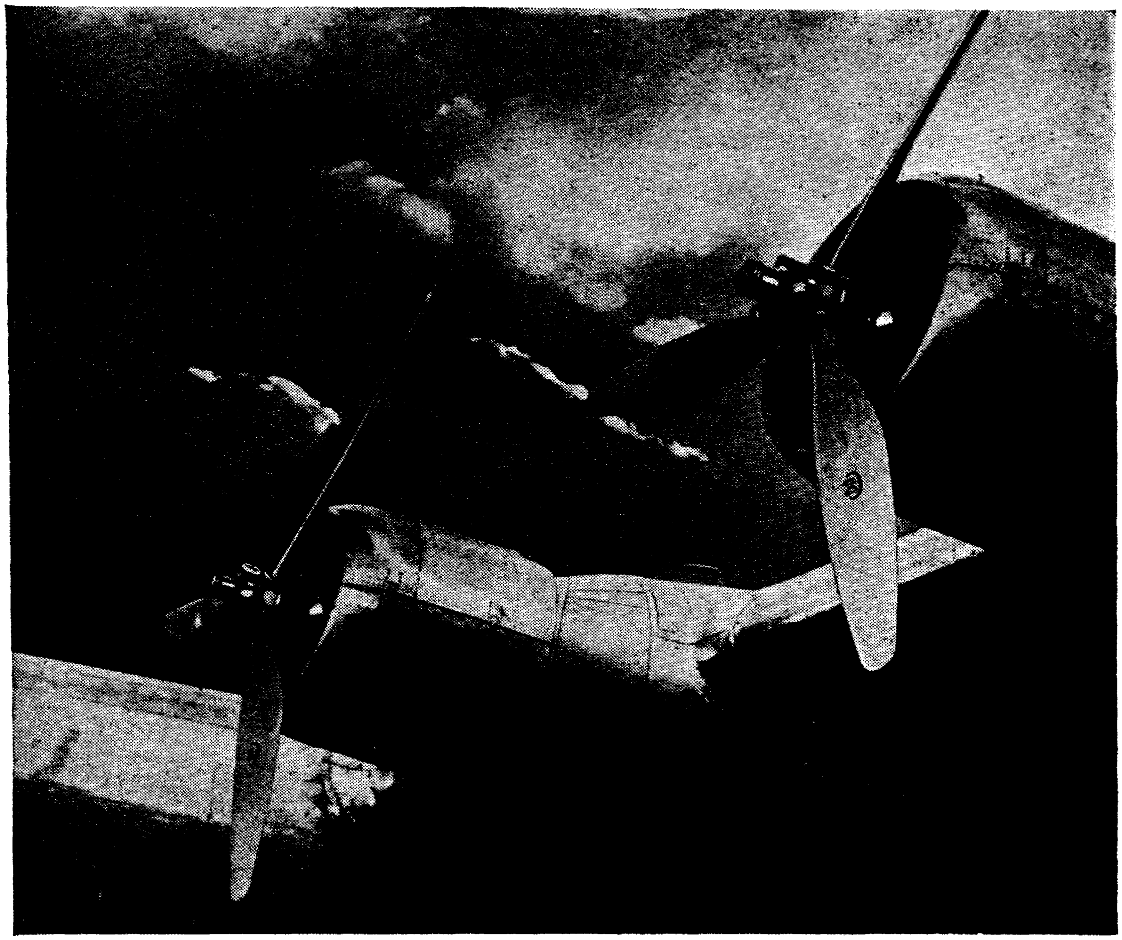
Airscrews

FOR THE AEROMODELLER

R · H · WARRING

2/-

AIRSCREWS



de Havilland Variable Pitch Airscrews as fitted to the Armstrong Whitworth "Ensign". The lessening of the blade angle from hub to tip is clearly apparent and the shape of the blades themselves is interesting.

N Hartl

AIRSCREWS
FOR MODELS

by

R. H. WARRING

THE HARBOROUGH PUBLISHING COMPANY LTD
ALLEN HOUSE, NEWARKE STREET
LEICESTER

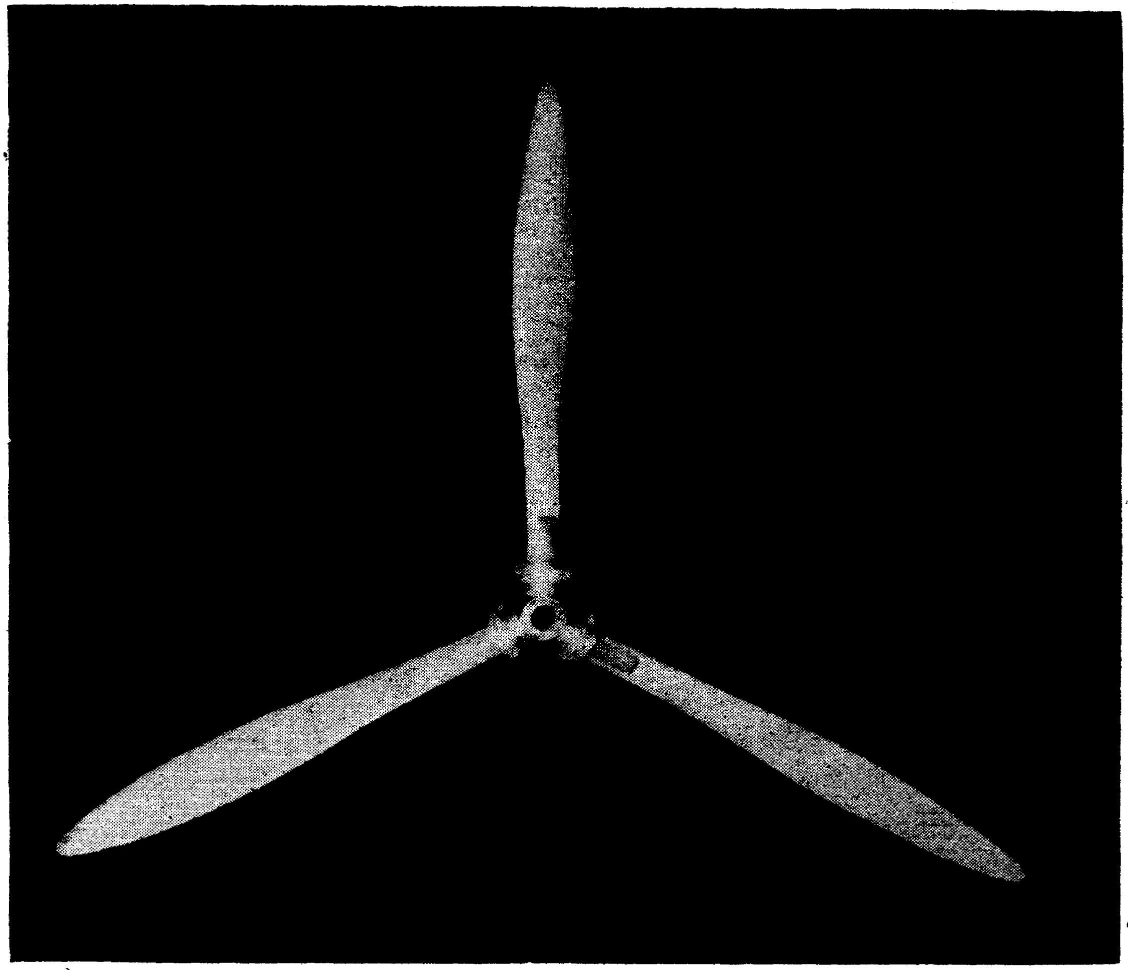
Sole Distributors to the Bookselling Trade :

HORACE MARSHALL & SON LTD
TEMPLE HOUSE, TALLIS STREET, LONDON, E.C.4

Made and Printed in England by
HARRISON & SONS, LTD., PRINTERS TO HIS MAJESTY THE KING,
44/47, St. Martin's Lane, London, W.C.2.

1942

MODEL AIRSCREWS



The three-bladed airscrew which is to be employed on D. A. Russell's 10 *ft. span scale model Lysander. The blades are of wood clamped into metal hubs and are adjustable for pitch. Diameter is* 26 *ins.*

CHAPTER I

DEFINITIONS. BLADE ELEMENT THEORY

THE word " propeller " is loosely applied to all forms of airscrews by the semi-technical minded, whereas it only strictly applies to a pusher arrangement on an aircraft. A more complete generalisation of the various types of airscrews and their application is as follows.

A *propeller* is an airscrew used for propulsion as on an aircraft, with which a high thrust is obtained for a given torque. A *windmill* is an airscrew used to obtain torque power by virtue of wind pressure or thrust on its blades. A *fan* is an airscrew used for obtaining a current of air. Finally, an *anemometer* is an airscrew used for measuring velocities from its speed of rotation. " Propeller " is used in a general sense to cover nearly all these, but no great harm is done in employing this term if the general distinction is known ; in fact, its use is almost universal in other than European countries.

From the historical standpoint it is interesting to note that some of the first model airscrews had feathers for blades, stuck into a cork which acted as the hub. Even some of the first " flying machines " used fantastic paddle wheels, like slats of wood on long arms, set at some " guesstimated " angle or other to " get a bite " on the air !

Nowadays the characteristics of airscrews are fully known, and rule-of-thumb methods are obsolete. The result is a tremendous gain in efficiency with a corresponding increase in performance. We will deal with the various theories first and then see how these are applied to model work.

The *pitch* of an airscrew is measured in various ways. The *geometric pitch* of a section of a blade element is the pitch of the helix traced out by that section. (This helix is the same as a path traced out on a cylinder of same radius as the blade element, and length equal to geometric pitch. The face is representative of rotational velocity about the axis, the length the forward velocity, so that, considering the *resultant* path of the blade element, it traces out a helix.)

For any particular section at radius r and blade angle θ a helix of radius r is traced out, the pitch of which is $2\pi r \tan \theta$. Thus it will be seen that the pitch varies with the radius of the blade, and in order to get the same forward advance for all blade elements from $r = 0$ to $r = R$, i.e., along the whole blade, θ, and thus $\tan \theta$, must decrease from hub to tip. In other words, the blade must be twisted so that the tip angle is the smallest, gradually increasing towards the hub.

The *geometric mean pitch* of a blade is defined as the geometric pitch of a section at ·7 tip radius,* and this is often referred to as the *theoretical pitch.* This can be calculated as follows :—

geometric mean pitch, $P_{gm} = 2{\cdot}2\ D \tan \theta_1$ .... (1)

(where D = diameter and θ_1 = blade angle at ·7 tip radius). Expressing this in easily measurable terms—those of the airscrew blank—we have :—

$$P_{gm} = 2{\cdot}2\ Dw/d \quad \text{.......................} \quad (2)$$

(where w and d = width and depth respectively of airscrew blank *at ·7 tip radius,* D = diameter as before).

To measure the geometric mean pitch of an airscrew already carved the blade angle at ·7 tip radius must be measured and substituted in the above formula.

Since air is not a solid medium the *practical* or *actual* pitch is less than the geometric pitch due to slip. If there were no slip at all the blades would be meeting the relative air-flow at zero angle of attack, giving little or no lift and consequently no thrust. Thus if we did not have slip there would not be any thrust. When the actual advance is less than the geometric pitch the blades are meeting the relative air-flow at a certain angle, which can be controlled by the design, giving lift in the same manner as a wing.

In our definition of geometric pitch the blade was supposed to advance at zero angle of attack, i.e., no slip. Now we use cambered blade sections, just like small wings, only of different plan form, and in general the angle of attack of zero lift is negative, i.e., *less than zero*. This means that if we find the pitch at which the thrust disappears completely the angle of attack will be some small

(* This definition of geometric mean pitch was standard for full size practice. Owing to the practice of cutting down airscrews for various designs, however, a new system has been introduced in the U.S.A. defining geometric mean pitch as pitch at a section 42 inches from hub. It is impracticable to apply such a formula to model work owing to the large range of model airscrew diameters.)

negative angle and this new pitch, the *experimental mean pitch,* will be *greater* than the theoretical or geometric mean pitch.

A further definition that may be met with is the aspect ratio. This is found in a similar manner to that of a wing, i.e., span/chord, but in this case the *maximum* chord (i.e., maximum blade width) is taken and not the *average* blade width.

Blade Element Theory

Now let us consider the airscrew theory developed by Lanchester and Drzewiecki, in which the blades are treated as twisted aerofoils For the purpose of investigation a small element of blade is taken. and the forces acting upon it are resolved into thrust and torque Any interference effect due to the influence of neighbouring blade elements is ignored.

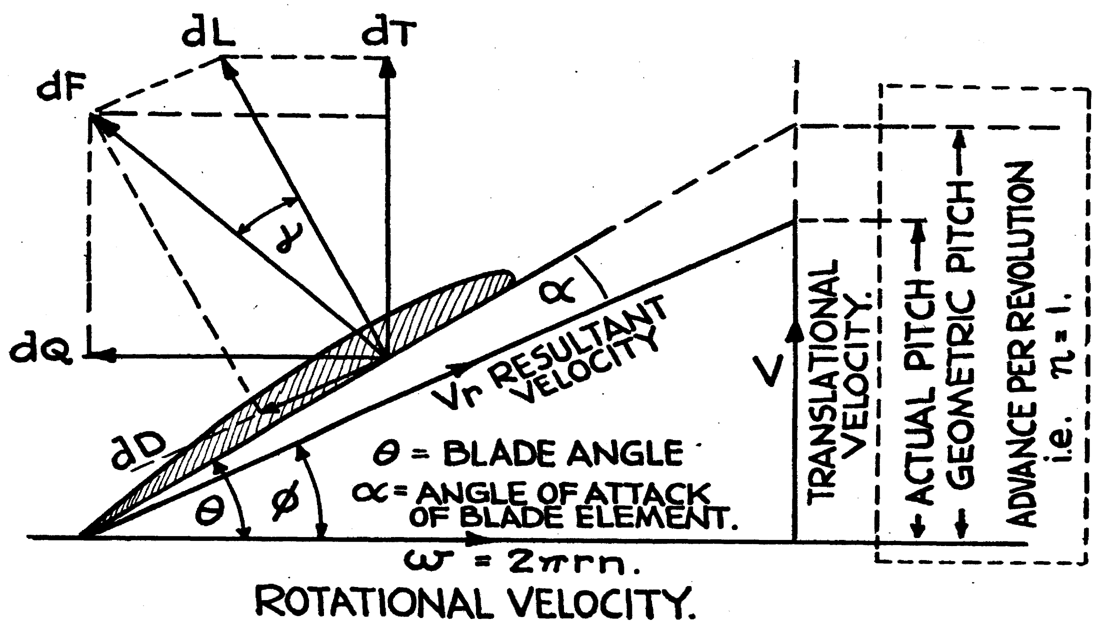


Diagram 1

In diagram 1 we have such a blade element, distance r from the centre, chord c and width dr. The blade angle θ is the angle which the chord of the blade section makes with the plane of rotation and ϕ is the angle of relative wind referred to the plane of rotation.

The element has a translational relativity V due to the forward motion and a rotational velocity ω where $\omega = 2\pi rn$, (n = number of revolutions per second). Thus from velocity diagram :

Actual velocity of blade element

$$V_R = \sqrt{V^2 + \omega^2} \quad \ldots\ldots \quad (3)$$

$$= \sqrt{V^2 + 4\pi^2 r^2 n^2}$$

and $\tan \phi = V/\omega$.

The angle of attack of the particular element is $\propto$ where

$$\propto = \theta - \phi.$$

$$\left.\begin{aligned} \text{Thus } dL &= C_L \frac{\rho}{2} c.dr.V_R^2 \\ dD &= C_D \frac{\rho}{2} c.dr.V_R^2 \end{aligned}\right\}$$ C_L and C_D being coeffs of lift and drag of aerofoil section used.*

It is easier, however, to resolve the *resultant* force into torque and thrust components than to consider lift and drag components separately. Now let angle between the resultant aerodynamic force on the blade element be y, i.e., $\tan y = D/L$.

$$\text{Then resultant, } dF = dL/\cos y = \frac{C_L \frac{\rho}{2} c.dr.\ V_R^2}{\cos y} \quad \ldots\ldots \quad (4)$$

The lift component is perpendicular to the direction of relative wind, V_R, and V_R makes an angle of ϕ with the plane of rotation. Thus dL makes the same angle ϕ with the direction of the airscrew axis. The resultant force is thus at an angle of $(\phi + y)$ to the direction of the airscrew axis.

We have then for thrust

$$dT = dF \cos(\phi + \gamma) \quad \ldots\ldots \quad (5)$$

$$= C_L \frac{\rho}{2} c\ dr\ V_R^2 \frac{\cos(\phi + \gamma)}{\cos \gamma} \quad \ldots\ldots \quad (6)$$

Similar for torque component

$$dDq = dF \sin(\phi + \gamma) \quad \ldots\ldots \quad (7)$$

$$= C_L \frac{\rho}{2} c\ dr\ V_R^2 \frac{\sin(\phi + \gamma)}{\cos \gamma} \quad \ldots\ldots \quad (8)$$

Now power absorbed by torque—i.e., power output necessary to drive airscrew—is equal to torque component force $\times$ distance travelled per second. The torque component force itself is the moment of dDq about the airscrew axis, i.e.,

$$dQ, = dDqr$$

$$= r\ dF \sin(\phi + \gamma) \quad \ldots\ldots \quad (9)$$

and thus power absorbed, $dPa = 2\pi n\ dQ$

$$= 2\pi nr\ dF \sin(\phi + \gamma) \quad \ldots\ldots \quad (10)$$

---

* Data must be corrected to aspect ratio of airscrew.

We can now arrive at the efficiency of each element.

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}} = \frac{\text{thrust} \times \text{velocity}}{\text{power absorbed}}$$
$$= \frac{VdT}{2\pi ndQ}$$
$$= \frac{VdF \cos (\phi + \gamma)}{2\pi nrdF \sin (\phi + \gamma)}$$

$$\text{But } 2\pi nr = \omega \text{ and } V/\omega = \tan \phi$$

$$\therefore \text{Efficiency} = \frac{\tan \phi}{\tan (\phi + \gamma)} \quad \text{(11)}$$

By differentiating the efficiency with respect to ø and equating the result to zero we find

$$\phi = 45° - \frac{\gamma}{2} \text{ for maximum efficiency.}$$

Knowing γ we can then calculate the value of ø for maximum efficiency.

So far we have only dealt with one tiny strip of the blade. By our original hypothesis each element is joined up tip to tip to give a warped or twisted aerofoil which constitutes the airscrew blade. To get the thrust and torque for the whole blade we must obviously sum up all these components, i.e., all the thrusts and torques for each element.

Unfortunately this is an unwieldly process mathematically. Thrust becomes

$$T = \frac{\rho}{2} C_L \sum \frac{V_R^2 \, c.dr \cos (\phi + \gamma)}{\cos \gamma}$$

$$\text{or } \frac{\rho}{2} C_L V^2 \int_O^R \frac{c. \cos (\phi + \gamma) \sin^2 \phi}{\cos \gamma} dr$$

and torque component

$$Q = \frac{\rho}{2} C_L V^2 \int_O^R \frac{cr \sin (\phi + \gamma) \sin^2 \phi}{\cos \gamma} dr$$

In practice these integrals are solved graphically. The blade is divided up into a number of strips, say 1 in. apart for a model airscrew and dT and dQ calculated for each from formulæ Nos. (5) and (9).

Thrust and torque grading curves are then plotted as in diagram 2. The area under the thrust curve will give the total thrust, that under the torque curve the total torque. If the graphs are plotted on squared paper these areas are easily found by counting the squares or by applying Simpson's rule.

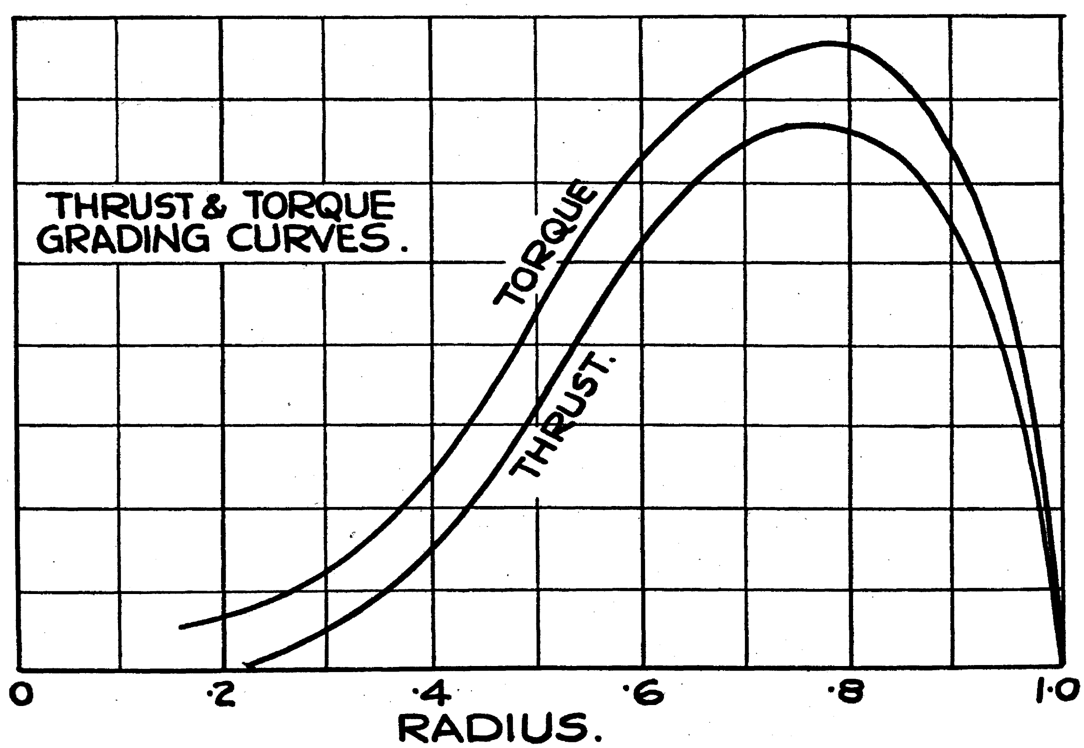


DIAGRAM 2

Alternatively thrust and torque may be calculated. Obviously thrust of whole blade is equal to the sum of all the thrusts of each strip. Torque is the sum of the moments of the torque components for each strip about the airscrew axis. Calculations for a simple blade shape are included in the appendix and reference should be made to this for further details.

Note that towards the hub, diagram 2, the blade elements give no thrust. Due to the thickening necessary for strength the aerodynamic qualities of the blade around this region are spoilt, V_R is also relatively low and ø large. Little or no thrust is to be expected, but large drag, so particular care must be paid during designing to cut down this latter figure as much as possible consistent with strength.

