Aircraft Engineering

The Monthly Scientific and Technical
Organ of the
Aeronautical Engineering Profession

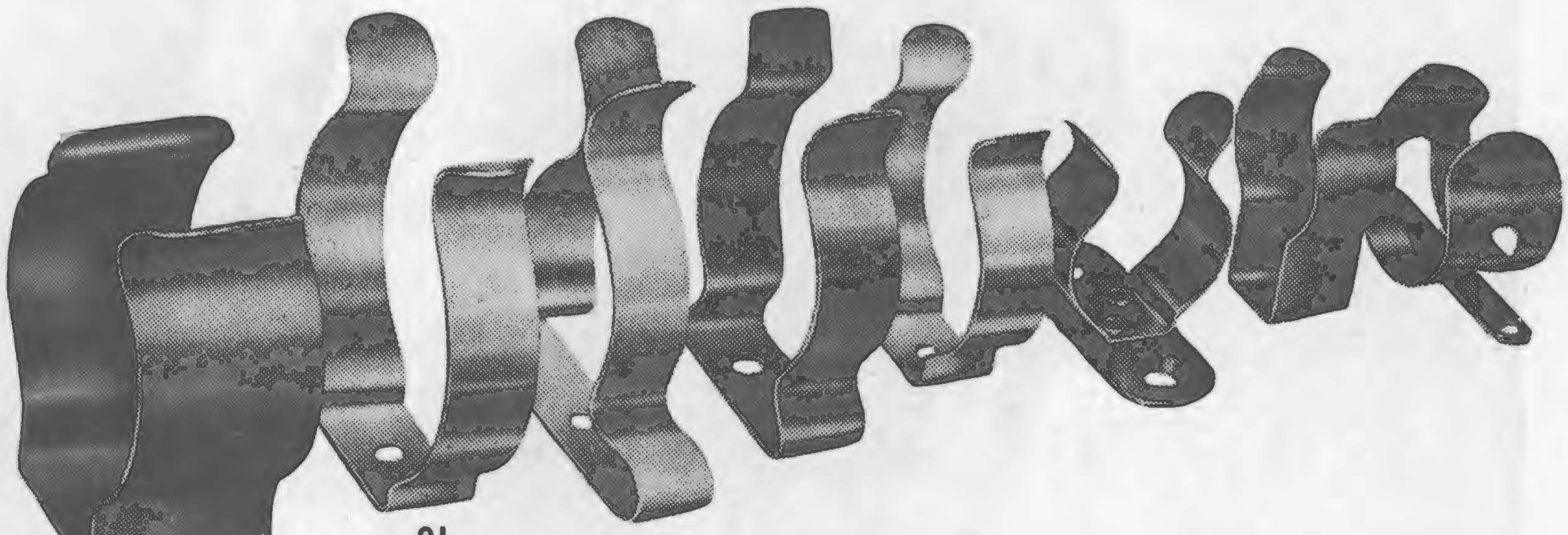
Vol. XVII

1945

A E

Published by the Proprietors, Bunhill Publications Ltd., at
12 Bloomsbury Square, London, W.C.1

CLIPS by TERRY SPRINGS



81 80

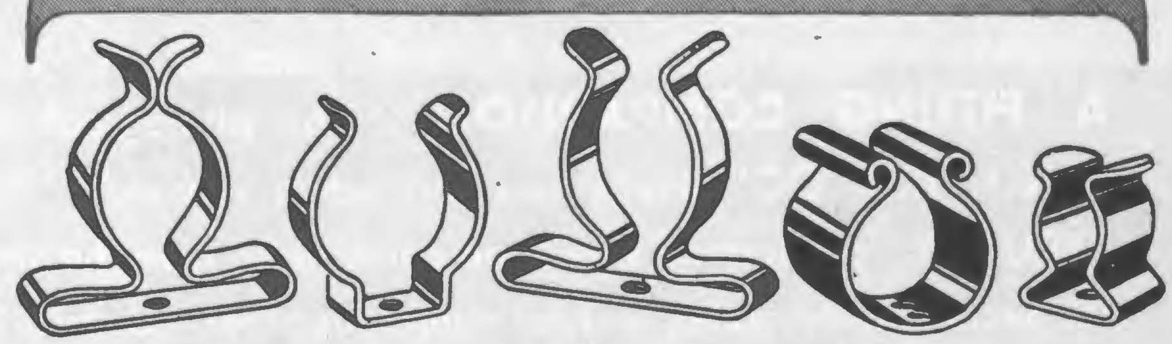
STEEL clips, bronze clips, stainless clips, big clips, little clips, wide clips, in fact clips in every conceivable shape and size.

Illustrated here—among others—are two of our stock patterns (80 and 81) made in a range of sizes to grip from $\frac{1}{4}$" to $1\frac{1}{2}$".

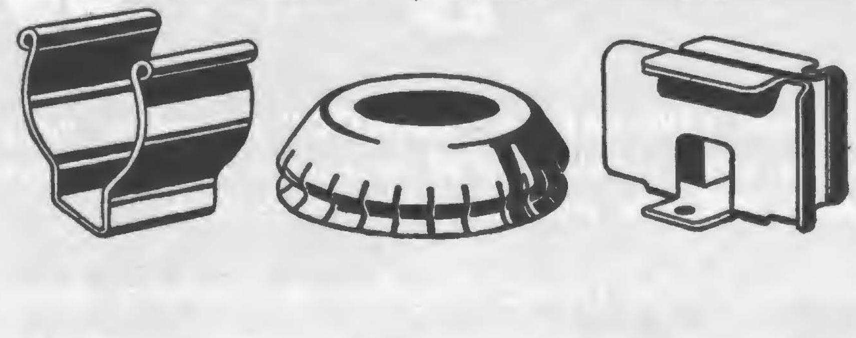
Maybe a clip of special shape would be necessary for the job you have in mind. Well, we can help you because we make clips for hundreds of uses. We can make to print or specification, or our Research Department will design for you.

Our knowledge of clips has advanced side by side with our 88 years' spring-making experience, and we should like to send you our wartime catalogue.

JUST A FEW STOCK PATTERNS



— AND A FEW MADE TO ORDER



Write to-day for comprehensive wartime catalogue showing a remarkable variety of clips and small metal goods.

Sole Makers:

HERBERT TERRY & SONS L^TD. REDDITCH

LONDON BIRMINGHAM MANCHESTER T.C.1.

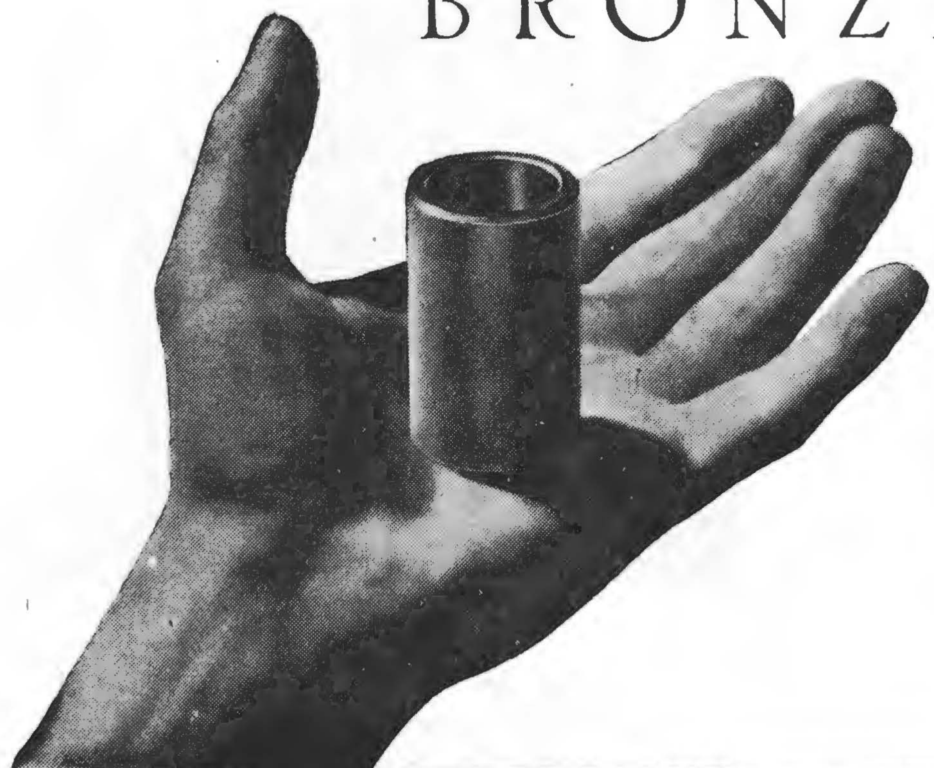
A FITTING COMPARISON This photograph (actual size) shows the smallest and largest "TRU-LOC" fittings now 'on active service.' "TRU-LOC" compression fittings and "TRU-LAY" pre-formed wire rope combine to give the strongest, lightest and cheapest cables for aircraft, automobiles, and for numerous other industrial and commercial applications.
B * W * P
The Trade Marks "TRU-LAY" & "TRU-LOC" are used for the purpose of indicating that the goods in respect of which they are used are goods complying in all respects with the specifications and directions of the AMERICAN CHAIN & CABLE COMPANY, INC., the proprietors of the Trade Marks.
All enquiries in the United Kingdom & Northern Ireland to:
BRITISH WIRE PRODUCTS LIMITED, WORCESTER ROAD, STOURPORT-ON-SEVERN


They Shall Stand
VULCANISED FIBRE L^TD
Broadford Mills.
GUILDFORD . . . . . . ENGLAND
S·B·A·C
THE SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS


THE DIESEL ENGINEER
who took us into his confidence
Hiduminium Applications Ltd., combines the technical experience of great organisations in the Light Alloys industry. The specialised knowledge which it commands is fully available to designers and constructors now engaged in planning their post-war products and equipment. Timely collaboration with Hiduminium Applications Ltd., will ensure that the outstanding advantages of HIDUMINIUM Aluminium Alloys are fully utilised. Further information sent on request.
HIDUMINIUM APPLICATIONS LTD.
ALUMINIUM ALLOYS · FARNHAM ROAD · SLOUGH · BUCKS.
HIGH DUTY ALLOYS LTD · REYNOLDS TUBE Co LTD · REYNOLDS ROLLING MILLS LTD.

OILITE

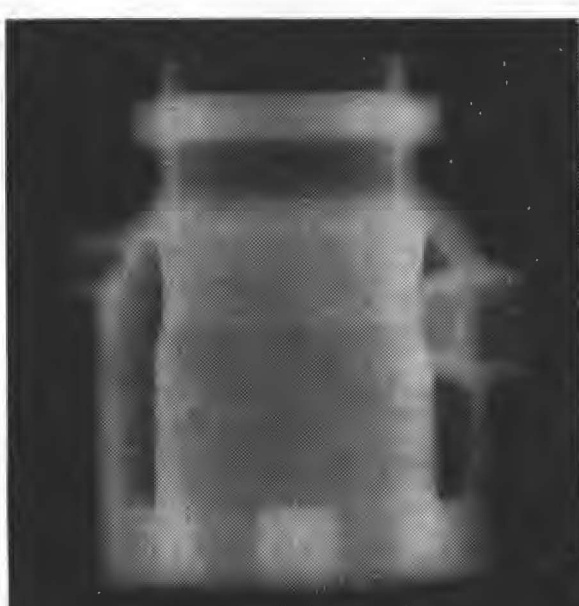
SELF-LUBRICATING BRONZE BEARINGS



"Oilite" reduces bearing failures to a minimum wherever it is applied to suitable components. The lubricant content is ample to cope with variations in speed and load over a considerable range, and will do this continuously during the life of the component, whilst, where necessary, additional lubrication can be readily embodied in the design without difficulty. The accuracy of finished dimensions and limits is equal to that of the highest grade machined bearings, thus making for ease of assembly and fitting.

THE MANGANESE BRONZE & BRASS CO. LTD
HANDFORD WORKS, IPSWICH TELEPHONE·IPSWICH 2127 TELEGRAMS "BRONZE IPSWICH"

ILFORD Lead Screens for Industrial Radiography



Without Screens

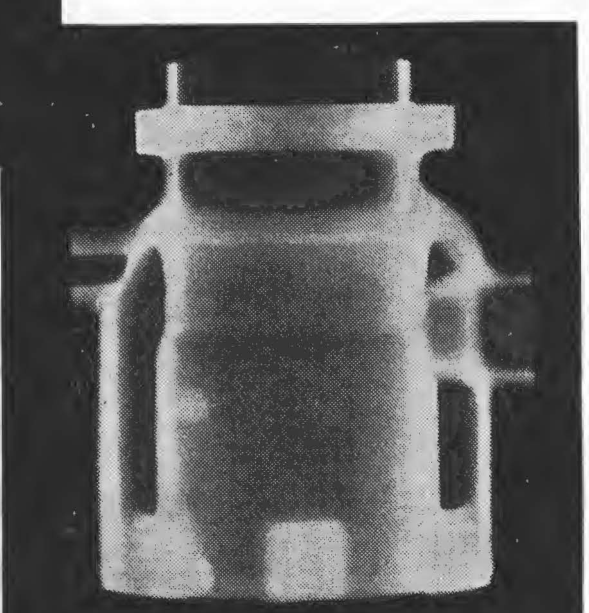
200 *kVp* 10 *mA* 5 *min.* 36 *in.*

Every discerning industrial radiographer is aware of the beneficial action of lead foil placed in contact with each side of the film in overcoming the harmful effects of scattered radiation.

Ilford Limited have made a thorough investigation into the problem of finding the most suitable lead alloy and of determining the optimum thickness of the foil. As a result they are now able to supply at economical prices lead screens consisting of front and back thicknesses of foil made of a lead alloy specially selected for its durability and radiographic efficiency. Ilford Lead Screens afford the following advantages :—

1. **Maximum reduction of scattered radiation reaching the film giving the greatest possible improvement in contrast.**
2. **Reduction of exposure times up to 50%.**
3. **Complete freedom from grain.**
4. **Definition indistinguishable from that obtained with non-screen exposures.**
5. **Maximum flexibility and pliability.**
6. **Maximum hardness of surface compatible with a useful intensifying action.**

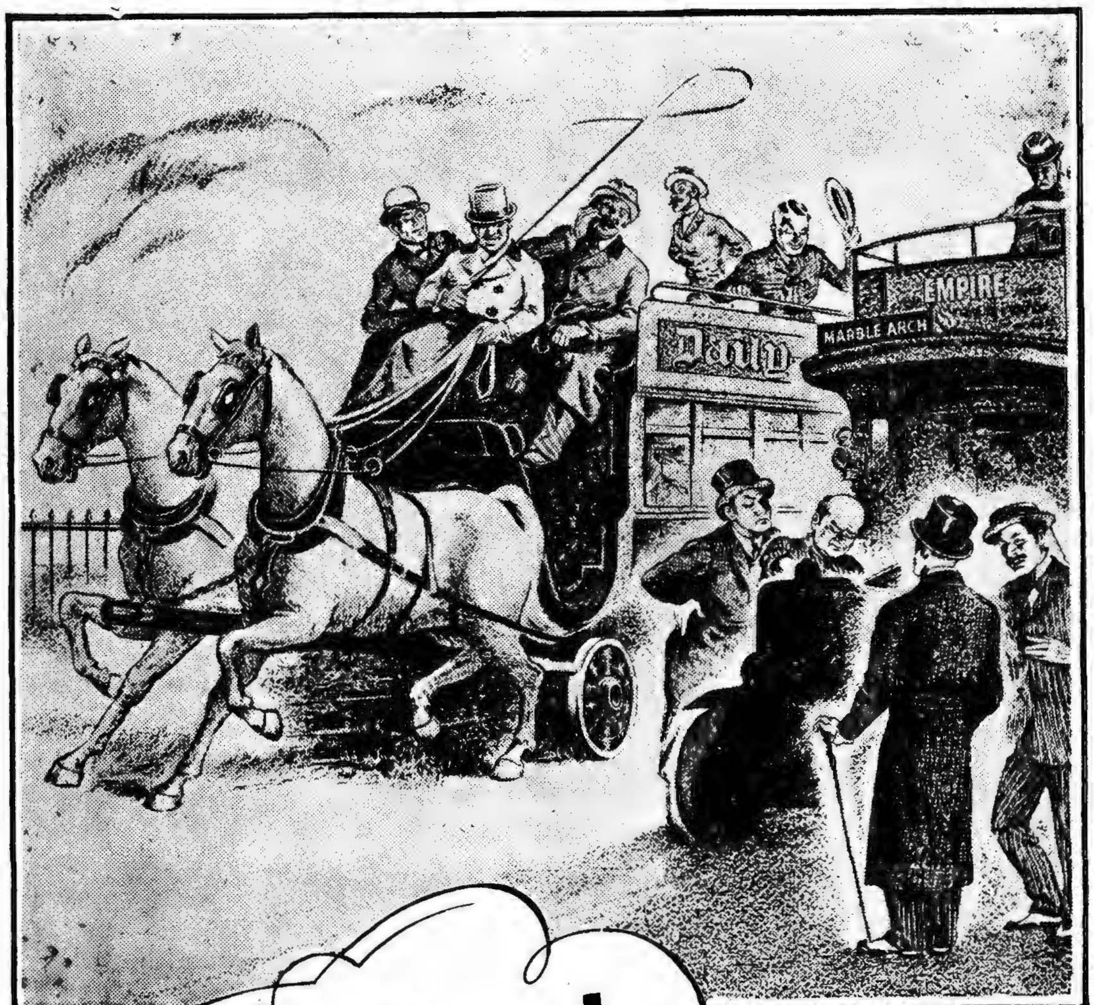
ILFORD LEAD SCREENS IMPROVE RADIOGRAPHIC QUALITY



With Ilford Lead Screens

200 *kVp* 10 *mA* 3 *min.* 36 *in.*

ILFORD LIMITED ILFORD · LONDON



Try a carrot!

There was a time — and some of us can recall it — when a motor-bus ride from Marble Arch to Golders Green was an adventure. You climbed immense hills or maybe you didn't; and the horse-drawn bus rattled gaily by, issuing catcalls and suggestions about putting on another lump of coal. But now the fun has gone out of motor-bus travelling. Dull certainty replaces the old thrill of hope and doubt and even a little fear. So it will be with air-travel. Running to schedule. Absence of "incident". Sure machines and sure pilots. And behind them sure ground service on which both men and machines must depend.

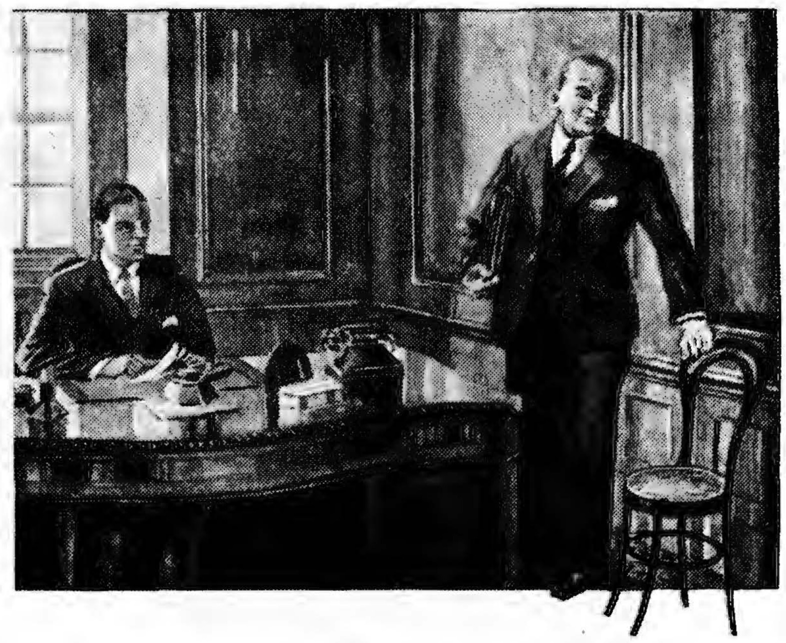
FIELD AIRCRAFT SERVICE

A Company of the Hunting Group

FIELD CONSOLIDATED AIRCRAFT SERVICES LIMITED
LONDON OFFICE: BYRON HOUSE, ST. JAMES'S STREET, S.W.1

C.R.C.4

The "Ha'p'orth of tar"...



What is that, Sir? You don't care to be offered a cheap "shop-counter" chair when you call on a man to offer him business? But, Sir, where is the difference? After all, a chair is a chair. It will bear your weight; you may sit on it with comparative safety. . . . We beg your pardon, Sir? You think it lowers the tone of the whole business? Not very complimentary to you as a customer? Looks confoundedly slip-shod in a decent office? In fact spoils the ship for a . . . . ?

Yes, yes, Sir. Of course. We see your point. As a manufacturer you would naturally be particular about that "finishing touch". You would for example specify precision holding components by Newton. You would know that security, speedy assembly—and often safety—depends upon Newton accuracy and dependability.

Precisely, Sir, the ha'p'orth of tar. . . .

NEWTON

HOLDING COMPONENTS

Bolts, Nuts, Screws, Precision Components.

L. H. NEWTON & Co. LTD.
NECHELLS, BIRMINGHAM 7
Telephone: EAST 1551 (16 lines)

London, Coventry, Manchester, Bristol, Dublin, South Africa, New Zealand, India

PRECISION SPEEDS PRODUCTION!

Vol. XVII No. 191
JANUARY - 1945

Published about the 18th of the month

Aircraft Engineering

FOUNDED 1929

Editor: Lieut.-Col. W. Lockwood Marsh, O.B.E., F.R.Ae.S., M.S.A.E., F.I.Ae.S.

EDITORIAL ADDRESS & ADVERTISEMENT OFFICE

12 Bloomsbury Square,
London, W.C.1

Telephone:
HOLborn 4842-3

Telegrams: Ikaros,
Westcent, London

PRINCIPAL CONTENTS

WORKSHOP AND PRODUCTION SECTION

Ordinary Subscription: Great Britain and all countries in the Postal Union 26/- post free. (Details of special rates will be found in the Classified Advertisement columns in this issue.) Single copies 2/3 post free.

Changes in Advertising Copy must be received 3 weeks prior to the date of publication. Orders for discontinuance of advertising must be received by the 1st of the month prior to the title month of the issue.


Have you any problems in Sheet Metal work?
Your difficulties will fly if you install
'BESCO'
SHEET METAL WORKING MACHINERY
It is expressly designed for modern needs, and simplifies the most intricate operations
SEND FOR OUR ILLUSTRATED LIST
All types NEW & USED
Telephone EUSTON 4681 (12 Lines)
'BESCO' ECCENTRIC PUNCHING PRESS with Adjustable Stroke
POWER PRESSES
GUILLOTINES
FOLDING AND BENDING MACHINES
SWAGING MACHINES
WHEELING AND RAISING MACHINES
NIBBLING MACHINES
PUNCHING AND SHEARING MACHINES
CIRCLE CUTTERS
NOTCHING MACHINES
Etc. Etc.
F·J·EDWARDS LTD
359-361, EUSTON ROAD LONDON, N.W.1.
MACHINE TOOLS
(NEW & SECONDHAND)
Please state your requirements.
All machines offered subject to M.T.C. regulations. (M.T.C. Licence No. 172.)


For awkward corners
Maximum adaptability combined with positive operation and light weight, are provided by Renold precision roller chains, which, with standard S.B.A.C. end connectors, cable spools and biplanar blocks, enable awkward angles and clearances to be dealt with in control systems.
END CONNECTORS
BIPLANAR BLOCKS
CABLE SPOOLS
RENOLD
CHAINS FOR AIRCRAFT
THE RENOLD AND COVENTRY CHAIN CO. LTD
MANCHESTER ENGLAND

The Failure of Struts

A Theoretical Examination Covering Various Materials and Sections

By A. N. Kinkead

IN present day structural design we are very often faced with the problem of a strut of some particular constant cross section with partially fixed or free pin-jointed end conditions and in which the line of action of the applied load does not coincide with the neutral axis of the strut. Indeed, it is unlikely that such coincidence is ever achieved, both on account of production errors and initial crookedness.

In the analytical determination of the crippling load in such cases several approximate formulae may be used to give safe results: e.g. Modified Rankine Gordon method, formula due to Professor Johnson, formula due to Professor Morley and formula due to Professor Andrews.

To the writer's knowledge, however, the most common formula in everyday use for pin-jointed end conditions is the Modified Euler Theory for Eccentric Loading which is generally set out in the form:

$$P=\frac{fA}{1+\frac{ey}{K^2}\sec.\sqrt{\frac{P}{EI}}\cdot\frac{L}{2}}$$

for materials other than Cast Iron, where

f = maximum allowable compressive stress for material — lb/sq. in.

E = value of Young's Modulus for material — ,,

I = moment of Inertia of section in plane of eccentric loading — inch units

K = radius of gyration of section in plane of eccentric loading — in.

A = area of section — sq. in.

y = half depth of section in plane of eccentric loading — in.

L = length of strut between end attachments — in.

P = crippling load — lb.

e = eccentricity — in.

This formula is difficult to use as it is necessary first of all to assume a value of P, insert this under the root sign and obtain a more correct value by making a series of successive approximations.

The need in design work to-day for a formula which will give the crippling load directly for such cases has led to the evolution by the writer of a formula, the proof of which is given in the following paragraph:

In some of the approximate formulae which have been evolved the variation of bending moment due to flexure has been neglected, the "apparent" bending moment being taken as constant and equal to Pe throughout.

Taking into account the incremental deflection in the plane of the applied bending moment, it can be seen from a consideration of the Howard Diagram for this case that the "apparent" bending moment diagram should be increased by the addition of a superimposed curve of parabolic shape.

Considering the shaded area of the true bending moment diagram (Fig. 1) and using the deflection formula:

$$Z=\frac{ax}{EI}$$

In this case

$$Z=\frac{PeL}{2EI}\cdot\frac{L}{4}+\frac{2}{3}\cdot Pz\cdot\frac{L}{2}\cdot\frac{5}{8}\cdot\frac{L}{2EI}$$

Transposing

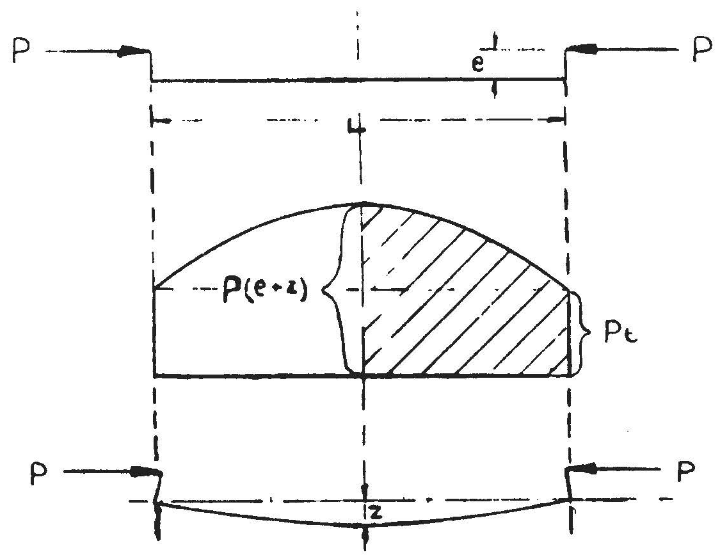


FIG 1. *True bending moment diagram*

$$Z\left(1-\frac{5}{12}\cdot\frac{P}{EI}\left(\frac{L}{2}\right)^2\right)=\frac{PeL^2}{8EI}$$

$$Z=\frac{Pe}{8EA}\left(\frac{L}{K}\right)^2\Big/1-\frac{5}{48}\,\frac{P}{EA}\left(\frac{L}{K}\right)^2$$

Let $\frac{P}{A}=f_{cr}$ = crippling stress.

$$Z=f_{cr}\frac{e}{8E}\left(\frac{L}{K}\right)^2\Big/1-f_{cr}\,\frac{5}{48E}\left(\frac{L}{K}\right)^2$$

and if $\frac{f_{cr}}{E}=X$ and $\left(\frac{L}{K}\right)^2=Y$

$$Z=\frac{6eXY}{48-5XY}$$

Now the total bending moment on strut at centre

$$=P(e+Z)$$

$$=P\left(e+\frac{6eXY}{48-5XY}\right)$$

Hence total tension stress at centre of strut

$$f=\frac{y}{K^2A}\left[Pe\left(1+\frac{6XY}{48-5XY}\right)\right]-\frac{P}{A}\quad\ldots\ldots\ldots\ldots(1)$$

which would give the criterion for failure in the case of cast iron.

Total Compressive Stress at centre of strut,

$$f=\frac{y}{K^2A}\left[Pe\left(1+\frac{6XY}{48-5XY}\right)\right]+\frac{P}{A}\quad\ldots\ldots\ldots\ldots(2)$$

$$=\frac{ey}{K^2}\left[1+\frac{6XY}{48-5XY}\right]f_{cr}+f_{cr}$$

$$=\frac{ey}{K^2}\cdot f_{cr}+\frac{ey}{K^2}\cdot f_{cr}\cdot\frac{6\,\frac{f_{cr}}{E}\left(\frac{L}{K}\right)^2}{48-5\,\frac{f_{cr}}{E}\left(\frac{L}{K}\right)^2}+f_{cr}$$

For some particular strut $\frac{ey}{K^2}$ = constant $=C$

$$f=f_{cr}(C+1)+f^2{}_{cr}\cdot 6C\left(\frac{L}{K}\right)^2\Big/48E-5f_{cr}\left(\frac{L}{K}\right)^2\ldots(3)$$

Expanding by use of the Binomial Theorem as follows:

$$f=f_{cr}(C+1)+f^2{}_{cr}\cdot\frac{6C}{5}\left[\frac{48E}{5\left(\frac{L}{K}\right)^2}-f_{cr}\right]^{-1}$$

$$f=f_{cr}(C+1)+f^2{}_{cr}\cdot\frac{6C}{5}\left[a^{-1}-a^{-2}f_{cr}+a^{-3}f^2{}_{cr}-\ldots\ldots\ldots\right]$$

where $a=\frac{48E}{5\left(\frac{L}{K}\right)^2}$

$$f=f_{cr}(C+1)+f^2{}_{cr}\cdot\frac{6C}{5}\left[\frac{5\left(\frac{L}{K}\right)^2}{48E}-\frac{25\left(\frac{L}{K}\right)^4}{48^2E^2}f_{cr}+\frac{125\left(\frac{L}{K}\right)^6}{48^3E^3}f^2{}_{cr}-\ldots\ldots\ldots\right]$$

$$f=f_{cr}(C+1)+f^2{}_{cr}\frac{C}{8E}\left(\frac{L}{K}\right)^2-f^3{}_{cr}\frac{30C}{48^2E^2}\left(\frac{L}{K}\right)^4+\ldots\ldots\ldots\ldots(4)$$

If we neglect the term with $f^3{}_{cr}$ and those following, and use the equation as a quadratic for f_{cr} we can obtain direct crippling stresses. A curve has been plotted using this formula with a value of $\frac{ey}{K^2}=\cdot 4$ and is shown dotted on Graph B.

From an examination of this curve as compared with the curve plotted for the same $\frac{ey}{K^2}$ value, but using the Modified Euler formula, it can be seen that safe results are obtained up to a certain slenderness ratio, beyond which the formula is too optimistic and would prove dangerous to use.

$$f=f_{cr}(C+1)+f^2{}_{cr}\frac{C}{8E}\left(\frac{L}{K}\right)^2\quad\ldots\ldots\ldots\ldots(4a)$$

This formula may be obtained much more simply by considering the bending moment on the strut as uniform and equal to Pe. We therefore see the importance of the effect of incremental deflection.

Referring back to equation 3, multiplying across by $48E-5f_{cr}\left(\frac{L}{K}\right)^2$

$$f\left(48E-5f_{cr}\left(\frac{L}{K}\right)^2\right)=f_{cr}(C+1)\left[48E-5f_{cr}\left(\frac{L}{K}\right)^2\right]+f^2{}_{cr}\cdot 6C\left(\frac{L}{K}\right)^2$$

$$48Ef=f_{cr}\left[48E(C+1)+5f\left(\frac{L}{K}\right)^2\right]-f^2{}_{cr}\left(\frac{L}{K}\right)^2(5-C)$$

We have thus arrived at a quadratic equation for crippling stress f_{cr} which will give direct results.

$$f^2{}_{cr}\left(\frac{L}{K}\right)^2(5-C)-f_{cr}\left[48E(C+1)+5f\left(\frac{L}{K}\right)^2\right]+48Ef=0\quad\ldots\ldots\ldots\ldots(5)$$

$$f_{cr}=\frac{\left[48E(C+1)+5f\left(\frac{L}{K}\right)^2\right]\pm\sqrt{\left[48E(C+1)+5f\left(\frac{L}{K}\right)^2\right]^2-4\left(\frac{L}{K}\right)^2 48Ef(5-C)}}{2\left(\frac{L}{K}\right)^2(5-C)}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

At first sight it would seem that this formula is too awkward and unwieldy ever to be of any practical use, but the writer has found that this is not the case. To show how it compares with the Modified Euler formula a series of points

TABLE I

$\frac{L}{K}$	$5f\left(\frac{L}{K}\right)^2$	b $48E(C+1)+5f\left(\frac{L}{K}\right)^2$	b^2	$4ac$	b^2-4ac	$\sqrt{b-4ac}$	$b-\sqrt{b^2-4ac}$	$2a$	f_{cr}
20	$1\cdot925\times10^8$	$16\cdot975\times10^8$	$288\cdot5\times10^{16}$	$103\cdot2\times10^{16}$	$185\cdot3\times10^{16}$	$13\cdot6\times10^8$	$3\cdot375\times10^8$	$3\cdot92\times10^3$	86100
30	4·335 ,,	19·385 ,,	375·5 ,	232 ,,	143·5 ,,	11·97 ,,	7·415 ,,	8·81 ,,	84300
40	7·7 ,,	22·75 ,,	518 ,,	413 ,,	105 ,,	10·23 ,,	12·52 ,,	15·68 ,,	80000
50	12·03 ,,	27·08 ,,	730 ,,	645 ,,	85 ,,	9·22 ,,	17·86 ,,	24·5 ,,	72900
60	17·33 ,,	32·38 ,,	1050 ,,	930 ,,	120 ,,	10·94 ,,	21·44 ,,	35·26 ,,	60900
70	23·59 ,,	38·64 ,,	1495 ,,	1264 ,,	231 ,,	15·2 ,,	23·44 ,,	48·0 ,,	48900
80	30·8 ,,	45·85 ,,	2100 ,,	1651 ,,	449 ,,	21·18 ,,	24·67 ,,	62·65 ,,	39400
100	49·1 ,,	64·15 ,,	4120 ,,	2580 ,,	1540 ,,	39·2 ,,	24·95 ,,	98 ,,	25400
120	69·2 ,,	84·25 ,,	7100 ,,	3717 ,,	3383 ,,	58·15 ,,	26·1 ,,	141 ,,	18630

$\frac{ey}{K^2}=0\cdot1$ $E=28\cdot5\times10^6$lb/sq. in. $f=43$ tons/□in.

$48E(C+1)=15\cdot05\times10^8$

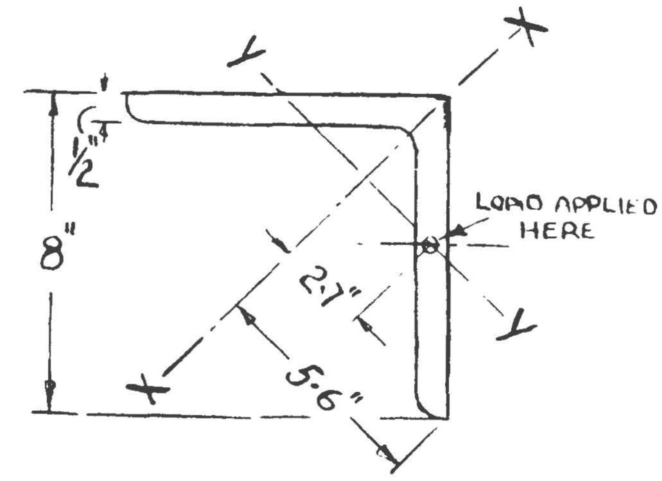


FIG. 2.—*Equal angle section used as strut*

have been worked out in Table I for a value of $\frac{ey}{K^2}=0\cdot1$ the values of f and E being as in Graph A. The slight discrepancy which arises may be attributed to slide rule inaccuracies, it being thus assumed by the writer that the new formula gives exactly the same results as the Modified Euler.

The main object of this treatise is not, however, as it may seem to have indicated so far, to impose on the already full to overflowing designer's notebook, still another somewhat cumbersome formula.

The graphs which accompany this article have all been drawn according to the Modified Euler Theory, not that it was any simpler to use or more accurate, but simply to instil a little more confidence into the reader, who may not like to switch over completely to such an unestablished method.

It is therefore the practical use of these graphs, demonstrated in the following examples, which is to be emphasised. The reasons for their production are listed below:

1. The Modified Euler formula, as was pointed out, before is very awkward to use.

2. In dealing with a strut which is eccentrically loaded in the plane containing its greatest moment of inertia (as is generally the case), or a strut eccentrically loaded in a plane which does not contain its least moment of inertia, it is apparent that when a sufficiently high value of $\frac{L}{K}$ is reached the strut will fail in the plane containing the least moment of inertia, due to only negligible eccentricity in that plane.

The method of attack which, to the writer's knowledge, is at present adopted in this case, is to calculate P from the Modified Euler formula, using the successive approximation method and the value of eccentricity which prevails, and, secondly, to check the crippling load if the strut were to fail in the plane containing the least moment of inertia. The smallest of these two loads is then the design compression strength of the strut under the conditions of loading.

The saving in time and paper which is afforded by the use of the graphs for a case such as this is shown clearly in the first three worked examples and herein lies the chief reason for their production.

3. The graphs have been drawn for four materials only but these embrace the entire range in structural engineering, with the exception of cast iron. The third and fourth worked examples show how the graphs may be factored up and down to give results for any other material provided that the maximum allowable compressive stress and value of Young's Modulus is known. The truth of this factoring method is apparent from a consideration of the method by which the graphs were produced and therefore needs no proof.

4. Certain specifications may call for a particular permissible eccentricity such as the Air Ministry allowable eccentricity and crookedness for tubes, where $e=\frac{2}{3}\left(\frac{d}{40}+\frac{l}{600}\right)$ l being the length and d the outside diameter. In this case, as the values of $\frac{L}{K}$ increase, values of $\frac{ey}{K^2}$ decrease. Hence by using the graphs it would be simple to plot a curve to comply with such conditions.

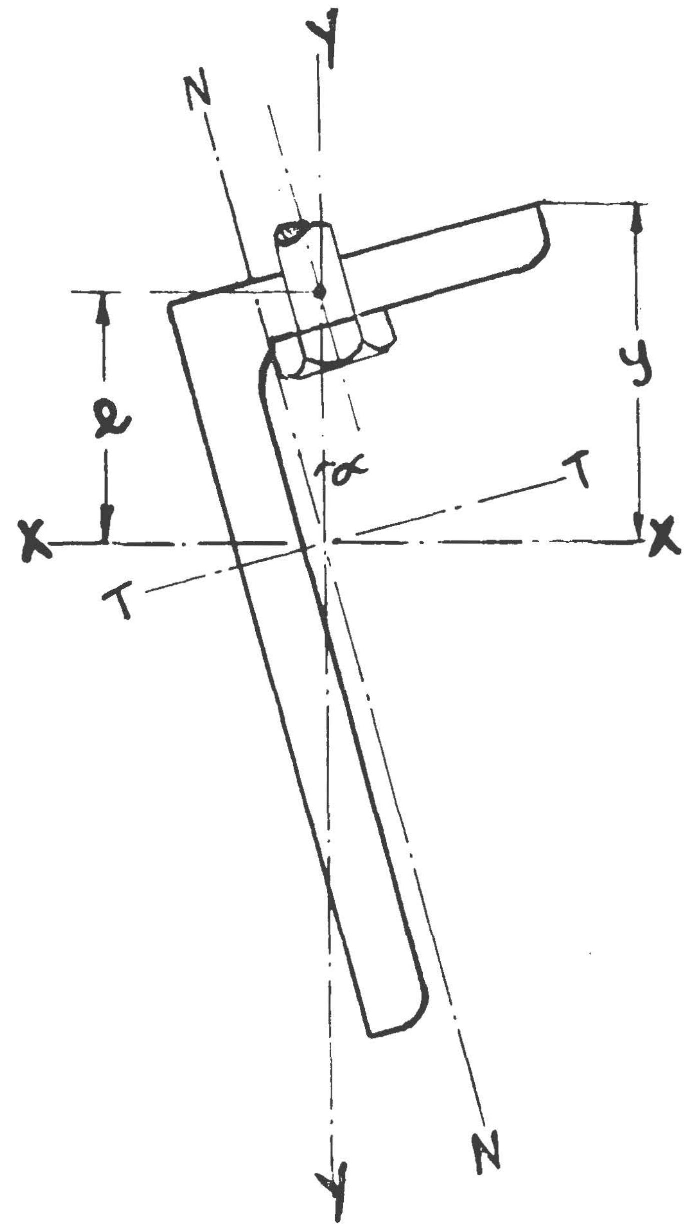


FIG. 3.—*Unequal angle section used as strut*

Incidentally, the dotted $\frac{K}{K_{min}}$ curve on graph B conforms to the above condition but is, of course, blown down to represent the crippling curve for a value of $\frac{K}{K_{min}}=2$ in the plane of the least moment of inertia. The dotted curves on graphs A, C and D are merely the blown down curves of $\frac{ey}{K^2}=0\cdot1$ for each particular graph.

5. If the strut ends could be considered as wholly fixed, then eccentricity would not be transmitted to the strut. However this condition very seldom occurs in practice and in the cases of partial fixation the length of the strut is reduced in the usual manner, and the graphs can be used in the same way as before.

For instance, if the strut were fixed completely at one end and free at the other it is only necessary to halve the values of $\frac{L}{K}$ on the scales of the graphs and then carry on as usual.

If the end moments due to eccentricity are unequal but in opposite directions, the maximum bending moment cannot be any greater than if they were both equal and equivalent to the maximum moment of the two.

If the end moments are unequal and in the same direction the strut should be designed for the $\frac{ey}{K^2}$ value due to the maximum moment.

Example I. To choose a simple case we shall consider a strut of British Standard equal angle section loaded by means of bolts at each end, which we will assume to constitute pin jointed end conditions. These bolts are positioned about the centre of one of the arms as shown in Fig. 2, the point of application of the load thus being in the plane containing the greatest moment of inertia.

$A=7\cdot75$ sq. in.

$L=163$ in.

K min. $=1\cdot58$

K max $=0\cdot408\times8=3\cdot26$

$\frac{K\text{ max}}{K\text{ min}}=2\cdot07$

$\frac{L}{K\text{ max}}=\frac{163}{3\cdot26}=50.$

$e=2\cdot7$ in.

$y=5\cdot6$ in.

