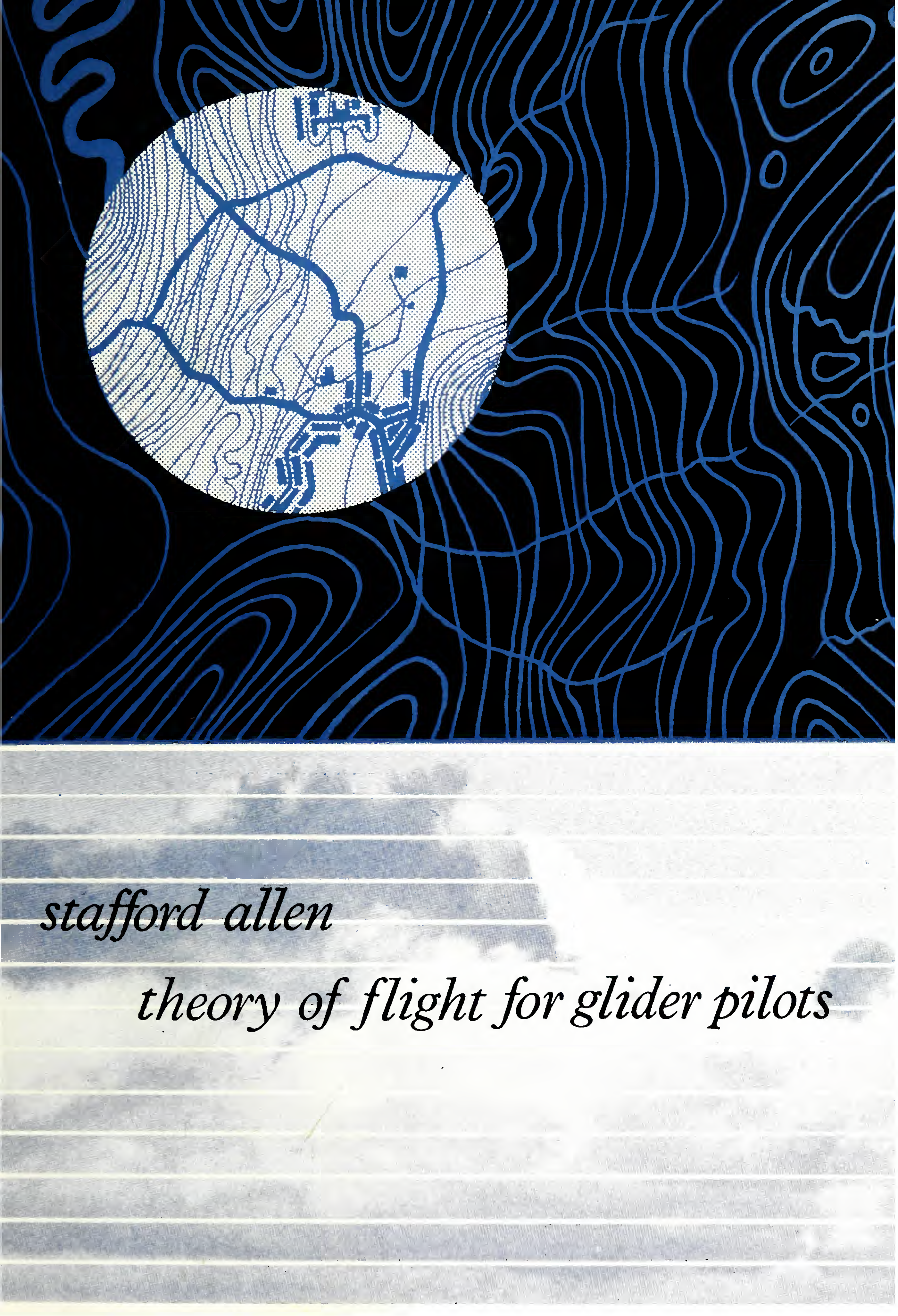


stafford allen

theory of flight for glider pilots

While there are several excellent books dealing with the theory of flight from the standpoint of aeroplanes, there is a need for a simple account of the subject explained on the basis of non-powered flight. Much that is of minor importance when dealing with aeroplanes is of vital significance when dealing with sailplanes and a great deal of aeroplane theory is totally irrelevant when applied to gliding.

Stafford Allen is well known in the world of gliding as an instructor, as a successful competitor in the British National Competitions and as Manager of the London Gliding Club. He has drawn upon his great experience to produce a book which simply and concisely enables the student glider pilot to acquire the necessary theoretical knowledge to support his practical training. The book has been written in a fairly light vein and the arithmetic and formulae have been kept to an irreducible minimum.

Jacket design by John Laing

NET PRICE 12s 6d

R. C. STAFFORD ALLEN

Theory of Flight for Glider Pilots

OLIVER AND BOYD
EDINBURGH AND LONDON

OLIVER AND BOYD LTD
Tweeddale Court
Edinburgh 1

39a Welbeck Street
London W1

First Published 1962

PRINTED IN GREAT BRITAIN BY
OLIVER AND BOYD LTD, EDINBURGH

INTRODUCTION

Nobody can learn to fly by reading a book, but it is equally true that nobody can become a really proficient pilot unless he imbibes a certain amount of the " how and why " of flight. He may read the subject up, attend lectures on Theory of Flight, or he may pick up the knowledge over the years in conversation with other pilots. This last method suffers from the disadvantage that it is slow, and the seeker after truth is liable to pick up many ideas which may be quite erroneous.

There are several excellent books on Theory of Flight but they all deal with the subject from the standpoint of aeroplanes, and merely mention gliders and sailplanes, if they mention them at all, as interesting oddities. Now, while the principles of flight remain unaltered, the emphasis is very often on a very different aspect. Much that is of minor importance, when dealing with aeroplanes, is of vital significance when dealing with sailplanes, and, of course, a great deal of aeroplane theory is totally irrelevant when applied to gliding. In consequence you will find nothing new in this book, but much that is presented in rather a different way.

It is my hope that this little book may enable the student glider pilot to acquire the necessary knowledge in the easiest and quickest way. I have avoided the use of formulae as far as is humanly possible, and the arithmetic has been kept to the irreducible minimum. I have also endeavoured to avoid trespassing on the sacred preserves of the gliding instructor. He is the man who will make, or mar, the pupil pilot and no amount of book reading can replace his teaching and example. This book, then, is intended to take some of the burden from the instructor's shoulders, and particularly, to save him the thankless task of eradicating some of the extraordinary ideas that some pupils manage to acquire.

It is very easy to read a book and to miss, or forget, many of the most important points. For those interested, a number of questions on each chapter will be found at the end of the book. Hopefully, these may supply the fuel for some thought and argument.

Finally I would like to express my thanks to my wife, to Professor G. C. Varley, to Lorne and Ann Welch for their helpful suggestions and criticism, to Elizabeth Hargrave for her humorous drawings, and to all the other many friends who have helped this book along in so many ways.

CONTENTS

"TAKE UP SLACK"

Chapter 1

THE AIR WE FLY IN

The Hall Barometer

The would-be motorist, before he ever takes the wheel of a car, has probably seen a road. He has therefore some idea, however rudimentary, of the elements of motoring and how a car is managed.

The glider pilot, at the beginning of his flying instruction, will undoubtedly see gliders flying through the air, but the very fact that this air is invisible makes the whole business of flight rather mysterious and magical. If only we could make this air visible; show him the smooth flow around the wings and tailplanes of the gliders flying overhead; the little eddies from every irregularity on the machines' smooth skins, then the understanding of the principles of flight would be a much simpler problem. Unfortunately, we cannot, except occasionally in a wind tunnel for special experiments, make the air visible to the student, but we can help him to visualise in his mind exactly what is happening to the air, and his glider in flight.

First, however, we must understand one or two basic facts about air in general. Air is a gas (a mixture of gases in actual fact) and in consequence has all the properties of a gas. Air has weight, a fact which surprises some people, but it is nevertheless true. At sea level in average conditions air weighs about 0·077 lb. per cubic foot, and we speak of this as the density of the air at sea level. One pound of air thus occupies about 12 cubic feet. Because of this weight, the great blanket of air surrounding this earth of ours exerts a pressure on the surface of the earth. Since air is a fluid, this pressure is transmitted in all directions and we do not feel any effect of it on our bodies. This pressure is quite considerable, however, and at sea level it is usually about 15 lb. per square inch. It is the pressure which is indicated by the barometer which probably hangs in your hall, although your barometer will almost certainly tell you the pressure in Inches of Mercury, or even Millibars, instead of pounds per square inch.

As we rise through the atmosphere, there is less air pressing down on us from above, and as we should expect, the barometric pressure of the air becomes less. At 10,000 feet it is only about 10 lb. per square inch and at 20,000 feet it has fallen to below 7 lb. per square inch. If you habitually fly a glider to greater heights than this you need read no further! This fall of pressure with increasing height gives us a very ready means of measuring our height, and in fact the altimeter fitted in most gliders is really a little barometer which reads in hundreds, or thousands, of feet instead of inches of mercury, or pounds per square inch. As we shall see later on, the altimeter must be intelligently used, as under certain circumstances it can give a very false impression.

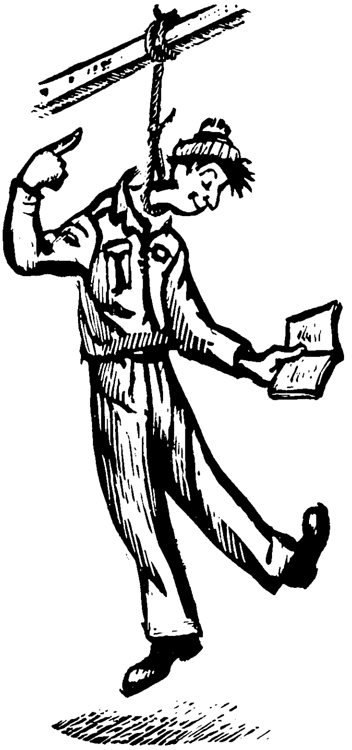
Like all gases, air is compressible. This does not affect us at all at the speeds at which our gliders fly, and we can forget about it, except for one aspect. This is that the density of the air becomes less as the pressure becomes less—or what amounts to the same thing—the higher we go. For instance, at 10,000 feet the density is about 0·056 lb. per cubic foot while at 20,000 it is only about 0·04 lb. per cubic foot. Water and most other liquids are nearly incompressible, unlike gases, so that a cubic foot of water at the bottom of the sea will weigh almost exactly the same as a cubic foot at the surface despite the fact that the pressure at the bottom may be several *tons* per square inch.

This business of density does give some trouble to quite a few people so perhaps a crude analogy may help here. Imagine two columns of bricks, each brick 1 ft. × 1 ft. × 1 ft. and each brick weighing 1 lb. Each column is 100 bricks high. The first column is made of solid, rigid, incompressible bricks while the second column is made of soft spongy rubber bricks, though the solid and soft bricks all weigh 1 lb. each. In the solid-brick column the top brick and the bottom brick weigh the same, 1 lb., and occupy the same volume, 1 cubic foot, so that their densities are each 1 lb. per cubic foot although the pressure on the top brick is nothing (neglecting barometric pressure) and the pressure on the bottom brick is 99 bricks or 99 lb. on 1 square foot. This corresponds to the case of water. In the soft-brick column, however, the lower bricks will be squashed, and the bottom one squashed most of all. Imagine it to be squashed to half its original height, i.e. from 1 ft. high to $\frac{1}{2}$ ft. high. Its volume is now $1 \times 1 \times \frac{1}{2} = \frac{1}{2}$ cubic foot though its weight is still 1 lb. so its density is 2 lb. per cubic foot. The pressure on it is 99 lb. per square foot exactly as in the other column. The top soft brick is unsquashed so its volume is unaltered and its density is 1 lb. per cubic foot. Thus the density of the soft, compressible bricks becomes greater, the lower down the column we go and less the higher we go. This corresponds to the case of air.

Air also possesses a quality known as viscosity, or stickiness, and has a tendency to cling to anything that moves through it. Most people discover in their early youth that treacle, glue, and jam are very sticky, viscous fluids, and it may come as a bit of a shock to realise that air possesses the same quality. The viscosity of air is, of course, infinitely smaller than that of treacle; in fact it is so small that in ordinary life we do not notice it at all, but at the speed of flight of our gliders it becomes appreciable. All fluids, gases as well as liquids, have some viscosity, however small, and it is actually true to say that if air had no viscosity at all, gliding as we know it would be impossible.

Lastly, as we rise through the atmosphere, the temperature of the air becomes less. The rate at which the temperature falls with increasing height varies somewhat from day to day, and may sometimes be reversed for some distance. We then have a temperature inversion. This matter of temperature of the air is, from our standpoint of theory of flight, comparatively unimportant, but it is vitally important when considering the technique of thermal and cloud flying. This latter is, however, outside the scope of this book, so we will leave the matter here.

Having outlined some of the more important properties of our new element, the air, we can now move on to discuss the movement of bodies in it. Here we run up against our first snag. Many people who learn to glide have a sound knowledge of Mechanics, and the Laws of Motion, and those people may skip the next chapter with an easy mind. For the benefit of those who have not this advantage, we had better probe these laws so far as they affect us.



" —*a string if the body is hanging up.*"

Chapter 2

THE LAWS OF MOTION

Sir Isaac Newton has gone down in history as the man who, when an apple fell on his head, invented gravity. Besides this, however, he studied many things, and amongst them he did a great deal of research on the behaviour of bodies at rest and in motion. He finally enunciated three Laws of Motion, and, these being Natural Laws and not subject to repeal by Parliament, they are as true today as when he first thought of them. Being a very eminent scientist, he of course, framed these Laws in very flowery language. We will try to examine them in more commonplace terms. Here they are:—

Law 1. A body stays at rest, or continues to move at a steady speed in a straight line, unless an unbalanced force acts upon it to make it change that state.

Law 2. The acceleration of a body is directly proportional to the force applied.

Law 3. To every action, there is an equal and opposite reaction.

Now let us examine the effects of these Laws. Law 1, to most people appears to be plain common sense and yet it is not quite so simple as all that. The states of " rest " or

" steady motion in a straight line " are states of " equilibrium " and in this state all the forces acting on a body are exactly balanced. There clearly must be some forces acting on any object since we cannot have a body without weight, and its weight is a force which acts always directly towards the centre of the earth. Therefore, for a body to remain at rest there must be an upward force upon it equal to its weight. This force may be supplied by the ground, a table, a string if the body is hanging up, or a chair in your case as you sit reading these words. This force must be supplied otherwise the weight of the body is unopposed and it will accelerate towards the earth, or in common terms, it will fall. So far so good. Nothing very incomprehensible about that, you may say. But here comes the second part which often causes a lot of difficulty. A body travelling at a " steady speed in a straight line " is also in equilibrium and all the forces on it are exactly balanced. Note particularly that the speed must be steady, or constant, and the motion must be in a straight line. This means that if a train is running along a straight track at 80 miles an hour the pull of the engine exactly balances the total resistance, friction, wind drag, etc. Similarly, a ball rolling on a level frictionless surface, and with no air resistance, would roll on for ever, once it was set in motion.

This is often rather a mouthful for the uninitiated to swallow; and it may take an hour or more of argument to convince a person of its truth. Yet, looked at this way, it becomes sense. An unbalanced force must be applied to a body to cause it to accelerate. Our train will not move until the engine's pull exceeds the friction of the whole train as it stands in the station. As long as that pull exceeds the resistances of the train, the whole train will go on accelerating. However, as soon as these two forces balance, the train will cease to accelerate and its speed will become steady, and, furthermore, it will continue at this steady speed indefinitely so long as those forces balance. As soon as the pull becomes less than the resistance of the train, the train will decelerate until either the forces balance once more, or the train stops. Why then can't we accelerate a train to an infinitely high speed? The answer is very simple.

The faster we go, the greater becomes the resistance of the train until we reach a point where the resistance is equal to the maximum pull of the engine. We have then reached the top speed of the train and the forces are balanced.

In the case of the ball rolling on a level frictionless surface and with no air resistance, there is no resistance at all to balance so no pull is required. The ball's weight is balanced by the pressure of the surface so all forces are balanced and the ball will remain rolling for ever if once started, or if we stop it by applying a force with a finger, it will remain stopped. Of course, such a state of affairs cannot exist, as we cannot get rid of air resistance entirely on this earth, nor can we completely eliminate all friction. In practice, therefore, once the ball is started rolling these resistances act upon it, and, since they are unbalanced, they cause it to decelerate until it stops. Thus we can now see that an unbalanced force is required to make a body alter its speed.

There is more to it than this, however. If the direction of motion of a body changes, a force is required to make it change direction, even though the speed of the body is unaltered. This is where the " in a straight line " bit of Law I comes in. Drive a car at 40 m.p.h. round a sharp bend. The friction of the tyres on the road supplies a force inwards toward the centre of the turn to change the direction of the car. If this force is large, the passengers may find that the outside doors of the car are pressing them inwards towards the centre of the turn. The passengers may regard themselves as being " slung out " against the doors, but this is because they are looking at things from the standpoint of the car, and not getting the view of an observer beside the road. If you cannot believe that it is the friction of the tyres which supplies this inwards force, try the same manoeuvre on ice! The friction there is very much less and the car probably will not turn the bend. But, you may say, this friction force is not balanced. Exactly; it *is not* balanced and is therefore producing an acceleration towards the centre of the turn, an acceleration which we call the Centripetal Acceleration. The car is *not* in equilibrium but is in accelerated motion. Thus we see that a change of *direction* of motion is just as much an acceleration as a change of speed, and requires an unbalanced force to produce it in just the same way.

Law 1 is the most important of the three, and is the one which usually causes the most difficulty and argument, but it is vital that it should be understood, as upon it hang most of the secrets of flight.

Law 2 is almost a corollary of Law 1. The acceleration of a body is proportional to the force applied, and this is exactly what we should expect. A powerful engine in a car can produce a large propelling force, and we get a good acceleration. Similarly in a really tight turn in a glider we receive a large force in the seat of our pants producing a rapid change in direction, which we now understand is an acceleration. In this book we are not concerned with mathematics so we will not attempt to investigate further.

Law 3 states that to every action there is an equal and opposite reaction. Again, this is common sense. One cannot push a car without something to push against, even if it is only the friction of one's feet on the ground. The pressure on one's hand is clearly the same as the pressure on the car. At any point where a force acts on a body it can be seen that there is an equal and opposite reaction on whatever is supplying the force. So in a tight turn in a glider, the machine is supplying a large force to the seat of our pants to produce a change of direction in our bodies but equally, the seat of our pants is producing an equal and opposite reaction on the glider's seat. It is this reaction which leads some people to talk of being " pressed down " in their seats when in reality they are being " pushed up " from below.

When talking about forces on a body, we must be careful to consider all forces. Some may balance others or partly balance them, and if all forces balance exactly we have " equilibrium " (rest, or steady motion in a straight line) from Law 1. If all forces do not balance, then it is the net unbalanced force which remains which is producing acceleration.

Chapter 3

DRAG, LIFT, AND AEROFOILS

It does not require much intelligence to see that if we move any object through the air, there is going to be some air resistance acting on the object in the opposite direction to its motion. This resistance we call Drag. Also if we are going to make a glider fly along at a steady speed in a straight line (equilibrium) we must arrange matters so that there are forces on the glider which will oppose, and exactly balance, this force of Drag, and also the Weight of the glider. Now the Weight of the glider is much larger than its Drag, some 15 to 20 times as large or even more, so that it is now clear that what we require to support the machine in the air is something which will produce a large force to balance the weight of the glider while having a small penalty in the way of Drag. This something is the Wing, and it is far and away the most important bit of the glider. The earlier experimenters in the dim, dark ages of flight originally imagined that flat plates drawn through the air at a small angle, would serve as wings. They were quite right, but they soon discovered that they could make much better and more efficient wings by shaping the surfaces into curves instead of making them flat. These curved surfaces produced a much larger lifting effect for a much smaller drag. These curved surfaces are called Aerofoils.

Now let us consider wings in the abstract, and not as bits of gliders. In Fig. 1 the shaded object is an aerofoil which is just another name for the shape of a wing when cut through fore and aft. The line *AB* represents the Chord Line which is merely the line made by a straight edge placed against the

Aerofoil. The dotted line arrow shows the direction in which the air is approaching our aerofoil and the angle between this arrow and the Chord *AB* is called α, the Angle of Attack. This is important, and please note right from the start that this angle has *nothing whatever* to do with the horizontal, vertical, or any other direction. It is purely and simply the angle at which the air is hitting the Chord Line, or what is the same thing, the angle at which the Chord Line is hitting the air. Now the effect of the air hitting our aerofoil is to produce a force on it which we call the Resultant Force in some direction such as is represented by the arrow *R*. Since we do not know the exact direction of *R*, it is much more convenient to split it up into two forces, one parallel to, and one perpendicular to the *direction of the airflow* (our dotted arrow). The first force we call Drag, and is indicated by the arrow *D*, while the second force we call Lift and is shown by the arrow *L*. We can now forget about *R*, and deal with his two components *L* and *D*.

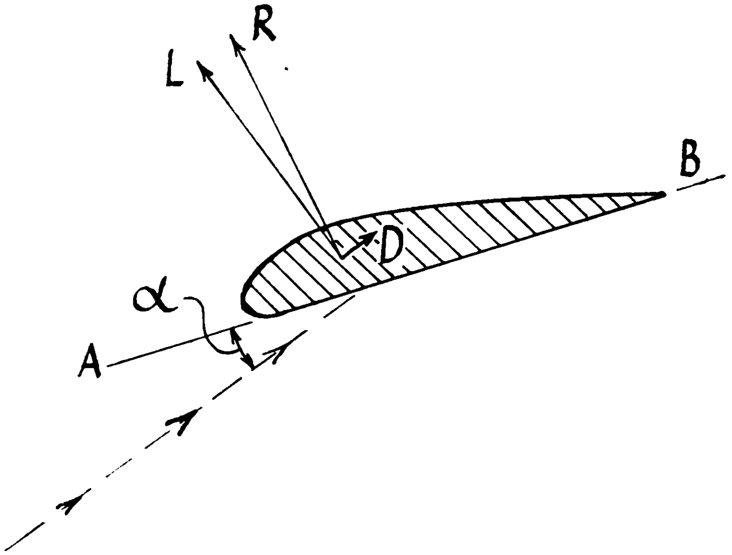


FIGURE I

The above definitions are so important that they are repeated here: Lift is the force at right angles to the airflow. Drag is the force parallel to the airflow. The Angle of Attack is the angle between the Chord Line and the airflow.

It will be noticed that Fig. 1 has been deliberately drawn on the slant to avoid any confusion with the horizontal or vertical.

There are, of course, many different shapes of aerofoil, or aerofoil sections, to give them their proper name and the characteristics of many hundreds of them have been very carefully investigated. Some are very thick and have a large amount of curve, or camber. These are usually the types giving very large lift, but they also have rather large drags which makes them somewhat inefficient at high speeds, though excellent at the lower speeds. Others, are much flatter and may even have convex under surfaces. These are the low drag sections, and while they suffer somewhat in lift they give a machine a good speed range, since it can fly fast without incurring a large increase in drag.

