

THE ART OF FLYING

CAPTAIN NORMAN MACMILLAN, M.C., A.F.C.



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Foreword by
AIR VICE-MARSHALL
SIR SEFTON BRANCKER
K.C.B., A.F.C.

Chas. Pears.

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WITH A FOREWORD BY
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K.C.B., A.F.C.
DIRECTOR OF CIVIL AVIATION



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THROUGHOUT the preparation of this book I have received much kindness, assistance, helpful advice and courtesy, from many individuals and companies. Among these, I wish to mention Mr. C. R. Fairey, Mr. A. V. Roe, Major T. M. Barlow, Mr. P. A. Ralli, Mr. C. G. Grey and *The Aeroplane*, Mr. C. M. Poulson and *Flight*, the American journal *Aviation*, Mr. Charles Pears, and all the Aircraft Companies who sent me many of the photographs which illustrate this book. To all these gentlemen and companies, I tender my acknowledgments and thanks for the kindness and very ready help which contributed so largely to my pleasure in writing this book.

NORMAN MACMILLAN.

2nd January, 1928.

FOREWORD

by

AIR VICE-MARSHAL SIR SEFTON BRANCKER,
K.C.B., A.F.C., DIRECTOR OF CIVIL AVIATION

I APPRECIATE the honour which Captain Norman Macmillan did me when he invited me to write a foreword to this book, his first—but I hope not his last—venture into the realms of literature.

So far as my experience goes, I believe this to be the first work on aviation written from the test pilot's point of view ; the result is not only instructive, but offers a fascinating insight to the romance and adventure inseparable from aeronautical progress.

Captain Macmillan is eminently fitted as an airman to undertake this task. He had a brilliant record in the War, and since he left the service has been in the forefront of British air development.

Immediately after the War, he took up test-flying with considerable success, but in 1922 he conceived the idea of flying round the world and establishing yet another British record, at a time when we were leading the way in long-distance flights.

One of my first and most pleasant recollections when I took up the appointment of Director of Civil Aviation in 1922 was wishing Macmillan

good luck when starting on his sporting effort to fly round the world. After various adventures, this enterprise, through no fault of his, wound up with a fifty hours' drift on a derelict seaplane in the Bay of Bengal. Undeterred by this experience, he decided to make another attempt in 1923.

This time it was decided to reconnoitre and establish fuel bases along part of the route by ship in advance of the flight. The ship started, but money ran out, and the undertaking had perforce to be abandoned.

These two failures in the adventurous realms of aviation led Macmillan to return to the more serious rôle of test pilot in 1924, and from that time on British aeronautical design has benefited much. He has the rare quality of being a perfect pilot, equipped with a sound and scientific brain, which enables him to translate ideas into clearly recorded action, and action back again to improved ideas.

This book brings out the vital importance of commercial aviation to the British Empire in the future—an importance which very few people even in aviation circles fully realize. It records the very marked progress in aeronautical design which has been accomplished by British brains and British enterprise during the last few years—and it takes the reader into the domains of the high heavens realistically and truthfully.

I wish it all good fortune.

SEFTON BRANCKER.

3rd January, 1928.

INTRODUCTION

FLYING is an art. Like all arts it requires practice. It is unfortunate that in the early stages of flying practice there is an element of danger. Although this may not deter the young enthusiast, it does withhold public confidence in flying by reason of the accidents which result.

For those who intend to take up flying, and who wish to learn to fly, the instruction which is given at the light-plane flying clubs covers the normal use of the flying controls. Several excellent private schools exist to-day. The instructional courses of the Royal Air Force train the Service pilot most thoroughly. Beyond the scope of such instruction, however, towers the accumulated experience of years of intensive research flying where problems are met and solved which do not present themselves to those undergoing normal instructional flying on standard type aeroplanes.

In the course of more than eleven years' continuous flying there have been presented to me, in the air and on the ground, many problems connected with the actual art of flying, the proper consideration and solution of which have proved of the greatest value to myself as a pilot. From this experience I have come to consider the art of applied flying by more far-reaching

values than movements of the controls in relation to the nose of the aeroplane on the horizon.

What I want to attempt in this book is to present clearly to the reader a picture of what flying is, with its possibilities and limitations, in relation to himself as the brains of the aeroplane. If I enlarge his conception of the art of flying, the result must be greater security of mind and greater certainty of hand, and an increase in the safety of flying to the individual. I hope that indirectly, through a resulting decrease in avoidable accidents, I may have played some part in building up the public confidence in aviation which aviation so badly needs.

Although this book is written primarily for the aeroplane pilot of to-day (and to be), I shall avoid technicalities, because the wider its appeal the greater will be its value. I hope that the fathers of sons who wish to fly will read it, as well as the sons themselves. I have met many people who, knowing nothing of flying, have been keenly interested in the many problems of flight. Their many questions are all answered in these pages. To all who are inclined to read this book I trust that I will arouse in them some of my own enthusiasm for, and belief in, flying.

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CHAPTER I

IS THE FLYING PROFESSION WORTH WHILE?

THE evolution of the aeroplane has been very swift. The War played a large part in this by virtue of unstinted funds. For three years after the War progress came to a standstill while economic forces levelled the aircraft industry to post-War valuation, but during the past three years tremendous strides have again been made in design, and methods of production. The present rate of development is greater than during the war years.

The reasons for this forcing of aeroplane development are that aeroplanes form the most formidable means of attack and defence in the event of war, provide the finest system of colonial policing and transportation, and promise to assume a great future in linking up fast communications in commerce. There is no other industry of its type in the world to-day. There is no country which is not already a user, or a potential user, of aircraft. And although commercial air transport is still uneconomic, aeroplane development and production are now progressing upon economic lines.

In the industry men of tremendous energy and vitality, men of intellect and brain power, all

youthful and in their prime, direct the civilized world along the path of aircraft evolution. There is no flash of invention which carries the industry ahead in one leap. The pace is forced by steady, relentless development pursued with an insistence that is almost fanatical.

In every aircraft-building country of the world there is a little group of men who, through some trick of determination of their life work, have remained pilots out of the thousands who flew beside them during the war years. They are to be found in the Air Services of the world, both military, naval, and civil. In addition, there is the infinitely lesser group of test pilots who go up into the air in new types of aircraft to prove the worth of calculations, and designs, and materials, and workmanship. These pilots fly in the van of progress and, although their names are often unfamiliar to the public, they are known internationally throughout the aircraft industry of the world. And not a little of the rapidity of the progress is due to their devotion to the work which has cast its fascination over them. In America they call this devotion to aviation having been bitten by the aviation bug.

There is a curious custom among the bull-fighters of Spain. When a matador retires from the bull-ring he hands his estoca to one of the rising generation of apprentice matadors. This prentice of the arena cannot become a master until this ceremony takes place. It might be well if some of the master pilots of the world were allowed a similar privilege in their profession, so

that they might have a say in the quality of the men who must one day fill their places.

At the present moment there are very few vacancies to be found outside the Service, but this is a condition which is far from permanent, for with an ever-expanding industry there must be an increasing demand for pilots. In the event of war the demand would far exceed the supply. The profession of aircraft pilot requires fine qualities in the man who would embrace it, but having these, and determination to succeed, it offers opportunities in the future to those who enter it to-day which do not pertain to every industry or profession.

CHAPTER II

THE MAN REQUIRED

WHEN one considers all the pilots one has met, the most outstanding feature that is common to all is the impression one has of their robust health. There is no doubt that anyone below a very high standard of physique should eschew flying as a profession. This does not mean that the pilot must be an individual possessed of tremendous muscular development. But it does mean that heart, lungs, ears, eyes, nose, throat, muscles, nervous reflexes must all be normal and healthy.

Beyond these there must exist an attitude of mind which inclines the individual towards flying. Even very fine physical specimens may produce very inferior pilots, or they may after a time lose confidence and wish to give up flying, simply because they have never really taken to the air. When this stage is reached the mere thought of taking an aeroplane into the air for a flight will induce a condition of nervous apprehension which will rapidly develop into a positive dislike of flying. Such a pilot is a danger to himself and to others, and was very commonly met during the later stages of the War, when pilots were being trained in thousands. To-day, he is more rare.

There can be no doubt that only those who want to fly to the exclusion of mostly everything else in life are likely to make pilots of the finest quality, and then only if endowed with the necessary combination of physical and mental characteristics. The physical requirements are dealt with effectively by the Royal Air Force Medical Staff. The mental side also comes within their scope, and in my opinion it is not likely to be accurately assessed by anyone else who has not himself had a very wide experience of actual flying.

I find that most people still consider flying in relation to the ground. When talking about flying to people who are completely ignorant of aircraft, but who are interested in learning something of flying I often hear them say that they would like to fly if they could only keep *one* foot on the ground. There is something in this which is akin to the timidity of the person who cannot swim and who recoils from the thought of getting out of his depth. But in the first experience of flying there is a peculiar charm in this very sense of complete detachment from the ground. One elderly lady who flew with me for the first time in the open cockpit of a military type fighter, remarked on landing, "It was delightful. Now at last I know what Elijah felt like when he was drawn up to heaven in the chariot of fire."

Later, however, when one becomes accustomed to being immersed completely in the fluid air, one considers the ground as being a place entirely apart. When this attitude of mind is reached

there is no accompanying sense of timidity in the thought of flying. The aeroplane in the air is one's complete and separate world of which one is master ; the earth below belongs to other people and exists only to be used by oneself when desired.

But it is very necessary to have due regard to the existence of the earth when one is flying in close proximity to its surface. On one occasion, a very well-known pilot was engrossed in chasing a hare across an aerodrome, endeavouring to spear it with the chassis skid of an Avro Biplane. Suddenly the hare went right about. Intent only on his quarry, the pilot executed a fast Immelmann turn and as the aeroplane swooped in the recovery from the swift reversal of its flight it struck the ground. Fortunately for the pilot only a broken leg resulted.

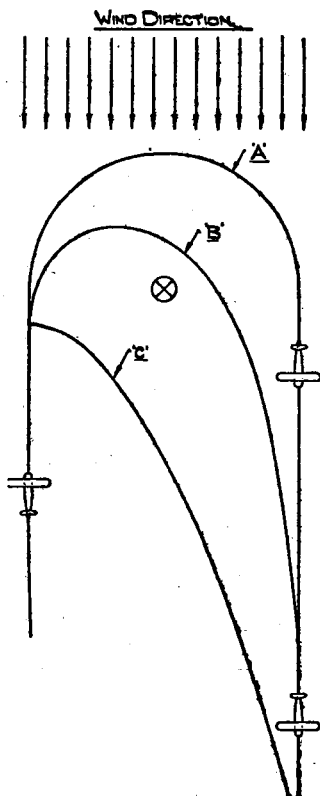
Thus, when flying near the ground, when taking off, or landing, and above all, when stunting low down the pilot should never forget the nearness of the ground. There are times during cross-country flying when ground observation may prove useful, for example when characteristic landmarks are known to exist, or necessary, as when varying altitudes are encountered. But for all other forms of flying it is better to fly in relation to the air and to ignore the ground completely.

There is a distinct case when unstudied observation of the ground while flying low may prove of actual danger. This is when turning up or down wind when the wind strength is considerable. When turning out of the wind to return

on one's course the ground speed of the aircraft changes from minimum to maximum between the commencement and the end of the turn, although the air speed remains the same. This means that while in still air the turn will be a true semi-circle as in A. Fig. 1, in a wind of half the forward speed of the aircraft the turn, if projected on to the ground, would appear as in B. Fig. 1., while in a wind of equal speed to the flying speed the turn would project as in C. Fig. 1. From this it is obvious that if the pilot attempts to manœuvre the turn by visual observation of any point on the ground he is liable to upset the natural air path of the aircraft to a degree which may result in a low speed range aeroplane approaching dangerously near to the stall while in the turn.

There are other cases which ought to be common knowledge to everyone who flies or who wishes to learn to fly, but up to date I do not know of any publication which has treated the subject from this point of view. It is not every pilot who has the faculty of analysing what he does in flying, but every pilot I have met is intensely interested in such analytical treatment and any contribution of this nature must help his mental attitude towards the art which he practises. Further it must prove of the very greatest benefit to the pupil pilot in illuminating many of his doubts as to what is likely to happen to him when in the air. If the young pilot can learn beforehand on the ground the situations which may arise while flying, and understand why they arise, and how to overcome them, he will have

THE GROUND COURSE WHEN TURNING IN VARYING WIND STRENGTHS



THE TURN A DEPICTS THE GROUND COURSE IN STILL AIR WHEN TURNING ABOUT THE POINT X. GROUND AND AIR COURSES ARE THE SAME. THE COMMENCING AND FINISHING GROUND SPEEDS ARE THE SAME. THE TURN B SHOWS THE GROUND COURSE WHEN TURNING DOWN WIND IN A WIND STRENGTH OF HALF THE FORWARD AIR VELOCITY OF THE AEROPLANE. THE COMMENCING AND FINISHING GROUND SPEEDS ARE AS 1 TO 3. THE TURN C DEPICTS THE GROUND COURSE WHEN THE WIND SPEED AND THE AIR VELOCITY OF THE AEROPLANE ARE EQUAL. THE COMMENCING AND FINISHING GROUND SPEEDS ARE AS ZERO TO WIND SPEED PLUS AEROPLANE SPEED I.E. TWICE WIND SPEED. THE AIR SPEEDS ARE CONSTANT IN EACH CASE, AND EACH TURN IS A TRUE AIR TURN ALTHOUGH THE PROJECTION ON TO THE GROUND, OR THE TURN AS VIEWED FROM THE GROUND, IS APPARENTLY WRONG IN CASES B AND C.

FIG. 1

gone a long way towards removing danger from the practice of flying. When a difficult or dangerous situation does arise instant action due to immediate comprehension will usually save it. When actually flying there is usually no time to sit and think.

This was very well illustrated in two individuals I came across when they were learning to fly in 1918. One was a Slav by descent, although a Canadian by birth. His brain was of an ordered, almost Teutonic, type. One day when flying a Camel—a rather tricky little single-seater landplane—he got into difficulties and commenced spinning at 2,500 feet. It was pitiable to watch him. If only someone had been able to whisper to him what to do he would not have crashed. But his own brain could not act quickly enough. Its processes were logical, but very, very slow. First he had to decide what had happened, then how it had happened, then how to correct it, and lastly the thought action to move the controls had to be framed. Those of us who watched could see him dropping in the spin, making no movement to correct it. Too late he acted and, before he could recover level flight, the Camel hit the ground. Amongst his kit we found the most precise details of all he had learned about flying, of things he had observed while flying solo, a complete rule-of-thumb dictionary on how not to go wrong twice. Had he lived until his reasoning powers had been provided with a complete basis of experience he would probably have made a very fine pilot.

Another pilot, a typical Britisher, alert and

quick, was at the final stage of his war-training. He, in company with many others coming under my instruction, had been given short, personal lectures on emergencies that might arise when flying Camels, how to recognize them, and combat them. The need for instant action was impressed on them. This pupil was diving and shooting at a ground target on a day when the weather was rough and gusty. He was turning the Camel over in stall turns, centring the nose on the target, then with the control stick forward, firing a few rounds before pulling out level; after climbing and repeating the process.

I was watching him from another aeroplane when I saw him over-emphasize a stall turn and go right over on his back. An eddy among the bumps let one wing drop, and instantly he began to fall in an inverted spin. I checked his height by mine. He was at a thousand feet. I kept my eyes on him, anxiously awaiting the result. He righted the Camel from the upside-down spin into an ordinary spin just about as rapidly as was possible, re-corrected his controls, and came out of the spin, vertical. To my horror he over-corrected, due to lack of experience, and commenced to spin in the opposite direction. Instantly he realized his error and corrected again. Just at the right moment in the resulting dive he pulled out and, as he flattened, his wheels touched the ground and kicked the dust about twenty feet into the air. He zoomed and, opening up his engine, went round the aerodrome and tried another dive on the target before giving

up and coming in to land, somewhat shaken. This little drama of a man's battle for life lasted exactly ten seconds, which may serve as illustration of the speed of thought and action required of the air pilot.

A more experienced pilot would have caught the Camel before she stalled on her back, and would have prevented the initial inverted spin. A less alert brain could not have corrected the series of spins and flattened out in time. Without the previous knowledge imparted in the lectures the pupil in question would not have known quickly enough what had happened and how to overcome it.

If the reader has never flown, and wishes to take up flying as a pilot, let him picture himself in an aeroplane in the air, alone, with only himself to rely upon to guide his craft, to sense its troubles, and ensure its safe return to earth at will. The sense of detachment which is found when flying alone at great heights is one which I have experienced nowhere else. It is one which is not good for every individual. Many people could not stand it. They would feel that they must get down, land, and speak to someone, feel that they were not alone, immersed in air, sitting high above the earth, in a winged craft, borne along on a rushing of air, accompanied by the roar of a mighty engine.

Mentality plays a greater part in the evolution of the finest air pilots than physique. Too much imagination places unnecessary strain on the individual, while too little places unnecessary strain on the aircraft.

CHAPTER III

HOW THE PILOT CONTROLS HIS CRAFT

AFTER having written as far as the end of the chapter on the water effects on seaplanes, I decided that a brief explanation of how an aeroplane flies and how the pilot controls it might well be inserted early in the volume. To all who already know something about aeroplanes the references and descriptions given will be simple, and probably unnecessary, but I hope that this book will appeal to many who know nothing at all about aircraft. So to ensure that the volume is self-explanatory, I digress at this point to describe what must be elementary matter to anyone who understands aeroplanes.

An aeroplane is sustained in flight by its own motion. Without forward motion relative to the air the wings cannot produce the lifting effort required to support the weight of the aeroplane, because this lift is derived from the reaction of the air flow over the planes. The simplest way to examine this reaction for oneself is to hold an ordinary tablespoon under a tap. When the spoon is held edgewise to the stream of water the flow is conducted around the very rough aerofoil shape (or camber) of the spoon and deflected from the lower edge at a consider-

able angle. The lift of an aeroplane wing is a resultant of this change of angle. The complicated distributions of pressure which take place on the surfaces of planes need not be enquired into here, but it must be obvious that changes in angle of attack to the flow are accompanied by alterations in centres of pressure. Variation of the angle of the spoon to the water stream will enable the operator to see the changes in the deflected flow which result, until at the stalling angle when the water breaks away from the curved back of the spoon which represents the upper surface of an aeroplane wing the lifting reaction completely breaks down.

An aeroplane in flight can move in three planes ; up and down, right and left, and roll over to either side. The normal aeroplane is designed so that stability is maintained automatically in all these directions. That is, the aeroplane tries to fly along a straight, level path without rolling from side to side. The terms used to denote these qualities are directional, longitudinal (i.e., fore and aft), and lateral stability. The quality in any one plane can vary from positive stability, through a neutral state (in which the aeroplane maintains whatever attitude it finds itself in) to definite instability when the flight of the aeroplane must be controlled continually. It is usual to design for complete stability, with which quality the aeroplane always tries to return to its original flight path whenever diverted from it.

There is a belief that absolute stability reduces controllability, but I do not think so, and I am

certain that with efficiently designed controls the stable aeroplane can be as powerfully, and more decisively, controlled than the neutral type which many favour.

It will be clear that the pilot must be able to control the movement of his craft in all three directions. He must be able to rise or descend, to turn left or right, and to control and adjust the lateral balance. In straight flight through calm air the pilot can fly a stable aeroplane without touching the controls, but in rough weather sudden eddies and changes in the air flow, and in hot weather rising and falling currents of air, disturb this flight path. In bad air the pilot operates his controls to check yaw and dip and roll as his craft flies through the swirling air. Sometimes these buffets hit the aircraft like the blast which hits the pedestrian turning the corner from a sheltered city block into a street down which a howling gale sweeps bottle-neck.

An aeroplane is a craft of considerable dimensions, and the eddies and swirls which occur in the air flow are usually much smaller in size. In its passage through rough air the wings and body and tail and fin and rudder are pummelled by larger or smaller gusts, which tilt or push at the part they come in contact with. The stable aeroplane will resist these disturbers of her flight and where pushed out of her path by a violent gust will come back again to an even keel. Her passage would be a rolling, yawing, pitching one, however, and in practice the pilot checks these "bumps" and keeps her on a steady course.

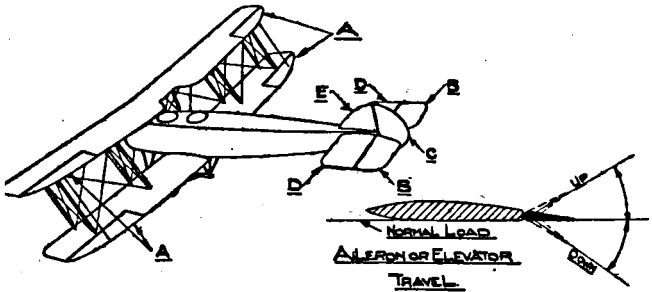
On each wing tip there is a hinged flap (A) Fig. 2, which can be raised or lowered some twenty to thirty degrees each side of the wing. They are interconnected and rigged so that when those on the starboard planes are lowered those on the port planes must go up, and vice versa. These flaps, called ailerons, are used to control lateral movement or roll.

Behind the tail plane is a flap (C), Fig. 2, sometimes cut away in the centre to permit movement of the rudder. This flap can be raised or lowered about thirty degrees each side of the tail plane. This flap, called the elevator, is used, as its name implies, to control the up-and-down movement of the aircraft.

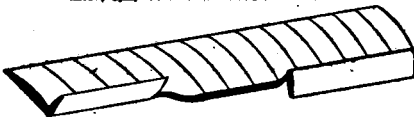
Usually there is a fixed fin (D), Fig. 2, which is fitted to balance the aircraft directionally like the feathers on an arrow. Behind this fixed fin the rudder (B), Fig. 2, is mounted. The aircraft rudder normally functions like the rudder of a ship, but does not always do so, as will be seen later.

In standard practice the ailerons and elevator are connected by cables to a vertical control column in the pilot's cockpit. This control column is universally mounted and free to move sideways and fore and aft at any angle. The ailerons are actuated by any sideways movement of the control column and, since the ailerons are in circuit, movement of the column to the left, which depresses the starboard ailerons, raises the port ailerons, thus raising the starboard planes and lowering the port planes; movement of the column to the right reverses this. The elevator

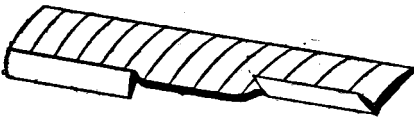
THE AIR CONTROLS OF AN AEROPLANE



PILOT'S CONTROL STICK CENTRAL



PILOT'S CONTROL STICK MOVED LEFT
WINGS TILT TO LEFT



PILOT'S CONTROL STICK MOVED RIGHT
WINGS TILT TO RIGHT

- A. AILERONS
- B. ELEVATOR
- C. RUDDER
- D. TAIL PLANE
- E. FIN

FIG. 2

is controlled by fore and aft movements of the control column, forward movement depressing the elevator when the nose of the aircraft goes down. Backward movement raises the elevator and the nose of the aircraft. It will be obvious that an angular movement of the control column will affect both ailerons and elevator. The top of the duralumin tube that forms the column usually terminates in a convenient hand-grip.

The rudder is controlled separately by the feet through a rudder bar placed across the aircraft and pivoted in the centre, or through pedals, either of these being connected by cables to the rudder itself. Pushing the left foot forward applies left rudder and swings the aircraft to the left. Pushing the right foot forward swings the aircraft to the right by the application of rudder to the right.

The engine is controlled by a hand lever which opens the throttle when pushed forward and closes it when pulled back.

In taking an aeroplane off the ground into the air the pilot opens the throttle gradually and pushes the control stick forward to raise the tail. When enough speed is gained to enable the tail to support itself, the control stick is brought back to neutral. When flying speed is reached a slight backward movement of the control depresses the tail and increases the angle of the planes, when the aeroplane will leave the ground and climb upward.

It will have been observed already that the controls are used to preserve steady flight in the

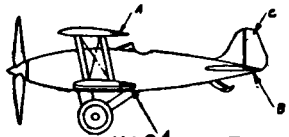
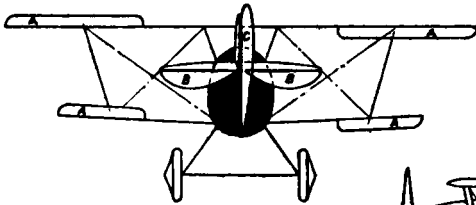
direction desired, but the pilot uses them also to direct his craft where and how he wishes.

Every motorist must know how much easier it is to turn a corner fast when the road banks the correct way. Centrifugal force affects the aeroplane in the very same way as a car, but the pilot is more fortunate than the car driver, for he can provide his own bank when required. When the pilot wishes to turn he tilts the plane over to the correct angle of bank by means of the ailerons at the same time that he applies rudder, and sometimes elevator as well. The angle of bank to be used varies with the speed of the turn and practice is required to determine how much to give. When banked up in a turn the lower sides of the wings cushion against the air and prevent the aeroplane from skidding out sideways as a car does when turning too fast on a level road.

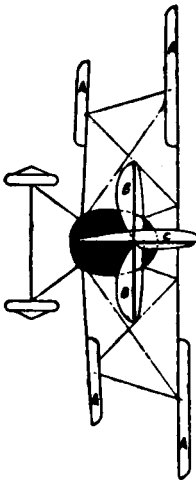
When an aeroplane is banked to such an angle that the planes are vertical, the elevator takes over the duty of the rudder in normal flight, while the rudder functions as an elevator and controls the vertical rise and fall of the nose of the aeroplane. This will be clearly understood from the diagrammatic illustration (Fig. 3). Variations between the vertical and gentle turns require combination use of the controls.

When it is desired to land, the engine is throttled down, and the nose of the aeroplane is kept down in a glide by a forward pressure on the control column. Gravity then acts as motor to the planes in their return to earth. The approach angle to the aerodrome must be judged and, when

HOW CONTROLS CHANGE ACTION IN A TURN.