Using Graph B $\frac{ey}{K^2}=1\cdot42$

$f_{cr}=23500$ lb/□"

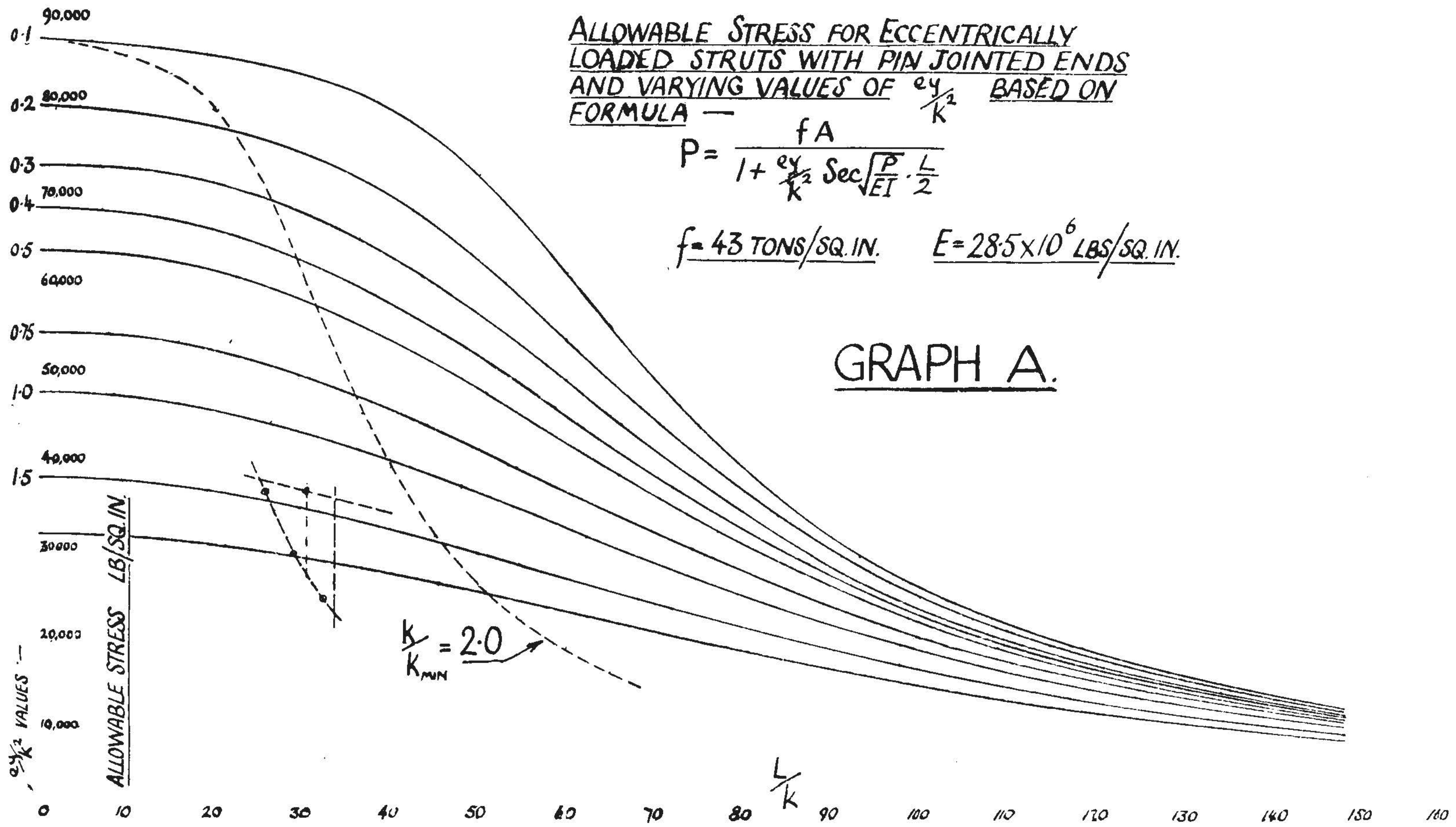
Crippling Load $=7\cdot75\times23{,}500=182{,}000$lb.

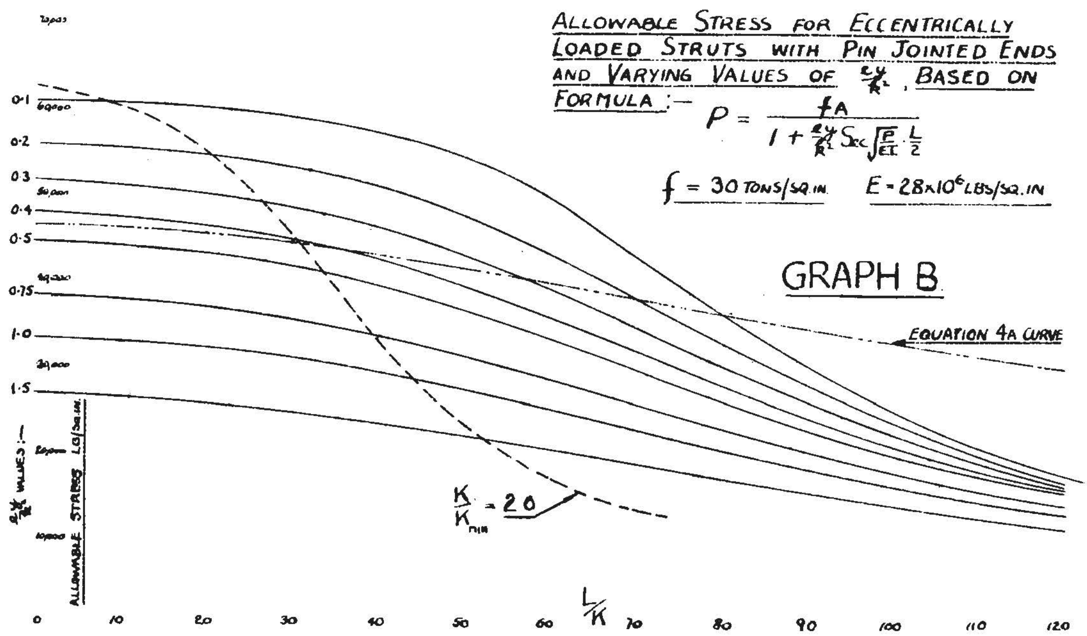
If this load is now inserted in the Modified Euler formula it will be found to give a fairly accurate result.

Referring to Graph B it may be noted that this point would be the critical point for this strut at which the failure might occur in either the plane containing the greatest or least moment of inertia, provided that the allowable eccentricity and crookedness curve for this particular section corresponded to that which is drawn at this point. If this were the case the design crippling stresses would have to be taken from this dotted curve for higher values of $\frac{L}{K}$.

It is not convenient to draw in blown down curves for every possible $\frac{K\text{ max}}{K\text{ min}}$ ratio and so another example is necessary to show the application more clearly.

Example II. A 6 in. × 3 in. × ½ in. British Standard unequal angle bar (Fig. 3) is used as a strut, being loaded by bolts in the shorter leg of the section in such a position that they are in the plane containing the greatest moment of inertia. If the strut is 60 in. between bolt centres, find the crippling strength. Material is high-grade structural steel with a maximum allowable stress in compression of 43 tons/sq. in. and $E=28\cdot5\times10^6$lb./□".





$A = 4{\cdot}25$ sq. in.

In this case with the usual notation.

$$e = \frac{J - \frac{t}{2}}{\cos\alpha} = \frac{2{\cdot}17 - {\cdot}25}{\cos 14{\cdot}50} = 1{\cdot}983''$$

$$Y = J\cos\alpha + 1\sin\alpha$$
$$= 2{\cdot}17\cos\alpha + 2{\cdot}32\sin\alpha$$
$$= 2{\cdot}68''$$

The greatest moment of inertia is given by formula:

$$I_{xx} = \tfrac{1}{2}\left[(I_T + I_N) + (I_T - I_N)\sec 2\alpha\right]$$

$$I_{max} = \tfrac{1}{2}\left[18{\cdot}13 + \frac{12{\cdot}89}{\cos 29^\circ}\right] = 16{\cdot}43$$

$$K_{max} = \sqrt{\frac{16{\cdot}43}{4{\cdot}25}} = \sqrt{3{\cdot}87} = 1{\cdot}967$$

$K_{min} = {\cdot}63$ $K/K_{min} = 3{\cdot}12$

$$\frac{ey}{K^2_{max}} = \frac{1{\cdot}983 \times 2{\cdot}68}{3{\cdot}87} = 1{\cdot}362$$

$$L/K = \frac{60}{1{\cdot}967} = 30{\cdot}5$$

Using Graph A $f_{cr} = 37{,}000$ lb/sq. in.

Let us suppose in this example that owing to initial crookedness and fitting errors a value of $\frac{ey}{K^2_{min}} = 0{\cdot}2$ is to be allowed.

In order to determine whether the strut will fail in the plane containing the least moment of inertia at a lower value of f_{cr} we proceed as follows:

At $f_{cr} = 37{,}000$ lb/$\square''$ curve for $\frac{ey}{K^2} = 0{\cdot}2$ gives $\frac{L}{K} = 80{\cdot}5$

$\therefore$ True blown down $\frac{L}{K}$ value for $K/_{K_{min}} = 3{\cdot}12$ value:

$= \frac{80{\cdot}5}{3{\cdot}12} = 25{\cdot}8$ giving a point on this curve.

As this point lies to the left of the original point plotted for $\frac{ey}{K^2_{max}} = 1{\cdot}362$ we see immediately that failure will in this case occur in K_{min} plane and by plotting a couple more points we shall obtain the intersection of the corrected $\frac{ey}{K^2} = 0{\cdot}2$ curve with $\frac{L}{K} = 30{\cdot}5$ ordinate giving actual f_{cr}

At $f_{cr} = 30{,}000$ lb/$\square''$, curve for $\frac{ey}{K^2} = 2$ gives $\frac{L}{K} = 91{\cdot}3$

$\therefore$ corrected $L/_{K} = \frac{91{\cdot}3}{3{\cdot}12} = 29{\cdot}25$

At $f_{cr} = 25{,}000$ lb./$\square''$, curve for $\frac{ey}{K^2} = 2$ gives $\frac{L}{K} = 101{\cdot}3$

$\therefore$ corrected $L/_{K} = \frac{101{\cdot}3}{3{\cdot}12} = 32{\cdot}43$

By drawing the curve between these three points we can see that the struts will have an actual crippling stress $f_{cr} = 27{,}800$ lb/$\square''$

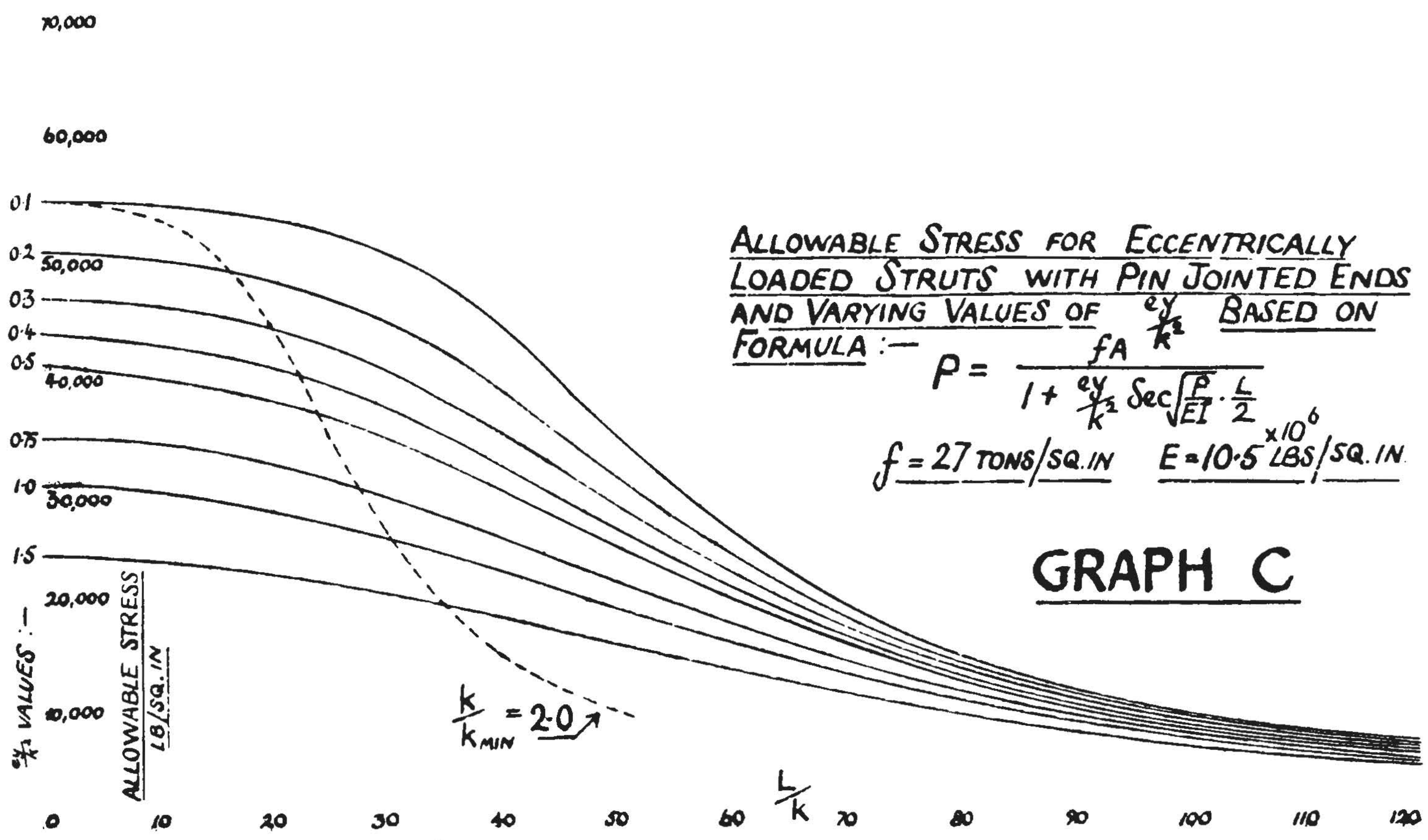
We could, of course, have obtained $\frac{L}{K_{min}} = \frac{60}{0{\cdot}63} = 95{\cdot}35$ and read the crippling stress $f_{cr} = 27{,}800$ lb/$\square''$ directly but the plotting method shows more clearly the position of the strut in relation to the two modes of failure.

Crippling load $= 27{,}800 \times 4{\cdot}25 = 118{,}000$ lb.

The critical $\frac{L}{K_{max}}$ value for this strut is $25{\cdot}2$ obtained from point of intersection of the two $\frac{ey}{K^2}$ curves and therefore

Critical length $= 25{\cdot}2 \times 1{\cdot}967 = 49{\cdot}5''$

If it is ever required to know immediately in which plane the strut may fail an analysis of



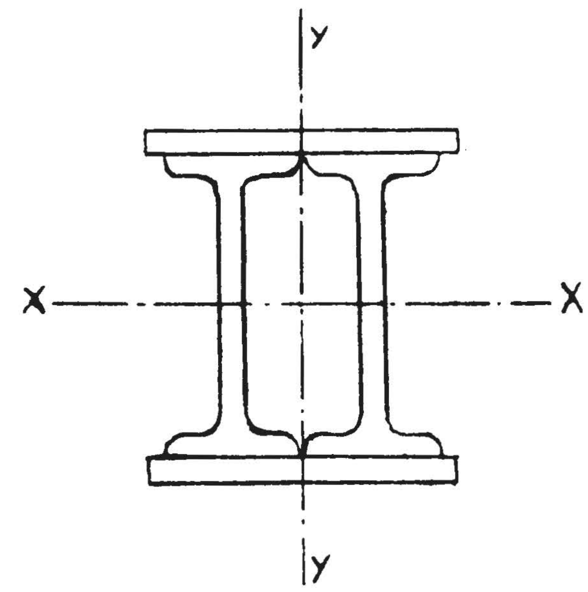


FIG. 4.—*Steel stanchion*

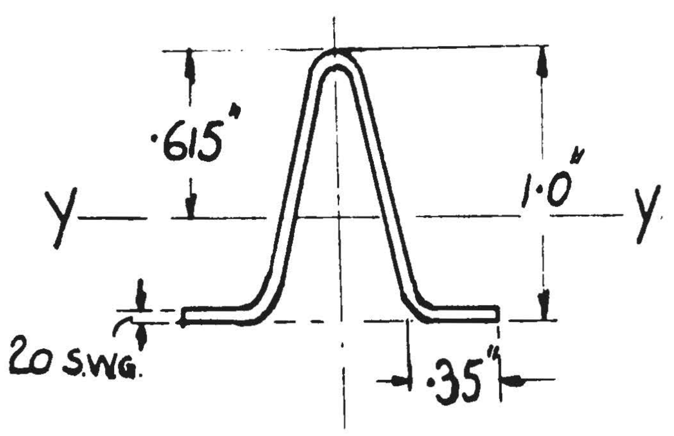
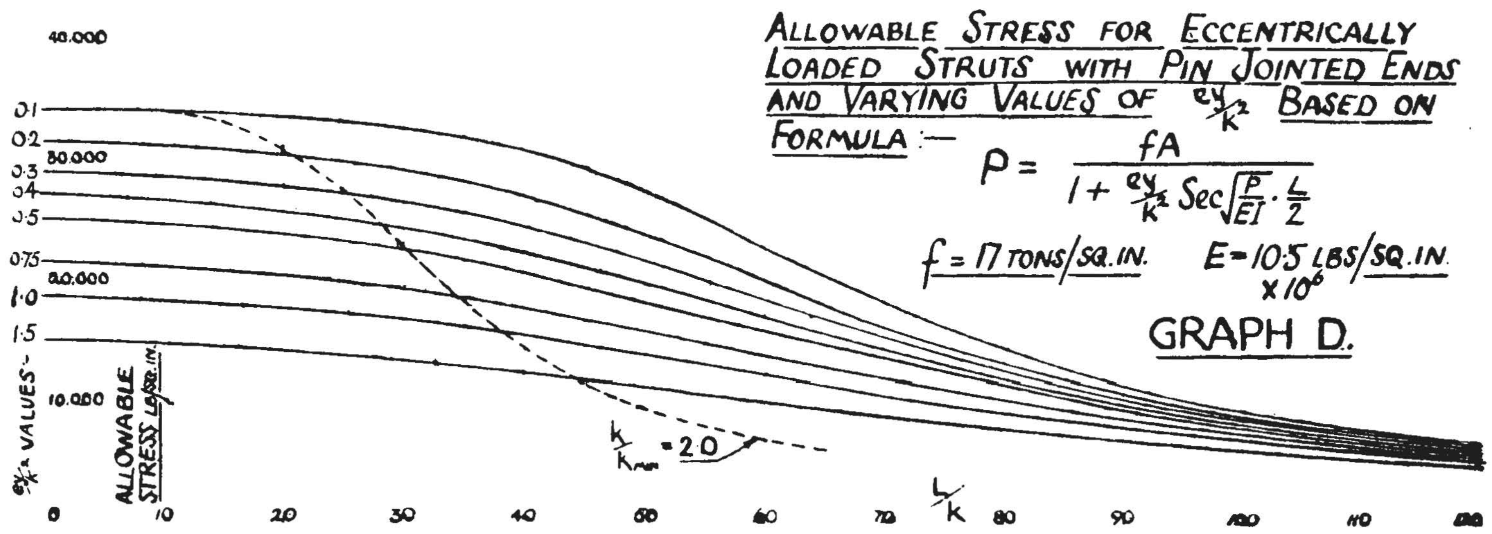
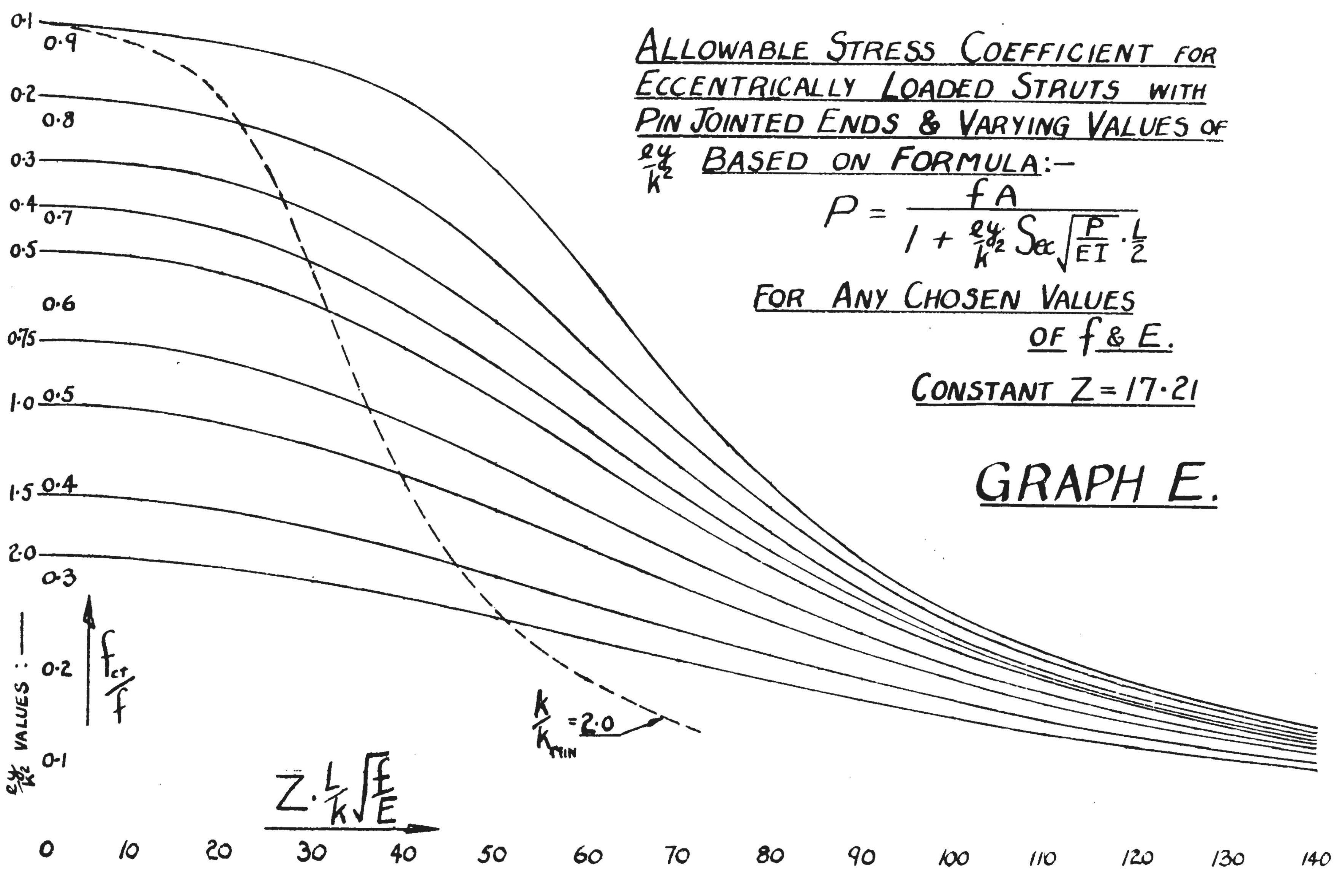


FIG. 5.—*Typical aircraft stiffener*





the above example gives the following method:

1. Calculate $\frac{ey}{K^2_{max}}$ and $\frac{L}{K_{max}}$ and plot point X, say, on graph.

2. Find the $\frac{ey}{K^2}$ value for permissible eccentricity in the plane of the least moment of inertia. If such permissible eccentricity is not prescribed choose a suitable value in conformity with the type of job (extrusion, machining, limits allowed, etc.) and its length. If the main eccentric loading is not exactly but nearly in the plane of the greatest moment of inertia find $\frac{ey}{K^2_{min}}$ value due to component in plane of least moment of inertia.

3. At the f_{cr} value given by the Point X read the $\frac{L}{K}$ value to suit the permissible eccentricity and divide this value by the K/K_{min} ratio to get the true $\frac{L}{K}$ value on this curve.

4. If this last point Y, say, has a greater $\frac{L}{K}$ value than point X, then the strut will fail in plane containing the greatest moment of inertia (or in the plane of bending). If X has a greater $\frac{L}{K}$ value than Y, strut will fail in plane containing least moment of inertia.

Example III. As an illustration of how the graphs may be factored to suit any material, take the same strut as in Example II made in duralumin with $f=18\cdot5$ tons/sq. in. and $E=10\times10^6$ lb./sq. in. the load being applied as before.

Any one of the four graphs may be used in this procedure, but we will use Graph A for convenience.

$E_1=28\cdot5\times10^6$lb/sq. in. $f_1=43$ tons/sq. in.

$E_2=10\times10^6$lb/sq. in. $f_2=18\cdot5$ tons/sq. in.

$\frac{L}{K}$ blow up factor

$$=\sqrt{\frac{E_1 f_2}{E_2 f_1}}=\sqrt{\frac{28\cdot5\times18\cdot5}{10\times43}}=1\cdot1076$$

Equivalent $\frac{L}{K}$ value for Graph A $=1\cdot1076\times30\cdot5$
$=33\cdot79$

With $\frac{ey}{K^2}=1\cdot362$ as before and $\frac{L}{K}=33\cdot79$

Using Graph A, $f_{cr}=36{,}250$ lb/sq. in.

Reducing this value in the ratio of $\frac{f_2}{f_1}$ we get

$f_{cr}\text{dural.}=36250\times\frac{18\cdot5}{43}=15{,}600$ lb/sq. in.

This stress would never be realized for the same reason as before. It is worthy of note, therefore, that in transferring from any one of the graphs to another material when the critical $\frac{L}{K}$ value is exceeded it is only necessary to find the crippling stress on the chosen $\frac{K}{K_{min.}}$ curve at the blown up $\frac{L}{K}$ value and then to factor this down in the ratio of the allowable stresses.

Thus, instead of reading $f_{cr}=36{,}250$ we should have read $f_{cr}=23{,}200$

$\therefore f_{cr}\text{dural}=23{,}200 \quad \frac{18\cdot5}{43}=10{,}000$

$P=42{,}500$ lb.

Checking the result of Example III in Modified Euler formula

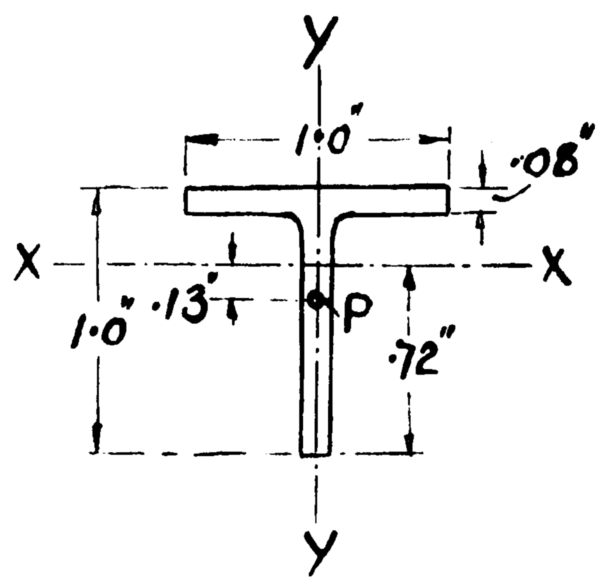


FIG. 6.—*Typical aircraft rib boom*

$$P=\frac{fA}{1+\frac{ey}{K^2}\text{ Sec}\sqrt{\frac{P}{EI}}\cdot\frac{L}{2}}$$

$$\sqrt{\frac{P}{EI}}=\sqrt{\frac{42500}{10^7\times4\cdot25\times\cdot63^2}}=\sqrt{25\cdot2\times10^{-4}}$$
$$=5\cdot02\times10^{-2}$$

$\alpha=30\times5\cdot02\times10^{-2}=1\cdot507$ radians $=86\cdot3$ deg.

$\frac{ey}{K^2}$ Sec$\alpha=0\cdot2\times15\cdot496=3\cdot1.$

$P=\frac{18\cdot5\times2240\times4\cdot25}{4\cdot1}=43{,}000$ lb.

The discrepancy in this result may be attributed to the inaccuracies which arise in the use of the Modified Euler formula at values of α approaching 90 deg. This discrepancy does not arise in the case of the new formula and is another point which it has in its favour.

Example IV. A steel stanchion of the form shown (Fig. 4) has a cross sectional area of $39\cdot88$ sq. in. and its least radius of gyration is $3\cdot84$ in. The stanchion which is to be taken as freely hinged at both ends is 32 feet long and its breadth parallel to XX is 14 inches. If the load per square inch of section is 4 tons, how much may the line in which the resultant force acts at the ends deviate from the axis YY without producing a greater compressive stress than 6 tons per square inch, the resultant thrust being in the line XX?

$E=13{,}000$ tons/sq. in. $=29\cdot1\times10^6$lb/sq. in.

Maximum allowable stress $=6\times2{,}240=$
13,430 lb/sq. in.

$\frac{L}{K}=\frac{32\times12}{3\cdot84}=100$

$f_{cr}=4\times2{,}240=8{,}960$ lb/sq. in.

$$\sqrt{\frac{E_1 f_2}{E_2 f_1}}=\sqrt{\frac{28\times6}{29\cdot1\times30}}$$
$$=0\cdot4387$$

Using Graph B.

Equivalent $\frac{L}{K}$ for Graph B $=0\cdot4387\times100$
$=43\cdot87.$

f_{cr} stanchion $=8960\cdot\frac{30}{6}=44800$

Hence $\frac{ey}{K^2}=0\cdot32$ and $e=\frac{0\cdot32\times(3\cdot84)^2}{7}$

$e=0\cdot692$ in.

Checking in Modified Euler formula

$$\sqrt{\frac{P}{EI}}=\sqrt{\frac{357500\times10^6}{29\cdot1\times(3\cdot84)^2\times39\cdot88}}$$

$$=\sqrt{20\cdot35\times10^6}=4\cdot511\times10^3$$

$L=4\cdot511\times192\times10^3=\cdot8655$ radians $=49\cdot56°$

Sec $\alpha=1\cdot543 \quad \frac{ey}{K^2}\cdot$ Sec$\alpha=0\cdot49\ 4.$

$P=\frac{13430\times39\cdot88}{1\cdot494}=358000$ lb.

The method of factoring to transfer to different materials other than those for which the graphs are drawn may be found difficult to keep in mind, aud so a set of similar curves have been drawn, using non-dimensional coefficients on all the scales. This is Graph E and two examples follow to illustrate its use.

Example V. A rolled "hat" section stiffener (Fig. 5) is used as a strut in an aircraft component, being loaded by means of rivets in each side of the "brim". It is required to know the crippling load over an equivalent free pin-jointed length of $8\cdot5$ in. The material is Alclad with a $0\cdot2$ per cent proof stress of $15\cdot5$ tons/□". $E=10^7$ lb./□".

$I_{yy}=0\cdot01. \qquad A=0\cdot0946$

$$\therefore K^2_{yy}=\frac{0\cdot01}{0\cdot0946}=0\cdot1058$$

$$\frac{ev}{K^2_{yy}}=\frac{(0\cdot385)^2}{0\cdot1058}=1\cdot4$$

$$\frac{L}{K}=\frac{8\cdot5}{\sqrt{\cdot1058}}=27\cdot6$$

$$\therefore\ Z\cdot\frac{L}{K}\sqrt{\frac{f}{E}}=17\cdot21.27\cdot6\sqrt{\frac{15\cdot5.2240}{10^7}}=28$$

From Graph E:

$f_{cr}/_f=0\cdot383 \quad \therefore f_{cr}=13{,}300$ lb/□".

Crippling load $=0\cdot0946\times13{,}300=1{,}250$ lb.

In the above type of example owing to the small difference between inertias in the two perpendicular planes, combined with the small $\frac{L}{K}$ ratio we see that it is unnecessary to check for failure in opposite plane.

Referring to Graph D the result seems fair enough.

Example VI. A certain aircraft trailing edge rib has extruded T section booms $1''\times1''\times0\cdot08''$. (Fig. 6). At the attachment to the wing main-spar it is found that the centroid of the rivet group, transferring in this case 100 per cent of the boom load to the wing spar, is $\cdot13''$ below the neutral axis of the T section member. If air load is to be neglected and the equivalent free pin-jointed length of strut with $\cdot13''$ eccentricity is $10\cdot6''$, find the crippling load in compression. The T section is of L 40 with max allowable compressive stress of 20 tons/□" and $E=10^7$lb./□".

$I_{xx}=\cdot0148 \quad A=\cdot1535$□"

$I_{yy}=\cdot0067$

$$K/K_{min}=\sqrt{\frac{I_{xx}}{I_{yy}}}=\sqrt{\frac{\cdot0148}{\cdot0007}}=1\cdot486$$

In Plane YY

$e=\cdot13'' \quad y=\cdot72'' \quad \frac{ey}{K^2_{xx}}=\frac{\cdot13\times\cdot72\times\cdot1535}{\cdot0148}$
$=\cdot97$

$\frac{L}{K_{xx}}=\frac{10\cdot6}{\cdot3105}=34\cdot2$

$$Z\sqrt{\frac{f}{E}}\cdot\frac{L}{K}=17\cdot21\sqrt{\frac{44800}{10^7}}\cdot34\cdot2=39\cdot4$$

From Graph E

$\frac{f_{cr}}{f}=\cdot426. \quad f_{cr}=19100$ lb/□"

$P=2{,}930$ lb.

In Plane XX

Assume a fitting error eccentricity $=\cdot015$ in.

$$\frac{ey}{K^2_{min}}=\frac{\cdot015\times\cdot5\times\cdot1535}{\cdot0067}=\cdot172\text{ say }\cdot2.$$

(*Concluded on page* 20)

Tailless Aircraft and Flying Wings

A Study of Their Evolution and Their Problems

By A. R. Weyl, A.F.R.Ae.S.

(*Continued from Vol. XVI, p. 360*)

The "Parabola", a Russian Flying Wing

In the First Russian Soaring Flight Competition at Feodosia (Crimea) in 1923, a very light "all-wing" sailplane took part. The parabola plan shape of its wing, its small span and low aspect ratio raised general interest. The designer and pilot of this Flying Wing was the Russian student of aeronautical engineering, B. J. Tscheranowsky.

On the occasion of subsequent competitions, remarkable flights were achieved with improved versions of the "Parabola" which seemed to indicate a fair amount of stability, controllability and a good performance, mainly due to the exceptionally low structural weight.

Wind tunnel research undertaken by the Joukowsky Laboratory of the Russian Central Aero-Hydrodynamical Research Institute (Z.A.H.I.) encouraged the construction of tailless Tscheranowsky light aeroplanes which though flying well, do not seem to have proved markedly superior to conventional types. It has been stated that the addition of a nacelle (instead of the previous Flying Wing) and of a tractor airscrew (instead of a pusher), the thin aerofoil sections chosen and the unfavourable disk-rudder arrangement were to blame as probable causes of the disappointing results.

The original Parabola sailplane had thick aerofoil sections and normal controllers. A vertical rudder was fitted behind the trailing edge. The pilot was housed within the wing, with only his head protruding.

In 1930 Tscheranowsky adopted a triangular plan shape for his wing. A nacelle was fitted and also disk rudders at the wing tips. A sailplane of this much simpler design proved to be very stable and manœuvrable. The controllers reached over the whole span; they were divided —unlike the "Delta I"—into an inner pair, employed for trimming purposes only, while the outer pair formed the actual controller.

FIG. 43.—*Tscheranowsky "Parabola" glider in the improved version of* 1925

Practically trapezoidal in plan shape, was the experimental "Khai-3" light aeroplane of 1933/34. It had twin nacelles and a 100 h.p. engine mounted above the wing and driving a tractor airscrew. This interesting experimental aircraft seems to have been equipped with tiltable wing tips and with inset trimming organs within the wing tips. No vertical control surfaces or fins seem to have been provided. The "Khai-4" tailless lightplane of 1934 was a development with the same "M-11" engine of 100 h.p. It had a total weight of 1,870 lb. and has been stated to have shown a maximum speed of 136 m.p.h. The design of these types was due to the Aeronautical Institute of Khankov.

Since the experiments with the "Bitch-7" tailless lightplane of B. J. Tscheranowsky 1931/32, not much more has been heard of his work with tailless aeroplanes. "Bitch-7" was a two-seater with 100 h.p. Bristol Lucifer and had a total weight of 1,870 lb., a wing span of 41 ft., and a wing area of not less than 325 sq. ft.

A giant "Flying Wing" of the Parabola type as a flying boat of 400 tons all-up weight was projected by the French designer Richard in 1930. Richard had been known as the successful designer of large flying boats.

The interior of the thick wing to this Parabola project was intended for the storage of gaseous fuel for engines, the total power of which was given as 40,000 h.p. The project demonstrated the adaptability of Tscheranowsky's idea for very large aeroplanes, but nothing further has been heard about this audacious enterprise.

French Flying Geometry

The triangular or trapezoidal wing plan form demonstrated by Lippisch, which was based on the use of aerofoil sections with a stationary centre of pressure all over the span incorporating a wash-out, has become the dominant feature of a number of tailless gliders and aeroplanes.

In 1930 Abrial and Auger designed a light aeroplane of this type which was claimed to be a solution of the problem of safety in the air. It had a trapezoidal wing with an aspect ratio of only 2·9, hence approaching the circular-wing type with its particular aerodynamical features (delayed stall). The aerofoil section had a reflexed camber line and medium thickness, and as the wash-out was small it may be assumed that the aerofoil sections employed had positive stability in virtue of their centre-of-pressure travel. The aeroplane was a low-wing arrangement with a tricycle undercarriage and disk rudders at the wing tips; it was powered by a 95 h.p. engine driving a pusher airscrew. Nothing has become known about the results of any flying tests.

At the Paris Aero-Salon of 1923, Nieuport-Delage (who had already shown interest in the tailless type twenty years ago) exhibited an interesting tailless low-wing monoplane which was—except for the aspect ratio of the wing—not dissimilar to the design of Abrial and Auger. It was a three-seater cabin aircraft with a wing of triangular shape, a 175 h.p. radial engine and a pusher airscrew. The wing structure belonged to the monospar variety built up from electrically-welded steel tubes and braced in the manner of the Stieger wing. Though flying quite well this Nieuport 941 was not further proceeded with; it also seems that the French Authorities did not grant a certificate of airworthiness for the design.

Fauvel's "Flying Wing"

The development work of the French engineer, Charles Fauvel, has been far more successful.

He began systematic investigations in about 1926, combining wind tunnel research with flying tests of gliders and light aeroplanes. Fauvel appears to have based his investigations upon the (erroneous) assumption that all previous workers in the field had contented themselves with securing a stationary centre of pressure, with neutral stability, aided and abetted by controllers, sweep-back wash-out, etc., in order to get positive inherent stability. It is, however, a fact that previous investigators many years before Fauvel had recommended and actually used aerofoil sections with a stable travel of the centre of pressure either in the shape of inverted normal aerofoils or of sections having a heavily cambered camber line. Ahlborn and Arnoux have already been referred to in this connexion.

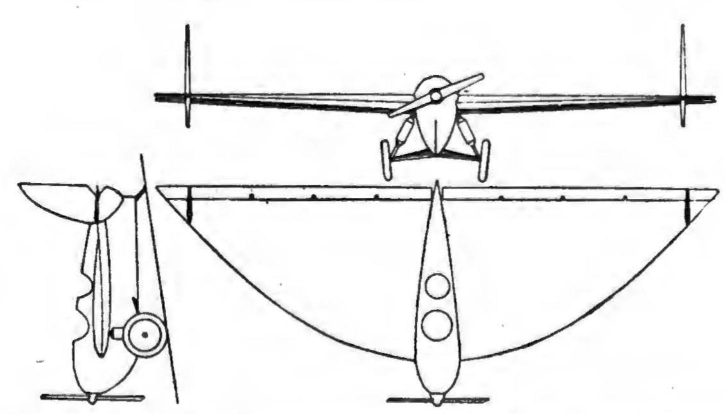
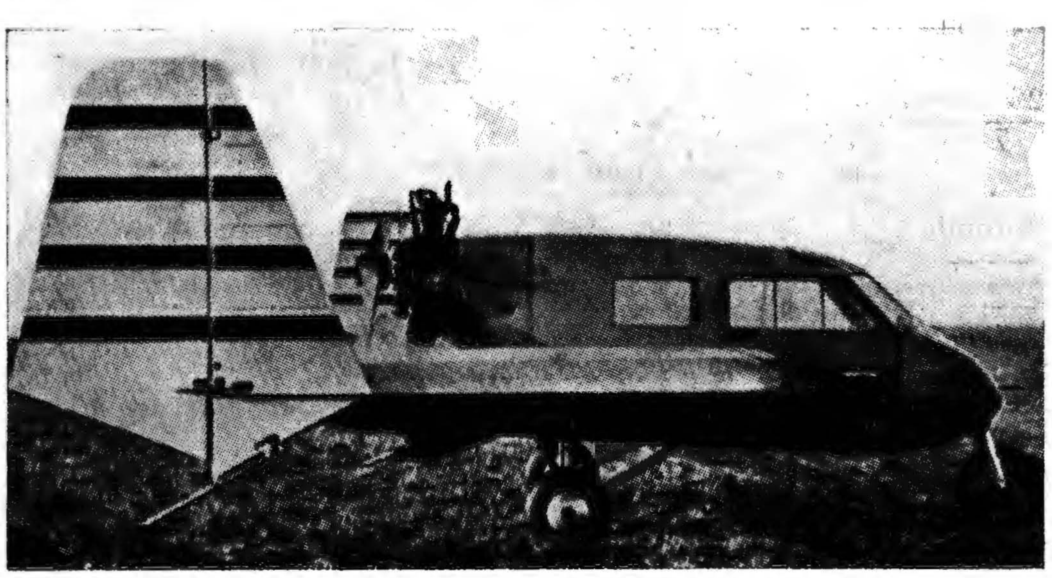
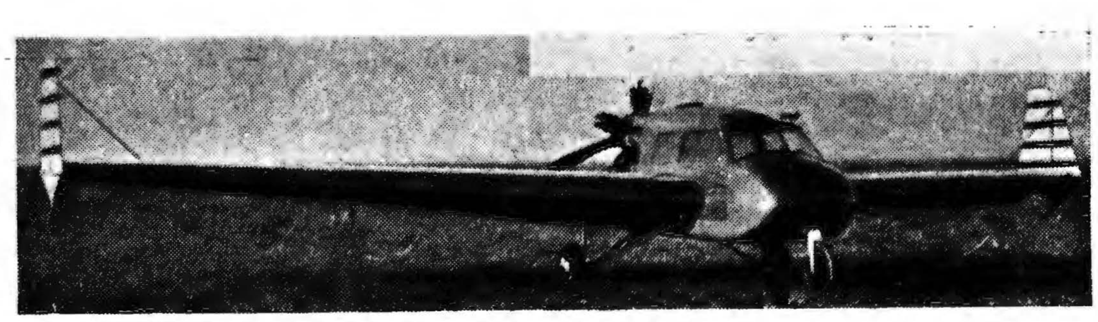


FIG. 44.—*The Tscheranowsky-Gruhon "Parabola" built by the Z.A.H.I. in* 1931. *The wing section had a thickness of* 7·7 *per cent*



FIGS. 45 and 46.—*The three-seater type* 941*T Nieuport tailless design of* 1935, *with a* 175 *h.p. Salmson engine, which was flown experimentally*



But Fauvel can claim merit for having pointed out clearly how vitally important for longitudinal stability the location of the centre of gravity is in relation to the "Aerodynamical Centre" (or "Neutral Point") of the wing system; thus easing the way for an understanding of the stability problem of the tailless principle. Fauvel went so far as to locate the centre of gravity of his aeroplanes between 12 per cent and 22 per cent of the wing chord from the (median) leading edge of the wing. He was able to do so without the balance supplied by a tail plane by reason of his heavily reflexed wing section.

