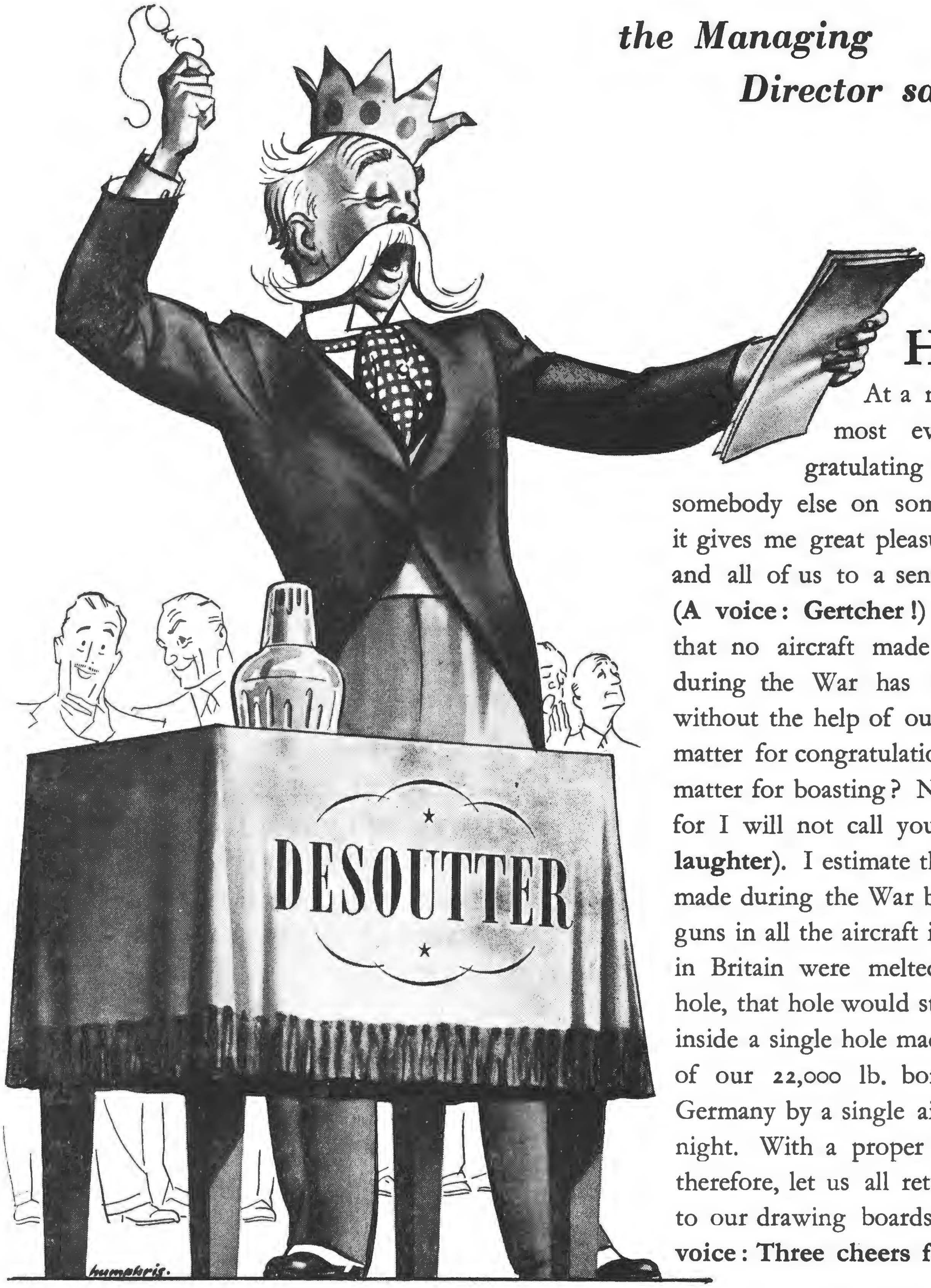
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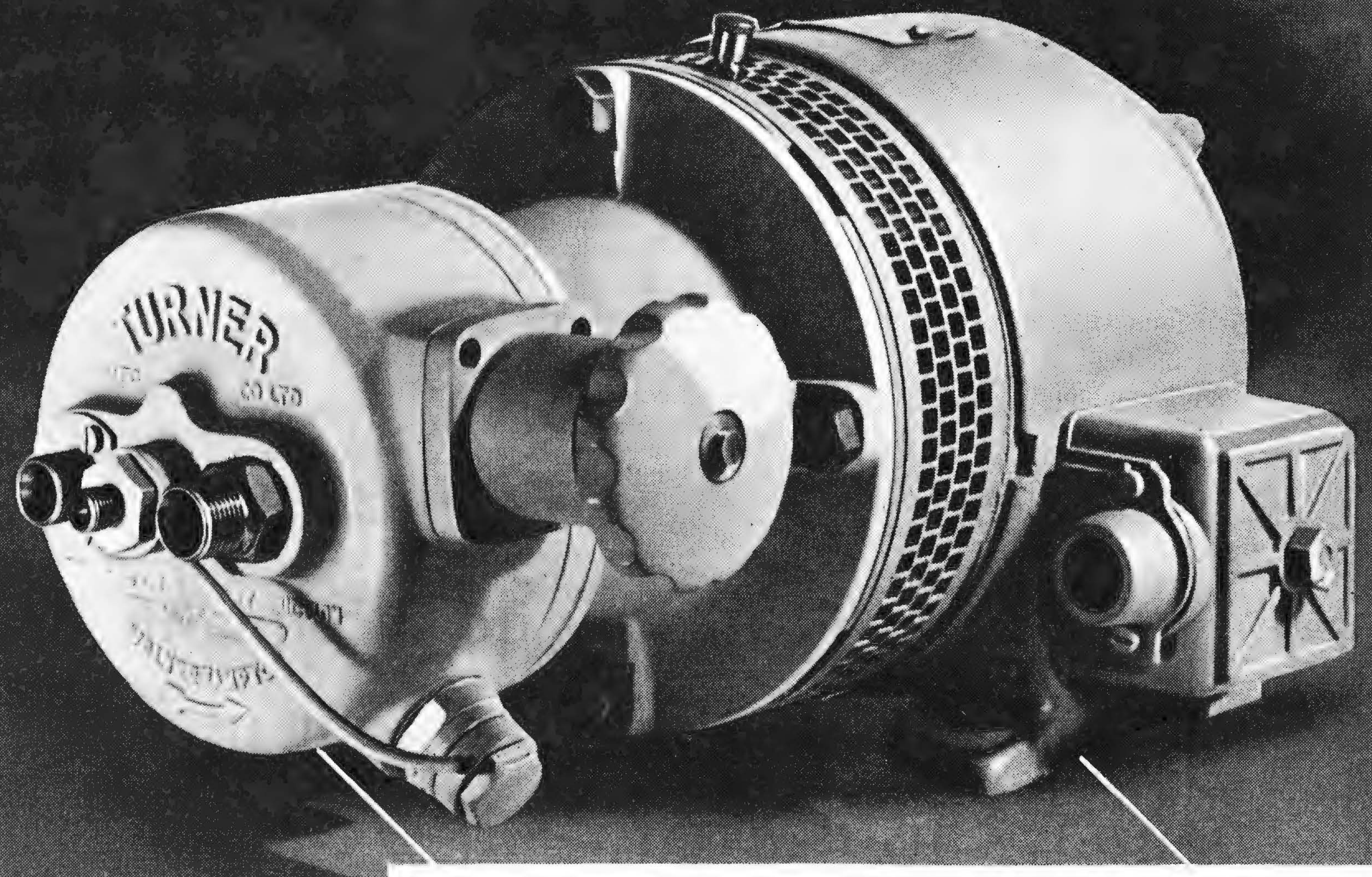
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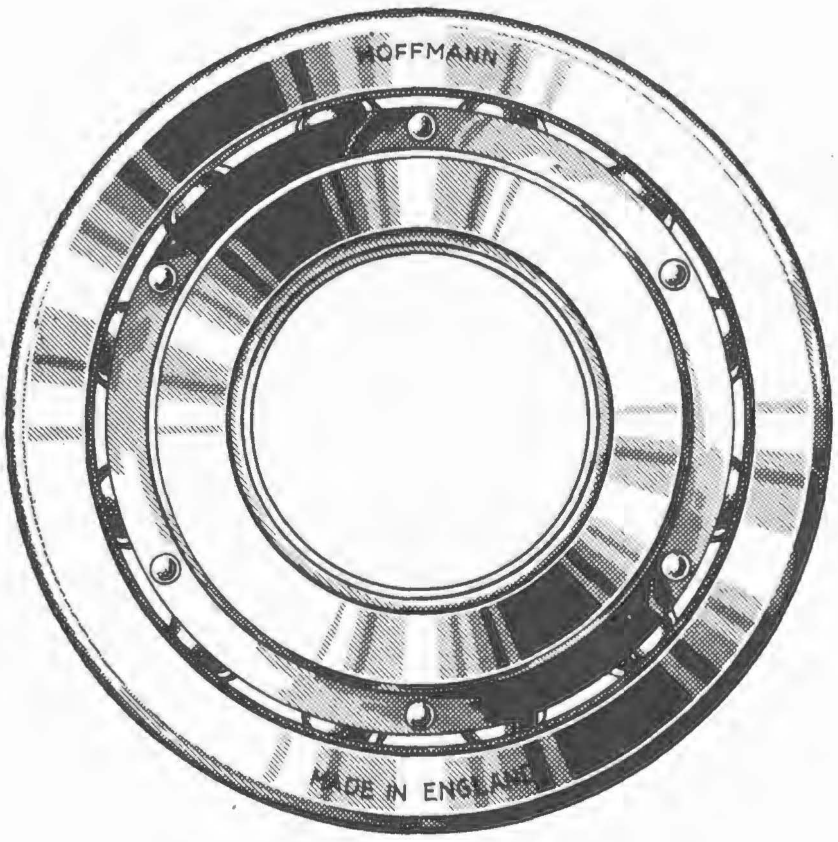

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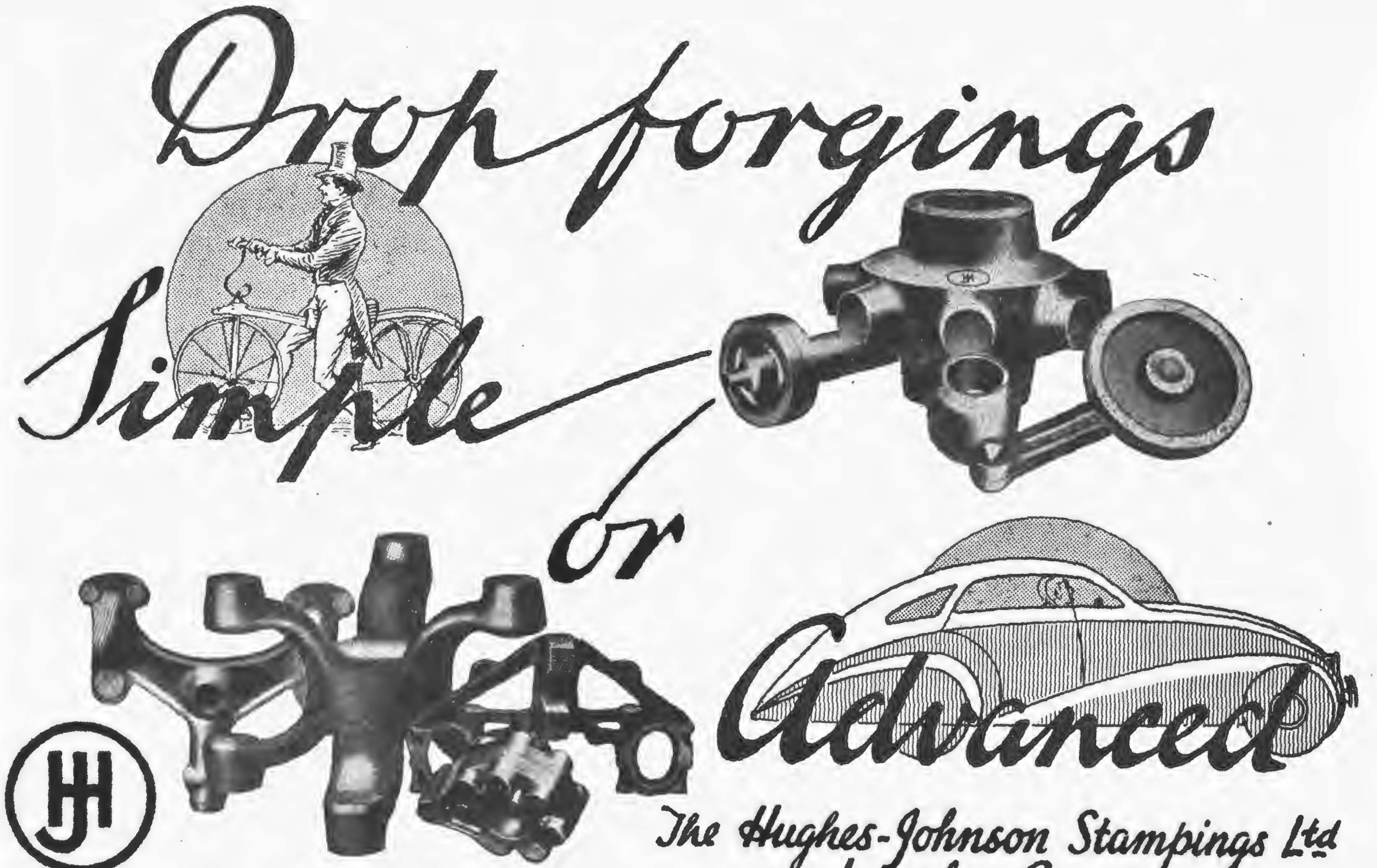
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Vol. XVII No. 199
SEPTEMBER - 1945
Published about the 18th of the month