IN LEVEL FLIGHT. THE AILERONS (A) CONTROL ROLL
THE ELEVATOR (B) CONTROLS
ANGLE TO HORIZONTAL.
THE RUDDER (C) CONTROLS
DIRECTION



IN A VERTICAL BANKED TURN.
THE AILERONS (A) CONTROL ROLL
THE ELEVATOR (B) CONTROLS DIRECTION
THE RUDDER (C) CONTROLS ANGLE TO HORIZONTAL

BETWEEN LEVEL FLIGHT AND THE 90° BANK
THERE IS A GRADUAL CHANGE IN THE FUNCTION
OF THE ELEVATOR AND RUDDER. THE CORRECT
USE OF THESE CONTROLS IN ALL CONDITIONS
REQUIRES CONSIDERABLE PRACTICE TO
ACQUIRE COMPLETE PRECISION.

FIG. 3

near the ground, the aeroplane must be levelled in a steady curve by means of a gentle backward movement of the elevator control, and held for a moment or two. Just as she is at minimum flying speed a quick backward movement of the control column will drop the tail skid to the ground and, at the same time, increase the wing angle to the maximum, thus producing the slowest possible landing. Skill and practice are required in this manœuvre of landing an aeroplane, as will be appreciated when it is remembered that the normal landing speed of an aeroplane in still air usually lies between forty and sixty miles an hour.

The control cables, which run from the pilot's controls to the movable flaps on the extremities of wings and tail, are like sinews which link up the body of the aeroplane with its brain and nerve centre, the pilot. Through these control cables the pilot can feel little impulses set up by the air through which his craft flies, and frequently sense in advance of its main effect the first attack of a change of air flow which tries to throw the plane out of its direct flight path. In this way the skilled pilot can damp out oscillations by using his controls to counteract them before their full effect is felt. There is a world of difference between pilots in this respect. Some will steer a steady, balanced course through rough weather, while others, less sensitive to the feel of their craft, cannot prevent it from pitching and yawing and rolling heavily as the buffets strike it.

Lightness, or sensitiveness, of hands and feet are important in the make-up of a good aircraft

pilot, but they must be allied to quickness of thought and rapidity of action. The sluggish brain and the heavy hand are better kept out of the pilot's cockpit for the safety of the aircraft.

CHAPTER IV

GROUND THINKING

WHEN I learned to fly many of the things which are now common knowledge and are practised as every-day stunts were unknown or imperfectly understood. The spinning nose-dive was the prelude to a certain crash. Pilots practise it deliberately to-day and think little of it. Then, its cause was not properly understood, and the control movements required to recover from it were the subject of controversy. Who to-day would dream of a pilot being detailed to visit aerodromes to demonstrate spinning and the recovery from the spinning nose-dive? Yet that was done in 1916 and early 1917 and it was very necessary, for aerodrome instructors themselves knew little or nothing about spinning.

The inverted spin (in which the aeroplane spins on its back with centrifugal force and gravity combined tending to throw the occupants out of the cockpits) was undiscovered. The full roll, of both the flick and slow varieties, and the half-roll on top of the loop were all unknown.

Before the War upside-down flying and looping were the star attractions at aviation meetings. By the end of 1916 the vertical turn, the stall, the half-roll, and the loop were the complete outfit

of the aeroplane acrobat ; in the case of a very few, upside-down flying and the normal spin were added to the list. By midsummer of 1917, however, at least one Squadron-Commander in France would not permit any of his pilots to fly the newly-arrived single-seater Camels until they had practised spinning nose-dives on their Sopwith two-seaters, which were being replaced. This illustrates the rapidity with which air knowledge was assimilated and propagated during the war years by the competition for supremacy in the air.

To-day, this international competition still exists, but its urgency is tempered by national economies throughout the world. The majority of the pilots of the Fighting Air Services of the world are concentrating on the practising of concerted manœuvres for aerial drill. Their young pilots are first trained to fly and then pass on to squadrons where they find their own aeroplane becomes one unit in an aerial structure. The civilian schools and flying clubs stop their training at the first stage.

To the pilots of both these schools there is much need to impart the latest research knowledge in so far as it affects the practical art of flying. Unfortunately, this very often filters through but slowly, and sometimes incorrectly, or in a form which is not properly understood by the practical pilot, who is only too often but a dull theorist.

There is no doubt that valuable co-operation can, and does, exist between the aircraft test pilot and the aeronautical mathematician who

flies only in terms of equations. The latter is usually engrossed in abstruse theory and is often the antithesis of the type of man who does the actual flying. I have known mathematicians to say that it was useless for them to visit aerodromes and watch actual flying because everything happened so quickly that it was impossible for them to see what actually took place. But if a pilot possesses the faculty of recording exactly what reaction was produced on his aeroplane by a definite control movement, the mathematical brain can reverse the result through a sequence of moments and lifts and stresses and arrive at a valuation of the forces involved. The mathematician and the test pilot who work hand in hand, the work of one often empirical and of the other practical and definite are continually shuffling and recasting theory and knowledge, devising rules, forming constants based on accumulated data, and suggesting means for obtaining information still more accurate and precise. From their ever-increasing research the certainty grows that the really skilled test pilot who knows his work, handling the full-size aircraft in the air, provides more reliable data for design than the scale models in the wind channels of the laboratories of the scientific research worker. This is no mean testimonial to the accuracy of the flying of the test pilot and the fidelity of his records in reading his instruments.

There is a belief that experimental flying is very dangerous, and while I do not deny that there is present a quality of the unknown about the first ascent of an entirely new design, there

are factors which ameliorate the risk. These are the qualities of the men engaged in the production of the aircraft ; the designer who conceives the undrawn picture of the plane, and his draughtsmen, the mathematician who determines the strength of the structure and the harmony of the forces which will be applied in flight, the chemist and the engineer who watch over the quality and type of material used and who build it into the aircraft ; the designer and engineers who produce the engine ; the mathematician and hands who shape the propeller ; the men who erect and rig the aircraft true to drawing ; the inspectors who safeguard the pilot from faults of workmanship.

The test pilot, himself, is used to his work. He watches the whole progress of production. He sees, perhaps, some of his own ideas incorporated in the latest craft. He vets the aircraft by eye. There is a saying that when an aeroplane looks right it is right, and the practised pilot can size things up very quickly indeed by eye. His faith in the work of the men who have designed and stressed, and built the craft is implicit. Every feature of the aircraft that can be determined before flight has been examined in detail. The centre of gravity has been taken to check design and make certain that it falls within the region which is safe. The pilot examines his controls, and tests their travel and correct operation. He tests the engine. Then he taxies across the ground to test the under-carriage, runs faster to test the air controls, and returns to the position which gives the longest run to take off.

A final look round his cockpit assures him that he knows exactly where each instrument and item of equipment is placed, because aeroplane gadgets are much more numerous and less standardized than those on motor-cars. He opens the throttle slowly, accelerating gradually, senses quickly that the balance of machine and controls is true, gives her more throttle and, leaving the ground, climbs upward into the air.

I have known designers who have turned their backs on a new aeroplane making its first flight ; who have watched it leave the ground with their tears starring its flight ; who have rushed into the hangar to avoid looking at it. They feel an awful responsibility as the child of their brain is borne upward into the air in the skilful hands of a man they know well. There are some designers who insist on flying in the aeroplane if it is larger than a single-seater, because they cannot bear to watch it from the ground.

The testing of a new type seaplane is complicated by the initial trials of the flotation gear, but is made easier in its air testing by reason of the unlimited aerodrome provided by the water's surface.

The amount of ground thought that is applied to experimental flying is not appreciated by anyone who has not come into actual contact with aircraft design. I believe that much good can be done by applying more ground thought to flying which is not experimental. There are teachers in all professions who are born with the gift of imparting knowledge to others. The young pilot who comes under the care of an

instructor of this type is fortunate, for much ground knowledge will be instilled into his flying education, and his air experience will be made easier thereby. But to all who take up flying or who do already fly, I wish to give this fundamental advice : *Think on the ground first.*

I remember when I was learning how to fly, for I cannot say that I was really taught, I used to sit in my hut in the evenings with a poker in one hand to represent the control column and my feet on an iron stove (which was black out for lack of fuel) for rudder-bar practising the movements required to make turns to left and right, and tilting my chair to simulate the movement of the aeroplane's seat in space. In this way I learned something of the synchronization of hand and feet required. I have no doubt that this helped greatly in my early efforts to make turns and other manœuvres ; and even to improve my taking-off and landing, through my becoming mentally used to the combined movements of hand and feet.

Before trying anything in the air the pilot should devote thought to it on the ground, so that he is accustomed to the processes of thought involved, then in the air no time will be lost in formulating the thought command to hands and feet.

To make the following story clear it should be explained that on an aeroplane there is an instrument board rather like a motor-car dashboard. Two of the many instruments fitted are the altimeter and the revolution counter, one showing the height in hundreds of feet and the other

revolutions of the engine in hundreds of revolutions per minute.

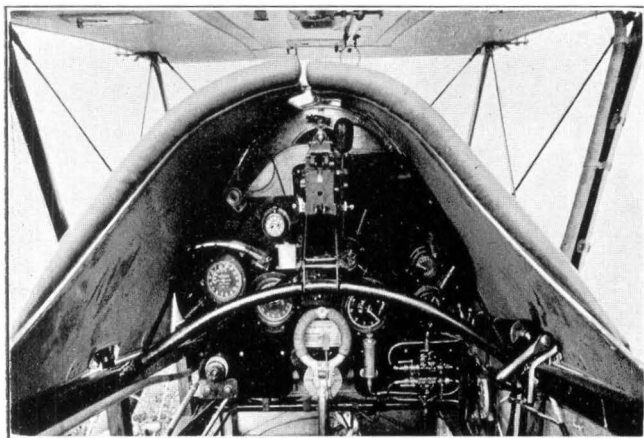
The story is told of a certain pilot who, many years ago, was seen to fly across the aerodrome about two feet off the ground, and to the astonishment of everyone, straight on into a stone wall at the far end. Picking himself up unhurt from amongst the wreckage he said to his friends who had rushed to his assistance, "Funny, I wasn't expecting to crash just then! I thought I was twelve hundred feet up, but I must have been looking at the rev counter."

The moral of this story is too obvious to stress.

THE INTERIOR OF A PILOT'S COCKPIT.

Part of Gun Control Gear.	Vickers Gun.	Loading Handle.		
Inclinometer or Transverse Level.	Watch.	Compass Card.	Water Thermometer.	Air Pressure Gauge.
Height Indicator.	Air Speed Indicator.	Engine Revolution Indicator.	Oil Pressure Gauge.	Hand Pump for Air Pressure
Starting Magneto Switch.	Control Column with Gun Trigger.	Air Release Valve	Air Pressure Control to Petrol Tanks.	Radiator Shutter Control.
Landing Light Switches for Night Landing.	Petrol Control Cock.			
Throttle Lever.	Part of Gun Control Gear.			

The Rudder Bar is out of sight below the photograph.
 The lower part of the Compass is visible below the top plane.



The Cockpit depicted is that of the BRISTOL FIGHTER. A Civil Aeroplane cockpit is similar, but the armament arrangements are not required. Fuel supply details and instrument lay-out vary with different designs of aircraft.

CHAPTER V

THE SENSE OF HEARING

MANY of the critical situations which arise in flight are the direct result of partial or complete failure of the power plant. So long as the engine continues to give power steadily and smoothly, flight can be maintained under almost all conditions likely to be encountered. Fog is a bad enemy, but fog and a failing engine combined are very much worse.

The young pilot who is practising flying will spend much of his time in the air flying over or near the aerodrome, and he may think that because of his proximity to the landing-ground he need be less alert than he would be were he flying across country. That this attitude is wrong is evidenced by the number of crashes which occur on or near aerodromes. These are mostly due to engine failure when taking off, or when stunting near the ground ; or to stunting in excess of the power reserve ; all resulting in a stall at a low height.

For the benefit of readers who do not understand the term, I had better explain the meaning of the word "stall." Everyone knows that the speed range of a motor-car is from rest to its maximum speed in miles per hour over the

ground. The speed range of an aeroplane, however, is a dual one. Before it can fly it must attain a definite speed in air miles per hour. In still air the speed which it must attain over the ground is identical with its speed in relation to the air. At the lowest air speed at which the excess in wing lift over the resistance of the aeroplane is equal to or slightly greater than its total weight, the aeroplane commences air-borne flight. The point of change over from partly ground-borne to completely air-borne is the stalling point and, at or below this critical point the aeroplane is said, when in the air, to be in a stalled condition.

In still air the taking off run is equivalent in speed range to that of the ordinary modern motor-car. It varies with the type of aeroplane, from rest to thirty-five at the lowest, up to seventy miles per hour, or even more with fast racing aircraft. It is said that the take-off and landing speed of the last French racer, which held the world's record for speed, was one hundred and twenty miles per hour. At this speed a quarter of a mile is covered in seven and a half seconds.

Would the average motorist care to contemplate landing an aeroplane at the maximum speed of which his car is capable? On the road there is the ever-present relation of the side of the road to one's car-bonnet or mudwings, by which to steer. In the air the pathway along which one climbs upward or glides down to land has no white line, hedge, or curb by which to guide one's craft. In the very act of landing, the air pilot must be accurate in his judgment of distance

from the ground and precise in his control movement. Yet, when one is accustomed to it, landing an aeroplane is infinitely easier than steering a fast car at high speed along an English country road.

The lifting speed (which corresponds in still air to the maximum speed of the average motor-car) is the lowest figure of the flight speed range of an aeroplane, which is calculated from its minimum air-borne level speed to its maximum, both being considered in relation to its passage through the air. The aircraft at rest on the ground when headed into wind already possesses an air speed. It is then necessary only to increase that initial air speed to the minimum air speed required for flight in order to take off. In this case the speed attained over the ground will be reduced by the amount of the wind velocity. The test pilot sometimes makes use of this to enable him to test air controls about the effectiveness of which he has some doubt. The reduced ground speed gives him in effect a larger aerodrome, and enables him to make a straight flight of sufficient duration at a speed in relation to the ground which precludes the possibility of serious damage to the aircraft should anything unforeseen occur.

Now it will be appreciated that below this minimum flight speed the aeroplane must remain on the ground or, if in the air, return towards the ground along a flight path the angle of which is dependent on the speed required to make the speed of the aeroplane equal to or in excess of its minimum. In actual practice this is always a

speed in excess, because the excess is required to control the flight path. There is, with any given aeroplane when stalled, a definite minimum drop which is necessary to restore the path of flight to normal. This required drop increases with a decrease in engine revolutions. Hence the extreme danger of a stall, or loss of flying speed, due to engine failure. In such cases the nose of the aeroplane is very likely to be up and, in consequence, speed falls off very rapidly. With the failure of the engine the speed required to correct the fore and aft trim rises at the same time, owing to the absence of propeller blast over the tail controls. It is the concurrence of these two which makes this situation in flight so frequently the forerunner of tragedy, because the time in which correction can be made is so very short.

The reason for the heading to this chapter must be plain. One's ears are the surest index to indicate a failing engine, and it is so vital to acquire a true sense of hearing that I would drum this into every young pilot of my acquaintance. Always whilst flying train your ears to listen to the music of your aircraft. Listen to the throb, or beat, or rhythm of your engine. Detect the slightest change in its steady note. Do so consciously at first. Soon the effort will become sub-conscious, but the early practice will remain to call instant attention to the slightest variation when it occurs. And when that change is heard, *Flatten out at once—Instantly*, if the nose of your craft is up.

I have heard the subtle change of an engine's

note just before or just after leaving the ground, in time to throttle down and remain on the ground. I have heard it when climbing up from the aerodrome and, flattening out, have had time to turn and land before the motor packed up. I have heard it just when starting a zoom from the level of the ground, and quickly I have changed the zoom to a gentle climb, through level, to a glide down to land. I have sat and listened to it becoming more and more insistent when flying through the monsoon storms of India, over hundreds of miles, until the engine packed-up at Agra.

When you hear it, and you are flying round an aerodrome, land and investigate the cause. When you are stunting near the ground listen to the motor with all your might, and stop stunting at once if the engine changes note. If you are flying across country and you know the note has changed, keep your eyes open for emergency places on which to land as you carry on. Don't laugh and think there is no need to worry until the engine does go wrong, seriously. This advice is not offered to the craven-hearted, it is just offered as common sense to the many who may never have thought of it.

In over eleven years' continuous flying I have only been let down twice by an engine without previous warning.

There are other ways to listen to an engine than by one's ears. That part of the person whereon one sits is extremely sensitive to vibrations and forms an excellent stethoscope to the well-being of one's craft. Unfortunately, the

present type of seat parachute damps this out to some extent.

Not only is there the motor to listen to. The rigging wires contribute to the sounds of an aircraft. A stream-line wire out of truth to the line of flight has a note which varies with its angular displacement. A rigging wire vibrating tells its own tale. The propeller vibrates in rough air, shudders, and sometimes flutters in bad bumps. In severe vertical turns, in looping, the gyroscopic forces and changes in lift produce propeller flutter, and anyone who has heard the distressing note of a fluttering propeller can recognize it quickly. It is a good thing to avoid fluttering an aircraft propeller, but it is sometimes impossible to prevent it.

Hearing and vibratory sense are very important in the make-up of a good aircraft pilot. As in most things, so in flying, intelligent anticipation is worth its weight in gold. And I feel convinced from personal experience of auditory warnings and from having observed accidents to other pilots during their occurrence, that the commonly arrived at conclusion of courts of enquiry into flying accidents that the crash was due to an error of judgment upon the part of the pilot, is very often initially a lack of hearing aright.

CHAPTER VI

THE ELEMENT IN WHICH MEN FLY

AIRCRAFT (with the one exception of the submarine) are the only craft which in their progress are affected by one element only. Unlike the submarine, the aeroplane has a tremendous vertical range, and it possesses manœuvre and speed capacity in excess of any other craft.

When Major Segrave broke the world's motor-car record his difficulty was to keep the car straight. He must have been very near to flying conditions for at speeds above two hundred miles an hour an aeroplane can support itself almost entirely on the air lift derived from the body or fuselage alone. At the very high speeds which air racers reach to-day the effect of the wings is such that their complete removal from the aeroplane would only increase the speed by some fifteen miles an hour, due to the absence of their resistance. Thus, for the purpose of increasing air speed near the ground the inventors' dream of retractable wings does not offer great possibilities. The wings of an air racer are necessary to enable it to take off, and fly, and land at reasonable speeds, and to provide stability and control at high speeds. That is, they provide the speed range and controllability.

In Major Segrave's car it was very necessary to prevent any considerable air flow from passing below the body, otherwise the car would have lifted from the ground. The fact that an aeroplane is entirely air-borne and free from the ground makes it a far safer vehicle in which to travel at such high speeds. This is a consideration not connected with the inutility of a vehicle which must be transported from England to Florida to enable it to be run all out, and it also explains the air pilot's admiration for Major Segrave's feat.

While the aeroplane pilot has only one element to know, that element is the most fickle and variable. Its extremes impose conditions on man, machine, and engine which can be most severe. The seaplane pilot must also know the art of seamanship, and I shall treat of this later on.

The air pilot can climb from sweltering heat on the ground, through icy clouds, where his breath turns to snow and ice in his nostrils, to temperatures colder than forty degrees below zero. As he climbs the pressure falls continually, the density is less, and the quantity of oxygen at each inspiration becomes fainter. If, on the way up, the aeroplane passes through any damp clouds, or humid air, the moisture breathed in through the air intake freezes in the carburetter as height is gained, and jams the throttle so that the pilot cannot control the engine or shut it off.

The worm and nut control to alter the tail plane setting becomes frozen solid with ice. The water in a water-cooled engine boils at lower

temperatures. The carburation of the engine becomes irregular as vaporization of the fuel is affected by the cold. The power of the engine falls off because the pressure and density are lower. Hence the demand for super-chargers to build the intake air up to normal. The lift on the wings, too, is less, and increase in wing area, especially in span, would be very valuable. Finally, a point is reached when at full throttle the aeroplane can climb no higher. It maintains its height at one speed. If speed is increased it glides downward again. If speed is reduced it stalls and sinks, losing height, because its lift reaction falls below its weight. This point is known as the absolute ceiling of the particular aircraft, because it is the maximum height it can attain. All the available horse-power is used up in maintaining level flight at that height. There is no speed range, because any change in speed results in loss of height.

When a pilot reaches the absolute ceiling of his craft for the first time it provides him with a most curious sensation. Way down below, through thousands of feet and patches of white cloud, lies the earth. Its surface appears saucer-shaped, the edge of the circle turning up all round its circumference to meet a curtain of blue mist that hangs from the lower sky. The blue of the upper sky is very pale. The aeroplane hangs, seemingly motionless, in the centre of a pear-shaped spheroid; the earth is very remote and dull brown in colour. The biting air freezes one's skin in its passage. The breath clogs in the nostrils and, snorting, one blows out

snow. Goggles mist over with the warmth from one's eyes and a layer of ice forms on the glass, obscuring vision. Raising them, one misses the warmth of their protection and one's eyes smart with the cold. The exhaust from the engine drums loud in the ears, louder than at lower heights, the result of the reduced external pressure on the ear drums. And all the time one is balancing the aeroplane, watching speed indicator and height indicator, keeping the two steady, for the aeroplane is above any horizon by which to steer. Earth and clouds lie far below the nose, foreshortened. All the controls are very light and not very quick, because their lift is nearly gone. The aeroplane is just at the stalling-point and the increased drag of one aileron being lowered will cause her to sink. A gentle undulation commences, like a long, slow swell at sea. The aeroplane rises and falls to it, and as she swings the height indicator needle records a hundred feet less. There was a cross current, or a slight fall in the air flow ; enough, at all events, to affect the aeroplane, to make her lose lift, and leave the pilot impotent to prevent the loss of height.

Then we go down, back through a thin cloud layer, scarce two hundred feet in depth, transparent, hardly impeding one's vision from above. Tiny particles of ice suspended in the air sting the face as one passes through the cloud. It is the mackerel sky which everyone admires, and which looks so beautiful from down below. One looks up from just below and sees their speckled whiteness, virgin pure against pale blue.

At fifteen thousand feet we rise and fall in irregular currents, with a swinging motion which is rather pleasant. At ten thousand feet the air feels distinctly warm. The thermometer out on the wing strut registers ten degrees below zero, and we realize that it is only comparative warmth that we feel. The tops of the cresting clouds reach up to our level, great peaks that look solid enough to land on, their edges clear-cut against the blue. Two thousand feet lower down we pass into the main cloud region, and soon our craft is swinging to the changing air currents, up and down, up and down, down. The air temperature rises quickly just before we enter the clouds, drops again for the first two thousand feet of cloud strata, then rises rapidly at five thousand feet above the ground. A thousand feet lower we have passed below the clouds, and looking up watch them sweep majestically across our upper plane. The earth looks a level plain again, tilted up at an angle, and very green. As the aeroplane bumps her passage down through fluky air towards the aerodrome where we wish to land, the air feels almost tropical.

When we step out of the aeroplane, exhilarated and warm, the people on the tarmac look as though they were feeling cold. We glance at our thermometer and find that it records eight degrees above zero Centigrade, and the damp ground and March wind combine to belie one's personal feeling of warmth.

The air is not always normal. On one occasion I took off near London on a day with no wind and a grey sky when the clouds looked about

a thousand feet up. I found immediately I rose that I was flying through heavy snow at less than a hundred and fifty feet. The ground underneath was green. I did not believe it, and landed. Looking up at the sky it appeared unchanged. The men on the tarmac said they saw the aeroplane disappear into what looked like smoke. They most obviously disbelieved me when I told them it was heavy snow. Looking up again I could hardly credit it myself, and I went up once more to make doubly sure. At a hundred feet I flew into heavy snow, the flakes passing my plane horizontally, flakes as large as any I have ever seen. I flew over the heads of the disbelievers, with the aeroplane flying through the snow, a hundred feet above them. When I landed again they believed my tale and, by looking intently, we could just discern grey streaks across the leaden sky. But not a single flake of snow descended on the ground !

Once, when flying across India I approached clouds at a height of seven thousand five hundred feet. I decided to pass below them. As I passed close underneath I looked up at the great monsters above the plane, and saw them begin to rotate around a vertical axis. Quickly I pushed the control column forward. Bumping, wires screaming, down we sped towards the earth. Glancing back along the upturned tail I saw the clouds rotating faster still, and descending faster than ourselves. The plane rocked from side to side. I opened the throttle and watched the clouds as our speed increased. Steadily, behind our tail, they followed our

downward path for nearly four thousand feet. We flattened out at two thousand feet and left that monsoon storm behind us and above.

On another occasion I started on a test climb, and at three thousand eight hundred feet, while climbing at full throttle and concentrating on making notes from the instruments, I felt the seaplane swerve violently as though we had hit something. I looked up instantly and saw nothing. There were no clouds, just clean air above and below. The seaplane had swung very suddenly and had turned round more than a half-circle. I descended and opened out some two thousand feet lower down to renew the climb. Again, at the same height, the nose of the plane swung violently to the left, the tail entered the disturbance and got a fresh kick which swung us still further round, until the thrust of the propeller fortunately pulled us out of it. During the swing the plane vibrated most horribly at being thrust out of its flight path. Twice again I tried to pass that invisible barrier. As rudely as before we were turned right about, with a final parting smack at our tail to send us speeding about our business. My passenger, who had been accustomed to flying for many years, was violently sick, and absolutely unaware of the cause of the strange behaviour of our craft. He imagined that I must be doing it deliberately for my own amusement at his expense, but he didn't know how. We had to give up our intention of climbing to test the ceiling of the seaplane, a conclusion that appeared ridiculous when the sky was devoid of cloud.