Fauvel's "Flying Wings" are characterized by the absence of sweep-back, of dihedral and of wash-out. His work is thus a direct continuation of the work of Arnoux; only with the significant difference that the wing is so much tapered that it has almost developed pointed wing tips. The aerodynamical peculiarities of such a plan shape at and near the stall do, however, not seem to be apparent, since the aerofoil sections employed show an extremely flat maximum in the lift curves without any pronounced peak in it. The trailing edge of the wing is well swept forward.

Fauvel's fundamental patent of 1929 (Brit. Spec. 344,653) relates to tailless aeroplanes having a wing system without any wash-out and with uniform aerofoil sections of heavily reflexed camber line. Additionally; protection is claimed for a thick central portion in such a wing with a symmetrical wing section replacing an ordinary nacelle.

As the optimum lift/drag ratios of Fauvel's stable aerofoil sections are at small angles of incidence, the induced drag is of less importance and thus moderate aspect ratios are admissible. Fauvel is said to have achieved with his A.V.3 sailplane of 1934 ("A.V." stands for "Aile Volante") a gliding ratio of not less than 21 with an aspect ratio of only 8 (which is very low for a sailplane of this performance).

A further design characteristic of Fauvel was the endeavour to secure a satisfactory field of view for the pilot. This endeavour has actually influenced the choice of the plan shape of the wing; for this (and for other) reasons he has also discarded wing tip rudders and fitted a central fin and rudder at the stern of the nacelle.

Fauvel's first light aeroplane, A.V.2, was a single-seater built by Caudron in 1933 and after a few tests not further proceeded with. Its engine, a 34 h.p. A.B.C. Scorpion, was mounted high above the wing with a pusher airscrew, the aeroplane originally having been designed as a glider. The change in trim with engine-off and engine-on must have given rise to difficulties.

The A.V.10 low-wing two-seater (side-by-side) of 1934 constructed by a company formed by Fauvel had a tractor airscrew driven by a 75 h.p. Pobjoy engine. It had an aspect ratio of 5·4 and a conventional undercarriage. Originally exhibited at the Paris Aero-Salon, this little tailless aeroplane belongs to the few unorthodox exhibits at the Salons which ever surprised by real flying performances. The lightplane not only satisfied the difficult requirements for a French certificate of airworthiness by obtaining, after exhaustive flying tests, the first certificate of airworthiness ever granted to a tailless aeroplane; it also performed an altitude flight up to 23,500 ft. in June 1936. This climb was proof of the aerodynamical qualities of the design, since an unsupercharged engine was used. The maximum speed was stated to be 115 m.p.h., the cruising speed 102 m.p.h., and a take-off run of only about 60 yards was claimed.

Contrary to hopes, the Société Anonyme l'Aile Volante had to cease activities for lack of orders, and nothing further has been heard of Charles Fauvel's activities in connexion with tailless aeroplanes.

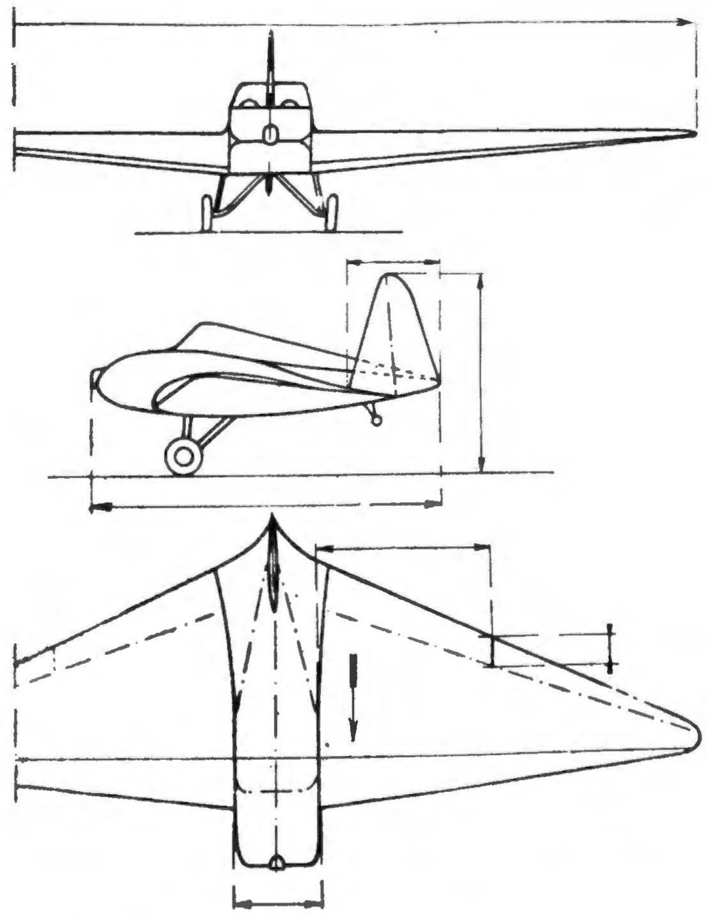


FIG. 47.—*Fauvel A.V.10 tailless light aeroplane of 1935 side-by-side two-seater with a 75 h.p. Pobjoy engine*

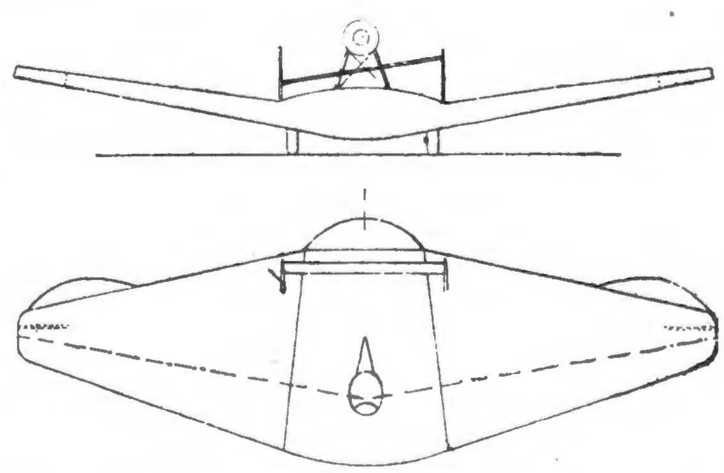


FIG. 48.—*Fauvel-Arnoux type flying wing from a 1930 patent. The central fuselage portion has a symmetrical aerofoil section, while the outer sections have heavily reflexed maxim camber line to give stable c.p. travel*

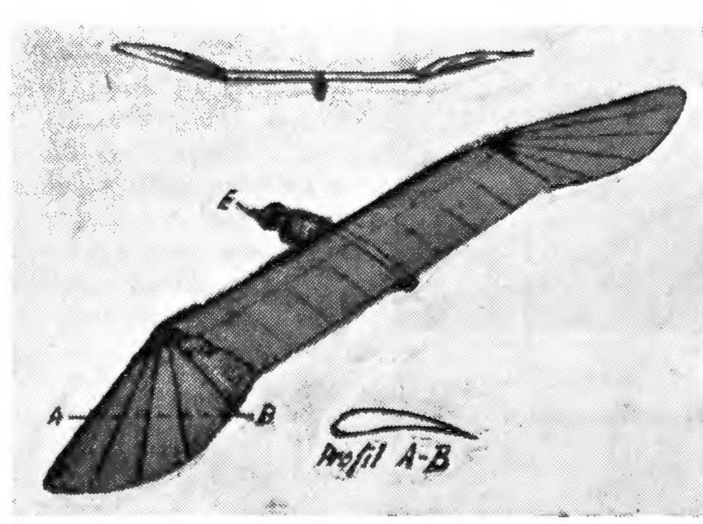


FIG. 49.—*The Schul "frilled wing", from a 1930 patent*

Northrop's Flying Wing

For a number of years, the American aircraft firm of J. K. Northrop has been active on the problem of the Flying Wing. The full-scale investigations began in about 1930 with a thick-winged aeroplane equipped with a conventional tail supported by girders. In order to house engine and passengers directly in the wing, without very large dimensions of the latter, the central portion of the wing was thickened. Nevertheless a sort of nacelle was apparent. A pusher airscrew was provided.

This experiment developed into a real Flying Wing without a tail. In the summer of 1940 flying tests were made with a $\frac{1}{2}$ to $\frac{1}{3}$-scale model of a large multi-engined transport aeroplane. A military version seems also to have been considered. Photographs and a few details of this man-carrying scale model were released for publication in 1941. The twin-engined Flying Wing has a triangular plan shape and 38 ft. span. The two air-cooled engines are completely buried within the wings and drive two pusher airscrews arranged behind the trailing edge. The centre part is thickened, and no sort of nacelle or fuselage is apparent. The only excrescence from the wing, apart from the drive and mountings of the airscrews, is a transparent cover over the pilot's head. The tricycle undercarriage is fully retractable. The original 65 h.p. engines were later replaced by 120 h.p. engines.

Patent drawings of this design show tilted-down wing tips, with controllers arranged within the trailing edges of these drooping wing tips. These wing tips were used on the scale model; they are adjustable in flight about a fore-and-aft axis in the same way as G. T. R. Hill's latest arrangement provides. The aerofoil sections used appear to be symmetrical.

This experimental aeroplane has ample facilities for adjustments in flight: sweep-back, dihedral and wing twist can be varied and the centre of gravity shifted. The controllers (termed "Elevons" by Northrop, being a combination of elevators and ailerons) are flaps in the trailing edge. Several high-lift devices have also been tested, but did not prove entirely satisfactory. No final solution seems to have been found for directional control.

Up to November, 1940, about 200 experimental flights were made with this scale model. It was said that the aeroplane had proved too stable and had to be modified. Since then, nothing more has been heard of it.

For the "novel drooped downward" wing tip it was claimed that it "takes the place of the conventional vertical control surface", and that "its use makes it possible to obtain almost any desired combination of lateral and directional stability, without loss of lift". Actually such wing tips cannot be considered novel since they have been suggested and tried many years ago, as, to give one instance, the Dunne monoplane of 1911 shows, but it is very encouraging that the claims which J. W. Dunne made in favour of such wing tips were found entirely justified by the flying experiments of the Northrop firm.

J. K. Northrop has the indisputable merit of having achieved and tested the first real "Flying Wing". By his example and by the publicity given to it, he has imparted a powerful impetus to the modern designer of aeroplanes.

Another American attempt has been the Akerman low-wing monoplane which appeared in 1936. The triangular wing was equipped with disk rudders at the wing tips and seems to have had slots all along the leading edge. Two pairs of slotted controllers were provided. The wing had no pronounced dihedral. This experimental single-seater had a three-cylinder engine and a tractor airscrew. The undercarriage was conventional and had a steerable tail wheel. No reports of the results of tests have become known, and nothing more was heard of any further development.

Schul's Flying Wing

Rudolf Schul of Magdeburg constructed tailless flying models of the "Frilled Wing" category which exhibited so satisfactory flying qualities and performances during the Rhoen Soaring Competition of 1930 that a year afterwards a man-carrying sailplane was constructed according to Schul's patent.

The basic idea of the patent is that of a "Flying Plank" of conventional (unstable) aerofoil sections, to the tips of which stabilising parts of a diffusor-like shape are attached. These "frills" are obliquely opening towards the back, forming part of a cone, the point of which is directed forward, and the hollow side of which is open downwards. There is no dihedral.

The rectangular main wing of the Schul sailplane had an aerofoil section with small travel of the centre of pressure, normal flap-like controllers at the point of the frilled wing tips, and end-disk rudders of the Lippisch type. This sailplane seems to have achieved satisfactory flights.

The Nazi terror compelled Schul to flee his country; no further development has become known.

The Work of the Horten Brothers

The Horten brothers had more luck in Nazi-Germany. Their enthusiastic development, beginning with a "Flying Wing" sailplane constructed at their parents' home in 1934, was an interesting and generally successful extension of Lippisch's research into the possibilities of this type.

The Horten sailplanes consisted originally of a thick wing of triangular plan shape with a thickened central portion for the pilot. Vertical surfaces and dihedral were absent. Symmetrical aerofoil sections were used in combination with wash-out towards the wing tips. Ailerons and elevators formed separate parts of the trailing edge. The directional control was effected by air-brakes at the under surface of the wing; later air-brakes were fitted on the top surface as well.

The 1938 version, "Horten III", specially designed for blind flying and for aerobatics, had a different plan shape with more sweep-back, so that the trailing edge was also swept back. This Flying Wing had three pairs of controllers in the trailing edges; the inner pair serving as landing flaps. The structure was mainly built up from steel tubes and the outer wing panels were easily detachable. Contrary to usual sailplane practice the machine had a single-track retractable-wheel undercarriage. The aerofoil sections again were symmetrical. One of the two sailplanes of this type which participated with great success in the Rhoen Soaring Competition was flown with a "Vorfluegel", i.e. a small arrow-shaped aerofoil above and somewhat in front of the leading edge of the central wing portion; this feature has been blamed as a contributory cause of the fatal crash of the experienced glider pilot Blech, with this sailplane during the competition. Otherwise, it was claimed for the Horten III that it could not be made to spin; moreover it had been deliberately dived at 290 m.p.h. With 66 ft. span and a wing area of 390 sq. ft., a gliding angle of 1 : 32 and a sinking speed of 1·65 ft./sec. were claimed. An altitude of nearly 17,000 ft. was reached during the soaring competition and several cross-country soaring flights performed.

Horten II, named "Habicht", was a large light aeroplane with a 60 h.p. Hirth engine and a pusher airscrew. It was intended as a sailplane with auxiliary engine. In opposition to Lippisch, the Horten brothers believe that the Flying Wing system is the ideal form of a sailplane, and they have indeed presented their views in a convincing way.

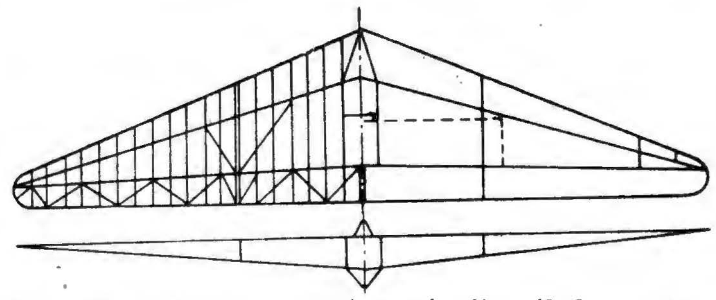


FIG. 50.—*The first "flying wing" sailplane of the Horten Brothers with symmetrical aerofoil section. No vertical surfaces, directional control being by air brakes lying flush in the wing when not in use*

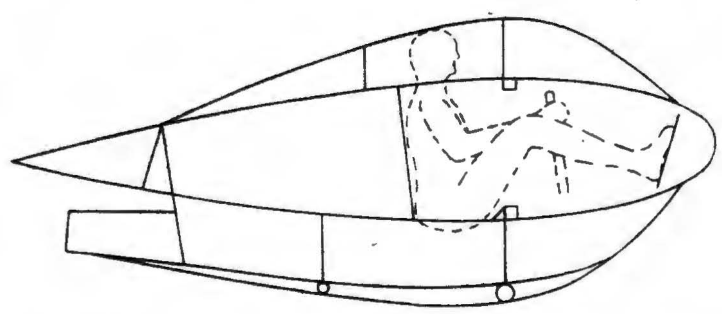


FIG. 51.—*Showing the pilot's accommodation in the Horten I sailplane of 1933*

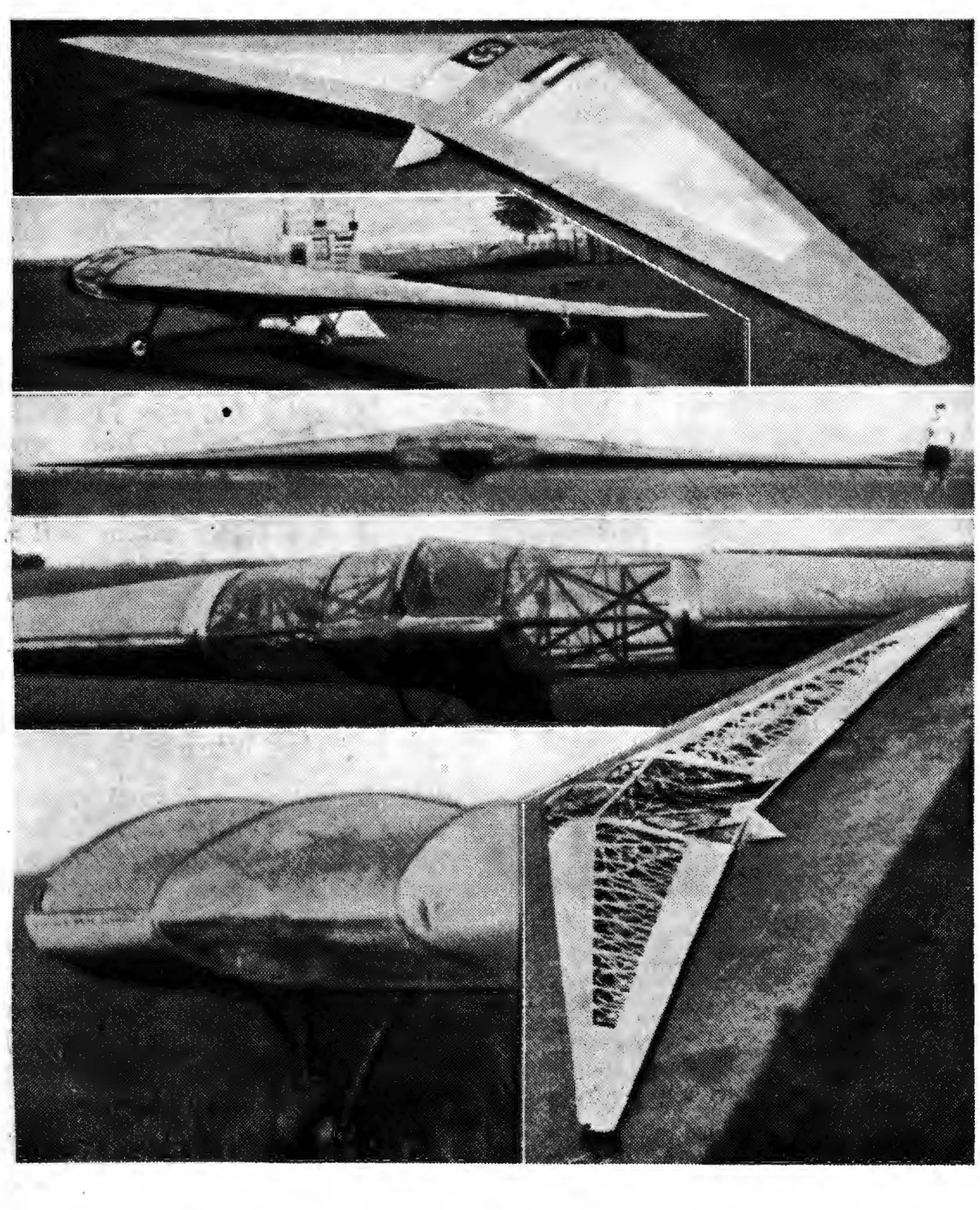


FIG. 52.—*The Horten II glider of 1935 in which the pilot lay prone. No vertical fins or rudder were fitted, directional control being by air brakes normally flush with the upper and lower surfaces*

The wing plan of the Habicht showed sweep back in both leading and trailing edges. All more recent designs of the Hortens show similar arrow-shapes.

In a Horten Flying Wing sailplane of 1942 the pilot has to assume a kneeling attitude. From the design point of view, this is an advantage, since it permits of housing the pilot completely within the contour of the wing; moreover, it brings the centre of gravity of the pilot more forward towards the leading edge and gives at the same time a much better field of view. The kneeling attitude may also have been chosen for the purpose of studying this attitude in flight, by reason of the problem of accelerations sustained with fast fighter aeroplanes during manœuvres.

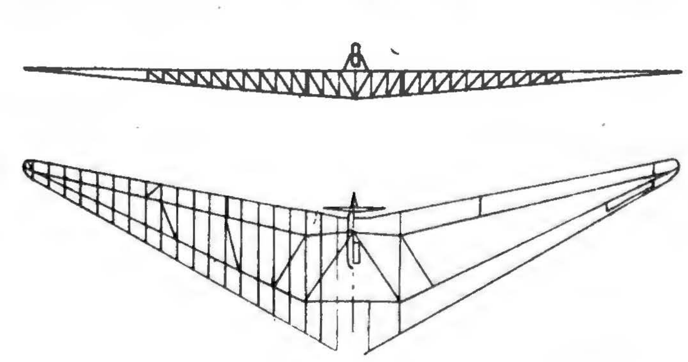
The wing shape of this Horten sailplane, which shows an aspect ratio of 21, reminds one strongly of the project of a high-performance tailless sailplane which was published by the then Squadron-Leader G. M. Buxton in 1938.

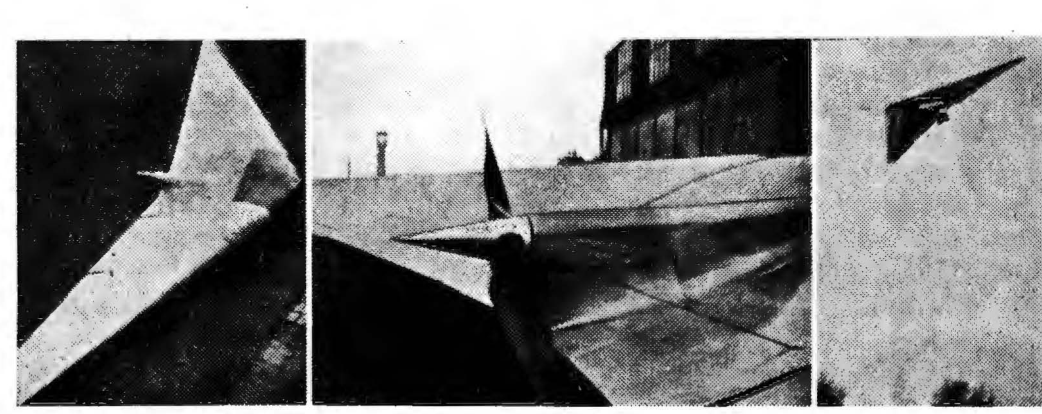
All Horten sailplanes and lightplanes have undergone extensive flying tests and valuable experience seems to have been gained. As for the sailplanes, it has been authoritatively stated that they have proved equal in performance to the best conventional and contemporary sailplanes during 1938 and 1939. Cross-country soaring flights of over 180 miles distance between the launching and the landing point have been performed with these Flying Wings, as well as thermal climbs to more than 21,000 ft. altitude above the launching point; moreover, these climbs necessitated circling through clouds, i.e. blind flying, and icing-up was occasionally experienced. The one and only fatal crash so far recorded (Blech) was caused by failure of the wing structure.

More recently the Hortens have designed a sailplane for the purpose of thermal soaring and high-altitude climbs. For reasons of increased manœuvrability, an aspect ratio of only 4·37 was chosen. The wing has a crescent-like shape with parabolic leading and trailing edge, in order to reduce the induced drag to a minimum by way of an appropriate lift distribution (making use of a method developed by A. Lippisch for swept-back wing systems).

In favour of the Horten Flying Wing light aeroplanes, it has been claimed that a corresponding conventional low-wing monoplane equipped with the same engine and having an equal useful load, had, at its best, 39 per cent less maximum speed, and that the Horten lightplane had actually a speed range of not less than 4·6 times the landing speed.

A more powerful "Flying Wing" which has been experimented with extensively before the outbreak of the war, was the twin-engined





FIGS. 53 and 54.—*The glider shown in Fig. 52 powered with a 60 h.p. Hirth engine, with an extension shaft to the airscrew, in 1936*

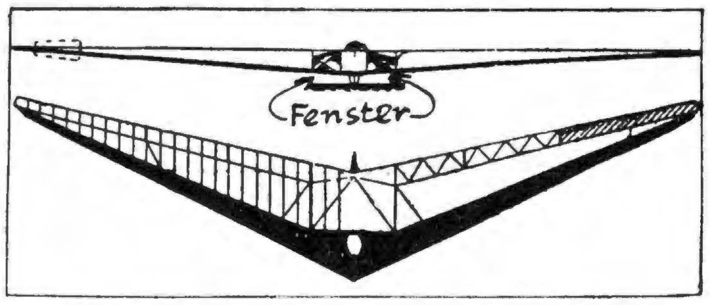


FIG. 55.—*Horten III successful soaring glider of the* 1938 *Rhon competition with three pairs of controllers—the inner being landing flaps and the outer elevators and aileron-rudders*

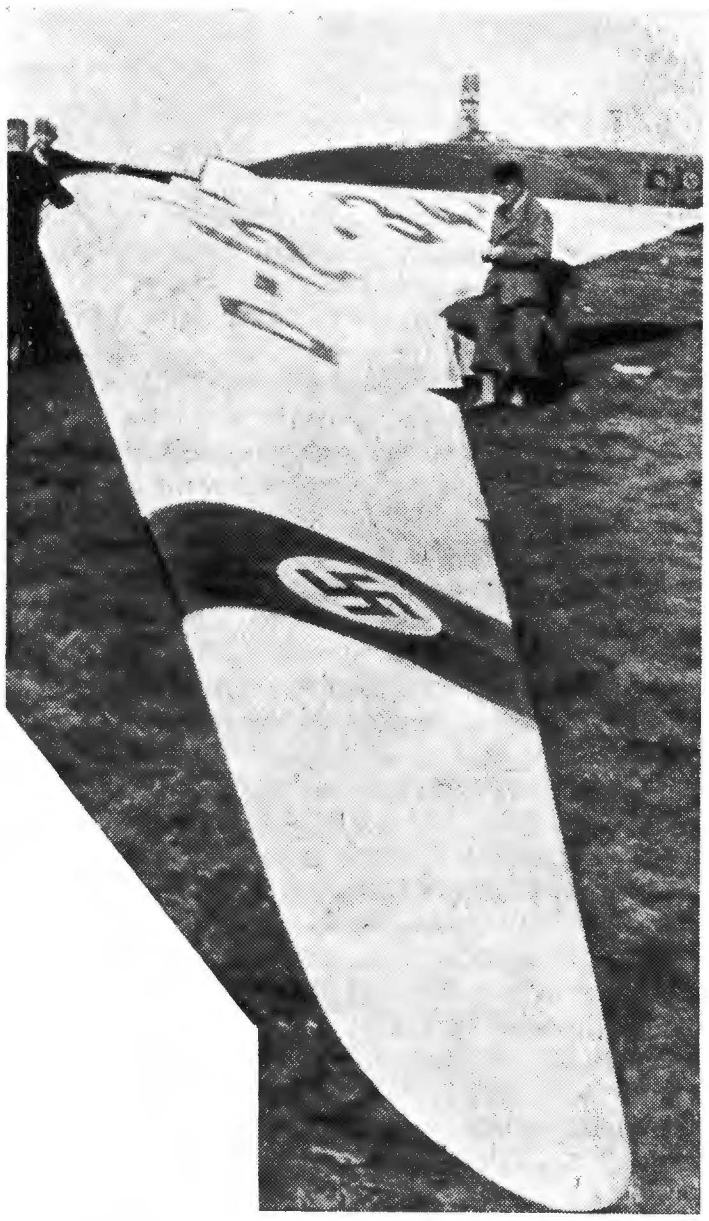


FIG. 56.—*The Horth glider successfully flown at the* 1939 *Rhon meeting*

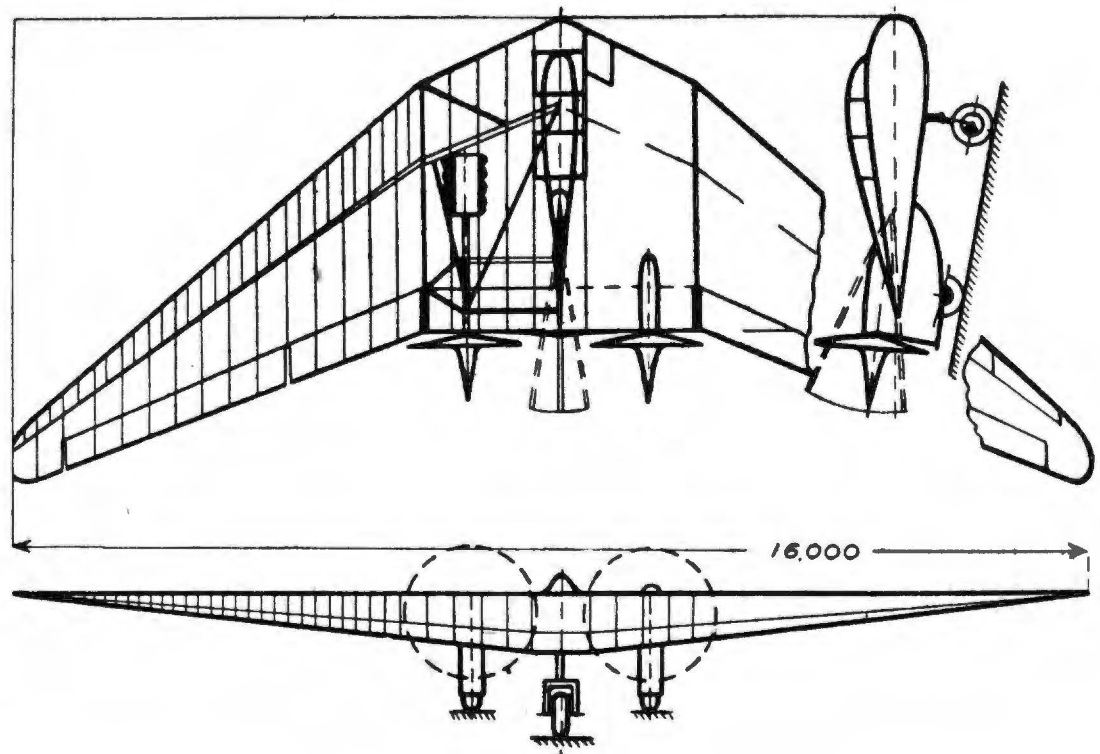


FIG. 57.—*The Horten V twin-engined tug for towing gliders*

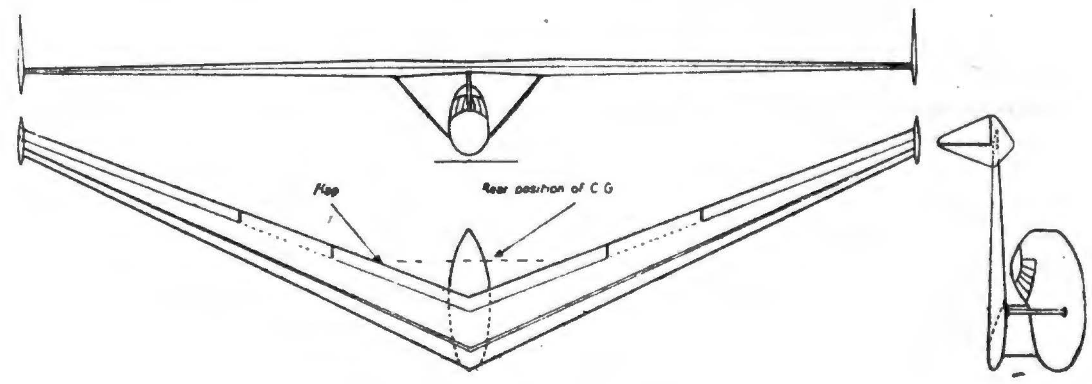


FIG. 58.—*The Buxton glider of* 1938 *similar in wing shape to some of the Horten types*

"Horten V". This aeroplane was conceived as a tug for towing glider and sailplanes. The absence of a tail makes the Flying Wing especially suitable for such purposes and obviates a number of difficulties experienced with conventional glider tugs. The Horten V had swept-back tapered wings with dihedral on the lower surface of the wing. The span was 52·5 ft. The two in-line engines were buried in the wings and drove pusher airscrews by means of long shafts. The fixed undercarriage was of the usual tricycle variety, the single-track version being discarded for this twin-engined design. The wing section was practically symmetrical. There were two completely enclosed seats in tandem, the pilot being in the leading edge. A small long cockpit fairing was the only excrescence, there being no nacelle. The attachment of a glider was effected by way of a swivelling post or beam extending backwards from the wing, in order to prevent fouling of the pusher airscrews by the tow-rope.

It is not known how far the experiments with this Flying Wing tug have been satisfactory. In any case, no similar type of aeroplane has up to now been employed as a glider tug by the Luftwaffe (in which both Hortens seem to be regular officers).

The work done by the Horten brothers can be valued as that of persistent and daring experimenters. Mainly based upon the results of Lippsich's investigations and, most probably, greatly helped by his assistance, they have endeavoured to employ modern methods and to exploit new uses for conceptions well known and investigated before their time. Apart from possible refinements, they have, however, scarcely added much to the imperfect solutions already established.

Geometrical Shapes

Apart from the ordinary tailless types, having a triangular or trapezoidal wing plan, two other categories of tailless (or quasi-tailless) aeroplanes deserve mention.

The first category comprises aeroplanes which have wings of an abnormally low aspect ratio, i.e. below the value of 3. Generally, such aeroplanes have no tail, and, usually, not much of a fuselage or nacelle, due to their very deep wings at the centre.

Wings of a very large chord and a small span have at all times formed the pet of inventors; certain early and not wholly unsuccessful aeroplanes (such as, for instance, the little "Demoiselle" monoplane of Santos Dumont) had indeed aspect ratios of only 2. Such aeroplanes, with the possible exception of some of the Parabola wings mentioned above, are, however, not of much interest for our survey. H. Hayden obtained in 1922 a patent for a rhomboidal wing of an aspect ratio of nearly 1 for which high lift and good flying qualities were claimed.

About 1932, however, serious attempts were made—mainly in the U.S.A.—to utilize the interesting aerodynamical properties of wings of very small aspect ratios, and the N.A.C.A. undertook research work in that direction.

It had been emphasized for a long time, that at aspect ratios approaching the value of 1 (i.e. square or circular wing plans), the laws of the Lanchester-Prandtl theory of induced drag do not hold. In fact, the values for induced drag predicted by theory were far higher than those actually measured in wind tunnel experiments. The reason for this phenomenon is the fact that in such wings the airflow is so decidedly three-dimensional that the theory does not hold.

The more important effect of this three-dimensional flow with a marked span-wise component is, however, that these wings of very low aspect ratios do not suffer from stall up to very high angle of incidence (45 deg. and even more), so that high maximum-lift values can be obtained, while the danger of autorotation (i.e. spinning) practically does not exist.

Such outstanding advantages of these wing systems give, of course, a sound reason for utilizing the characteristics of very low aspect ratios in the construction of aeroplanes. An aeroplane with which safe "parachute" landings can be made, indicates an important step towards safety and practical utility.

One of the first "Flying Flatfish" or "pancake" aeroplanes constructed was the "Arup" monoplane of C. L. Snyder and R. J. Hoffmann. The wing had the shape of a semi-circle to which tip-controllers (apparently of the floating variety) were added to serve as ailerons. The straight edge of the semi-circle formed the leading edge. The aspect ratio was 2·2, i.e. above the optimum range C. H. Zimmermann of the N.A.C.A. had found. The elevators were inserted in the curved trailing edge. In order to secure longitudinal stability, an aerofoil section having low centre-of-pressure travel was used.

All "Arup" Flying Wings had a tractor airscrew. Their flying qualities were praised, and the performance figures reported made the mouths of manufacturers of conventional aeroplanes water. The gliding angle was given as 1 : 2·6. The very similar Flying Wing of Raoul Hoffmann with an 85 h.p. Cirrus engine had a wing employing the stable M-aerofoil sections (M.6, and M.1 at the tips); it also flew well. Since 1935, nothing more has been heard of these designs.

Very similar, but with a rhomboidal wing plan, was the Italian Canova tailless. Here normal ailerons with skewed axes were used. Italian wind tunnel tests indicated promising results with this design. It appears that, after experiments with a glider, an aeroplane with a 130 h.p. engine was constructed and flown, but again, further development was discontinued.

In another American attempt, a true circular-disk wing was mounted high above a fuselage, Farman constructed, in 1933, an experimental aeroplane having an aspect ratio of only 1·9 which proved extremely stable.

Annular Wings, the second category have a much older past. However, their potential

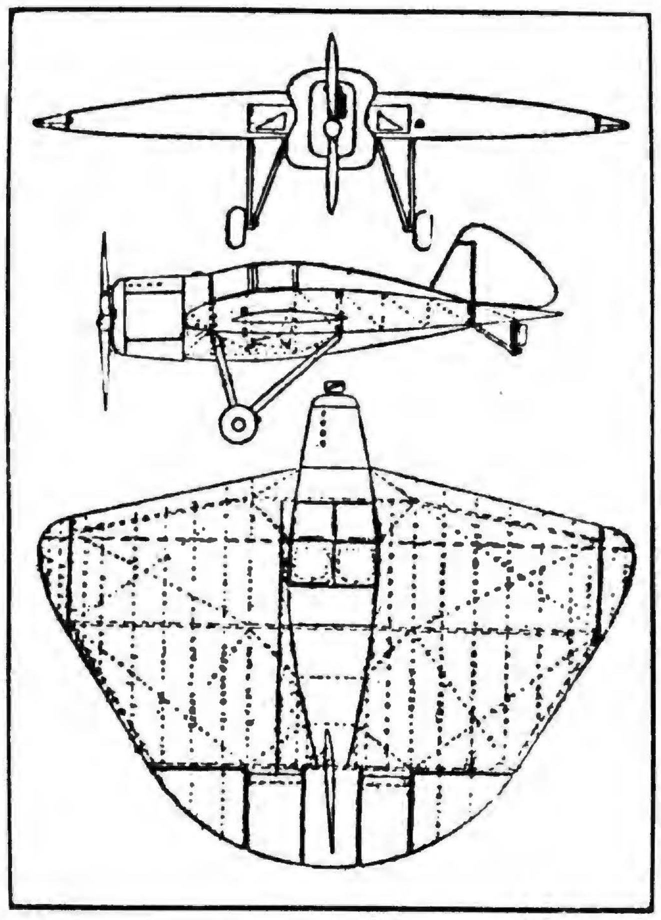


FIG. 59.—*Hoffman disk type aeroplane with an* 85 *h.p. Cirrus engine*

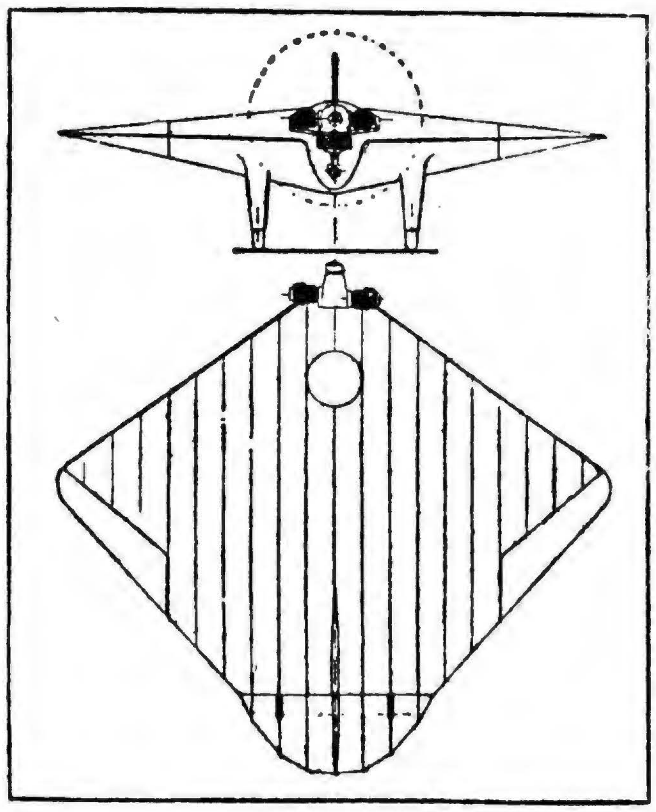


FIG. 60.—*The Italian Canova disk-type aeroplane with a* 130 *h.p. engine*

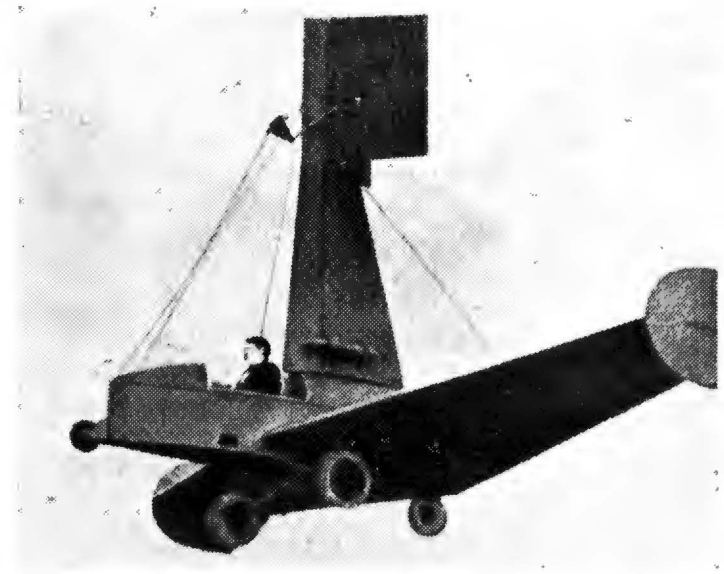


FIG. 63.—*The Rougé "Elytroplan" with rudder above the mainplane of* 1939

advantages are theoretically not so evident and/or established by scientific experiment. But it is a well-known fact that paper rings properly loaded exhibit quite an amazing flying stability (which is apparently not easily explained away by the scale effect and the laminar-flow condition). Small wonder that aeroplanes with annular wing plans have originated in the past in different countries at about the same period.

The first annular-wing aeroplane actually built was probably the biplane of Fritz Huth, a German aeronautical engineer of sound knowledge and with the instinct and tenacity of a pioneer, by profession a school teacher. Huth's annular biplane was constructed in 1908, secured promptly the nickname of "Flying Hat Brim" ("Hut" means "hat"), and was for a long time flight-tested on the Johannisthal aerodrome. But the results were discouraging, mainly, however, on account of the power unit, so that after the construction of two prototypes by the works of Schultze-Herford and of Schueler, further development was discarded, in favour of an (otherwise orthodox) all-metal monoplane which performed better.

The British conception was a year or so later and far more successful. This was the Cedric Lee annular-wing aeroplane which was designed by G. Tilghman Richards according to an idea of G. J. A. Kitchen. Though this type was in its latest version not genuinely tailless like the Huth biplane, it well deserves to be recalled in this survey. After patient development work, during which three different types were successively evolved, many successful flights established the practical value of the conception. The main advantage claimed was that, employing only half the span of a conventional aeroplane, an equal performance could be achieved, and that angles of incidence up to 30 deg. could be safely reached. The war of 1914 unfortunately terminated this interesting work, which to-day would deserve a closer investigation.