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,
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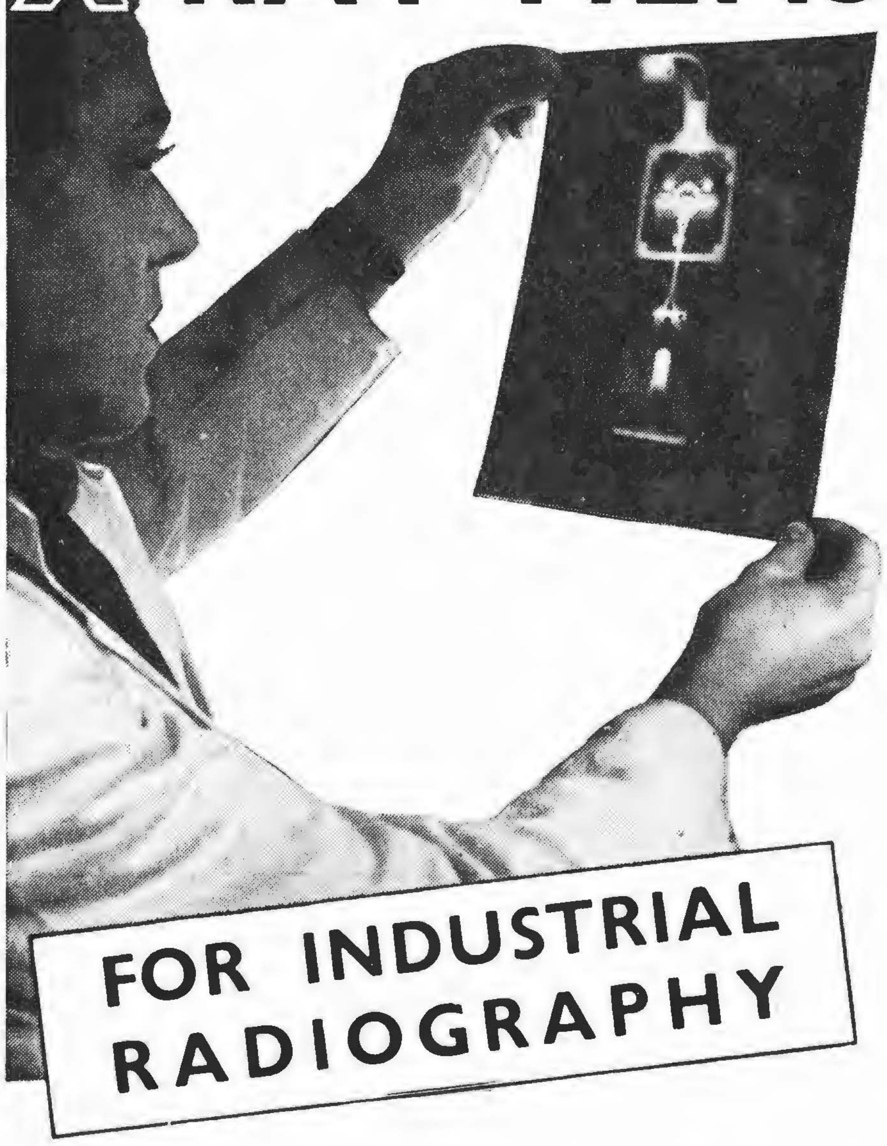

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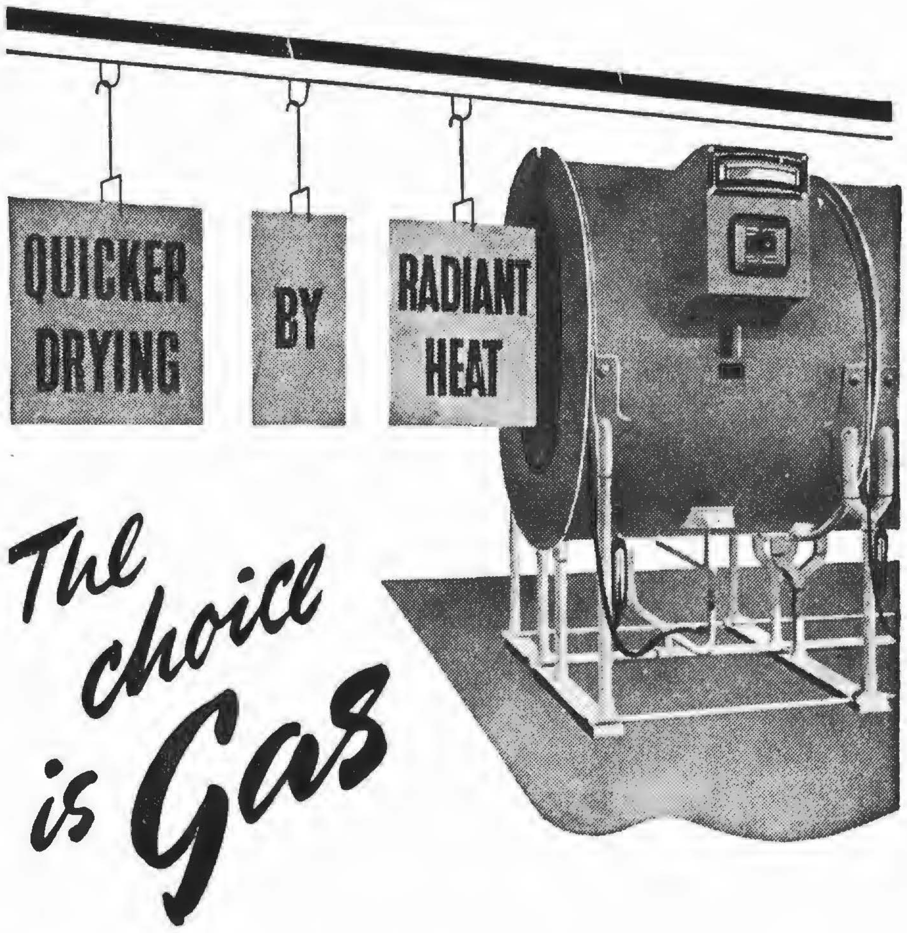

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Aircraft Engineering

The Monthly Scientific and Technical Organ of the Aeronautical Engineering Profession

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

Vol. XVII. No. 199. September, 1945

A PLACE FOR RESEARCH

NEWS that is gradually filtering through as a result of the visits of various missions of investigation to Germany show that in that country notable developments have been made in the last six years in various aspects of aeronautics. Indeed it appears that the stress of war has been allowed to interfere comparatively little with research—properly so called—as distinct from development work.

On This Picture and on This

In England, on the other hand, the position that we envisaged in these columns in September, 1939, and again in November, 1940, has to a very large extent developed. One has only to look at the expansion of the production side of the Ministry of Aircraft Production, and the publicity and recognition accorded to the leading personalities employed there, compared with the obscurity and lack of encouragement of the work of the individuals engaged on research, to realize the contrast. We are very far from saying that no advances in fundamental knowledge have been made over here during the war—to argue such a thesis would be absurd—but we do feel that day-to-day opportunism has to a regrettable extent been allowed to overcast long-scale investigations.

We believe that, however understandable this preoccupation with immediate problems may in the circumstances have been, the time has come for a new outlook and for the whole position to be reviewed. We do not think, for one thing, that a nearly adequate position is allotted to the Directorate of Scientific Research in the organization of the Ministry of Supply and Aircraft Production. It, to our mind, occupies altogether too lowly a place.

Adequate Recognition

A great deal of lip service has been paid, particularly in political circles, to the importance of research and the " neglect " of this branch of our life in England in the past, but there is as yet no sign of a proper appreciation of what should be done to remedy this state of affairs. Admittedly, since in 1909 a wise Government, at the instance of the far-seeing LORD HALDANE, inaugurated the Advisory Committee for Aeronautics (developed into the present Aeronautical Research Committee in 1920), aeronautical research has been far better organized than any other branch of science in England and the " set up " has been widely copied in other countries. But if we are to maintain the leading place we had established before the war, not only must there be—as is indeed already in train—a considerable expansion in equipment but a fuller recognition of the importance of the subject must be given in Governmental—and, particularly, departmental—circles.

A Matter of Prestige

Frankly, sufficient funds and " priority " for research and experiment will never be allotted until far greater prominence is given to the department organizing them. In civil service circles, however regrettable it may be, the degree of prestige and amount of support given to a matter largely depends upon the size of the department administering it and the prominence or lowliness of the position it occupies in the table or "tree" of functions pinned up on the walls of senior staff. Who can doubt, for instance, that a Director General of Scientific Research would get a larger proportion of the funds allowed by a grudging Treasury to his Department than would a Director ? If only for this reason, we are perfectly certain that when the final home of research in the Government organization is decided upon, strenuous efforts must be made for adequate recognition of the importance of the subject. It is to our mind quite nonsensical, for example, that there should be a separate Minister of Civil Aviation while Research, on which the future of civil, as all other, aviation depends, is dealt with by a department obscurely merged in an Air Ministry or Ministry of Aircraft Production.

The Wider Question

The whole question of the future organization of air matters is one that must be decided by the Government eventually and until this has been settled it is difficult to formulate any scheme as to the position of research. The Ministry of Aircraft Production has already been merged in the Ministry of Supply and it seems possible that both may ultimately disappear. In that case, two separate Ministries for Air (Service) and Civil Aviation may or may not survive—and if they do it is not easy to fit in research without one or other of its aspects being overshadowed by the other. In any event, we are quite clear that Research and Development must have separate representation from Production on the Board or Council of the Ministry in which they are placed; otherwise they will suffer, as they have done in the past.

A Responsible Minister

One possible solution that occurs to us is that a fuller recognition should be given to the fact that research in general—apart from aeronautical—is in this country administered by the Lord President of the Council, through the Department of Scientific and Industrial Research; though as one of many amorphous, and constantly varying duties.

A Tentative Proposal

We hesitate to advocate adding another to the already too numerous Ministries and therefore compromise on the suggestion that the member of the Government already responsible might perhaps have an addition to his title and be called Lord President of the Council and Minister of Research. Aeronautical research is tending to become more and more closely intertwined with research on other matters—witness, for instance, the case of radiolocation in the Army and the Navy (and Merchant Service) as well as in the air ; and the metallurgical developments in new metals of increasing interest to other industries than the aircraft—and it may be that it would be better to remove it from its " watertight compartment " and bring it into closer touch with research for other industries. This would, at any rate, place it in congenial surroundings removed from the obstruction from which it tends to suffer at present.

The Time Has Come

We do not know. We are merely trying to list the various possibilities for those in authority to consider and weigh one against another. What we are quite unequivocally pressing for is a definite place for it in the Governmental hierarchy commensurate with its undoubted importance as the life-blood of the long-scale future of British aviation, both military and civil, in the world. We have always possessed the brains, let us now see to it they are given the support and supplies that they need if they are to keep abreast of, and in advance of, the aeronautical scientists of other countries. Aeronautical research started as an appendage to technical development—it was then accorded its own Director—later still it was given representation on the Air Council, but tacked on to Supply—in 1940 it became merely a department in the Ministry of Aircraft Production. It has now reached the stage when it should be given its own spokesman on the council of the Ministry, whichever that may be, in which it is incorporated.

Aeroplane Weight Analysis

By W. I. M. Nightingale

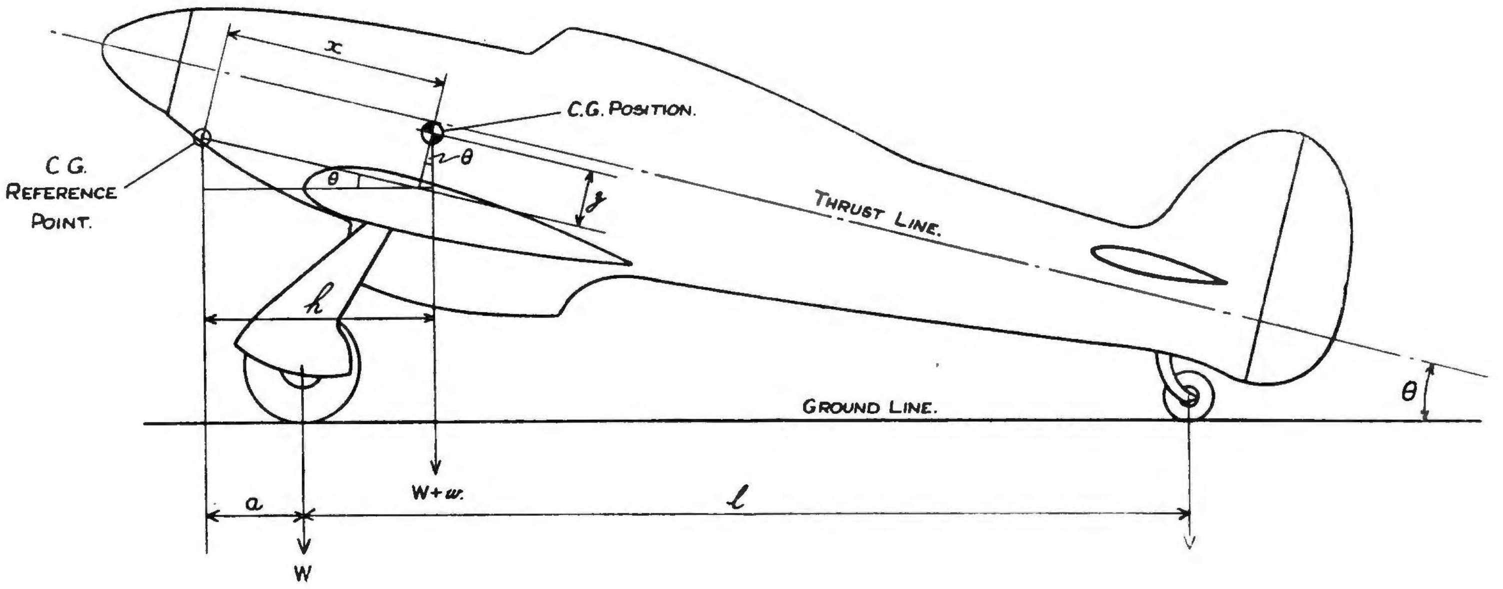


FIG. 1.—*Weights readings to be obtained for determination of centre of gravity*

EVERYBODY connected with the design of aeroplanes appreciates the importance of weight and C. G. position, yet it seems to be the one subject about which very little has been published in this country.

