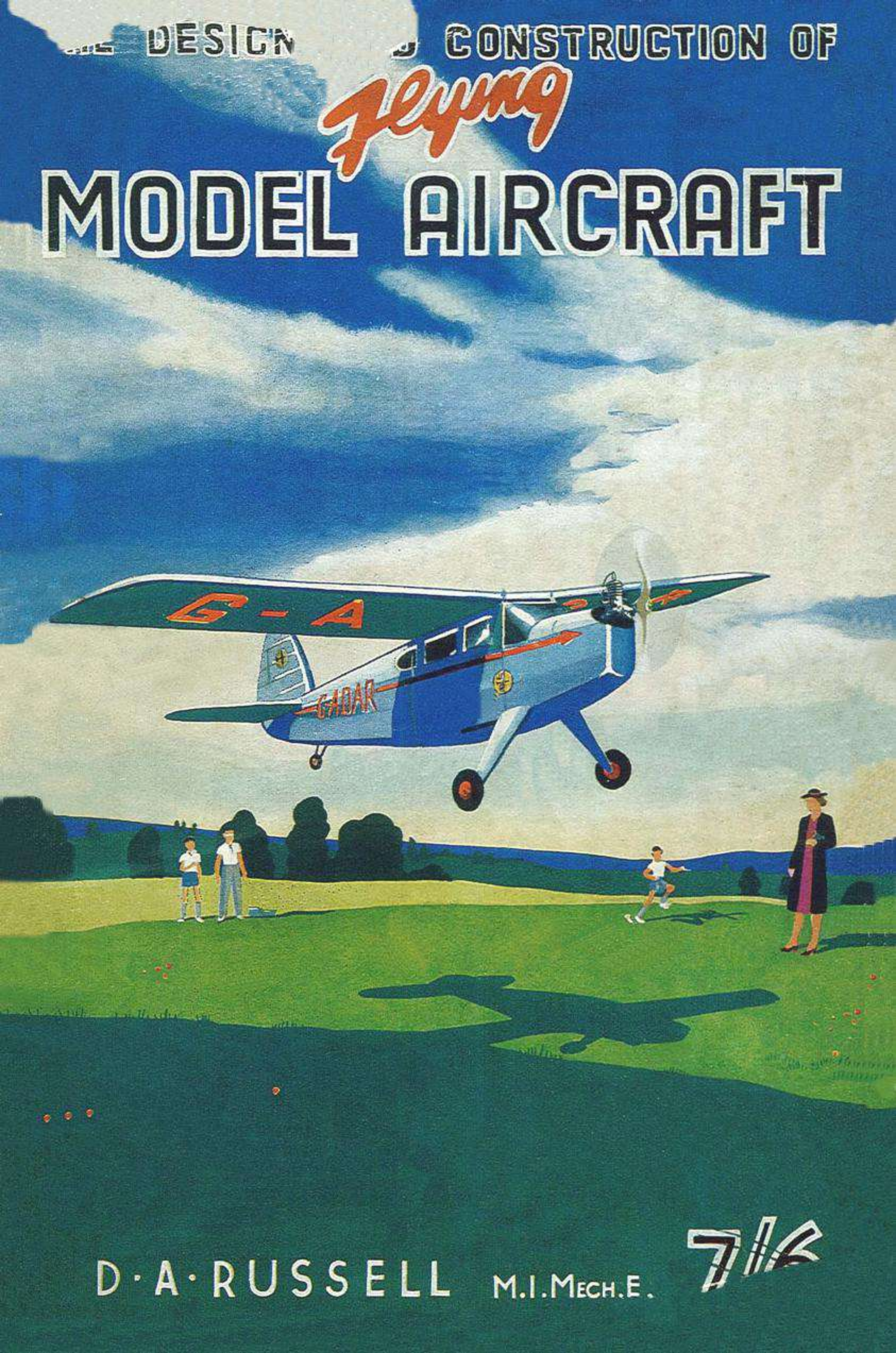
THE DESIGN AND CONSTRUCTION OF *Flying* MODEL AIRCRAFT



D·A·RUSSELL M.I.MECH.E.

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THE DESIGN AND CONSTRUCTION OF FLYING MODEL AIRCRAFT

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By

D. A. RUSSELL

A.M.I.Mech.E.

THE HARBOROUGH PUBLISHING COMPANY LTD
ALLEN HOUSE, NEWARKE STREET
LEICESTER

Sole Distributors to the Bookselling Trade:
HORACE MARSHALL & SON LTD.
TEMPLE HOUSE, TALLIS STREET, LONDON, E.C.4

Made and Printed in England by
The Sidney Press Limited, London and Bedford

1940

Author's Note

THIS book in no way deals with full-sized aerodynamics. It was first published in 1937, the intention being to provide a text-book, by the use of which an aero-modeller could work out the complete design and peformance estimation, of medium and large-sized model aircraft, both power and rubber driven.

That the first edition sold out well, and that there has continued to be a demand for the book, has led to the publication of this second, and considerably enlarged, edition.

Whilst the technical part remains essentially as before, the opportunity has been taken to provide a complete set of new sketches, and introduce some further data in the chapter on rubber motors. The practical part of the book has been enlarged by the addition of several new chapters, together with the inclusion of a considerable number of new photographs and sketches.

Except where otherwise stated, the results of researches described in the book and in the Appendices, are the original work of the author, carried out with the aid of a wind tunnel and other equipment specially designed and built for the purpose.

The author realises that model aircraft constructors are keenly individualistic, each with his own theories and ideas, and no attempt has been made to direct the reader into any particular viewpoint. It is hoped that the technical chapters will encourage the reader to design his own 'plane, and that from the photographs and sketches with which the book is illustrated, he may find inspiration sufficient to enable its construction to be undertaken and achieved with success.

The author acknowledges with grateful thanks the co-operation of Mr. C. A. H. Pollitt in providing a set of new sketches for the book; also the assistance of Mr. J. H. Elwell in correcting proofs and compiling the index.

Acknowledgment is made on page 243 to those model aircraft firms which have kindly loaned blocks and photographs for use in this book, and acknowledgment is also made to the Editors of *The Aero-Modeller*, *Practical Mechanics*, and *Popular Flying*, for permission to quote from the text of several of the author's articles published in these journals, and for the use of several blocks, sketches and photographs which accompanied them.

Market Harborough.
1940.
D. A. RUSSELL.

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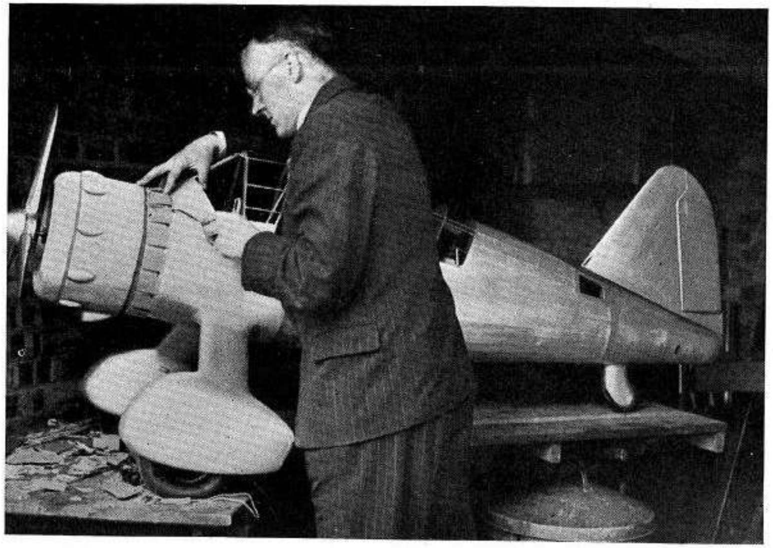
APPENDIX 1.—FORMULÆ.

(Rubber-driven models only.)



The Author at work on his latest 'plane. This is a flying scale model of the Westland " Lysander." It is one-fifth full size, and is thus 10 ft. span and 6 ft. long. It is equipped with a $1\frac{1}{2}$ h.p. 4-cylinder engine, which is described in the chapter on Engine Testing. The machine will be fitted with flaps, slots, and an automatic stabilising control.

CHAPTER I

AIRFOILS

How an airfoil lifts—" Flat plate " and double-surfaced cambered airfoils—Formula for calculating flying speeds—Lift and drag coefficients of airfoils—The boundary layer—Maximum thickness-to-chord ratio of airfoil sections—The geometric chord and angle of attack—The angle of attack of zero lift—Various types of airfoil sections.

(1) In considering the movement of a flat plate airfoil through the air it must be appreciated that if it moves in a horizontal plane it does not generate any lift—but only drag. In this position the airfoil is said to be at the " angle of attack of zero lift."

As soon as the airfoil is tilted, so that the leading edge is higher than the trailing edge, the airfoil is said to be inclined at a " positive angle of attack," and lift is generated. At the same time the drag is increased, due to the greater resistance of the inclined surface of the airfoil. If the angle of attack is increased to much beyond 14 to 16 degrees the ratio of lift to drag falls off to a figure lower than it would be for a smaller angle of attack. If the angle of attack is increased to much beyond 18 to 22 degrees the airfoil is likely to stall.

The aim of the designer, therefore, is to evolve an airfoil section which gives the highest lift/drag ratio—and to know at what angle of attack this section should be set.

In comparing the lift coefficients of different airfoil sections, it is useful to consider them in relation to that of a flat plate—since this may be considered the most elementary airfoil section, and therefore serves as a useful basis for comparison with the various curved sections which have been developed—with the object of obtaining as great a lift as is possible from a given wing area.

The pressure acting on the plate may be ascertained from the formula—

$$P_v = P\frac{2 \text{ Sin } a \text{ Cos } a}{1+\text{Sin}^2 a} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

i.e., $P = P_v \frac{(1+\text{Sin}^2\, a)}{2\ \text{Sin}\ a\ \text{Cos}\ a}$

(As the size and shape of the flat plate would affect its efficiency as an airfoil, this formula, as it stands, would give only an approximate result, and in actual practice other factors would have to be taken into consideration. However, the example here given is sufficiently accurate to show, quite definitely, how low is the lift efficiency of a flat plate airfoil compared with one of normal design).

Assuming the plate to be inclined at an angle of attack of 5 degrees.

$$P = \frac{1\ (1+{\cdot}0872^2)}{2 \times {\cdot}0872 \times {\cdot}9962}$$
$$= 6{\cdot}1914 \text{ pounds.}$$

The velocity of the wind necessary to support the plate at this angle may be ascertained from the formula—

$$V = \sqrt{\frac{P}{{\cdot}0032}} \text{ miles per hour} \quad \ldots \quad \ldots \quad (2)$$
$$= 43{\cdot}99 \text{ miles per hour.}$$

Similarly the speed may be found for any angle of attack by appropriate substitution in the formula.

(2) Now for light model aircraft with wing loadings not exceeding 3 or 4 ounces per square foot of wing area, the simple " flat plate " type of airfoil may be used. For, whilst its efficiency as regards lift is poor, it possesses the advantage of being very easily and lightly constructed, and thus its ratio of weight to surface area is very good.

But, as the minimum flying speed at which an airfoil will support a given weight increases as the square of the loading, it will be appreciated that as soon as the loading increases beyond 4 or 5 ounces per square foot of wing area, relatively high speeds are necessary to sustain the flat plate type of airfoil in flight—and it is for this reason that the double-surfaced " shaped " airfoil has been developed, since its greater efficiency allows of a correspondingly slower minimum flying speed being obtained.

For every given airfoil section, and for every angle of attack at which this airfoil section is fixed in relation to the horizontal plane, there obtains a definite set of lift and drag conditions—and these are ascertained by means of wind-tunnel tests of models of the airfoil section.

By plotting the results obtained from these tests in the form of " lift to drag " curves, the relative efficiency of the airfoil section, at varying angles of attack, may be readily observed, and comparison made with the results obtained from tests on other airfoil sections.

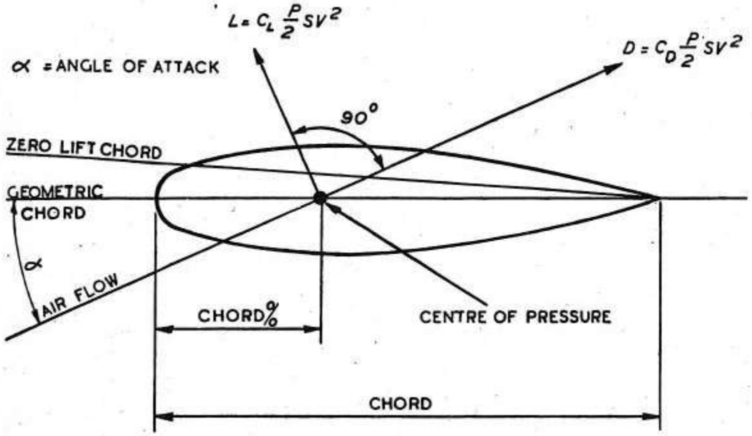


FIG. 1.

For the purpose of calculations, the terms " Lift Coefficient " (C_l) and " Drag Coefficient " (C_d) are introduced, their numerical value depending on the shape, and angle of attack, of the airfoil section to which they refer. Their application in the appropriate formula, allowing of flying speeds being calculated for any set of conditions.

The formula is $L = C_l \frac{p}{2} SV^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$

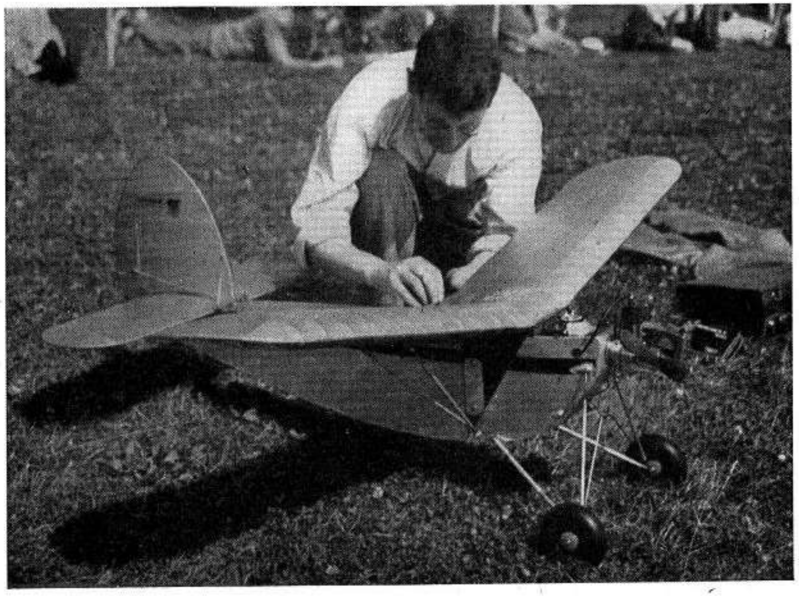
where L = Weight in pounds.
p = Mass density of air.
= ·002378 in slugs per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.
C_l = Lift coefficient.

This formula may be rewritten $C_l = \frac{L}{\frac{p}{2} SV^2}$

and applied to the "flat plate" type of airfoil section to obtain values of C_l.

Taking the example quoted above (where wing loading = 1 pound per square foot of lifting surface)

$$C_l = \frac{1}{\frac{p}{2} \times 1 \times 64{\cdot}5^2} = {\cdot}202 \text{ (at angle of attack of 5 degrees)}$$



Mr. Trevethic, with one of his petrol 'planes. This model has an adjustable fin controlled by time-switch, and is described in the chapter on "Flying the Model."

Since, at the same angle, any well designed airfoil section will have a lift coefficient of approximately ·8, it will readily be seen how relatively inefficient (except for very light wing loadings) is the "flat plate" type of airfoil section.

(3) All well-known airfoil sections published in the Reports and Memoranda of the Air Ministry's Aeronautical Research Committee contain values for C_l at varying angles of attack, for the particular airfoil section covered by each report. And, provided the model aircraft designer keeps rigidly to the airfoil section, when constructing his wing, and

mounts it at the correct angle of attack, he may be assured of reliable results from his calculations.

Suppose it is required to find the lift obtainable from an aircraft designed to the following specification:—

Span = 10 feet.
Wing Area = 10 square feet.
Speed = 30 feet/second.
C_l = 1·6

Substituting in the equation $L = C_l \frac{p}{2} SV^2$

$$\text{Then } L = 1{\cdot}6 \times {\cdot}001189 \times 10 \times 30^2$$
$$= 17{\cdot}1 \text{ pounds.}$$

Continuing the example, the same aircraft may be designed with an airfoil with $C_l = 1{\cdot}3$,

In which case

$$L = 1{\cdot}3 \times {\cdot}001189 \times 10 \times 30^2$$
$$= 13{\cdot}9 \text{ pounds.}$$

If, however, the aircraft using this airfoil is desired to lift the same weight, i.e., 17·1 pounds, then the flying speed must be increased, and the formula $L = C_l \frac{p}{2} SV^2$ may be re-written.

$$V^2 = \frac{L}{C_l \frac{p}{2} S} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Substituting the appropriate figures from the example

$$V = \sqrt{\frac{17{\cdot}1}{1{\cdot}3 \times {\cdot}001189 \times 10}}$$
$$= \sqrt{\frac{17{\cdot}1}{{\cdot}01545}}$$
$$= \sqrt{1105}$$
$$= 33{\cdot}3 \text{ feet per second.}$$

Unfortunately, whilst a great number of airfoil sections have been made available, together with full particulars of their characteristics, not much use appears to be made of them; instead, certain formulæ have crept into common use, from which it is thought that minimum flying speeds may be calculated.

For instance, a formula often used by model aircraft designers is that which states that the minimum flying speed at which an airfoil will lift may be ascertained from

$$V=\sqrt{840\times L} \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

when V = minimum flying speed in feet per second, and L = wing loading in pounds per square foot.

Thus for a wing loading of 1 pound per square foot

$$V=\sqrt{840\times 1}=29 \text{ feet per second}$$
$$= 19{\cdot}75 \text{ m.p.h.}$$

Another formula commonly used, is that which states

$$V=\sqrt{W}\times 6 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

where V = minimum flying speed in miles per hour, and W = wing loading in ounces per square foot.

Here, for the *same* wing loading, the minimum flying speed $V=\sqrt{16}\times 6$

$= 24$ miles per hour ! ! !

Such formulæ as these two above quoted can only apply each to one definite airfoil section inclined at a given angle of attack.

The minimum flying speed, generally speaking, varies as the square root of the loading; and whilst, therefore, these formulæ *do* give the speeds for different wing loadings, they can only apply to *one given airfoil section, inclined at one given angle of attack; and in the absence of this vital information, the use of these formulæ can be of little help.*

(4) The drag of an airfoil is dependent partly on the angle of attack, partly on the aspect ratio, and partly on the degree of smoothness of the airfoil surface, and its value may be ascertained from the formula—

$$D=C_d \frac{p}{2} S V^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

where D = Drag in pounds.
p = Mass density of air.
= ·002378 in slugs per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.
C_d = Drag coefficient.

As the angle of attack increases so does the drag, but so also does the lift—the ratio remaining fairly constant until within a few degrees of the stall, when the drag increases very rapidly, this *lowering* the ratio of lift/drag.

Practical research supplemented by theoretical considerations show that an airfoil of infinite span would not have any *induced* drag due to generated lift; but only turbulent drag—due to eddies in the airstream leaving the trailing edge; and frictional drag—due to the airstream flowing over the airfoil surface.

The drag resulting from the eddies leaving the wing tips is considerable, and for this reason the aspect ratio should be as large as possible, since the farther apart are the wing tips the smaller is their percentage effect on the wing as a whole.

For model gliders, aspect ratios up to 20 : 1 may be used. For rubber-driven models the ratio varies from 8 : 1 up to 12 : 1; whilst for large power-driven models the aspect ratio is usually about 7 : 1. (This lower figure is perhaps accounted for by limitations in present day supplies of material, as suitable wood for wing construction is not generally procurable in lengths exceeding 4 feet—thus tending to limit the wing span to some 8 feet.)

To obtain the necessary area of lifting surface, the designer is compelled to use a chord of 14 or 15 inches—and thus an aspect ratio of only 7 : 1 is used.

As will be shown in a later chapter—it is possible to construct wings of the cantilever type of considerably greater span than 10 feet—and in view of the increased efficiency obtained by keeping the wing tips as far apart as possible—it is considered that the aspect ratio of flying model aircraft of any type should not be less than 8 : 1.

(5) When the chord of an airfoil approaches 15 or 16 inches, break up of the " Boundary Layer " near the trailing-edge is likely to occur, with a consequent *increase* in drag due to turbulence, and *decrease* in lift due to the breakaway of the airstream flow from the surface of the airfoil.

J. V. Connoley* states that " In a moving fluid, which flows along a body, there is a thin layer adjacent to the body which is at rest at the surface of the body and has an increasing velocity until it is moving at the speed of the stream."

---

* " Aerodynamics for the Aero-modeller," *Aero-Modeller*, Jan.-Feb., 1936.

This is the boundary layer—its thickness is small, and is defined as " the distance from the surface at which the air is moving at a velocity from 95 per cent of that of the airstream."

The thickness of the layer can be found from the formula developed by Van der Hegge Zijnen:

$$T = 4{\cdot}5\sqrt{\frac{KL}{V}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

where T = Thickness of layer, in feet.
K = ·00016.
= Kinematic viscosity of air.
L = Distance from the leading edge of the airfoil in feet.
V = Airspeed, in feet per second.

In the above formula it will be observed that as the distance (L) from the leading edge increases so does the thickness of the boundary layer.

Taking a point 18 inches from the leading edge of an airfoil of say, $18\frac{1}{4}$ inches chord, and assuming an airspeed of 40 feet per second:

$$T = 4{\cdot}5\sqrt{\frac{{\cdot}00016 \times 1{\cdot}5}{40}}$$

$$= {\cdot}01102 \text{ feet (or about } \tfrac{1}{8} \text{ inch).}$$

(6) Now as the boundary layer increases in thickness, so it tends to form into " ripples "; these grow into " waves," which finally " break " and roll over each other in much the same way as real waves on the sea shore.

This " break up," and consequent increase in drag due to the turbulence created, usually occurs at a Reynold's number of about 3,000.

The Reynold's number of the thickness of the boundary layer may be calculated by multiplying the thickness of the layer by the speed and dividing by the kinematic viscosity.

$$\text{i.e., R.N.} = \frac{TV}{K} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

In the example quoted above

$$\text{R.N.} = \frac{{\cdot}01102 \times 40}{{\cdot}00016}$$

$$= 2760$$

Thus it will be seen that for an airfoil moving at a speed in the neighbourhood of 40 feet per second—the chord must not exceed 17 or 18 inches, if turbulence of the boundary layer is to be avoided at the trailing-edge of an airfoil unless, of course, special means are adopted to delay the development of the turbulent layer for as long as possible. This can be done, to a certain extent, by ensuring that the surface of the airfoil is made as smooth and even and as free from obstructions as possible.

Petrol 'planes are built in considerable numbers in Italy. Here is a biplane built in 1939 at the Parma School of Model Aeronautics.

(7) The aim of the designer is at all times to keep the drag as low as possible—and to do this the natural inclination is to use an airfoil section which is thin and has very little camber. Such an airfoil would have a ratio of maximum thickness to chord of about 1:18; and a ratio of maximum camber to chord of 1:50.

Airfoil sections in this class are suitable for lightly-loaded rubber-driven models of small span; and whilst the thin airfoil section permits of a very light framework (which in some cases need not even be double-surfaced), it does not lend itself to the construction of large spans, due to the impossibility of incorporating a stout " backbone " in the section.

To obtain the highest value for C_l the airfoil section must be " thickened-up," so that the maximum thickness to chord ratio is about 1:9. At a ratio of 1:8 the best L/D ratio is obtained, any further " thickening-up " putting the rear upper surface of the airfoil at such a large angle of incidence as to cause " breakaway " of the airstream.

This class of airfoil section, which should always be used for large power-driven aircraft, allows the designer to incorporate, at the thickest part, a main spar of immense strength, running throughout the span of the wing.

For large rubber-driven and small power-driven aircraft, where the wing loadings may vary from 4 to 10 ounces per square foot of lifting area, there is a choice from any of the well-known airfoil sections published in the Aeronautical Research Committee's Reports and Memoranda; or the development of an airfoil section by the model aircraft designer himself.

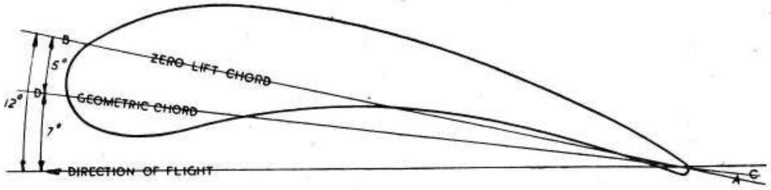


FIG. 2.

(8) Fig. 2 shows a typical " slow-flying " high lift/drag ratio airfoil section in which A B is the " zero lift chord " (i.e., if the airfoil is arranged so that A B is panelled to the direction of the airstream, no lift is generated).

C D is the geometric chord and is usually the further distance (in a straight line) between the leading- and trailing-edges.

All angles of attack are measured from the geometric chord, and thus for the airfoil to be set at an angle of attack

of 0 degrees, the geometric chord must be inclined at a *negative* angle to the direction of the airstream.

For an airfoil of the section illustrated, this angle will be about 6 degrees.

It follows, that when any airfoil is arranged so that the geometric chord is parallel to the airstream, actually it is inclined at an angle of attack equal to the amount known as the " angle of attack of zero lift."

Thus, if a specification calls for an angle of attack of 12 degrees (and the angle of attack of zero lift for the particular airfoil section is 3·5 degrees)—then the angle that the geometric chord subtends to the line of flight is 12 - 3·5 = 8·5 degrees.

A method for finding the direction of the zero lift chord which gives results accurate to within ·4 of a degree, is that given by K. D. Wood,* and which consists of drawing a line from the trailing-edge through a point located half-way between the upper and lower surfaces of the airfoil, at a distance ·4 of the chord from the leading-edge—as shown in Fig. 3.

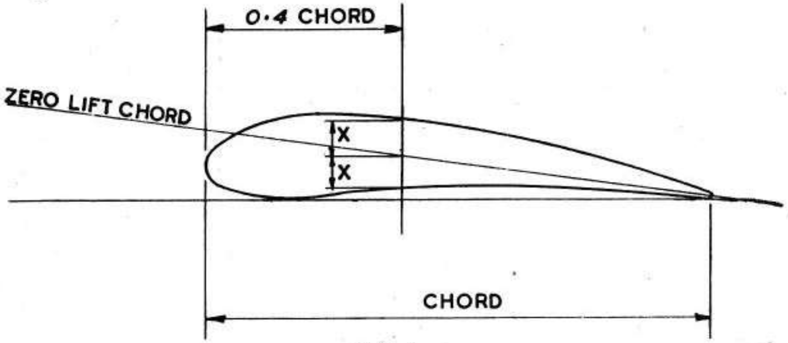


FIG. 3.

If the geometric chord is then drawn, the angle included by the zero lift chord and the geometric chord is the angle of attack of zero lift.

(9) In choosing the most suitable airfoil section to use for a particular aircraft—the following points should be considered:

(*a*) For very light loadings, a thin and nearly flat airfoil

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* K. D. Wood, *Technical Aerodynamics*.

section of maximum thickness to chord ratio of 1:18 should be used.

(*b*) For very light loadings, but where duration of flight is of importance, a slightly heavier airfoil section, of maximum thickness-to-chord ratio of 1:15 should be used; care being taken to see that the thickest part of the airfoil section is not more than ·25 of the chord distance from the leading edge.

(*c*) For medium loadings—say from 4 to 10 ounces per square foot of lifting area—there are available a number of well-known sections, choice from which may be made, giving preference to the slightly thicker sections for slow flying combined with heavy loadings; and to the slightly thinner, though not less deeply cambered sections, for faster flying aircraft.

(*d*) For speed record work—since adequate lift is easily obtainable owing to the high speed—a fairly thin airfoil, with a perfectly flat under-surface should be used; great attention being paid to obtaining as smooth and even a finish as possible to the airfoil surfaces, so that the C_d is kept to a minimum.

(*e*) For loadings of 12 ounces and upwards per square foot of lifting surface—i.e., for power-driven aircraft, airfoil sections of maximum thickness to chord ratios of between 1:10 and 1:8 should be used.

Firstly, this section allows of the introduction of substantial spars throughout the span of the airfoil, and secondly, the higher C_d of the thick section keeps the speed down; whilst, at the same time, due to the high C_l, the necessary lift is obtained.

(*f*) It is obvious that any airfoil, given the opportunity, will adjust itself to that angle at which the C_d is at its lowest value, regardless of how large, or small, the C_l may be. Consideration must, therefore, be given not only to its lift and drag characteristics when in power flight, but also when in a free glide; obviously, then, an airfoil which generates very little lift, when moving at its angle of minimum drag, should not be used for a heavily-loaded aircraft.

The minimum drag of the majority of the fairly thick airfoil sections used for power-driven aircraft occurs at an angle of about 4 degrees; whilst the angle of attack of zero lift is usually about 6 degrees.

Thus the airfoil is actually at an angle of 1 or 2 degrees

positive inclination to the line of flight, when in a natural glide.

However, for the same angle of attack, the C_l varies somewhat for different airfoils, and therefore care should be taken, when considering an airfoil section, to see that when the C_d is at its minimum, the C_l is sufficient to give the aircraft a useful lift during the glide.

(*g*) The aspect ratio should be kept as large as possible, as this tends to improve the general efficiency of the airfoil.

(*h*) The chord should be kept as small as possible. As the angle of attack increases, so the centre of pressure of the airfoil moves. The shorter the chord, therefore, the smaller is this movement.

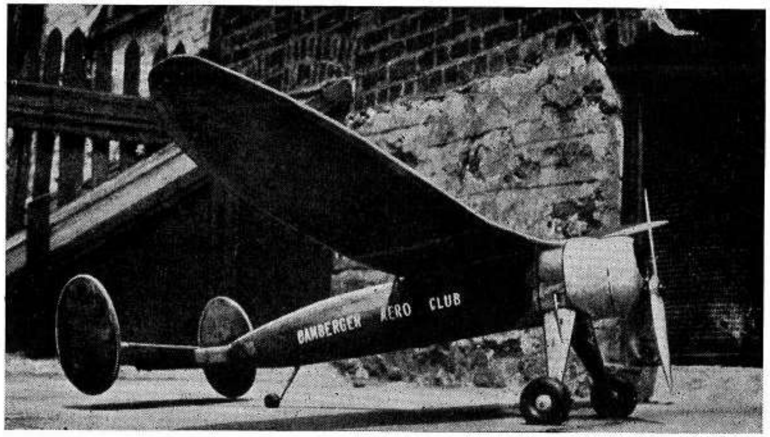
(*i*) The centre of pressure appears to move least in airfoils of thick section, whose angle of attack of zero lift is 5 or 6 degrees, and whose under-surface is well cambered.

The movement being from about 40 per cent chord distance from the leading-edge, to about 33 per cent chord, for angles of attack up to about 13 degrees, and then slightly *backwards* as the stall approaches.

In airfoils with flat under-surfaces the centre of pressure movement appears to be somewhat larger, and to vary from 40 per cent chord at small angles of attack, to 33 per cent chord as the angle of stall is approached.

In airfoils with upswept trailing-edges, the centre of pressure is initially nearer the leading-edge, and moves slightly *backwards*, as the angle of attack increases.

Airfoils of this latter type, whilst having good L/D ratios at small angles of attack, are not so well favoured as the angle increases; until, at the stall, the drag increases very rapidly; they are, however, very stable at most normal angles, the centre of pressure remaining practically stationary.



This interesting machine was built in America, and is a typical example of the type of power-driven model aircraft built in that country. The fuselage is of monocoque construction, and the fully cantilever undercarriage legs are fitted with shock absorbers.

CHAPTER II

AIRFOILS AND FUSELAGES FOR MONOPLANES AND BIPLANES

Trailing-edge vortices—The lift distribution of an airfoil—Streamlines—Plan form of airfoils—Tapered airfoils—" Down-wash "—The effect of trailing-edge vortices on the drag of (A) low-wing fuselages, (B) high-wing fuselages—Suitable fuselage sections—Prevention of " breakaway " and stall at the junction of an airfoil with a fuselage—The low wing versus the high-wing monoplane—The lift of a biplane—Advantages of biplane design—The distribution of lift over the wings of a biplane—Position of the stabiliser in a biplane—The position of thrust-line in a biplane.

(1) In the preceding chapter mention has been made of the drag due to the trailing vortices which originate at the wing tips of an airfoil. Vortices originate also all across the trailing-edge of an airfoil due to the fact that the lift is not constant across the span, but generally is proportionate to the ordinate of an ellipse whose major axis is equal to the span,

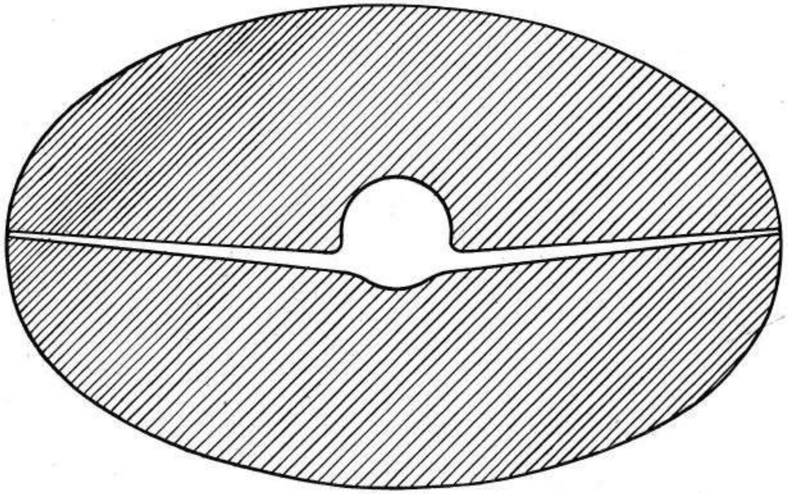


FIG. 4.

Diagram illustrating the empirical assumption that the air affected by an airfoil is contained within an ellipse whose major axis is the span of the wing, and the minor axis four-fifths of the span. The mass of air contained within this ellipse may be regarded as the region of air disturbed by the passage of the aircraft.

and whose minor axis is about equal to four-fifths of the span.

In Fig. 4 the shaded portion indicates the mass of air affected by an airfoil, from which it will be seen that the lift is greatest at the centre of the span, and decreases to zero at the tips. This is known as "elliptic loading."

The effect of this unequal distribution of lift is that there is a considerable decrease of pressure above the centre of the airfoil, and a considerable increase of pressure underneath the centre, resulting in the "streamlines" above the airfoil tending to flow inwards (due to the partial vacuum formed) and those underneath tending to flow outwards (due to the pressure), as shown in Fig. 5. At the trailing-edge the two streams meet, and since their paths are crossing, rotating vortices are formed, those on one side of the fuselage rotating in the opposite direction to those on the other side.

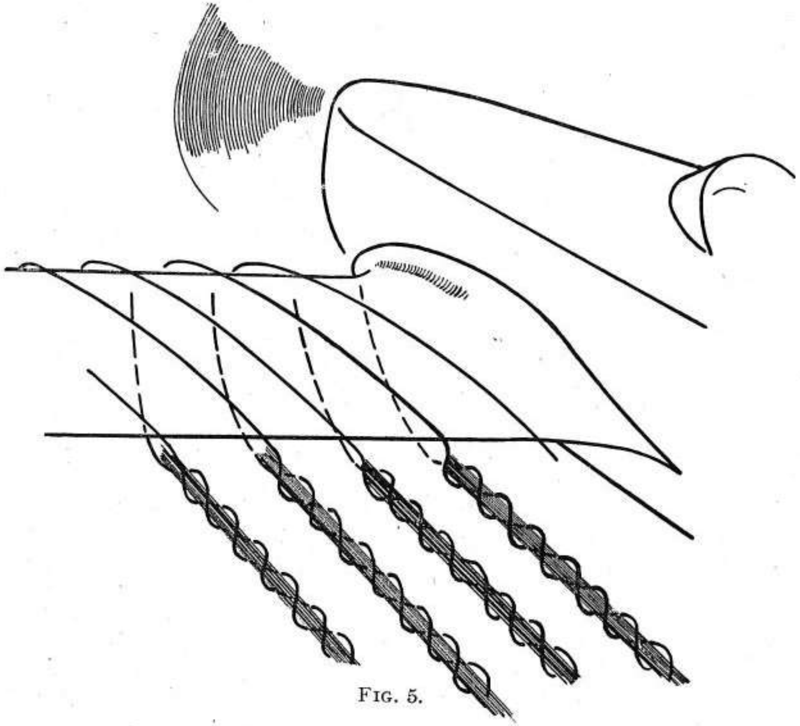


Fig. 5.

Formation of trailing edge vortices.
The sketch above illustrates the flow of air round a wing. It will be seen that the air passing over the top surface of the wing is flowing slightly inboard towards the fuselage, while the air on the underside of the wing tends to flow outboard and away from the fuselage.

Finally, as the vortices of each system are unstable, they roll up into a pair of vortex tubes and pass downstream, one on either side of the fuselage, at a distance apart somewhat less than the span of the airfoil.

Now several points of interest arise from a consideration of the foregoing:

(2) Firstly, there is the effect on the plan form of the airfoil—certainly it should not be rectangular in shape. As the strength of the tip vortex depends on the chord, the shorter this is, the smaller is the drag, and the degree of turbulence which will originate at the tip.

(As a logical deduction from this it follows that in an airfoil which tapered to a *point*, the strength of the tip vortex would be at a minimum; but on account of considerations noted later, this is not feasible in practice).

However, the indication definitely is for the airfoil to be tapered to a reasonable degree, such that a good aerodynamic balance is preserved. If the chord is constant the "downwash" from the tips is relatively large, and the incoming airflow to the leading edge is also given an induced "downwash," thus reducing the effective angle of incidence of the tip; resulting in the *centre* portion of the airfoil stalling first.

If the airfoil is tapered, the "downwash" is reduced, due to the shorter tip chord, and there is less reduction in the effective angle of incidence so that, if the taper is correct, the airfoil will stall all along its span at the same moment. If the degree of taper is excessive, the "downwash" at the tips becomes less even than that normally present at the centre of the airfoil, and the tips stall *first*—since they are now at a relatively larger angle of incidence than the centre section of the airfoil.

Whilst, therefore, a constant chord may tend towards better lateral stability, it does so only at the expense of an increase in drag due to the large tip vortices it originates.

Further, since the greater portion of the lift of an airfoil is generated about its centre section, large surfaces at the wing tips should be avoided; and the careful introduction of a certain degree of taper will have the effect of transferring useful lifting surface from where it is least effective, to a position where it is most effective.

The tip chord may be made equal to from $\frac{7}{8}$ to $\frac{3}{4}$ of the centre section chord, or even $\frac{5}{8}$, provided, in the case of a low-wing monoplane, a fair degree of dihedral angle is used.

In all cases the taper should mainly be effected by bringing forward the trailing-edge, and keeping the leading-edge at right-angles to the fuselage. If, for the sake of appearance, it is desired to set back the leading-edge, the amount of this " set-back " should not be more than 25 per cent of the total chord reduction. For example, if the chord is to be reduced from 10 inches at the centre of the span to 6 inches at the tip, the leading-edge should not be set back more than 1 inch; and the trailing-edge be brought forward by the other 3 inches.

(3) Secondly, there is the effect on the drag of the aircraft as a whole, consequent on the position of the fuselage in relation to the airfoil.

Considering, for a moment, the horizontal " streamlines " of the airflow round the front of a fuselage, it will be appreciated that there is a parting of the air, to either side, as it were; resulting in a local increase of pressure along each side of the fuselage.

Now if the fuselage is mounted *above* the airfoil, these " streamlines " from the nose of the fuselage will be meeting those passing over the top of the airfoil, and which, as was previously pointed out, are converging inwards.

Thus there is a region of high pressure along the upper side of the fuselage, which will persist to the tail of the aircraft. Meanwhile, since the streamlines beneath the airfoil are tending to diverge, there is a tendency to create a region of low pressure along the underside of the fuselage, tending to pull it downwards.

For this reason, the fuselage of a low-wing monoplane should be " egg-shaped "—wide at the bottom, and tending to be pointed at the top. The rudder dimensions (for the moment, taking no account of its area) should be such that it is rather high, and of not too large a chord, neither should it be highly tapered. Thus a useful operating surface is positioned *above* and away from the region of turbulence running along the upper sides and top of the fuselage.

When the aircraft is of the high-wing type the position is more or less reversed.

The streamlines parting from either side of the fuselage tend to follow a path approximately parallel to the diverging (lower) airfoil streams, and whilst the *strength* of the resultant pair of opposing rotating vortex tubes may be somewhat greater than in the case of the low-wing type of aircraft, the degree of turbulence will be less.

The converging upper " streamlines " will follow an uninterrupted path; and except that in meeting over the centre of the fuselage they tend to create a narrow stream of increased pressure, will not cause any great degree of turbulence.

The formation of a downward slope to the top of the fuselage, from the trailing-edge of the airfoil, will tend to keep this increased pressure at a minimum.

It will readily be appreciated that it is over its upper surface that the air finds the greatest difficulty in following the contour of an airfoil section, and consequently, when the fuselage is laid on the top, there can easily occur at its junction with the top surface of the airfoil a break-away of the air-stream, and the creation of large trailing vortices. In effect, the trailing-edge of that portion of the airfoil adjacent to either side of the fuselage becomes stalled.

Despite this, it is, of course, noteworthy that in recent years the low-wing monoplane has been developed to a very large extent; and this has only been made possible by very careful attention to streamlining, and " flaring " the upper surface of the airfoil into the sides of the fuselage, which, to a very large extent, prevents the formation of trailing vortices and " break-away."

(4) In full-sized practice, and from the point of view of manufacturing costs, the low-wing monoplane is at an advantage in certain respects. It is cheaper, and easier, to build a landing chassis which retracts into a low wing instead of into a high wing; whilst from the point of view of landing, the proximity of the ground to the low wing promotes a certain beneficial " cushioning " effect, resulting in a slightly shorter " pull up." Whether this benefit is obtainable with model aircraft, and at speeds in the neighbourhood of 15 to 20 m.p.h. is somewhat doubtful.

The general question, as to whether the high- or low-wing type of aircraft is the more efficient, is seemingly one which is much debated amongst model aircraft designers.

As regards efficiency, however, there is very little to choose between either type, *provided* each has been properly designed for the performance it is expected to give.

A fuselage designed for use in conjunction with a low wing will not be so efficient if used with a high wing, and vice versa —and each type of aircraft should always be considered entirely on its own merits, with the realisation that the problems of design require different angles of approach, and those of flying a different technique.

(5) The positioning of one wing above another, as in a biplane, is simply a means of arranging the required amount of lifting surface in the most convenient position in relation to the fuselage.

This arrangement, however, will not produce the same lift for a given wing area as that of a monoplane of a similar wing area—and it may be generally understood that, in so far as full-sized aircraft are concerned, the type is mainly used where structural or storage conditions set a limit to the span.

In model work, no such limits need apply, and the biplane design, in fact, possesses certain structural advantages which may be said to balance the disadvantages of its somewhat lower " lift factor."

A biplane of a given wing area will produce between ·7 and ·9 of the lift that would be produced from a monoplane of equal wing area; the actual figure depending mainly on the gap chord ratio; and, to a lesser extent, on the degree of stagger of the two wings.

H. Glauert* gives the undernoted " correction factors " for an *un*staggered biplane compared with a monoplane of the same wing area inclined at the same angle of incidence.

Gap/Chord Ratio.	Correction Factor.
·5	·730
·75	·800
1·0	·855
1·25	·895
1·50	·920

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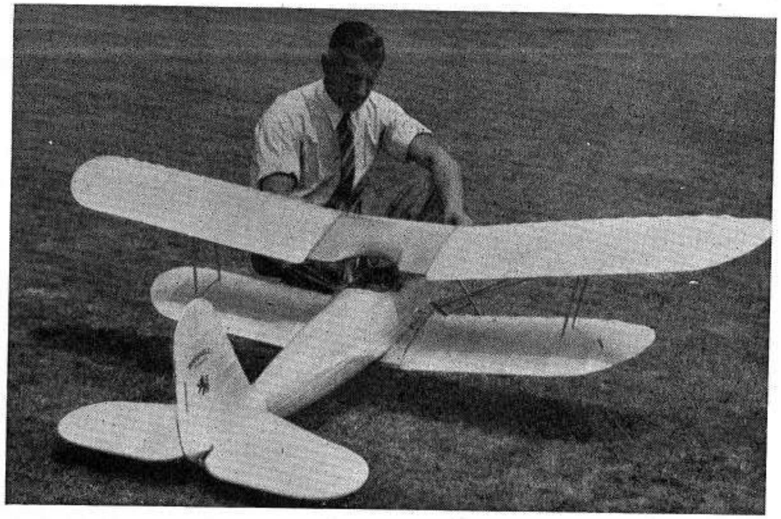
* H. Glauert, *Aerofoil and Airscrew Theory.*



Here is one of the finest power-driven model aircraft that has been built in England. It is a 7 ft. span biplane, with fuselage of monocoque construction, and is powered with a 9 cc. engine. The designer and builder, Mr. Sharvell, is about to start up the engine.

Thus is immediately seen the disadvantage of a small gap. To a limited extent this may be offset by giving the wings an exaggerated " stagger," but this calls for somewhat more complicated inter-wing struts, and does not allow of true scale reproduction; a certain small amount of " stagger " does, however, improve the longitudinal stability; and this may be regulated by moving the top wing ahead of the bottom wing by an amount equal to about one-sixth of the chord.

(6) The advantage accruing from the biplane design lies in the fact that, due to the bracing of the inter-wing struts, a much lighter wing structure may be used; so that whilst the lift produced, compared with a monoplane of the same size, is a little less, the weight of the wings is considerably less; resulting in the wing loading being kept at the same value for both types of aircraft.

In a normal type of biplane, where both wings have the same span and chord, the top wing appears to produce rather more than half the total lift, and for this reason special care should be taken to see that its surfaces should be kept as free as possible from disturbances, and the formation of vortices.

From a consideration of the previous explanation of the direction of the streamlines above and below the wings, it might be thought that the best position for the fuselage was close up to the under surface of the top wing, and raised clear of the upper surface of the lower wing, and to a certain extent this is correct. In full-size practice this design is not often seen, since the arrangement does not allow of sufficient depth to the fuselage, unless a very large gap is used (although, on occasions, it has been used in large military aircraft of the " night bomber " type).

In recent years, such great advances have been made in the " art " of streamlining that it is possible to arrange the fuselage so as to fully occupy the gap between the two wings, and still obtain a low drag figure, and comparative freedom from the formation of " break-away " or objectionable vortices.

(7) In flying models, other than those which are built to exact scale, the gap/chord ratio should not be less than 1·25 to 1, when the " lift factor " will be approximately ·9.

The fuselage should be kept as narrow as possible, and carefully " flared " into the wings where it joins them.

The disposition of the stabiliser in relation to the two wings of a biplane calls for special consideration—it has already been shown how the stream of vortices leaving the trailing-edge of a wing gradually converge, and form into two oppositely rotating vortices, passing down either side of the fuselage—and in the case of the biplane *two* such systems exist, one for each wing. Thus there are two vortices on each side of the fuselage; the pair on one side rotating in the *same* direction, but oppositely to the pair on the other side of the fuselage. Each pair of vortices eventually combines, the upper one dropping rather more than half-way, due to the " down wash," to meet the lower one.

Unless the design of the whole aircraft is essentially a very stable one, it is considered undesirable to place the stabiliser directly in the path of these trailing vortices, and since their path lies nearer to the bottom wing, it should be placed so as to " sit " on the top of the rear of the fuselage.

The secret of a successful model biplane design lies in the correct positioning of the thrust-line in relation to the centre of drag of the whole aircraft. The centre of resistance of each wing must be carefully ascertained, and a " mean " for the two found. Then, if this position can be arranged to coincide with the centre of resistance of the fuselage, landing gear, etc., and also the thrust-line as well, the aircraft will possess inherent stability.

But it is not often possible to arrange such a happy state of affairs.

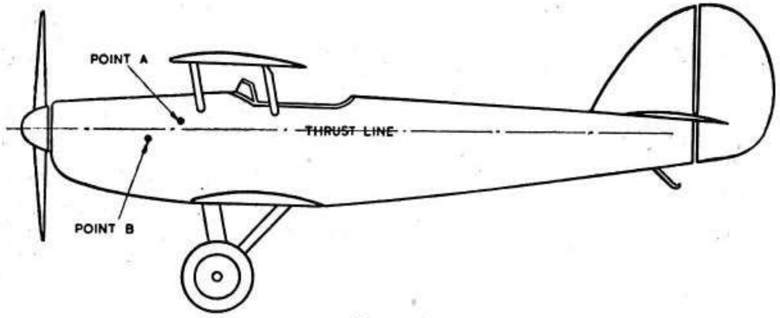


FIG. 6A.

Note that thrust line is arranged to pass *below* point A—the centre of resistance of the fuselage, etc., and *above* point B, the mean centre of resistance of the top and bottom main planes.

Fig. 6a shows the centre of resistance of the fuselage, etc., (*a*) above the centre of resistance of the mean of two wings, (*b*) which tends to pull the nose up—rotating about (*b*). The thrust-line must therefore be arranged to pass through a point between (*a*) and (*b*). Similarly Fig. 6b shows the centre of resistance of the fuselage *below* the centre of resistance of the wings, and the thrust-line must now pass *below* (*b*) to counteract the tendency of (*a*) to pull the nose down.

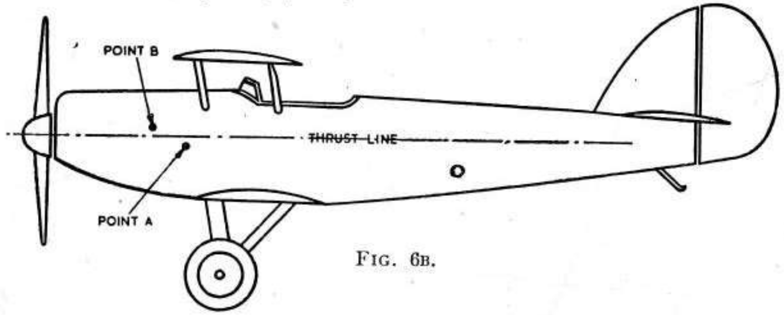


FIG. 6B.

Observe how the thrust line is still arranged to pass *between* points A and B. In this case point A is *below* the trust line and point B *above* it.

At the time the author built this low-wing monoplane of 10 ft. span it was one of the largest, and certainly the heaviest, of models to be built. The span of the 'plane is 10 ft., and the weight is 14 lb. The model is powered with an 18 cc. " Comet " engine, and it was awarded a " Highly Commended " diploma at the *Model Engineer* Exhibition in London, 1935. The 'plane was also awarded first prize at The Concours d'Elegance at the Northern Rally, organised by the Lancs M.A.S. in Manchester in 1936.

The actual position of the thrust-line will, of course, depend on the relative values of (*a*) and (*b*), and their distance apart—and must generally be found by experiment.

On no account should the engine of a biplane be given " down " or " up " thrust to obtain the correct trim, and if the designer remains in doubt as to the accuracy of his calculations, he should provide for a small " up-and-down " movement of the engine-mounting to enable him to bring the thrust-line to the same level as the centre line of resistance.

CHAPTER III

DRAG

Parasite and induced drag—Values of K for fuselage drag—Circular and rectangular section fuselages—Engine positions—Values of K for: tail-planes, rudders, landing chassis, struts, wheels, engines and—flat plates—Advantages of circular or elliptical section fuselages—Calculations for parasite drag of various parts of an aircraft.

(1) The drag of an aircraft may be divided into two parts—wing drag and parasite drag.

Wing drag consists of two kinds: " Profile," which is dependent only on the particular wing section used; and " Induced," which varies with the lift and aspect ratio.

As the aspect ratio *decreases*, so the " downwash " *increases*, thus reducing the effective angle of attack. Conversely, as the aspect ratio increases, so the " downwash " decreases, and the wing works at a better angle—another point in favour of as high an aspect ratio as is possible.

Parasite drag is also of two kinds: that which varies with the angle of attack, and that which does not. Instances of the former kind are square section fuselages, wing sections, and tail surfaces; whilst those of the second kind include fuselages and components having, in general, *good " Streamline " shapes*.

The drag of a fuselage of circular or elliptical section does not vary very much with a change of angle of inclination; but with rectangular section fuselages, any appreciable variation in the angle results in a considerable increase in drag. For instance, at an angle of inclination of 10 degrees, the increase in drag will be about 40 per cent in the case of a rectangular section fuselage, and only about 5 per cent in the case of a circular section fuselage.

(2) The drag of a fuselage may be calculated from the formula

$$D = KAV^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots (10)$$

where K = the drag coefficient of the fuselage, and depends on its particular characteristics.

A = the projected cross-sectional area, in square feet, at the largest section.
V = the speed—in miles per hour.
and D = is given in pounds.

K varies from about ·0002 to about ·0009, and averages about ·0004 for totally-enclosed fuselages of approximately circular cross-section.

For rectagular section fuselages of the type shown in Fig. 7—a type in fairly common use owing to its being easily and quickly constructed—

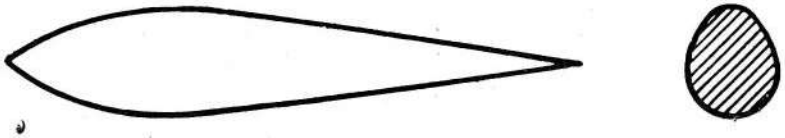
K may be taken as approximately ·0009.

In Fig. 8 is shown a fuselage of the same overall dimensions, and the same cross-sectional area, but which has been streamlined, and provided with a slightly rounded nose, resulting in the drag being reduced by half.

$K = {\cdot}00046$.