Efficiency remains as before E or $\mu = \frac{\tan \phi}{(\tan \phi + \gamma)}$ and is always less than unity. The smaller γ, and thus $\tan(\phi + \gamma)$, the greater the efficiency. This means C_D/C_L min. is required, i.e., C_L/C_D max.; *thus the airscrew should be designed so that sufficient thrust is developed when the angle of attack of the blades is that giving L/D max. for the particular blade section used.*

Similarly the efficiency depends upon $\tan \phi$;

but $\tan \phi = \frac{V}{\omega} = \frac{V}{2\pi rn} = \frac{V}{\pi nD}$

Thus $\tan \phi \propto \frac{V}{ND}$. This quantity V/ND is denoted by J and plays an important part in airscrew characteristics. (For further information on J see Mr. D. A. Russell's book, "The Design and Construction of Flying Model Aircraft.") From the above we can see, then, that for a given L/D ratio for blade section, μ depends upon J.

Thrust and Torque Coefficients

Referring back to the diagrams of thrust and torque grading curves, diagram 2, we can find the thrust of the whole airscrew as follows: The *thrust coefficient* may be found by dividing the total area under the thrust curve (i.e., the total thrust of the blade), by $\frac{\rho}{2}n^2D^4$. The mathematical reasoning for this is too involved to include in a small handbook, but it *can* be so proved. The thrust coefficient found above must be multiplied by the number of blades when the equation for thrust of the whole airscrew is $T = \frac{\rho}{2} C_T n^2 D^4$ where C_T = thrust coefficient.

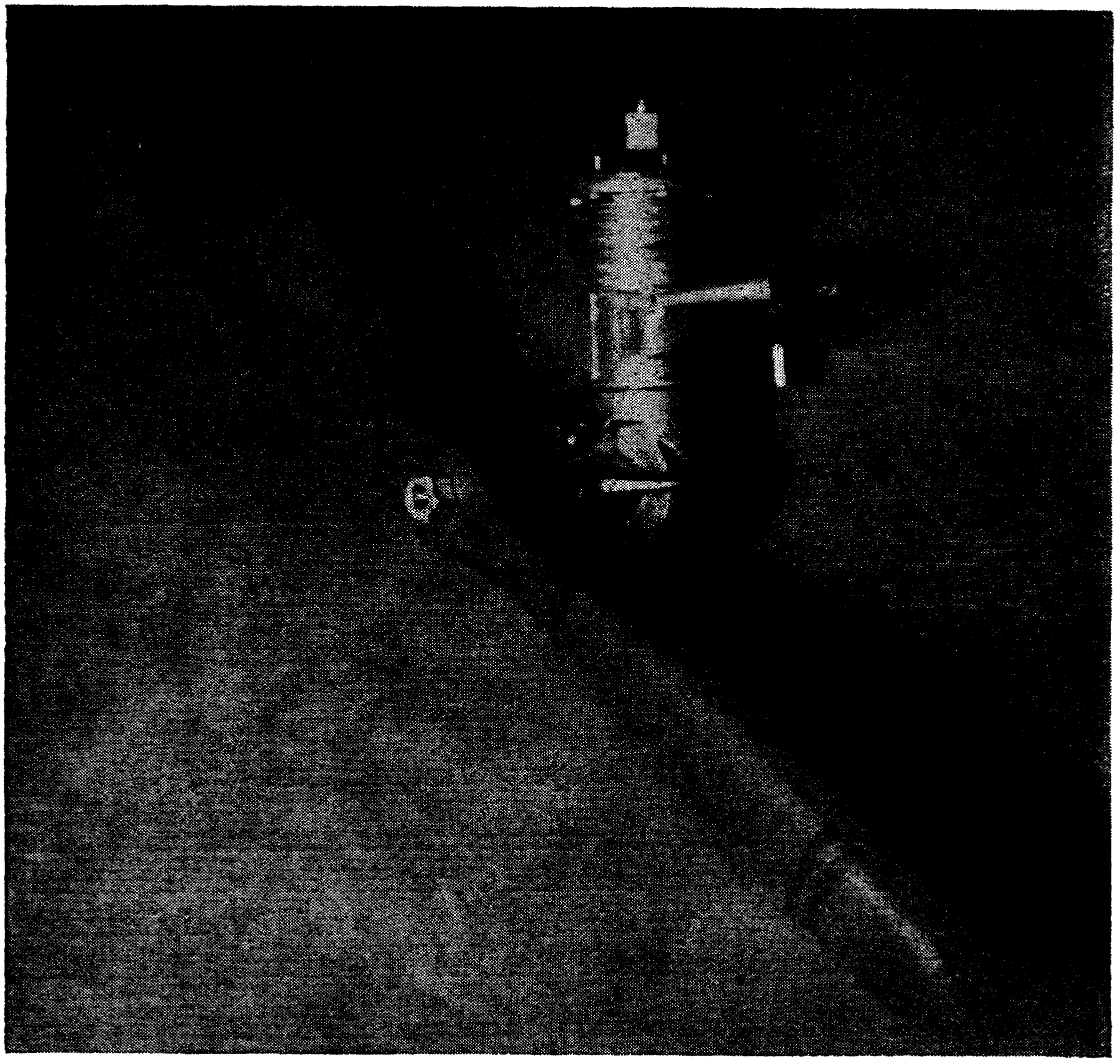
Similar treatment for the torque coefficient gives as the equation for power absorbed

$$Pa = \frac{\rho}{2} C_Q n^3 D^5$$

The efficiency in terms of these coefficients is given by

$$\mu = \frac{1}{2\pi} \frac{V}{nD} \frac{C_T}{C_A} = \frac{JC_T}{2\pi C_Q}$$

POWER



A "Gwyn Aero" petrol engine of 7·5 c.c. capacity and a 14 in. diameter airscrew designed to give maximum efficiency. The Brake Horse Power is about ·2

CHAPTER II

MOMENTUM THEORY. SIMPLIFIED VORTEX THEORY

The momentum theory of airscrews and propellers was one of the first to be advanced and its development is mainly due to Rankine and Froud.

In this theory the airscrew is represented by an actuator disc of diameter D over which the thrust T is uniformly distributed. It is also assumed that no twisting or rotating of the airflow takes place after passing through the disc and that the flow remains streamline. Modifications are thus necessary for practical application, as noted later in the chapter.

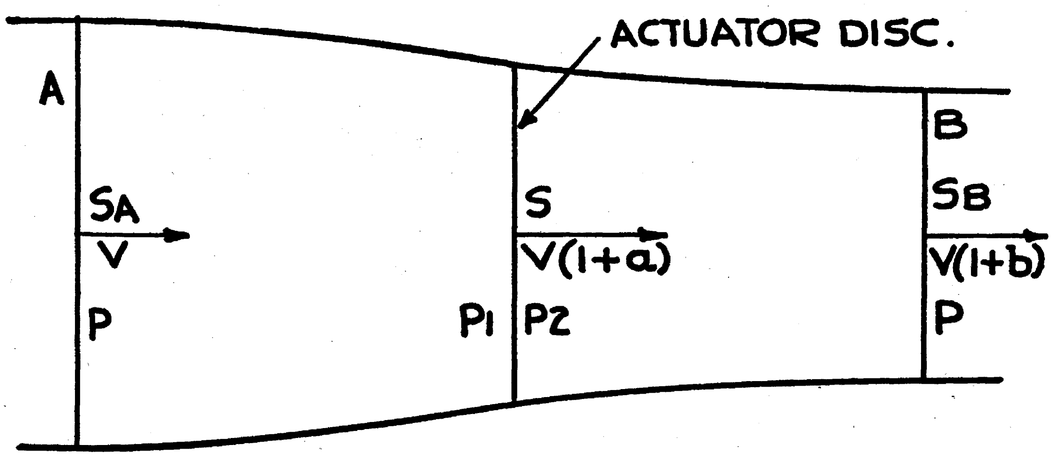


DIAGRAM 3

Referring to diagram 3, A is a point in the airstream in front of the disc at atmospheric pressure and B is a point downstream where the pressure has again fallen to atmospheric.

Let P = Atmospheric pressure, i.e., static pressure at A and B.
P1 = Static pressure just ahead of actuator disc.
P2 = Static pressure just behind actuator disc.
V = Velocity of airstream at X.
V (1 + a) = Velocity of airstream at actuator disc.
V (1 + b) = Velocity of airstream at Y.
S = Area of actuator disc.
S_A = Area of air column at X.
S_B = Area of air column at Y.

Now when equilibrium is reached the volumes of air flowing through A, B and the disc are the same per unit time.

$$\text{i.e., } S_A.V = S.V\ (1 + a) = S_B.V\ (1 + b)$$

The flow is streamline and therefore Bernoulli's theorem may be applied to the flow inside and outside the slipstream :

$$P + \frac{\rho}{2} V^2 = P1 + \frac{\rho}{2} V^2 (1 + a)^2$$

$$P + \frac{\rho}{2} V^2 (1 + b)^2 = P2 + \frac{\rho}{2} V^2 (1 + a)^2$$

whence by subtraction

$$P2 - P1 = \frac{\rho}{2} V^2 \left((1 + b)^2 - 1\right)$$

$$= \frac{\rho}{2} V^2 (b^2 + 2b)$$

By consideration of momentum, thrust equals mass of air affected per second times the velocity induced.

$$\text{i.e., } T = \rho SV\ (1 + a)\ \{V\ (1 + b) - V\}$$

$$= \rho SV^2\ (1 + a)\ b \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

But thrust also equals difference in pressures inside and outside slipstream near actuator disc times the area of the actuator disc.

$$\text{i.e., } T = S\ (P2 - P1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

$$\therefore S\ (P2 - P1) = \rho SV^2\ (1 + a)\ b$$

$$\text{i.e., } \frac{\rho}{2} V^2\ (b^2 + 2b) = \rho V^2\ (1 + a)\ b$$

$$b^2 + 2b = 2b + 2ab.$$

Whence $a = b/2$ or, of the total increase in velocity given to the slipstream on passing through the actuator disc one half is given at the disc itself.

The velocity at the disc is $V\ (1 + a)$ and a is now called *the inflow factor.*

Now actual rate of doing work is equal to the rate of increase of kinetic energy. This is also equal to the difference in kinetic energies at A and B. The kinetic energy at B is

$$KE_B = 1/2.\rho SV\ (1 + a) \left(V\ (1 + b)\right)^2$$

$$= \frac{\rho}{2} SV^3\ (1 + a)\ (1 + b)^2$$

And kinetic energy at A is

$$KE_A = 1/2.\rho SV\ (1 + a)\ (V^2)$$
$$= \frac{\rho}{2} SV^3\ (1 + a)$$

Therefore increase in kinetic energy between A and B

$$= \frac{\rho}{2} SV^3 \left((1 + a)\ (1 + b)^2 - (1 + a)\right)$$
$$= \frac{\rho}{2} SV^3 \left\{(1 + a)\ (b^2 + 2b)\right\}$$

But we have already found that $b = 2a$

$$\therefore \text{Increase in KE} = \frac{\rho}{2} SV^3 \left\{(1 + a)\ (2ab + 2b)\right\}$$
$$= \rho SV^3 b\ (1 + a)^2$$

This is equal to the power input.

$$\text{Now power output} = TV$$
$$= \rho SV^2\ (1 + a)\ bV$$
$$= \rho SV^3\ (1 + a)\ b$$
$$\therefore \text{Efficiency, } \mu = \frac{\text{power output}}{\text{power input}}$$
$$= \frac{\rho SV^3\ (1 + a)\ b}{\rho SV^3\ (1 + a)^2 b}$$
$$= \frac{1}{1 + a} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (14)$$

where a is the inflow factor as before.

This really means that the greater the diameter, and consequently the smaller a, the greater the efficiency. *For a given thrust the diameter should be as large as possible.*

Finally the thrust coefficient, which we will call Tc this time :

$$Tc = \frac{T}{\rho V^2 D^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (15)$$
$$= \frac{\pi a}{2}(1 + a) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (16)$$

It is now possible to calculate the ideal efficiency of an airscrew for a given 'plane.

Example : A model weighs 8 ozs., has a speed of 15 m.p.h. and a L/D ratio of 8 : 1. Find the *ideal* efficiency of an 18-in. airscrew for this model.

Solution : 15 m.p.h. = 22 feet per second.

Now T = D = 1 oz. (since L/D = 8 : 1)

$= \cdot 0625$ lbs.

$$Tc = \frac{\cdot 0625}{\cdot 00238 \times 22^2 \times 1\cdot 5^2} \quad \ldots \text{(from (15))}$$

$= \cdot 02412$

$$\therefore a\,(1 + a) = \frac{2Tc}{\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(from (16))}$$

$= \cdot 01535.$

Whence a = ·015 (by solving above quadratic) and thus

$$\mu = \frac{1}{1 + \cdot 01535}$$

$= 98\cdot 5$ per cent.

This, of course, *is* ideal in that it has only taken into account losses due to the kinetic energy gained by the axial velocity of the slipstream. Additional losses due to the drag of the blades, the kinetic energy of the rotary component of the slipstream and the unequal distribution of thrust over the actuator disc reduce the *practical* ideal efficiency to about 85 per cent.

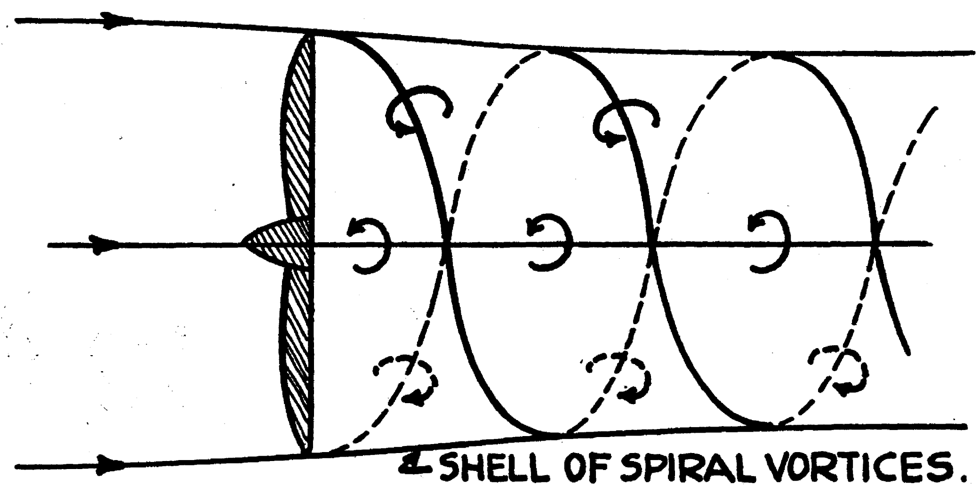


DIAGRAM 4

The two theories, the blade element and the momentum, are usually combined for complete analysis, but of recent years the inflow theory which takes into account the rotational velocity given to the slipstream is more generally adopted. The Prandtl-Lanchester theory of circulation and vorticity and Glauert's work have done a lot to advance these modern theories. However, they are not intended to replace the older ones, only modify them to meet new requirements.

Although, as we have seen above, no rotation is assumed in some workings the error is usually negligable, especially if the rotational velocity is small as in model airscrews, but we will try to find out just what does happen to the slipstream.

Just in the same way as a wing casts off vortices from its trailing edge the blades of an airscrew cast off vortex sheets, but of a slightly more complicated nature. These pass downstream in a helical form (not a true helix due to the contraction of the slipstream at first), at the same time rotating about their own path—see diagram 4. The interference at the disc is wholly due to the trailing vortices and the farther downstream we go the less the effect.

The most probable form that the slipstream will assume is a shell of spiral vortices, which mark the boundary of the slipstream, due to vortices thrown off from the blades. If circulation is not constant along the blades there will be a whole series of these shells, one inside the other and all of the same form. There is also another purely rotational vortex or system of vortices passing downstream along the shaft line as an axis. Such a stream will be deflected by the presence of fuselage, etc., behind it.

Rotation is confined to the slipstream so that air outside the boundary has plain irrotational flow. The contraction of the slipstream is small for lightly loaded and slow revolving airscrews, but may be noticed on petrol model work.

Now the revolving blades are obviously inducing a rotational effect on the air immediately in front of it and, as we have seen above, this is zero and so this effect must be balanced by an equal and opposite effect arising from the trailing system.

Irrotational air set in motion at the disc receives one half of its spin from this trailing system and one half induced by the circulation around the blades themselves. From Kelvin's theorem which states that " the circulation around a closed circuit moving at every point with the fluid (i.e., always formed of some parts of the fluid) remains constant in regards to time," we see that farther downstream as the blade induction is lessened the spin caused by the trailing vortices increases. Thus we are able to deduce that the rotation (at the disc), interfering with the blade incidence is one half of that at the " waist " or narrowest part of the slipstream.

BENT—BUT NOT BROKEN.

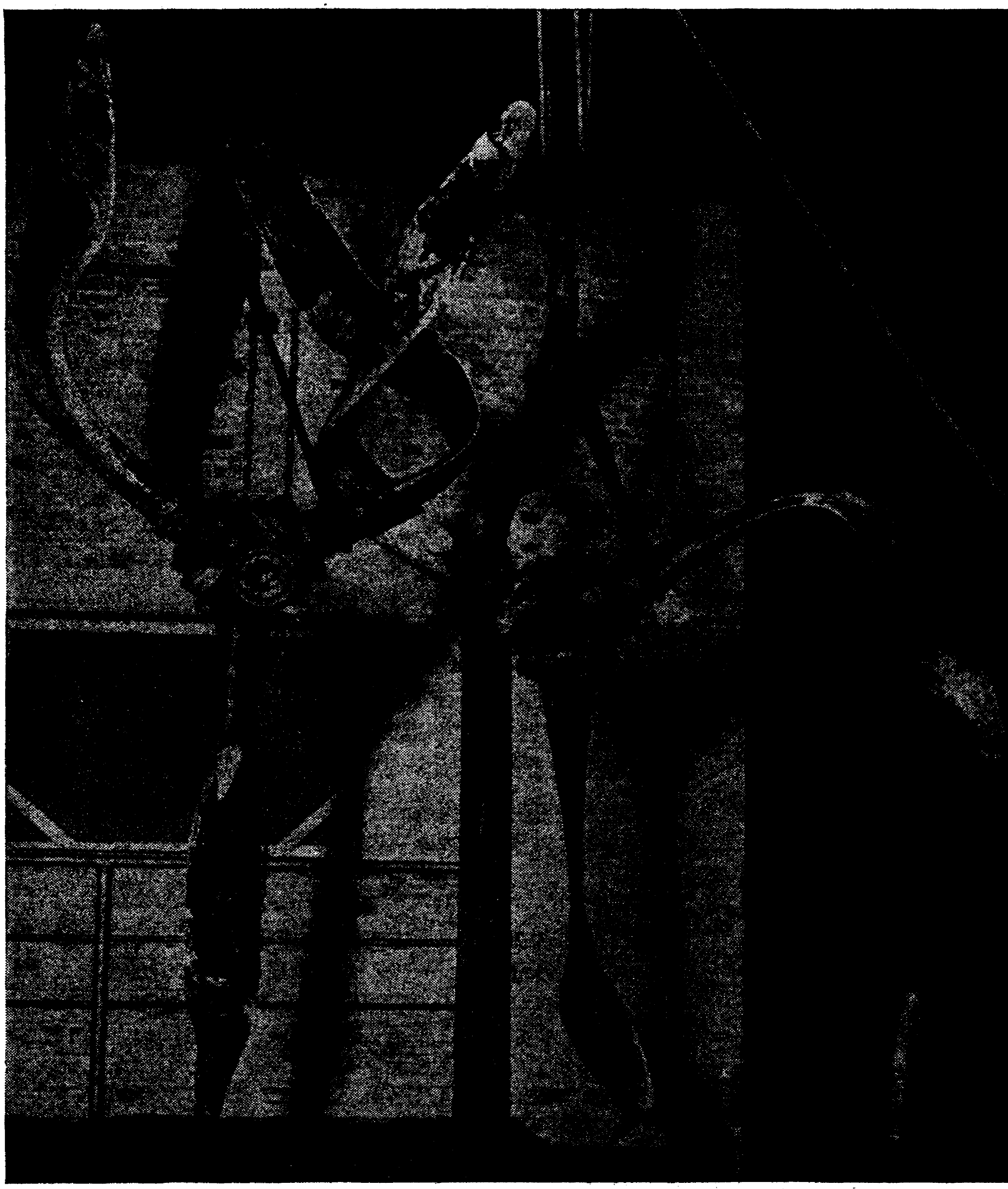


Photo by courtesy of de Havilland Aircraft Co.

Two badly damaged metal airscrews returned to the factory for repair. About 80 per cent. of such " casualties " are capable of being made fit for service again.

CHAPTER III

SLIPSTREAM. AIRSCREW INTERFERENCE

By the slipstream of an airscrew or propeller we mean the column of air thrown back during revolution. To take into consideration all of its effects would necessitate a volume in itself so we must confine ourselves to the more important generalisations. The exact velocity of the slipstream is important, but again difficult to find accurately. An empirical formula developed from that advanced by the Engineering Division of the United States Air Corps is

$$v = \frac{T}{\rho AV} \quad \text{.................................} \quad (17)$$

Where T = Airscrew thrust in lbs.
A = Area of slipstream in square feet.
V = Forward velocity of airplane in feet/seconds.
ρ = ·00238.

The area of the slipstream is given by

$$A = \frac{\pi}{4}\left(D^2 - (D/5)^2\right) \quad \text{..................} \quad (18)$$

v, the *component velocity* of the slipstream, is then given in feet per second.

Now one half of this component velocity is induced in front of the airscrew disc and so should be taken into account when designing an airscrew. However, since v for Wakefield models has a value of about 2·5 ft./sec., it is possible to ignore this effect unless aiming at meticulous accuracy. If you *do* wish to take it into consideration then the forward translational velocity of the *airscrew* is $V + v/_2$ and working formulæ should be modified accordingly.

This slipstream velocity also means that the drag of bodies influenced by it is slightly increased above these values obtained by calculations based on the airspeed alone. Again this effect is small, and may be neglected in the majority of cases, but is rather more important in models driven by a small petrol engine. The fuselage, and to a certain extent, the wings, undercarriage and empennage have a greater drag during power flight. Average values for a Wakefield model and a typical medium sized petrol driven-machine are as follow :

Wakefield ... Engine on 7 per cent. increase in total drag.
Petrol Model... Engine on 20 per cent. increase in total drag.

For quick comparison the following generalised formulæ may be employed as used in full scale practice :—

$$\frac{\text{Increase in drag}}{\text{Normal drag}} = 2{\cdot}55 \frac{T}{\rho V^2 D^2} \; ø \quad \ldots\ldots\ldots\ldots \quad (19)$$

(D being in feet, T, the thrust, in lbs.)

The lift of that part of the wing under the influence of the slipstream is also increased and a rough approximation is given by assuming that the area influenced by the slipstream is operating in an airspeed of $V + v$. The increase in lift on small models is very minute.