I took the trouble to trace this particular disturbance and found that it began as a ground cyclone at Newport, Monmouthshire, then blew the dust from off the streets of Bristol and, rising slowly, crossed the Isle of Wight at nearly four thousand feet, where we met it. The line of demarcation of the air flow must have been sharp as a knife, yet on the ground at Osborne one would never have suspected such things to be happening overhead.

The African wind which blows northward across the Mediterranean, burning hot, rises as it blows, and spends itself at some twelve thousand feet amongst the Swiss Alps where it is called the Pfonn. Periodic bursts of wind whistle down the valley of the Rhône and blow southwards out across the Mediterranean. Visitors to the Riviera know this unpleasant fellow as the Mistral. The natives say that it blows for periods of three days. If it continues beyond three days it lasts for six, or nine, and on the Bouche du Rhône in summer the air is filled with choking dust that finds its way everywhere and stills, for the time being, the incessant clamour of the myriads of insects that abound there. At the end of a three days' mistral I have found my fuselage filled with dust and centipedes.

The Chinook wind which blows over the Rocky Mountains from the Pacific is responsible for freak conditions. In winter, near Calgary, it will produce a difference of eighty degrees Fahrenheit in two days, from forty below zero to eight degrees above freezing point. Sledge parties sometimes drive out from home over the

snow and have to walk back. The Chinook usually gives warning of its presence before it makes itself felt on the ground. It blows over the Rockies high up, cleaving a blue channel in the sky, and takes about two days to spill down the reverse side of the mountain to ground level. Pilots flying up into the Chinook just after it commences to blow have found their air temperature thermometers record sixty to eighty degrees warmer at ten thousand feet than at ground level. This wind plays strange tricks in the mountain gullies, and winds are sometimes met which blow at right angles within a quarter of a mile of each other.

There are many such strange local winds in various parts of the globe, all of which affect the aviator who flies across their path, in addition to the better known and oftentimes dreaded hurricane, typhoon and monsoon.

Apart from dangers which may arise through winds of gale force, with their accompanying disturbances of thunder and rain, wind affects the pilot in other ways as he flies at cruising speed with it, or against it. When flying against the wind it pays to open the throttle and travel at a higher air speed than normal maximum best cruising speed, because a decrease in time of flight means a corresponding decrease in adverse windage. For any given wind speed there is a definite cruising speed for a particular aircraft, which will produce the maximum range or maximum ground miles covered per gallon. This also applies when flying down wind or across the wind, but the air flying speeds will vary

EFFECT OF WIND-SPEED ON RANGE.

To determine the maximum range condition with varying wind strengths it is necessary to take as a basis the Cruising Speed for maximum range in still air.

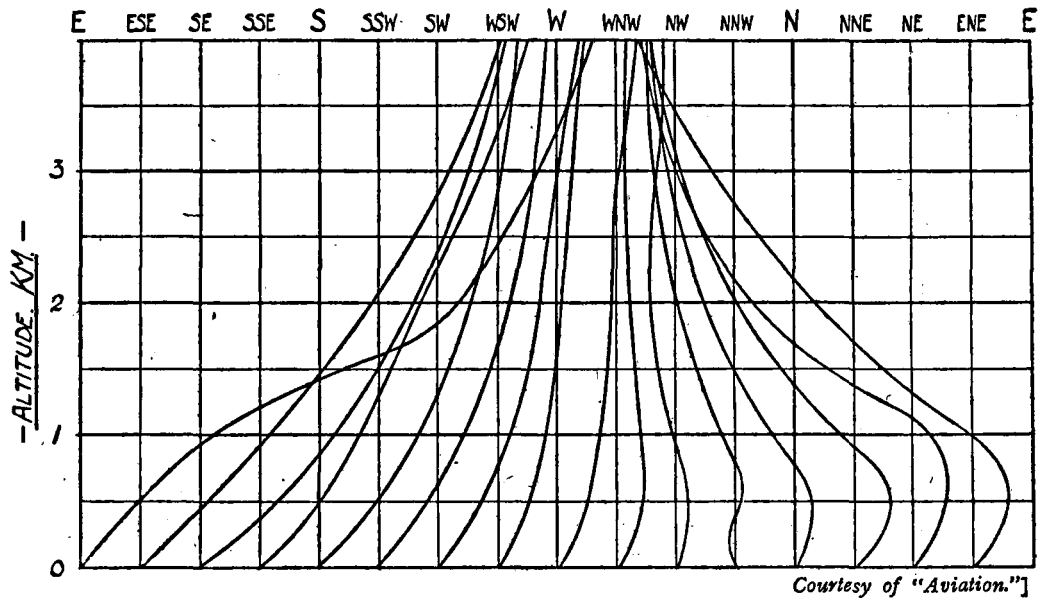
	WIND SPEED	CRUISING SPEED.		RANGE.		DURATION.
		Relative to Air.	Relative to Ground.	Air Range.	Ground Range.	
	MPH.	MPH	MPH	Miles.	Miles.	Hours.
Throttle set for maximum range in still air.	0	80	80	870	870	10.86
Throttle set for maximum range in still air.	40 mph Head Wind.	80	40	870	435	10.86
Throttle set for increased cruising speed to compensate for head wind.	40 mph Head Wind.	100 or 120	60 80	800 640	480 427	8.00 5.53
Throttle set for maximum range in still air.	40 mph Tail Wind.	80	120	870	1305	10.86
Throttle set for altered cruising speed to (a) increase the advantage of a tail wind.	40 mph Tail Wind.	(a) 75	115	856	1310	11.40
(b) to shorten duration of flight.	40 mph Tail Wind.	(b) 90 100	130 140	848 800	1222 1120	9.43 8.00

FIG. 4

in each case. I have met many experienced pilots who were unaware of this natural law, and there must be many young pilots to whom the knowledge will prove useful. See Fig. 4.

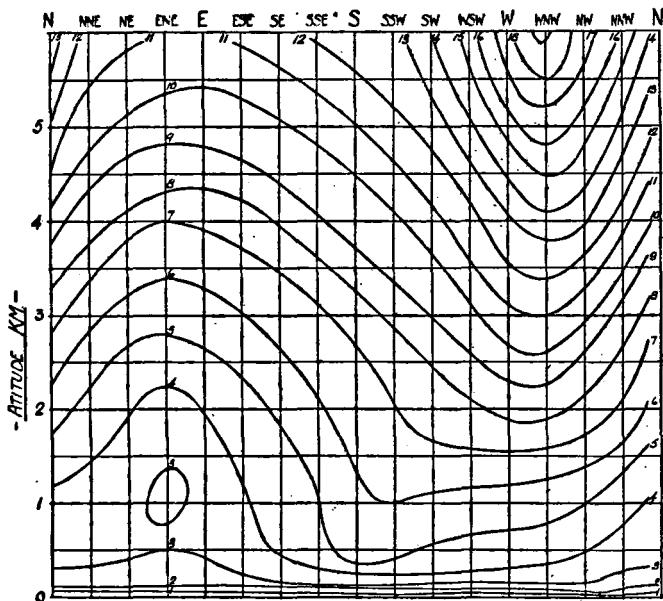
The height at which the aircraft flies materially alters the windage which it must encounter. Generally, wind veers and increases in velocity very rapidly with quite moderate increases in height above sea level. To acquire a working knowledge of the science of meteorology as it affects his aircraft and his flying should be a definite object with every young pilot, who will then be more able to appreciate aerial phenomena which he must encounter and combat. In Great Britain and Western Europe the pilot can make a better ground speed against a head wind by flying low, while he can decrease his flying time down wind by keeping well up. In other parts of the world this general rule does not apply. In parts of Africa local winds arise during the day which blow quite strongly at ground level and increase in velocity up to about three thousand feet. At six thousand feet they die out completely. In this case it is desirable to fly high when travelling in a direction contrary to the ground wind, although the normal rule holds when flying with the wind up to a limited height. See Figs. 5 and 6.

When flying out East during the hot hours of summer days, I have found the bumpy air due to heat currents extend up to over ten thousand feet. I have flown through sand driven up by sand-storms at eleven thousand feet. Then it is wise to fly above the disturbed areas if one can



Courtesy of "Aviation."]

FIG. 5. THE EFFECT OF HEIGHT ON WIND DIRECTION IN THE NORTH ATLANTIC.



AVERAGE ANNUAL INCREASE OF WIND VELOCITIES
ABOVE SURFACE VELOCITY FOR DIFFERENT SURFACE,
DIRECTIONS.

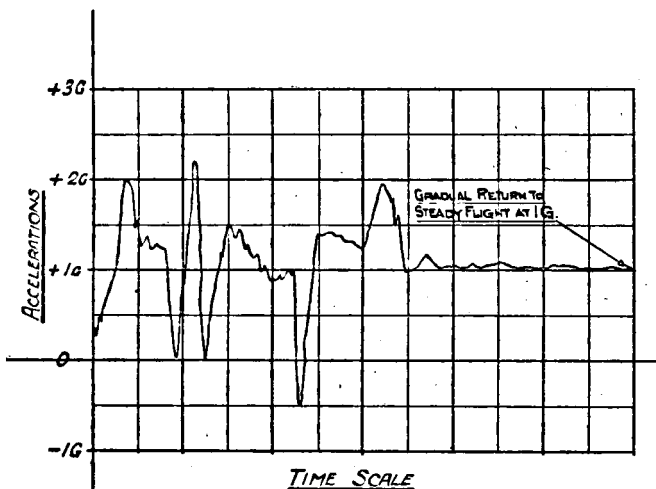
FIGURES ON CURVES ARE WIND VELOCITIES IN METRES PER SECOND.

Courtesy of "Aviation"]

FIG. 6.

climb above them. The experienced cross-country pilot knows full well how speed is lost flying through bumps when the buffets of the changing air currents send the needle of the speed indicator surging up and down the scale. The changing accelerations on the aircraft use up power and petrol, and retard the steady progress of the craft. It is equivalent to the difference in driving a motor-car an equal distance over smooth-surfaced, level roads as against a potholed, hilly course. This is shown graphically in Fig. 7, and if one pictures the flight of the aircraft in this manner the reason for the loss of time and increase of fuel consumed for an equivalent journey, is easily understood.

There are times when the nature of the ground flown over exaggerates this condition to the extreme limit of a powerful aeroplane's capacity. The Guadarramas is a range of mountains about forty miles north of Madrid, which runs east and west and rises fairly steeply from the south to some eight thousand feet, while the north slope falls away very gradually to the level plain of Burgos, which stands three thousand feet above sea level and about a hundred and fifty miles to the north of the mountain summit. I remember flying south from Burgos in a De H.4, carrying only petrol, oil, myself and a suit-case, against a southerly wind. When one leaves Burgos aerodrome behind the altimeter needle rises steadily but the ground does not fall away as it would in England. Instead it rises up underneath one. As I approached the final rise of the Guadarramas, I found the ground beating me in the climb. I



EFFECT OF AIR CURRENTS OR GUSTS ON
AIRCRAFT ACCELERATIONS

IN STEADY NORMAL FLIGHT AN AIRCRAFT
IS ALWAYS SUBJECT TO 1G.

FIG. 7

opened the engine full out and watched the ground a few hundred feet below. I pulled back and back until the craft was just above the stalling point. With the engine roaring full out I scarce maintained my relative rate of climb in the battle with the heightening mountain range. Fighting for every foot of height we just staggered over the crest of the range. Conditions changed instantly. With the throttle half shut we gained height with a rush. I pushed the nose down till we levelled out at a hundred and twenty-five miles an hour, registered on the air speed indicator. While it had taken the De H. 4 all she knew to climb up through the additional angle imposed by the downwash on the reverse slope of the range, she romped along lightheartedly with a whiff of gas on the uprising current of air on the windward face.

Royal Air Force pilots on the North-West Frontier of India have told me that they have had to sit in these uprising currents to enable them to cross from one valley to another among the hills. On one side of the valley they can barely maintain height, while on the other they soar vertically upward for all the world like an electric lift. From my own experiences, albeit a trifle less sensational, I can well believe it.

The effect of such air flows when taking off and landing can be appreciated from the sketches, Fig. 8. Fortunately, such extreme cases are not met on the ground in Western Europe, although the pilot flying through the tropics must be prepared to encounter conditions of this nature.

Another serious aspect of flying in tropical

EFFECTS OF UPWASH AND DOWNWASH
ON AIRCRAFT.

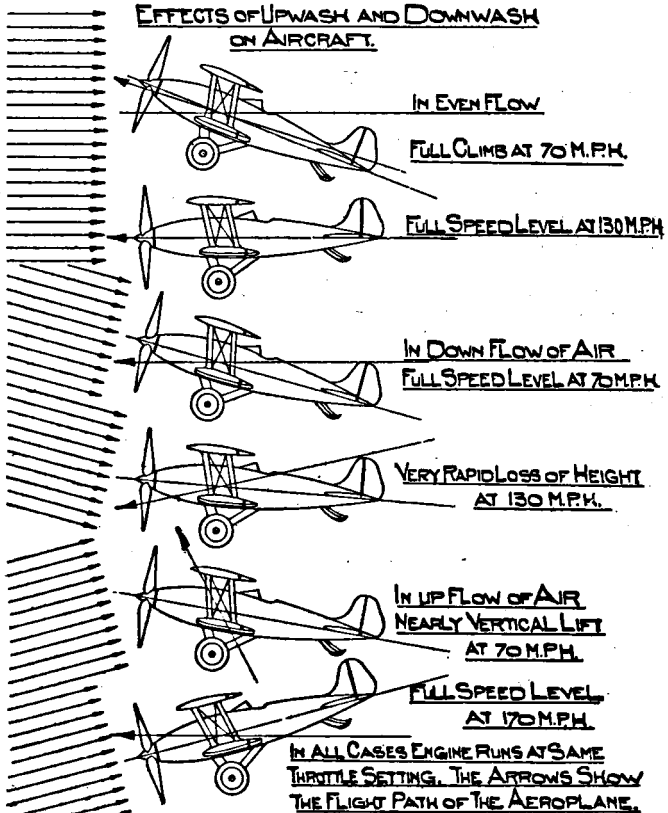


FIG. 8

countries in the hot seasons is the effect of the temperature on the density of the air close to the earth's surface. The radiation of heat is sometimes very intense. I have known spanners laid down in the sunshine to become so hot in a few minutes that it was impossible to lift them again with bare hands. This happened to us in the Sind Desert when attempting to fly round the world. The shade temperature was 125 degrees, and the temperature in the sun over 180 degrees. We could set our watches by the mirage which shimmered into life on the aerodrome at a quarter to eight each morning. There was no such thing as an early cold tub, for the night temperature never fell below 105 degrees and the cold water was always warm. We had to take off before eight o'clock or remain on the ground until the following day. After that hour the heat waves danced higher than our planes, and the air became so rarefied that the wings would not develop enough lift to support the weight of the aeroplane and crew. One morning we got off before eight and had to return. As we flattened out to land the planes stalled at a speed far in excess of their normal stalling speed and we dropped heavily through the hot air on to the hard-baked sand, damaging part of the undercarriage.

The difficulties of taking off and landing under such conditions are aggravated by the increased speed required near the ground. The stalling speed at surface level is higher than the stalling speed a hundred feet up, and this entails a faster speed of approach. This makes a successful

landing in an emergency a matter of much greater uncertainty than in Western Europe, where the normal conditions provide a cushioning of the air under the lower planes when the aeroplane flattens out.

The section of meteorology which deals with cloud structures and cloud phenomena, is available in a form which is entirely suitable for the air pilot in many publications ; and it is not necessary for me to deal with it except in so far as I have found peculiarities in actual flying which are possibly unknown to the meteorologist. Of these I have previously in this chapter mentioned one or two instances.

My first experience of the effect of clouds on the engine of an aeroplane occurred when flying in France during the War. Our formation ran into very dirty weather when returning from a reconnaissance. The leader fired a signal cartridge for formation to break up and machines to return to the aerodrome individually, for the weather was too bad for the formation to pass through. Great cumulus clouds rose from below us, green underneath our planes, and towered far above our twelve thousand feet level. Their peaks reached to over twenty thousand feet, and their white walls were lined sharply against the blue sky. As we broke formation I saw the other machines gliding downward, silhouetted against the clouds. I turned my own bus towards a broken lane amongst the clouds, which led towards the aerodrome. With her head down, and engine running, we entered the lane. Thousands of feet overhead the cloud tops

almost met, leaving only a tiny ribbon of blue between. Far below, the earth was blotted out in shadows too deep for our eyes to penetrate. The lane closed in until our wing tips all but brushed the clouds. Suddenly our nose went down and we plunged earthwards. Fighting every lurch and roll, we descended with sickening accelerations. I opened out the engine to try to keep up height, and found it would not run. A few feeble bursts preceded silence, followed by a vibrating turning of the propeller, and again, silence. Lightning flashed across the lane down which we travelled, jumping across from cloud to cloud, sometimes very close. I could not tell what conditions lay below us. The clouds appeared to rest on the surface of the earth. Vainly I strove to maintain height. The engine was out of action, useless save for an erratic burst or two. We were tossed about from side to side, and down, and the main effect was always violently down.

You must have noticed the cold air that follows in the wake of thunder-storms. It spills over from the great heights and falls in places like a cascade, pouring down to replace the warm air that before the storm blanketed the ground. We were in the midst of it, like a winged barrel tumbling through an aerial waterfall. The air controls of our craft were impotent against the might of the forces that surrounded us. The colour of the clouds had changed to green, dark and ugly. My observer's face looked sickly in the evil light. The flashes of the lightning were intensely blue. I managed with the utmost

difficulty to keep our craft right way up as we tumbled down through the lane among the thunder-clouds, wondering what fate lay at the bottom of the clouds. Should we be forced to land on the enemy side with our engine out of action? We fell out below the clouds into blinding rain. At a hundred feet we levelled out and, like magic, our engine recovered its tune. We saw a Flanders canal that we knew was not far from Ypres. We flew on through the gloom that enshrouded the base of the thunder-clouds, our engine running perfectly in spite of the stream of water through which we flew; until we came to our aerodrome on the further edge of the storm, where we landed first of the formation.

Never again will I voluntarily fly down through the heart of a great thunder-storm, nor would I counsel anyone else to do so, even for the experience. I did it in my inexperienced flying days, when my air knowledge was not very highly developed, but it is relegated now to the category of things not to be done, where it ranks with, but takes precedence over, the tail slide, which was another of my unknowledgable follies. On many subsequent flights I have found thunder-storms, some lurking in mountain passes, others roaming over great plains. They vary much in size, grandeur, and intensity, but, one and all, I fly round them. Once a little fellow tried to pen me in a mountain pass, but I succeeded in dodging round him with one wing-tip tickling his mushroom shape and the other grazing the mountain side.

Experience has taught me that electrically charged clouds can upset the ignition system of an aeroplane engine. Knowing this, I have frequently observed the peculiar engine cut-out that occurs when flying close to certain types of clouds. The clouds that cause this trouble are usually dry. I have not observed it with clouds which are very moist. Often one meets a succession of detached clouds at about three to six thousand feet on a summer's day in England. They are very white and clear-cut against blue sky; just the very clouds that artists love to paint above a summer seascape. If one flies through these clouds no moisture gathers on the instrument glasses, or the wings. These clouds become charged with static electricity, and often I have heard my engine completely cease firing for several revolutions as we have flown close beside one drifting cloudberg. I have known a pupil pilot hear his engine suddenly cut out and, with a panic thought of safety first, shut his throttle and land. Subsequent investigations having failed to reveal any mechanical defect, the poor *ab initio* has been accused of possessing friends in the district, an unfair impeachment. Here, then, is the true cause for his descent, a temporary ignition cut-out. Let him carry on next time and he will find his engine run without further disturbance if he keeps a little way from the offending clouds. The true gallants will then be made known in future.

A day or two ago I was testing a new aeroplane for climb, not far from London. I passed up through quite ordinary clouds into the blue skies

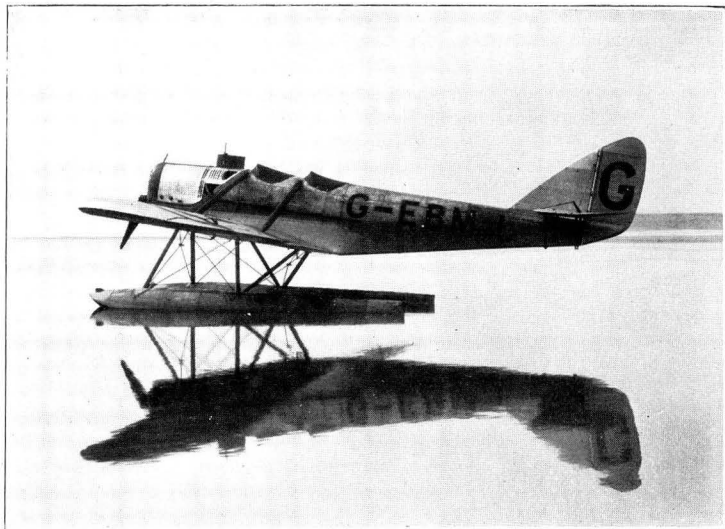
beyond. The engine ran perfectly and the times I noted for each thousand feet climbed were normal. I knew that the particular plane would climb to 18,000 feet quite easily, and that her absolute ceiling was above that height. When I got to 15,000 I found her cease climbing. Mentally I framed these questions. Was the load carried in excess of normal, thus reducing the ceiling? No, it could not be that, because the time taken to reach 15,000 feet was consistent with standard load. Was the height indicator faulty? No, not that either, for the same reason. These eliminated, the answer was that we were immersed in a down current of air at 15,000 feet. The month was September, summer was over, the equinox was at hand, and cold air was emptying down from the heights. People down below would soon be forced to don overcoats, and before long winter would be upon us.

I tested the speed range of the plane and found it was six miles an hour, sometimes less. For ten minutes I kept her nose up, waiting to pass out of the downfall of air. Then, surely enough, the finger of the altimeter passed at normal speed across the hundreds of feet graduated on the dial, and I felt the lift of the craft in normal air again.

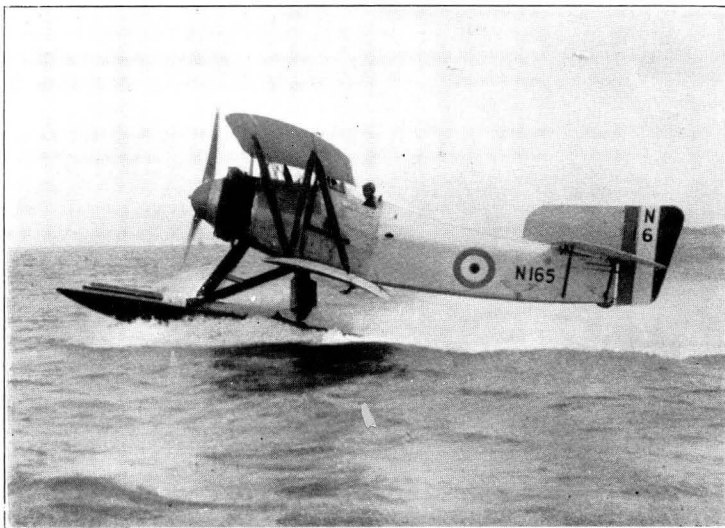
A little above 17,000 feet I met the same conditions, but with less reserve of power and lift to fight them. The air flow was more erratic than at 15,000 feet, and the plane oscillated fore and aft to the changing currents. I kept her head at it for a long time, losing a hundred feet, then gaining two hundred, again balancing out.

But for all practical purposes, the ceiling of the plane on that day in that air strata was two thousand feet below normal. During the following two days one could see from the ground wispy fingers of cloud trailing downwards from the higher cloud layers, visible confirmation of that flight experience.

It can easily be understood that the test pilot who takes new types of aeroplanes into the air to prove their aerodynamic qualities, their strength, and their manœuvrability, must have long experience of flying conditions to make his work successful. Instruments have been designed to record photographically the true flight path of aeroplanes, but they do not directly assist the pilot, since they operate out of the pilot's sight. There is no one up there, but himself, to dissociate aircraft performance and air phenomena, and place them in their true relations. Much of the advance of aircraft design and performance of recent years has been built upon the painstaking and sometimes hazardous work of the test pilot who, working continually in the cause of science, reaps but little reward and no glory for his work. Yet he is the man who, to-day, knows more of the science and art of flight than any other.



A LOW WING LIGHT MONOPLANE TWO-FLOAT SEAPLANE TWO-SEATER.
THE SHORT MUSSEL—27.80 h.p. Four-cylinder A.D.C. Cirrus Air-cooled Engine.



A STAGGERED EQUAL WING BIPLANE AMPHIBIAN TWO-FLOAT SEAPLANE SINGLE SEATER.
THE FAIREY FLYCATCHER—385 h.p. Armstrong Siddeley Jaguar, 14 cylinder Radial Air-cooled Engine.

CHAPTER VII

THE WATER ELEMENT IN SEAPLANE FLYING

AEROPLANES are usually divided into two types ; landplanes, which cannot take off from water, and seaplanes, which must take off from water. There is the amphibian, which is intended to combine the properties of both types, but, like most non-specialized things, loses some of the qualities or performance of each in consequence.