AVERAGE VALUE FOR K = ·0009 FIG 7

AVERAGE VALUE FOR K = ·00046 FIG 8



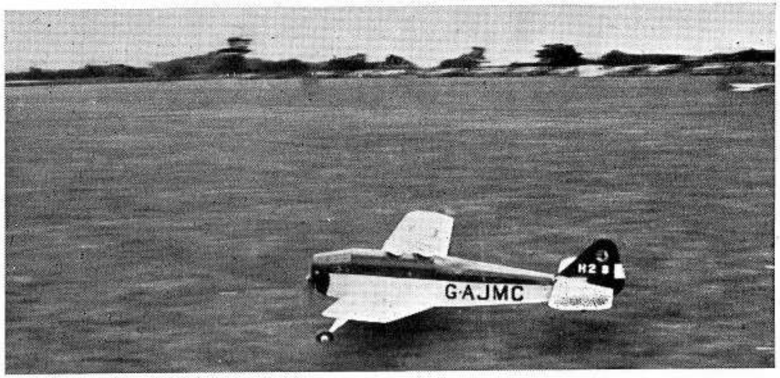
AVERAGE VALUE FOR K = ·00025 FIG 9

Fuselages of the shape shown in Fig. 9, where the section throughout is nearly circular and which have a fairly fine taper to the tail, have the lowest drag.

K = approximately ·00025.

As an example of the great reduction which may be obtained by proper care and attention to streamlining, the drag of the fuselages shown in Figs. 7 and 9 may be calculated for a speed of 15 m.p.h. The cross-sectional area being taken as 48 square inches in each case.

Substituting in the formula $D = KAV^2$
the drag of fuselage, Fig. $7 = {\cdot}0009 \times {\cdot}33 \times 15^2 = {\cdot}0668$ pound
and the drag of fuselage, Fig. $9 = {\cdot}00025 \times {\cdot}33 \times 15^2$
$= {\cdot}0186$ pound.



In this photo is shown the winner of the 1939 Bowden Trophy taking-off on one of its flights. The 'plane was built by Mr. T. M. Coxall, who is shown holding the model in another photo on page 92.

Considering now the effect of a variation in the angle of inclination of 10 degrees for these two fuselages—the drag of fuselage, Fig. 7, is increased (by 40 per cent) to ·0935 pound, and that of fuselage, Fig. 9, is increased (by 5 per cent) to ·01953 pound.

Thus it is seen that, under conditions which may not only occur in flight, but *do* occur when the aircraft is taking off, and until the tail has lifted, the drag of the rectangular section fuselage is nearly five times that of the fuselage of circular cross-section. Surely a strong enough argument in favour of the latter type, in spite of the added time required for its construction?

(3) The thickest part of a fuselage should be at a point about one-quarter to one-third of the overall length distant from

This shoulder-wing petrol 'plane, designed and built by the Author, is of 7 ft. span, weighs 6 lb., and is powered by a 6 cc. "Baby Cyclone" engine. It is of fairly typical design to the aircraft described in Figs. 10 and 11.

the nose, and should be as nearly circular in section as is possible. That portion from the nose to this thickest part should be kept free from obstructions such as control knobs, "domed" inspection doors, etc., since it is over this portion of the surface of the fuselage that the air pressure is greatest.

On rubber-driven models, dummy motors of the radial type, if of overall diameter exceeding that of the nose of the fuselage, can easily double the drag; and in power-driven aircraft the disturbance caused by a cylinder projecting above the top of the fuselage can cause a noticeable increase in drag.

If the design of the aircraft allows of the thrust-line being placed below the centre line of the fuselage (as in a high-wing monoplane with a long and heavy landing chassis), the engine may be fitted in the "upright" position. But if the thrust-line requires to be above the fuselage centre line, then the engine should be inverted, so as to avoid any part of it extending beyond the fuselage.

The coefficients for K which are given apply to fuselages which are totally enclosed, and in which there are no large cracks between detachable panels, doors, etc.

The increase in drag due to failure to appreciate the importance of this last point is considerable—particularly if there should be two openings, one at each end of the fuselage which

would allow the resultant flow of air to set up all kinds of disturbances at the point of exit.

When flying scale models of the type with open or semi-open cockpits are under consideration, the value of K should be increased by from 50 to 100 per cent, according to the "openness" of the cockpit, or the degree of turbulence it is considered likely to be set up behind such erections as wind-screens, machine-gun "cupolas," etc.

(4) An average value for K for tail-planes which have a flat under-surface and a thickness-to-chord ratio of about 1 : 18 may be taken as ·000075. But if the thickness-to-chord ratio is greater, or the section is cambered, then the tail-plane will be of the "lifting" type, and the drag must be calculated from the formula $D = C_d \frac{p}{2} SV^2$.

For fins and rudders the value of K may be taken as approximately ·00006 per square foot of area.

The drag of a landing chassis is as much due to "interference" as to direct resistance offered to the flow of air. This "interference" consists of vortices and cross-currents caused by the streamlines from one strut encountering another strut before they have had time to reform into a uniform air-stream. "Interference" is also caused at the junction of the struts with axle-plates, fuselages, etc.

An average value for K for struts is ·00025—the drag being in pounds per square foot of projected area: but thus must be increased by from 50 to 100 per cent, according to the amount of "interference" which may be thought to exist.

The drag of wheels varies with the ratio of diameter to tyre width, and is also dependent on the degree of "fairing" between the tyre and the hub; also the value of K is relatively greater for small diameter wheels—say 2 to 4 inches—than it is for those of from 6 to 9 inches diameter.

For wheels of from 2 to 4 inches diameter—with a diameter/width ratio of about 2·5 to 1, the value for K is about ·0029, whilst for wheels of from 6 to 9 inches diameter, with a diameter/width ratio of about 4 to 1, the value of K drops to about ·0015.

The drag of an engine installation will depend to a large extent on the type of mountings to which it is affixed. Aluminium "cones" which enclose the petrol tank, and are of tapered form, have low drag values, whereas the type of mounting which consists of two brackets extending from the front of the fuselage to form a platform on which the engine "sits," will create a certain amount of interference.

For average conditions the drag of a single-cylinder engine may be taken as being equal to $\cdot 0006\ V^2$ pound, where V is in m.p.h.

Certain parts of some flying model aircraft—particularly those of the rectangular section fuselage type, may present flat surfaces at right-angles to the direction of the airflow; and, in pointing out that in such cases the value of K is ·003, emphasis is given to the great reduction in drag which is made possible due to good "streamlining," since it has already been shown that the drag of a well-designed fuselage is about ·0004, which is approximately one-eighth of that of a rectangular section and "flat-nosed" fuselage of the same projected cross-section area.

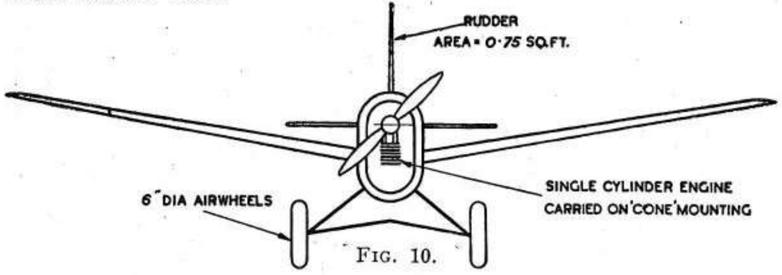


FIG. 10.

(5) As an example of how the total parasite drag of an aircraft is arrived at, calculations, for the drag at 15 m.p.h., may be made for a typical power-driven low-wing monoplane, as shown in Figs. 10 and 11, and built to the undernoted specification and dimensions.

(*a*) Fuselage—flat sides, tapering to a point at the tail. Top and bottom of fuselage rounded with a radius equal to half its width. Projected area at largest cross-section

= 1 rectangle 4 inches × 3 inches.
= 12 square inches.
and 2 half circles = 1 circle 3 inches diameter.
= 7·1 square inches.
Total = 19·1 square inches.
= ·132 square foot.

(*b*) Stabiliser—section thin, flat under-surface, area
= 2·25 square feet.

(*c*) Rudder area = ·75 square foot.

(*d*) Landing chassis, built from streamline section 1·5 inches × ·5 inches. Total length 5 feet 6 inches, projected area
= 5·5 × ·042 square feet.
= ·23 square foot.

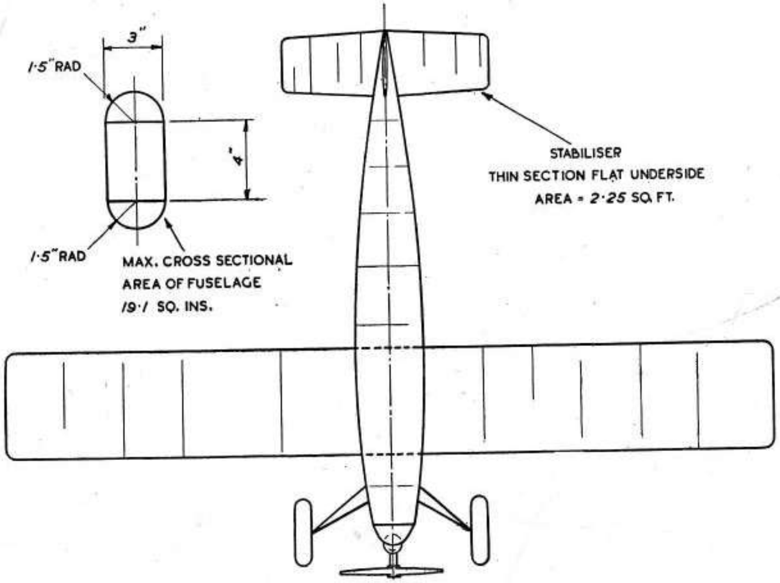


FIG. 11.

(*e*) Two wheels 6 inches diameter × 1·5 inches wide, total projected area $= 2 \times 6 \times 1{\cdot}5$ inches.
$= {\cdot}125$ square foot.

(*f*) Single-cylinder engine—height about 5 in., width about 2 in.. mounted on tapered metal " cone " 1 in. of cylinder extending beyond the fuselage.

(6) Proceeding to estimate:

(*a*) The fuselage is a " cross " between the circular and " square section " type—the taper to the tail is good, but the nose is somewhat " blunt." The value for K would be arrived at by averaging the values of ·0002 for a perfect streamline, and ·0009 for a "square section," giving ·00055, which in view of the blunt nose might be fairly increased to ·0007. The drag of the fuselage is therefore $\cdot 0007 \times \cdot 132 \times 15^2$
$= {\cdot}0208$ pound.

(*b*) The value of K for the stabiliser is taken as ·00007; the drag is therefore $\cdot 00007 \times 2{\cdot}25 \times 15^2$
$= {\cdot}0355$ pound.

(*c*) The value of K for the rudder is taken as ·00006; the drag is therefore $\cdot 00006 \times \cdot 75 \times 15^2$
$= {\cdot}0101$ pound.

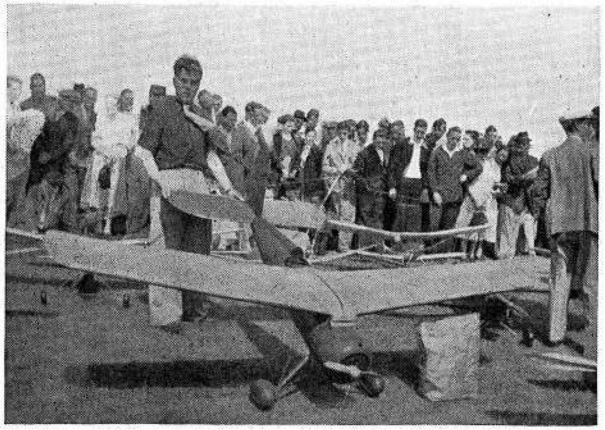
(*d*) The projected area of the chassis struts is ·23 sq. ft. There are four points of attachment to the fuselage, at which " interference " will occur, and at the two at the front there will also be turbulence due to the deflections of the airstream from the " blunt " nose. There will also be " interference " where the wheel axles join the lower ends of the struts, and where the horizontal "tie-bar" strut meets the two front struts. The total drag of such an arrangement will probably be doubled. Assuming, therefore, a projected area of twice ·23 = ·46 square feet, and taking the value of K as ·00025 the chassis drag $= \cdot 46 \times \cdot 00025 \times 15^2$
$= {\cdot}0259$ pound.

(*e*) The total projected area of the two wheels is ·125 sq. ft.—the hubs do not project, so the drag
$= \cdot 125 \times \cdot 0015 \times 15^2$
$= {\cdot}0422$ pound.

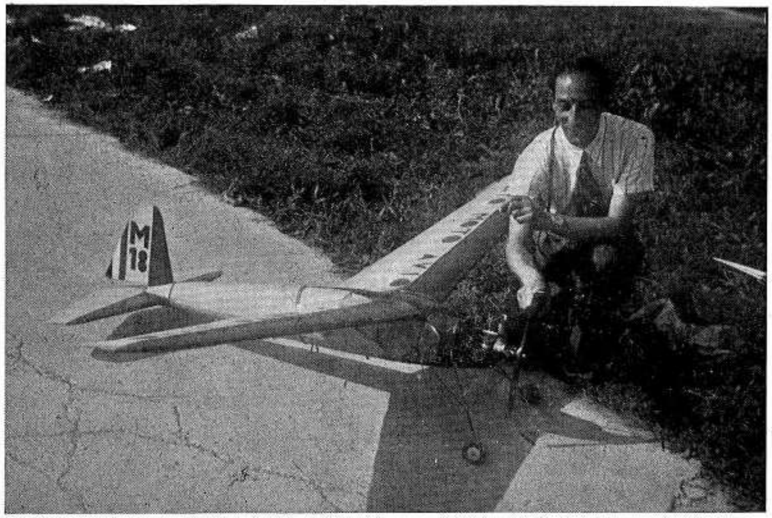
(*f*) The drag of the engine will be
$(\cdot 0006\ V^2) = \cdot 0006 \times 225$
$= {\cdot}135$ pound.

The total parasite drag of the aircraft is therefore found to amount to the sum of ·0208 + ·0355 + ·0101 + ·0259 + ·0422 + ·135 = ·2695 pound.

To which must be added the drag of the wings, which may be calculated from Formula (7).



Mr. " Bunny " Ross, with a semi-scale petrol 'plane of his own design and construction.



Here is another Italian petrol 'plane, built by Signor Clerici, of Milan.

CHAPTER IV

CONTROL SURFACES

Lift of tail-planes with controlled elevators—Stabilisers—Relation of aspect ratios to tail-plane areas—Formula for stabiliser areas—Calculations for correct disposition of main wing and tail-plane—Rear fins—Rudder areas—Formulas for fin areas for power and rubber-driven aircraft.

THE control surfaces of a flying model aircraft consist of horizontal and vertical airfoils—the former being either of the "lifting" or "non-lifting" (stabiliser) type; and the latter consisting of a vertical fin, part of which may or may not be hinged to form a rudder.

Unless the model aircraft is equipped with some form of automatic stabilising device such as a gyroscope or pendulum connected to elevators, the tail-plane should be of the "non-lifting" type, i.e. its axis should lie parallel to the thrust-line, and its function should be purely that of a stabiliser.

If it is intended that the tail-plane of an aircraft shall provide lift, as well as function as a control, it may be of any well-known airfoil section provided that it is not of exaggerated form. Clark Y and R.A.F. 25 are suitable sections.

To have the tail-plane forming part of the total lifting surface of the aircraft is, of course, a very useful feature, but one not to be introduced without certain reservations.

The "lifting" tail-plane is, in effect, a "mixed blessing" and sometimes a very definite handicap, due to the fact that as its lift will increase with the speed of the aircraft, the greater this is, the greater will be the tendency for the tail to rise; thus the degree of longitudinal control varies with the speed of the aircraft—not a good feature, but one which, to a large extent, can be balanced by providing automatically-controlled elevators.

If controlled elevators are fitted, their area should be about 40 per cent of the total tail-plane area, and their movement comparatively small; i.e. a large area with a small up-and-down movement, rather than a small area with a large movement.

If the tail-plane is arranged as a stabiliser it does no work as a lifting agent, but serves solely to keep the aircraft flying in a horizontal position; but since its axis lies parallel to the thrust-line, it only commences to control the flight of the aircraft *after* a diversion has been made from the horizontal; then, if the nose of the aircraft drops, the stabilizer is tilted at a negative angle, and the air pressure on the top surface forces it downwards and so brings the aircraft back to an even keel. Similarly, if the nose rises, the air pressure then acts on the underside of the stabiliser, and forces the tail of the aircraft upwards, and once again the balance is restored. Thus it is seen that, in actual theory, the aircraft must first lose its fore-and-aft balance before it can regain it—and because of this, the stabilisers of flying model aircraft require to be comparatively large, so that they are very sensitive to changes in direction of flight, and exercise a degree of control which, in practice, may be considered as instantaneous.

The determination of the most suitable area for the tail-plane depends on a number of factors, all influencing each other, and chief of which is the ratio of the distance from the centre-of-lift of the main wing to the centre-of-chord of the tail-plane, compared with the span of the main wing. The greater this distance, the greater is the leverage exerted by the tail-plane, and the smaller may be its area.

The higher the aspect ratio of the main wing, the smaller need be the area of the stabiliser. Thus a stabiliser which is suitable for an aircraft with a main-wing aspect ratio of 7 : 1 would require to be increased by about 25 per cent for an aspect ratio of 5 : 1.

The aspect ratio of the stabiliser *itself* has an influence on its size relative to that of the main wing; and a stabiliser with an aspect ratio of 5 : 1, which was suitable for a certain-sized aircraft, would require to be increased in area by about 12 per cent if its aspect ratio were reduced to 3 : 1.

As a general rule the stabiliser area should be about 38 per cent of the main wing area for a rubber-driven aircraft, and about 33 per cent for power-driven machines.

The distance from the centre-of-lift of the main wing to the centre-of-chord of the stabiliser is known as the "moment arm," and should be taken as equal to ·6 of the overall length

in the case of rubber-driven, and ·65 in the case of power-driven aircraft. Being a percentage of the overall length, it will naturally vary with it in relation to the main wing span, and, as already has been pointed out, will have a considerable influence on the area of the stabiliser according to whatever the span to overall length ratio is. But, in relation to the overall length *itself*, the ratios of 60 per cent and 65 per cent should never be departed from by more than 4 or 5 per cent.

An empirical formula for calculating the area of a stabiliser, which takes account of all desiderata mentioned above is

$$\text{Sa} = {\cdot}257\text{W} \times \frac{15}{\text{AR}+6{\cdot}4} \times \frac{3{\cdot}9}{ar+{\cdot}05} \times \frac{{\cdot}65}{\text{M}} \times \sqrt{\frac{\text{S}}{\text{L}}} \qquad (11)$$

Where W = Main wing area in square inches.
AR = Main wing aspect ratio.
ar = Stabiliser aspect ratio.
M = Moment arm divided by overall length.
S = Main wing span in inches.
L = Overall length of aircraft, in inches.
and Sa = Required area of stabiliser in square inches.

For example:

Consider the characteristics of an aircraft of which the main wing area is to be 1,250 square inches, and of an aspect ratio of 9 : 1.

The stabiliser aspect ratio is to be 3·1 : 1; the ratio of overall length to moment arm is to be ·62; and the ratio of span divided by overall length is to be 1·7. Calculations may be made as follows:

(1) By substitution in formula (11)

$$\text{Sa} = {\cdot}257 \times 1250 \times \frac{15}{9+6{\cdot}4} \times \frac{3{\cdot}9}{3{\cdot}1+{\cdot}05} \times \frac{{\cdot}65}{{\cdot}62} \times \sqrt{1{\cdot}7}$$
$$= 321 \times {\cdot}975 \times 1{\cdot}24 \times 1{\cdot}05 \times 1{\cdot}3$$
$$= 528 \text{ square inches.}$$

(2) Assuming that the main wing is of rectangular plan form, its chord may be calculated from the formula

$$\text{C} = \sqrt{\frac{\text{W}}{\text{AR}}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \ (12)$$

Where AR = Aspect ratio
and W = Wing area in square inches.

$$\text{Thus } C = \sqrt{\frac{1250}{9}}$$

$$= 11{\cdot}8 \text{ inches.}$$

and the span = 106 inches.

(3) As the aspect ratio of the stabiliser is given as 3·1, and its area has already been calculated to be 528 square inches, then, assuming it to be of rectangular plan form, its chord

$$= \sqrt{\frac{528}{3{\cdot}1}}$$

$$= 13{\cdot}1 \text{ inches.}$$

and its span = 40·4 inches.

(4) As the ratio of span divided by overall length is given as 1·7, the overall length is calculated to be

$$\frac{106}{1{\cdot}7} = 62{\cdot}5 \text{ inches.}$$

Thus it is seen that the fuselage length is only a little more than half the span, and this accounts for the fairly large stabiliser surface of 528 square inches compared with the main wing area of 1,250 square inches.

(5) The moment arm ratio is given as ·62, and since the overall length has been calculated to be 62·5 inches, the moment arm distance is calculated to be $62{\cdot}5 \times {\cdot}62 = 38{\cdot}8$ inches.

(6) The chord of the stabiliser has been calculated to be 13·1 inches, the rearmost location of the moment arm is therefore one-half of the chord distant from the tail of the aircraft, i.e. $13{\cdot}1 \times {\cdot}5$

$$= 6{\cdot}55 \text{ inches.}$$

(7) As the moment arm has been calculated to be 38·8 inches, its foremost location is at a point $(38{\cdot}8 + 6{\cdot}55) = 45{\cdot}35$ inches distant from the tail, and thus is found the *centre of gravity of the whole aircraft*, as also the centre of lift of the main wing.

(8) Since the main wing chord has been calculated to be 11·8 inches, its leading edge will be one-third of this distance ahead of the centre of gravity, i.e. $(45{\cdot}35 + 3{\cdot}93)$ inches $= 49{\cdot}28$ inches from the tail; or $(62{\cdot}5 - 49{\cdot}28) = 13{\cdot}22$ inches back from the *nose* of the aircraft.

If, when an aircraft is completed, it should be found that the centre of gravity does not coincide with the centre of lift

This 8 ft. span high-wing petrol 'plane, designed and built by the author, made many successful flights in 1939.

of the main wing, a redistribution of weight must be made to effect the desired balance. This may be done, in the case of a rubber-driven machine, by swinging the landing chassis backwards or forwards as may be necessary; and in the case of power-driven aircraft, by an alteration in the position of the battery or coil.

The main wing should *not* be moved, as doing this would alter the length of the "moment arm," which is one of the factors controlling the area of the stabiliser.

Stabilisers should be of uniform section, i.e. without camber, and fairly thin, the maximum thickness-to-chord ratio not exceeding 8 or 9 per cent. They should be mainly of rectangular plan form with rounded tips, and should be without dihedral.

The primary function of the rear fin is to effect directional control, but in a flying model aircraft it has also to provide lateral control in the event of a side slip; and not only its area, but also its *shape*, is of fundamental importance.

Considering the fin as an element designed purely for the obtaining of directional control, it should consist of a plane surface, erected vertically at the tail end of the machine, with its axis parallel to the centre line of the fuselage; and be of such an area that, in conjunction with the leverage obtainable according to the length of its "moment arm," it will keep the nose of the aircraft pointing into the wind.

The area of the fin is also partly dependent on the shape of the forward portion of the fuselage and type of landing chassis used. It is obvious that, in any machine of the tractor type, the centre of drag is behind the airscrew, and thus there is a natural tendency for the aircraft to be "self steering," due to the "castoring" effect introduced.

In the case of an aircraft of which the fuselage is thin at the front, and thick and unstreamlined at the rear, the centre of drag would be at such a distance behind the centre of gravity that this "castoring" effect would be quite pronounced, and only a small fin would be required. But in the vast majority of cases, the reverse is the case, and on account of the drag of the engine and a fairly blunt (though streamlined) nose, the drag of the main wings, and also the landing chassis, the centre of drag is not so very far behind the airscrew, consequently the "castoring" effect is not very pronounced, and thus a fin of fairly large size is introduced to create the necessary degree of drag, or side resistance, as soon as the tail of the aircraft swings or "yaws."

But it is in regard to its area and shape, when being considered as a *vertical stabiliser*, that most careful thought must be given to the design of the fin, so as to ensure that an equal proportion of side area of the whole aircraft is presented in front of, as well as behind, the centre of gravity. The area of the fin should bear a relation to the length of the "moment arm" (in this case the distance from the centre of the chord of the main wing to the centre of the chord of the fin), the main wing span, and the total weight, and an average value, for power-driven aircraft, may be calculated from the empirical formula

$$A = K \times \sqrt{\frac{WS}{M}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

Where W = Weight of aircraft in pounds.
S = Span of aircraft in feet.
M = Moment arm in feet.
and A = is given in square feet.
and K = ·25 for high-wing monoplanes.
= ·30 for mid-wing monoplanes.
and = ·35 for low-wing monoplanes and biplanes.

The several values for K are necessary because the lower the wing is, in relation to the fuselage, the greater is the dihedral required; and the larger must be the fin to equal the increased projected area of the main wing.

This projected area may easily be ascertained by drawing out to scale a side elevation of the fuselage and projecting the main wing; if this is done on "squared" paper, it is then an easy matter to "count up" the area, and sketch in a fin of equal size.

In all cases this graphical method should be used as a check on the figure obtained from the formula, and in the event of a difference being found, the *larger* figure should be used.

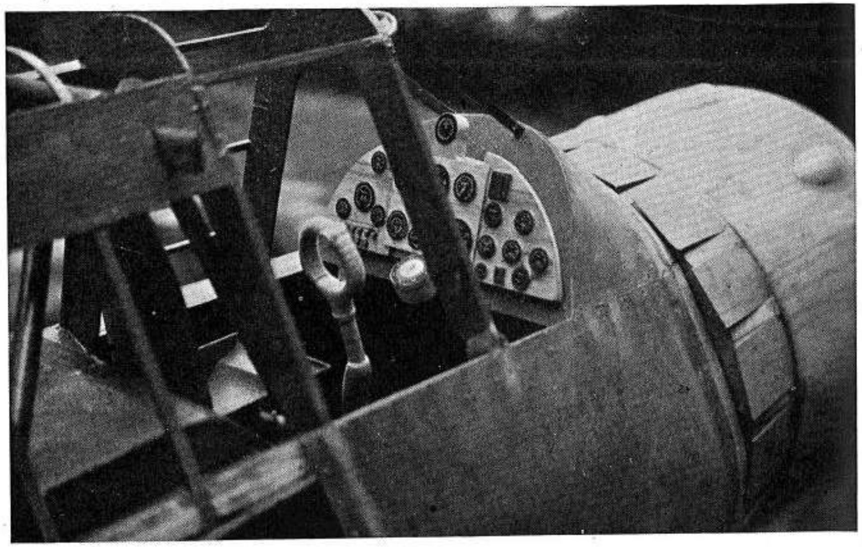
In the case of rubber-driven model aircraft the fin area should be equal to about 10 per cent of the main wing area—but if it is desired to take into consideration all the factors affecting the fin, and to obtain an exact result, use may be made of a formula by C. H. Grant, which states that

$$AF = 0{\cdot}1\,\frac{A}{(M)}\,(3 + N + 0{\cdot}58\sqrt{ST}) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

Where A = Main wing area.
M = Moment arm.
N = The distance from the centre of gravity to the airscrew bearing face.
S = The wing span.
T = The tip rise of the main wing—i.e. the distance the tip is above the centre section of the wing.
and AF = The required fin area.
(All the values being either in inches or square inches).

The exact shape of the fin is not of very great importance, provided the height is approximately equal to the chord.

The fin should be double-surfaced, of symmetrical section, and with a maximum thickness to chord ratio of not more than 1 : 20 in the case of rubber-driven models, and not more than 1 : 10 in the case of power-driven aircraft.



Aircraft performance of full-size aircraft is recorded by an elaborate set of instruments. Here is the set of instruments in front of the pilot in the one-fifth full size flying scale model of the "Lysander" built by the Author. The joy stick may be noted, and in front of it the compass.

CHAPTER V

AIRCRAFT PERFORMANCE

The value of performance calculations—Formula for (*a*) "Stalling speed," (*b*) H.P. required for steady horizontal flight—Minimum value of VD—A series of calculations for ascertaining the performance of aircraft—Formulæ for (*a*) Rate of climb (*b*) Tractive resistance, (*c*) H.P. required to overcome tractive resistance, (*d*) Tractive effort available for acceleration —(*e*) Distance travelled during take-off.

IN so far as light rubber-driven aircraft are concerned, the obtaining of increased duration of flight is ever the aim of the aero-modellist, and since this type of machine has a comparatively slow flying speed, it may with perfect safety be launched innumerable times in the course of its trials without suffering damage. Thus the process of arriving at its best performance is essentially the practical one of "trial and error"—the ultimate object being the obtaining of as high a power/weight ratio as is possible.

In the case of large multi-spindle rubber-driven machines, and more particularly in the case of power-driven aircraft, the "trial and error" method generally results in so many "errors" that the "trials" of the aero-modeller are increased enormously! Especially are increased the number of hours spent in the workshop on *repairs!* The cost of these large machines often amounts to several pounds, whilst the time spent in their construction extends to several months of the aero-modeller's spare time.

The investigation, therefore, by a series of calculations of the probable performance of the proposed aircraft, *before the design leaves the drawing board*, will do much to prevent disappointment arising from a performance which does not come up to expectation.

In addition, the calculations may often disclose that a small alteration in the design will make all the difference between the performance being a success instead of a failure.

For instance, the use of the highest lift/drag ratio would seem to be an obvious rule to work to, and it *is*, for very light, slow-flying rubber-driven aircraft, but for wing loadings exceeding 8 ounces per square foot—requiring speeds of from 10 to 12 miles per hour and upwards—this rule does not hold good; as the highest lift-drag ratio always occurs at a fairly low C_l which naturally calls for a relatively high speed.

The adoption of a lift/drag ratio, somewhat lower than the highest available, will enable a considerably higher C_l to be used, *at a considerably lower speed;* and since the drag varies as the square of the speed, it follows conversely that if the speed can be reduced by half, the drag will be reduced to one-quarter of its previous value, obviously calling for a very much smaller power output.

The following series of calculations clearly demonstrate the valuable information which may be obtained from such an investigation.

The minimum flying, or "stalling speed," of an aircraft may be calculated from the formula—

$$V = 19{\cdot}77\sqrt{\frac{W}{C_l\ \text{Max.} \times S}} \quad \ldots \quad \ldots \qquad (15)$$

Where W = Weight of aircraft, in pounds.
S = Main wing area, in square feet.
and V is given in miles per hour.

In Chapter III calculations were made to ascertain the parasite drag of a particular aircraft at a speed of 15 miles per hour.

Assuming this same aircraft to have

(1) A wing area of 7 square feet;
(2) A wing section R.A.F. 32;
(3) A total weight of 6 pounds; and
(4) Noting from the Aeronautical Research Committee's R. and M. No. 928, that

C_l max. of R.A.F. 32 = 1·308
at which C_d = ·1518

calculations may now be made to ascertain the minimum flying speed of this particular aircraft.

(1) Substituting in the formula (15);

$$V = 19{\cdot}77\sqrt{\frac{6}{1{\cdot}308 \times 7}}$$

$$= 16 \text{ miles per hour,}$$
or 23·5 feet per sec.

(2) Next, by using formula (7)—in which, be it noted, V is given in *feet per second*—calculations may be made to ascertain the drag of the wing of this particular aircraft.

$$D = {\cdot}1518 \times \frac{{\cdot}002378}{2} \times 7 \times (23{\cdot}5)^2$$

$$= {\cdot}698 \text{ pound.}$$

(3) The total parasite drag of this aircraft, at a speed of 15 miles per hour, has already been calculated to be ·2695 pound. This is equivalent to $\cdot2695 \times \left(\frac{16}{15}\right)^2 = \cdot307$ pound at 16 f.p.s., to which must be added the wing drag—making a total of 1·005, say 1 pound.

(4) The power required to maintain an aircraft in steady horizontal flight may be calculated from the formula—

$$\text{H.P.} = \frac{DV}{375} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (16)$$

where D = Total drag, in pounds.
and V = The speed, in miles per hour.

Continuing the example, and taking the value of V as 15·6 miles per hour for the whole aircraft.

$$\text{H.P.} = \frac{1 \times 16}{375}$$

$$= {\cdot}0427 \text{ (or roughly)} \frac{1}{24} \text{ H.P.)}$$

Now the stalling speed, apart of course from being the minimum flying speed, is also the speed at which the lift/drag ratio is at its lowest value—in this case 6 : 1.

The highest lift/drag ratio of R.A.F. 32 is 18 : 1, and occurs when the airfoil is set at an angle of ·8 degrees—when C_l = ·49 and C_d = ·0272.

(5) Under these conditions the minimum flying speed is now found to be equal to

$$19{\cdot}77\sqrt{\frac{6}{{\cdot}49 \times 7}}$$

$$= 26{\cdot}2 \text{ miles per hour.}$$
or 39·4 f.p.s.

(6) Since the C_d is now only ·0272, the wing drag is found to be equal to $\cdot 0272 \times \frac{\cdot 002378}{2} \times 7 \times (39\cdot 4)^2$

$$= \cdot 35 \text{ pound.}$$

(7) The total parasite drag has been calculated to be ·2695 pound at 15 miles per hour—and since the drag increases as the square of the speed—at 26·2 miles per hour it will be equal to

$$\cdot 2695 \left(\frac{26\cdot 2}{15}\right)^2$$
$$= \cdot 822 \text{ pound.}$$

Which gives a total drag of 1·172 pounds for the aircraft, flying at a speed of 26·2 miles per hour.

(8) Substituting in the formula $\text{H.P.} = \frac{DV}{375}$

The H.P. required to maintain steady horizontal flight is found to be $\frac{1\cdot 172 \times 26\cdot 2}{375}$

$$= \cdot 082 \text{ (or roughly) } \frac{1}{12} \text{ H.P.)}$$

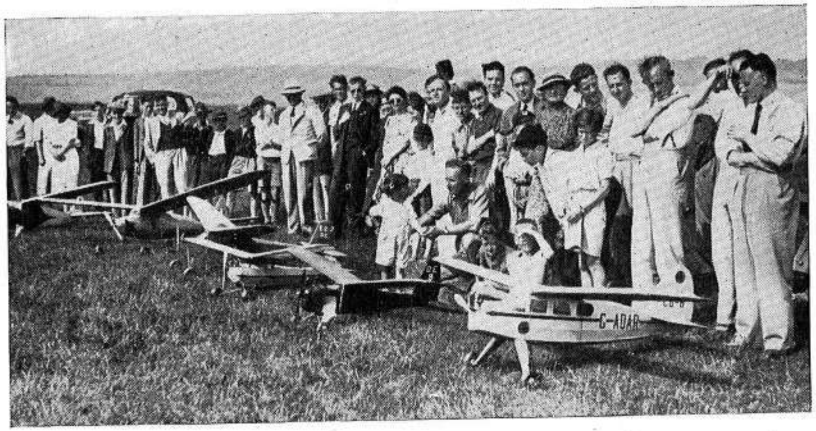
Examining the results so far obtained, it may be noted that when the wing is set at the angle of incidence which gives the highest lift/drag ratio, the power required to fly the aircraft is nearly double that required to maintain flight at the "stalling speed."

The difference in speeds between 16 miles per hour and 26·2 miles per hour may also be noted. Somewhere between these limits lies a speed which, multiplied by the drag, gives a minimum value for VD; when obviously the required H.P. will also be at a minimum.

It has already been pointed out that drag is of two kinds—parasite and induced, parasite drag being divided into that which varies with the angle of attack, and that which does not.

Now parasite drag varies directly as the square of the speed, but induced (wing) drag varies *inversely* as the square of the speed; and thus is explained the reason why, at some intermediate speed between the "stalling speed" and the minimum flying speed with maximum lift/drag ratio, the

drag is at its lowest value, lower than at either of the two limits given. As the speed increases above the "stalling speed," the induced (wing) drag at first decreases, and then increases rapidly, whilst the parasite drag increases all the time. It is at a speed approximately 15 per cent greater than the "stalling speed" that the drag is found to be at its lowest value; and thus, to obtain the best power/weight ratio the aircraft should be designed to fly at this speed.



This photo was taken on Sussex Downs in August, 1939, at a meeting organised by the Brighton Model Aircraft Club. The Author is on the extreme right, standing behind his high-wing 'plane.

In the case of the aircraft under consideration the designed flying speed would be equal to 16 + (15 per cent of 16) = 18·4 miles per hour, or 27 f.p.s.

To find the C_l of the wing at this speed, the formula $L = C_l \frac{p}{2} SV^2$ may be re-written

$$C_l = \frac{L}{\frac{p}{2} SV^2} \qquad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

(9) Substituting the appropriate figures in the example,

$$C_l = \frac{6}{\cdot 001189 \times 7 \times 27^2}$$
$$= \cdot 99$$

Reference to the coefficients for R.A.F. 32 shows that when $C_l = \cdot 99$, $C_d = \cdot 066$; and the angle of incidence of the wing = 5·9 degrees.

Repeating the previous steps—with

$$V = 18{\cdot}4 \text{ miles per hour}$$
$$= 27 \text{ feet per second}$$
$$\text{and } C_d = {\cdot}066$$

(10) The wing drag $= {\cdot}066 \times {\cdot}001189 \times 7 \times 27^2 = {\cdot}4$ pound.

(11) As the parasite drag at 15 miles per hour was ·2695 pound, at 18·4 miles per hour it will be

$$\cdot 2695 \left(\frac{18{\cdot}4}{15}\right)^2$$
$$= {\cdot}406 \text{ pound.}$$

which gives a total drag of ·806 pound.

(12) Substituting in the formula H.P. $= \frac{DV}{375}$

The H.P. required to maintain the aircraft in steady horizontal flight at the speed of 18·4 miles per hour.

$$= \frac{{\cdot}806 \times 18{\cdot}4}{375}$$
$$= {\cdot}0396 \text{ as against } {\cdot}0427 \text{ for the stalling speed.}$$

Now the H.P. of ·0396 is only sufficient to maintain steady horizontal flight, and allows no margin for climb; and a further calculation may be made to ascertain the performance when the stalling speed H.P. (·0427) is available.

(13) The formula H.P. $= \frac{DV}{375}$ may be re-written DV= 375 H.P. and thus, in the example under consideration,

$$DV = 375 \times {\cdot}0427 = 16$$

(whereas, when the available H.P. was ·0396, DV = 14·85.

The difference between these figures is a measure of the increased speed, or rate of climb, available due to the extra H.P.

(14) Keeping to the same angle of wing incidence (5·9 degrees), a simple calculation shows that at a speed of 18·9 miles per hour the total drag will be ·85 pound, absorbing the ·0427 H.P. available.

Tabulated, the results from the foregoing calculations are as follows:—

Speed m.p.h.	Angle incidence	C_l	C_d	Parasite drag	Wing drag	Total drag	L/D ratio	H.P.
16·0	14·7	1·308	·1518	·307	·698	1·0	6 : 1	·0427
18·4	5·9	·99	·066	·406	·4	·806	7·46 : 1	·0396
18·9	5·9	·99	·066	·428	·422	·85	7·06 : 1	·0427
26·2	·8	·49	·0272	·822	·35	1·172	5.11 : 1	·082

By analysis of these figures, the following information is obtained:

(1) The minimum horizontal flying speed is 16 miles per hour; at which the H.P. required is ·0427; and the wing angle of incidence=14·7 degrees.

(2) The minimum H.P. required to maintain steady horizontal flight is ·0396; when the flying speed is 18·4 miles per hour, and the wing angle of incidence = 5·9 degrees.

(3) The maximum horizontal flying speed—with H.P.= ·0427, and the wing angle of incidence = 5·9 degrees—is 18·9 miles per hour.

(4) The most effective lift/drag ratio is 7·06:1; with a wing angle of incidence of 5·9 degrees.

All the above calculations are aimed at ascertaining the minimum, or near minimum H.P. required to fly the aircraft; but before a final decision is made as to the engine size, calculations should be made for the rate of climb, to check that the excess H.P. available is sufficient to meet the requirements of the designer.

In the present example the E.H.P. is equal to ·0427—·0396 =·0031. Not a very large margin.

The rate of climb of an aircraft may be calculated from the formula:

$$R/C = E.H.P. \times \frac{33{,}000}{W} \quad \dots \quad \dots \quad \dots \quad (18)$$

where EHP = Excess H.P. available.
W =Total weight of the aircraft.
and R/C = is given in feet per minute.

(15) Thus in the example quoted above

$$R/C = {\cdot}0031 \times \frac{33{,}000}{6}$$
$$= 17{\cdot}1 \text{ feet per minute.}$$

This rate of climb is on the low side, and a more reasonable minimum figure would be 100 feet per minute; which, at a flying speed of 18·4 miles per hour, gives a rate of climb of approximately 1 in 16, i.e., a 5-foot hedge would be cleared at a distance of about 80 feet from the point of take-off.

(16) The formula (18) may be re-written in the form

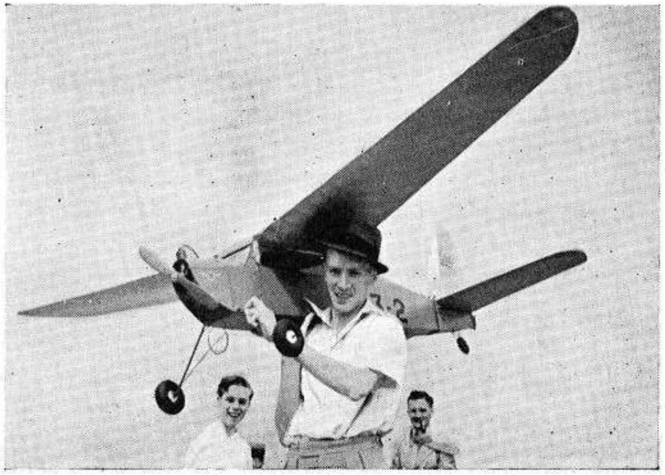
$\text{E.H.P.} = \frac{R/C \times W}{33{,}000}$ and thus, for the aircraft under consideration, the H.P. required for climb at the rate of 100 feet per minute

$$= \frac{100 \times 6}{33{,}000}$$

$= {\cdot}018$—which, added to that required for minimum flight (·0396), gives a total of ·0576 H.P.

Finally, a simple calculation shows that this H.P. would make possible a maximum speed, in steady horizontal flight, of 20·9 miles per hour. The total drag would be 1·04 pounds; the angle of incidence of the wing being, of course, the same as before = 5·9 degrees.

This final figure of ·0576 H.P. is of considerable interest—in short, it represents the power required to fly an aircraft, weighing 6 pounds, at a maximum speed of about 21 miles per hour; or to enable it to climb at the rate of 1 in 16, at a speed of about 18 miles per hour.



A well-known designer and builder of petrol 'planes, Mr. C. R. Jefferies, is shown in this photo carrying a 'plane of his own construction. Span is some 8 feet.

With the reservations that the fuselage cross-section is slightly on the small side, the type of aircraft taken for this example is similar to that often powered by a 10-cc. " Brown Junior " engine, advertised as delivering about ·2 H.P. which is about four times as much as that required for the performance above mentioned.

This difference is, of course, accounted for by the fact that the rate of climb of 1 in 16, taken in the example, is much below that actually obtained by present-day models.

Assuming the aircraft in the example to be powered with an engine of ·2 H.P., then the E.H.P. available for climb = ·2 – ·0396 = ·1604.

Thus the rate of climb now $= \frac{{\cdot}1604 \times 33{,}000}{6}$

= 884 feet per minute, which, at a speed of 18·4 miles per hour, gives a rate of climb of about 1 to 1·83, or a climbing angle of approximately 30 degrees. Actually, due to the increased drag resulting from the increased angle of attack of the main wing, the rate of climb would be somewhat less, but an approximate figure of 750-850 feet per minute is in general accord with that obtainable, under good conditions, from the type of aircraft under consideration.

It must be appreciated that, throughout this series of calculations demonstrating how the flight performance of an aircraft may be ascertained, settled air conditions have been assumed; and *given* these conditions, ·0576 H.P. would just fly the 6 pounds weight aircraft taken for the example, and give it a very small E.H.P. for climb. Whilst ·2 H.P. would be sufficient for climb at an angle of approximately 30 degrees, or an increased speed in horizontal flight. However, when calculations are made with the object of ascertaining the *minimum* H.P. required for flight, consideration must be given to the power likely to be required to overcome tractive resistance during the take-off—as under certain conditions an appreciable addition may be required.

During the take-off, the tractive resistance becomes less as the machine becomes air-borne; but also the drag increases;

and it is quite possible for there to be a speed at which the sum of the two kinds of resistances is greater than the total drag. In which case, if the H.P. was only sufficient for flight, the aircraft would be unable to take off.

(19) The tractive resistance may be calculated from the formula

$$R = \frac{W \times F}{2{,}240} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (19)$$

where W = the weight of the aircraft, in pounds
F = Co-efficient of friction, which is expressed in pounds per ton weight—it is equal to about 60 pounds/ton for rubber tyres on a good macadam surface.

And R is given in pounds.

Thus for the aircraft under consideration

$$R = \frac{6 \times 60}{2{,}240}$$
$$= {\cdot}16 \text{ pound.}$$

On the closely-mown grass of a tennis court F = about 220 pounds/ton; and on the average aerodrome field F = about 350 pounds/ton. For average conditions F may be taken as 300 pounds/ton; when, in the above example, R would be equal to ·8 pound—roughly equal to that of the whole machine when in flight.

Of course, this value would be dropping as the aircraft was becoming air-borne; but, at the same time, it must be borne in mind that the retarding effect of tufts of grass, small hillocks, etc., can be considerable; and, on balance, it is as well to consider the tractive resistance as being fully effective, until the aircraft has actually left the ground.

(20) The H.P. required to overcome this tractive resistance may be calculated from the formula

$$\frac{R \times S \times 5{,}280}{60 \times 33{,}000} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (20)$$

where R = Tractive resistance in pounds
and S = Speed in miles per hour.

Thus, in the example

$$\text{H.P.} = \frac{{\cdot}8 \times 18{\cdot}4 \times 5{,}280}{60 \times 33{,}000}$$

= ·04, approximately equal to that

required to overcome the total drag of the aircraft, when flying at about 18 miles per hour.

The general conclusion, therefore, is that to provide a minimum effective performance the machine taken in the example should be powered by an engine of not less than about $\frac{1}{10}$ H.P., whilst $\frac{1}{5}$ H.P. would enable the machine to take off and fly under practically all conditions.

(21) A final performance calculation, and one of more than passing interest, is that to find the length of take-off run.

Continuing the example, and assuming a total H.P. of ·2, the tractive effort available for acceleration may be obtained from the formula

$$F = \frac{\text{H.P.} \times 33{,}000 \times 60}{D \times 5{,}280}$$

where D = speed, in miles per hour.
and F = Tractive effort available for acceleration in pounds.

$$\text{Thus } F = \frac{{\cdot}2 \times 33{,}000 \times 60}{18{\cdot}4 \times 5{,}280}$$
$$= 4{\cdot}06 \text{ pounds.}$$

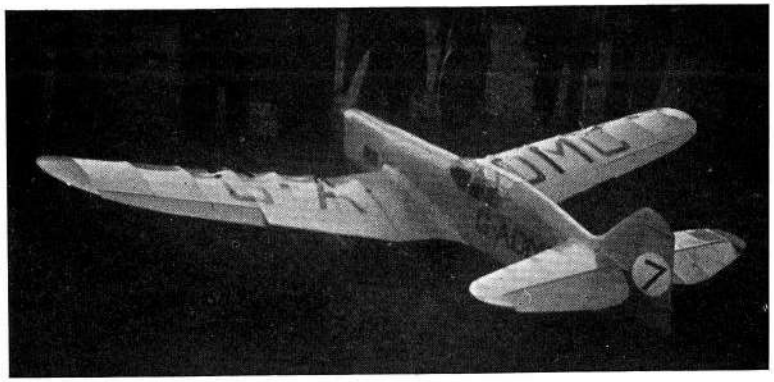
(22) Now to accelerate a mass of 1 pound at a rate of 1 foot per second, requires a force of ·0312 pound—thus in the example (·0312 × 6) = ·187 pound force would be required.

As the force available for acceleration is 4·06 pounds, the rate of acceleration is equal to $\frac{4{\cdot}06}{{\cdot}187} = 21{\cdot}8$ feet per second, per second.

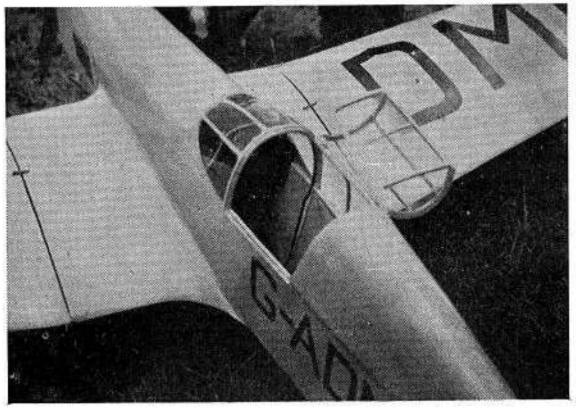
(23) The distance travelled during the take-off may be calculated from the formula $S = \frac{V^2}{2a} \quad \ldots \quad \ldots \quad \ldots \quad (22)$

where V = Take-off speed in feet per second.
a = Rate of acceleration, in feet per second, per second.

$$\text{Thus, in the example } S = \frac{27^2}{43{\cdot}6}$$
$$= 16{\cdot}7 \text{ feet.}$$



The petrol 'plane is of 11 ft. span and 6 ft. length. It is a scale model of the Percival "Mew Gull," and was built by Mr. Newman. Weight of the 'plane is 8 pounds. and it is powered by a 15 cc. engine, a "close-up" of which is on page 150. Below is a "close-up" of the pilot's cockpit.



CHAPTER VI

AIRSCREW DESIGN

General considerations affecting the design of airscrews—Blade airfoils—Blade width—Blade thickness—Thrust grading lines of airscrew blades—Boss drag—Pitch-Diameter ratio—Metal *v.* wooden airscrews—Formula for calculating the pitch and diameter of power-driven airscrews.

In designing an airscrew for use on a power-driven model aircraft, it must always be borne in mind that the limiting factor is the maximum power available from the motor which will be used to drive the airscrew; since in the absence of any throttle control, or speed limiting device, the airscrew will always revolve at that speed at which it absorbs the full power available from the motor.

The power from a rubber motor, however, gradually falls off from the moment of release, and thus the airscrew cannot be considered by itself, but must always be considered in relation to the power available at any given moment from the rubber motor; and its characteristics must be such that the average of the resultant of the airscrew speeds meets the requirements of the overall design.

Airscrews for use with rubber motors are therefore dealt with under a separate heading in Chapter VIII.

In full-size practice an airscrew will be designed to produce the required amount of thrust at the required forward speed; and a suitable power unit, under the control of a pilot, is then provided.

In model work, however, the designer has available but a limited number of engines, the majority of which are two-strokes, from which to make his choice; and in the absence of a pilot, must make use of such "gadgets," usually adapted clockwork motors, as he can devise and arrange, to effect some measure of variable control, during and after the take-off.

Appreciating, then, that in the absence of any such throttle control, or speed-limiting device, a petrol engine will "rev-up" to that speed at which its full power is being absorbed by the airscrew, it follows that for a given airscrew diameter the finer the pitch, the higher will be the engine speed; and if extremes are considered it will readily be seen that too fine a pitch will allow the engine to " rev " at a speed higher than it is designed for; whilst too coarse a pitch will " hold down " the engine speed to such an extent that it is, to all intents, " stalled," and unable to develop its full power.

Whilst, therefore, the aim of the designer should always be to so " match " the airscrew size with the engine speed, that the power available equals the power required; this may not always be possible, and gearing must then be introduced between the airscrew and engine shafts, a matter not easily arranged and to be avoided if at all possible.

Thus it is seen that the best airscrew, from the aerodynamic point of view, may not necessarily be the best airscrew from the operating point of view, and a compromise may have to be effected. It must, therefore, be appreciated that the following considerations, set out as affecting airscrew design, and the subsequent formulæ, by means of which the dimensions may be ascertained, relate only to the *best* airscrew for any given set of aerodynamic conditions: and that when considered in relation to the characteristics of the engine, some revision in regard to diameter or pitch of the airscrew may have to be made.

(1) The blades of an airscrew are simply airfoils, and operate on the air in exactly the same way as the wings of an aircraft—producing both lift and drag; but whereas the wings are required to produce only lift, the airscrew must produce the required lift (thrust) at a *certain required forward speed.* That is to say, the function of an airscrew is two-fold—firstly, to displace a certain volume of air, thereby producing thrust (which must at least equal the total drag of the aircraft), and secondly, to produce this thrust at a certain forward speed.

(2) The most important factor influencing the performance of an airscrew is the total width of *all* the blades, regardless of the width of each blade, or the number of blades.

Thus a two-blade airscrew will have the same performance as a four-blade airscrew of similar diameter and pitch, if the blades of the former are twice the width of those of the latter —i.e. making the total width the same in each case.

(3) The usual width for the blade of an airscrew is ·05 of the diameter, and the usual thickness about ·125 of the width, in the case of wooden airscrews, and about ·075 of the width in the case of metal airscrews.

The width and thickness being measured at a point ·75 of the radius distant from the centre of the airscrew.

(4) The plan form of airscrew blades is not of very great importance, and provided the blades are tapered, and their tips are rounded, the exact shape and degree of taper has little effect on the efficiency.

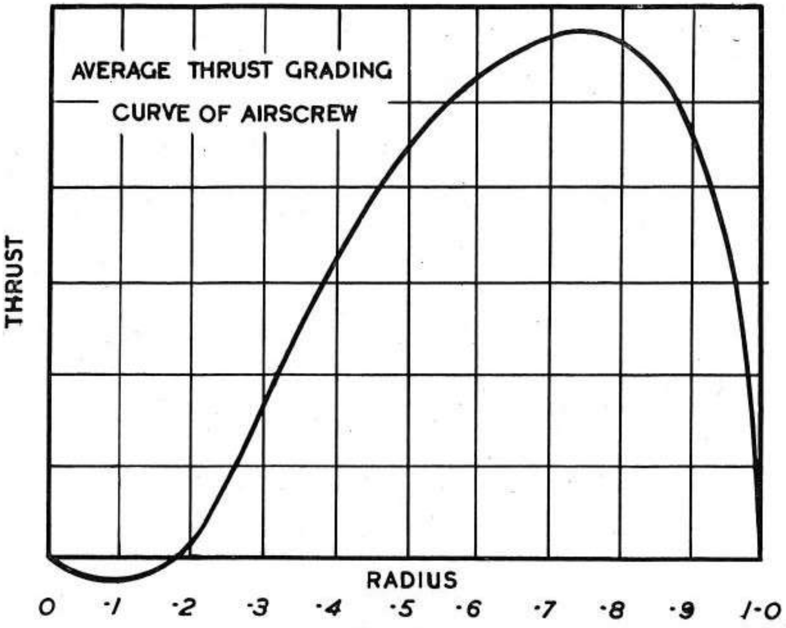


FIG. 11.