We have seen in a previous chapter that one component of the slipstream was a vortex whose axis of rotation was the airscrew axis and this will materially effect the attitude of the empennage if the slipstream is at all powerful. The direction of rotation* of the majority of model airscrews is anti-clockwise and thus the airflow over the fin will not be parallel to the fuselage datum line but flowing across it from left to right. Thus to be in a neutral position for power flight, the fin will need to be offset slightly to the right but, when the power is exhausted, the airflow in this region is straight once more.† Thus this offset must not be overdone otherwise a spiral dive on the glide may result. The slipstream effect on models is quite small and other design factors take precedence. Thus whilst it may appear advisable in some cases to raise the tailplane out of the slipstream the greatest gain in this case accrues from the fact that it is now out of the wake of the wing. A knowledge of the behaviour of the slipstream, however, is of value in checking possible faults or instability resulting from a divergence of engine-on and engine-off trim.

Airscrew Interference

Airscrew interference is not of very great importance on small models but brief reference to it is made here as it may be helpful, especially as regards the design of large power-driven 'planes.

---

* The direction of rotation is that when the airscrew is viewed from the front, i.e., looking towards the tail of the machine.

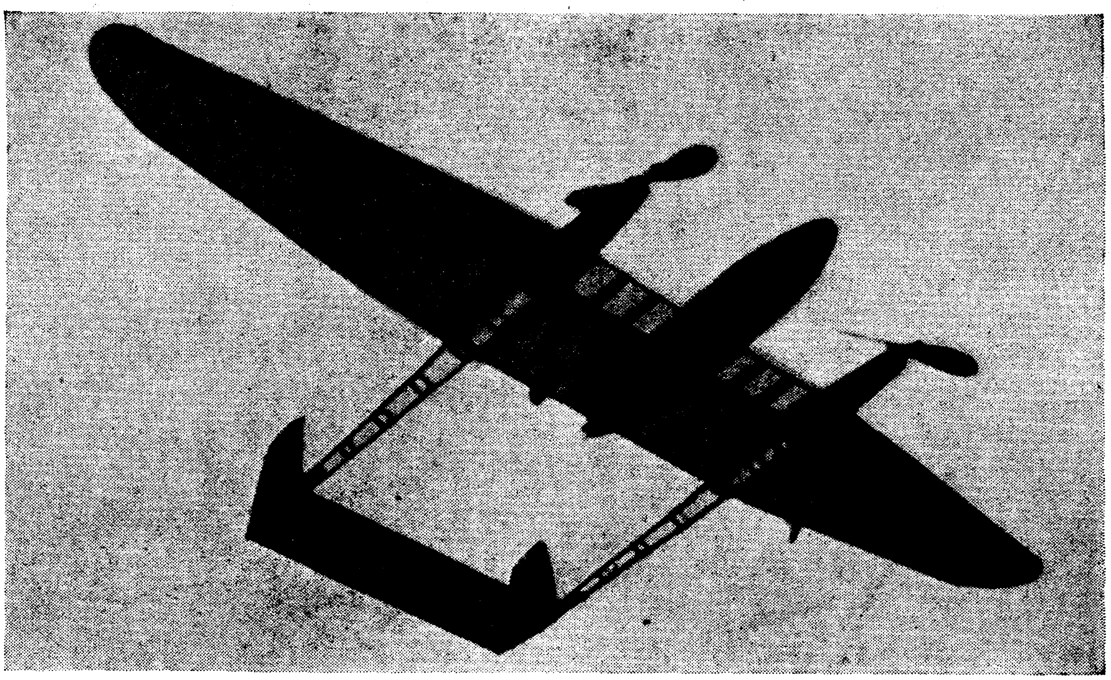
† A freewheeling airscrew may impart a rotary component to the airflow when the power is exhausted but this effect is slight.

ø This formula is now the subject of experimental verification for low speed work and should be employed with discretion.

A typical layout showing the " paddle wheel " type of airscrew employed on the rubber-driven duration model. To reduce drag the airscrew automatically freewheels at the end of the power run.

From theoretical and practical considerations it would appear that both the pitch and the efficiency of an airscrew are increased by the slowing up of the slipstream as it passes over the body. Actually, however, this effect is neutralised by the increase in drag of the body and other components exposed to this slipstream and, in fact, this latter increase reduces the *total* efficiency of the airscrew.

In any case there will be some shielding and interference. In a tractor the nose is to a certain extent blanketed by the hub and blade roots and vice-versa in the case of a pusher. This effect can be minimised by employing a spinner which is nicely faired into the front of the fuselage, or, in the case of a petrol model, fairing the whole engine in. In the latter case no exceptional cooling difficulties should be experienced for a small inlet or scoop will provide adequate air circulation for the short duration over which such engines are usually run. The main trouble will be accessibility, but here again it should be possible to locate the ignition control outside the cowling as well as throttle and air. This would undoubtedly lead to an increase in efficiency.



A unique layout employing two airscrews. The rubber motors are housed in the two booms which also serve to carry the tailplane and fins. For minimum interference the airscrews must be mounted distant from the wing.

Tractor Arrangement

We have seen that there is a small increase in drag due to the slipstream effect and we will consider this as proportional to k_ρ (pressure drag coefficient). Now obviously to balance this extra drag the thrust of the airscrew must increase. Call the apparent thrust Ta; Se its effective disc area $= \pi \; (R^2 - r_1^2)$ where $r_1 = \cdot 2R$; Da and D the drag of the body with and without airscrew and A the maximum cross sectional area of the fuselage.

$$\text{Then } Ta = \frac{T}{1 - k_\rho \; (A/Se)}$$

$$\text{and } Da - D = Ta \; k_\rho \; (A/Se).$$

Assuming that A is sufficiently small in proportion to Se, we have

$$\frac{Da}{D} = \left(\frac{Vs}{V}\right)^2 = (1 + 2a)^2. \quad (a = \text{inflow factor.})$$

$$\text{But } Ta = \rho v \; (1 + a) \; Se \; 2aV$$

$$\text{i.e., } 2a + 2a^2 = \frac{Ta}{\rho V^2 \, Se}$$

$$\text{But } 2a + 2a^2 = (1 + 2a)^2 - (2a^2 + 2a) - 1$$

$$\therefore (1 + 2a)^2 = 1 + 2\,(2a + 2a^2)$$

$$= 1 + \frac{2Ta}{\rho V^2 \, Se}$$

$$\text{Also } (1 + 2a)^2 = Da/D$$

$$\therefore Da/D = 1 + \frac{2Ta}{\rho V^2 \, Se}$$

By introducing another factor kv we take into account the slowing up of the slipstream by the body parts and our formulæ now becomes

$$Da/D = 1 + \frac{kv \, Ta}{\rho V^2 \, Se} \quad \text{.......................... (20)}$$

Finally, taking into account all other factors such as shielding, etc., we get :

$$\frac{Da}{D} = G + H \frac{Ta}{\rho V^2 \, Se}$$

where G and H are two constants determined by practice. These values vary for different designs and for fine streamlined bodies with spinnered propellers they are such that Da tends to be equal to D, i.e., the difference in drag when the airscrew is revolving and when it is not tends to disappear.

PUSHER PROPELLERS

The same formula for drag increase as above applies but this time with different values of G and H. There is obviously no increase in thrust by the presence of a body behind the propeller, but at the same time there is very little increase in body drag as only the rear part of the fuselage is affected.

With good streamlined shape and careful design of components there is a reason to believe that the pusher arrangement should be more efficient than the tractor. Unfortunately severe structural and stability problems appear which results in a falling off in performance.

There are several builders today who still build pushers and fly them in competitions, but the results obtained are seldom outstanding. There is no reason why such a type could not be improved upon but, as mentioned above, the design requirements usually lead to a model with lowered efficiency.

AIRSCREW DESIGN

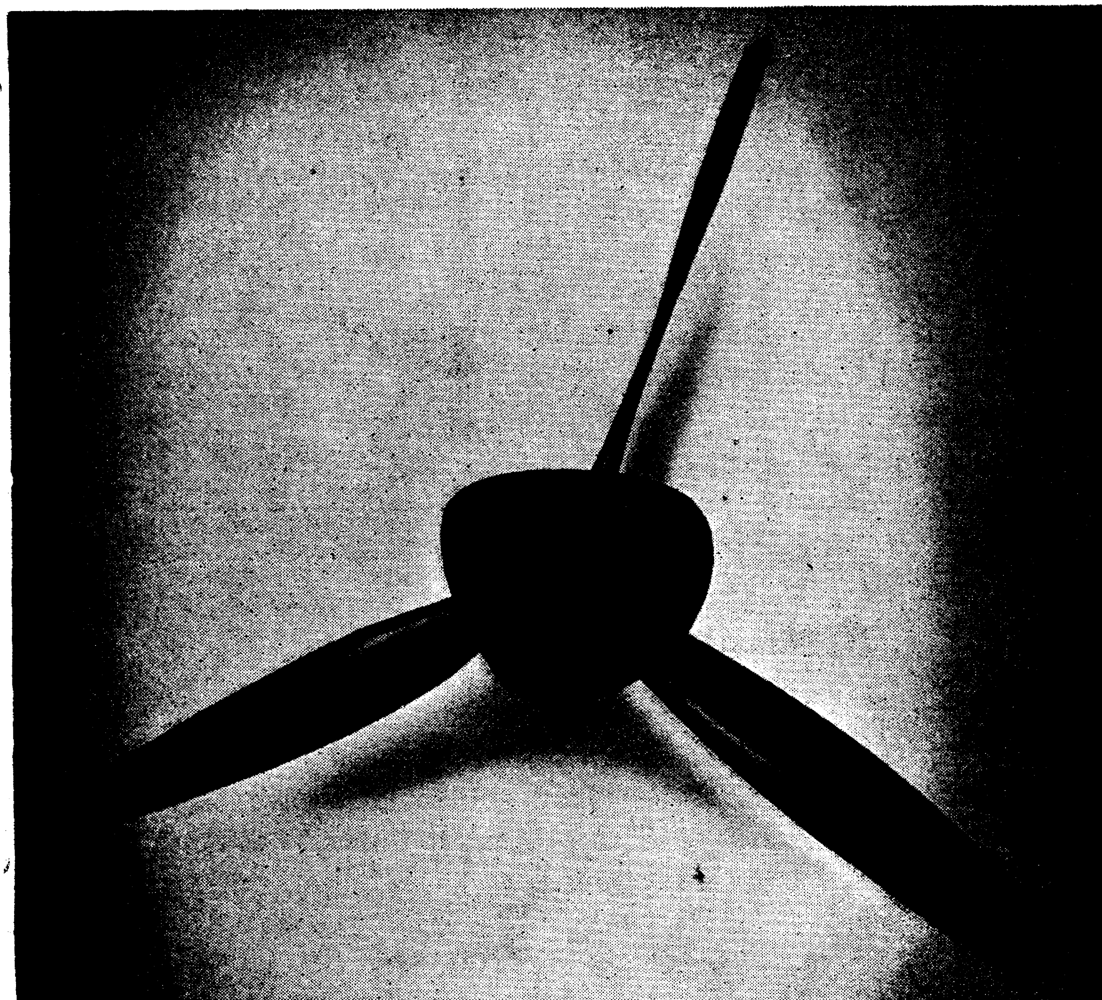


Photo by courtesy of de Havilland Aircraft Co.

The large spinner and the careful fairing of the blade roots is a typical example of modern full size practice. The shape of the blades themselves is also interesting.

CHAPTER IV

AIRSCREW DESIGN AND LAYOUT

For otherwise geometrically similar airscrews the thrust, torque and efficiency at any value of J vary with the P/D ratio. Diagrams 5, 6 and 7 show variations of C_T, C_Q and η with J for different pitch/diameter ratios for a two-bladed airscrew. It will be noticed that in each case the efficiency reaches a definite maximum at some particular value of J and falls away on either side. This maximum occurs at a greater value of J (i.e., at greater advance per revolution in terms of the diameter), for increasing values of P/D.

Before we go on to discuss the actual design of an airscrew let we say a few words about the incorrect, or rather "free" use of the word "pitch". On studying a number of plans you will notice the words "pitch, so many inches". This, by itself, means very little and indeed we find different pitches quoted for airscrews carved from the same sized blanks! It should be stated definitely which pitch is meant, theoretical or actual, otherwise the data is useless for comparison purposes. Other plans refrain from giving the pitch at all—perhaps they are wise!

Now to find the correct airscrew for our purpose. It must be carefully noted that we find the *experimental mean pitch* by this method, but it is a fairly easy matter to calculate the geometric mean pitch from the equations :—

$$\text{E.M.P.} = 2\pi r \tan(\theta - \beta)$$

$$\text{G.M.P.} = 2\pi r \tan \theta$$

β is the angle of no lift for the airfoil section employed for the blades and since this is negative for combined sections the experimental mean pitch is greater than the geometric mean pitch. From the above :—

$$\text{G.M.P.} = \frac{\text{E.M.P.} \times \tan \theta}{\tan(\theta - \beta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(21)}$$

since all the factors on the R.H. side of the equation are known the G.M.P. follows.

β is found from tables of aerofoil characteristics and in model sizes is usually very small so that little error is introduced in assuming G.M.P. = E.M.P.

The two deciding factors in design which we must determine first are D, the diameter, and the value of J at maximum efficiency. The diameter is usually chosen by experience ; in rubber models

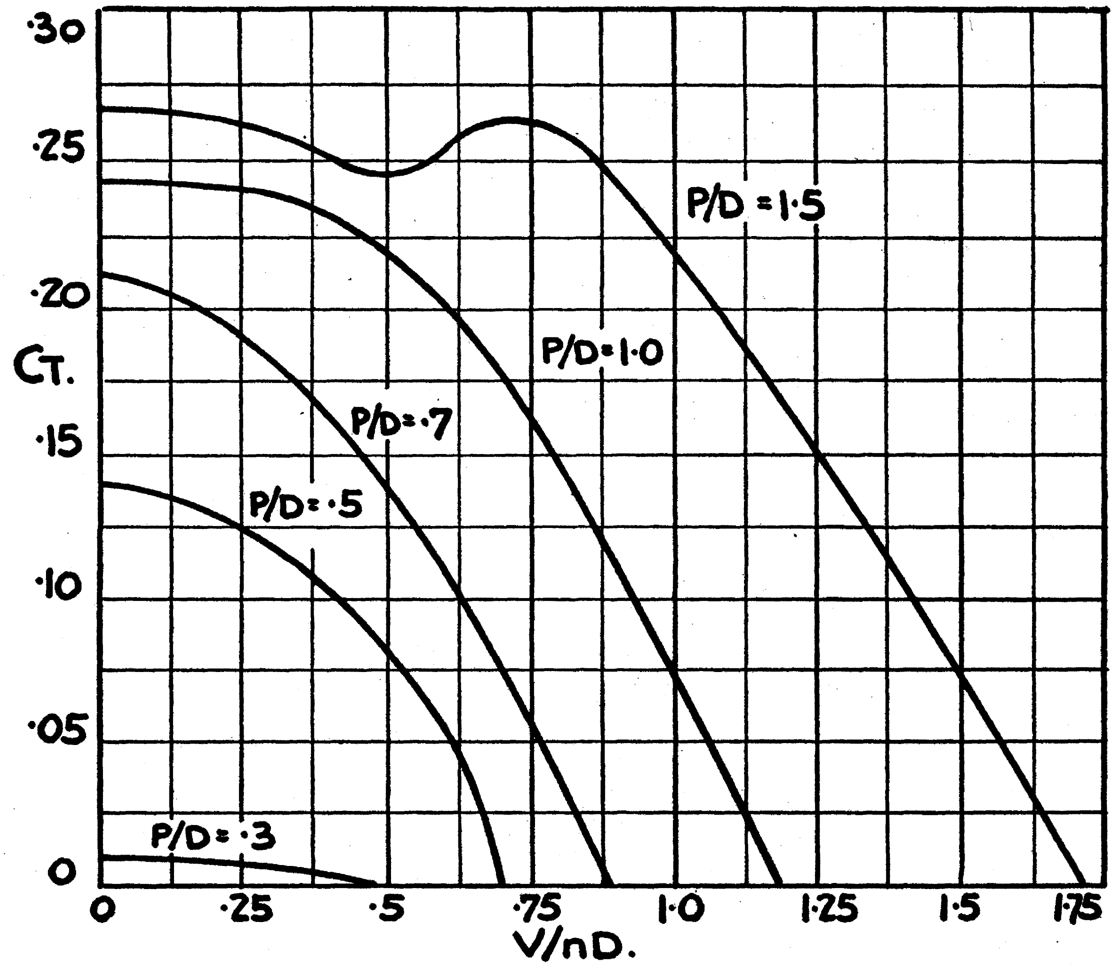


DIAGRAM 5

it depends upon the wing span (regulating torque control), and the size of the motor. For petrol models a suitable size is chosen so that the engine will not be overloaded and working in a stalled condition, or "racing."

A formula giving the diameter of a two-bladed airscrew is

$$D = \sqrt[4]{K. \frac{Pm}{\partial} \frac{\times 10^{10}}{n^2 V}} \quad \text{.................. (22)}$$

where K is a constant determined by practice, e.g., comparison with similar types :

Pm = power of motor
∂ = solidarity of airscrew.

Actually, however, for rubber models it is usual to take the diameter as a certain percentage of the wing span. For models where the weight of rubber is not restricted by any rules the diameter should not exceed 40 per cent. (outdoors), and the rubber (whose optimum weight is 30–40 per cent. of the *total* weight), arranged to suit this. For Wakefields the usual size is 16–18 in. diameter.

Where the weight of rubber is less the diameter will have to be decreased accordingly, or power run shortened, and, here again, a practical solution decided by experience is the best.

For "power" models Mr. Russell gives the following formula for the diameter :—

$$D = \frac{88V}{nJ} \quad \text{when } J = \cdot 5. \qquad (23)$$

These diameters may be corrected for radial losses if desired to find the effective diameter formula (17), but little error is introduced in ignoring this.

In order to find the second determining factor, J, we must first of all decide at what part of the model's flight we want the airscrew to be operating at maximum efficiency. This is more important in rubber models where the power output is continually changing as the motor unwinds. In the case of a petrol model the power output is constant for a given throttle setting and, naturally enough, we then usually design for maximum efficiency for climbing.

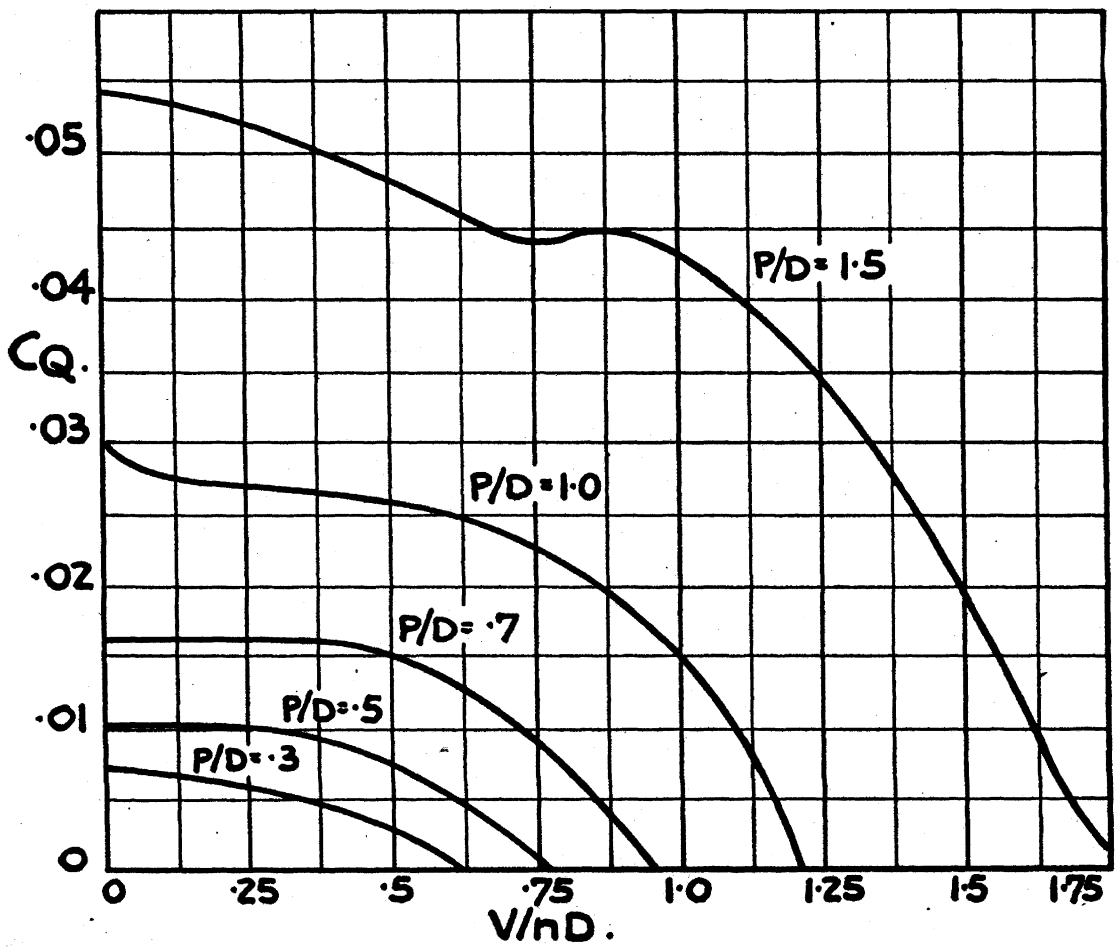


DIAGRAM 6

If, too, the designer wishes to take into account the component of slipstream velocity as explained in Chapter III the forward or translational velocity must be increased by this amount. That is, the velocity equals V + v/2, where v is the slipstream component. As this latter figure is particularly small it is ignored in the following design procedure for simplicity.

Firstly let us examine the case of the rubber powered model. We want to find J at maximum efficiency. If we design our model for best rate of climb we must find J for the first part of the power run; for a moderate climb and maximum efficiency as rubber power first falls off the value of J for a point approaching mid-way on the power run is calculated; or, if slow climb and long cruise is required, by designing our airscrew for maximum efficiency towards the end of the power run we shall achieve this purpose.

Thus we have got to decide right at the beginning if we want a "snappy" climb at maximum efficiency followed by a short cruise at lower efficiency; a moderate climb and moderate cruise; or slow climb and long cruise, the efficiency reaching maximum towards the end of the flight and thus conserving the power run.