(*Continued opposite*)

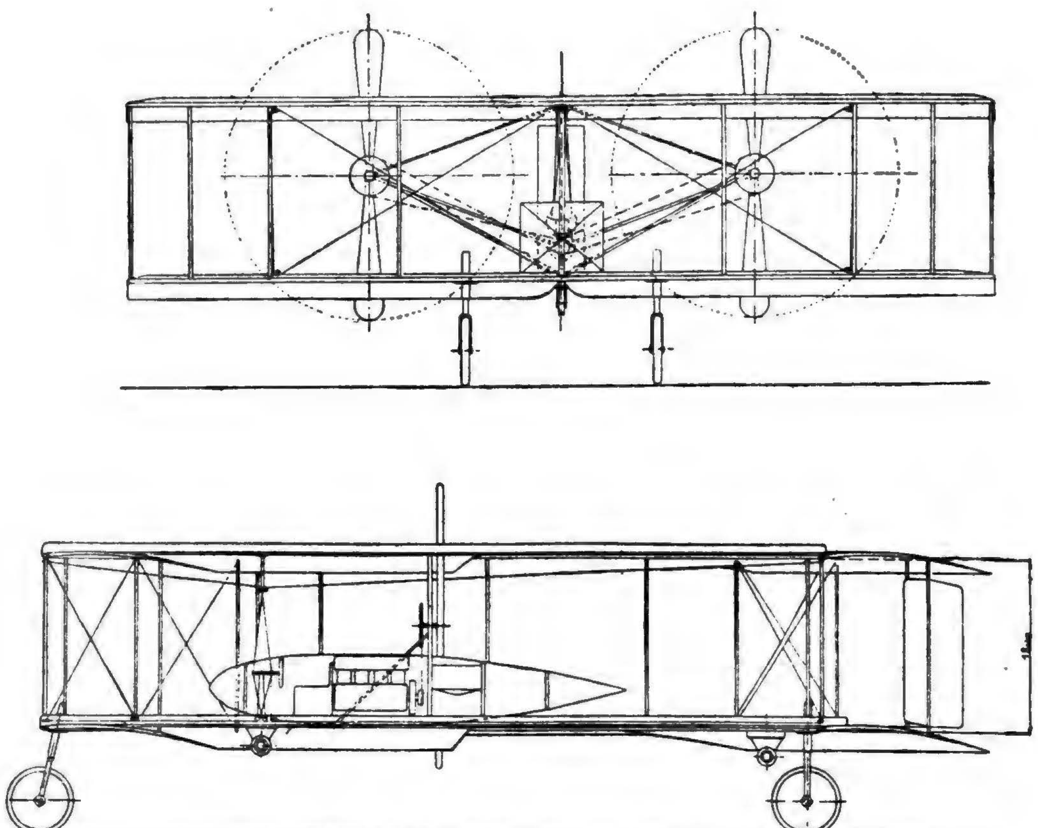


FIG. 61.—*The Huth annular-wing biplane of* 1908 *flown at Johannisthal*

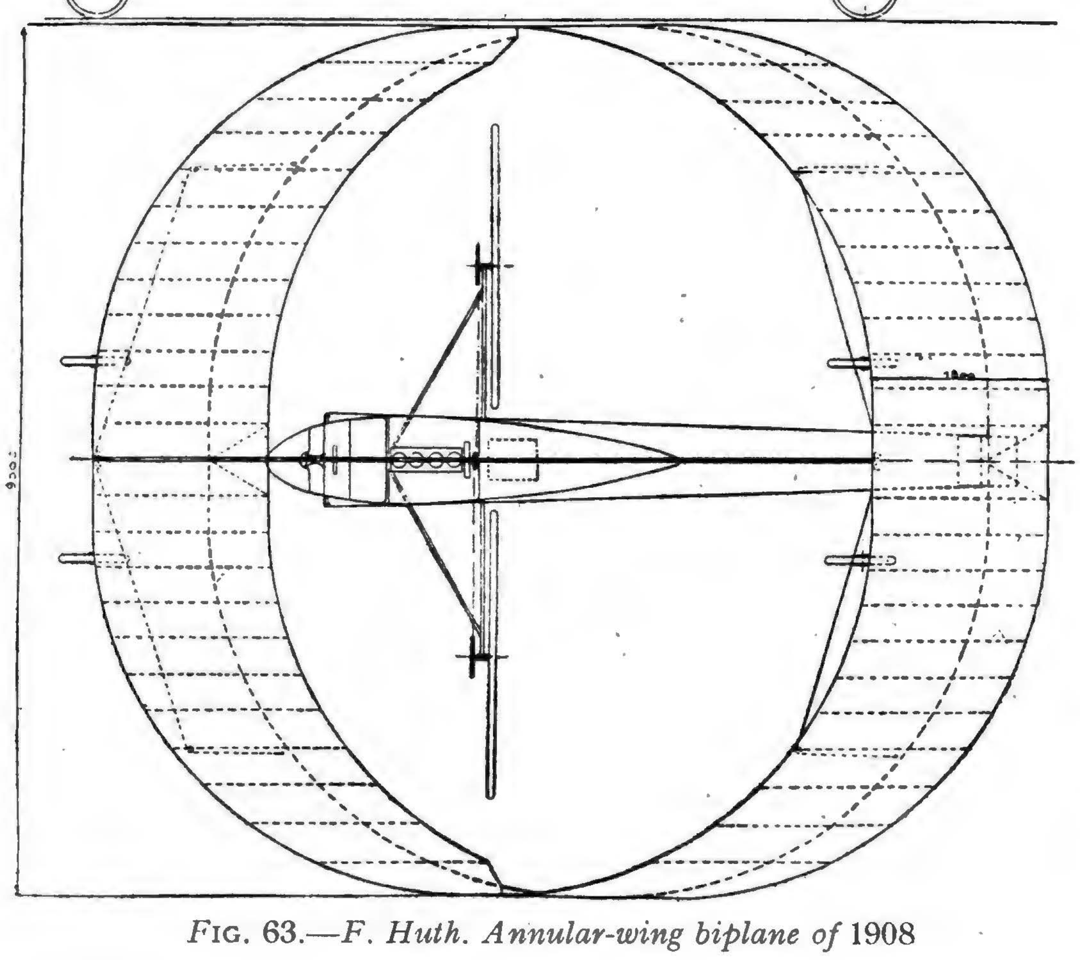


FIG. 63.—*F. Huth. Annular-wing biplane of* 1908

FIG. 62.—*The Cedric-Lee "Circleplane", designed by Tilghman Richards and flown at Shoreham in* 1911-12

List of Selected Translations

APPLICATIONS for the loan of copies of translations mentioned below should be addressed to the SECRETARY (R.T.P.3), MINISTRY OF AIRCRAFT PRODUCTION, LONDON, S.W.1, *and copies will be loaned as far as availability of stocks permits. Suggestions concerning new translations will be considered in relation to general interest and facilities available. Lists of selected translations have appeared in* AIRCRAFT ENGINEERING *since September,* 1938

LIST No. 76

Translation No. and Author	Title and Reference

Aero and Hydrodynamics

(2345) FINNER, W. ... *The Principle of the Potential Theory Applied to the Circular Wing.* (Ing. Archiv. Vol. 8, 1937, pp. 47-80).

(2352) KELLER, C. ... *The Place of Research in Turbine Design.* (Escher Wyss Mitt. No. 15/16, 1942/3, pp. 42-53).

(2361) CHEBYSHOVA, K.V. *The Problem of Calculating Labyrinth Packings.* (Trans. C.A.H.I. No. 142, 1937).

Aircraft and Accessories

(2162) *Improved Landing Gear Incorporating Skid and Wheel. German Patent No.* 732,486. (Flugsport Vol. 35, No. 10, 16/6/43, p. 34).

(2164) *Snowbrake Brake Applied to Skis. German Patent No.* 731,811. (Flugsport, Vol. 35, No. 10, 16/6/43, p. 36).

(2166) *Fowler Flap with Aileron Action, German Patent* 732,917. (Flugsport Vol. 35, No. 9, 19/5/43, p. 23).

(2353) ROTH, H. W. ... *The Temperature Distribution in Light Alloy Blocks during Heating and Cooling.* (Z. f. Metallk, Vol. 33, No. 1, Jan. 1941, pp. 13-15).

(2354) PAPOK, K. K. ... *The Influence of Aero-Engine Oils on the Sticking of Piston Rings.* (Pub. Res. Inst. Red Air Fleet, Moscow 1934).

(2360) SCHOPKE ... *Continuously Variable Gears for Machine Tools.* (Z.V.D.I., Vol. 87, No. 49/50, Dec. 1943, pp. 773-780).

Materials

(2339) GRENNER, P. ... *Stress Corrosion Tests for Light Alloys (Review of Methods including new form of clamp for Test Sample).* (Aluminium Vol. 25, No. 10, Oct. 1943, pp. 346-353).

(2340) KLYATSCHKO, J. A. *Colloidal Phenomena in Metals.* (Kolloid-Beihefte Vol. 44, No. 8/12, pp. 387-426).

(2356) SCHNORREN-BERG, W. *German Standard Specifications, Aluminium Alloys: Wrought, Cast or Secondary.* (Aluminiun Vol. 25, No. 7/8, 1943, pp. 267-269).

Wireless and Electricity

(2341) JACOTTET, P. ... *Atmospheric Influences on the Insulation of High Voltage Systems, with special reference to high altitudes.* (Archiv. f. Elekt. Vol. 36, No. 11, 1942, pp. 629-651).

(2351) ZINCKE, O. ... *Sideband—and Swinging Vector Theory of Frequency Modulation for Sinusoidal and Rectangular Modulation.* (E.N.T. Vol. 20, No. 4, April 1943). (Translated by the Post Office Research Station).

(2298) WOLMAN ... *The Frequency Variation of the Eddy current effect in Transformer Sheets.* (Z. f. Tech. Phys. No. 12, 1929, pp. 595-598).

Instruments

(2348) *A Micro-Hardness Tester.* (Z. f. Metallk Vol. 32, No. 2, Feb. 1940, pp. 35-38).

(2350) WISCHER, K. ... *A New Method for Volumetric Determination of the Water Content of Liquid and Solids.* (Z. Angew, Chem. Vol. 48, No. 26, 1935, pp. 394-396).

Professional Publications

Under this heading are given each month the principal articles of aeronautical interest appearing in the current issues of the Journals of the leading Professional Societies and Institutions

Institute of the Aeronautical Sciences

JOURNAL (QUARTERLY)

Vol. 11, No. 4, October 1944.

"Some Two-Dimensional Adiabatic Compressible Flow Patterns." H. Kraft and C. G. Dibble.
"Efficiency of Lateral Stiffeners in Panels." A. Zahorski.
"Prediction of Longitudinal Dynamic Stability." H. P. Liepman.
"Causes of Nighttime Thunderstorms over the Middle West." D. M. Crowley.
"An Iterative Method for Determining Dynamic Deflections and Frequencies." N. A. Boukidis and R. J. Ruggiero.
"The L.P.C. Method of Performance Computation." J. V. Foa and B. M. Leadon.
"Periodic Aerodynamic Forces on Rotors in Forward Flight." C. Seibel.
"Stress Analysis of Open Cylindrical Membranes." L. Beskin.
"Contracting Cones Giving Uniform Throat Speeds." R. H. Smith and Chi-Teh Wang.
"Aero-Elastic Instability in Unbalanced Lifting Rotor Blades." R. Rosenberg.
"Drag of Airfoils in Grids of High Solidity." J. R. Weske.
"Flexural Strength in the Plastic Range of Rectangular Magnesium Extrusions." F. A. Rappleyea and E. J. Eastman.
"Corrections for Lengths of Columns Tested between Knife Edges." W. R. Osgood.
"On the Mechanism of Friction." B. W. Sakmann and J. T. Burwell, Jr.
"The Response of Helicopters with Articulated Rotors to Cyclic Blade Pitch Control." A. F. Donovan and M. Goland.
"Buckling Loads of Beams or Plates on Continuous Supports." E. Saibel.

AERONAUTICAL ENGINEERING REVIEW (MONTHLY)

Vol. 3, No. 9, September 1944

"Unit Cabins to Increase Comfort of Light Aircraft." K. B. Turner.
"Soundproofing of Military Aircraft." A. A. Arnhym.
"Packaged Power." F. G. Rohm.
"Aircraft Hangars and Terminal Buildings of Reinforced Concrete." C. S. Whitney.

Vol. 3, No. 10, October 1944

"Aircraft Power-Plant Fire Protection." H. L. Hansberry.
"Demagnetization during Magnetic Particle Inspection." M. L. Mages.
"The Electronic Turborogulator." W. H. Gills and H. T. Sparrow.

The American Society of Mechanical Engineers

MECHANICAL ENGINEERING (MONTHLY)

Vol. 66, No. 11, November 1944

"A Lightweight Floor for Airplanes." J. R. Fitzpatrick.
"Compreg as a Laminated Wood and as a Plastic." J. F. Dreyer.
"Metalbond—A Metal Adhesive for Aircraft." G. G. Havens.
"Fatigue-Testing Methods and Equipment." H. W. Foster and V. Seliger.
"Induction Furnace for Melting Aluminium." M. Tama.

The Society of Automotive Engineers

S.A.E. JOURNAL (MONTHLY)

Vol. 52, No. 11, November 1944.

"An Investigation of Chafing on Aircraft-Engine Parts." H. G. Gray and R. W. Jenny.
"The Design for Production of Sheet Metal Aircraft Parts." F. M. Mallett.
"An Improved Indicator for Measuring Static and Dynamic Pressures." C. E. Grinstead, R. N. Frawley, F. W. Chapman and H. F. Schulte.

The Royal Aeronautical Society

JOURNAL (MONTHLY)

Vol. XLVIII, No. 408, December 1944.

"Cooling and Governing Problems on a Water-Cooled Auxiliary Generating Plant." R. B. Winn.
"Stresses Due to Internal Hydrostatic Pressure in Thin-Walled Vessels of Stream-line Form." A. M. Binnie and J. C. Ward.

Tailless Aircraft and Flying Wings

(*Continued from page* 12)

A few years ago, a similar annular wing shape raised much interest in German model circles. The Antes annular wing exhibited, by virtue of its peculiar shape, so surprisingly stable flight, that it was praised as a new discovery of great importance for the future of aeronautics. Aerodynamically, the conception of this "flying ring" reminded one somewhat of the unfortunate "Delta-8" monoplane experiment of the late M. Willoughby. A related, but rhomboidal, ring wing formed, incidentally, the essence of a 1912 patent taken out by A. H. Edwards. Edwards claimed a longitudinally stable centre of pressure for his arrangement. Willoughby's aim was to obviate the dangers of inadvertent stalling. Antes claimed to have discovered the solution of the problem of the giant flying boat. More recent suggestions for tailless aeroplanes of the ring-type have come from Warren-Young (rhomboidal wing) and from L. Peel.

As a special curiosity among the hundreds of tailless aeroplanes projects, another class may be mentioned which has, so to speak, the tail above the wing. Such a tailless aeroplane with the elevator situated above the wing was already in 1909 constructed by Levy-Gaillard and tested without success. The more recent version of the same idea was the "Elytroplane" of De Rouge and Bouffort. This tailless monoplane provided with wing-tip disk rudders and a 38 h.p. engine had, in its latest version of the spring of 1939, a slightly tapered wing with aerofoil sections giving stationary centre of pressure. Short flights have been made. A constructional feature is that the elevator can also be tilted about a longitudinal axis.

(*To be concluded*)

Redundant Pin-Jointed Frames

By H. E. Vincent, B.Sc., A.F.R.Ae.S.

THERE is an old saying that before you can cook your hare you must first catch it. The stressman might interpret this as "before you can stress a redundant frame you must first find the redundancy".

Determining the redundant members in a space frame is not always as simple as might be thought on first inspection. For a structure to be triangulated, i.e. built up of a series of triangles, does not necessarily mean that it is a perfect frame without redundancies. Consider the frame shown in Fig. 1a, a typical bay between an engine mounting, attached to points A, B, C and D, and a front bulkhead attached to points E, F, G and H. The cross-bracing of the front panel is obviously redundant. If the member AC is removed, as in Fig. 1b, the frame would appear to be triangulated, yet if the fixation of each joint is traced through the structure, starting from the rigid base E, F, G, H it will be found that member BD is also redundant.

The number of members in a perfect pin-jointed space frame is given by the formula $(3J-6)$, where J is the number of joints, but where the frame is attached to a bulkhead at four points, as in Fig. 1, and is dependent on the bulkhead for the fixity of the attachment points this formula should be modified to $(3J-12)$. If the number of members is less than the figure given by the formula appropriate to the frame then the structure is incomplete, and if the number of members is in excess of that value then a redundancy exists. Thus, if the frame shown on Fig. 1b is checked by the second formula it will show one member to be redundant.

Having, thus, established that the structure is not a perfect frame it is now necessary to decide which are the redundant members. This may be done in a variety of ways. Perhaps the most readily understood method is to consider the fixity of each joint in turn starting from a fixed base such as a triangular panel or, where the structure is mounted on a rigid bulkhead, from the bulkhead attachment points. For example, considering the frame in Fig. 1b, the position of Point C is fixed by the tripod formed by members HC, GC and FC. Point D is determined by a similar tripod consisting of members CD, HD and ED. The tripod fixing Point A is made up of members DA, EA and FA, whilst Point B is at the apex of the three members AB, FB and CB. Thus, starting from the fixed base, E, F, G, H, the positions of Points A, B, C and D are rigidly determined without the use of member BD. Therefore, member BD is redundant. Any structure may be checked in this way and those members not required to determine the position of any of the joints will be redundant members.

Having decided the redundancies, the next step in the solution of this type of structure is, in effect, to remove these members and reduce the frame to a perfect pin-jointed structure. This reduced frame may now be solved for any system of applied loads by the method of sections, by the method of direction cosines or by any other preferred method. For the purposes of this article the sign convention assumed for the endloads in the members will be—Compressive endloads, positive—Tension endloads, negative. The loads in the redundant members may be taken as compression loads of values p, q, r, etc. It is important that they be compression loads or else, by the sign convention just stated, they would have to be negative quantities. These compression loads apply thrusts to the joints of the perfect frame of

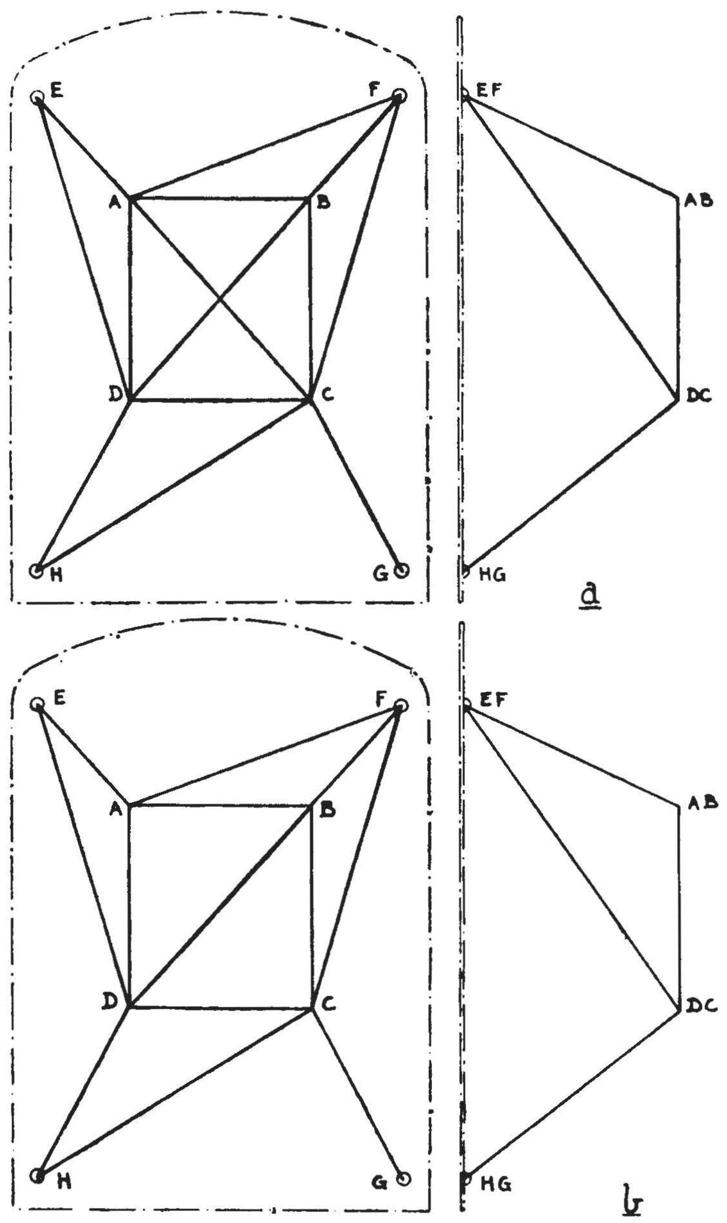


FIG. 1

magnitude p, q, r, etc. and in the direction of the redundant members. Thus, these loads may be regarded as external loads applied to the reduced frame and the loads in the members solved as for a system of applied loads. Therefore, for any condition of loading, it is possible to obtain the load in each member of the structure in terms of p, q, r, etc. and constant terms.

i.e. $P=$

$$aW_1+bW_2+cW_3+\ \ldots\ldots \\ +nW_r+\alpha p+\beta q+\gamma r+\text{ etc.} \quad \ldots\ldots\ldots \quad (1)$$

where P is the endload in any member, aW_1, bW_2, cW_3, etc., are the components of the load in the member due to applied loads of W_1, W_2, W_3, etc. respectively.

αp, βq, γr, etc., are the components of the load in the member due to the loads in the redundant members.

Now the energy, u, stored in this member is given by—

$$u=\frac{P^2\cdot l}{2A\cdot E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where l is the length of the member,

A is the cross-sectional area of the member,

and E is Young's Modulus for the material of the member.

Thus, the energy, U, stored in the whole structure is given by—

$$U=\sum\frac{P^2\cdot l}{2A\cdot E} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

It is a natural phenomenon that the energy stored in any structure under any system of loads is the minimum possible. Ignoring the redundant members, the energy stored in the rest of the frame is a fixed quantity determined by the externally applied loads, therefore, the extra energy stored in the structure due to the loads in the redundant members will be adjusted so that the total is the minimum possible.

Since p, q, r, etc. are all variable—

$$\frac{\delta U}{\delta p}=\frac{\delta U}{\delta q}=\frac{\delta U}{\delta r}, \text{ etc.}=0 \quad \ldots\ldots\ldots\ldots \quad (4)$$

gives the conditions under which U is a minimum.

$$\text{But—}\frac{\delta U}{\delta p}=\sum\frac{P\cdot l}{A\cdot E}\cdot\frac{\delta P}{\delta p}$$

$$=\sum\frac{\alpha\cdot P\cdot l}{A\cdot E} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Thus, the condition for the energy stored to be a minimum can be rewritten, by similarity,—

$$\sum\frac{\alpha\cdot P\cdot l}{A\cdot E}=\sum\frac{\beta\cdot P\cdot l}{A\cdot E}=\sum\frac{\gamma\cdot P\cdot l}{A\cdot E}, \text{ etc.}=0$$

$$\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

It will be found that this condition can be solved for the values of p, q, r, etc. and so the load in any member can be evaluated.

TABLE I

LOADS IN MEMBERS DUE TO UNIT APPLIED LOADS

MEMBER	LOAD DUE TO—								
	DOWNLOAD (1 lb)	FORWARD LOAD (1 lb)	SIDELOAD (1 lb)	PITCHING MOMENT (1 lb.in.)	YAWING MOMENT (1 lb.in)	TORQUE (1 lb in)	REDUNDANCIES p	q	etc
EA									
FB									
GC									
HD									
ED									
FC									
FA									
HC									
AB									
DC									
AD									
BC									
AC									
BD									

THESE VALUES ARE THE a's, b's, c's, etc., OF EQUATION (1)

THE COEFFICIENTS OF p IN THESE TERMS ARE THE α's OF EQUATION (1)

THE COEFFICIENTS OF q IN THESE TERMS ARE THE β's OF EQUATION (1)

TABLE II
CONSTANTS OF MEMBERS

MEMBER	MATERIAL	YOUNG'S MODULUS (LB/SQ.IN)	SECTIONAL AREA (SQ.INS)	LENGTH (INS)	$\frac{l}{A.E \times 10^6}$
EA					
FB					
GC					
HD					
ED					
FC					
FA					
HC					
AB					
DC					
AD					
BC					
AC					
BD					

TABLE IV
ENERGY STORED IN MEMBERS

MEMBER	P_1	$\frac{l}{AE \times 10^6}$	α	β	$\frac{\alpha.P_1.l}{A.E \times 10^6}$	$\frac{\beta P_1 l}{AE \times 10^6}$
EA						
FB						
GC						
HD						
ED						
FC	FROM TABLE 3	FROM TABLE 2	FROM TABLE 1.	FROM TABLE 1.		
FA						
HC						
AB						
DC						
AD						
BC						
AC						
BD						
				TOTALS.	$\sum \frac{\alpha P_1 l}{A E \times 10^6}$	$\sum \frac{\beta P_1 l}{A E \times 10^6}$

TABLE III
LOADS IN MEMBERS DUE TO FACTORED APPLIED LOADS

MEMBER	LOAD DUE TO—								TOTAL $= P_1$
	DOWNLOAD (LB)	FORWARD LOAD (LB)	SIDELOAD (LB)	PITCHING MOMENT (LB.IN)	YAWING MOMENT (LB.IN)	TORQUE (LB.IN)	REDUNDANCIES p_1	q_1	
EA							THESE TERMS WILL BE THE SAME AS THE CORRESPONDING TERMS OF TABLE 1.		
FB									
GC									
HD									
ED									
FC									
FA									
HC									
AB									
DC									
AD									
BC									
AC									
BD									

TABLE V
ACTUAL LOADS IN MEMBERS

MEMBER	$P_1 - \alpha p_1 - \beta q_1$	αp_1	βq_1	TOTAL $= P_1$
EA	THIS IS THE SUM OF THE FIRST SIX COLUMNS OF TABLE 3.			
FB				
GC				
HD				
ED				
FC				
FA				
HC				
AB				
DC				
AD				
BC				
AC				
BD				

This solution lends itself to a method whereby any redundant structure may be solved by means of a series of standard tables.

Standard Tables

As an example, the solution of the redundant frame shown in Fig. 1a will be set out and a series of tables drawn up suitable for the solution of a typical engine mounting case. The way in which similar tables may be adapted for the solution of other structures will be apparent.

The first table should show the loads in the members due to unit loads applied to the reduced structure, i.e. with the redundant members removed, and also the loads in the members due to the redundancies.

The second table deals with the physical constants of each member.

These two tables are applicable to all conditions of loading on the structure, but from this point on each design case must be considered separately. The number of the case should be stated, followed by its description and a reference to the authority detailing the requirements for that condition.

For example—

Case 1.

Maximum normal acceleration, etc., *A.P.*970, Chap. 204, Table I.

Then should follow the factors to be applied to the unit loads given in Table I.

Factors to be applied to unit loads—

Download ... ...
Forward load ... ...
Sideload ... ...
Pitching moment (nose down) ...
Yawing (to starboard) ... ...
Torque (starboard wing down) ...

Table I can now be redrawn showing the actual load in each member due to each of the component loads, i.e. download, sideload, torque, etc. and the summation of these loads. This resultant load will be P of equation 1.

In order to avoid confusion with later cases, it is advisable to add a suffix 1 to P, p, q, r, etc. for this case and suffix 2, 3, 4, etc. for subsequent cases. This will be Table III.

Table IV is self-explanatory.

Since $\frac{l \cdot 10^6}{A \cdot E}$, α, β, γ, etc., are constant numerical quantities, the values of $\frac{\alpha P_1 \cdot l}{A \cdot E}$ $\frac{\beta P_1 \cdot l}{A \cdot E}$, etc., the summations of these quantities, will contain only first powers of p, q, r, etc., and no products of these unknowns. Therefore, from the summations a series of simple simultaneous equations will be obtained and, since there is always the same number of summations as redundancies, a full solution can be derived.

It sometimes happens that in these summations all but one of the unknown quantities vanish. This simplifies the result considerably but the method detailed above will give a solution under any circumstances.

The loads in the redundant members have now been obtained but the evaluation of the case is not yet complete. The true loads in the members have to be found.

Finding the True Loads

The load in each member is still in the form—

$$P_1 = K_1 + \alpha p_1 + \beta q_1 + \gamma r_1 + \ldots \text{ etc.} \quad (7)$$

All these quantities are known and the addition can again be carried out in tabular form. This is shown in Table V

This method may be used to solve any redundant frame under any condition of loading, and the five tables, adapted to the particular needs of any problem, should enable an accurate solution to be obtained without difficulty.

The Fundamentals of Flutter*

By W. J. Duncan, D.Sc., M.I.Mech.E., F.R.Ae.S.†

Introduction

A NUMBER of attempts have already been made to present a simple and easily understood account of wing flutter [1, 2, 3, 4, 5, 6], but it appears that the subject is still obscure and difficult to many. Accordingly another elementary presentation of the subject is given in this paper, and the problem is approached in a new way. Emphasis is placed on explaining how flutter can happen; that is, on the physical mechanism by which an aeroplane wing can become a species of air engine and extract energy from the passing air. This explanation is greatly helped by experiments with a mechanism which has been called the "flutter engine", consisting of a rigid aerofoil so arranged that when placed in an airstream it can oscillate and drive a flywheel.

The first part of the paper gives a non-mathematical explanation of flutter and of its prevention, while the second part is devoted to an easy introduction to the theory. The first part is self-contained, and those readers who are not interested in the theory can ignore the second part. An attempt has been made to simplify the mathematics of the theory to the utmost, and all the details are given in the Appendices.

Although the paper is purely expository and intended primarily for the non-expert reader, it is thought that the method of treatment and some of the detailed results may be of interest even to experts.

Readers wishing to pursue the subject further should consult the papers given in the list of references, especially items 1, 4 and 7.

The paper aims at giving an easy introductory exposition of the phenomena and theory of wing flutter. Part I is non-mathematical and complete in itself. In it an attempt is made to give a clear account of the cause of flutter in simple language, and the discussion is illustrated by reference to experiments with the "flutter engine". This consists of an aerofoil which is moved in roll and pitch by cranks on a single shaft. The angular setting of these can be varied so as to exhibit the vital influence of the phase relation of the motions upon the stability. Part I also contains a discussion of flutter prevention and of wing divergence.

In Part II the elements of the theory are presented in easily assimilable form, and most of the mathematical details are given in Appendices. Those are devoted to phase and amplitude relations in flutter, the test function for stability and the energy account.

Although the paper is primarily intended for non-expert readers, the treatment and some of the results in the text and Appendices may be of interest to experts.

REFERENCES TO LITERATURE

(1) R. A. Frazer and W. J. Duncan. "Introduction to 'The Flutter of Aeroplane Wings'." *R. & M.* 1155, 1928 (A.R.C. Monograph.)

(2) R. A. Frazer and W. J. Duncan. "A Brief Survey of Wing Flutter, with an Abstract of Design Recommendations." *R. & M.* 1177, 1928.

(3) R. A. Frazer. "The Flutter of Aeroplane Wings." *Jour. Roy Aero. Soc.*, June 1929.

(4) R. A. Frazer and W. J. Duncan. "Introduction to 'The Flutter of Monoplanes, Biplanes and Tail Units.'" *R. & M.* 1255, 1931 (A.R.C. Monograph).

(5) B. Lockspeiser. "A Simple Approach to the Wing Flutter Problem." *Jour. Roy. Aero. Soc.*, July, 1933.

(6) A. G. Pugsley. "A Simplified Theory of Wing Flutter." *R. & M.* 1839, 1937.

(7) W. J. Duncan. "The Representation of Aircraft Wings, Tails and Fuselages by Semi-Rigid Structures in Dynamic and Static Problems." *R. & M.* 1904, 1943.

(8) R. A. Frazer and W. J. Duncan. "On the Criteria for the Stability of Small Motions." *Proc. Roy. Soc. A.*, Vol. 124, 1929, p. 642.

(9) H. Glauert. "The Force and Moment on an Oscillating Aerofoil." *R. & M.* 1242, 1929.

(10) W. J. Duncan and A. R. Collar. "Resistance Derivatives of Flutter Theory." *R. & M.* 1500, 1932.

(11) H. M. Lyon. "A Review of Theoretical Investigations of the Aerodynamic Forces on a Wing in non-uniform Motion." *R. & M.* 1786, 1937.

(12) R. A. Frazer and W. P. Jones. Paras. 8 and 10 of "Wing-Aileron—Tab Flutter." *A.R.C.* 5668, 1942.

(13) W. J. Duncan and H. M. Lyon. "Calculated Flexural-Torsional Flutter Characteristics of some typical Cantilever Wings." *R. & M.* 1782, 1937.

(14) J. Williams. "Methods of Predicting Flexure-Torsion Flutter" *A.R.C.* 6574, 1943.

(15) P. Cicala. "The Torsion Bending Oscillations of a Wing in a Uniform Current." (Translation dated July 1937.) *A.R.C.* 3030.

(16) H. Stüder. "Experimental Study of Wing Flutter." (Translation dated December 1936.) *A.R.C. Oscil. Paper* No. 60.

(17) M. Victory. "Flutter at High Incidence." *A.R.C.* 6537. January 1943.

PART I

NON-MATHEMATICAL DISCUSSION

The Phenomena of Flutter

The aim is to make plain the physical causation of flutter, which is still mysterious to many, but first it is necessary to describe the typical phenomena. For definiteness, consider a cantilever wing without aileron mounted in a wind tunnel at a small angle of incidence and with rigid support at the root. Some means for imposing a momentary disturbance is provided, such as a rod which can be made to deflect the wing tip. When the wing is slightly disturbed in still air or in a current of moderate speed, the oscillations which are set up decrease in amplitude more or less quickly, and finally the wing comes to rest. However, at the *critical wind speed* an oscillation can just maintain itself with steady amplitude, while at a slightly higher wind speed the motion grows until the amplitude may become large enough to break the wing. At wind speeds a little above the critical a very small accidental disturbance of the wing, such as might be caused by a slight irregularity in the air stream, can serve as a trigger to initiate an oscillation of great violence. In such circumstances the wing suffers from oscillatory instability and is said to flutter.

Experiments on wing flutter reveal the following outstanding facts:

(*a*) The oscillation is self-maintained, i.e. no external oscillator or forcing agency is required.

(*b*) The motion can maintain itself or grow for a range of wind speeds which is more or less wide according to the design of the wing and to the conditions of the test. For a simple cantilever wing, flutter will usually occur at any wind speed above the critical. In other instances there may be one or more ranges of speed for which flutter occurs, and these are bounded at both ends by critical speeds at which an oscillation of constant amplitude can just maintain itself.

(*c*) For a given wing under constant conditions of incidence, temperature, humidity and air density, the critical flutter speeds are constant.

(*d*) The oscillatory motion has essentially both flexural and torsional components. If the wing is constrained so that either bending or twisting is prevented, then flutter does not occur.‡

(*e*) The steady oscillations which occur at the critical speed are simple harmonic. The flexural movements at all points are at least approximately in phase with one another, and likewise the torsional movements are all at least approximately in phase with one another, but the flexural and torsional movements are not in phase. (In fact, the torsional displacement lags considerably behind the bending.)

(*f*) The critical flutter speed depends largely on the flexural and torsional elastic stiffnesses of the wing. A proportional increase of both of these raises the critical speed approximately in proportion to the square-root of either.

(*g*) The critical flutter speed is greatly influenced by the way in which the mass of the wing is distributed, especially along the wing chords. Flutter can usually be completely prevented by suitably arranging the mass distribution.

The Causation of Flutter

It is evident that a fluttering wing acts as an air engine or mechanism whereby energy is absorbed from the air-stream and imparted to the wing itself; a fluttering wing in a wind tunnel could by suitable arrangements be made to do useful external work. A clue to the manner in which this can happen is provided by items (*d*) and (*e*) above. When the wing twists, the angle of incidence is altered, especially near the tip, and this entails a corresponding change in the lift force acting on each fore-and-aft strip of the wing. During an oscillation the additional lift force due to the twist varies cyclically and the bending displacement also varies cyclically. In general, the lift due to the twist will be doing positive work upon the wing during part of the cycle and negative work during the remainder of the cycle, and the motion will maintain itself when the net positive work done per cycle just balances the dissipation of energy due to the various damping actions which are present. A little consideration shows that the sign and magnitude of the net work done upon the wing by the additional lift force which is due to the wing twist depends on the phase relation of the flexural and torsional motions. Take first the case where torsion is in phase with flexure. At mid-swing (see Fig. 1A) both the flexural displacement and twist are zero. As the wing moves up, the wing twists in the nose-up sense in proportion to the bending displacement and the lift due to the twist does positive work on the wing during the quarter cycle until the flexural displacement reaches its upward maximum. On the return stroke, however, the lift due to the twist opposes the motion, and by the time the wing returns to its mean position the net work done by the lift is zero. The same is true for the second half cycle during which the flexural displacement is downwards, so that the net work done by the lift during a complete cycle is zero. Next, suppose that the twist lags 90 deg. behind the flexure (see Fig. 1B) and let the wing be at the beginning of an upward flexural swing.§ At this instant the twist is zero, but as the wing moves up, a nose-up twist develops, which is at its maximum at mid-stroke, and dies away to zero at the upper end of the stroke. Consequently the extra lift due to twist does positive work during the whole up-stroke. During the whole down-stroke the twist is nose-down, so that the extra lift is downward and does positive work. Hence the extra lift due to wing twist here does

 The wriiter is indebted to Mr. John Williams of the National Physical Laboratory for carrying out the calculations on which Figs. 4, 5, 12 and 13 are based.

† Wakefield Professor of Aeronautics at University College, Hull.

‡ This is not necessarily true when the angle of incidence is at or near the stalling angle. The argument is restricted to "classical" flutter, such as occurs at small incidences. On stalling flutter, see later under this heading.

§ As usual, flexural displacement is positive downward and torsional displacement is positive when T.E. moves down relative to L.E. If either one of these sign conventions were reversed it would be necessary to change "lagging" into "leading".

positive work on the wing at all times, and the net work per cycle is of course positive.*

When a given wing oscillates freely in an airstream of given speed, density and direction, the phase difference between the flexural and torsional motions is definite.† This phase difference is, as has been shown, of great significance in determining whether the wing can or cannot abstract enough energy from the airstream to overcome the damping actions, and its value depends on the mechanical and aerodynamic charactersitics of the wing, and largely on the air speed. Thus, without attempting at the moment to give any precise analysis of the causation of flutter, we can say that an adequate cause is known and that it will become effective in suitable circumstances.

* The dependence of work done on phase difference is, of course, very familiar in relation to alternating currents, where power in watts=volts × amperes × power factor, and power factor=cosine of angle of phase difference between current and voltage. In making a comparison with flutter, it should be remembered that electric current is the rate of change of the electric quantity, which corresponds to displacement, while voltage corresponds to force. For a wattless current this lags (or leads) the voltage by 90 degrees, but then the electric quantity or displacement is in phase (or 180 degrees out of phase) with the voltage.

† The wing can oscillate in a variety of different modes, but to simplify the argument attention is confined to that mode which develops into flutter at the lowest air speed.

The Flutter Engine

The manner in which the phase difference between the flexural and torsional oscillations of a wing influences the energy input can be strikingly illustrated by experiments with an apparatus which has been named the "flutter engine". This apparatus was devised by Mr. D. L. Ellis and the writer, and a rough but effective model was constructed at the National Physical Laboratory in 1932. This has been frequently exhibited at the National Physical Laboratory, at the Royal Air Force School of Aeronautical Engineering, Henlow, and elsewhere. Photographs of the model flutter engine are reproduced in Figs. 2A and 2B.

The flutter engine consists essentially of a rigid aerofoil which is carried by a spindle running spanwise and about which it can rotate in pitch, while the spindle can rotate in roll about a fixed axis which is parallel to the chord of the aerofoil when the latter is in its normal or undisturbed position. The pitching and rolling motions are separately imparted by means of connecting rods and cranks, and the special feature of the design is that the angular setting of the cranks can be varied at will by means of a gear placed between them, so that the phase relation of the oscillations in pitch and roll can be correspondingly varied and controlled. The phase-changing gear consists of an adaptation of the differential gear which is illustrated in Fig. 3. When the bracket supporting the intermediate pinion is rotated through any angle the angular setting of the cranks is changed by twice the angle.