We cannot do anything about the aerofoil sections of our gliders. They were decided upon and built into the machines by the designers. It is interesting, however, to have a look round the hangar at any Gliding Club and to note the aerofoil sections of the machines and to try to visualise the thoughts in the designers' minds when they decided upon these sections. The trainers have good, all-round sections. Fairly thick, fair amount of camber, giving a reasonable performance and viceless flying. The strutted sailplanes, G.B., T.21, and suchlike machines, have thicker sections, more camber and tapered wings. Here the designer is after maximum lift and good soaring qualities, though these qualities will only be present over a reasonably small speed range. Above this speed range the drag will become excessive and the gliding angle will suffer. The higher performance sailplanes have thick sections, too, but this is partly due to the necessity of putting a heavy spar in the wing as these machines usually have no struts. The aerofoil sections however, have very little camber, flat or nearly flat, under surfaces, giving low drag at high speed, at the price of sacrificing some lift at low speed. These are the machines which can fly fast nearly as efficiently as they can fly slowly. They have a big speed range. In the last few years a new type of aerofoil section has invaded the gliding world, and it is now almost universal in the highest performance machines. This type is the so-called Laminar Flow section. There are, of course, many varieties of Laminar Flow section, but they are all characterised by having the thickest point of the wing considerably further aft than usual. The effect of this is to produce an aerofoil that has an exceptionally low drag when flying at small angles of attack. The reason for this is worth investigating.

When air flows over any surface it can do so in one of two ways. First, the flow may be laminar, that is, each layer of air may slide smoothly over the layer below so that the air actually in contact with the surface will be at rest. Viscosity causes the air to stick to the surface. Second, the flow may be turbulent. In this case viscosity again causes the air to stick to the surface and be dragged along with it but successive layers of air above this do not flow smoothly over each other, but tend to form a sheet of rolling eddies, or vortices, that flow along the surface. A short distance from the surface the flow is smooth again and this sheet of eddies is, if you like, sandwiched between the main flow and the surface. The Aerodynamicist calls it the Boundary Layer. If the flow in the Boundary Layer is turbulent much energy is wasted in creating the eddies, and this causes extra drag.

Air will usually flow in a laminar manner over a wing up to the thickest point, but there it tends to become turbulent in the boundary layer. Hence the reason for the thickest point of the laminar flow wing being so far aft. You will notice too that the curves of the wing section of the laminar flow wings are very gentle and smooth. Both these points tend to keep the flow laminar over a much greater proportion of the wing. Typical examples of machines using laminar flow sections are the Skylarks, Eagles, and the Olympia 419 and 460.

You never get something for nothing in this world, and of course these laminar flow section have their snags. The biggest snag is that anything that spoils the shape of the section has a very bad effect on its performance. Rain on the wings is enough to spoil the efficiency to a very marked degree, and ice will reduce the performance of a high efficiency sailplane to that of a third-rate trainer.

Imagine that Fig. 1 represents a little model of an aerofoil section fitted up in a wind tunnel. What we want to know is how the forces of lift (*L*) and drag (*D*) vary in different circumstances, and what are the factors which affect them. Firstly, they are both affected by the density of the air. The greater the density, the greater become both *L* and *D*. This seems quite natural and obvious. We can do nothing about the density of the air, so we may forget about it for the time being, merely noting that if we try a winch launch from the top of Mount Everest we shall probably find that our sailplane seems somewhat short of lift!

Secondly, we find that both *L* and *D* are affected by the speed of the airflow. If everything else is kept constant and the speed of the air is varied, we find that the lift and drag vary almost exactly as the square of the speed, i.e. double the speed and *L* and *D* both become four times as great.

Thirdly, both *L* and *D* become greater as the area of our model increases. However, in a glider the area of the wing is fixed. We can do nothing about this, and it is a matter which concerns the designer of the machine rather than the pilot.

Fourthly, and most important, both *L* and *D* are affected by the angle of attack, though not in precisely the same way. Take lift first. Fig. 2 (yes, I know its a graph, but don't be frightened of it) shows what happens to *L* if we vary the angle of attack keeping everything else constant. Rather surprisingly we see that there is some lift when the angle of attack is 0°. This is due to the fact that our aerofoil is cambered slightly, and the actual centre line of the section, curved though it may be, is at some small, but positive angle of attack. If our section were symmetrical top and bottom, there would be no lift at $\alpha = 0$. Sections like this are sometimes used for tailplanes. Next notice that, as α increases, so does *L*, and almost in direct proportion. This state of affairs does not last for ever, though, and there comes a point, usually when α is about 15°, where *L* no longer increases, and any further increase in α results in

LESS lift. This point is the Stall of the aerofoil and the angle at which it occurs is called the Stalling angle. Funnily enough, all aerofoils stall at more or less the same angle and if we assume that it takes place at 15° to 16° we shall not be far wrong whatever aerofoil section we may be playing with. This phenomenon of the Stall is very important and we will investigate it more thoroughly later. Meanwhile, let us see what happens to *D* when we vary the angle of attack keeping everything else constant. Fig. 3 shows that *D* behaves rather as we should expect. It is least when α is about 0 or, with some aerofoils, perhaps 2° and as we increase α, so does *D* increase, but rather more rapidly. When we reach the stall, *D* begins to increase more rapidly still.

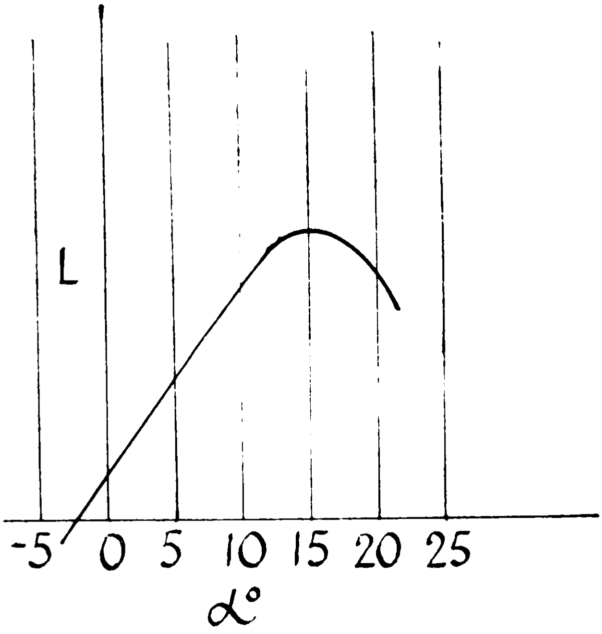


FIGURE 2

Now for this business of the Stall. It helps considerably if we understand exactly what happens to the air when an aerofoil stalls. The behaviour of *L* then becomes more rational. Fig. 4 is a sketch of an aerofoil flying at a small angle of attack, i.e. unstalled. The air flows smoothly under and over it and a region of high pressure is formed underneath it, while above it there is a region of low pressure. You can look at it if you like in the following way. The air below is caused to change its direction downwards by the under surface of the aerofoil. This change of direction requires a force, and the reaction of the air on the aerofoil supplies some of the lift. On the top surface, things are a little more complicated. Here the air has to flow over quite a sharp hump and again to make the air turn, or change direction, a force is required. This force is supplied by the fact that there is a reduction of pressure on the top surface of the aerofoil compared with the atmospheric, or static, pressure. This reduction of pressure (or " suction " if you like) is actually more important than the

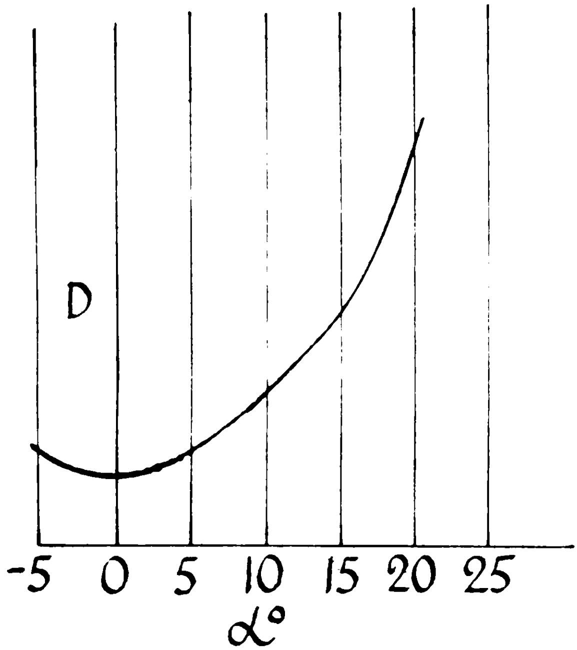


FIGURE 3

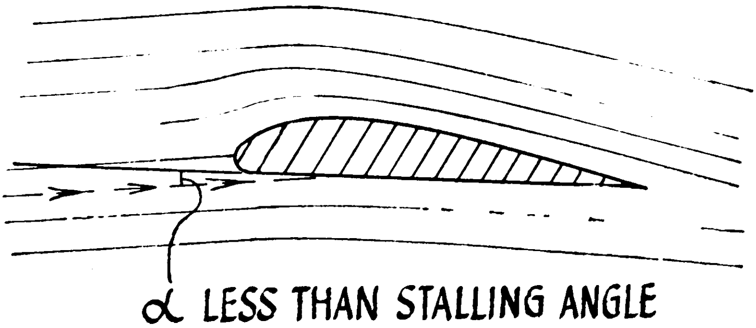


FIGURE 4

increase of pressure below the aerofoil, and in normal conditions contributes much the greater part of the lift. In Fig. 5 the aerofoil is flying at an angle of attack greater than the stalling angle. It is Stalled. Notice that the under surface is still more or less doing its job, but the air can no longer flow " around the corner " over the top surface and it breaks away in a series of eddies. The top surface is no longer working and the lift decreases sharply. The wild, turbulent, mass of eddies also create a considerable increase in drag.

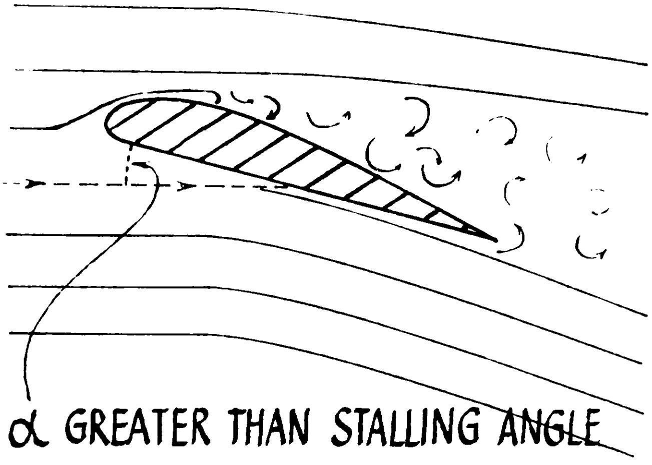


FIGURE 5

The above is a horrible over-simplification of the state of affairs but it is a perfectly sound way of looking at it.

There is one more rather important thing to consider about these forces of lift and drag. This is the point on the aerofoil where they act. We call this point the Centre of Pressure. If we were to make a test to find out where this Centre of Pressure lies, we should find that it moves about as the angle of attack alters. At the ordinary angles of attack it is in the region of one-third of the way back from the leading edge, or nose of the aerofoil. At smaller angles it is further back, perhaps half way back at 0°. As we increase the angle of attack the Centre of Pressure moves forward until, at, or just before, the stall it begins to move back again. This movement of the Centre of Pressure, or *C.P.* is rather a nuisance as we shall see later when discussing stability and control. Lots of attempts have been made to design aerofoils with stationary *C.P.*'s with more or less success. Unfortunately, what you gain on the roundabouts you lose on the swings, and all these attempts result in penalties in the way of more drag or less lift. In our gliders we want efficiency in flight, and these penalties are too great to pay. We therefore accept the nuisance of a moving *C.P.* and deal with it by fitting a tailplane to control its errant ways. Of this, more later.

Chapter 4

THE WING IN THE GLIDER

Steady Flight (Equilibrium). Now let us turn our attention to a complete glider. Your flying instructor will have demonstrated to you the three main controls of the glider and how they are operated, so we need not go into great detail here, but there are one or two terms that we shall use which need a little explanation.

The Rudder controls the machine in *Yaw.* Press the right foot, nose Yaws or slews to the right and *vice versa.* The plane in which this occurs is called the *Yawing Plane.* Similarly the Ailerons control the machine in *Roll.* Stick right, machine Rolls to the right, and the plane in which this occurs is called the *Rolling Plane* (nothing to do with Wild West films!). Also the Elevators control the machine in *Pitch.* Stick forward, machine *Pitches,* nose down, etc. This plane is the *Pitching Plane.*

A glider *Yaws* about its *Normal Axis.* It *Rolls* about its *Longitudinal Axis* and it *Pitches* about its *Lateral Axis.* These *Axes* may be regarded as three imaginary lines, all at right angles to one another, which pass through the *Centre of Gravity* of our glider, and this *Centre of Gravity* may be taken as the point somewhere inside the glider, where it would balance if supported on a pin point. We are speaking, of course, of a fully loaded glider complete with pilot.

Take first the ideal state of affairs. Fig. 6 shows a glider flying at its best gliding angle. The weight *W* is acting vertically downwards, through the Centre of Gravity, the lift *L* is acting at right angles to the airflow, or path of flight, and the drag *D* is acting parallel to the path of flight. Note, please, that since in a glider we cannot maintain steady flight indefinitely with the path of flight horizontal, this path must slope downwards. The minimum slope we call the *Best Gliding Angle.* This means that the lift is not vertically upwards nor is the drag horizontal. The glider is flying at a steady speed in a straight line so all the forces on it must exactly balance, and balance in every direction. There must be no unbalanced force in any direction. This leads us to the odd discovery that the lift is very slightly less than the weight because the drag is acting slightly upward. In practice this is so small a difference that we can neglect it and assume that Lift = Weight, but we must reconsider this assumption when we are dealing with states of flight other than best gliding angle.

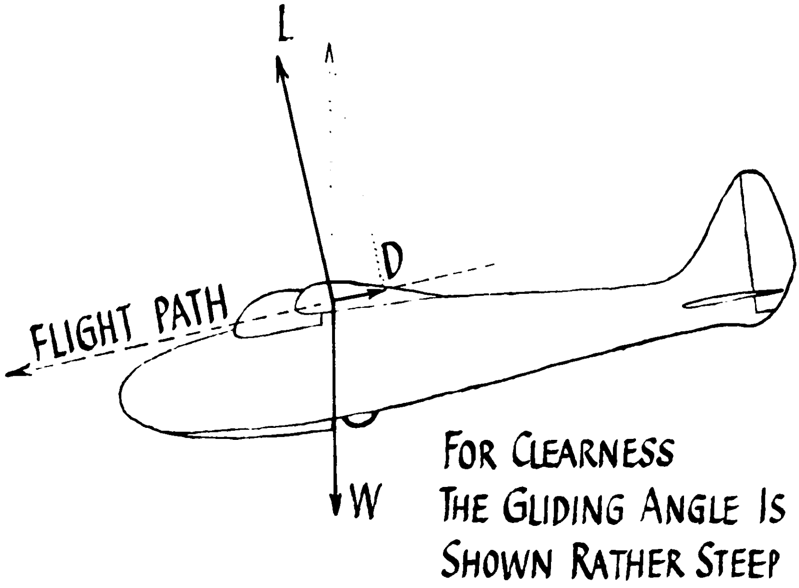


FIGURE 6

There is one other condition that must be satisfied if the glider is to remain in equilibrium. This is that all the forces acting together, must not produce a turning Moment or twisting effect tending to raise or lower the nose. In Fig. 6 the forces have been carefully drawn so that they all meet at one point and so have no turning moment. This is cheating, and is why we have called this the ideal state of affairs. Had the lift been acting in front of the weight, the glider would have tended to bring its nose up and *vice versa.* This ideal state of affairs very rarely obtains in practice, and if it does not obtain, then we have to arrange for a balancing force, up or down, to be provided by the elevators and tailplane. It does pay to try to get as near the ideal as possible though, because the provision of a tail balancing force does involve some extra drag, and drag is the one thing we want to avoid. Since, however, the *Centre of Gravity* of the glider will vary with different pilots, and the *Centre of Pressure,* the spot where the lift acts also moves about, it becomes clear that it is not easy to ensure that the ideal state of affairs does exist. From a practical point of view it is preferable that the lift shall be slightly behind the weight, as a glider with a nose-down tendency is much safer than one which tries to climb and stall if given a chance.

It now appears that, in ordinary straight flight, what we want from the wing is a lift approximately equal to the weight of the glider. In the last Chapter we saw and investigated the things which affect the lift of a wing. The only two things over which we have any control are the speed and the angle of attack. *But the lift we want in ordinary straight flight is constant.* Therefore, if, say, the speed increases and the lift tends to increase then the angle of attack must be decreased to keep the lift constant. Similarly, if we decrease the speed the angle of attack must be increased. The pilot in the glider very often may know nothing about angles of attack. He merely sets the nose of the machine in the correct attitude with his elevators to give him the speed he desires. He is, however, actually selecting an angle of attack with his elevators. The glider then settles down to the speed appropriate to that angle of attack. We saw earlier on that an aerofoil section always stalls at one particular angle of attack. Now since there is one speed for every angle of attack in straight and steady flight there is one speed at which the angle of attack has reached the stalling angle. This is called the *Stalling Speed* and it is the slowest speed at which our glider can fly. Slower than this the wing is unable to produce enough lift to balance the weight, and the glider will begin to drop. Notice that if the weight becomes less, by installing a lighter pilot for instance, then the stalling angle will be reached at a slower speed than before, and the Stalling Speed is slower. With a heavier pilot the Stalling Speed is higher. This change of weight is not very large in most gliders, though it may become appreciable in the case of two-seaters which may be flown dual or solo, and we tend to regard the Stalling Speed of a particular glider as a fixed speed. It depends on the type of glider, of course, as the designer may have decided on a huge wing area in proportion to the all up weight, or, as we sometimes put it, a low wing-loading. In this case owing to the large wing we shall reach the stalling angle at a very low speed, because we saw earlier on that lift also depends on the wing area. If we have a small wing and high wing loading we get a higher stalling speed for the same reason. It is worth while noticing here that with a heavily loaded bomber aeroplane, its stalling speed on take off may be very different from its stalling speed when landing, after dropping a few tons of bombs and burning up all its fuel. The important point to remember is that the aerofoil, or wing, will stall when the angle of attack exceeds the stalling angle, usually about 15°, and note again that this angle has nothing to do with up, down, horizontal or vertical. For a given glider this angle is reached in steady straight flight at the ordinary Stalling Speed.

Accelerated Flight

Do not be alarmed at this title. We have been considering, so far, a glider in steady straight flight. A glider in " equilibrium ", in fact. Accelerated Flight merely means flight in which the speed, or the direction of flight, or both, are changing. Just that. It includes all such states of flight as turns, dives, zooms, and most aerobatics. We will leave aerobatics alone for the moment, but when you start trying to circle in thermals you will realise that you spend a good deal of your airborne life in accelerated flight.

Perhaps the state of flight in which speed is changing is the simplest so let us deal with that first. Many uninitiated folk look at a glider in the air and exclaim " But what makes it go? " They fail to see that the glider is nothing more than an aerial toboggan and most people can see what makes a toboggan go. (If you can't I suggest you take a course in tobogganing rather than aviation.) It is really the fault of the designers in making our aircraft so incredibly efficient, that it becomes almost impossible to see that they are really flying slightly " downhill ".

Look again at Fig. 6 and imagine that the pilot of the glider depresses the nose of his machine very slightly. The effect of this is to rotate the forces *L* and *D* very slightly anticlockwise. *W* is unaltered so that the net result is that there is a small unbalanced force in some direction roughly along the flight path. From the laws of motion this force produces an acceleration and the machine picks up speed. It will go on picking up speed until the forces balance again and this happens when the drag increases sufficiently. The machine is then in equilibrium again flying at a higher speed and steeper gliding angle. Exactly the reverse takes place if the nose is raised slightly. In these changes a very small change takes place in the value of *L* since the vertical component of both *L* and *D* must balance *W*, and also a small change takes place in the angle of attack due to the change in speed.

We have no engines in our aircraft so the changes in speed are in general not very large, except during aerobatics, and they take place fairly slowly. Changes in direction are another story altogether.

If a glider is diving at a fairly high speed and pulls out of the dive into level flight, quite clearly there has been a change of direction of flight. From what we have learned about the laws of motion, an unbalanced force is required in the direction towards the centre of the curve that the glider is describing. The only way we can obtain this force is by increasing the lift of the wing. All the pilot does is to pull back on the stick and raise the nose of the glider. This has the effect of increasing the angle of attack and immediately the lift becomes much greater. The lift is now doing two things. It is still opposing and balancing the weight of the glider though the drag may be assisting it in this, but at the same time the lift is supplying the force towards the centre of the curve of the glider's path. The lift in this state of flight is much greater than the weight of the glider. How much greater depends, upon the speed of the glider and how sharp is the pull-out. Gliders can usually stand much more loading in this state than their pilots can, and as a rough guide, most pilots will " black-out " when the lift becomes more than 4 to 5 times the weight of the glider. Notice that, although the speed of the glider is high, the angle of attack is fairly large as we are demanding a large amount of lift from the wing. If too much lift is demanded from the wing, the angle of attack may even reach the stalling angle and the wing will stall. This is the explanation of the oft repeated warning of your flying instructor that " the stalling speed goes up in a turn or pull-out ".

An example may help here. Take a glider which stalls in normal flight at 30 m.p.h. At 60 m.p.h., if the angle of attack be increased to the stalling angle, the lift will be $\left(\frac{60}{30}\right)^2$ i.e. 2^2, or 4 times what it was when stalling at 30 m.p.h. because the lift varies as the square of the speed.

A glider flying round a steady turn is in a somewhat different state. As before, it requires a force directed inwards towards the centre of the circle round which it is flying, but in this case the circle is horizontal, whereas in the case of the pull-out the circle was vertical. If you drive a car round a curve, this inwards force is supplied by the friction of the tyres on the road. Even in the case of a boat, the inward force can be supplied by the water pressure on the side surfaces of the boat, because the boat is cunningly designed to offer the smallest resistance to being pushed forwards but a very large resistance to being pushed sideways. This idea leads some folk to imagine that an aircraft can be turned merely by moving the rudder. If this is attempted the aircraft will yaw to one side, but since the only inward force on it is that caused by the fuselage striking the air somewhat sideways it will only turn very slowly.

The drag is enormous, as you would expect, since everything is travelling half-sideways and the result, if the aircraft be a glider, is a frightful loss of height, or speed, or both. This is, therefore, a most inefficient method of going about things.

As we have seen before, the only force over which we have any direct control is the Lift, and we make the Lift do the job for us by banking the glider. Fig. 7 is a sketch of the state of affairs in a medium turn. *W* is the weight of the glider, acting as usual vertically downwards. *L* is the lift of the wings, and as can be seen, it is doing two jobs. To simplify this we have split the lift up into two pieces L_1 and L_2. L_1 is balancing the weight of the glider while L_2 is providing the large inwards, or centripetal, force to make the glider change direction. The forces *do not* balance horizontally because the glider is accelerating (changing direction). Notice particularly that the lift is much greater than the weight of the glider. We are demanding much more lift from the wing than it would normally produce at the speed it is flying and we obtain it by pulling back on the stick and increasing the angle of attack. If we overdo it and demand too much lift the angle of attack may reach the stalling angle and the glider will stall. If the glider happened to be flying slowly, and therefore at a large angle of attack when the pilot decided to do a steep turn, there will not be much increase of angle of attack left before the stalling angle is reached. That is the reason why your

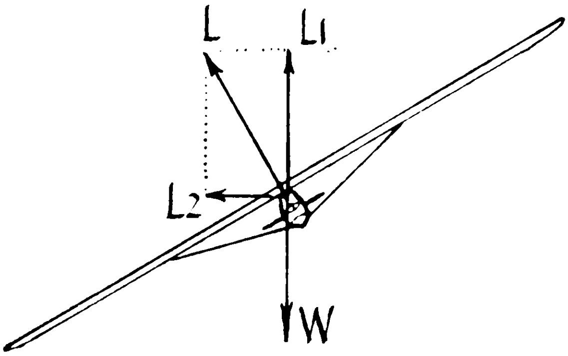


FIGURE 7

instructor tells you " Don't try steep turns at low speed ", and why the stalling speed increases the more you tighten your turn.

