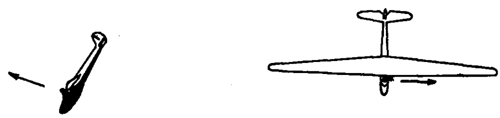
A full examination of a parachute must be very thorough and should be made by a specially trained man, but the soaring pilot should carry out a daily inspection of his parachute and check the red safety thread, locking pins, elastic cords and quick-release box.

THE JUMP FROM THE SAILPLANE

In the case of an accident in the air, the breaking up of the sailplane or collision with another machine, it is most important for the pilot to control his nerves and to keep calm. The sailplane should be abandoned in the shortest possible time, the method of leaving the cockpit depending on the position of the sailplane in the air.

When the sailplane is in a normal gliding position the pilot should release the safety harness and climb overboard, keeping his body close to the fuselage. He should first move his feet to the pilot's seat and then push the upper part of his body overboard head down, an energetic kick by his feet now resting on the side of the cockpit or on the instrument panel will then send him clear of the sailplane.

When in a steep dive the pilot's body will have the tendency to fall down and the weight will be supported by the feet on the rudder bar. The first move in this case is for the feet to be firmly rested on the bulkhead as near the pilot's seat as possible, then the safety harness is released. As the sailplane approaches the ground rapidly these actions should be performed in the quickest possible time. The jump can be made straight from the seat (Fig. 180), or sideways when the



(a) (b)

FIG. 180. THE JUMP CAN BE MADE FROM THE SEAT
(a) Straight forward. (b) Sideways.

pilot should climb overboard trying to rest his hands on the struts bracket or skid, and sending himself clear with a hard kick of the feet. The danger in the latter method is in getting involved with the wing.

When the sailplane is in a spin the pilot should try to abandon it as in the gliding position, but climbing overboard into the direction of the spin—in a left spin over the left side of the cockpit.

When in an inverted spin the jump from the sailplane is quite simple and it is sufficient to move the feet as near the pilot's seat as possible and release the safety harness, when the pilot will be thrown out immediately.

On no account should the rip cord handle be held whilst abandoning the sailplane.

Opening the Parachute

The pilot should wait to open the parachute until he is clear of the sailplane. If it is opened too early there is the danger of the parachute becoming entangled with part of the sailplane, especially when it has broken up in the air.

While leaving the sailplane the pilot should look around and see if there are any parts flying loose such as the rudder or ailerons. If so the opening of the parachute should be delayed if there is sufficient height to permit it. The pilot should not rely on the altimeter reading in such cases as the instrument will not show the correct height due to the high sinking speed. It is better to judge the height by looking at the ground.

A pilot of average weight in a free fall will reach a terminal velocity of about 120 m.p.h.* in a period of 11 seconds after falling 1200 ft. After that time the speed of fall is fairly constant. There is no need to be afraid of a delayed opening of the parachute as there is no danger in it, and it can be prolonged for about 800 ft if necessary.

If there is a possibility of collision with falling parts the speed of fall away from the sailplane and flying parts should be increased. This can be done by moving the knees up close to the body and folding the hands across the chest with the right hand feeling for the handle of the rip cord.

Pilots should be particularly careful with the opening of the parachute when leaving the sailplane in clouds, ahead of a thunderstorm, or strong thermal currents. There have been cases in the past when an early opening of the parachute in clouds prevented a normal descent as the very strong up-currents lifted the parachute and pilot to very great heights where lack of oxygen and low temperatures are liable to prove fatal. It is generally better when possible to delay the opening of the parachute until free of the cloud, as the base of cumulus or cumulo-nimbus cloud is seldom lower than 1000 ft which gives the parachute time to open before reaching the ground.

In a normal free fall the hands should always be kept close to the body with the right hand across the chest holding the handle of the rip cord.

The parachute is opened by pulling the rip cord out of the pocket with a sharp jerk. Immediately after this action the right hand should return to its previous position across the chest. The parachute should open in about 1·5 seconds during a normal free drop.

Control of the Parachute

The motion of the parachute in the air and the path of descent can be controlled by the pilot. Quite often the parachute is caused to swing by air disturbances and this is very unpleasant for the pilot. He should try to make the descent as steady as possible, which will also simplify the landing.

When in a pendulum motion and when the pilot's body swings outwards, the rear rigging lines should be pulled, and when swinging the other way the front rigging lines should be pulled.

During descent the pilot may notice that the path of fall is in line

* These figures depend, of course, on the height from which the fall is made, and therefore the density of the surrounding atmosphere.

with high tension cables, buildings, trees or water. He should try to avoid landing in these areas by sideslipping while at some distance from the ground. It should not be done near the ground as side-slipping always increases the speed of descent and a heavy landing may result.

The sideslip is made by pulling down the rigging lines which are on the side towards which the pilot wishes to move. The pulling of the rigging lines will be followed by the collapse of that part of the canopy, the air pressure will be directed to the opposite side and the parachute with the pilot will sideslip. It should be remembered that a sideslip with the wind takes more time and more height, and the pilot must be careful not to overdo it.

During the descent the pilot must face the direction of drift, as this will enable him to observe his landing place. To turn into the direction of drift the pilot should take hold of the rigging lines above his head in the direction of which he wishes to turn. He should then lift his body and turn sharply into the direction of turn and release the rigging lines which he holds. As the pilot's body drops down the parachute will rotate.