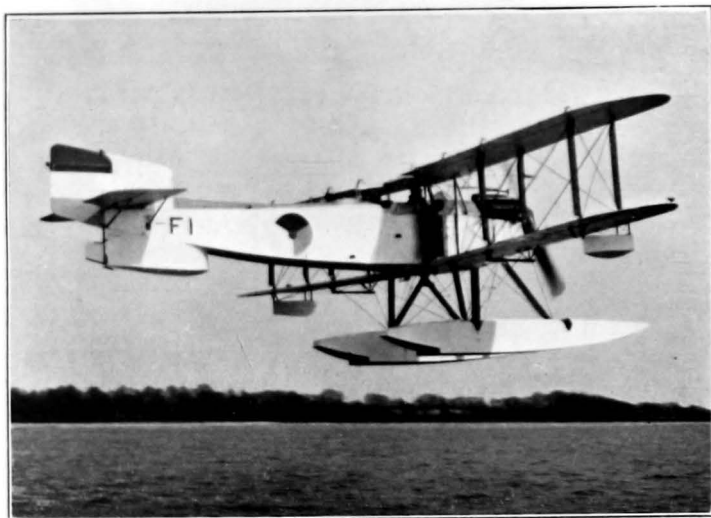
The testing of seaplane types has frequently taken me to one of the great yachting centres, where all manner of sea-loving amateurs are to be found during the summer months. I have found that yachtsmen are keenly interested in the water-handling of the seaplanes which they see taxiing past them in the river, to rise from the water and roar through the air at speeds which they must envy. The yachtsman is compelled to study wind and tide, and I have often been asked how they affect seaplanes.

The special feature of a seaplane which differentiates it from all other sea-going craft is that it has a large area exposed to the wind which is constant and cannot be altered. At rest and at low speeds flotation is secured by water displacement, while at high speeds this is achieved by hydro-planing. Thus at low speeds a seaplane

is akin to an auxiliary engined yacht with sail up. At high speeds it is more like a fast hydroplaning racing motor-boat, but differentiated because it still carries the same equivalent of sail area represented by the wings. Because of these differences the handling of a seaplane on the water is not the same as that of any sea craft.

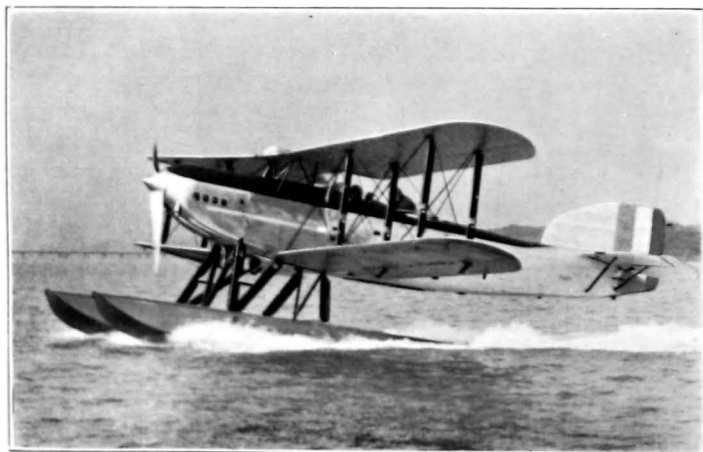
For purposes of right of way in congested waters, a seaplane is considered as a power-driven craft, which must give way to sailing craft. In other respects it must conform to all ordinary rules of navigation.

In flight a seaplane must conform to the ordinary aerodynamic requirement of directional stability. There is nothing more trying to fly than an aeroplane which will not maintain direction in the horizontal and vertical planes. Because of this a seaplane is usually directionally stable to the wind on the water with engine stopped, a quality which is described as being "weathercock." This weathercock stability is essential on the water and, if not inherent with the aerodynamic directional stability, provision must be made for it. To make it clear that this need is fundamental, let us suppose that a seaplane is forced to alight with engine failure when there is a considerable wind blowing. Assume the landing to be successful and that no damage has resulted in spite of rough seas. If the seaplane is weathercock, she will ride head to wind and drift backward; the wind pressure will be equal on both port and starboard planes, and she will be in lateral balance. If the seaplane is not weathercock she will be liable to yaw with tide



Photo, Beken, Cowes.

AN UNSTAGGERED EQUAL WING BIPLANE THREE FLOAT SEAPLANE.
THE FAIREY III. D Three-seater—450 h.p. Napier Lion 12 cylinder Broad Arrow Water-cooled Engine. This type of Seaplane requires a tail float and two wing tip floats to provide stability on the water because of the short length of the main floats.



Photograph, Beken, Cowes.

AN UNSTAGGERED EQUAL WING BIPLANE TWO FLOAT SEAPLANE.
THE FAIREY III. F Three Seater—450 h.p. Napier Lion 12 cylinder Broad Arrow Water-cooled Engine. The long floats of this type of Seaplane provide complete stability both fore and aft and laterally, and auxiliary floats are not required.

or sheer instability ; while still drifting before the wind, the air pressure under the unsquared planes would become unbalanced, and the couple produced by the air and water moments would result in a very bad list. The stability provided by the wing-tip float, if fitted, might save the seaplane for some time, but the yawing drift and the running sea would eventually smash wing-tip float, or wing, or aileron, or all three, and sooner or later the seaplane would turn turtle.

This quality of directional stability in flight and on the water determines that the seaplane must always take off and land into wind. There are exceptions, but these are freaks. For instance, a very light seaplane with a small reserve of buoyancy, fitted with a very powerful engine may heel over considerably, when the throttle is opened, in the opposite direction to that in which the propeller turns. This is called "torque reaction," and the effect is to cause one float to dig deeper into the water than the other ; the drag is thus increased on one side and the seaplane then tries to turn out of the wind in that direction, when the wind under the wing increases the list and aggravates the condition. In this plight the seaplane pilot may be forced to point his seaplane deliberately out of wind to the other side when he first opens up his engine ; so that the out of straight wind and the torque reaction cancel each other out. As soon as the seaplane commences to hydroplane, he must rudder into wind, otherwise the seaplane would slide sideways over the water and strain the floats or chassis, and at the very worst turn over at a high

speed ; or, to save the situation, the pilot must throttle down and begin all over again. But, as I have said, such craft are freaks.

One, and that the normal, reason for always taking off into wind, applies equally to both landplanes and seaplanes. It is that the required minimum lift is obtained most rapidly and at the slowest ground or water speed, thus reducing the strains on chassis and wheels, or floats, to the minimum. Such strains and stresses, although they may be absorbed partly by tyres and or some form of shock absorber, are passed on in their undamped percentage to the main structure of the aircraft, and so affect the aeroplane as a whole.

Taking-off more or less side to wind produces in either case side loads on wheels or floats and chassis. These may be partly balanced by the pilot tilting his craft so that the drift is compensated. This is very much easier with a landplane than with a seaplane. With a landplane taking-off down wind there would be no drift, but the running speed required to leave the ground would be increased over that required in still air by the speed of the wind ; and by twice the speed of the wind compared with a take-off into the same wind. This can be understood most readily by the following explanation.

The lowest speed at which any aeroplane will fly is that minimum at which the wing lift reaction is equal to the total weight of the aircraft. Since all the wing lift is derived from the air, it is obvious that air speed over the planes is the

governing factor. Speed over the ground plays no part in this at all. Therefore, if the minimum speed through the air at which the planes can produce the required reaction is fifty miles an hour and there is no wind, then the aeroplane must reach a speed of fifty miles an hour over the ground or water before it can take off. If the wind is blowing at twenty miles an hour and the aircraft starts the run into wind, it has a handicap of plus twenty, and it will take off when it reaches thirty miles an hour over the ground. If it commences the run down wind, its handicap is minus twenty, and it must attain seventy miles an hour over the ground before reaching the necessary fifty through the air.

With a landplane this is a simple, straightforward problem. Can the wheels and chassis stand seventy miles an hour? Is the run long enough to enable the craft to reach this speed over the ground safely? These questions are entirely apart from the undoubted foolishness of taking off down wind, for which there can be no excuse, except when dire necessity forces the experienced pilot to do so under exceptional circumstances.

With a seaplane the whole question is much more complicated and this is why I have considered it so fully. With the landplane the problem is purely mechanical, geometrical, and aerodynamic. With the seaplane the question of restricted run may be ruled out, leaving only the mechanical and aerodynamic problems of the landplane, but a far more difficult fellow takes the missing one's place; this is the hydrodynamic properties of the floats. The landplane deals

with one solid and one fluid. The seaplane deals with what may be termed for convenience two fluids, each of which has a definite reaction on separate parts of the complete craft.

Now the flotation gear of a seaplane is designed to meet the following requirements :

It must be capable of supporting the fully-loaded weight of the seaplane on the water at rest, in a state of stable balance, with a sufficient reserve of buoyancy to meet emergencies, usually about eighty per cent.

It must be able to attain the required minimum flight speed on the water in a stable condition. The air controls may be used to assist in providing this stability ; this is, in fact, sometimes desirable.

It must have a sufficient factor of safety (i.e., reserve strength) to meet all loads imposed in taxiing, taking-off, flying, and alighting ; in addition those met with in handling on beach, slipway, or ship must be considered and allowed for. The man-handling of a seaplane is very often the cause of unnatural strains, which may do much damage.

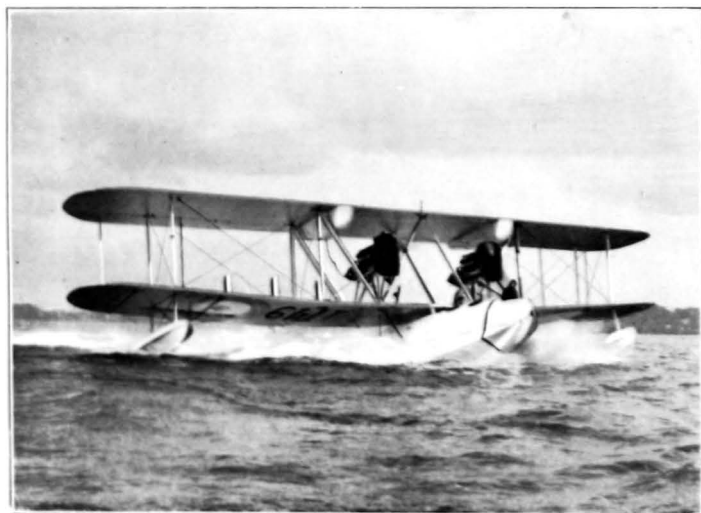
The buoyancy required can be ascertained readily. Factors of safety are calculable, and provision can be made to fulfil requirements. But the hydrodynamic qualities of the floats when in motion are not so easy to determine beforehand, even with model testing in water tanks reduced to a fine art.

There was a time when seaplanes often refused to pass "the hump," the term used to describe the point at which the float climbs out of the partly immersed state on to the surface of the water and



A SINGLE ENGINE AMPHIBIAN FLYING BOAT.

THE VICKERS' VIKING—450 h.p. Napier Lion 12 Cylinder Broad Arrow Water-cooled Engine. The photograph was taken on the Thames with the Houses of Parliament in the background.



A TWO-ENGINE FLYING BOAT.

THE SUPERMARINE SOUTHAMPTON—2 x 450 Napier Lion Engines.

This type of craft is being used by the Royal Air Force for the Far East 25,000 miles cruise.

commences to plane. To-day, with the greatly increased horse-power available in modern aero engines at a much lower weight per horse-power, this difficulty is rarely met with except when seaplanes are deliberately overloaded. Usually the acceleration to hump speed (about twenty knots) is slow, but once the hump is crossed and hydroplaning commences, acceleration is very rapid. Some years ago skilled seaplane pilots were often forced to adopt devious means to coax unwilling craft past the hump. They rocked them violently fore and aft with the elevator, hoping to lever them on to the step, or with the rudder swung the seaplane first in one direction then the other, hoping that the increased speed produced by the swing would cause each outer float in turn to cross the hump. On a calm day any broken water, such as the wake of a passing vessel, was pounced on as a means of reducing the water resistance of the floats by getting the air between the waves underneath the float bottoms. This problem of passing hump speed is very largely one of weight per horse-power. With ample power available the critical point is hardly noticeable. If one watches a seaplane take off, one can observe the action of the floats. As the throttle is opened and the thrust from the propeller drives the seaplane forward through the water a wave is built up under and ahead of the float bows. The floats rise at an angle on this wave and as speed increases they throw more and more water out sideways from their path. At the hump speed, if there is sufficient power available, they ride over the top of this wave or water

hump of their own creation and commence hydroplaning.

There is one feature in seaplane design which tends to spoil float action both before and after the hump. Owing to the necessary large diameter of an air propeller, and the water clearance required to enable it to revolve unimpeded by contact with water or spray thrown up by the floats, the engine on which the propeller is mounted must be carried high above the water. The resistance of the water against the floats tries to hold the seaplane back against the centre of thrust of the propeller high in the air, pulling the seaplane forward. The couple produced thrusts the nose of the floats down all the time the engine is running. Watch a seaplane the instant the pilot first opens the throttle, and you will see the nose go down and the tail come up. In describing the action of the floats when taking-off, I assume this condition to be understood as being present.

When hydroplaning first commences, acceleration is very rapid because the thrust required to hydroplane at speeds slightly in excess of hump speed is very much less than the thrust required to pass the hump. Hence there is a lot of spare horse-power instantly let loose to provide acceleration.

With seaplanes of somewhat restricted power there is a second critical point almost at the end of the hydroplaning run just before the speed required for flight is reached. Water resistance increases again and horse-power available to overcome it becomes vital once more.



Courtesy of "Flight."

A THREE-ENGINE FLYING BOAT.

THE BLACKBURN IRIS—3 x 650 h.p. Rolls-Royce Condor 12 Cylinder Vee Water-cooled Engines.
It was on a similar type craft that Sir Samuel Hoare flew on the recent Baltic cruise.



A FOUR-ENGINE FLYING BOAT.

THE FAIREY TITANIA—4 x 650 h.p. Rolls-Royce Condor 12 Cylinder Vee Water-cooled Engines mounted in Twin Tandem.

In past years, when testing seaplanes and amphibians of new types, I have found examples which crossed the hump and accelerated to within two miles of their taking-off speed in still air and calm water. Nothing could induce them to gain that additional two miles per hour but the fitting of an engine of increased horse-power. True, with the smaller engine they could take-off when wind was blowing because the water speed required was reduced by the speed of the wind. But a seaplane must be able to take off under all conditions, and in still air and water the resistance of those floats at two miles per hour less than flying speed was greater than the thrust horse-power output of the airscrew. Now in this case tide could play an important part, for with a four-knot tide running and no wind the pilot could by taking off down tide reach air flying speed two miles an hour before this critical water speed was reached, because he started with air speed zero and water speed minus four.

With a fairly heavily loaded amphibian I found that the utmost precision of float trimming angle to the water level was necessary to enable me to take off. If the angle of the floats was altered two degrees to either side of a definite angle of trim the water resistance increased sufficiently to defeat the engine's ability to produce the speed required. This particular case proved extremely interesting, because there was a partly telescoping shock-absorbing leg incorporated in the chassis between the fuselage and the after mounting of the floats. It was intended that this chassis should take up taxiing and landing shocks on land

and water. Now I found when hydroplaning at high speeds that the floats adopted a certain running angle which did not correspond with the angle of minimum water resistance. When I used the elevator to correct this float angle the chassis legs extended and the float angle remained unaltered, while the wing angle was reduced. Thus the hydrodynamic stability of this type of float was greater than the moment of the air elevator damped out by the oleo chassis. This amphibian refused to take off except in the most fluky manner, because the excessive float resistance remained unaltered and the wing lift was reduced.

We cured the trouble by preventing the upward extension of the shock absorber mechanism. Then I was able to direct the trim of the float as I wished and I could take off under the most adverse conditions by forcing the floats to take up the float angle which resulted in the minimum water resistance, an angle which was smaller than that to which the float naturally trimmed. I found that other pilots handling this particular craft were unable to take off, and I had to go to their assistance and explain her idiosyncrasies to them. After demonstrating the only method of handling her they had no more trouble. Yet never at any time was there the least difficulty in getting this amphibian to take off from land. Which shows that there is much more in the design and handling of seaplanes than is generally believed.

There are many different types of seaplane floats, some stable and some unstable, some short

and some long, and each has its own particular virtues and vices. To-day, with our modern engines and improved knowledge of design and construction, there is little danger of taking a seaplane out on a glassy swell and running, running in the attempt to take off, until the bottom is bounced out of her, as used to happen in the bad old days. But even to-day the aerodynamic and hydrodynamic qualities of the seaplane are not always perfectly blended.

The question of taking off down wind which has been considered for landplanes, we can now apply to seaplanes. The floats may be perfect to take off into the wind under conditions of a twenty miles an hour wind. They may be good to take off in a flat calm when the water speed to be reached is fifty miles an hour. But if an attempt is made to take off down a twenty miles an hour wind the result may well prove disastrous. The wings will not lift until a water speed of seventy miles an hour is reached, and it is quite possible that the hydrodynamic reaction of the planing floats may be powerful enough to throw the whole seaplane clean off the water before that speed is reached. The pilot may be quite unable to prevent the throw off with his air controls, which are still below minimum flying speed. The seaplane is then thrown into the air, and unable to sustain her own weight in flight, must fall heavily on to the water again, most probably on one side, at a speed of some sixty miles an hour, with a certain crash as climax, and that a bad one.

A crash in a seaplane on water is different to a

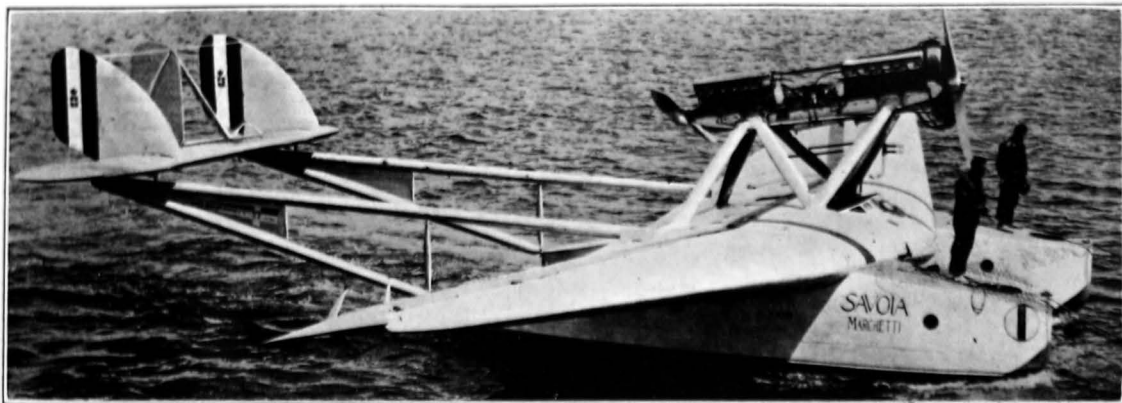
crash in a landplane on land. In the latter the pilot is uninjured, hurt, or killed. In a seaplane he is more often uninjured than in a landplane, but there is the added risk of being entangled in wreckage under the water and drowned, or that a temporary stun may render him unable to help himself. Many seaplane pilots have been stunned and drowned before a boat could get to their assistance to pull them clear.

It has been my good fortune to test many new types of seaplanes, and to carry out the very first full-scale comparative hydrodynamic research on seaplane floats ever attempted. I have found that the qualities of floats vary very greatly with design under the same conditions of sea, tide, wind, seaplane, load, engine and propeller. From this work I know that a seaplane can be made just as easy to take off and land as the very easiest landplane, and I will not rest content with my present knowledge until this most desirable feature is thoroughly established. As it is, I have flown one seaplane which can take off hands off, and indeed takes off better when left completely alone than when interfered with. All the pilot has to do is simply to open the throttle and the seaplane will take herself off. Landing is not quite so easy, but that, I am convinced, can be made simple too.

It only remains to be added that the best seaplane landing, like the best landplane landing, is that which is made at the minimum possible speed consistent with the least alighting shock. In rough weather the lowest possible speed is more than ever necessary to prevent damage by

Photo 6

AN UNUSUAL TYPE OF SEAPLANE.



[*Photograph, "Topical Press."*]

A TWIN HULL FLYING BOAT—THE SAVOIA 55
on which the Marchese de Pinedo made his wonderful flight from Italy to South and North America and back.

waves, and always this landing should be made on a crest, never in the trough. In rough weather the seaplane, unlike the landplane, has to take off from a broken, moving surface. In these circumstances it is very easy to have a propeller smashed by a sea breaking over the nose of the floats when attempting to take off. The best way to take off in rough water is to watch the wave run carefully, and wait for the gentler "ninth" wave. Open the throttle instantly it comes along, at the same time holding the elevator column hard back to keep the bows up. When the bows are held up the water line comes further aft and the break-away of the sea from the floats will be more likely to pass behind the propeller disc. Remember that it is before hump speed is reached that the propeller is liable to breakage. The hump will be reached quickly and passed. The seaplane will then rock and buffet on top of the wave crests. Correct her lurching, hold her to it, and pull her off into the air as soon as ever it is possible to do so. As with many occasions when flying, common sense is the best mentor, but a hint or two in addition is worth a lot of costly experimenting.

CHAPTER VIII

TYPES OF AIRCRAFT AND WHY

There are many different types of aircraft in existence to-day, from tiny light planes driven by motor-cycle engines, to high-powered single-engined single-seater fighting planes built for war ; from single-engined multi-seaters for passenger work carrying from four to ten passengers, to large three and four engined passenger carriers carrying up to forty passengers ; and some aircraft designers of to-day are contemplating building passenger-carrying aeroplanes fitted with ten or twelve motors and capable of carrying a hundred passengers. On the military side, in addition to the fighters, there are single engined, fast, two and three seater bombers and reconnaissance aircraft, and larger two, three, and four engined land and water planes, capable of transporting very large bombs and torpedoes for attacking towns, troops, and ships.

The reason for the great diversity of types is that the aeroplane is a highly specialized vehicle of transport, and that maximum efficiency can only be obtained by utilizing a definite type of plane for a given job. During recent years,

TYPES OF MONOPLANE.



Courtesy of "Flight."

A PARASOL MONOPLANE.

THE WESTLAND WIDGEON LIGHT PLANE—27 80 h.p. A.D.C. Cirrus Air-cooled 4 Cylinder in-line Engine.



A HIGH WING MONOPLANE.

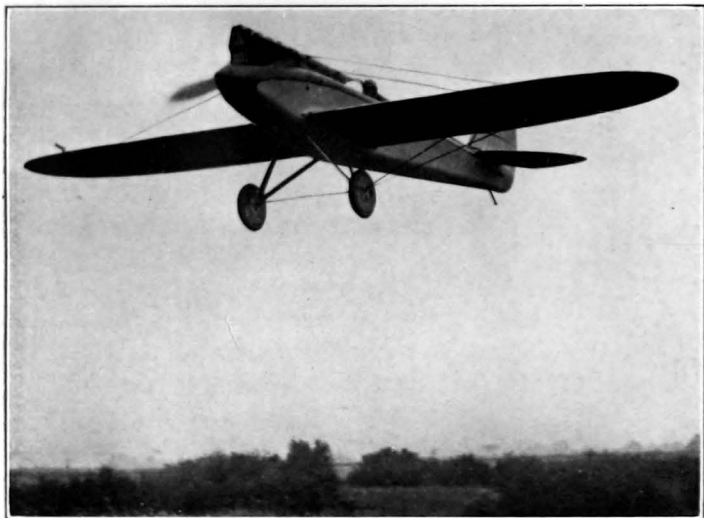
THE BRISTOL MONOPLANE—100 h.p. Bristol Lucifer 3 Cylinder Air-Cooled Radial Engine.
p. 86

owing to the need for economy, there has been a tendency to use aeroplanes in the Royal Air Force designed to meet the requirements of several different classes of work. Recent manœuvres have disclosed the somewhat disquieting fact that a squadron of specialized aeroplanes completely outclassed the purely economy type. There can be no doubt that for military purposes the utmost specialization on one class of aircraft for one type of operations is necessary to get the maximum performance for the particular work to be done. Without the maximum performance the efficiency of the pilots manning the planes must suffer and national safety be jeopardized in consequence.

In the days before the Great War, 1914-1918, we relied upon our Navy as our principal defence, and we knew that the capital cost and annual maintenance charges of our fleet were so great that none of the lesser nations could ever hope to equal our sea strength. To-day, the situation has changed. Throughout the world we see less and less rivalry in naval strength, and more and more competition in air strength. The significant feature of this is that air armament is so much cheaper in first cost and in running costs that even the smallest nations can equip themselves with a striking display of military air power. If we are to maintain our position as leader of the nations of the world (not out of bravado or selfish desire, but because of our proven ability as a nation to lead and uplift) then we must specialize on aircraft because it is in the air more than on the sea that we may expect to have to meet a challenge to our position.

The only types of aircraft which are worth possession by a military or naval air service are those which possess the very utmost capacity of performance to do their particular job. This means diversity of type, one for each requirement.

In the past few years since the termination of hostilities, the development of civil aircraft in all countries, except Germany, has followed the development of military aircraft. The reason is simply that orders for military aircraft have run into millions of pounds, while orders for civil aircraft have only been reckoned in thousands. Germany is an exception, because under the Versailles treaty she was not permitted to build military aircraft, and limitations were imposed to prevent civil aircraft development which could be turned to military use. The German aircraft engineers who wished to continue the development of military aircraft, entered Switzerland, Russia, Denmark, and Sweden, and the home development of aircraft in Germany perforce proceeded along the line of medium size passenger carrying aircraft. The limitations then imposed on civil aircraft in Germany have since been abolished and Germany is now free to build anything she likes except military aircraft. This explains why Germany runs more miles of civil aircraft than any other nation to-day. In addition to her European routes, she has sole rights to operate air lines within Persia, and is interested indirectly in air transport in South America. The central position of Germany in northern Europe also gives her a geographical advantage



Courtesy of "Flight."

A LOW WING MONOPLANE.

THE DE HAVILLAND TIGER MOTH—30/130 h.p. De Havilland 4 Cylinder in-line Air-Cooled Engine.

This Aeroplane, piloted by Capt. H. S. Broad, holds the world's speed record for Light Planes and is capable of a speed of nearly 200 m.p.h.

which our insular position denies to Great Britain. Geographically, at the dawn of the air era, Great Britain lies either too close to Europe, or too far away. If these islands lay a few hundred miles out in the Atlantic they would command the independence to European intrigue which America enjoys, have a most magnificent position for a commercial centre between the old world and the new, and an ideal aerial stopping-place. As it is, our position makes us a terminal point, and the strip of Channel leaves us too close to our neighbours to be outside their political calling list.