The general particulars of new type aeroplanes when released, invariably quote some weight figures; few people consider the amount of work associated with the figures quoted.

It is intended in this article to give some indication of the possible methods of detail weight analysis and centre of gravity determination.

Primary considerations for the operation of any scheme connected with aeroplane weight should be given to staff and equipment. The staff should be adequate in number and educational standard. The number employed will depend on the type manufactured, the extent of dispersal and the amount of sub-contract work used in the construction. The equipment, which must be good, should be of sufficient quantity to allow for dispersal.

Of these two primary considerations, equipment is the more important, for if this is bad, inaccurate weighing will result.

The range to be covered by the scales is, of necessity, very great; from those capable of the accurate weighing of small fittings, to those upon which the completed aircraft can be weighed. The equipment should, as far as possible, exclude spring balances, as they tend to become more inaccurate with use than the other types of weighing apparatus and are not so readily adjusted.

There should be separate equipment for the experimental and research side, where maximum accuracy is needed because of the small quantities involved.

Of the large selection of scales available, a number are particularly suitable, within their peculiar ranges. First the experimental side, where a really accurate balance is required, for weighing samples of new materials, new methods of construction, new finishes, etc., and also new proprietary articles of small size. (It is, of course, always possible to obtain data from the manufacturers, but the data given will tend towards the minimum and a personal check is considered beneficial.)

The next scale up the range is a bench-type weighing machine, capable of $\frac{1}{4}$ oz. accuracy up to 112 lb., for weighing fittings and small sub-assemblies. It may be considered an advantage to utilize a graduated scale up to 1 lb. in this type of scale, thus eliminating the use of small weights, which so often become mislaid.

Next there is a transportable platform scale, of 5 to 10 cwt. capacity with accuracy of 2 to 4 oz.; this scale is useful to weigh large components of awkward shape and the heavier sub-assemblies.

Another very useful weighing machine is the suspended-type weigher, working on the steel yard principle, with capacity of $2\frac{1}{2}$ to 3 tons, with 1 lb. accuracy. This apparatus is most useful for weighing large assemblies, engines and airscrews, as it can be interposed between the hook on the lifting tackle or crane and the slings attached to the actual component.

For production weighing, all the scales mentioned above must be repeated, with the possible exception of the small accurate balance, because accuracy, for small parts, can be obtained by weighing quantity in production.

An additional item may be found useful, and that is a spring balance say up to 15 lb. in $\frac{1}{2}$ oz., for use in stores where space is restricted. Since a spring balance of this size is so easily carried, time can be saved by weighing items at the bins in which they are stored, instead of carting them to scales elsewhere and back again. This is considered the exceptional case for the use of spring balances, the time and trouble saved under these circumstances justifying their use.

Time can also be saved by mounting the bench type-scales on a well shock-absorbed trolley, so that these may be taken to the various stores.

Finally, the equipment required when weighing the complete aeroplane for centre of gravity determination must include scales, steal measuring tape, plumb bobs, straight edge, inclinometer and hydrometer.

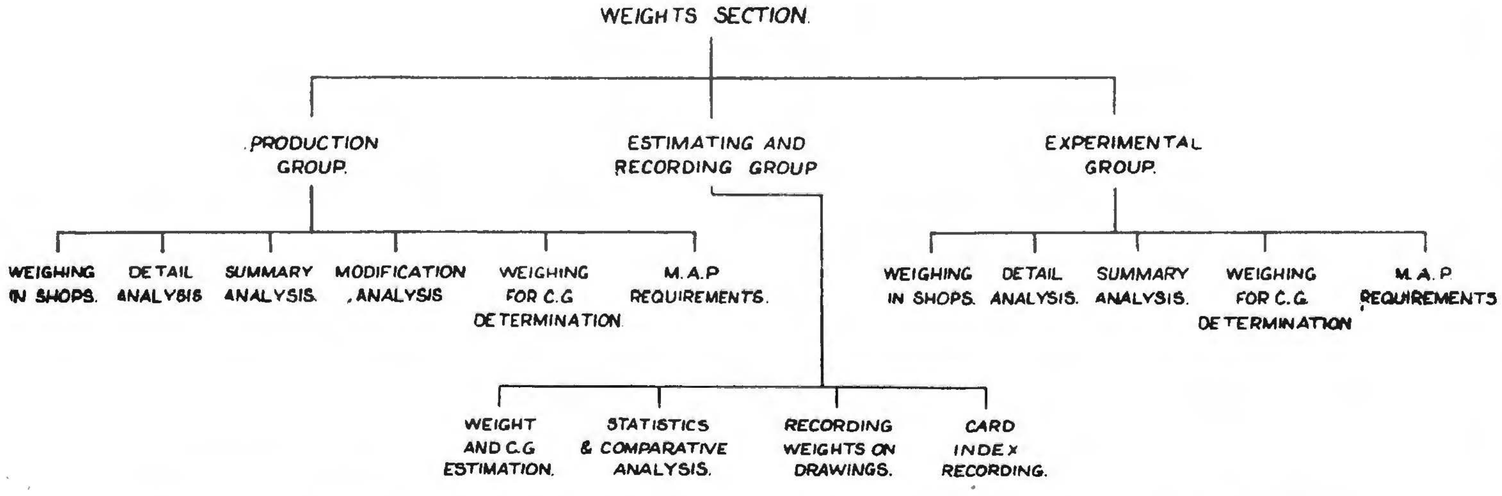
There are various arrangements of scales for weighing aeroplanes, the most satisfactory being the utilization of three separate scales, giving readings in pounds. These are installed flush with the ground and arranged to run on sunken rails of cruciform or "T" pattern in plan view, so that they may be adjusted for various undercarriage tracks and nose or tail wheel positions. The use of the various items mentioned above will be discussed later.

All weighing equipment used by the staff employed on weight analysis should be under the direct control of the person in charge of this staff. Since he is responsible for the figures obtained, he should be given every facility for ensuring the careful use and regular maintenance of the equipment. How often are large masses of sheet or bar banged down on scales in raw material or other stores, in order to find the weight to the nearest two or three lb. or so, and subsequently used by some unsuspecting "weight walla" to obtain accurate data for his analysis?

There are certain general principles, to which one should adhere, for weight analysis of either prototype or production aircraft.

At the time of design or immediately upon completion of the drawing, an estimated weight of every part should be quoted on the drawing. It is debatable whether this figure should be obtained by the Weights Section or the draughtsman concerned. The job would probably be done more quickly by the weights personnel, because of their familiarity with facts and figures; whereas the draughtsman might be able to make some saving in weight during design, when he found his figures coming out rather high. In any case it is of paramount importance that the draughtsman should know the weights of his own designs, thus pointing out to him his responsibility in the ultimate weight of the aeroplane. It is thought that this revelation would astound a good many people in drawing offices and every effort should be made to obtain the figures quickly and accurately, so that improvements can be made, if not on prototype, certainly on production machines; or in the case of production parts before final tooling.

To assist in the estimation of the weights of assemblies a comprehensive set of data sheets must be available, giving the weight data of standard parts and materials. The preparation of these sheets is no small job by itself, when one considers that the best method of obtaining the figures is by averaging from actual weighing and that the range to be covered includes bolts, nuts, pipe unions, clips, bearings, distance tubes, rolled and extruded sections, tubes and sheet to different specifications. It is of interest that the S.B.A.C. are working on a set of weight data sheets and these may be a boon to many.



Specimen organization of a Weights Section, giving an idea of ground to be covered

Having quoted an estimated weight on the first issue of a drawing and clearly indicated that it is an estimate; this figure will be superseded by one obtained by weighing as soon as the part is available. Where any excessive variation exists between the weighed weight and the estimate, this should be pointed out to the person responsible for the estimated figure, thereby tending to increase the accuracy of subsequent estimation. It is extremely important that the weighed figures quoted on the drawing should be accurate and in order to assure this, a specific method of weight analysis is adopted. One satisfactory method is outlined below.

Weight analysis consists of the arrangement of the data obtained by weighing, so that the final figures are of practical value for comparative or statistical purposes.

The basis for this analysis is the general arrangement drawing and the basic weight sheet will be of tabular form with headings for part number, description, specification, number off and weight; this latter heading being subdivided into pounds, ounces and, possibly, drams unless it is intended to work in decimals of a pound. Each sheet will have the title of the aircraft type and the description of the unit with its G.A. drawing number.

These basic or detail weight sheets will be compiled in the following manner. Primarily the G.A. drawing is obtained and, under the heading of its description, a complete list of sub-assemblies and detail parts is made, quoting the number off required for one aeroplane; only components actually called for on the drawing will be listed, parts quoted for reference must be neglected. The next stage is to take each assembly drawing and list the parts called for on that and then each sub-assembly, treating all in a similar manner, until basic detail parts are reached. In all cases it is important to note the issue of the drawing from which the work is done, so that subsequent reference to the drawing will soon show if the weight sheets are up to date.

By preparing weight sheets in the manner outlined above for all units on the aeroplane, the first step in weight analysis is complete and can be put to various uses. Where it is possible to weigh an assembly or sub-assembly, the weight thus obtained can be compared with the summation of the weights of the detail parts, thus forming a check on the accuracy of the weighing of all components concerned. When accuracy has been accepted, the total weights of the parts as listed under their assemblies and the weights of the components which go to make those totals, will be the figures to be placed on the original drawings, as the approved weights of those part numbers. When recording these weighed weights on the drawings, reference to the issue will ensure that the weight quoted is up to date with the drawing.

The basic or detail weight sheets do not constitute complete weight analysis and further sheets must be prepared, again of tabular form; if so desired, these sheets may be called summary sheets. For manufacturing purposes, drawings very often call for parts which really have no association with the unit to which they are assembled in the course of fabrication. For example, undercarriage parts, and engine mounting parts may be called for on spar drawings and pipes for various systems called up on numerous assemblies. The object of summary sheets is to extract weight data from the detail analysis and re-arrange the items into the units to which their weights are appropriate, so that the real weight of the unit may be obtained. If this scheme is adhered to for two or more aircraft, accurate comparison may be made between similar units on different aircraft types.

Further use may be made of the summary sheets if they are arranged under headings agreeing, as nearly as possible, with the current type of weight data sheet required to be filled in by the Ministry of Aircraft Production or Air Ministry. If this is done, the figures arrived at on the summary sheets may be transferred *en bloc* to the M.A.P. sheets. Furthermore, if the scheme was used throughout the industry, M.A.P. could compile useful, accurate and true comparative and statistical figures of great value to all concerned with project work.

The final stages of analysis are the preparation of comparative sheets for different aeroplanes, and the working out of any percentages or ratios considered necessary. There are, of course, many interesting statistics readily obtainable.

In the preparation of all the weight sheets mentioned above, consideration must be given to the ultimate distribution of the information and to that end the sheets should be typed or printed on thin paper or linen, so that they may be easily reproduced for the benefit of all concerned.

The foregoing principles of analysis apply equally to both prototype and production aircraft. There are a number of problems, however, which are peculiar to prototype weighing. The most essential of these is maximum co-operation from the Shops. The men erecting the job should be informed of the importance of weighing all parts before assembly, and a scheme should be in operation, whereby a man can tell immediately, whether the part he is assembling has been weighed or not. This scheme need not be elaborate, the judicious use of a rubber stamp "WEIGHED", and a few labels is quite sufficient; but the men must co-operate. The whole crux is that if the first prototype part is not weighed before assembly, there may never be another to the same drawing and the record is irretrievably lost.

The use of production parts on prototype machines is another problem. These must all be weighed again, and the particular weights obtained, used in the prototype analysis. The variations obtained in weights of production parts is such that their cumulation on a prototype may have an adverse effect on the weight of the complete machine, and every effort must be made to reduce the possible deviation between the final weight of the aircraft and the summation of the detail parts. Another point is that the careful selection of production parts may even reduce the weight of a prototype aeroplane.

In addition to the weight analysis sheets which will be filled in as the manufacture of the prototype proceeds, there is also the all important C.G. position, which must be constantly watched and periodically checked. Working from the final weight and C.G. estimate, sheets are prepared, which are basically a copy of the comparative weight data for the type, in which all figures are estimated and for reference these sheets may be called "Estimate" sheets. Estimate sheets have two columns for weights, "estimated" and "weighed", and also columns for the moment arms and moments of the centres of gravity of each item about a given reference point. Summary sheets are prepared as the drawings are issued to the shops, utilizing the estimated weights quoted on the drawings; again the weight columns are duplicated under headings "Estimate" and "Weighed".