That this is quite in the " natural order of things " will be appreciated from a study of Fig. 11 which shows, graphically, the thrust grading of an average airscrew.

It will be seen that by far the greater portion of the thrust is developed by that portion of the blade which lies between ·6 and ·8 of the radius distant from the centre of the airscrew.

(5) It will also be noted that the thrust-grading curve has a slightly *negative* value at a point near the boss, which is

indicative of the drag caused by the uneven airflow through the airscrew at its centre.

It will be appreciated that for the airflow through an airscrew to be constant across the diameter, the *angle* of the blades must increase towards the centre, but from a point about ·15 of the radius distant from the boss, and inwards, the shape is such that the angle is far too large for that portion of the blade to operate efficiently; consequently the airflow is slower at the boss than across the rest of the airscrew diameter, resulting in a decrease of propulsive effort at this point, or in effect, the creation of a small amount of drag.

The introduction of a " spinner " tends to divert the airflow away from the hubs; and by bringing up a small diameter of the fuselage close behind the airscrew, the creation of an area of relatively lower pressure is prevented.

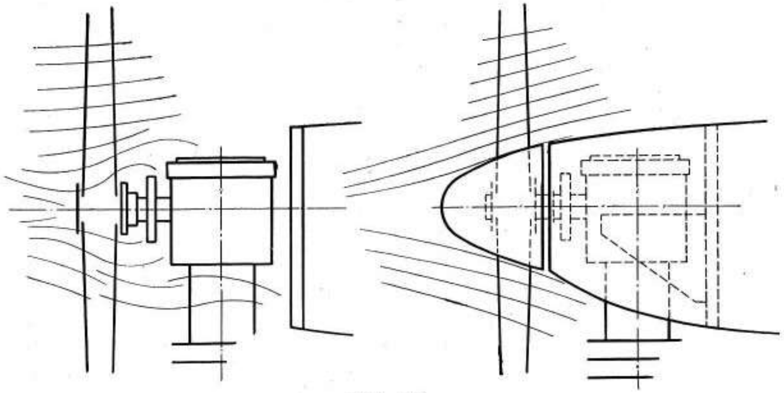


Fig. 12.

Fig. 12 shows, diagrammatically, the airflow through an airscrew with, and without, a spinner, and " backing " of fuselage.

The proportion, as shown, is generally considered the best; where the fuselage diameter at the point immediately behind the airscrew is ·3 of the airscrew diameter.

Whilst the presence of a small diameter of the fuselage in close proximity to the rear of the airscrew hub will prevent a negative thrust at this point, the effect of the fuselage as a whole is to reduce the efficiency value by an amount depending on the ratio of fuselage diameter to airscrew diameter.

This reduction in efficiency value varies from about 3 per cent for a fuselage/airscrew diameter ratio of ·4 to about 13 per cent of a ratio of ·75.

(6) It will also be evident from the thrust-grading curve, that variations in the pitch along the blade of an airscrew will not be of great moment; the *average* pitch of the whole blade, and in particular the pitch at the point 75 per cent of the radius distant from the airscrew centre, being the important thing.

The ratio of pitch to diameter has an influence on the efficiency of the airscrew; *full-size* tests having shown that it will increase from 68 per cent in the case of a P/D ratio of ·45 —up to 82 per cent in the case of a P/D ratio of 1:1. In practice P/D ratios do not usually exceed ·8.

In model aircraft practice the P/D ratio should not exceed about ·7 when the wing loading is 16 ounces per square foot and over; whilst for wing loadings below that figure the P/D ratio should not exceed ·8.

(7) Regarding the choice between metal and wood airscrews, the matter is more a question of practical consideration (and finance!) rather than design.

Owing to the thinner blade section which may be used with metal airscrews, the drag is a little less, resulting in a slightly higher efficiency (70 per cent for metal, 65 per cent for wood, being about the best values obtainable in model practice).

The blades of wooden airscrews *may*, of course, be made as thin as those of metal, and speeds of 4,000 r.p.m. with diameters of 18-20 inches have been obtained during tests, without signs of splitting.

Wooden airscrews are, of course, much cheaper than those of metal, and thus may more easily be replaced in the event of a breakage; on the other hand, a metal airscrew, whilst costing about four times as much as a wooden one of similar size, will often outlive several wooden airscrews, as quite severe bends to the blades may fairly easily be straightened out, provided care is taken; and within reasonable limits the pitch may be varied.

A model aircraft airscrew, for power work, will be working at its highest efficiency when the value of "J" is approximately ·5; and by use of the formula

$$D = \frac{88 \times \text{MPH}}{\text{RPM} \times \left(\frac{V}{ND}\right)} \qquad \ldots \quad \ldots \quad \ldots \quad (23)$$

An approximate figure for the airscrew diameter may be calculated, *provided that*, under "in flight" conditions, the value of "J" *is* ·5.

(NOTE.—"J" is defined as "the rate of advance per revolution expressed as a fraction of the diameter"—and is dealt with fully in Chapter VII.)

Suppose it is required to find the diameter and pitch of an airscrew for an aircraft to fly at a speed of 25 m.p.h., the airscrew speed to be 3,000 r.p.m.

$$\text{Then } D = \frac{88 \times 25}{3{,}000 \times {\cdot}5}$$

$$= 1{\cdot}46 \text{ feet.}$$

For a metal airscrew, if "J" = ·5, the efficiency will be 70 per cent. Thus the pitch will require to be such as to give a theoretical forward speed of 35·7 m.p.h., or 52·2 feet per second.

As the airscrew speed is 50 revolutions per second

$$\text{pitch} = \frac{52{\cdot}2}{50}$$

$$= 1{\cdot}04 \text{ feet.}$$

$$\text{and the P/D ratio} = \frac{1{\cdot}04}{1{\cdot}46}$$

$$= {\cdot}712 \text{ foot.}$$

Suppose, however, that it is desired to find the diameter and pitch of a metal airscrew for an aircraft to fly at a speed of 18 m.p.h., the airscrew speed to be 4,000 r.p.m.

$$\text{Then } D = \frac{88 \times 18}{4{,}000 \times {\cdot}5}$$

$$= {\cdot}79 \text{ feet.}$$

With the value of "J" taken as ·5, the efficiency will be 70 per cent—thus the theoretical forward speed will be 18 ÷ ·7 = 25·8 m.p.h., or 37·7 feet per second.

As the airscrew speed is 66·6 revolutions per second

$$\text{pitch} = \frac{37{\cdot}7}{66{\cdot}6}$$

$$= {\cdot}565 \text{ foot.}$$

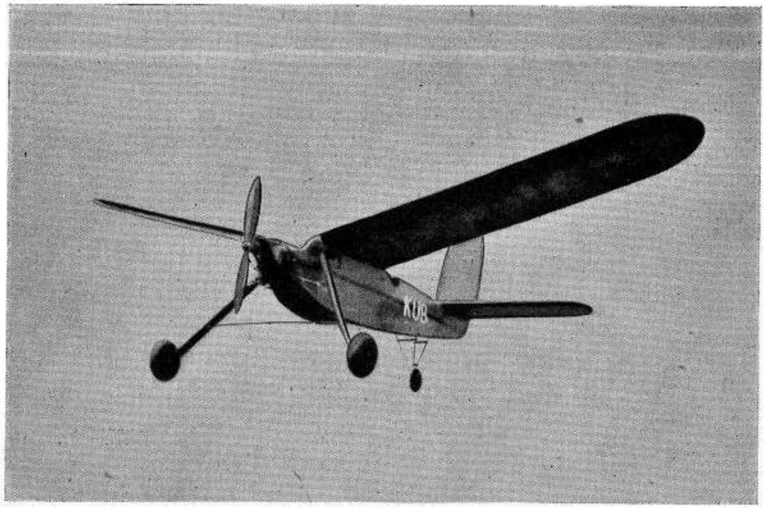
Now the thrust available from such an airscrew, running at 4,000 r.p.m., would be approximately 1·7 pounds, requiring about ·16 b.h.p. from the engine, which would be of about 5-6 cc. capacity.

Suppose, however, a 10-cc. engine were the only one available; then, if given full throttle, it would run up to well over 4,000 r.p.m.

Thus the value of "J" would be decreased, indicating that the airscrew was not working under such good conditions; any increase in aircraft speed which might be thought to accrue, due to the higher airscrew revolutions, would be cancelled out by the lower efficiency.

Here then would be a definite case for some form of throttle control, or a slight increase in the airscrew diameter or pitch, so as to absorb the full power of the engine, and keep the revolutions down to 4,000.

In short, nothing is gained by overdriving the airscrew, and serious damage may result to the engine due to the increased speed.



One of the most successful designers of petrol 'planes is Lt.-Col. C. E. Bowden. Here is the " Kanga Kub," which won the " Sir John Shelley " Cup in 1937. It was built and flown by Mr. C. R. Jeffries, to Lt.-Col. Bowden's design.

CHAPTER VII

AIRSCREW PERFORMANCE

Formula for calculating ideal thrust of airscrews—Static thrust—Value of J—Actual thrust—Method of estimating airscrew performance—Empirical formula for estimating the static thrust of power-driven airscrews.

THEORETICALLY—that is assuming 100 per cent efficiency—the static thrust developed by an airscrew may be calculated by use of the formula

$$T = 3{\cdot}142 \times r^2 \times p \times n \times {\cdot}076 \quad \ldots \quad (24)$$

where r = Airscrew radius, in feet.
p = ,, pitch, in feet.
n = ,, revolutions, per second.
·076 = Weight in pounds, of 1 cubic foot of air,

and T is given pounds.

Actually, of course, 100 per cent efficiency cannot be obtained as, due to the " fluidity " of the air, a certain amount of " slip " inevitably occurs; and the resultant figure of thrust obtained by use of this formula must be multiplied by an " efficiency " factor—which may be anything between ·8 and ·88, according to the type of airscrew under consideration.

For a well-designed metal airscrew working under its " best " conditions, this factor will be about ·85, and for a similar wooden airscrew, about ·8.

Now static thrust is that which is developed when an airscrew is revolving in a fixed plane: when it is, in effect, acting as a fan.

Under this condition the efficiency is said to be zero, since although the thrust will be quite large, as the forward velocity is zero, no useful work is being done.

A measure of the efficiency of the conditions under which an airscrew is working may be obtained by use of the formula

$$J = \frac{V}{ND} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (25)$$

where V = Aircraft velocity in feet per second.
N = Airscrew revolutions per second.
and D = ,, diameter in feet.

Thus when the efficiency is zero, " J " is zero. As the value of " J " increases (with increase in V) so the efficiency increases until it reaches a maximum point, after which it falls very quickly.

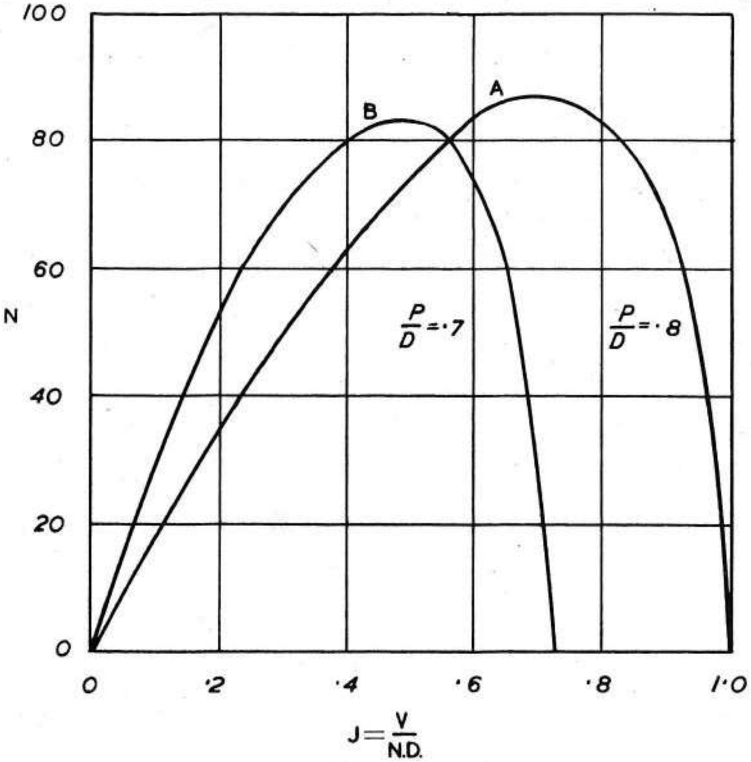
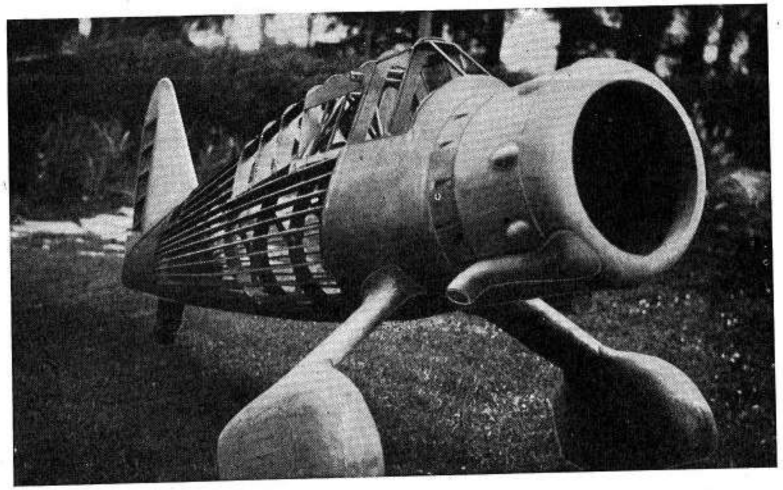


FIG. 13.

Curve A, Fig. 13, is typical of average full-size airscrews —from which it will be seen that the efficiency reaches its maximum of ·88 when the value of " J " is a little over ·75. In model airscrew practice, however, the efficiency appears to reach a maximum of ·83 when the value of " J " is approximately ·5, and curve B is typical of metal airscrews of diameter of from 14 inches to 18 inches.

As the forward velocity of an airscrew increases, as in



Here is the fuselage, 6 ft. long, of the Author's " Lysander." This fine photograph shows how the construction of the full size machine has been faithfully imitated. There are some forty longerons in the fuselage. The front part, and the front portion of the fin, which are of metal construction, are in the model built of balsa and three-ply, $\frac{1}{32}$ in. thick. The spats, which house 8 in. diameter pneumatic-tyred wheels, are carved from solid blocks of balsa.

flight, the thrust developed becomes less, due to the blades meeting the air at a reduced angle of attack; and in model practice this reduction is of the order of about 17 per cent of the static thrust developed when the value of " J " is zero.

The net result of these reductions is to indicate that the maximum working efficiency of a metal airscrew is approximately 70 per cent of the theoretical value as calculated by means of formula (24).

Size for size, wood airscrews are usually from 4 per cent to 6 per cent less efficient than those of metal, thus the maximum working efficiency may be taken as approximately 65 per cent of the theoretical value obtained by means of the same formula.

These efficiencies, of course, only obtain when the value of " J " is approximately ·5; and compare with maximum values of 85 per cent and 78 per cent—with a value for " J " of approximately ·6—obtained in full-size practice.

Generally speaking, large airscrews revolving at relatively slow speeds are the most effective, and full-size airscrews rarely turn at much more than 2,200 r.p.m., compared with 3,000-4,000 r.p.m. commonly obtained in model practice.

Steps in the performance estimation of an airscrew are as follows:—

Consider a metal airscrew 1·5 feet in diameter, of 1-foot pitch, running at 3,500 r.p.m.

(1) If the airscrew is to operate under the best conditions "J" must equal approximately ·5; when the efficiency will be 70 per cent.

In the case of the example

$$J = \frac{1 \times 58{\cdot}5 \times {\cdot}7}{58{\cdot}5 \times 1{\cdot}5}$$

$= {\cdot}466$ which may be considered quite satisfactory. If the result of this calculation had been to yield an answer much above or below this figure—one or other of the three factors—pitch, diameter, or airscrew revolutions—would have required to have been altered accordingly.

(2) By formula (24)

$$T = 3{\cdot}142 \times {\cdot}75 \times {\cdot}75 \times 1 \times 58{\cdot}5 \times {\cdot}076$$

$= 7{\cdot}86$ pounds thrust (100 per cent efficiency).

Allowing for slip $7{\cdot}86 \times {\cdot}85$

$= 6{\cdot}68$ pounds thrust (static). Allowing for reduced thrust, due to reduced angle of attack of blades $6{\cdot}68 \times {\cdot}83$

$= 5{\cdot}55$ pounds thrust (actual).

[NOTE.—Ratio of 5·55 pounds (actual working thrust) to 7·86 pounds (assuming 100 per cent efficiency) = ·705.]

For ordinary purposes these two calculations may be consolidated into one—by an overall reduction to 70 per cent in the case of metal airscrews, and to 65 per cent in the case of wood airscrews, of the value obtained by use of formula (24).

(3) The actual velocity may now be calculated by multiplying together the pitch, the number of revolutions, and the efficiency of the airscrew.

In the case of the example quoted above

$$V = 1 \times 58{\cdot}5 \times {\cdot}7$$

$= 41$ feet per second.

An empirical formula often used in full-size practice for

calculating static thrust is that developed by W. S. Diehl,* which states that

$$T = 6{,}000 \left[18{\cdot}7 - 9{\cdot}5 \left(\frac{P}{D}\right)\right] \frac{\text{B.H.P.}}{\text{r.p.m.} \times D} \quad \ldots \quad (26)$$

where P = Airscrew pitch, in feet.
D = Airscrew diameter, in feet.
and T = Actual static thrust developed.

This formula may be re-written

$$\text{B.H.P.} = \frac{T \times \text{r.p.m.} \times D}{6{,}000\left(18{\cdot}7 - 9{\cdot}5\left(\frac{P}{D}\right)\right)} \quad \ldots \quad \ldots \quad (27)$$

and used to ascertain the power required to drive a given airscrew, *provided* J = ·5.

For use with model airscrews, it would seem that a coefficient of 1·15 must be introduced, when the resultant answer fairly accurately agrees with results obtained from a series of tests carried out with a number of airscrews of the sizes commonly used in model aircraft practice.

In the case of the example quoted above

$$\text{B.H.P.} = 1{\cdot}15 \left(\frac{6{\cdot}68 \times 3{,}500 \times 1{\cdot}5}{6{,}000 \times (18{\cdot}7 - (9{\cdot}5 \times {\cdot}667))}\right)$$

$= {\cdot}543$

Finally, reference must be made to the engine power curve, to ascertain whether the required power will be delivered at the specified number of airscrew revolutions.

In the case of the example ·543 B.H.P. *must* be available at 3,500 r.p.m.

If this were not the case, either the diameter or pitch of the airscrew—or perhaps both—would require to be altered accordingly.

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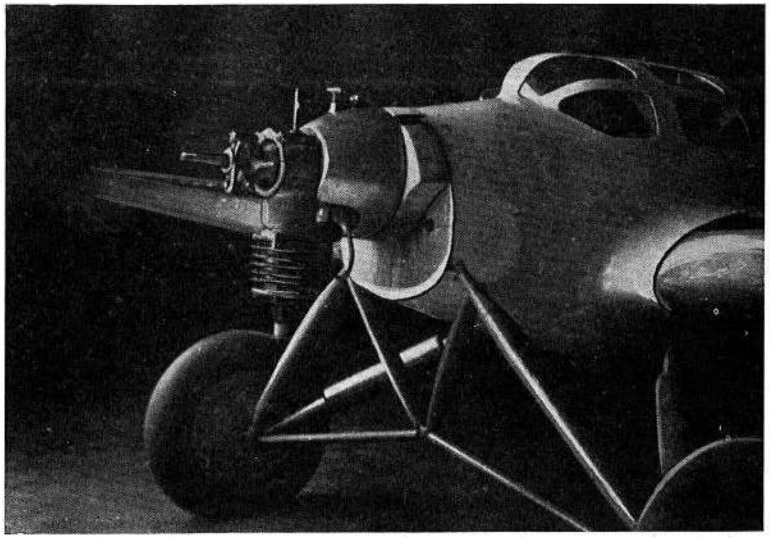
* W. S. Diehl, *Engineering Aerodynamics.*



This photo gives a very good idea of the construction of the front of the fuselage and undercarriage of the 10 ft. span low-wing 'plane designed by the Author. Note the smooth flaring of the wing root into the fuselage.

CHAPTER VIII

RUBBER MOTORS

The energy stored in twisted rubber—Number of turns available in different types of rubber motors—Equipment for measuring thrust of rubber-driven airscrews—Curves showing typical results obtained with this apparatus.

A TWISTED rubber motor suffers from the handicap that its power output is not constant, but decreases—very rapidly in the first few seconds—during the time of unwinding.

The energy stored in a rubber motor, wound up nearly to breaking strain, may be quite accurately calculated on the basis of 2,000 foot-pounds of energy per 1 pound weight of rubber; but the estimation of the amount of power available at any given moment during the unwinding is not possible except by means of very complicated calculations.

Further, since the strands of rubber in a motor can be arranged in a great number of different ways, all of which will give different results—and any of which might be described as the "best," depending on the conditions under which it has to work—it follows that it is quite impossible to lay down "hard and fast" any one rule as to how best the strands of a rubber motor shall be arranged.

Only by testing out various arrangements of the strands of a motor can an idea of the power available be obtained—and then only as applying to the particular airscrew used for the tests—since the rate of unwinding of *any* rubber motor will be controlled by the diameter and pitch of the airscrew it is driving.

An equipment for testing out various arrangements of rubber motors may be easily and cheaply built, and will yield very useful results. The aero-modellist will find that, after carrying out a number of tests with a series of certain arrangements of the strands of rubber, he will be able to predict, with a quite fair degree of accuracy, the probable performance of a series of somewhat different arrangements of the strands of rubber.

Following is a description of the apparatus built by the author, and with which many tests have been carried out; the results of some of them, in the form of thrust power and airscrew revolution curves, being given.

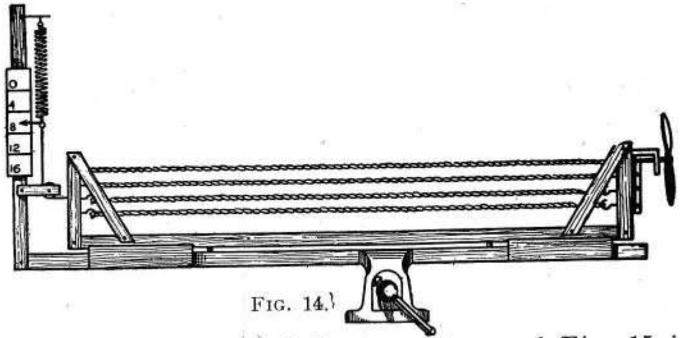


FIG. 14.

Fig. 14 is a sketch of the apparatus, and Fig. 15 is a photo showing the 4-spindle gearbox and airscrew mounting.

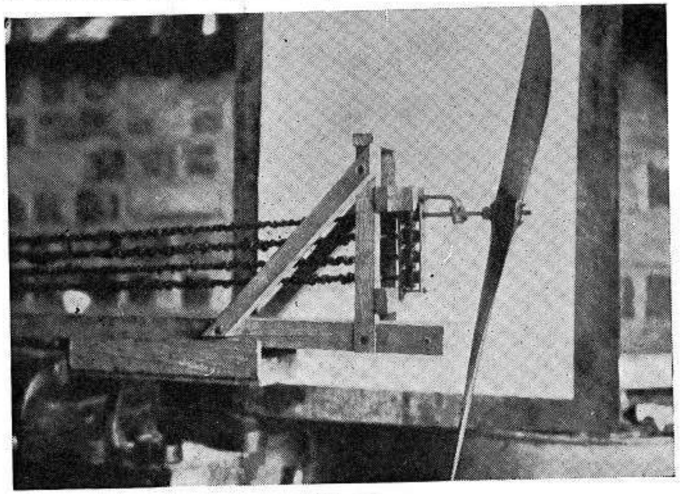


FIG. 15.

The four-spindle motor shown on the test rig in the above photograph was specially built for airscrew testing. All spindles are mounted with ball thrust bearings, and the propeller shaft also carries a set of roller bearings to reduce friction.

Essentially the apparatus consists of a "carriage" on which is mounted the rubber motor and airscrew to be tested, the carriage being free to move on rollers in a fore and aft direction along the sloping runway. This runway is held for convenience in a bench vice, and is thus easily adjustable

as to its angle of inclination. When a given motor and airscrew have been assembled, the runway is set so that the carriage will just *not* run down the incline. This has the effect of reducing the "tractive resistance" (in this case the friction of the rollers on which the carriage runs) to a negligible quantity.

To the back end of the carriage is attached a thread which passes under a pulley and up to the lower end of a vertically-mounted spring which, up to a certain limit, has a constant rate of extension per ounce of added weight. To the lower end of the spring, where the thread joins it, is fixed a pointer which moves across a scale marked in ounces. (This scale has, of course, been previously calibrated by weights hung direct on to the spring.)

In operation, after the motor and airscrew to be tested have been mounted on the carriage and wound up, the thread is detached from the spring, and the runway adjusted as already described. The thread is then fixed to the spring and the motor released; immediately the carriage moves forward, the thrust in ounces being indicated by the pointer on the scale. As the power falls off, the spring pulls the carriage backwards, until finally, when the motor has completely unwound, the pointer is back at zero.

During the test, 5-second (and with practice, 3-second) readings are taken with the aid of a stop-watch, and thus accurate curves may be drawn showing the rate at which the power falls off. Readings are also taken with a revolution-counter and the results compared with the thrust, and this information allows the rubber motor to be so arranged that it will (say for a duration flight) deliver as constant an output for as long as possible, at a figure just in excess of the minimum at which the machine will fly.

Fig. 16 shows curves of two rubber motors of average arrangement, in each case driving a 16-inch diameter × 14-inch pitch airscrew. Curve "B," representing the 10-strand motor, showing how the extra power, at the take-off, is obtained, though at the expense of shortening the length of flight a little. Fig. 17 shows the power output of the same rubber motors recorded in ounces of thrust, as compared with r.p.m., as recorded in Fig. 16.

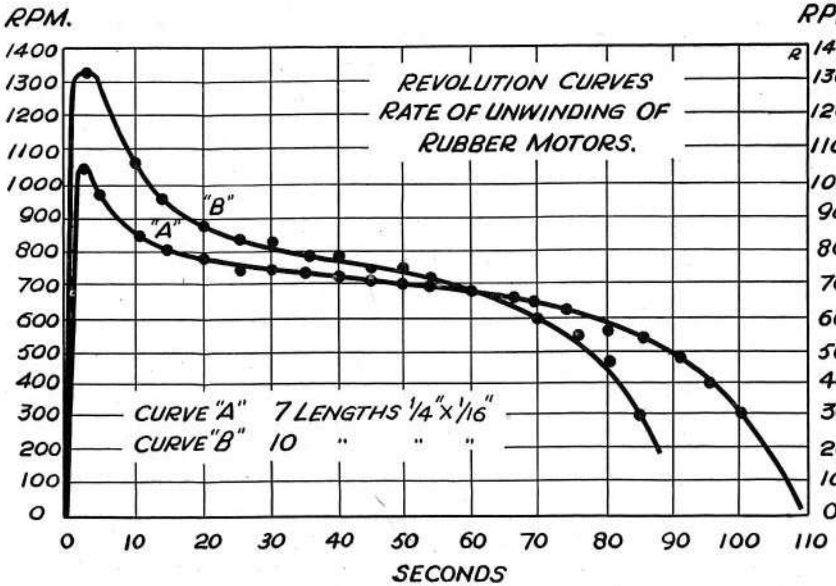


Fig. 16.

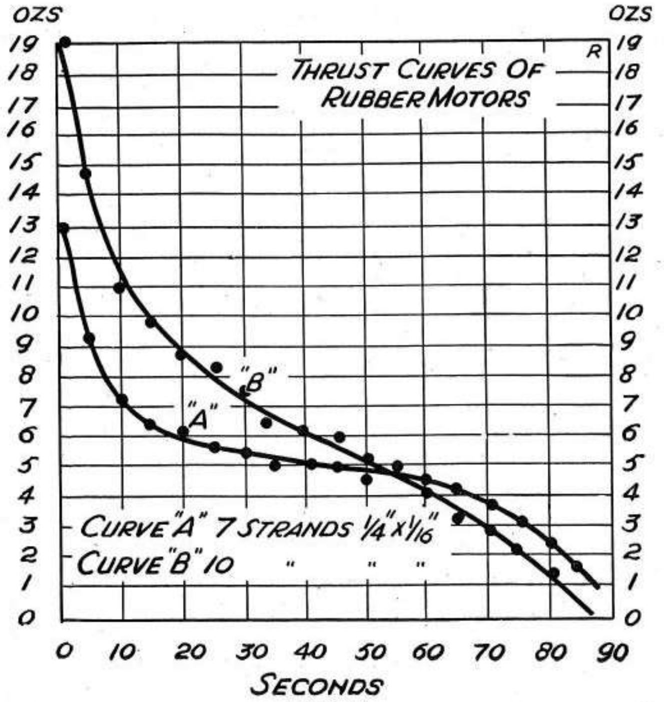


Fig. 17.

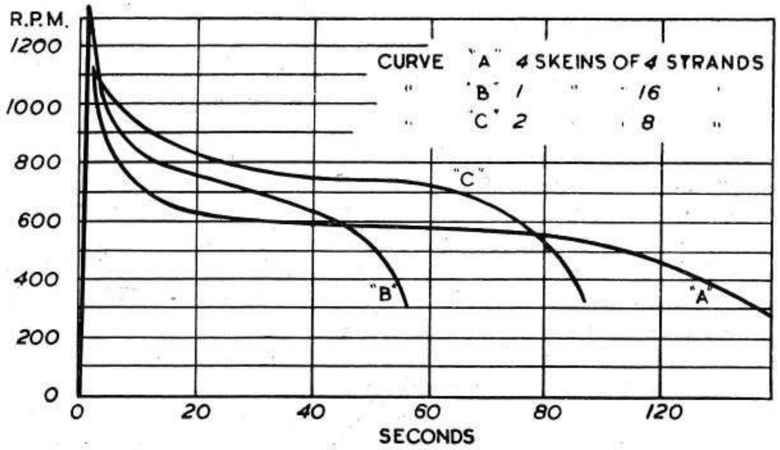


Fig. 18.

Fig. 18 shows curves of results obtained with 48 feet of $\frac{1}{4}$-inch × $\frac{1}{30}$-inch rubber arranged in three different ways, in each case driving an 18-inch diameter × 14-inch pitch airscrew. Curve " A " 4—36-inch skeins, each of 4 strands, on the 4 hooks of the motor. Curve " B "—with *all* the rubber on one hook, i.e. 16—36-inch strands; and Curve " C " showing the results obtained by using the rubber arranged as 2—36-inch skeins, each containing 8 strands.

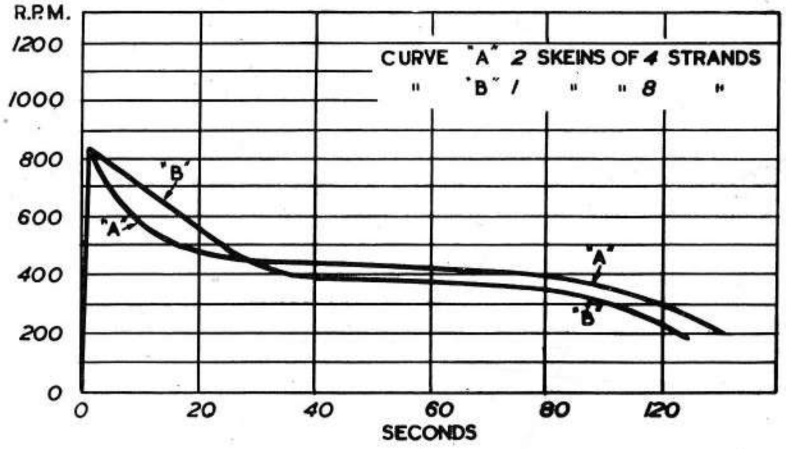


Fig. 19.

Fig. 19 shows results obtained by using 24 feet of $\frac{1}{4}$-inch × $\frac{1}{30}$-inch rubber. Curve " A " with 2—36-inch skeins, each of 4 strands, and Curve " B " with all the 8 strands on one hook.

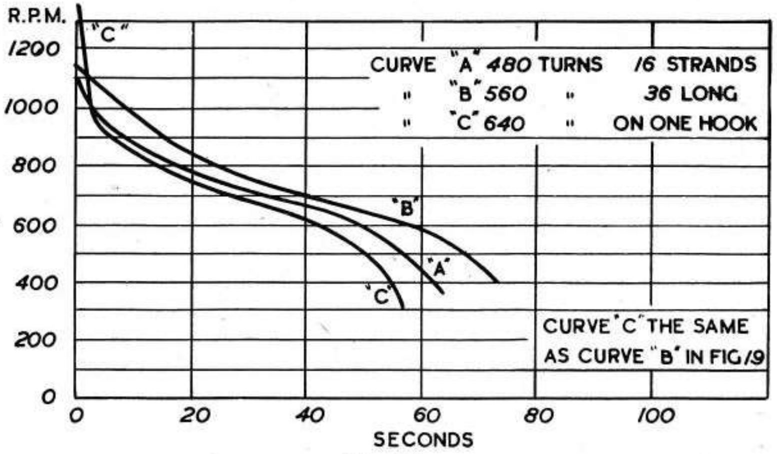


FIG. 20.

Fig. 20 shows the results obtained by winding up the same motor to different numbers of turns—to 480, 560 and 640 respectively, out of a permissible maximum of approximately 700.

The interesting feature is that *both* A and B show a " peak " of 1,100 revolutions per minute, with B, as one would expect, running for a longer period than A. But curve C shows how the power rapidly increases with the last 100 turns, giving a " peak " of 1,400 revolutions per minute, but falling off so rapidly that the total duration is a little *less* than A. From this it is seen that when a motor has a great number of strands on it, too great a number of turns will produce a motor quite unsuitable for flying.

Fig. 21 shows results obtained using very long rubber motors, specially arranged for duration flying, driving the same airscrew.

Fig. 22 shows two torque curves of different rubber motors, each showing the rapid rise in torque as the number of twists imparted to the rubber approaches breaking point.

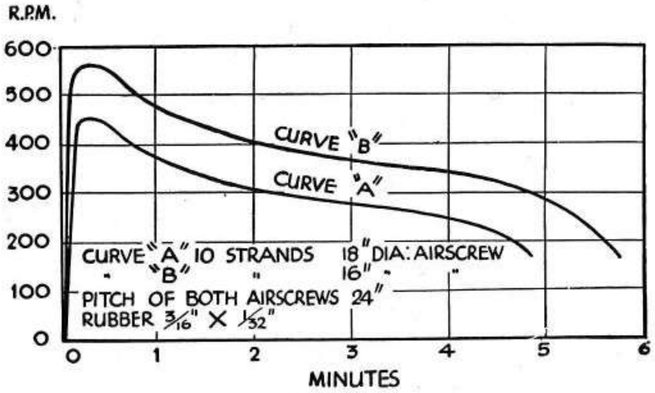


FIG. 21.

Here again is indicated the value of " bench tests " of the power unit, since by careful experimenting it is possible to so arrange the strands of rubber that the extra power is available for just as long as it is wanted, after which it falls off to the minimum required to fly the machine, this giving as long a flight as possible.

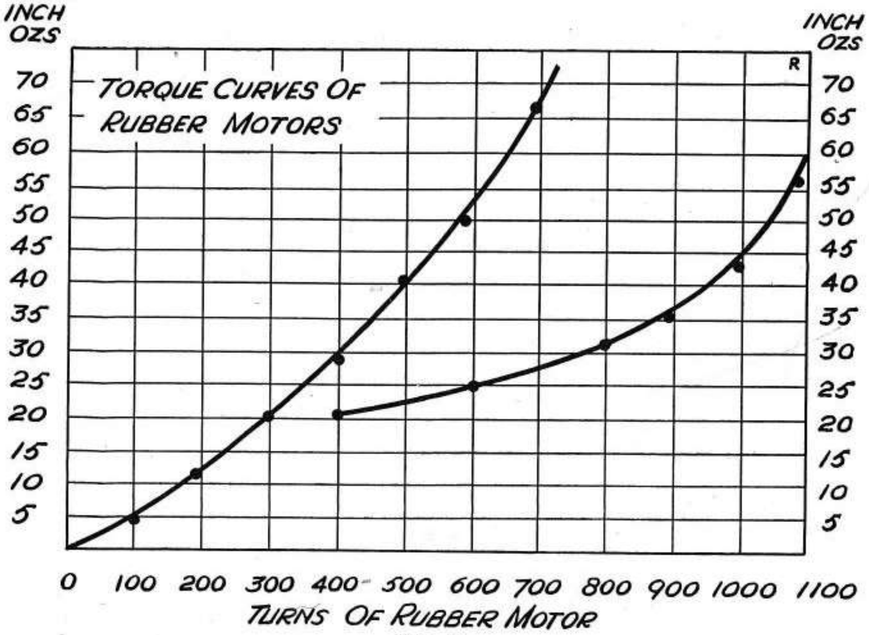


FIG. 22.

The following formulæ may be used in estimating the performance of rubber-driven model aircraft:—

(1) The distance a model will travel under power =

$$D = \frac{K\ WR}{W}\ \text{feet} \quad \ldots \quad \ldots \quad (28)$$

where WR = Weight of rubber motor.

W = Total weight of model with motor.

K = Approx. 3,000 for models with high lift wing sections and not specially streamlined—4,000—5,000 for streamlined models.

(2) The number of turns a rubber motor will stand =

$$N = \frac{KL\sqrt{L}}{\sqrt{W}} \quad \ldots \quad \ldots \quad \ldots \quad (29)$$

where L = Length of skein unstretched in inches.

W = Weight of rubber per skein in ounces.

K is usually taken as 4, but if the motor is stretch wound may be safely increased to 5.

(3) The propeller pitch, allowing 25 per cent slip =

$$\frac{D}{N \times R \times \cdot 75}\ \text{feet}$$

R = gear ratio = 1 if the propeller is driven direct.

Taking as an example a non-streamlined model with 200 square inches wing area, and weighing 3 ounces + 1 ounce of rubber, with a single skein 30 inches long.

$$D = \frac{3{,}000 \times 1}{4} = 750\ \text{feet.}$$

$$N = \frac{5 \times 30 \times 5 \cdot 5}{1} = 825$$

$$\text{Propeller pitch} = \frac{750}{825 \times \cdot 75} = 1 \cdot 21\ \text{feet} = 14\tfrac{1}{2}\ \text{inches.}$$

The propeller pitch should be from one to one-and-a-half its diameter for rubber driven models.

In order that a given rubber motor shall store the maximum amount of energy it is obvious that all the particles of rubber in that motor shall be equally stressed. Now if a dry rubber skein be twisted, i.e. wound up, there will be a tendency for the strands on the surface of the skein to be stretched considerably more than those at the centre. Since each strand in the length of the skein passes several times from the surface through the centre it will be seen that if the strands are lubricated and allowed to slide over each other, the strain will be more equally divided, and hence the energy stored will be increased.

The energy can be still further increased by stretching the skein to about five times its original length before starting to wind, and gradually decreasing the length when approaching the full number of turns.

The following tables, compiled by R. M. Glass from some recent experiments he has made, show the torque at various turns on motors unlubricated, lubricated unstretched, and lubricated stretch wound.

Each sample consisted of 8 strands of $\frac{1}{8}$ inch × 1/30 inch rubber 16 inches long, 12 inches between hooks. All the samples were cut from the same hank, and each weighed $\frac{1}{4}$ ounce.

Turns, Torques, Breaking Points.

Unlubricated—Unstretched.

A.

Turns.	Torque.
100	2
200	4
298	Breaking point.

Lubricated—Unstretched.

B.

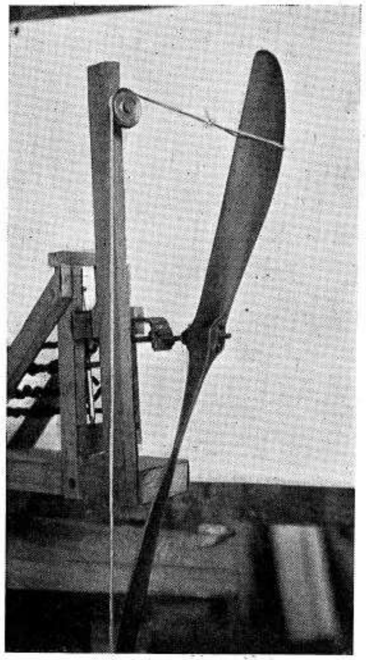
Turns.	Torque
100	2
200	$2\frac{1}{2}$
300	3
350	$3\frac{1}{2}$
400	5
450	$6\frac{1}{2}$
486	Breaking point.

C.

Turns.	Torque Winding.	Torque Unwinding
100	2	$\frac{1}{2}$
200	$2\frac{1}{2}$	1
300	3	1
350	$3\frac{1}{2}$	$1\frac{1}{4}$
400	4	2
450	$5\frac{1}{2}$	—

Lubricated—Stretched.

D. Prewound.		*E. First Wind.*		
			Torque	
Turns.	Torque	Turns.	Winding.	Unwinding
200	1	200	2	—
400	2	400	3	—
500	2	500	3	—
600	2½	600	3½	—
700	3½	700	6	—
800	4½	800	8	1
900	6½	900	10	2
1000	8½	950	12½	4
1025	10½	975	13	—
1040	12	1000	15	—
1050	13	On rewind breaking point		
1070	13		=1128	
1075	Breaking point.			



In this photo is shown the set-up for measuring the torque of a rubber motor. At the end of the piece of string, which passes round the pulley, is a hook on which are hung weights to balance—and so measure—the force which is being exerted by the rubber motor to turn the airscrew round.

FIG. 23.

As an examination of the results shows, the number of turns required to break a stretch wound skein is more than twice that for a lubricated unstretched skein, also the torque at breaking point is much higher, although the average torque as the motor is unwinding is slightly less for the stretch wound motor. The thick lines on the curves show the torque when winding, and the dotted lines when unwinding. The area below the dotted curves represents the energy delivered by the motor.

Other interesting facts concerning rubber motors are:—

(1) When a motor is wound up nearly to breaking point and held in this condition, the torque decreases very rapidly.

(2) A motor will stand considerably more turns after it has been wound up and run out a few times, although the torque at breaking point is considerably reduced. The total energy which can be obtained from a motor does not vary much, if well lubricated, during the first ten or more flights; it is usually considered to be a maximum on the third.

(3) If a motor is wound up slowly it will stand more turns and give less torque than it would if wound quickly.

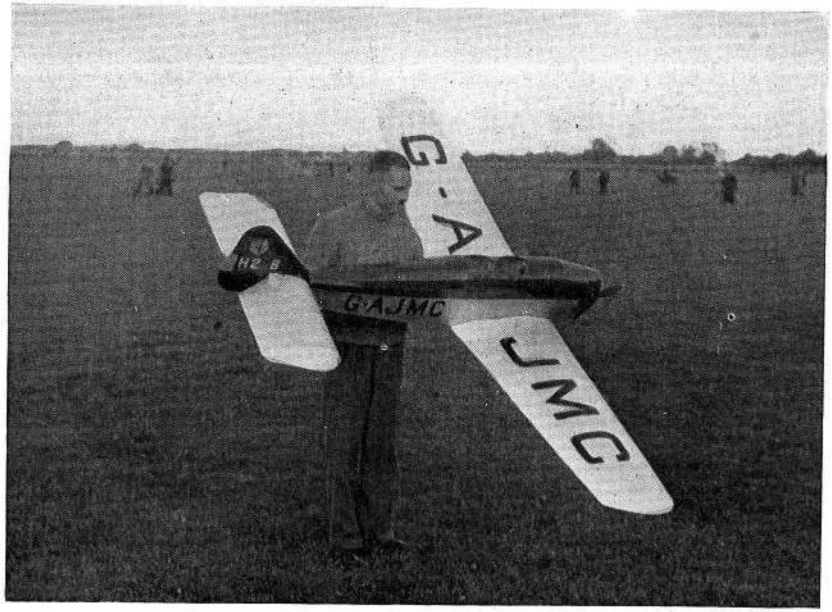
A skein consisting of a large number of small strands will stand more turns than one of the same length and weight consisting of a few thick strands.

When rubber is first produced in the form of strand for model aircraft motors it is of a soft, sticky nature. If this rubber is exposed to air, or more particularly, to light, it gradually dries and hardens. When sold by model firms it is usually in about the best condition for flying, and to prevent deterioration stock should be kept in an airtight tin.

A week's exposure to sunlight will completely ruin a motor, as the rubber becomes brittle. For this reason it is necessary to frequently replace rubber bands when they are used in exposed places, such as to hold wings or tail unit in position.

A motor should be lubricated and the lubricant well rubbed in at least an hour, and preferably a day before winding. If it is going to be out of use for a period of more than a fortnight it is advisable to rinse the lubricant off, dry the skein and return it to the airtight tin.

As has already been pointed out, a quantity of rubber may be arranged in a very great number of ways on the hooks



The " Bowden Trophy "—an International Competition for petrol 'planes —was won in 1939 by Mr. J. M. Coxall, who is shown here with his winning plane. A photo showing the model taking-off on one of its competition flights is on page 39.

of a single or multi-spindle motor—but from a study of the curves and tables given in this chapter, the aero-modeller will gain a general idea of how the power output is delivered during the time of unwinding, whilst from a test apparatus as here described he may obtain power outputs to suit practically any set of conditions.

CHAPTER IX.

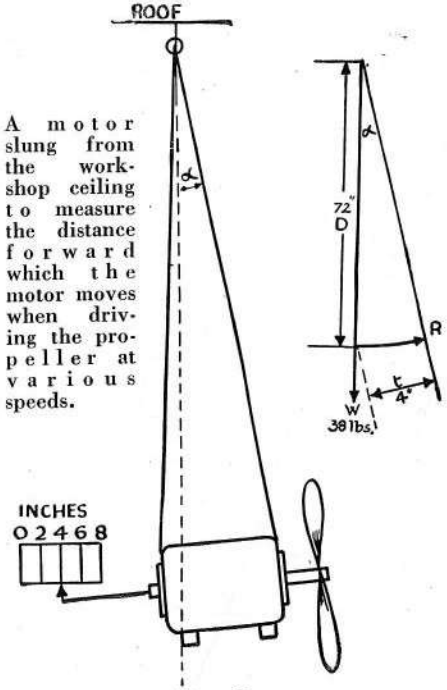
TESTING POWER-DRIVEN AIRSCREWS

Method of ascertaining thrust of power-driven airscrews —Value of K for electric motors—Curves of test results of metal airscrews.

THE " Carriage and Spring Balance " equipment described in Chapter VIII cannot be used for the testing of the larger and much faster-revolving airscrews used on petrol-driven aircraft, since these may require anything up to $\frac{3}{4}$ h.p. to drive them, and the weight of the necessary motor, some 25-35 pounds, introduces so much friction on the carriage bearings that accurate results are difficult to obtain.

By slinging the driving motor from a suitable support about 6 or 8 feet above the airscrew centre, and measuring the distance forward which the motor moves when driving the airscrew, a direct measurement of the static thrust may be obtained, allowance of course being made for the air resistance offered by the electric motor.

Fig. 23 shows diagrammatically the method of slinging the motor for test; the distance from the support to the motor



A motor slung from the workshop ceiling to measure the distance forward which the motor moves when driving the propeller at various speeds.

FIG. 23.

shaft being not less than 6 feet. Care should be taken to see that the motor leads are flexible, and that they are arranged to hang freely from the support; they must *not* be led to the motor from the side or their weight may have a restraining effect on the movement of the motor.

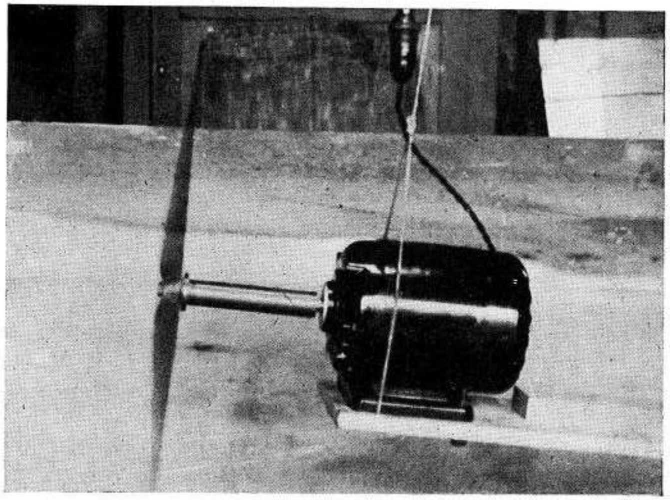


FIG. 24

This photograph shows a metal airscrew being tested in the Author's workshop. The motor and board weigh nearly 30 lb., and as can be clearly seen, it is being pulled forward several inches by the airscrew.

To the back end of the motor is fixed a pointer, so arranged as to pass across a scale, graduated in inches, as the motor swings forward under the *pull* of the airscrew. It is important to see that the direction of rotation of the motor and the "hand" of the airscrew, are such that the motor is *pulled* and not *pushed* forward, i.e. the arrangement *must* be as shown in Fig. 24. To have the motor being *pushed* forward is not safe, as the arrangement is not stable.

During test there will be a tendency for the motor to swing round, due to the torque reaction of the airscrew, and this may be counteracted by means of a fine wire led from the back of the motor to a point at the side some 3 or 4 feet away. This then allows the motor to swing backwards and forwards, with a practically straight motion.

Having measured the exact distance from the point of suspension to the centre of the airscrew, and obtained also the exact weight of the motor, airscrew, supporting wires, and electric cables—in fact, *all* the suspended weight—tests may proceed.

Firstly, the motor should be run up to say 1,000 r.p.m., this being checked by a revolution-counter, whilst the motor is held steady by hand. Secondly the motor is released, and allowed to move forward under the influence of the pull of the airscrew thrust, the distance moved being measured on the scale. The motor speed is then increased by 200-300 r.p.m., and the process repeated, until a series of readings over the airscrew speed range has been taken.

The value of the actual static thrust developed is then calculated from the formula $T = \frac{WC}{D}$ ... ... (28)

where W = Total suspended weight, in pounds.
C = Distance the motor moves forward in inches.
D = Distance from point of suspension to airscrew centre in inches.
and T = Static thrust in pounds.

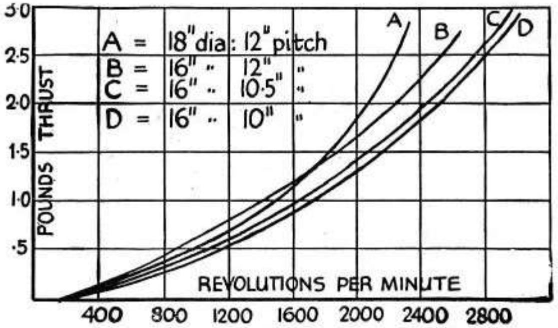


FIG. 25.

Fig. 25 shows a typical set of readings obtained from testing a number of airscrews in this manner. It must not be forgotten that the thrust measured is *static* thrust, at zero advance; and thus, as explained in Chapter VII, a reduction must be made to estimate the thrust available actually in flight. All static thrust readings obtained in this manner should be multiplied by ·83.

Allowance must also be made for the drag of the motor driving the airscrew, if the actual net thrust value is required, and this, of course, depends on the shape of the motor.

In the case of those in use by the author, it has been found, by experiments in the wind tunnel, that the value for K varies between ·001 and ·002, according to the individual shape characteristics of each motor.

A value of ·0015 may be taken for the average circular section type of motor of some 6-7-inch diameter.

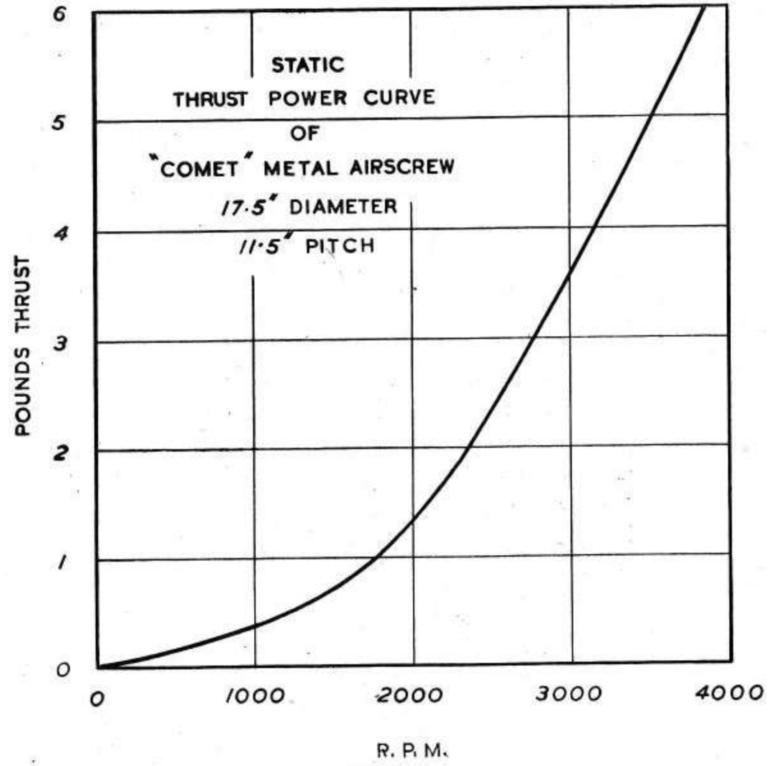


FIG. 26.

Fig. 26 shows an actual result obtained by this method of testing; using a motor 6-inch diameter, driving an airscrew of 17·5-inch diameter × 11·5-inch pitch.

The thrust delivered by this airscrew at 3,800 r.p.m. is seen to be 5·7 pounds, and an example may be taken of this figure to check up how it compares with the estimated performance as calculated by formula 24.

(1) 3,800 r.p.m. = 63·5 revolutions per second, which,

with a pitch of 11·5 inches (·96 foot) and an assumed efficiency of 70 per cent, gives a rate of actual forward advance of 42·7 feet per second.

$$\text{Therefore } J = \frac{42{\cdot}7}{63{\cdot}5 \times 1{\cdot}46}$$
$$= {\cdot}46$$

The efficiency will more likely be about 67 per cent, indicating a flying speed of approximately 41 feet per second.