This may appear to be a digression, but it serves to show why we must have diversity of types of military aircraft in this country, and why the commercial type has been the former's very little brother in Great Britain. I really think that the true hope for the future of the British aircraft industry lies in striving to become the chief producer of aircraft for the world's use, commercially, as well as for military purposes. We rose to this position in shipbuilding, and we must strain every muscle to repeat that supremacy in aircraft design and construction. We stand in a more difficult position to do so, because America of to-day is in a much stronger position to compete with us in aircraft than she was to challenge our shipbuilding. That is why, from a national standpoint, I view with concern the sudden outburst of American world flying. They were far behind us in the States when the War ended, but they have forged ahead since. Their wealth of money and land, and their remote fear

of war, make their wonderful country a tremendous forcing-ground for a huge commercial aircraft industry which can sell abroad in competition with us.

We have one feature in our favour in this country, that the British insurance corporations have been quietly securing the chief interest in the insurance of aircraft throughout the world. Their rates will in time set up a standard of construction and material in commercial aircraft, which will become equivalent to the rating at Lloyd's of sea craft. The British aircraft manufacturer ought to be able to profit by this British standard to see to it that British aircraft lead the world. But this must not be done regardless of selling price, and here again we find that the troubled state of international finances resulting from the War has not put us in the happy position of being, at the present critical time in our aircraft industry, a cheap producer internationally. It says much for British standards of design, material and workmanship that to-day more than ever, we are exporting aircraft to foreign customers, in spite of our prices being higher than those of any other aircraft producing country in the world. But these exports are still very, very small, compared with what our aircraft industry needs to make it a strong healthy industry, bringing money into this country from abroad.

After having considered some of the economic factors which have and which will affect aircraft design we can now turn to a brief study of some of the whys and wherefores of detail differences.

For the purposes of argument a normal aeroplane may be considered as having a body or fuselage housing an engine at the forward end which drives the craft by means of a propeller mounted on the engine shaft, the after part of the body thinning down in section and carrying the stabilizing and some of the control surfaces at the rear end. Underneath the body is attached the undercarriage. The wing or wings are suitably mounted and braced to the body. Now, an aeroplane in flying through the air encounters resistance to its passage. It is when this resistance equals the thrust horse-power available at the same time that the wings produce a lifting effect equal to the weight of the aeroplane, that maximum level speed is reached. Any further increase in speed can be gained only by flying down hill, losing height, like a motor-car which, when running down hill all out, will travel faster than on the level.

At very high speeds, such as the racing air speeds of to-day, the air resistance is tremendous, and any further increase in speed builds up the resistance out of all proportion to the increase in miles per hour. For this reason decrease in head resistance is a greater factor in the production of speed aircraft than increase in horse power. So that, to obtain still faster speed, any increase in horse power must be obtained without increasing the overall cross dimensions of the engine, otherwise the size of the body would increase in girth, and head resistance go up. It is of little use to install a larger engine and say that the horse power has been increased,

unless the increase in horse power is in proportion greater than the increase in head resistance involved.

The actual resistance of the maximum girth of any body passing through the air can be reduced by stream-lining, so that there is a minimum disturbance to the airflow as it passes over the body. The perfect stream-line should reduce the resistance to one-seventh of that of a flat plate of equal area. In the high performance aeroplane of to-day, the reduction is usually to about one-fifth. This is why every part of an aeroplane is stream-lined as carefully as possible.

It will be clear that if the engine can be housed completely in the body so that there is a clean unbroken line for the air flow over the nose of the aeroplane, then the maximum speed for power will be obtained. This is why all the really high-speed racing aeroplanes of to-day are fitted with water-cooled engines which can be completely covered in. The present-day radial air-cooled engine must have part of the cylinders exposed to the air to keep the engine cool; these cylinder heads form obstructions to clean air flow, and prevent as great speed from being obtained from a radial air-cooled engine of equal horse-power, in spite of the weight saved by air-cooling. That this saving in weight is considerable may be seen from the fact that a present-day water-cooled aero engine of about 500 horse power carries from twelve to fourteen gallons of water in the cooling system, and that water weighs ten pounds to the

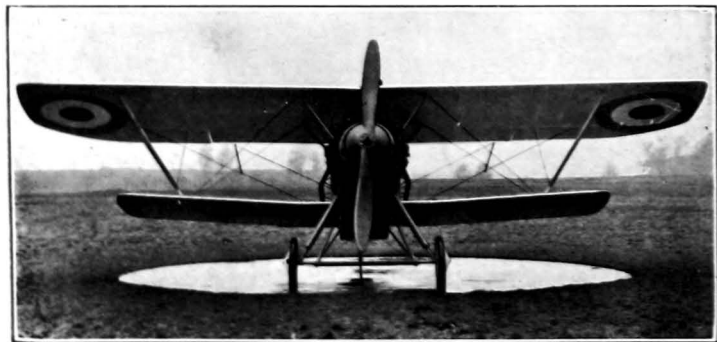


**AN EQUAL WING,
UNSTAGGERED BIPLANE.**

**THE FAIREY III. F—450 h.p.
12 Cylinder Broad Arrow Water-
Cooled Napier Lion Engine.**

Four of these Aeroplanes flew from
Cairo to Cape Town and back as a
Royal Air Force exercise flight early
in 1927, and were again selected for
the same flight in 1928. .

Courtesy of "Flight."



**A SESQUIPLAN BIPLANE, that is, one having a large top plane and small lower plane.
THE ARMSTRONG SIDDELEY SISKIN III. A—385 h.p. Armstrong Siddeley 14 Cylinder Air-
Cooled Radial Engine.**

gallon ; then there is the weight of the radiator and the connecting pipelines, and the water-pump and the mechanical-provision to drive it ; altogether the complete water-cooling system weighs about 250 lbs., or half-a-pound per horse-power. This is in relation to a normal six to twenty pounds per horse-power weight ratio i.e., from two-and-a-half per cent. to eight-and-a-half per cent of an aeroplane's weight per horse power.

It is to this saving in weight, plus the added advantages of avoiding the complication of water-cooling and the chance of water leaks, that the air-cooled designers have pinned their faith, and there is no doubt that for certain classes of work the air-cooled radial engine is of great value. But for maximum speed, power for power, the water-cooled engine will always beat the air-cooled radial because it can be stream-lined effectively inside the nose of the aeroplane, and at high speeds the difference in head resistance absorbs more power than the difference in weight.

When one considers air, one is apt to think of something which is always with us, which is taken for granted ; something which is warm in summer and cold in winter, which can smell sweet and fragrant, or nasty of odour and throat-gripping with fog ; a still and languorous, or gently moving element in our lives which brings us pleasure. Yet sometimes we know that it can rise in wrath and sweep fearfully across wide spaces, lashing oceans to fury, tearing down trees, houses, destroying whatever ob-

struction lies in its path. It can smite hard with the hammer blow of the mighty tornado. Not one of those demonstrations of nature equals the speed of flight of the racing aeroplane of to-day.

The air-flow that breaks before the onrush of the modern speed aeroplane is as unlike the air that we know and breathe and feel almost as water. Its resistance properties and its flow are more akin to water phenomena than those of slow-moving air. This determines that the stream-line form of high speed aircraft must grow in appearance more like that of fast swimming fish, because the relative speeds in the two elements demand approximately the same physical outline to reduce to the minimum the power expended in imparting motion. But there is this difference, that the fish can float stationary by displacement, while the aeroplane can only remain in flight by air displacement produced through motion. The fish-like appearance of some of our present-day high performance aeroplanes is worth observing. See especially the accompanying photographs of some of the racing seaplanes built in Great Britain for the 1927 Schneider Trophy Race.

These considerations have been taken as applying to small, very fast aeroplanes flying at or near sea-level. When the same aircraft climbs the problem becomes somewhat different. Any aeroplane climbs fastest at a certain speed. This speed is approximately that at which the ratio of the lift obtained to the resistance met



Courtesy of "The Aeroplans."

A SMALL TOP WING BIPLANE—THE PARNALL PIXIE III. A LIGHT PLANE,
a Cylinder Anzani Inverted Vee Air-cooled Engine. This Aircraft is convertible to a Low Wing Monoplane when desired.

with is at its maximum. Usually this best climbing speed near sea-level is about one-third up the speed range ; that is, if the minimum speed is forty miles an hour and the maximum is one hundred, then the speed range is sixty miles an hour ; the best climbing speed will be one-third of sixty ; this twenty miles an hour must be added to the minimum flying speed of forty miles an hour and the best climbing speed is found to be approximately sixty miles an hour. If the minimum speed is fifty and the maximum one hundred and seventy, then the best climbing speed at low altitudes will be :

TOTAL WEIGHT OF AEROPLANE 5,050 lbs.

170 — 50 = 120 m.p.h. speed range.

$(\frac{120}{3}) + 50 = 90$ m.p.h. best climbing speed.

This rule must not be taken as more than a rough guide, for individual features in any particular aeroplane such as unusual wing section, unusual wing angle to body, may throw it out. But it is sufficiently close to be of considerable use to the pilot who may have to fly aeroplanes with which he is not familiar, when he has no time to find out the best climbing speed by making special tests. The rule covers different conditions of load between wide limits because, as the load (or weight carried) increases, the minimum speed goes up and the range decreases. Taking the last case in an overloaded condition when the minimum speed rises to sixty m.p.h., owing to the increased load on the same wings, the maximum speed would drop owing to the added resistance due to the greater wing angle required to support

the additional weight ; top speed would then drop to 165 m.p.h. The best climbing speed would then become :

TOTAL WEIGHT OF AEROPLANE 7,250 lbs.

165 — 60 = 105 m.p.h. speed range.

$(\frac{105}{3}) + 60 = 95$ m.p.h. best climbing speed.

It will be observed that the best speed of climb is not very greatly affected by change of load, but that a slightly increased speed is required to carry it. This can only be achieved at the expense of decreasing some of the lift and increasing some of the minimum resistance (technically called "drag") because of the altered angle of wings and body. Therefore, the rate of climb, and the height to which the aeroplane can climb, falls off.

This may be a little confusing to the motorist who drives by his speedometer, and who knows when his speed increases on a hill that he is climbing faster. But if he remembers that an aeroplane makes its own hill just as it makes its own bank in a turn he will realize the difference. The speed has gone up not on the same gradient, but because the hill is less steep ; just as his car can climb one hill at thirty miles an hour, and one with an easier slope at thirty-five miles an hour. Here again the aeroplane pilot is more fortunate than the car driver, because he can, within quite wide limits, determine his own hill gradient to suit his load.

From this it will be clear that the air-cooled radial engine's saving in weight is of greater use to a fast climbing aeroplane than to a high speed

AIR-COOLED AND WATER-COOLED FIGHTERS.



A VERY MANŒVRABLE AIR-COOLED ROTARY-ENGINEED SINGLE-SEATER FIGHTER.
THE SOPWITH SNIPE—200 h.p. Bentley 9 Cylinder Air-Cooled Rotary Engine.

aeroplane, because the air resistance is very much less at the lower speed of climbing, and the weight saving becomes important as the air density falls with height gained.

At sea level we all know that the atmospheric pressure is fifteen pounds to the square inch. As the aeroplane climbs the pressure falls and the air becomes less dense, until at just under nineteen thousand feet it is half sea level pressure. In consequence the aeroplane obtains less and less lift from the lighter air and must decrease its angle of climb and increase its forward speed until it reaches the point where all the speed of which it is capable is required to support its weight. Then it can climb no higher ; it has reached its ceiling. Approximate figures might read like this :

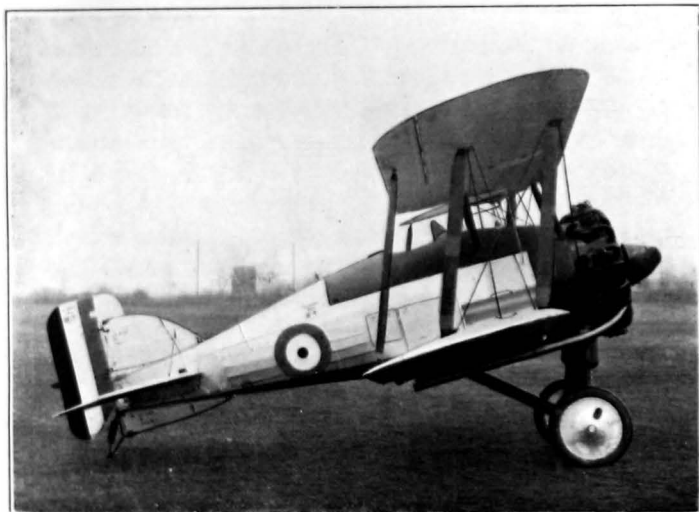
Minimum Speed	50 m.p.h. at sea level.
Maximum Speed	125 " " " "
Best Climbing Speed	75 " " " "
Speed at top of Climb	88 m.p.h. at a ceiling of 20,000 ft.

Now here are two curious features which are of considerable interest. One is that the speed shown on the Air Speed Indicator (which is the pilot's speedometer) would only be sixty-five m.p.h. at 20,000 feet. Yet he started climbing from the ground at seventy-five m.p.h., and at 20,000 feet he is actually travelling at eighty-eight m.p.h. The reason is that the fall in pressure with height affects the reading of the speedometer, because the instrument measures the speed of passage through the air by means of the air pressure on a diaphragm. As the pressure falls the true speed increases if the same instrument

reading is maintained. This would result in too fast a speed through the air when high up to obtain maximum climb. Actually the pilot reduces speed on his instrument to prevent the true speed of the craft rising too high. Thus, at the top of the climb the true speed is higher than the true speed which was correctly indicated on the instrument near the ground, while all the way up the pilot has been steadily reducing speed on the instrument.

The engine, too, has suffered from the change of air density and pressure. The quantity of air by volume drawn into the engine by the suction of the pistons has remained the same, but the density of this air has fallen so that there is less oxygen per cubic foot of air. To maintain the correct mixture of petrol and air, and to prevent waste of fuel through running on too rich a mixture, the pilot is forced to cut down the supply of fuel as he climbs upward. This reduction of fuel and air causes a drop in horse-power, which is progressive all the way up and is the other main contributing factor in addition to wing lift loss in determining the maximum height to which the craft can climb.

Owing to the lighter air, propeller efficiency has suffered. It is not difficult to understand that the blade area and the pitch of the airscrew cannot be equally efficient in normal air and in air of half the density. So, to maintain propeller efficiency at different heights, an airscrew, the pitch of which can be varied by the pilot, has been and is still being sought after by the aircraft designers of the world. It is too much to hope



A FAST CLIMBING AIR-COOLED RADIAL-ENGINEED SINGLE-SEATER FIGHTER.
THE GLOSTER GAMECOCK—420 h.p. Bristol Jupiter 9 Cylinder Air-Cooled Radial Engine.



A HIGH-SPEED WATER-COOLED ENGINEED SINGLE-SEATER FIGHTER.
THE FAIREY FIREFLY—430 h.p. Fairey Felix 12 Cylinder Vee Water-Cooled Engine.

for variable blade area. The problem of a variable pitch propeller is not easy of solution, owing to the tremendous centrifugal forces acting on a fast revolving air propeller. Perfect balance, extreme rigidity of mounting, and minimum weight are of paramount importance.

It will be realized that at considerable heights the reduction in air density reduces the head resistance to be met with at equivalent speeds at ground level. On this is based the dream of the future, of aircraft flying very high carrying variable surface wings, fitted with super-charged high compression engines which develop more power at height than they can give at sea level, equipped with variable pitch propellers, and travelling at tremendous speeds. The cold and rarefied air encountered would be kept outside a cabin supplied with warmed and oxygenated air. This picture is as yet little more than a novelist's dream, even although we are to-day experimenting with and producing aero engines designed to give maximum power output some thousands of feet above sea level.

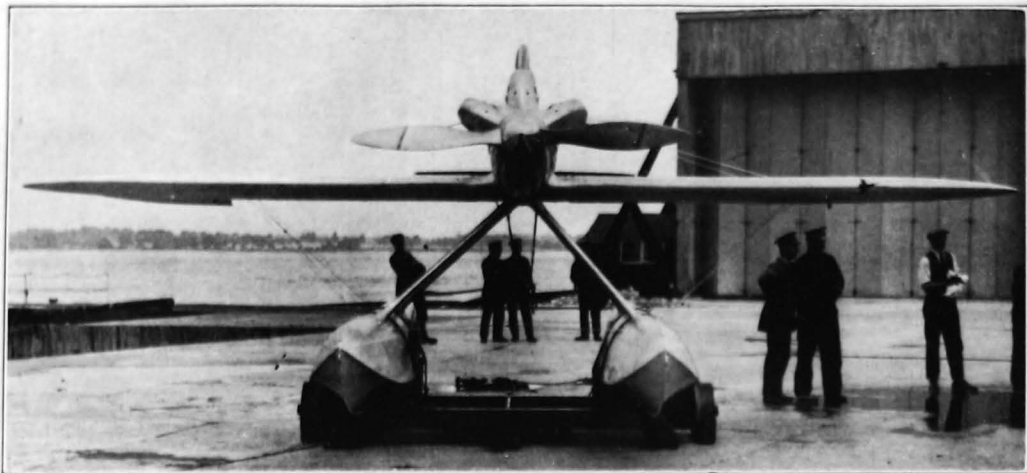
The reader will have formed some idea of the limitations of the air, the element which sustains flight. To enable him to follow the reasons for the diversity of types of aircraft, we must consider other factors.

It may be accepted that the ordinary maximum weight in pounds per horse-power which the practical aeroplane of to-day can carry, including its own weight, is about twenty pounds per horse-power. That is, an aeroplane having an engine of five hundred horse-power must not weigh

more than ten thousand pounds, or about four and a half tons. It is true that this weight to horse-power figure has been exceeded, but only for stunt purposes of long-distance record-breaking flights. From this it will readily be understood that the weight required to be carried determines the minimum horse-power needed ; and this in turn may decide the number of engines.

The individual designer may select for a multi-engine design two, three, or four engines to supply the required horse-power. To-day there is a fashion in three-engined aeroplanes. This type of aeroplane must be able to run on any combination of two of its three motors ; the centre engine is housed in the nose of the fuselage, and the two outboard motors are mounted on the wings, one either side. Four-engined aeroplanes, both land-plane and seaplane, have been built in this country having two engines in tandem, mounted between the wings on each side, the front engine driving a tractor airscrew and the rear engine a pusher airscrew. This tandem arrangement has also been used by German and Italian designers for two-engined aeroplanes. This method is not really efficient for, although it reduces head resistance, it places the rear airscrew in the swirling slipstream of the front airscrew, and destroys some of its efficiency ; the maximum speed of this type of aircraft is not high enough to enable the head resistance saved to outweigh the loss of efficiency from one propeller. Also the higher revolutions of the rear propeller, due to the disturbed air, are a factor in increasing

A WATER-COOLED RACING SEAPLANE.



Courtesy of "Flight."

THE SUPERMARINE S5 LOW WING MONOPLANE TWO-FLOAT SEAPLANE.

Napier 12 Cylinder Water-Cooled Engine fitted with a Fairey Reed Duralumin Propeller. This Seaplane flown by Flight Lieut. S. N. Webster won the Schneider Trophy for Great Britain in Italy, 1927. The low head resistance due to the small frontal area is well illustrated in the photograph.

petrol consumption. The twin-engined aeroplane with motors mounted on or between the wings has done a great amount of very useful work in past years since 1917, but there was always a tendency to overload this type, and so make it impossible for it to maintain level flight on one engine ; or half power. Hence the present popularity of the three-engined type which, with one engine out of action, possesses two-thirds power. This present fashion was ushered in by this stinting of horse-power, or overloading. But another reason is also advanced. This is, that with the twin-outboard engined aeroplane the involuntary stoppage of one motor when taking off involved a vicious swerve produced by the out-of-centre thrust of the other outboard motor running full out. This swerve could be so sudden that the pilot had no time to correct it before the aircraft crashed.

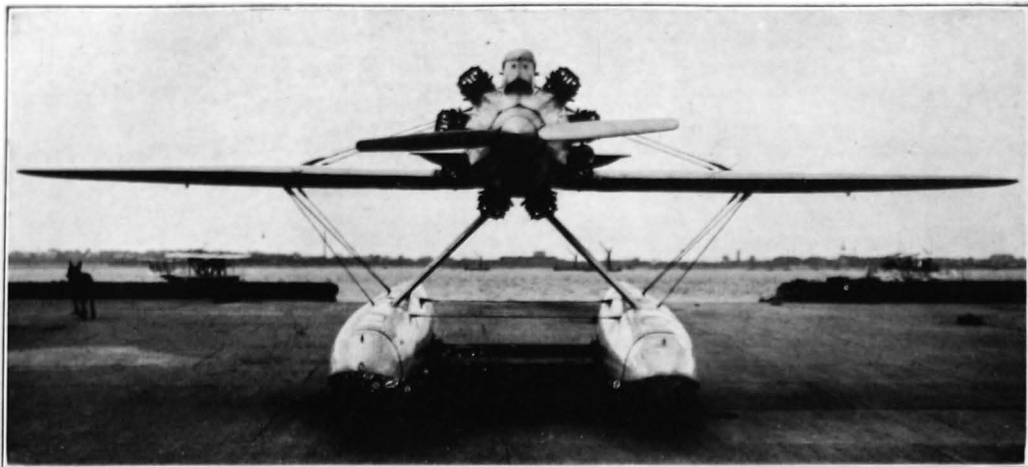
The take off is, in my opinion, the most dangerous moment of any normal flight. The pilot has no height and, in consequence, no time to elect what to do ; he has little speed, and therefore limited control and manœuvre ; and during the run he is travelling away from his landing-ground, and possibly towards obstacles. Therefore it behoves every pilot always to take every precaution before opening out his engine or engines to take off, and always he should listen for the slightest change in note from any engine.

Admittedly it is more difficult to detect the change of note in one of two motors than in a single engine, and it is very difficult sometimes to determine which is the faulty one. Therefore,

the three-engined aeroplane has achieved popularity because the loss of power with the failure of one engine is only one-third instead of one-half, and the out-of-balance thrust is also one-third at most, and may be nil if it is the centre engine which fails. Slipstream speed over the tail controls is useful with the central engine when taking off and in flight, but is no better when throttled to land than with a twin-outboard engined craft.

There is much to be said for the three-engined aeroplane, but the reasonably loaded twin is not dead. For military purposes the latter provides a free field of fire from the unengined, unpropellered nose. And if the twin is designed, and used, so that it can take off and climb to several thousand feet on one engine, then it can be a very useful craft indeed. Although its larger engines and consequently bigger diameter propellers may mean engines mounted further from the body than three-engined craft with smaller engines and propellers, thus increasing swing on one engine, there are precautions which can be taken to minimize this. Engines can be mounted offset so that the slipstream action on tail surfaces tends to reduce offset thrust with one engine only running. The body can be reduced in width to the minimum, thus reducing head resistance at the same time as engine width. The three-engined aeroplane is truly a commercial type, the two-engined a military craft. The three-engined flying boat is in a different class, because in the flying boat the engines are all carried high up in the wings to provide water clearance for the propellers and do not restrict forward gunfire and view.

AN AIR-COOLED RACING SEAPLANE.



Courtesy of "Flight."

THE BRISTOW-SHORT-CARTER LOW WING MONOPLANE TWO-FLOAT SEAPLANE.

Bristol 9 Cylinder Air-Cooled Radial Engine. This seaplane unfortunately crashed before its maximum speed was properly established, but the photograph shows conclusively that much more power would be required from the Radial engine to produce the same speed as the water-cooled engine owing to its greater head resistance and the more uneven air flow set up by its ring of projecting cylinders.

There was a four-engined aeroplane built in France (and one in Britain many years ago) in which all engines were outboard, two on the lower wings and two on the upper wings of a biplane ; all engines were tractors. Engine failures could produce out-of-balance forces in both lateral and longitudinal directions, and the latter proved fatal on at least one craft of the type. The British aeroplane was a triplane, but the effect of the engine mounting positions was the same ; it crashed on its first attempt to take off. This type is undesirable.

The single-engined aeroplane with the motor mounted in the nose driving a tractor airscrew is the predominant type in the world to-day. This type was not the first in the world to achieve free flight for the Wright Brothers' biplane was a tail first, single-engined aeroplane, driven by two pusher airscrews, nor the first to fly in Britain, which was Mr. A. V. Roe's pusher biplane of 1907-1908, in which he made the first flight in England on the 8th of June, 1908. But the single-engined tractor type shortly after became prominent. Mr. Roe's second aeroplane, the nine horse-power J.A.P. motor-cycle engined triplane, which also flew in 1908, was of this type, as was the famous Bleriot monoplane, which was the first to cross the Channel on the 25th of July, 1909. The single-engined tractor type of aeroplane is the most efficient in the world to-day. More attention has been paid to it, and more different designs of this type have been built and tested than of any other. It holds all the world's ultimate speed records, height records, duration

records, and distance records. It is the cheapest type to produce and more is known of its aerodynamic qualities than of any other type of single or multi-engined aircraft to-day.

After having adjusted the problem of total weight and horse-power and number of engines, the other great fundamental question in the layout of any aeroplane is the weight per square foot of wing surface. Here again there is a definite limit in the practical aeroplane, and that is about sixteen pounds' weight to the square foot. It will be noted that the maximum permissible weight to the square foot is less than to the horse-power. The reason for this is that the minimum speed is mainly a function of the wing loading, and this speed must be kept within a reasonable figure to enable a safe emergency landing to be made in the event of engine failure.

Taking again the case of an aeroplane with a single five hundred horse-power engine loaded to the outside limit of ten thousand pounds, we find that the outside limit in wing loading must be ten thousand divided by sixteen, which is equal to six hundred and twenty-five square feet of wing surface.