The Effect of Speed

Earlier on in this chapter, when we were discussing steady flight, we saw that a glider can fly at various speeds. The slowest speed at which it can fly is its stalling speed. The fastest speed is, theoretically, its terminal velocity in a vertical dive, but in practice few machines are designed to stand this maltreatment and the maximum speeds at which they may fly are laid down by their designers and are displayed on notices in the cockpits. What we want to investigate now is the effect of flying a glider at various speeds.

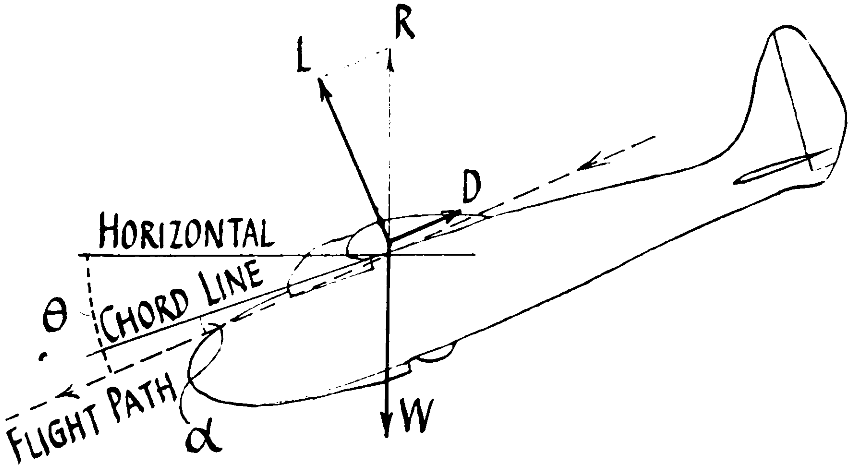


FIGURE 8

Fig. 8 is more or less a reproduction of Fig. 6 with the addition of a bit more detail. The glider is in steady flight and is descending along a flight path which we will say makes an angle of θ with the horizon. We know from our discussion on aerofoils that L and D are really only two bits of the Resultant Force R and that if we add L and D together, taking their directions into account of course, we get R which balances W the weight, since the glider is in equilibrium. This adding is what we have done graphically and LR is merely our old friend *D* planted onto the end of *L*. Now we can see an interesting fact. Since *L* is at right angles to the flight path and *R* is at right angles to the horizon the angle between *L* and *R* is the same as that between the flight path and the horizon; the angle we decided to call θ. Therefore, the ratio *D*/*L* is the tangent of θ for those who like trigonometry. For those who don't, we can put it that if the angle θ is 1 in 10 then the lift is 10 times the drag. If θ is 1 in 17 then the lift is 17 times the drag and so on. It now appears that the gliding angle of our glider is purely dependent on the ratio of *L*/*D*. If we make *L*/*D* large, say 25, then the gliding angle is 1 in 25, that is, our glider will fly forward 25 feet for every foot of height that it sinks. This ratio *L*/*D* will depend on the particular aerofoil that the designer has settled upon for our glider, but it will also depend upon the angle of attack at which the wing is flying. If we obtained the lift curve and the drag curve (Figs. 2 and 3) of this particular aerofoil and divided the lift at any angle of attack by the drag at that angle, and repeated the process for all angles of attack we should obtain an *L*/*D* curve which is shown in Fig. 9. To be accurate we have to consider the total lift of the whole glider, wing, tail, fuselage, struts,

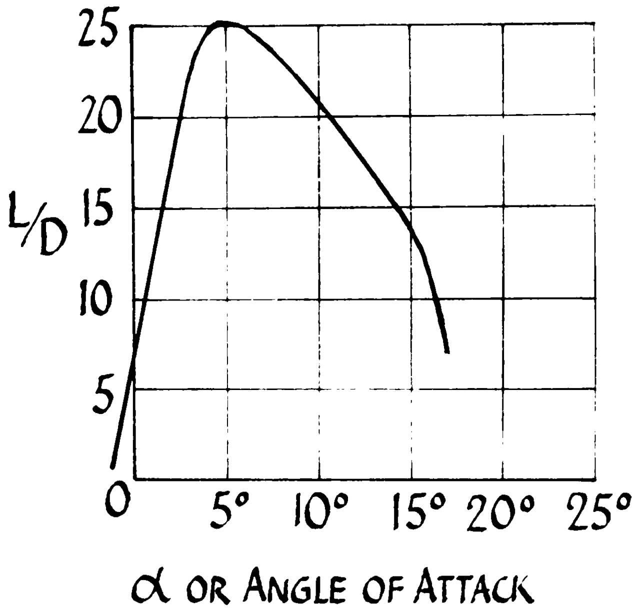


FIGURE 9

etc., and the total drag when compiling this curve for the glider. The first thing we notice from this curve is that there is only one angle of attack, in this case about 4°, where we get our maximum L/D ratio. At this peak value L/D is about 25 so we shall get a gliding angle of 1 in 25. If α is greater or less than this value, then our L/D becomes less, so our gliding angle becomes worse. For instance, at $\alpha = 10^\circ$ $L/D = 20$ so gliding angle is 1 in 20 and also at $\alpha = \frac{1}{2}^\circ$ $L/D = 15$, gliding angle is 1 in 15. In the glider there is no method of telling the pilot just what the angle of attack is at any particular moment, but we now know that, if the glider is in equilibrium, every angle of attack corresponds to a certain speed (given that the weight of the glider is constant). The pilot has got an instrument to tell him his speed, his A.S.I., (short for air speed indicator) so instead of thinking in terms of angle of attack we can think in terms of air speed. Therefore, there is one airspeed at which the gliding angle is at its maximum and one airspeed only. Faster, or slower, than this the gliding angle becomes steeper. What is the effect of a change in the weight of the glider? A heavier pilot will mean that more lift will be required to balance the weight. The characteristics of the aerofoil and machine are unaltered, the best L/D ratio will occur at the same angle of attack, but, since more lift is required this angle of attack will now correspond to a slightly greater speed. Oddly enough, we see that the best gliding angle remains the same; it merely is achieved at a slightly higher airspeed than before. With a lighter pilot the reverse is true. When the designer is creating a machine with great penetration, or with a big efficient speed range, he does his best to choose an aerofoil, and a layout for his machine, which will make the L/D curve as " flat-topped " as possible and not " peaky ". This means that there is a range of angles of attack where the gliding angle is very nearly as good as the best. Consequently, the pilot has a wider range of airspeeds at which he may fly without unduly spoiling the gliding angle.

There is another important speed for every glider. This is its minimum sink airspeed. This is the speed at which the power required to drive the glider is a minimum. But a glider has no power! Oh yes it has, my friend. It is using up energy all the time; energy supplied by the fact that it is sinking in the direction that the weight is acting. The physicist calls this potential energy and the glider's potential energy is exhausted when it lands. It possesses quite a lot of potential energy at 5000 feet and double that amount at 10,000 feet. The power that the glider uses is the *rate* at which it is sinking through the air. When the power is a minimum, the sink is a minimum. The glider is still using up energy when climbing in a thermal, but in this case energy is being supplied to the air in which the glider is flying so there is a net gain of energy by the glider and it rises. On looking at the drag curve we might be tempted to say that the drag is a minimum somewhere about $\alpha = 0°$ to $2°$, therefore, the power must be least there. That is only half the story because the drag curve was worked out for one constant airspeed and the power is the product of drag × speed. At $\alpha = 0°$ the speed is high: at $\alpha = 15°$ (the stalling speed) the speed is at its lowest but the drag is large. Somewhere between these two extremes drag × speed is a minimum and that is the speed to fly for minimum sink. In this book we are deliberately avoiding mathematics as far as is possible so we will leave this subject with the remark that in most sailplanes the minimum sink airspeed is somewhat slower than the best gliding angle airspeed. The pilot has got a direct indication of his rate of sink on his variometer and can find his minimum sink airspeed by experiment. It is worth noting, however, that an increase of weight does mean an increase of minimum rate of sink and *vice versa*.

Chapter 5

CONTROL AND STABILITY

Primary Effect of Controls. It is not the slightest use designing and building the most efficient and beautiful looking aircraft unless we provide the pilot with a satisfactory system of controlling its flight. If this is not done, the aircraft becomes a death trap. Needless to say no aeroplane, or glider, can ever get a Certificate of Airworthiness until the most exhaustive tests have been made to ensure that its control system is satisfactory in every way.

Any aircraft moves in three dimensions so it must be equipped with three controls. We have touched on this subject in the last chapter when we were defining the Pitching, Rolling, and Yawing Planes, but we must now investigate more fully. We will take the Pitching Plane first as this is the simplest of the three.

At the trailing edge of the tailplane of a glider are movable flaps known as Elevators. They are connected to the stick in the cockpit by means of cables, or occasionally by means of rods, in such a manner that backward movement of the stick causes the elevators to move upwards, thereby depressing the tail of the glider and raising the nose. In consequence the speed decreases. Similarly, the forward movement of the stick lowers the nose of the glider and increases the speed. So far so good, but, for the elevators to work at all there must be a reasonable speed of airflow over them. At high speeds the elevator control of most gliders becomes much more sensitive than usual, and a pupil doing his first aero-tow launch, when his glider is being towed up behind an aeroplane, may find that his glider is very over-sensitive on its elevator control. This is because he will be towed at a speed considerably greater than the usual flying speed of the glider. At the other end of the scale, as the speed gets down near the stalling speed of the glider, the pilot will find the elevators becoming more and more sluggish, and, in fact, if he stalls his glider, he will find that the machine will not obey its elevators if he tries to hold its nose up. In spite of all his efforts it will put its nose down to pick up more speed. We shall return to this point later on when discussing the stall and spin.

The Rudder is a movable flap hinged to the trailing edge of the vertical fin at the tail of the fuselage. It is operated by the pilot's feet, via pedals and cables, in the direction that left foot forwards pulls the rudder across to the left, swings the tail to the right, and hence the nose moves to the left. Right foot forwards, of course, produces the opposite motion. The rudder control suffers from the same troubles as the elevator, from the point of view of change of speed. It is somewhat over-powerful at high speeds and at the stall it becomes sluggish but, provided the rudder is satisfactorily designed it should always be effective, even when the machine is stalled. Even so, at the stall, the pilot may have to use the full travel of the rudder to yaw the machine. On the ground, at take off, or landing, if the pilot needs to correct a tendency to swing he will certainly have to make very large movements of the rudder owing to his slow speed.

Control in the Rolling Plane is achieved by means of the Ailerons. These are hinged portions of the trailing edges of the wing tips and are connected to the stick in such a way that moving the stick over to the left causes the left aileron to move up and the right one to move down. The net result is an increase of lift on the right wing tip and a decrease on the left so the glider rolls to the left. Move the stick to the right and the opposite happens. It is with the ailerons that we really begin to run into trouble. They are of course more powerful the faster we fly, but if we fly slowly they get very sluggish, and at the stall, they may refuse to work at all in rolling the machine. In exceptional cases they may even roll the machine the wrong way when used violently at the stall. The reason for this is not very obvious but can be seen if we consider what happens to the wing tips when we stall the glider. Putting one aileron down in effect increases the camber, or curve, of the aerofoil section at the wing tip and this increases its effective angle of attack. This results in an increase of lift, and similarly a decrease of lift on the other wing tip where the aileron moves up, but this only holds good if the angle of attack is less than the stalling angle. If the glider is stalled, we know that an increase of angle does not result in any increase of lift, but rather a decrease, so the ailerons may even roll the machine the wrong way. Near the stalling speed, say 2 m.p.h. above it, the glider will be flying at very nearly the stalling angle of attack and if we look at the lift curve (Fig. 2) it is obvious that a small increase or decrease of angle of attack of the wing tips has only a small effect on the lift, hence the sloppy and useless feel of the ailerons as we approach the stall. To minimise this effect, most gliders wings are " Washed out " at the tips to some extent. " Wash out " means that the wing is designed with a slight twist so that the angle of attack is less at the tips than at the centre section of the wing. By this means the designer ensures that the centre section of the wing shall reach the stalling angle before the tips, so that the ailerons shall still be effective when the glider stalls. The effectiveness of this arrangement varies with different machines, and at best is only a palliative; the disease is still there.

Secondary Effect of Controls

The use of the elevator in a glider has no effect on the machine in the Rolling or Yawing Planes. It makes the machine pitch, nose up, or down, and that is all it does.

However, when we use the ailerons, or rudder, in flight, we find that each has an effect in the plane of the other. This is known as the Secondary Effect.

Take the ailerons first. Imagine a glider flying straight and the pilot decides to bank to the left. He moves his stick across to the left, the left aileron rises and the right aileron is depressed.

This results in an increase of lift on the right wing tip, and a decrease of lift on the left so the machine rolls to the left. But this is only half the story. In depressing the right aileron we have increased, in effect, the angle of attack and we know that an increase of angle of attack means an increase of drag. The reverse happens on the left wing tip and there will be a decrease of drag. The result of these unequal drags on the wing tips is that the machine will yaw to the right. This is most annoying because the yaw is the wrong way. If we are starting a turn to the left and bank the machine to the left, we do not want the nose of our glider to swing away to the right. The cure for it, if it can be called a cure, is to prevent the nose yawing away by the use of the rudder, in this case to the left. Thus, in brief, causing a roll, results in a yaw the opposite way. This secondary effect of the ailerons is often spoken of, colloquially, as Aileron Drag. It becomes worse and worse the slower we fly, chiefly because, at slow speeds, more movement of the ailerons is required to make the glider roll. It reaches its worst at the stall, when the primary effect of the ailerons (that of rolling the glider) is at its minimum, and to make matters still more distressing, the rudder is at its feeblest. We shall investigate this state of affairs again more fully when we examine the Spin.

Now for the Rudder. If, when flying straight, the pilot of a glider presses his right foot forward on the rudder pedal the rudder will cause the nose of the machine to swing to the right, but, in doing so, the left wing tip will be speeded up and the right wing tip slowed down. The result of this is an increase of lift on the left wing tip and a decrease on the right, giving a tendency to roll to the right. So, while the primary effect of the rudder is to produce a yaw, the secondary effect produces a tendency to roll in the same direction. This rolling effect does, at any rate, work in the right direction, which is more than can be said for aileron drag, so, in general, the secondary effect of the rudder is not such a problem. After all, if we apply left rudder it may not really be such a bad thing if the machine tries to bank to the left as well. The snag is that, at the stall, the secondary effect becomes rather too powerful and use of the rudder may start a spin. The reason for this is that at, or near, the stall the lift at the wing tips is altered quite a lot by comparatively small changes of speed. Again, we shall be discussing this problem in more detail when we come to examine the Spin.

These two secondary effects, aileron, and rudder, are much more pronounced in our gliders than in powered aircraft. The main reason is that our gliders usually have a very large span in relation to the area of wing, a large Aspect Ratio in fact. Aspect ratio is defined as the ratio $\frac{\text{Span}}{\text{Chord}}$ or in the case of tapered wings where the chord varies $\frac{(\text{Span})^2}{\text{Area}}$. If we have a very large span it is clear that any unequal drag of the ailerons has a much greater leverage and yawing effect than if the span were short. Similarly if we yaw the glider with the rudder the speeding up and slowing down of the wing tips is much greater with a machine of large span than with one with short, stumpy wings.

What can the designer do about these secondary effects? As regards the rudder he cannot do very much, and as we saw the rolling effect of the rudder is not altogether a bad thing. Provided the rudder is big enough, and powerful enough, to work reasonably well at the stall, it does give us a means of controlling the roll of our glider when, through stalling, the ailerons are virtually useless for rolling purposes. However, this unequal drag of the ailerons is an unmitigated nuisance, and the clever designer does his utmost to minimise it. One very popular method which is employed on most gliders is the system of Differential Ailerons. All this amounts to is, that, by means of rather cunning linkage in the controls, the up-going aileron is made to go up much more than the down-going aileron goes down. This system undoubtedly helps, but it does not effect a complete cure. Another method which is very popular on powered aircraft is the use of Frise Ailerons. In this scheme the ailerons have their hinge line set back somewhat and are shaped with a rather pointed nose on the underside. The result is as shown in Fig. 10. When the aileron goes down the pointed nose is shielded by the forward part of the wing. There is the usual increase of drag, of course, but on the other side the up-going aileron pushes its nose down below the surface of the wing and causes extra drag. By careful design this extra drag can be made to balance, approximately, the drag on the down-going aileron. We now see the objection to this scheme for gliders. It means extra drag, and drag is the one thing we must keep at the irreducible minimum if our glider is to be efficient. In spite of this, modifications of the Frise aileron principle are sometimes found on gliders.

It should now be clear why, in normal flying, we use the ailerons and rudder together. Take for example, a glider making a turn to the right. The pilot moves his stick over to the right to apply the necessary bank, but, at the same time he

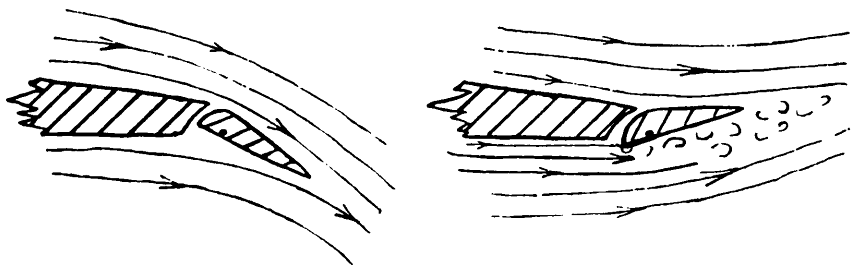


FIGURE 10

must apply rudder to prevent the nose of the glider yawing away to the left due to the secondary effect of the ailerons. When he has attained the angle of bank that he requires, and the machine has begun to turn, the outer wing tip will be travelling faster than the inner one and will therefore be producing more lift. To keep the bank constant—the essence of a good turn—the pilot must centralise the ailerons and may even have to use them slightly the other way to prevent the bank from increasing (" Holding off bank "). The drags of the wing tips are approximately equal now so the rudder must be centralised also. This last statement is not strictly true as the drag of the outer tip may be slightly greater than the inner, due to its higher speed. On the other hand, holding off bank may increase the drag of the inner wing tip to over-compensate this. It is impossible to be dogmatic about this as gliders vary in this respect. The point is that the rudder is central, or very nearly so, while turning steadily, since we have seen, earlier on, that it is the lift force, and not the rudder, which is compelling the glider to move in a circular path. On attempting to resume straight flight, the pilot levels the wings by moving the stick to the left and, again, he must use left rudder to oppose the yawing effect of the ailerons. All through the turn, of course, the pilot must use the elevators to keep the nose in the same position relative to the horizon. The pilot who has learnt how to do satisfactory turns, knows that he does these things, but he may have only the sketchiest idea of why he has to do them. Hopefully we may have given him a few points to think about.

One last point on the subject of controls. For a glider to feel really nice to fly it should not only respond quickly to the movement of the controls, but the effort needed to move them should be reasonable, and more important still, the effort needed to operate all three controls should feel similar. When these conditions are fulfilled we say that the controls are nicely " Harmonised ". We all know that some types of gliders are nicer to fly than others, and the faults nearly always boil down to the fact that one control is much less effective, or seems to need much more effort to operate than the others.

Auxiliary Controls

The pilot of a sailplane, which is only another name for a soaring glider, has one or two other knobs and levers to make his task simpler (or more complicated, if you like). He will almost certainly have an *Elevator Trimmer.* This is a small lever, usually mounted on the side of the cockpit and by its use the pilot can trim his machine to fly " hands off " at whatever speed he chooses. This is a great advantage when undertaking long flights, as the pilot is spared some of the fatigue of controlling the machine, and it is of great assistance when flying blind. The trimmer also enables pilots of different weight to " trim out " the effects of the slightly different positions of the Centre of Gravity. Without a trimmer, a heavy pilot will usually find that he must exert a small back pressure on the stick to maintain his best speed. This is because the extra weight of the heavy pilot has resulted in the Centre of Gravity being slightly further forward than usual and the glider has a nose down tendency. We are speaking, of course, of an ordinary glider in which the pilot sits well forward in the nose. If the configuration of the glider is such that the pilot sits well behind the *C.G.* of the whole machine, then extra pilot weight will have the reverse effect, but this is very unusual. The trimmer lever works, by cables, a small tab on the elevator moving it up or down, and many folk are baffled to start with because it appears to work the wrong way round. That is, to trim nose down we push the lever forward and the tab goes up, and *vice versa.* At first sight one might expect raising the tab to depress the tail and raise the nose instead of lowering it. In fact, the tab does not depress the tail at all, it depresses the elevator alone. This has the same effect as putting the stick forward and depressing the elevator. Some older sailplanes have no trimmer at all, and a form of trimmer is found on others which consists of nothing more than a spring or piece of rubber shock cord attached to the stick or elevator cable and whose tension can be adjusted in flight. While this works quite well it does have the snag that it interferes somewhat with the " feel " of the elevator control. With the true trimmer tab, the pilot can feel the effect of the air on the elevator surface, whereas with the spring arrangement this may be a trifle masked by the pull of the spring. A small point maybe, but really nice controls are only achieved by attention to a multitude of small points.

The other auxiliary control which we shall almost certainly find in our sailplane is a lever mounted on the left side of the cockpit, looking rather like the throttle lever of the power pilot's aeroplane. This is the *Spoiler* or *Airbrake* lever, and it is put in the same place as the aeroplane's throttle because its functions are rather similar. It works in the same sense also, i.e. lever forward, spoilers or brakes closed, corresponding to " engine on "; lever back, spoilers or brakes open, corresponding to " engine off ". Spoilers should not be confused with brakes though their actions are very similar and since spoilers are simpler we will consider them first. Spoilers are thin plates some three feet long or so and about three inches wide. They are set in the top surface of the wing, spanwise, at about the thickest point of the section. When closed they lie flush with the top surface of the wing but they are hinged at their forward edges, and, when the lever is pulled, they rise up perpendicular or nearly so to the surface of the wing. Usually there is one spoiler on each wing, arranged well inboard of the aileron, but sufficiently far outboard so that its effect is well clear of the tailplane. Spoilers were first fitted because, as designers produced better and better gliders, they became more and more difficult to land accurately, or rather to bring in on an accurate approach. The very shallow gliding angle meant that a very small error of judgement resulted in a large over or undershoot, and this made the business of getting down in a small field very difficult. What the pilot wanted was some means whereby he could steepen his gliding angle at will without increasing his speed, and in spoilers he got exactly what he wanted. When the spoiler plate is raised it ruins the smooth airflow over the top of the wing over that portion of the span occupied by the spoiler. The lift over this part of the wing is " spoiled ", and, to keep the total lift equal to the weight, the angle of attack has to be increased. There is a considerable increase in drag from the spoilers, and the net effect is a decrease in the L/D ratio, or, what is the same thing, a steepening of the gliding angle. The pilot can adjust his angle of descent with ease and spot landing becomes relatively simple. However, as more and more pilots began indulging in cloud flying, a need was felt for something a bit better. While spoilers do provide extra drag, their effect is not very pronounced at high speeds and one of the difficulties of cloud flying is that if the glider is inadvertently allowed to put its nose down in the turn, it can pick up a very high speed in a very short time. What pilots now asked for was some way of producing so much drag that, no matter what the glider did, it could not exceed its safe speed when the drag producer was in action. The answer is described on the following pages.