(2) Taking the value of K = ·0015 the drag of the motor may be calculated to be equal to

$${\cdot}0015 \times {\cdot}196 \times 28^2$$
$$= {\cdot}231 \text{ pound.}$$

(3) Thus the actual static thrust delivered by the airscrew at 3,800 r.p.m. = 5·7 + ·231

$$= 5{\cdot}931 \text{ pounds.}$$

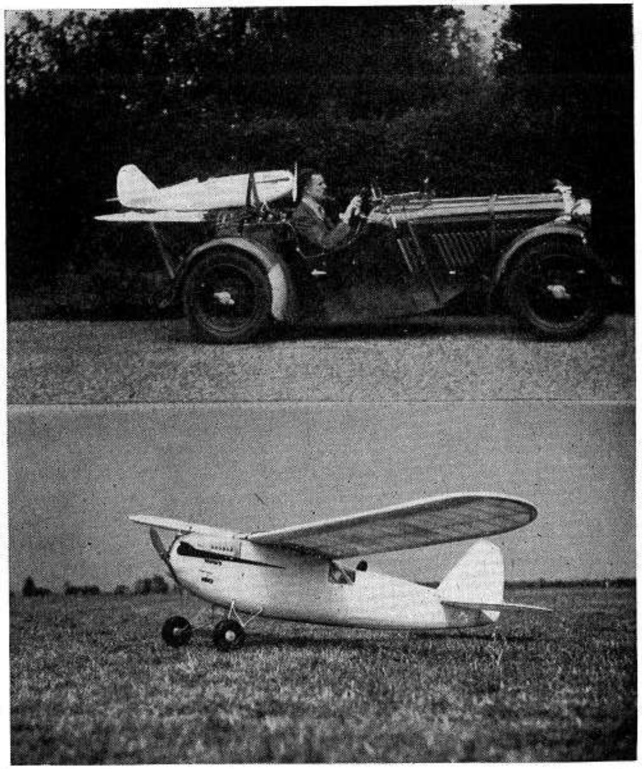
(4) Taking 83 per cent of this figure gives the actual thrust delivered during flight of 4·93 pounds.

(5) Using formula 24, the theoretical thrust delivered by the airscrew would be equal to

$$T = 3{\cdot}142 \times {\cdot}73^2 \times {\cdot}96 \times 63{\cdot}5 \times {\cdot}076$$
$$= 7{\cdot}75 \text{ pounds.}$$

(6) Taking 67 per cent of this figure gives 5·2 pounds as the actual thrust delivered during flight, which compares with the figure of 4·93 pounds ascertained by the test.

The conclusion is therefore justified that the airscrew is working at an efficiency of approximately 67 per cent when J = ·46, and that, at a slightly slower rate of revolutions, the airscrew would be operating under its maximum conditions of efficiency.



Petrol 'planes may easily be carried to and from the local flying field if a small bracket is fitted to the rear of a car!

CHAPTER X

WIND-TUNNEL TESTING

Description of a wind tunnel—Method of operation—The visual observation of airflow—The measurement of lift and drag—Examples of results obtained from wind-tunnel tests.

WITH power-driven model aircraft flying at speeds of from 15-40 m.p.h., the effect of wind resistance can no longer be ignored, and to obtain the best results it is essential that proper attention be paid to " streamlining," and the reducing of drag and " interference " to a minimum.

As in full-size practice, so in the sphere of model aeronautics the wind tunnel provides the means of making tests and observations of parts of an aircraft, under similar conditions to those which operate during flight.

A wind tunnel consists esentially of a large tube, in which is suitably suspended the object about which it is desired to obtain information, and a means of providing a " wind," or flow of air, past the object at a speed similar to that at which

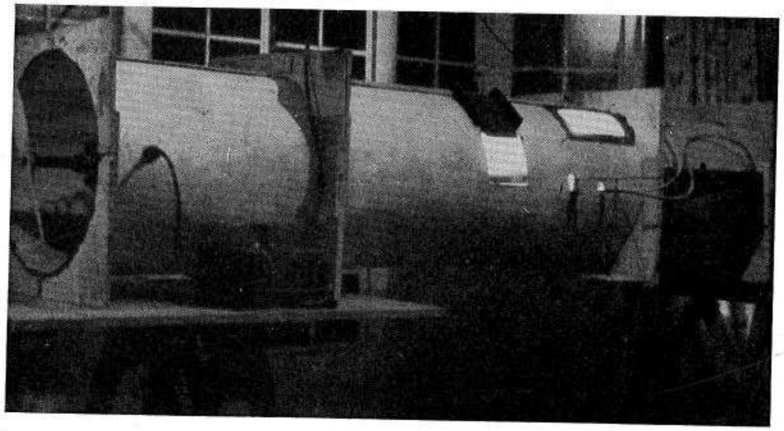


FIG. 27.

In the middle of the centre section is an opening, through which units to be tested can be inserted into the tunnel. To the right of the flaps is one of the two celluloid-covered inspection windows. On the table in the foreground is the rheostat for controlling the speed of the fan motor.

it would move when passing through the air when in flight.

Fig. 27 shows a general view (less the section at the inlet end) of the wind tunnel constructed by the author and used in his research work. It is 10 feet long by 20 inches bore, and is divided into 4 sections for convenience in storing. There are one 4-foot section and three 2-foot sections, the flanges of each section being concentric and held together by short screws.

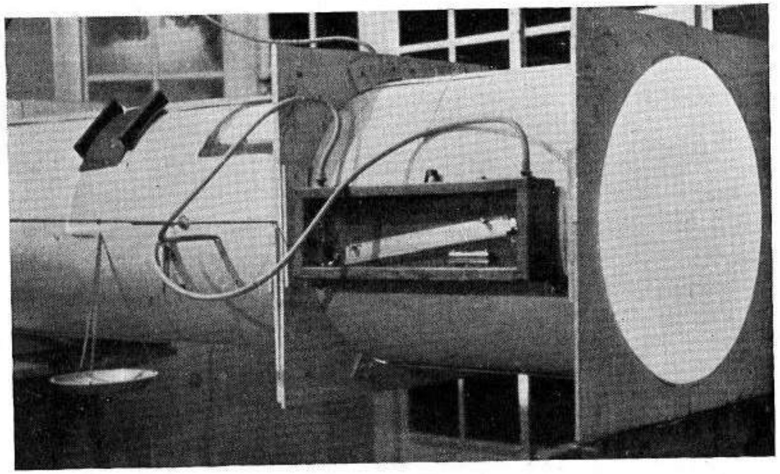


FIG. 28.

In the centre of the photograph is shown the manometer for measuring the air pressure. The rubber tubes lead to the pilot tube which is inserted in the side of the tunnel.

The tube forming the tunnel is made of $\frac{3}{16}$-inch three-ply—each section of " tube " being inserted into a pair of flanges made from $\frac{3}{8}$-inch three-ply—these being each 2 feet square.

Fig. 28 shows the balance arm and the manometer at the discharge end. Vanes are arranged inside the tunnel, in both vertical and horizontal planes, to prevent rotation of the column of air as it passes through.

Celluloid " windows " are provided for observations of parts under test, and electric light is installed inside the tunnel to enable photographs to be taken.

The motor used will deliver up to $1\frac{1}{2}$ h.p. and, driving an 18-inch diameter airscrew, will produce airspeeds up to 30

m.p.h. in the tunnel, a regulator being provided to enable any speed below this figure to be obtained.

The *exact* efficiency of the airscrew is known over its full working range, and the calculated airspeeds are checked by means of a pitot tube. The tunnel has also been calibrated by means of readings with an anemometer.

Broadly speaking, the information which may be obtained from wind-tunnel testing is of two kinds—that obtained by direct observation of the flow of air around the object being tested, and that obtained by means of direct readings with the aid of a balance or other mechanical apparatus.

Direct observation of the flow of air is made possible by attaching very thin " streamers," consisting of 3—5-inch lengths of wool, to the object to be tested. By this means not only the direction of the airflow may be observed, but also its condition as regards stability and tendency to form vortices or " whirls." If the airflow is steady the pieces of wool will remain stable or " rigid "; whereas if the airflow is uneven the ends of the " streamers " will waver.

Figs. 29, 30 and 31 show an airfoil section being tested in the tunnel, the " breakaway " as the stalling angle is approached, being indicated by the spreading of the wool streamers. Figs. 32, 33, and 34 are views looking up the tunnel taken during the same test.

Measurements of drag are obtained by means of a balance, the actual value of the drag being obtained direct.

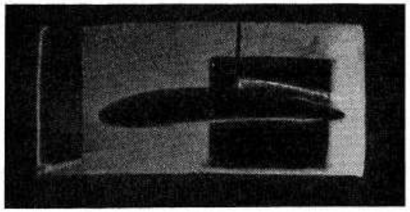
Supported on a pivot fixed to the outside of the tunnel is a horizontally-mounted " balance arm," which passes through a clearance hole in the side of the tunnel. This arm carries the test object at one end (inside the tunnel), and a suitable counterbalance weight at the other end (outside the tunnel)—this consisting of a scale pan in which are placed the necessary counterweights, so keeping the " balance arm " horizontal.

At the outer end of the " balance arm " also is fixed a length of fine thread which is led over a pulley mounted on a spindle which projects horizontally, and at the same level as the " balance arm," from the side of the tunnel. To the other end of this thread weights are attached to balance the drag of the test object.

The pivot rod is mounted on a thrust ball-bearing which

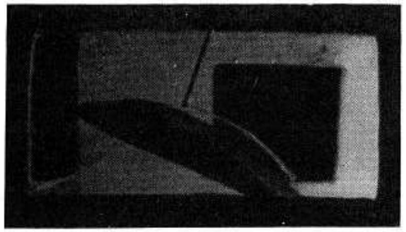
(a) In Figs. 29, 30 and 31, end views of the airfoil sections are shown photographed through the inspection window described in Fig. 27. Figs. 32, 33 and 34 are photographs which were taken looking up the tunnel from the outlet end.

FIG. 29.



The airfoil section is normal to the air stream, and the white streamers can be seen following the curve of the upper portion of the airfoil.

FIG. 30



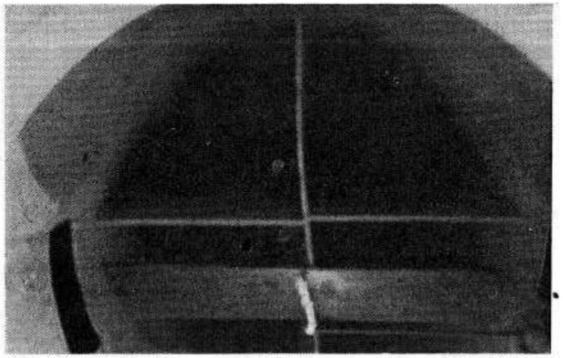
The airfoil has now been tilted and the streamers are starting to lift away from the top surface.

FIG. 31.

The airfoil has now been tilted until it is stalled, and the streamers are spreading out due to the "breakaway" of the air stream.

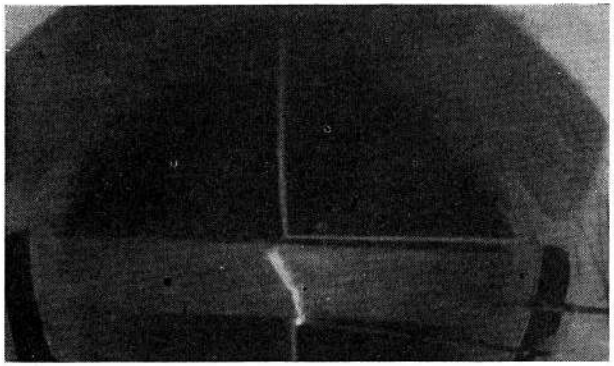
Airfoil Section R.A.F. 32. 10-inch chord.
Wind speed approx. 30 m.p.h.
(all six photographs taken by J. C. Eck, Esq.)

FIG. 32.



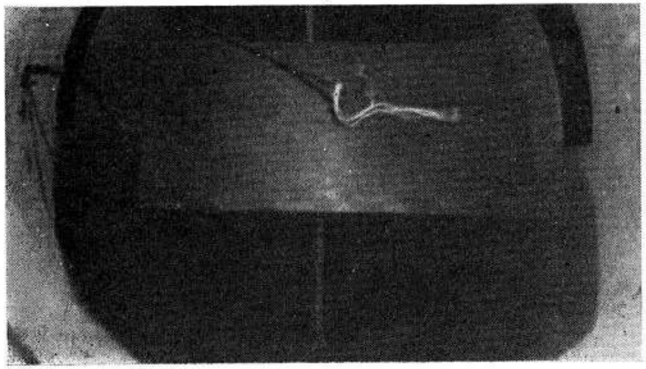
There are several streamers of wool, but in the normal position they are lying close together.

FIG. 33.



With the tilt of the airfoil approaching stalling point, the wool streamers are starting to waver.

FIG. 34.



With the airfoil in the stalled position the air flow has broken down, and the streamers are flowing about all over the top surface.

takes the weight of the test object and its counter-balance, and the "balance arm" itself is mounted on a universal bearing which enables it to move in any direction.

The whole apparatus is sufficiently sensitive and friction free for a weight of $\frac{1}{10}$ ounce, at the end of the fine thread, to swing the "balance arm" round.

Fig. 35 shows a pneumatic-tyred wheel mounted inside the tunnel ready for testing; the counter-balance, as a matter of convenience, being a similar wheel. The arrangement of the mounting of the "balance arm" on the pivot may be noted, as also the spindle and pulley (above and to the right of the wheel used as the counter-balance), over which the thread is passed, and to which are attached the weights balancing the drag of the test object.

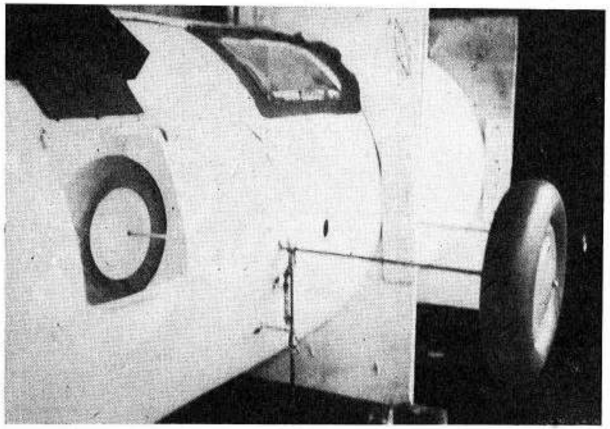
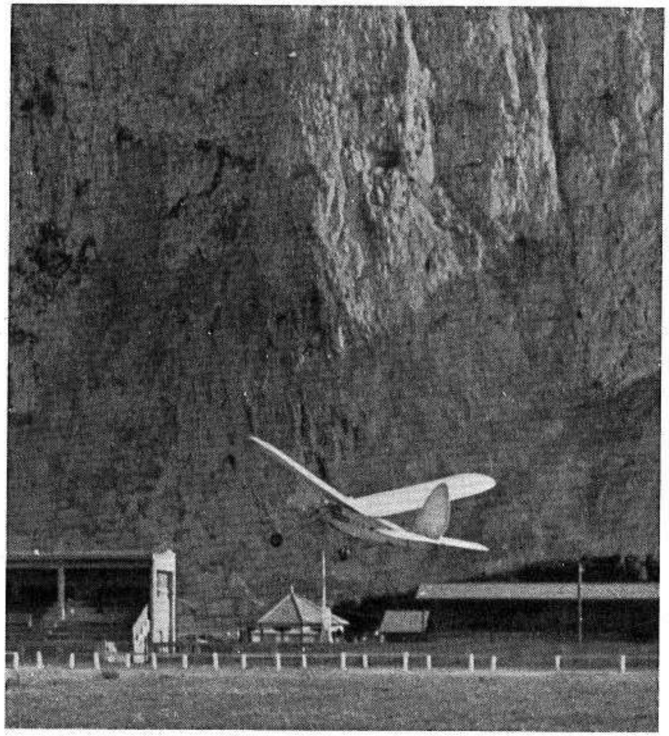


FIG. 35.

Here is shown one of the 8 in. diameter pneumatic power wheels described in another chapter, mounted inside the tunnel at one end of the balance arm, with its mate at the other end to statically balance it. The supporting bracket at the side of the tunnel carries a ball-bearing universal mounting, on which the balance arm can move.

To carry out a test, the motor is run up to the desired speed and, due to the drag, the wheel in the tunnel swings "downstream." Weights are then attached to the thread, and are so adjusted that when the "balance arm" is moved back and is placed exactly at right-angles to the axis of the tunnel, it stays there.

It will be appreciated that as soon as the "balance arm" swings the smallest distance away from this position, the wheel is no longer lying with its diameter coincident with the axis of the tunnel, but is tending to lie "across" it. Thus a greater area is presented to the airstream, and consequently it swings still more obliquely across the tunnel. It will thus be seen that unless the wheel is positioned with its diameter *exactly* coincident with the axis of the tunnel (and it can only remain so if the weight adjustment to balance the drag is exact) the "balance arm" will not "stay put" when the operator releases it, but will swing either up- or downstream.



This photo shows one of Lt.-Col. Bowden's 'planes just after taking-off from the sand at the foot of the Rock of Gibraltar.

To measure the lift and drag of an airfoil, a section of suitable size is fixed at its centre of lift, and at the desired angle of incidence, to the inner end of the "balance arm";

counter-balance weights being placed in the scale pan at the outer end so as to balance the arm horizontally.

When the desired airspeed has been obtained in the tunnel, weights necessary to approximately balance the drag are attached to the end of the thread passing over the pulley.

During this operation, the " balance arm," which due to the lift has been trying to rise inside the tunnel, has been prevented from doing so by a light touch from the operator. As soon as the drag has been roughly balanced, weights are *removed* from the scale pan, until the " balance arm " will remain in a horizontal position.

Readjustments are then made to the drag balance weights, and, if necessary, to the lift counter-balance weights, until the test piece will remain exactly horizontal, and with the balance arm at right-angles to the axis of the tunnel; when the drag is as indicated by the weights attached to the thread, and the lift is as indicated by the value of the weights *removed* from the scale **pan.**

A fine wire, stretched horizontally across, and at right-angles to the axis of, the tunnel, just in front of the leading-edge, serves as an excellent guide for correctly aligning the position of the airfoil section in relation to the airstream.

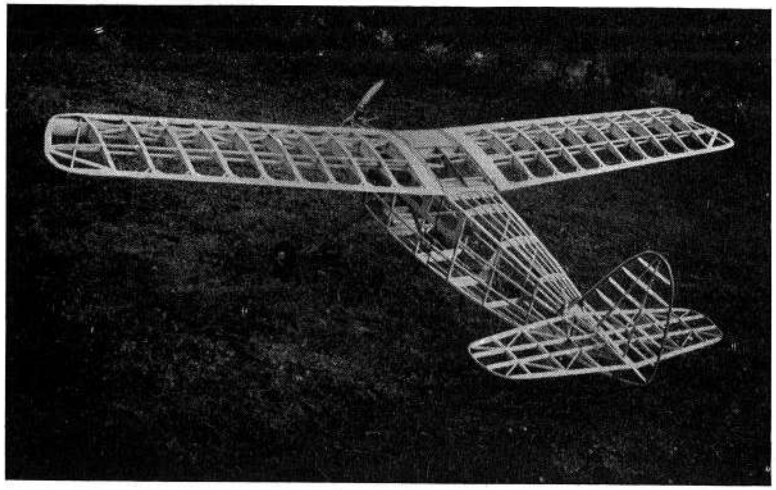
Below is given a set of readings (typical of many) obtained with this apparatus. The values are for drag of a wheel fitted with an 8-inch diameter × 2-inch wide pneumatic tyre—actually the wheel shown in the tunnel in Fig. 35.

Airspeed	Position of wheel			
Miles per Hour	Normal to wind Projected area = ·105 sq. ft.		At right-angles to wind Projected area = ·345 sq. ft.	
	Ounces drag	K =	Ounces drag	K =
17·3	·571	·00113	3·219	·00193
19·2	·781	·00126	4·395	·00215
22·6	1·020	·00119	5·895	·00205
		Average = ·0012		Average = ·002

The actual drag of many small model aircraft parts is not of great amount, and it might be thought that several parts, with drag values as small as ·5 ounce, could not much matter on a machine powered perhaps with an engine giving 2 or 3 pounds thrust. Apart, however, from the fact that these small amounts have an awkward habit of " adding up " to a total higher than at first might be expected, the losses in aerodynamic efficiency due to turbulence and " interference " may be of a much greater value than the actual drag itself.

For example, the drag of a pair of wheels might be 2 ounces, and the drag of the landing-chassis struts 1 ounce, and the drag of the fuselage 6 ounces; each figure being ascertained with the unit tested separately, but of course at the same speed in the tunnel.

When, however, these parts are all assembled together, the measured drag will exceed, sometimes by a large margin, the sum total of their respective drag values—in the case of this example, 9 ounces—due to the high degree of turbulence and mutual interference set up. The value of a wind tunnel, as a means of testing out various arrangements and assemblies, will therefore be appreciated, in addition to its normal use as an apparatus for measuring the lift and drag of aircraft components.



This photograph is of the Author's 1939 high-wing cabin petrol 'plane. Span is 8 ft. and overall length 4 ft. 6 in. The engine is a 9 cc. "Dennymite."

CHAPTER XI

WING CONSTRUCTION

A suitable assembling board—Method of simple wing construction—Detailed method of large wing construction—The pressure distribution over the surface of an airfoil—Detailed method of stressed skin construction.

It is essential when building wings of *any* size that the work shall be carried out on a perfectly level board, so that accuracy of construction and uniformity of shape may be assured. Such a board should be at least 6 inches longer than the wing (or half-wing as the case may be) and at least 6 inches wider than the greatest chord. It should not be less than $\frac{3}{4}$-inch thick, and should be well battened at each end and in the middle. When finished it should be dead level for the full length and breadth.

A piece of wood 1-inch square, the same length as the board, and dead straight, should be screwed down to the board to serve as a guide up against which the leading edge of the wing may be held during construction.

Fig. 36 shows a typical assembling board as used for a half-wing some 5 feet long.

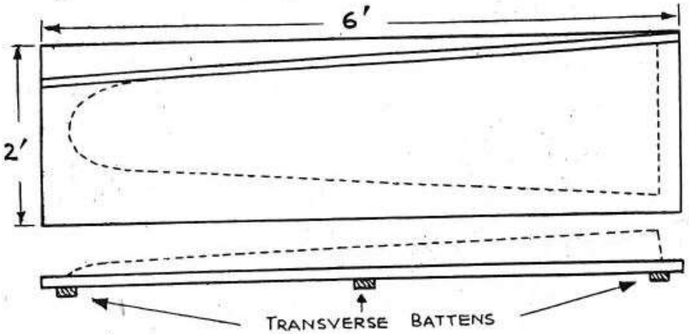


FIG. 36.

The simplest type of wing construction is that shown in Fig. 37, in which ribs of three-ply or balsa are spaced at fairly large intervals, and have a number of longitudinals set into notches cut as shown.

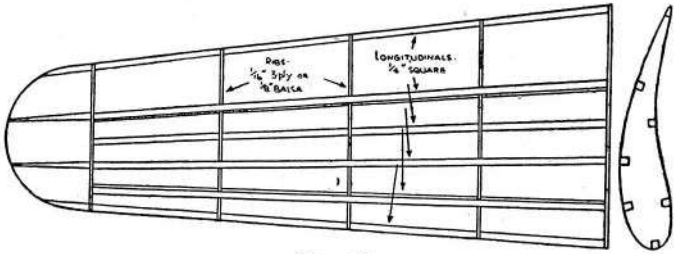


FIG. 37.

This design, whilst simple and easily and quickly built up, should not be used for wings of above about 5 feet span, as it allows of comparatively large areas being unsupported, and the tautness of the fabric alone is relied upon to keep its surface to the required shape; also the type of construction does not lend itself to large spans due to the absence of a vertical "backbone" running down the length of the span, without which the wing will tend to "droop."

For spans above 5 feet the wings should be built in halves, and either fixed into the sides of the fuselage or joined together, according to the design of the aircraft, by means of dowel rods of birch passing into each wing. These rods should not be glued in position, but should slide into a series of holes cut in the first 3 or 4 ribs, as shown in Fig. 38. Thus, in the event of a bad crash, if a rod should break, the broken piece may easily be removed from the tube and a fresh rod inserted.

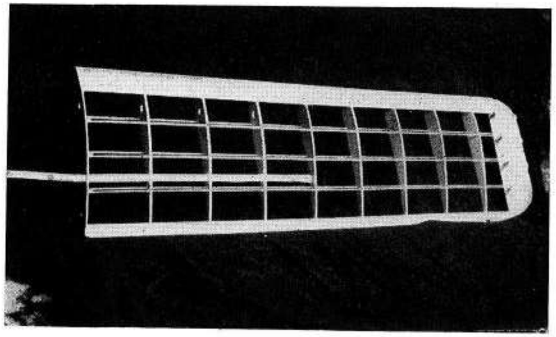


FIG. 38.

Two rods should always be used, and they should be of

$\frac{3}{8}$-inch or $\frac{1}{2}$-inch diameter, according to the size of the wing. Not be less than 15 inches long for a 3—4-foot half-wing, and about 20 inches by $\frac{1}{2}$-inch diameter for wings above 8-foot span.

There is one disadvantage to the method of fixing the two half-wings direct into the side of the fuselage, and that is that the angle of incidence cannot too easily be altered. If the machine has been carefully designed no great variation should be necessary. However, to allow of major adjustment being made in the angle of incidence, the fuselage must be constructed in such a way that the wing unit rests on the top, and it is best in this case to construct the centre section the width of the fuselage, into which the two half-wings are jointed. This method of construction is shown in Fig. 39.

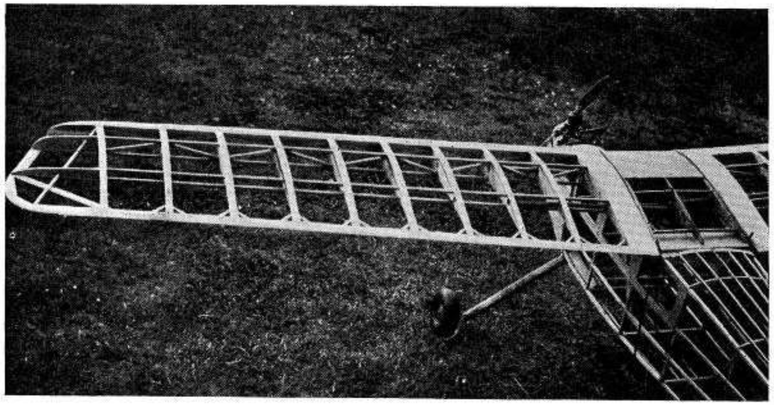


FIG. 39.

The centre section is held to the fuselage by rubber bands, and the two half-wings are joined to it by the rods, as already described. These can be seen in the photograph projecting into the wing through the first three ribs.

The construction of this type of wing is of interest. It is entirely of balsa, and each half-wing is 3 feet 8 inches long with a chord at the root of 14 inches, and the area is just under 4 square feet. Weight of each half-wing covered and doped is 10 ounces. The ribs are built from $\frac{1}{8}$-inch balsa, overlaid with strips of balsa $\frac{1}{2}$-inch wide and $\frac{1}{32}$-inch thick. These protect the edges of the ribs and also the silk stretched over them. (See

Fig. 40). The leading edge is covered with $\frac{1}{16}$-inch balsa. This construction allows the wing unit to be shifted backwards and forwards, and also the angle of incidence to be varied. In a severe crash the whole unit can be knocked off without either it or the fuselage suffering a great amount of damage.

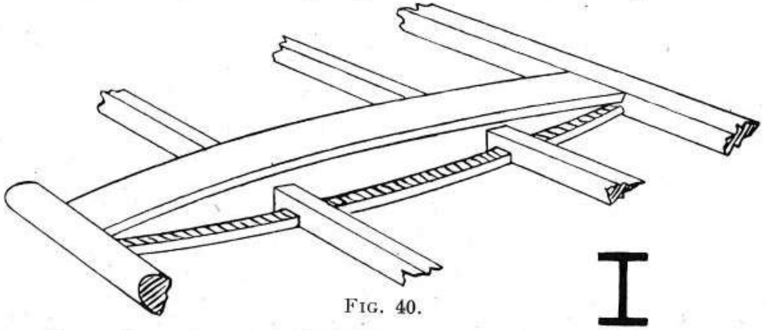


FIG. 40.

For wings of models of 10 feet span and over, it is essential that the design allows for the incorporation of a "backbone"—in effect a solid vertical panel—running throughout the length of the span at its deepest section. The construction recommended is that in which a number of wing-ribs are linked together by a number of longitudinals; these latter consisting of relatively thin, but fairly deep sections, arranged vertically in the ribs in such a manner that the top and bottom pair at the deepest section may be joined by a series of panels of three-ply, inserted in between each wing-rib—thus forming a vertical panel or "backbone" running throughout the length of the span.

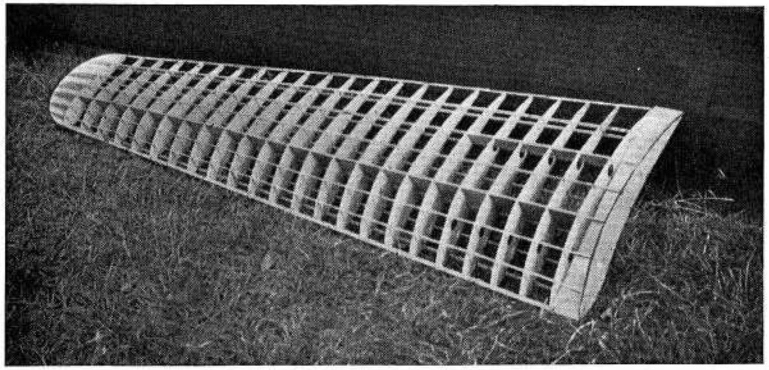


FIG. 41.

Fig. 41 shows an example of this method of construction, the half-wing being 4 feet 6 inches long by 18-inch chord at the widest part.

The series of holes for the dowel "tubes" may be clearly seen, as also the panels between each wing-rib, forming the "backbone."

This type of wing is immensely strong, permits of assembly in a reasonable length of time, and leaves no part of the wing covering unsupported for more than 2 or 3 inches in either direction. The ribs may be of $\frac{1}{32}$-inch three-ply or $\frac{1}{16}$-inch balsa, and the longitudinals of $\frac{3}{16}$-inch × $\frac{1}{16}$-inch birch, with a leading edge of $\frac{1}{4}$-inch × $\frac{1}{8}$-inch and a trailing edge of $\frac{3}{8}$-inch × $\frac{1}{8}$-inch.

The method of construction is as follows:—

First, the wing-ribs should all be cut out, each one smaller than its neighbour by the same amount, depending on the degree of taper given to the wing. They should then be assembled as shown in Fig. 42, whereby the lines of centre of lift are all superimposed and the top edges are all flush; a saw-cut is then made to accommodate one of the longitudinals.

Next, while the lines of centre of lift are still superimposed, the bottom edges of all the ribs are brought flush and another saw-cut made. Similarly two more cuts are made in the leading and trailing edges—the work now being as shown in Fig. 43.

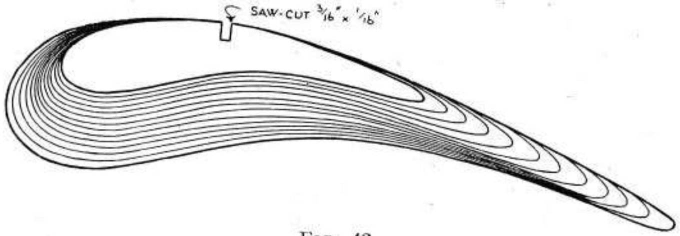


FIG. 42.

Having now decided on the number of intermediate longitudinal spars to be inserted, these positions should be marked off on the largest and smallest ribs, A1, A2, A3, etc. (See Fig. 44).

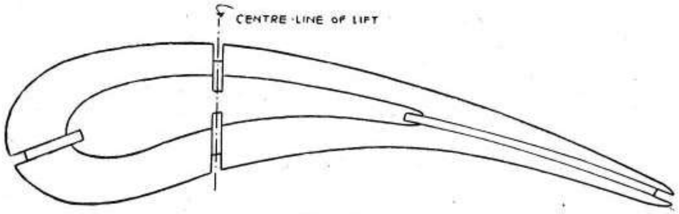


FIG. 43.

If the ribs are now assembled as originally—the points A.1, A1 : A.2, A2 : etc., can be joined up—thus all the intermediate ribs are marked in their correct places. When cutting these remaining saw-cuts, care must be taken that all edges, at the point of the cut, are flush to ensure the same depth.

This work completed, the assembly of the wing may be proceeded with. The piece of 1-inch square wood is screwed to the large board to give the required angle of "rake" which the wing design calls for, and the ribs are set out at 2-inch intervals. They are held upright and equally spaced by suitable pieces of wood provided for the purpose, as shown in Fig. 45. The top longitudinals are inserted first, then the wing turned over, and the bottom one inserted in the saw-cuts. These should be such that the longitudinals are a nice tight push-fit in the notches cut in the ribs.

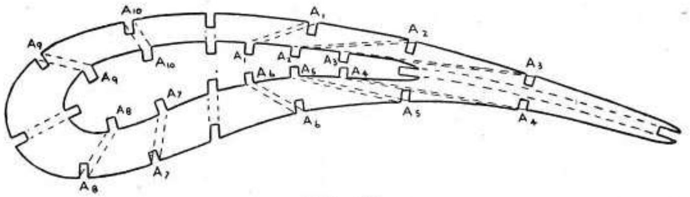


FIG. 44.

All joints should be glued, but this is best done after *all* the longitudinals have been inserted and the wood blocks removed. The longitudinals may then be withdrawn one by one, dabbed with glue and reinserted.

Pieces of $\frac{1}{32}$-inch three-ply should now be nailed between each rib, joining the top and bottom longitudinals which are over the line of centre of lift, as shown in Fig. 46.

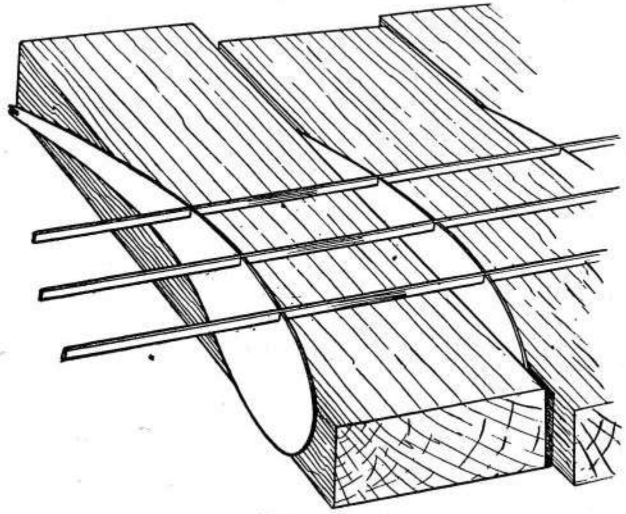


FIG. 45.

Thus are formed the rigidly-braced girders, which run the whole length of the wings, and the cantilevers (formed by the $\frac{1}{32}$-inch three-ply ribs) which project from each side. On these cantilevers are carried the intermediate longitudinals, which thus form an extremely strong framework on which the fabric, when stretched, is at no place unsupported for more than $2\frac{1}{2}$ inches in either direction.

To prevent any possible warping while the glue is drying,

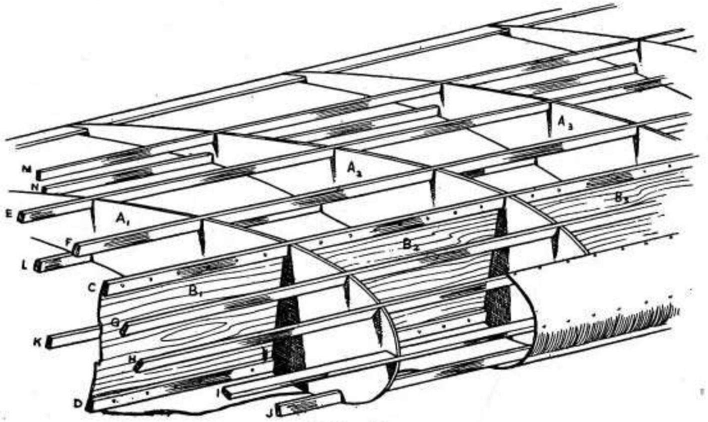


FIG. 46.

long pieces of perfectly straight wood may be laid along the top of the wing.

Finally, three-ply is soaked in very hot water, and bent to fit round the leading edge of each rib. If glue is smeared over the edge of each rib, and the three-ply laid over it and held in position by a length of elastic tied round and round the three-ply as shown in Fig. 47, it will be found that when dry it has firmly stuck to the ribs.

When covering the wing the under-surface should be fixed first. The fabric should be sewn up to the underside of each rib for its full length—a tedious job, but very necessary if the proper shape is to be maintained. The upper surface may then be fixed in place and the wing doped and painted. During construction the wing should be kept as much as is possible on the board and held in position by long lengths of wood. When both half-wings have been completed they should always be held together, under-surface to under-surface, by elastic bands, and stored in a vertical position.

The question of dihedral angle between the two half-wings is best dealt with by setting the first rib at the required angle from the vertical, so that when the two half-wings are joined these two ribs will be flush together.

It is very important that the leading edge of a wing should be given a perfectly smooth surface, and that its shape should be uniform throughout the span; and this can only be done by covering the front portion with thin three-ply or balsa.

Fig. 48 gives a general idea of the pressure distribution over the upper and lower surfaces of a wing, from which it will be seen that the highest pressure occurs at the nose, and at the front of the upper surface—hence the reason for recommending that this portion should always be covered with $\frac{1}{32}$-inch three-ply or balsa, so as to ensure that the profile is symmetrical and regular throughout the span of the wing.

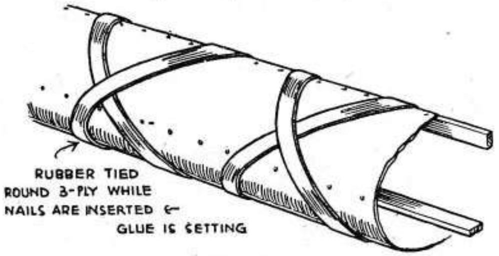


FIG. 47.

Another method of construction best applied to large wings, is that in which the wing covering is of $\frac{1}{32}$-inch balsa, overlaid with silk, and finally painted. If the ribs are made of $\frac{1}{16}$-inch or $\frac{1}{8}$-inch balsa, and spaced not more than 3 inches apart, large half-wings of 5 or 6 feet length may be satisfactorily built by this method.

Steps in the construction are as follows:—

First the complete set of ribs is cut out in the usual way—and three sets of saw-cuts made to accommodate 3 longitudinals of $\frac{3}{16}$-inch × $\frac{3}{16}$-inch birch; cuts are also made for the leading and trailing edges as shown in Fig. 49. These and the 3 longitudinals are then glued in positon, and the framework allowed to set quite dry—long pieces of wood being laid along the wing to keep it perfectly flat on the assembling board.

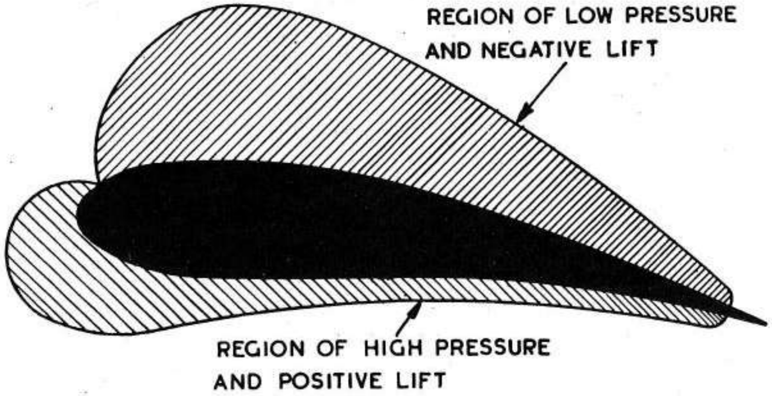


FIG. 48.

Panels of $\frac{1}{32}$-inch three-ply are then nailed and glued between each wing-rib, forming the triangular-shaped backbone as shown in Fig. 50.

FIG. 49.

The top covering of $\frac{1}{32}$-inch balsa is applied first, as this can be done with the wing lying flat on the assembling board; strips of balsa, as wide as may be obtained, are laid up edge-to-edge and parallel to the leading edge; and are glued direct on to the wing-ribs, after which the wing is allowed to dry out with suitable weights laid along the full length so as to ensure that the covering is glued to the full chord of the ribs. After which the wing is turned over and the underside covered, suitable weights being laid on long strips of wood so as to ensure that the balsa conforms to the concave camber of the wing section.

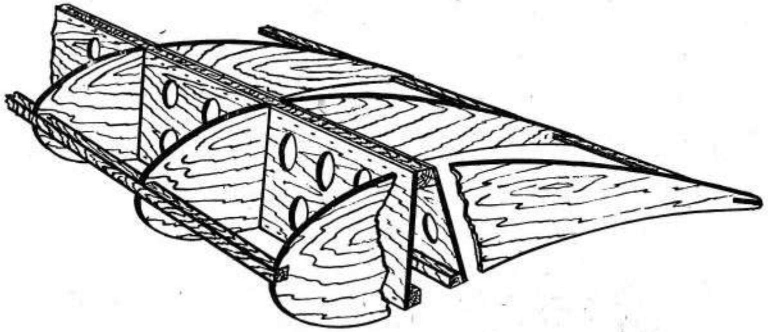


FIG. 50.

Finally, the wing is carefully rubbed down with very fine-grade sandpaper, after which it is covered with silk affixed with photo paste—no stretching is necessary—the material being slightly damped and then laid smoothly over the balsa—the whole of which has been previously smeared with a thin layer of photo paste. Dope must *not* be applied, as it will shrink the wood as well as the silk.

This " stressed skin " method of wing construction has the great advantage that a very rigid wing is formed with a good degree of resistance to torsion—this ensuring that the trailing edge at the tips will not " droop," a common fault found in many large wings.

Whilst quick-drying cement may be used in the building up of a small wing, it should not be used in large wing construction, as, due to its quick-setting properties, one part of the wing will become quite rigid before another part is completed, and as not all of the assembling can be carried out with the wing actually on the board, there is a risk that it may not dry out perfectly flat.

Instead, one of the several proprietary brands of glue should be used, as with these a certain degree of flexibility exists for the first 2 or 3 hours; so that, when the wing is completely assembled, any small twists or warps will " fade out " during the subsequent drying and hardening of the glue if weights are placed on the " high " parts.

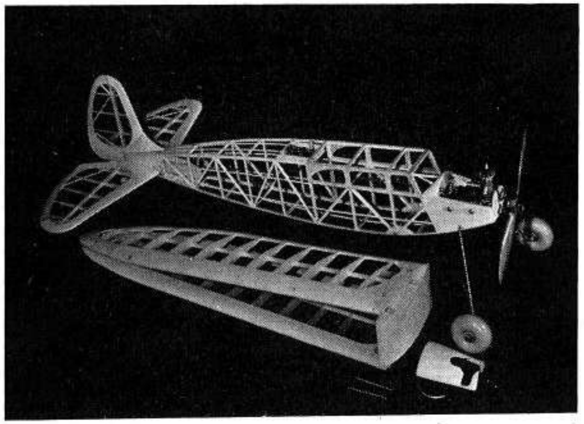
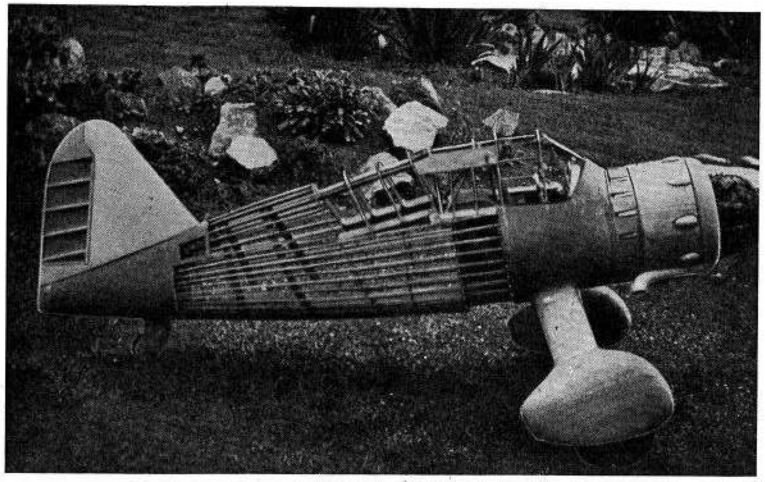


FIG. 51.

Here is an interesting method of construction which makes for easy assembly. Note how the main wing is in two halves hinged to a centre section. The tail assembly is shown in greater detail in Fig. 69.



This photograph shows the fuselage of the Author's 10 ft. span "Lysander." The overall length is 6 ft. The spats are some 14 in. long. Three-ply $\frac{1}{32}$-inch thick is used to represent metal sheeting on the full-size aircraft.

CHAPTER XII

FUSELAGE CONSTRUCTION

Stresses in fuselages—" Compression " struts for use in fuselages—Methods of constructing fuselages of (*a*) rectangular section, (*b*) circular section—Methods of constructing fuselages with " moulded " lines, (*c*) with stressed skin of thin three-ply, (*b*) with laminations of thin balsa, and with stringers.

THE fuselage of a model aircraft, whilst serving no useful *flying* purpose, since it produces no lift, *does* provide a means of linking up the various component parts. Additionally, in the case of the rubber-driven motor, the fuselage has to serve as a " stretcher " for the rubber; a factor which calls for quite different considerations in construction when comparison is made with a fuselage for a petrol-engined aircraft.

A fuselage which is to accommodate a rubber motor will *always* be in compression, whilst the petrol-engined aircraft, strictly speaking, will be in tension; since the motor is pulling at the front, whilst the air resistance offered by the stabiliser and fin is acting as a drag at the rear.

From the point of view of landing strains, both types of fuselage are, of course, subjected to the same kinds of stresses, which tend in the main to break the back of the fuselage as the wheels touch the ground.

Since the longerons are in compression—due to the tension of the rubber motor—the top and bottom tie-bars are in tension, and thus may be flat and of comparatively thin section. The side tie-bars are also in tension *during flight*, but in landing, those forming the anchorage for the rear legs of the landing chassis are in compression—sometimes very much so! —and therefore a considerably stronger section must be used.

A suitable design for " compression " struts is that in which an angle is made up from 2 pieces of birch or spruce, say $\frac{1}{4}$-inch × $\frac{1}{16}$-inch and $\frac{3}{16}$-inch × $\frac{1}{16}$-inch. These should be pinned at intervals of about $1\frac{1}{2}$ inches, after having been thinly coated with glue, and laid up together at right-angles.

Fig. 53 shows this method of construction applied to a large fuselage powered by a multi-size spindle, rubber-driven motor, the distance between hooks being 36 inches, and the maximum cross-section of the fuselage being 10 inches high by $4\frac{1}{2}$ inches wide. The longerons are $\frac{3}{16}$-inch × $\frac{3}{16}$-inch, angle struts at the front built from $\frac{1}{4}$-inch × $\frac{1}{16}$-inch and $\frac{3}{16}$-inch × $\frac{1}{16}$-inch, and those at the back from $\frac{3}{16}$-inch × 1-24 inch and $\frac{1}{8}$-inch × 1-24 inch.

It should be noted how the landing stresses are distributed in several directions from the point where the rear chassis strut is attached to the fuselage. The weight of the fuselage proper, i.e., excluding landing gear and rudder, was 7 ounces.

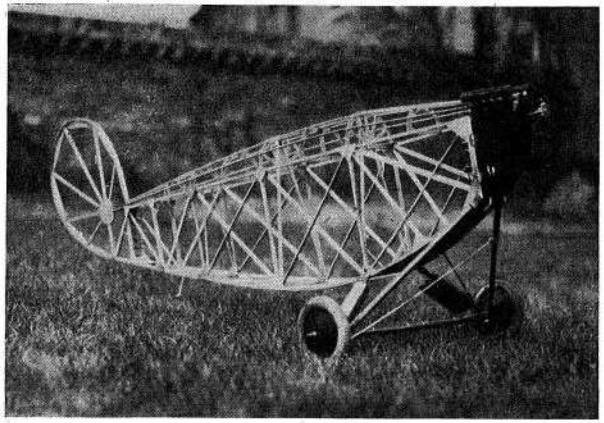


Fig. 53.

It will be noticed that three-ply formers, as often used in small rubber-driven models, have not been used, the reason being that as the longerons are in tension (and therefore trying to " bow outwards ") they could not properly be anchored to the former—whereas a "lapped" joint, braced top and bottom by fishplates, is so strong as to be practically indestructible.

The fuselage of the petrol-engined machine has to contend with a somewhat different set of conditions. It is part of a machine weighing up to 10 or 12 lb., and thus must withstand landing shocks of some considerable magnitude. It also has to accommodate the coil and battery somewhere in its " inside," as well as the engine at its extreme front.

If the fuselage is to be of rectangular cross-section, the principles of construction as illustrated in Fig. 53 should be used—suitable modifications, of course, being made according to the type of aircraft.

In constructing a fuselage which is of circular cross-section, three-ply formers, suitably lightened are, of course, ideal for supporting the longerons. For large machines the formers should not be less than $\frac{1}{16}$-inch thick at the rear and $\frac{1}{8}$-inch at the front.

From the point of view of appearance, the greater the number of longerons the better, as they naturally allow of the truly circular cross-section being retained between the three-ply formers. The disposition of these latter will naturally depend on the positions of the battery, coil, wing, and landing-gear attachments—as the formers should, of course, be so positioned that they provide suitable points of anchorage for the above-mentioned components.

These closely-spaced longerons should be about $\frac{3}{16}$-inch × $\frac{1}{16}$-inch, but the two to which the struts of the landing chassis are attached should be $\frac{3}{16}$-inch × $\frac{3}{16}$-inch. If the aircraft is a high-wing machine, then two of the top longerons should also be of this heavier size.

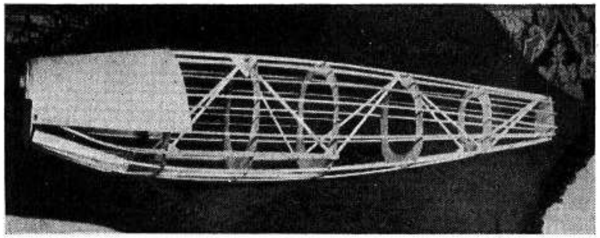


Fig. 54.

Fig. 54 shows a large fuselage built to the above specification—the greatest diameter is 11 inches and the overall length is 5 feet. The 2 longerons to which the landing-chassis struts are anchored consist each of two lengths of $\frac{1}{4}$-inch × $\frac{1}{8}$-inch birch, spaced $\frac{1}{8}$-inch apart. The longeron at the top and 2 main ones at each side are of $\frac{3}{16}$-inch × $\frac{3}{16}$-inch, whilst the remainder are of $\frac{3}{16}$-inch × $\frac{1}{16}$-inch—the material in each case being birch. All the bulkheads are of $\frac{1}{8}$-inch three-ply. This fuselage was built for a high-wing 10-foot span monoplane, and as shown (but, of course, less the landing chassis and engine) weighed $13\frac{1}{2}$ ounces.

When it is desired to construct a fuselage with fully "moulded" lines—i.e. in which truly curved surfaces, and radiused "flarings" of the wing roots into the fuselage, are designed, the whole fuselage may be covered with $\frac{1}{32}$-inch three-ply, or $\frac{1}{16}$-inch balsa.

An example of this type of construction is shown in Fig. 55, which shows the partly-finished fuselage of the 10-foot span low-wing monoplane, described in the last chapter of this book. The overall length is 4 feet 6 inches, and the largest diameter is of nearly circular section—actually 11 inches deep by 10 inches wide.

The framework consists of 8—$\frac{3}{16}$-inch × $\frac{3}{16}$-inch birch longerons, let into notches cut in a series of $\frac{1}{16}$-inch three-ply bulkheads, the whole fuselage then being covered with $\frac{1}{32}$-inch three-plybirch, laid up in sections, after steaming and curving to shape. Wherever joints in the sections occur, the edges are butted, and strips of $\frac{1}{32}$-inch three-ply laid along the joint, and glued and nailed up in position on the inside of the fuselage. Thus the outer surface is quite smooth.

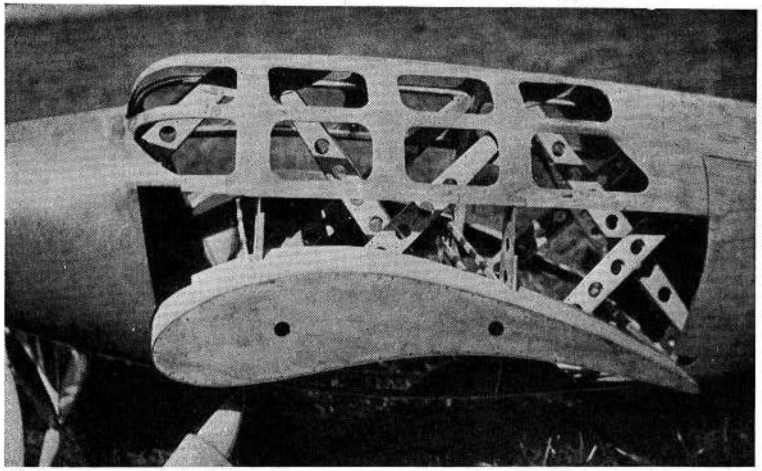


Fig. 55.

Fig. 56 shows how the "flaring" of the wing roots into the fuselage is carried out—this being done by forming a series of "petals" in a sheet of $\frac{1}{32}$-inch three-ply, and steaming up to shape.

The whole secret of making a satisfactory job lies in the fact that the cuts in the three-ply are made in such a manner that they extend past and in between each other as shown in the illustration.

It will also be noted that the sharper the angle, the more close together are they positioned. The cuts are made with a pair of scissors. The three-ply is well soaked in very hot water, glued on the underside, and then carefully formed in position. It will be noted that when coming round a convex surface, as at the front of the wing, the arranging of the three-ply leaves triangular gaps between each section, and these must afterwards be fitted with carefully-cut wedge-shaped pieces.

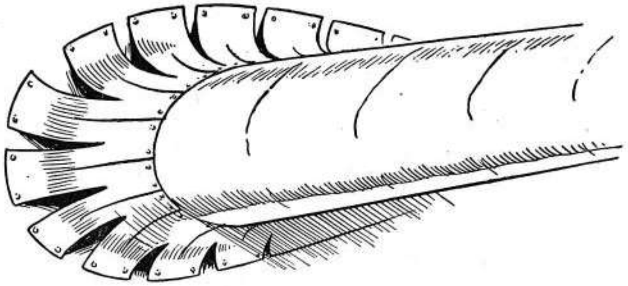


Fig. 56.