Suppose that the gear is set for a phase difference of θ degrees. Then for one direction of rotation of the flywheel the pitching (which corresponds to torsion) will lag behind the rolling (or flexure) by θ degrees, while for the reversed direction of rotation it will lead by θ degrees. Let the flutter engine be fixed in a wind tunnel and exposed to a wind of, say, 50 feet per second. With the phase setting at

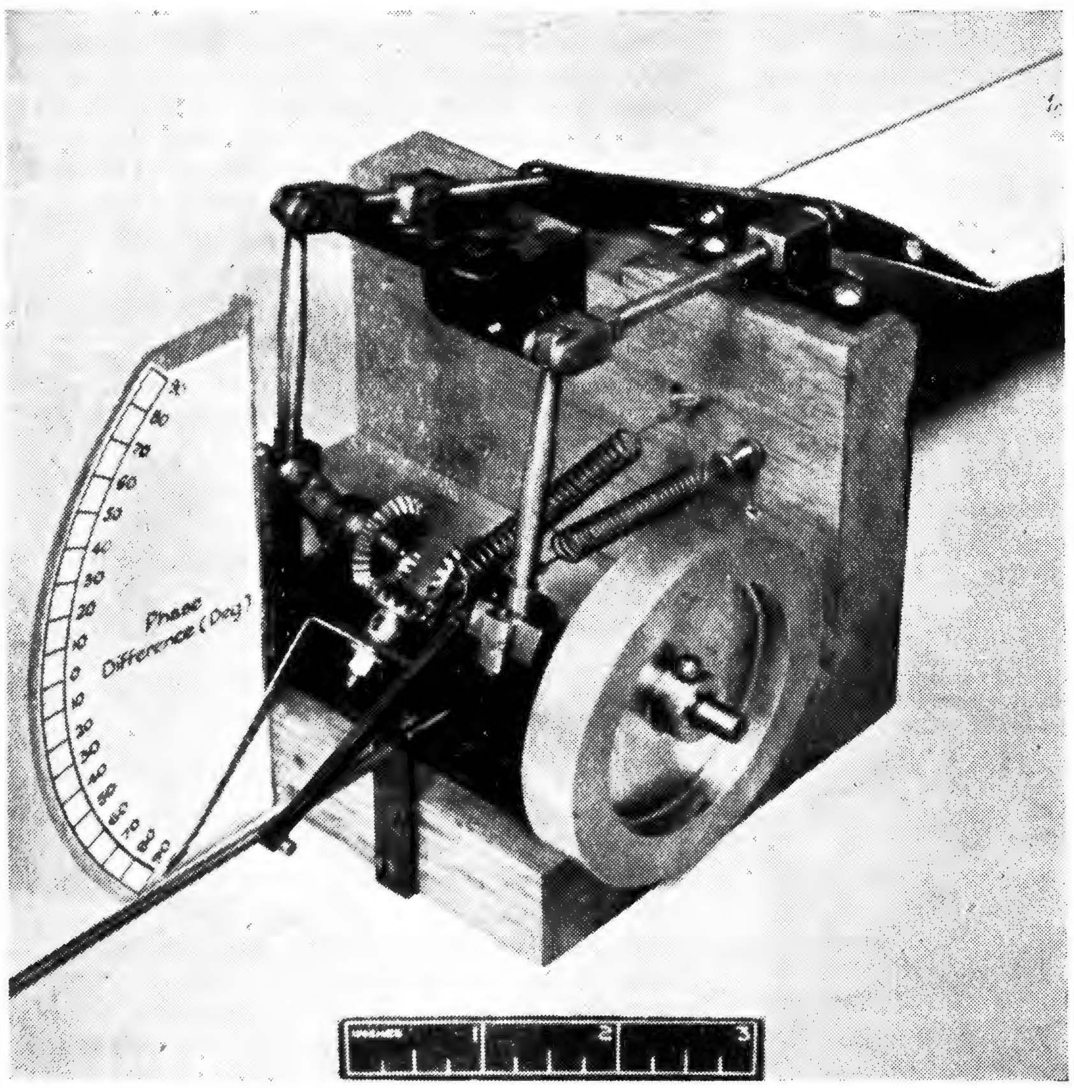


FIG. 2 (a).—*Details of gear of flutter engine. Rolling crank on right. Pitching crank on left. Spring on right for pull. Rolling crank off dead centre. Return spring for phase-changing gear on left*

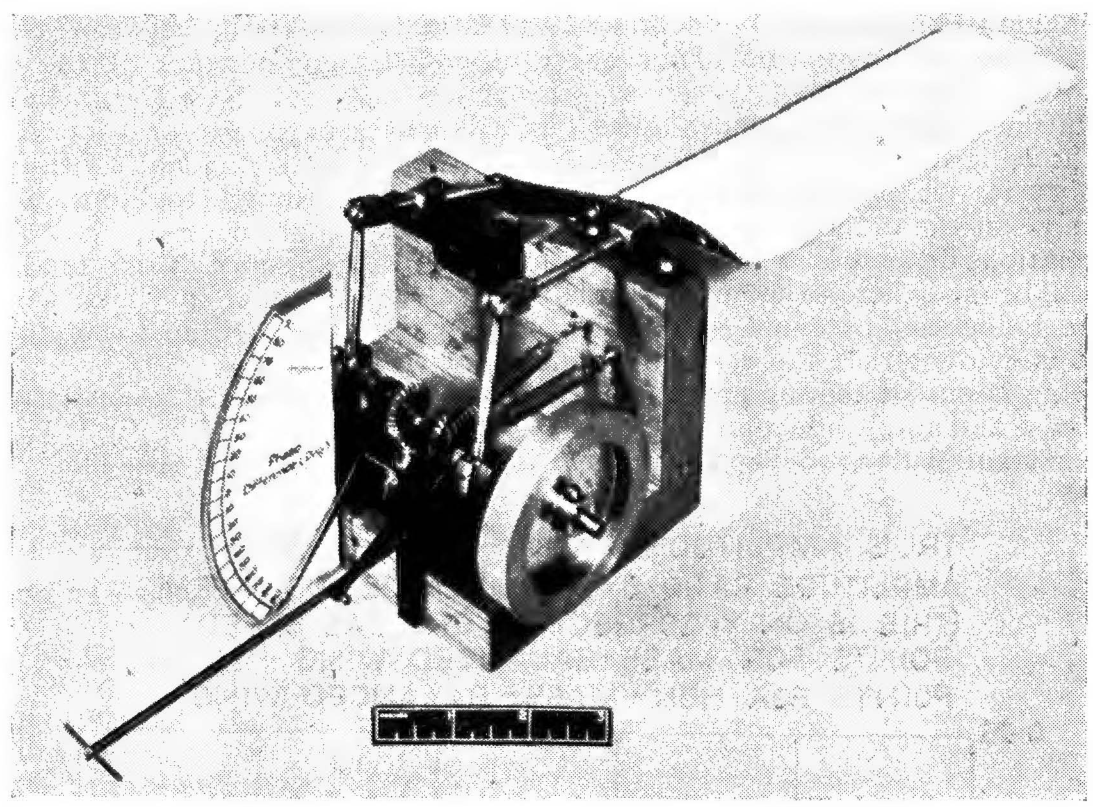


FIG. 2 (b).—*General view of flutter engine. The rod for control of phase projects to the left*

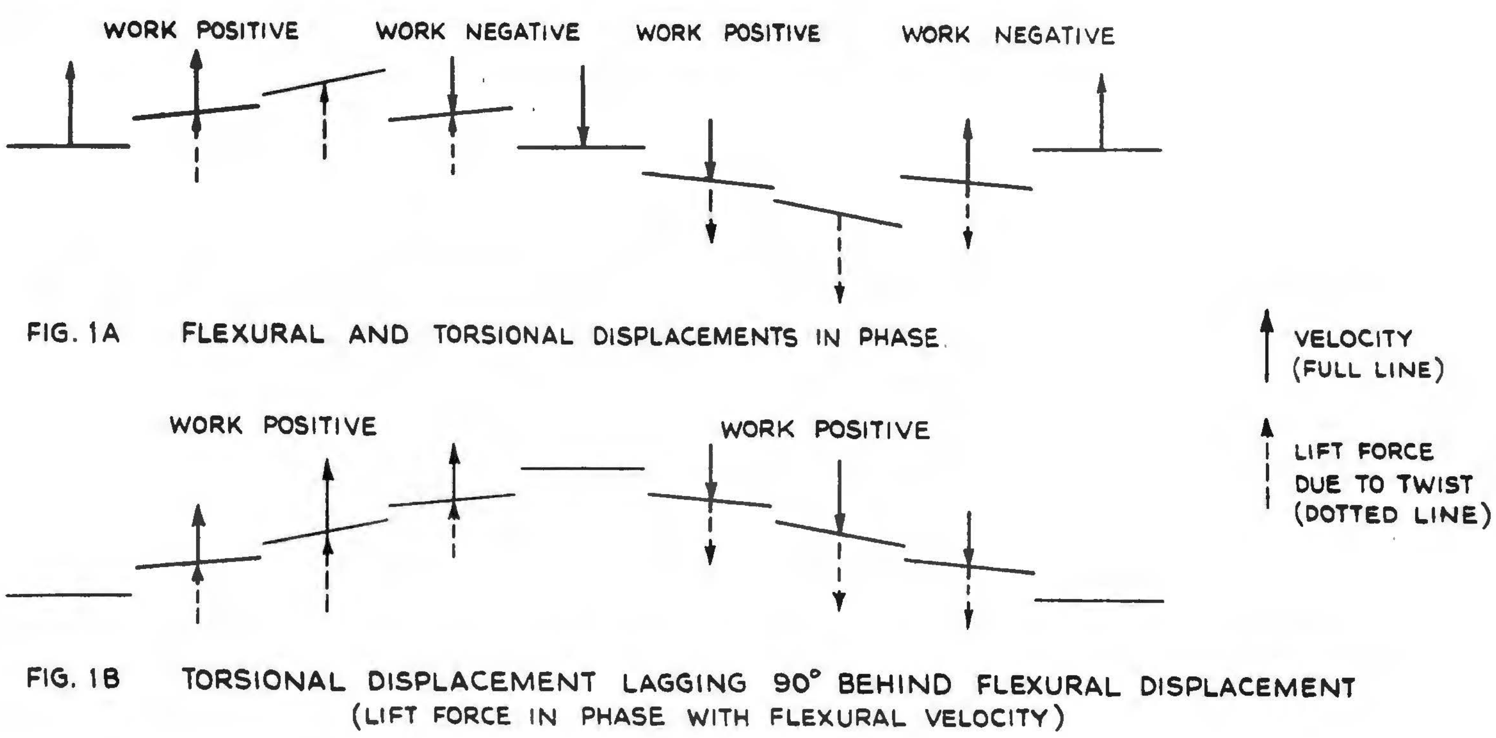


FIG. 1.—*Dependence of work done by aerodynamic force on phase difference. Flexural and torsional wing displacements during a complete cycle, showing wing tip in end view at intervals of 1/8th of a period—relative wind blowing from right to left*

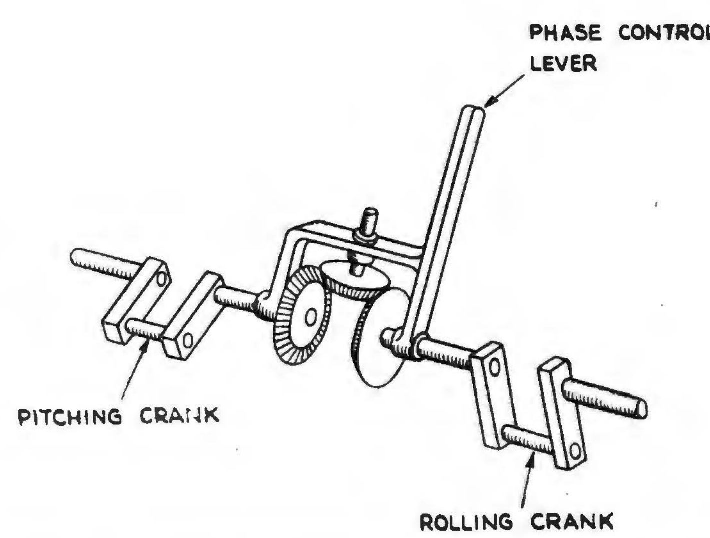


FIG. 3.—*Detail of phase-changing gear for flutter engine*

90 degs. the engine will run freely in such a direction that the pitching lags behind the rolling (it may be necessary to give the engine a start by hand, as otherwise the rolling crank may stick at dead-centre). As the phase angle is reduced the engine runs more and more slowly until at about 10 deg. it stops. If, when the engine is running freely, the phase setting is suddenly reversed, the engine will stop and then run in the opposite direction, so that the phase difference is finally unaltered. All this is completely analogous to the manner in which a steam engine responds to the operation of its valve gear.

The Existence of Critical Flutter Speeds

It is a fact of fundamental importance that the amplitude ratio and phase difference of the flexural and torsional wing motions which follow an imposed disturbance depend largely on the speed with which the air streams past the wing. This is illustrated in Figs. 4 and 5, which refer to a cantilever wing of 24 ft. overhang and 6 ft. mean chord. When such great changes of phase angle accompany change of wind speed, it is not difficult to understand, on the basis of the argument already given, that flutter may begin at some definite critical speed. To make this clear, it might be supposed that the phase setting and crank radii of the flutter engine were automatically controlled by the wind speed so as to give the same amplitude ratio and phase relation as for the wing at all speeds. To complete the analogy, the flywheel of the engine would have to be so braked (or assisted) that the total dissipation of energy corresponded to that for the wing. When so arranged, the flutter engine would show critical speeds like the wing itself.

It is not possible without mathematics to show in detail how the amplitude and phase relations depend on wind speed, but an attempt will be made here to show clearly that they must be influenced by wind speed. To begin with, it is evident that the torsional stiffness of the wing is one of the factors which influences the phase and amplitude relations. Now the effective torsional stiffness depends on the wind speed; for it is the sum of two parts, which are elastic (due to the wing structure) and aerodynamic respectively. The origin of the aerodynamic torsional stiffness is that when the wing twists and the incidence consequently changes, the aerodynamic forces brought into play have a twisting moment, which is in proportion to the angle of twist. When a moment varies proportionately to angular displacement there is, in effect, a stiffness, because the same result could be obtained by the attachment of suitable springs. The aerodynamic torsional stiffness is proportional to the square of the wind speed, for the aerodynamic forces themselves depend on wind speed in this manner, but it also depends on the position of the torsion axis of the wing in the wing chord. It is easy to see that if twist occurs about the leading edge the aerodynamic forces will oppose the twist, and this corresponds to a positive stiffness. But if twist occurs about the trailing edge the aerodynamic forces will assist the twist, so that the stiffness is negative (see also Fig. 10). There is an intermediate position, at about one quarter of the chord behind the leading edge, for which the aerodynamic stiffness is zero. It should be added that detailed analysis shows that the composite nature of the torsional stiffness is not the only cause of the variation of the phase and amplitude relations with wind speed.*

The Prevention of Flutter

The preceding discussion has shown how flutter can occur when there is a suitable phase relation between the torsional and flexural components of the oscillatory motion of the wing. Now the existence of *any* definite relation in phase or amplitude between the flexural and torsional motions depends on these being coupled together. In general, two kinds of motion or deformation are coupled when the presence of one tends to induce the other. The manner in which wing flexure and torsion are coupled must therefore be examined.

As a first step it is necessary to be clear and definite about the ways in which bending and twist of the wing are measured, and, for brevity, attention will be confined to the method which has now become standard. A *reference section* of the wing is chosen fairly near to the tip†, and the twist is defined as the angular displacement (in radians) from the position of equilibrium of a fore-and-aft slice of the wing at the reference section. This slice is assumed to move as a rigid body‡ and the twist is taken to be positive when the leading edge moves up in relation to the trailing edge. In order to define precisely the measure of the bending displacement a *reference point* is chosen in the reference section, and the displacement of this point perpendicular to the plane of the wing defines the flexural displacement. As it is convenient to use a non-dimensional measure of flexure, this is taken as the displacement of the reference point divided by its distance from the wing root; i.e. the angular displacement in radians of the reference point about the wing root. The flexural displacement is positive when downward.

Consider now static loading tests of the wing. If a pure twisting couple be applied at the reference section the reference point will, in general, move, so that a flexural displacement is induced and this implies the elastic coupling of flexure and torsion. Reciprocally, a normal bending load applied at the reference point will produce twist as well as bending. However, there is a point in the section, usually known as the *flexural centre* or *elastic centrum*, which has the following reciprocal properties:

(*a*) It does not move when a pure twisting couple is applied at the section.

(*b*) No twist is produced when a normal bending load is applied at the centrum.

The results of applying a given normal load near the leading edge, at the flexural centre and near the trailing edge respectively are shown diagrammatically in Fig. 6, together with the result of applying a pure twisting couple. Let it be agreed, in accordance with the convention

* It can be shown that if the flexural and torsional elastic stiffnesses were both zero the phase and amplitude relations would be independent of wind speed. Such a wing would either flutter at all speeds or not flutter at all.

† The British practice is to take the reference section at 0·7 of the total overhang from the wing root.

‡ This means that the small local distortions are ignored.

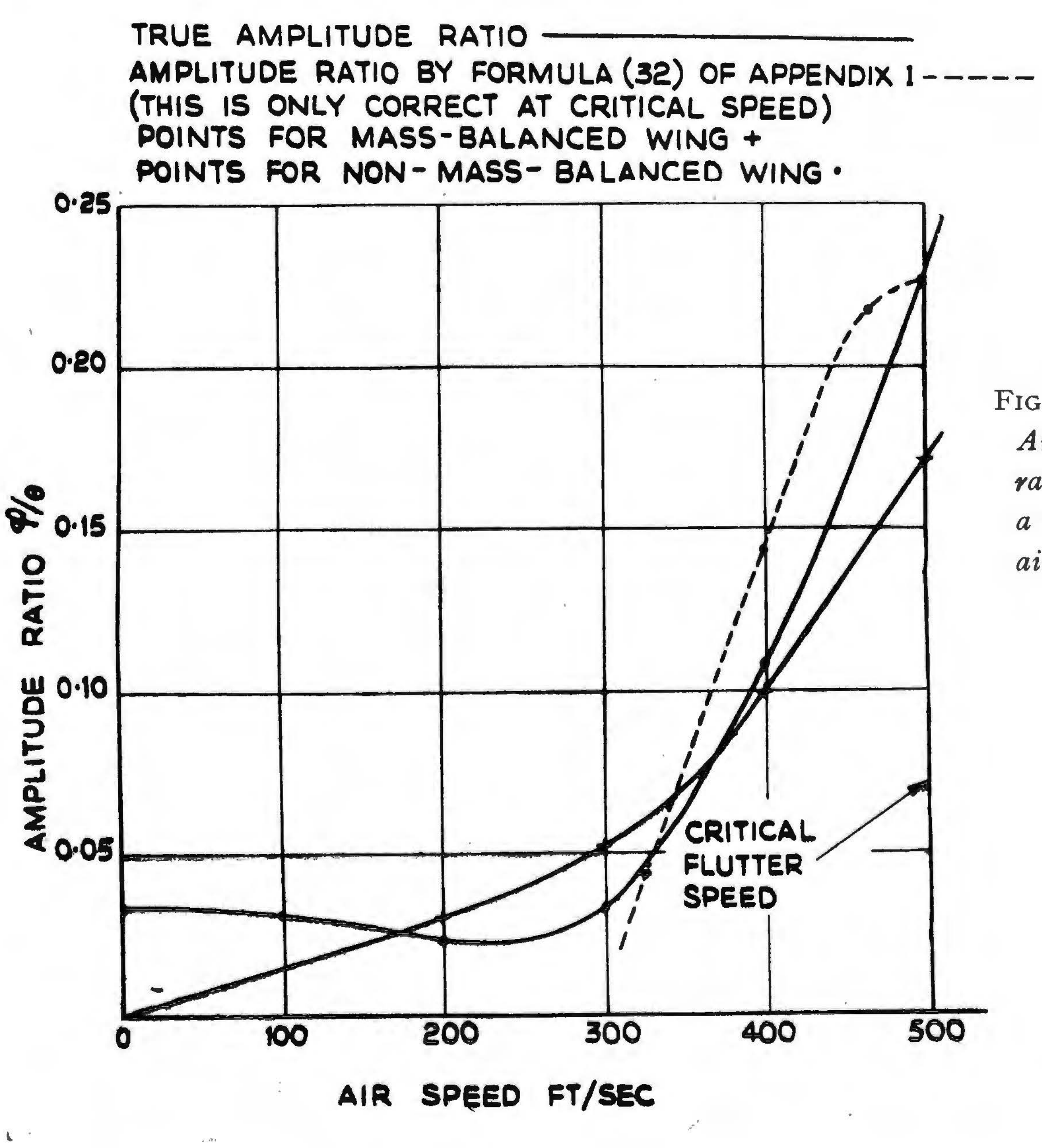


FIG. 4.—*Amplitude ratios for a range of airspeeds*

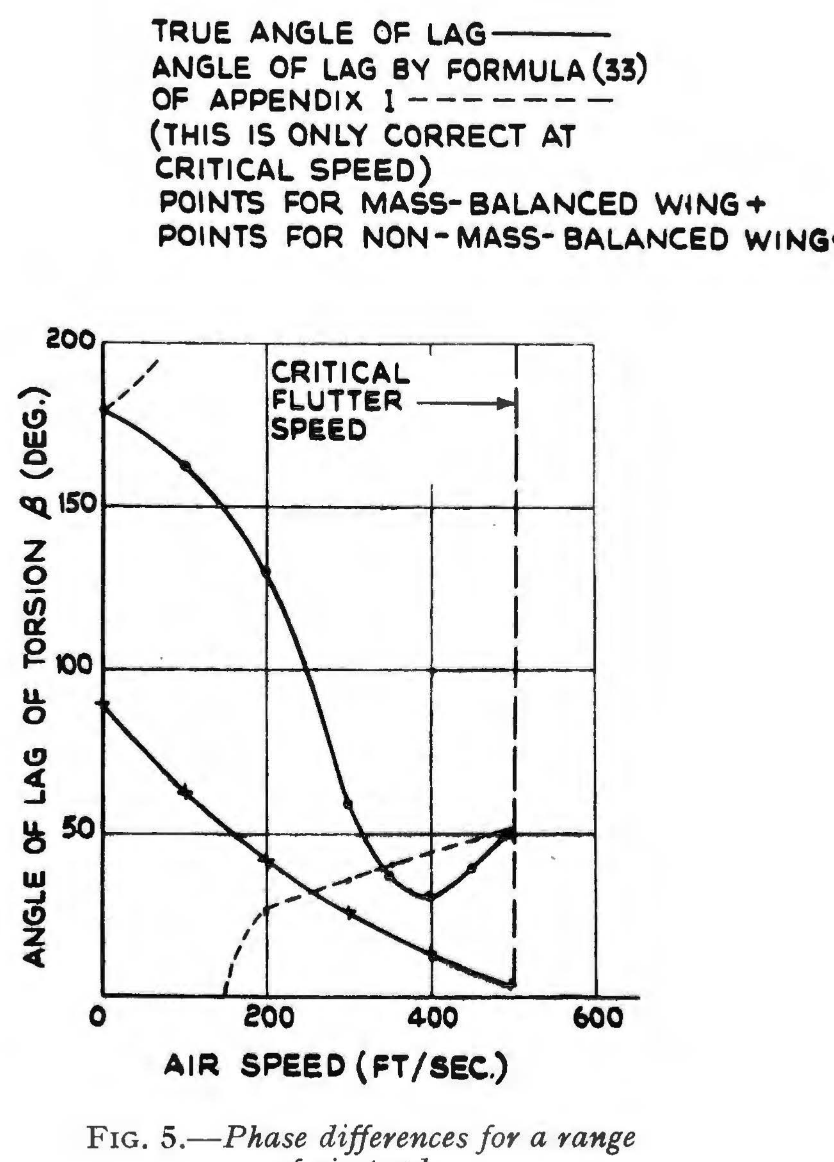


FIG. 5.—*Phase differences for a range of airspeeds*

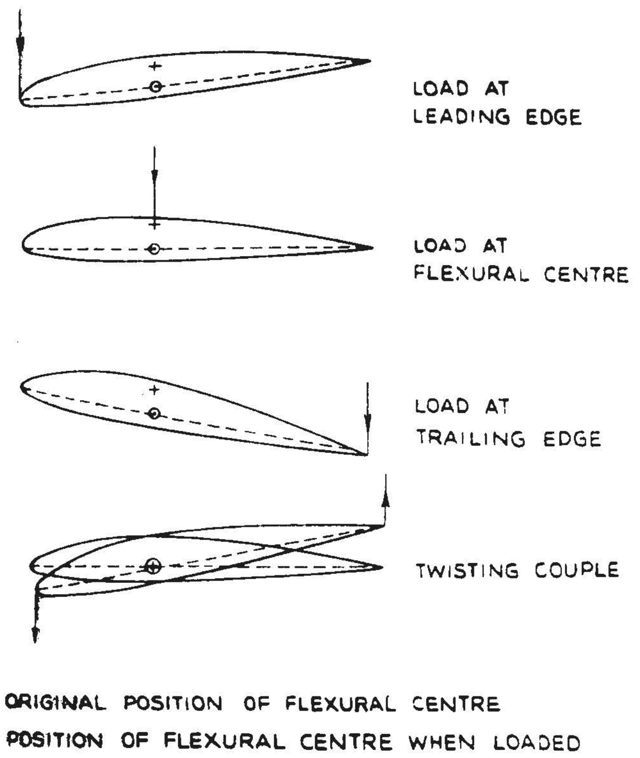


FIG. 6.—*Effects of flexural loads and twisting couple*

which is now universal, to adopt the flexural centre in the reference section as the reference point. Then a pure flexural load produces bending without twist, and reciprocally a pure twisting load produces twist without bending. Hence, with this choice of reference point, flexure and torsion are not coupled by elastic forces.

Next consider oscillations of the wing in still air. Suppose that the wing is held twisted in such a manner that the reference point (flexural centre) is not moved from its position of equilibrium, and then suddenly released. In general it will be found that the ensuing motion is not purely torsional, so that some coupling of flexure to torsion must be present. Since there is no elastic coupling and since the aerodynamic forces in such a test are very small, it follows that the coupling must be of inertial origin. The way in which inertial coupling of flexure and torsion can arise will be clear from Fig. 7, which shows the wing accelerating upwards (and untwisted). Since the acceleration is upward, the force applied to the wing by any carried mass is downward. Thus, if the mass is near the leading edge there is a nose-down (negative) twisting moment, whereas, if the mass is near the trailing edge, the twisting moment is nose-up (positive). Lastly, if the mass is at the flexural centre there will be no twisting moment, and it is easy to see that the resultant twisting moment due to a number of masses in the reference section will be zero when their centre of mass coincides with the flexural centre. It is thus clear that flexure and torsion will, in general, be coupled by inertia, and the magnitude of this coupling is measured by what is called the *product of inertia*. Further, it is possible to arrange the masses of the wing in such a manner that the product of inertia is zero; the wing is then said to be *mass-balanced*. For such a wing a pure flexural (or a pure torsional) oscillation can occur in still air without any tendency to induce the other kind of movement.

Lastly it is necessary to consider the couplings which are due to the aerodynamic forces when the wing moves bodily through the air, and attention will be confined here to cases where the angle of incidence of the wing is small. It is obvious that flexural loads are induced when the wing twists, since the angles of incidence of the various parts of the wing are altered by the twist. Thus flexural moments are produced by torsional displacements. On the other hand, a flexural displacement of the wing does not alter the angles of incidence, so that there is no twisting moment due to flexural displacement.*

* The coupling terms due to elasticity or inertia are ***symmetrical;*** i.e. the corresponding coupling coefficients in the equations of flexural and of torsional moments are equal. As just shown, however, the aerodynamic couplings are not symmetrical and it is largely on account of this that the aerodynamic forces can render the wing unstable (see Appendix III).

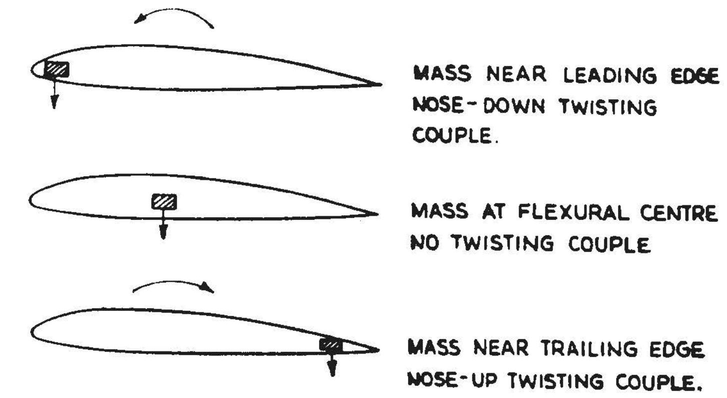


FIG. 7.—*Twisting actions due to masses in various positions—wing in upward acceleration. Arrows show directions of inertia force and twisting couple*

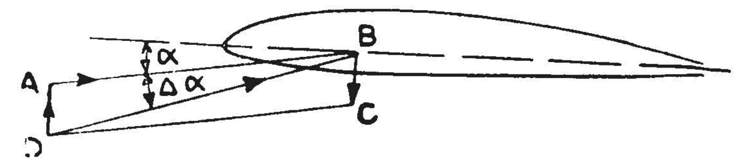


FIG. 8.—*Incidence change due to flexural velocity of wing*

AB = *Velocity of air relative to stationary wing*

BC = *Flexural velocity of wing*

DA = *Flexural velocity of wing (reversed)*

DB = *Resultant velocity of air relative to wing in flexural motion*

There is, in general, a coupling term in the equation of torsional moments due to *flexural velocity*. The reason for this is that when the wing has a flexural velocity (say downward) the angle of incidence of the air current relative to the wing is altered (increased), as will be clear from Fig. 8. Hence the lift will be increased and there will be an induced twisting moment unless the centre of pressure of the additional lift force happens to coincide with the flexural centre. The effective centre of these additional lift forces, when imagined to be transferred to the reference section, is called the *centre of independence;* it is a kind of averaged aerodynamic centre for the entire wing. Thus there will be a coupling term due to flexural velocity in the equation of torsional moments unless the wing is so constructed that the flexural centre at the reference section coincides with the centre of independence. There are other coupling terms which, however, need not be considered now as they are unimportant in relation to the understanding of the practical methods of flutter prevention.†

The basic principle in flutter prevention is the elimination, so far as possible, of the couplings between the motions in the several degrees of freedom, so that these motions become (ideally) independent of one another. Then, provided that each of these motions is damped, as it will be for small angles of incidence of the wing, flutter will be completely prevented. It remains to show in detail how this can be achieved.

Consider a wing whose flexural centre (in the reference section) coincides with the centre of independence and which is mass-balanced about the flexural centre. Then the torsional motion is uninfluenced by the flexural motion because all the coupling terms in the equation of torsional moments have been removed. For:

(i) There is no coupling due to flexural acceleration since the wing is mass-balanced.

(ii) There is no coupling due to flexural velocity since the centre of independence coincides with the reference centre (flexural centre).

(iii) There is no coupling due to flexural displacement since flexural displacement does not give rise to any aerodynamic moment and the elastic coupling is absent in virtue of the choice of the flexural centre as reference centre.

Any torsional movement of the wing initiated by a gust or manœuvre proceeds inde-

† There is a coupling term in the equation of flexural moments due to torsional velocity, and there are aerodynamic coupling terms due to torsional and flexural accelerations. The latter, called acceleration derivatives, can be included with the product of inertia of the wing itself.

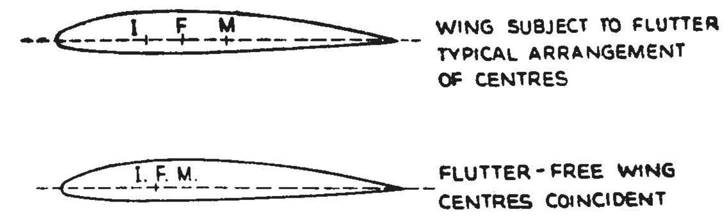


FIG. 9.—*Arrangement of centres for wings subject to and free from flutter*

I = *Centre of independence*

F = *Flexural centre*

M = *Mass centre*

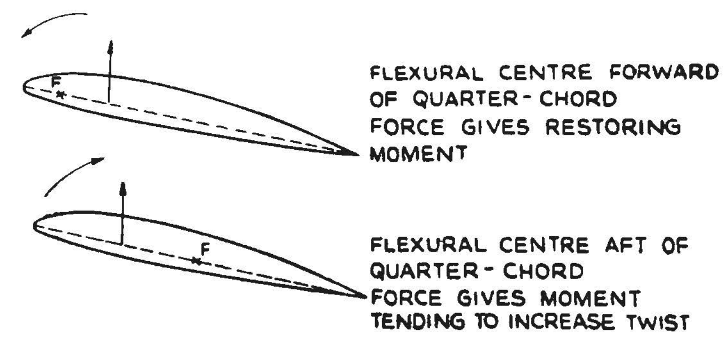


FIG. 10.—*Twisting action of aerodynamic force due to wing twist—Wing twisted in nose-up sense*

pendently of the flexural movements which may be present, and ultimately dies out since the pure torsional movement is damped, provided that the wing is not near to stalling incidence. The coupling terms in the equation of flexural moments cannot be completely eliminated‡, but this is of no consequence because the torsional motion itself dies away and therefore cannot continue to affect the flexure. The flexural motion is damped and ultimately dies away, so that complete rest is the final state after any disturbance. Thus the wing is stable and flutter is prevented. A flutter-free wing and another capable of flutter are compared in Fig. 9.

The foregoing argument has shown that flutter will certainly be prevented when the flexural centre coincides with the centre of independence and the wing is mass-balanced about this common centre. There is, however, some tolerance on the mass-balance and position of the flexural centre, so that flutter may still be completely prevented when the ideal conditions are not exactly satisfied. Even when these conditions are seriously violated the critical flutter speed may be above any attainable speed of flight, and this can always be ensured by making the torsional elastic stiffness of the wing sufficiently large.

Wing Divergence

Flutter is an oscillatory instability, i.e. a free oscillation of growing amplitude, but an instability in which the motion is uni-directional is also possible, and is called a *divergence*. The manner of occurrence of wing divergence will now be briefly discussed.

Divergence of a wing takes place when its total torsional stiffness vanishes or becomes negative. This stiffness is compounded of an elastic part, which is positive and independent of the speed of flight, and of an aerodynamic part which is proportional to the square of the speed and is positive or negative according to the design of the wing. Divergence can only happen when the aerodynamic torsional stiffness is negative.

When the wing twists through a small angle (say in the nose-up sense) the additional lift force caused by the increase in incidence acts at the aerodynamic centre§. It will be evident from the diagram (Fig. 10) that this force will tend to twist the wing in the nose-down sense, i.e. to resist the twist, when it acts behind the flexural centre, whereas it will tend to increase the twist when it acts forward of the flexural centre. In either case the force will, for small

‡ The aerodynamic coupling term due to torsional displacement is necessarily present.

§ This is at or near the quarter-chord point.

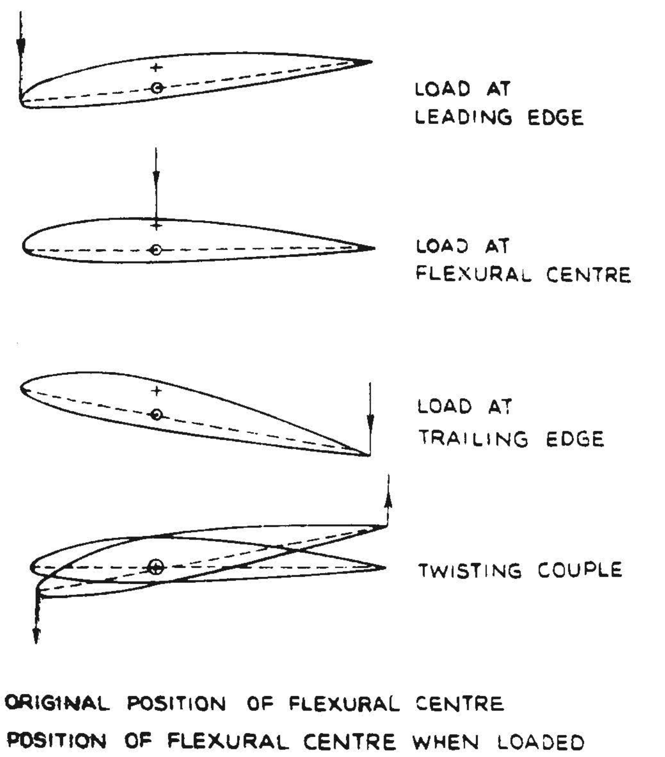


FIG. 6.—*Effects of flexural loads and twisting couple*

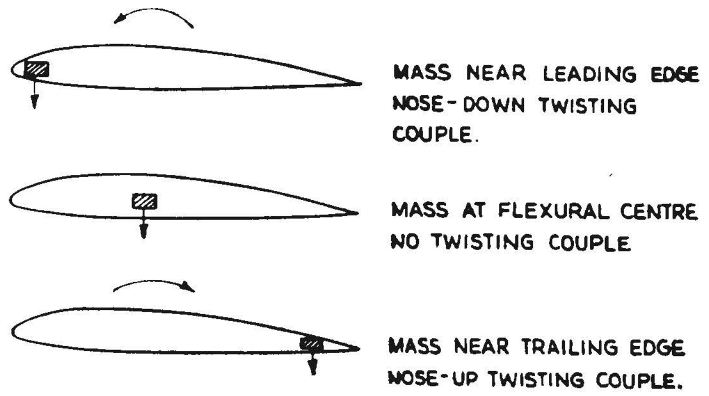


FIG. 7.—*Twisting actions due to masses in various positions—wing in upward acceleration. Arrows show directions of inertia force and twisting couple*

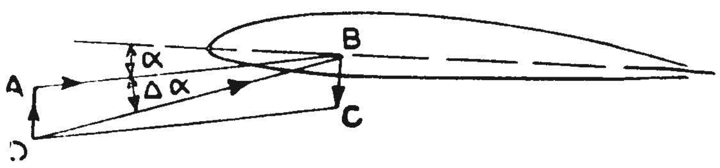


FIG. 8.—*Incidence change due to flexural velocity of wing*
AB = Velocity of air relative to stationary wing
BC = Flexural velocity of wing
DA = Flexural velocity of wing (reversed)
DB = Resultant velocity of air relative to wing in flexural motion

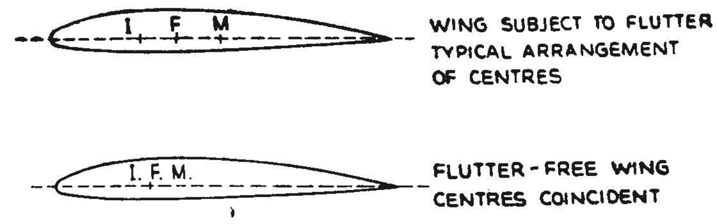


FIG. 9.—*Arrangement of centres for wings subject to and free from flutter*
I = Centre of independence
F = Flexural centre
M = Mass centre

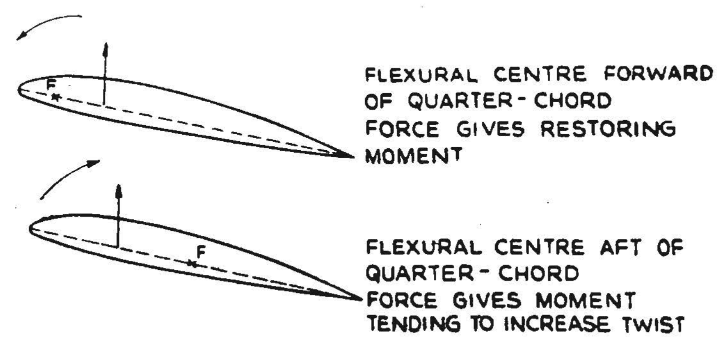


FIG. 10.—*Twisting action of aerodynamic force due to wing twist—Wing twisted in nose-up sense*

which is now universal, to adopt the flexural centre in the reference section as the reference point. Then a pure flexural load produces bending without twist, and reciprocally a pure twisting load produces twist without bending. Hence, with this choice of reference point, flexure and torsion are not coupled by elastic forces.

Next consider oscillations of the wing in still air. Suppose that the wing is held twisted in such a manner that the reference point (flexural centre) is not moved from its position of equilibrium, and then suddenly released. In general it will be found that the ensuing motion is not purely torsional, so that some coupling of flexure to torsion must be present. Since there is no elastic coupling and since the aerodynamic forces in such a test are very small, it follows that the coupling must be of inertial origin. The way in which inertial coupling of flexure and torsion can arise will be clear from Fig. 7, which shows the wing accelerating upwards (and untwisted). Since the acceleration is upward, the force applied to the wing by any carried mass is downward. Thus, if the mass is near the leading edge there is a nose-down (negative) twisting moment, whereas, if the mass is near the trailing edge, the twisting moment is nose-up (positive). Lastly, if the mass is at the flexural centre there will be no twisting moment, and it is easy to see that the resultant twisting moment due to a number of masses in the reference section will be zero when their centre of mass coincides with the flexural centre. It is thus clear that flexure and torsion will, in general, be coupled by inertia, and the magnitude of this coupling is measured by what is called the *product of inertia*. Further, it is possible to arrange the masses of the wing in such a manner that the product of inertia is zero; the wing is then said to be *mass-balanced*. For such a wing a pure flexural (or a pure torsional) oscillation can occur in still air without any tendency to induce the other kind of movement.

Lastly it is necessary to consider the couplings which are due to the aerodynamic forces when the wing moves bodily through the air, and attention will be confined here to cases where the angle of incidence of the wing is small. It is obvious that flexural loads are induced when the wing twists, since the angles of incidence of the various parts of the wing are altered by the twist. Thus flexural moments are produced by torsional displacements. On the other hand, a flexural displacement of the wing does not alter the angles of incidence, so that there is no twisting moment due to flexural displacement.*

There is, in general, a coupling term in the equation of torsional moments due to *flexural velocity*. The reason for this is that when the wing has a flexural velocity (say downward) the angle of incidence of the air current relative to the wing is altered (increased), as will be clear from Fig. 8. Hence the lift will be increased and there will be an induced twisting moment unless the centre of pressure of the additional lift force happens to coincide with the flexural centre. The effective centre of these additional lift forces, when imagined to be transferred to the reference section, is called the *centre of independence;* it is a kind of averaged aerodynamic centre for the entire wing. Thus there will be a coupling term due to flexural velocity in the equation of torsional moments unless the wing is so constructed that the flexural centre at the reference section coincides with the centre of independence. There are other coupling terms which, however, need not be considered now as they are unimportant in relation to the understanding of the practical methods of flutter prevention.†

The basic principle in flutter prevention is the elimination, so far as possible, of the couplings between the motions in the several degrees of freedom, so that these motions become (ideally) independent of one another. Then, provided that each of these motions is damped, as it will be for small angles of incidence of the wing, flutter will be completely prevented. It remains to show in detail how this can be achieved.

Consider a wing whose flexural centre (in the reference section) coincides with the centre of independence and which is mass-balanced about the flexural centre. Then the torsional motion is uninfluenced by the flexural motion because all the coupling terms in the equation of torsional moments have been removed. For:

(i) There is no coupling due to flexural acceleration since the wing is mass-balanced.

(ii) There is no coupling due to flexural velocity since the centre of independence coincides with the reference centre (flexural centre).

(iii) There is no coupling due to flexural displacement since flexural displacement does not give rise to any aerodynamic moment and the elastic coupling is absent in virtue of the choice of the flexural centre as reference centre.

Any torsional movement of the wing initiated by a gust or manœuvre proceeds independently of the flexural movements which may be present, and ultimately dies out since the pure torsional movement is damped, provided that the wing is not near to stalling incidence. The coupling terms in the equation of flexural moments cannot be completely eliminated‡, but this is of no consequence because the torsional motion itself dies away and therefore cannot continue to affect the flexure. The flexural motion is damped and ultimately dies away, so that complete rest is the final state after any disturbance. Thus the wing is stable and flutter is prevented. A flutter-free wing and another capable of flutter are compared in Fig. 9.

The foregoing argument has shown that flutter will certainly be prevented when the flexural centre coincides with the centre of independence and the wing is mass-balanced about this common centre. There is, however, some tolerance on the mass-balance and position of the flexural centre, so that flutter may still be completely prevented when the ideal conditions are not exactly satisfied. Even when these conditions are seriously violated the critical flutter speed may be above any attainable speed of flight, and this can always be ensured by making the torsional elastic stiffness of the wing sufficiently large.

Wing Divergence

Flutter is an oscillatory instability, i.e. a free oscillation of growing amplitude, but an instability in which the motion is uni-directional is also possible, and is called a *divergence*. The manner of occurrence of wing divergence will now be briefly discussed.

Divergence of a wing takes place when its total torsional stiffness vanishes or becomes negative. This stiffness is compounded of an elastic part, which is positive and independent of the speed of flight, and of an aerodynamic part which is proportional to the square of the speed and is positive or negative according to the design of the wing. Divergence can only happen when the aerodynamic torsional stiffness is negative.

When the wing twists through a small angle (say in the nose-up sense) the additional lift force caused by the increase in incidence acts at the aerodynamic centre§. It will be evident from the diagram (Fig. 10) that this force will tend to twist the wing in the nose-down sense, i.e. to resist the twist, when it acts behind the flexural centre, whereas it will tend to increase the twist when it acts forward of the flexural centre. In either case the force will, for small

* The coupling terms due to elasticity or inertia are *symmetrical;* i.e. the corresponding coupling coefficients in the equations of flexural and of torsional moments are equal. As just shown, however, the aerodynamic couplings are not symmetrical and it is largely on account of this that the aerodynamic forces can render the wing unstable (see Appendix III).

† There is a coupling term in the equation of flexural moments due to torsional velocity, and there are aerodynamic coupling terms due to torsional and flexural accelerations. The latter, called acceleration derivatives, can be included with the product of inertia of the wing itself.