Airbrakes

There are several types of airbrake but the effect of all of them is similar. Basically they consist of flat plates rather like spoilers and operated by a lever in the same way. When closed these plates are concealed in, or lie flush with, the wing surface. However, in the case of airbrakes we usually have one plate above and below each wing, and the plates are not hinged at their forward edges, but are arranged to stand up perpendicular to the airflow on rods, well clear of the wing itself, when in action. Their effect at slow speeds is very similar to that of spoilers, though brakes are usually more violent in action, but at high speeds brakes do produce a large increase in drag. It is this large increase which prevents the glider from exceeding its maximum permitted speed. Spoilers, when opened tend to produce a nose down effect on the glider. Brakes, since they operate above and below the wing, usually produce little or no change of trim. Some types of brake, however, tend to suck open in flight and in these cases the control has to include some means of locking them shut.

Spoilers and airbrakes must not be confused with flaps. Flaps are rarely used on gliders, though almost universal on powered aircraft. Flaps, though they do increase drag, also increase the lift and enable the aircraft to fly more slowly. Spoilers and airbrakes *decrease* the lift while increasing the drag, and therefore our glider will have a *higher* stalling speed when they are in use. Many people do not fully realise this and it is probably the reason for quite a few broken skids and damaged fuselages.

Brakes, and to a lesser extent spoilers, have one other rather valuable property. When used to hold the speed down, should a pilot temporarily get into difficulties in cloud, they usually produce a marked increase in stability in pitch. This means that the glider will return to steady gliding flight if left to itself.

Stability

When we say that something is Stable we mean that if it is disturbed it will tend to return to its original state. The best analogy for this one which has been used many times before in other books, but it is worth repeating. In Fig. 11(a) a ball is balanced on top of a curved surface. If we give the ball a prod it will roll away off the surface no matter how gentle the original prod. The ball is *Unstable* because any disturbance increases of its own accord. In Fig. 11(*b*) the ball is resting on a flat level surface and in this case a gentle prod merely means that the ball will move and come to rest again in a different position. It does not try to roll away and it does not try to come back to its original position. We call this *Neutrally Stable.* But in Fig. 11(*c*) the ball is resting in a shallow saucer and if we prod it, it will return again to its original position. We call this *Positively Stable.* The ball may well wobble back and forth a few times before it stops but this does not affect the fact that it does try to return to its original state.

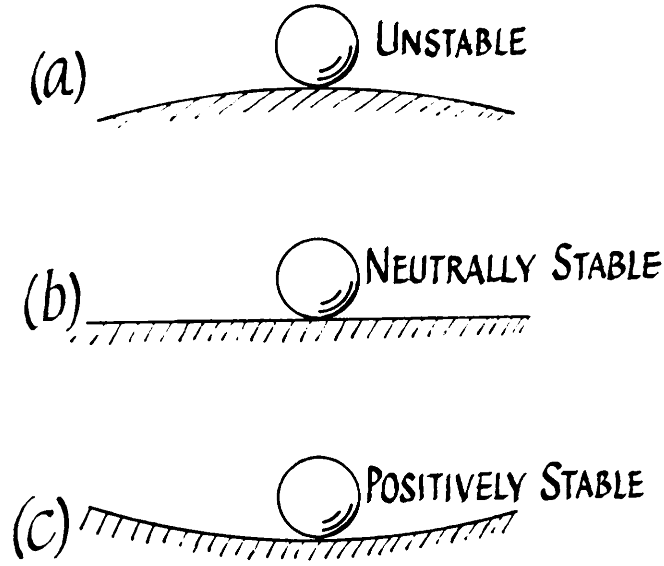


FIGURE 11

Positive stability, or the ability to return unaided to a given state of flight, when disturbed, is a very useful quality in a glider. An unstable glider would be a menace, because this would mean that if the nose of the glider dropped for any reason the glider would dive away steeper and steeper, unless the pilot took action with the elevator control. A Neutrally Stable glider is permissible, since this means that if the glider is disturbed from its flight it remains in the new state without any attempt to correct of its own accord, but also without any tendency to make the disturbance worse. That is, if the nose of the glider drops for any reason, it will stay in that attitude. A Positively Stable glider, however, will try to return, of its own accord, to the state of flight for which it is trimmed. Blind flying in cloud is made far simpler if the glider has good positive stability since the pilot can, to a large extent, let the glider fly itself. Like everything else, you can have too much of a good thing, and, as we shall see, excessive stability may spoil an otherwise good design of glider.

When we were discussing controls, we found we could examine the effect of elevator control separately, while the effects of aileron and rudder were rather bound up together. Exactly the same situation occurs with this business of Stability. An aircraft may be stable in Pitch, and unstable in Roll but stable in Yaw, or any combination of the three. In practice no glider is ever found to be actually unstable, or it would never get a Certificate of Airworthiness, but its stability in one plane may be very small or even neutral.

We can consider stability in Pitch separately so let us take it first. When investigating the properties of aerofoils we noticed that the Centre of Pressure, the point where the lift can be considered to act, moves about under different circumstances. At the ordinary angles of attack, corresponding to normal gliding flight, the *C.P.* will be about one-third of the chord aft of the leading edge of the wing, the place, in fact, where the clever designer has put the great main spar which runs from wing tip to root inside the wing. But suppose that, while gliding serenely along something causes the nose of the glider to rise ever so little. The angle of attack increases, the lift increases, and the glider accelerates upward; but this is not all. As the angle of attack increases, the *C.P.* moves forward slightly so that if the glider was in equilibrium before the nose was raised, the slight forward movement of the *C.P.* and the lift force will make the nose tend to rise even more. Precisely the opposite occurs if something caused the nose to drop. A wing therefore, *by itself*, is unstable in pitch, and to make it stable we must use other means, and the easiest way of doing this is to fit a tailplane at the end of a fairly long fuselage.

Look again for a moment at Fig. 8. Since *L*, *D*, and *W* balance, and they all meet at one point, the glider is in equilibrium, and will stay in this state so long as nothing disturbs it. But as we have said before, this is the ideal state of affairs and rarely occurs in practice. Usually the lift *L* and the weight *W* do not quite coincide, and if they do not, then the lift must either be in front of, or behind the weight *W*. Suppose the lift acts in front of the weight. Then there will be a tendency to raise the nose of the glider and if we are to maintain equilibrium we must so arrange matters that there is an up load on the tail plane to balance this. Similarly if the lift be behind the weight we shall need a down load on the tail to balance the glider. Fig. 12 shows these two cases. Now in both these cases the glider can be in balance, or equilibrium, provided that the tail load is exactly right, but this alone will not ensure that the glider is Stable in Pitch. Remember that for Stability the glider must return, or at any rate, try to return, to the state of flight that it was in before being disturbed. We know that if the angle of attack be increased, the *C.P.* will move forward (until the stall, when it moves back again) and this tends to raise the nose and increase the angle of attack still further. However, if the change in tail load due to the increase

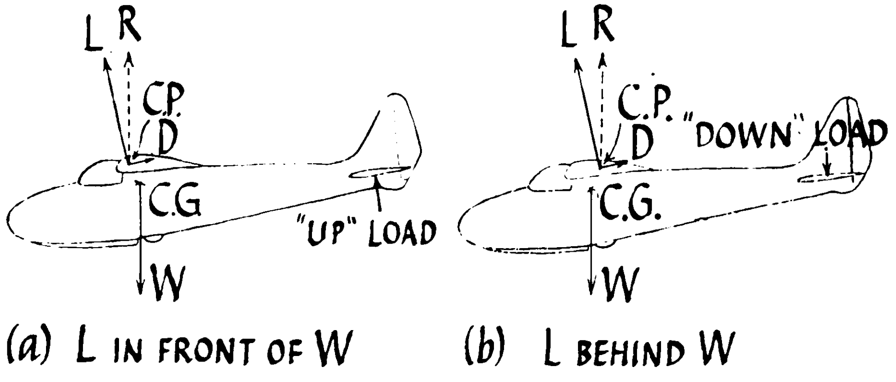


FIGURE 12

in angle of attack more than counterbalances this tendency, then the glider will try to put its nose down again into the original attitude. In Fig. 12 case (*a*) this would mean an increased up load, and in case (*b*) a decreased down load, or even an up load. As an example, a glider is flying, in equilibrium, with its wings at an angle of attack of 6° and tailplane at 2°. This means that there is an up load on the tailplane. A gust momentarily increases the angle of attack by 2°. The angle of attack of the wings is now 8° and there is an increase of lift to 8/6, or $1\frac{1}{3}$, of its previous value. The tailplane's angle of attack, though, has increased from 2° to 4°, so its up load is doubled. This produces a strong nose down tendency which tries to return the angle of attack of the wings to the original value of 6°.

In the event of some disturbance decreasing the angle of attack by depressing the nose, the tail loads will alter in the reverse sense. The factors that the designer can play with to get just the degree of stability that he wants are the area of the tailplane, its distance from the *C.G.* (or if you like, its " leverage "), the aerofoil section of the tailplane, and the angle at which it is set on the fuselage. On this last point it is the actual angle of attack of the tailplane which interests the designer and this may not be quite the angle that it appears since the tailplane is working in the downwash of air behind the main wing. To be accurate, the angle of attack of the tailplane only affects *trim*, but does not affect stability.

A glider which is Stable in Pitch may, in fact, behave in one of four ways. It may return quickly and gently to normal gliding flight: this is called *Dead Beat Stability* and is not often found in practice; but is a delightful quality. Some sailplanes approach this ideal when trimmed to fly with brakes open. This is shown in Fig. 13 (*a*). The more usual result of a disturbance in pitch is that the glider overcorrects (just like you used to do in your early lessons!) but, after a few oscillations resumes normal gliding flight (Fig. 13 (*b*)). It may possibly start oscillating up and down and go on doing this steadily; the oscillations neither increasing nor dying out (Fig. 13 (*c*)), or finally, as shown in Fig. 13 (*d*), the oscillations may increase until the glider is doing steep zooms and stalls. In this last case we say that the glider is *Dynamically Unstable*, though, statically it is stable because it does try to correct.

All the foregoing, of course, assumes that the pilot does nothing to correct the glider, but leaves it to its own sweet will.

We have so far assumed that the Centre of Gravity (*C.G.*) of the glider remains fixed. In practice it must vary slightly

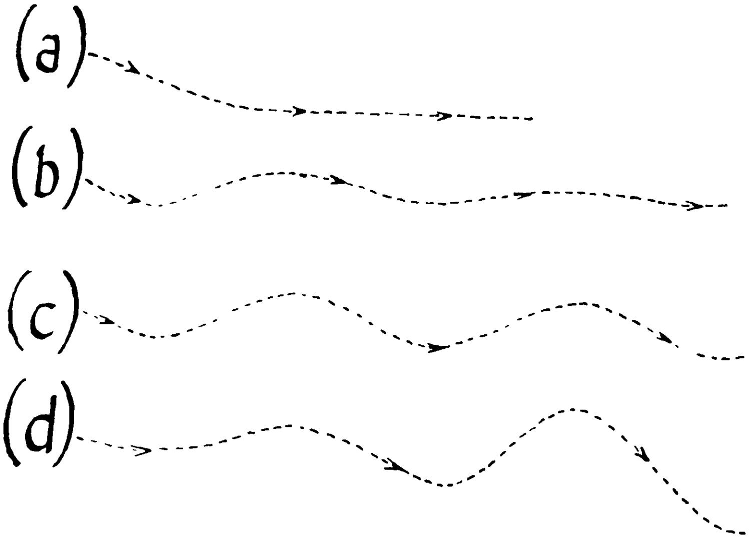


FIGURE 13

with different weights of pilot, and movements of the *C.G.* have a very big effect on the stability in pitch. When a glider is awarded its Certificate of Airworthiness many tests have to be made to find the range of *C.G.* positions where the stability and balance are satisfactory and this range of *C.G.* positions is stated on the Certificate of Airworthiness document. Woe betide you if you fly the glider with the loading such that the *C.G.* is outside these limits. If you break the glider as a result, you may find that the Insurance Company take rather an old fashioned view of such behaviour. To safeguard against this sort of thing, all gliders have, in their cockpits, a notice which states the maximum and minimum weights of pilot, and whether any ballast must be carried, and under what circumstances.

A glider is most efficient if it can be so arranged that at its minimum sink airspeed, or best gliding angle airspeed, (these two are usually different but fairly close) the tail load, up or down, shall be a minimum, since all tail loads mean a little extra drag. Best of all, of course, is our " Ideal State of Affairs " with no tail load. If you own your own glider, it is well worth finding out the exact *C.G.* position with you aboard, and, if it does not coincide with the *C.P.* position at the above airspeeds, adjust it by means of a little ballast judiciously placed. (You then have to guard against middle-age spread interfering with your own, personal, avoirdupois, but this is a medical matter and need not be pursued here.) Some manufacturers do go to the trouble of specifying the ideal *C.G.* position which saves you quite a lot of calculation. There are a few gliders, mostly older designs, which have what are known as Pendulum Elevators. In this system the whole tailplane moves when the stick is moved fore and aft and there is no fixed portion at all. The stability in pitch of these gliders is a very complex problem as it depends on so many things, not the least of which is the friction in the elevator control circuit. In some newer types of sailplane the Pendulum Elevator has come back in a new form. While it is our old friend, it has a tab, or tabs, on the trailing edge which completely alters the situation. These tabs move the same way as the elevator, that is, they move up when the elevator moves up and *vice versa*. The elevator is thus made self-stabilising, since if the pilot raises the elevator, the tab tries to push it down again. By altering the gearing of the tab, the stability can be made as great or small as the designer likes. Usually the setting of the tab relative to the elevator can be adjusted from the cockpit, and then the tab works as a trimmer as well.

Directional Stability, or Stability in Yaw, is sometimes called " Weathercock " stability. All gliders are stable in Yaw; if they were unstable they would try to turn round and fly backwards! Whether the degree of stability in Yaw is the best possible is another matter. The stability is governed by two things. First, the amount of area presented to an airflow which strikes the glider from one side, and, second and most important, where that area is in relation to the Centre of Gravity of the glider. Imagine a glider in normal flight and something causes it to turn left, unbanked, so that the air, instead of striking the fuselage head on, strikes it at an angle from the right. This will cause an increase of pressure on the side surfaces of the fuselage which the air is striking, and probably some decrease of pressure on the other side. The glider, therefore, tends to accelerate sideways to the left, but this is not all. Those side surfaces which lie in front of the *C.G.*, nose, cockpit, sides, pilot's face, etc., in being pushed to the left tend to turn the glider still more to the left, while the surfaces behind the *C.G.*, rear fuselage, fin, rudder, etc., tend to turn the glider to the right, i.e. make it head into the airflow. Notice that it is not only the area of the surface, but whether it is close to, or far away from, the *C.G.* which governs how much turning effect it will have. The fin and rudder are furthest from the *C.G.* so their turning effect is large, and in practice they more or less govern the stability in Yaw. However, a small fin and rudder on the end of a long fuselage may have just as much correcting effect as a large fin and rudder on a shorter fuselage. The actual shape, in plan form of the fuselage, has its effect too, because if we think of the fuselage as being a very long, thin, aerofoil set vertically on edge we can see that the centre of pressure on the side of the fuselage will move slightly for varying " angles of side attack ", in exactly the same way that the *C.P.* of a wing moves with varying angles of attack. We may, therefore, get a situation where a glider is quite powerfully stable for angles of yaw of about 6° or 7° but which is almost neutrally stable at small angles of 1° or 2° of yaw. A glider, or for that matter a powered aircraft, with this type of yaw stability is an infuriating thing to fly, as it continually wanders a few degrees from side to side as it flies. Fortunately, we very rarely find this sort of behaviour these days. It is worth noting, though, that if any modifications are done to a glider which affect the side area, such as fitting a closed canopy instead of an open cockpit, the stability in yaw will almost certainly be affected. To sum up: we must have stability in yaw, and all gliders have it. We can have too much of it and the consequences of this will be seen very shortly.

We have left the subject of Rolling Stability, or Lateral Stability, till last because it is rather more complicated than the stability in the other two planes. As before, a glider which is stable in Roll will try to return, of its own accord, to an even keel when disturbed. Now if a wing is flying normally, i.e. unstalled, and we try to make it roll, the rising wing will be flying at a reduced angle of attack and the down going wing will be flying at an increased angle of attack while the roll is taking place. This means more lift on the down going, and less on the rising wing, tending to stop the motion. The faster the rate of roll, the stronger is this opposing action. This effect is only present while the wing *is rolling.* It does not try to roll the wing back to level again once the rolling has stopped. It merely tries to stop any rolling motion. Also this only applies when the wing is unstalled. We shall investigate this business when the wing is stalled later on in the chapter on the Stall and Spin. We can say then, that an unstalled wing resists rolling. This is not good enough, though. For stability we require that the wing shall return to level when a roll of a few degrees has taken place.

If a glider rolls through a few degrees, and the machine does not turn, it will slip bodily sideways towards the lowered wing tip. If the centre of pressure of the side force on the glider due to the slip is well above the *C.G.* of the glider there will be a tendency to roll the glider back to an even keel. This force is not very large though and its centre of pressure is rarely very much above the *C.G.* so its leverage is small and we cannot rely on this alone to roll the glider back level again. In special cases it is useful, as in some Primary gliders. In these machines the wing is high, and the *C.G.* low, and in addition the " A " shaped frame above the wing which carries the landing wires is covered with fabric. If a machine of this type slips, the air striking this " A " frame from the side has quite a considerable correcting effect since the force is well above the *C.G.*

We do not want to fly Primaries for the rest of our lives, so something better is needed, and the most usual method of obtaining good stability in roll is to give the wings " a bit of Dihedral ". The Dihedral angle is the angle between the wing and a horizontal line when the glider is set up level. Fig. 14 illustrates this, and most gliders have a small amount of dihedral angle. The way in which it works is not so obvious as is sometimes stated. One often hears people say that, with a bit of dihedral angle, a glider rolls back level again because one wing is " more horizontal than the other ". This is muddled thinking and should be put down with a firm hand. What actually happens is this. If the glider is rolled slightly, and does not turn, it will slip towards the lowered wing (Fig. 15). We said that before; but it is repeated because it is so important. As soon as it does slip then the lower wing is flying at an increased angle of attack and produces more lift, while exactly the opposite happens to the raised wing. This causes a rolling effect which persists as long as there is any slip, i.e. until the wing is level again. If you find difficulty in comprehending this, imagine a glider like that in Fig. 15, but with

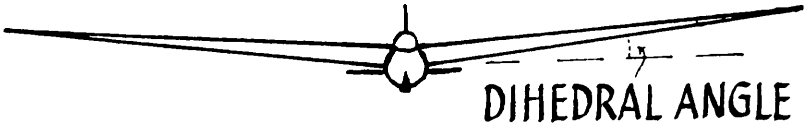


FIGURE 14

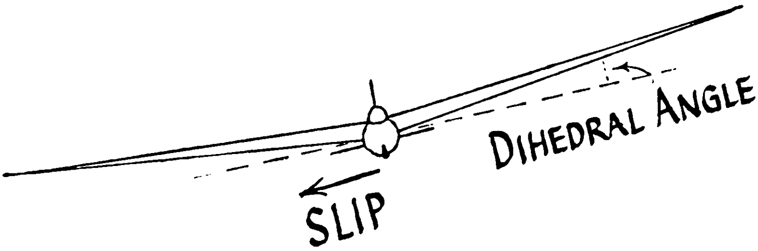


FIGURE 15

an absurd amount of dihedral angle slipping sideways and the effect will be much clearer.

Another dedge which helps to achieve Stability in Roll is to give the wings a bit of Sweepback. This is shown in Fig. 16 which also shows the method by which this works. The glider is slipping to the left and it is clear that the left wing is hitting the air properly while the right (upper) wing is being dragged somewhat root first through the air. There is, therefore, more lift from the left wing than the right and the glider rolls back level until the slip stops. Sweepback also gives a hand in Yaw stability as well since the left wing is presenting more frontal area to the air than the right, so the wing helps the fin and rudder to turn the glider head on to the air again. Sweepback has to be fairly pronounced before its effects are strong enough and this involves some design snags. The main spars of the wings do not meet end on in the middle and the wings have a twisting effect on their root fittings. All this means extra structure and therefore extra weight to cope with these forces.

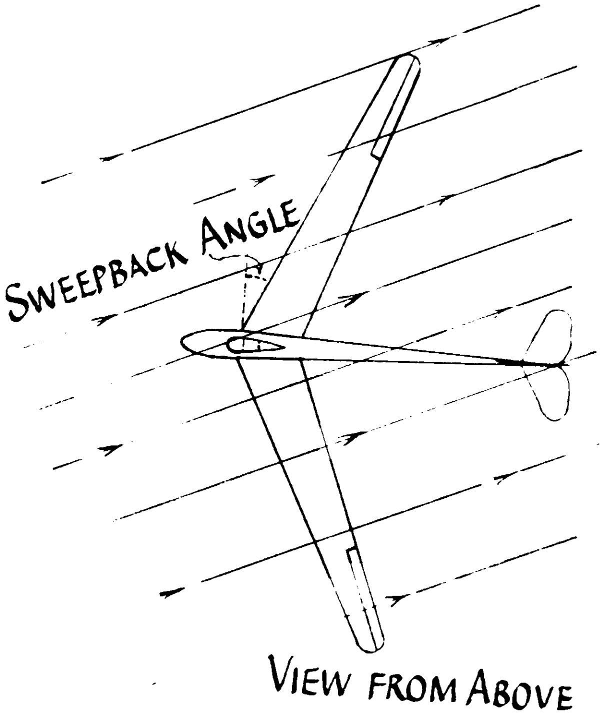


FIGURE 16

Sweepback at any rate is not much used now in gliders, except in some tailless designs. In these cases the sweepback is so great that the wing tips are far enough aft to act as tails. In fact far from being tailless, these gliders have two tails!

Whatever system, or combination of systems we employ to obtain stability in Roll one fact stands out. There will be no correcting effect to restore a glider to a level keel *until the glider slips*. Then the forces come into play and level the wings again. This is where we begin to run into trouble, because as soon as the glider slips, the stability in Yaw is involved and the fin and rudder do their best to turn the glider into the slip, i.e. head on to the air. This means that the Stability in Roll and Yaw are bound up together and too much of one may spoil the other. For example, suppose we have a glider with fairly good Roll Stability and exceptionally powerful Yaw Stability and let this glider be rolled until it has a 5° bank to the right. After a second or two there will be an appreciable slip to the right and the Roll Stability will begin to return the wings to level. Before this can happen, the powerful Yaw Stability will have started the glider turning to the right and once the glider starts to turn, the left wing on the outside of the turn will be travelling faster than the right. More lift on the left wing, less on the right, so the glider rolls more to the right, slips more to the right and the effect builds up. Also the Yaw Stability in its frantic attempts to keep the glider head on to the air by steadily forcing the nose round to the right is now forcing the nose below the horizon due to the angle of bank. The speed builds up and now the Pitch Stability starts to join the fray by trying to pull the nose up but, since the glider is well banked over by now, all it can do is to tighten the turn. This leads to the High Speed Spiral Dive. Hence it is clear that if the Stabilities in the three planes are not balanced in degree we can get what is known as Spiral Instability even though the glider is positively stable in all three planes separately.