When coming round a concave surface, as in the case of the underside of the wing, the sections will overlap, and the overlapping pieces must be carefully cut away.

When dry, plastic wood may be smeared along the joins to fill up tiny cracks and the whole "flare" well sandpapered down.

The photo on page 80 shows the "flaring" completed. This fuselage was finally covered with silk and given several coats of paint—the resultant surface being quite smooth.

The weight, complete with suitable steel fish-plate anchorages for the landing chassis and nose-block for the engine mounting; also suitable supports for the coil and batteries, was 4 pounds 3 ounces; and the strength was such that, when stood on its nose, it would support the weight of a man without showing the slightest sign of breakage.

Compression struts for use in large fuselages may be made in the following way—the type of strut being as shown in Fig. 57.

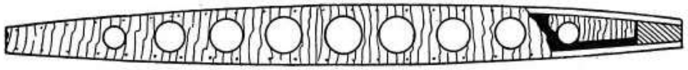


FIG. 57.

From a sheet of $\frac{1}{32}$-inch three-ply, two identical pieces are cut and lightened with suitable holes punched out with the type of punch used for cutting leather washers. These two pieces are separated by 2 pieces of $\frac{1}{8}$-inch × $\frac{1}{8}$-inch, curved to follow the edges of the pieces of three-ply. The maximum width should be $\frac{1}{12}$ of the length, and the width at each end should be $\frac{1}{24}$ of the length, i.e., a 6-inch long strut will be $\frac{1}{2}$-inch wide at the middle and $\frac{1}{4}$-inch at the ends, where the $\frac{1}{8}$-inch × $\frac{1}{8}$-inch ribs touch. For sizes above 6 inches long there will be a gap between the ribs at the ends which must be filled with a piece of $\frac{1}{8}$-inch thick wood neatly shaped to suit. Birch must be used for the ribs and these fillets and the three-ply should be glued and pinned to them.

When introducing the spars into the fuselage frame care should be taken to see that they fit exactly. It is best to make the spars with square ends, and then trim them to a point to fit snugly between the junction of former and longeron. Finally the spar should be glued and pinned into position, and triangular gusset plates, also $\frac{1}{32}$-inch three-ply, fixed on each side as shown in Fig. 58.

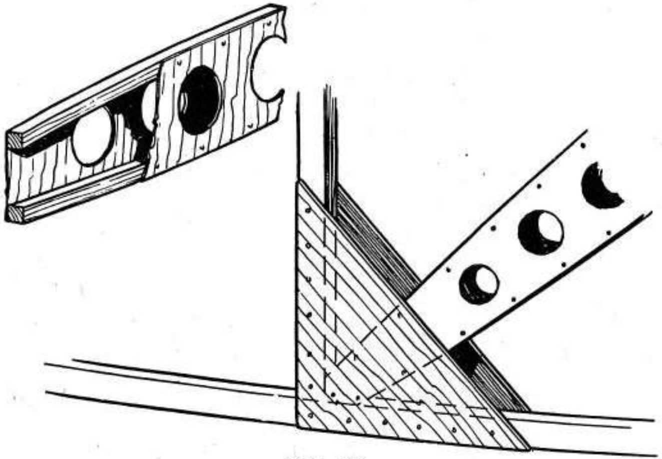


FIG. 58.

The method of construction in which sheets of thin balsa are used for covering the fuselage may be used for both small and large fuselages, and whilst the finished product will not be quite as strong as the fuselage covered with $\frac{1}{32}$-inch three-ply, it will be amply strong enough for all ordinary purposes, and has the advantage of being extremely light.

Essentially the method of construction consists of building up a skin or " shell " of balsa on a wooden former which has been carved and shaped to the exact finished size of the fuselage.

Commencing with the tail end of the fuselage, sheets of $\frac{1}{32}$-inch balsa are laid up edge-to-edge over the surface of the block of wood, and held in position by means of drawing pins and rubber bands. As work proceeds towards the nose, the strips will require to be shaped so that they conform to the contour of the wood block.

When the block has been completely covered with strips of balsa, all butting edges are carefully gone over with fine sandpaper to ensure that there are no " humps " or ridges standing.

Next a second layer of strips of $\frac{1}{32}$-inch balsa is glued over the first layer, these running diagonally across the first.

Commencing at the tail of the fuselage, a few drawing pins are removed, sufficient to allow of the first strip being glued into position, after which the pins are replaced; and so, strip by strip, the outer covering is glued in position.

During this operation great care must be taken to see that no glue creeps down between any cracks between the strips of the inner layer.

Immediately the outer covering has been fixed in position, a length of fairly thick rubber say $\frac{1}{4}$-inch × $\frac{1}{16}$-inch, is tightly wound from end to end of the fuselage, the drawing pins and temporary rubber bands being gradually removed as the taping up proceeds. Thus the outer layer of strips is brought into intimate contact with the inner layer; and if glue, and *not* quick-setting cement, is used, the inherent flexibility possessed by these glues for the first 2 or 3 hours allows of slight "bedding-down" movements taking place between the layers of balsa.

Quick-drying cements must *not* be used.

The fuselage should be allowed to remain in a warm, dry atmosphere for not less than 48 hours, after which the rubber taping may be removed, and the entire surface carefully rubbed down with fine sandpaper. A circular cut, round the largest diameter, is then made with a razor blade, whereupon the two sections may be withdrawn from the wood block.

Suitably shaped bulkheads are then made from $\frac{1}{16}$-inch or $\frac{1}{8}$-inch three-ply and inserted at intervals along the length of each section, care being taken to arrange that they are positioned so as to strengthen the fuselage where the wings and the landing chassis are attached. In large fuselages several longerons of $\frac{3}{16}$-inch × $\frac{3}{16}$-inch may, with advantage, be glued throughout the length of each section.

The nose will require to be strengthened with pieces of solid balsa, and brackets fixed to carry the coil and batteries.

When all interior work has been completed the whole of the inside of each section should be given a good coat of hot glue; after which the two sections may be joined together in the following manner:—

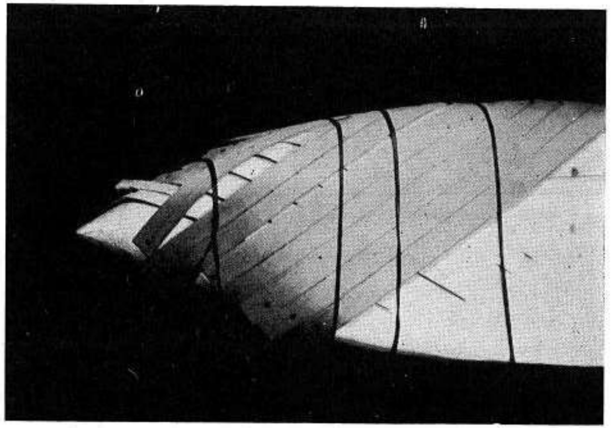


Fig. 59.

A liner of $\frac{1}{16}$-inch three-ply is made by bending a strip about three inches wide into a circle, whose diameter is such that the sleeve so formed just fits into one of the fuselage sections, and having been pushed in half-way, it is glued in position and a bulkhead inserted inside this ring. The other section of the fuselage is then slipped over the projecting portion of the sleeve, and thus the joint is made in exactly the same manner as the two sections of a cardboard Easter egg fit together.

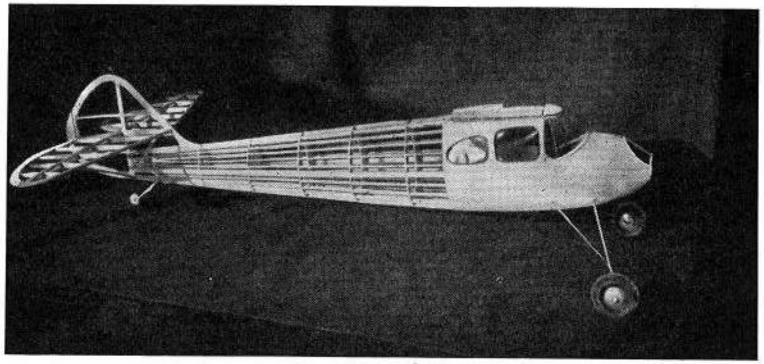


Fig. 60.

As the sleeve is supported by the bulkhead, a length of rubber may be quite tightly wound round the joint to ensure contact between the fuselage sections and the sleeve whilst the glue is drying.

Finally, the whole fuselage is covered with a layer of silk, stuck down with photo paste, and given two coats of cellulose paint.

Fig. 59 shows the nose of a large fuselage in course of construction by this method.

The width of the strips of balsa used in this method of construction will, of course, depend on the size of the fuselage, but normally 2 inches to 3 inches wide strips may be used, although these will require to be narrowed down to conform to the contours at the nose and wing-root "flarings."

With the considerably increased attention being given to the construction of Scale Model Aircraft, in which monocoque construction is not always used, the aero-modeller has had to develop his art by devising suitable constructions, which allow of the appropriate number of longerons being incorporated, so as to imitate the full-sized aircraft. In light-weight models the bulkheads may be cut from $\frac{1}{8}$-inch thick sheet balsa of fairly hard grade, the longerons being notched into them in the usual way. An example of this construction is shown in Fig. 60, which is of a 21-ounce all-up weight petrol 'plane, driven by a 2·5 cc. engine.

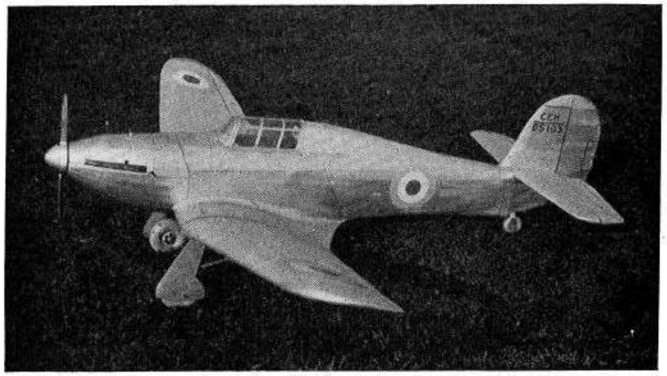


FIG. 61.

In constructing larger models the bulkheads should be of three-ply $\frac{1}{16}$-inch thick. A very interesting model, in which the workmanship is of high order, is a scale model Hawker "Hurricane," built by Mr. D. J. Miller. Fig. 61 shows the completed model. It is of 6 feet 8 inches span and driven by a 9 cc. Ohlsson petrol engine. The engine is totally enclosed, and to achieve this it had to be set back some inches from the nose of the fuselage, and the drive to the airscrew arranged through a shaft with universal coupling.

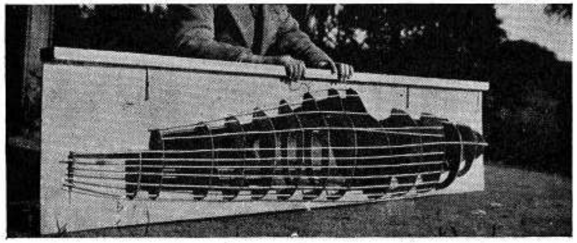
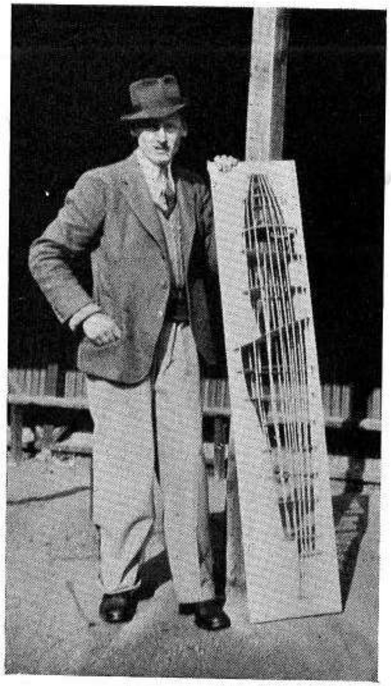


FIG. 62.

FIG. 63.



There is a full description of Mr. Miller's 'plane, and a set of scale drawings spread over three pages, in the May, 1939, issue of *The Aero-Modeller*.

In constructing the fuselage of this model, Mr. Miller mounted the bulkheads in a diaphragm and then let in the longerons on either side.

Fig. 62 shows the bulkheads mounted in the diaphragm, and Fig. 63 Mr. Miller holding the unit. In Fig. 64 is shown the completed fuselage ready for covering.

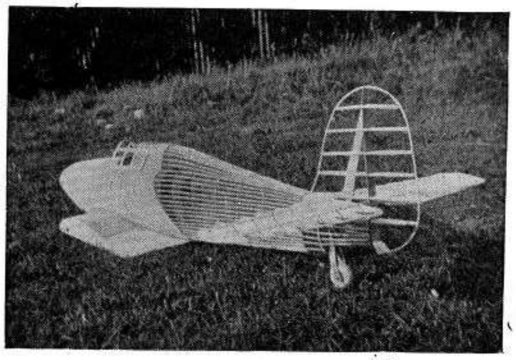
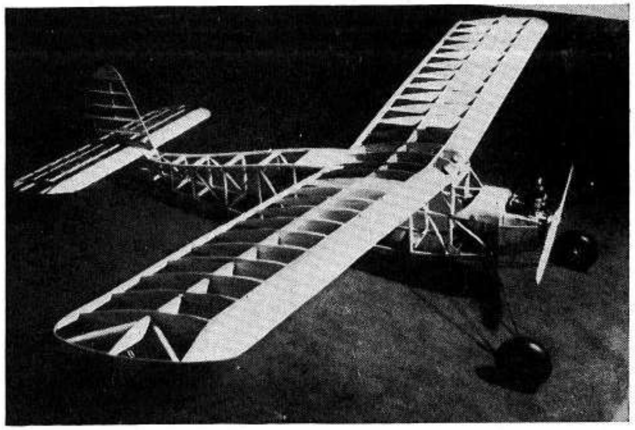


FIG. 64.



This 'plane was built by Mr. Stevens to a well-known design. Span is 7 ft. 6 in., and the engine is a 9 cc. "Dennymite."

CHAPTER XIII

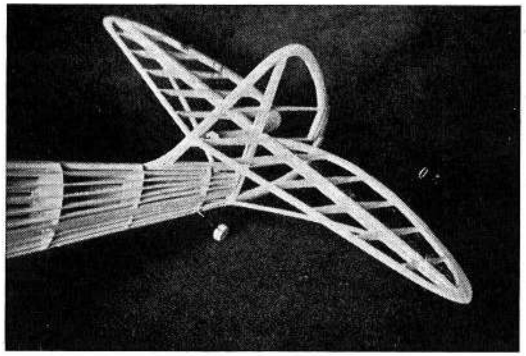
TAIL UNITS

IN power-driven model aircraft construction the control surfaces may be built up in three different ways. On small light models the fin and elevator may be built straight in to the fuselage, with the tail 'plane being set at no angle of incidence, and functioning purely as a stabiliser, as explained in Chapter IV. For larger models, for the sake of portability, the tail-plane and fin are built separately from the fuselage.

Fig. 65 shows a tail-plane and fin built integral with the fuselage. This is the tail unit of the fuselage shown in Fig. 60.

FIG. 65.

This photograph is of the tail unit shown in the photograph of a complete fuselage in Fig. 60, on page 129.



In Fig. 66 is shown the fin and elevator built as one unit, which also incorporates what is in effect the tail end of the fuselage. Beneath the leading edge of the fin will be seen a raised block, which registers into the tail end of the fuselage. Whilst this method of combining the fin with the stabiliser is a little cumbersome, it has the merits of rigidity, and the unit

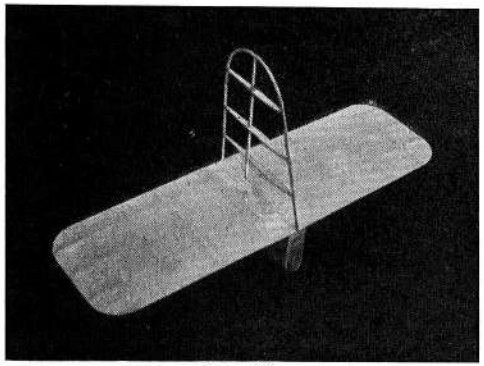


FIG. 66.

as a whole may easily be adjusted. It is held up to the tail end of the fuselage by a short length of rubber twisted round opposite pairs of hooks at its junction to the fuselage. By the insertion of thin packing pieces at the top or bottom, or at either side, of the fuselage, variation in incidence and in direction of the fin may be made.

Fig. 67 shows the rear end of another model built by the author, in which the tail unit may be seen, held up by rubber bands, to the rear end of the fuselage.

Cantilever spring mounting for the tail wheel and the connections for the booster battery, may be noticed in this photograph.

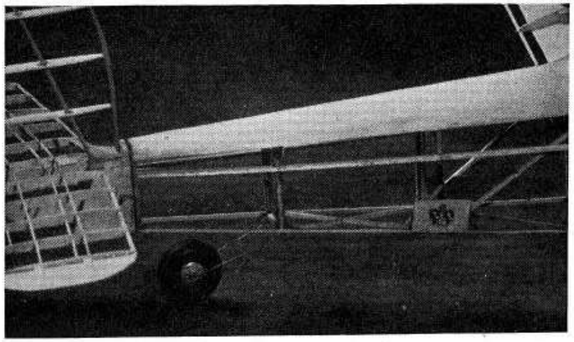


FIG. 67.

The construction of tail units should be as light as possible to avoid unnecessary weight. In Fig. 68 are shown the control units for the high-wing cabin monoplane described by the author. The stabiliser is built as a separate unit, and is located on a platform formed at the rear end of the fuselage. The span of this unit is 30 inches, with a chord of 10 inches, and completed and covered with silk and doped the weight is 3 ounces. The fin has balsa ribs with strips overlaid on their edges to support the silk, as is described in the chapter on Wing Construction. The outline is made from a piece of $\frac{3}{16}$-inch diameter cane steamed to shape. It will be noticed that there is a vertical post and a raking post, both of which rise to the highest point of the fin. The purpose of this is that in the event of the machine making a " nose-over " landing, and the top of the tail hitting the ground, the blow is distributed throughout the whole framework of the unit, and no damage is sustained. The vertical post carries through to the bottom of the fin and is located in a middle plate fixed to the bottom of the fuselage. At the front end of the fin there is a small peg over which a short rubber band passes down to either side of the fuselage, as may be seen in the photograph. The construction is such that the fin may be deflected to either side of the centre line by a few degrees, and the stabiliser may also be adjusted for variation of angle of incidence. The method of fixing the fin holds the stabiliser in position, yet on release of the rubber band both units may immediately be detached.

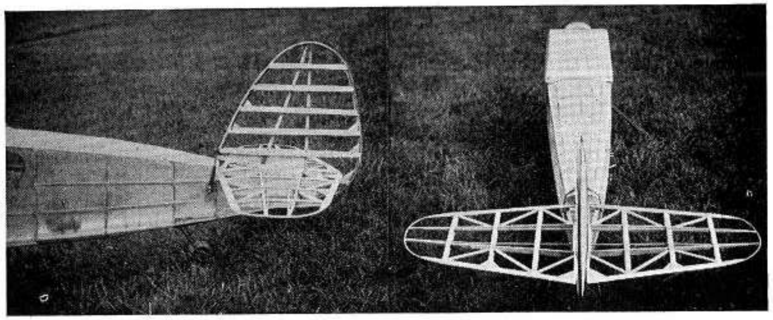


FIG. 68.

In this photo is shown the tail unit of the Author's 'plane, illustrated on page 108.

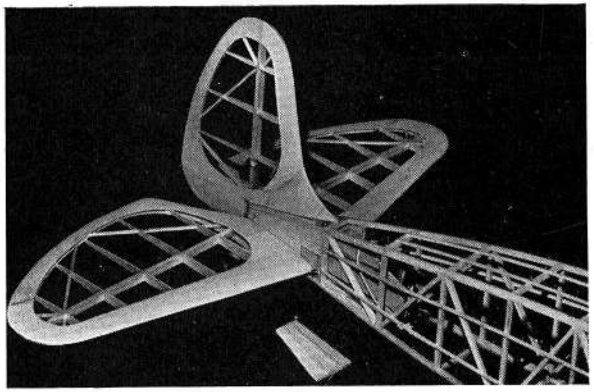
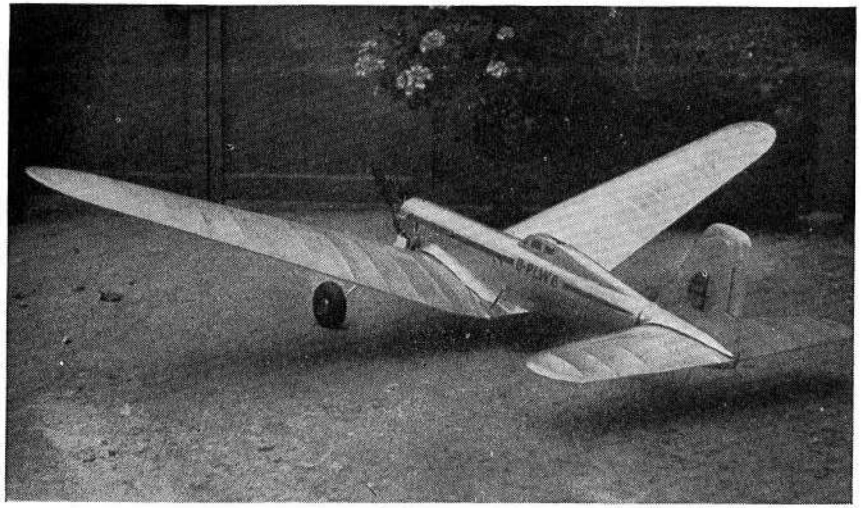


FIG. 69.

In this photo is shown the construction of the tail unit of the 'plane illustrated in Fig. 51.



This well streamlined 'plane is a very successful one of several built by Lt.-Col. C. E. Bowden in 1938. The badge of membership of the National Guild of Aero-Modellists—of which Lt.-Col. Bowden is Hon. Chairman—can be seen on the tail unit.

CHAPTER XIV.

LANDING CHASSIS, TYRES, AND WHEELS

Types of landing chassis—Details of various constructions—Factors affecting the design of landing chassis—Pneumatic tyres—Airwheels—Semi-solid tyres—Solid and built-up wheels—Axle tubes and methods of fixing to wheels.

NO matter what size or type of model aircraft is under consideration, the first point to be settled in regard to the take-off and landing apparatus—i.e. the chassis and wheels—is whether the chassis shall be constructed from a purely practical point of view—as light and as strong as possible without much attention to appearance—or whether it shall be a copy of some type in actual use—which will be obviously more elaborate, and weighty.

Similarly it must be decided whether the wheels shall be " solids "—either of metal or wood—or whether penumatics shall be used.

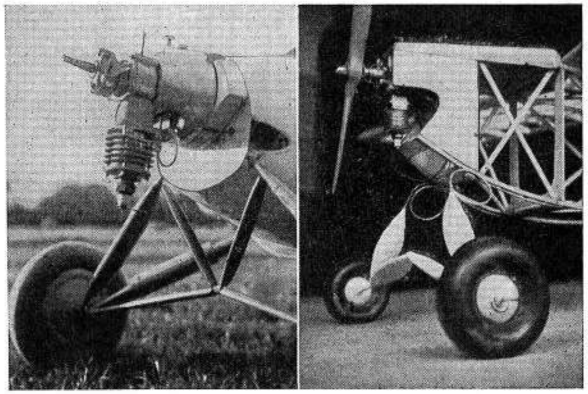


FIG. 70.

Now unless a model aircraft has a fairly light wing-loading resulting in a reasonably flat glide, it will not make a 3-point landing, but will " come in " at an angle of anything between 10 and 20 degrees to the ground.

For this reason it is essential that any type of landing chassis should be capable of a " backwards " movement instead of an " up-and-down " movement. A good test of any landing chassis is to drop the whole aircraft vertically from a short distance above the ground, when no appreciable movement of the wheels should take place. If, however, the aircraft is thrown " into the ground " at an angle, the wheels should move backwards, and so reduce the landing shocks to the rest of the aircraft.

In this respect, the simple " strut and wire " type of chassis is ideal, since the " safety-pin " type of coil spring which it incorporates allows of a backwards movement of several inches. This type of undercarriage is illustrated on the right of Fig. 70.

However, the great drawback of this type of chassis is that it is not " real " looking, and cannot be used on any scale type of model. If the machine is being built to a " performance " specification, the need for lightness will compel the designer to adopt a simple " strut and wire " type similar to that shown in Fig. 71, which is easy to construct, will stand a lot of hard wear, and may be built in any size. For aircraft up to 3 pounds weight, the spring-steel wire should be of $\frac{1}{8}$-inch diameter; from 3 to 6 pounds weight it should be $\frac{3}{16}$-inch diameter, and above 6 pounds it should be not less than $\frac{7}{32}$-inch diameter.

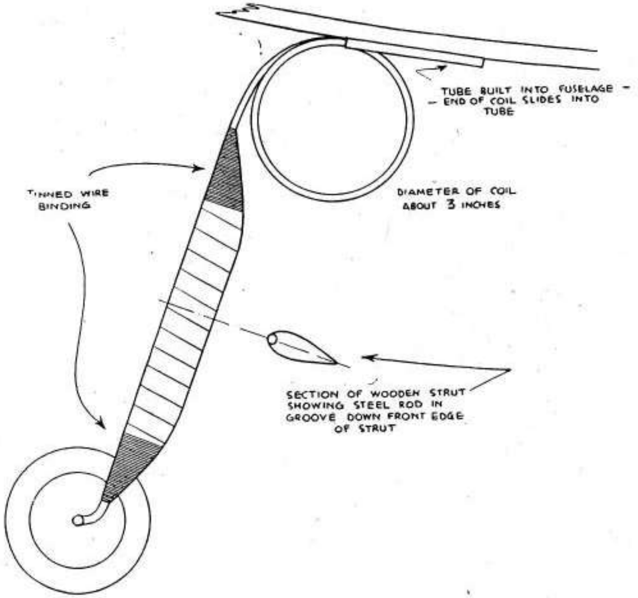


FIG. 71.

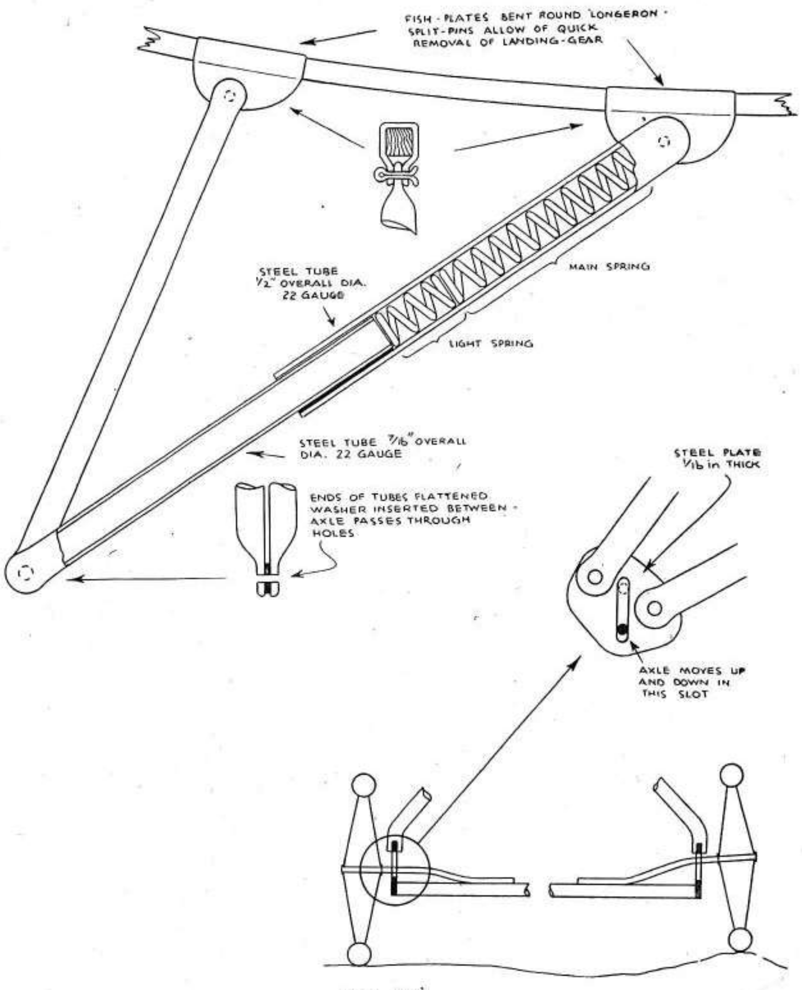


FIG. 72.

The wooden " fairings " may be either of birch or balsa and should be tightly bound with strips of silk after affixing, in halves, to the steel rod.

In Fig. 72 is shown a somewhat more elaborate landing chassis in which use is made of compression springs contained in tubes which slide one within the other; suitable "fairings" of balsa being afterwards affixed to the tubes if it is desired to " improve their looks." Built with the sizes or tubes as shown such a chassis would be suitable for a machine of about 5-7 pounds in weight.

Fig. 73 shows a chassis built on this principle for a large high-wing machine weighing some 9 pounds. The tubes were of steel, and of $\frac{1}{2}$-inch and $\frac{9}{16}$-inch diameter respectively, a movement of 2 inches being obtainable. The rods were of $\frac{3}{16}$-inch diameter *mild* steel, this being used since the fairings were of birch, and quite large sections—some 2 inches deep by $\frac{3}{4}$-inch wide—to match the size of the machine, the span of which was 11 feet.

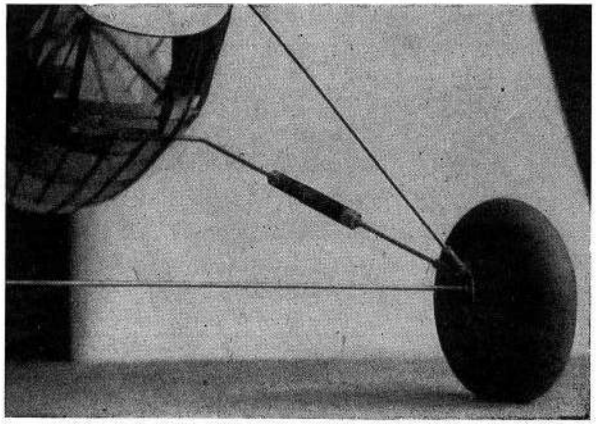


FIG. 73.

Fig. 74 shows the general details of the construction of a fairly elaborate landing chassis suitable for large machines, which will stand up to a great deal of hard wear, and which is very realistic looking. Built to the dimensions shown in Fig. 72, the chassis is suitable for a machine weighing about 6-8 pounds.

Fig. 75 shows the general construction of the shock-absorber units, from which it will be noted that the steel rods are of $\frac{1}{8}$-inch diameter. It is essential that at the points where the rods enter the lugs they are welded—otherwise there is a risk of their snapping off. If welding facilities are unobtainable, as, say, at a small village garage, the rods should be increased in diameter to $\frac{3}{16}$-inch and soldered after screwing into the lugs.

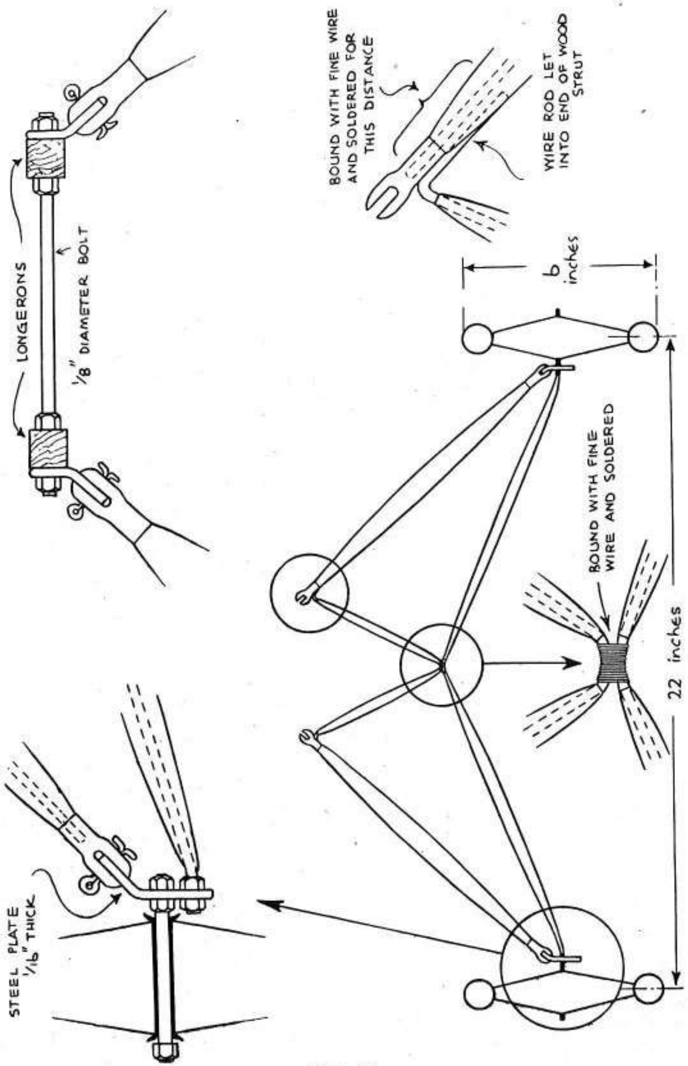


FIG. 74.

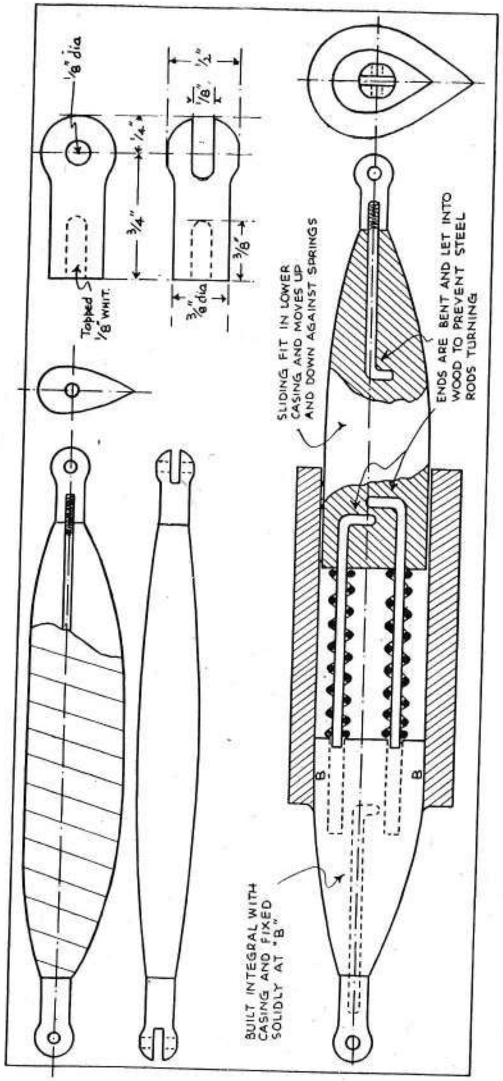


FIG. 75.

This method of construction was adopted for the 10 ft. span low-wing petrol 'plane, a photograph of which appears on page 59, and with the diameter of the steel rods increased to $\frac{3}{16}$-inch, and the size of the lugs also increased, the whole unit functioned well with an all-up weight of 14 pounds. The track was 2 feet 2 inches, and the weight of the whole unit 1 pound 6 ounces.

The struts are all made by laying up two half sections of birch (*not* balsa), each with a semicircular groove down the centre to accommodate the steel rod. The halves are pinned and glued together, finally shaped, and taped with two layers of silk.

This type of classis can be made to work equally as well as the simpler types, *provided* attention is given to 2 points. Firstly, the front struts *must* hang vertically; and secondly, the rear struts, incorporating the shock-absorbing springs, *must* be anchored to the fuselage at a point well behind the front strut anchorages, both these features being shown in Fig. 76. A good rule is to make the distance between the anchorage points at least equal to the vertical distance from the front strut anchorages to the ground. By this arrangement the front struts act solely as radius arms, and during landing take not much more than the actual weight of the aircraft; whilst the rear struts, being inclined, are not so very far out of line with the direction of the glide into the ground, and are thus directly able to move " backwards " under the force of impact.

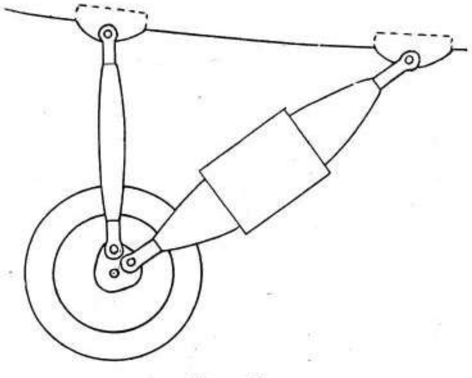


FIG. 76.

The type of landing gear which the author has originated, and which has given extremely good results, is that shown fitted to the high wing cabin monoplane illustrated in this book. Essentially it consists of two cantilever legs, which are mounted on a rigid support in the centre of the fuselage. The legs of the model described were made of solid drawn steel tubing of light gauge and 1-inch × $\frac{3}{8}$-inch section. At their bottom ends were bolted two $\frac{3}{16}$-inch diameter spindles, on which the pneumatic-tyred wheels revolved. At their upper ends the two tubes were flattened, and through them passed a single bolt, which acted as a pivot. The support for the bolt was built up from a box frame of $\frac{1}{16}$-inch three-ply, so designed that the stresses were distributed from the nose to halfway down the length of the fuselage. Fig. 78 is a plan view looking down into the fuselage, and Fig. 79 shows the near side leg projecting through the slot in the bottom of the fuselage. The pivot bolt may also be seen. Rubber bands are looped round each leg, and led up into the nose of the fuselage, where they are anchored to a $\frac{3}{16}$-inch diameter wood dowel, which passes through from side to side. This dowel may be seen in Fig. 77.

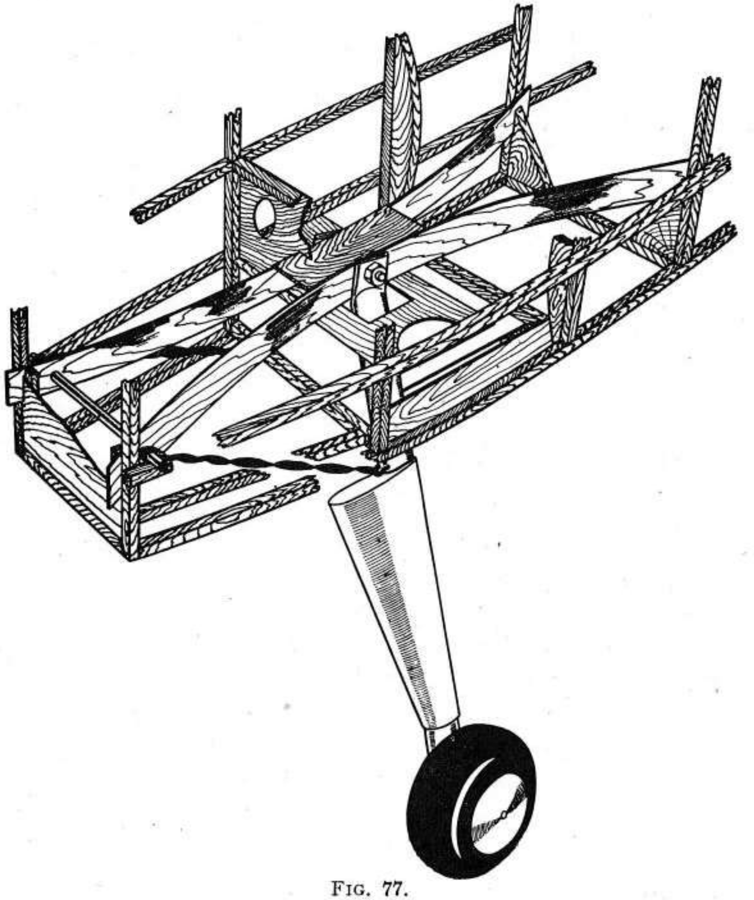


FIG. 77.

In Fig. 78 may be seen the platform on which the battery is placed, and located in position by rubber bands. In Fig. 79, below, may be seen the guide in which the leg moves backwards and forwards. Note also the battery leads provided with "crocodile" clips, as referred to in Chapter 15.

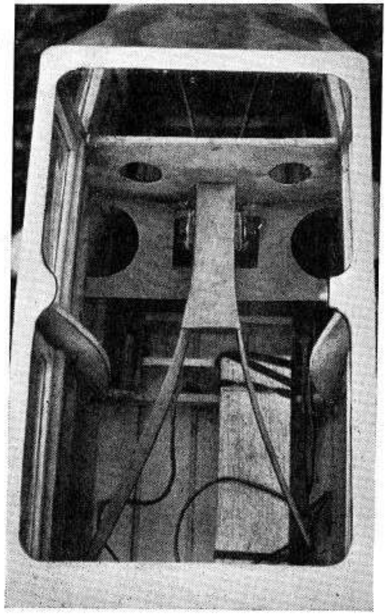
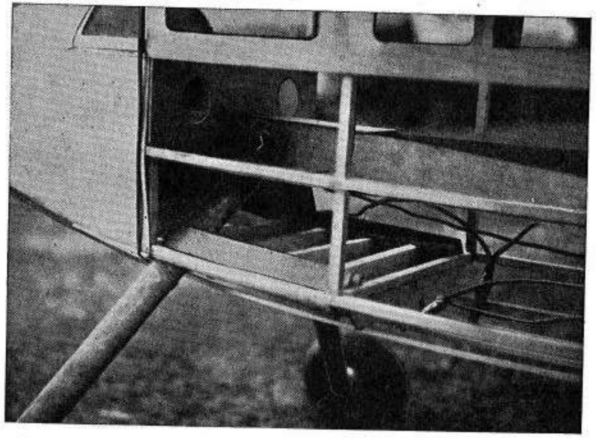


FIG. 78.

FIG. 79.



The advantages claimed for this type of landing gear are:

(1) The completely independent springing of each wheel.

(2) The length of movement of the legs may be varied at will.

(3) The tension in the rubber may also be varied. Several strands of $\frac{1}{4}$-inch × $\frac{1}{16}$-inch rubber are used, and are arranged in tension so that the legs are always held in the forward position. In the model here described the movement along the slot shown in Fig. 79 was about 3 inches, so that the wheels were able to move back about 6 inches when the machine touched down. The efficacy of this arrangement has been thoroughly well tried out, and the author is content that it cannot be bettered. It is essentially simple, extremely robust, and gives that backward and forward movement that is so desirable in the undercarriage of a petrol 'plane. To see the machine glide in to land, touch down, and watch the legs move back, or perhaps only *one*, if one wheel touches before the other, is a very pleasing sight.

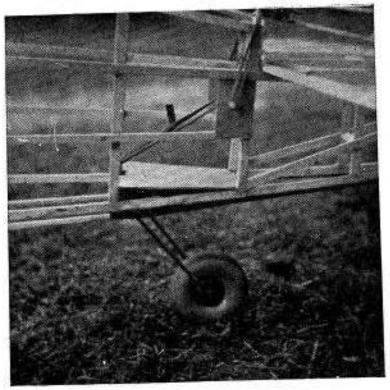
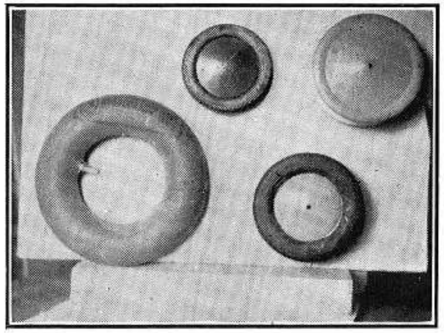


FIG. 80.

The author has adopted the same principle of suspension for the mounting of tail wheels, as shown in Fig. 80. A single length of wire is bent to pass through a tubular support, after which the ends are turned down and inwards to carry the tail wheel. Thus the lugs have only to be pulled apart for the wheel to drop out. The length of rubber forming the tensioning device can be seen in the photograph anchored at its top end to a horizontally located dowel rod. To the two outer ends of this is affixed the rubber band which holds the fin in position, as illustrated in Fig. 67 in the chapter on tail units.

The type of landing chassis illustrated in Figs. 77—79 offers no "up and down" movement, which is not required for landing, but is required for taking-off. It should, therefore, only be used in conjunction with pneumatic-tyred wheels, which will be found to provide the necessary degree of resiliency. For use on large aircraft, where a wheel diameter between 6 and 8 inches is required, use may be made of small inner tubes, size 8 inches × 2 inches, as used inside normal type covers and fitted to light trolley and barrow wheels. These inner tubes weigh $4\frac{1}{2}$ ounces, complete with the usual type of cycle valve, and may be purchased from Messrs. Dunlop Rubber Co. Ltd., for 2s. 6d. each. In Fig. 81 is shown an inner tube, and at top right the hollow balsa wheel on which it is mounted. Fig. 82 shows the tyre and wheel on a machine, and Fig. 83 is a scale drawing showing the construction of a wheel. It will be noted that the wheel is made in halves,

FIG. 81.



At top right is shown the hollow balsa wheel on which is fitted the Dunlop tyre shown at bottom left. The two other wheels are built up from discs of 3-ply to take Meccano motor tyres.

FIG. 82.

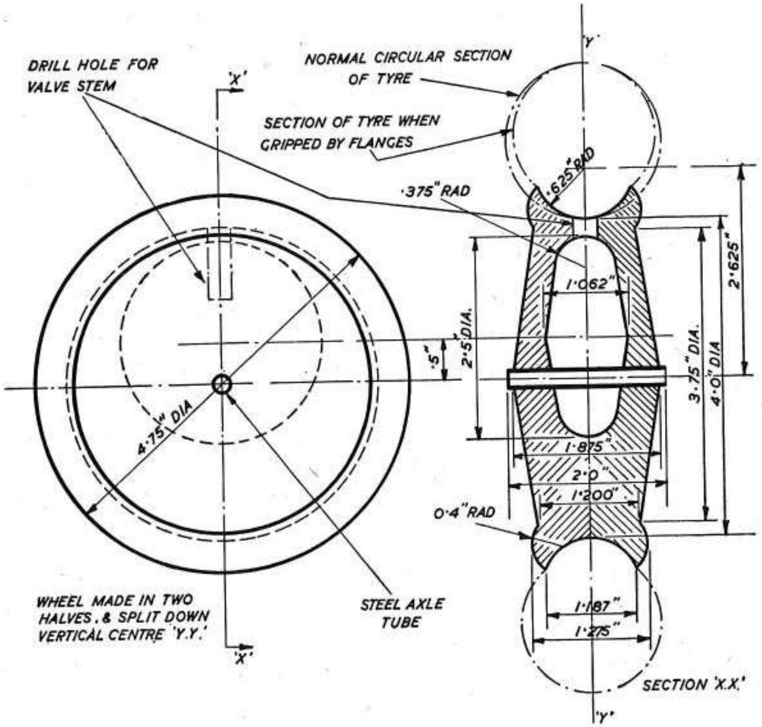


FIG. 83.

each of which has been hollowed out *eccentrically* to balance the weight of the valve.

The diameter of the wheel is made about $\frac{1}{8}$-inch greater than the inner diameter of the tyre (measured when inflated to the desired pressure). So that when it has been sprung over the wheel flange it grips the wheels snugly. The flanges are brought well up the sides of the tyre to prevent it being pulled off in the event of a side landing.

For sizes below 8-inch diameter a range of pneumatic-tyred wheels, complete with miniature valves, may be obtained from various model aircraft firms.

The *width* of the tyre mainly determines the area of the tyre in contact with the ground, and whilst narrow tyres are satisfactory for a take-off from a road or other hard and level surface, they are quite unsuitable for heavy aircraft when taking off from the average grass field, as the concentration of weight on the narrow wings will cut a path *through* the blades of grass. On the other hand, pneumatic tyres of the correct proportion offer a relatively much larger surface area in contact with the ground, and consequently the weight distribution is much less per unit of area, resulting in the tyre " riding over " the grass instead of cutting into it.

Solid balsa wheels, sometimes fitted with rubber rings let into grooves cut round the circumference, are very light and may be made to look quite realistic if the rubber ring is of the correct thick section to represent a tyre.

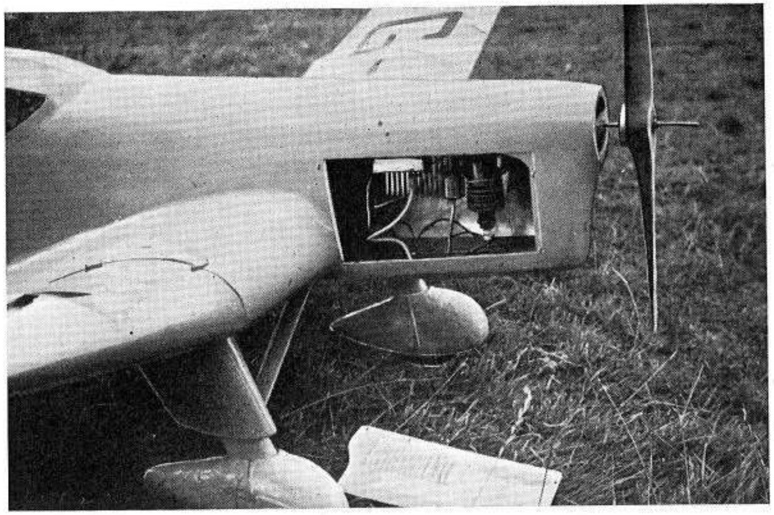
Satisfactory wheels, fitted with solid tyres as sold by Messrs. Meccano, may also be made by forming two convex discs from three-ply which are fixed on either side of a disc of hard wood, through which the axle tube passes—the tyre being gripped between the two flanges so formed. Such a wheel, fitted with a 4-inch diameter tyre, is also shown in Fig. 81.

Owing to the softness of balsa wood it is not advisable to insert the axle-tube direct; it should first be driven into a bushing of hard wood of a diameter equal to about three times that of the tube. This cylinder is then glued into the centre of the wheel.

All wooden wheels of any size may, with advantage, be made hollow (unless, of course, weight is actually required from the point of view of aiding stability) by forming two flanges, scooped out in their centres, which are then glued and pinned together. The wheel shown in Fig. 83 was made of balsa wood and, complete with steel axle-tube, weighed $3\frac{1}{2}$ ounces.

Weight low down is always an advantage from the point of view of lateral stability; and weight at the nose keeps the main wings well forward, and thus well separated from the stabiliser, which helps longitudinal stability.

Thus it is seen that several valuable advantages accrue from the use of pneumatic-tyred wheels of reasonable weight, and in conjunction with a scale type of landing chassis, are recommended as well worth the cost or time involved in their construction, as well as adding very considerably to the appearance of the aircraft.



This " close-up " photo of Mr. Newman's " Mew Gull " shows how the engine is mounted in the front of the fuselage. The engine is a 15 cc. " Grayspec " two-stroke. A photo of the complete machine is on page 66.

CHAPTER XV.

THE MOUNTING OF ENGINES AND ACCESSORIES

Typical engine mountings—The " Comet " cone—The electrical circuit — Batteries — Coils — Condensers — Time switches—Contact breakers—Advantage of complete assembly on one panel.

THE engine of a power-driven model aircraft can be mounted in one of several ways—either by itself, with the petrol tank and electrical equipment located in the fuselage, or it may be mounted on a sub-frame on which is also fixed the petrol tank, or it may be mounted as a " self-contained " unit, with petrol tank, coil, condenser, ignition switch, and throttle control all on one framework. If the engine is to be mounted by itself by far the best way is to use a light electron casting, as shown in Fig. 84. This was designed by Lt.-Col. C. E. Bowden, and is to be highly recommended.

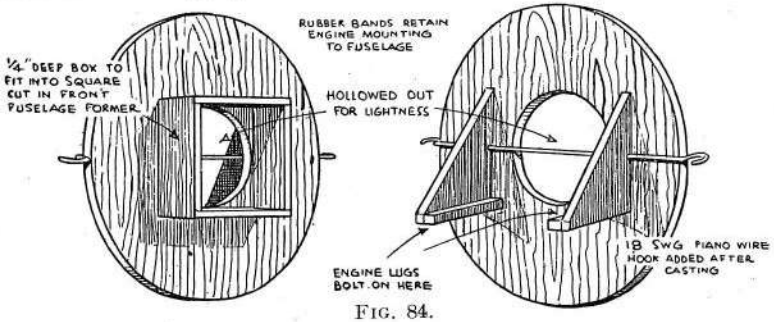


FIG. 84.

On the left of the illustration is shown the rear side of the mounting. The box section fits into a similar shape recess built into the nose of the fuselage, against which the circular disc lies. As will be seen from the right-hand illustration, two triangular shaped lugs project forward, to which the engine flanges are bolted. It will be seen that the engine may be mounted upright or inverted. The length of wire which passes horizontally through, and which has hooks formed on its two ends, is for fixing lengths of rubber which are laced back to suitable anchorages at either side of the fuselage. This form of mounting has two advantages, firstly packing strips of metal or 3-ply wood may be inserted between the circular disc and the nose of the fuselage, to vary the angle of thrust both up or down or sideways; and secondly in a " nose-over " landing the mounting may be knocked off from the nose of the model due to the stretching of the rubber. Through the hole in the centre of the disc pass the petrol pipe and electrical connections.