As the total under each sub-heading on these summary sheets is obtained, using as many weighed weights as possible, this figure is compared with that on a master copy of the estimate sheets, and the weight on the latter is altered accordingly, together with all totals and moments affected thereby. This scheme makes it possible to have up-to-date information concerning the weight and C.G. position, at any time during the construction of the aeroplane. Periodically the master estimate sheets are "frozen", the last set of figures is finallyfilled in and the sheets are printed for distribution. A fresh set of figures is started immediately and the process continued, using more and more weighed data and less estimated, until finally, just before the complete machine is weighed for practical C.G. determination, there is a set of figures using 100 per cent weighed weights.

The totals of this final "estimate' should give the all-up weight and corresponding C.G. position, in agreement with that deduced from the weighing of the finished aeroplane. Complete agreement is not always obtained and the object of any prototype analysis scheme is to reduce this discrepancy.

Production weight analysis involves problems of its own, which are not encountered in the experimental shop. The biggest of these is the modification, and in passing, it does seem strange that airframe manufacturers are expected to produce data showing the effect of modifications on the weight and C.G. position of their product, for the guidance and use of the services, but the engine manufacturer can change his engine weight by 100 lb. or so and the services will know nothing about it, nor will the airframe manufacturer, unless a regular check is made.

A scheme to cover the effect of an airframe modification on the weight analysis is based on modification weight sheets. Under the heading of each drawing affected by the modification, these sheets record the change in issue of that drawing, together with lists of all items called up, which are altered, i.e. a list of items redundant and/or a list of items introduced. The weights of all items are shown, the tabular form used for detail weight sheets being used here as well. Should an entirely new assembly be introduced, detail analysis for the item will be compiled as part of the modification sheets, and a copy of this sheet filed with the main detail analysis for reference.

The detail, summary and comparative weight sheets may now be brought into line with the modification by clearly indicating the changes in detail analysis for each assembly affected, adjusting the totals accordingly and carrying the alteration through the summary to a master copy of the comparative sheets.

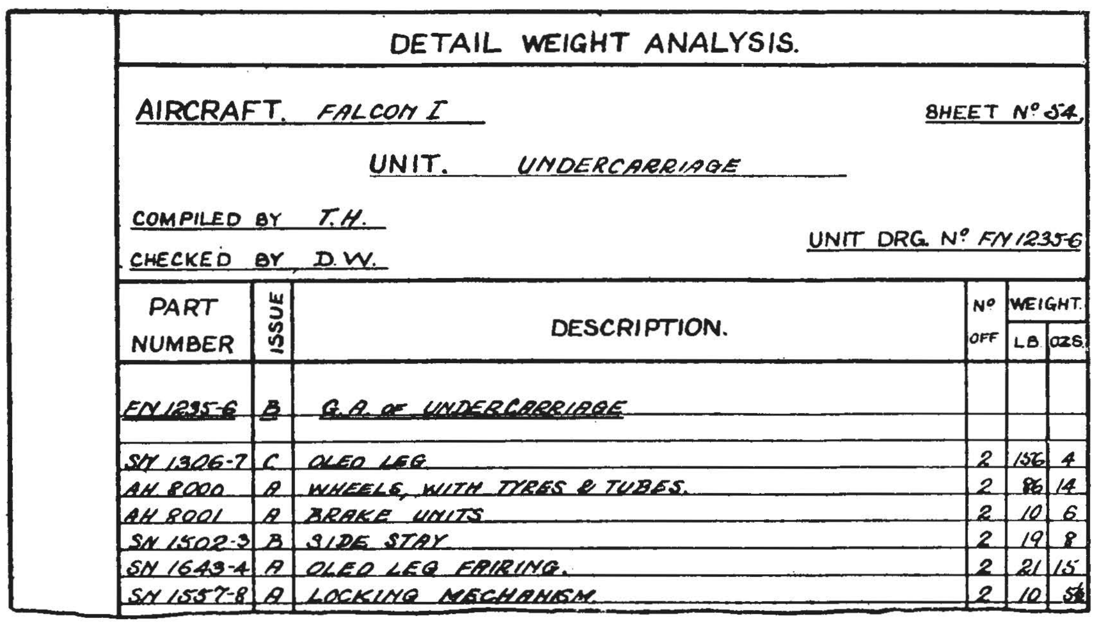
It is a great help, in dealing with modification analysis, if the drawing office and shops will co-operate with the weights section with regard to the trial installations, which are often carried out on production machines. This enables weighed data to be obtained from the outset of the modification and ensures an accurate weight change being quoted at the time of approval.

Variation in weight of production parts made from the same drawing necessitates a periodic check-up on the main items involved. When weighing components in the production shops it is not sufficient just to weigh one of each. From the fairly heavy parts to the main components, a number of readings must be obtained and the summation of the variations observed will give a clear indication of the range of all up weights which it is possible to obtain for the complete machine. Where this variation is excessive, the reason for it should be found and if possible the deviation must be controlled. The periodic check, previously mentioned, must be carried out on all components where the weight variation is average or over, to see that the range has not been increased nor the maximum exceeded.

Sub-contracted work is another thing which comes into production weight analysis to a much greater extent than for a prototype. The sub-contractors should be asked to supply weights of the detail parts of the assemblies made by them.

The final job to be done by the weight section on any one aeroplane is the weighing of the complete machine, to obtain the data from which it is possible to calculate the position of the centre of gravity. Certain preliminary conditions must be satisfied before this can be carried out; these are:—

(*i*) Engines to have been ground run.
(*ii*) Fuel tanks used for engine run, filled to capacity.
(*iii*) Fuel tanks not used for engine run to be



DETAIL WEIGHT ANALYSIS.

AIRCRAFT. FALCON I SHEET Nº 54.

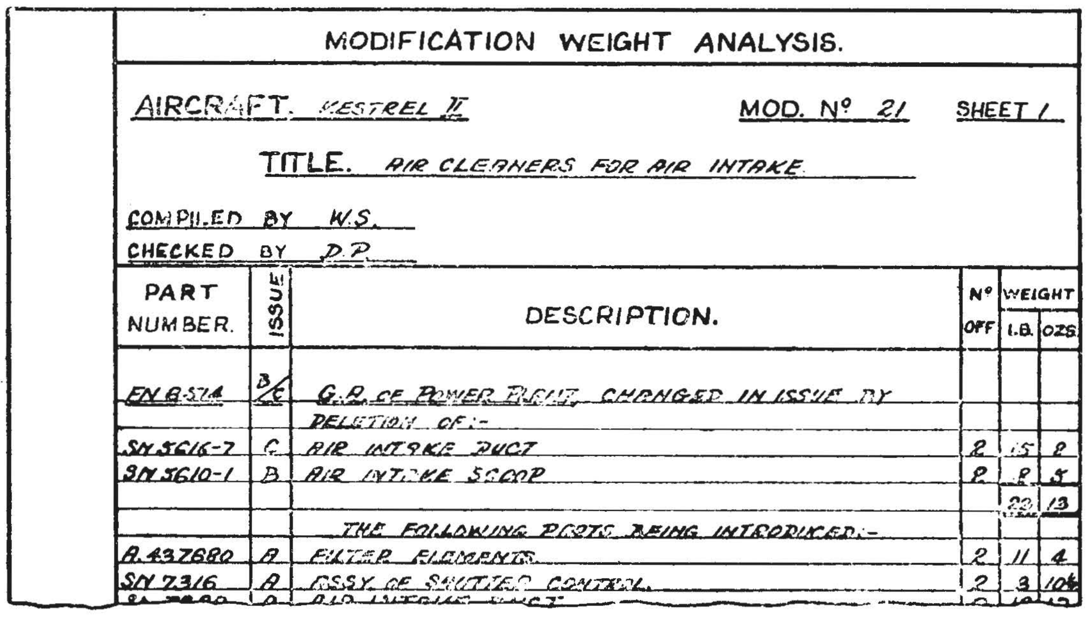
UNIT. UNDERCARRIAGE

COMPILED BY T.H.

CHECKED BY D.W.

UNIT DRG. Nº F/N 1235-6

PART NUMBER	ISSUE	DESCRIPTION.	Nº OFF	WEIGHT. LB	WEIGHT. OZS.
F/N 1235-6	B	G.A. OF UNDERCARRIAGE			
S/N 1306-7	C	OLEO LEG	2	156	4
AH 8000	A	WHEELS, WITH TYRES & TUBES.	2	86	14
AH 8001	A	BRAKE UNITS	2	10	6
SN 1502-3	B	SIDE STAY	2	19	8
SN 1643-4	A	OLEO LEG FAIRING.	2	21	15
SN 1557-8	A	LOCKING MECHANISM.	2	10	5½



MODIFICATION WEIGHT ANALYSIS.

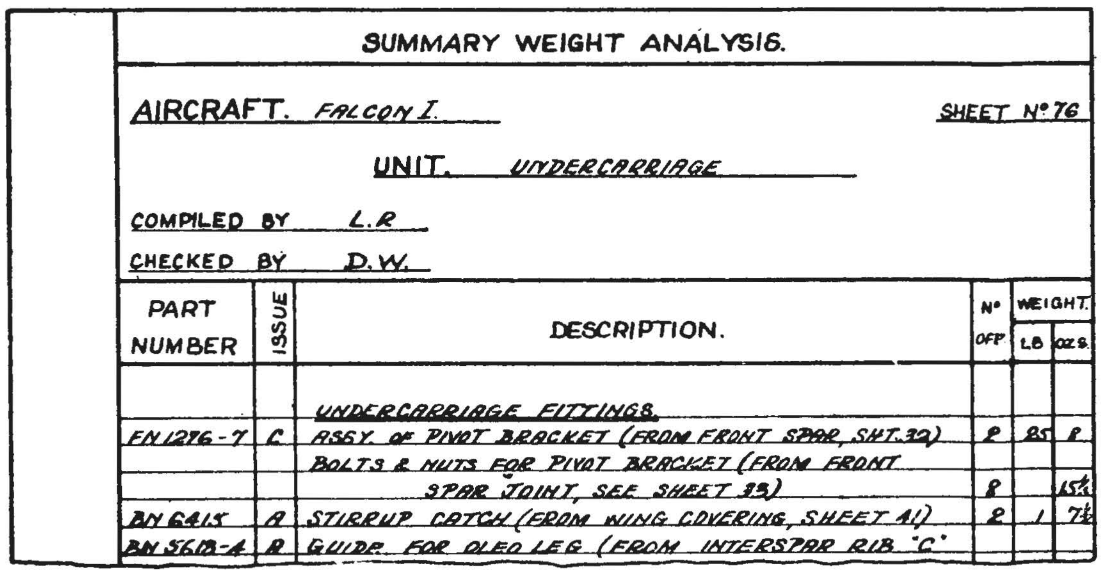
AIRCRAFT. KESTREL II MOD. Nº 21 SHEET 1

TITLE. AIR CLEANERS FOR AIR INTAKE

COMPILED BY W.S.

CHECKED BY D.P.

PART NUMBER.	ISSUE	DESCRIPTION.	Nº OFF	WEIGHT. LB.	WEIGHT. OZS.
FN 8574	B/C	G.A. OF POWER PLANT, CHANGED IN ISSUE BY			
		DELETION OF:-			
SN 5616-7	C	AIR INTAKE DUCT	2	15	8
SN 5610-1	B	AIR INTAKE SCOOP	2	8	5
				22	13
		THE FOLLOWING PARTS BEING INTRODUCED:-			
A 437680	A	FILTER ELEMENTS.	2	11	4
SN 7316	A	ASSY. OF SHUTTER CONTROL.	2	3	10½



SUMMARY WEIGHT ANALYSIS.

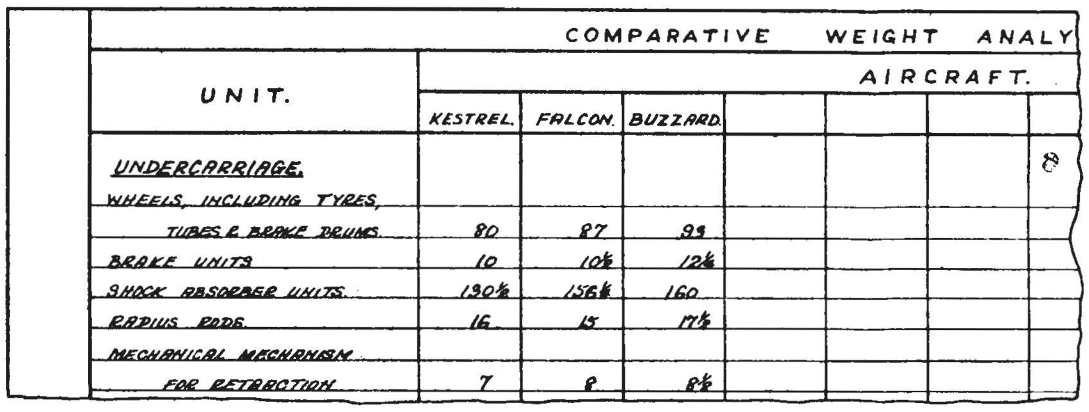
AIRCRAFT. FALCON I. SHEET Nº 76

UNIT. UNDERCARRIAGE

COMPILED BY L.R.