Excessive stability in any of the three planes is, then, a thing to be avoided. Excessive stability in pitch frequently gives rise to Dynamic Instability and also means that more control movement is needed to make the glider overcome its pitch stability.

Excessive Roll Stability means poor aileron response and large aileron drag or secondary effect, while as we have just seen, too much Yaw Stability may mean Spiral Instability. Happy indeed is the designer whose brain child, besides all its other qualities, has just the right amount of stability, in each of the three planes, to give easy flying and sweet controls.

Chapter 6

STALLED FLIGHT

Most glider pilots spend relatively little of their flying time in the condition of stalled flight (though talking to their instructors might lead one to believe otherwise!) so it may seem odd that we have devoted a whole chapter to this subject. We have done so because, in the aerodynamic sense, most of the dangers of any form of aviation lurk around the stall. We shall try, in this chapter, to drive these dangers out into the daylight where we can inspect, and dissect them, for it is really in ignorance of them that the real menace lies. Understand how the stall and spin occur; learn to recognise the symptoms in the air, and practice recovery until it is instinctive, and their power over you is gone.

The Stall

We have touched on this subject in earlier chapters and we know now that a wing stalls when the angle of attack is increased to more than the critical, or stalling angle. Once again this angle has nothing whatever to do with the horizontal, vertical, or any other direction. It is simply the angle between the chord line of the wing and the direction from which the air is approaching. This last can, if you like, be defined as the direction *through the air* in which the wing is travelling. In straight gliding flight if we decrease speed we have to increase the angle of attack to maintain a constant lift equal, to all intents and purposes, to the glider's weight. If we go on decreasing speed and increasing the angle of attack, eventually we reach the stalling speed at which the angle of attack reaches the stalling angle. This is the ordinary straight stall with which everybody is, or should be, familiar. The important point to remember about a straight stall is that the glider is temporarily out of control, or very nearly so. The ailerons will be practically useless at best. They may even work the wrong way due to the big secondary effect and negligible primary effect. The glider will disobey its elevators and will put its nose down, even though the stick may be hard back against its stop. The rudder is your best bet as it will still work to some extent though its secondary effect, that of rolling the glider, will be very powerful compared with its effect on the yawing. This is not altogether a bad thing as it does at least give the pilot some control in rolling should a wing drop at the stall. The pilot usually says he " picked it up with the rudder ". To regain full control we must get the angle of attack down below the stalling angle and this means an increase of speed. The glider will put its nose down when stalled, so in a sense, a stall is self curing, but a pupil is very inclined to drag the nose up as soon as the elevators begin to work again and before the glider has really picked up enough speed, and he may stall the glider again.

Every stall involves a loss of height, and, worse, a loss of height while the glider is more or less out of control. Here lies the main danger of the stall; that there may not be sufficient height for recovery. The height loss is not very great for most gliders, being of the order of 50 to 75 feet, but if the glider is allowed to stall at say 25 feet from the ground a crash is well nigh inevitable. High up in the air, a stall cannot hurt anyone and it behoves everyone who flies to familiarise himself with the symptoms of the onset of the stall. These differ for different gliders but the usual ones are: comparative quiet as the speed dies away, nose of the glider above the normal position, sloppiness of controls, particularly the ailerons, and possibly a buffeting sensation from the tail as the turbulent wake of the wing strikes the tailplane. The recovery from the stall is obvious. Put, or keep, the nose down until sufficient speed has been gained, then raise it gently back to its normal position relative to the horizon.

Since a stall results if the angle of attack is increased beyond the stalling angle, we could, theoretically, stall a glider at any speed simply by increasing the angle of attack sufficiently (in vulgar parlance, by hauling back on the stick). Suppose a glider weighs 500 lb. and stalls at 30 m.p.h. If this glider was flying at 60 m.p.h. and the pilot suddenly pulled back the stick and managed to increase the angle of attack to the stalling angle, the glider would stall. However, we know that at 30 m.p.h. and at the stalling angle the wing of this glider will just produce 500 lb. of lift. If we double the speed and still keep the angle of attack the same, i.e. the stalling angle, we shall get four times as much lift (2,000 lb.) and the glider will accelerate violently upward. The reason for this large increase in lift is simply that at a given angle of attack the lift varies as the square of the speed. Double the speed, four times the lift; treble the speed and you get nine times the lift, and so on. This is the so-called High Speed Stall, and please note that it can be produced in any attitude. The glider does not have to be nose up, but may be in a very steep turn, or even pulling out of a dive. At speeds well above the stalling speed the loading is very large and the pilot says he " feels lots of g " or that he was " squashed down into his seat ". Well above the stalling speed the high speed stall is therefore difficult to produce, and at high speeds it may be impossible without danger to the structure of the glider. For your peace of mind, however, we may point out that you will " black out " long before the structure of your glider is in any danger.

If you are flying only one or two miles per hour above the stalling speed of your glider the story is very different. Coarse movement of the elevator in this case may well precipitate a stall and the extra lift produced will not be very great. In addition, the stall may well be very sudden. It therefore behoves you to fly delicately (like Agag) when very near the stall.

A stall can be sprung upon you by another circumstance which is outside your control. If a glider is flying into wind near its stalling speed, a sudden drop in the wind may reduce the airspeed of the glider to below its stalling speed. If the wind be blowing horizontally this will not, *of itself*, stall the glider since it does not alter the angle of attack, but it will reduce the lift of the glider and the machine will drop. As it drops, the angle of attack increases, (if you like because the air is " coming up to meet it ") and may exceed the stalling angle, and a stall results. To make matters worse, the inexperienced pupil may well be tempted to pull the nose of his glider up, when he feels the machine begin to drop. This type of stall also may be very sudden in its onset, and exactly the same thing happens if the glider is facing downwind and is struck from behind by a sudden *increase* in the wind.

A stall may be produced by a sudden change in direction of the wind in a vertical plane. This has been known to catch out quite experienced pilots. If you are soaring over a ridge very near your stalling speed, and you fly into air which is rising more steeply, the effect of the rising air may be that your wings' angle of attack increases beyond the stalling angle suddenly with no change of attitude. The stall will be sharp and sudden.

A glider may also be stalled by flying into wind down through a wind gradient. This is almost the same thing as the case of the sudden lull in wind strength which has been discussed above, except that the stall is more progressive and may creep up on you unawares. It also occurs very close to the ground, the very worst possible place.

The moral to all this is fairly obvious. Do not fly near the stall unless you have ample height for recovery. In rough, or turbulent conditions, near the ground, keep an extra reserve of speed in hand to guard against changes in wind velocity and direction.

The Spin

For some reason or other many pupils seem to regard the spinning of a glider with a certain amount of awe. This may be due, in part, to the extraordinary ideas which some folk hold concerning the spin. Many of these ideas are half-truths, and some are myths. When analysed, and understood, there is nothing very mysterious about spinning, and, provided it is not indulged in accidentally and low down, nothing dangerous. First we must understand how a spin is produced; next we must learn the recovery procedure and see how this procedure does stop the spin. For, remember, the recovery action is not what you would think. It is perfectly logical if you understand what is happening in the spin, but it is not instinctive. It must be learnt.

When talking about Rolling Stability, we saw that, in ordinary flight, a wing offers a resistance to being rolled. For, if we roll it, the downgoing wing meets the air at a larger angle of attack and produces more lift, while the opposite happens on the upgoing side. But this is only true if the wing is unstalled i.e. is flying at an angle of attack less than the stalling angle. As soon as the angle of attack is increased beyond the stalling angle and the wing stalls, things take on a very different aspect. If the wing be now given a slight roll the downgoing wing meets the air at a larger angle of attack as before, but, since the angle of attack is already beyond the stalling angle, this increase of angle results in *less* lift. Similarly on the upgoing side the decrease in angle of attack results in rather more lift. (If this is difficult to understand, refer back to Chapter 3 and re-read the section on lift and the lift curve Fig. 2). The net effect is that the wing has become Unstable in Roll, and once disturbed, wants to *go on rolling.* Meanwhile, things have been happening to the drag. The downgoing wing, with its increased angle of attack, will have a larger drag than the upgoing wing, stall or no stall, and therefore the wing will try to yaw towards the downgoing wing, and moreover it will go on yawing so long as the wing goes on rolling. There is the spin; simply a continuous rolling and yawing motion with the wing stalled. The glider describes a vertical cork-screw motion, usually with the nose fairly well down. This is about as far as we can go with generalisations on the spin because every aircraft has its own attitude, speed, and characteristics in a spin. The speed is not usually very high, but, since the path of the glider is nearly vertical, the rate of loss of height is considerable.

The standard method of recovery which your instructor will have taught you is " Apply full opposite rudder, pause, move the stick steadily forward until the spin stops, and then ease the glider up gently out of the dive to normal flight ". Gliders recover from spins very quickly but this standard method is taught because it has been found best in dealing with some powered aircraft which show a reluctance to recover from a spin. The reason for applying rudder first is that, on some powered aircraft with funny spinning habits, the use of the elevators has a blanketing effect on the rudder if used first, and the pause is made to let the rudder take effect. The surprising part of this recovery action, though, is the instruction to " move the stick steadily forward until the spin stops ". All one's instincts are shouting " pull the stick back and raise the nose ", but this will only prolong the spin. Let's see why.

As said before, the spin is a continuous rolling and yawing motion with the wing stalled. The first thing to do is to oppose the yawing motion and this we do by applying full opposite rudder: that is, if spinning to the right, we apply full left rudder. To stop the rolling motion one might imagine that we could use the ailerons, but a moment's reflection shows that this will not do any good because the wing is stalled, and the ailerons will probably make things worse, since the secondary effect of them, the yawing effect or aileron drag, undoes our efforts with full opposite rudder. The only way to stop the rolling motion is to unstall the wing; in other words to reduce the angle of attack below the stalling angle and this is achieved by moving the stick forward. As soon as the angle of attack is decreased to less than the stalling angle the wing shows its customary resistance to being rolled and the rolling stops. The glider is now diving, and if the rudder is centralised, the machine may be eased up out of the dive to normal flight again. If attempts are made to recover from the spin by pulling the stick back, the only effect will be to tend to increase the angle of attack still further beyond the stall, and the spin will continue. Only when the wing is unstalled will the glider obey its elevator to raise the nose, and, once the spin is stopped, the stick-back movement to return the machine to normal flight from the dive should be made gently, otherwise there is a possibility of re-stalling the wing.

No aircraft can spin unless it is stalled first. Whenever it is stalled there is the possibility of a spin developing if for any reason the aircraft should begin to roll or yaw. Hence the simplest way to start a deliberate spin is to stall the aircraft and apply rudder in the direction in which it is desired to spin. This rolls and yaws the machine in the desired direction. It may be necessary to use the ailerons in the opposite direction, i.e. left rudder and stick to the right to produce a spin to the left. The reason for this is that once the glider is stalled, moving the stick to the right produces a feeble attempt to roll to the right, but a strong attempt to yaw to the left. During all this, it will probably be necessary to hold the stick fully back if you are going to produce a decent spin, because your glider, being an intelligent creature, will unstall itself if given half a chance due to its Pitch Stability; and once it is unstalled the spin will stop. It follows from this, that if a glider is stalled with one wing down there is a probability of a spin developing since in this case, as the glider stalls it slips towards the lowered wing, and the fin and rudder, fulfilling their normal function of keeping the glider head on to the air, will yaw the glider towards the lowered wing. (Another example of the necessity of having just the right balance between Rolling and Yawing Stability.)

Earlier on in this Chapter we saw that a glider, or for that matter a powered aircraft, can in theory be stalled at any speed by violently increasing the angle of attack beyond the stalling angle. It follows then that we ought to be able to produce a spin at any speed by sharply moving the stick back and applying rudder. This is actually the case, except that we call the maneouvre a Flick Roll instead of a spin. The path of the machine is still a corkscrew, but the axis of the corkscrew is more or less horizontal, instead of vertical in spin. A Flick Roll has been done *UPWARDS* at the top of a loop in a powered aircraft.

All Flick manoeuvres, however, are absolutely prohibited on gliders, unless the glider has been specially designed for them. The stresses are very large, and even on powered aircraft designed for these antics, flick manoeuvres are usually done only slightly faster than the normal stalling speed to keep the loads on the machine and pilot as low as possible.

Spinning Jenny or
B. S. C.

All pilots must learn to spin and to recover from a spin. Most important, all pilots must learn to recognise the beginning of a spin and to take recovery action promptly. Most gliders are very forgiving in this way, and recover instantly when action is taken. Many gliders in fact cannot be spun at all. The Tyro may well be tempted to ask " Why not make all gliders so that they cannot be spun? " The answer is that if you design an unspinnable glider you have got to sacrifice other qualities and the net result is a glider which is not as efficient as it could be. Besides, like all aerobatics, spinning can be rather fun.

It only remains to describe what we may call the Clot's Spin. This is the spin into the ground from the final turn of a circuit. It is so unnecessary, and so criminally stupid, but has been done so many times in the history of aviation that its description is worthwhile. It is much rarer in the gliding world than the world of power aircraft, but if this description should save one person from falling into the trap, this little book will have justified its existence.

Although as far as I am aware, no specification has been issued to cover him, the British Standard Clot is a man who, insofar as he thinks at all, thinks he knows best. He flies badly, but will brook no criticism from his instructor. He is fortunately rare these days, but one does catch a glimpse of him now and again. One day when he is flying a circuit of his aerodrome, flying slowly on his last crosswind leg it occurs to him that he is cutting it rather fine and may undershoot. He therefore raises the nose of his glider slightly and starts to turn into wind. (Raising the nose is, of course, pure lunacy since it almost guarantees that he will now undershoot.) His turns are bad at the best of times, but on this particular occasion, being rather near the ground, he has an inclination to under bank and force the glider round the turn with lots of rudder. This merely skids the glider and results in further loss of speed. By this time the glider is beginning to stall with one wing down, and the nose swings round the turn and starts to go down. He still does not reckon that there is anything abnormal about this, but tries to pull the nose up by further backward movement of the stick. The nose goes down further and he pulls the stick back further, in the meantime quite oblivious of the fact that his rudder is still hard over. The glider is now beginning to spin and it dawns on him that the turn is a little odd, and a good deal steeper than he intended. He still has not recognised it for what it is; a real honest spin, and in a vain endeavour to reduce the steepness of the bank he puts the stick across to the other side of the cockpit. The aileron drag of the inner wing joins forces with the rudder and into the spin goes the glider, good and hearty. There is, of course, insufficent height to recover and the glider crashes.

Written out like this, it seems incredible that anyone could be so stupid, and yet it has happened time and again. People have even climbed from the wreckage and still been unaware of what went wrong. The moral is clear. Fly accurately, get to know the stall and spin symptoms until they are printed on your mind, and never, never, fly too slowly near the ground.

Chapter 7

TYPES OF GLIDER

It is now time that we took a closer look at the various types of glider that can be seen in the hangar of any gliding club. In the light of what we have learned, we should now be able to see much more of the " whys " and " wherefores " than before.

Taking first things first, consider the Primary Glider. This is a creature which is slowly becoming extinct, but there are still quite a few of them about. It has no fuselage at all; just a very simple framework of wood, or sometimes, steel tubes, carrying the pilot's seat and tail unit and supporting a very simple rectangular wing mounted high up above the pilot's head. This wing is usually braced by wires to the main frame, above and below. The portion of the main frame above the wing is usually fabric covered, forming an inverted V-shaped fin above the wing. The controls are quite conventional but extremely simple; in fact, the control cables are probably visible for almost their entire length. The accent all through is simplicity, lightness and cheapness, combined with great toughness. The Primary's function is to teach people to fly by the solo instructional method. In consequence it has to be able to take a vast amount of mal-treatment without complaint. Wire braced wings are therefore indicated, since a damaged wire is much easier, and cheaper, to replace than a strut. Also, in the event of a minor prang, the pilot, in his harness, will be much better off with no fuselage around him since there is no danger from splintered plywood.

In flight, the glider is enormously stable in all three planes.

It has to be; since it will be flown by pilots with practically no experience. Hence the reason for the abnormally large tail plane, and the above-mentioned fin above the wing. This great stability, of course, has to be paid for; and the price is sluggish and heavy controls. The controls are nicely arranged, however, so that while the pilot has ample control for ordinary flying, he will find it extremely difficult to get the glider into any abnormal attitude. Most well designed Primaries are completely unspinnable.

The wing is of rectangular plan form, so that all the ribs are of the same shape, and the span is relatively short. Both these make for a light, cheap wing.

In performance the Primary is, one as would expect, pretty poor. The gliding angle is of the order of 1 in 8 or 10, and the rate of sink somewhere about 5 ft./sec. minimum. However, it does its job admirably and is slow flying, cheap, and safe. Perhaps the worst criticism that can be levelled at the poor Primary is that it is too stable and easy to fly. Though these qualities are obviously necessary, they do tend to produce slovenly flying habits in Primary-trained pilots; habits which often are difficult to eradicate later on.

Some Primaries have been fitted with " nacelles ", small egg-shaped fuselages to streamline the pilot and main frame. While this does nothing to improve the bad points of the Primary, it does have a very marked effect on the performance; and Nacelled Primaries have been used for many years as elementary soaring trainers at sites where there is a good ridge for hill soaring.

Primaries have a very peaked L/D curve and this means that there is only a very small speed range where any efficiency at all can be expected. Above and below this speed the gliding angle begins to resemble that of a brick.

Examples of Primaries are the Dagling, Eon Primary, and the German Zogling, and S.G.38.

Next, in order of efficiency, come the Intermediate Sailplanes. This is a very loose term which is applied to a fairly wide range of gliders. Generally, one may say that it covers all gliders which are efficient enough to soar, or stay up and climb in favourable conditions, but which have not got a big speed range; which in fact have not got good " penetration ". Types included in this category range from the Cadet, Tutor T.31 two-seater to the Grunau Baby, T.21 or Sedbergh two-seater and many others. In these types we have a proper fuselage, usually of a simple form with flat sides; a fairly simple wing supported by struts, and a generally much more aircraft-like appearance than the Primaries. The most striking difference, however, is that the ratio of span to chord, or Aspect Ratio, is much greater in the Intermediates, and the wings are usually tapered in plan form, and in thickness to some degree. We shall discuss this matter of Aspect Ratio later on in rather more detail. The more efficient Intermediates have a gliding angle of the order of 1 in 20 and a minimum sinking speed of round about 2½ to 3 feet per second. They still have a peaky L/D curve, i.e. they are only efficient over a relatively small speed range. Their response to control movement is much quicker than the Primaries and they are not so stable. This is not to say that they are unstable; they have, of course, positive stability, but the stability is not excessive to the point of interfering adversely with the quickness and lightness of control. It may be said that an efficient Intermediate Sailplane like the Grunau Baby or Sedbergh two-seater will do almost anything that a High Performance Sailplane can do *except fly fast.*

The Intermediates in general have a fairly low wing loading, giving a slow flying speed, though not usually as slow as the Primaries. The wings usually have a certain amount of wash-out at the tips to give reasonable aileron control near the stall, and the ailerons are usually of the differential type to minimise aileron drag. A central landing wheel is usually fitted.

Now, why, in the search for more efficiency, do we have to go in for bigger Aspect Ratios? To find the answer to this we must go back to first principles. Efficiency, or good gliding angle, depends as we have seen on the L/D ratio of the glider as a whole. Anything which reduces drag without reducing lift, or conversely, increases lift without increasing drag, will increase the L/D ratio and improve the gliding angle. The one thing which has the biggest effect on the *L/D* ratio is the wing itself. In the earlier chapters we looked at wings and aerofoils in side view, but this is not quite the whole story. Let us now look at a glider wing head on.

Imagine a glider flying straight towards you out of the page. Due to the lift that the wing is producing there is a region of reduced pressure above the wing and a region of increased pressure below the wing. In consequence the air *tends* to flow outwards under the wing, round the tips, and inwards over the top surface. It does not of course actually succeed in doing this, but the effect is to deflect the air flowing under the wing slightly outwards and to deflect the air flowing over the wing slightly inwards. This effect is greatest near the tips and least in the middle of the wing. Just behind the wing, these outward and inward flowing tendencies meet again and they join up in forming a vortex, (a sort of trailing whirlpool) which trails from each wing tip. The energy which is wasted in these vortices comes from the glider itself and the drag that they cause is known as *Induced Drag.* Now since the wing-tips are the main criminals in causing this induced drag the idea would be to have no wing tips! Nobody has yet thought of a practical way of building a wing with no wing tips, but we can make the wing tips small in comparison with the efficient middle part of the wing. Fig. 17 shows the plan form of three wings of equal area. The shaded areas show the relatively inefficient

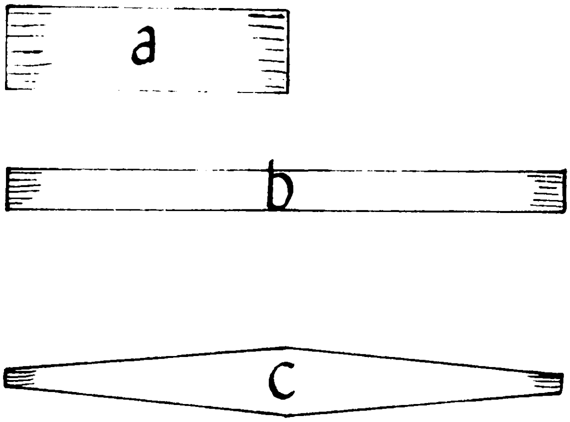


FIGURE 17

tip portions. In Fig. 17(*a*) the shaded area is a fairly large proportion of the whole wing. In Fig. 17(*b*) we can see the enormous improvement made by doubling the span and halving the chord (doubling the aspect ratio in fact). Now the tips are quite a small proportion of the wing and the induced drag is much less. We can go even better than this if we like to taper the wings as well (Fig. 17(*c*)) and here the inefficient tip proportion is very small, and so is the induced drag. We must finish this little homily on induced drag with an apology to the aerodynamicists for a frightful over-simplification of what is really quite a complicated business.

Thus, if we want good efficiency we must have a big *L/D* ratio and we can only get this if we cut the induced drag as low as possible. We can only do this by using a large Aspect Ratio. Naturally, there is a limit to the Aspect Ratios we use, because as we make wings longer and narrower, it becomes more and more difficult to make them strong, and stiff enough for their job without making them prohibitively heavy. Tapering the wings helps here because the lift is concentrated more in the middle and less out at the tips, and this reduces the bending in the wings. Wash-out does the same thing, except that if you try to fly the glider upside down, the wash-out becomes *wash-in* and the lift is concentrated out at the tips. This is one reason why inverted flight is prohibited on most gliders.

The last type of glider which we have to consider is the Cross Country or High Performance Sailplane. Into this category come all the Laminar Flow sailplanes, the Skylarks, Olympia 419 and 460, the Eagles, etc., the older types with conventional aerofoils such as the Sky, Weihe, Gull IV, Kite II, and many others. Recent competitions have shown that the laminar flow types are considerably more efficient. Whatever their efficiency, all these types have the same purpose, that of cross country and cloud flying so we can consider them as a class. In all cases these machines have wings of great span and large aspect ratio to give great efficiency. The wing sections are very carefully chosen to give as flat a *L/D* curve as possible so that there is a fairly large speed range over which the glider has a good gliding angle. We say in fact that these machines have good penetration. To keep the drag to the absolute minimum, the fuselages are usually rounded out to a smooth oval section and the cockpit is enclosed with a plastic bubble canopy. Brakes, or spoilers are always fitted, and indeed these aids are becoming usual now even on Intermediate types. A single central landing wheel is usually fitted, though, on machines of the highest performance, this may be omitted, since it does undoubtedly add a little drag. Everything is streamlined to the last degree to give the absolute minimum of drag.