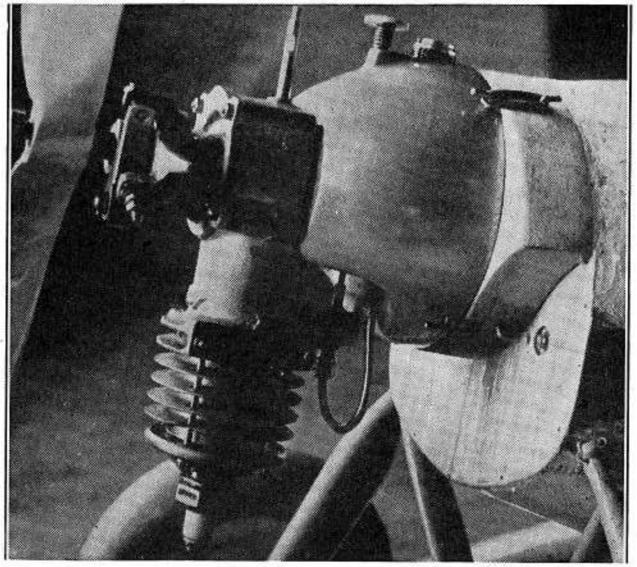
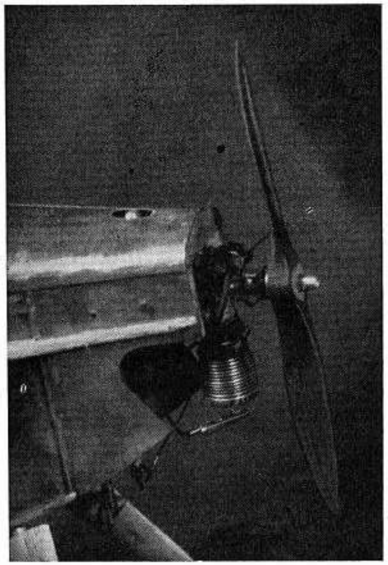


FIG. 85.

Another way in which an engine with its petrol tank may be mounted in a semi-flexible manner, is by the use of an aluminium or electron " cone." In Fig. 85 is shown the electron mounting developed by the manufacturers of the 18 cc. " Comet " engine. There are 4 pegs equally disposed round the circumference of the " cone," to which lengths of rubber are twisted to and from 4 oppositely located pegs at the front of the fuselage. At the top right hand corner of the photograph may be seen a pair of pegs with the rubber band tightly laced between them. To the left, and at the top of the " cone," is the filler cap of the petrol tank, which is a separate unit bolted inside the hollow " cone." To the left of the tank filler is the throttle control, which passes down through the " cone " to the carburetter, which is bolted to the cylinder crankcase. At the back of the cone is a raised projection, rectangular in shape, which fits into a small recess formed in the front of the fuselage. This locates it accurately in position, at the same time allowing the whole unit to be knocked out of place in the event of a " nose-over " landing. Most engines are supplied by the manufacturers mounted on a wooden test frame. Two examples of these frames are shown in Fig. 103 of the 2·5 cc. " Spitfire," on page 170, and the photograph of the 6 cc. " Baby Cyclone " engine, Fig. 100, page 166. Quite a good way of mounting any engine is to mount the test frame direct into the front of the fuselage. In Fig. 86 is shown a " Baby Cyclone " mounted in the inverted position direct into the fuselage of one of the author's planes. The front of the fuselage consists of two $\frac{3}{16}$-inch thick panels of 3-ply, through which two wood screws pass into the wooden engine test frame. A great advantage of this method is that the engine pivots about the two screws, and in the event of the machine



The " engine room " of the " Cyclonic." One of the screws on which the engine mounting pivots may be seen.

FIG. 86.

landing on its nose, as soon as one blade of the propeller strikes the ground the whole engine unit is tipped up. It can soon be set back to its normal position, and if the two screws which form the pivot are retightened the friction is quite sufficient to hold the engine in position. This method of engine mounting is also shown in the right hand photograph of Fig. 70, page 137.

A very neat and practical design for an all-in-one engine mounting is that shown in Fig. 87, designed by the manufacturers of the 'plane shown on page 193. The mounting for the engine consists of an inverted U-shaped frame of spring steel, which is mounted to a bulkhead at the front of the fuselage by three bolts, arranged in triangular fashion. The top one may be seen in the photograph, and the near side lower one can be seen just above the petrol tank, which is behind the exhaust pipe. The mounting being of spring steel, allows of a certain amount of flexibility, and by adjusting the nuts on the three steel rods, side and up-and-down adjustment to the engine position may be made. There is a cowling which fits closely over this " engine room," totally enclosing it.

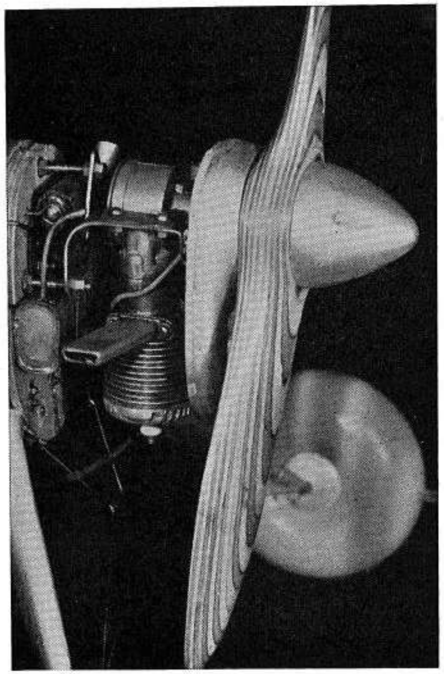


FIG. 87.

In this photo is shown the special flexible and adjustable engine mounting, designed for the 'plane illustrated on page 193, in the chapter on high-speed petrol 'planes.

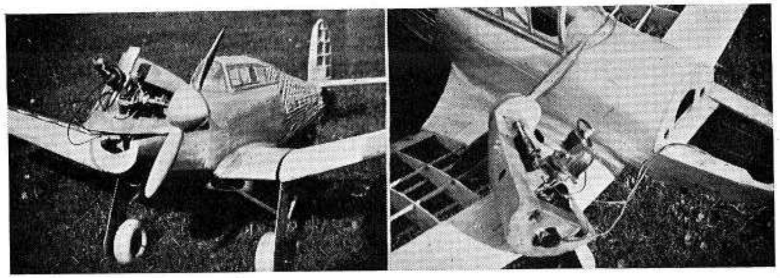


FIG. 88.

In Fig. 88 are shown two photographs of the engine mounting on Mr. Miller's Hawker " Hurricane." The 9 cc. " Ohlsson " engine is mounted in the inverted position, and drives the propeller shaft through an extension mounted on ball bearings. For large aircraft the author is in favour of mounting the engine separately, and the electrical equipment all on one panel. In Fig. 89 is shown the unit as used on the 10-foot span low-wing model described in the last chapter of

Instead of using dry batteries, the aero-modeller may use a very small accumulator. An example of the type suitable for use on model aircraft is shown in Fig. 94, page 159.

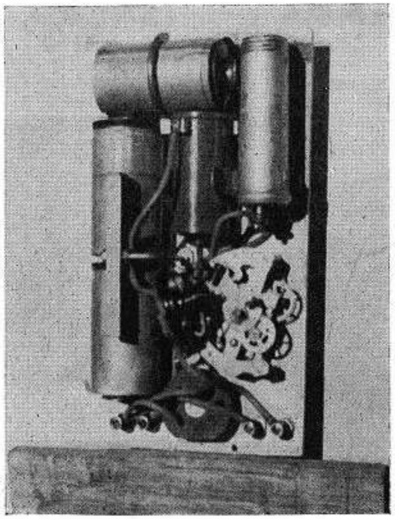


FIG. 89.

this book. At the top right-hand corner is the condenser, and to its left, in the centre, is the coil. Along the left of the panel and across the top are three $1\frac{1}{2}$-volt cells, making up the $4\frac{1}{2}$-volt battery. At the lower right is the time switch, built from a small clock, and at the centre bottom is the change over switch from booster battery to the cells on the panel. On the left of the switch are sockets into which are plugged the booster battery connections, and on the right are two more sockets into which are plugged the wires leading to the contact breaker on the engine shaft. The advantage of mounting all the electrical equipment on one panel is that all assembly and testing may be done on the workshop bench. The unit slips into position on the underside of the fuselage, as shown in Fig. 90.

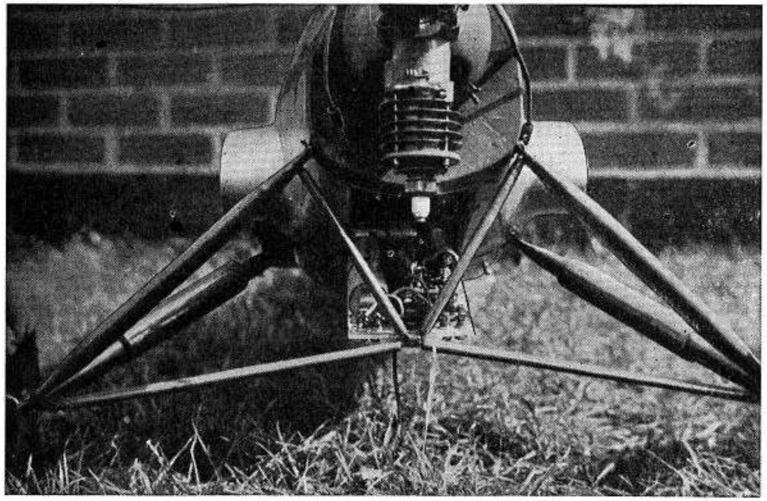


FIG. 90.

In Fig. 91 is shown the mounting of the 9 cc. " Dennymite " engine of the author's high-wing cabin monoplane illustrated in this book. In this case the engine is mounted on aluminium brackets bolted to a 3-ply bulkhead which slides into grooves formed on either side of the fuselage. The petrol tank is behind the crankcase, and the coil and condenser are slung between the aluminium brackets. The battery is mounted in the centre of the fuselage, and the time switch and

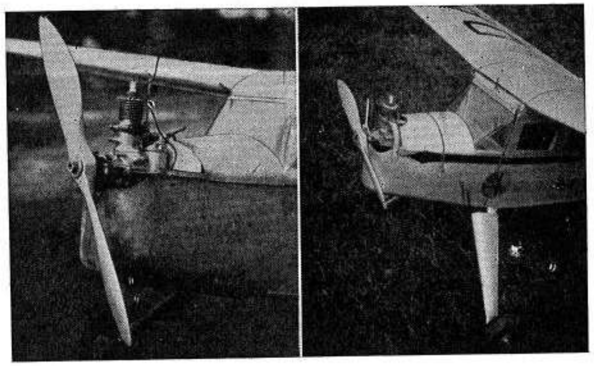


FIG. 91.

connections for the booster battery are towards the tail. The wiring is so arranged that by disconnecting two wires behind the engine bulkhead the complete unit may be slid out of the fuselage. This particular aircraft was designed for "heavy" flying, and the front of the fuselage is panelled with $\frac{1}{32}$-inch 3-ply, and reinforced with a block of balsa at the bottom front centre part. As will be seen from the right-hand photograph in Fig. 91 a shaped wooden cowling is fixed over the fuselage from the windscreen close up to behind the cylinder, pretty well closing in the lower part of the engine. Some idea of the strength of this type of construction may be gained from an examination of the three photographs in Fig. 92. None of these have been in any way retouched. They show the engine and front of the fuselage exactly as the machine was lifted off Fairey's Aerodrome in the summer of 1939, when the machine made a power nose-dive from over 100 feet! (The

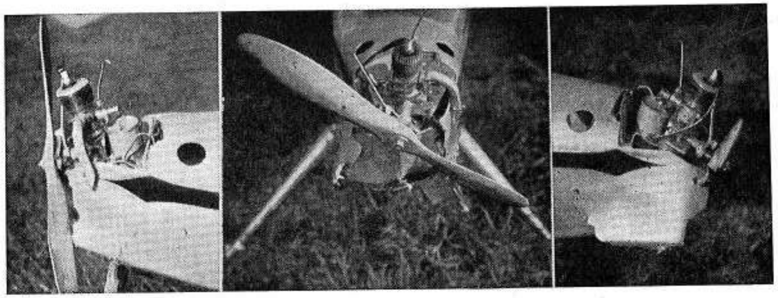


FIG. 92.

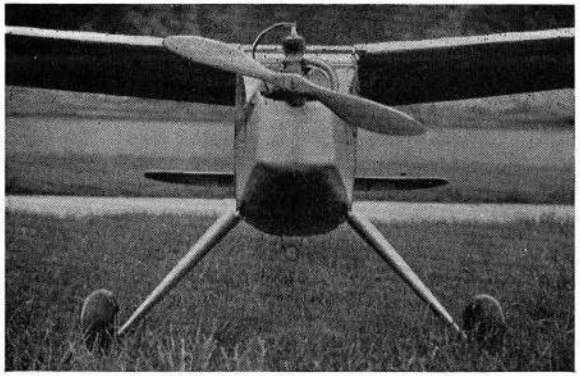


FIG. 93.

cause of this was that the machine had been sent up on a very windy day, and in a previous flight one of the rods supporting the wings had been cracked but not noticed. Consequently, when the machine was well up, the wings gradually "folded up," and the machine went into a vertical dive!) In the middle photograph it will be observed that the lower part of the fuselage has been knocked in and the lower blade of the airscrew has been cracked, but not broken off. The engine was completely undamaged, and repair work consisted of dismantling the engine assembly, straightening out the aluminium brackets, and mounting the unit on a new 3-ply bulkhead. As for the front of the fuselage, the portions were gently eased back into position. A sheet of $\frac{1}{32}$-inch 3-ply was curved and placed round the inside of the nose, and after a liberal application of glue a piece of silk was applied to the outside. The repair took just over two hours to complete, and the nose was rebuilt as new, as shown in the photograph, Fig. 93. Incidentally, the circular holes which may be seen on the photographs, behind the engine, are those through which a wire hook is inserted to attach the rubber bands used as shock absorbers for the cantilever legs, as illustrated in Fig. 77, page 144. This portion of the fuselage is covered normally by the cowling shown in the right-hand photograph in Fig. 91, being held in position by a rubber band stretched over the top and looped round the $\frac{3}{16}$-inch diameter dowel rod which passes from one side of the fuselage to the other, from which the shock absorber rudder bands are looped.

The electrical system in model aircraft, and in particular

methods of wiring same, often leave much to be desired. Many aero-modellers, whilst possessed of excellent skill in the design and construction of their models, seem to think that "any old piece of wire," twisted to "any old clip or bolt," will do! On many occasions has the author seen a good performance marred by an engine misfiring, due to faulty connections in the electrical circuit. All connections in the wiring of model aircraft should be made as strongly and as carefully as possible. Soldering alone is not always sufficient, and where possible the ends of wires should be formed into loops and threaded to a bolt and locked into position with a nut, the end being soldered in position. The high tension lead in particular should be of irreproachable quality; it should be as short as possible, which is an argument in fovour of mounting the coil as near to the engine as possible. The lead should on no account come in contact with any metal part, and if it is necessary to pass through a hole in the metal engine mounting this hole should be bushed with a short length of rubber tube. Many are the devices adopted for making connections to the

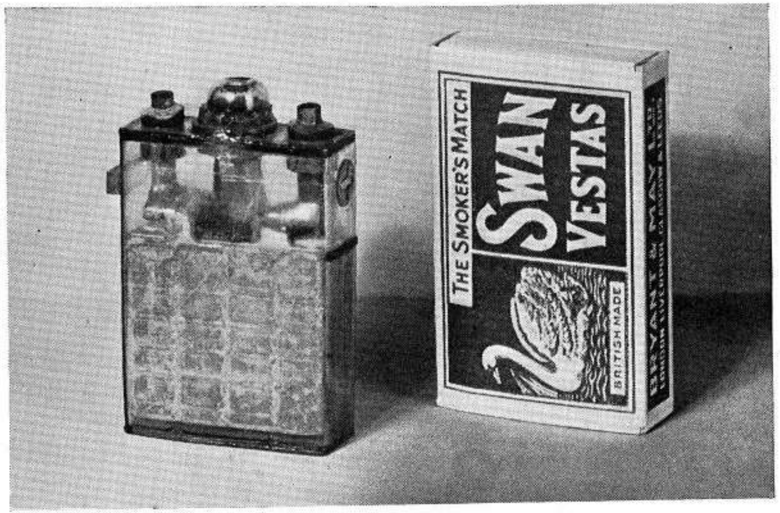


FIG. 94.

popular $4\frac{1}{2}$-volt pocket flash-lamp type of batteries, which are used in model aircraft. The type of connection which consists of contacts against which the tongues projecting from the battery are pressed, is definitely condemned by the author. The contacts have an awkward way of loosing their " springyness " or tension at the wrong moment! The practice adopted by the author for the past two or three years is to twist the ends of the contacts into circular shape, as if being wound up like a clock spring. The two wires that are to be connected are joined to " crocodile " clips, which may be purchased for about 3d. or 4d. per pair from wireless accessory shops. These clips are so named because the operative portions are shaped like the jaws of a crocodile, and are held in the closed position by quite a powerful little spring. In connecting to the torch battery one jaw is passed through the circular hole formed by looping the tongue, and the other jaw passes outside the loop. A sure and positive contact is thereby made, and will never part from the battery, however rough the landing. A crocodile clip is also used by the author at the end of the high tension lead where it is connected to the sparking plug.

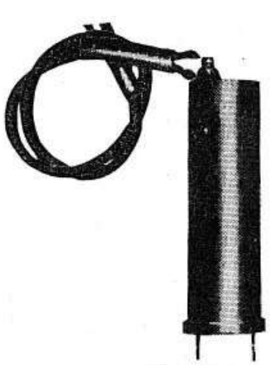


FIG. 95.

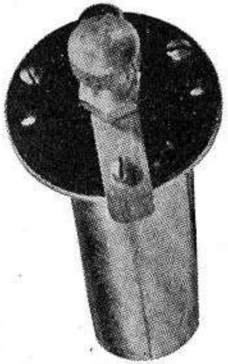


FIG. 96.

Coils should be of the best obtainable, and weigh anything from 2—4 ounces. Any engine up to 6 or 9 cc., if in good trim, should be capable of being started up from a 4½-volt pocket flash-lamp battery. Heavier coils weighing from 10—14 ounces may be operated also from this type of battery, but will require replacement after some 15—20 minutes use!

However, a really " hot " spark may be obtained from these heavier coils, and if the additional weight can be carried on the 'plane, it is better practice to use a large heavy coil with one battery rather than a light coil with two or more batteries in parallel. Most proprietary engines are supplied complete with a suitable coil and condenser, and it is most important that the combination of condenser and coil, as supplied, should be maintained. Condensers are " matched " to the coils with which they are sold, and if at any time a replacement condenser is required, care should be taken to see that it is of similar capacity, if not of similar make, as that originally supplied with the engine, as an unsuitable condenser can completely spoil the proper functioning of a good coil.

Up till a short while ago, time-switches were usually made from adapted clocks, or clockwork motors, as used in small toys. Recently time switches specially designed for use in model aircraft have been put on the market, and it is strongly recommended that these should always be used in preference to the " home-made " variety. All sensible aero-modellers will realize that if there is one part of their 'planes which must be 100 per cent efficient and foolproof in operation, it is the *time switch*. Many a time anxiety has been caused by a 'plane flying away until the petrol in the tank was used up, due to the time switch not having operated at the correct moment; and apart from the loss which may result if the 'plane cannot be found, of far greater importance is the damage to person or property which may be occasioned by the 'plane flying beyond the confines of a safe flying ground.

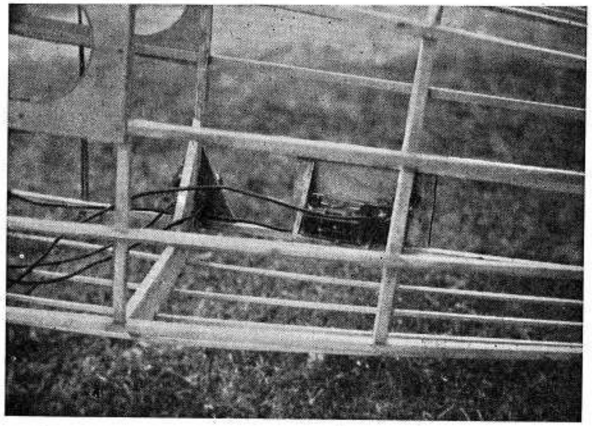


FIG. 97.

One type of clockwork-driven time-switch which has given excellent results may be seen on one of the author's 'planes in

Fig. 97. Another type, which consists of a small cylinder from which air is expelled by a powerful spring—the rate of expulsion being controlled by a sensitive valve—is shown in Fig. 96.

Miniature sparking plugs have been produced by well-known plug manufacturers, and if reasonable care is taken 100 per cent good results should be obtained from them.

In Fig. 99 are shown photographs of two sizes of plugs, the photographs being actual size. There is also a type of plug manufactured which is detachable for cleaning. It is, of course, essential that the points of miniature sparking plugs should be kept clean, and the porcelain surround of the central electrode should always be kept free of carbon. Difficulty is sometimes experienced in cleaning the narrow annular space between the central electrode and the bore of the screwed portion of the plug, and this is best achieved by careful scraping with a long, thin knife blade. Good cleaning can also be carried out by using a small portion of a stiff wire brush, as used for the cleaning of files or the teaselling of wool.

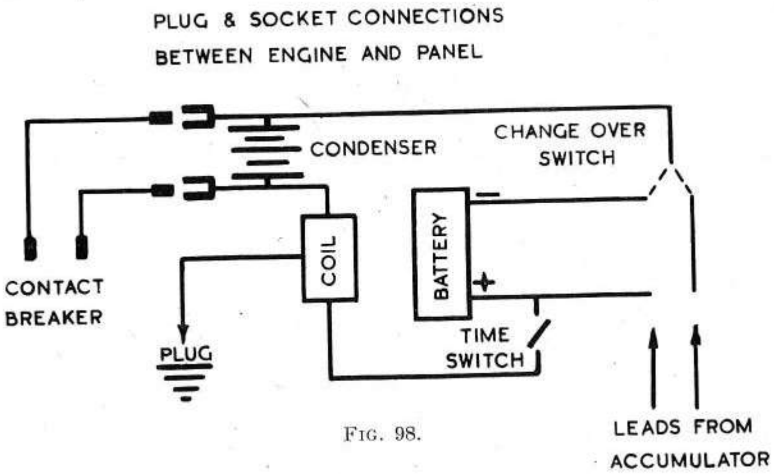
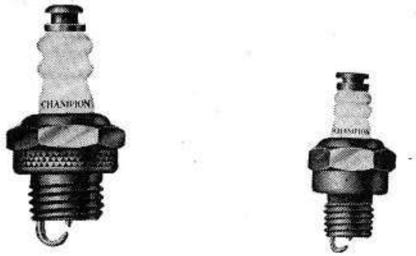


FIG. 98.

Contact breakers, as supplied on proprietary engines, are of good quality, and should give no trouble.

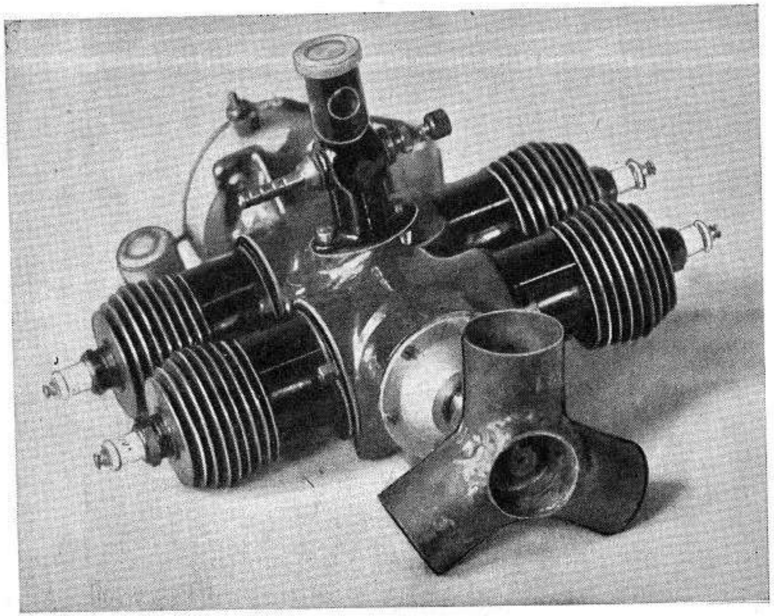
Contact breakers, as supplied by well-known manufacturers, may be relied upon to stand up to their work, but if the aero-modellist has built his own engine, or perhaps obtained one of a non-proprietary brand, he is advised to consider using a proper motor-cycle type of contact breaker, in preference to building one himself from "bits and pieces." It must not be overlooked that when a two-stroke engine is running at 4,000 r.p.m., the contact breaker (*and* plug, of course) have to operate 66 times per second—thus it is essential that the "make and break" shall function correctly. As this is best achieved by a properly designed spring which has been tested by the manufacturers to operate up to speeds as high as 10,000 r.p.m., it is preferable to equip the engine with a contact breaker of this type rather than experiment with pieces of clock spring, etc.



These two photographs are actual size.
FIG. 99.

It is most important to see that the surfaces of the contact points truly meet over their full area. If this is not the case, and the two discs are only touching at one point, sparking and pitting will soon occur. Particularly for high-revving engines the spring pressure should be quite strong. The author has on a number of occasions speeded up engines shown to him, about which the complaint was made that they were not giving their usual high revolutions, by placing his finger on the spring make-and-break and applying a small amount of pressure. A remedy which can easily be carried out on the field if the spring should become distorted is to put a couple of turns of rubber round the unit.

In Fig. 98 is shown the correct electrical circuit which should be used on petrol 'planes. A simplification is to cut out the change-over switch shown at the right-hand top corner, and plug the accumulator leads directly in parallel with the leads coming from the battery. Prior to releasing the aircraft



The above photograph shows the " Condor " four-cylinder engine to be used in the author's 1-5th full-size scale model of the Westland " Lysander." The bore is 1-inch, and the stroke ¾-inch, which gives a cubic capacity of the four cylinders of just under 40 cc. The rating is 1·6 h.p. at 7,500 r.p.m., but preliminary calculations have shown that a speed of 4,500—5,000 r.p.m. should give sufficient power to fly the model. The crankcase is of cast iron, and carries three large ball races supporting the crankshaft. As the engine is a two-stroke, opposite pairs of cylinders fire together. At the rear of the engine is a case in which is contained the contact-breakers, there being two units, each with its own coil and condenser.

they have to be detached, but great care must be taken that they are so connected that it is impossible to plug the positive of the accumulaator to the negative of the battery, otherwise the coil will soon melt!

CHAPTER XVI

ENGINE TESTING AND TUNING

Engine testing and tuning—Test benches and revolution counters—Running in of engines—Tuning—Power-weight ratios.

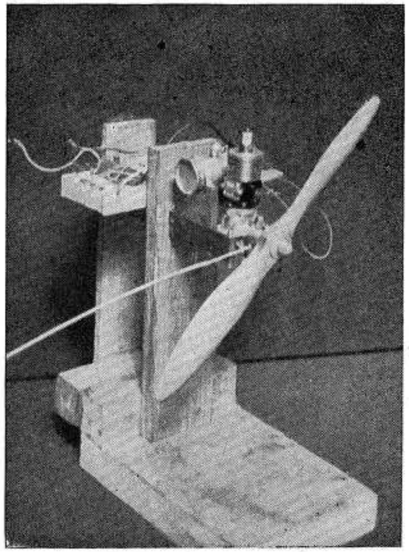
ENGINE testing and tuning is one of the most interesting features of model aircraft work—one to which a great deal of time may be devoted, and one from which some very useful results may be obtained.

A " test-bench " on which the engine may be mounted can quite easily and quickly be constructed from material to be found in any workshop; and with the aid of a revolution counter the aero-modeller may tune up his engine to its best efficiency.

Fig. 99 shows a typical test bench, of the type which can be constructed quite easily from a few pieces of hardwood, and screwed down in any convenient position. Alternatively, the engine may be mounted on bearer brackets, or a test-

FIG. 99.

The engine shown in this photograph is a 6 cc. " Baby Cyclone," and the test bench on which it is erected was designed and built by Mr. Ross.



frame can be gripped in a stout vice, as shown in Fig. 100.

For serious bench testing on miniature petrol engines it is essential that a revolution counter should be available.

The most useful type of revolution-counter is that which incorporates a clock mechanism, and gives direct readings of the exact number of revolutions made in the period during which the clock is working—a period under the control of the operator. Such a speed indicator, however, costs about £3.

Quite accurate results may be obtained by two operators, one controlling a stop-watch, and the other operating a " counter " of the type which counts up to 10,000. These counters may be purchased for as little as 10s., and whilst not *supposed* to be operated at speeds above 1,000 r.p.m., will

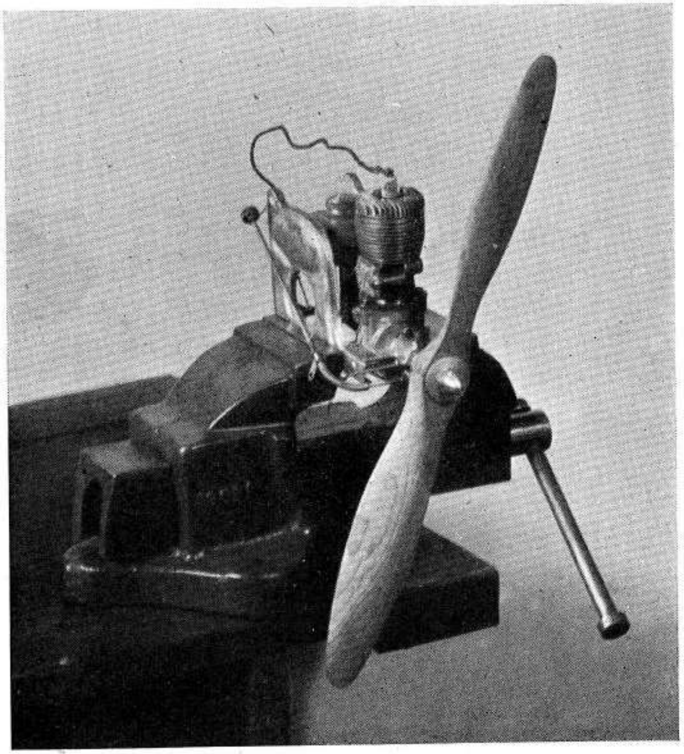


Fig. 100.

Here is shown one of the latest " Baby Cyclone " engines, on the pressed steel mount-cum-petrol-tank, designed and supplied by the makers of the engine.

stand up to speeds as high as 4,000 r.p.m., provided they are not held to these high speeds for more than 15—20 seconds at a time.

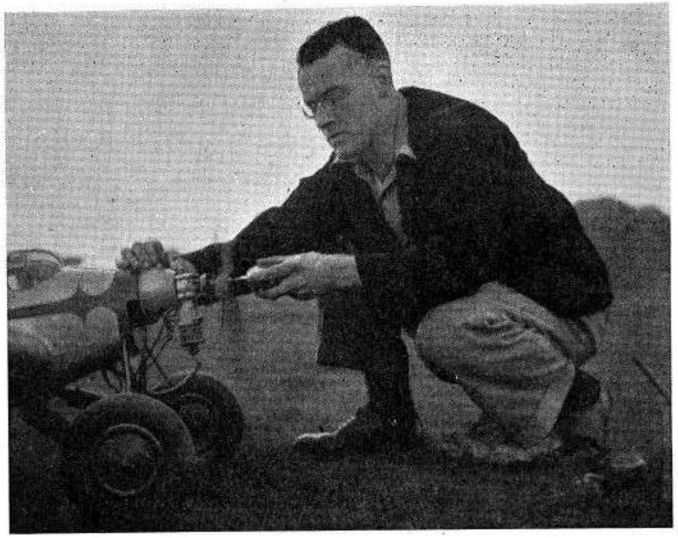


Fig. 101.

The Author practising what he preaches!—checking the r.p.m. of the engine on the flying field, preparatory to sending the the 'plane off on a test flight.

It is surprising the amount of internal friction which may be developed in a new engine—not " run in "—and as a suitable " running-in " bench may be easily made, it is recommended that this process should always be carried out before running an engine under load.

If a suitable electric motor is not available in the workshop, the domestic vacuum cleaner, or sewing-machine motor may perhaps be borrowed and quickly coupled up with a short length of rubber hose slipped over the ends of the engine and motor shafts.

Fig. 102 shows one of the author's " Comet " engines being run in—the simple mounting and flexible drive may be noted.

The process of " running in " may be described as of two kinds, the lapping together of newly-paired surfaces, and the polishing of surfaces which have already been lapped.

If the engine is absolutely brand new, the piston ring (or rings) must be lapped to the cylinder bore. This is carried out by driving the engine at some hundreds of r.p.m., lubricated with a mixture of the correct engine oil and metal polish, mixed in equal portions. If an old piston is available to which the rings may be fitted, so much the better, and the lapping should be continued until they are seen to be " bedding " over their *full width and circumference.*

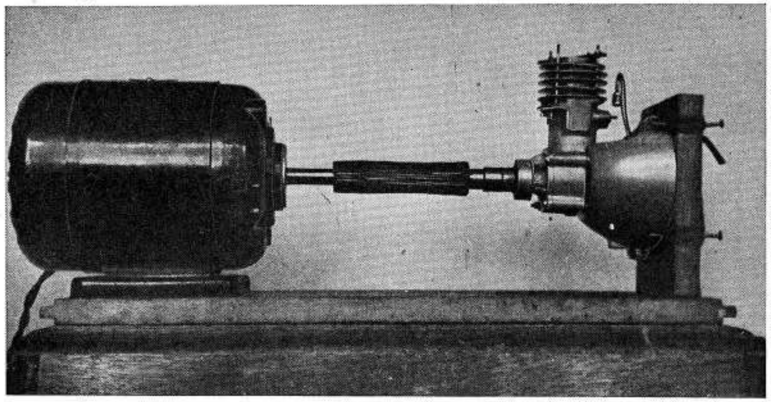


FIG. 102.

The engine shown in this photo is an 18 cc. " Comet." It is mounted on the special streamlined " cone " supplied by the makers of the engine. The flexible coupling between the motor and engine shafts is a short length of garden hose pipe.

After lapping in of the rings the engine should be thoroughly cleaned and again run with lubricating oil only. After some two or three hours' running, it should be completely dismantled and the piston and other bearing surfaces examined for "high spots," these being very carefully removed by scraping.

Scrupulous cleanliness and attention to detail work are, of course, of primary importance with the small petrol engines used in model aircraft, and after any parts have been dismantled and attended to in any way, they should always be thoroughly washed in petrol before being reassembled.

Particularly with two-strokes, complete " gas-tightness " *must* be obtained; and all " mating " surfaces, such as crankcases and covers, cylinder-heads and barrels, should have

metal-to-metal joints, made by lightly grinding the surfaces together with the finest grinding paste obtainable.

Leakage of air past the crankshaft bearing is a " fault " which may develop in an engine with plain journal bearings, as these become worn, or even in a new engine if ball bearings are fitted; and special attention should be paid to see that as effective a seal is made at these parts as possible.

Ball-bearings may be packed with a "high melting-point" *grease* which will effectively prevent the passage of air, and plain journal bearings may be quite well sealed by placing a fibre washer which is a fairly tight fit on the crankshaft—between the end of the crankcase cover and the back of the cam. This washer *must* be made an exact fit in the gap between these two surfaces, and, being a tight fit on the crankshaft, will revolve with it, lightly rubbing against the face of the crankcase.

If this fibre washer is kept " wet " with engine oil it will be found that a very nearly 100 per cent airtight seal is effected.

The desirability of smoothing and polishing all gas passages is, of course, well known, and provided this is done, the engine made really gas tight and internal friction reduced to a minimum by careful " running-in," a powerful and reliable performance will result.

The starting up of miniature petrol engines is one which often gives the newcomer to them considerable trouble. Certainly, any previous experience with motor-cycles or other types of combustion engines is of little use, and the aeromodeller is wise who will forget all he has learned about full-size petrol engines, and approach the subject with an open mind. It is well that there should be a consideration of the following points, which arise from the fact that the best combustion is obtained when there is a ratio of approximately 14 parts of air to one of petrol when measured by *weight.*

(*a*). 1 cubic foot of petrol weighs about 47 pounds.

(*b*). 1 cubic foot of air weighs ·076 pounds.

This means that 1 cubic foot of petrol weighs approximately 640 times 1 cubic foot of air. Since the best air to petrol ratio is that of 14—1, it follows that there should be approximately 8,700 times the *volume* of air to the *volume* of liquid petrol to give the best combustion.

Now, assuming that the inspiration efficiency of a 10 cc. 2-stroke petrol engine, running at 5,000 r.p.m., is 100 per cent, the engine would inspire approximately $1\frac{3}{4}$ cubic feet of air per minute. A 1-8,700 part of this volume equals 6·1 cc., and this is the volume of liquid petrol which the engine will use per minute. A 1-5,000 part of this 6·1 cc. of liquid petrol equals $\frac{1}{4}$ of 1-1,000 of a cubic inch per stroke—about the size of a pin's point!

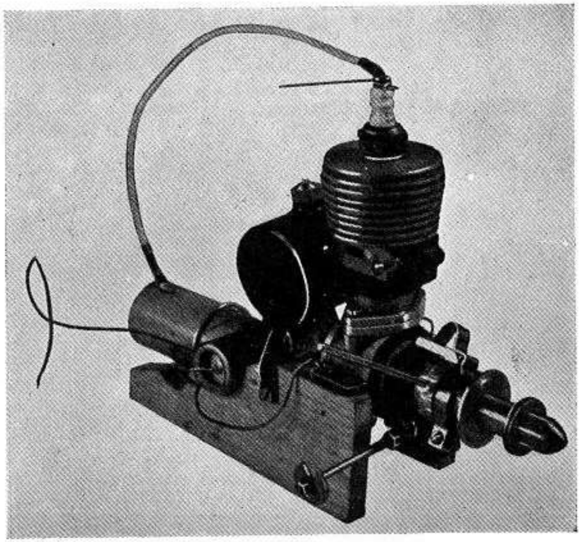
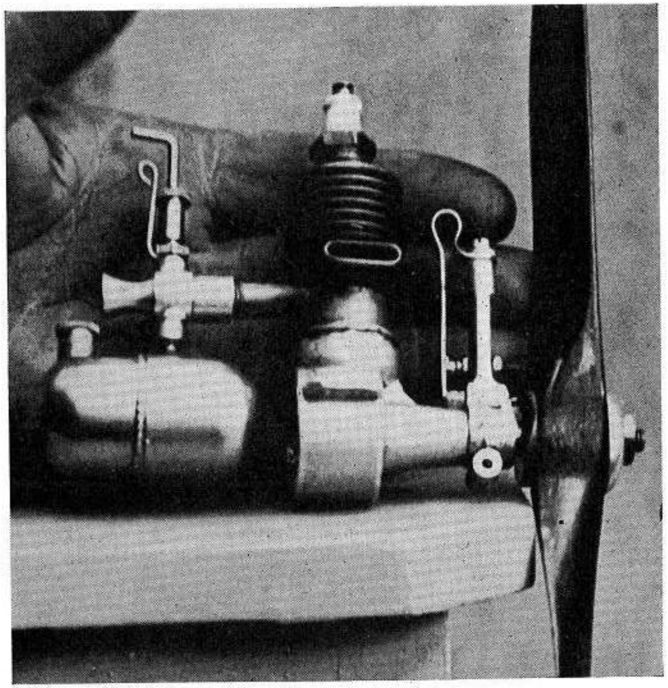


FIG. 103.

In this photo is shown the 2·5 cc. "Spitfire." Of British manufacture, this engine is of robust yet light construction. The ignition control is variable, and induction is via a rotary valve and hollow crankshaft.

If the reader can bring himself to understand what this minute quantity of liquid represents, he will get a better understanding of the difficulties which are involved in tuning the carburetters of small petrol engines. On a number of occasions the author has seen an aero-modeller flood the carburetter of his engine, and then attempt to start up with petrol dripping from it! Now this is quite useless. Petrol is a liquid, and everybody knows that it is inflammable. But petrol to be ignited in a cylinder of a petrol engine must be in *gaseous* form, and, as pointed out above, the most efficient ignition is obtained when the ratio of air to petrol is about 14 to 1 by weight, or nearly 9,000 to 1 by volume. If petrol is drippping from a carburetter intake of perhaps only a quarter of an inch bore, it will be realised that it is quite impossible for 9,000 times this volume of air to be drawn through the intake, or for the petrol to become vapourised. The result of this is that the mixture is far too rich, and the engine will not start. Another way of appreciating this important point is to consider what is happening at the place where the needle valve seats. As the throttle valve is unscrewed, and the tapered part of the needle is moved away from its seating, there is provided a steadily increasing annular space around the needle, up which the petrol passes. A simple calculation in the above case would show that the 6·1 cc. of liquid petrol, when considered as a thin column passing into the engine during one minute's running, would be like a very fine wire, so small in diameter that a tube of only a few thousandths of an inch bore would (in theory) pass the required amount of liquid. However, due to



Several engines of Italian manufacture have recently become available. Here is a 3 cc. "Giglio."

what is known as capillary attraction, the liquid would have to be forced up a tube of such a small bore as this. Consequently, a tube of at least $\frac{1}{16}$-inch bore is necessary, but this will pass far more petrol than is required.

From the foregoing it will be seen that the annular space round the throttle valve will actually be larger than is really required, even when the throttle needle is unscrewed perhaps only two turns. It is for this reason that needle points are given such a fine taper, so as to make their control as sensitive as possible. It is for this reason, also, that the author is in favour of running an engine with as strong a mixture of oil to petrol as the engine will take without the sparking plug oiling

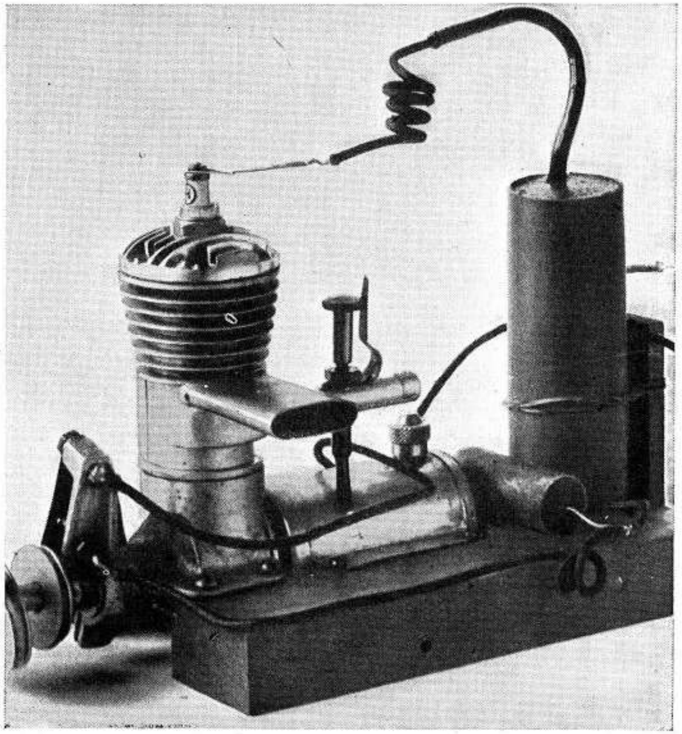


Fig. 104.

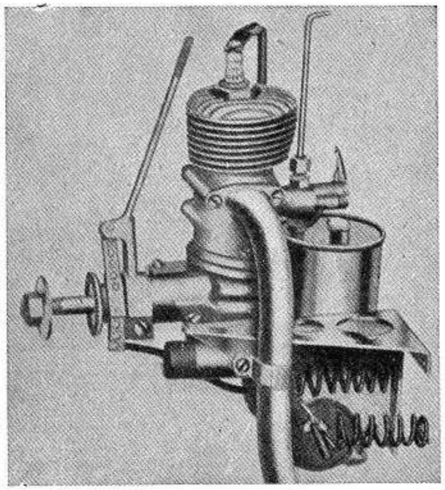
Here is the 7·5 cc. "Gwyn Aero," a powerful engine which may be run either upright or inverted. Induction is via crankcase and transfer port, and the ignition control is variable.

up. After all, the cost of oil used in a miniature engine is negligible! Oil, of course, is considerably more viscous than petrol, and by using a mixture of about 1 part oil to 3 of petrol there is a larger and bulkier mixture passing through the throttle valve than if the mixture was reduced to a ratio of only 1 part of oil to 5 of petrol. Proof of this argument may easily be obtained by tuning an engine on a 3 to 1 mixture and then changing over to the 5 to 1 mixture. It will at once be found that in the latter case the engine is a good deal more "sensitive," and a slight variation in the position of the throttle control will have a considerably greater effect on engine speed than in the case where a 3 to 1 mixture is used.

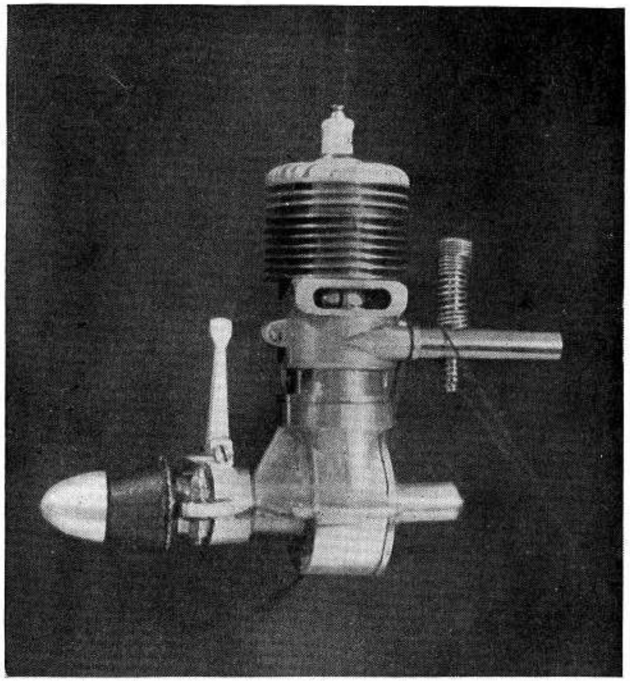
Now obviously different makes of engines will have their own particular characteristics, but the following general instructions for starting up a miniature petrol engine may be taken as applying throughout the general range of petrol engines at present in use in model aircraft.

Fig. 105.

This photograph is of the 9 cc. "Dennymite" de-luxe unit. A long lever is fitted to the variable ignition control, and a long pipe leads the exhaust clear of the fuselage. The coil and condenser are mounted between the aluminium engine bearer brackets.



Usually, the throttle position for full speed is somewhere between one-and-a-half and three turns of the throttle needle for engine sizes ranging from 2·5 cc. to 18 cc., and it is best to set the throttle between these positions, according to engine size. To start, one finger should be placed over the air intake (or, of course, if there is a slide fitted, as is on the "Dennymite," it should be closed), and the propeller given three or four sharp " flips " with the other hand. Not more than four should be given. The reason for the first operation should be clearly understood. No matter if the petrol feed is by gravity, the fuel may still not flow naturally through a small bore pipe. If it is by suction, it must be sucked up into the carburetter, for a start. Therefore, the air intake is completely closed, so that the full power of the suction caused by the engine being revolved is devoted to inducing petrol into the carburetter intake. Next, and immediately the first operation has taken place, the finger is removed from the air intake and the throttle valve completely closed. Following this, the third operation takes place, and consists of starting the engine. During the second operation the hand not used in starting should be gripping the throttle control ready to open it the moment the engine starts.



Quite a number of aero-modellists design and build up their own engines. Here is a quite " professional-looking " 9 cc. two-stroke built by Mr. J. Forster, of Bromley.

From the foregoing it will be seen that the engine is started up with the throttle valve *completely closed;* that is the secret of successful starting, and where so many newcomers to miniature petrol engines make their mistake. If any attempt is made to start the engine with the throttle valve open, once the intake has been flooded with petrol the liquid will continue to flow at a faster rate than is used at the nominal few revolutions at which the engine is being turned when flicked over by hand. So the inevitable too-rich mixture is produced. With the throttle valve closed, and the air intake unobstructed, only air can enter the engine, and so in the course of two or three revolutions by hand-flicking, the correct ratio of petrol vapour to air is arrived at, and the engine starts. Immediately on this taking place, the throttle is opened about one turn, and a few seconds afterwards it may be opened as far as is necessary to allow of the engine to give its full r.p.m.

Recapitulating, the process of starting a miniature petrol engine can be divided into three separate phases. Assuming the reader is right-handed the operations are as follow:—

(1) The left hand having opened the throttle one to two turns, and the air intake having been closed by a finger or the slide valve, the propeller is given three or four sharp flicks with the right hand.

(2) The air intake is uncovered and the throttle closed by the left hand. This remains holding the throttle control, whilst the engine is flicked with the right hand until it starts.

(3) Immediately on starting the throttle is opened by the left hand, and the engine run up to speed.

The three operations are carried out consecutively, and (for the purpose of this set of instructions, it being assumed that the electrical gear is all in order, and a good spark is arriving at the point of the plug), should not take more than half-a-minute.

The Author about to launch his large low-wing 'plane from a moving car. Photo (taken from another car travelling alongside) was obtained by Mr. A. King, at Digby Aerodrome, 1939.

CHAPTER XVII

FLYING PETROL MODELS

A NUMBER of people seem to think that following the design and construction of a petrol 'plane comes the *flying* of it, but this is not so—there is an intermediary stage—testing and trimming the model for glide. Theoretically, it should be possible for a machine to be flown " off the board " after it has been trimmed so that the centre of gravity coincides with the centre of lift of the main wings. In full size practice of course, the weight of every part is " taken out," and the centre of gravity of the completed machine will invariably come quite close to where it was meant to be. In model practice this should follow also, but there may be differences according to the class and grade of wood and glue used. One modeller might use more nails, binding wire, or glue, in the construction of the tail unit than another modeller; and naturally at a point so far distant from the centre of gravity a little difference in weight would make quite a difference in the balance of the 'plane. It is, therefore, good practice to leave the location of the battery to the very last; it is a handy unit of weight, and it can be lashed to a little platform by rubber bands, so that it can be moved backwards and forwards to give trim to the model when it is completed. In Fig. 78, page 145, which shows a view looking down into the cabin of the author's high-wing 1939 model, may be seen on the right a platform across which are stretched two or three rubber bands; these hold the battery in position. When the machine is ready for balancing, it should be suspended from a point exactly over the centre of lift, on a line passing through the airscrew centre to the centre-line of the fin. The model must then be trimmed by movement of the battery, so that the thrust line is exactly horizontal. (No down thrust used).

(Whilst the author does not wish to appear to be dogmatising, he submits that *down thrust* on a petrol 'plane is definitely bad practice. It is used on rubber-driven model aircraft to counteract the excessive thrust developed during the first few seconds run of a powerful rubber motor. Nevertheless, downthrust means wasted power, and it should not be resorted to in petrol 'planes. The thrust line is therefore defined as being parallel to the datum line of the fuselage.)

When the correct trim has been found, suitable blocks of wood should be arranged to hold the battery so that it can always be located in the same position. Next comes the question of trimming for lateral balance. The model should be supported at the airscrew boss, and at a point located at the fin in line with the trailing edge of the stabiliser. It should hang in that position, due to the centre of gravity of the whole model being below these two points of support. Normally, for machines up to about 4 or 5 ft. span trimming should be so effected that the 'plane hangs level. It may be that one wing is slightly heavier than the other, in which case the battery must be shifted sideways across the fuselage to obtain the correct balance.

With this effected, and the fin set in dead straight ahead position, the main wing at the correct angle of incidence, and the stabiliser arranged according as to whether it is to be "lifting" or "non-lifting," the 'plane is ready for its first gliding trials.

According to the size and wing loading of the model so must this procedure vary. Apart from its overall size, the

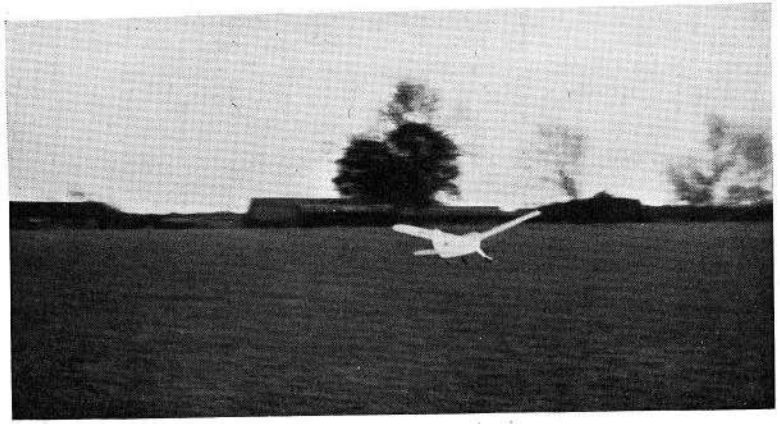


FIG. 106

The shoulder-wing 'plane illustrated on pages 40 and 41 just after taking off.

FIG. 107.

The correct way to carry a petrol 'plane. (May also be used as a protection from rain or sunshine!)

lighter the wing loading the slower the 'plane will fly, and the minimum flying speed will therefore determine the gliding procedure. If the wing loading is only about 8 to 10 ounces per square foot, the 'plane may be launched forward with the launcher stationary, and he can then run forward and often catch the 'plane before it has reached the ground. If the wing loading is over 12—14 ounces the aero-modeller will have to run before launching the machine forward. If the wing loading exceeds 1 pound per square foot the minimum flying speed will exceed that at which a man can run (for any distance!), and therefore the only thing that can be done is to "ground-hop" the model under control. Taking the case of the lighter machines first, they may be hand-launched into the wind with the nose slightly downwards. If there are no warps in the wings and the various units have been correctly mounted, very little adjustment should be required to ensure that the model will glide forward in a straight line. Care should be taken to see that the machine lands level, i.e. that both wheels touch the ground at the same moment, and that their tracking is correct, so that the machine continues to run straight forward.

If it is found that there is any tendency to turn in a circle

Mr. J. C. Smith, Hon. Competition Secretary of the S.M.A.E., test flying a small petrol 'plane at the end of a short length of string.

this will be found to be due to a warp in one or other of the wings, fin, or stabiliser planes. If there is a warp it can be easily and effectively removed by holding the affected portion close to a fire for about half-a-minute; the unit should then be twisted by the two hands in a direction opposite to the warp by about the same amount as the original twist. This movement should take several seconds, and should be gradually but deliberately done, still in front of the fire. Finally, whilst the reverse warp is held, the unit should be carried away from the fire, and the arms lifted up and down to cool the unit as quickly as possible by waving it through the cool air. With little practice it will be found that quite bad warps (these, of course, are not encouraged!) can be permanently removed.

Returning to the first trimming glides: In addition to checking that the machine travels on an even keel, care must be taken to see that it descends at a constant speed. If the glide is too steep it is possible that the wing has not sufficient incidence, or that it is a little too far back—so far as *balance* at the moment is concerned. In the latter case it would be

best to move the wing slightly forward, but if it is arranged in a fixed position, as on a scale model, then the battery must be moved farther to the rear of the fuselage. Packing up the leading edge of the stabiliser will naturally lift the tail and keep the nose down, whilst packing up the trailing edge will cause the nose to rise.