It should be borne in mind that this aeroplane represents the safe practical limit. The minimum speed will be high, about seventy miles an hour ; and, owing to the heavy horse power loading, the time and run taken to reach this speed will be very considerable. Such an aeroplane would require a large aerodrome to operate from and would not be easy to land in an ordinary sized field. If the designer fears these considerations,

AIR-COOLED AND WATER-COOLED RACING SEAPLANES



Courtesy of "Flight."

THE SUPERMARINE S5 LOW WING MONOPLANE TWO-FLOAT SEAPLANE.

Napier 12 Cylinder Water-Cooled Engine.

The care taken to stream-line every detail and the fish-like appearance of these fast-flying Racing Seaplanes are noteworthy.



Courtesy of "Flight."

THE BRISTOW SHORT-CARTER LOW WING MONOPLANE TWO-FLOAT SEAPLANE.

Bristol 9 Cylinder Air-Cooled Radial Engine.

Note the fish-like outline of the after part of the fuselage and the floats.

he must reduce the total weight, or increase the horse-power, or the wing area ; or he may elect to modify any combination of these three factors. For example, he may find that he cannot increase horse-power for that is fixed by the type of engine available. Then he can reduce total weight at the expense of the useful load carried, thus reducing the take off run and the landing speed and increasing the top speed ; or he can use the weight cut out to increase the wing surface, thus reducing the take off run and the landing speed, but reducing the top speed also because of the additional air resistance offered by the increased wing size.

From this it will be clear that the designer knows his limitations, but inside these boundaries lies a wide choice of combinations of factors to give play to individual style. For the purpose of determining relative efficiency it is usual to take the wing loading and the horse-power loading and multiply these two, the resulting product giving a common basis for comparison. In the case we have considered the wing loading was sixteen, the power loading twenty, and the product three hundred and twenty, thus :

Wing Loading	×	Power Loading	=	Product.	Type of Aeroplane.
16	×	20	=	320	Practical limit.
12	×	20	=	240	Weight carrying Bomber or Passenger.
12	×	15	=	180	Normal passenger carrier.
12	×	10	=	120	Military two-three-seater.
10	×	6	=	60	Military Single-seat Fighter.

To show how these figures can be converted into practical dimensions, we can take the last case, the military scout fighter.

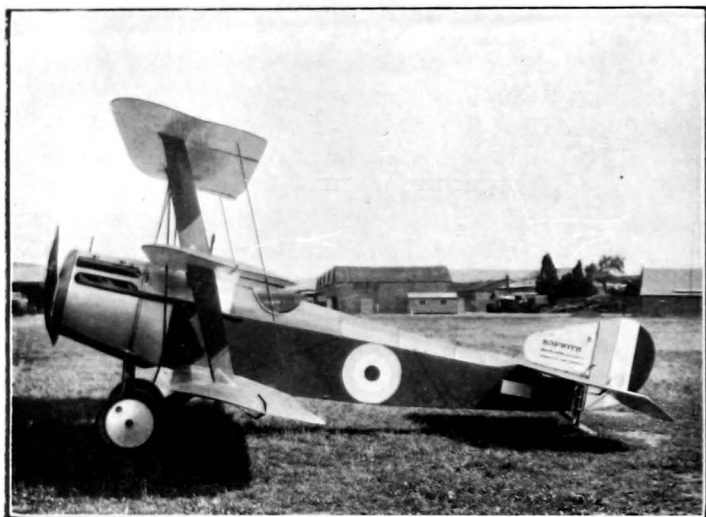
The engine is a standard one of 450 horse-power. Power loading in lbs. is six lbs. per horse-power. Therefore, the total loaded weight is $6 \times 450 = 2,700$ lbs. The wing loading is ten lbs. per square foot of wing surface. Therefore the total number of square feet of surface is 270.

If we consider this aeroplane as a biplane (the normal type of military scout in use in this country) the dimensions of the wings would be 270 divided by 2, equal to 135 square feet each. The span could then be determined at 30 feet and the chord 4.5 feet.

Since the aeroplane is a scout the span must be kept low so that manœuvre is easy and quick, but the best results aerodynamically are obtained from wings which are reasonably narrow across the line of air flow. This ratio of span to chord is called the *aspect ratio* and it should never be less than five to one; eight to one is a very satisfactory ratio. In the case we are considering, requirements of small span for manœuvre and strength of wing limit the designer, and a very satisfactory compromise is reached at an aspect ratio of 6.6 to 1, a span of 30 feet, and a chord of 4.5 feet.

Now, just as the width or chord of the plane must not be too great to disturb unduly the air flow over it and increase the surface friction of the plane's passage through the air, so also must the upper and lower planes of the biplane be spaced sufficiently wide apart to prevent the

TYPES OF TRIPLANE.



A SINGLE-ENGINE SINGLE-SEATER FIGHTER TRIPLANE.

THE SOPWITH TRIPLANE—150 h.p. 8 Cylinder Vee Water-Cooled Hispano Suiza Engine.

disturbed air flow from one wing interfering with the air flow over the other. This space is called the *gap*, and it should never be less than the chord and preferably rather greater.

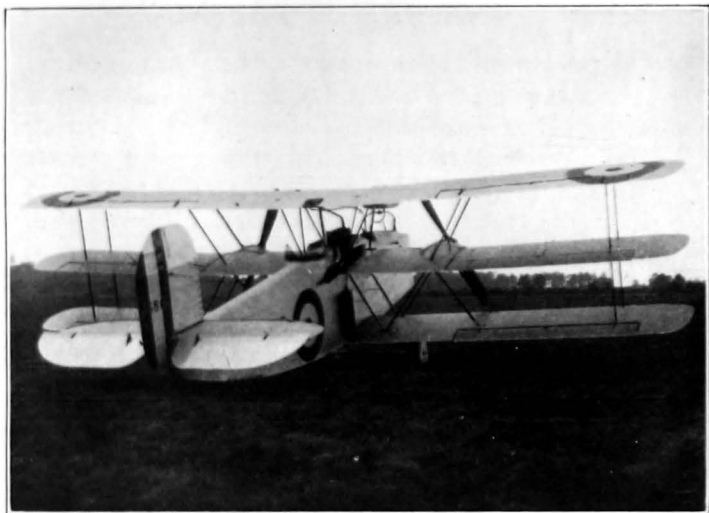
The next question which besets the designer is the wing section which he will employ, for there are many different kinds to choose from, most of them with properties of lift and resistance which are well known. This feature in the aeroplane I shall leave until the next chapter.

Having got as far as this and decided on his wing section, the designer then draws the general outline of his aeroplane, in plan, elevation, and front view. The drawing is made to scale, and shows the engine as it will be housed in the aircraft. The maximum cross dimensions of the body are decided by the provision of room for the pilot, and guns, ammunition boxes, petrol and oil tanks, oxygen apparatus, and radiator, and the hundred and one component parts called for in a fighting scout. The outline of the body is stream-lined as perfectly as these restrictions permit and a reasonable length provided to assure stability. Tail surfaces are drawn in, fin and rudder, tail plane and elevators; a propeller, undercarriage, and tail skid are added, and the first picture of the aeroplane is complete.

Before the aeroplane is built several such general arrangement drawings (as they are called) may be made, showing differences in details; possibly a larger top plane and a smaller bottom plane may be substituted for the two of equal dimensions first selected; the gap may be increased or decreased to permit a better view for

the pilot over the top plane ; the position of the two planes on the body may be moved backwards or forwards in relation to each other, thus altering the *stagger* of the planes to compensate centres of lift and weight which must lie within certain limits in relation to each other. Then detail calculations of lift and resistance are made, and converted into figures of speed and climb ; the percentage of the total weight to be allowed for structure is arrived at, and the type of structure proposed examined theoretically for strength ; the disposition of the remaining weight is made in order of the fixed items first ; power plant and propeller, pilot, guns and equipment, then fuel and tanks. It may be found that there is not enough weight available for fuel to provide the required range of action because the original estimate has altered in the detailed examination of lift and resistance ; or the performance may not be good enough ; or the strength factor too low. Then the arrangements must be re-shuffled to meet the new estimates of requirements.

Finally, the detail drawings are made and supervised, checked and approved, and passed out to the shops as blue prints. There may be anything up to some two thousand drawings for one such aeroplane. The organization of manufacture of the detail parts passes into the hands of the works manager and his assistants and, at first slowly, then rapidly, the paper and figure aircraft grows into a real aeroplane ready for the test pilot to take up into the air to prove the truth of the theories and figures, the value of strength calculations and premises.

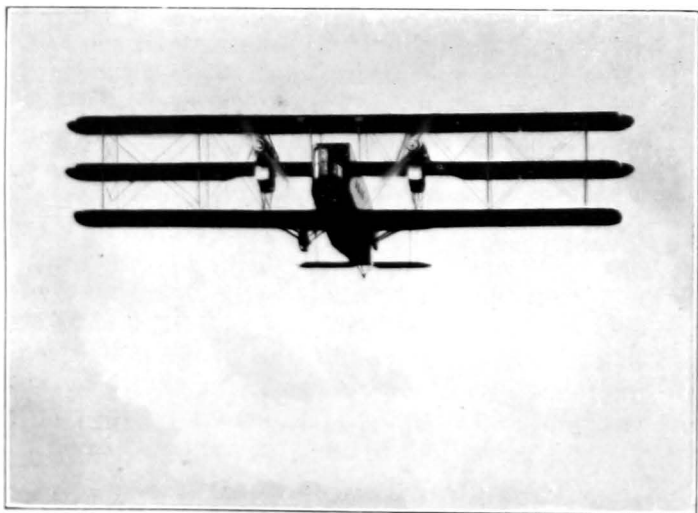


A SINGLE-ENGINED TWIN PROPELLER SHAFT AND GEAR-DRIVEN TRIPLANE.

THE PARNALL POSSUM—450 h.p. 12 Cylinder Napier Lion Engine.

The water-cooled engine is housed in the fuselage and started up by hand from inside.

The centre plane houses the shaft drive out to the twin propellers.



A FOUR-ENGINED TWIN TANDEM TRIPLANE.

THE BRISTOL FULLMAN LIMOUSINE—4 400 h.p. 12 Cylinder Vee Water-cooled Liberty Engines.

There are many different ways of arriving at a roughly similar conclusion to the problem of how to carry the most weight and provide the fastest speed in the air. There are monoplanes with wings mounted above the body, or rooted at the "shoulders" of the body, or still lower at the "hips." These types are known respectively as the parasol monoplane, the high wing monoplane, and the low wing monoplane.

In biplane design there are aeroplanes with equal dimensioned planes top and bottom, many with larger top planes, and a few with smaller top planes. Some of these have a big stagger, or throw forward of the top plane ; a few have back stagger ; some no stagger at all.

Triplanes have been not uncommon, and one or two quadriplanes (aeroplanes having four planes mounted one above the other) have been built. With the higher speeds and greater efficiency of to-day the triplane and quadriplane have fallen into disfavour, because they are difficult to make constructionally robust without sacrifice of weight, and the additional head resistance of the necessary struts slows them down in top speed compared with the monoplane or biplane.

To-day the race lies between the monoplane and the biplane. A classification of use can be formulated very roughly thus. With big aeroplanes build the monoplane for weight carrying, and the biplane for performance in speed and range ; with small aeroplanes build the monoplane for speed, and the biplane for strength.

In Germany (and with Germany may be

included that international designer, Antony Fokker, Dutch citizen, then German, again Dutch, now American) the monoplane has become the standard type since the War. The biplane remains the normal type of British aeroplane. Now, apart from aerodynamic theory, there are conditions which are imposed upon a nation by geographical necessity. The chief wood used in aircraft construction is high-grade spruce, the largest supplies of which timber, none too plentiful, stand in Canada. Out of every shipment from Canada the British market selected what it wanted, choosing the highest quality. France got second choice. Germany had to be content with the remainder. Thus, Germany, partly from geographic necessity and partly from choice, turned to all-metal construction and, as one of the principal manufacturers and users of duralumin in the world, she naturally chose that material whenever possible in preference to steel. One of the main reasons for employing biplane construction is to enable a thin section wing to be employed, which must rely on the external bracing of struts and wires for strength. In Great Britain duralumin is not considered suitable for thin sections because of the corrosive properties of the alloy. And that is why Germany turned her attention to the thick wing cantilever monoplane, which requires no external bracing owing to the massive internal members of the wing structure.

In Britain to-day we are gradually turning over to the metal construction of aircraft, but we are mostly using steel for wings and fuselage. This



THE BLERIOT MONOPLANE.

The engine was a 3 Cylinder fan-shaped air-cooled motor of 28 h.p., and the longest flight this engine ever made was that when M. Louis Bleriot flew the English Channel for the first time on the 25th of July, 1909. The photograph shows the actual plane on which this historical flight was made, with M. Bleriot standing up in his machine just prior to the start. The diminutive crowd of spectators testifies to the lack of interest shown in aviation in its early days.

is partly because of our knowledge of, and greater familiarity with, thin wing sections; partly because of our distrust of some of the properties of duralumin, such as crystallization due to vibration, and corrosion. This British policy has been dictated in part by our military needs, which could not hope to obtain the enormous supplies of seasoned timber required in the event of a large-scale war. At the end of the last war we were forced to use artificially (kiln) dried timber, and I have seen wing spars break in flight owing to the inferiority of the wood. Further, wood does not stand up well in the hot countries of the British Empire.

The Germans use sheet duralumin, often corrugated for strength (the reader must have noticed how a sheet of corrugated roofing iron does not bend as easily as a flat plate) to cover the wings. We still use linen as standard, but occasionally, in very fast aeroplanes, duralumin or wood planking. And there is much to be said for the fabric covering because it is easy to repair and replace, and quick to strip to enable inspection of the wing structure to be made. Some of our aircraft are constructed almost completely of duralumin, but these are exceptions to our usual practice in this country. We are using dural for seaplane floats and hulls, for this is the only metal which is suitable at present owing to considerations of weight. The saving in weight due to the absence of water soaked up by the wood of a similar old-type flying boat hull may be as much as five hundred pounds. In some of our large biplanes, too, we are employing dural

for wing construction, because the wing section is deep enough to make this feasible. Here again there is a big saving in weight.

Research is going on continually to prevent corrosion of both steel and dural, especially the rapid corrosion due to sea water. The present chromium rustless steel used for cutlery is not commercially usable for aircraft; it costs about four times as much as ordinary steel, and it is almost too hard to work with the ordinary manufacturing cutting tools in the workshops, making the cost of production excessive. Protective coatings provided by electric baths are largely used, anodic, tin, and cadmium plating. Spray cellulose painting is good.

In leaving the question of monoplane and biplane, it may be said that the type of either craft which the designer will employ will be decided by the factors which dominate the performance. These are, as has been shown, head resistance, horse-power loading, wing loading, and to a lesser extent the wing section employed. After that he will take into consideration ease of construction, inherent stability, pilot's view, ease of installation of fuel system, disposition of load to centre of lift of wings, comfort of passengers, military or commercial requirements, and cost of production.

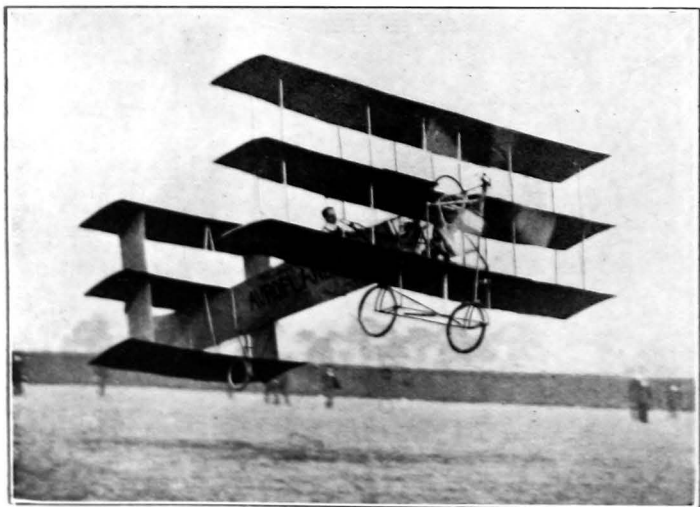
To-day we have two different classes of aero-engine, the air-cooled and the water-cooled. It has been shown that the latter type is the speed producer, while the air-cooled radial engine is capable of faster climb, power being equal, owing to its lesser weight.



Courtesy of "Flight."

THE WILBUR AND ORVILLE WRIGHT BIPLANE—Wright Engine.

This Aeroplane was a single-engined pusher with two pusher airscrews driven by chains. Launching was effected by running along a rail towed by a launching rope actuated by a weight dropping in the derrick seen in the photograph.



THE A. V. ROE TRACTOR TRIPLANE—The Engine was a 9 h.p. Jap Motor Cycle Engine.
The photograph shows Mr. A. V. Roe flying his triplane at Lea Marshes, north of London, in June, 1908.

Other differences appear when the qualities of the two types are analysed. When flying very high and the air density falls off the difference in head resistance falls off in like proportion. The water-cooled engine aircraft will still be faster, but the percentage difference will be less. It is possible that given equal super-charging of engines the air-cooled radial might prove faster than the water-cooled, and have a higher ceiling, at enormous heights. At considerable heights the air-cooled engine is liable to be over-cooled because of the low temperature of the air. This might upset its theoretical advantage by a reduction of power through running too cold. The fuel consumption of the air-cooled engine is higher than that of the water-cooled, because its cylinders are not kept at a consistent temperature, which was determined beforehand by the designer, but vary with the air temperature and speed of the aircraft.

On small, fast aeroplanes the air-cooled engine is slower than the equal-powered water-cooled motor, because the engine resistance forms a large proportion of the total. This difference is not so marked on large aeroplanes where the percentage difference of engine resistance is much less. For military requirements, which demand the utmost in performance at all costs, nothing but the maximum is worth considering; therefore the best type of engine for military work to-day appears to be the water-cooled, and this in spite of any extra complication which may be introduced by the water-cooling system. The air-cooled radial is more truly a commercial type

engine. The medium sized air-cooled radial is a very efficient, sweet running, simple, and very reliable aero engine, and an ideal type for commercial aircraft. Small, in line air-cooled engines, are at present in use on light aeroplanes, and it is feasible that they may be developed to produce much higher horse-power output in the future.

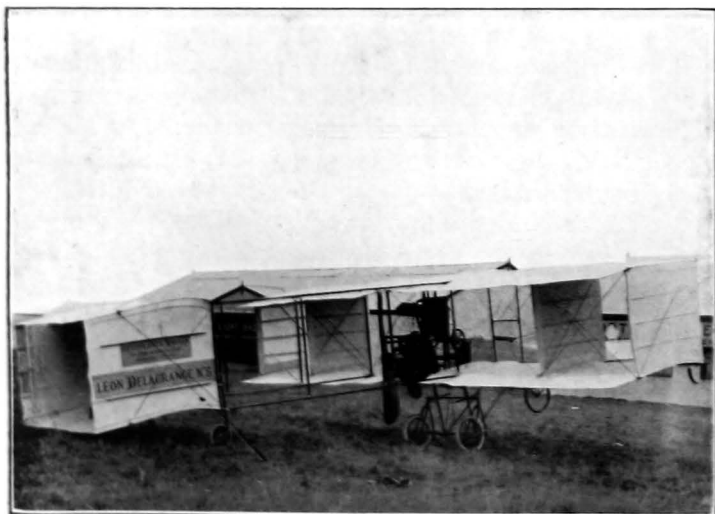
The competition between air and water cooling in aero engines has been of great benefit in the reduction of weight per horse-power. This commercial competition must continue until the steam-cooled engine, perhaps, is produced to offer the compromise of even and controlled cylinder temperature, ability to cowl the engine in the fuselage nose, and light weight due to the absence of gallons of cooling water.

Engines are either direct drive or geared down. That is, the speed of rotation of the propeller is the same as that of the engine shaft, or less. The geared engine is the more efficient aerodynamically because present-day aero engines run faster than it is desirable to run propellers. At high speeds of rotation air propellers must be so reduced in dimensions that they suffer from lack of blade area and diameter. The take-off is then not so good, and in flight the fast revving propeller suffers from an increased percentage of slip, or lost thrust. For any given forward speed on a given aircraft there is a certain maximum efficiency propeller which should run at a definite number of revolutions. The ideal reduction gear is that which adjusts the ratio between engine revolutions and propeller revolutions to give maximum useful horse-power. But it must be remembered



Courtesy of "Flight."

THE SANTOS DUMONT CANARD OR TAIL FIRST AEROPLANE.
 This aircraft was fitted with side curtains to provide lateral as well as directional stability. The Aircraft flew successfully.



Courtesy of "Flight."

THE VOISIN AEROPLANE.
 A pusher fitted with side curtains and a nose elevator. This aircraft flew successfully.
 Note the rudder mounted in the centre of the box tail.

that there is an increased weight to be carried due to the gears, which offsets some of the advantage.

As conclusion to this chapter, it may truly be said that aircraft designing is a resolving of compromises in the endeavour to produce the best possible compromise.

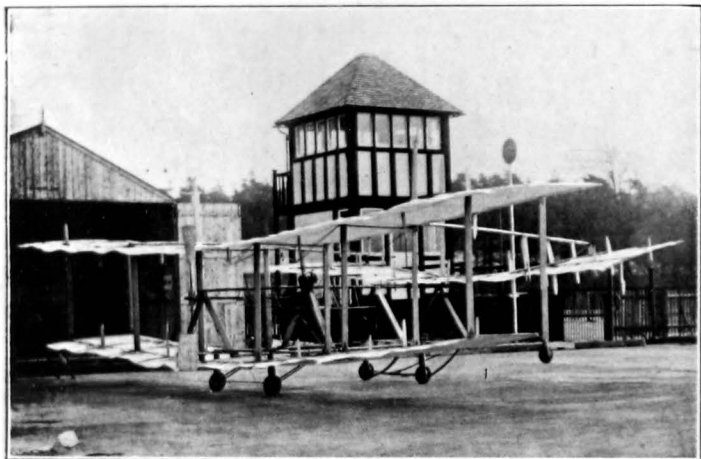
CHAPTER IX

DETAILS IN DESIGN

To the ordinary individual, an aeroplane has wings and that is all there is to be said about it. He realizes that there are monoplanes, and biplanes, and triplanes, because that difference is patent to all. The triplane usually excites his curiosity most, for it has the greatest number of wings.

To the designer (whether the craft is mono-bi- or tri-plane) the section which he will use in the construction of the wing requires careful consideration.

When a plane is driven forward, the air flow striking the leading edge is diverted over the upper and under the lower surfaces of the plane, and ripples over the wing covering in a series of globules, the main volume of air riding on top of these globules. Owing to the obstruction which the wing makes to the air flow, the air is forced to increase its speed as it passes over the nose of the plane, particularly on the upper side. This increase may easily be twenty miles an hour as the plane squeezes the air out in its passage. The ideal plane carries the air back as evenly as possible, and discharges it from the trailing edge with the minimum



MR. A. V. ROE'S FIRST AEROPLANE AT BROOKLANDS, 1907-1908.

This tail first pusher Biplane was fitted with a 9 h.p. J.A.P. Motor-cycle Engine, which was later changed for a 24 h.p. Antoinette Engine. With the Antoinette Engine it made the first flight ever made in Great Britain on the 8th of June, 1908. The contrast between this biplane and the one produced by Mr. A. V. Roe's firm in 1927 and illustrated on next page portrays most graphically the striking advance in aircraft design and construction during these twenty years, in which the art of flying has become a reality instead of a dream.

disturbance. If one could see the air leaving the plane, one would see a lot of tiny air bubbles breaking away alternately from the upper and lower surfaces all along the wing, and trailing out behind like a comet's tail until the turbulence died away. Visualizing this, the reader will appreciate that the shape of the nose or leading edge, the maximum thickness, and the camber or shape of the wing surface from front to rear, must all affect the air-flow passing over the plane and away from the trailing edge.

A fast-flying racer must have a thin wing with a sharp, cutting, leading edge, and to reduce resistance to the minimum, not too great a drag at small angles to the air flow. A slow flying freight or passenger aeroplane can well be fitted with a thick, high-lift wing which sinks gently through the air at low speeds and big wing angles, thus making for easy and safe landings, and which can be built in one unit without external struts or wires to provide the strength required. The racing type wing section at big angles and slow speeds drops suddenly when stalled, and requires external bracing to complete the structure.

Between these two types, there is a wealth of different sections with minute variations in form. The properties of many of these are well known and established. They have been examined by scientists in laboratories throughout the world in model form. The method employed is to place a model wing of the section to be tested in a wind tunnel through which a controlled air current is passed from a blower. Measure-

ments of the lift and drag of the wing are taken at different angles and plotted, and charted. The results establish co-efficients which are comparative between models of different section, and these co-efficients are used by the designer in deciding which wing section to employ. As with much purely scientific analysis of this nature, there is what is called scale effect; which means that the figures obtained from the model in the wind channel are not always equalled by the full-scale aeroplane in free flight in the air. This difference may be caused by body interference, propeller interference, and slipstream, air flow and temperature, the pilot's handling of the aircraft, and numerous other minor effects on the complete machine which cannot be allowed for on the model. Many of the wing sections regularly employed have been tested again and again on different type aeroplanes fitted with different engines by expert test pilots, and the full-scale values of the wings on the complete aircraft established beyond all doubt.

A number of different wing sections commonly used in aircraft of to-day are illustrated in Fig. 9, to give a graphic idea of the outline of the section of different wings. The designer knows which type will suit the construction of his particular aeroplane, and from the known co-efficient of the different sections of the type (thick wing or thin wing) can select the one which theoretically will enable the best results to be obtained. The purely model figures must be accepted with a certain amount of caution, however, for I have known one section which was proclaimed to



**THE AVRO AVIAN MARK III. 1927 MODEL—27/80 h.p. A.D.C. Cirrus Mark II. Four Cylinder
Air-cooled Engine.**

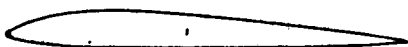
This is the latest light Aeroplane produced by the firm of A. V. Roe & Co., Ltd., and is a direct descendant of the early Biplane depicted in the previous photograph. It was on a land plane of this type that Mr Hinkler made his fine flight from London to Australia in 16 days in February, 1928.