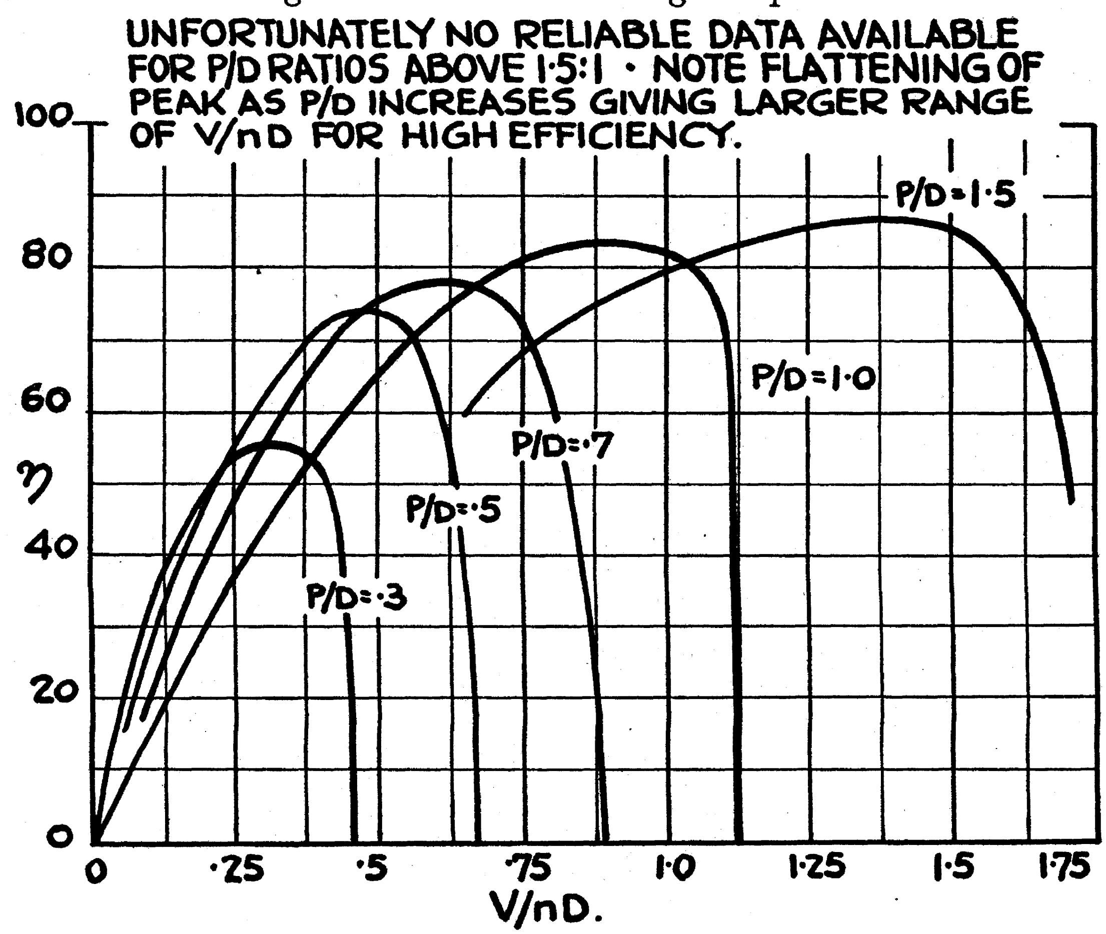
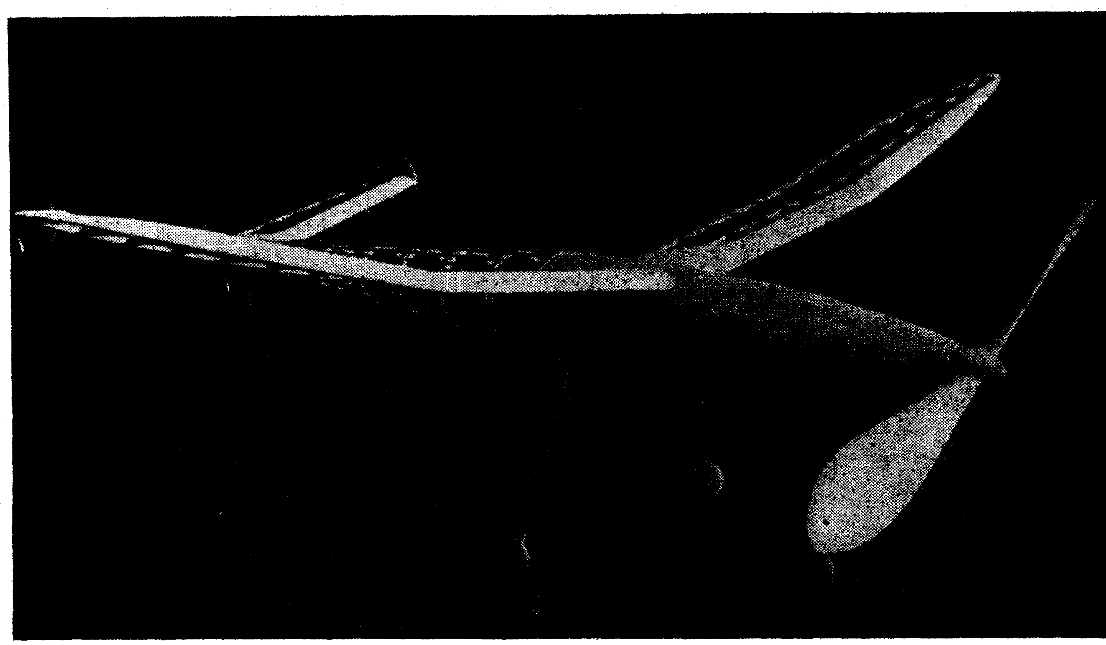


DIAGRAM 7



A well designed airscrew as fitted to the W.A.D. 20 designed and built by W. A. Dean. The roots are cut away to fine limits and faired into the fuselage lines by means of a spinner.

To find J we have to know n, rev. per sec., V, velocity in feet per sec. and D, the diameter, in feet. We already know D so it is merely a case of finding the other two. Taking three typical cases :—

Model A. Max. turns 1,200, pwr. run 100 secs. ∴ *average n* =12 rps
,, B. ,, ,, 900 ,, ,, 80 ,, ,, ,, =11 ,,
,, C. ,, ,, 1,400 ,, ,, 160 ,, ,, ,, = 9 ,,

giving an average value of *n*, the rate of revolution of the propeller, as approximately 11 r.p.s.

However, for the climb, i.e., the first burst of power, *n* will be about 14 r.p.s., for cruising 11 r.p.s. and towards the end of the cruise 9 r.p.s. With these figures and assuming V for climb = 16 ft./sec., V for cruise = 20 ft./sec. and V for end of cruise = 24 ft./sec. we are now able to calculate J for the three cases :—

(i) maximum climb $J = \frac{V}{nD} = \frac{16}{14 \times 1{\cdot}5} = {\cdot}76$

(ii) moderate climb $J = \frac{20}{11 \times 1{\cdot}5} = 1{\cdot}21$

(iii) long cruise $J = \frac{24}{9 \times 1{\cdot}5} = 1{\cdot}775$

assuming an 18 in. diameter airscrew in each case.

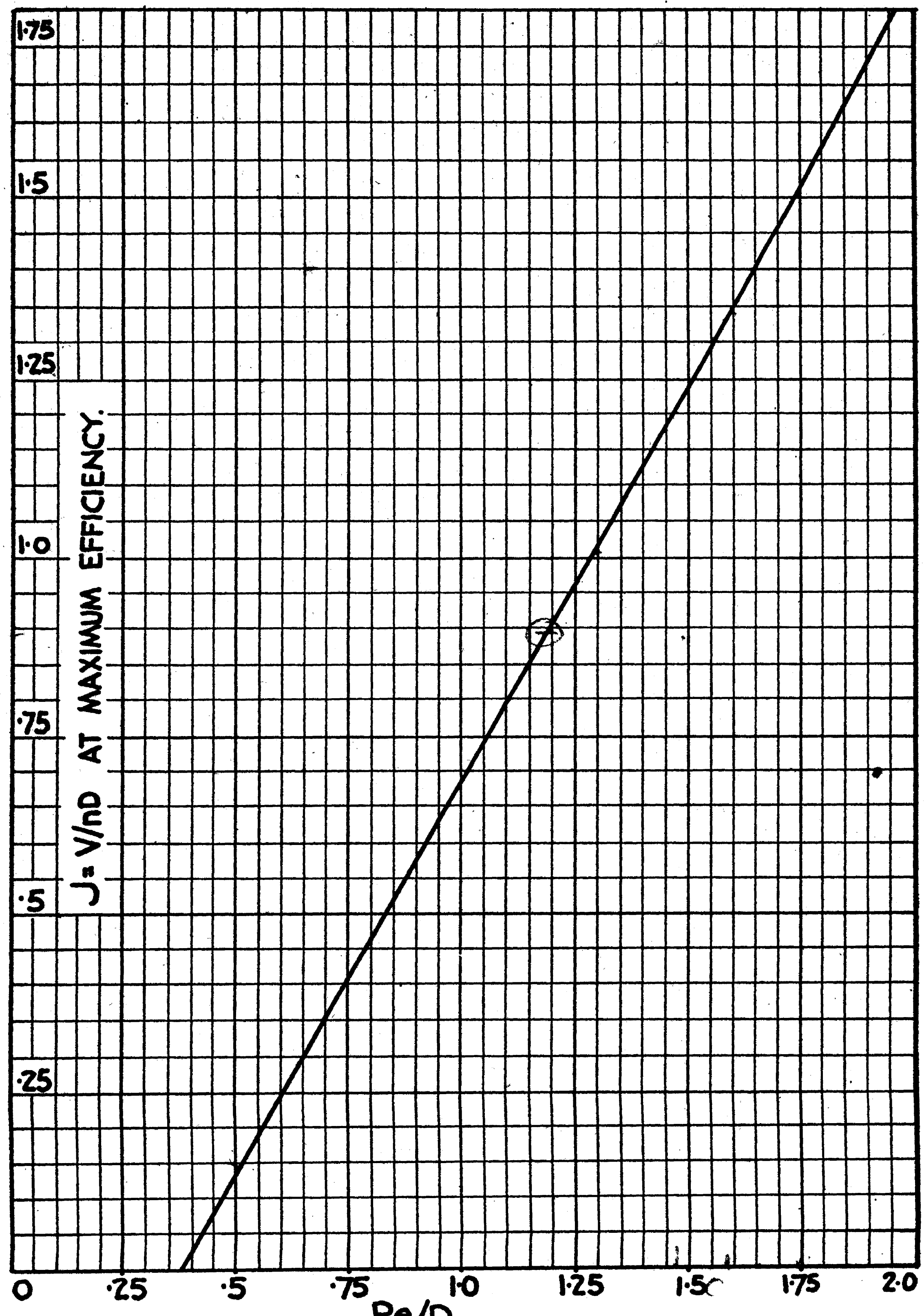


DIAGRAM 8
Airscrew design graph

Now by referring to diagram 8 we are able to read off the correct Pe/D ratios for each case and we find that :—

(i) maximum climb Pe/D = 1·075
(ii) moderate climb Pe/D = 1·48
(iii) long cruise Pe/D = 1·975

By applying accurate values of n and V, determined by experience, to your own particular model and following the above method you can determine the *exact* Pe/D *ratio required* for that model, having first of all decided what sort of performance you require. It is only by experience that you will obtain finesse especially in regard to matching the motor—i.e., getting your design value of n the same as your flight value.

Having got Pe/D the geometric pitch follows (D is already known), and thus you can obtain your block dimensions remembering again :

geometric mean pitch = 2·2 D w/d — formula (2).

A mathematical expression for diagram 8 is :—

$$J = \cdot 92\,Pe/D - \cdot 275 \qquad (24)$$

From this you may plot your own graph if you so desire. *Make a careful note of this formula for it is one of the simplest to apply and yet one of the most important in the book.*

Now take the case of a petrol model. As we have seen before we want maximum efficiency for climbing. In this case n is constant, for the engine at once speeds up until the power is absorbed by the airscrew when n is usually of the order of 50–65 revs. per second. Anything below this value leads to the danger of a "stalled" engine, loss of power and unreliability, especially as the majority of engines are two strokes. Anything above is detrimental to the engine and tends to shorten its life. Gearing down might advantageously be employed to reduce n, but the mechanical difficulties and increased weight usually preclude its use.

The value of D, the diameter, is governed by the engine capacity and is again chosen to avoid overloading or "speeding." The makers usually specify the correct airscrew size for their particular engine and the value of D for any "own design" can be estimated by comparison.

For our calculations we will assume that we have a 6 c.c. engine with a 13 in. diameter airscrew and that V, when climbing, = 34 ft./sec.

$$J = \frac{V}{nD} = \frac{34}{60 \times 1{\cdot}083} = {\cdot}5232.$$

From the graph Pe/D is ·75 : 1. Therefore we can find the geometric proportions of our airscrew after deciding the blade width and area.

Thus we have a simple and accurate method of finding the theoretical pitch of our airscrew for maximum efficiency governed by the requirements of the design. It involves no lengthy calculations and yet is backed by sound mathematical arguments. I sincerely advise every aeromodeller to try it as it has given me excellent results over many years of designing and flying models and, although I say it myself, led to more than average results.

As a check we can now refer back to diagram 7 and find the *efficiency* of our airscrew at the calculated Pe/D ratio and value of J. This should obviously be a maximum and, if not so, it means that we have taken false values of D, *n* or V. In this case one or more of these should be altered and Pe/D re-calculated until maximum efficiency is obtained.

The correct values for the two variables V and *n* will probably be the greatest source of trouble. The velocity, of course, can be calculated but in the absence of reliable low speed data it is best to find V by means of an accurate *air-speed indicator* fitted to the model. Such an instrument is fairly easy to make and full details are given in the book "Model Gliders", published by the Harborough Publishing Company, price 4s.

With regard to the value of *n* this can be checked by plotting a graph of *n* against time by the method given in Chapter VI. The amount of power must be so adjusted that flight values of *n* co-incide with the design values used. The rate of revolution is also controlled to some extent by the *solidarity* of the airscrew. The airscrew will speed up until the torque of the motor is absorbed by the "drag" forces set up. Calculations for torque and thrust of a blade are given in the Appendix to which the reader is referred. It is interesting to note here that for airscrews with an extreme blade width, such as those used on duration machines powered by rubber motors, there are theoretical grounds for anticipating a reduction in the effective lift coefficient. On the other hand there appears to be an *increase* in the *maximum* lift coefficient and a considerable postponement of the stall.

The preceding text has shown us that thrust, torque and efficiency all vary with the geometric characteristics of the airscrew and also with J (i.e., V/nD). Referring to the thrust grading curve, diagram 2, it will be seen that the thrust is mainly concentrated towards the ends of the blades and particular attention should be paid to this point. Diagram 9 shows the variation in efficiency along the blade length.

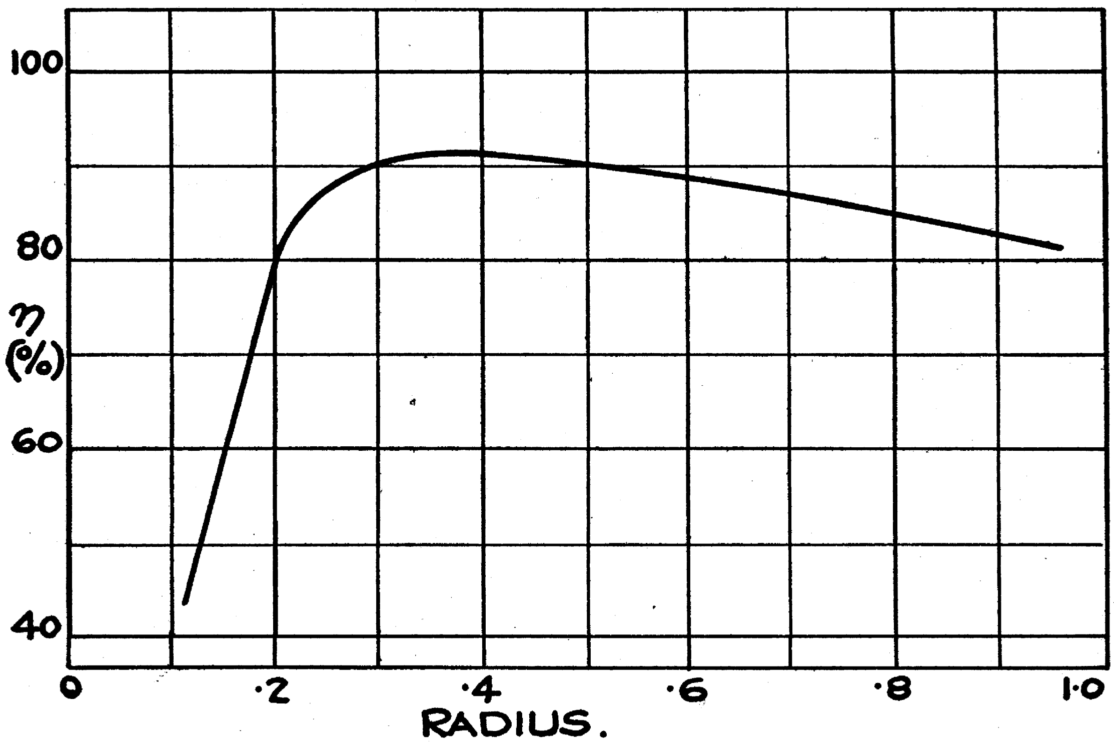


DIAGRAM 9

It will be seen that near the hub the thrust disappears completely and the efficiency is very low. Blade sections should be as thin as possible (i.e., high L/D ratio) consistent with rigidity, but near the hub thickness is unavoidable, and altogether it seems doubtful if any attempt to get thrust from this latter part is at all worth while. The best we can do is to reduce the drag there as much as possible, at the same time keeping it strong enough.

A spinner is an invaluable aid to smoothing out the uneven flow here, and should always be employed where the design of the machine allows it. Even in a slabsider it pays to fair in the nose to a circular section and use an airscrew with a spinner. The first ·2r (i.e., one-fifth radius) of the blade should then be as thin as practicable and cut away—see diagram 10. This will obviously weaken the blade to a certain extent, and a binding of silk or tissue is often used at this point, especially with normal carved airscrew, in order to resist shocks due to awkward landings, etc. A folding airscrew has a great advantage in this respect because it is far less liable to damage. The hub can be cut away to much finer limits with a corresponding reduction in drag—see diagram 10.

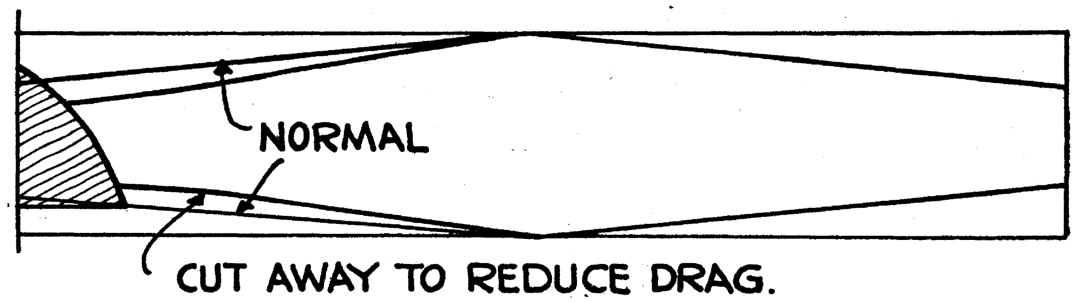


DIAGRAM 10

The remainder of the blade should be carved to a thin but definite *airfoil section.* Clark Y and R.A.F. 6 are extremely good for power models when modified by thinning down, whilst on rubber-driven types an under-cambered section is to be preferred. The degree of under-camber varies—a " wind shovel " has quite a large amount but, owing to its slow rate of revolution, the increase in drag is not prohibitive. For faster revving airscrews only slight under-camber should be used—about ⅛ in. on an 18-in. diameter being the maximum.

The blade also tapers towards the tips, which means a decrease in thickness of section, as the maximum blade width or chord occurs somewhere about midway between hub and tip. On a

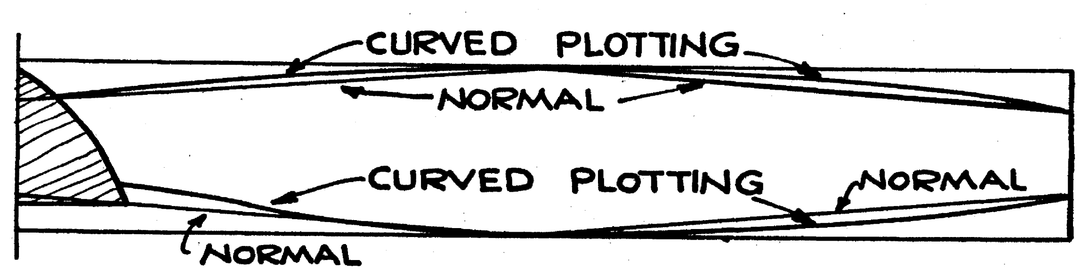


DIAGRAM 11

folding airscrew the tip thickness can be as small as 1/32 in., but for the fixed type 1/16 in. is a minimum for rubber models, and still more for power types.

The pitch angle change should be gradual, and the usual practice of cutting blanks to straight edges is not to be encouraged for maximum efficiency. Diagram 11 shows an elevation of the block and the marking of the blank; the curved lines give true pitch gradation. An exact method of doing this is as follows.