The performances these gliders can achieve are gliding angles of 1 in 25 to 30 and more, combined with minimum sinking speeds of about 2 feet per second. The wing loadings are usually somewhat higher than the Intermediates and the best speeds are in the 40 to 50 m.p.h. range as against the 32 to 38 m.p.h. of the Intermediates. The High Performance Sailplanes will still have gliding angles of the order of 1 in 20, however, even when flying at speeds of 60 and 7 m.p.h. and even more.

The fact that their best speeds are somewhat higher than the Intermediates does put the High Performance Sailplanes at a slight disadvantage on certain days when thermals are small and difficult to circle in, since the higher speeds means a large turning circle for a given angle of bank. However, their greater efficiency at high speed means that they can cut through down draughts fast, where Intermediates would lose a great deal of height in flying through them slowly. The High Performance machines also can put up high average speeds across country.

The characteristics of these gliders are, generally, fair stability, and good, light, and quick controls. Machines vary of course in this, and those gliders with very large spans are the most difficult to equip with really nice aileron controls.

In layout these gliders are nearly all cantilever jobs, i.e. no struts at all, to keep down the drag. A point in the layout is that these types must be simple and quick to rig and de-rig since they will often have to be trailed home by road. Many of them have a very complete panel of blind flying instruments, and all have provision for carrying a pilot's parachute. Most of them are permitted to carry out a limited range of aerobatics, the usual ones being loops, stall turns, and spins.

Chapter 8

INSTRUMENTS

In nearly all gliders, except Primaries, there is an array of instruments mounted on the panel in front of the pilot. In a High Performance machine there may be quite an alarming number, while humbler gliders manage very well with a meagre two or three. Now it is not suggested that you need become an expert instrument repairer if you want to fly, but an understanding of how some of these instruments work is going to be of great help.

Aircraft instruments will in general, tell the truth, but to obtain the truth from them they have to be read with a little intelligence. In this chapter we will investigate the principles on which the more important instruments work and see what are the limitations of them. Then, perhaps when your instruments seem to be telling odd stories you will know why, and not be confused.

Firstly, what instruments are we likely to meet? The usual ones are: Air Speed Indicator (usually abbreviated to A.S.I.), Altimeter, Variometer and Compass. In addition, there are several instruments designed mainly for blind flying including Turn and Bank Indicator, Artificial Horizon and Cross Level and Fore-and-Aft Level.

We will deal with the former group first, and take them in order.

The Air Speed Indicator, or A.S.I., oddly enough, indicates the airspeed of the glider. It is a little instrument with a dial and pointer rather like the speedometer of a car, and it is calibrated in M.P.H. or knots (or even in Kilometres per hour in the case of some foreign instruments). It shows the speed of the glider relative to the air through which it is flying. It has nothing whatever to do with the speed of the glider *over the ground.* Strictly speaking, it does not even indicate the air-speed truly, as we shall see later.

The instrument works by measuring the pressure in an open ended tube poking forward into the air stream. This pressure is very small; at 45 m.p.h. it only amounts to about one inch of water in a U-tube, so the instrument is fairly delicate. Inside the instrument there is a flat disc-like capsule with concentric corrugations to make it springy, and this capsule is connected by a pipe to the open ended tube of the Pitot head. The latter is the contraption usually fitted on the top of the nose of most gliders and consists of two tubes pointing forward into the air. One tube is open ended, and one is closed with a series of small holes drilled along the sides. Pressure caused by the impact of air on the open ended tube causes the capsule, which is of very thin metal, to bulge, and this bulging is multiplied up by levers and gear wheels and made to move the pointer. The first question everyone asks is, what is the closed ended tube for? Well, if you are measuring a very small increase of pressure, you must have something to compare it with. What the instrument requires to know is how much the pressure in the open ended tube is increased by the impact of the air above the ordinary static pressure of the air. Therefore, the case of the instrument, which should be airtight, is connected to the second tube, the closed ended one with the small holes along its sides, and thus the pressure inside the instrument case is the atmospheric, or static, pressure at the point where the open ended tube is. If we left the case of the instrument open to the pressure of the cockpit we might introduce quite large errors since air may tend to blow in or out of the cockpit and make the pressure slightly above or below the pressure outside. Since we are measuring a very small pressure increase, this is quite important.

Now for the errors. We call the reading of the A.S.I. the Indicated Air Speed or I.A.S. and this is only truly the Air Speed at sea level. At all heights above sea level the A.S.I.

reads low. This is because the pressure increase in the open ended tube varies directly with the density of the air. This is of relatively small importance until we reach great heights; at 20,000 feet for instance 30 m.p.h. I.A.S. is in fact 41·2 m.p.h. True Air Speed, and in any case we are not much concerned with True Air Speed in the gliding world though it is very important to navigators in powered aircraft. As it happens, the lift and drag of the glider are affected in exactly the same manner by the density of the air, both decreasing with decreasing density. We mentioned this when dealing with the lift and drag of aerofoils in Chapter 3. In air of lowered density then, a glider will stall at a higher airspeed (true) but since the A.S.I. reads low by the same amount, the glider will stall at the same reading " on the clock ". As an example a glider stalls at 30 m.p.h. true airspeed at sea level. At 20,000 feet (if you ever get there) it will stall at 41·2 m.p.h. true airspeed, but in both cases the A.S.I. will read 30 m.p.h. Similarly, the speed for minimum sink, or for maximum glide angle, stay at the same points on the dial for all heights although the true airspeed increases with height. We can look upon this error then as a positive advantage, since it saves the pilot much mental effort. The instrument in fact tells us something more useful than the True Air Speed.

The next error we must consider is Position Error. The air all round an aircraft is disturbed somewhat for quite a fair distance above, below, and in front of it as well as behind. The only satisfactory place to put the Static pipe is about 25 yards away from the nearest bit of the glider but this is faintly impracticable! The designer goes to considerable trouble to find the best place to fit the Static pipe but even when he has found it he then has to find out how much the nearness of the glider's nose, or wing, affects the reading. In many cockpits there is a small placard giving the corrections required at various speeds. This matter is further complicated by the fact that at only one angle of attack, does the air really hit the open ended tube dead head on. However, a reasonably good result is obtained, with most gliders, by fitting the Pitot Head on top of the nose. Do not be misled, by the way, by the single tube affair on the nose of some gliders. It isn't a single tube at all. It is the same two tubes, only the closed ended one has been fitted outside the open ended one.

Pitot Heads have an irritating tendency to ice up and stop working in icing conditions in cloud. Sometimes an electric heater is fitted to melt off the ice, but more usually these days the open ended tube is turned back and buried inside a little can affair which is sunk into the nose of the aircraft. This latter type is more or less immune from icing troubles. Also in the search for efficiency there is a tendency for the static pipe to disappear these days. It is replaced by two carefully positioned holes in the fuselage, one each side, to avoid errors due to yaw. If the position of these holes is properly chosen, they can give a very accurate static pressure, and, of course, they do avoid the little bit of drag that would be caused by a pipe sticking out of the fuselage.

Lastly, there may be some errors in the A.S.I. instrument itself. These should be known if they are present, and if the instrument is serviceable, they should be so small that they can be neglected. If suspected the instrument should be checked.

With all these errors and icing troubles, it seems surprising that nobody has yet produced anything better able to indicate airspeed. Nobody has however. If you think you can, please do so.

The Altimeter does *not* indicate the height of the glider above the ground. Many people have a touching faith that the instrument does just this. They all learn the truth in the end, but some learn it the hard way. You can, of course, find out the height of your glider above the ground by the use of the altimeter, but you need to use your intelligence as well. To see why this should be so, we must first understand how the instrument works.

Inside the altimeter case there is a capsule, rather like that in the A.S.I., except that in this case the capsule is exhausted of air, and sealed up. It is prevented from collapsing, due to the atmospheric pressure, by the action of a strong spring. If the atmospheric pressure varies, the capsule will be squeezed flatter, or allowed to bulge more, according to whether pressure increases or decreases. This movement of the capsule is multiplied up by levers and gears and is shown by a pointer on a dial. In point of fact most modern altimeters have three pointers, one for hundreds, one for thousands, and one for tens of thousands of feet, but the principle is unaltered. It is in fact, a perfectly ordinary little barometer, calibrated in feet, or metres, and with a much bigger range than the one which probably hangs in your hall. The inside of the case of the instrument is connected to the static pipe (the closed ended one) of the Pitot Head. Many pilots are lazy about this and leave the altimeter connection open to the cockpit and in actual fact this does not matter much, as the pressure changes that the altimeter measures are quite large, and tiny variations between the pressure outside the cockpit, and inside it, have very little effect on the instrument's reading.

Since the altimeter works by measuring the static, or atmospheric, pressure, any changes in that pressure will affect it. To enable the pilot to set it to zero, the altimeter has a little knob, which, when rotated will move the pointer or pointers. If the pilot sets the instrument to zero before taking off, the reading on the dial in flight will be a true reading of his height above the point of take-off. Suppose, for example, he climbs to 5000 feet above his take-off aerodrome, then his altimeter will show 5000 feet. If he now flies off across country and crosses a range of hills 1500 feet higher than his take-off point, even though the altimeter should still read 5000 feet, he has 5000—1500 = 3500 feet between him and the hills. If his altimeter should read 1500 feet he is actually down to hill top height. Now the pilot has a map which gives the height of various points of the country in feet above sea level, and these points are joined by contour lines. The various heights are coloured differently on the map so that the pilot can see at a glance the height of the ground over which he is flying, and that of the country ahead of him. He can, therefore, work out very simply how high above the ground he is at any moment, provided he knows exactly where he is. Most pilots, when flying at a Club site and not intending to fly across country, set their altimeters to read zero before take-off. The altimeter then reads in actual height above the take-off point. When flying across country, however, the usual practice is to set the altimeter, before take-off, to read the actual height above sea level of the take-off point. By this means the pilot saves himself some mental arithmetic since the altimeter reads height above sea level while he is in the air, and his map contours are marked in heights above sea level.

There is a further source of error which must be guarded against. Often when you put a glider away for the night with the altimeter reading zero, you will find next morning that the pointer may read 200 feet or so. This is because the atmospheric pressure has decreased during the night. If it had increased the altimeter would be reading minus 200 feet or so. Now if you took off, having set the altimeter to zero, and flew for several hours and the atmospheric pressure changed by this amount while you were in the air, your altimeter would not read zero when you landed, even though you landed on the same spot where you took off. Fortunately, the atmospheric pressure does not often change very much in a few hours in this country, but in freak weather conditions you must watch out for this. Also, if you are flying from one side of this island to the other the atmospheric pressure may be quite different at the spot where you land from that at your take-off point. It behoves the wise pilot to have a look at the weather map, therefore, before making a long cross-country flight, so that he will know what to expect.

Some altimeters have a small scale on the dial which shows the actual pressure in millibars at which the instrument will read zero. This is really a legacy from the sphere of power flying. Its purpose is that a pilot of an aeroplane approaching his destination can call up, by radio, the aerodrome controller and receive from him the pressure in millibars on the aerodrome. Armed with this information, the pilot can then twiddle the setting knob until this millibar reading comes opposite the index mark. He then knows that his altimeter reads true height above his destination aerodrome.

There is, actually, an altimeter which does read true height above the ground. It is called the Radio Altimeter and is really a radar set which finds out the distance of the ground below the aircraft on the echo-sounding principle. However, it wants all sorts of electricity, weighs quite a lot by our standards and you would not be able to afford to buy one anyway. It is not for us.

The Variometer is the one really vitally important instrument for the soaring pilot. In fact it is true to say that serious cross-country soaring had to wait until the invention of a practicable variometer, and even the best of today's pilots are almost helpless without a good variometer. The function of the instrument is to tell the pilot whether he is rising or sinking relative to the earth. It is an instrument peculiar to the gliding world, and though it is true that powered aircraft are often fitted with a climb and descent indicator, this latter is a very clumsy and insensitive contraption compared with our variometer.

There are many different types of variometer and somebody is always inventing a new one, but nearly all of them work on basically the same principle. This principle is that if you have a bottle of air and you raise, or lower it, the pressure outside the bottle will become less, or more, than the pressure inside the bottle, since the atmospheric pressure becomes less as we rise through the atmosphere, and *vice versa*. In consequence, as we rise the air in the bottle will try to get out, and as we sink air will try to get into the bottle. The variometer simply detects this flow of air and measures it to indicate how fast the glider is rising or sinking.

Fig. 18 illustrates the working of perhaps the most widely used type of variometer. *B* is a bottle; often in fact, an ordinary vacuum flask of exactly the same type that you use to keep your tea or coffee hot. The reason for using a vacuum flask is to insulate the air inside from any sudden changes of temperature which would alter its pressure. This bottle is connected to two small tapered tubes of transparent plastic mounted on the instrument panel, and it is connected to the top of one tube and the bottom of the other. The other two ends of these tubes are connected to the static pipe of the Pitot Head. Inside these two tapered tubes are two small, light, hollow balls or pellets, one red and one green. Now imagine that the glider in which this affair is installed starts to rise. The pressure at the Static Head decreases so air tries to get out of the bottle. It cannot flow down past the red ball since this is a fit in the bottom of its tube, but it can, and does flow up the other tube past the green ball lifting it up its tube as it does so. The faster the glider

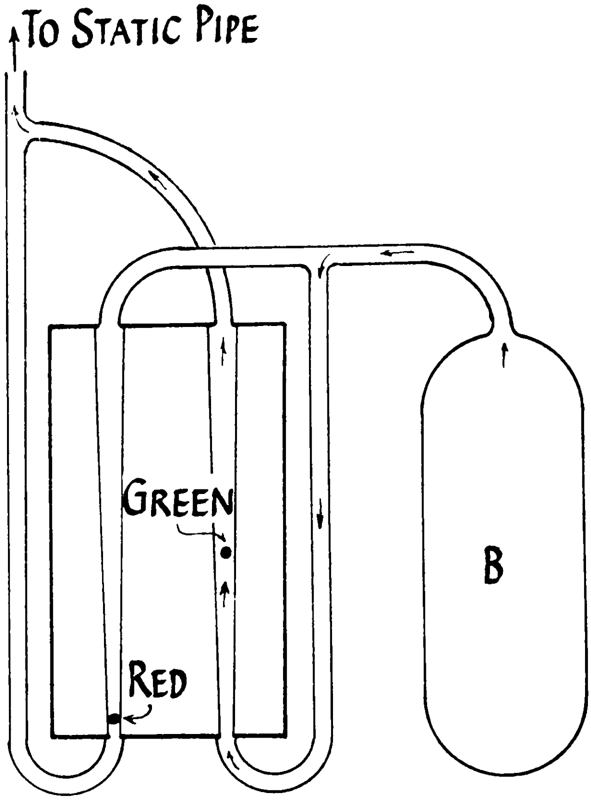


FIGURE 18

rises, the faster the air flows out of the bottle, and the further the green ball goes up its tube into the bigger part of the taper. Thus the position of the ball gives an indication of the rate of climb, and figures in feet per second or metres per second are marked behind the tube. Exactly the same happens if the glider sinks, except that in this case air is flowing into the bottle. It cannot get down past the green ball since this is now snug in the bottom of the tapered tube, but it can go up past the red ball. In exactly the same way the position of the red ball in its tube shows the rate of sink. If both balls rest at the bottom of their tubes then the glider is neither rising, nor sinking. The Static pipe of the Pitot Head is used because if we left the pipe open to the cockpit any tiny variations in cockpit pressure, caused perhaps by opening or closing windows, ventilators, etc. would cause considerable errors for remember, as in the case of the A.S.I., these are very small changes of pressure that we are dealing with. These days the tubes of the variometer are made to a rather different plan. The tubes themselves are parallel, but they have a tapered slot machined up the backs of the tubes. The red and green balls are replaced by similarly coloured pistons, which are rather easier to see, but the principle of operation is exactly the same.

Lately, there has been a spate of electric variometers, and somebody seems to be inventing a new one almost every day. The basic principle remains the same, however. We have the same capacity, or bottle, and we measure the air going in or out of it. The big advantage of the electric variometer, though, is that we do not have to make the air move any pistons, or needles on its way in or out of the bottle. We can let it flow quite freely, and simply detect its flow by means of some electrical gadget, hot wire, thermistor, or what you will. In consequence the electric variometer can be made much more sensitive, and be much quicker in responding to changes of height.

The things we want from a variometer are sensitivity, i.e. ability to detect small rates of rise or sink, combined with absence of lag. By this we mean that the variometer should show a climb as soon as the climb starts, and should stop showing climb as soon as the climb stops, and the same, of course, with sink. In fact, we want to know what is happening *now*, not what was happening half a minute ago. It may seem surprising that an instrument working on these apparently primitive principles can do the job. The fact remains that it does. If you require convincing, put the vacuum flask under your arm, hold the instrument in your hand, connect the two with a piece of rubber pipe, and walk slowly up and down stairs. You will be surprised at its incredible sensitivity.

(We should, perhaps, mention that this experiment is easier if the instrument is first removed from the glider.)

The main errors in variometers are due to varying airspeed of the glider. Strictly speaking this is not an error at all, it is the variometer telling the too-literal truth. The way of it is this. In rough and lumpy thermals it is often very difficult to keep the airspeed of the glider steady. The glider gets buffeted about, and the nose rises and falls slightly causing fluctuations in the airspeed. These fluctuations may be regarded as tiny dives and zooms. The variometer shows the dives as " sink " or more probably " reduced climb ", and the zooms as " increased climb " but this may be misleading, although it is the literal truth, since the zooms may, or may not, occur where the thermal is lifting fastest, and the pilot wants to find this best part of the thermal.

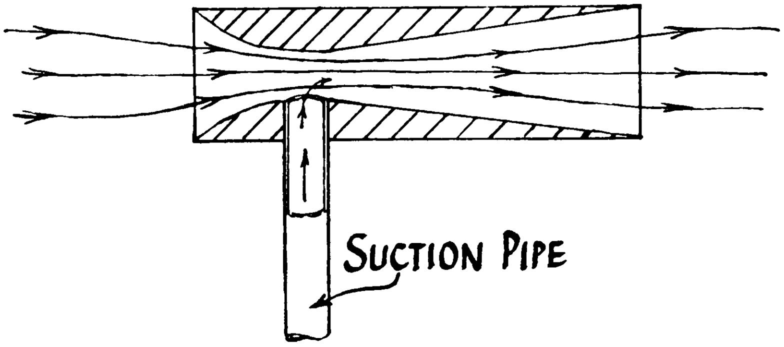


FIGURE 19

To get round this difficulty many gliders have now been fitted with a Total Energy Venturi to which the variometer is connected, instead of connecting it to the Static Head. To understand how this works we must first have a look at the Venturi itself. Fig. 19 is a section through a Venturi tube so-called after its inventor. It is simply a hollow tube with a smooth constriction near one end, and a smooth gentle bell-mouth at both ends. The bell-mouth at the rear end is generally much longer than the front one. This little tube is set up on the glider so that the air flows straight through it. In doing so the air at the throat of the constriction undergoes a very sharp reduction of pressure and if we connect a pipe to the throat as shown, the Venturi will suck air up through it. The faster the air flows through the Venturi, the harder it will suck. At first sight this may be very surprising. However, with any fluid, if you cause it to move faster *without supplying any energy to it*, it loses in pressure what it gains in velocity. This is known as Bernoulli's Theorem. It should be obvious that the air is moving much faster through the throat of the Venturi than through the open ends, since the area of the hole is much smaller. The bell-mouths are smooth-contoured to make the speeding-up, and slowing-down again of the air as free from turbulence as possible. Granted then that a Venturi tube sucks, where does that get us? Well, firstly, the Total Energy Venturi for the variometer has to be very carefully made so that its " suction " at any airspeed is exactly equivalent to the pressure or " puff " of the open ended tube of the Pitot Head. Now connect the variometer to the Total Energy Venturi instead of the Static pipe of the Pitot Head leaving the bottle connection etc., exactly as before. Now launch the glider to 40 m.p.h. The Venturi immediately starts to suck and it sucks air out of the bottle until the pressure in the bottle equals the pressure at the throat of the Venturi. During this time the green ball rises indicating " climb " even though no climb may have taken place. From now on, *so long as the airspeed stays at* 40 *m.p.h.*, the variometer will behave exactly as before, indicating climb or descent as appropriate. But if the airspeed varies then the Venturi starts interfering with things. Imagine that, while circling and climbing at 4 ft./sec. in the thermal, the pilot unintentionally allows the airspeed to fluctuate between 40 and 50 m.p.h. While the glider is gaining speed, the rate of climb becomes less since the extra speed is picked up by gentle diving. Hence the rate at which air flows out of the bottle would normally decrease and the green ball would show " less climb " perhaps 2 ft./sec. However, due to the increasing airspeed, the Venturi suction is becoming greater and this augments the flow of air from the bottle and the green ball shows the same rate of climb as before (4 ft./sec.). While the glider is losing airspeed, or zooming, it will be climbing faster than before, say about

6 ft./sec., but as the falling airspeed is causing the Venturi suction to decrease the extra flow of air from the bottle is discouraged and the green ball shows the same rate of climb, 4 ft./sec.

The Total Energy Venturi, then, eliminates the effects on the variometer of varying airspeeds, or, as some pilots put it, " it irons out the Stick Thermals ". This is very useful, since the pilot knows that if the green ball shows " increased climb " in one part of his circle, then the increased rate of climb really is due to the glider hitting the more active part of the thermal, and is not a false reading caused by pulling back on the stick.

In icing conditions the Venturi may become blocked with ice, so to guard against this trouble and the subsequent one of the resultant water getting into the instrument, a small water trap, with a tap on it, is usually fitted between the venturi and the variometer. When this tap is opened it allows any water in the pipes to drain off, and it also allows the variometer to work as an ordinary variometer again, using cockpit pressure. As we have said before, this may not be quite the same thing as Static pressure, so the pilot should not be surprised if, when flying with the tap open, the variometer behaves a little oddly when he opens or closes windows, ventilators, etc., or even when the machine yaws or slips, since this may well cause air to blow in or out of the cockpit.

A different type of Total Energy system has come into favour lately. This is the variable capacity type. Instead of applying suction to the static side of the variometer, we use the ordinary static pressure, but, between the instrument and the bottle we include a small extra capacity. This capacity has a thin membrane as one wall, and the pressure from the Pitot Head is applied to the other side of the membrane. Thus changes of airspeed cause the total capacity to vary since the Pitot pressure causes the thin membrane to deflect. This produces exactly the same effect as applying the venturi to the static side of the instrument, and it has the advantages that there is no need for a pipe to stick out into the airflow, and, provided that the Pitot is immune from icing, the variometer is unaffected by ice.

In very gusty conditions the Total Energy system may give rather queer indications. This is due to the fact that the Venturi is quite unable to distinguish between an increase of airspeed due to a dive, and one due to a gust hitting the glider. In both cases it tries to encourage the green ball. In such conditions, it may sometimes be better to open the tap and revert to normal operation, bearing the previous remarks in mind. The advantages far outweigh this minor snag, however, and few pilots who have used a Total Energy Variometer ever want to be without it again.

Why the curious name Total Energy? Well, what the instrument is actually doing for you is running a sort of " bank account " of your stock of energy. If you turn some of your height into extra speed, it says " Total Energy unchanged " while the ordinary variometer would have said " Loss of Height ". If you turn your extra speed back into height again the Total Energy variometer will say once more " Total Energy unchanged " while the ordinary variometer would say " Gain of Height ". All these statements are true, but in the case of the Total Energy variometer the instrument is keeping an eye on your Kinetic Energy, or energy due to speed as well as your Potential Energy, or energy due to height, and it credits or debits you according to whether your speed increases or decreases. The ordinary variometer tells you how your Potential or Height energy is changing. The Total Energy variometer tells you how your Potential, and Kinetic, energy is changing: in fact, your " Total " Energy.