Landing

Landing by means of parachute during a calm day is quite safe and harmless. As the sinking speed is about 20 m.p.h. it is equivalent to a free jump from a height of about 8 ft which every able bodied person can do without harm.

When near the ground both knees should be slightly bent up with the muscles relaxed. Both hands should be placed as high as possible on the suspension straps, holding them tightly. The moment the feet touch the ground the pilot should pull both straps down very hard as this may ease the shock of landing. When on the ground the pilot should let his body follow its natural tendency of direction and motion and keep his arms and hands close to his body, and his feet together. It is always better to fall sideways if possible as it is then much easier to reach the quick release and get free from the parachute and harness.

When landing in a river or lake, or where there is danger of being dragged along rough ground by a strong wind, the pilot's right hand should rest on the quick-release box when nearing the ground, and the moment his feet touch ground or water he should turn the release in a clockwise direction and give it a sharp blow inwards, so releasing himself from the parachute in the shortest possible time.

CHAPTER XIII

INSTRUCTING

At the present time soaring has become so popular that it calls for a detailed study of methods of instructing and the proper preparation of those who have chosen instructing in soaring centres as their career or part-time job. From the teacher in a school or university a very high standard of knowledge of his subject and of the psychology of his pupils is required, and a great deal of time is spent on investigation and experiment as to the correct approach to the pupil, his mental state and his ability to understand and remember the items of the subject he studies. Now soaring is one of the most difficult subjects to study seriously, owing to the large number of various sciences which it is necessary for the qualified soaring pilot to understand. It can therefore be seen that a very detailed study must be made in order to bring the methods of instruction to perfection.

The main difference between soaring and powered flying training is that in soaring the pupil is left alone in the cockpit from the very beginning, and must rely on his own judgment when in the air. This judgment, however, is learned from the instructor who must take full responsibility for the actions and reactions of the pupil, and for his life, during flying training.

During discussions on the abilities of instructors, the two expressions "a good instructor" and "a bad instructor" are often used; but a bad instructor must not be employed in training as this would mean danger to the pupils' lives. Here the line must be carefully but sharply drawn. Only a good instructor can be permitted to instruct in soaring.

The soaring instructor must be a good teacher and psychologist, able to foresee and correct a pupil's future reactions. When the pupil is in the air it is impossible to correct him or even to shout a word of warning, and the instructor must be able to warn him beforehand against any faulty manoeuvre which he may be liable to make. To judge every pupil individually in a group of ten or fifteen requires appreciable skill, and a knowledge of human character. In a group of unknown pupils the instructor will be well advised to study each individual's behaviour, how he speaks, acts, works and studies. Rather than concentrating on remembering their names he should try to build in his mind a picture of their characteristics and positive and negative values in relation to soaring.

The instructor will find that his pupils fall into several type-groups—the good and keen sportsman; the quiet, serious individual; the happy-go-lucky fellow; the nervous and shy type; the intelligent man with great flying abilities. Naturally it is impossible to quote here all the various characteristics of pupils which the instructor will meet in his flying career, and his grouping will depend mainly on his own outlook.

A good instructor is also a good companion. If his talk with pupils is not only confined to soaring but covers many other subjects, this will not only help to break down the barrier which may exist between a man with hundreds of hours flying experience and the very young pilot, but will help the instructor to understand his pupils. Questioning them and noticing their way of expressing themselves in answer may show the instructor the lines which his pupils' minds follow in both technical and non-technical matters. Between the instructor and the pupil there should be fellowship and co-operation, and the pupil should have complete confidence in the judgment of his instructor.

Every action in the cockpit and in the air must be explained to the pupil as clearly and as briefly as possible, and the instructor should avoid long and involved explanations. The aim should be to give the pupil a clear picture of the action to be performed in a given circumstance, so that he will react immediately and not have to think and analyse the situation.

When a pupil makes a flight, every movement of the controls must be watched by the instructor, particularly during initial training, and after the flight any mistake should be explained. However, during the first flights it is rather difficult for some pupils to overcome the excitement and feeling of novelty which they first experience in the air, and care should be taken not to criticize too much. When explaining a faulty manoeuvre it is most necessary to give a sound reason why it happened, and it must be remembered that one mistake while flying can be made by ten different pupils in ten different ways. The instructor should be very careful to give the correct explanation. It is entirely wrong to correct a mistake in the same way to every pupil. As they will all take the correction in a different way they must be treated individually. Some pupils do not trouble about their faults and they need very watchful attention. Others are shy and lack confidence, and they should be treated more gently and encouraged to overcome their diffidence.

The instructor makes a pilot of the pupil. He is his constant guardian at the soaring centre and whatever he teaches will probably become a lifelong habit. Apart from teaching the pupil how to fly the instructor can also help him to develop his character. Soaring pilots form a world-wide brotherhood, and friendship and the willingness to help each other are the main factors which keep this brotherhood together. When a pupil once becomes a member of it and feels the atmosphere and spirit within it, he will never leave it. But here again it is up to the instructor to guide the pupil towards an appreciation of these qualities.

Some people join soaring clubs and become pilots with the wrong ideas. A seagull badge in the buttonhole attracts some of them, or the prestige of being called a pilot. It is for the instructor to show them the value of motorless flight and the adventure of soaring in the air, experiences which not every man is permitted to enjoy. The field of instruction has a much wider scope than the correction of pupils' faults during initial training, and it is to be hoped that those who have chosen to build the future soaring generation will realize and fulfil the unique opportunity which is theirs.

INDEX