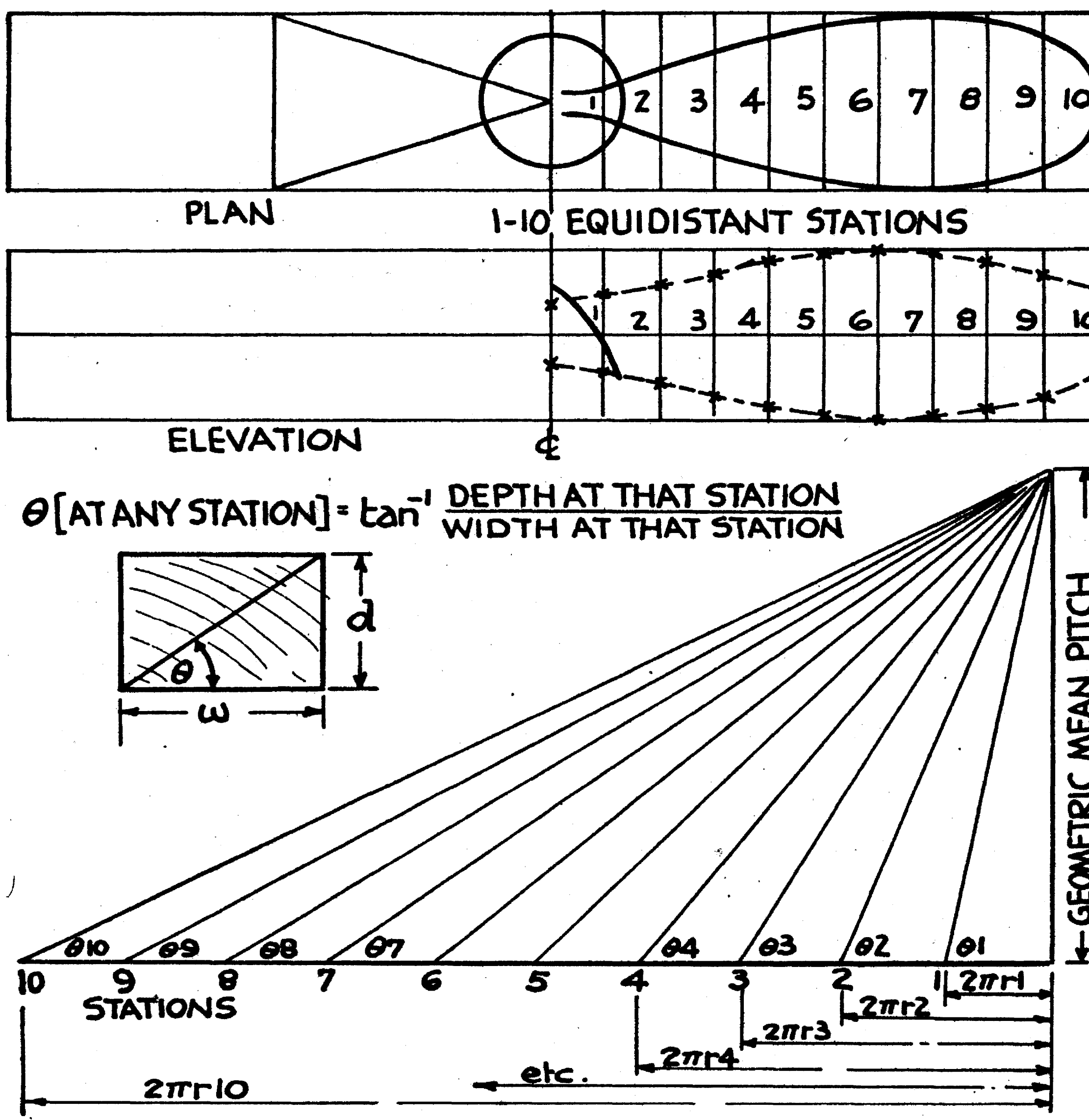


DIAGRAM 12

Firstly, the plan view of the airscrew is worked out on the block and lines drawn at 1-in. intervals from $r = 0$ to $r = R$ (see diagram 12). The actual shape is generally determined by experience and is often a matter of that particular modeller's fancy. Then on a piece of paper draw a straight line and mark off to any convenient scale lengths, $2\pi r_1$, $2\pi r_2$, $2\pi r_3$, etc., representing the positions of station 1, station 2, station 3, etc., on the plan view with respect to circumference ($r_1 = 1$ in., $r_2 = 2$ ins., $r_3 = 3$ ins., etc.). At the hub end, i.e., r_o, erect a perpendicular representing the *geometric mean pitch* to the same scale. From the top of this line draw more straight lines to each point on the circumference line. The angles θ_1, θ_2, θ_3, etc., now give the exact blade angles corresponding to stations 1, 2, 3, etc.

Knowing the width of the airscrew block and the geometric mean pitch, the exact depth can be calculated and the block cut down to this. A centre line is drawn on the block elevation and marked off with lines spaced 1 in. apart as on plan view. We have got the width of the *blank* at each station (by measurement of *blade* width on *plan* view), and we know the blade angle θ at each station, so it is now an easy matter to calculate the exact depth of the blank at 1, 2, 3, etc., for

$$\tan \theta = \text{depth/width}$$
$$\text{or depth} = \text{width} \times \tan \theta.$$

Thus, at the first station, $\text{depth}_1 = \text{width}_1 \times \tan \theta_1$,
at the second station, $\text{depth}_2 = \text{width}_2 \times \tan \theta_2$, etc.,
enabling us to mark out our elevation correctly by plotting these depth values about the elevation centre line. These points are joined by a smooth flowing curve, and the result is an accurate blank marked out—do not spoil it in the cutting process !

If a number of geometrically similar blanks are required it is far easier to make templates for the plan and elevation of the blank (the latter calculated as above), and the actual blanks marked by scribing around these.

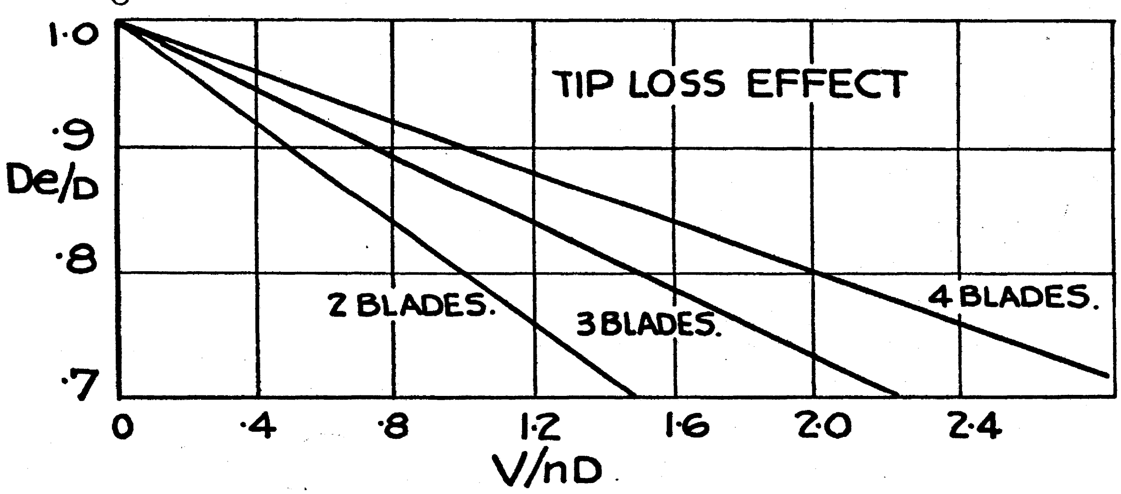


DIAGRAM 13

At the tip of the blade we get certain losses due to the radial components of velocity in the slipstream and circulation around the blades. This loss is equivalent to a reduction in diameter, and a formula giving De, the effective diameter, is :—

$$\frac{De}{D} = \frac{1{\cdot}386\ J}{B\sqrt{\pi^2 + J^2}} \qquad (25)$$

Compare this with formula (20).

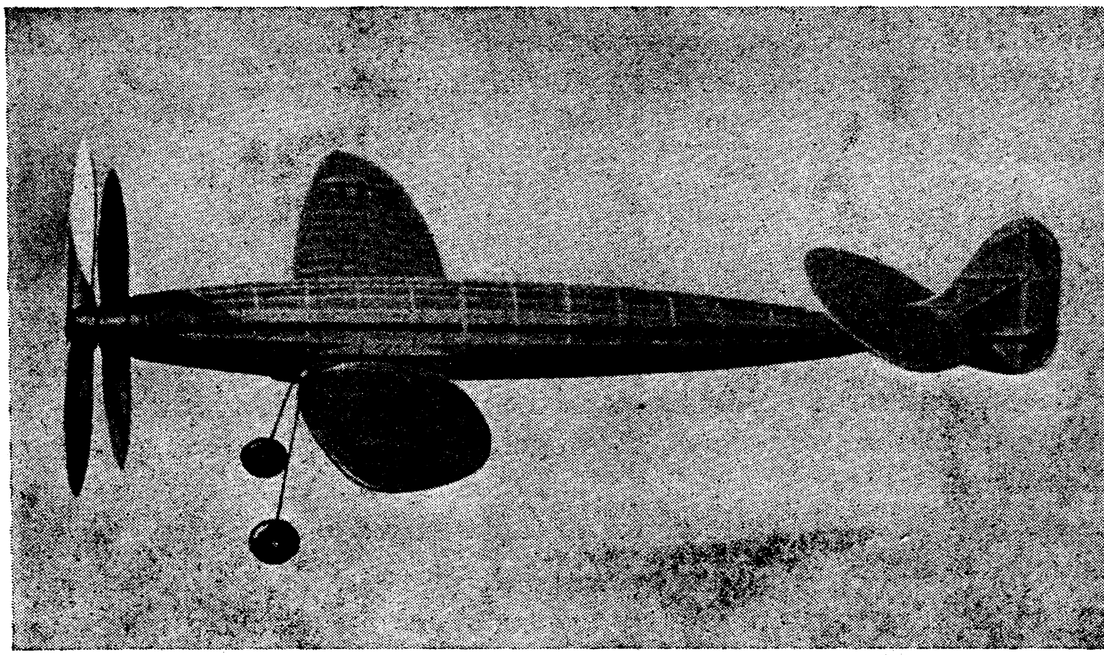
Graphically represented, as in diagram 13, it is apparent that this effect is most noticeable for large P/D ratios, and it would seem that a three- or even four-bladed airscrew of the same solidarity is to be preferred. (Solidarity is the ratio of the blade area to the disc area of the propeller.) However, in model practice this loss of effective diameter is usually compensated by an increase in actual diameter, this being preferred to a multi-bladed airscrew with its added weight and constructional difficulties.

Actually, to have the same properties an airscrew with more than two blades would require a slightly greater solidarity, which would mean an increase in form drag. (At high speeds the loss of solidarity of a three-bladed airscrew over one of two blades is less than one-half the gain in respect of effective diameter).

Blade shape does not appear to be important except that the maximum area should be concentrated around a point approximately ·75 of the tip radius. At one time the Chauvière type was greatly favoured, as it was thought that the leading edge of the blade should be larger than the trailing edge. The modern tendency has seemed to indicate the reverse, especially on large model airscrews, but the plan form is more usually symmetrical. A symmetrical plan form helps to balance out blade stresses at high speeds, but this factor is not of very great importance in model work.

Little more remains to be said about airscrew outline except to emphasise that the blades should be as smooth as possible. A highly polished finish is desirable to minimise form drag and also render the component waterproof. An untreated balsa airscrew, especially if it is made of soft wood, will absorb a surprising amount of moisture from damp atmosphere, dew, etc., and might even seriously affect the trim of the model under these conditions.

CO-AXIAL



Contra-rotating airscrews are featuring more prominently in modern aircraft practice and this model by C. F. Hedges and R. V. Bentley illustrates its application to model form. The two airscrews are driven by a single motor through an ingenious gearing system. Full size working plans of this machine are available through the Aeromodeller Plans Service, price 3/– post free.

CHAPTER V*

FIXED, FREE-WHEELING AND FOLDING AIRSCREWS

So far we have only considered the airscrew when it is working. Now let us pass on to the next stage, i.e., when the power has run out, and examine the conditions then existing. We will also discuss the question " To fold or not to fold."

A normal airscrew not fitted with a free-wheeling device will reach a stationery position some time after the power has run out, i.e., when the slack of the motor has been taken up, and will stay there unless air disturbances such as speed variations cause it to move slightly.

In this position it is a considerable source of drag as well as giving a rotary motion to the air flowing past it and over the rest of the model. Such a condition is very unsatisfactory and may well lead to instability if the airscrew is at all large.

The drag will obviously depend upon the projected blade area (in the direction of motion) and thus a high pitch, fixed airscrew will have less drag than an otherwise geometrically similar one but with less pitch. Even so we cannot afford to have this state of affairs with the " wind-shovels " used today. The drag is out of all proportion to its usefulness on the power run and completely ruins the glide.

The first step taken to reduce drag was to arrange the airscrew so that it could windmill or free-wheel after the power was exhausted. This was first introduced *circa* 1930 and has been accepted almost universally for the past ten years.

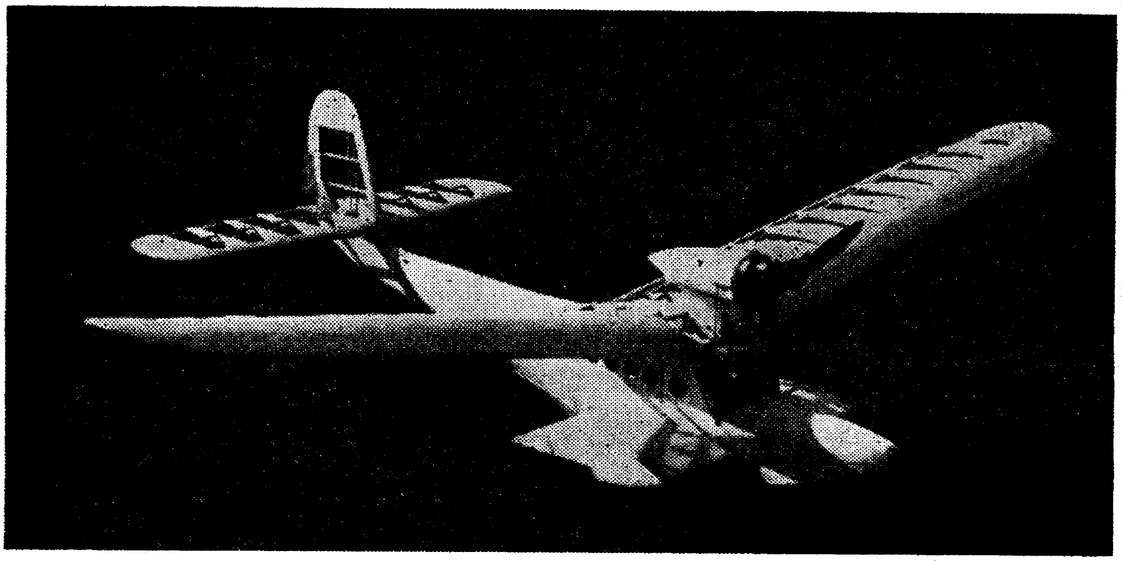
The drag of a free-wheeling airscrew is given by the formula :—

$$D_F = \frac{6\,\delta\,D^2\,V^2\,\sigma}{J_o^3 \times 10^4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(22)}$$

(Where σ = solidarity, J_o = value of J at zero thrust, i.e., at angle of no lift of airscrew blades, δ = relative air density = 1 at sea level.)

---

* N.B.—This discussion is confined to rubber driven models although considerable advancement has been made recently in the United States on folding airscrews for petrol driven models. Unless the latter type of model is particularly " clean " it is hardly worth while to court the mechanical difficulties involved as the blade area is relatively small. When design has, however, more or less reached stagnation this is the next logical step towards an increase in gliding performance.



A first class design by an experienced model builder. This petrol driven flying boat, the "Mermaid," is capable of rising off water and landing on it again. Correct airscrew design is important in this instance to obtain the maximum performance.

This formula assumes no torque present but actually there is always a little due to the friction of the free-wheeling parts. This must be made a minimum by good bearing surfaces.

After the free-wheel came the feathering propeller. This was so constructed that when the power ran out the blades automatically assumed their position of minimum drag, i.e., turned edge on to the relative wind. This gave a still further reduction in drag and a smoother motion to the airstream behind it, but the mechanism involved was usually very delicate.

A slight knock was sufficient to upset the spring arrangement and, as knocks are quite frequent even in the best of models, this can hardly be considered the solution to the problem.

Finally there came the folding airscrew whereby the blades folded back against the fuselage at the end of the power run and, to all intents and purposes, turned the model into a sailplane. The idea did not receive universal approval at first, appearing on only a few models, but at the present time there is a definite favouring of this type. It may even eventually replace all the others for competition models.

The folding airscrew gives the least drag of them all. It was argued that the presence of these folded blades at the nose of the fuselage would upset the airflow over the remainder, but practical results have proved otherwise. Even this method is not without its drawbacks, however, and we will deal with these first.

For minimum drag and minimum interference the blade or blades *must fold flat against the fuselage. The importance of this cannot be over emphasised and is especially true in the case of the single blade type.* If the single blade lies along the fuselage at an angle when folded it is not only contributing an appreciable amount of drag but is liable to affect the lateral trim of the model. It is like putting a rudder on the nose of the fuselage and turning it to a considerable angle relative to the flight path.

With two blades the effect of one will neutralise that due to the other as regards lateral trim (except that certain rotary components will be doubled), but the *drag* is doubled.

By setting the blade hinges on the skew it is quite an easy matter to arrange each blade to fit snugly against the fuselage side thus cutting out interference and minimising drag.

Another change of trim involved is the shifting of the C.G., affecting longitudinal control. When the blades fold it is obvious that the C.G. of the whole machine is shifted back slightly, resulting in a tendency to stall on the glide. If the model is trimmed for a non-stalling glide then the climb is not as efficient as possible because the model is slightly underelevated at that part of the flight. Mr. N. Lees of Halifax told me that this was the main trouble he had experienced, but he has solved this in a particularly brilliant way by forward retraction of the undercarriage at the end of the power run, the two C.G. shifts balancing.

This C.G. shift is, I think, noticed more on high aspect ratio models. With low aspect ratio, and consequently greater average chord, the C.G. shift *expressed as a percentage of the chord* is less. The C.G. shift of a single-bladed folding airscrew is, of course, less than that of a two-bladed one, but more than 50 per cent. relative solidarity is required in the former case (i.e., the area of the single blade is about 120 per cent. of one blade of two bladed airscrew or 60 per cent. of total blade area of latter).

The only other disadvantage is the increased constructional difficulty in producing a thoroughly reliable unit.

With a single-bladed airscrew motion is inclined to be uneven, but this may be overcome by bending back the arm carrying the balance weight. Rotation then tends to straighten this arm, due to the centrifugal force acting on the weight, and this forward pressure balances the thrust of the blade.

Its main recommendation is its simplicity as only one blade has to be carved, but, as a leading modeller aptly pointed out to me, " It is almost an admission that you cannot carve a true airscrew, sticking to one blade ! " Certainly a two-bladed airscrew is to be preferred especially, as we have seen earlier, for higher pitches. No difficulty should be experienced if the airscrew is carved normally, the two blades cut off and then hinged to the hub.

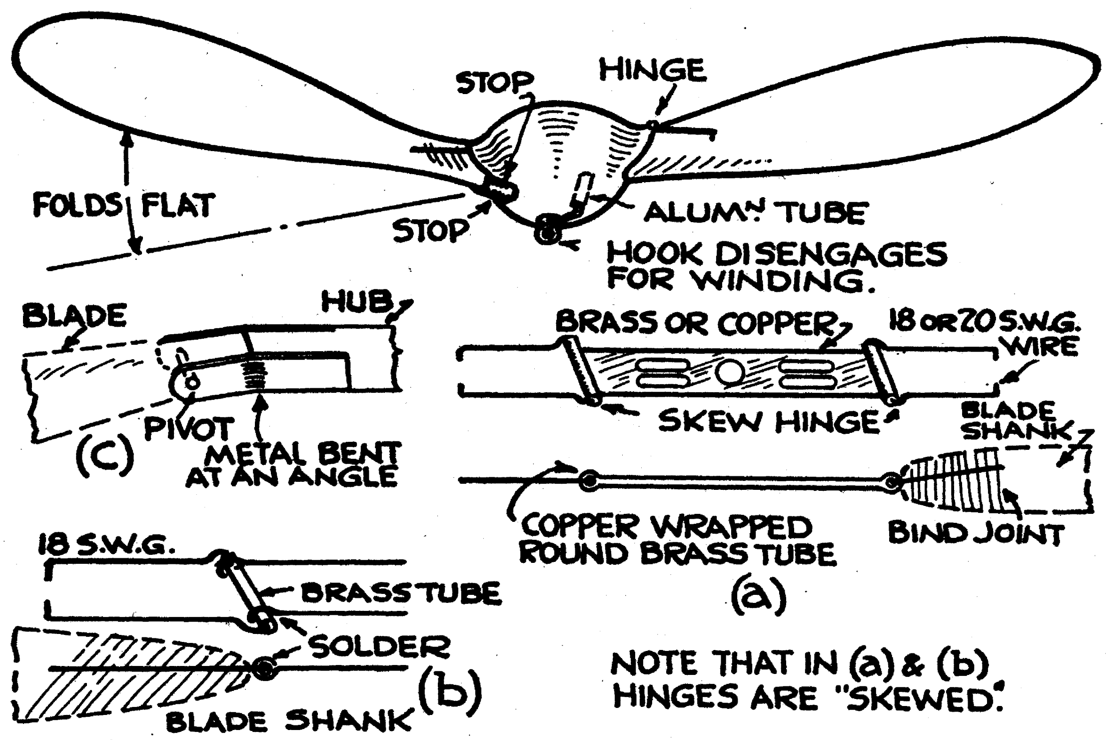


Diagram 14

The folding airscrew possesses many advantages ; we have already dealt with some of the aerodynamic ones. There is also another extremely important point, though, in that it allows us to cut down the hubs to finer limits, thus reducing drag, because the liability to breakage is greatly reduced. On striking a solid object the blade will fold back and not snap off, this in itself being a very strong recommendation for its adoption.

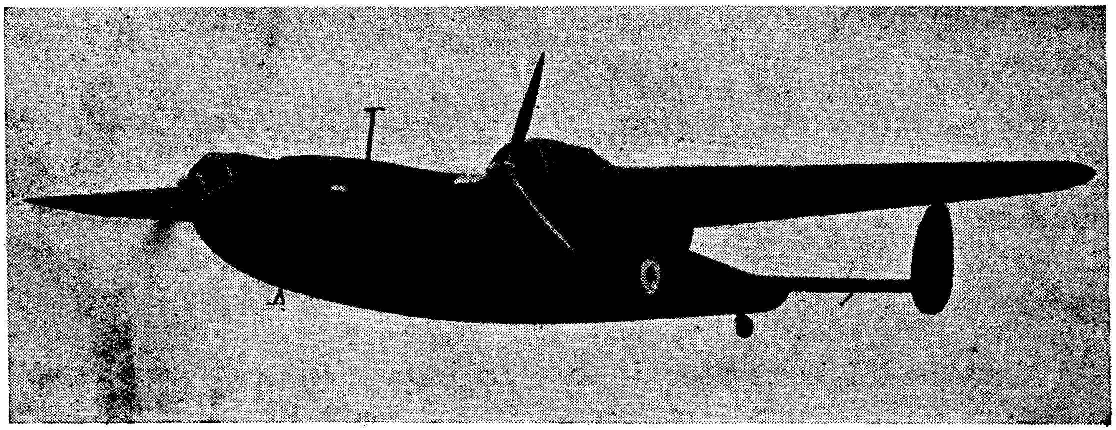


Photo by courtesy of The Aeroplane

A de Havilland "Flamingo" with port engine stopped and the airscrew fully feathered. In this position its drag is minimised and it remains stationary. Under such conditions the absolute ceiling on one engine is 11,000 *ft.*

I have had a Wakefield dive in at a very steep angle from a height of 200–300 feet (when the rubber bunched at the tail forcing the leading edge of the tailplane up), resulting in considerable damage to the nose area but the *folding airscrew was unbroken*, simply because it was folded back and there was nothing to break. I hardly think a free-wheeling airscrew would have remained undamaged.

The main secret of success lies in a good, firm hinge which holds the blade securely in position during the working period and allows it to fold back flat when the motor has run out.

Several types of hinges are illustrated in diagram 14, the one most favoured being type (a). In this a short length of 20 s.w.g. brass or copper strip is doubled back over a piece of 18 or 20 s.w.g. brass tube (approx. ½ in. long). This strip is securely attached to the hub and runs across the whole length for two blades, i.e., from hinge to hinge. It may be lightened by drilling out as shown.