‡ The aerodynamic coupling term due to torsional displacement is necessarily present.

§ This is at or near the quarter-chord point.

angles of twist, be proportional to the angle of twist, and the twisting moment will likewise be proportional to the twist. Thus there will be an aerodynamic resisting moment-rate or effective stiffness, and this will be positive when the flexural centre is forward of the aerodynamic centre but negative when the flexural centre is aft of the aerodynamic centre. For most actual wings the flexural axis lies aft of the quarter-chord position, so that the aerodynamic torsional stiffness is negative. For such a wing the total torsional stiffness will be given by

$$m_t = m_\theta - kV^2 \qquad \text{.........................(7.1)}$$

where m_θ is the elastic torsional stiffness and k is a positive constant. Clearly m_t will vanish at the divergence speed V_d given by

$$V_d = \sqrt{\left(\frac{m_\theta}{k}\right)} \qquad \text{.........................(7.2)}$$

It is important to note that the divergence speed is proportional to the square-root of the torsional elastic stiffness, so that the divergence speed can always be raised beyond the range of possible flight speeds by a sufficient increase of the elastic stiffness. Divergence can be completely prevented by placing the flexural axis at or forward of the quarter-chord point.

There are two practical points about wing divergence which require comment. In the first place, it would never be possible to approach closely to the divergence speed in flight because the effective torsional stiffness would become so small well below the divergence speed that excessive wing twists and correspondingly heavy wing loads would occur. Secondly, the prevention of wing divergence is seldom or never an effective design condition because the avoidance of flutter or of reversal of aileron control imposes more severe requirements.

Stalling Flutter

Ordinary flutter, sometimes called classical flutter, is an oscillation in which at least two distinct kinds of movement participate, and the instability is essentially due to the coupling of the movements. There is another kind of flutter which can occur with a single degree of freedom, and is due to the aerodynamic damping coefficient changing from positive to negative. This kind of flutter can be exhibited by a rigid aerofoil mounted so that it can oscillate in pitch under the constraint of a spring about a spanwise axis lying within the aerofoil. When the angle of incidence is small the aerofoil is stable, but when the incidence is near the positive or negative stalling angle self-maintained oscillations may occur. Detailed studies at Reynolds numbers up to 2 million made in the Compressed Air Tunnel at the National Physical Laboratory show that the instability does not occur when the spring is so stiff that the natural frequency exceeds a value which depends on the air speed; the critical quantity is really the "frequency parameter". This is a non-dimensional quantity proportional to the product of the frequency and the wing chord, divided by the air speed. The exact mechanism of stalling flutter is not fully known but it is associated with periodic breakaway and subsequent re-attachment of the flow about the aerofoil.

Stalling flutter obviously cannot be prevented by such measures as mass-balancing which merely uncouple two kinds of movement. Prevention is secured by arranging that the frequency parameter at any possible stalling condition is not lower than the limit mentioned above. For aeroplane wings stalling flutter occurs seldom or never, but stalling flutter of airscrews at take-off and in the spinning test is not unknown. Further information on stalling flutter will be found in References 16 and 17.

Flutter of Various Elements

The discussion given above has, for simplicity, centred on flexural-torsional wing flutter, but there are many other kinds of flutter which can occur on aircraft. First, a wing provided with an aileron may flutter at an air speed much below the critical speed for flexural-torsional flutter, and in such flutter the aileron plays an essential part. When the aileron moves about its hinge the effect on the aerodynamic forces and moments is very similar to what would be produced by a somewhat smaller torsional movement of the wing itself. Hence it is easy to see how flutter involving the aileron can occur. Such flutter is prevented by arranging that, so far as possible, flexural and torsional wing movements do not induce aileron movements. The most important measure in this class is mass-balance of the aileron, which eliminates the inertial coupling.

It is obvious that a tail plane with an elevator is very like a wing with an aileron, and tail flutter of a type similar to wing flutter can occur but is not common. Other types of tail flutter involve distortion of the fuselage and sometimes movement of the rudder, and are of much practical importance. It is, however, beyond the scope of this paper to enter into further details. Other important matters which cannot be discussed here are the flutter of wings carrying engines or other very large concentrated masses, and the influence of the freedom of the aeroplane as a whole on the various kinds of flutter.*

* Further information will be found in references 4 and 7.

The Failure of Struts

(*Concluded from page* 7)

True blown down

$$\frac{L}{K_{\min}} = \frac{75\cdot 3}{1\cdot 486} = 50\cdot 6 \text{ at } f_{cr}/f_f = \cdot 426.$$

Here we see that the strut will fail due to the main eccentric loading in the plane containing the greatest moment of inertia.

When there is appreciable eccentricity in the plane containing the greatest moment of inertia, together with appreciable eccentricity in the plane containing the least moment of inertia in any given strut, if the methods which have been described are applied, optimistic results will be obtained due to the combination of the stresses at the max. distant comp. fibre from the neutral axis. The correct method to apply in such cases is to draw the momental ellipse on the section, and the parallel through the centroid to the tangent drawn to the ellipse at the point where the plane of loading cuts it, is the neutral axis. In the case of the strut under such conditions of loading, the plane of loading is the plane containing both the point of application of the load, and the centroid of the section.* Hence, having found the neutral axis the $\frac{ey}{K^2_{NA}}$ may be found, e and y being both measured perpendicularly to the neutral axis, and the f_{cr} value may then be read from the graphs.

The theory of design outlined in this present article, however, will be found to not fall very far short of the ideal for sections having a fairly large $K/K_{\min}$ ratio for all types of eccentricity.

Eccentric loading is costly and much more so when the margin of safety used is an unknown quantity. It is hoped that this treatise will enable designers to deal with eccentricity more easily, when it inevitably arises, with an assurance that there is no wastage of material beyond that which is essential for strength requirements.

In this treatise no equivalent graph has been drawn for Cast Iron, or a material of similar properties, but the reader can see, if he should care to do this himself using either the Modified Euler Formula for Cast Iron, which is:

$$P = \frac{f_t A}{\frac{ey}{K^2}\ \text{Sec.}\sqrt{\frac{P}{EI} \times \frac{L}{2}} - 1}$$

where f_t = maximum allowable tension stress, or the correction applied to the new formula, which gives:

$$f_{cr} = \frac{-\left[48E(C-1)+5f_t\left(\frac{L}{K}\right)^2\right] \pm \sqrt{\left[48E(C-1)+5f_t\left(\frac{L}{K}\right)^2\right]^2 - 4\left(\frac{L}{K}\right)^2 48Ef_t(C+5)}}{2\left(\frac{L}{K}\right)^2 (C+5)}\ .$$

that the same methods as have been used in the above examples may be applied to Cast Iron struts.

* Strength of materials—F. V. Warnock.

The Ellipse as Applied to Aircraft

To the Editor,

SIR,—

Mr. V. R. Billings' article, "The Ellipse as Applied to Aircraft" in the August, 1944, issue of AIRCRAFT ENGINEERING struck a familiar note.

Here in the States we have been using line development methods not unlike those suggested by him and have found them very successful. In one experimental airplane we were able to develop the lines for the complete body group without having to fair a single line. This was done mathematically, utilizing the properties of the conic section as suggested by Mr. Billings.

The lofting work in this case was reduced from months to days since it consisted merely in checking ordinates and making templates; the degree of accuracy was astounding.

Very truly yours,

MARIO DI GIOVANNI,
Development Engineer

Curtiss-Wright Corporation,
Development Division,
Bloomfield, New Jersey. *October* 25, 1944

Books Received

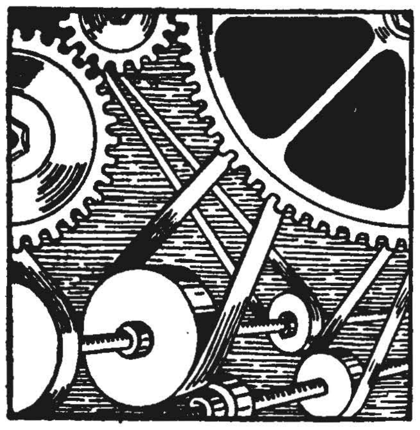
Aircraft of the Fighting Powers. Vol. 5. 1944 Aircraft. 70 pages, illustrated. [The Harborough Publishing Co. £1 11s. 6d.]

A Constructional Engineer's Compendium. 905 pages, illustrated. [Appleby-Frodingham Steel Co., Scunthorpe. £1 1s. 0d.]

An Outline of Industrial Metallurgy. D. G. P. Paterson and J. Bearn. 183 pages, illustrated. [Chapman & Hall. 12s. 6d.]

United States Government Manual—Summer 1944. 711 pages. [Office of War Information, Washington. $1.00.]

Steel Prices and Costs. Pamphlet. [British Iron and Steel Federation. Free.]



Workshop and Production Section

Electrical Equipment in Multi-Engined Aircraft

By T. Kearns, A.M.I.E.E., A.R.Ae.S.

The author of this article had before the war experience on the design and installation of the networks of various electricity supply undertakings. His wartime specialization on the electrical installations of British bombers has made him highly critical of present-day aircraft practice. He has expressed his views in deliberately controversial language with a view to arousing discussion, from which he believes benefit will result.

Introduction

THE forbearance of readers is requested at the outset for a personal note, considered to be inseparable from the basic purpose of this paper. The author's professional duties for many years prior to this war were concentrated on the specialist work of the design of distribution and transmission networks of various electricity supply undertakings, covering the main development period of electricity supply in this country, and also including the change-over of direct current consumers to alternating supply. The author was directed for the period of the war into the aircraft industry and again specialized on the electrical side, and the similarity of the technical problems which have arisen in both his experiences leave no doubt that aircraft electrical systems can benefit from the hard-won success of the electricity undertakings, whose achievements and mistakes alike are given publicity and opportunity for discussion. The technical success of supply systems is generally admitted to be in a large measure due to the freely-pooled contributions from the experience of engineers in the profession. The author airs very decided personal views, many of them contrary to present practice and forecasts, and in order that the criticism it is hoped to arouse should not be marred by any misunderstandings, it is made clear that his experience is limited to British aircraft; with no knowledge of American practice. The scope of electrical applications in aircraft is very great and it does seem that as each new application arises, those responsible endeavour to design suitable systems and apparatus *de novo* instead of ascertaining first whether or no there is a similar application in the electrical industry which has been tried out over the years, and which if applied with suitable modification to aircraft would cut out the inexcusable "teething" troubles. For example, the risk of fire being carried along by cables has been very thoroughly studied in switching stations; the deleterious effects of oil upon rubber insulation were appreciated years ago; and telephonic intercommunication has been utilized always in generating stations where the noise is quite equal to that which obtains in aircraft; also the practice of endeavouring to classify cables by their current carrying capacities was abandoned a very long time ago. These are only a few examples in which the author feels that aircraft electrical systems can be improved as a result of experience in the allied industry.

Discussion if aroused by this paper will furnish far more of value than ever the author could hope to submit, and frankness is therefore utilized in order to provoke this. The author therefore states that his four years' aircraft experience has convinced him that a competent distribution supply engineer with no great aeronautical experience could design an electrical system for a multi-engined aircraft with approximately 50 per cent of the wiring, etc., at presented incorporated and which would be more efficient, reliable, and maintainable than is normal under present British practice—taking into account all pleas of "expediency", "standardization" and "unskilled labour"; with the latter, for example, is not "simplicity" the answer, and would any member say that our aircraft electrical systems embody simplicity or flexibility to cater for subsequent modification? The aircraft industry will have to realize that it now requires the assistance of specialists, not necessarily with extensive aeronautical experience, and this particularly in the electrical and radio spheres. Let us have then a reasonable code of practice for aircraft electrical systems to guide the specialist designers for the competitive years ahead, and do not handicap them with archaic prohibitions and safety factors inherited from early days of aircraft. Sweeping observations as above are only legitimate if accompanied by constructive criticism, and this is now initiated in the following comparison of the points in which the aircraft industry is considered identical with the supply undertaking analogy; in which latter is given in order of importance, the desirable characteristics, also identical and primary, in both spheres:—

(i) Reliability;
(ii) Economy;
(iii) Standardization;
(iv) Quick and easy replacement.

(i) Supply systems in ground installations are designed with reliability as the main consideration, and of course in aircraft also, with most of the major electrical apparatus inaccessible until return to home base, this consideration has chief and primary attention. It is not a matter of just a few lights, but often of life and death itself in a modern warplane—ask an air-gunner what it means to him for his reflector sight light to fail in combat. All electrical engineers agree on certain main principles in the designing of an electrical system, which have to be rigidly adhered to in order to obtain maximum "reliability," viz.:—

(*a*) Minimum number of joints and connexions.
(*b*) Minimum number of control "gadgets."

No underground mains engineer engaged in finding a fault in a cable system would excavate first at a position indicated by a fault location instrument if there be a cable joint adjacent: and also how many shut-downs of major generating plant owe their origin to small control "gadgets"? In aircraft similarly it has been the experience that the main number of electrical faults is at joints and terminations, followed closely in number by the refusal or anticipatory operation of small ancillary apparatus—apart from faults due to enemy action.

(ii) "Economy" in the design of ground systems generally means first and foremost financial economy; whereas with aircraft are also added considerations of weight and space economy. Success in the former, however, will almost always result in the reductions in the weight and space utilization so desirable in aircraft.

(iii) In wartime, "standardization" is essential for quick and effective results in all spheres of engineering, but there are optimum limits (particularly where there are many diverse designs such as aircraft types) to this standardization and if these are exceeded a neutralization results of the benefits obtained from the process of standardization in iteslf, together with loss of efficiency.

(iv) "Easy replacement" (or simplicity of design) is always one of the goals of engineers with many years' experience in the supply industry, and with no disparagement to the excellent Service courses, how much more is this essential to the hundreds of thousands of young men who have to attend to the intricate equipment of modern warplanes—men who a short time previously had no practical experience of engineering?

As previously stated, it is the opinion that the electrical side of the aircraft industry is in a "teething stage," and although the foregoing will be to most readers, to say the least, obvious and elementary, their tolerance is requested in the interests of this growing section of the aircraft industry which has unlimited possibilities of a major part in aeronautical advancement if carefully nurtured so as to establish a reputation for reliability which will be the main measure of its success for the future. The persons who decide whether or no a certain aircraft service shall be electrical can only so decide on the basis of past experience and if the reputation of electrical service stability is not so good as, say, that of hydraulic power, then an unnecessary handicap will be imposed upon what can give after all ideal service if intelligently designed and installed. If these latter are fulfilled then the author is convinced that electricity is the best means of furnishing *all* auxiliary power requirements in aircraft, but this ideal will be set-back considerably if ever a report should be received such as—"The Chief Test Pilot reports that Modification X is unsatisfactory. Arrange for this to be deleted from future machines until same has been redesigned;" for there is far stronger competition to electricity in aircraft applications from alternative services than is offered, say, by the gas system in the public supply field.

The author's comments on the main sections of aircraft electrical systems are now put forward, not in detail, as particularizations are apt to fog the main issue.

Electrical Systems

The chief controversy before the war was whether one pole of the supply should have an "earth" return or no. (It is surprising by the way, how the aircraft frame, in practice, becomes so easily accepted as "earth"). As a supply engineer with no previous experience of aircraft, the author at first wondered how there could be any dissension at all with such an obvious alternative available as the "earthed" return system. First experience on aircraft, with the insulated 2-wire system, resulted in a quick revision of opinion, due to the comparatively large number of earth faults that occur; together with some trepidation at the thought of what would be the consequence of an "earthed" return system with the same number of faults occurring: with which latter system an "earth" would result in a shutdown of the particular circuit equivalent to a "short" on a 2-wire circuit. Further careful investigation into "cause and effect" brought forward the following considered opinion:—

(*a*) Comparisons of examples outside aircraft with the number of aircraft faults are not just, as in most aircraft the whole of the structure to which *all* electrical apparatus is *secured'* is at *solid* "earth" potential.

(*b*) A great amount of the assembly work owing to the tremendous expansion in wartime is done with diluted or semi-skilled labour, which obviously has little appreciation of the potentialities of, say, a few "floating" strands of wire. It must be stated in all fairness, however, that the author has found that the semi-skilled, once duly impressed with the importance of their superficially minor work, have turned out better performances than some skilled men, who perhaps feel some false justification for carelessness in such "low voltage" work as 24 volts. All this slack work can be and is definitely overcome by propaganda and education:—the girl soldering at the bench should be taken to the completed aircraft and shown where her detail work fits into the whole. Allowing for an increased number of "earth" faults under the first cause (*a*) then can an "earthed" return system be satisfactorily designed and introduced to have at least the same reliability as the insulated 2-wire scheme? Such a possibility, the author suggests, is quite practicable, and in fact desirable also, in that for approximately the same cabling, duplicate supply facilities could be furnished where required together with a big reduction in voltage drop (so important as will be seen later, on low voltage (24v.) systems) owing to the comparatively low resistance of the aircraft frame return. This proposal will be considered in detail a little later in order to counter at the outset an objection that will be put forward against an "earthed" return system—radio interference; this is not considered likely in modern all-metal aircraft, as all sections of the airframe are well secured, and the electrical contact of same verified by the thorough "bonding" test given to all parts of the aircraft, with consequentially little chance of intermittent sparking.

The "earth" (or frame) return system suggested has two main spheres for which to cater:—

(i) Apparatus within reach of the crew while airborne.

(ii) Apparatus inaccessible whilst airborne.

Which of the categories the circuit under consideration is placed under would affect the method of layout and the following generalizations are made:—If, in view of the maximum economies in all directions desirable in aircraft, it is considered essential to instal a certain piece of apparatus, surely this piece of apparatus is essential at all times and not just during the life of, say, a lamp, which might be its main component. Certain items of electrical equipment legitimately have a limited life—lamps being the most obvious—and unless therefore they come under category (i) and are easily replaceable, then such items should either be duplicated, or specially designed—say a lamp with 2 filaments in parallel—so that *total* failure does not result immediately from normal breakdown at the end of useful life. If considered essential completely to duplicate the item of electrical apparatus, then the frame return system would be ideal in being able to furnish a duplicate feed with the same cabling required for a single supply on the insulator system. Electrical equipment such as switches, motors, etc., which are reasonably dependable, if performing vital functions, could with the frame return system be provided with two "live" feeds as is standard on the so-called "solid" system of underground electricity distribution. In this latter system the normal fused feed also incorporates a "circuit opener" (actually a totally enclosed fuse of the same size) at the electrical piece of apparatus. If an earth fault should develop on this feed then the supply fuse would blow. The duplicate feed and all such others are laid to a test fuse in the fuselage, which when inserted is large enough to stand the fault current which operates the "circuit opener" thus clearing the faulty section and allowing the duplicate feed to be then fused normally. There is nothing revolutionary in the above scheme which would only be used for the few really vital inaccessible services, and which would only require the "circuit opener" and test fuse equipment over and above that required for non-alternative supply by the insulated 2-wire system The small additional apparatus required for the foregoing scheme would not be necessary if a *single* feed frame return system be adopted, and in practice it is felt that the frame return system if incorporated would combine both *duplicate* feeds and *single* feeds according to importance and accessibility of the respective circuits. It is pertinent to point out at this juncture that as single pole fusing is normal aircraft practice then with an insulated 2-wire system, as at present, an earth fault which develops anywhere on the aircraft in fused negative system is not automatically cleared and the entire system is then in the same position as the single feed frame return system, despite its extra cabling.

An objection of major potentiality against the "frame" return scheme is that of indiscriminate and bad "earthing" at the various items of load. This, in the author's opinion, is the one most likely to lead to rejection of the scheme, but should be easily overcome with careful planning and efficient supervision, if the following suggestions be accepted: Every item of apparatus be in itself insulated 2-wire type, with the frame connexion made at an adjacent standard lug and terminal which is the "earthing point" for the particular section of the aircraft. These points to be identical for the type of aircraft (e.g. one for engine, another in engine nacelle, etc.) and as such would be included in regular maintenance inspection. Such a scheme is already in operation on the radio system which utilizes main earthing terminals on the airframe for the connexion of the various earth cables. If these points are fitted at "centres of gravity" then the length of insulated cable terminations will be kept down to a minimum. To sum up, whatever expediency dictates during times of war, the author feels that in the more easy times of peace the "frame return" system should, as broadly outlined above, be seriously considered with a view to standard incorporation.

System Voltage is generally 24 volts. Consideration of the use of higher voltages is very important and is connected with the matter of cable sizes; which are obviously determined by drop in voltage along them rather than their current carrying capacity in many circuits, this in view of the fact that for a given power the current at 24 volts is much larger than with a higher voltage, and also there is not much latitude with such low voltage to allow of appreciable voltage loss if the load is to receive anything near the rated voltage. If the electrical loads continue to increase at the present rate then a maximum allowable voltage *drop* will have to be imposed as is operative on electricity supply systems. In view of the above, it is likely that the future upper limit system voltage will be determined by consideration of danger to air crews, as the higher voltage systems have such decided advantages.

System—A.C. or D.C. The author considers that recent statements that the electrical aircraft system of the future will be all "A.C. 3-phase" have been influenced to some degree by the present fashion in the supply world to wholesale change-over from D.C. to A.C., and cannot believe that this would be the opinion of an engineer who has experienced such change-overs. The present supply system change-over was mainly dictated by transmission problems, in which over many miles the A.C. system has incomparable advantages. No such problem arises of course in aircraft, and even the most ardent advocate of A.C. underground distribution would admit the superiority of D.C. over A.C. in certain applications—chiefly speed control of motors. To the student, 3-phase, 4-wire, A.C. systems give the highest efficiency, theoretically, whereas in practice owing to the impossibility of ensuring that the 3-phases each have the same simultaneous load requirements from a number of 1-phase items divided over the 3-phases, and under individual control, the actual system efficiency sometimes approaches that of a 1-phase or D.C. 2-wire supply. Bad out-of-balances on the 3-phase system can cause, at the receiving end of the lightly loaded phase, voltages in excess of the sending end. The author feels that the scheme for an *all A.C.* aircraft, even with rectifiers for conversion to D.C. where required, has no practical basis for the following reasons:—

(1) The heavy current required, and provided by mobile ground starting batteries for the starter motors at considerable distances from the hangars.

(2) The only reasonable method of providing emergency standby supply is by batteries and the A.C. circuits would require some complicated form of inverter to be supplied from these.

(3) What alternative would be provided for the excellent design system of instrument indication?

(4) Speed control of A.C. motors if required would eliminate the weight advantage of the simple A.C. induction motor and necessitate A.C. commutator motors.

(5) The main aircraft engines (with their variable speeds) are not suitable for a fixed frequency supply, and this tends towards a separate power plant in the fuselage, which surely would not have the same efficiency as the main engines, and would be a case of "all eggs in one basket" besides providing an additional target in warplanes?

(6) Single wire A.C. metal braided cables are not practical: the same lead and return current has always to be under the same metal sheath to avoid excessive heating.

(7) The frequency of the supply furnished by an alternator is either the revs. per sec. figure or *products* of that figure, according to the number of pairs of magnetic poles; it obviously can never be below the speed of the alternator. Conversely, the speed of an A.C. motor with 1 pair of poles is that of frequency of supply, and half that figure with 2 pairs of poles, etc. The frequency figures suggested of between 200 and 400 cycles per sec. by the "all A.C." supporters give motor speeds with 2 poles of 12,000/24,000 r.p.m. To obtain the economies proposed, the A.C. motors would be a high-speed type therefore, with severe service conditions, and possibly weighty reduction gears, and the speed of such motors would be roughly in step with the alternator supplying same.

(8) A static rectifier will only convert A.C. to D.C. and not vice versa.

(9) With weight comparisons the fuselage set would be debited with extra fuel weight, and its main venue would appear to be in commercial aircraft.

(10) The weight of motors of comparable horsepower is for D.C. four to six times that of some A.C. types, but it must be remembered that these latter are of exceptionally high speeds, e.g. with 10 lb. per horse-power for the very best D.C. performance, a figure of 14 lb. is published for a 6 H.P., 3-phase, 110 volt A.C. motor—but the speed is 22,500 r.p.m.

The wholesale conversions of networks from D.C. to A.C. have provided many headaches to the distribution engineers, who I am sure (if it were possible as it is in aircraft) would prefer a mixed A.C./D.C. system, and this is confirmed by the number of rectifiers that are immediately installed on the new A.C. networks to change the supply back again to D.C. In view of the excellent multi-head drives for auxiliaries on the main aircraft engines there is no reason why the aircraft should not have both D.C. and A.C. supplies for the purposes best served. On the A.C. side there would appear to be a special future for self-generating gear utilizing the excellent synchronous properties of multi-phase supply. It is the author's considered opinion therefore that the aircraft system of the future will be a composite A.C. D.C. supply (mainly D.C.) and that the all A.C. system with rectifiers for D.C. conversion would not furnish any additional advantages but rather introduce complications. If a fixed frequency A.C. supply is found essential, then an engine in the fuselage would have to be provided, and for a variable frequency supply the alternators on the different engines would only be standby to each other and not work in parallel owing to the various differences of the respective frequencies. No future economies will be gained by raising the D.C. voltage.

Cables and Connexions

The aircraft industry has its own cable specification (B.S.S. 4E. 3) for wires with sizes given in terms of current-carrying capacity; the most common sizes being 4, 7, 19, 37, and 64. At first this would appear to be a practice long discontinued in the electrical world, but these cable sizes are approximations abstracted from the *I.E.E Wiring Tables for V.I.R. Cages in Buildings*. In this connexion it is felt that in view of the large and ever-increasing amount of cabling in a modern aircraft an investigation would be of value into the conditions that obtain, particularly in regard to temperature, with the high altitudes and low ambient temperatures normal to large aircraft. The extensive use of rubber insulation, which was general practice, requires further consideration, particularly in such positions as the engines, etc., likely to be subject to excessive oil flooding and also hot spots of temperature. There are many excellent alternatives—particularly paper—which should be considered. The well-tried paper insulation is also suggested for all the larger cable sizes, 37 and 64 (0·0145 □" and 0.040 □" respectively) and over, in view of the 50 per cent increased carrying capacity which would result over V.I.R. for the same size of wire core.

The performance of the most excellent cable system is entirely dependent upon joints and terminations, and in this field, in the author's opinion, is the greatest scope for good design in aircraft. A complete aircraft is not a permanent entity—wings, engines, and even portions of the fuselage can be and are replaced at short notice, particularly with warplanes. If the aircraft electrical system is considered as a supply network with sections liable to be replaced, then the accumulated experience of distribution engineers over many years is available as a

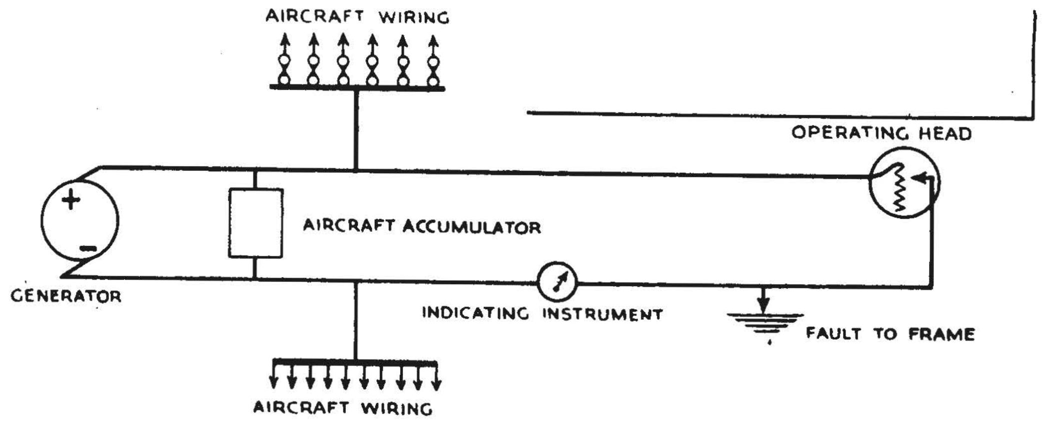


FIG. 1.—*With a fault to frame on the indicating system, another fault anywhere on the aircraft wing would affect the indicating instrument. Separate supply for indicating systems would give increased reliability*

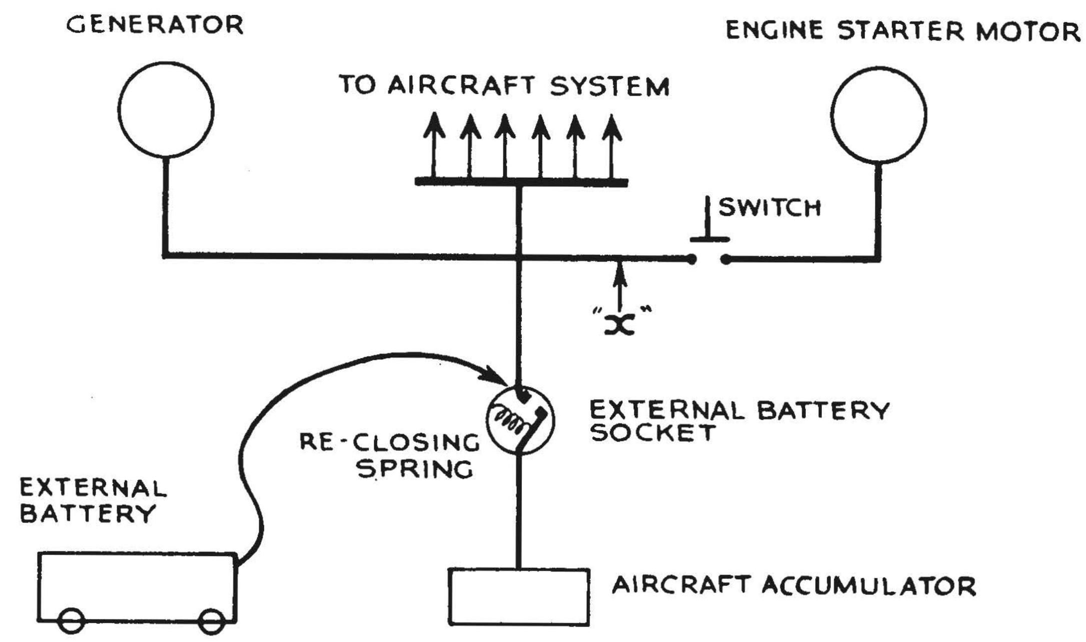


FIG. 2.—*When external battery is removed (generator normally started) the return of aircraft accumulator supply to the aircraft would be dependent upon the socket-retaining spring. This socket (especially if fitted externally) would be better at point "x" with other facilities for supplying external aircraft wiring from external battery provided*

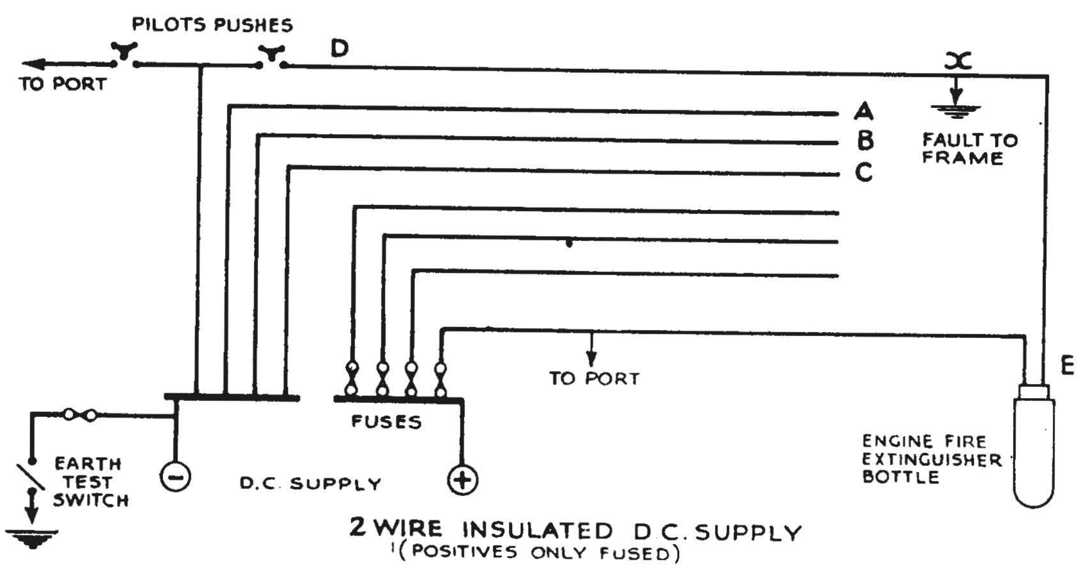


FIG. 3.—*With this system, especially if earth test switch is fitted on negative pole, it is important that all switches (including push switches) are on positive poles. Otherwise, as shown above, an earth fault on the negative length "DE" (e.g. at "x") would not affect normal operation of the circuit—but the fire bottle would be blown by closure of earth testing switch, or by an earth fault (in addition to "x") on any of the unfused negatives, A, B, C, etc. This type of inadvertent operation (often unnoticed on occurrence) could not occur with a D.C. single-wire frame-return system, as the frame is permanently of opposite polarity to all switch wires*

guide. Presuming sufficient lengths of cable were available, the average distribution system would run through the manholes, leaving there sufficient slack length *in case* a replacement has to be made, so that a cut and subsequent joint to the new portion can be effected. Normal aircraft practice often anticipates this replacement (which might never be made) and thus adds numerous terminal connexions; all potential breakdown points and all adding resistance which can be ill afforded with systems of such low voltage. The author suggests that a better alternative would be to copy the distribution analogy and run circuits straight through the normal disconnexion boxes with requisite slack length and usual identification sleeve, but initially *not cut and connected to the normal terminal blocks.* Even if this latter be done in anticipation no time would be saved as *disconnexion* and *reconnexion* would still have to be made at the terminal blocks for the replacement. It is not completely applicable everywhere in the aircraft, in view of certain special details which of necessity have to be connected on the work-bench, but there is no reason why it should not be adopted in principle. Criticism might be put forward of this proposal that such is unnecessary if disconnecting points utilize a plug and socket joint. The author is definitely against this system (unless it is the only possibility) for aircraft for the following reasons:—

(*a*) The number of actual jointing points is trebled:—(1) a soldered joint in the plug; (2) the joint of the male pin into the female socket; (3) a soldered joint in the socket.

(*b*) The above male and female joint is obviously not open to inspection, and is reliant upon "normalities" which surely should be eliminated as much as possible in main aircraft power work—radio systems apart.

On aircraft no straight through joints are allowable under any circumstances on cabling, and all joints have to be made by means of the normal terminal blocks, or by means of multi-pin plugs and sockets, and both these are standard British practice. The latter method brings forward the subject of soldered joints; a well-soldered joint is the ideal electrical connexion of course from the point of view of contact, but in positions subject to excessive vibration such as aircraft, any fault in the soldering quickly materializes into a break. The author's experience has been that most of the open circuits which have occurred are on soldered connexions, particularly those hidden from view and subject to strain, such as when plugs are badly inserted or removed from sockets. Prior examination of the soldered connexion, although essential, is not infallible, and most faults occur at the point where the strands lose their flexibility in the solder. Where soldering is not essential as the *only* possible method, e.g. radio, the author prefers a normal terminal block with the wires terminated in a hand-pressed lug, and the connector screw prevented from coming completely out by the terminal block cover. Even with such a method, if vibration causes the terminal screw to slacken, the connexion although bad will not be broken unless the terminal block cover falls off, thus giving obvious indication.

It is axiomatic that cables should always be easily accessible both for periodic examination and maintenance and replacement if necessary. Indiscriminate runs are to be deprecated as leading to trouble, chiefly due to mechanical damage, and the best system would consist of special well-defined runs in channels in which the cables are kept in position by spring clamps, or better still by straps, as being less likely to cause mechanical damage due to initial slackness and the inevitable vibration.

The engine bulkhead is especially worthy of consideration from the cable viewpoint, as this is the fire-proof partition between the engine and the inside nacelle (containing petrol and oil tanks) and as many as a dozen cables might have to pass through it at different positions. If the cables are broken and the circuit passed through the bulkhead by means of plugs and sockets, this would result in 24 such items, with most of the forward ones being connected by very short lengths to the various electrical apparatus on the engine, which also have their terminal connexions and which former sockets therefore generally would not facilitate any more the quick replacement of engine apparatus. The experience of the supply industry in making cable openings fire-proof in positions, such as under oil switches, liable to flow of burning oil, might be of considerable use in designing a method

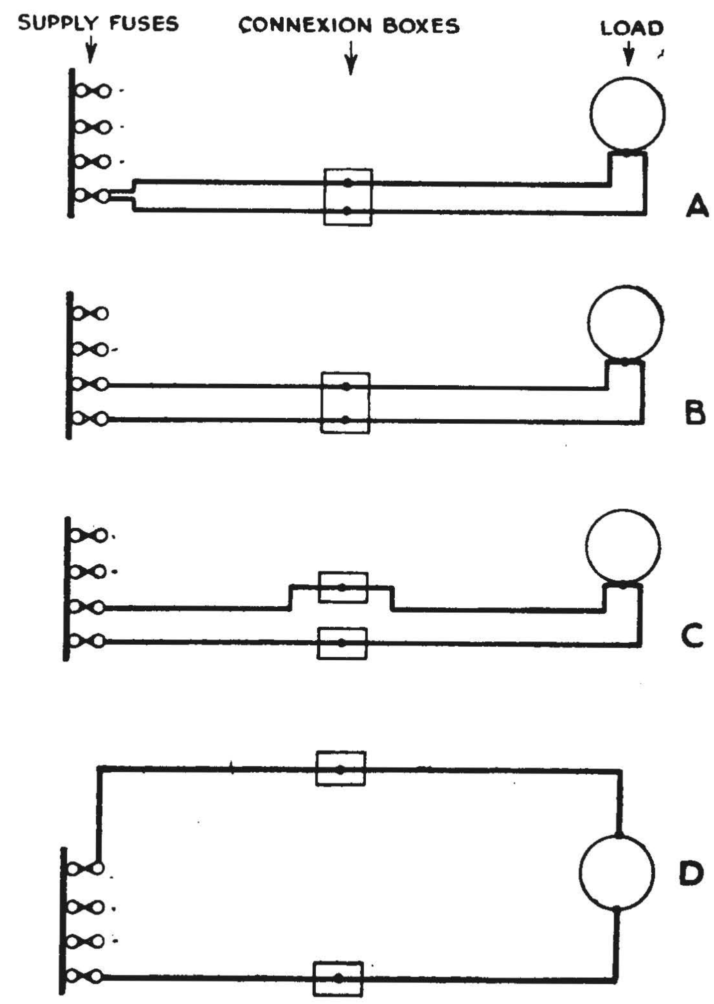


FIG. 4.—*Elementary duplicate supply lay-out—approaching ideal in order A, B, C, D*

of passing cables straight through the engine fire-proof bulkhead.

To sum up, a golden rule for the designer of cable run outs for aircraft is given in the phrase, "Straight-through Simplicity."

Electrical Apparatus

The electrical apparatus of aircraft follows normal electrical practice generally but is worthy of special mention if only for the multiplicity of items. A rough check on a large 2-engine warplane gave the following figures: over 60 electro-magnetic relays and auto-switches, 100 manual switches, 70 fuses, 16 electrical indicating instruments, and for lamps, over 30 for indication, 20 for signalling and recognition, and 20 for lighting purposes: all on an aircraft not extensively electrified even by present standards. Items of electrical apparatus worthy of special mention are now commented upon:—

(*a*) *Generators* (*D.C.*)

As the speed of aircraft engines and hence voltage is apt to vary over wide limits, many excellent methods of voltage regulator have been evolved. One of the most satisfactory in practice is the automatic variation of the field current of the generator, and this gives almost instantaneous response to engine speed fluctuations.

Mention has been made in the technical press of generators with a weight of about 8 lb. per horsepower, but this is exceptionally low, as in the author's experience a weight of double the above figure is more normal on small generators, for voltages of 24 volts. Possibly the former figure was given for a higher voltage scheme. As generators, and motors, generally incorporate moving contacts, the main cables have to be metallically screened until a suitable position is reached where a suppressor can be conveniently installed. These are of the type normal for radio anti-interference purposes. All rotating contact circuits in the machine require such suppressors, the alternative being the screening of the radio equipment itself, which is no mean undertaking in these days of extensive utlization of radio, particularly in warplanes.

(*b*) *Generators* (*A.C.*)

Whereas in the D.C. case the speed of the aircraft engines can be compensated for by variations of shunt field current, there is the major difference with alternators in that the r.p.m. directly affect both the frequency and voltage, and whilst the latter can be kept reasonably constant by the same method as the D.C. case, there is no such simple method of fixing the frequency; to which is tied the speed of all motors supplied by same, unless of the commutator type (similar to the D.C., with no economic gain). Variable frequency in addition to controlled speed variation also would introduce many complications for the designers of A.C. electromagnetic gear which is normally designed for a nominal frequency. An alternator for a fuselage engine would require a D.C. supply for field excitation either from batteries or from a small D.C. generator on the same shaft, in which case arrangements would be made for the residual magnetism to provide sufficient fields at initial starting up of the set, after which the voltage regulator would control the D.C. current in the alternator field windings. Weight figures have been published recently for a large A.C. alternator (17 h.p. approx., 110 volt, 400 cycles per sec., 3-phase) of about 6 lb. per h.p.

(*c*) *Batteries*

These are normally sulphuric acid accumulators floating across the system to stabilize the voltage on sudden fluctuations and also to provide emergency supply in case of generator failure. The capacity required for this purpose presents a rather interesting problem:—On a nominal 24 volt system, accumulators of 40 ampere hour capacity weigh some 100 lb. which is approximately the weight of a 1500 watt, 24 volt generator together with its associated equipment, suppressor, voltage regulator, cabling, etc. If it is assumed that 10 hours is the normal duration of an operational flight, then the weight of accumulators required to provide the same potential capacity as the 1500 watt generator would be:—

$$\frac{1500}{24} \times \frac{10}{1} \times \frac{100}{40} = 1562 \text{ lb.}$$

Difference in weights of batteries and generators equalling $1562 - 100 = 1462$ lbs.

From figures published, $\frac{1}{20}$ of a gallon per horsepower per hour can be assumed as the petrol consumption of large aircraft engines, and with this figure the generator fully loaded for 10 hours would utilize $\frac{1500}{746} \times \frac{10}{1} \times \frac{1}{20} = 1$ gallon of petrol; weighing, say, 9·8 lb. and leaving $1462 - 9{\cdot}8 = 1450$ lb., against the battery scheme. This in weight would be equivalent to another 150 galls. of petrol, or another 240 miles cruising range, again using published figures for performance of large multi-engined aircraft. The foregoing idea of using batteries entirely has not of course been suggested, but is worked out in detail in order to show that the only justification for installation of storage batteries in aircraft is to stabilize the supply and provide standby generator failure and *not* to augment the generator supply. There are two types of total generator failure on a multi-engined aircraft, depending upon whether each engine has a generator or no. If not then if the engine or engines with the generator should fail it is possible that the machine might fly on its remaining engine for a considerable time, in fact might even carry out its scheduled operational flight (with generators). As has been put forward above, it is not economical to provide loads for considerable periods from batteries, and the loads should obviously be supplied from generators on the remaining serviceable engines. It would appear axiomatic therefore to divide the required generator capacity over all engines. This scheme would leave to the aircraft accumulators only such loads as are required whilst gliding or floating, which should not require particularly large accumulator capacity. It will be put forward, perhaps, that such a scheme will involve complications in wiring, etc., due to parallel operation, but it must not be forgotten that electricity supply has a tremendous importance in modern aircraft, particularly as the "lifeblood" of radio: for as Sir Stafford Cripps said, a warplane without radio is as effectively grounded as if it had no wings. Again, the electricity industry will be able to supply well-tried systems for the control of such a scheme.