TYPICAL AEROFOIL WING SECTIONS

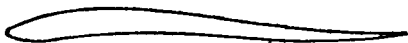


WING SECTION

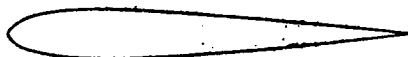
HIGH LIFT
SLOW LANDING



LOW LIFT
HIGH SPEED



REFLEX TRAILING EDGE
CONSTANT TRIM



SYMMETRICAL
USED ON TAIL UNIT



FLAT UNDER-CAMBERED SECTION
AIRSCREW SECTIONS & AVERAGE SPEED AIRCRAFT

ILLUSTRATION OF DIFFERENT WING SECTIONS.

FIG. 9

be superior on model research give on full-scale flight test precisely the same results as the older established section previously used.

The plan form of wings varies. The type of construction and the question of production cost, sometimes result in ugly shapes. Parallel wing spars are cheaper to produce, as are ribs of equal size and shape ; thus wings of equal size and shape and with square-cut ends, or tips as they are properly called, are the cheapest. Cantilever wings taper in profile when viewed from in front, being thicker at the root than at the tip ; sometimes the section varies and the chord remains approximately constant, sometimes the section remains the same and the chord tapers towards the tip. The rounded form of wing tip is usually considered the best. A crude wing tip form offers considerable resistance by causing turbulence in the air flow at the wing extremity.

Owing to the total wing surface being determined by the total weight of the aircraft, and the necessary structural limitation in the span of cantilever monoplanes, the biplane always possesses a narrower chord, a thinner wing, and a higher aspect ratio than the monoplane. These factors often outweigh any advantages of the monoplane type in obtaining performance, and produce a more compact and perhaps a cheaper aeroplane.

Wing sections are also used in the lay-out of tail planes and sometimes of fins.

The plan form of wings must allow for the fitting of the ailerons which provide the lateral

control. There are many different shapes of aileron employed to-day, some of these being provided with differential control; that is the uprising aileron is designed to rise higher than the depressed aileron goes down. In this way the yaw, or turning moment, produced by the depressed aileron is compensated, and lighter weight of control is also provided. Some wings are provided with flaps which are hinged to the rear spar, and can be lowered by the pilot at will along the complete rear edge of the plane. Lateral control is then provided by the outermost part of the flaps being detached and acting also as ailerons. Taking off and landing speeds are reduced by this device by about twelve-and-a-half per cent., and climb is improved. These flaps can also be turned slightly upward to reduce wing lift, and consequent strains when a land plane or seaplane is left in the open, and a strong wind is blowing. Sometimes the slot is combined with the flap. The slot is a small false nose which may be brought back flat on the wing nose, or pushed forward to leave a space between. The slot produces extra lift, and reduces stalling dangers, and may be used in conjunction with ailerons to provide better lateral control at slow speeds. The automatic slot recently introduced is the most effective form of this device so far produced. All these methods of control are patented by British aircraft companies.

The position and size of the tail surfaces are determined by the forces involved in producing stability and control. In the normal aeroplane in normal flight, the load on the tail is downward,

and in a steep dive this down load becomes very pronounced. A tail plane quickly adjustable for angle by the pilot is usually fitted to deal with varying loads. Ample strength must be provided to deal not only with the normal loads encountered, but to assure a factor of safety high enough to cover all emergencies of flight.

The elevator is hinged to the rear spar of the tail plane, and the rudder to the rear member of the fin, called the rudder post.

All controls, ailerons, elevator, and rudder, must be light enough to be easily and quickly operated. This is frequently achieved by balancing the surfaces, that is, placing a percentage of the surface in front of the hinge line, so that the air pressure on that part assists the pilot to apply the larger trailing surface. There are several different methods of providing balance, some using plane surfaces, others using wing sections or *aerofoil* surfaces. It is vitally important that all controls should be sensitive; that is, that the response to the pilot's movement of the control column and rudder bar or pedals should be immediate and not sluggish. To use a pilot's expression, the plane should follow the stick. The control surfaces in disposition and area must be capable of producing correcting moments on the aeroplane at speeds below the minimum speed of flight to enable the pilot to deal with any emergency. It may be that a seaplane is thrown clear of the water by rough seas before it has reached flying speed when taking off; or a sudden gust under one wing of a land plane when running along the

ground momentarily threatens to capsize it sideways ; or in flight the aeroplane is accidentally stalled ; or stalled through encountering a severe downwash of air ; all of these situations and many others, demand good controllability at low speed.

The stall is generally conceded to be the danger point in flight, the situation when sustained flight has ceased, say a mile an hour below the minimum speed of flight. The spinning nose dive, both the normal and the upside down, always follow the stall, and can never precede it, because in a spin the aeroplane is in a stalled condition. Now, stalling and spinning have been the cause of more fatal flying accidents than anything else, and even though the fighting pilot practises spinning as an evolution, that does not absolve the designer from doing all he can to prevent involuntary stalling and spinning. It is easy enough to prevent a stall in level flight, but not so easy to accomplish when a fighting scout or two-seater is making a fast turn in practising aerial fighting. In the vertical turn an aeroplane obtains its wing lift from the air through centrifugal force, and the wings in the turn are at a big angle. The speed at which the aeroplane stalls is then much higher than that of normal level flight, and the controls when turning are in the same position as when spinning. If the pilot attempts to turn too fast, and allows his speed to fall too low, he may stall and spin instantly. The spin from level gives some warning of its happening. The spin from the

vertical turn gives no warning and, if the pilot is flying low, his machine may crash before he can recover from the nose-down position. With sudden engine failure taking off the pilot may attempt to turn to land on the aerodrome; here again low speed may result in disaster.

Apart from fitting controls (and in this I include flaps and slots) which will deal effectively with the dangers of low speed in the air, the designer should aim to produce an aircraft which if it does spin will, when in the spin, rotate slowly and try to stop spinning automatically. With biplanes this can successfully be done by giving a large stagger to the planes, so that the "windmill" effect of the rotating planes offers a large surface resistance. Biplanes with little or no stagger always rotate very rapidly in a spin, and are less stable longitudinally and laterally than those with a big stagger. The latter, owing to the slower rotation, increase downward velocity more rapidly, which adds to the weight of the elevator control, and thus tends to make the pilot stop spinning automatically. Longitudinal stability is very important in anti-spinning aircraft.

Before passing a design, the question of inverted flight must be considered. The aeroplane is stress calculated to prove that her factor of safety will cope with the reversed loads due to stunt flying, or to accelerations in the airflow. But this is not enough. The aerodynamic qualities of the aircraft must be looked into, and no doubt be entertained that the craft can fly and be controlled if necessary when upside

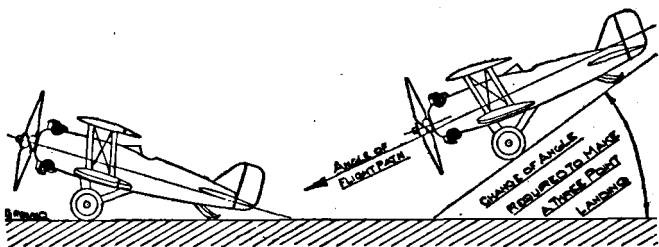
down. Aeroplanes have gone into the air in very recent years which when turned upside down in flight would not come right way up again whatever the pilot did with the controls. If an aeroplane is stable in flight right way up, she will be unstable when upside down, and must then recover quickly ; but an unstable aeroplane in normal flight becomes stable when inverted, and may be very difficult to return to normal. Which is another argument in favour of complete stability. The possibility of inverted spinning must be investigated in connection with any anti-spinning features which may be incorporated in the design and their value examined for inverted flight.

The stream-lining of aircraft has been considered in relation to speed, but there is another aspect of stream-lining which has not been widely realized, and which affects the ease of landing an aeroplane. This is that good stream-lining produces a fine gliding angle, but a broken air-flow creates a coarse gliding angle. If one considers two aeroplanes of equal weight and wing loading, one beautifully faired, and the other covered with lumps and protuberances, both gliding down with engine shut off under the same motor, gravity, and at the same speed, it is obvious that one will glide further and at a flatter fuselage angle than the other. Apart from the usefulness of a long glide when the engine fails and a forced landing is inevitable, the angle of the fuselage is important when making the actual landing. The flatter this angle is, the smaller is the vertical distance

through which the tail has to come down to make a three-point, tail down, landing; the more gradual is the change in the flight path; the less critical is the point at which the initial change in flight path must commence; a smaller elevator moment is required, and the easier it is for the pilot to make the landing. I have traced reported difficult landing in certain aeroplanes to this very cause many times. An easy landing aeroplane is one in which it is easy to make the approach, and which does not require too great a tail drop to flatten out. (See Fig. 10).

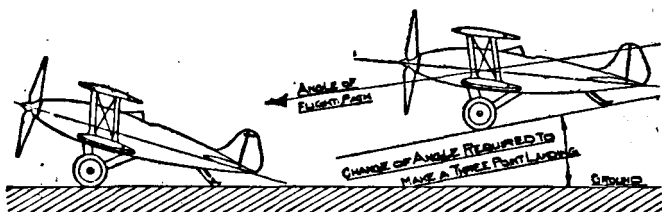
And here let me give a word of advice to the young pilot. Do not look too close in front of the plane when flattening out to land. Look at least a hundred yards ahead, and over the side, never over the nose. If the ground is flat and difficult to deduce height from, it is often very sound to judge one's height by the horizon. The reasons for not looking too close ahead when landing are that, if one does, the impression of speed is very great, and the time allowance for judgment consequently becomes too small; also, that the relative angle of eye-line to fuselage line goes through a bigger change in the landing process, and this makes absolutely correct judgment every time more difficult.

The effect of stream-lining on speed has already been shown, and it remains only to add that at equal speeds in the air change of attitude involves smaller moments with a well stream-lined aeroplane; therefore controllability is better with good stream-lining. Another point of importance is the more even flow of air over



COARSE GLIDE DUE TO HIGH HEAD RESISTANCE

SPEED 70 M.P.H. - ENGINE COMPLETELY THROTTLED.



FINE GLIDE WITH LOW HEAD RESISTANCE

SPEED 70 M.P.H. - ENGINE COMPLETELY THROTTLED

ILLUSTRATION OF VARYING GLIDING ANGLE

FIG. 10

the tail surfaces when the air flow is not broken up. This produces steadier high speed flight.

When deciding on materials for construction the designer must consider the questions of corrosion, effect of heat and cold, and humidity. The last of these is very important in relation to wood, glue and linen.

Airscrews are made of wood, steel, or duralumin. The wood and dural blades are solid, the steel blades hollow (and welded) on account of the weight of the material employed. The wood propeller, in walnut or mahogany, is light in weight, but liable to damage by rain, hail, or sea spray. The steel type has had a short design life, and is now out of date, being superseded by the dural propeller, which is fast becoming the standard type. The latter type is heavier and more expensive than the wood propeller, but it is productive of increased performance because its much finer blade tips are more efficient at high speeds. Its life is infinitely greater than the wood propeller, it stands heat, humidity, rain, hail, or spray, and can be repaired if damaged.

Dural propellers are made in three ways. One is to cut a flat plate to the outline and curvature required, then to twist it to the correct angles in a special machine designed for the purpose. Heat treatment of the metal plays an important part during this process of manufacture. Another type is forged to shape and angles from the solid, and then finished off by hand. The third type has a special hub fitted with detachable and adjustable blades. The advantage of this last type is that with a very few hubs and a number of

NOTE

Page 128. Lines 14, 15, 16, 17

This sentence applies solely to propellers fitted to small and medium size aeroplanes equipped with engines which produce power at high revolutions, thus creating a high propeller tip speed. Steel and duralumin propellers are largely complementary, overlapping occurring at diameters between nine and ten feet. In the larger diameters the hollow steel blade gains the advantage of lighter weight when well designed. Two of the four Southampton Flying Boats flying on the Empire Cruise are equipped with steel propellers which have given excellent service, and manufacturers of this type of airscrew are designing airscrews for H.M. Airship R. 101, and are now in process of developing propellers for light aeroplanes to compete with the small diameter duralumin airscrew.

different blades, the whole range of aircraft could be covered with much lower manufacturing and maintenance costs, although only at the expense of maximum efficiency. Unfortunately, this type is not yet entirely reliable, and cases have occurred where one blade has become detached in flight with serious consequences. In Britain the first type is the standard production type to-day, and it is a very efficient type of aircraft propeller.

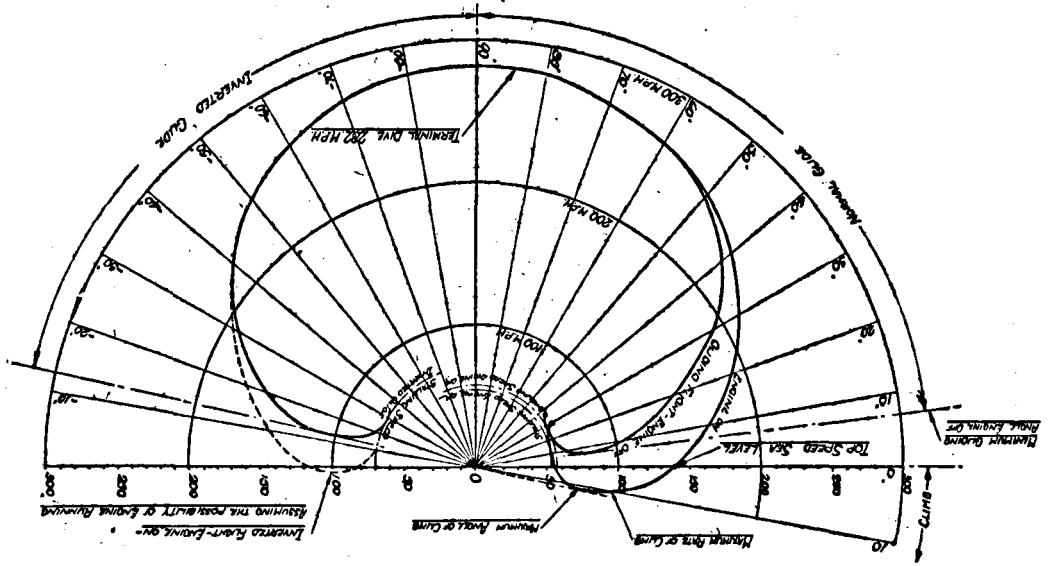
In the early days of flying the commonest way of damaging a landplane or seaplane was through making a heavy landing. Engine power was very limited and engine weight relatively very high, and every part of the aircraft had to be built very lightly to meet the weight to horsepower condition. Landings had to be perfect each time otherwise the flimsy chassis crumpled up. To-day, except on the very lightest of aeroplanes, the oleo undercarriage has become the standard type. Shock is absorbed by oil and compression rubber, the principle of design being the same as the recoil mechanism of a gun. Undercarriage failures are very rare occurrences now, and the standard of good landings has suffered as a result. Except for the cost of repairs it would be advantageous to pupils to teach them to land on chassis no stronger than the old piano wire-braced undercarriages of the early days before putting them on the fool-proof types of to-day. The modern V-shaped bottom of the latest seaplane floats and flying boat hulls has also done much to save water-borne aeroplanes from alighting shocks.

CHAPTER X

THE COMPLETE SPEED RANGE

THE diagram which accompanies this chapter was specially drawn for this book to illustrate the complete speed range of an aeroplane. The type of craft which it depicts was a single-seater fighter of 385 horse-power, fitted with an air-cooled engine. I do not think that a graph of this nature has been published before ; it shows at a glance the complete flight characteristics of a typical aeroplane. The horizontal datum line is the line of level flight. It is composed of two radial lines branching from a central point which may conveniently be considered as representing the aeroplane when stationary on the ground. The other radial lines all indicate angles of inclination of the aeroplane's flight path to the horizontal, and the outer sweep of the curve cuts each radial line at the point of maximum speed which the aeroplane can reach at that flight path angle. Thus it will be seen that the maximum speed attainable is achieved in the vertical radial line, and that this terminal speed is not affected by the engine throttle setting, although the initial acceleration in a dive due to propeller thrust is clearly shown by the two curves depicting the

FIG. 11. DIAGRAM OF THE COMPLETE SPEED RANGE.



engine on and engine off conditions. The curves to the left of the vertical line denote the characteristics of normal flight, while to the right of this line are those characteristic of inverted flight.

Details of interest which can be read off from this graph are :

LEFT IN NORMAL FLIGHT.

1. The maximum angle of climb which can be sustained under engine power.
2. The speed at which maximum rate of climb is developed.
3. Maximum level speed.
4. Stalling speeds with engine on and with engine off. These differ slightly.
5. Angles of descent at stalling speed with and without engine.
6. Minimum level speed.
7. Speed range of the aeroplane.
8. Maximum speeds attainable with and without engine for any angle of descent.
9. Minimum gliding angle without engine.

RIGHT IN INVERTED FLIGHT

10. Stalling speed when the aeroplane is upside down. Note that this is higher than when the aeroplane is right way up.
11. Angle of descent when stalled upside down with the engine starved for fuel and not firing.
12. Assuming that the engine can be made to run when the aeroplane is upside down.
 - (a) Minimum level speed inverted.
 - (b) Maximum level speed inverted.
 - (c) Speed Range inverted.
 - (d) Maximum angle of climb inverted.
 - (e) The speed at which the maximum rate of climb inverted is developed.
13. Maximum speeds attainable when inverted for any angle of descent.

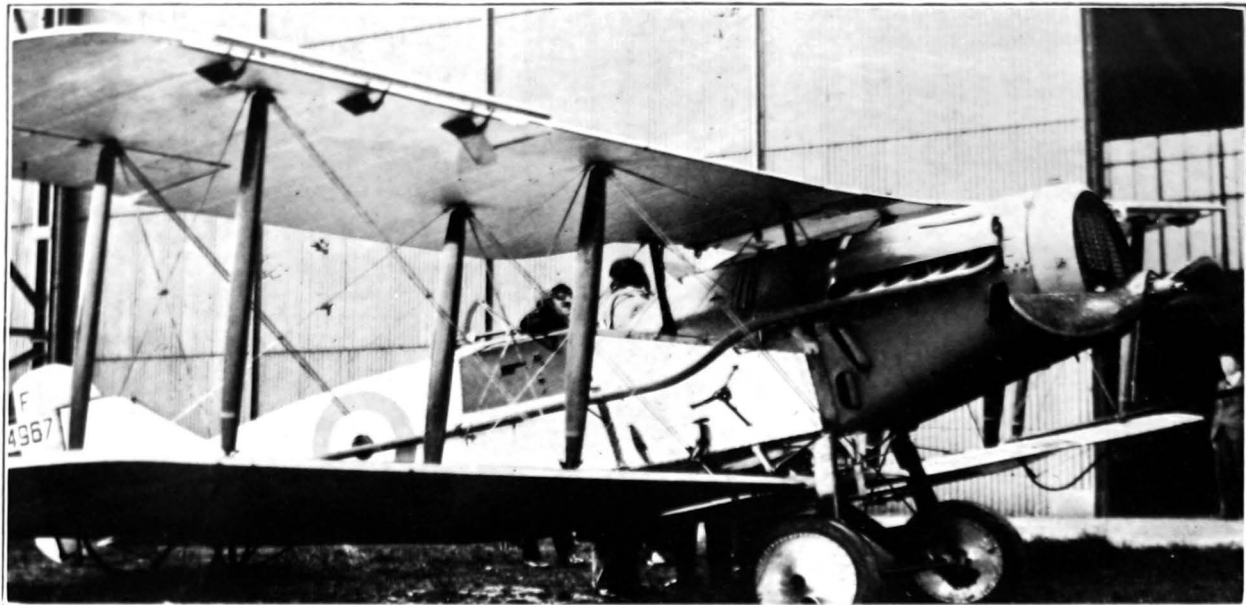
It should be noted that all the curves are drawn on a basis of constant conditions of density and pressure, and that those taken are those pertaining to normal sea level conditions. The ultimate speed reached in the vertical nose dive can very seldom be achieved in actual flight, because the ceiling of an aeroplane rarely allows sufficient depth in the dive towards the ground to permit of acceleration to its terminal velocity before the pilot is forced to pull out to avoid crashing into the ground. Twenty-one thousand feet is just under four miles and at a speed of one hundred and eighty miles an hour the dive to earth would be completed in eighty seconds. The curve shows the rapid acceleration at the commencement of the dive, especially when assisted by the engine, but the acceleration at high speeds is very much slower as is shown by the curve flattening out at the bottom. This slowing down of the acceleration admits a time factor which in effect cuts the dive short before the bottom of the curve is reached. The maximum speed in the vertical dive is reached when the total air resistance is equal to the total weight of the aeroplane. This is the ultimate speed, beyond which no aircraft can pass.

Below the stall there are two conditions, one on the ground, the other in the air. On the ground the case is simple, and represents a certain range in taxiing from rest to minimum flying speed. In the air the below-stall condition is not quite so simple.

Some aeroplanes, which possess very good controls can be held balanced at a big wing angle

with a little engine in the stalled condition a few miles per hour below minimum flying speed. When this is done (and it must be remembered that this is trick flying) the aeroplane will descend almost perpendicularly at a low forward speed, but with considerable vertical velocity ; a strong undercarriage could withstand the shock of such an alighting when, at the last moment, the pilot, by movement of the control column, could change some of the vertical drop into forward motion. The delicacy of handling required for this stunt, and the danger attendant on any misjudgment producing a violent stalled nose-dive near the ground, make it absolutely inadvisable for anyone to try it on a ground landing. Quite a lot of fun can be had, and considerable knowledge of slow handling acquired, by practising this stunt landing on a cloud top. I can only recall one pilot who was a past master in this method of landing, and the effect was much the same as that of the auto-giro-plane, or of the automatic slot-winged Bristol fighter.

A very gentle stall in a longitudinally stable aeroplane results in a slight dip of the nose and an immediate restoration of minimum flying speed. The same stall on an aeroplane unstable fore and aft may be quite serious near the ground. It may be that the tail plane is too small, and that it stalls before the wings, and the sudden drop in the tail produces an unintended big wing angle, which results in an uncontrolled catastrophic stall. Now, this stall is really dangerous, especially when it occurs near the ground, because the fall off in miles per hour below flying speed is



Courtesy of "The Aeroplane."

Discovered by Mr. F. Handley Page. This device is used to increase lateral control at slow speeds and decrease the severity of a stall. It consists of a small aerofoil fitted to the leading edge of the upper plane, which opens and closes automatically with greater or lesser wing angle. When open

very sudden, and very great; to recover the speed required to sustain flight the aeroplane puts her nose down violently and dives vertically. This feature in one of the finest war-time designs which has been used continuously ever since the War ceased (and is still in use, although replacement craft are now on order) has been the direct cause of many very bad crashes. I refer to the Bristol Fighter, which is now being fitted with Handley-Page automatic slots to prevent catastrophic stalling.

It is interesting to produce a catastrophic stall intentionally high up as a manoeuvre on any machine, but it is extremely dangerous to stall ever so gently by accident near the ground on an aeroplane which may aggravate that stall to catastrophic proportions. I would counsel every young pilot to test the stall of the planes he flies at a good height. Let him discover whether wings or tail stall first, and, if the latter, let him treat his craft when manoeuvring low down, or when coming in to land, with regard to the stalling speed of the tail plane and not the main planes.

The speed of the stall will be affected by height. The higher one flies the higher the stalling speed. Normally a stall at height is serious only when in aerial fighting it causes one to lose height in relation to the opposing aircraft, so that the enemy gains the advantage of height. But in flying in many countries overseas aerodromes will be found which are many thousands of feet above sea level. On the north-west frontier of India they lie about six thousand feet up, and in the hot season the temperature of the

air may easily make this equivalent to nine thousand feet on a normal day in England. The aerodrome at La Paz in Bolivia stands on a great level plain thirteen thousand feet above the sea. When flying under conditions like these it behoves the pilot to find out his indicated stalling speed well above ground level before coming in to make his first landing, otherwise he may find an impending stall result in a heavy landing. Owing to the lighter air at height a stall produces a quicker drop-away than at sea level and makes a stall near high ground, if possible, more dangerous.

The level speed range is the difference between the maximum and the minimum level speeds at sea level. This range is at its greatest at sea level on the normal aeroplane, and with every thousand feet in height the minimum goes up and the maximum comes down, until they meet at the absolute ceiling of the particular aircraft. High compression and super-charged engines, which cannot be opened to full throttle at sea level, increase the maximum speed level up to several thousands of feet in height before the falling off in top speed commences. The increase in minimum speed with height remains the same with any engine.

The relative factors of strength required for aircraft can well be taken from the speed range, for it will be obvious that the greater the speed range in relation to the minimum flying speed the greater will be the power of manoeuvre. The loads met with in normal straight flight rarely exceed twice the weight of the aircraft, and never

exceed three times. The loads imposed in rapid manœuvring can be as high as six to eight times the weight of a fast, quick-handling, single-seater fighter. A normal two-seater does not usually exceed three to four times its weight in fast turns. These figures are taken from tests which I have made with an accelerometer on different types of aeroplanes. When turning, an aeroplane is affected by centrifugal force which tends to thrust it outwards. The banked wings resist this until the force applied by the tightness of the turn breaks down their resistance and the whole craft squashes outwards. This determines the limiting load which can be applied in that manœuvre, and determines the minimum radius in which the craft can be turned. The load rises rapidly to a peak after the commencement of a level turn, and cannot be sustained because the wing angle in a turn changes as in a climb, and so the speed falls rapidly. With the fall in speed the load eases slowly from the peak, until it reaches the stable loading consistent with the speed possible with the wing angle in the turn. Any effort to tighten the turn at this stage will stall the wings and produce a half roll into a spinning nose dive, unless corrected in time. To reduce radius of turns to a minimum, I have adopted an over-the-vertical-bank level turn, thus gaining gravity as an ally to the wing resistance in counteracting centrifugal force, and have found this very effective.