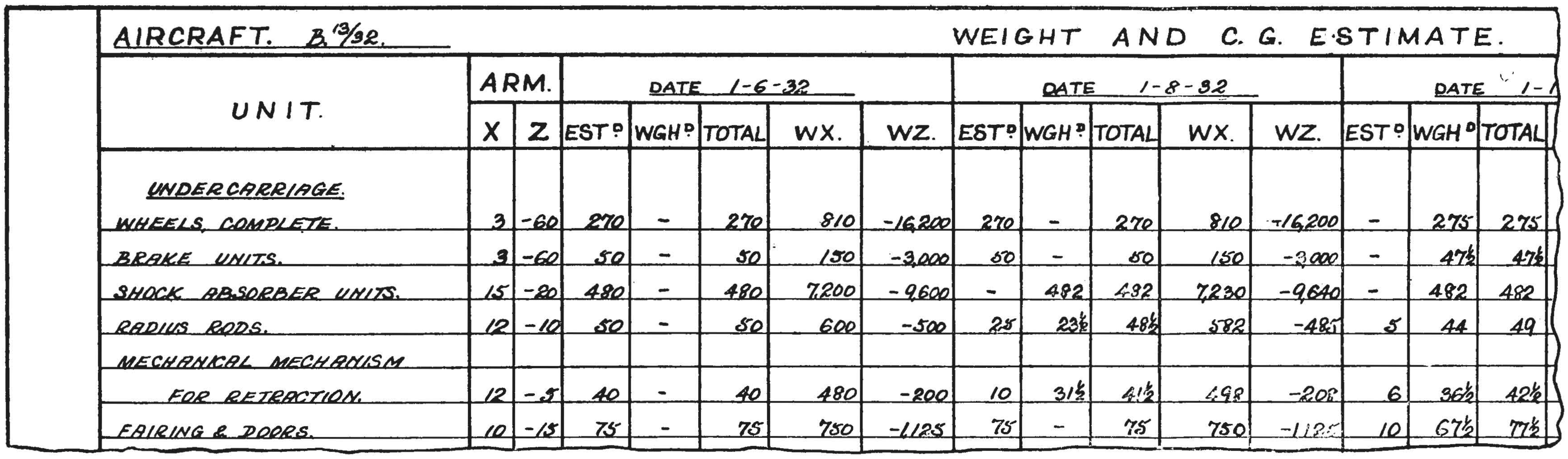
CHECKED BY D.W.

PART NUMBER	ISSUE	DESCRIPTION.	Nº OFF	WEIGHT. LB	WEIGHT. OZS.
		UNDERCARRIAGE FITTINGS.			
FN 1276-7	C	ASSY. OF PIVOT BRACKET (FROM FRONT SPAR, SHT. 32)	2	85	8
		BOLTS & NUTS FOR PIVOT BRACKET (FROM FRONT			
		SPAR JOINT, SEE SHEET 33)	8		15½
BN 6415	A	STIRRUP CATCH (FROM WING COVERING, SHEET 41)	2	1	7½
BN 5613-4	A	GUIDE FOR OLEO LEG (FROM INTERSPAR RIB "C"			



COMPARATIVE WEIGHT ANALY

UNIT.	AIRCRAFT. KESTREL.	FALCON.	BUZZARD.				
UNDERCARRIAGE.							8
WHEELS, INCLUDING TYRES,							
TUBES & BRAKE DRUMS.	80	87	93				
BRAKE UNITS	10	10½	12½				
SHOCK ABSORBER UNITS.	130½	156½	160				
RADIUS RODS.	16	15	17½				
MECHANICAL MECHANISM							
FOR RETRACTION	7	8	8½				



AIRCRAFT. B.13/32. WEIGHT AND C.G. ESTIMATE.

UNIT.	ARM. X	ARM. Z	DATE 1-6-32 ESTᴰ	WGHᴰ	TOTAL	WX.	WZ.	DATE 1-8-32 ESTᴰ	WGHᴰ	TOTAL	WX.	WZ.	DATE 1- ESTᴰ	WGHᴰ	TOTAL
UNDERCARRIAGE.															
WHEELS, COMPLETE.	3	-60	270	-	270	810	-16,200	270	-	270	810	-16,200	-	275	275
BRAKE UNITS.	3	-60	50	-	50	150	-3,000	50	-	50	150	-3,000	-	47½	47½
SHOCK ABSORBER UNITS.	15	-20	480	-	480	7,200	-9,600	-	482	432	7,230	-9,640	-	482	482
RADIUS RODS.	12	-10	50	-	50	600	-500	25	23½	48½	582	-485	5	44	49
MECHANICAL MECHANISM															
FOR RETRACTION.	12	-5	40	-	40	480	-200	10	31½	41½	498	-208	6	36½	42½
FAIRING & DOORS.	10	-15	75	-	75	750	-1125	75	-	75	750	-1125	10	67½	77½

Typical examples of weight analysis sheets, indicating methods of compiling data. The sheets should be printed on thin paper or linen and filled in by typing or printed lettering, to facilitate duplicating

completely drained, or if this cannot be done, to be completely filled.

(*iv*) Accurate tank capacities must have been obtained by measurement.

(*v*) The quantity of oil in tanks must be known.

(*vi*) The quantity of military or service equipment fitted to the machine must be ascertained.

Prototype and some production aeroplanes should be weighed before and after engine run, in order to determine the weight of oil and fuel circulated throughout the engines, airscrews and systems during the run. This figure may be as much as 60 lb. per engine.

The reasons for the six conditions mentioned are as follows:—

(*i*) If this condition is waived, all figures based on the weighing will exclude the oil and fuel circulated in engine, etc., when run.

(*ii*), (*iii*), (*iv*) and (*v*) Without satisfaction of these conditions, accurate Tare and All Up Weights are unobtainable.

(*vi*) This condition, coupled with the other five, enables an accurate Bare Weight to be deduced.

The Tare Weight of the machine is its weight in flying trim including all items of fixed military or service equipment but excluding all removable, expendable and consumable load.

The Bare Weight is the Tare Weight less the weight of all fixed equipment.

For C.G. determination it is necessary to have decided upon a point on the aeroplane from which it is possible to drop a plumb line to the ground. This point must be rigidly located in relation to the main structure of the machine and will be called the C.G. Reference Point.

At the time of weighing the following readings are obtained, for the normal landplane (see Fig. 1):—

W = The reaction at the centre of the main wheels.

w = The reaction at the centre of the tail or nose wheel.

l = The horizontal distance between the centres of the main and tail or nose wheels.

a = The horizontal distance between the centre of the main wheels and the C.G. Reference Point.

θ = The angular attitude of the aeroplane, i.e. the thrust line or fuselage datum line to the horizontal.

If the C.G. position is required in the horizontal plane only, one set of readings is sufficient; these being taken when $\theta = 0$ deg. For marine aircraft, of course, beaching trolleys and other convenient methods of support replace the landplanes' wheels; but the principle is the same.

Should the C.G. position be required in the vertical and horizontal planes, then two or more sets of readings are necessary and by substitution in the formula:—

$$x + z \tan\theta = \frac{\dfrac{w\,l}{W+w} + a}{\cos\theta}$$

two or more simultaneous equations are obtained and solved for "x" and "z".

The formula is derived in the following manner:—

By taking moments about the centre of the undercarriage wheels

$$w \times l = (W+w)(h-a) \text{ or } \frac{w\,l}{w+w} = h-a$$

Now $h = x\cos\theta + z\sin\theta$

$$\therefore \frac{w\,l}{W+w} + a = x\cos\theta + z\sin\theta$$

Then dividing through by $\cos\theta$

$$x + z\tan\theta = \left(\frac{w\,l}{W+w} + a\right)\frac{l}{\cos\theta}$$

An example of the use of this formula is given below:—

θ	0 *deg.*	3 *deg.* 42 *min.*	12 *deg.* 7 *min.*
$\frac{w\,l}{W+w}$	$\frac{652 \times 269\cdot 2}{10{,}501} = 16\cdot 75$	$\frac{809 \times 272\cdot 2}{10{,}501} = 20\cdot 97$	$\frac{1{,}163 \times 275\cdot 2}{10{,}508} = 30\cdot 45$
a	$-35\cdot 3$	$-38\cdot 47$	$-45\cdot 16$
$\frac{w\,l}{W+w} + a$	$-18\cdot 59$	$-17\cdot 5$	$-14\cdot 71$
$\cos\theta$	1	$0\cdot 9979$	$0\cdot 9777$
$\tan\theta$	0	$0\cdot 0647$	$0\cdot 2147$

Equation 1, $(\theta=0^0)$ $x = -18\cdot 59$

,, 2, $(\theta=3°42')\,x+0\cdot 06470\,z = \frac{-17\cdot 5}{0\cdot 9979} = -17\cdot 54$

,, 3, $(\theta=12°7')\,x+0\cdot 2147z = \frac{-14\cdot 71}{0\cdot 9777} = -15\cdot 05$

$$\left.\begin{array}{lll} \text{From equations 1 \& 2} & z = \frac{1\cdot 05}{0\cdot 0647} & = 16\cdot 23 \\ \text{,, ,, 1 \& 3} & z = \frac{3\cdot 54}{0\cdot 2147} & = 16\cdot 49 \\ \text{,, ,, 2 \& 3} & z = \frac{2\cdot 49}{0\cdot 15} & = 16\cdot 6 \end{array}\right\} z = 16\cdot 44 \text{ (average)}$$

Substituting the average figure for "z" in equations 1, 2 and 3:—

$$\left.\begin{array}{ll} 1 & x = -18\cdot 59 \\ 2 & x = -18\cdot 6 \\ 3 & x = -18\cdot 58 \end{array}\right\} 9 = -18\cdot 59 \text{ (average)}$$

Hence C.G. position is 18·59 ins. forward and 16·44 ins. above the C.G. Reference Point.

This method is considered preferable to others, because the simple introduction of the third equation gives a good check on the accuracy of the other two sets of readings. Due to the small angles involved, this check assists considerably in the accurate determination of the vertical C.G. position.

The usual method of supporting the aeroplane, when weighing it at any angle other than the normal standing position, is to place the nose or tail wheel on an adjustable trestle, the base of which is on the scale platform. It is then a simple matter to make final adjustment on the trestle, for any particular angle of the aircraft. An alternative method of supporting the rear fuselage is sometimes used, instead of the trestle under the tail wheel. A sling is placed round the fuselage and attached to a weighing machine suspended from a tackle or crane. This method is not so satisfactory, because of the practical problems of ensuring that the tackle and sling are absolutely vertical and of measuring dimension "l". Any horizontal component of the load in the sling will give a wrong reading on the weighing machine and result in the calculated C.G. position being aft of the true one. This is most important on small aircraft; as the size of the machine increases, the mean chord and C.G. range increase, and the possible error becomes negligible.

Both these methods of supporting the aircraft leave the main undercarriage wheels resting naturally on their scale platforms and assume equal deflection of port and starboard undercarriage units. For greater accuracy, however, the machine ought to be adjusted until each wing tip is the same height above a given horizontal plane.

There is a method in which the aeroplane is raised off the ground by means of jacks supporting it at definitely located points on the main structure, and this allows easy adjustment about both axes. Since the relative position of the points of support is the same for all aircraft of the type, and can be obtained from dimensional drawings, with a possible check on one aircraft, only the weights "W" and "w", together with the angles "θ", need be obtained practically, to be able to calculate the C.G. position.

The use of all the items of equipment, previously mentioned as being required for this final weighing, has not been explained. The purpose of scales and steel measuring tape is obvious, the plumb line is used for projecting points on the aircraft on to the horizontal plane, i.e. Reference Point and wheel centres on to the ground. The straight edge with inclinometer, when placed on the levelling marks of the fuselage, give a measure of the attitude of the machine. The hydrometer, usually graduated from S.G. = ·70 to S.G. = ·75, is used to determine the specific gravity of the fuel in the tanks; this is an important consideration when big quantities are carried, because of the rapid change of density with temperature.

Having calculated the "Weighed" C.G. position, relative to the C.G. Reference Point, the ordinates are now altered to give the position from the C.G. Datum Point. The Reference Point and Datum Point may be one and the same thing, but sometimes the Datum is a theoretical point, such as the leading edge of the Standard Mean Chord. Referring the C.G. to a datum on the S.M.C. facilitates aerodynamic comparison, not forgetting that such comparisons normally consider the machine with the undercarriage retracted and the C.G. must be corrected for undercarriage movement. It is also necessary, in some cases, to allow for the effect of flap movement on C.G. position.

The C.G. position relative to the Datum Point is now corrected to the position corresponding to the Tare Weight of the machine. Moments are taken about the Datum Point and all items of removable load, that were on the machine when it was weighed, together with their moments, are deducted from the "Weighed" weight and its moments. If any items of "fixed" load were not installed at the time of weighing, their weights must be added as well as their moment effect. The summation of these weights and moments gives the Tare Weight of the machine, with corresponding horizontal and vertical moments, from which the Tare C.G. position is obtained.

The All Up Weight and C.G. position are then deduced by the same procedure. The weights and moments for all items of the Typical Service Load being added to those of the Tare condition and from the totals the C.G. position is worked out. The weight of fuel included in the T.S.L. is based on the S.G. laid down by M.A.P. for the particular type required

It is not intended to suggest methods of Weight Control here, as this is considered an individual subject and cannot possibly be put into practice unless the estimating and analytical sides are well established on sound bases. A certain amount of control may be introduced into the analysis scheme previously outlined, but real wieght control must cover a much wider range of subjects.

In conclusion, should any points in this article tend to raise controversy, so much the better. It is high time more discussion was held on the subject of weights section activity, and the general status of weights personnel improved. If we are to compete favourably with our present Allies in the post-war era, we must get away from this "one man and a couple of boys" outlook, as it has been described. In the United States, for example, the Boeing concern employs no less than ninety people on weights only.

What about the Society of Aeronautical Weight Engineers of America? Where is even the nucleus of its counterpart in this country? It is not suggested that a similar society should be formed in this country, but it it considered that a means for more general exchange of views, principles and information would be widely appreciated.

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.

The Institute of the Aeronautical Sciences

AERONAUTICAL ENGINEERING REVIEW (MONTHLY)

Vol. 4, No. 6, June 1945.