The A.S.I. Altimeter and Variometer may be regarded as the basic flight instruments of our gliders and one can enjoy an enormous amount of flying with just those three. For serious cross-country flying you will need to fit a Compass, but since this is basically similar to any other type of magnetic compass, we shall not investigate it much further. When installed, however, it should be " swung " by a competent person. This involves setting up the glider on various headings, noting the readings and correcting out as much of the errors as possible. This should be done because the metal in the structure of the glider may somewhat upset the accuracy of the compass. When the compass has been corrected as far as possible the errors on each heading should be noted and recorded on a card on the instrument panel. Methods of correction vary, but the most usual are either fitting tiny magnets into a special box on the compass, or by turning screws which move magnets already fitted inside the compass case.

If the glider is going to be flown into cloud, the above array of instruments is not sufficient. Any pilot who flies without any fixed visible objects on which he can orientate himself, will, after one or two minutes, lose completely his sense of direction. He will be unable to distinguish between a steady accurate turn and straight flight, and his compass will not help him here as its indications are very erratic when the aircraft is turning. He will also be quite unable to distinguish between level flight and nose up or down attitudes, although his A.S.I. and the noise and feel of his glider will help him. Unfortunately, the speed of the glider is related more to the attitude that the glider was in a few seconds ago, than to its attitude now. Consequently, the pilot is very inclined to overcorrect in pitch and build up an oscillation. It is worth noting that not even birds can fly blind. Bats, of course, cheat, since by squeaking, and listening to the echoes, they, in effect, use a form of radar.

To provide the pilot with the information he requires, when flying blind, the glider must be fitted with " Blind Flying " Instruments. These include the Turn and Bank Indicator and the Artificial Horizon. The Cross Level and Fore and Aft Level are not strictly speaking blind flying instruments but they are of considerable help in cloud. It is quite sufficient for blind flying, to fit a Turn and Bank Indicator to supplement the basic flight instruments. It makes things much easier if, in addition, an Artificial Horizon is installed.

The Levels being the simpler instruments we will describe them first. The Cross Level is really nothing more than our old friend the carpenter's spirit level, with a bit more curve in the tube, mounted crosswise on the instrument panel. If the glider is flying straight and the wings are level the bubble will be central. However, in a correctly banked turn the bubble is also central, indicating that there is no unbalanced force acting on the side surfaces of the glider. If the glider skids or slips, whether in a turn, or when flying straight, then the bubble will move out of the central position. The Cross Level, then, does not indicate the angle of bank. It merely shows whether the bank is correct for the rate of turn, if any. The bubble has the disadvantage that the indication appears to be the wrong way round. For this reason pilots are sometimes advised to " chase the bubble with the stick " instead of attempting to " move the bubble back with the stick ".

In a better form of this instrument the glass tube is curved the other way, i.e. concave upwards, and filled with spirit as before, but, instead of using a bubble to give the indication, a metal ball is used. This ball can roll freely along the curved tube, through the spirit, and the ball does appear to obey the movement of the stick rather than having to be " chased ". This ball form of Cross Level is often fitted into the Turn Indicator in which case the instrument is usually known as a Turn and Bank Indicator. This is an unfortunate name as the ball does not indicate angle of bank. A better name, which is sometimes used, is Turn and Slip Indicator.

The Fore and Aft Level is an instrument which works on very similar principles. It shows the pilot, by means of the height of a column of coloured liquid in a glass tube on the instrument panel, his attitude, nose up, or down. A scale is usually fitted behind the tube for reference purposes. Fig. 20 shows the main features of the instrument, and it will at once be apparent that it is really only a peculiarly shaped spirit level. The constriction in the lower limb is put there to stop the liquid from surging about violently in rough conditions. There is no doubt that the Fore and Aft Level is an extremely useful instrument when blind flying. It can almost take the place of the A.S.I., when blind, and it has the advantage that it has much less lag, i.e. it shows what is happening to the attitude now, whereas the A.S.I. shows the effect of the attitude several seconds ago. Also it does not ice up just when you want it most.

The really vital blind flying instrument is the Turn Indicator. The dials of Turn Indicators vary somewhat in appearance, but all of them contain a vertical needle which moves across some reference mark to right or left. When the needle is central the glider is not turning, i.e. is flying straight. When the needle is over to the left the glider is turning to the left and *vice versa*. The further over the needle goes, the greater is the rate of turn. It accomplishes this rather clever feat by means of a small gyroscope inside it. Fig. 21 shows this " brain " of the Turn Indicator. The gyroscope, which spins very fast, is mounted so that its axis is span-wise in the glider. The frame in which it is mounted is pivotted fore and aft so that the gyro, complete with frame, can roll, but this rolling motion is controlled by a spring which holds the frame level.

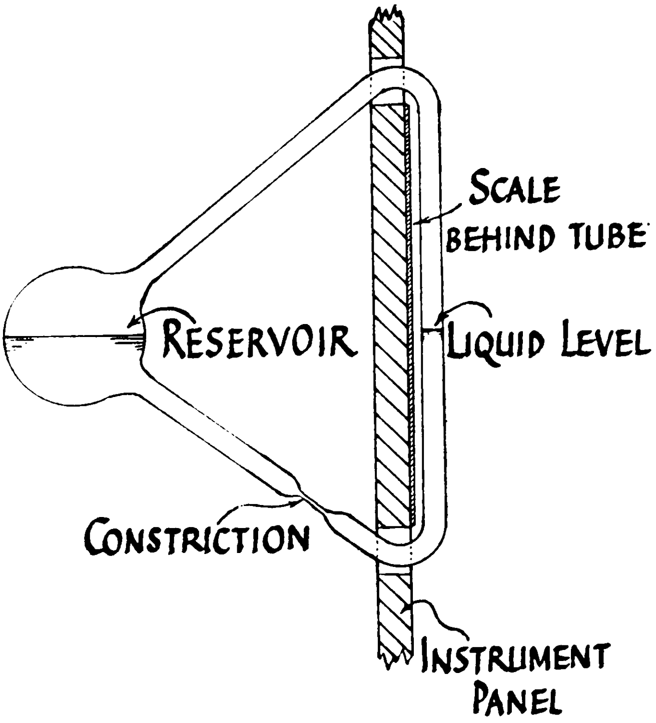


FIGURE 20

Now it is one of the strange properties of a gyroscope that if, when it is running, you turn the axis round, the gyroscope will turn itself in a direction at right angles to the turning motion, until its own axis of spin coincides with the axis of turn. This is called precession and sounds most involved and if you cannot grasp it, no matter. Referring again to Fig. 21 if the whole instrument be rotated in yaw, as it must be if the glider is turning, then the gyroscope will try to roll itself, with its frame, until its axis coincides with the true vertical. It cannot do this, because the spring prevents it but it will try to roll, and its effort varies with the rate of turn. This rolling movement of the frame is shown by the needle through the usual levers, etc. The sensitivity, or the needle movement for a given rate of turn, can be adjusted by altering the tension of the spring. To reduce the sensitivity the spring tension is increased. Turn Indicators designed for powered aircraft usually need to have their sensitivity considerably decreased for use in gliders because the rates of turn normally used are far higher. If this is not done, the needle is right over against its stop for quite a gentle turn.

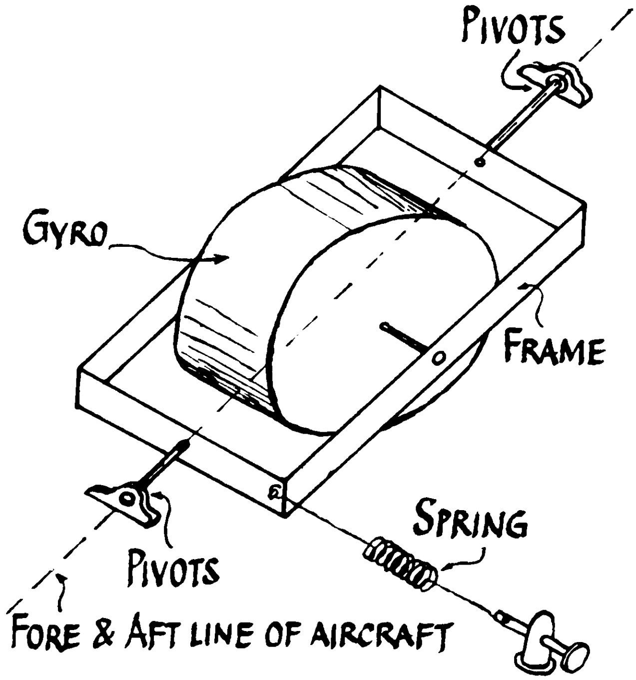


FIGURE 21

How do we keep the gyroscope spinning? Well, the simplest way is to cut little buckets in the rim of the gyro wheel, suck air out of the case by means of a venturi, and arrange a little jet to admit air from the cockpit into the case, impinging onto the gyro wheel. This has serious snags for glider use. First, we need a whacking great venturi to give enough suction owing to our low airspeeds, and second, the venturi has an infuriating tendency to ice up just when you want it most, in cloud. This system works beautifully on powered aircraft, though, since the higher airspeed means a reasonable sized venturi, and you can put the venturi right close up to a lovely hot exhaust pipe to keep the ice at bay. The best way of driving the gyroscope for a glider is by electricity. The gyroscope wheel now becomes the armature of a small electric motor. A small dry battery supplies the power, and since the electric motor is not driving anything except itself, the current consumption is quite small, usually of the order of 0·1 amp. Included in the motor is a centrifugal switch which opens when the armature reaches its normal speed and this prevents overspeeding and economises in current. The switch closes again as soon as the speed of rotation falls off and turns on the power once more. The Turn Indicator is a relatively fool-proof instrument, but the sensitivity often varies between one instrument and another. It is therefore a good plan to familiarise yourself with each installation in clear air, and get some idea of what a given needle indication really means in terms of rate of turn.

If you can afford it, and your glider can cope with the extra weight involved without exceeding its permissible all up weight, the instrument for you is the Artificial Horizon. This instrument will not necessarily enable you to fly blind any better, but it will undoubtedly make it much easier. There are plenty of pilots who are quite happy flying blind on a Turn and Slip Indicator with the normal basic flight instruments, and who find no trouble in making the most prodigious climbs in cloud. There are probably more pilots, however, who use, in addition an Artificial Horizon when flying blind. The truth of the matter seems to be that the Artificial Horizon does a good deal of your thinking for you. While the Turn and Slip

Indicator and the basic flight instruments will tell you all you need to know, to fly successfully in cloud, their information does have to be co-related and interpreted before your brain can form a picture of exactly what is happening, and this at a time when your senses may be telling you the most appalling lies. The Artificial Horizon collects the same information, basically, but presents the result to you in the form of a picture whose message is obvious.

Looking at the Artificial Horizon on the instrument panel, the pilot sees a small white model aircraft viewed from behind against a black background. Behind the little aircraft is a white horizontal line and this line is the actual Artificial Horizon from which the instrument takes its name. When running, (for this is a gyroscopic instrument, remember) this line stays parallel to the actual horizon outside, and, moreover, follows it up and down. That is to say, if the glider's nose is depressed below the horizontal, the white line will rise up above the little aircraft, and if the glider's nose is raised above the horizontal, the white line sinks down below the model. Also, should the glider be turning, the white line will take up a sloping attitude still parallel to the true horizon outside. The instrument thus shows the pilot an actual picture of the position of his glider relative to the horizon. When the pilot can no longer see the horizon he simply transfers his attention to the little aircraft, and proceeds to fly that, with reference to the white line, or artificial horizon, behind it. It sounds just too easy, but it is nothing of the sort. The main trouble, of course, is that one's senses are liable to tell one lies and then one is inclined to doubt the evidence of the instrument. However, with a bit of practice, blind flying with an Artificial Horizon can be done with far less mental effort than with just a simple Turn and Bank Indicator and the basic flight instruments.

How does it work? Well, a whole book could be written on that subject and we should have to begin with a treatise on the properties of a gyroscope. It is worth just investigating the basic principles of the instrument but we shall not attempt to go further than that.

Inside the case of the instrument is a gyroscope wheel, but this gyroscope is rather different from the one in the Turn and Bank Indicator. It is what is called a free gyroscope, that is, it is mounted in gimbals, so that it can swing in any direction untrammelled by any springs, etc. In the Turn and Bank Indicator, you will remember, the gyro could only roll, and even that movement was controlled by a spring. In the Artificial Horizon the gyro is free to roll and to pitch. The gyro spins with its axis vertical. (Strictly speaking this is not *quite* true as we shall see.) Now one of the properties of a gyroscope is that, if it is freely supported at its centre of gravity in gimbals it will try, when spinning, to maintain its position in space unaltered, however the gimbals be rolled, or pitched. This means that however we roll or pitch our glider about, the gyro will try to keep its axis pointing vertically up and down. Couple up the movement of the gyro to the white line on the dial of the instrument, and you have an Artificial Horizon. An instrument as simple as this, however, would have serious faults. Firstly, it is virtually impossible to balance the gyro perfectly in its gimbals, and even if it were perfectly balanced, the friction in the gimbal pivots would cause it to wander over a period of time. Secondly, you would have to set the pivot vertical to start with. To overcome these troubles all Artificial Horizons have some gadget in them which brings very small forces into play to erect the gyro vertical if it should wander away. Here comes the first snag. This erecting mechanism can only detect " out of vertical " of the gyro by comparing its position with that of some sort of pendulum. This pendulum affair will of course try to bring the axis of the gyro into the line of the lift of the glider when the glider is circling correctly banked, in just the same way as the ball or bubble of the Cross Level stays in the centre. This introduces an error as the glider circles, but since the pendulum affair is exercising a push on the gyro axis which moves round the whole circle as the glider circles the error is not large. In most instruments the axis is very slightly inclined, fore and aft, and by this means the error can be made to cancel out by the " precession " of the gyro. It will only cancel out completely, though, at one particular rate of turn. At all other rates of turn there will be some error and the horizon, the white line, may wander very slightly. By making the gyro spin very fast this error can be kept very small, but it is worth finding out exactly what rate of turn any particular instrument has been corrected for.

Now as to the methods of driving the gyro, we have the same choice as before, venturi suction, or an electric installation. The venturi-driven suction type, which works so well on power-driven aircraft, suffers from the same troubles as the venturi-driven Turn and Slip Indicator, when installed in gliders. The most satisfactory method of driving the gyro is again by electricity, but things are not quite so simple in this case. Since the gyro is a " free " gyro, really the only satisfactory way to spin it electrically is by making the gyro wheel the rotor of a small induction motor. This means alternating current, and usually 3-phase alternating current at that. Direct current, the sort you can get out of a battery, will not serve here because it has to be led into, and out, of the spinning armature, and it is virtually impossible to do this without interfering with the gyro wheel's freedom. The installation now becomes quite a formidable undertaking. First you need a source of power, usually a 12 or 18 volt accumulator, then to make the necessary A.C., you require a rotary converter which the accumulator drives. This rotary converter is a sort of motor-generator affair and it takes the direct current from the accumulator and gives 3-phase alternating current to the Artificial Horizon. You, therefore, have to dispose around your sailplane three fairly heavy items, the instrument itself, the rotary-converter, and the accumulator, and by the time you have got them all in, and fixed, and wired, the weight penalty may be quite large. In fact, in quite a few cases, the installation would, with a fairly heavy pilot, exceed the all up permissible weight of the glider, and, of course, the Certificate of Airworthiness of the machine would then have to be amended to limit the maximum weight of pilot permitted.

However, the fact remains that a good electric Artificial Horizon is a very useful instrument to have in a sailplane, if you intend to fly in cloud.

Chapter 9

PITFALLS

When riding a push bicycle, you are unlikely to ride, head on, into the front of an oncoming bus. The danger, and consequence, of such action is obvious. It is the bus or car, that you do not see which is the real menace. The air, as we have said before, is invisible and therefore, the dangers in it have to be thought out, rather than seen. The good glider pilot does, however, " see " the air and its behaviour, in his mind, for he has trained himself to think, all the time, of what the air is doing. With the object of helping the student pilot to acquire this second sight, this chapter is devoted to some of the obvious traps which may be found.

Wind Gradient

When a wind is blowing, the lower strata of air are slowed up by friction with the ground. The air one inch above the ground may be almost stationary, at four feet there may be a fair breeze, and at 500 feet quite a strong wind. This effect of increased wind speed with height is most pronounced near the ground, and is known as a wind gradient. It is always present to some extent, and is affected by many things, the most important probably being the type of country that the wind is blowing across. Hilly, wooded, country will slow up the air more than flat, open, plains as we would expect. Also the wind gradient effect is stronger in strong winds than light breezes. To see how this affects a glider let us take an extreme case. Imagine a wind blowing at 30 m.p.h. at 300 feet and at 290 feet the wind speed is zero. If a glider is flying into wind at, say, 35 m.p.h. airspeed, at 350 feet his actual ground speed will be 5 m.p.h. As the glider sinks through the air and reaches 300 feet the airspeed suddenly decreases, until, at 290 feet in dead calm air the airspeed is only 5 m.p.h. In consequence, the glider stalls, and stalls very sharply and suddenly. Such an extreme state of affairs is, of course, virtually impossible in practice, but it is quite possible for the wind speed to differ as much as 20 m.p.h. and more between 300 feet and 20 feet above the ground. In this case as the glider, approaching into wind to land, descends from 300 feet there will be a steady and insidious tendency for the airspeed to decrease, which may, if the pilot is stupid enough, leave the glider dangerously near the stall as it approaches the ground. The counter measures are obvious. Approach with sufficient airspeed, and prevent the airspeed from falling off by putting the nose down as necessary. The wind gradient effect is often very marked when landing on the top of a soaring ridge. One further point needs mentioning. If you try to do a steep turn in a very marked wind gradient, the actual airspeeds of your upper and lower wings may be quite different, and this difference becomes more marked the greater the span of the glider. When facing downwind the lower wing tip will have the greater airspeed and the glider will need a lot of aileron to force it into the turn. As it turns round into wind, descending the while, the upper wing tip now has the greater airspeed, and the glider may well show a violent tendency to over-bank. The moral is obvious. Do not turn steeply near the ground.

Turbulence

Unfortunately, by no means all common objects like houses, hangars, trees and hills, are of perfect streamline shape. As a result, they all cause eddies, as the wind blows round and over them. These eddies may be small, and insignificant, or they may be large and powerful. As an example look at Fig. 22. This represents a cross section of a soaring ridge, with a wind blowing against a face with a somewhat sharp edged summit. Depending on many circumstances, the wind may follow many patterns, but it may well flow in the manner illustrated, that is, a smooth up-flow in front of the ridge, a large vortex, or " roller ", on the top and various eddies down wind of the crest. A glider at positions A, B, or C, will find relatively good steady lift, but let him stray back to D and see what happens. First, he is in a strong down draught and losing height fast. Second, as he dives frantically for the forward edge of the ridge, he flies into an area where the wind is actually blowing from *behind* him, thereby reducing his airspeed. He flies, in fact, through the mother-and-father of all wind gradients, and if he has allowed himself to be carried far back, he can count himself lucky if he reaches the edge of the ridge again without being forced down. The danger of stalling onto the top of the ridge is quite considerable. Moral, think what the air is likely to do and do not drift back low down over a sharp ridge.

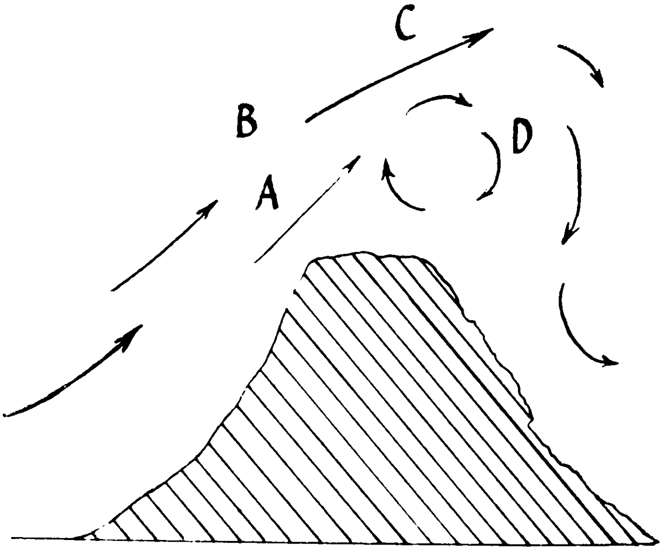


FIGURE 22

The turbulence caused by hangars, houses and trees, etc., is very difficult to assess, and since the effects will be felt very low down on the approach, the only advice that can be offered is to keep well clear. If you have to land in the lee of some large obstacle, approach with plenty of speed to increase the effectiveness of the controls, and to deal with the large wind gradient effect which the sheltered lee of the obstacle will almost certainly cause. We once saw a beautiful demonstration of the effect of turbulence. An R.A.F. pupil was approaching to land in a Tiger Moth. The wind was almost of gale force and he chose to approach low, with his starboard wing over the corner of the rifle range stop butt wall. He made a perfect landing upside down. The aircraft was half rolled most neatly by the terrific updraught under his starboard wing caused by the wall. Owing to the ridiculously low ground speed of the approach, the machine was virtually undamaged.

Ice and Frost

Anything which interferes with the aerofoil shape of the wings of a glider will reduce the lift and increase the drag. Ice is the main culprit here, though the effects are similar if you allow the wings and particularly the leading edges to become rough or mud spattered. Now ice can form on wings in two ways. First, it can be deposited as frost while the glider is on the ground. If this occurs it is advisable to clean the wings down before flying the glider or you will get a poor launch, and the glider's efficiency will be impaired in the air. There is quite a danger in attempting to launch with ice on the wings, particularly if the glider is one of the new laminar flow types. The loss in performance is quite surprising. Of course, this type of icing is a real menace to powered aircraft. Several heavily loaded aeroplanes have failed to take off and consequently piled up at the end of the runway through neglecting the effects of frost on wings. The second way ice can form on wings is in the air; in cloud, in the icing layer. This layer, which may be at any height, is usually around the temperature of 0° C. to −10° C. If a glider flies for some minutes in this layer then ice may build up fairly quickly on the leading edges of the wings and any odd excrescences on the machine such as Pitot Heads etc. The effect on the wings is, of course, to reduce lift and increase drag. However, icing is not often met below 5,000 feet to 6,000 feet so the loss of efficiency of the glider does not put the pilot in any serious danger, and in any case, the ice will have melted off again by the time the glider reaches the ground. It is, however, well to remember that one's ideas of the distance one can reach from a given height may need considerable revision if the glider is carrying much ice—particularly if the glider is one of the new laminar flow types. Also the glider is heavier, on account of the ice, so the stalling speed will be higher. We have already discussed the effect of this type of icing on the Pitot Heads and venturis, but it is a curious fact that they often do not block up until the ice starts melting again. This type of icing, then, does not form any real hazard to gliders, but, again, many heavily loaded power aircraft have crashed from this cause. In their case, of course, the loss of efficiency is serious, and as the rate of descent is high, the aeroplane may not be able to shed the ice before hitting the ground. For this reason most modern aeroplanes have the most elaborate de-icing systems.