Diagram 14 (*b*) shows a variation of this using wire instead of the metal strip and 14 (*c*) shows another type sometimes employed.

The hinge part that attaches to the blades is of 18 or 20 s.w.g. wire bent to shape as shown. The ends should be turned in slightly so that, when "sprung" on the blade shanks and several coats of cement applied, a secure fixing should be obtained. A silk or thread binding is often used at this part, and does materially increase the strength.

To keep the total weight of the airscrew down—we have already increased the amount of metal fittings—and also to minimise the C.G. shift, the blades should be of light balsa and carved thin. They will not experience so many knocks as the fixed type and so need not be so strong.

A method I have used is to scarf-joint a piece of ***hard*** balsa on to the blade shank to reduce wear and make for a more secure hinge fixing. This joint may be reinforced by a bamboo peg if desired (see diagram 15).

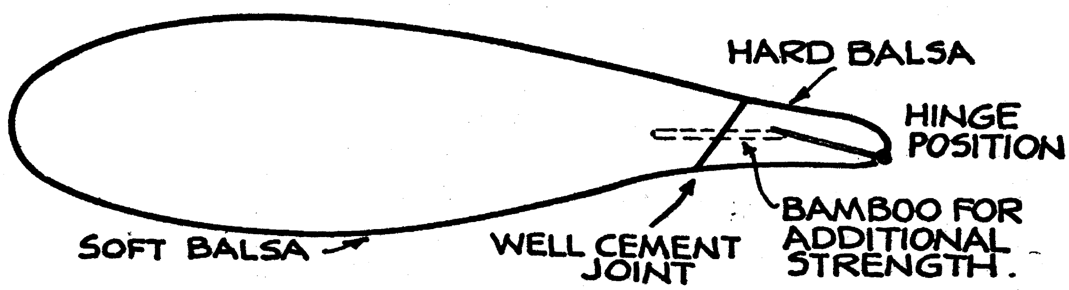


Diagram 15

To take a certain amount of strain off the hinges when the airscrew is revolving the blades should fit flush against " stops " of hard balsa when in the " open " position. At the same time these stops must not interfere with the folding. By careful arrangement each blade shank can be made to fit into a socket on each side of the spinner or hub when open, and easily fold clear when the power runs out (see diagram 14).

No difficulty should be experienced in launching a model with a double-bladed folding airscrew. One blade is held open in the usual way, the other almost certainly remaining folded as the model is heading into the wind for take-off. On releasing the airscrew the folded blade immediately opens under centrifugal force and its own thrust, there being no appreciable lag.

It is generally advisable to fit a stop, worked on the motor tensioner principle, to the noseblock so that when the power runs out the blades are stopped in a horizontal position and fold back along each *side* of the fuselage. For a single blade the stop should be arranged so that the blade folds along the top. Actually, in the latter case, as soon as the blade folds the counterweight, being more powerful, now falls to a vertical position and so no stop is really necessary. If the blade does not fold flat, though, it may still try to rotate, causing excess drag ; thus a stop is a wise precaution.

Such an arrangement may be simply worked in conjunction with the normal spring type of rubber tensioner, the airscrew being automatically stopped when the shaft locks. The main disadvantage here is that it is not possible to wind the motor with a hand drill in the normal manner with the airscrew floating on the shaft unless some form of catch is fitted to hold the spring in compression and allow the airscrew to be disengaged from the shaft. Quite a small, but rather annoying, point which can, however, be overcome with a little ingenuity. The most direct solution is to have a third party holding the airscrew back against the noseblock during winding although with a winder of the type that can be fixed, such as a converted " grindstone " mounted on a stick and pushed into the ground, this operation can be performed by the free hand by the one operator.

With the stop only worked on the spring tensioner the action is not so powerful and winding can usually be carried out in the normal manner. In this case the motor is tensioned by pre-winding but the obvious advantages of combining the two operations in one should convince the serious model builder that the former method is to be preferred.

In conclusion it must be emphasised that whichever type of hinge is employed it must be *reliable and sturdy*. It will probably have a few hard knocks in the course of its useful life and thus must be capable of taking a reasonable amount of hard wear without distortion. A weak or " wobbly " hinge is always a source of danger and annoyance and should the fitting ever reach this stage it should be repaired at once or scrapped in favour of a stronger unit.

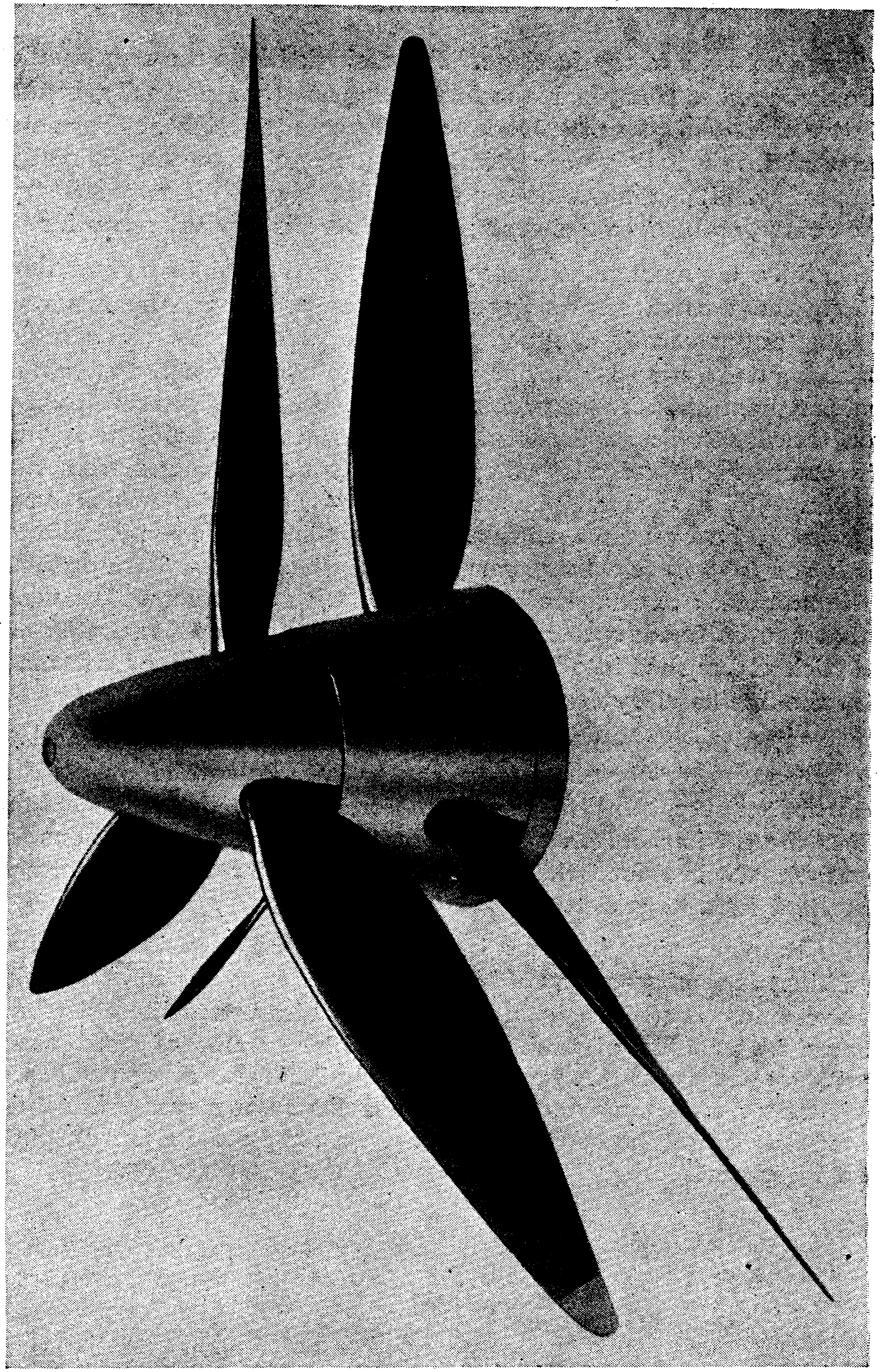


Photo by courtesy of de Havilland Aircraft Co., Ltd.

CHAPTER VI

VARIABLE PITCH AIRSCREWS

It has been noted in Chapter IV that the rate of revolution of a rubber-driven airscrew is not constant; at first it is quite high and then drops off rapidly. In other words, the power is not constant but is continually dying away. This means at once that J, one of the all-important design criteria, is continually changing, and thus the airscrew had to be designed for maximum efficiency *at some particular point on the power curve only*. At any other part of the power curve, where J is altered, the efficiency will fall. Study diagram 16, showing variation of maximum efficiency with departures from the design value of J.

Thus for maximum efficiency throughout the power run J must always be equal to its design, value, i.e.,

$$\frac{V}{nD} = \text{const.}$$

Of the three deciding factors, V varies slightly during flight, but for the sake of simplicity may be assumed approximately constant for the moment; n varies with time, as the power output is continually dying away; and D, the diameter, is fixed.

DOES IT?

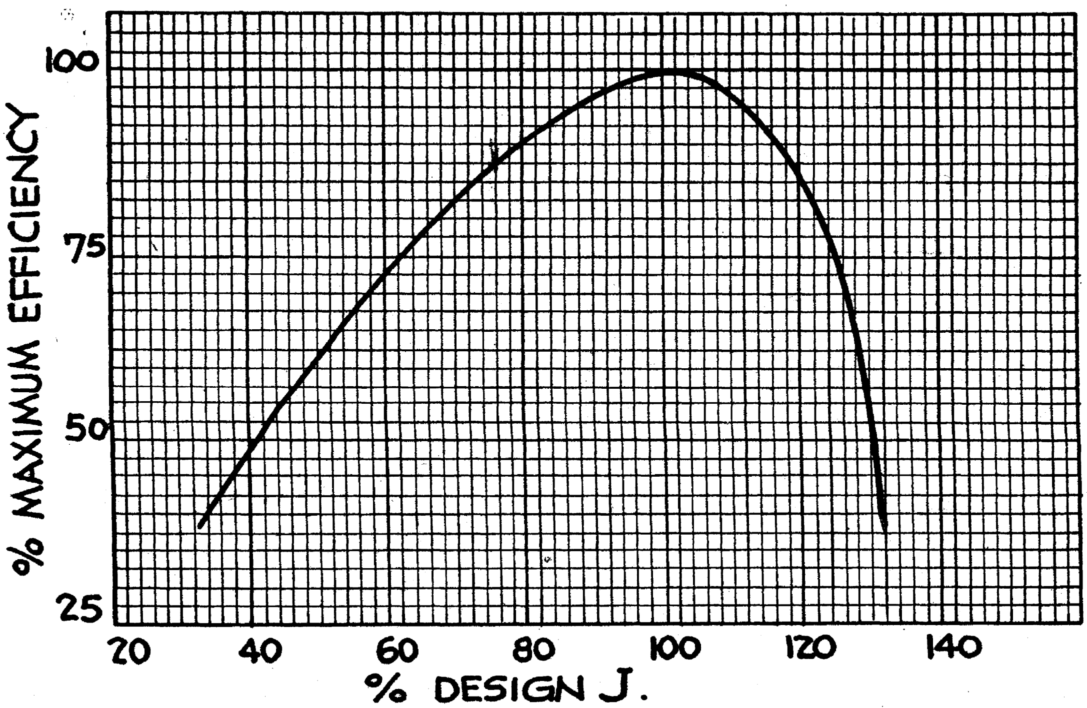


DIAGRAM 16

This variation of *n*, which is the main source of trouble, can be found in the following manner. Take a standard combination of airscrew and rubber motor for the design under consideration and wind nearly to maximum turns, noting carefully the actual number of turns put on. Now allow the airscrew to revolve for a fixed time, say, 10 seconds, and then stop it. Unwind the remaining turns, e.g., by connecting the winder and then winding in the reverse direction, and count the number of turns left on. Thus if 1,000 turns were put on the motor in the first place and after a 10-second run there were 800 turns left on, the average rate of revolution over this period was (1,000 — 800) ÷ 10, i.e., 20 revs. per second. Now repeat by winding on the amount of turns left on after the first 10-second run, allowing the revolve for 10 seconds again, stopping and counting the number of turns left on again. Continue this for the whole length of the power run and you then have the average rate of revolution over the power run at 10-second intervals. A typical curve of *n* against turn is shown in diagram 17 plotted at 5-second intervals. Although somewhat tedious, the results obtained are most instructive and can be set to a useful purpose.*

* For meticulous accuracy this test should be carried out in a stream of air equivalent to flying speed.

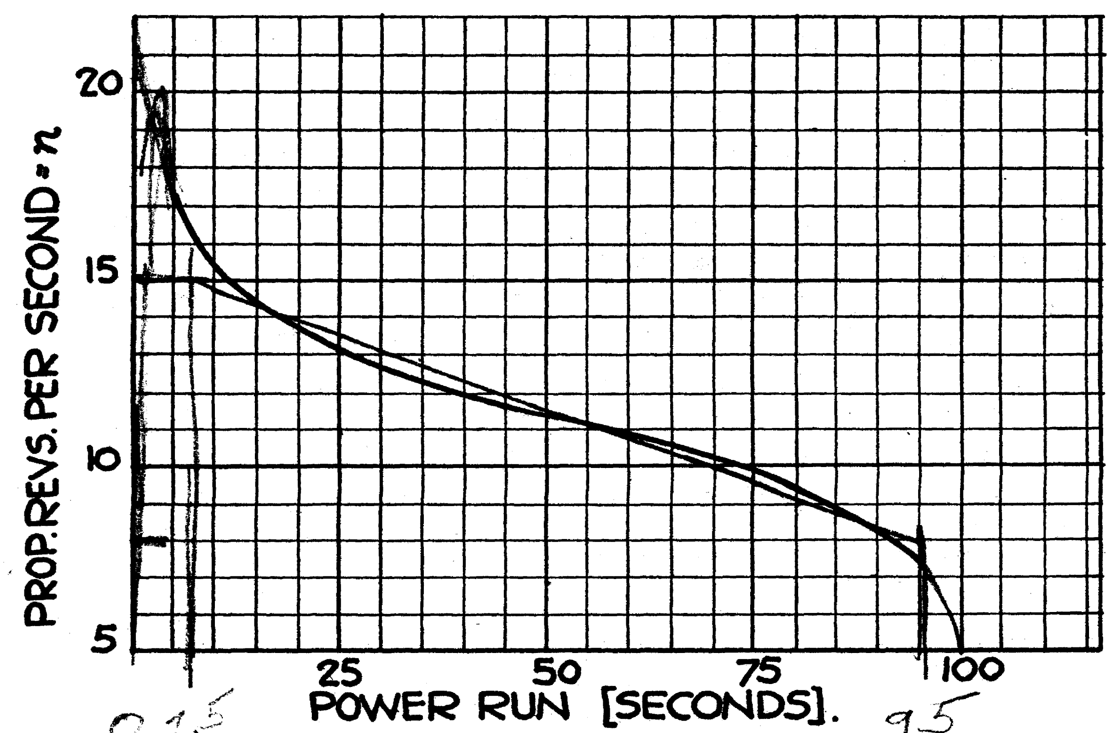
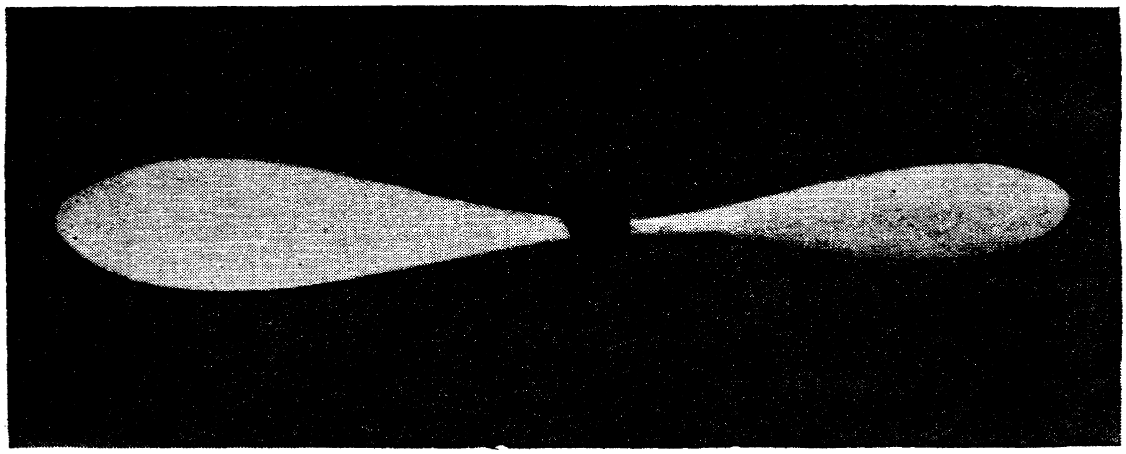


DIAGRAM 17



A large rubber driven model airscrew. Note that the main blade area is concentrated around the three-quarter radius point and the roots cut down as small as possible consistent with strength.

After a study of this curve the problem of the varying value of n will be readily appreciated. The first solution was offered by R. N. Bullock, who suggested a constant speed airscrew. This effect was obtained by expanding blades. At the beginning of the power run the increased rate of revolution resulted in increased centrifugal force on the blades, which were free to move outwards against the pull of a rubber band or spring. This increase in diameter naturally led to a slowing down in the rate of revolution, thus tending to keep n approximately constant. The main draw-back to this ingenious idea is the mechanical difficulties involved in such a unit. Then, again, although n is nearly constant, D varies, and thus J will also vary (still assuming that V remains constant). In view of this a better solution must be sought.

Under our present assumption we require a means of keeping the product nD constant throughout flight range. No such method is readily available, and thus we must turn to the variable-pitch airscrew as the best means of ensuring that J does not vary from its design value.

Diagram 8 shows P_E/D plotted against J at maximum efficiency. The object in view is to adjust P_E so that, whatever the value of n, J and P_E/D always lie on the straight line graph

$$J = \cdot 92\, P_E/D - \cdot 275.$$

The equation of this curve may be rewritten :—

$$P_E = V + \frac{\cdot 275\, nD}{\cdot 92\, n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

Thus, having a fixed diameter and leaving n to within a high degree of accuracy from our graph, diagram 17, the value of the required experimental mean pitch, PE, at any part of the power curve can be calculated. We are also in a position to introduce any variation in velocity that may occur during flight range, but to do this accurately an airspeed indicator should be fitted to the model and velocity at various parts of the flight found.

The following condensed figures are those for a number of tests carried out with a model of 172 sq. ins. wing area, weight 5·75 ozs. powered by 2 ozs. of rubber turning a 16-in. diameter airscrew, giving a power run of approximately 100 seconds. Diagram 17 of n against time was used for this particular model. These results are merely given to illustrate the method. For a more accurate analysis the power run must be divided into a greater number of parts and J calculated for each. Also the whole process is simplified as far as possible and presented in a manner readily understood by the average reader.

From diagram 17 we get :—

n for climb = 13 revs. per second.
n for cruising = 11 ,, ,, ,,
n end of cruise = 9 ,, ,, ,,

We also want the velocity of the model under the same conditions and the figures given below are from actual flying tests with a small airspeed indicator fitted to the model.

V for climb = 14· ft./sec.
V for cruise = 15·25 ,, ,,
V end of cruise = 16·25 ,, ,,

Now D = 16 ins., so we can calculate J.

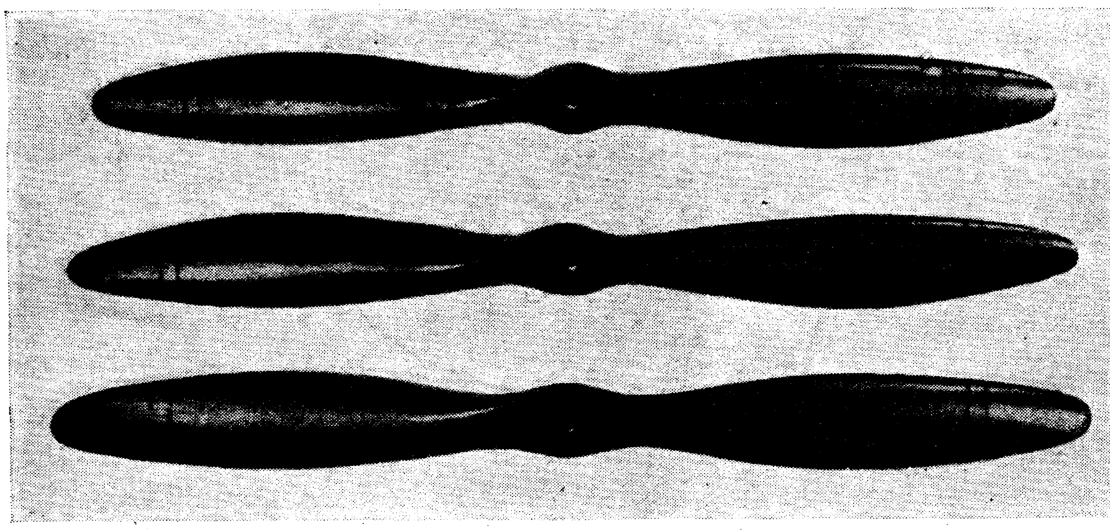
J for climb $= \frac{14 \times 12}{13 \times 16} = \cdot 81$

J for cruise $= \frac{15\cdot 25 \times 12}{11 \times 16} = 1\cdot 04$

J for end of cruise $= \frac{16\cdot 15 \times 12}{9 \times 16} = 1\cdot 36$

From diagram 4 we can read off the correct PE/D ratios corresponding to maximum airscrew efficiency under each condition.

Thus PE/D for climb = 1·05 i.e., pitch = 16·8 ins.
PE/D for cruise = 1·275 i.e., pitch = 20·4 ,,
PE/D end of cruise = 1·625 i.e., pitch = 26·0 ,,



A group of airscrews for petrol models. The blade shape is typical of such types.

Now having a fixed pitch airscrew I had to compromise on the model, having maximum efficiency for one part of the flight only. For this particular case I used a P/D ratio of 1·5 : 1, giving maximum efficiency about midway along the cruise with a corresponding reasonably long power run.

For the airscrew to have maximum efficiency throughout flight it would appear that we want to change the pitch from 16·8 ins. at the beginning of the flight to 26 ins. at the end, but, unfortunately, changing the pitch will also cause n to vary again, so the solution is not as simple as that.

We can approximate if we wish, and this should give results accurate enough for practical work. The average value of n is 11 revs. per second, whilst for climbing this is increased to 13 revs. per second, i.e., $2/11 \times 100$ per cent. of the average value $= 18$ per cent. increase. In this case there is also an 18 per cent. decrease in N (average) towards the end of the power run. Now n for climbing has been taken as occurring 10 seconds after commencement of flight, and is on the low side, whilst n for end of cruise is probably relatively high, and in any case the thrust is falling off here.