"Design Principles for Electrical Landing-Gear Control Systems." H. J. Finison.

"Some Design Considerations of Electrohydraulic Power Supply Systems," W. C. Trautman.

"Aircraft Electrical Equipment." T. B. Holliday.

Vol. 4, No. 7, July 1945.

"The Development of the Lockheed Constellation." C. L. Johnson.

"The Relation between Illumination and Depth Perception and Its Significance for Aircraft Pilots." L. De Florez.

"The Radio Navigator." S. B. Littauer.

Journal of the Aeronautical Sciences (Quarterly)

Vol. 12, No. 2, July 1945.

"Plastic Bending—Further Considerations." W. R. Osgood.

"A Consideration of Calculated *versus* Flight Test Take-Off Performance." M. A. Kiehle and A. Vantine.

"The Relation of Stress and Strain in Magnesium Base Alloys." E. J. Eastman, J. C. McDonald and A. A. Moore.

"Design and Application of High-Pressure Coefficient Axial Flow Fans." J. G. Sawyer.

"The Buckling of Sandwich-type Panels." N. J. Hoff and S. E. Mautner.

"The Stress-Arm Method of Designing Beams." G. C. Best.

"Correction of Aluminium-Alloy Compressive Test Results for Material Properties Using Reduced Moduli." J. Karol.

"Effect of Pressure Variations on Speed Runs." R. M. Head.

"Operational Methods in Servomechanism Design." W. E. Restemeyer.

"A Review of the Aerodynamics of Flight Load Factors in Relation to the Safety Regulations." H. B. Freeman.

"The Attenuation Method for Compressible Flow Systems." L. M. Greene.

"Strength of Magnesium-Alloy Columns." F. A. Rappleyea.

"Performance Methods for High-Speed Aircraft." W. D. Hayes.

"A Vibration Theory Combining the Dynamic Stiffness and Mobility Methods." H. B. Stewart.

"Curved Aluminium-Alloy Sheets in Compression for Monocoque Constructions." G. Welter.

"Elementary Considerations of Longitudinal Stability." M. T. Hockman.

"Buckling of Plates with Intermediate Rigid Supports." E. Reissner.

The American Society of Mechanical Engineers

MECHANICAL ENGINEERING (MONTHLY)

Vol. 67, No. 6, June 1945.

"Use and Evaluation of Some Speciality Adhesives." F. Wehmer.

"Design Aspects of Supercharged Diesel Engines." R. L. Boyer.

"Radial Rake Angles in Face Milling. I." J. B. Armitage & A. O. Schmidt.

Vol. 67, No. 7, July 1945, *not received.*

Vol. 67, No. 8, August 1945.

"Radial Rake Angles in Face Milling. III." J. B. Armitage & A. O. Schmidt.

"An Analytical Method of Cam Design." W. B. Carver & B. E. Quinn.

(*Concluded on p.* 266)

Letters to the Editor

Appreciation of Landing Problems

DEAR SIR,

In his interesting article, "Appreciation of Landing Problems", in the July 1945 issue of AIRCRAFT ENGINEERING, Mr. G. W. Drury makes a number of observations on reversible pitch braking propellers, on which further comment seems desirable.

His statement that the advent of such propellers for small aircraft appears a long way off, would suggest that he has not seen the statements published in the press, to the effect that the new de Havilland "Dove", small feeder line transport, will have feathering and braking D.H. hydromatic propellers. This particular model of D.H. propeller has not yet flown, but it has run successfully on bench test, and it represents a practical appreciation and realization of the points made by Mr. Drury, namely, that the need for braking propellers is by no means confined to very large aircraft.

Quite extensive experimental work has been carried out at the de Havilland Propeller Division and elsewhere on braking propellers. A number of different types of aircraft have now been experimentally fitted with braking propellers to shorten the landing run, with extremely satisfactory results. For example, the average landing run on a four-engined Lancaster bomber with all four propellers reversing, has been reduced to roughly one-third of the value with only wheel brakes operative.

With the reversible pitch propellers, the technique has been to select braking pitch just before touch down, and then, once the aircraft wheels are firmly on the ground, to open the throttles up again to take-off boost. The wheel brakes are then used only for the purpose of keeping the aircraft straight.

Swinging tendencies have not proved unduly troublesome; in fact, they have only proved at all serious on high-powered small aircraft, and there are very good reasons to expect that the use of a tricycle undercarriage, or oppositely rotating propellers on twin-engined aircraft, or counter-rotating propellers, or a combination of several of these features, will eliminate the swinging difficulty, even in these cases. In no case has the modified slipstream from the reversed-pitch landing-brake propeller affected the aircraft control. The fact that the aircraft tail is pushed down on to the ground and the wing lift in the slipstream reduced, does in fact make some contribution, rather than otherwise, to the solution of the landing problem.

It is by no means certain that the use of reversible pitch propellers as a form of glide control during the approach, may not become desirable for certain applications in the future. However, the technique of reversing pitch as a means of shortening the landing run is, as stated above, to select the braking pitch just before touch down. In this connexion it is important to note that it is highly desirable to have the propellers fully reversed and the throttle open as early as possible during the landing run, since it is for these conditions that the maximum braking effect is obtained. For this reason, the writer regards Mr. Drury's suggestion of operating the propellers by pumps driven from the aircraft landing wheels without much favour. The use of such an expedient would result in pitch reversal taking place much later than is desirable for best results.

On the other hand, Mr. Drury's suggestion that propellers with high rates of pitch change should preferably use their own hydraulic system with a special working fluid, rather than rely on the engine oil system, is a very good one. Rightly or wrongly, one receives the impression that perhaps Mr. Drury believes propeller designers might have some preference for retaining the use of engine oil, but he may be interested to learn that propellers with this feature of a self-contained hydraulic system using low viscosity fluids have been in existence for some time. The present standard system of using the engine oil for the requirements of the propeller pitch change system has, it is true, been in use for many years, but it has had many attendant disadvantages, and can only be justified on grounds of convenience. It is not an ideal arrangement for braking propellers, although the use of the self-contained hydraulic system for such propellers cannot be regarded as absolutely essential unless the very highest rates of pitch change are demanded.

Mr. Drury suggests that 30–40 deg. per second is probably the minimum requirement for successful braking propellers. As far as the landing brake application of reversible pitch propellers is concerned, this is an unduly severe estimate of the situation. While it is true that the higher the rate of pitch change obtained the better, it is nevertheless a fact that quite satisfactory landing brake propeller applications can be made with something nearer to half the rate of pitch change suggested by Mr. Drury. One is rather inclined to agree with the statement that once the propeller has been put into braking pitch, it will be unsafe to restore the blades to a positive pitch position for a take-off from a baulked landing. Such a change of mind on the part of the pilot would certainly not be acceptable unless and until propellers with a rate of pitch change even higher than Mr. Drury's 30–40 deg. per second were available. However, this situation is not as serious as might be thought. The mere fact of the aircraft being fitted with reversible pitch propellers makes the baulked landing case much less likely to occur, since the pilot will have a much better chance of putting the aircraft down safely in a limited available space. Also, it is in any case rather unlikely that he would want to change his mind and go round again, having once reached an altitude only some 10 ft. from the aerodrome surface, which is about the position at which he would normally select braking pitch on his propellers.

Yours faithfully,
for the de Havilland Aircraft Co. Ltd.,
A. V. CLEAVER,
Chief Project Engineer
(Propellers).

DEAR SIR,

The section of my article referred to by Messrs. de Havilland was written before the Dove was hatched. It is gratifying to note that braking airscrews will soon be available for the smaller aeroplane. As the advent of the Dove will probably be their first introduction to a purely civil type, the behaviour of this machine should arouse interest in ground performance generally and focus attention on a trend of development which, to venture a prophesy, is to modify considerably previous conceptions of the landing problem.

The application of reversible pitch airscrews to experimental aircraft in this country has not always been attended with the satisfactory results suggested by Mr. Cleaver—in my own opinion, largely, because of failure to appreciate the demands upon the pilot's skill during the landing process. The success of the Lancaster installation is, in no small measure, attributable to the perception of a small group of de Havilland engineers, who, realizing the significance of the human element, laid down (and adhered to) a very rigid specification for the controls of the four braking airscrews. They also achieved a high rate of pitch change, which, considering the material to hand and the expedients adopted, was in itself a commendable performance. This velocity of pitch change and simplicity of the controls (entailing the minimum of manual effort) is the essence of installation design.

Even on the Lancaster, in the performance already achieved, certainly on other, not so successful, aircraft, the need for automatic or, at least, more simple controls is most apparent. I myself, after one particular demonstration landing in the Lancaster, was unable to sit comfortably for some days—the result of a very small error of judgment on the part of a pilot well practised on the machine.

Too much cannot be made of the fact that the loss of lift over that part of the wings affected by the modified slipstream will cause the aeroplane to become ground borne more quickly. The effect on the empennage to produce a sudden increase of wing incidence *does* call for the tricycle undercarriage if the previous advantage is not to be nullified.

The flying technique employed—reversal of pitch some feet above the ground, (my own estimate, incidentally, is nearer five than ten feet), particularly considering the effect of the modified slipstream, places a premium upon the pilot's judgment. In conditions of poor visibility this technique might be dangerous.

Surely, the admission of the necessity of reversing pitch prior to touch down, contradicts the later statement by Mr. Cleaver that pitch change rates of half those (30 deg. to 40 deg. per sec.) quoted in my article, would be satisfactory.

Considering round figures of a required pitch change of 45 deg. at a ground speed of 120 ft./sec.—a machine travels 60 yds. before the movement is completed and reverse thrust can be applied.

If the pitch change rate is halved this distance is doubled, probably equalling the further distance travelled before the reverse thrust becomes totally effective, i.e., the landing run is increased 50 per cent.

It is an established fact that the increase of engine speed to "take off" revs. *does*, in most present designs, produce a tendency to swing and the pilot's attention is taken up in anticipating and correcting. It is not suggested that the tendency is necessarily alarming or that it cannot be remedied by one or other of the means advocated by Mr. Cleaver, but it is as well to emphasize the fact that the pilot has plenty to think about in the few seconds devoted to the operations of bringing the aeroplane safely to rest at a desired point on the aerodrome.

In the case of the "glide in" landing at an angle of, say, 10 deg., reversal of pitch at 5 ft. altitude reduces the ground run by only 10 yds. Is this saving of distance (assuming it *is* saved), worth the hazards and discomfort attached to the vertical drop in a more or less uncontrolled condition? Having judged the height to a nicety and dropped the aeroplane, the pilot is then under the necessity of *realizing* that airscrews have completed their movement and opening up the throttle to develop braking thrust.

In the proposed scheme of operation and control by wheel pumps, it is intended that high capacity pumps (the fluid horsepower output being very much greater than that of any pump which could normally be accommodated on the engine), would not only secure operation of the airscrew but would also, through a sequence valve, open the throttle and require no attention by the pilot. Initial selection, etc., could be carried out at any stage of the approach, at any altitude, and any subsequent manual control applied would not be prejudiced until the aeroplane is ground borne. The landing process would then be entirely automatic if desired—*and safe*. Also, the actual time taken (and distance traversed) would be much less than that resulting from manual operation of airscrew and engine controls.

Engine operated pumps for airscrew operation suffer from the handicap of only low revs. (idling at 800 or so r.p.m.) being available at the instant when maximum output is required. Any pump fitted to the engine, to secure high velocity pitch change, would require a high fluid horsepower output for a maximum period of two seconds in each flight; the remainder of its life is spent idling or at very low delivery when the overall efficiency is lowest.

In the most efficient pump design, under these conditions, the horsepower input is considerable, entailing loss of energy, wear and tear on pump and drive, wastage of fuel and tankage and space and weight in the engine installation. There is also to be considered the necessity of constant servicing, the vulnerability to any other service supplied and the grave risk, always attaching to any accessory running constantly at high speeds over long periods, of failure at the psychological moment.

It would appear singularly odd to anyone not familiar with the aircraft industry of this country that, while everyone apparently agrees on the strong claims of the low viscosity hydraulic oils for use in airscrews, the practice of using the engine oil circuit still persists. Whatever truth lies behind Messrs. de Havilland's statement on the existence of airscrews employing an efficient fluid, the fact remains that they are not in use. A pertinent question: Is the new, as yet untried, airscrew for the Dove to use engine oil?

On the subject of baulked landings, provision of braking airscrews will go far towards obviating such adventures in normal conditions with a pilot physically and mentally fresh and alert, but I disagree as to the unlikelihood of a harassed, perhaps tired pilot, wishing to change his mind when 10 feet above the ground. It frequently happens, particularly with a conventional undercarriage, that with wheels almost touching ground a machine has to be flown off. It is desired, of course, to consider all conditions of visibility.

It must be borne in mind that, with manually controlled braking airscrews, the pilot coming in with throttle hand at the ready, is keyed up to decide the precise instant at which to operate the airscrew pitch and to follow up with a nicely judged throttle and mixture opening. Simplified throttle lever movements, preferably in a directional sense, will naturally reduce the amount of skill and practice necessary to make the shortest and safest landing.

There would appear to be no disadvantage, and a great deal to be gained, by control and/or operation of the aeroplane braking arrangements, in which airscrews will be included, as suggested in my article, by wheel pumps or other similar means indicated or in mind.

The diagram of the proposed hydraulic system was unfortunately omitted from the issue containing Part I of the article to which it referred.* Messrs. de Havilland and other readers might like to consider this as one of the methods referred to in the text. The pump mounted in the wheel would generally be geared up in order to secure the maximum speed of rotation in preference to using the direct drive shown.