If the pilot wishes to experiment with sustained high manœuvre loadings, he can do so by losing height in a tight spiral turn, using gravity

to supply the additional power required by the increased wing angle. These loadings are considered technically as multiples of the weight of the aircraft. The static weight is one times gravity, a loading of two is twice the weight, or two times gravity. They are referred to for brevity as 1G, 2G, or 6G. The question of G affects the pilot as well as the aeroplane, and this is considered in the next chapter.

Now, it will be clear that the safety factors of aircraft are expressed in terms of G ; that power of manœuvre is directly a function of speed range, for if there is no speed range there can be no manœuvre. That, assuming equivalent controllability, the maximum speed of an aeroplane determines the maximum load that can be applied, and the design the maximum load that can be sustained. For example, the elevator control may be too heavy for the pilot to apply and maintain full manœuvre load.

The safety factors of aeroplane wings are different for front and rear spars. This is because the centre of pressure of a wing is not fixed, but moves backwards and forwards with change of angle. The wing factors are expressed in terms of centre of pressure forward or back. When the aeroplane is flying at small angles of attack the C.P. moves back. When a change to large angles is made the C.P. moves forward.

Thus, when flying straight and level at high speed a quick turn increases the angle of attack suddenly, and the centre of pressure moves forward. Similarly, when pulling out of a nose dive, the load on the front spar is applied sud-

denly, and is far in excess of that on the rear spar. Therefore the front spar must be stronger and possess a higher factor of safety than the rear spar.

Every part of the complete aeroplane must be stressed to assure that it will withstand the loads imposed upon it. In cases of doubt, when calculations may be uncertain because of abnormal forms of construction, proof loading can be resorted to ; that is, the aircraft is actually loaded with ballast on the ground to a total weight representing the factor designed to, or if required, to destruction.

The following pages of this chapter will be devoted to a consideration of the proper handling of an aeroplane under certain conditions.

The usual aeroplane is fitted with a tail plane which has a control in the pilot's cockpit to vary its angle of incidence. This control is designed so that the pilot can set the tail plane to trim the longitudinal balance of the aeroplane as he wishes. This balance will vary on most aeroplanes with the throttle setting. The more throttle is used the greater the slipstream downwash from the top plane. This downwash strikes the tail plane with greater force as the throttle is opened and more incidence is required to counterbalance it. With alterations of throttle the position of the thrust line in relation to the resistance line will produce a couple affecting longitudinal trim if they do not harmonize. The movement of the centre of pressure of the wings will affect fore and aft stability. The tail plane must be designed to stabilize all these varying conditions and in addition give the pilot control over them.

To take off, the normal aeroplane will require the tail plane to be set in the upper half sector of its incidence, because of the top plane downwash ; to land it will require the lower half sector. Whenever he is stunting, especially when nose-diving, the pilot should always set his tail plane so that the aeroplane is tail heavy. In nose-diving particularly, the centre of pressure of the wings moves back, and there is a possibility of the aeroplane exceeding the vertical and going over on her back, when it would be more difficult, and take more time, for the pilot to restore level flight. The aeroplane must always be made to feel tail heavy before nose-diving, or before commencing any stunt which involves the nose-dive to recover, such as looping, half-rolling, or spinning. In stunting, the pilot should always handle his craft as gently as possible. He should avoid all unnecessary strains in performing any evolution. The variable incidence of the tail plane can be used to advantage in turning, and in looping, to avoid some of the strain on elevators, cables, and kingposts.

In stunting, the pilot should remember the effect of wind on stunting as a spectacle from the ground. If there is a considerable wind blowing a true air loop across wind will appear as a horizontal spiral of one turn from the ground, and a series of loops will give the impression of a corkscrew evolution across the aerodrome, down wind. If the pilot wishes to show a true loop he must loop into or down wind, and preferably the former because of the relative ground speed at the conclusion of the loop, and the ability to land then

without turning, if required. Slow flying should always be demonstrated into wind, because it looks slower from the ground, and it is safer to fly slowly into wind than down wind. Fast flying should be demonstrated down wind because it appears faster, and a turn at the end of the run slows the aeroplane down and brings it into landing position at the same time. Always, when flying near the ground, the pilot should listen most carefully to his engine. Several times I have been about to make a climbing turn off the ground when a *something* in the engine's note has made me alter to a straight and gentle climb. The warning has never been unnecessary, and has in every case prevented the almost certain possibility of a crash. There are times when I believe in making a practice of taking off in a climbing turn, as when taking off on a not too heavily loaded aeroplane towards obstacles. The very fact of being on the turn places one most rapidly in the position in which a landing can be made. In coming out of a climbing turn near the ground, hurriedly, in emergency, the instant application of the rudder is more necessary, and more effective, than the elevator to bring the nose down to the glide. The pilot should never forget that, if his engine fails with the nose up on a climb near the ground, he must manœuvre his craft instantly not only to level, but through that angle to the attitude required to maintain minimum gliding flight. Failure to do this rapidly has resulted in numerous accidents. In a straight climb the pilot has only the elevator to help him to do this, and with the elevator must alter the

elevation of the tail to the wings through a big angle. On a climbing turn he can use rudder to alter the fuselage angle with little resistance from the wings, as gravity pulls the nose down ; a little aileron and elevator are then required to restore balance and the craft will glide down straight to land. Because of this amenity to rudder control, I believe that it is actually safer in a high powered aeroplane to take off in a climbing turn which affords a good view of the landing-ground throughout the take off, than in a straightaway climb when view of the ground is lost at once.

The part of the landing that must be completely mastered is the approach. This must be practised until perfection is gained on a straight glide, on a turning glide, and on a sideslip approach. Some aeroplanes are more difficult to approach than others, but this part of the landing must be considered for each different type individually. The flattening-out process is a secondary and independent one.

It must be remembered that to flatten out at all, a certain moment must be applied by the elevator. Therefore, the elevator must have enough reaction to apply that moment. With many aeroplanes, especially very stable aeroplanes, too slow speed of approach makes the elevator unable to apply the necessary load quickly enough. This results in a wheel landing with tail up. With such aeroplanes a slight increase in the speed of approach will be found advisable, and the flattening out should then begin slightly higher from the ground. When flattening out centrifugal force affects the aeroplane, and restores some

of the speed lost through change of wing angle. If the flattening out has been too sudden this will cause the plane to climb upwards a few feet from the ground ; failure to correct this by a burst of engine, or by a very quick forward and back movement of the elevator control, will result in a heavy landing, but it is better to remember that speed is not lost instantly on flattening out, and to allow for this by making the whole process a more gradual one ; and this is more easily accomplished (as has been said in a previous chapter) by looking well ahead of the aircraft.

CHAPTER XI

THE HUMAN FACTOR

MAN has learned how to fly after centuries of dreaming and scheming towards that object. Throughout the ages there have been men, described by their fellows as fools, who tried to fly. Aircraft to-day have justified their folly, and have surpassed the wildest dreams of even twenty years ago, and in his craft the pilot goes aloft to meet conditions which have never been imposed on the human body before.

The aircraft of to-day attains heights higher than the highest mountains in the world, and achieves speeds in excess of any other form of locomotion. Over forty thousand feet have been climbed, and as much as five miles a minute flown. What then are the conditions imposed upon the man who flies?

Twenty thousand feet is the safe limit line to climb to without oxygen. Above that height the air is so rarefied that it is necessary for the pilot to breathe oxygen to maintain consciousness. Failure of the oxygen plant above that height means fainting, loss of control, and a tumbling fall down through thousands of feet to lower altitudes. Fortunately recovery is usual some thousands of feet below the limit line.

As the aeroplane climbs the temperature drops. In an English winter zero or freezing point is common on the ground. In summer zero ranges between eight thousand and eleven thousand feet. In winter the temperature of the air at twenty thousand feet may fall as low as thirty degrees below zero Centigrade. Temperatures down to sixty below zero Centigrade (or seventy-six Fahrenheit) have been recorded at greater heights. The arctic explorer knows when it gets really cold and wind blows that he must turn into shelter and wait until the blizzard ceases because of the danger of freezing his lungs. Yet the aircraft test pilot leaves the warm earth and flies up into arctic temperatures at speeds higher than blizzard speed in the space of less than an hour. Electrically heated clothing and oxygen breathing apparatus keep him alive where without their artificial aid to life he would assuredly die.

Before he leaves the ground the pilot dons waistcoat, socks, and gloves, threaded through with fine wires, and over these wears massive fur, fleece, and waterproof garments that resist the cold. Helmet of fur and leather, electrically heated goggles to resist the formation of ice on the glass, chin and mouth mask for oxygen, and fur gloves, complete his kit. The oxygen turned on, the electric heating connected up, he sits and records the performance of his craft in conditions unbelievable to those who have never flown, and flown high. Isolated, miles above the earth, his plane flies through space, while the thin frost-biting air hurtles past in the roar of the engine's exhaust. Pure speed has no special

effect at low heights. Low down it is only the nerve tension that counts, and that one can find equally in a fast car. But high up, in the cold, it drains the warmth from everything that contains heat.

The noise of the exhaust drumming continually in his ears goes on, sometimes for days, after a flight at height. I have known of more than one pilot who suffered from irritation of the aural nerves, so that always the engine noise drummed, day and night, preventing sleep, reducing him physically to rags. Fumes from exhausts sometimes swirl into the cockpits and are breathed by the crew and some severe cases of gassing have occurred.

Eyes have lost their sight, high up in the cold air, amid clouds which reflected blindingly the glare of the dazzling sun, undiminished by dust or other impurities in the air ; a combination of snow-blindness and frozen optic nerve, which produces intense pain and blindness, fortunately rare. Sight is usually recovered on descending, sometimes out of control, to altitudes where temperatures are comparatively warm, and where the glare is hidden below the cloud-base.

Manœuvre, at speed, places strains on crew as well as on craft. The fast turn, the pull out of the terrific dive, send surges of blood about the blood channels of the body, strain the supports of internal organs, drain the brain anæmic while the pressure lasts. If the head is down in a really tight turn, the neck muscles are not powerful enough to raise the head upright again. The pilot feels himself gripped by a giant which

presses on his shoulders, forcing him into his seat, pushing him down into his plane; eight times his own weight pushing him down for a few seconds would kill him, after depriving him of sight and his other senses one by one. When sight is lost under the effect of G, everything goes black gradually, and this in itself constitutes a warning. Removal of the load removes the blackness, and vision is restored.

But these things only occur to those who fly to extremes, to the pilots who go up to test new developments and theories, to racing pilots, and record breakers, to those who fly under the rigorous conditions of war and war training. Those who fly for pleasure, and those who fly in commercial aircraft need not fear them. The commercial aircraft pilot has the strain of long hours, and often of bad weather, and the responsibility of the lives of his passengers, but he does not fly in conditions of extremes of cold or pressure. His job is essentially safe flying. The test pilot, however, must take risks, must try new things, must ever be in the van of progress. None can say to-day what the effect will be in after years of work done in flying of the nature outlined, how it will affect the human body, or if that body is sufficiently adaptable to meet the strange conditions imposed upon it. The medical men who look after those who fly are deeply interested in the result, which can only be made known after a term of many years of such flying. It is not generally realized that the experimental pilot of to-day may be staking much more than the ordinary hazards of flight on his work.

The effect of normal flying is one of pleasure and exhilaration. A short flight in cool, clean air is as uplifting in effect as a glass of champagne to a teetotaller. One lands with sparkling eyes, and an animated manner. Like all open air sports, flying is a good sleep inducer. And, if one has a nasty cold and wraps up very warmly, a flight at ten thousand feet for twenty minutes or so will go far towards curing the cold, by the introduction of germ free air into the nose, and throat, and lungs.

To make the pilot's work in flight as easy and simple as possible ought to be one aim of the designer. Controls should be easy to operate and placed in the right position for use. View should be good, the aeroplane stable in flight, easy to take off, and to approach and land. In this way he can do much to ease the work of the pilot in handling his craft.



Courtesy of "Flight."

THE DE HAVILLAND MOTH—A Two-Seater with Dual Control,

27/10 h.p. 4 Cylinder Air-cooled A.D.C. Cirrus Engine.

Other planes in the same class also illustrated in this volume are the Westland Wigeon, the Avio Avian, and the Short Mussel. These little planes are popularly described as of the private owner type and are used by all the Light Plane Flying Clubs.

CHAPTER XII

THE ART OF TEST FLYING

THE air-testing of a modern aeroplane consists of much more than merely taking it into the air and flying it. That part of the work is comparatively easy, because the knowledge of the aerodynamics and mechanics of aircraft design and construction is now so well established in straightforward aeroplane design that the correct flying of the craft should be a certainty before flight. Sometimes details in design and engine installation are impossible to assay before flight and may cause minor troubles to develop in the air, but (except in freak aircraft) the main structure and lay-out, and the controls, are definitely known to be safe for flight before the initial air test is made. The first flight troubles that have occurred during recent years are attributable more to carelessness than to ignorance.

The early days of flying when the pilot went aloft on a new type aircraft to test unknown qualities of stability and strength are past. The mere ability to fly exceptionally well served the test pilot in those days, but more is required of the pilot who handles this branch of flying to-day. He is essentially a specialist. His knowledge of theory must be sound, his conception of design

must be visionary, and his understanding of materials, constructional methods, and ease of production must be wide and practical; in addition, he must possess excellent hands for the delicate handling of his craft, long experience and skill in performing every manœuvre of flight, and a temperament which is not too nervously apprehensive, nor yet too stolid.

The more experience the test pilot has the more valuable he becomes. He stores away in the memory of the feel of different aircraft a quality of discrimination which enables the old hand to spot any weak qualities in a new design. Old lessons learned can be turned to account in the assaying of new craft, and time and money saved by the rapidity of the work done in the air. The first-class air test pilot can sum up more of the qualities of an aeroplane which he flies for the first time in ten minutes than the ordinary pilot can discover in as many hours; the tester knows what the fault is, can put his finger on the cause, and say how to cure it. This faculty is partly intuitive in the individual and partly developed by practice. The natural tester with long experience in his work, and who is also a very fine pilot, is worth a great deal to the aircraft industry of his country. His devotion to his work is that of the scientific research worker. Owing to the fact that he works in the forefront of new ideas, and developments in design and construction, his work is carried out in secrecy. The public learns little or nothing of his successes, cannot share his pride in having discovered and eliminated faults and played his large part in the production of a new

aircraft which redounds to the credit and prestige of the nation. The new record broken, the great race won, the increased safety of flying, are built up on the work of test pilots whose names rarely figure in the press or come before the public.

During the design and constructional stage the test pilot constantly follows the progress of the aircraft, aiding the designer and engineer by the application of his special knowledge to their work. Throughout the period of construction the materials used and the workmanship embodied in them are subjected to constant inspection. Completed units are weighed to check design. When complete the aircraft is subjected to a rigorous final inspection. The fuel system is tested and the engine run and tuned. Rigging and control runs are checked. Under present conditions the work of the constructing company is usually check duplicated by the stress department of the Air Ministry and the inspectors of the Aeronautical Inspection Directorate.

The aircraft is weighed to corroborate the estimated weight of the structure, and the centre of gravity is measured to determine that stability will be normal and according to design. If nothing abnormal is found the aircraft is handed over to the test pilot. On the first flight the pilot flies alone and, if the aeroplane is a multi-seater, ballast is used to trim the craft truly. The first tests are always made carrying as little load as possible so that the take off and landing speed is the minimum, the power and wing loading in the

best possible ratio, and the structure submitted to the minimum stress.

After the pilot takes his seat and tests the engine he tests the air controls. In doing this he will always move the controls to the limit in each direction and look to assure himself that the air surfaces work in the correct direction and to normal angles. A surprising number of crashes have occurred (although not to test pilots) through aeroplanes having been flown off the ground with the control cables crossed. Before every flight, without exception, every pilot should check that his controls move correctly. Then the pilot signals the mechanics to take the chocks away from the wheels and taxies out on to the open aerodrome. First he tests the taxiing qualities of the craft, the directional stability of the run, the sufficiency of tail weight to prevent her tipping on her nose, and the steering left and right. Several high speed ground runs may be made to determine that the air control surfaces are functioning as they should. I remember finding no rudder control on one biggish aeroplane during these tests. There was no wind that day, and I postponed the first flight test until we got a strong wind of about thirty-five miles an hour. Then I took off over the aerodrome, which was none too large, flying at about fifty miles an hour, but crossing the ground at only fifteen miles an hour with the wheels about two feet above the grass. This gave me enough time to test the rudder on a straight flight within the aerodrome boundaries and I found, as I had expected, that there was no rudder control at all at low flying speeds. Had

I flown the aeroplane on the first day I should have been crossing the ground at fifty miles an hour instead of fifteen. There would not have been time to test the rudder before reaching the end of the aerodrome, and I would have been forced up into the air at the further hedge on a machine deficient in rudder control with the alternative of having to make a complete turn before being able to land again, or of flying some twenty miles in a straight line and landing among fields. As it was, a two days' wait for wind avoided this contingency, during which time a new and larger rudder was put in hand. This was fitted with the minimum delay after the conclusive test in the wind, during which the spectators saw the aeroplane flying slowly across the aerodrome with rudder hard over to the left, then, on a second run, to the right, without deviating from a straight line.

It is the test pilot's job to discover and rectify faults, but not at the expense of smashing up his craft.

When he has decided that the aeroplane is perfectly normal on the ground, that all controls work as they should, and that the undercarriage is not too far forward, or too far aft, or too high, and that, if adjustable for shock, it is correctly set, the pilot will take the aeroplane into the air. If the craft is a seaplane it will be necessary to test for propeller clearance from the bow wave at low speeds, manoeuvrability, and for trim and controllability when hydroplaning at high speeds. The unlimited aerodrome provided by the sea is ideal for this purpose.

After taking off and climbing to a reasonable

height in straight flight during which the reaction to the individual air controls can be tested, the setting of the tail plane adjusted as required, and the general stability sensed, the pilot will level out and test the craft at normal cruising speeds. Turns to left and right, gentle at first, then steeper, will show the nicety of weight and sensitivity balance of the controls. Full throttle manœuvres can then be made for comparison. Tests for stability in all directions must be made, and low speed control tested. If everything is satisfactory the stalling speed should be taken, and some idea formed of the controllability at the stall. Top speed may then be checked.

It must be remembered that the aeroplane is carrying a light load and that the figures obtained are not representative of the fully-loaded conditions. This first flight is really a handling test and due regard must be had to the difference in feel and performance between light and full loads in making any report after landing. Many unfounded beliefs in wonderful performances have resulted from first flight, light load optimism.

If the aircraft is suited to it, some pilots would proceed to give an exhibition of stunting to the spectators assembled to watch the first flight. With an entirely new aeroplane on its first flight I think that this is unwise, and I advocate leaving the stunting, even though everything appears satisfactory, until a post flight inspection of the craft has been made ; and also it is wiser to give all the component parts a chance to bed down and be re-adjusted before placing the greater strains of spectacular flying on the structure.

When light handling trials have demonstrated the satisfactoriness, or cured the faults, of the aircraft the full load trials commence. Then the qualities of a good test pilot with fine hands are demonstrated.

The aeroplane is loaded to its maximum weight, usually with lead ballast. All the instruments are calibrated to ensure accuracy. A thermometer is fitted to the wings to record the air temperature through which the plane passes. A statoroscope (a delicate barometer recording variations in air pressure) is fitted to inform the pilot when he is flying level high above the earth's surface. Stopwatch, speed indicator, height indicator, engine revolutions indicator, engine water or cylinder temperatures, engine oil pressure and temperatures, position of radiator, setting of wing flaps and tail plane ; all these have to be read by the pilot as he climbs upward from the ground and the readings written down faithfully at regular intervals in height.

Let me describe a typical quantitative analysis of a fully loaded aeroplane.

First the engine power must be determined by a propeller calibration test, and this particular test can be made irrespective of the weight of the aeroplane. The aeroplane is flown at any constant height at a series of different forward speeds and the speeds of flight and engine revolutions noted, together with the height and air temperature, the ground barometer at the time of flight, and any additional head resistance such as amount of radiator exposed, although this last condition has only a secondary effect on the calibration.

The speeds taken should be at regular intervals from low to high ; all must be made at full throttle ; the lowest speeds will be read on fast climbs, the medium on gentle climbs ; the highest speeds recorded will be flying level and on the glide. The aeroplane attitude for each speed must be recorded. Analysis of the pilot's figures will convert the indicated speeds and height into the true speeds and height. Now at a given forward speed and air pressure and density a definite horse-power will be required to drive a certain airscrew at a given number of revolutions per minute. The pilot's test will disclose what horse-power the engine has developed over the aeroplane's normal speed range. This is compared with the engine manufacturers' power curve and any deficiency questioned before further air tests are made. A newly-designed airscrew complicates this test by the necessity to calibrate the propeller first.

A series of comparative climbs at different speeds over a few thousand feet will establish the indicated speed at several heights at which the aeroplane develops maximum climb. The pilot can commence with a mean of one third up the speed range, and then test at intervals of five miles an hour each side of that figure, or he may be given a calculated mean and intervals. The method adopted is to read the time to climb two thousand feet on a stop-watch at the different speeds, and plot the result. The best speed can thus be read off. Since the best indicated speed varies with height, tests must be made at more than one height to establish the variation. Outside factors,

such as the fitting of flaps, will complicate these tests exceedingly. Rate of climb meters may be used to establish, or check, the best climbing speed. These instruments indicate relative changes of pressure. Once these speeds are known the complete climb to ceiling is made. On fast climbing aircraft the pilot has to write down figures as fast as he can read them, for the climb may commence at a rate of two thousand five hundred feet per minute. During that one minute he has to note readings from all his instruments, air temperatures, and positions of any variables such as radiator, flaps, and tail plane. The stop-watch time must be read to fifths of a second. And all the time he must control the craft most carefully for there must not be any deviation from the best climbing speed, for any alteration will reduce the rate of climb.

The chief quality called for in this work is absolute concentration. The pilot must fly his craft entirely by instruments with his head inside his cockpit. He must note his instrument readings rapidly and accurately, and write them down without loss of time. He must entirely disregard the ground and the air outside. The accuracy of his observations is all-important, and the difference between a good and a poor test pilot soon shows up in the evenness or otherwise of the points plotted on the curve which reduces his climb to paper and comparative data.

At the top of the climb the qualities of control are tested and any deficiency due to the lighter air noted. Then a series of maximum level speeds is taken at different heights on the way

down to earth again. It takes time for the aeroplane to accelerate to her utmost speed and the pilot must allow for acceleration before noting the speed.

All these tests are made at full throttle because this is the only way to guarantee equality of power output each time and because it measures the maximum performance of the aeroplane. Aircraft test flying is much more tiring than any ordinary flying on account of the concentration required, and because of the continual full throttle exhaust noise, and the flying at height.

There is a further test which can be carried out in two ways, one by flying level at a constant height and different speeds and reading the varying engine revolutions ; the other by gliding at different speeds and varying the engine revolutions to produce a propeller speed giving neither thrust nor resistance. These are special tests, not always made, to determine the aerodynamic efficiency of the aeroplane dissociated from the engine.

During these full-scale measurement tests still air conditions are required. Any up and down currents, any uneven flow, or irregular air temperature, will reduce their accuracy and undermine their value. Repetitions of some or all of the tests may be required for confirmation, and comparisons made between the estimated performance and the measured performance. The cause of any discrepancy must be searched for to provide reliable data for future estimates by eliminating some basic unsoundness in assumption.

The accuracy of the Air Speed Indicator must be determined by testing the position error of the pitot head which is normally mounted on one of the wings, or wing struts. The proximity of the wing, or strut, causes uneven air flows which may produce a slight plus or minus error in the speed reading. Any discrepancy is checked by making measured speed runs over a ground course ; also by means of a special head suspended below the aeroplane where it is free from disturbed air.

When the measurement tests are completed, the pilot must test the aeroplane for manœuvre and strength. Fast diving and turning tests at speed, aerobatics, stalling and spinning and ease of recovery from difficult situations in flight are necessary if the craft is a military fighting type. An ordinary commercial slow-flying aeroplane does not require all of these tests, and is not designed to meet such conditions. But it is up to the honour of the test pilot that the aircraft he flies are safe to be handled by less skilled pilots when they pass out of his hands to the aeronautical community, and that the designer has profited by the fidelity of his work in an increase of knowledge and a chance of still further improvement in design next time.

THE ART OF

BY

CAPTAIN NORMAN MACMILLAN

M.C., A.F.C.

With a foreword by AIR VICE-MARSHAL

SEFTON BRANCKER, K.C.B., A.F.C., Director

of Civil Aviation, and 44 Illustrations

Captain Norman Macmillan will be remembered as the pilot of the first attempt ever made to fly round the world when, after a succession of thrilling adventures, his seaplane was wrecked and overturned amidst the monsoon storms of the Bay of Bengal. Few, however, outside the more intimate circles of aviation realise the Empire importance of the test-flying which Captain Macmillan has been engaged on ever since the cessation of hostilities, because his work of necessity must be carried on in secret. The advance of aeronautical science has been very rapid since the war, and the knowledge and experience gained in the course of eleven years continuous flying are here presented to the reader in the guise of a fascinating study of flight and the art of flying. Into the pages of this book are woven much of the romance and adventure of aeronautical progress, and a very great deal that will help the young pilot. To all who, knowing little or nothing about aeroplanes are interested in them, this book will make a ready appeal because here they will find the answers to their many questions, written and illustrated in a way which will remove the mystery which surrounds aviation to those outside the aeronautical community.

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