Thus we can give as a general rule, n (climb) is 20 per cent. greater than n (average) and n (end of cruise) is 15 per cent. less than N (average).

Associated with the average value of N, calculate J and find the pitch as above. Then required pitch range is from 20 per cent.

below average pitch to 15 per cent. *above* average pitch. From this we can design the mechanical arrangement to suit.

It is not necessary to have a very fine pitch for take-off even though V, and consequently J, is small at first, since there is usually ample acceleration from the size of motors normally employed. This point may be of importance in large, heavily loaded models, however.

At the other end of the scale the ideal arrangement would be for the blades to feather—i.e., have infinite pitch, when the power has run out to lessen the drag under gliding conditions. Better still, it should be made to fold, but both of these arrangements greatly complicate the necessary working parts and so perhaps it is better to proceed one step at a time and leave this for further development.

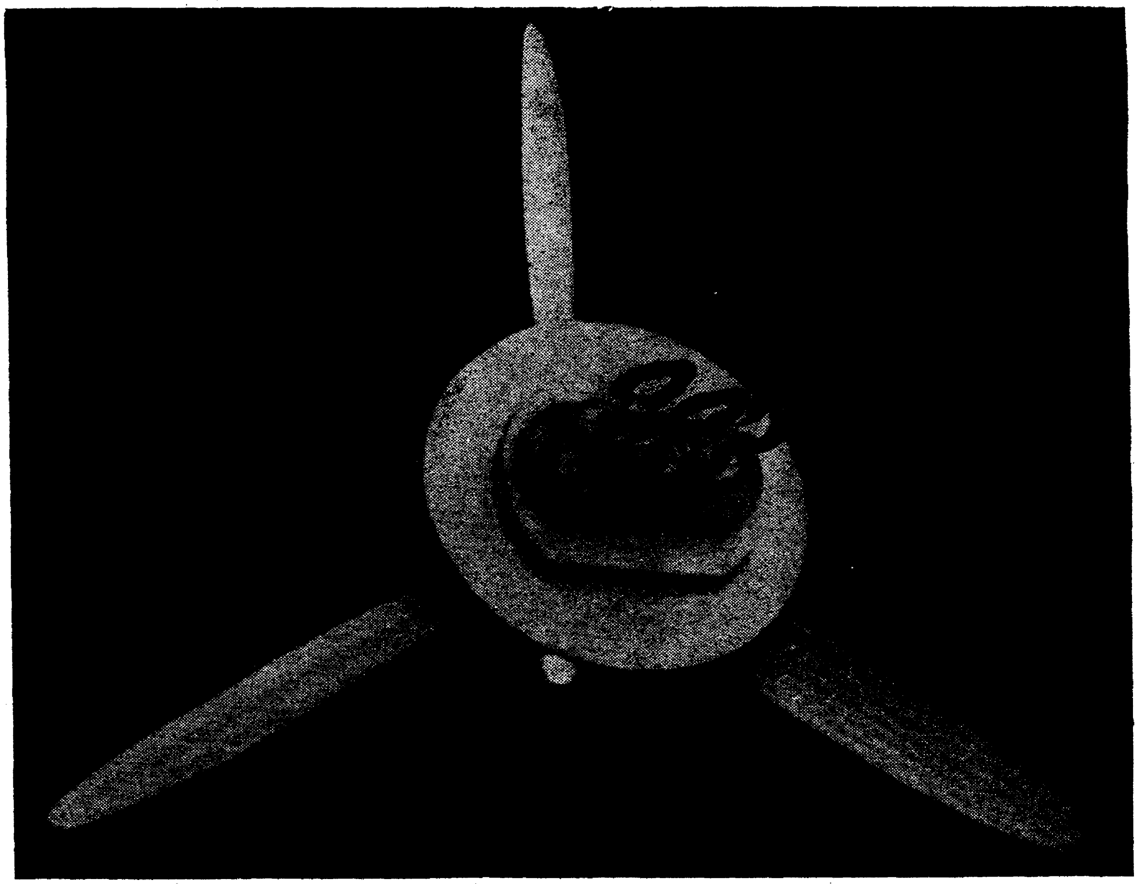
The equation of the line graph diagram 8 must be satisfied throughout flight if J (actual) is to remain at 100 per cent. J (design)—i.e., for maximum airscrew efficiency throughout.

From formula (18) it is possible to calculate the required pitch for any conditions of the variables V and *n*, and work out the actual pitch range knowing V and *n* throughout the flight. This is more accurate than the " percentage rule."

The practical side of the variable-pitch airscrew is a little more ominous. For a successful unit the whole must be foolproof, light, yet strong enough to withstand a certain amount of knocks. At the time of writing this ideal had not been reached. A number of experimental versions have appeared from time to time which, whilst praiseworthy, have never been suitable for general adoption.

The main error in such types is that the design is such that the pitch change is brought about by the varying tension of the rubber motor. This, however, is most unsatisfactory, for movement is practically confined to the extreme latter part of the power run. The only solution which would appear practicable is an arrangement worked by the *torque of the motor*. This does vary appreciably *and n is directly dependent upon it.*

The blade shanks would then be free to rotate in the hub—but *not* free to fly out under centrifugal force—and a lever and spring mechanism which under full torque (maximum turns) would turn the blades to fine pitch. The torque would be transmitted to the airscrew via a spring acting against it, so that when the torque



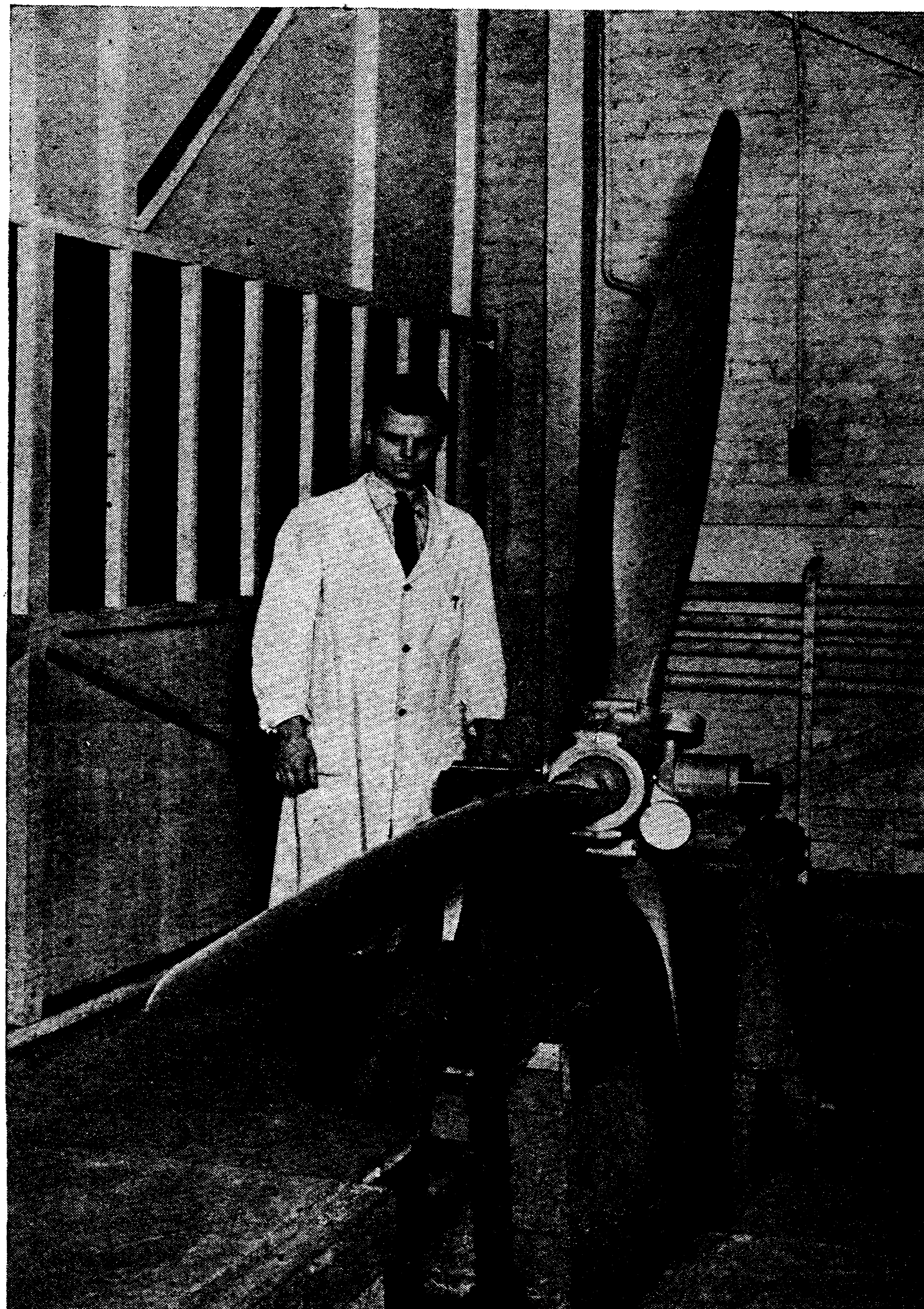
A neat gear-box and airscrew drive suitable for a flying scale model. The four skeins of elastic drive a three-bladed airscrew. Gearing tends to reduce the peak r.p.m., i.e. even out the initial burst of power from a rubber motor.

lessened the spring would slightly release, moving the blades to a coarser pitch. *Thus the pitch would be governed by the torque*—the ideal we are after—and a truly effective variable pitch airscrew would be the result.

Experimental work along these lines is being carried out at the present moment, but in the absence of concrete details the principle only is given here and the application left to the ingenuity of the reader.

A further method which relies on centrifugal force as the operating power also has possibilities but the original working unit was unable to stand up to normal flying conditions.

Thus reliability in such types would appear hard to achieve—but comparatively little serious development has taken place.



Balancing a full size three-bladed V.P. airscrew in a de Havilland factory. The weight of a postcard on one of the blades would be sufficient to cause them to rotate.

CHAPTER VII

CARVING THE AIRSCREW

The final chapter in this handbook will be devoted to airscrew carving and, although the example given is for an 18 in. diameter Wakefield type, the general principles apply to all. Diagram 18 shows the layout of the blank which should result in a reasonably high efficiency airscrew for a streamlined Wakefield, weight 8–8½ ozs. and power 18 strands 3/16 × 1/30 rubber or 14 strands ¼ × 1/30.

Firstly procure the airscrew block, which, in this case, is a block of medium-hard balsa 18 × 2⅜ × 1 21/32 in. Soft or light balsa is useless for outdoor models on account of its lack of strength. Grain direction is important also. This should be straight and quartered so that the grain is the same for each blade.

Now drill a vertical hole through the exact centre of the face, making sure that it *is* vertical, and use this as a datum point for laying out your templates. The latter are cut from thin card to the shape shown in the diagram 18.

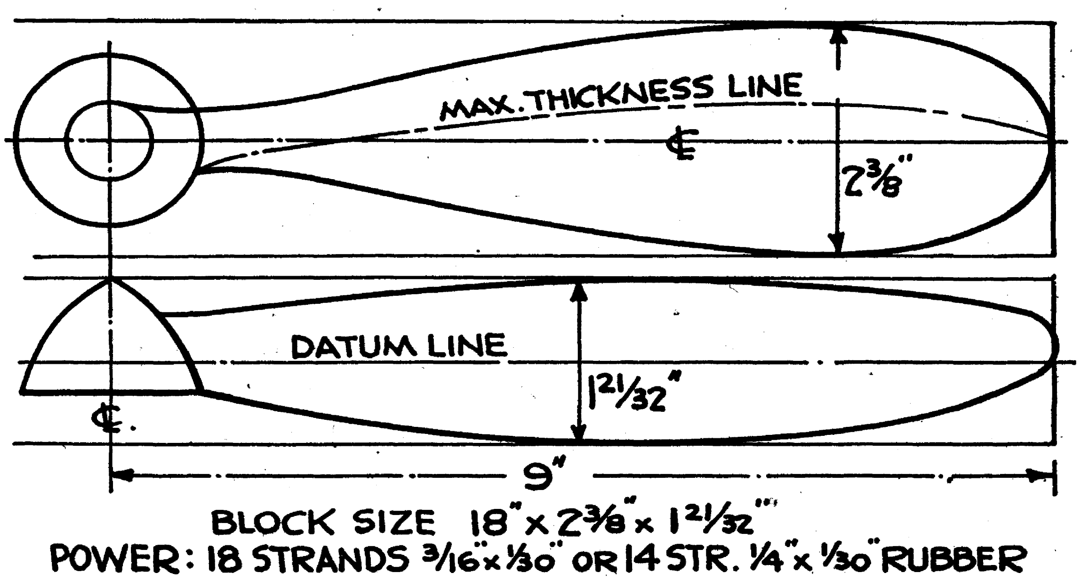


DIAGRAM 18

The best plan is to mark out the *elevation* first, laying the template on the block and marking around its edge and then cut down to this with a small saw or knife. *Take great care* in doing this to keep the blank *square* so that the elevation on each side is the same.

The airscrew should now weigh about ¾ oz. Slight variation above or below this value is permissible but preferably on the lighter side. Do not cut down the weight too much or the resulting airscrew will be very weak.

Balancing is the next thing to consider. Even for the slowly revolving airscrews used on rubber-driven models a fair accuracy is required. This becomes more important at the higher speed of rotation of petrol models where even slight unbalance may cause undue wear of the engine.

For smooth running the airscrew must be balanced both dynamically and statically. The former is taken care of in the carving. Both blades must be of identical form, same angle, etc., whilst the latter is to ensure vibrationless running and evening up of internal stresses.

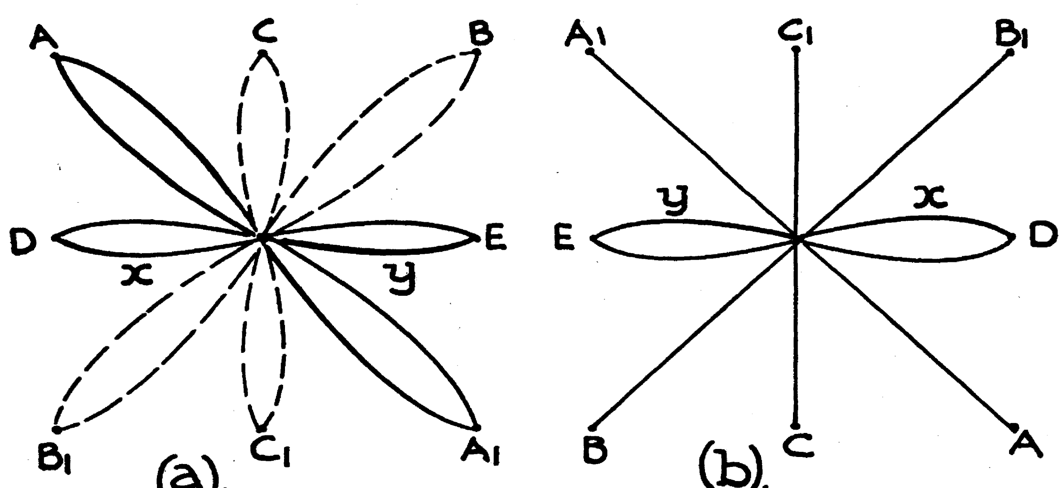


Diagram 20

The airscrew should be bushed, fittings attached (e.g., free-wheel clutch, etc.), and slipped onto a shaft allowing free rotation. With the shaft horizontal the airscrew should remain in any position it is put, see diagram 20. It is highly improbable that this will occur straight away, one blade will almost certainly be heavier than the other and rotate to the bottom.

Wood must then be sanded off the heavier blade until the airscrew will balance in positions AA_1, BB_1 and CC_1. By running the blades between finger and thumb any slight variations in thickness can be felt and also blades compared to see where excess wood is present.

Turn the blank around and repeat for the other blade, working as before. Make sure that each blade back is exactly the same before proceeding any further. Check the degree of under-camber on each by means of a straight-edge laid across leading and trailing edges and check each side at several stations.

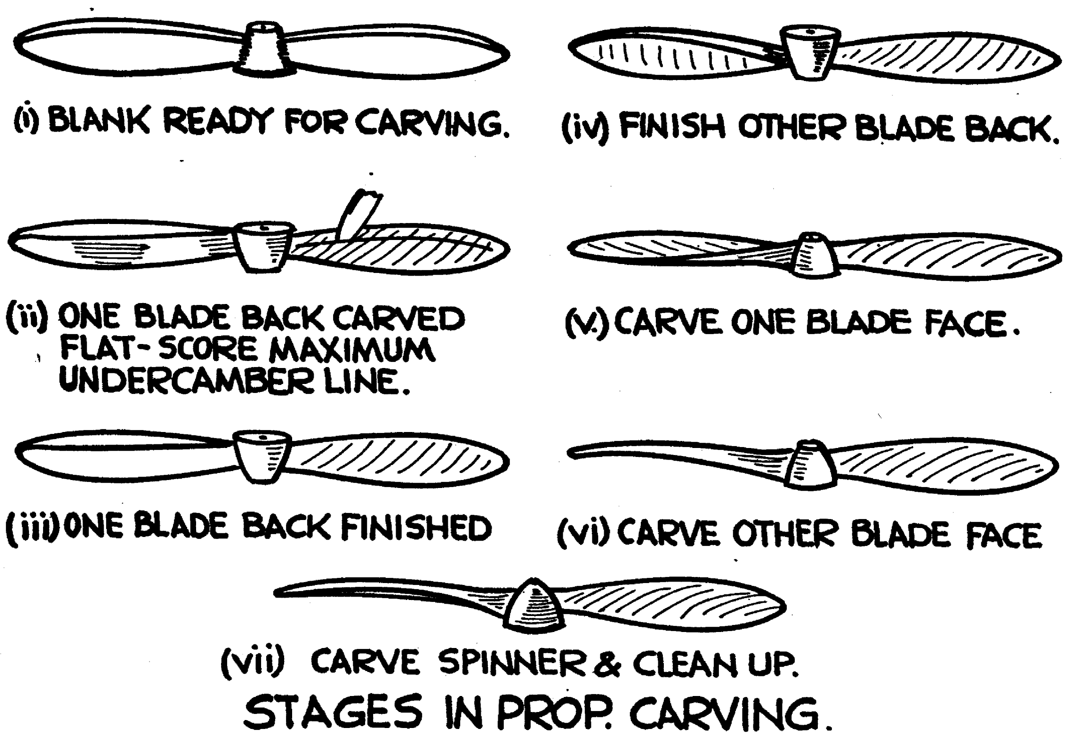


DIAGRAM 19

The face of each blade is carved, one at a time, with the same sweeping cuts of a knife, but pay attention to the maximum camber line and carve this true. Sandpaper should be used at an early stage and, although this increases the labour time, it is safer and provides a more even result. Any bumps or hollows can usually be seen or felt and must be removed. Also note that the *thickness* of the blade gradually tapers from about $\frac{1}{4}$ in. at the hub to 1/16 in. at the tip.

Having finished each blade as above clean up the hub, cutting down and sanding to a nice spinner shape (*not too pointed*), and smoothing in the blade shanks. Cut out and hollow the back of the spinner to a depth of about $\frac{1}{4}$ in. to lighten and also to hide the usual free-wheel fitting, ball thrust, race, etc.

Then, using your " plan " template, mark out the plan view carefully. It will be noticed that this has to be done on a curved surface and that if the template is kept flat certain inaccuracies may creep in. That is why the cutting of the elevation is advised first since the greater curves occur on the plan.

Let me emphasise now—*go slowly and work carefully.* The greater majority of airscrews displayed on models are relatively poorly carved and, although their efficiency may be only 10 per cent. less at the most than that of a well carved airscrew, it seems such a lack of appreciation of aeromodelling to be content with a " good enough " article.

I know airscrews get broken. We all suffer from that and this does unfortunately lead some people to think that it is a waste of time to spend too many hours on carving. By proper design and correct choice of wood a well carved airscrew is *stronger* than its poorly carved counterpart and is far more pleasing to the eye.

Follow diagram 19 through as an aid to carving—we have now got to stage (i), i.e., the blank is shaped. Now, make sure you know which is the leading and trailing edge of each blade, turn the blank on its face and start carving the back of one blade. This is best done by holding the blank against a piece of thick material on the bench, to prevent damage to the balsa by contact and pressure of harder woods, and shaving off balsa with a sharp knife.

Do not take too much off with one cut; go slowly and gradually form a flat back to the blade. (This " flat " is twisted of course due to blade angle variation from hub to tip.) Then mark the line of maximum under-camber. With the point of a knife score along this line $\frac{1}{8}$ in. deep starting from about one-third of the radius from the centre and reducing depth of cut gradually to about 1/16 in. at the tip.

The blade can then be finished to the correct under-camber by cutting away the surplus wood on either side of the cut at the same time keeping to the under-camber line of the section chosen for the blades. This final stage is best done with sandpaper, starting with " coarse " and working down to " fine " grade. The result should be a smooth, even under-camber.

Now although the total blade weights balance one another one *side* of the airscrew may be heavier than the other. In other words the airscrew may balance at DE but not at ED. In this case small, equal amounts must be sanded off x and y until finally the airscrew will remain stationary when put in any of the positions shown in the two diagrams.

Normally this is sufficient for all types. Petrol types are the most exacting and a more delicate method of balance is often advisable. Remember that the smaller the shaft you do your balancing on the more accurate the results, so never attempt to balance a power airscrew on a ¼ in. shaft. The best method is to temporarily bush the shaft hole to take an 18 s.w.g. wire and balance on this. It is not advisable to drill a small hole in the airscrew, balance from this and then drill out the correct sized hole for the shaft owing to the great danger of the final hole "creeping" and completely throwing out the balance, both static and aerodynamic.

When balanced the airscrew is finished by filling with several coats of banana oil or dope, rubbing down between each coat with fine sandpaper. 0000 or finer garnet paper is advisable and a slight polish may be given by finally rubbing with the *back* of the sandpaper. For a high gloss finish a final coat or two of gloss dope or cellulose lacquer (clear), is given, but this increases the weight.

After these operations the balance must be again checked and any variation corrected. To save spoiling a high gloss finish, if the airscrew is unbalanced an extra coat of gloss or part coat (e.g., at the tip), may be given to the lighter blade. Check balance when *dry* for dope loses in weight during the drying-out process.