The "pitch change jack" shown is merely a diagrammatic means of completing the circuit. In practice it would represent the airscrew hub or a control valve to the pitch change circuit where the latter uses engine oil.

It would be interesting to learn of any technical reasons to support the possibility of use of a braking airscrew as glide control. It is usually very easy to produce a stall in a too slow glide without such assistance and suitable wings and flap design is the usual adopted remedy.

I am grateful for this opportunity of replying to criticisms of my articles and would like to take advantage of it in order to emphasize their main point that they purport to be a constructive criticism of present methods and expedients with suggested alternatives to eliminate the hazards attaching to and also the human element involved in procuring a really safe landing under any conditions.—Yours faithfully,

G. W. DRURY.

August 30th, 1945.

Power-Plant Efficiencies

SIR,

In the June number of AIRCRAFT ENGINEERING there was published a very interesting article by Mr. A. V. Cleaver on "Power Plant Efficiencies" with special reference to the propulsive or Froude Efficiencies of Airscrew-Engine Combinations, Jet Units and Rockets. I wish to endorse the editorial comments on Mr. Cleaver's "good services in dispelling some of the clouds" of mystery which are apt to surround new ideas in general and jet propulsion in particular.

I feel, however, that the subject could have been clarified still further if Mr. Cleaver had not used the thermal efficiency of the engine when obtaining expressions for propulsive efficiency, but had used instead the air/fuel ratio which he also introduces.

Using the definition:

$$\text{Propulsive Efficiency} = \frac{\text{Useful propulsive work}}{\text{Useful propulsive work} + \text{Kinetic Energy in jet not used for propulsion}}$$

it becomes unnecessary at this stage to consider either the initial kinetic energy of the fuel or its Calorific value. Thus in the general case considered by Mr. Cleaver of an aircraft travelling at a steady speed, V_o f.p.s., propelled by a device which draws in a slugs of air per sec. for every slug/sec. of fuel burnt and expels the total mass of $(1+a)$ slugs/sec. at a velocity V $(=V_o/r$ f.p.s.) relative to the aircraft we can use the writer's expressions:

$$\text{Useful propulsive work} = V_o^2\left(\frac{1+a}{r}-a\right)$$

$$\text{Energy not used in jet} = \frac{1+a}{2}\left(\frac{V_o}{r}-V_o\right)^2$$

to write down the propulsive efficiency

$$\eta_P = \frac{V_o^2\left(\frac{1+a}{r}-a\right)}{V_o^2\left(\frac{1+a}{r}-a\right)+\frac{1+a}{2}V_o^2\left(\frac{1}{r}-1\right)^2}$$

$$= 2r.\frac{1+a\,(1-r)}{(1+r^2)+a(1-r^2)} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

This expression at once shows the origin of the formula for the propulsive efficiency of a rocket and the approximate formula for that of an airscrew or a propulsive jet.

For in a rocket $a=0$, as no air is drawn in for combustion and therefore from (1)

$$\eta_P=\frac{2r}{1+r^2}$$

In a jet propulsion engine, however, a is at present not likely to be less than 50, so if we write $a=1/q$, where q is the fuel/air ratio, Equation (1) becomes

$$\eta_P=2r.\frac{q+(1-r)}{(1+r^2)\,q+(1-r^2)}$$

and as q tends to zero

$$\eta_P \rightarrow \frac{2r\,(1-r)}{1-r^2} \text{ or } \frac{2r}{1+r}$$

An engine-airscrew combination can also be regarded as a device in which the mass of fuel is negligible and therefore has the same approximate formula as a jet engine, if the losses due to blade profile drag and slipstream rotation are ignored.

It is therefore possible to obtain the formulae for propulsive efficiency quoted by the writer without considering the thermal efficiency of the cycle.

The thermal efficiency can then be treated in a similarly general manner making allowance, as Mr. Cleaver does, for the intial K.E. of the fuel (though the writer is incorrect in stating that his Equations 3 and 4 apply to both a jet unit and a rocket, since they, of course, refer only to a rocket).

Using the same notation as above with the addition of L for the calorific value of the fuel (ft.-lb./slug) the "kinetic" thermal efficiency in the general case can be expressed:

$$\eta'_{th} = \frac{\text{Energy available for propulsion}}{\text{Input Energy}}$$

$$= \frac{\text{Useful propulsive work} + \text{Wasted K.E. in jet}}{\text{Heat Energy input} + \text{initial K.E. in fuel}}$$

$$= \frac{\frac{1}{2}V_o^2\left[a\left(\frac{1}{r^2}-1\right)+\left(\frac{1}{r^2}+1\right)\right]}{L+\frac{1}{2}V_o^2} \quad \ldots\ldots \quad (2)$$

and thus from equations (1) and (2) the overall efficiency, η, is given by:

$$\eta=\eta_P \times \eta'_{th}$$

$$=\frac{2}{r}.\frac{1+a\,(1-r)}{2L/V_o^2+1} \text{ or } \frac{V_o\,[(1+a)V-aV_o]}{L+\frac{1}{2}V_o^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

For a rocket, when $a=0$

$$\eta=\frac{2}{r\left(\frac{2L}{V_o^2}+1\right)} \text{ or } \frac{VV_o}{L+\frac{1}{2}V_o^2}$$

and for a jet unit the overall efficiency approximates to

$$\eta=\frac{2a}{r}\,\frac{(1-r)}{2L/V_o^2} \text{ or } \frac{aV_o\,(V-V_o)}{L}$$

since a is now large compared with unity, and the K.E. of the fuel is likely to be less than 0·1 per cent of the heat energy even at aircraft speeds of 600 m.p.h. Illustrating Mr. Cleaver's point that the K.E. of the fuel is not negligible in the case of a rocket, it is of interest to note that at 3,000 m.p.h. the Input Energy of a V2 type of rocket would include a Kinetic Energy term equal to about 10 per cent of the Heat Energy. (The calorific value of the fuel being only about a fifth of that of fuels used in jet engines.)

As stated above, Mr. Cleaver's Equation 4 shows the relationship between the "kinetic" thermal efficiency and the "internal" thermal efficiency for a rocket, but not for a jet unit. The relationship for a jet engine might also be written down but would serve no useful purpose, for unlike rockets, where the "internal" thermal efficiency of a particular rocket is independent of forward speed (since for a given expenditure of fuel the same jet velocity is attained at all forward speeds) in jet engines this efficiency varies with forward speed due to the varying ram

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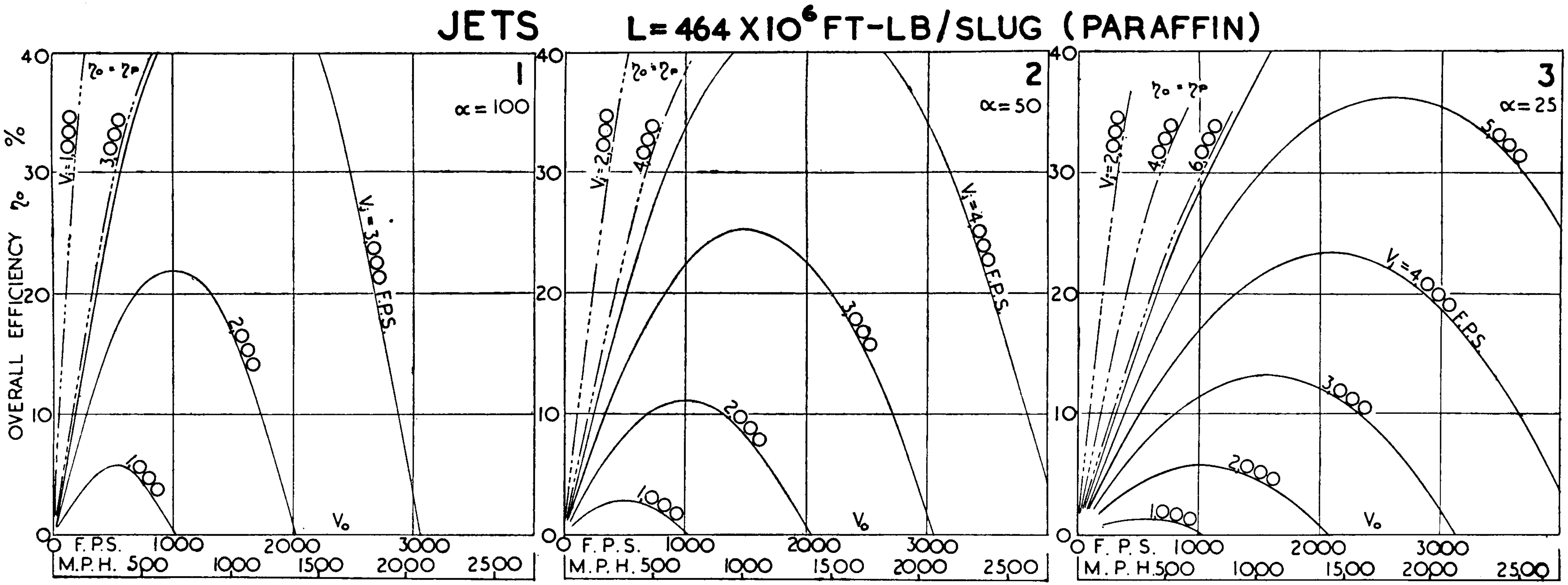
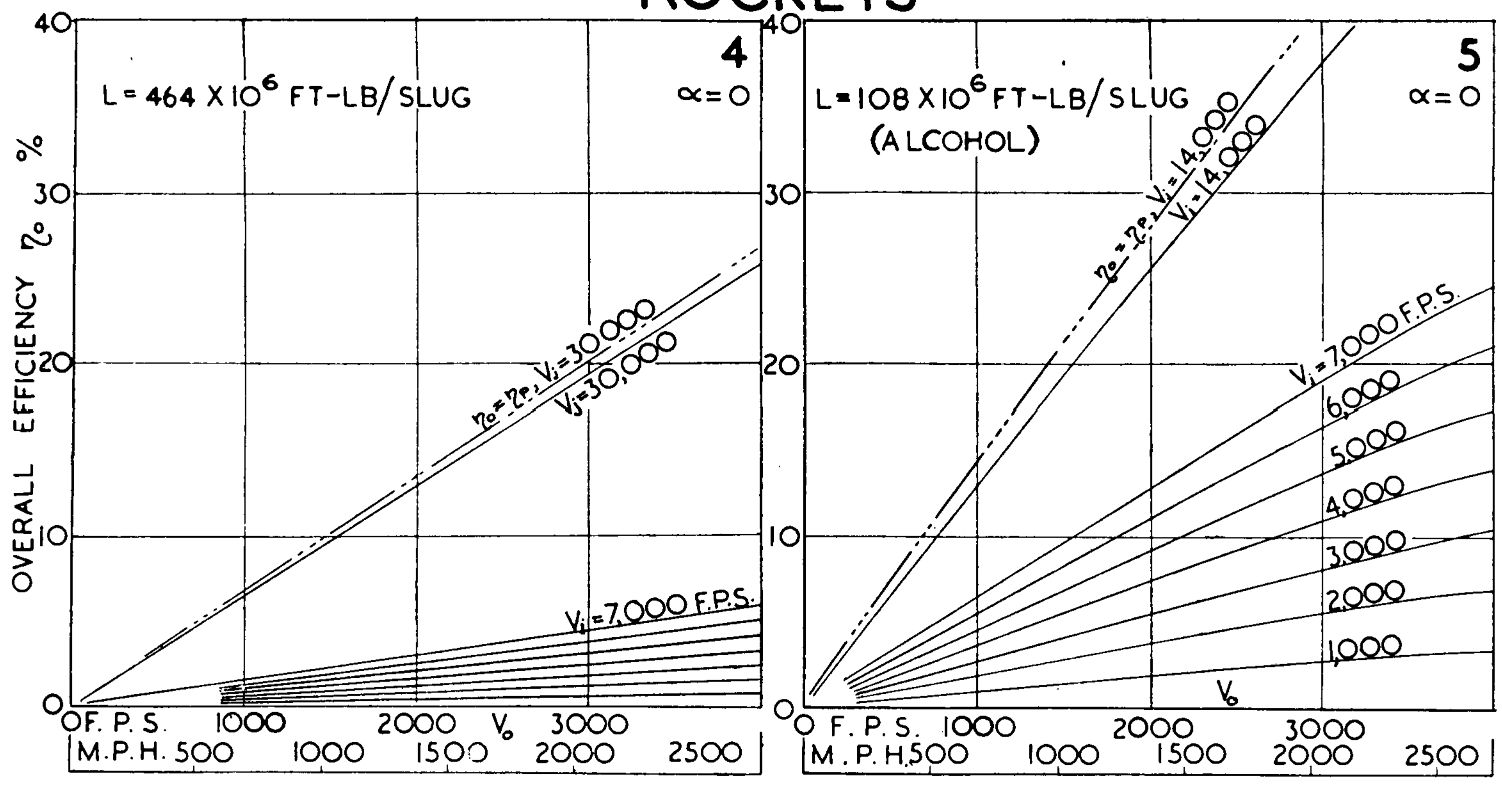
* Reproduced in Part II, AIRCRAFT ENGINEERING, August 1945, p. 222.