Chapter 10

AN ANALYSIS OF SOME ABNORMAL CONDITIONS OF FLIGHT

Launching. Before a glider can fly at all, it must by some means or other, be launched into the air. Leaving out launching by rockets, which is, at present, very expensive, and only in the experimental stage, the four usual methods are Catapult or Bunjy launch, Car tow launch, Winch launch, and Aerotow launch. Since in all these launches an external force has to be applied to the glider to get it into the air, the conditions are somewhat different from ordinary flight. Take the Bunjy launch first.

Bunjy launches are normally only given from the top of soaring ridges, though they may for practice purposes be given on a flat site. The Bunjy is merely a long length of rubber rope to which is attached, in the centre, a steel ring. A short length of rope, usually knotted to give good hand grip, is tied to each end of the rubber rope. The glider is brought to the brow of the ridge, and the rubber rope laid out in a wide V in front of it. The ring at the apex of the V is slipped onto an open, downward facing hook, on the nose of the glider. Four men go to each end of the bunjy, take up the knotted rope, and await a signal from the pilot. Meanwhile one man grasps the tail skid of the glider to hold it back. On the signal being given the two teams of four men run forward stretching the rubber rope. When the tailskid holder can no longer hold on, the glider accelerates forward, and flies out over the valley dropping the ring and rubber rope as it goes. The glider should not be pulled up by the pilot, but should be flown off horizontally out into the hill lift. This is rather important since while the glider is moving forward at the start of the launch the wind is more or less horizontal, while a few yards out over the valley in the hill lift, it is blowing somewhat upwards. In consequence, as it flies out into this area, the glider undergoes an increase in angle of attack without any change in attitude. If the glider should get a very poor launch, and fly off near the stalling speed, this increase in angle of attack may be sufficient to stall it. Therefore, if there is any doubt about the strength of the launch the pilot should play safe, by depressing the nose, and even diving gently away from the launch point until he is certain that he has sufficient speed. The launching force in a bunjy launch is applied fore-and-aft, more or less, and so does not inflict much extra load on the glider except to the drag bracing. This is the part of the structure which prevents the wings from folding backwards. However, most pilots are surprised after their first bunjy launch, by the very low acceleration. Far from being slung violently out over the valley, the sensation is smooth, gentle and the launch is over almost before it has begun.

The car tow launch and winch launch are, from the point of view of the glider, very similar. In both cases the glider is launched by the pull of a long length of cable or wire. At the start of the launch the cable is lying on the ground so the pull is horizontal. As soon as the glider has enough airspeed to rise off the ground, it progressively climbs above the point where the pull is being applied to the cable, be it by car, or by winch. This means that the pull of the cable changes direction on the glider as the launch proceeds. In the initial stages the pull is in the fore-and-aft direction and at the top of the launch the pull is almost downwards, or what amounts to the same thing, almost at right angles to the wing chord line. This means that the cable must be attached to the glider by a positively closed release hook, operated by the pilot when he wishes to release. In fact, most release hooks have a safety device which will drop the cable automatically if the pull exceeds a certain angle. When the cable is pulling more or less fore-and-aft, a heavy pull will only accelerate the glider forwards thereby increasing its speed. The loads on the structure in consequence are relatively small, except on the drag bracing. However, as soon as the glider starts to climb things are very different. Fig. 23 illustrates this state of affairs. The first thing we see is that the lift on the wing is much larger than the weight since it is opposing the downward part of the cable's pull *P*. Now, normally if the lift is appreciably greater than the weight, the pilot feels himself " pressed into his seat " because the glider is accelerating in the direction of the lift, but in this particular case the pilot does *not* feel it since the two forces, lift and cable pull, are pulling more or less in opposite directions while the pilot is sitting on the link between the two, i.e. the glider. The pilot may well be quite unaware of the large lift on the wings, and so it is well to realise that the loads on the wing are considerable in a winch or car tow launch. If the weather is rough, and the launching airspeed high, the loads may be severe. For this reason all gliders are placarded in the cockpit with the maximum permitted speed for car tow, winch launch, and aerotow launch. To prevent these loads reaching a dangerous value, a " weak link ", is included in the cable at the glider end. This will break if the cable pull exceeds a certain value. The second point of interest is that

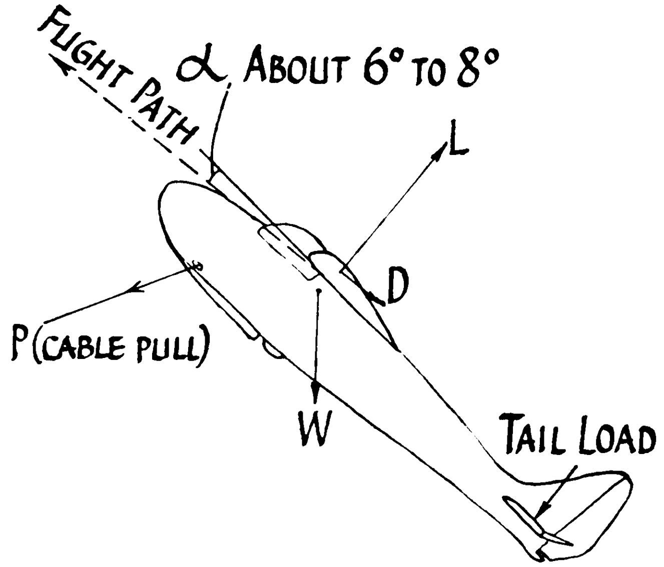


FIGURE 23

the cable pull acts on the glider well in front of the lift. This gives a nose down tendency to the glider, and this has to be balanced by a down load on the tailplane. The pilot supplies this load by pulling back on the stick and raising the elevators. This, of course, is a nuisance, because not only does it cause a bit of extra drag but the wing has to produce more lift still to balance this tail load. The cure for this trouble which immediately suggests itself is to move the release hook, the point of action of the cable, further back, so that the lift and the cable pull act more nearly in a straight line. This is done in nearly all gliders these days and the hook is spoken of as the " belly hook ". Its actual position must be chosen with some care since, if it is put too far back, the glider has a very pronounced nose up tendency at the very beginning of the launch. This is a bad feature, because, if the cable should break, or the winch fail, when the glider is in a very nose up attitude near the ground, there may be insufficient height to recover from the resultant stall. It is for this reason that your instructor will have told you to climb the first 150 odd feet gently, and particularly so, if the airspeed seems on the slow side. He will also have pointed out to you that, provided you do observe this rule, the cable can break at any time without embarrassing you. Winch and car tow launches will provide the glider with heights of 1,000 feet or so, depending upon circumstances such as wind strength, available run, and type of glider, etc.

Aerotow launching is done with the aid of a powered aircraft which has a release hook fitted to its tail, frequently on the tail skid. About 200 feet of light rope is used for towing, though sometimes a shorter rope is used. Preferably the glider should have a release hook fitted in the nose, for aerotowing since this reduces the nose up tendency on the glider which occurs if the pull is applied from the belly hook. Most aeroplanes suitable for towing have a stalling speed well above that of most gliders and this means that the glider, on tow, will be flying much faster than usual. As a result the pilot will have to resist the tendency of the glider to climb. Also, since the angle of attack of the wings will be very small owing to the high speed, the centre of pressure on the wing will be further back than usual. This results in a fairly heavy down load on the tailplane. To all this assortment of loads must be added the pull of the rope. This pull ought to be more or less fore-and-aft, but in fixing the maximum permissible towing speed, the designer has to take into account all the various directions the rope may pull, if the glider is badly out of position on tow. When being towed, the glider pilot endeavours to fly straight behind the tug aircraft, but either above or below its slipstream. This is the turbulent spinning wake from the propeller. The usual position is just above the slipstream, as this gives the tug pilot the best chance of seeing what is going on behind him. The low tow position, just below the slipstream, has something to be said for it as the two aircraft are more stable as a combination, and it is sometimes used for long air retrieves. If a glider pilot wishes to use the low tug position he should arrange quite clearly beforehand with the pilot of the tug just what they are going to do, and get the latter's approval. One curious phenomenon occurs when tug and glider are turning. In a turn the glider pilot should have the same view of the tug as in straight flight, i.e. the fin should appear edge-on and bisect the fuselage. If he gets this view in a turn it means that the rope's pull on the aeroplane is in line with its fuselage centre line, which is correct, but the tug will no longer be dead ahead of the glider as in straight flight. It will be somewhat to one side, left in the case of a left turn, and *vice versa.* Thus the rope puts a side force on the glider in the direction of the turn. This means that the glider will not require as much bank as usual. The turn will feel wrong, and the cross level will show skid, but in spite of this the turn will be correct. This can be shown to be true by fitting a little streamer on some point such as the Pitot Head in front of the pilot. This streamer will stream straight aft if the turn be correct, however awful it may feel.

Aerobatics

The usual aerobatics permitted to sailplanes are loops, stall turns, and spins. Very rarely, in the case of specially designed gliders, the list may also include rolls, and inverted flight. A placard will be found in the cockpit of every glider stating what aerobatics, if any, may be carried out. Earlier on in this book we have devoted quite a lot of space to the subject of spins so we shall say no more about them. The loop is a fairly simple manoeuvre, but it is interesting to analyse. It consists of a complete rotation of the glider in the pitching plane. This requires extra energy, so the first requirement is extra speed. The actual airspeed necessary varies with different types of glider and must, of course, be picked up by diving. This dive should preferably be fairly shallow, because if it is steep, some of the speed acquired will be used up in the pull out of the dive before the loop, proper, begins. Fig. 24 shows the sort of path traced by a glider in a loop. Having dived and picked up the extra speed, the pilot begins the loop at point *A*. In the dive, the airspeed will be high, of the order of 75 to 85 m.p.h. and, in consequence, the angle of attack will be quite small, perhaps 1° to 2°. At the point *A* the pilot begins to bring the nose of the glider steadily up and at point *B* the angle of attack will be increased to something of the order of 5° to 6°. This is because we are going to need a lift force about two or three times the weight of the glider. The lift force is not only supporting the weight of the glider but supplying the large force, (the centripetal force) needed to make the glider follow the curved path. At point *C* the glider is travelling vertically upwards and the lift is acting horizontally

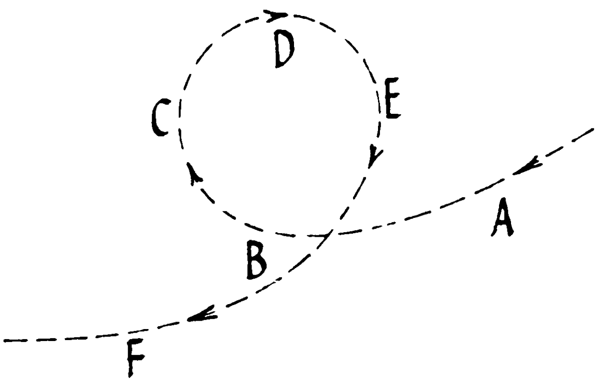


FIGURE 24

providing only the Centripetal force. The weight is unopposed except by the inertia of the glider, so the glider will decelerate rapidly. It is between *A* and *C* that a loop can be made, or marred, by the pilot. If he does not pull up hard enough the glider will have lost a lot of speed by the time it reaches *C*. The loop will be large, slow at the top, and the glider may appear to fall round the top rather than fly round. If, on the other hand he pulls up too sharply at *A*, he will increase the angle of attack more than necessary, the lift force will be very large, and so will the drag; the loop will be very tight, and the glider will appear to " mush " round it. Assuming, however, that the pilot pulls up approximately correctly he will arrive at the point *D* upside down and with an airspeed somewhere near the stalling speed. The lift is now acting vertically *downwards* and is assisting the weight to provide the Centripetal force. This may be surprising at first sight, but, in a properly executed loop, there is no tendency for the pilot to fall out of his seat. Looked at logically, it is the lift which is pressing the seat downwards onto his inverted bottom. At point *D* the airspeed will be at its lowest and the stick will probably be fully back. From point *D* the glider continues round to point *E* where the conditions are very similar to point *C*, except that here the weight is causing the glider to accelerate rapidly. From point *E* to point *F* the maneouvre is simply a pull out from a dive and the pilot's object is to regain level flight without excessive loading on the glider, and without excessive gain of speed or loss of height. Done neatly, the speed at the end of the loop and the loading, will be similar to the conditions at the start.

A Stall Turn is in its initial stages very similar to a loop. Fig. 25 illustrates roughly the path followed by the glider. Starting with a gentle dive to gain speed, the glider is pulled up progressively until it is pointing vertically upwards. From points *A*-*B* to *C* the manoeuvre is basically the same as a loop, but once the glider is going vertically upwards, the pilot ceases his pulling on the stick, and merely uses his elevator to keep the glider pointing straight up. The weight, and the drag, are now both acting vertically downwards, and are unopposed, so the glider will decelerate rapidly. Somewhere between points *C* and *D* the pilot applies full rudder in the direction he wishes to turn. If he does this neatly, and at the right moment, the glider will yaw over until, at point *E*, it is lying on its side, wings pointing vertically up and down, and with almost no speed at all. The glider then drops vertically sideways, the directional, or yaw stability steps in and swings the nose down vertically until the glider is once more pointing in the direction that it is going. From then on the manoeuvre is simply a gentle pull out of the dive to level flight again. Exactly the same considerations apply here as in the finish of a loop. Stall turns are rather frowned upon these days, as there is a genuine risk if they are performed badly. The main danger is that if the pilot is too late in applying the rudder, the glider's speed may have fallen too low, in its vertical climb, for the rudder to have any appreciable effect. The glider is then left pointing vertically upwards, and instead of yawing over, it may start to drop back tail first. This is a tail slide, and is to be avoided like the plague. The glider is completely out of control for the time being, and if it picks up enough speed falling backwards, the control surfaces may well be damaged by slamming over.

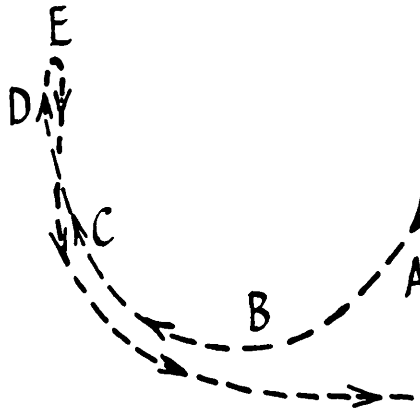


FIGURE 25

We cannot leave the subject of aerobatics without saying a few words about diving at high speed. All gliders have a maximum permissible speed, which is placarded in the cockpit, and many students are puzzled by this. At first sight it might seem that if one stuffed the nose of the glider down vertically, the speed would increase until the drag equalled the weight, and then all would be in equilibrium once again, and the speed would remain steady. This is quite true, but is only half the truth, however. With a heavily-braked glider like the Olympia it is the whole truth *if the brakes are out.* In this state the drag is so great that the glider cannot exceed its maximum permissible speed even in a vertical dive. With the brakes in, however, it is a different story. Long before it had reached a speed where the drag, now small, would have equalled the weight other things would have happened. To understand fully, the situation, take a look at Fig. 26. This illustrates the state of affairs when a glider is diving steeply at high speed. First, since the speed is very high the angle of attack of the wings will be very small, probably somewhere about 0° to $-2°$. The lift will be less than the weight because the drag is helping to support the weight. As we have seen

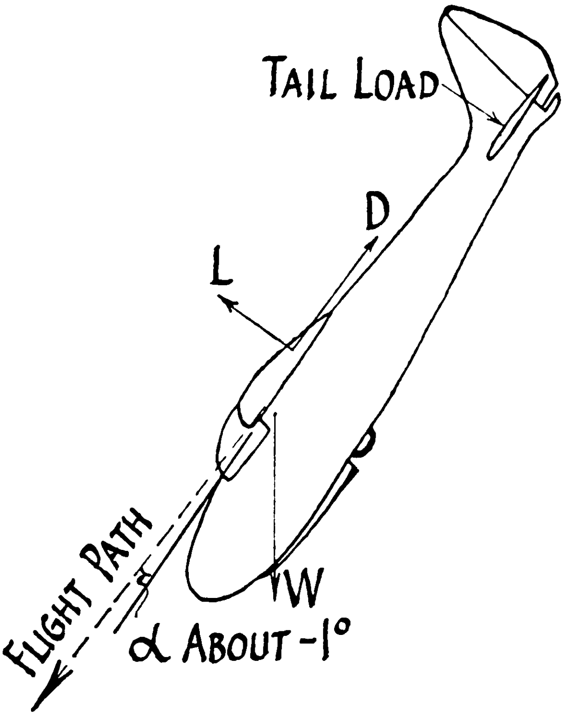


FIGURE 26

earlier on, if the angle of attack is small the centre of pressure or spot where the lift acts is very far back. In consequence, although the lift may be fairly small, there is a large twisting effect on the wings, tending to twist them off the fuselage in an anticlockwise direction as seen in Fig. 26. To oppose this, there is a large download on the tailplane, and this puts a big bending stress on the fuselage. As if this were not enough, the wings are probably being subjected also to a large amount of bending. This is due to the " Wash Out " which is present to some extent in nearly all gliders. It works like this. Suppose there is a wash-out of 3° on the wing from root to tip. If the angle of attack of the root is $-1°$ then the angle of attack of the tip will be $-4°$ and this will probably mean that the tips of the wing are not lifting at all, but are pressing downwards. It is now clear that practically every part of the structure of of the glider is being subjected to large stresses. The drag of a modern sailplane is very low, and in consequence the speed at which the drag equals the weight is fantastically high, and before this speed is reached the structure of the machine is in danger of breaking up. However, the designer, and the stress-man, have taken great care to ensure that the glider is, to all intents and purposes, indestructible in the air, provided it is flown within the speed and loading limitations imposed in its Certificate of Airworthiness. So do not think that these limitations, which are plainly placarded in the cockpit of every glider, are put there just for fun. They are put there for your safety.

" *All Out* "

QUESTIONS

Chapter 1

1. A box measures 6 ft. × 4 ft. × 1 ft. What is the weight of the air inside it at sea level?
2. The box in Question 1 has a leak in it. It is lifted up to 20,000 ft. What is the weight of air in it now?
3. Does the density of air increase, or decrease, with height? Is the *same true of water*?

Chapter 2

4. State Newton's three Laws of Motion.
5. A man is whirling a stone round on the end of a piece of string. Is the stone in equilibrium?
6. A bullet is half way up the bore of a rifle an instant after firing. Is the bullet in equilibrium?
7. An Olympia sailplane is diving vertically, brakes out, at a steady speed of 125 m.p.h. Is it in equilibrium?
8. A man is pulling up a bucket of water from a well by means of a light rope. Is the man pulling up harder, less hard than or just as hard as the bucket is pulling down?

Chapter 3

9. The Angle of Attack of an aerofoil is measured between what?
10. Where would you expect the Centre of Pressure to be when a glider is:
    (*a*) Flying at high speed?
    (*b*) Stalling?
11. What are the snags to using an aerofoil with a stationary *C.P.*?

Chapter 4

12. Why does a glider need a Tailplane?

13. Why do we speak of the Stalling Angle of an Aerofoil, but the Stalling Speed of a glider?

14. What is meant by Accelerated Flight?

15. In a pull out from a dive is the lift equal to, greater than, or less than the weight?

16. In a turn, how does the lift compare with the weight? Why?

17. What happens to the Stalling Speed in a turn? Why?

18. What is the effect of substituting a heavy pilot for a light one upon (*a*) the stalling speed, (*b*) the best gliding angle, (*c*) the minimum rate of sink, (*d*) the airspeeds at which (*b*) and (*c*) are achieved?

Chapter 5

19. Why do we need three controls in a glider?

20. What is the object of Wash Out?

21. What is the Secondary Effect of (*a*) the Ailerons and (*b*) the Rudder? Why is (*a*) more of a problem than (*b*)?

22. What are Differential Ailerons? What is their purpose?

23. What is the purpose of Spoilers and Brakes? How do they differ in form, and in effect?

24. Do Brakes and Spoilers increase or decrease the Stalling Speed?

25. Why is it that the Yaw Stability, and Roll Stability are inseparably bound up together?

Chapter 6

26. What are the conditions which may spring a Stall upon you unawares?

27. What causes a Spin?

28. Why must the wing be stalled before it can be made to Spin?

29. What is the Standard Method of Recovery from a Spin?

30. Recite the Clot's Spin. Resolve not to be a Clot.

Chapter 7

31. Why is there a fin above the wings of most Primary Gliders?

32. What is the purpose of tapering the wings of a high performance sailplane?

33. What are the points for and against struts, and cantilever wings?

Chapter 8

34. What is the object of the Static pipe of the Pitot Head?

35. The altimeter reads the height above what? Can it always be relied upon? Suppose you fly from Lasham to Lowestoft (congratulations) will your Altimeter still tell the truth?

36. What is the difference between a normal variometer and a Total Energy variometer?

37. Why is a Turn and Slip Indicator necessary when flying blind?

38. What are the snags attendant on suction driven Blind Flying instruments in gliders?

Chapter 9

39. How can a Wind Gradient catch you out: (*a*) in straight flight, (*b*) in a turn?

40. Can ice cause any real danger to a glider? Can it cause danger to a powered aeroplane? In what circumstances?

Chapter 10

41. You are given a rather poor bunjy launch from the top of a soaring ridge. What do you watch out for, and how do you deal with it?

42. During a winch launch, or car tow launch, is the lift greater, less than, or equal to the glider's weight? Why?

43. Why is inverted flight prohibited on nearly all gliders?

44. Is a glider heavily stressed when flying at very high speeds? If so, what parts of the glider are under load, and why?

ANSWERS TO QUESTIONS

If you have difficulty in answering any of these Questions the solution or a guide to the sections in which questions are discussed are given in the pages following.

ANSWERS

Chapter 1

1. About 2 lb. *See* p. 2.
2. About 1 lb. *See* p. 2.
3. *See* p. 3.

Chapter 2

4. *See* p. 5.
5. No. Not a " straight line ". *See* pp. 6, 7 and 8.
6. No. Not " a steady speed ". *See* pp. 6, 7 and 8.
7. Yes. Steady speed and in a straight line. *See* pp. 6, 7 and 8.
8. The man is pulling just as hard as the bucket.

Chapter 3

9. *See* p. 10.
10. *See* p. 16.
11. *See* p. 17.

Chapter 4

12. *See* pp. 17, 41.
13. *See* pp. 20, 21.
14. *See* pp. 20 to 24.
15. *See* pp. 20 to 24.
16. *See* p. 24.
17. *See* pp. 24 and 25.
18. (*a*) Stalling speed is increased.
    (*b*) Best gliding angle is unaltered.
    (*c*) Minimum rate of sink is increased.
    (*d*) The airspeeds at which (*b*) and (*c*) are achieved both increase. *See* p. 27.

Chapter 5

19. *See* p. 29.
20. *See* p. 31.
21. *See* pp. 31, 32 and 33.
22. *See* p. 33.
23. *See* pp. 36, 37 and 38.
24. Both increase the stalling speed. *See* p. 38.
25. *See* p. 49.

Chapter 6

26. *See* pp. 53 and 54.
27. *See* p. 54.
28. *See* pp. 55, 56 and 57.
29. *See* p. 56.
30. *See* p. 58.

Chapter 7

31. *See* pp. 46 and 60.
32. *See* p. 63.
33. *See* p. 65.

Chapter 8

34. *See* p. 68.
35. *See* pp. 70 and 71.
36. *See* pp. 36 and 76.
37. *See* p. 80.
38. *See* p. 84.

Chapter 9

39. *See* p. 88.
40. *See* p. 91.

Chapter 10

41. *See* p. 94.
42. *See* p. 95.
43. When inverted, " wash out " becomes " wash in ", and this tends to concentrate the lift out at the tips, putting heavy bending loads on the spar.
44. *See* p. 101.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