(*d*) *Instruments*

Remote indication has an ideal medium in electrical transmission; particularly in aircraft, where the flexible qualities of the electrical interconnector are a great asset. Some applications require a supply from the aircraft electrical system whilst others, e.g. temperature and r.p.m. indication, have their own particular electrical supply, and are not susceptible to the normal faults on the aircraft supply. Multi-phase alternating current is ideal for indication of variable speeds in view of the inherent synchronous qualities of such a system; these are practically independent of distance and resistance. If electrical indication is to obtain a reputation of reliability—again this word appears—then it should be designed on the principle that "no indication is better than a false one," and this sphere in particular calls for the minimum number of joints and connexions; also if possible, instruments should be supplied separately from other than the main aircraft supply.

(*e*) *Switches*

These are of all types varying from the single pole tumbler switch to the automatic closure electromagnetic switch. The latter have an ever-increasing application, with the undesirability of leading the heavy cables to the central control position, which is getting increasingly complicated. In certain positions liable to excessive amounts of petrol vapour, switches with similar characteristics to the flameproof mining type are required, and there should be ample data in this direction available.

The design of the layout, of course, should endeavour to place as many switches as possible accessible whilst airborne, and when it is essential that switches have to be fitted externally, then these switches, especially if automatic, should be so arranged that their most probable or noticeable failure will occur whilst grounded, rather than in flight. For example, if advantage of the heavy starter cables to the engines be utilized for some other airborne purpose by means of an automatic change-over switch, then it would be better if possible to arrange for the normal at rest position of this switch to be that for the airborne operation, so that any failure to operate in this case, would occur whilst starting the engines, which is of course a ground operation, and consequently with repair facilities immediately available. It should also be a hard and fast rule that all manual switches should have their positions *plainly* idented, also that all electro-magnetic switches should operate at voltages as low as 50 per cent of their nominal rating.

(*f*) *Lamps*

These vary in size in an average warplane from 250 watts down to 1 watt, and are used for such varied purposes as lighting, navigation, recognition, signalling and indications.

Normal aircraft lighting practice utilizes an almost flame-proof type of fitting, often installed with a dimming device. It is suggested that in view of the good conditions now prevailing in large all-metal aircraft some relaxation in these matters might be allowed, with consequential better cooling conditions and longer life of lamps. Before any such relaxation could be permitted exhaustive tests would have to be instigated of course. A lamp filament normally has to stand up to the greatest stress at the instant of the current being applied, and any added impact from the action of switching should be avoided; the combined snap switch and lamp fitting is therefore not ideal.

The regulation navigation lights depend upon colour differences to give the course of aircraft at night, to others in the vicinity, and these lights together with some signalling lamps are obviously inaccessible and perhaps out of view, to the air crew whilst airborne. The author suggests that the requisite colours should *always* be obtained from the filament glass, and not be dependent upon any outer coloured glass fitting, subject to breakage, with danger of subsequent incorrect indication. It is interesting to note that many of the essential lamps are in such compact positions as to allow very little natural ventilation, and as this applies to most of the larger lamps installed, these therefore cannot be used continually unless airborne with resultant increased cooling. This matter of cooling is particularly important with lamps indicating some particular state of important apparatus as, in such instances, reliability, or life in other word, is their most desirable characteristic. The same axiom of "a false indication is worse than none" of course is very pertinent, and important indications depending upon the life of a filament would appear rather hazardous. This risk if taken can be minimized by specifying well-ventilated fittings, to prolong life; duplicate lamps, where possible, or otherwise easy facilities for lamp renewals and test.

(*g*) *Starter Motors*

In modern aircraft of large engine horse-power, the currents required for starting are well over 100 amps. and the cable size has to be of appreciable copper section with V.I.R. insulation in order to limit the heating affects with a recalcitrant engine. The normal size is 248 0·018 (0·063 sq. in.) for a 24 volt system. With cables of this capacity it will be appreciated that in aircraft of large overall dimensions the weight of the starter system is considerable, if the starter motors (of some 50 lb. weight each) are included. In the author's opinion, there appears to be no vital need with modern bombers for all this apparatus to be carried whilst airborne, for the following reasons: assuming of course that the some alternative means of starting engines can be fitted at the base aerodromes:—

(*a*) If it is desired to restart an engine whilst in flight, then this would be effected by turning the airscrew blades to the "fine pitch" position when the forward motion of the aircraft will "windmill" the airscrew in the correct direction, and the engine, if O.K., should start upon ignition being initiated.

(*b*) Any forced landing in enemy territory is not likely to leave a large aircraft, such as those being considered, in so serviceable a state as to be able to take to the air again without major repairs, and still less the use of a runway suitable for such a purpose.

The above suggestion for an alteration in starter installations is not a technical matter only, but is obviously one in which the opinions of flying personnel should have the determining influence. The opinion of technicians, however, could give a decided answer on the question of utilizing starter motors, *if installed*, for subsequent use as generators whilst airborne, in order to make maximum utilization of dead weights, as this would appear to be a matter of design and mechanical limitations only.

(*h*) *Testing*

No set scheme of testing can obviously be given owing to the many diverse types of aircraft, but considerable experience in this direction, particularly with new installations, has resulted in certain broad principles being impressed, and these are given, as possibly being of interest :—

Whilst checking that the desired functions operate as initiated is of course important, it is more important, (and far more difficult be it said) to check that undesired functions do not operate as well. An example is given:—A test of the starting circuit would be taken before the starter motors are connected; generally with a lamp, or better still an audible item. If this is connected port (and functioned on port push) and then starboard (and also functioned on starboard push), there is nothing in such a test to ensure that, amongst the tightly packed wiring, a cross connexion might not also allow the port starter motor to be operated on the starboard push button, and vice versa. This is a simple example which is easily checked by pressing both pushes on each test, but there are others not so easily overcome, and still others which are beyond the bounds of reasonable precautions, and even if allowed to pass into service, might never occasion faulty operation.

Megger tests should be the first operation ,as fault localizing is apt to result in additional operational faults—not necessarily earth faults.

Coincidences appear to have an affinity to the electrical installations of aircraft, and the obvious solution should not be seized upon in troublesome situations, without an exhaustive investigation of all possibilities however remote. An almost common occurrence is cited. A certain indication system has a port and starboard instrument with duplicate lamps for reliability. Upon installation the circuit is operated by hand for inspection purposes with new indicator lamps. The port side worked satisfactorily with both lamps indicating. On the starboard side, no response was obtained from either the first lamp or its duplicate wired-in parallel. The above opinion

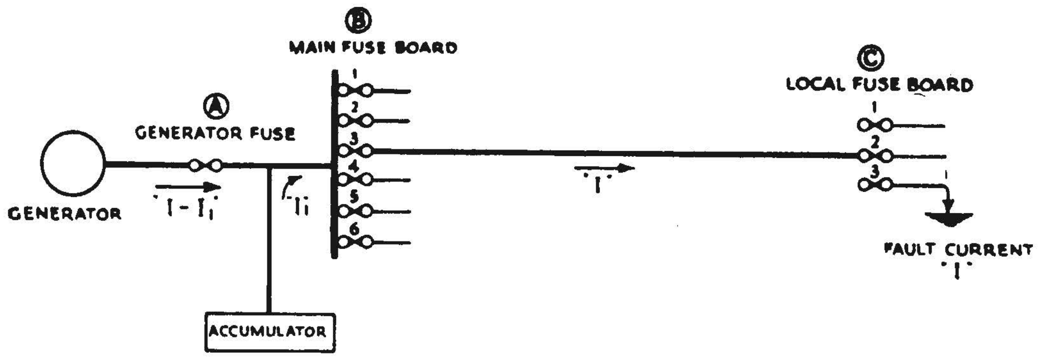


FIG. 5

THE HIGH SHORT-TIME OVERLOAD QUALITIES OF ELECTRICAL APPARATUS SHOULD NOT BE CURTAILED BY FUSES BLOWING ON MOMENTARY OVERLOADS NORMAL ELECTRICAL PRACTICE IS FOR THE RATING OF A FUSE TO BE THAT WHICH IT WILL CARRY CONTINUOUSLY: THE BLOWING CURRENT BEING ABOUT 150% OF THE NOMINAL RATING FIGURE. e.g. A "5AMP" FUSE WILL BLOW AT 7·5 AMPS APPROX. WITH A FAULT ON C3. CIRCUIT BOTH C3 AND B3 FUSE WILL BE CARRYING THE SAME FAULT CURRENT ('I'): C3 SHOULD BE RATED, OBVIOUSLY, TO BLOW BEFORE B3, THE PURPOSE OF THE LATTER BEING TO CLEAR A FAULTY SECTION B.C. OR TO OPEN IF THE COMBINED LOADS ON C1.2.3 WERE TOO HIGH FOR THE CABLE B/C - SIMILARLY FOR ALL B FUSES; WITH C FUSES RATED TO CLEAR TROUBLE WITH AS LITTLE C 'DISLOCATION' AS POSSIBLE. A FUSE IS MORE TO PREVENT DANGEROUS OVERLOAD ON GENERATOR RATHER THAN CLEAR FAULTS (AS MOST OF SYSTEM IS PROTECTED BY B C FUSES) AND SHOULD THEREFORE HAVE THE HIGHEST CONTINUOUS RATING.

led to new lamps being first installed rather than undertaking the dissection of the circuit; with resultant correct operation! Four new lamps were originally installed, two were faulty, and both installed on the starboard side. This would obviously have been found out sooner or later, but the point is made, because there are obviously many other unwanted technical occurrences which might be passed over without close investigation, because of an obvious reason, which might be wrong, and thus leave potential trouble; possibly of major importance in some critical situation. Test at a voltage below rated figure should be stipulated also.

(*i*) *Variable Pitch Control of Airscrew Blades*

The electrical control consists of two main functions; firstly to automatically maintain the engine revolutions at a pre-determined optimum figure (decided by the pilot) by automatically varying the "pitch" (or bite) of the airscrew blades through all positions of engine throttle opening. Secondly, in case of engine failure to quickly turn the airscrew blades to a neutral position ("feathered") to prevent "windmilling" with consequent drag on the aircraft and damage to the shut-down engine.

Present electrical systems for the above functions are on direct current supply, but the author considers that future systems will incorporate a special multi-phase alternating current supply, the synchronous properties of which should be of great application in the function of constant speed control, which is of course used the more of the two purposes, the "feathering" being an emergency operation. A current of over 100 amps. is normal on a 24 volt D.C system for this latter function, and it will be appreciated that in view of the vital section of the aircraft affected the greatest care in design and installation of the control wiring is imperative.

(*j*) *Radio*

Very little may be written in wartime on this subject, except that it is solely dependent upon electrical supply, and that a fault anywhere on the aircraft electrical system, however remote and apparently irrelated, might deleteriously affect the vital radio installation.

(*k*) *Fuses*

These obviously should be of the totally enclosed type, and as the rupturing capacity, as measured by supply system standards, is not great the body of the fuse should allow quick inspection to be made of its serviceability. Glass tubes make a very good fuse body, and the size, of course, should always be plainly indicated. There can be no question, of course, of rewiring fuses whilst airborne, and all fuse covers should carry one spare fuse for each circuit, the fuse contacts of which are plainly marked with the size of fuse required. Needless to say fuses should not be indiscriminately positioned over the aircraft, but at a central position where all circuits merge. The recent innovation of "flight engineers" will now allow, in large aircraft, the re-positioning of the electrical central control from the near pilot's position to nearer the "centre of gravity" of the electrical system, with consequential economies in cable runs.

(*l*) *Ignition*

Duplicate magnetos of excellent quality are normal on each engine. An axiom of the electricity supply industry to separate duplicate supplies as much as possible should be adopted on the system for the switch control of the magnetos and the cables to same should not be run through the same joint boxes in which a "floating" piece of metal might shut-down both magnetos.

(*m*) *Motor*

Such excellent types are available that the hope is expressed that these are not jeopardized by badly designed connecting boxes and switches

Conclusions

In the author's opinion, naturally, the complete electrification of aircraft is inevitable, especially in warplanes, but when will depend upon the reputation for reliability, or otherwise, associated with the electrical service of aircraft. To obtain this dependability will require careful design in every detail however apparently irrelevant, and particularly in the layout having regard to the confined spaces involved. An electrical fault of minor proportions in other spheres, might be a major disaster to an aircraft, for it must always be remembered that they are not comparatively stable entities such as ships, etc.

The term, complete electrification, does not in the author's opinion, just comprise those functions, often hydraulically operated, such as chassis, landing flaps, gun turrets, etc., but also includes the electrical replacement of the present numerous mechanical link controls for engines and flying surfaces, with all the possibilities of duplicate facilities, etc., so open to electrical service. In warplanes especially the electrical supply should have great possibilities, if carefully designed, due to less vulnerability to damage from enemy action—a bullet nicking a hydraulic pipe would render the associated system unserviceable, whereas the smaller diameter electric cable would have to be completely severed perhaps, to bring about the same unfortunate result.

Most of the installations in an aircraft are of course to one purpose, that is to enable it to fly, and to keep it flying, and thus civil and war aircraft are identical in many respects, and many of the practices initiated in war aircraft will be perpetuated in civil aircraft, and the suggestion is made that the present time is suitable for the compilation—if such has not already been commenced—by authority of rules for the electrical equipment of aircraft, as a companion to those valuable aids for the electrical equipment of buildings and ships, which are such vade mecums in the industry. The word "aid" is used advisedly in that it is realized that it is not always possible to enforce such rules, but even so, such is the worth of the above two existing publications that their rulings are often accepted voluntarily.

The author's experience has been limited to some British warplanes, and within such limits, his opinion has often been expressed. No apology is made in this respect, however, in view of the already mentioned scarcity of technical literature on the subject, and if, as it is hoped, opportunity will be given for readers to criticize this paper, then these freely expressed and controversial opinions of the author's might result in valuable experience and views being brought forth from experienced engineers. Elementary broad principles have also been discussed, because it is realized that future design of electrical equipment will sooner or later be in the hands of various specialists, in their own line, who obviously cannot have extensive aircraft experience of their own account, and which of course would not be required if certain guiding rules were available, expecially if published with the approval of authority.

There is a tendency in the aircraft industry to consider the electrical system as a mysterious power, ministered to by lowly born acolytes who unfortunately have the means to hold up an aircraft whilst searching for a gremlin-like "earth"—and who when brought to task "blind one with science." In actual fact these unfortunate men are serving often an elementary power system which is called upon to function under conditions which cannot be considered as reasonable; and the "earth" is a very material entity, due either to bad design, bad installation, or damage. A more broad-minded and technical outlook will be necessary if the industry is to progress in the fierce competition bound to ensue legitimately in the post war era,—from both formalites and enemies— and the aircraft electrical system will have to be considered not ancilliary to but as important as "engines" and "flying controls."

Modern Aeroplane Types

The Supermarine Spitfire XIV

WHEN it is possible to trace in detail the evolution of the Spitfire from the prototype conceived by the late R. J. Mitchell to whatever may be the ultimate version, it will prove to be an absorbingly interesting history of more than a decade of development in aircraft engineering. The present aeroplane has an engine that is considerably larger and gives over twice the power of that in the first machine, yet the basic structure and aerodynamic form are comparatively unaltered—a proof, if such were needed, that the designer's ability and vision were of an order that approached genius.

In the F. XIV the wing, tail plane and undercarriage are similar to the ubiquitous Mk. Vc except for minor changes to take the loads imposed by greater weight and performance.* The fuselage has been re-designed at the front to take the Rolls Royce Griffon engine and at the rear to provide a larger integral fin. The changes in the cockpit, retractable tail wheel and larger radiator fairings had been introduced on other Marks. In this short note only the changes peculiar to the F. XIV will be commented on.

Few details of the F. XIV or its engine have yet been released; however, by taking the latter first, it is possible to examine some of the features. The Griffon 65 has a rated power of over 2,000 h.p. and its cylinder capacity is a good deal larger than that of the Merlin. This mark of the engine has a two-speed, two-stage supercharger. The extra power has been absorbed (without the undercarriage having to be lengthened) by fitting a five-bladed Rotol airscrew. The extra side area caused by the longer nose and the five-bladed airscrew has been balanced by a larger fin and rudder. The Griffon has a slightly lower thrust line than the Merlin and the cylinder blocks project from the top cowling.

The armament can be varied: four 20 mm. cannon, or two 20 mm. cannon and four ·303 in. machine guns, or two 20 mm. cannon and two ·5 in. machine guns being the most common combinations. A 500 lb. bomb can be carried under the fuselage, with a 250 lb. bomb under each wing—making a bomb load as large as that of the standard medium bomber with which the R.A.F. started the war, the Blenheim.

The few facts that have been released on the F. XIV are as follows:

Span	36 ft. 10 in. (11.22 m.)
Length	32 ft. 7¾ in. (9.94 m.)
Wing Area	248.5 sq. ft. (23 sq. m.)
Gross weight (approx.)	8,000 lb. (3,628 kg.)

* The Spitfire V was illustrated in this series in Vol. XIII, November 1941, p. 306.

Air Registration Board

Notices to Licensed Aircraft Engineers and to Owners of Civil Aircraft

No. 3

DUTIES OF AIRCRAFT ENGINEERS LICENSED IN CATEGORIES 'A' and 'C'

1. The Air Navigation regulations require that the certification of an aircraft before flight shall be made, in respect of the airframe, by an aircraft engineer licensed in Category "A" and in respect of the engines by an aircraft engineer licensed in Category "C".

2. To remove any doubt regarding the division of duties when two individuals make the certification, the duties of engineers licensed in Categories "A" and "C" respectively are detailed in the attached appendix.

APPENDIX

1 The aircraft engineer licensed in Category "A" is required to certify all parts of the aircraft EXCEPT the engine(s) and its installation:—
(See 2 below)

1.1 ALL PARTS OF THE AIRFRAME STRUCTURE including:
For condition and assembly
Fuselage; Hull; Engine bearers; Wings; Ailerons; Slots; Flaps; Tailplane; Elevators; Fins; Rudders; Struts; Undercarriage; Wheel brakes. Floats; Landing wheels; Tail skid; Bracings; Connexions to the airframe structure of items classified in this and section 2 below.

1.2 ALL FLYING CONTROLS AND TRIMMING DEVICES.
For condition, assembly and functioning

1.3 ALL FLYING INSTRUMENTS including:—
For installation and arranging for correction of reported faults
Watches; Aneroids; Airspeed indicators; Turn indicators; Directional gyros; Artificial horizons; Longitudinal incline indicators; Compasses; Rate of climb indicators.

1.4 ITEMS OF EQUIPMENT including:—
For attachment to the airframe structure
Radio equipment.
For condition, assembly and functioning
Electric lighting; Safety belts; Safety harness; Fire prevention apparatus; Cabin heating; Towing gear; Batteries; Life belts; De-icing system; Oxygen system.

1.5 ALL PARTS OF INSTALLATIONS REQUIRED FOR OPERATING ANY OF THE ITEMS SHOWN UNDER 1.1 to 1.4 ABOVE, including:—
For condition and installation
Air-driven generators; Venturis.
For condition, installation and functioning
All parts of flap operating gear; All parts of retractable undercarriage operating gear; All parts of brake operating gear; Pressure storage chambers, except in the case of air engine starters; Wiring or piping leading to any items classified under Column 1.

1.6 EMERGENCY EXITS*
For condition and functioning

* When periodical opening tests of an emergency exit are necessary to ensure that it is in working order, the appropriate interval between tests is determined by the Board.

1.7 ALL BONDING CONNECTED TO THE AIRFRAME.
For condition and attachment to airframe structure

2 The aircraft engineer licensed in Category "C" is required to certify the engine(s) and all parts essential to its installation.

2.1 ALL PARTS OF THE POWER PLANT, including:—
For condition, installation, functioning and in the case of engines, power output
Engines; Vacuum pumps; Pressure pumps; Fuel pumps; Engine driven generators; Engine starting systems; Ignition system; Induction system; Exhaust system.

2.2 ALL CONTROLS CONNECTED WITH THE ENGINES OR THEIR ANCILLARY SYSTEMS.
For condition, assembly and functioning

2.3 ALL ENGINE INSTRUMENTS† including: —
For installation and functioning
Revolution indicators; Pressure gauges; Contents gauges; Boost gauges; Temperature indicators; Flowmeters.

2.4 AIRSCREWS
For condition assembly and smooth running, and in the case of V.P. airscrews functioning

2.5 ALL PARTS OF INSTALLATIONS REQUIRED FOR OPERATING ANY OF THE ITEMS SHOWN UNDER 2.1 to 2.4 ABOVE,† including:—
For condition, installation and functioning
All fuel system parts, including tanks; All oil system parts, including tanks; All cooling system parts, including engine cowling; All wiring and piping, except as defined above.

2.6 BONDING OF PARTS CLASSIFIED UNDER COL. 2.
For condition

† When removal of an instrument or repair of an installation system involves the detachment of wiring or pipe lines from the airframe, or the opening up of the airframe, the work of removal and replacement should be done in collaboration with an aircraft engineer licensed in Category "A".

No. 4

AIRSCREWS APPROVED FOR USE ON CIVIL AIRCRAFT

1. Airscrews to the designs quoted in the attached appendix are approved for use on civil aircraft.

While these are listed for convenience under types of engines, each airscrew is approved only for the specific engine-airframe combinations shown.

2. An airscrew drawing number is frequently followed by an "issue" number. Such issue numbers are used mainly to indicate minor modifications to the airscrew which do not affect safety. When an issue number is not quoted in the list it may be assumed that all issue numbers are approved.

3. In this notice, only airscrews which may be fitted to aircraft holding British Certificates of Airworthiness are quoted. The list includes certain aircraft manufactured in U.S.A. which, under wartime procedure, have been granted British Certificates.

4. If it is desired to use an airscrew not included in the list, application for approval should be made in writing to the Secretary of the Board.

APPENDIX

Drawing No.	Diam. (ft.)	Pitch (ft.)	Aircraft
CENTAURUS VII			
Type R.17/4B6/2	14·75	V.P.	Warwick V.
CIRRUS MAJOR—Mk I			
61456. A/X1.	6·75	6·02	Miles Hawk
61456. A/X2	6·75	5·77	Miles Hawk
A.66016/X4	7·00	4·58	Cygnet
LA.520	6·67	4·59	Cygnet
CIRRUS MAJOR 150			
A.66019/1.X1	7·00	4·98	Percival Gull
A.66038/X1	7·00	5·31	Miles Hawk
94518.A/X3	7·00	5·31	Miles Hawk
Z.3754	6·30	5·15	Miles Hawk
A.66290/X1	7·00	4·58	Cygnet. Owlet
A.66317/3/X2	7·00	4·66	Percival Gull
CIRRUS MINOR			
LA.505/2	5·87	3·38	Taylorcraft Plus
GIPSY MAJOR I.			
Z.970	6·23	5·72	Miles Hawk
Z.971	6·23	5·26	Miles Hawk. Miles Monarch Miles Whitney Straight
Z.972	6·50	5·98	Miles Hawk
Z.973	6·23	5·50	Miles Hawk. Miles Monarch Miles Whitney Straight
Z.1510	6·36	5·20	D.H.84
Z.2010	6.50	5.65	Miles Hawk
Z.2011	6·50	5·49	Miles Hawk
Z.3101	6·42	5·22	D.H.90
Z.3104	6·50	5·42	D.H.90
Z.3105	6·50	5·46	D.H.90
D.H.5212/A	6·17	5·25	D.H.90
D.H.5212/C	6·17	5·17	D.H.84
D.H.5212/D	6·17	5·42	Miles Whitney Straight D.H.84. D.H.90
D.H.5212/G	6·17	5·14	D.H.84
D.H.5218/B	6·50	5·10	D.H.82. D.H.84
D.H.5220/G	6·33	4·58	D.H.82A
D.H.5220/H	6·33	4·92	D.H.82A. D.H.84
D.H.5220/MX/20	6·33	4·50	D.H.82A
D.H.5228/A	6·00	5·25	D.H.84
D.H.5228/B	6·00	5·12	D.H.84
D.H.5232/A	6·50	5·10	D.H.82. D.H.84. D.H.85
D.H.5232/B	6·50	5·30	D.H.82. D.H.84. D.H.85
D.H.5234/A	6·75	5·08	D.H.85
D.H.5234/B	6·75	4·95	D.H.85
D.H 5234/D	6·75	4·80	D.H.85. D.H.87
D.H.5234/E	6·75	4·50	D.H.85. D.H.87A. D.H.87B
D.H.5234/H	6·75	4·30	D.H.87B
D.H.5234/J	6·75	4·40	D.H.87B. D.H.85
D.H.5250/B	6·33	5·17	D.H.90
61187A/X1	6·75	5·50	Miles Whitney Straight Miles Hawk
61187A/X3	6·75	5·80	Miles Hawk
61187A/X5	6·75	5·77	Miles Hawk
61187A/X9	6·75	5·24	Miles Hawk. Miles Monarch
61189A/X5	7·00	6·96	Miles Hawk
61326A/X1	6·17	5·92	D.H.85. Miles Whitney Straight. Miles Hawk
61326A/X2	6·17	5·56	Miles Whitney Straight
61326A/X4	6·17	6·58	D.H.85
61326A/X6	6·17	6·27	Miles Hawk
61326A/X8	6·17	6·01	D.H.85. Miles Whitney Straight
61326A/X9	6·17	5·72	Miles Whitney Straight Miles Monarch
62326A/X10	6·17	5·85	Miles Whitney Straight
61456A/X2	6·75	5·77	Miles Hawk
61987C/X1	6·50	5·77	Miles Hawk
A.66016/X1	7·00	5·58	Cygnet
A.66016/X2	7·00	5·24	Cygnet
A.66016/X4	7·00	4·58	Cygnet
B.66131/X1	5·92	5·92	Miles Monarch
B.66143/X1	6·74	5·49	D.H.85
67104A/X2	7·00	5·10	D.H.85
67104A/X3	7·00	4·95	D.H.87
67104A/X4	7·00	4·77	D.H.82. D.H.85. D.H.87B
67104A/X6	7·00	5·33	D.H.85
67104A/X7	7·00	4·71	D.H.82. D.H,87
67104A/X9	7·00	4·40	D.H.82
67104A/X10	7·00	4·60	D.H.82A. D.H.85. D.H.87B
67104A/X11	7·00	5·52	D.H.85
67104A/X12	7·00	5·18	D.H.85. D.H.87B
67104A/X13	7·00	5·40	D.H.85
67104A/X14	7·00	4·52	D.H.85. D,H.82
67104A/X15	7·00	5·01	D.H.85
67575A/X1	7·00	4·71	D.H.82A
84723A/X1	7·00	4·84	D.H.82. D.H.87B
O.P.60/B	6·61	5·42	Miles Whitney Straight
B.A.211/2	6·18	5·41	Miles Whitney Straight. Miles Hawk
L.A.506	6·50	4·35	D.H.82
L.A.510	6·50	5·36	Miles Monarch Miles Whitney Straight
L.A.520	6·67	4·59	D H.90
L.A.550/1	6·67	5·05	D.H.85. Miles Hawk
GIPSY MAJOR (High Compression)			
61187A/X1	6·75	5·50	Miles Sparrowhawk
61187A/X4	6·75	5·83	Miles Hawk
61187A/X6	6·75	6·29	Miles Sparrowhawk
61187A/X7	6·75	6·10	Miles Sparrowhawk. Miles Hawk
61187A/X8	6·75	6·19	Miles Sparrowhawk
GIPSY MINOR			
D.H.5258/A	5·88	3·96	Moth Minor
D.H.5258/E	5·88	4·19	Moth Minor
D.H.5258/J	5·88	4·03	Moth Minor
D.H.5258/K	5·88	4·00	Moth Minor
GIPSY SIX I			
Z.1800	6·92	6·20	Miles Hawk
Z.2192	6·75	6·18	D.H.89
Z.2680	6·72	6·34	D.H.86
Z.2681	6·72	6·20	D.H.86
Z.2682/1 to 6	6·72	6·20	D.H.86. D.H.89
Z.2682/7 or later	6·56	6·18	D.H.89
Z.2685/1 to 5	6·72	6·44	D.H.86
Z.2685/6 or later	6·56	6·42	D.H.86
Z.2687	6·56	6·43	D.H.86. D.H.86B
Z.2688	6·56	6·29	D.H.89
Z.2689	6·56	6·50	D.H.86. D.H.86B
D.H.5238/A	6·92	6·30	D.H.86
D.H.5238/D	6·75	5·95	D.H.86
D.H.5238/F	6·75	6·30	D.H.86. D.H.89
D.H.5238/G	6·75	6·40	D.H.86. D.H.89 Hendy Heck
D.H.5238/H	6·75	6·40	D.H.89
D.H.5238/J	6·75	6·20	D.H.89
D.H.5244/A	6·75	6·40	D.H.89
D.H.5244/B	6·75	6·30	D.H.89
D.H.5244/C	6·75	6·56	D.H.86
D.H.5246/B	6·75	6·20	D.H.86. D.H.89
D.H.5246/C	6·75	6·10	D.H.86
61025A/X2	7·00	6·47	D.H.86. D.H.89
61025A/X3	7·00	6·29	D.H.89
61025A/X4	7·00	6·64	D.H.86
61025A/X5	7·00	6·03	D.H.89
61186A/X1	7·00	6·83	D.H.86
61186A/X2	7·00	6·66	D.H.86. D.H.86B. D.H.89
61186A/X3	7·00	6.56	D.H.89
61186A/X4	7·00	6·48	D.H.89
61186A/X5	7·00	6·39	D.H.89
61186A/X6	7·00	6·33	D.H.86B. D.H.89. Vega Gull
61189A/X1/1	7·00	6·73	Miles Hawk
61189A/X1/2 or later	7·00	7·11	Miles Hawk
61189A/X5	7·00	6·96	Miles Hawk
61189A/X7	7·00	6·84	Miles Hawk
61189A/X8	7·00	7·29	Miles Hawk
61203A/X1	7·00	7·07	Hendy Heck
61203A/X3	7·00	6·30	Hendy Heck
61267A/X2	7·00	6·66	Hendy Heck
61267A/X5	7·00	6·37	Hendy Heck
61375A/X1	7 00	6·76	Vega Gull
61375A/X2	7·00	7·03	Miles Hawk
61375A/X5	7·00	6·59	Vega Gull
61375A/X6	7·00	6·50	Vega Gull
61375A/X7	7·00	6·35	Vega Gull
61375A/X10	7·00	6·94	Vega Gull
C.66026/X1	6·67	6·81	D.H.89
C.66093/X1	6·75	6·66	D.H.86B. D.H.89
C.66014	6·79	6·78	D.H.86. D.H.86B
B.66128/X1	6·75	6·75	D.H.89
C.66017	6·75	6·79	D.H.86. D.H.86B
L.A.507	6·67	6·05	D.H.86
GIPSY SIX II			
Blade P.51150/B/1 Hub P2-1-0-3	7·50	V.P.	Vega Gull
Blade P.51156 Hub P2-1-0-1	7·00	V.P.	Vega Gull. Hendy Heck
Blade P.51156 Hub P2-1-0-3	7·00	V.P.	Vega Gull
Blade P.51159 Hub P2-1-0-2	6·75	V.P.	Reid-Sigrist Trainer
Blade P51156 Hub P2-1-0-6	7·0	V.P.	Proctor
Ratier 1380	6·89	V.P.	Vega Gull
Ratier 1586	7·21	V.P.	Percival "Q' Type. Vega Gull
GIFSY SIX III (QUEEN)			
61186A/X4	7·00	6·48	D.H.89A
HERCULES (BRISTOL)			
Blade 60134/1 Hub P.20006	14·50	V.P.	Short S.26
Blade P.4551151 Hub 33-EX-2	14·50	V.P.	Short S.26
LYCOMING 0-290 3			
Z 5600/2	6·5	3·48	Auster V.
Z.5594	6·0	3·67	Auster V.
MERLIN 22			
Type A5/138 Blade 6353 A-0	13·00	V.P.	Lancaster
Type A5/122 Blade 6359 A-12	13·00	V.P.	York
MERLIN 23			
Type A5/146 Blade 6519 A-12	12·00	V.P.	D.H.98
Type A5/147 Blade P.4551212A-50	12·00	V.P.	D.H.98
Type 5/36 Blade P.4551212A-50	12·00	V.P.	D.H.98

Drawing No.	Diam. (ft.)	Pitch (ft.)	Aircraft
MERLIN T.24			
Type A5/159 ... Blade 6519A/0	13·0	V.P.	Lancaster
PEGASUS XC			
Blade P.55253 ... Hub P3-5-0-1 ... Hub P3-5-3-1 ... Hub P3-5-3-4 ...	12·75	V.P.	Short S.23
Blade P.55253 ... Hub P3-5-3-1 ...	12·75	—	Short S.30
Blade P.55250 ... (and all crops) Hub P3-5-7-1 ... Hub P3-5-7-4 ... Hub P3-5-7-6 ...	13·00	V.P.	Short S.30
PEGASUS XVIII			
Type 5/28 ... Blade P.551553	12·75	V.P.	Short S.25 Mk.III
Type 5/42 ... Blade P.551953A	12·75	V.P.	Short S.25 Mk. III
Type 5/45 ... Blade P.55256 ...	12·50	V.P.	Short S.25 Mk. III
Type DR2/345/2 Blade P.454853A	12·75	V.P.	Short S.25 Mk. III
PEGASUS XXII			
Blade P.55253 ... Hub P3-5-3-1 ...	12·75	V.P.	Short S.30
PERSEUS XIIC			
Blade P.55250 ... Hub P3-5-7-1 ... Hub P3-5-7-4 ... Hub P3-5-7-6 ...	13·00	V.P.	D.H.95
Blade P.55253 ... Hub P3-5-7-4 ...	12·75	V.P.	D.H.95

Drawing No.	Diam. (ft.)	Pitch (ft.)	Aircraft
PERSEUS XVI			
P.455253 A-50 ...	12·75	V.P.	D.H.95
PRATT & WHITNEY TWIN WASP SIC3G			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	Douglas C.47 (Dakota)
Blade 6353 A-18 Hub 23E50 ...	11·50	V.P.	Douglas C.47 (Dakota)
Blade 6353 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 28 (Catalina)
Blade 6477 A-0 Hub 23E50 ...	11·58	V.P.	Douglas C.47 (Dakota)
Blade 6153 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 28 (Catalina)
PRATT & WHITNEY TWIN WASP S3C4G			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6153 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 32 (Liberator)
Blade 6227 A-0 Hub 23E50 ...	10·58	V.P.	Lockheed 414
Blade 89303-18 Hub C532D-F22	11·50	V.P.	Consolidated 32 (Liberator)
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6353 A-18 Hub 23E50 ...	11·50	V.P.	Consolidated 32 (Liberator)
PRATT & WHITNEY TWIN WASP S4C4G			
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	Consolidated 32 (Liberator)
Blade 89303-18 Hub C532D-F22	11·50	V.P.	Consolidated 32 (Liberator)

Drawing No.	Diam. (ft.)	Pitch (ft.)	Aircraft
RANGER 6 CYL			
Z.3960	7·25	4·03	Fairchild 24
WALTER MIKRON II			
A.66049/1X1	4·75	3·59	Tipsy B.
L.A.511	5·05	3·92	Tipsy B.
66167/4/X4	5·50	3·44	Tipsy B.
WARNER SUPER SCARAB			
L.A.527	7·00	5·20	Fairchild 24
WRIGHT CYCLONE GR 1820-G 102A			
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	A.W.27
WRIGHT CYCLONE GR 1820-G 205A			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6179 A-0 Hub 23E50 ...	10·50	V.P.	Lockheed 414
Blade 6339 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
WRIGHT DOUBLE ROW CYCLONE GR 2600-A2A			
Blade 6243 A-3 Hub 23E50 ...	14·75	V.P.	Boeing 314A
Blade 6443 A-3 Hub 23E50 ...	14·75	V.P.	Boeing 314A

Note:—Before fitting a V.P. airscrew it is essential to ensure that the basic pitch range setting conforms with the latest setting approved for the particular engine-airframe combination.

Negative-Rake Milling*

By J. Q. Holmes† and R. C. Holloway‡

SOME truly remarkable results in high-speed or "hyper" milling of steel forgings have been attained on a production basis at Eastern Aircraft's Linden, N. J., plant. To date, work has been confined to tough 4140 chrome-molybdenum steel forgings; some annealed and some heat-treated to 40-41 Rockwell C and 180,000 lb. per sq. in. tensile strength. Milling rates range from about five to nearly 15 times those previously attained with conventional cutters run as fast as usual procedure dictated.

Besides stepping up the rate of cutting, a greatly superior finish is secured and close limits, held only with difficulty before, are readily held now. Many more forgings are machined per grind, hence down time is decreased. In no case is more than one cut required, the depth ranging from $\frac{1}{8}$ to $\frac{1}{2}$ in. Some surfaces which had to be ground after milling with prior practice are now finished in a single cut, that is, without grinding, and yet have an approximately equal finish.

These results were not attained without considerable experimentation and are not necessarily the best securable, but they do represent a marked advance in milling. The new methods and cutters are in regular use and others of the same type will be applied much more extensively.

Inserted-Blade Cutters

Cutters now in use are of 6- and 8-in. diameters and have 10 and 14 blades, each of which has an inserted carbide tip of the grade known as Firthite T-16 or equivalent. Grinding is with negative rake and negative helix angle, as shown in the detail sketches. This grinding is now standard for the type of cutters here dealt with, and was arrived at after extensive tests.

Cutter speed ranges from 489 to 597 r.p.m. and from about 800 to 1285 surface feet a minute, but the time saving results from the higher table speed (or feed) which is from 15 in. to as high as 21 in. a minute as against 1 to 3 in. a min. for former conventional milling cutters turning at surface speeds of only 40 to 70 ft. a min. At the high speeds and feeds now used, sparks fly somewhat as for grinding (though not in equal volume) and only when this condition is reached is the cutter considered to be working to good advantage. Many of the cuts made are intermittent.

Chips produced come off at blue to red heat and range from 0·002 to 0·003 in. in thickness. Strangely enough, however, neither the cutter nor the work are, as a rule, warmer than the hand can bear when touched immediately upon completion of the cut. An exception is in thin forgings machined in heat-treated condition, although even they do not run, apparently, much above 200 to 300 deg. F. Chips in such cases are red hot. All milling of the high-speed type is now done dry. No measurements of power consumed have been made, but no indications of overheated motors have been encountered. Cutters are usually run back across the work on the return stroke of the table, especially when the forging is a thin one and may spring slightly on the forward cut.

Fixtures are the same ones employed before with conventional milling, and the same standard milling machines are used. There is nothing to indicate excessive stresses on machines or fixtures, and no significant vibration has been noted. Observation of the milling operation gives the impression that the material is of the freest cutting type rather than the hard, tough steel actually being machined, except that the chips are evidently very hot. They are hot enough, in fact, to set fire to a wood-block floor, especially where heat-treated stock is machined. Figures in the accompanying table give the pertinent facts on each of several jobs effectively run in production among many others of similar character. Savings are so great

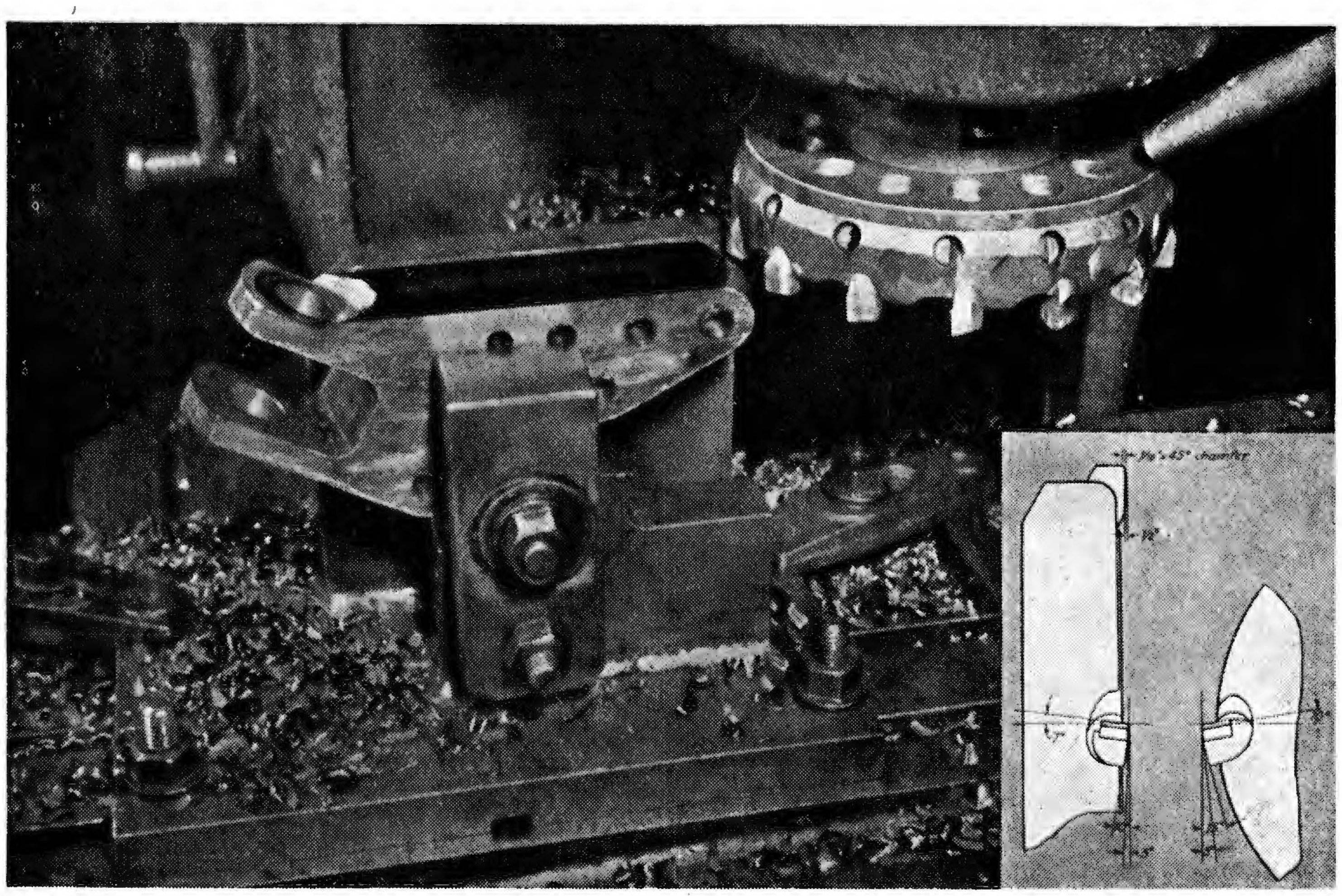


FIG. 1.—*Hyper-milling of a typical chrome-moly* 4140 *annealed steel forging for the Navy's* Wildcat (*see piece* 3 *in table on Fig.* 4). *The* 8-*in. cutter has* 14 *blades with T*-16 *Firthite tips and turns at* 598 *r.p.m. Table feed is* 14½ *in. a min. The cut is* ⅛ *in. deep at edges of forging and* $\frac{5}{16}$ *in. deep at the central parting line. Sparks fly and chips come off blue-hot, but the work, as well as the cutter, runs cool. No coolant thus is needed for the operation*

For further examples of this new milling technique, see overleaf

* Reprinted from the April, 1944, issue of "*Wings*: the U.S. Army and Navy publication for the Aircraft Industry," pp. 5—967.