It follows from the foregoing that there are really two methods of trimming a petrol 'plane in regard to longitudinal stability. Firstly, the stabiliser can be set in the " non-lifting " position, i.e. with its fore and aft axis normal to the thrust line, and with the main wing in a fixed position, the whole of the trim being adjusted by the backward or forward movement of the battery, and up or down movement of the wing for variation in incidence. The second method is where the stabiliser is expected to contribute to the lift of the machine, in which case it is set at a positive angle of incidence. In this latter case, every adjustment of the stabiliser will have to be made in conjunction with a readjustment of the angle of incidence, and also a variation in the location of the main wing. With the stabiliser " non-lifting " trimming is

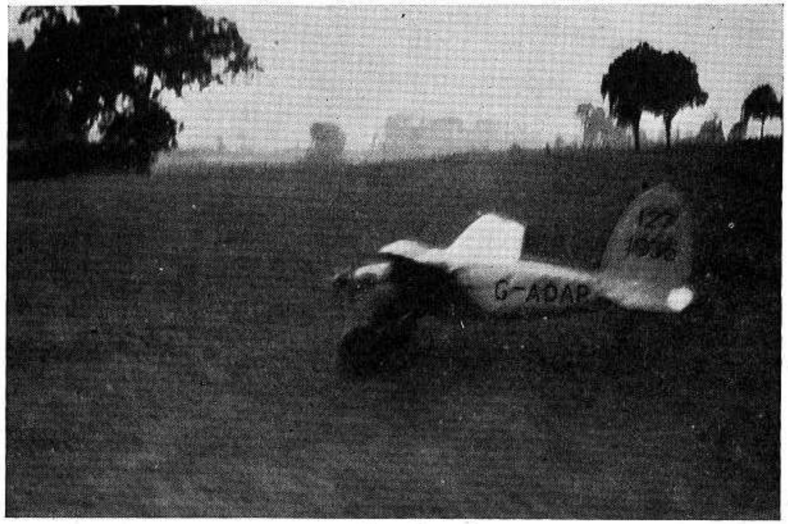


FIG. 106

The 10 feet span low-wing monoplane illustrated on page 36 travelling at 20 m.p.h.—tail up, and just about to take-off. Photo taken from car travelling alongside the 'plane.

somewhat easier, but if this unit is arranged for lifting it helps to get the tail up quickly off longish grass, which is a great help with the larger type of models.

When the gliding and trimming tests have been satisfactorily carried out short test flights may then be made, but it is most essential to see that wing and tail unit fixings are so arranged that there is no doubt that they go back to their same settings each time the machine is assembled. An aeromodeller who has his 'plane correctly trimmed and adjusted and "knows" his model, can take it to a field, assemble it, and fly it straight off the ground. (In entering competitions it is the practice of the author to proceed on these lines. There is always the odd chance of a crack-up on a trial flight, or even someone else's 'plane flying into one's own! So the author's advice is: Test out the machine at least a day before the competition, so that there is time (if only the night before!) to carry out any necessary repairs. Obviously, if the 'plane is to stand a chance in any serious competition, it must be in tip-top condition, and there is little point in tempting the fates within a few minutes of zero hour on the actual day).

The trend of American design in medium size petrol 'planes is shown in this photograph of Gordon Lawson with his parasol-type model.

So much for trimming the 'plane for *gliding*. This ensures a clear start to the model, and also that, as soon as the engine is cut off, the model should glide to earth in a straight line and at a constant angle. But *during power flight*, a different set of conditions obtains. There is the torque developed by the engine to be controlled. Now this may be explained as follows: There is an elementary law of mechanics that teaches that to every action there is an equal and opposite *re*action. The revolving airscrew presses against the air, and due to the reaction offered by the air the airscrew travels forward, taking the machine with it. Now, whilst the main power developed by the airscrew is directed to moving the 'plane forward through the air, there is a small component whose reaction is exerted at right angles to the direction of travel, and this tends to rotate the 'plane about its longitudinal axis. All miniature petrol engines revolve in an anti-clockwise direction when viewed from the front. This reaction, therefore, causes the machine to tend to rotate in a clockwise direction,

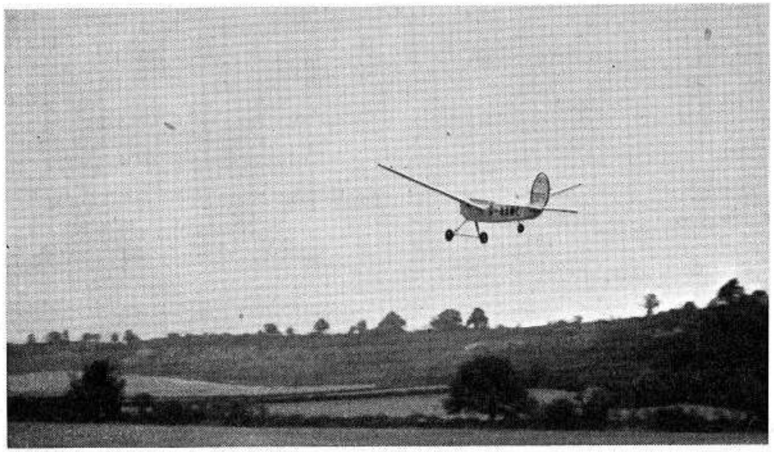


FIG. 109.

" Over the hills and far away " . . .

and this must be effectively counteracted, otherwise the machine will tend to travel with one wing lower down than the other—which can only lead to disaster! In further explaining this aspect of the trimming of petrol 'planes, the reader is asked to consider himself standing *behind* a 'plane and looking forward in the same direction in which it is flying. He is thus viewing the engine from behind, and it is revolving, therefore, in a clockwise direction—the airscrew torque reaction being equal and opposite tends to cause the machine to rotate in an *anti*-clockwise direction—thus, as the machine is viewed from behind the *left* wing tends to drop. If the machine were allowed to take off in this condition it would circle to the left and continue in steadily diminishing circles until it crashed in a tight spin!

To counteract the effect of this torque it is the usual practice to offset the engine a few degrees to one side of the centre line of the fuselage, i.e. in the case above described the engine would be twisted to the *right* so that the effect to the airscrew would be that it would be tending to cause the machine to travel "crab-wise," bearing to the right. When the correct adjustment is found, i.e. when this offset of the engine balances the torque, the machine travels forward in a straight line. In practice, this method is not 100 per cent correct, as 3 or 4 per cent of the effective power of the airscrew is lost. There is a further small disadvantage, that if the engine speed is varied, i.e. the plane is flown on different throttle settings the amount of torque will vary. But in practice this latter disadvantage does not appear to be of any great consequence.

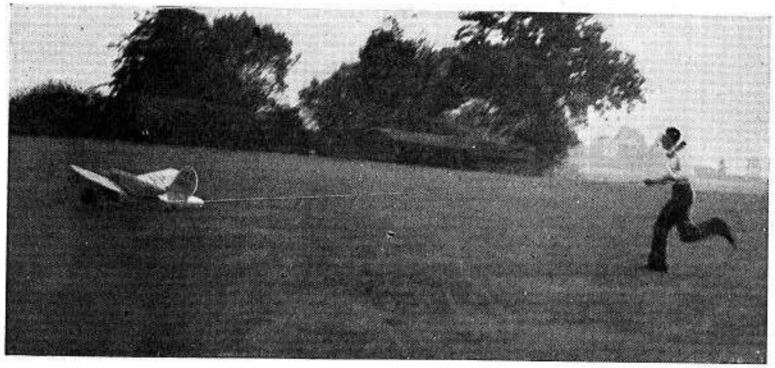


FIG. 110.

"Ground-hopping" a large 'plane by the method described in this chapter. (Photo by Author; violent exercise by friend!)

FIG. 111.

The Author's high-wing 'plane photographed after taking-off during a rainstorm at the 1939 Northern Rally.

Another method of dealing with engine torque is to offset the fin. In the above example, the leading edge of the fin would be set over to the left of the centre line of the fuselage tending to make the machine circle to the right. This is not good practice because, as soon as the engine stops, and therefore the torque ceases, the offset of the fin will make the machine glide in a circle to the right.

An interesting model is that shown on page 16. This was built by Mr. Trevethick, and amongst several novel features is one by which the fin is hinged and connected by suitable link mechanism to the time switch. The engine is set facing straight forward with no side thrust, and its torque is counterbalanced by the fin being offset. However, when the time switch cuts out the engine it also trips a catch, which allows a spring to return the fin to its straight ahead position, thus maintaining the glide in a forward direction.

Generally speaking, about 3 or 4 degrees of engine offset is sufficient, but it is best to conduct experiments to find out the best position for each individual model. The correct setting can be found if the model can be tested on a perfectly level piece of ground. By setting the stabiliser at a considerable angle of positive incidence, and the main wings at *no*

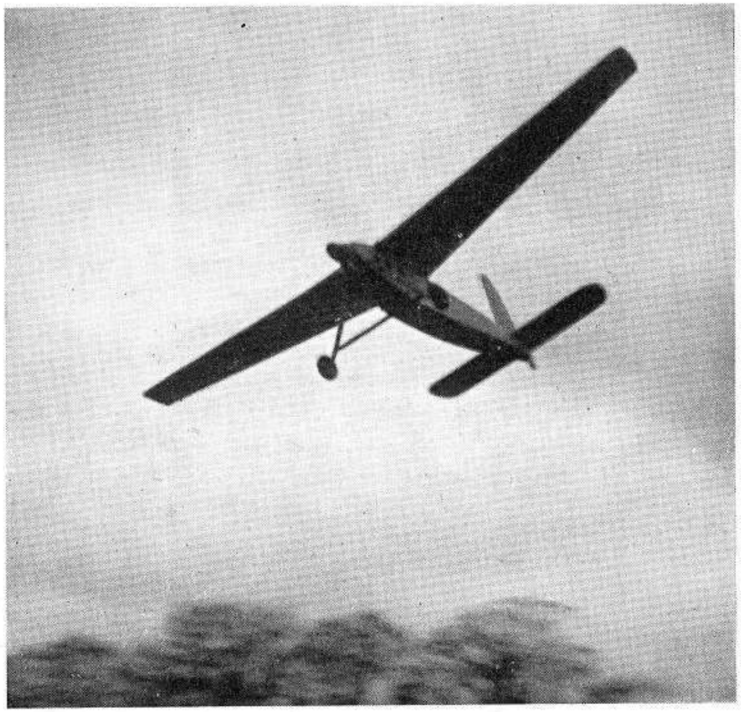
FIG. 112.

The Author launching his large low-wing monoplane from a moving car. Photo taken at a demonstration given at Lincoln in 1939.

angle of incidence, and allowing the 'plane to taxi, if the engine is started up, and the machine allowed to run along the ground, the tail will soon rise, but the machine will not, due to no lift being obtained from the main wings. Three or four such trips will soon enable the aero-modeller to find the correct position for the engine, so that the 'plane will taxi along the ground in a *straight line;* the time switch, of course, being set for a few seconds, so that there is no chance of the 'plane hitting the hedge on the far side of the field!

When circular flight is required a combination of adjustment of the engine position and of the fin may be used, but, of course, circular flight normally means circular gliding as well.

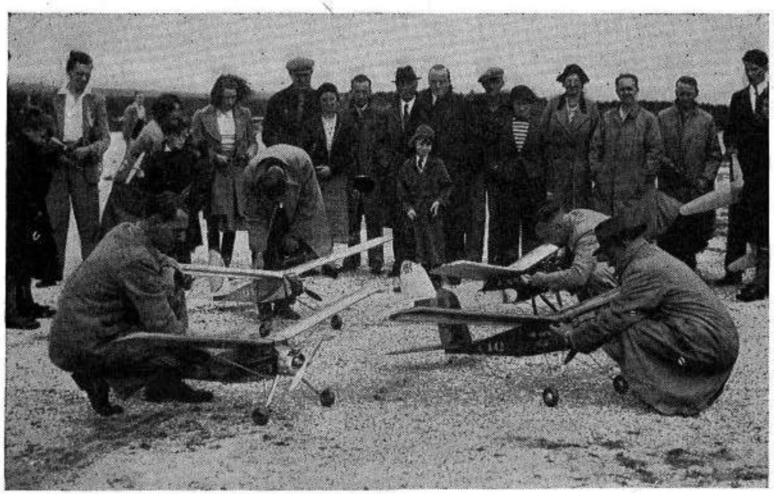
The test flying of large model aircraft is certainly a problem. Machines of 10 feet span and high-wing loading cannot be hand-launched—and anyway, most aero-modellers, certainly the author, are afraid to try it! The author's practice with large machines has been, therefore, to " ground-hop " them, the technique being as follows: A long length of string is tied to the tail end of the model, and is laid out on the ground behind it. The aero-modeller stands about 20 feet behind the 'plane, and holds the string lightly but firmly in one hand. The engine is started up and the machine released, the aero-modeller running behind, and increases his speed with that of the model. When the speed of the model rises above that at which the aero-modeller can run, he allows the string to run through his fingers. By this means the machine can be kept under control until it leaves the ground. Perhaps its take-off speed will be 18 m.p.h.—if the aero-modeller can sprint at 14 m.p.h., then when that speed has been reached the string will run between his fingers at only a speed of 18 – 14 = 4 m.p.h. It will thus be seen that if a piece of string, about 200 feet long, is used, it is possible to keep some useful measure of control on the machine until it takes off, and in effect for time enough to see if the climb is going to be satisfactory. If things are not developing as they should, the aero-modeller increases his grip on the string, which in effect pulls the 'plane down. This, of course, is a tricky business, and it is not claimed that a machine may be pulled back to



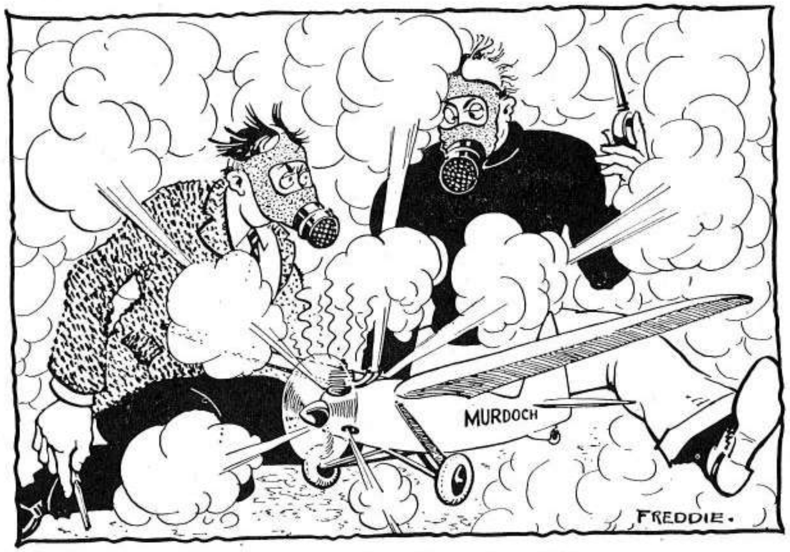
A 10 ft. span petrol 'plane built by Mr. Hornsby.

the ground entirely without damage; but that which *may* be sustained by pulling a 10 or 14 pound 'plane back to the ground from a few feet, will be much less than that which would *definitely* be sustained if a 'plane of that size gets away and then crashes!

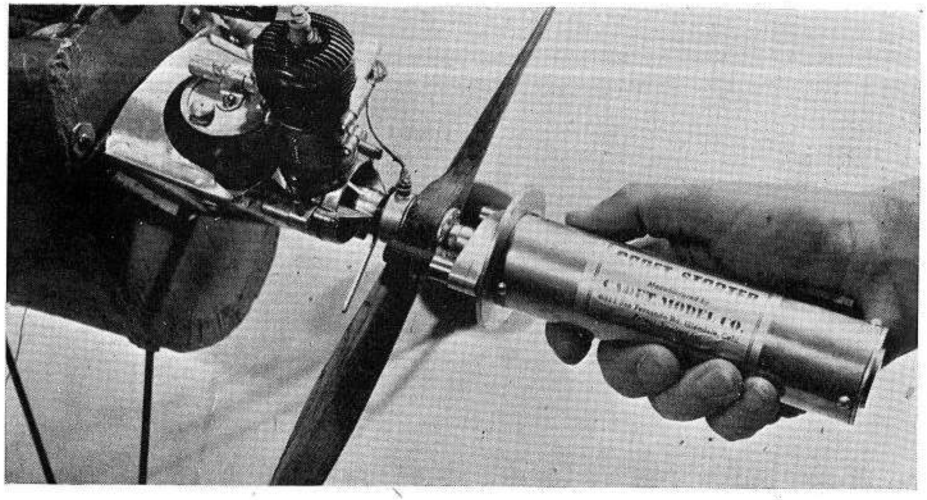
Another method of testing out a large 'plane which the author has developed is that of the so-called " Mayo-launch." Here the aero-modeller stands up through the open roof of a car, whilst an assistant starts up the engine of the 'plane and then hands it up to him. The assistant then gets into the car and gradually accelerates it up to the take-off speed of the 'plane; this has been previously calculated, of course, and by the driver of the car carefully watching the car speedometer, it is possible to get to, and maintain, a speed when the 'plane will just rise from the hands of the person supporting it. After several attempts it will be found that given a level road and a calm day, it is possible to travel along underneath the 'plane at just about its flying speed; by this means sufficient hold can be maintained on it to prevent it rising and flying away, and yet sufficient freedom be allowed to the aero-modeller to quite fairly judge whether the balance and trim is correct.



This photograph was taken at Haldon Aerodrome, and shows members of the Devonshire clubs tuning up the engines of their models.



" You *are* right, it is a gas job."



Motor-car engines are not the only ones provided with self-starters! Here is a unit, containing a powerful spring, specially made for the starting up of miniature petrol engines, and introduced from America into Great Britain in 1939.

CHAPTER XVIII

HIGH SPEED PETROL 'PLANES

At the present time, speed is often the " essence of the contract," and as, no doubt, there are aero-modellers who have contemplated the building of a high-speed petrol 'plane, the following investigation into the possibilities of obtaining a speed of 60 m.p.h. is offered. The author has *not* built a *'plane* that has attained this speed . . . he has not attempted to . . . but he *has* made some engine tests with a view to ascertaining if the necessary r.p.m. could be achieved.

The following calculations serve not only to show that a speed of 60 m.p.h. should be obtainable, but also as an example of how the various formulæ given in this book may be utilised.

No attempt has been made to " pre-select " the type of 'plane, or the initial conditions of performance, so as to obtain a " satisfactory " answer. The only data available being the fact that a 6 cc. engine is capable of developing a static thrust of approximately 3 pounds, which the author has ascertained from personally conducted tests; and the question to which an answer is sought, being: " Can a 6 cc. petrol engine fly a 'plane at 60 mp.h.? "

Steps in the investigation are as follows:—

(1) The horse-power required to maintain an aircraft in level flight may be calculated from the formula:—

$$\text{H.P.} = \frac{\text{D.V.}}{375}$$

when D = drag in pounds.
and V = speed in m.p.h.

Substituting in the above formula we get,

$$\tfrac{1}{5} = \frac{60\ \text{D}}{375}$$

$$\text{Therefore D} = \frac{375}{60 \times 5}$$

$$= 1{\cdot}25 \text{ pounds.}$$

$$= \text{maximum drag permissible.}$$

(2) We have a flying speed of 60 m.p.h. = approximately 90 feet per second; a maximum drag limit of 1·25 pounds, and a maximum thrust available of 3 pounds. Obviously, the machine cannot be too large; obviously, too, the airscrew must revolve at a fairly fast rate to give the necessary forward speed. Therefore, it cannot be too large, otherwise it will require more power to drive than is available.

Let us "work things out" for an airscrew of 10 inches dia. and a pitch of 9 inches, and see what result we obtain. To be on the safe side we will assume the efficiency of the airscrew will be $66\frac{2}{3}$ per cent, though actually it could be a trifle over 70 per cent under ideal conditions.

With a pitch of 9 inches and an efficiency of $66\frac{2}{3}$ per cent the actual forward travel per revolution would be 6 inches = ·5 foot. Therefore, to give a forward travel to the aircraft of 90 feet per second, the rate of revolutions must be 180 per second = 10,800 per minute—a pretty high figure.

However, we must keep to the rules, so let us proceed.

(3) The next calculation is to find the thrust that would be developed. Maybe it will be found that it will require more power than the engine can deliver!

Theoretically, the thrust which would be developed by an airscrew may be calculated from the formula:

$$T = 3{\cdot}142 \times r^2 \times p \times n \times {\cdot}076.$$

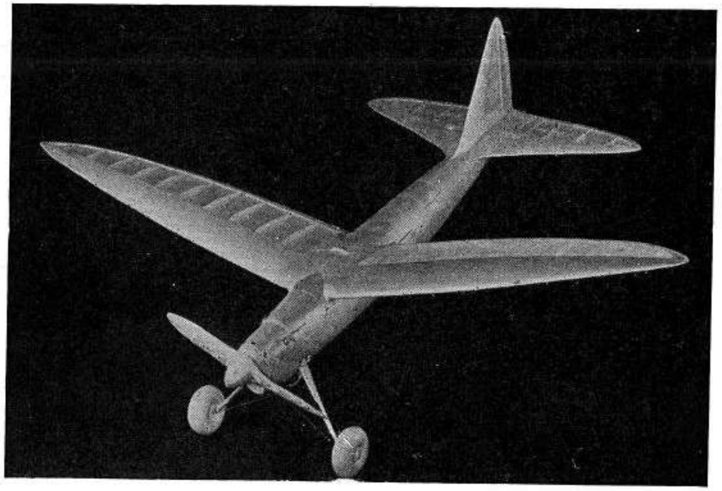
When r = radius of the airscrew in feet.
p = effective pitch in feet.
n = revolutions per second,
and ·076 = weight of one cubic foot of air, in pounds.

In other words, we calculate the volume, and thus the weight, of the column of air through which the airscrew will pass in one second.

Actually, due to "flexibility" of the air, the airscrew "slips," and does not travel forward, an amount equal to its pitch in one revolution, and as we have already allowed for an efficiency of only $66\frac{2}{3}$ per cent—by taking the *effective* pitch as 6 inches—we can calculate the thrust which will actually be developed, by taking p in the formula as 6 inches.

Thus we find the thrust:

$$= 3{\cdot}142 \times {\cdot}416^2 \times {\cdot}5 \text{ foot} \times 180 \times {\cdot}076$$



An ideal design for a high-speed petrol 'plane is shown in this photo of a well-known proprietary model. The span is 5 feet, and the engine is a 6 cc. "Baby Cyclone." The undercarriage legs are fully cantilever, and all wing fixings are internal, thus ensuring the lowest possible drag.

Thus thrust = 3·73 pounds.

Now this is too much, as the engine will only deliver 3 pounds thrust. However, we can rearrange the formula to give us the diameter our 9-inch pitch airscrew must be reduced to. Thus

$$r^2 = \frac{3}{3{\cdot}142 \times {\cdot}5 \times 180 \times {\cdot}076} = {\cdot}14.$$

Therefore r = ·375 foot.
= 4·5 inches.
Therefore dia. = 9 inches.

Thus we find that we must reduce the diameter of the 9-inch pitch airscrew from 10 inches to 9 inches, to ensure that it will not overtax the engine.

What would happen, of course, with a 10-inch dia. airscrew would be that the engine would not reach its designed speed of 10,800 r.p.m.

The following data is now available:

(*a*) 60 m.p.h. = 90 feet per second.
(*b*) 3 pounds thrust.
(*c*) 9 inches dia. × 9 inches pitch.
(*d*) 10,800 r.p.m.

Before proceeding with the next step in the investigations we may pause to consider the dimensions we have now arrived at for the airscrew. In power model work—as distinct from rubber-driven aircraft—it is usual to limit the pitch of an airscrew to about three-quarters of the diameter, because, if the pitch is any greater, the efficiency will drop, owing to the blade angle being too great, unless the speed is very high.

In the case now under consideration, if the pitch were any less the engine r.p.m. would require to be greater, and as no doubt we shall be agreed that the r.p.m. are quite high enough already, perforce we must stick to the figure of 9 inches!

However, there is this point which is favourable: the efficiency of a model airscrew increases with its speed, and, as in the case of our example, the r.p.m. are about twice the normal figure, the airscrew efficiency will probably not suffer so very much.

And now, what sort of aircraft can be designed to have a drag not exceeding $1\frac{1}{4}$ pounds, and which will provide a suitable streamline housing for our $\frac{1}{5}$ h.p. engine?

Suppose we consider a fuselage, circular in shape, with a diameter of 6 inches and a length of 42 inches. Presuming that the fuselage has no excrescences and the skin is well smoothed, the drag coefficient would be approximately ·0004.

The drag of the fuselage may be calculated from the formula:—

$$D = KAV^2.$$

When K = drag coefficient.
A = projected cross sectional area in square feet at the largest section.
V = speed in m.p.h.
and D is given in pounds.

Thus

$$D = {\cdot}0004 \times \frac{3{\cdot}142 \times 3^2}{144} \times 60^2$$

$$D = {\cdot}0004 \times {\cdot}196 \times 60^2$$

$$= {\cdot}282 \text{ pound.}$$

Next let us consider the wing; its size, of course, is tied up with the weight of the whole machine, the type of airfoil to be used and its angle of attack. It is desirable that the wing loading should be fairly high, and as the drag must be kept as low as possible, the wing must be set at the angle at which the lift drag ratio is highest.

An airfoil section specially designed to have a very low minimum drag and to be suitable for a high-speed aeroplane wing is R.A.F. 25, full particulars of which are published in R. and M. No. 915 of the Aeronautical Research Committee.

The max. L/D ratio is 23·5 (in most airfoils it is between 15 and 18). At an angle of 0·7, K_1 is ·145—somewhat on the low side By increasing the angle to 2·6 degrees the L/D ratio is only reduced to 20·8, but the K_1 value rises to ·210 (i.e. by some 50 per cent).

We are " getting nearer," but still have two " unknowns " —the area of the wing and the total weight of the machine —one of which must be settled before we can use the well-known formula:—

$$L = C_1 \frac{p}{2} S\ V^2$$

to calculate the wing area.

Suppose we allow that the complete model will weigh 5 pounds " all up," we can now calculate the wing area required.

In the above formula,

C_1 = Lift coefficient of the airfoil under consideration.
p = ·002378.
S = Wing area in square feet.
V = Velocity in feet/second.
and L is given in pounds.

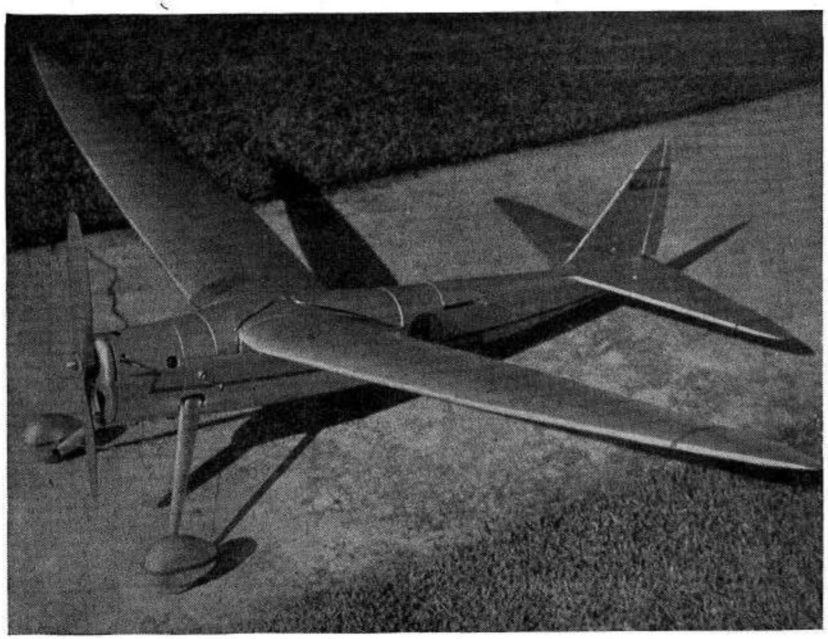
As S is the value we wish to calculate, we rewrite the formula in the form:—

$$S = \frac{L}{C_1 \times \frac{p}{2} \times V^2}$$

and substituting our particular figures in the formula we get:

$$S = \frac{5}{{\cdot}21 \times {\cdot}001189 \times 90^2}$$

$$= 2{\cdot}48 \text{ square feet.}$$



Here is another photograph of the proprietary petrol 'plane kit, which may be built up into such a fine-looking streamlined model. This model was built by Mr. S. Gardener, of Belfast.

Now before we can accept this figure, we must find the drag of the wing. This we calculate from the formula:—

$$D = C_d \times \frac{p}{2} \times S \times V^2$$

When C_d = The drag coefficient of the particular airfoil section.
p = ·002378. 2
S = Wing area in square feet.
V = Velocity in feet/second.
and D is given in pounds.

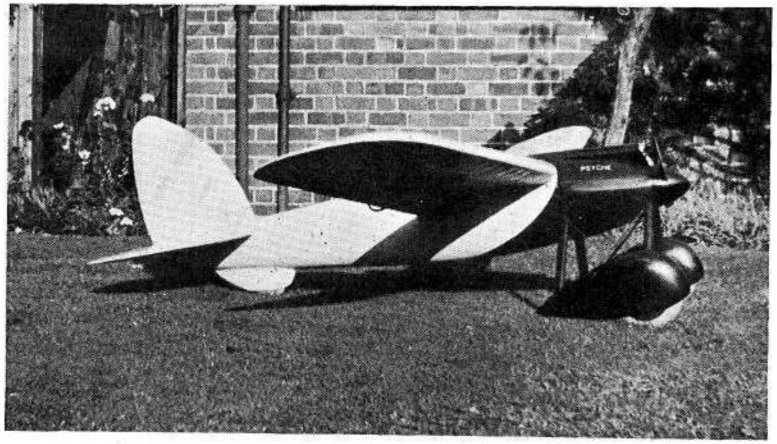
Referring to R. and M. 915 we find that the drag coefficient when the lift coefficient is ·21, is ·0101.

Substituting in the formula we get:

$$D = \cdot0101 \times \cdot001189 \times 2\cdot48 \times 90^2$$

$$\text{Thus } D = \cdot241 \text{ pounds.}$$

This added to the figure of ·282 pound calculated from the fuselage drag makes a total of ·522 pound.



One of the finest looking petrol 'planes built in this country; this model, built by Mr. Allman, has a totally enclosed 6 cc. engine, and monocoque fuselage extremely well finished.

Now obviously we must leave a margin out of our maximum of $1\frac{1}{4}$ pounds so we can reckon that the drag of the tail unit, engine cylinder and landing gear must not exceed a further $\frac{1}{2}$-pound. Rough calculations I have made indicate that this condition could be met, so at long last we may draw up a general specification for our speed model.

Designed speed = 60 m.p.h.
Engine revolutions = 10,800 per minute.
Airscrew diameter = 9·1 inches.
Airscrew pitch = 9·0 inches.
Fuselage (circular and fully streamlined) = 6 inches dia. × 42 inches long.
Wing area = 2·5 square feet.
Total weight of machine = 5 pounds.

Many members of the R.A.F. are keen aero-modellers. This photo was taken at a meeting near London in the summer of 1939.

CHAPTER XIX

Description of the models built by the Author: the "Cyclonic"—The "Improved Cyclonic"—The 10 feet span low-wing 'plane—The 8 feet span high-wing cabin 'plane—The "Lysander."

As most of the photographs illustrating various parts of model aircraft in this book have been taken by the Author, and are of his own machines, it is thought that a general description of them would be of interest. The main constructional features of the aircraft are described, not so much as implying that these are necessarily the best, but because they will give a general idea of the type and kinds of material used in model aircraft of the size described.

The first model described is the "Cyclonic." A photograph of the machine uncovered is shown in Fig. 113, whilst Fig. 66 shows the tail unit.

The fuselage was of rectangular box-section shape, and consisted of four birch longerons, $\frac{3}{16}$-inch × $\frac{3}{16}$-inch, arranged at the four corners of a series of rectangular three-ply formers; the first two of these were of $\frac{1}{8}$-inch three-ply birch, and the remainder of $\frac{1}{16}$-inch, all of them, with the exception of the first one, being fretted out for lightness.

Cross-bracing struts were of $\frac{1}{8}$-inch × $\frac{1}{4}$-inch birch. All fixings being by means of very fine nails and glue.

From the front bulkhead forward the two bottom longerons were steamed and curved upwards, the space between them and the upper longeron being filled in with $\frac{3}{16}$-inch three-ply birch panels, which formed a very solid framework between which the engine unit was gripped. The wooden framework (called the "test" frame on which the engine is mounted) was inverted and held between the two sides of the fuselage by two wood screws which passed through holes (in the side frames), and direct into the "test" frame. Thus, in effect, the whole engine unit could pivot about these two screws, either upwards or downwards in the event of a crash.

(By this method it will be found that if two fairly thick steel screws are used, and washers are placed under their heads, quite sufficient grip will be obtained to keep the engine fixed in position. A small amount of glue may be smeared between the engine frame and the fuselage side-frames; this prevents the engine position from being altered by any sudden " jar "; but will " crack " in the event of a bad landing, or may be split by the insertion of a thin knife if it is desired to remove the whole unit from the fuselage.)

Adjustment for side thrust, of which only a small amount was required, was obtained by removing the engine bolts, and carefully " ovalling " the holes in the engine frame with the aid of a " rat's tail " file. The engine could then be " swivelled " into the desired position, and bolted up tight again in the wooden " test " frame.

The landing chassis consisted of a length of $\frac{5}{32}$-inch spring steel rod braced by a tie rod of $\frac{1}{8}$-inch diameter spring steel rod, which was welded to the two ends of the $\frac{5}{32}$-inch rod, and formed the axle for the two $2\frac{1}{2}$-inch diameter air-wheels which were fitted.

" Fairings " of balsa wood were laid up on either side of the rods and bound with strips of silk; these formed effective " streamline " struts, which were finally doped and painted.

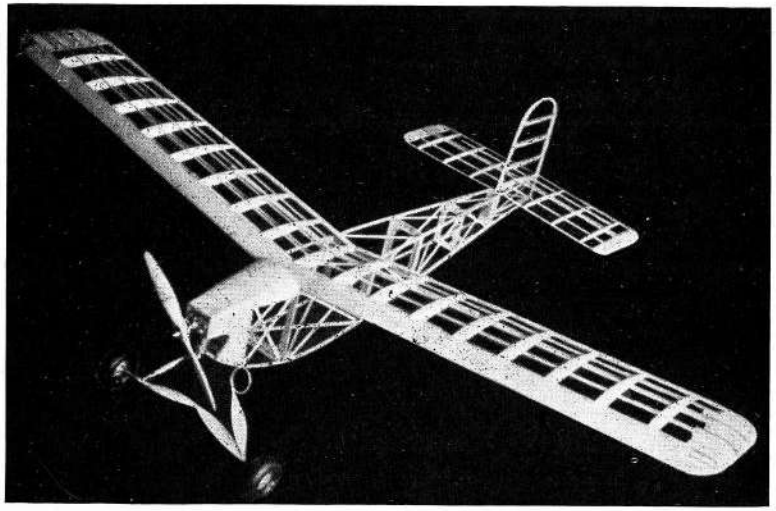


FIG. 113.
The " Cyclonic."

The main wing was made in halves, which were joined together by $\frac{3}{8}$-inch diameter wooden dowels about 3 feet long.

When assembling the wings, two rods were inserted into the tubes in one half-wing, and then the other half-wing was slipped on to the protruding lengths, the whole being held together by the usual rubber bands.

This method of wing fixing allows of the two 3 feet dowel rods acting as strengthening members through the centre of the wing, and yet, if in a crash the aircraft lands on one wing, the rods will break in the centre, when the halves may be quickly withdrawn and new rods inserted. Alterations in the angle of dihedral may be made by first steaming the rods to the correct angle before insertion into the half-wings.

The wings were built up from a series of longitudinal " stringers " of $\frac{3}{16}$-inch × $\frac{1}{16}$-inch birch let into former ribs of $\frac{1}{8}$-inch balsa, spaced at 4-inch intervals. The leading edge was of $\frac{1}{4}$-inch × $\frac{1}{4}$-inch, and the trailing edge of $\frac{3}{8}$-inch × $\frac{1}{8}$-inch birch. The tips of the wings were made from $\frac{3}{16}$-inch cane, the ends of which, for a distance of 4 inches, were bound to the leading and trailing edges.

The stabiliser and fin were built as one unit with the tail part of the machine, and connected by rubber bands looped round oppositely located pairs of hooks in the fuselage and tail unit.

The leading and trailing edges of the stabiliser, and also the edge of the fin, were all made from $\frac{3}{16}$-inch diameter cane steamed to shape. The formers were of $\frac{1}{8}$-inch balsa.

The main wing was held to the top of the fuselage by rubber bands which passed right round it, and were so arranged that there was a tendency to pull the wing forward hard up against the " step," which was built on the top of the fuselage.

* * * * * *

The model shown in Fig. 114 was an improved version of the " Cyclonic," where considerably more attention was paid to the profile appearance of the model. The wings were tapered and mounted more in a " mid-wing " position, whilst the undercarriage legs were mounted as cantilevers.

The fuselage was built up in exactly the same manner as before, that is, it consisted of four $\frac{3}{16}$-inch × $\frac{3}{16}$-inch birch longerons at the four corners of a series of rectangular bulkheads cut from three-ply.

The semi-circular shape to the top of the fuselage was obtained by forming sheet balsa (two thicknesses of $\frac{1}{32}$-inch) over a series of balsa stringers supported on shaped supports which rested on top of the bulkheads.

The wing roots were cut from $\frac{1}{16}$-inch three-ply birch, and were suitably mounted and braced to the sides of the fuselage.

$\frac{3}{8}$-inch diameter birch dowel rods passed through these into the wings, for a distance of 12 inches. It should be noted that there were no external fixings for the wings . . . neither were there any inside. The rods were slightly stiff " sliding fit " in the three-ply, and the whole arrangement was such that, whilst the wings could quite easily be drawn on and off the rods, the friction grip was quite sufficient to prevent them working loose in flight.

The rods, of course, could be withdrawn from the fuselage, and broke in the event of a real crack-up.

The landing gear was of a new type, which I originated and developed, and which worked well. It was totally enclosed, and had a stroke which could be controlled from 0 inch to 5 inches in a backwards direction; "springing" was by means of loops of rubber so arranged that the tension could be varied, and the whole unit could be removed from the fuselage in under a minute.

Essentially it consisted of two aluminium tubes which projected up inside the fuselage, where they crossed, their upper ends being housed in suitable recesses constructed adjacent to one of the bulkheads.

That is to say—viewing from the front—the left leg passed through a slot in the underside of the left of the fuselage, and did so at such an angle that it passed diagonally up through the fuselage, so that its top end fitted up against the *right* longeron. Similarly, the right leg passed from the right bottom to the *left* top of the fuselage.

Thus the legs crossed at a point approximately in the centre of the (cross-section) of the fuselage.

From the top of the bulkhead in front of the one against which the ends of the legs abutted, a loop of rubber, $\frac{1}{4}$-inch × $\frac{1}{16}$-inch, of eight strands, was run, passing behind the two

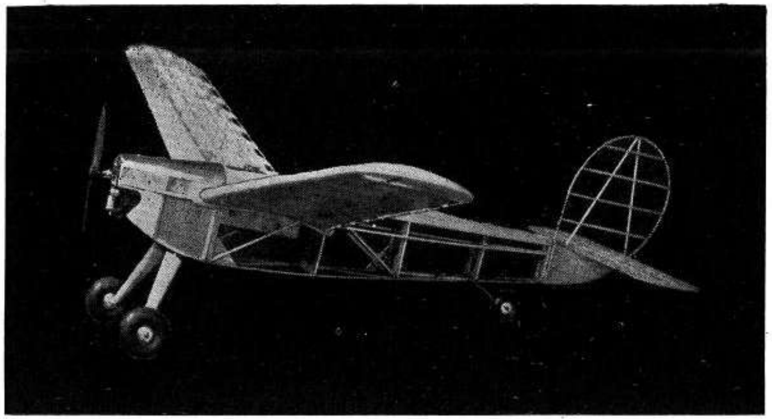


FIG. 114.

The shoulder wing 'plane illustrated on pages 40, 41, 187, and 183. A photo of the engine mount is on page 153, and part of the tail unit is illustrated in Fig. 67 on page 134.

tubes where they crossed, and back to the bulkhead again. By varying the length of rubber used, the tension could be varied, and by inserting suitable " buffers " of rubber in the two slots the length of the stroke could be varied.

The legs were of aluminium tube $\frac{3}{8}$-inch bore, and they were reinforced with $\frac{3}{8}$-inch diameter birch dowel rods, which were a tight fit throughout the length of the tubes. The streamlined fairings were of balsa covered with silk.

At the bottom ends the legs were slightly flattened and drilled to take $\frac{1}{8}$-inch diameter spring steel axles for the wheels. These were a pair of $4\frac{1}{2}$-inch diameter pneumatics.

The tyres were of ample section, and had, of course, totally enclosed valves. Ample resiliency was thus provided in the " up and down " directions.

The tail wheel was a $2\frac{1}{2}$-inch diameter pneumatic, and was mounted on a wire axle looped through the fuselage, and with both ends brought down and turned into the wheel axle to meet in the middle. Thus, by springing the two ends apart, the wheel could be removed.

Under the " M " of the lettering on the sides of the fuselage were the two plugs on to which the accumulator leads were fixed. No change-over switch was provided, the wiring being so arranged that the accumulator was connected in parallel with the usual 4-volt pocket flash-lamp battery used during flight.

The time-switch was mounted on the underside of the hatch, which was normally held in position by internal rubber bands. The opening was large enough to allow of inserting an arm inside the fuselage.

An aluminium cowl covered the engine-room, and the compartment containing the undercarriage legs, and was held in position by one light rubber band.

The fin and stabiliser were built as one unit, which was held to the end of the fuselage by a single rubber band; alterations in incidence, etc., being effected by introducing thin packing pieces between the unit and the end of the fuselage.

The wing was tapered from 12-inch chord at the roots to 9-inch at the tips, the section being R.A.F. 32.

The total weight of the model was 5 pounds which, with a wing area of $5\frac{3}{4}$ square feet, gave a loading of something under one pound per square foot.

* * * * * *

The 10 feet span low-wing monoplane has been illustrated in various parts of this book, but certain detailed descriptions of some of the parts may be of interest.

The fuselage was of monocoque construction, the covering being of $\frac{1}{32}$-inch three-ply birch, laid over a series of $\frac{3}{16}$-inch × $\frac{3}{16}$-inch birch longerons, spaced evenly round the circumferences of a number of bulkheads, the first two of these being of $\frac{1}{8}$-inch three-ply, whilst the remainder were of $\frac{1}{16}$-inch three-ply.

An interesting feature was the system of cross-bracing. Each of the struts was made from two lengths of $\frac{1}{8}$-inch × $\frac{1}{8}$-inch birch "sandwiched" between two pieces of $\frac{1}{32}$-inch three-ply, in which lightening holes were punched. These struts were approximately 11 inches long, and only weighed $\frac{1}{4}$-ounce each, yet were so strong that when held between the two hands and subjected to a "compression" stress they could not be broken.

To conform to the rounded curves of the fuselage the three-ply "skin" had to be built up of a considerable number of pieces. All joints were "butted" and backed by strips of the same material, being further strengthened by fine nails $\frac{3}{16}$-inch long.

These were pushed through the ply with the aid of a pair of light pliers, and then clinched over by a heavier pair. The fuselage, complete with windows, built-up wing-roots, engine "platform," and stabiliser roots, weighed $4\frac{1}{2}$ pounds; the largest diameter was 11 inches, and the overall length 4 feet 3 inches. When stood on end the fuselage has supported the author's full weight.

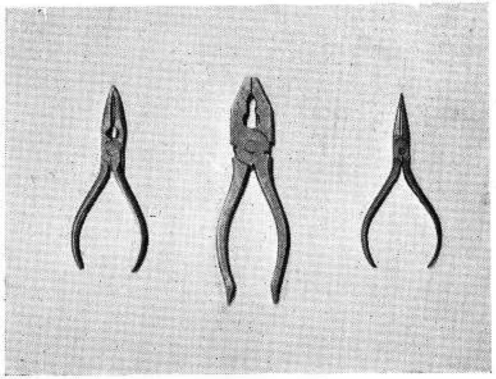


FIG. 115

The pliers on left and those on right have had their jaws slightly curved so that fine nails can be gripped right at the plier ends. The centre pair of pliers is used for clinching the nails—the gap between the jaws clearing the pieces of wood being joined together.

The two "half-wings" were each 4 feet 4 inches long, with root chords of 18 inches and tip chords of 10 inches.

The ribs were of $\frac{1}{32}$-inch three-ply, and were spaced 2 inches apart. The longitudinals, being of $\frac{3}{16}$-inch × $\frac{1}{16}$-inch birch. The leading edge was reinforced with a sheet of $\frac{1}{32}$-inch three-ply.

The weight of each half-wing was 11 ounces uncovered, and $1\frac{1}{4}$ pounds when covered with fairly thick silk, over which was spread several coats of aluminium paint.

The sole support for each wing consisted of an 18-inch length of $\frac{3}{8}$-inch diameter birch dowel rod, 12 inches of which passed through a series of holes punched in the first six wing-ribs, whilst the other 6 inches passed into a steel tube fixed in the fuselage. This tube, which was thus 12 inches long, was bent in the centre to the correct dihedral, and was permanently located in the fuselage. As the dowel rods passed into the wings at a point one-third of the chord distant from the leading edge, and it was thus possible to rotate the wings about the rods, and so vary the angle of incidence.

Steel pegs, suitably positioned in the fuselage and wing roots, were connected by loops of rubber, and so held the

FIG. 116.

A good idea of the size of the 10 feet span low-wing 'plane, a number of photographs of which appear throughout this book, may be obtained by comparison with the enthusiasts at work on it.

wings hard up to the fuselage. In the event of a " crash " the dowel rods broke, the ends being easily withdrawn and new rods inserted, the wings in consequence suffering little damage.

The stabiliser was mounted in an exactly similar manner to the wings, whilst the fin was fixed to a point down the centre line of the fuselage; a very small adjustment was, however, provided.

The landing chassis consisted essentially of a framework of $\frac{3}{16}$-inch diameter mild steel rods, suitably encased in birch streamlined fairings.

The rear legs contained strong coil springs, which moved over steel guide rods inside wooden fairings.

At the four points of anchorage to the fuselage the rods were screwed and welded to forked shackles, which engaged with steel plates bolted to rods, which passed across the fuselage, the actual connections being effected by four $\frac{1}{8}$-inch diameter split pins. By withdrawing these four pins the whole chassis could be removed from the fuselage.

At the bottom ends of the struts, the internal rods were also screwed and welded, this time to steel plates, to which

were screwed the wheel axles. Should these later become bent, they could be removed by the sliding off of one nut and new ones substituted.

The wheels were of $4\frac{1}{4}$ inches diameter, and were made of hardwood with $\frac{3}{16}$-inch bore brass axle tubes.

They carried 8-inch diameter by 2-inch section rubber tyres. These were standard products of the Dunlop Rubber Company, cost 2s. 6d. each, and were sold as inner tubes to fit inside covers in the usual way, the tyres being used on light trolleys, barrows, etc. The inner tubes, complete with valves, weighed $4\frac{1}{4}$ ounces each.

* * * * * *

The model flown by the author in 1939 was a high-wing 'plane of 8 feet span, as shown in photographs on pages 51, 208, and 209. An attempt was here made to produce a semi-scale model capable of a good performance, yet of robust enough construction to stand up to the average conditions encountered in this country. The fuselage was built from $\frac{3}{16}$-inch square birch longerons on three-ply bulkheads.

A photographs of the complete machine uncovered is on page 36, and individual parts of the aircraft are shown in photographs on pages 135, 145, 146, 157 and 158. Thus, in effect, the most interesting parts of this machine have already been described in different chapters of the book. The machine was powered with a 9 cc. Dennymite engine, as shown in Fig. 105, page 174, which gave sufficient power for a good performance, even when the machine was loaded up to an " all-up " weight of $8\frac{1}{4}$ pounds. With the omission of certain additional weight, and the introduction of slightly lighter sectioned members in certain places, this machine could easily be built down to a weight of as little as $6\frac{1}{2}$ pounds. A diagrammatic sketch of the arrangement of the springing of the undercarriage legs is on page 144.

As the model appeared to be popular, Mr. Pollitt, *Aero-Modeller* staff draughtsman, has drawn out a set of full-size plans for building the model. These can be obtained from the offices of *The Aëro-Modeller*, price 10s. 6d. per set, post free.

* * * * * *

The author's latest model is a very ambitious project—a one-fifth full-size scale model of the Westland Army Co-operation Aircraft, " The Lysander."

The fuselage bulkheads are all of $\frac{1}{16}$-inch three-ply birch, into which fit the longerons. These are of $\frac{1}{2}$-inch × $\frac{1}{8}$-inch hard balsa, there being 40 of them.

The cutting of the slots in the bulkheads for these longerons presented a nice little problem. About 200 slots were required to be cut, each exactly $\frac{3}{8}$-inch deep by $\frac{1}{8}$-inch wide. As the longerons were $\frac{1}{2}$-inch wide, this meant that they would stand " proud " of the edges of the bulkheads by $\frac{1}{8}$-inch, and thus prevent the fabric touching the bulkheads. It was essential that the slots should be exactly to size, to afford a snug fit on the longerons.

To do this a special tool, consisting of a striking die of steel $\frac{3}{8}$-inch × $\frac{1}{8}$-inch, was made. This was actuated by a hand lever in such a way as to punch the slot out of the bulkheads.

(This ' gadget " took about four hours to construct out of scrap, but enabled all the slots to be accurately cut to shape in under half-an-hour.)

No jig was used in assembling the longerons in the slots. They were pushed into position, and rubber bands tied round to hold them during the drying of the glue, with which they were fixed.

FIG. 117.

This $\frac{3}{4}$-front view shows the clean lines of the fuselage, and, on the near side, the slot in which the undercarriage leg moves. Note the N.G.A. transfer on side of fuselage.

FIG. 118.

This photo shows the graceful curves of the fin, on which may be noted the N.G.A. transfer and S.M.A.E. petrol 'plane registration numbers. Full-size scale plans of this model, in which all parts are fully detailed, may be obtained from the offices of *The Aero-Modeller*, Allen House, Newarke Street, Leicester, price 10s. 6d. post free.

In the full-sized aircraft, the end of the fuselage, as far forward as the front anchorage of the fin, and the forward portion, are built of metal, and on the model this is represented by sheets of $\frac{1}{32}$-inch three-ply birch, silk covered.

The fuselage, as shown in Fig. 120, and with the forward covering of three-ply, not shown in the photo, weighs about 2 pounds.

The spats are carved from solid blocks of balsa, are some 13 inches long, and weigh about $2\frac{1}{2}$ pounds the pair. They are, of course, hollowed out to accommodate the wheels.

The question of springing the whole undercarriage was considered. After designing a somewhat elaborate arrangement, whereby the legs were hinged and able to move backwards and forwards, the author discarded this, and made the spats and legs solid with the fuselage, partly because they are so in the full-size aircraft, and partly because it was possible to construct a much stronger anchorage by this means. Suspension is thus entirely by the pneumatic tyres, Dunlop 8-inch × 2-inch, as on the 10 feet span low-wing 'plane.

It is considered that it will be well worth while to fit ball races to the wheels, as the author has found that quite an amount of friction can be developed when these wheels, of

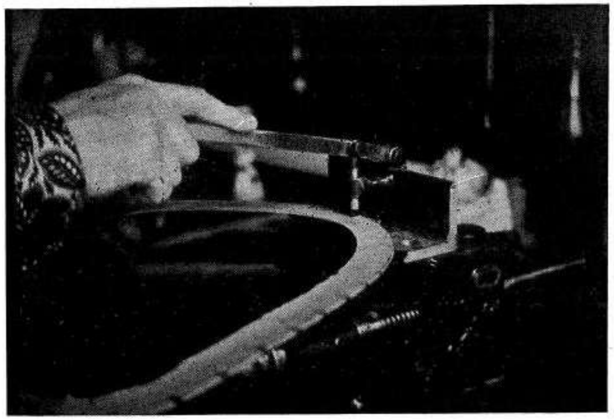


FIG. 119.

Cutting slots for the longerons in a 3-ply bulkhead, as described at foot of the previous page.

such small diameter, are revolving at a speed of close on 1,000 r.p.m. This is a point not realised by all petrol 'plane enthusiasts, but the figures are right! (The diameter of these wheels is 8 inches. Say the circumference is 2 feet. 20 m.p.h. is approximately 30 feet per second, so a wheel must revolve 15 times per second, or 900 times per minute.)

The undercarriage legs are carved from $4\frac{1}{2}$-inch × $1\frac{1}{2}$-inch hard balsa, and are reinforced by $\frac{1}{2}$-inch diameter birch dowels, where they join the spats. The legs are carried through the fuselage, and where they meet they are interlaced in the same way that one can interlace the fingers of one's hands. A very strong joint is thus formed, to which is anchored a " tension plate " of $\frac{1}{8}$-inch three-ply birch, several inches wide, which is carried right back along the floor of the fuselage to the tail of the model.

In addition, the interlaced joint is braced by compression struts, which run up to the front bulkhead; and finally there are two tubes, in compression when landing, and in tension when flying, which run up to a cross tube at the top of the fuselage, and which form the anchorage to which the wings are attached.

Altogether, the construction is very robust, and a complete " crack-up " will be necessary to disturb the landing gear.

The weight of the fuselage, covered, doped and painted, with fin, spats, wheels, and all instruments, is some 15 pounds.

The engine weighs $3\frac{1}{2}$ pounds; twin coils, 1 pound; and with battery, leads, switch, etc., will bring the total up to about 20 pounds. The elevators weigh 1 pound. The wings at the time of writing are not yet built, but should weigh about 2 pounds each, thus bringing the all-up weight to about 25 pounds. As the wing area is about 10 square feet the wing loading will be $2\frac{1}{2}$ pounds per square foot.

As the Westland " Lysander " is still one of this country's latest types of military aircraft, it is not possible to obtain full particulars of the airfoil characteristics, but by various means the author considers he has got pretty near to the correct section. With slots and flaps it is possible to increase the lift fourfold, and this means that the flying speed (with flaps and slots operating), can be reduced to half that of the flying speed when they are in the normal position. According to calculations the speed with flaps and slots operating should be approximately 20 miles per hour, and thus about 40 m.p.h. with them in the normal or closed positions.