PROFILE ORDINATES FOR "POWER" MODEL AIRSCREWS
10 PER CENT. R.A.F. 6

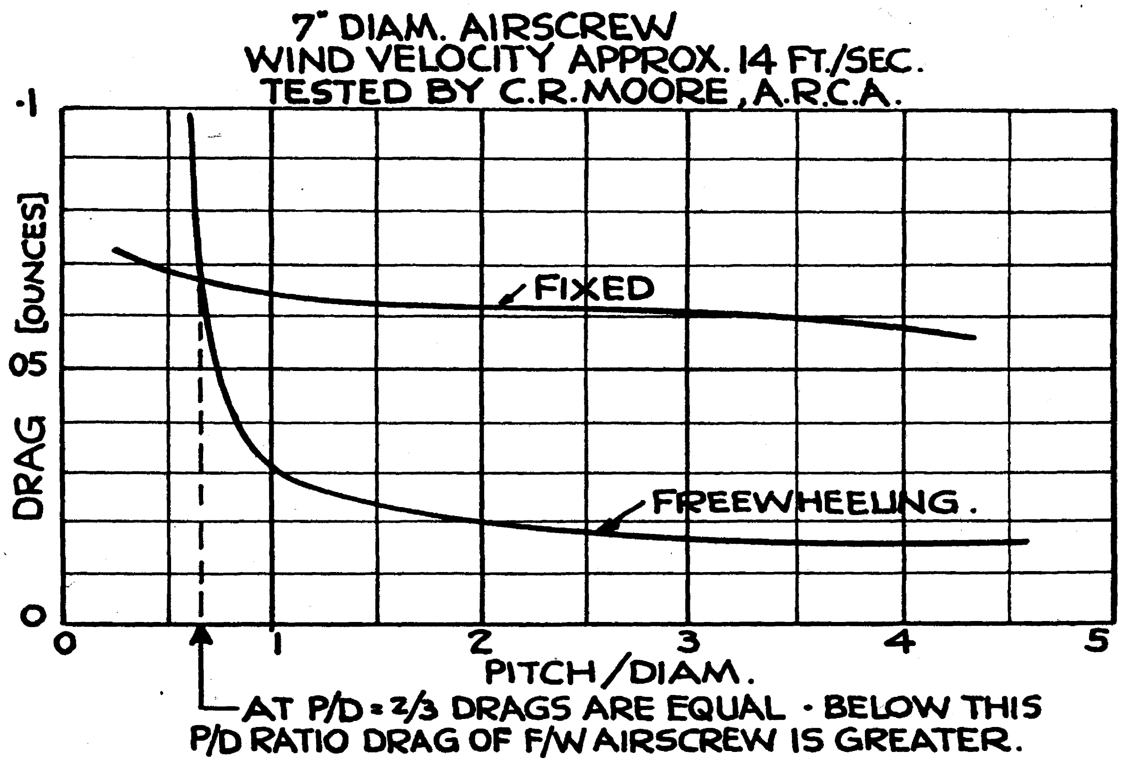
Distance from L.E.	0	5	10	20	30	40	50	60	70	80	90	100
Upper ...	0	6·1	8·1	9·9	10·3	10·2	9·9	9·0	7·7	5·9	3·8	0
Lower ...	0	0	0	0	0	0	0	0	0	0	0	0

PROFILE ORDINATES FOR RUBBER DRIVEN AIRSCREW

Distance from L.E.	0	5	10	20	30	40	50	60	70	80	90	100
Upper ...	·6	3·9	5·2	7·35	7·6	7·35	6·7	5·85	4·75	3·55	2·15	0
Lower ...	·6	0·0	·7	2·4	3·4	3·7	3·6	3·1	2·5	1·7	·85	0

APPENDIX I

AIRSCREW DRAG



A comparative graph showing the reduction in drag of a freewheeling airscrew at normal P/D ratios.

APPENDIX II

Calculation of Thrust and Torque of an Airscrew

10 in. diameter airscrew. G.M.P. = 12 ins.

(Refer to Chapter I for explanation of calculations.)

Rate of revolution, $n = 27$ r.p.s.

Forward (translational) velocity = 20 ft./sec.

Blade section R.A.F. 32.

Actual pitch = 9 ins. $\theta - \phi = 32°30' - 25°27'$

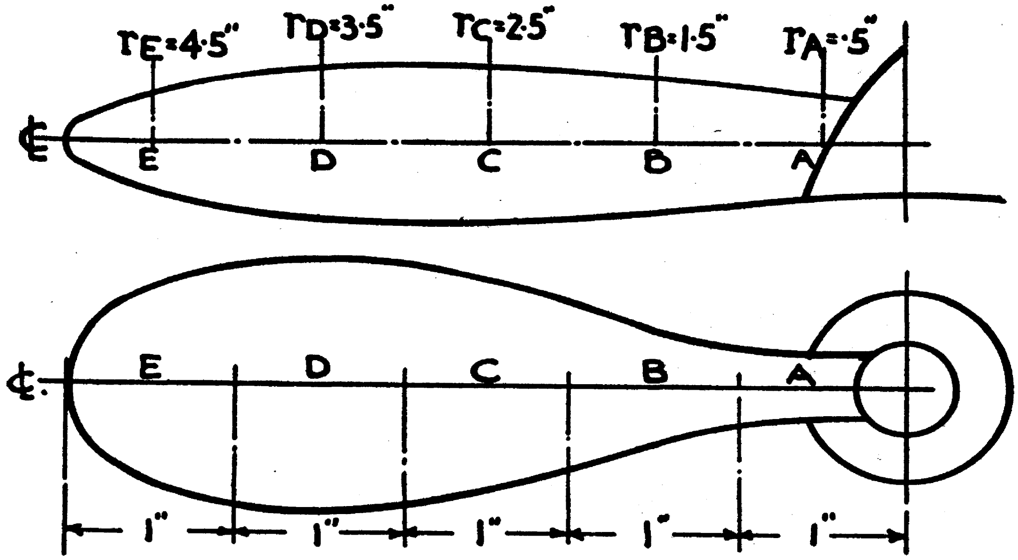
i.e. $\alpha = 7°3'$

i.e., Angle of attack of blades = 7°3″

L/D R.A.F. 32 at 7°3′ angle of attack = 1/14

$\therefore$ tan $y = 1/14$, i.e., $y = 4°5'$

LAYOUT OF TYPICAL AIRSCREW



Segment	Distance from hub (ins.)	Blade angle, θ, $= \tan^{-1} \frac{GMP}{2\eta r}$	$\phi = \theta - \alpha$	$y = \tan^{-1}$ D/L of blade at angle of attack α	Area of segment (sq. ins.)	Resultant velocity of segment $= \sqrt{V^2 + 4\pi^2 r^2 n^2}$	$dT = \frac{C_L \frac{P}{2} cdr \cos(\phi + y) V_R^2}{\cos y}$	$dQ = \frac{r C_L \frac{P}{2} cdr \sin(\phi + y) V_R}{\cos y}$
A	·5	$79^{\circ}\,20^{1}$	$68^{\circ}\,17^{1}$	$4^{\circ}\,5^{1}$	neg'd	450·3	—	—
B	1·5	$51^{\circ}\,51^{1}$	$44^{\circ}\,48^{1}$	$4^{\circ}\,5^{1}$	1·213	850·2	·00316	·005370
C	2·5	$37^{\circ}\,23^{1}$	$30^{\circ}\,20^{1}$	$4^{\circ}\,5^{1}$	1·700	165·6	·0104	·01775
D	3·5	$28^{\circ}\,37^{1}$	$21^{\circ}\,34^{1}$	$4^{\circ}\,5^{1}$	1·792	2·950	·02322	·03892
E	4·5	23°	$15^{\circ}\,57^{1}$	$4^{\circ}\,5^{1}$	1·366	446·5	·04976	·08125

Total thrust, T = sum of thrust of each segment
= $2\Sigma dT$ for whole airscrew
= ·17308 lbs.
= 2·769 ozs.

Total torque, $Q_T = 2\Sigma dQ$
= ·28658 in. lbs.
= ·02388 ft. lbs.

Power $= 2\pi n / Q_T = 4{\cdot}2$ ft. lbs.

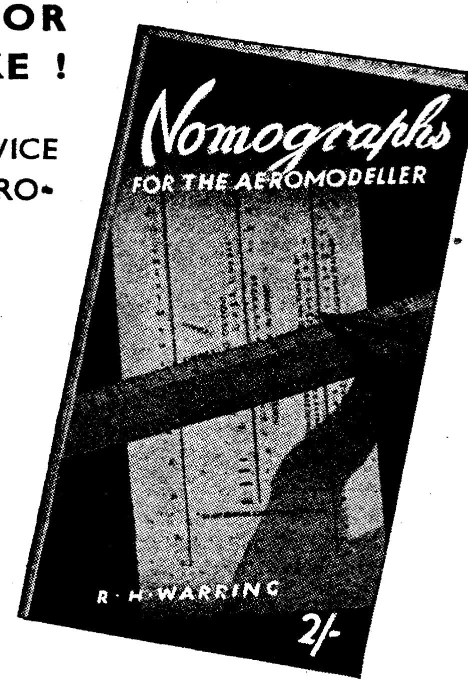
$$\therefore \text{H.P. absorbed} = \frac{4{\cdot}2}{550} = {\cdot}00763$$

NOTE.—Combined with the design procedure outlined in Chapter IV this sample calculation illustrates the *complete* design procedure for any airscrew. Thrust is balanced against drag for level flight and the H.P. required is found. The motive power is arranged to suit.

OF AERO MODELLING . . .

THE HIGH SPEED CALCULATOR THAT CANNOT MAKE A MISTAKE !

THE MOST EFFICIENT LABOUR SAVING DEVICE YET INTRODUCED TO THE MODEL AERO-PLANE DESIGNER.



Price 2/-, or 2/2 post free.

A complete set of nomographs printed on fine quality paper and bound in stiff covers

This remarkable little book combines a series of NOMOGRAPHS specially designed to cover all the principle formulae used by the model designer. These nomographs are far simpler to use than a slide rule and are just as accurate. They possess two great advantages over all other methods of calculation. **Firstly** they are foolproof and it is nearly impossible to make a mistake in using them. **Secondly** they are the most rapid method of calculation available. **Thirdly** their use entails **no skill.** It is simply a matter of lining up two points on a scale and reading the answer direct from a third scale.

This is one of the most unique features ever made available and not a single aeromodeller should be without a copy of this book. It is a handy pocket size, 9½ × 4½ ins., and is printed on good quality paper with a stiff card cover in full colours. Price 2/–, or 2/2 post free.

★ ★ ★ ★

OTHER BOOKS AVAILABLE ARE

THE DESIGN AND CONSTRUCTION OF FLYING MODEL AIRCRAFT, by D. A. Russell, M.I.Mech.E.

This book is a complete treatise on the design and construction of model aircraft, dealing particularly with models up to 12 ft. span. It should particularly appeal to the petrol model enthusiast and the serious model builder.
256 pages. 8½ × 5½ ins. Price 7/6, 8/– post free.

THE DESIGN OF WAKEFIELD MODELS, by S. B. Stubbs.

A masterly little handbook dealing with the theoretical and practical aspects of the design of the highly specialised Wakefield model.
64 pages. 8½ × 5½ ins. Price 2/–, 2/2 post free.

AIRFOIL SECTIONS, by R. H. Warring.

The standard book on the subject of wing sections. Besides giving a brief outline of wing theory and its practical application full data and a drawing of 36 different sections used by aeromodellers. A handy reference book.
64 pages. 8½ × 5½ ins. Price 2/–, 2/2 post free.

SOLID SCALE MODEL AIRCRAFT, by J. H. Elwell.

The standard instructional book for those interested in the construction of scale models for recognition purposes, display, etc. Absolutely complete and with plans and building instructions for four different models.
96 pages. 11 × 8½ ins. Price 3/6, 3/10½ post free.

SCALE PLANS OF MILITARY AIRCRAFT.

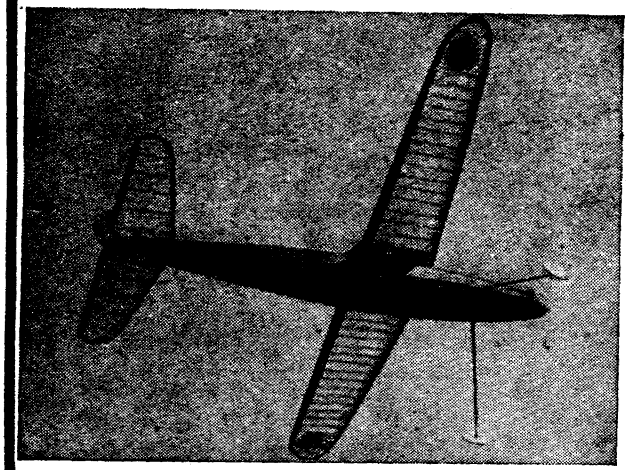
Nearly 40 scale plans of various modern military aircraft together with a photograph and full details of each type. Invaluable to the scale modeller.
96 pages. 11 × 8½ ins. Price 4/6, 4/10½ post free.

ANY OF THE ABOVE MAY BE OBTAINED FROM YOUR LOCAL BOOK SHOP OR DIRECT FROM THE PUBLISHERS

ALLEN HOUSE, NEWARKE STREET, LEICESTER

FLYING MODEL PLANS—

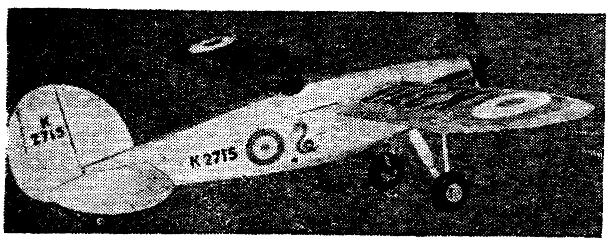
A WIDE RANGE EMBRACING ALL TYPES



DURATION MODELS

*Copland's Wakefield, 44-in. span ...	1/3
Warring's Wakefield, 45-in. span ...	3/6
Air Cadet, by C. A. Rippon	1/3
Isis, 44-in. span, by A. F. Houlberg ...	3/6
Kamlet, 31-in. span, by M. R. Knight ...	1/6
W.A.D.20, 43-in. span, by W. A. Dean...	3/–
R.A.H.37, by R. A. Hill	3/6
George, 34-in. span, by C. A. Rippon ...	2/6

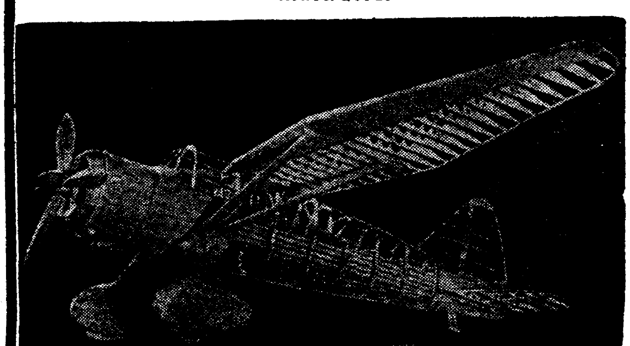
And many others.
***Illustrated.*



FLYING SCALE

Spencer-Larsen, 68-in. span, by H. J. Towner	6/–
Heinkel He 112, 18½ in. span	1/3
Miles M.9, 39-in. span, by H. J. Towner	3/6
Airspeed Envoy, 52-in. span, by H. J. Towner	3/6
Mew Gull, 16-in. span, by C. B. Chadwick	1/3
*Lysander, 50-in. span, by Howard Boys	5/–
Albacore, 50-in. span, by H. J. Towner	7/6
Lysander (petrol model), 60-in. span, by Cpl. Welsberg	7/6
Moth Minor, 35-in. span, by G. E. Day	2/–

And many others.
** Illustrated.*

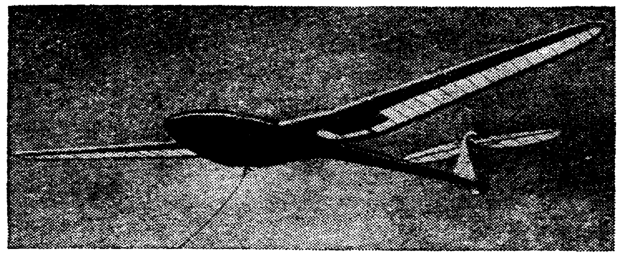


ALL THE PRODUCTS OF THE FINEST MODEL BUILDERS IN THE COUNTRY AND ALL FULLY FLIGHT TESTED

GLIDERS

Aegeus, 42-in. span, by R. H. Warring ...	2/6
Stothers Glider, 60-in. span	1/3
A.P.6, 72-in. span, by Dr. Ing. Piatelli ...	5/–
*Aeolus, 48-in. span, by R. H. Warring...	3/–
XPS-841, 84-in. span, by L. G. Temple	6/–
Kirby Kite, 72-in. span, by Ing Piatelli ...	3/6
Leander, 48-in. span, by R. H. Warring	3/6
King Falcon, 76-in. span, by R. E. Bower	5/6
Curlew, 46-in. span, by K. W. S. Turner	3/–

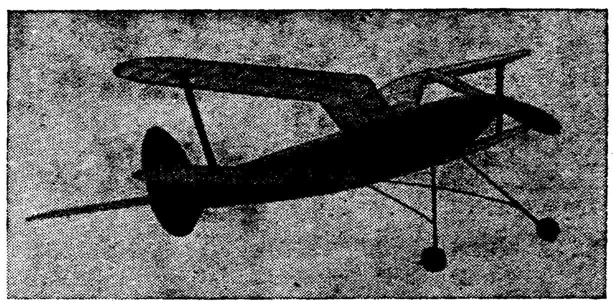
And many others.
**Illustrated.*



SEMI-SCALE

A.M. Cabin Monoplane, 23-in. span ...	1/6
*Viper II, 48-in. span, by C. R. Moore ...	6/–
Jackdaw II, 35-in. span, by C. R. Moore	2/–
Cabin Biplane, 20-in. span	1/6
Pterodactyl, 60-in. span, by S. E. Capps	2/–
G-ADAR (petrol model), 96-in. span, by D. A. Russell...	10/6

**Illustrated.*



BIPLANES

*Minerva, 36-in. span, by J. E. Fraser ...	2/6
Beginner's Biplane, 25½-in. span ...	1/6
Biplane Sports, 29-in. span, by D. D. Edwards	2/6

** Illustrated.*

★ ★ ★ ★

AND A HOST OF OTHERS, including Petrol Models, Indoor Models, Stick Models, etc., etc.

Send 2½d. stamp for fully illustrated catalogue.

Plans show each and every part full size.

OBTAINABLE FROM YOUR LOCAL MODEL SHOP OR DIRECT FROM:—

AEROMODELLER PLANS SERVICE LIMITED.

1/72 SCALE DRAWINGS

Bristol Beaufighter

ACCURATE, FULLY DETAILED PLANS OF NEARLY 200 MODERN AIRCRAFT

6d. each plan
1/3 for 3 plans
2/6 for 6 plans
3/6 for 12 plans

Douglas Boston

These detailed drawings are the result of months of painstaking research and are absolutely accurate and up-to-date in every feature. Never before has such a comprehensive range of plans been prepared, covering as they do all the better known modern aircraft as used by the nations of the world in this present war. Ideal for the scale model builder, for recognition purposes or the student of aircraft design.

SEND 2½d. TO-DAY FOR COMPLETE LIST

PHOTOGRAPHS } THE SAME RANGE AS ABOVE { **3d.** each / **1/6** dozen } *post free*

AEROPLANES OF THE LAST WAR

Complementary to the range above similar plans are available of last war 'planes. Fully detailed and absolutely accurate. Complete list on request.

Price { **6d.** each / **3/–** per dozen } *post free.*

Fokker Triplane

A REVOLUTIONARY FEATURE!

Price **6d.** each post free.

SETS OF TAPERED WING SECTIONS ESPECIALLY FOR THE MODEL BUILDER.

ACTUAL SIZE OF SHEETS IS 30 × 10 ins. EACH SHEET CONTAINS 31 SECTIONS. THE LARGEST IS 9 in. CHORD, THE SMALLEST IS 3 in. CHORD. SECTIONS STEP UP IN SIZE BY 1/5 in.

Complementary to AIRFOIL SECTIONS are sheets of each of the 36 airfoils dealt with in the book. Each sheet gives 31 accurate profiles, ranging from 9 in. chord to 3 in. chord by 1/5 in. steps. The sections are printed in black on thin white paper, as per reproductions at side, and may be pasted direct on to balsa sheet, or thin ply for cutting out as templates. Wings of any degree of taper may thus be built with ease. In addition, each sheet has a graph which gives the chief characteristics of the section from zero lift to the stalling angle.

SEND 2½d. STAMP FOR FULL LIST

Take advantage of our Special Offer. The complete set of 36 sheets for 15/– post free.

Obtainable from your local model shop or direct from :—

ALLEN HOUSE, NEWARKE STREET, LEICESTER

ROYAL AIR FORCE PERSONNEL . . .
AIR TRAINING CORPS CADETS
AIRCRAFT SPOTTERS . . .
SCALE MODELLERS . . .
AND ALL INTERESTED IN MODERN AIRCRAFT SHOULD GET

AIRCRAFT OF THE FIGHTING POWERS

Size :
11 x 8½ ins.

★ ★ ★

Nearly 300 pages

★ ★ ★

Printed on art paper, cloth bound in stiff boards, thread sewn and gilt blocked

★ ★ ★ ★

Dust cover in full colours

★ ★ ★ ★

PRICE
13/6
POST FREE

Volume I contains full particulars of prototype, development and military use of 87 British, French, American, German, Italian, Dutch, Belgian and Polish aircraft used in 1940. Each is depicted by a large photograph which is accompanied by full particulars of engine(s), dimensions, specifications and identification markings. In addition there are 87 three-view 1/72 scale plans, ideal for recognition tests and for the use of solid scale model builders.

★ ★ ★ ★

Volume II contains particulars of prototype, development and military use of 88 British, American, German, Italian, Canadian, Australian, Grecian, Jugoslav, Iraqi and Russian aircraft used in 1941. Full particulars, photographs and a scale plan of each machine is given as for Volume I above.

★ ★ ★ ★

Just as Volume I is representative of 87 aircraft flown in 1940, so is Volume II representative of 88 aircraft flown in 1941. Volume III is now in active preparation, and will, of course, be representative of aircraft used by the Fighting Powers in 1942.

"As a reference book on a subject of paramount interest to-day to everyone in and out of the Services, and as an identification guide to those responsible for civil defence, this volume will be invaluable."
—FLIGHT.

"To both the 'Spotter' and air-conscious layman this book may be recommended as an authoritative and valuable work of reference. In particular, it is remarkable for that accuracy of detail which is all too absent in publications purporting to deal with aviation subjects."
—WAR ILLUSTRATED.

"It is beautifully produced on art paper, and obviously an immense amount of painstaking research has gone into its preparation. The result is the best book of its sort which has yet appeared."
—THE AEROPLANE.

★ ★ ★ ★

There is no question of late volumes being "more up-to-date" than earlier ones. Each is representative of the aircraft flown in a particular year, and the complete set of volumes will be necessary to form a complete record of all the aircraft used by the Fighting Powers in this present war.

HARBOROUGH PUBLISHING CO., LTD., ALLEN HOUSE, NEWARKE ST., LEICESTER