† Master Mechanic.

‡ Supt. of Small Tools, Eastern Aircraft Division, General Motors Corp.

Drawing No.	Diam. (ft.)	Pitch (ft.)	Aircraft
MERLIN T.24			
Type A5/159 ... Blade 6519A/0	13·0	V.P.	Lancaster
PEGASUS XC			
Blade P.55253 ... Hub P3-5-0-1 ... Hub P3-5-3-1 ... Hub P3-5-3-4 ...	12·75	V.P.	Short S.23
Blade P.55253 ... Hub P3-5-3-1 ...	12·75	—	Short S.30
Blade P.55250 ... (and all crops) Hub P3-5-7-1 ... Hub P3-5-7-4 ... Hub P3-5-7-6 ...	13·00	V.P.	Short S.30
PEGASUS XVIII			
Type 5/28 ... Blade P.551553	1-·75	V.P.	Short S.25 Mk.III
Type 5/42 ... Blade P.551953A	12·75	V.P.	Short S.25 Mk. III
Type 5/45 ... Blade P.55256 ...	12·50	V.P.	Short S.25 Mk. III
Type DR2/345/2 Blade P.454853A	12·75	V.P.	Short S.25 Mk. III
PEGASUS XXII			
Blade P.55253 ... Hub P3-5-3-1 ...	12·75	V.P.	Short S.30
PERSEUS XIIC			
Blade P.55250 ... Hub P3-5-7-1 ... Hub P3-5-7-4 ... Hub P3-5-7-6 ...	13·00	V.P.	D.H.95
Blade P.55253 ... Hub P3-5-7-4 ...	12·75	V.P.	D.H. 5
PERSEUS XVI			
P.455253 A-50 ...	...12·75	V.P.	D.H.95
PRATT & WHITNEY TWIN WASP S1C3G			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	Douglas C.47 (Dakota)
Blade 6353 A-18 Hub 23E50 ...	11·50	V.P.	Douglas C.47 (Dakota)
Blade 6353 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 28 (Catalina)
Blade 6477 A-0 Hub 23E50 ...	11·58	V.P.	Douglas C.47 (Dakota)
Blade 6153 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 28 (Catalina)
PRATT & WHITNEY TWIN WASP S3C4G			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6153 A-12 Hub 23E50 ...	12·00	V.P.	Consolidated 32 (Liberator)
Blade 6227 A-0 Hub 23E50 ...	10·58	V.P.	Lockheed 414
Blade 89303-18 Hub C532D-F22	11·50	V.P.	Consolidated 32 (Liberator)
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6353 A-18 Hub 23E50 ...	11·50	V.P.	Consolidated 32 (Liberator)
PRATT & WHITNEY TWIN WASP S4C4G			
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	Consolidated 32 (Liberator)
Blade 89303-18 Hub C532D-F22	11·50	V.P.	Consolidated 32 (Liberator)
RANGER 6 CYL			
Z.3960	... 7·25	4·03	Fairchild 24
WALTER MIKRON II			
A.66049/1X1 ...	... 4·75	3·59	Tipsy B.
L.A.511 ...	... 5·05	3·92	Tipsy B.
66167/4/X4 ...	... 5·50	3·44	Tipsy B.
WARNER SUPER SCARAB			
L.A.527 ...	... 7·00	5·20	Fairchild 24
WRIGHT CYCLONE GR 1820-G 102A			
Blade 6153 A-18 Hub 23E50 ...	11·50	V.P.	A.W.27
WRIGHT CYCLONE GR 1820-G 205A			
Blade 6139 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
Blade 6179 A-0 Hub 23E50 ...	10·50	V.P.	Lockheed 414
Blade 6339 A-12 Hub 23E50 ...	10·50	V.P.	Lockheed 18 (Lodestar)
WRIGHT DOUBLE ROW CYCLONE GR 2600-A2A			
Blade 6243 A-3 Hub 23E50 ...	14·75	V.P.	Boeing 314A
Blade 6443 A-3 Hub 23E50 ...	14·75	V.P.	Boeing 314A

Note:—Before fitting a V.P. airscrew it is essential to ensure that the basic pitch range setting conforms with the latest setting approved for the particular engine-airframe combination.

Negative-Rake Milling*

By J. Q. Holmes† and R. C. Holloway‡

SOME truly remarkable results in high-speed or "hyper" milling of steel forgings have been attained on a production basis at Eastern Aircraft's Linden, N. J., plant. To date, work has been confined to tough 4140 chrome-molybdenum steel forgings; some annealed and some heat-treated to 40-41 Rockwell C and 180,000 lb. per sq. in. tensile strength. Milling rates range from about five to nearly 15 times those previously attained with conventional cutters run as fast as usual procedure dictated.

Besides stepping up the rate of cutting, a greatly superior finish is secured and close limits, held only with difficulty before, are readily held now. Many more forgings are machined per grind, hence down time is decreased. In no case is more than one cut required, the depth ranging from $\frac{1}{8}$ to $\frac{1}{2}$ in. Some surfaces which had to be ground after milling with prior practice are now finished in a single cut, that is, without grinding, and yet have an approximately equal finish.

These results were not attained without considerable experimentation and are not necessarily the best securable, but they do represent a marked advance in milling. The new methods and cutters are in regular use and others of the same type will be applied much more extensively.

Inserted-Blade Cutters

Cutters now in use are of 6- and 8-in. diameters and have 10 and 14 blades, each of which has an inserted carbide tip of the grade known as Firthite T-16 or equivalent. Grinding is with negative rake and negative helix angle, as shown in the detail sketches. This grinding is now standard for the type of cutters here dealt with, and was arrived at after extensive tests.

Cutter speed ranges from 489 to 597 r.p.m. and from about 800 to 1285 surface feet a minute, but the time saving results from the higher table speed (or feed) which is from 15 in. to as high as 21 in. a minute as against 1 to 3 in. a min. for former conventional milling cutters turning at surface speeds of only 40 to 70 ft. a min. At the high speeds and feeds now used, sparks fly somewhat as for grinding (though not in equal volume) and only when this condition is reached is the cutter considered to be working to good advantage. Many of the cuts made are intermittent.

Chips produced come off at blue to red heat and range from 0·002 to 0·003 in. in thickness. Strangely enough, however, neither the cutter nor the work are, as a rule, warmer than the hand can bear when touched immediately upon completion of the cut. An exception is in thin forgings machined in heat-treated condition, although even they do not run, apparently, much above 200 to 300 deg. F. Chips in such cases are red hot. All milling of the high-speed type is now done dry. No measurements of power consumed have been made, but no indications of overheated motors have been encountered. Cutters are usually run back across the work on the return stroke of the table, especially when the forging is a thin one and may spring slightly on the forward cut.

Fixtures are the same ones employed before with conventional milling, and the same standard milling machines are used. There is nothing to indicate excessive stresses on machines or fixtures, and no significant vibration has been noted. Observation of the milling operation gives the impression that the material is of the freest cutting type rather than the hard, tough steel actually being machined, except that the chips are evidently very hot. They are hot enough, in fact, to set fire to a wood-block floor, especially where heat-treated stock is machined. Figures in the accompanying table give the pertinent facts on each of several jobs effectively run in production among many others of similar character. Savings are so great

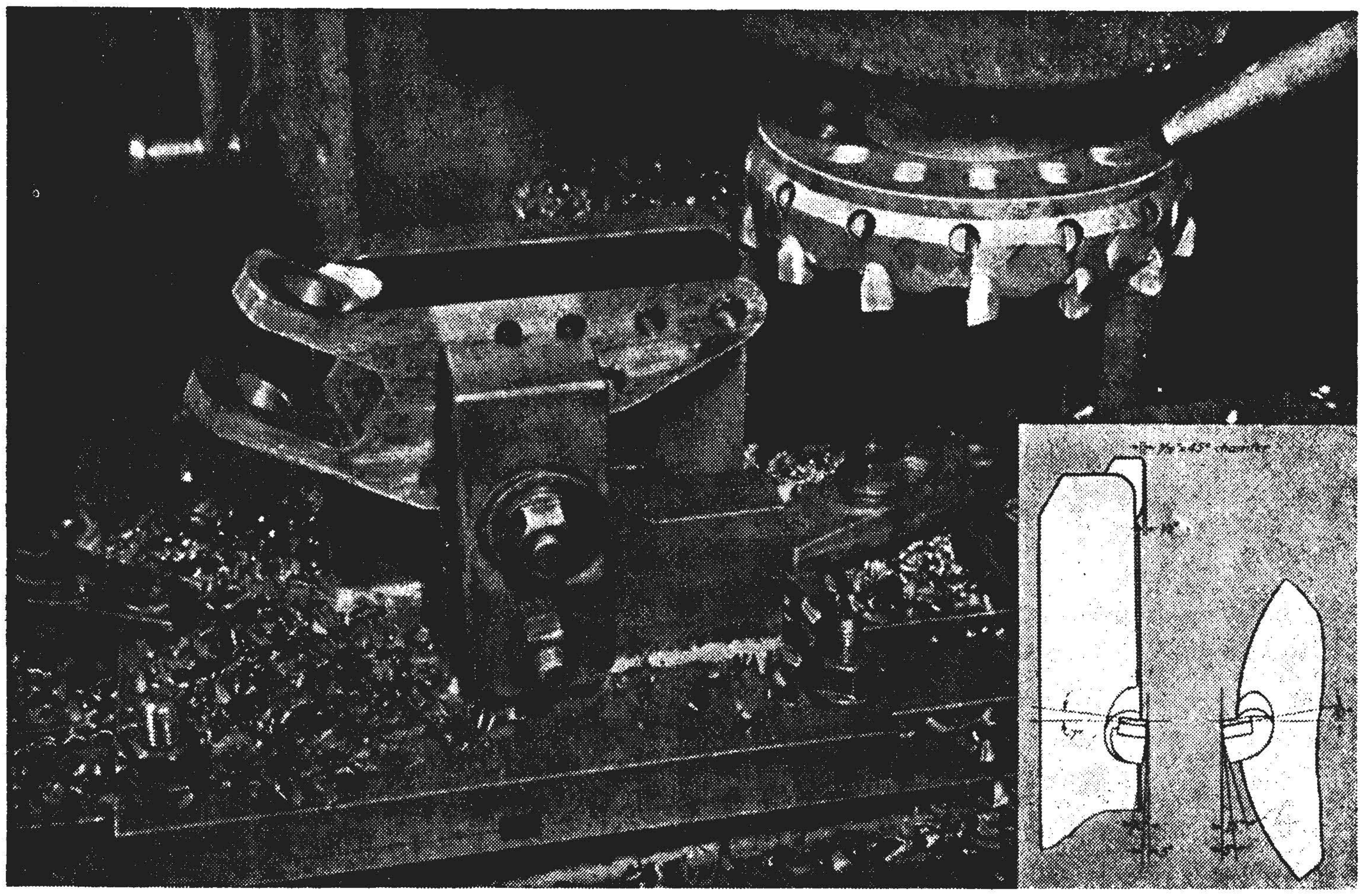


FIG. 1.—*Hyper-milling of a typical chrome-moly* 4140 *annealed steel forging for the Navy's* Wildcat (*see piece* 3 *in table on Fig.* 4). *The* 8-*in. cutter has* 14 *blades with T-*16 *Firthite tips and turns at* 598 *r.p.m. Table feed is* $14\frac{1}{2}$ *in. a min. The cut is* $\frac{1}{8}$ *in. deep at edges of forging and* $\frac{5}{16}$ *in. deep at the central parting line. Sparks fly and chips come off blue-hot, but the work, as well as the cutter, runs cool. No coolant thus is needed for the operation*

For further examples of this new milling technique, see overleaf

* Reprinted from the April, 1944, issue of "*Wings*: the U.S. Army and Navy publication for the Aircraft Industry," pp. 965—967.

† Master Mechanic.

‡ Supt. of Small Tools, Eastern Aircraft Division, General Motors Corp.

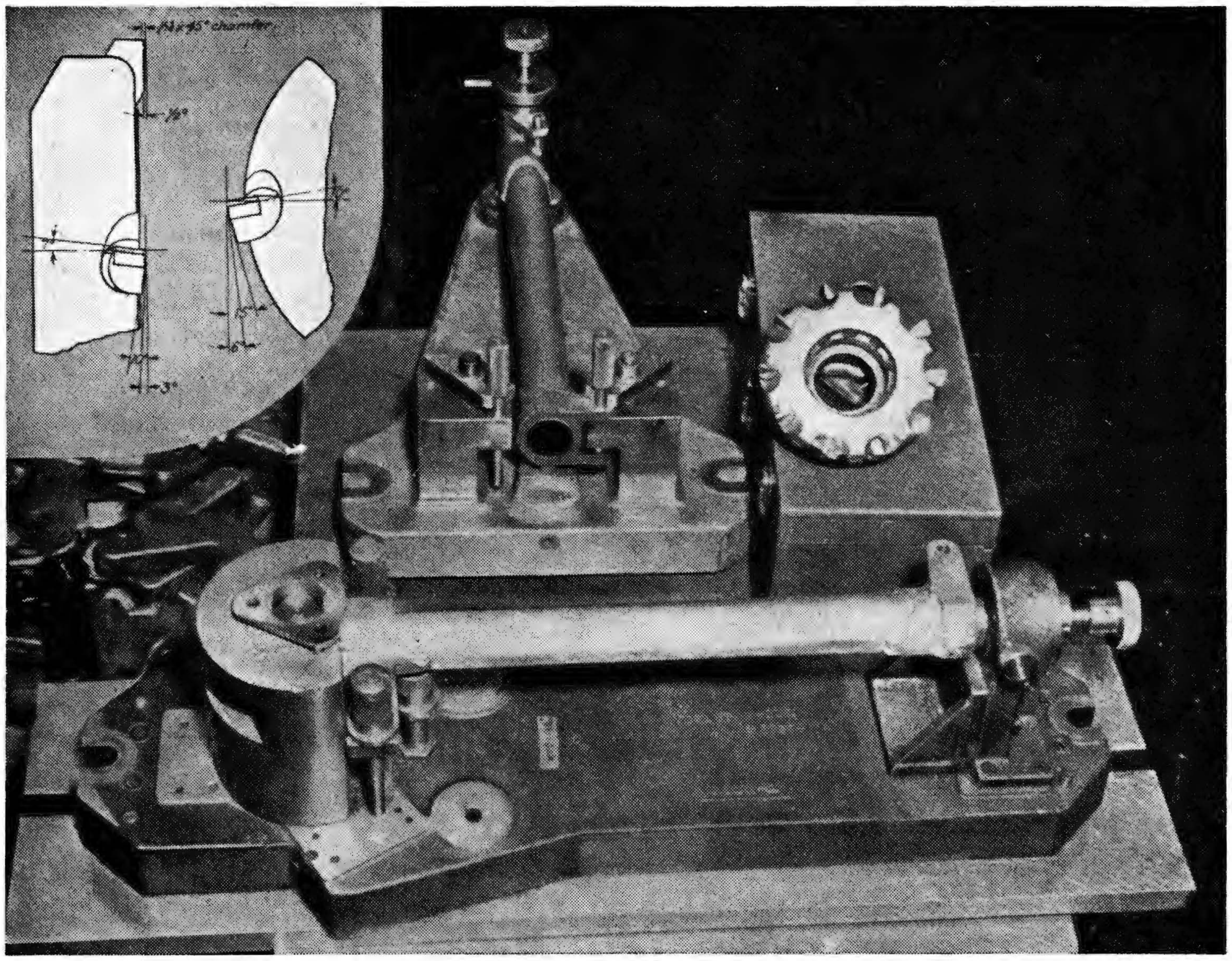


FIG. 2—*Two fixtures and the cutter employed in milling forgings welded to the ends of a landing-gear compression-link assembly (see piece 5 in table on Fig. 4). The cutter is 6 in. in diameter and turns at 489 r.p.m. Feed is 15 in. a minute. Forgings are heat-treated to 165,000 lb. per sq. in. tensile and 36 to 37 Rockwell C. Chips come off red hot. Some critical dimensions are held within 0·002-in. or closer limits, the cuts being so smooth as to appear ground*

that extension of high-speed milling to all steel forgings in our plant is contemplated as rapidly as the new cutters can be substituted for older types at present in use.

Facts on High-Speed Milling available§

Twenty loose-leaf sheets dealing with high-speed milling of steel and aluminum have been prepared at the request of the Office of Production Research and Development, WPB, by The Manufacturing Engineering Committee of the American Society of Mechanical Engineers. These sheets give examples of actual practice in high-speed milling, most of it in aircraft plants. Steel has been milled at cutter speeds as high as 2,600 sfpm. and on aluminum at 19,000 sfpm. Cutters, in general, have negative rake and negative helix angles, and feeds are high. Sets of sheets are available without charge to production executives of plants manufacturing aircraft and their components. The sheets can be secured by addressing the Manufacturing Committee, A.S.M.E., Room 802, 40 W. 40th St., New York, N. Y., on company letterhead, giving title and stating minimum number of sets required.

§ An article on this subject, entitled: "Using Negative Rake Tools in Aircraft-Parts Production", by J. Q. Holmes, appeared in the September, 1944, issue of *Mechanical Engineering*, the monthly journal of The American Society of Mechanical Engineers.

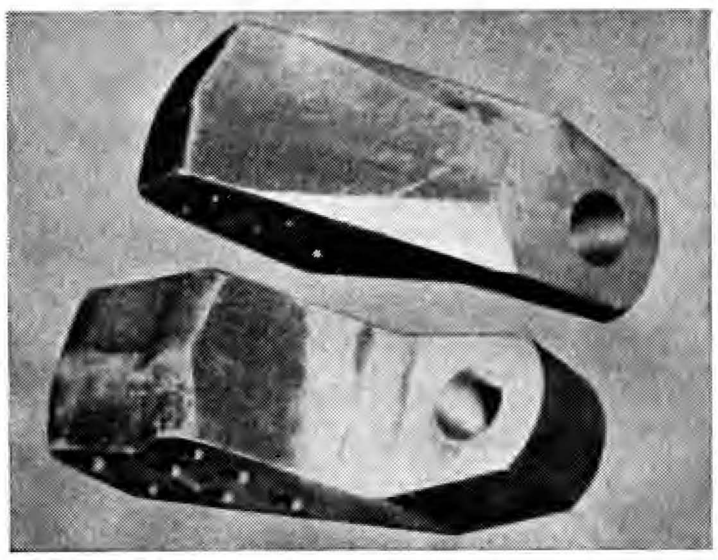
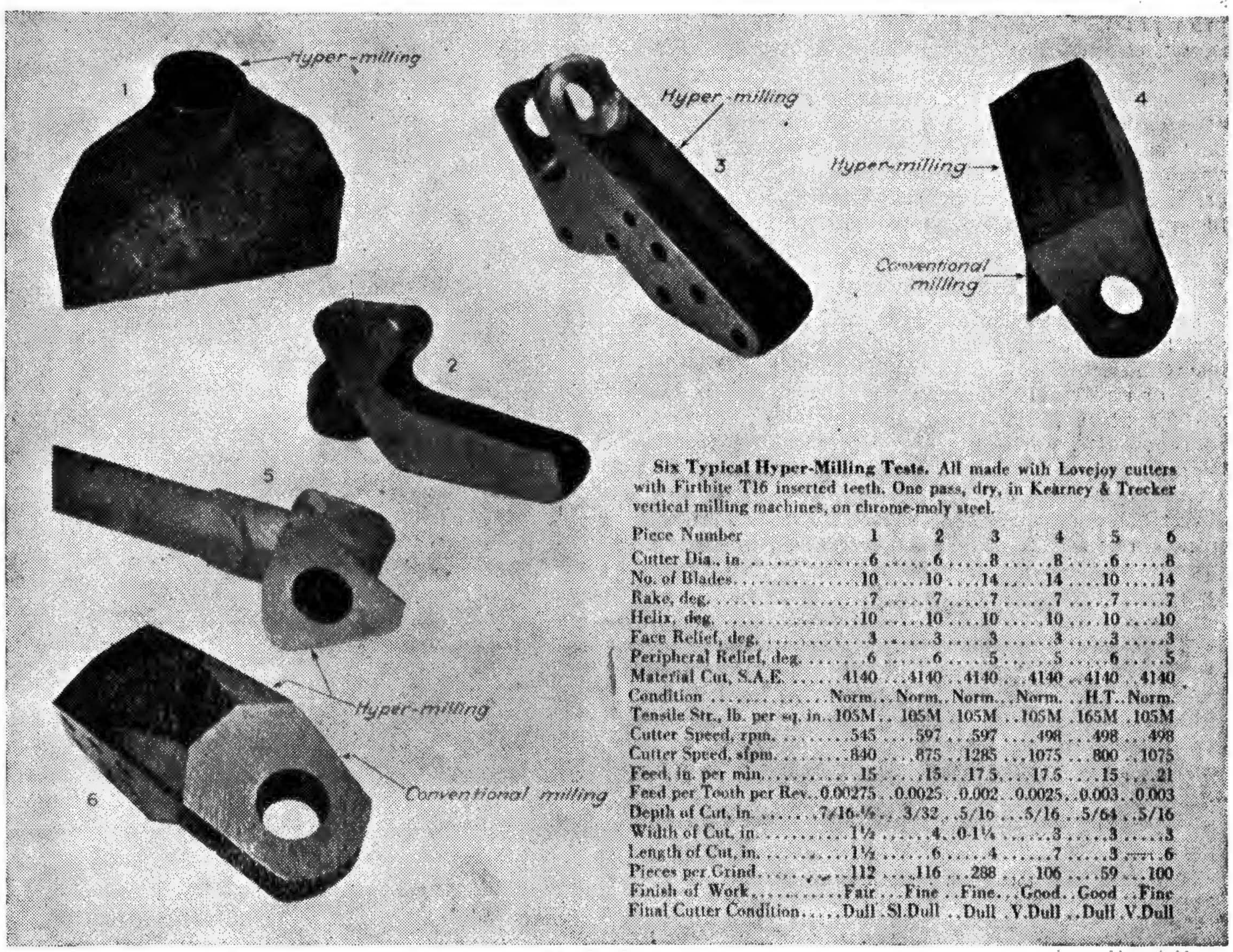


FIG. 3.—*These forgings have some surfaces hyper-milled and some faced with conventional cutters, the former being much smoother than the latter*

Further Examples of Negative-Rake Milling Practice

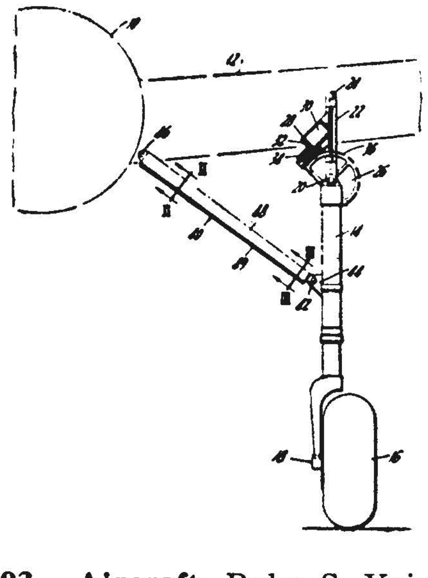


Six Typical Hyper-Milling Tests. All made with Lovejoy cutters with Firthite T16 inserted teeth. One pass, dry, in Kearney & Trecker vertical milling machines, on chrome-moly steel.

Piece Number	1	2	3	4	5	6
Cutter Dia., in.	6	6	8	8	6	8
No. of Blades	10	10	14	14	10	14
Rake, deg.	7	7	7	7	7	7
Helix, deg.	10	10	10	10	10	10
Face Relief, deg.	3	3	3	3	3	3
Peripheral Relief, deg.	6	6	5	5	6	5
Material Cut, S.A.E.	4140	4140	4140	4140	4140	4140
Condition	Norm.	Norm.	Norm.	Norm.	H.T.	Norm.
Tensile Str., lb. per sq. in.	105M	105M	105M	105M	165M	105M
Cutter Speed, rpm.	545	597	597	498	498	498
Cutter Speed, sfpm.	840	875	1285	1075	800	1075
Feed, in. per min.	15	15	17.5	17.5	15	21
Feed per Tooth per Rev.	0.00275	0.0025	0.002	0.0025	0.003	0.003
Depth of Cut, in.	7/16-⅛	3/32	5/16	5/16	5/64	5/16
Width of Cut, in.	1½	4	0-1¼	3	3	3
Length of Cut, in.	1½	6	4	7	3	6
Pieces per Grind	112	116	288	106	59	100
Finish of Work	Fair	Fine	Fine	Good	Good	Fine
Final Cutter Condition	Dull	Sl.Dull	Dull	V.Dull	Dull	V.Dull

FIG. 4.—*Six specimens tested, with detailed data on each*

U.S. Patent Specifications*

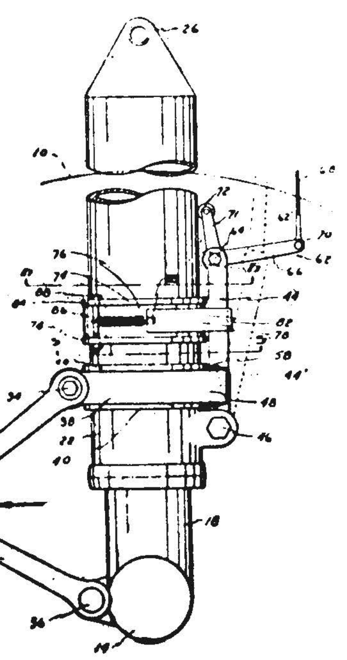


2,351,893. Aircraft. Pedro S. Yujuico, Great Neck, and David B. Thurston, Jamaica, N.Y., assignors to Brewster Aeronautical Corporation, Long Island City, N.Y. Application November 27, 1941. Serial No. 420,656. 2 Claims. (Cl. 244—102.)

An aircraft retractable undercarriage comprising a landing wheel strut having pivotally articulated upper and lower sections, a landing wheel carried at the lower end of said lower section, said upper section being pivotally mounted at its upper end upon said aircraft, a worm wheel sector fixed to said lower section concentrically with the pivot axis of said articulated connection, a worm meshing with said sector, a bearing rotatably mounting said worm upon said upper section to be positionally fixed thereto and to have its thrust axis directed generally upwardly toward the upper pivoted end of said upper strut section with the strut in extended position, a prime mover mounted upon said upper section adjacent the position of said worm and operatively connected to the latter, and strut-brace means pivotally connected to said strut and extending laterally therefrom into pivotal connection with said aircraft at a position spaced from said pivotal connection of said upper strut section.

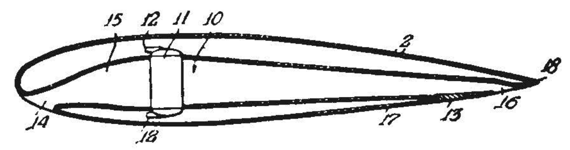
2,351,935. Emergency Braking Device. Leo J. Devlin, Los Angeles, Harold W. Adams, Santa Monica, Fred Landgraf, Los Angeles, and Charles S. Glasgow, West Los Angeles, Calif., assignors to Douglas Aircraft Company, Inc., Santa Monica, Calif. Application December 21, 1940. Serial No. 371,190. 12 Claims. (Cl. 244—103.)

In an aircraft emergency braking device adapted for use when the aircraft contacts a landing surface, a pair of supporting struts fixed to the aircraft and extending downward toward the landing surface, landing wheels disposed to roll in a direction parallel to the normal direction of motion of the aircraft and carried by the lower extremities of said struts, lever means for locking said wheels in their parallel relationship during normal operation of the aircraft, quick release mechanism operable by the aircraft pilot to move said lever means to an unlocked position whereby said wheels are free to swing to a position in which their relationship to the direction of motion of the aircraft is non-parallel, and means simultaneously released by said lever means and operating in conjunction with the forward motion of said aircraft to force said wheels to swing.



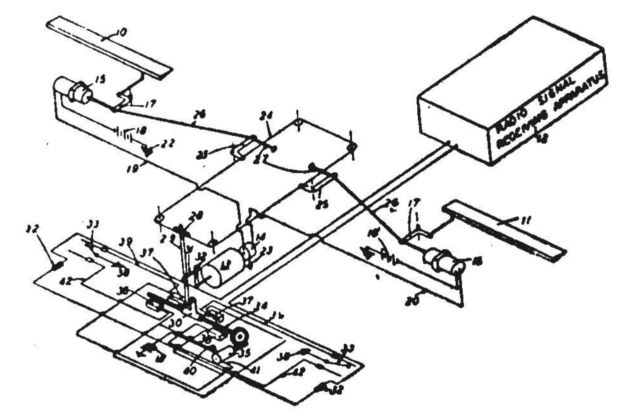
2,352,144. Wing Slot Closure Member. Robert J. Woods, Grand Island, N.Y., assignor to Bell Aircraft Corporation, Buffalo, N.Y., a corporation of New York. Application August 22, 1940. Serial No. 353,747. 3 Claims. (Cl. 244—42.)

An airplane wing having a positive angle of incidence, said wing having a duct extending therethrough, said duct having an inlet aperture within the area of the locus of pressure stagnation points adjacent the leading edge of the wing and an outlet aperture adjacent the trailing edge of the wing in the under-surface thereof, a closure member for said duct having its forward edge hinged to the



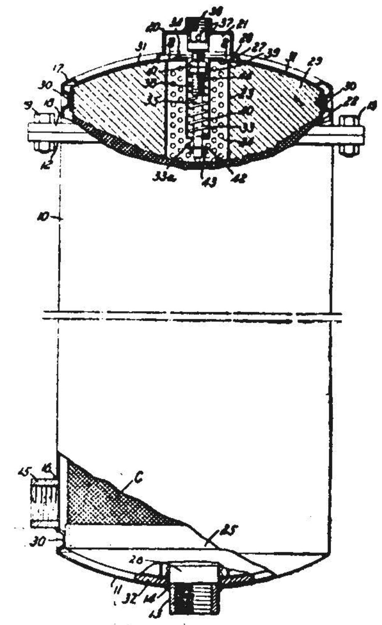
forward edge of the outlet aperture and extending rearwardly to a point short of the rear edge of said outlet aperture, when lying in the normal profile of the under surface of the wing thereby leaving the rear portion of the outlet aperture open, the depth of said duct being less than the length of said closure member so that said duct may be closed by upward swinging movement of the closure member into engagement with the upper wall thereof.

2,352,308. Lateral Control System for Aircraft. Robert A. Bailey, Burbank, Calif., assignor, by mesne assignments, to Lockheed Aircraft Corporation, a corporation of California. Application December 23, 1940. Serial No. 371,274. 3 Claims. (Cl. 244—14.)



A lateral control for an airplane comprising a pair of spaced ailerons arranged with interconnected linkages adapted to produce simultaneous and opposite deflections, separate solenoids each arranged for one-way operation of one of said ailerons and to simultaneously operate the other aileron in an opposite direction by means of said interconnected linkage, a source of electrical energy for said solenoids, a gyro, a switch controlled by the gyro to energize one or the other of said solenoids in response to changes in lateral trim of said airplane, a follow-up linkage associated with the interconnected aileron linkage and the gyro controlling said switch, said follow up linkage including a lever connected at one end to the follow up linkage and normally pivoting about its other end, the gyro being connected to said lever intermediate its ends in such a manner as to restore said gyro controlled switch to its neutral position upon movement of said follow up linkage upon energization of either solenoid by said switch, a remotely controlled radio receiving set, and means for laterally shifting the normal pivot point of said lever in response to electrical impulses from said remotely controlled radio receiving set, whereby the lateral shifting of the lever pivot is adapted to produce a constant angle of bank in said gyro controlled aileron control system.

2,352,315. Lubricating Oil Filter for Airplane Engines. Geoffrey Gilbert, Plainfield, N.J., assignor to Gilbert Process Corporation, Plainfield,

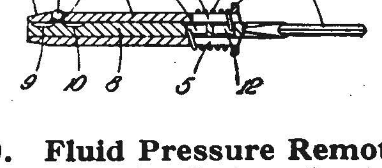


N.J., a corporation of Delaware. Application December 24, 1942. Serial No. 470,063. 10 Claims. (Cl. 210—131.)

A lubricating oil filter for the pressure lubricating oil systems of airplane and other engines, comprising in combination a container and co-operating removable cover therefor; a filter cartridge containing oil-permeable filtering medium and having imperforate top and bottom, a perforated peripheral wall and a perforated core wall defining a central open core space therein, said filter cartridge being spaced from the wall of said container to provide an annular outlet space and likewise being spaced from said cover to provide a by-pass between said core space and said annular outlet space; an inlet means in said container for introducing oil to be filtered, under pressure, into said central open core space; an outlet means in said container for discharging oil from said annular outlet space; a gas-venting means in communication with said open outlet space and adapted at all times to vent gas from within said filter; and a relief valve carried by said cover and disposed generally within said central open core space, said relief valve normally seating against the top of the filter cartridge whereby to close said by-pass and adapted to be unseated, so as to open said by-pass, under an abnormal pressure condition within said core space.

2,352,414. Connecting Device. Reginald Arthur William Spooner, Walton-on-Thames, England, assignor to Woodfield Engineering Limited, London, England, an English joint-stock company. Application December 17, 1942. Serial No. 469,344. In Great Britain December 20, 1941. 5 Claims. (Cl. 85—5.)

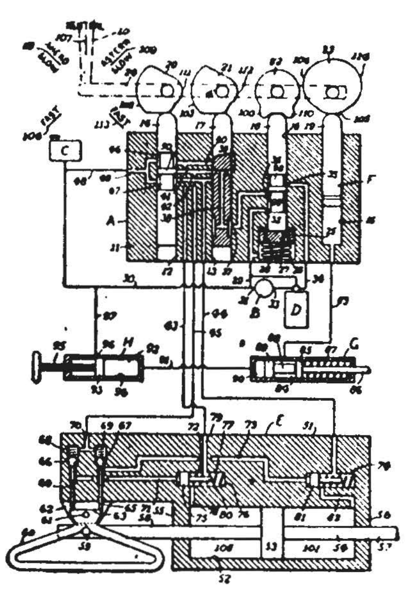
A connecting device comprising a tubular member, an axially movable member therein, at least one radially movable member in a passage in the wall of said tubular member from which said radially movable member cannot escape outwardly but through which a portion of said radially movable member projects beyond the external surface of said tubular member when said axially movable member is in its normal position, means permitting said radially movable member to move inwards to a position at least flush with the external surface of the tubular member on displacement of the axially movable member in either direction and spring means effective on said axially movable member and tending to restore it to normal position.



2,352,470. Fluid Pressure Remote Control System. Quintin Healey Carlton, Leamington Spa, England, assignor to Automotive Products Company Limited, Leamington Spa, England. Application June 26, 1942. Serial No. 448,640. In Great Britain March 24, 1941. 7 Claims. (Cl. 121—38.)

A motor unit for a fluid-pressure control system, including a block-like unit formed with a closed cylinder, a piston member operative in the cylinder and dividing the same into two working chambers, the block unit being formed with a conduit opening into one end of the cylinder and with a second conduit opening into the opposite end of the

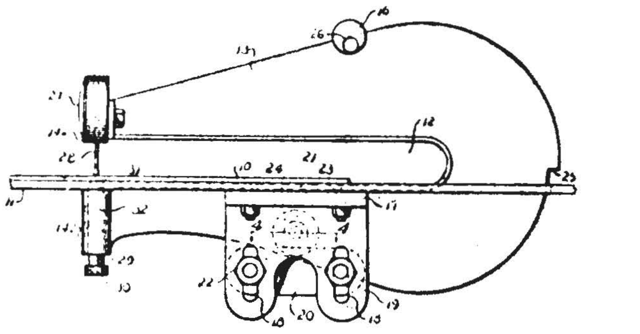
* These abstracts of patents granted in the United States are taken, by permission of the Department of Commerce, from the *Official Gazette of the United States Patent Office*. Printed copies of the full specification can be obtained, price 10 cents each, from the Commissioner of Patents, Washington, D.C., U.S.A. They are usually available for inspection at the British Patent Office, Southampton Buildings, Chancery Lane, London, W.C.2.
Except where otherwise stated, the specification is unaccompanied by drawings if none is reproduced.



cylinder, valves mounted in the block unit and respectively controlling conduits leading into the respective ends of the cylinder, distributing valve means for selectively directing the pressure fluid into either end of the cylinder through the conduits or to both valves to admit pressure flow through the valve-controlled conduits, means operated in the movement of the piston member for selectively opening either valve in accordance with piston member movement, a source of fluid under pressure, a timing valve, means biasing said timing valve to closed position, means connecting the source of fluid under pressure with the inlet of the timing valve means connecting the outlet of the timing valve with the inlet of the distributing valve means, manually operated means for biasing the timing valve to open position to establish connexion between the source of fluid under pressure and the distributing valve means, and damping means acting on said timing valve to interpose a time lag intermediate the manual opening thereof and the return to normal closed position.

2,352,571. Thickness-Measuring Apparatus. Edward A. Sprigg, Wadsworth, Ohio, assignor to The B. F. Goodrich Company, New York, N.Y., a corporation of New York. Application March 21, 1942. Serial No. 435,606. 5 Claims. (Cl. 33—147.)

Thickness-measuring apparatus comprising a table support for contact with material to be measured, a C-frame having an elongated aperture to accommodate the material, a leg of said frame being below the table support and having a pivotal



mounting with respect to said table support and an upper leg of said C-frame being in overlying relation to the table support, an adjustable gauging element carried by the lower leg, a second gauging element carried by the upper leg and having a movable feeler co-operable with the lower gauging element for measuring the material between said elements, said table support having an aperture through which the lower gauging element is movable, and a weight adjustable positioned on the upper leg of the C-frame for adjusting the unbalance of the frame about the pivot whereby the lower gauging element is adapted by virtue of the movability of said C-frame to contact a face of the material despite surface irregularity of the latter.

PACKING AND SHIPPING

R. & J. PARK, LIMITED, 143/9 *Fenchurch Street, E.C.3. 'Phone: Mansion House* 3083. *Aircraft Packers, Casemakers and Woodworkers. Contractors to the Air Ministry and foreign governments.*

WIRE-CLOTH AND GAUZE

THE PATENT PROCESS WIRE WEAVING CO. (*The United Wire Works, Ltd.*) *GRANTON, Edinburgh. 'Phone:* 83245. *A.I.D. Approved.*

TECHNICAL BOOKS

FOYLES have large stocks of New and Secondhand Books on Aeronautical and allied subjects. 119-125 *Charing Cross Road, W.C.2. Phone: GERrard* 5660. *Open* 9-6, *including Sats.*

PATENTS

KING'S PATENT AGENCY, LTD. (*B. I. King, A.I.Mech. E., Registered Patent Agent*), 146 *Queen Victoria Street, London, E.C.4. ADVICE, Handbook, and consultations on Patents and Trade Marks free. 'Phone: City* 6161.

HAND CLEANER

CLEAN HANDS FOR ENGINEERS by using famous Gre-Solvent. Bulk kegs for factory or works. 42 *lbs.* 14*s.* 3*d.*, 64 *lbs.* 17*s.* 6*d.*, 1 *cwt*, 32*s. carriage paid. Gre-Solvent Co., Whitehall Road, Leeds,* 12.

ELECTRIC HIGH-SPEED GRINDERS

"*CENTEC*" *Portable Electric Grinders* 22,500 *r.p.m. for stones up to* 1¼*in. diameter, also* **Drilling at 22,000 r.p.m.** *for holes up to* ⅛ *in, Particulars from Central Tool and Equipment Co., Church Terrace, Richmond, Surrey.*

Classified Advertisements

Minimum* (12 *words or less*): 3*s.* 6*d.
Each additional word: 3d.

TIME RECORDERS

TIME RECORDERS.—Sales—Rental—Service. Tel.: Vigilant 4731.—*Time Recorder Supply and Maintenance Co.,* 28 *Mayfield Road, Sutton, Surrey.*

CATERING

INDUSTRIAL Catering Contractors—We have a first-class organisation for unsurpassed service to secure efficient and adequate canteen arrangements for your employees. We are specialised contractors for catering for works and factory canteens and our staff of experienced personnel are at your disposal for consultation, advice or estimate. Write, giving details of your requirements, when we will immediately submit our suggestions. All enquiries dealt with promptly.—Newton and Hickmet Ltd., Dept. E, 11 *Wardour St., London, W.*1 (*Tel. Gerrard* 6811).

MACHINERY FOR SALE

NOBLE & LUND 54*in.* "*Fluifeed*" *High Speed Cold Sawing Machine for non-ferrous metals, to cut up to* 36*in. by* 21*in., with hydraulic feeds and* 20-*h.p. A.C.* 3-*phase electrical equipment. F. J. Edwards, Ltd.,* 359-361, *Euston Road, London, N.W.*1.

SCRAP METAL

SCRAP: High Speed Steel, Nickel Alloy Scrap, Stainless Steel Scrap, please consult BRITISH UNICORN LTD., 36/38 *Southampton Street, Strand, London, W.C.*2.

WIRE ROPE SPLICING

A COMPLETE range of hand-tools for forming and holding loops in 5 *cwt. to* 5 *in. circ. wire rope, now ready for sale. Save twine and* 50 *per cent labour by eliminating whipping and seizing. Soldo Co. Ltd.,* 5 *Sicilian Avenue, London, W.C.*1.

Bunhill Publications Ltd.

Proprietors of
Aircraft Engineering

SPECIAL SUBSCRIPTION RATE

A SPECIAL reduced rate of direct subscription of 21*s. per annum, post free, is available to the following: Associate, Graduate and Student Members of the R.Ae.S.; Members of any branch who are not Fellows or Associate Fellows of the Society; Students of an aeronautical course at any University or recognized Technical College or Technical School; Non-commissioned officers and other ranks of the R.A.F.; British Licensed Ground Engineers; Resident A.I.D. and Approved Firms' works inspectors.*

Obtainable only on direct application to the Editor.

THE TESTING OF METALLIC MATERIALS. By E. Skerry.
Price 3*s.* 6*d.* (3*s.* 10*d. post free*).

REPRINTS

DESIGNING FOR MACHINABILITY. By James E. Thompson.
Price 2*s.* (2*s.* 2*d. post free*).

QUALITY CONTROL AND SAMPLING INSPECTION. By H. Rissik.
Price 2*s.* 6*d.* (2*s.* 8*d. post free*).

PERSPECTIVE DRAWINGS FOR AEROPLANE HANDBOOKS. By J. H. Stevens.
Price 1*s.* 6*d.* (1*s.* 8*d. post free*).

WOOD AND PLASTIC CONSTRUCTION.
Price 2*s.* 6*d.* (2*s.* 8*d. post free*).

In Preparation

AIR-LINE ENGINEERING MANAGEMENT. By Ivor Lusty.
Price 2*s.* 6*d.* (2*s.* 8*d. post free*).

**12 Bloomsbury Square
London, W.C.1
England**