The centre-of-pressure travel is quite small, even with the slots and flaps fully extended. It is intended to use the two coils as a pendulum, suspend them inside the dummy petrol tank (which is located over the centre of gravity of the whole machine), and connect them by a simple link control to the elevators, which will be arranged to pivot.

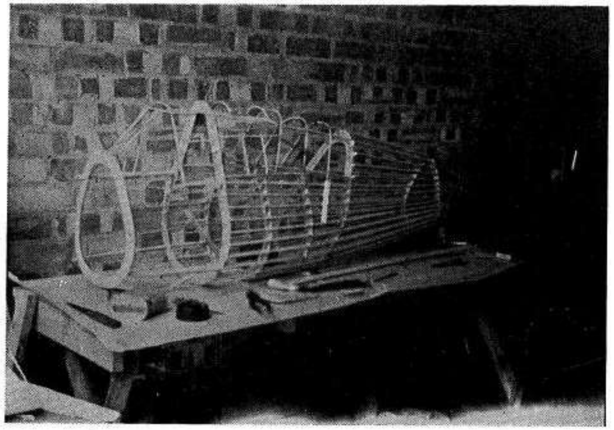


FIG. 120.

Fuselage of the " Lysander " under construction.

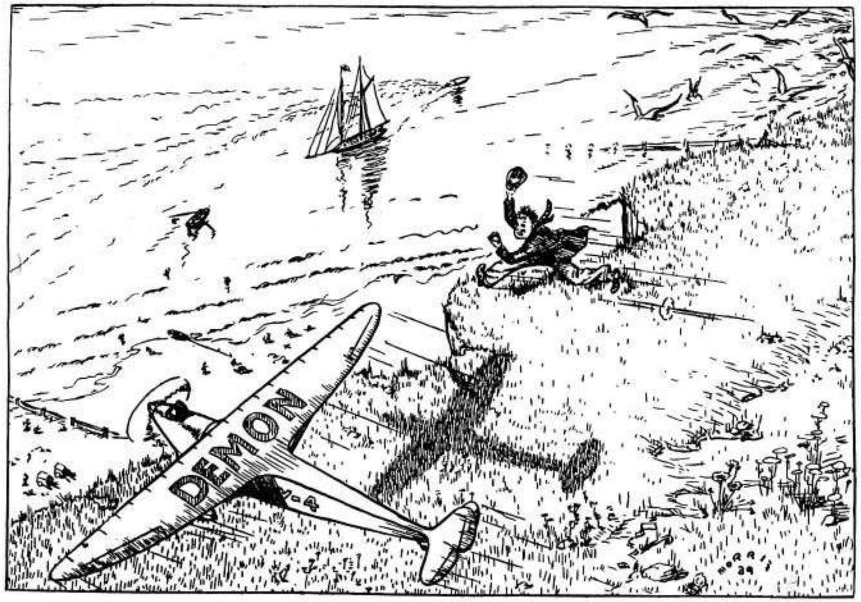
The slots and flaps will be held in the " open " position by springs or rubber bands, so tensioned that as the machine gathers speed the air pressure will tend to close them. This means, of course, that as they close the lift coefficient of the airfoil (considered as a whole) decreases; but at the same time the *drag* decreases much more rapidly, this enabling the machine to more quickly gather speed, until, at the take-off, the flaps and slots are fully closed. This is actually what happens on the full-size aircraft; the operation is entirely *automatic*, and not controlled by the pilot.

When in flight, and power is cut off, the immediate failure of the propulsive thrust of the airscrew causes the 'plane to slow down; and so, due to the decreased air pressure, the slots and flaps commence to open.

The airscrew diameter is 2 feet 2 inches, the 3 blades being of Clark Y section. They are mounted in a steel hub, provision being made to allow of adjustment of pitch.

According to preliminary calculations, an engine speed of 4,000 r.p.m. will be sufficient to fly the model, giving a thrust of 7 or 8 pounds, depending on the pitch of the blades; and there is little doubt that the engine will provide this power.

This machine has been built essentially as an experiment, and as such it must be regarded; as to what will happen when an attempt is made to fly it . . . Well! " 'Tis better to have tried and failed, than not have tried at all."



" Gosh! Bet there'll be something in *The Aero-Modeller* about this! "

APPENDIX 1.—FORMULÆ.

APPENDIX 2.

APPENDIX 3.

APPENDIX 4.

APPENDIX 5.

APPENDIX 6.

APPENDIX 7.

Formula 1.—Pressure on a Flat-plate Type of Airfoil.

The pressure acting on a flat-flate type of airfoil may be ascertained, approximately, from the formula:

$$P_v = P\,\frac{2\ \mathrm{Sin}\ a\ \mathrm{Cos}\ a}{1 + \mathrm{Sin}^2\ a}$$

$$\text{i.e. } P = P_v\,\frac{(1 + \mathrm{Sin}^2\ a)}{2\ \mathrm{Sin}\ a\ \mathrm{Cos}\ a}$$

Formula 2.—Velocity of Wind Necessary to Support a Flat-plate Type of Airfoil.

The Velocity of the wind necessary to support the plate at this angle may be ascertained from the formula:

$$V = \sqrt{\frac{P}{\cdot 0032}}\ \text{miles per hour.}$$

Where P is in pounds per square foot.

Formula 3.—Lift of an Airfoil.

The formula is $L = C_l\,\frac{p}{2}\,SV^2$.

where L = Weight in pounds.
p = Mass density of air.
= ·002378 slug per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.
C_l = Lift coefficient.

Formula 4.—Speed of a 'Plane.

$$V^2 = \frac{L}{C_l\,\frac{p}{2}\,S}$$

where L = Weight in pounds.
p = Mass density of air.
= ·002378 slug per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.
C_l = Lift coefficient.

Formula 5.—Drag of an Airfoil.

$$D = C_d\,\frac{p}{2}\,SV^2.$$

where D = Drag in pounds.
p = Mass density of air.
= ·002378 slug per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.
C_d = Drag coefficient.

Formula 6.—Thickness of the Boundary Layer.

The thickness of the boundary layer can be found from the formula developed by Van der Hegge Zijnen:—

$$T = 4{\cdot}5\sqrt{\frac{KL}{V}}$$

where T = Thickness of layer, in feet.
K = ·00016.
= Kinematic viscosity of air.
L = Distance from the leading edge of the airfoil in feet.
V = Airspeed, in feet per second.

Formula 7.—Reynold's Number of Thickness of Boundary Layer.

The Reynold's number of the thickness of the boundary layer may be calculated by multiplying the thickness of the layer by the speed and dividing by the kinematic viscosity.

$$\text{i.e. R.N.} = \frac{TV}{K}$$

where T = Thickness of layer, in feet.
V = Airspeed, in feet per second.
K = ·00016.

FORMULA 8.—PARASITE DRAG.

Parasite drag may be calculated from the formula

$$D = KAV^2.$$

where K = the drag coefficient of the fuselage, and depends on its particular characteristics.
A = the projected cross-sectional area, in square feet, at the largest section.
V = the speed—in miles per hour.
and D is given in pounds.

K varies from about ·0002 to about ·0009, and averages about ·0004 for totally-enclosed fuselages of approximately circular cross-section.

(4) An average value for K for tail-planes which have a flat under-surface and a thickness-to-chord ratio of about 1 : 18 may be taken as ·000075.

For fins and rudders the value of K may be taken as approximately ·00006 per square foot for area.

An average value for K for struts is ·00025—the drag being in pounds per square foot of projected area: but this must be increased by from 50 to 100 per cent, according to the amount of " interference " which may be thought to exist.

The drag of wheels varies with the ratio of diameter to tyre width, and is also dependent on the degree of "fairing" between the tyre and the hub; also the value of K is relatively greater for small diameter wheels—say 2 to 4 inches—than it is for those of from 6 to 9 inches diameter.

For wheels of from 2 to 4 inches diameter—with a diameter/width ratio of about 2·5 to 1, the value for K is about ·0029, whilst for wheels of from 6 to 9 inches diameter, with a diameter/tyre ratio of about 4 to 1, the value of K drops to about ·0015.

For average conditions the drag of a single-cylinder engine may be taken as being equal to ·0006 V^2 pounds, where V is in m.p.h.

FORMULA 9.—AREA OF STABILISER.

An empirical formula, developed by the Author, for calculating the area of a stabiliser, is:—

$$Sa = \cdot257W \times \frac{15}{AR + 6\cdot4} \times \frac{3\cdot9}{ar + \cdot05} \times \frac{\cdot65}{M} \times \sqrt{\frac{S}{L}}$$

Where W = Main wing area in square inches.
AR = Main wing aspect ratio.
ar = Stabiliser aspect ratio.
M = Moment arm divided by overall length.
S = Main wing span in inches.
L = Overall length of aircraft, in inches.
and Sa = Required area of stabiliser in square inches.

FORMULA 10.—CHORD OF RECTANGULAR WING.

Assuming that the main wing is of rectangular plan form, its chord may be calculated from the formula

$$C = \sqrt{\frac{W}{AR}}$$

Where AR = Aspect ratio.
and W = Wing area in square inches.

FORMULA 11.—AREA OF FIN (PETROL 'PLANE).

The area of a fin for power-driven aircraft may be calculated from the following empirical formula, developed by the Author:—

$$A = K \times \sqrt{\frac{WS}{M}}$$

Where W = Weight of aircraft in pounds.
S = Span of aircraft in feet.
M = Moment arm in feet.
and A = is given in square feet.
and K = ·25 for high-wing monoplanes.
= ·30 for mid-wing monoplanes.
and = ·35 for low-wing monoplanes and biplanes.

FORMULA 12.—AREA OF FIN (RUBBER MODEL).

The area of a fin for a rubber-driven model may be calculated by C. H. Grant's formula:—

$$AF = 0{\cdot}1\,\frac{A}{(M)}(3 + N + 0{\cdot}58\sqrt{ST})$$

Where A = Main wing area.
M = Moment arm.
N = The distance from the centre of gravity to the airscrew bearing face.
S = The wing span.
T = The tip rise of the main wing—i.e. the distance the tip is above the centre section of the wing.
and AF = The required fin area.
(All the values being either in inches or square inches).

FORMULA 13.—MINIMUM FLYING OR STALLING SPEED.

The minimum flying or "stalling speed" of an aircraft may be calculated from the formula:—

$$V = 19{\cdot}77\sqrt{\frac{W}{C_l \text{ Max.} \times S}}$$

Where W = Weight of aircraft, in pounds.
S = Main wing area, in square feet.
V = is given in miles per hour.

FORMULA 14.—POWER REQUIRED TO MAINTAIN STEADY HORIZONTAL FLIGHT.

The power required to maintain an aircraft in steady horizontal flight may be calculated from the formula:—

$$\text{H.P.} = \frac{DV}{375}$$

Where D = Total drag, in pounds.
and V = The speed, in miles per hour.

FORMULA 15.—TO FIND THE LIFT COEFFICIENT OF A GIVEN AIRFOIL AT A GIVEN SPEED.

To find the C_l of the wing, the formula

$$L = C_l\,\frac{P}{2}\,SV^2 \text{ may be re-written}$$

$$C_l = \frac{L}{\frac{P}{2}SV^2}$$

Where L = Weight in pounds.
p = Mass density of air.
= ·002378 slug per cubic foot.
S = Wing area in square feet.
V = Velocity in feet per second.

FORMULA 16.—RATE OF CLIMB.

The rate of climb of an aircraft may be calculated from the formula:—

$$R/C = \text{E.H.P.} \times \frac{33{,}000}{W}$$

Where EHP = Excess H.P. available.
W = Total weight of the aircraft.
and R/C = is given in feet per minute.

FORMULA 17.—TRACTIVE RESISTANCE OFFERED TO AIRCRAFT BY SURFACE OVER WHICH IT MAY BE TAXIING.

The tractive resistance may be calculated from the formula:—

$$R = \frac{W \times F}{2{,}240}$$

Where W = the weight of the aircraft, in pounds.
F = Coefficient of friction, which is expressed in pounds per ton weight—it is equal to about 60 pounds/ton for rubber tyres on a good macadam surface. On the closely-mown grass of a tennis court F = about 220 pounds/ton; and on the average aerodrome field F = about 350 pounds/ton. For average conditions F may be taken as 300 pounds/ton.
And R is given in pounds.

FORMULA 18.—H.P. REQUIRED TO OVERCOME TRACTIVE RESISTANCE OFFERED TO AIRCRAFT BY SURFACE OVER WHICH IT MAY BE TAXIING.

The H.P. required to overcome tractive resistance may be calculated from the formula:—

$$\frac{R \times S \times 5{,}280}{60 \times 33{,}000}$$

Where R = Tractive resistance in pounds.
and S = Speed in miles per hour.

FORMULA 19.—TRACTIVE EFFORT AVAILABLE FOR ACCELERATION.

The tractive effort available for acceleration may be obtained from the formula:—

$$F = \frac{\text{H.P.} \times 33{,}000 \times 60}{D \times 5{,}280}$$

Where D = Speed, in miles per hour.
and F = Tractive effort available for acceleration in pounds.

FORMULA 20.—DISTANCES TRAVELLED DURING TAKE-OFF.

The distance travelled during the take-off may be calculated from the formula $S = \frac{V^2}{2a}$

Where V = Take-off speed in feet per second.
a = Rate of acceleration, in feet per second, per second.

FORMULA 21.—DIAMETER OF AIRSCREW.

A model aircraft airscrew, for power work, will be working at its highest efficiency when the value of "J" is approximately ·5; and by use of the formula:—

$$D = \frac{88 \times \text{MPH}}{\text{RPM} \times \left(\frac{V}{ND}\right)}$$

An approximate figure for the airscrew diameter may be calculated, *provided that*, under "in flight" conditions, the value of "J" is ·5.

FORMULA 22.—STATIC THRUST FROM AN AIRSCREW.

Theoretically—that is assuming 100 per cent efficiency—the static thrust developed by an airscrew may be calculated by use of the formula (usually an efficiency as about 60—66 per cent):—

$$T = 3{\cdot}142 \times r^2 \times p \times n \times {\cdot}076.$$

Where r = Airscrew radius, in feet.
p = ,, pitch, in feet.
n = ,, revolutions, per second.
·076 = Weight in pounds, of 1 cubic foot of air, and T is given pounds.

FORMULA 23.—EFFICIENCY OF AIRSCREW.

A measure of the efficiency of the conditions under which an airscrew is working may be obtained by use of the formula:

$$J = \frac{V}{ND}$$

Where V = Aircraft velocity in feet per second.
N = Airscrew revolutions per second.
and D = ,, diameter in feet.

(Thus when the efficiency is zero, "J" is zero. (As the value of "J" increases (with increase in V) so the efficiency increases until it reaches a maximum point, after which it falls very quickly.)

FORMULA 24.—STATIC THRUST FROM AN AIRSCREW (FULL SIZE).

An empirical formula often used in *full-size* practice for calculating static thrust is that developed by W. S. Diehl, which states that

$$T = 6{,}000\left[18{\cdot}7 - 9{\cdot}5\left(\frac{P}{D}\right)\right]\frac{\text{B.H.P.}}{\text{r.p.m.} \times D}$$

Where P = Airscrew pitch, in feet.
D = Airscrew diameter, in feet.
and T = Actual static thrust developed.

FORMULA 25.—H.P. REQUIRED TO DRIVE AN AIRSCREW.

$$\text{B.H.P.} = \frac{\text{T} \times \text{r.p.m.} \times \text{D}}{6{,}000\left(18{\cdot}7 - 9{\cdot}5\left(\frac{\text{P}}{\text{D}}\right)\right)}$$

Where P = Airscrew pitch, in feet.
D = Airscrew diameter, in feet.
and T = Actual static thrust developed.

The following formulæ may be used in estimating the performance of RUBBER-DRIVEN model aircraft:—

FORMULA 26.—DISTANCE A MODEL WILL TRAVEL UNDER POWER.

$$\text{D} = \frac{\text{K WR}}{\text{W}} \text{ feet}$$

where WR = Weight of rubber motor.
W = Total weight of model with motor.
K = Approx. 3,000 for models with high lift wing sections and not specially streamlined—4,000—5,000 for streamlined models.

FORMULA 27.—NUMBER OF TURNS A RUBBER MOTOR WILL STAND.

$$\text{N} = \frac{\text{KL}\sqrt{\text{L}}}{\sqrt{\text{W}}}$$

where L = Length of skein unstretched in inches.
W = Weight of rubber per skein in ounces.
K is usually taken as 4, but if the motor is stretch wound may be safely increased to 5.

FORMULA 28.—PROPELLER PITCH (ALLOWING 25 PER CENT SLIP).

$$\text{P} = \frac{\text{D}}{\text{N} \times \text{R} \times {\cdot}75} \text{ feet}$$

R = gear ratio = 1 if the propeller is driven direct.

APPENDIX 2.

DESCRIPTION OF THICK AIRFOIL SECTION PRODUCING HIGH LIFT, AND POSSESSING GOOD SLOW-FLYING CHARACTERISTICS.

THE main characteristics are the thick nose, the deep under camber at the trailing edge, and the fairly fine angle of taper between the upper and lower surfaces at the rear half of the wing.

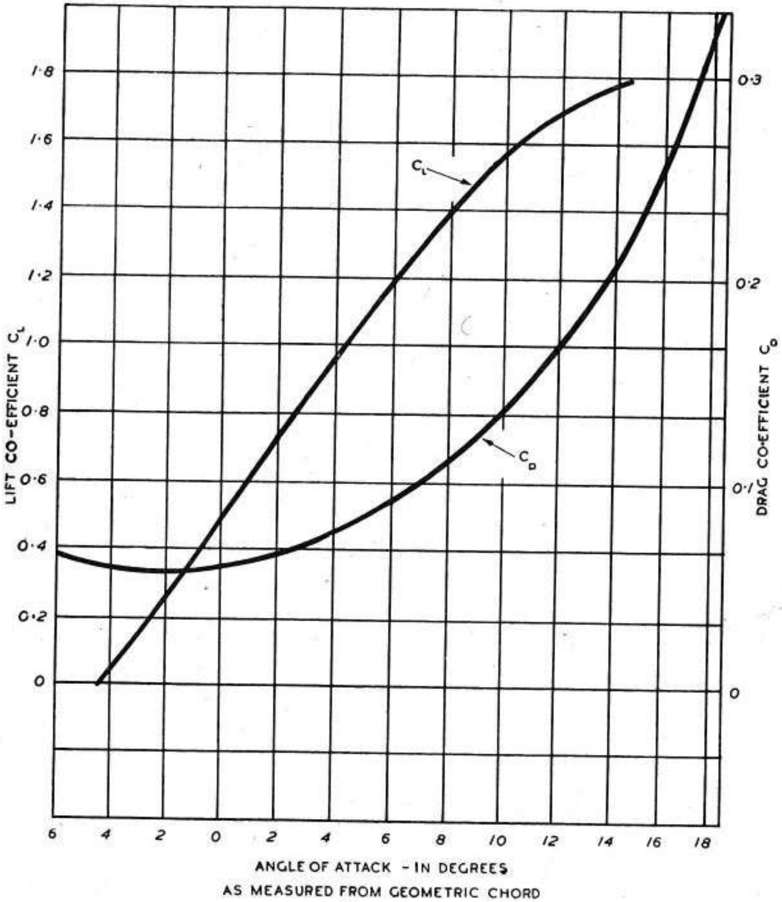


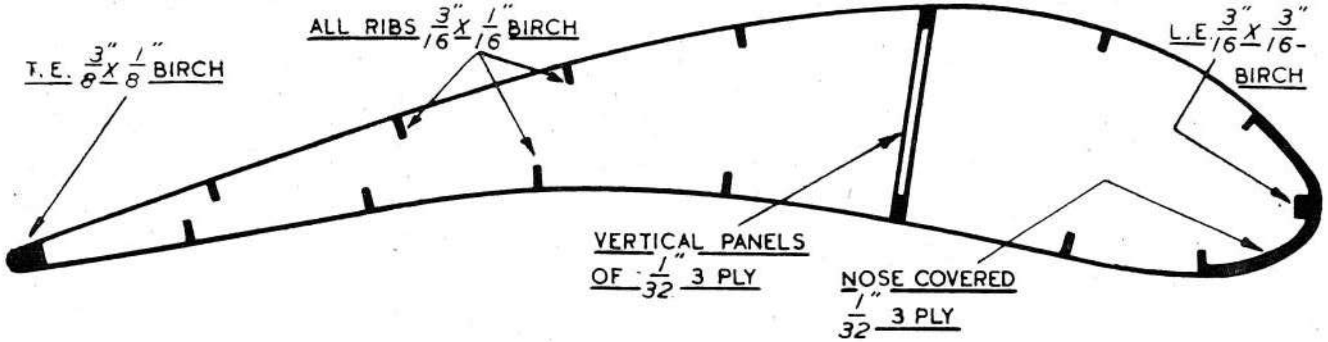
FIG. 121.

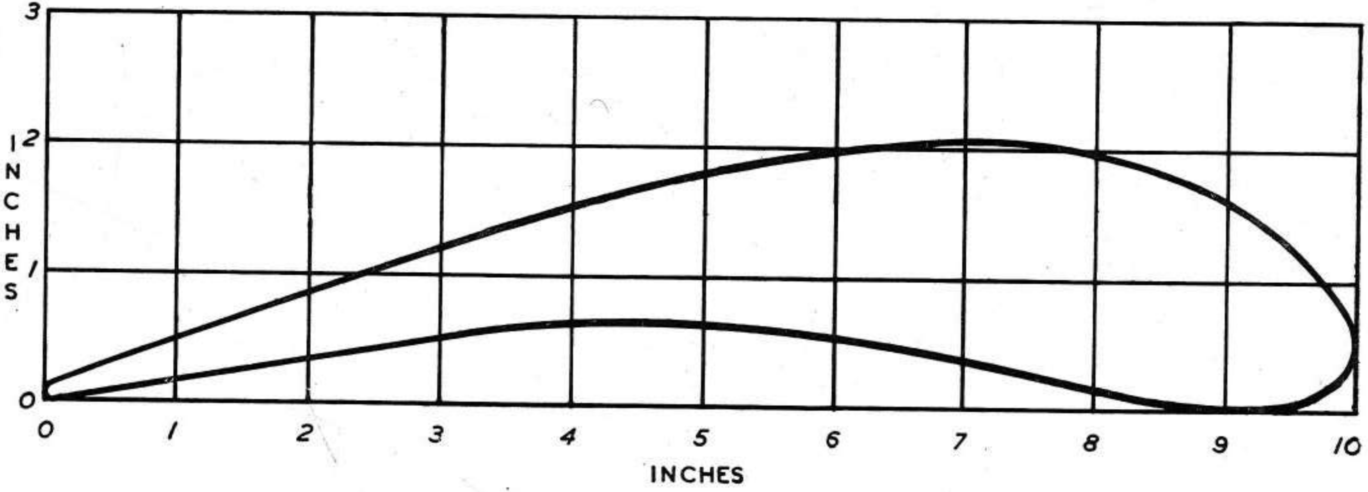
The considerable under camber was introduced to give the wing section a " slow flying " characteristic, in effect similar to that produced by a " flap."

The thin section towards the rear results from the requirement that " breakaway " of the air-stream from the upper surfaces of the trailing edge shall occur at as high an angle of attack as possible; and as the type of wing section is essentially one meant to operate at a fairly large angle of attack, it is necessary to keep the upper surface as *nearly parallel* to the lower surface as is reasonably possible.

This does not weaken the section really, as due to the under camber, the nose drops, and thus it is still possible to obtain a fairly thick section near the leading edge.

Fig. 121 shows lift and drag curves for this section; they represent the averages of a number of tests made at different angles of attack, and tests made with a model in my wind tunnel. I cannot guarantee the dead accuracy of these latter, as I am unable to correctly assess the appropriate correction factor to allow for scale effect. However, a number of flight tests have been made with different wing settings, and these two curves may be taken as reasonably accurate.


ALL RIBS 3/16" X 1/16" BIRCH
T.E. 3/8" X 1/8" BIRCH
L.E. 3/16" X 3/16" BIRCH
VERTICAL PANELS OF 1/32" 3 PLY
NOSE COVERED 1/32" 3 PLY


3
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APPENDIX 3.

NOTE ON THE "ANGLE OF INCIDENCE" OF AN AIRFOIL.

WHEN an airfoil is set at an "angle of attack of zero lift," i.e. when the zero lift chord is parallel to the line of flight, no lift is generated.

The geometric chord of an airfoil is really an arbitrary dimension, and is specified by the designer. Broadly speaking, it may be defined as the greatest distance between the leading and trailing edges, measured as between two perpendiculars. Thus, in any airfoil of curved section, it would be at a *negative* angle when the airfoil is set at the angle of zero lift.

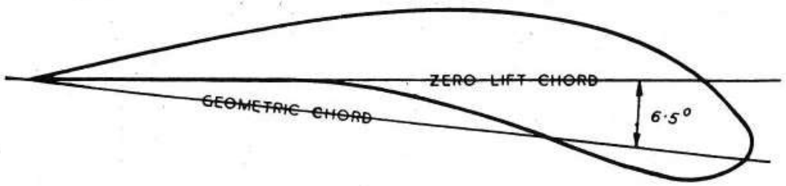


FIG. 122.

In the case of the airfoil shown in Fig. 122 the angle between the two chords is approximately 6·5 degrees.

It is very important that this feature of airfoil nomenclature should be understood, as otherwise confusion may result when considering various wing settings.

A description to the effect that "The wing is set at an angle of incidence (or of attack) of 5 degrees," is not of much use if no indication is given as to whether this is measured from the zero lift chord or geometric chord.

It is the *usual* practice to measure the angle of incidence as from the geometric chord. Thus, the actual effective angle is increased by the amount of negative setting of the geometric chord below the zero lift chord.

For example, when the angle between the two chords is 6·5 degrees, and the angle of incidence is given as 7 degrees, the effective operating angle is $6{\cdot}5 + 7 = 13{\cdot}5$ degrees.

APPENDIX 4.

SOME NOTES ON THE DESIGN OF THE 10-FOOT SPAN LOW-WING MONOPLANE DESCRIBED IN THIS BOOK.

THIS 'plane was built entirely as an experiment. No attempt was made to obtain a "sparkling" performance—in fact, the reverse was the case, as all the time the 'plane was kept loaded up to the maximum to tax the engine to its utmost.

The design was completely worked out, and an estimate of performance made, before a start was made on the construction.

The wing area was 10 square feet, and the designed weight 13·5 pounds—and some folk said that the 'plane would never fly! However, it *did* fly!—but not before the author had had some good fun, and learnt a lot that a 'plane doing 20 m.p.h. on the ground can do! Once, one of its wheels seized on the axle, causing the aircraft to suddenly swing round, and the airscrew to "bite" the legs of the unfortunate constructor; who, by a superhuman effort, was equalling the best "100 yards-in-ten-seconds" style of an Olympian sprinter, and was close behind at the end of the ubiquitous piece of string!

(1) The power required to fly an aircraft may be calculated from the formula:—

$$\text{H.P.} = \frac{DV}{375}$$

where D = drag of the aircraft, in pounds, and V = the speed of the aircraft in m.p.h.

(2) A well-tuned 18 cc. "Comet" engine will develop a good ·5 h.p. So, rewriting the formula in the form

$$D = \frac{375\ \text{H.P.}}{V}$$

and taking a value for V of 25 m.p.h.

$$D = \frac{375 \times {\cdot}5}{25}$$

$$= 7{\cdot}5 \text{ pounds.}$$

i.e. at a speed of 25 m.p.h. ·5 h.p. will fly an aircraft whose total drag does not exceed 7·5 pounds.

(3) My bench tests have shown that a metal airscrew 17½ inches diameter × 12 inches pitch, running at 3,800 r.p.m., will develop a static thrust of 6·2 pounds, which means that under correct flying conditions the effective propulsive thrust will be approximately 5·1 pounds.

(4) The difference between the figure of 7·5 pounds drag (as that which—theoretically—could be dealt with by ·5 h.p.), and that of 5·1 pounds (as the effective propulsive thrust available) represents, of course, the sum total of the engine and airscrew losses,

$$\text{i.e. } \frac{5{\cdot}1}{7{\cdot}5} = 68\% \text{ efficiency.}$$

(5) Assuming a figure of 65 per cent for the efficiency, the forward flying speed is calculated to be ·65 × 63·3 (revs. per sec.) × 1 (foot pitch) = 28·2 m.p.h.

Thus, *theoretically*, it is shown that a speed of over 25 m.p.h. could be obtained by an aircraft powered with a ·5 h.p. engine, provided the total drag did not exceed 5 pounds.

(6) The value of K for a totally enclosed fuselage of the type used is about ·0004; and the maximum cross sectional area of the fuselage = ·66 square feet. Thus, at a speed of 25 m.p.h. the drag is found (from the formula $D = KAV^2$) to be $\cdot0004 \times \cdot66 \times 25^2 = \cdot165$ pound.

(7) The aircraft was originally planned to have a wing area of 10 square feet and a weight of 13·5 pounds.

Rewriting the formula

$$L = C_l \frac{\rho}{2} SV^2$$

in the form

$$C_l = \frac{L}{\frac{\rho}{2} SV^2}$$

and taking a value of 25 m.p.h. for V

$$C_l = \frac{13{\cdot}5}{\cdot001189 \times 10 \times 36{\cdot}7^2}$$

(Note in this formula V is in feet per second).

Therefore $C_l = \cdot845$

(8) Reading from the chart, Fig. 2, the value of C_d (when $C_l = \cdot845$) is found to be ·07.

(9) The drag of the wings is then found from the formula

$$D = C_d \frac{\rho}{2} SV^2$$

Inserting the appropriate figures

$$D = \cdot07 \times \cdot001189 \times 10 \times 36{\cdot}7^2 = 1{\cdot}12 \text{ pounds}$$

(10) With a total drag of 1·28 pounds for the fuselage and main wings it is obvious that the drag of the rest of the aircraft would not increase this figure to much beyond 2 pounds; and since a maximum of 5 pounds was permissible it followed that the proposed power unit should be sufficient to fly the aircraft.

Since a propulsive thrust of some 5 pounds is available, it follows that a *smaller* engine, provided it developed say 3½ pounds thrust (effective) should fly this machine—that it might not do so is also possible, since an airscrew must not only develop a certain thrust, but must do so at the correct forward speed, and under certain conditions the proper combination of these two features is not possible.

Attention is drawn to the fact that a power/weight ratio of 1·33 cc./pound weight is definitely possible; and it is hoped that this figure will be of some assistance to those aeromodellers who are contemplating designs incorporating one or other of the petrol engines now on the market.

(11) The original designs for this aircraft were got out on the basis of a flying speed of 23 m.p.h.; when $C_l = 1{\cdot}03$ and the wing setting was 4·5 degrees angle of attack measured from the geometric chord.

(12) During trials it was found—due to the margin of thrust power in hand—that the angle of attack could be increased to 12 degrees, which increased the C_l to 1·68 and reduced the speed to approximately 18 m.p.h.

(13) Since a test flight with extra load was found possible, wheels of hardwood, instead of balsa, were fitted, with the object of slightly lowering the centre of gravity, which incidentally is some 2 inches below the thrust line; also certain strengthening members were added to the landing chassis anchorages. Finally, a heavier coil was installed, bringing

the total weight up to 14 pounds; this gives a power/weight ratio of 1·29 cc./pound weight.

At this wing loading, the 'plane made several flights after being hand-launched from a moving car, as described in Chapter 17.

The final flights of the 'plane were made at Cranwell R.A.F. Aerodrome in the summer of 1939, where, at an all-up weight of 14 pounds 3 ounces, it took off from the tarmac under its own power.

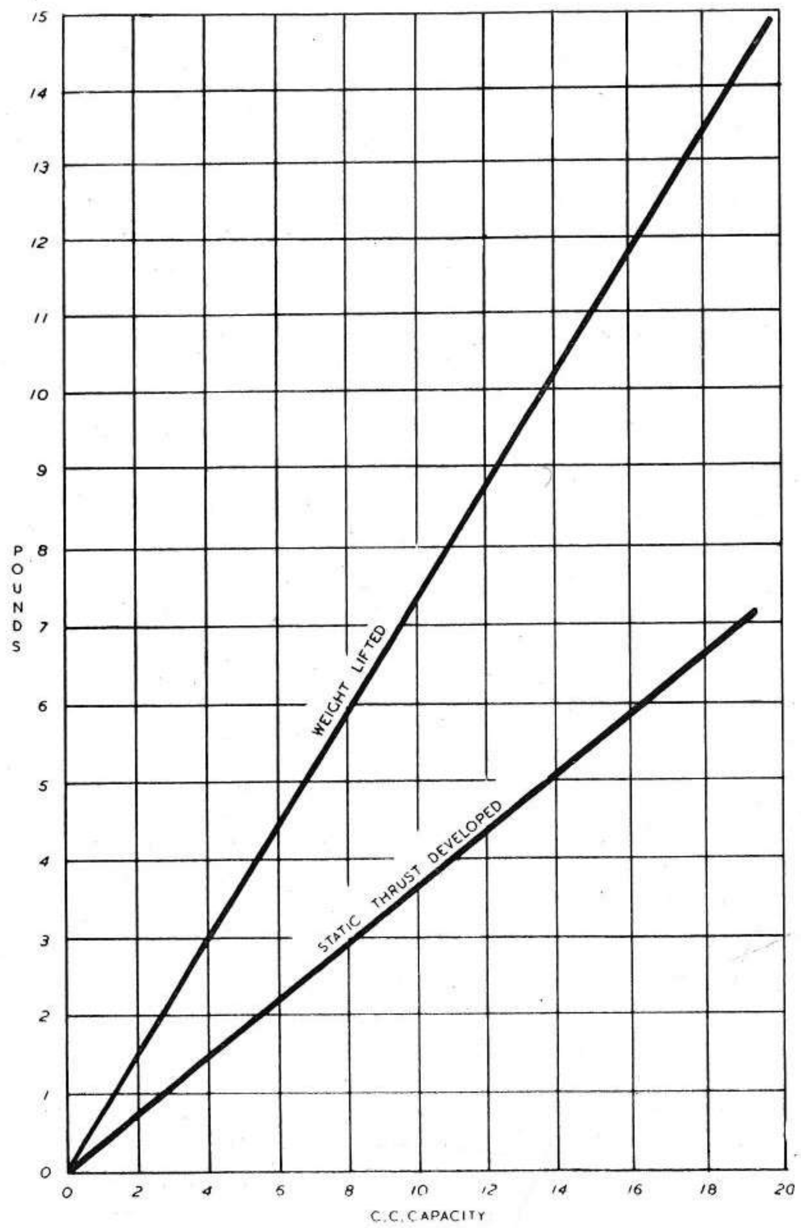
As previously pointed out, this 'plane was built solely as an experiment—to determine whether one of this size and weight could be flown.

In attempting its design and construction, the author was entering an hitherto unexplored sphere of model aircraft construction; and whilst no claim is made that the 'plane was capable of flying in anything but calm weather, owing to its being deliberately loaded up to the maximum, it has been a matter of satisfaction to the author that the performance estimated was obtained; and that, despite the prophecies of the sceptics, the 'plane *did* definitely take off under its own power and fly!

The fuselage has now passed into honourable retirement, very little the worse for several very severe " bumps "; whilst the main wings and engine " live to see another day "—being incorporated in the author's latest 1940 model, for which a new fuselage and tail unit have been designed.

APPENDIX 5.

In the chart on the opposite page is summarised the position as to the relation between power, as represented by cc. and weight to be lifted. From this it will be seen that for every one cc. of " engine size " a weight of approximately ·75 pounds may be lifted, and a static thrust of approximately ·37 pounds developed. These figures represent the average good performance obtainable in the light of present-day knowledge.



APPENDIX 6.

SOME NOTES ON THE DESIGN OF AIRSCREWS FOR POWER-DRIVEN AIRCRAFT.

AN airscrew blade is, of course, an airfoil, and under working conditions produces lift (i.e. thrust) and drag, in exactly the same way as an aircraft wing; and when it is remembered that most airfoils " stall " at angles exceeding 20—25 degrees, it will be seen that any part of the blade of an airscrew which is called upon to operate at an angle exceeding this figure will only do so at a very low efficiency.

That this question of blade angle has a very marked effect on the efficiency of an airscrew may be appreciated from a study of Fig. 123, which shows the static thrust developed by two metal airscrews of same diameter and blade area but of different pitches—these being 12 inches and 22 inches respectively.

It will be seen that despite an increase of nearly 100 per cent in pitch angle the coarse-pitch airscrew develops very little extra thrust " all along the line."

Now it is well known that two-strokes develop their power at fairly high speeds, and the effect of such a coarse pitch as 22 inches is to slow down the engine speed considerably. (An 18 cc. " Comet " engine will drive the 12-inch pitch airscrew at 3,800 r.p.m.; but with the 22-inch pitch airscrew it will only go up to about 2,500 r.p.m., the resulting efficiency, therefore, being a good deal less.)

It will, of course, be appreciated that if the pitch of an airscrew is to be constant across the blade radius of the blade, the blade angle will increase towards the boss, resulting in the lowering of the efficiency of the centre portion of the airscrew—and a series of experiments with airscrews, the pitch of which *decreased* towards the boss, thus keeping the blade angle less acute, showed a useful improvement could be obtained.

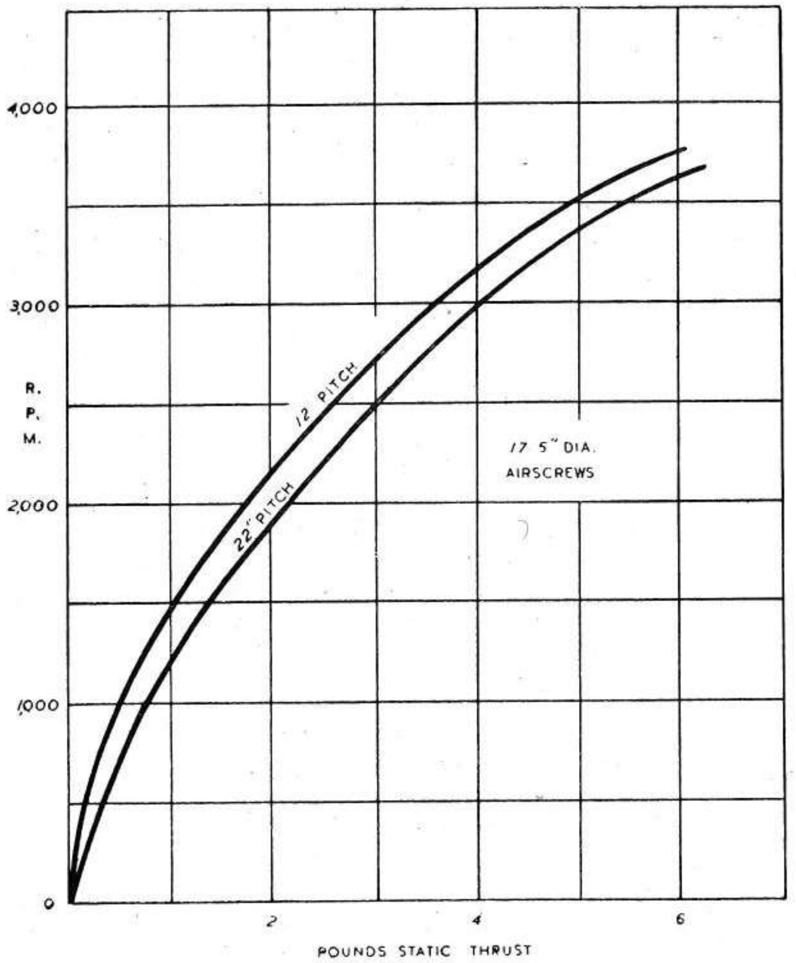


FIG. 123.

One comparison was between a 17½-inch diameter × 12-inch pitch airscrew, the blade of which was twisted to 10 inches at the tips, and a wooden airscrew made with a pitch at the tips of 9½ inches, which decreased to 8 inches at a point ·4 of the radius from the boss. The blade areas and thickness were, of course, the same in each case.

The actual pitch and blade angle at various points along the blades was as indicated in Table A.

TABLE A.

Distance from boss.	17½ in. dia. wood.		17½ in. dia. metal.	
	Blade angle. deg.	Pitch. in.	Blade angle. deg.	Pitch. in.
·4 radius	20	8	28	12·6
·5 ,,	19	9·1	23	11·8
·6 ,,	17	9·9	18	11·5
·65 ,,	16	9·9	18	11·5
·7 ,,	15	10·0	16	11·0
·75 ,,	14	9·95	14·8	10·7
·8 ,,	13	9·9	13·5	10·5
·85 ,,	12	9·65	12·5	10·3
·9 ,,	11	9·4	11·5	10·1
Average from ·65 to ·9		9·8		10·7
		=·816 ft.		=·89 ft.

The results of static thrust tests from these two airscrews are shown in Table B.

TABLE B.

Airscrew.	Speed r.p.m.	Ideal thrust. lb.	Static thrust. lb.	Propulsive thrust. lb.	Overall efficiency. %
9·8 in. wood	3,900	6·72	5·6	4·65	69
10·7 in. metal	3,900	7·35	4·85	4·03	55

It should be noted that the "ideal" thrust is calculated from the formula given in this book, and the "propulsive" thrust is taken at 83 per cent of the static thrust actually developed.

Noting the efficiencies, the actual forward speed theoretically obtainable may be calculated by multiplying the pitch by the number of revolutions multiplied by the efficiency—which gives speeds of 36·5 feet per second for the wooden airscrew and 31·6 feet per second for the metal airscrew—and, substituting these figures in the formula,

$$J = \frac{V}{ND} \text{ we get } \frac{36{\cdot}5}{65 \times 1{\cdot}46} \text{ and } \frac{31{\cdot}6}{65 \times 1{\cdot}46}$$

which gives values for J of ·385 and ·332 respectively.

To further investigate this aspect of airscrew design two more airscrews, both 17½ inches diameter, the first with a tip pitch of 12 inches, which decreased to 10 inches at ·4 radius distance from the boss; and the second with a tip pitch of 14 inches, which decreased to 11 inches at ·4 radius from the boss, were made. The average effective pitches, therefore, being 11 inches and 12½ inches respectively.

When tested at 3,900 r.p.m., static thrusts of 6·5 pounds and 7·2 pounds respectively were obtained from these two airscrews. These results comparing with the figures of 5·6 pounds from the wooden airscrew and 4·85 pounds from the metal airscrew previously tested.

Tabulated, the results obtained from the four airscrews are as shown in Table C.

TABLE C.

No.	Airscrew details of pitch.	Average pitch inches.	Speed R.P.M.	Ideal thrust lb.	Static thrust lb.	Pro-pulsive thrust.	Overall efficiency.
1	10 in. *in*creasing to 12½ in.	10·7	3,900	7·35	4·85	4·03	55%
2	9½ in. *de*creasing to 8 in.	9·8	3,900	6·72	5·6	4·65	69%
3	12 in. do. 10 in.	11·0	3,900	7·6	6·5	5·4	71%
4	14 in. do. 11 in.	12·5	3,900	8·62	7·2	5·96	69%

The original airscrew fitted to the large low-wing monoplane was of 17½ inches diameter × 12 inches constant pitch which, when running at 3,800 r.p.m., developed just over 6 pounds static thrust. Here, now, in airscrew No. 4, is an airscrew of the same diameter, of only slightly larger *average* pitch, which, running at practically the same speed, develops an extra pound of thrust, whilst the efficiency rises to 69 per cent—from the figure of 65 per cent for the original airscrew.

Another way of demonstrating the increased output which may be obtained by decreasing the pitch of an airscrew towards the boss is to compare the results obtained by driving the various airscrews by an engine so controlled as to deliver a predetermined horse-power of exactly the same value in each of the tests.

Results from such a series of tests, on the four airscrews under consideration, are as shown in Table D.

Compare the results obtained from Nos. 2 and 4 airscrews :—

TABLE D.

H.P. absorbed.	Airscrew No. 1. 17½ in. dia. × 10·7 in. p.		Airscrew No. 2. 17½ in. dia. × 9·7 in. p.	
	R.P.M.	Static thrust lb.	R.P.M.	Static thrust, lb.
·29	3,460	3·60	3,220	3·6
·5	3,900	4·85	3,900	5·6
	Airscrew No. 3. 17½ in. dia. × 11 in. p.		Airscrew No. 4. 17½ in. dia. × 12½ in. p.	
·29	2,950	3·8	2,730	3·8
·5	3,740	6·2	3,580	6·5

In the first case the ideal thrust at 3,900 r.p.m. = 6·72 pounds, which, compared with the developed *propulsive* thrust (83 per cent of the static thrust, as shown in Table C) = 4·65 pounds : gives an overall efficiency of 69 per cent; and in the second case the ideal thrust at 3,580 r.p.m. = 7·9 pounds, which, compared with the developed *propulsive* thrust = 5·4 pounds, gives an overall efficiency of 68 per cent, i.e. although the average pitch has been increased from 9·7 inches to 12·5 inches—due to the new design—the efficiency has not dropped by any amount which matters—*but a gain of approximately 1 pound of effective thrust has been obtained*, from 4·65 to 5·4 pounds, an increase of 16 per cent.

Finally, the actual flying speeds may be calculated to be, in the first instance, equal to—
65 (revs. per sec.) × ·815 (pitch in feet) × ·69 (efficiency %)
= 25 m.p.h. and in the second case equal to
60 (revs. per sec.) × 1·04 (pitch in feet) × ·68 (efficiency %)
= 29 m.p.h.

Summed up, No. 4 airscrew gives a speed increase from 25 m.p.h. to 29 m.p.h., and propulsive thrust increases from 4·65 pounds to 5·4 pounds over No. 2 airscrew, *whilst absorbing no more power from the engine* (whose speed is reduced from 3,900 r.p.m. to 3,580 r.p.m.).

Next, the investigation was extended to cover a family of airscrews of 13 inches diameter, as used on the 6 cc. " Baby Cyclone."

First of all, experiments were carried out with an airscrew 13 inches diameter × 6·6 inches average pitch—the actual pitch at various radii from the boss being shown in Table E.

TABLE E.

Distance from boss.	No. 1 airscrew pitch.	No. 2 airscrew pitch.
	in.	in.
·4 radius	5·5	4·5
·5 ,,	5·8	5·4
·6 ,,	6·2*	6·2*
·7 ,,	6·5*	6·5*
·8 ,,	6·8*	6·8*
·9 ,,	6·8	7·1
Tip	6·9	7·4

* *Average between ·6 and ·8 radius*
6·5 inches in both airscrews.
Average of No. 1 = 6·36 inches.
Average of No. 2 = 6·27 inches.

The actual static thrust developed by these two airscrews, tested over a wide range of speeds, is shown in Table F. No. 2 airscrew was made of same diameter and *average* pitch, but, as will be seen from the table, the tip pitch was slightly greater, whilst (and this is the important point) the pitch decreased considerably from ·6 to ·4 radius from the boss.

(The most operative part of an airscrew blade is that part which lies between ·6 and ·8 radius from the boss, and the " average " pitch of this family of airscrews is calculated as between those points.)

From a study of these figures it will be seen that there is approximately a 10 per cent increase in static thrust throughout the speed range—without any increase in power required.

As a " Baby Cyclone " engine in good fettle will run up to some 5,000 r.p.m., driving either of these airscrews, it

TABLE F.

Airscrew No. 1.		Airscrew No. 2.	
R.P.M.	Static thrust.	R.P.M.	Static thrust.
	lb.		lb.
2,600	·55	2,600	·65
3,120	·86	3,100	·98
3,900	1·25	3,910	1·4
4,540	1·7	4,500	1·88
5,140	2·15	5,100	2·38
5,580	2·7	5,600	3·0

will be seen that a good $2\frac{1}{4}$ pounds of static thrust may be obtained at this speed—or about $1\frac{7}{8}$ pounds propulsive thrust in actual flight.

Now calculations for the " ideal " thrust gave a figure of 3·22 pounds at 5,100 r.p.m., whilst taking 83 per cent of the static thrust developed (2·38 pounds), gave a figure of 1·97 pounds as the maximum propulsive thrust, the resulting figure for efficiency being 61 per cent—rather on the low side. (Calculations for the value of J give a figure of ·3, also low).

It, therefore, seemed as if the decreasing of the pitch had been carried out *too* drastically; and after a consideration of all the information which had been obtained throughout this series of experiments, four more airscrews—all of 13 inches diameter and same blade area as before—were made.

In these airscrews the decrease in pitch was not so great; and, as will be seen from the results given in Table A, a considerable increase in static thrust developed was obtained.

For comparative purposes, the results obtained from the tests on the second of the first two airscrews tested are given in column 1 in table G.

Comparing airscrews Nos. 2 and 3 it will at once be seen that the less severe decrease in pitch has resulted in a useful increase in static thrust developed; with a consequent increase in efficiency from 61 per cent to 74 per cent.

The average pitch, be it noted, is the same for each airscrew; as was also the power absorbed at the speed of 5,100 r.p.m.

Examining the results obtained from the rest of the airscrews, it will be noted that whilst the static thrust developed increases, it does not do so at the same rate as the " ideal " thrust—i.e. above 7 inches to 8 inches average pitch, the blade angle is becoming too coarse, and the efficiency falls off.

TABLE G.

	Airscrew 2.	Airscrew 3.	Airscrew 4.	Airscrew 5.	Airscrew 6.
Pitch at tip ..	7·4 in.	7 in.	8 in.	9 in.	10 in.
Pitch at ·4 rad. from boss ..	4·5 in.	6 in.	6·875 in.	7·75 in.	8·625 in.
Average pitch ..	6·5 in.	6·5 in.	7·4 in.	8·4 in.	9·3 in.
Speed, R.P.M. ..	5,100	5,100	5,130	5,090	4,960
Static thrust ..	2·38 lb.	2·9 lb.	3·0 lb.	3·12 lb.	3·3 lb.
" Ideal " thrust..	3·22 lb.	3·32 lb.	3·7 lb.	4·2 lb.	4·5 lb.
Propulsive thrust	1·97 lb.	2·4 lb.	2·5 lb.	2·6 lb.	2·75 lb.
Efficiency ..	61%	74%	67%	62%	61%
J = ...	·30	·37	·38	·4	·44

To sum up, the following conclusions seem to be indicated:—

1. The *average* pitch of an airscrew should be not less than half the diameter, nor more than 7/10 the diameter.
2. Matters should be so arranged that the value of J is not less than ·35; greater, if possible.
3. If the *average* pitch of an airscrew is to be half the diameter, then the tip pitch should be 1·1 × the average; whilst that at ·4 radius from the boss should be ·9 × the average, i.e. if the diameter is 16 inches and the average pitch is 8 inches, then the above-named limits should be (8 × 1·1) = 8·8 inches; and (8 × ·9) = 7·2 inches respectively.
4. If the *average* pitch of an airscrew is to be 7-10 the diameter, then the tip pitch should be 1·13 × the average; whilst that at ·4 radius from the boss should be ·87 × the average, i.e. if the diameter is 10 inches and the average pitch is 7 inches, then the limits are (7 × 1·13) = 7·9 inches; and (7 × ·87) = 6·1 inches respectively.

ACKNOWLEDGMENT, WITH THANKS, IS MADE TO THE FOLLOWING MODEL AIRCRAFT FIRMS WHO KINDLY LOANED BLOCKS OF THE UNDERNOTED ILLUSTRATIONS FOR USE IN THIS BOOK.

Page 119, Fig. 51. The "Club" Conquest. Kit of parts, price £3 10s. The Model Aerodrome, 144 Stratford Road, Birmingham.

Page 129, Fig. 60. The "Eaglet." Kit of parts, price £1 10s. The Model Supply Stores, 17 Brazennose Street, Manchester 2.

Page 133, Fig. 65. The tail unit of the model shown in Fig. 60. The Model Supply Stores, 17 Brazennose Street, Manchester 2

Page 135, Fig. 69. The tail unit of the model shown in Fig. 51. The Model Aerodrome, 144 Stratford Road, Birmingham.

Page 151, Fig. 84. Engine mounting. (Price on application). Kanga Aeromodel Co., Colonnade Passage, New Street, Birmingham.

Page 152, Fig. 85. The 18 cc. "Comet" engine. (Price on application). Model Aircraft Stores (Bournemouth) Ltd., 127b Hankinson Road, Bournemouth.

Page 154, Fig. 87. The "Drome" flexible engine mounting. (Price on application). The Model Aerodrome, 144 Stratford Road, Birmingham.

Page 159, Fig. 94. Light-weight accumulator. (Price on application). Model Supply Stores, 17 Brazennose Street, Manchester 2.

Page 160, Fig. 95. Nathan Smith, "Firecracker" coil. Price 14s. 6d. Cloud (Model) Aircraft, 304-6 High Street, Dorking, Surrey.

Page 160, Fig. 96. Austin Airdraulic Flight Timer. (Price on application). Cloud (Model) Aircraft, 304-6 High Street, Dorking, Surrey.

Page 161, Fig. 97. Time-switch incorporated in model. (Price on application). Model Supply Stores, 17 Brazennose Street, Manchester 2.

Page 163, Fig. 91. Sparking plugs, ¼ and ⅜. Price 5s. Cloud (Model) Aircraft, 304-6 High Street, Dorking, Surrey.

Page 166, Fig. 100. Baby Cyclone engine. Price £4 17s. 6d. Atlas Motors, 14 Oswald Place, Dover.

Page 170, Fig. 103. "Spitfire" 2·5 cc. engine. Price £4 12s. 6d. Model Aircraft Stores (Bournemouth) Ltd., 127b Hankinson Road, Bournemouth.

Page 172, Fig. 104. Bunch "Gwyn-Aero" engine. Price £4 2s. 6d. Model Supply Stores, 17 Brazennose Street, Manchester 2.

Page 173, Fig. 105. The "Dennymite" engine. Price £4 17s. 6d. Cloud (Model) Aircraft, 304-6 High Street, Dorking, Surrey.

Page 193. The "Club" Scientific. Kit of parts, price £5 10s. The Model Aerodrome, 144 Stratford Road, Birmingham,

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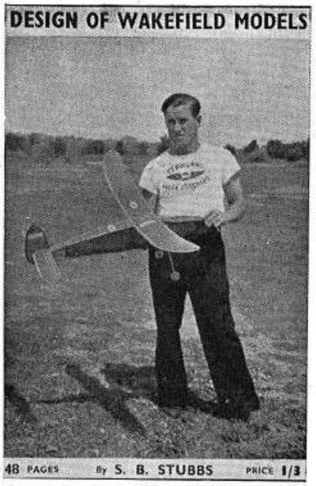
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