GRAPHS OF

$$\eta_o = \frac{V_o[(1+\alpha)V_j - \alpha V_o]}{L + \frac{1}{2}V_o^2}$$

WHERE

η_o = OVERALL EFFICIENCY
V_o = FORWARD SPEED
V_j = JET VELOCITY
L = CALORIFIC VALUE OF FUEL
α = AIR/FUEL RATIO

LINES SHOWN THUS ———·····——··——
INDICATE WHERE $\eta_o = \eta_P$, i.e. WHERE η_{TH} = 100%, FOR A STATED JET VELOCITY
η_P = PROPULSIVE EFFICIENCY
η_{TH} = THERMAL EFFICIENCY
$\eta_o = \eta_P \times \eta_{TH}$

compression of the air before it enters the compressor proper. Moreover the internal thermal efficiencies of either a particular rocket or jet are not independent of altitude. These are, therefore, additional reasons for agreeing with the author's suggestion that the propulsive and thermal efficiencies are of academic interest only and that it is the "overall efficiency which really matters."

Consequently your readers may be interested in the attached figures showing the variation of overall efficiency with aircraft velocity for different values of jet velocity, air/fuel ratio and calorific value of the fuel; the relationship between the various quantities being that given in Equation 3.

Using a calorific value equal to that of paraffin, Figs. 1 to 4 show the variation of overall efficiency for air/fuel ratios of 100, 50, 25 and 0 respectively. Fig. 4 therefore represents a rocket using very high calorific value fuel. In actual fact, however, since a rocket fuel has to embody the oxygen required for its combustion, the calorific value is likely to be much lower. Fig. 5 therefore represents a rocket employing a fuel with a calorific value approximately equal to that of alcohol-oxygen mixture. The overall efficiency is plotted against aircraft velocity and lines of constant jet velocity in thousands of f.p.s. are shown. On each figure there is plotted the highest jet velocity line to lie entirely within the domain where thermal efficiency is less than unity. This domain of course lies below the line on which, for the given jet velocity, the overall efficiency equals the propulsive efficiency of the device (given in Equation 1). It is clear that on such a line the thermal efficiency must be unity.

The feature which is most apparent from Figs. 1, 2 and 3 is that in a jet unit maximum efficiency for a given jet velocity occurs when the velocity of the aircraft is approximately half that of the jet (actually when $V_o = \frac{a+1}{2a} V$). This is clearly shown by all the curves. It will also be seen from these figures that, not unnaturally, as the air/fuel ratio is decreased, higher jet velocities are obtainable though the efficiency for given jet and aircraft velocities is reduced. A high jet velocity is, however, desirable as it increases the amount of thrust obtainable per slug of working fluid and therefore decreases the size of the engine required to give a certain thrust.

The thrust obtained from $(1+a)$ slugs or air + fuel per sec. is $(1+a)V - aV_o$ lb., therefore:—

Thrust $= V - \frac{a}{a+1} V_o$ lb./slug of (air + fuel) per sec.

We might term this the specific thrust. Taking, as an example, conditions which give an overall efficiency of 23 per cent at an aircraft speed of 2,000 f.p.s. the figures show that for $a = 100$, 50 and 25 respectively V is approximately 2,500, 3,000 and 4,000 f.p.s. and the specific thrusts in the three cases are therefore approximately 525, 1,050 and 2,100 lb. per slug per sec.

In a rocket, where $a = 0$, the specific thrust becomes even greater. With the high calorific value fuel on overall efficiency of 23 per cent is unobtainable at a projectile speed of 2,000 f.p.s. and even with alcohol it would correspond to an extremely high thermal efficiency. However, assuming for the moment that it were possible, Fig. 5 shows that the specific thrust would then be of the order of 13,000 lb./slug/sec.

Similar considerations should be borne in mind when studying Figures 4 and 5 in order to avoid the misconception that it pays to employ low calorific value fuels in a rocket. Although the efficiency for a given jet velocity is higher for a low calorific value fuel, at a given efficiency and flight speed greater jet velocity, and therefore greater specific thrust, may be obtained by the use of fuels with higher calorific value. It is not being suggested of course that rocket fuels with a calorific value equal to that of paraffin are at present likely to be used. The main purpose of Fig. 4 is to illustrate the limiting case of Figs. 1 to 3 when a becomes zero, but with Fig. 5 it serves to show the influence of fuel calorific value on the performance of rockets.

In addition, therefore, to the conclusions regarding overall efficiency which may be drawn from a study of the figures, primarily, that if the size of engine is unimportant, the highest efficiencies are obtained at high air/fuel ratios, it should also be said that the development of more powerful jet engines, that is, engines having greater specific thrust, lies in decreasing the air/fuel ratio. Such development is of course limited by the high temperatures involved and must go hand in hand with the development of high temperature resisting materials.

Yours faithfully,

23rd July, 1945 D. H. MALLINSON

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The Geometry of a Structural Joint

By C. F. Allen

THE author makes no claims of originality in the following article. It is written with the idea of assisting students when doing the preliminary layouts of a structural joint with compound angles.

It has been the experience of the author that in a proposition of this sort a certain confusion of thought arises when the true angles between various members meeting at the joint are required, involving a considerable amount of layout work which when completed is not always easy to check.

The method to be described shows one way of tackling the problem where, by the use of a few sketches, the required true angles and other dimensions can be found without resorting to layouts. The problem has been simplified to the extent that no offsets have been shown at the joint in question, but these could be catered for by the use of the same principles.

Fig. 1 purports to be a typical structure in which it is required to detail Joint No. 1, an enlarged view of which is shown in Fig. 4.

(Concluded overleaf)

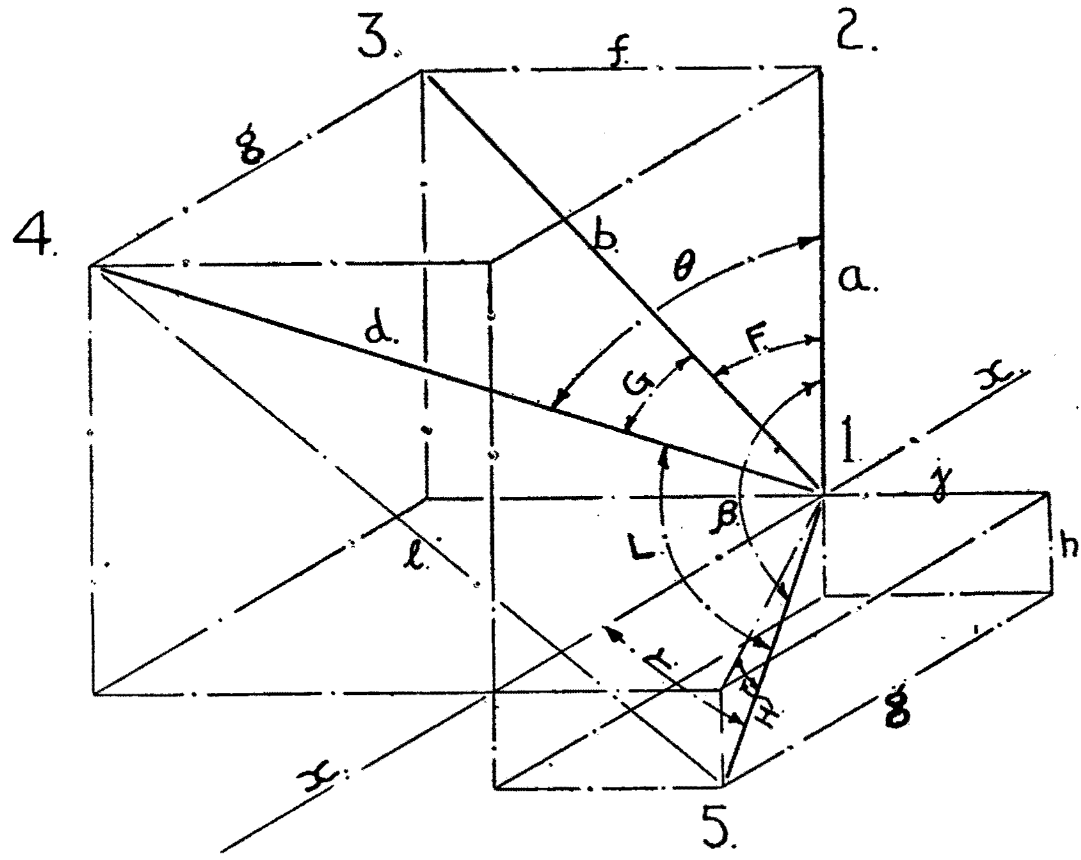


FIG. 2

FIG. 2.—

Length $b=\sqrt{a^2+f^2}$

,, $d=\sqrt{a^2+f^2+g^2}$

True angle between struts a & b $=\text{Sin } F=\dfrac{f}{b}$

,, ,, ,, ,, b & $d=\text{Sin } G=\dfrac{g}{d}$

True angle between struts a & d $=\text{Cos } \theta=\dfrac{a}{d}$

Length $C=\sqrt{h^2+j^2+g^2}$

True angle strut C to horizontal $=\text{Sin } H=\dfrac{h}{c}$

True angle between struts a & c $=\beta=90^\circ+H$

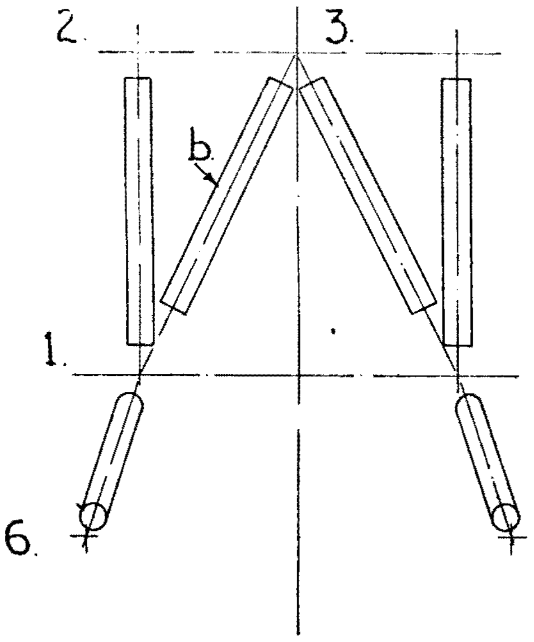
,, ,, ,, *Line x–x & strut c* $=\text{Sin } \gamma$

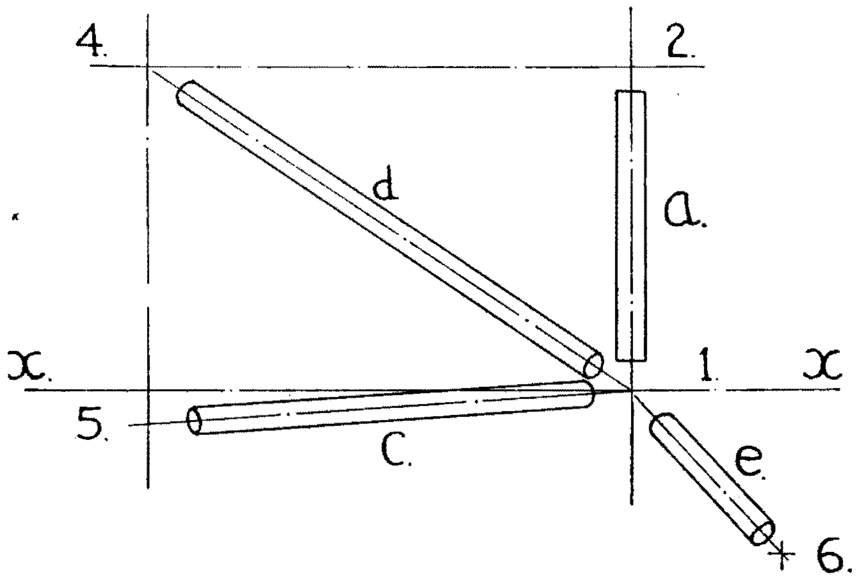
$$=\frac{\sqrt{h^2+j^2}}{c}$$

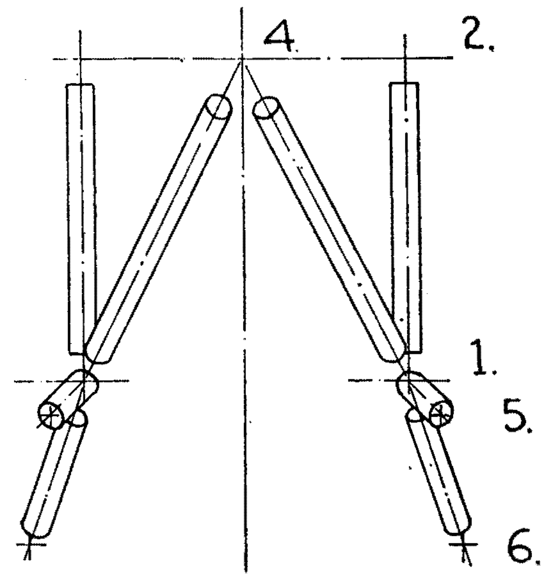
True angle between struts c & d $=\text{Cos } L$

$$=\frac{c^2+d^2-l^2}{2.c.d}$$

l = *Line joining* 4 *to* 5.







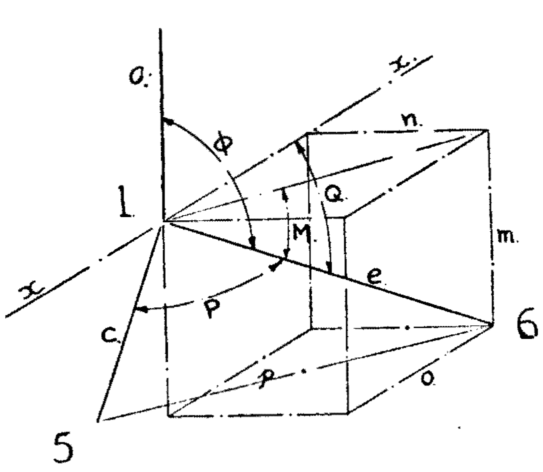


FIG. 3

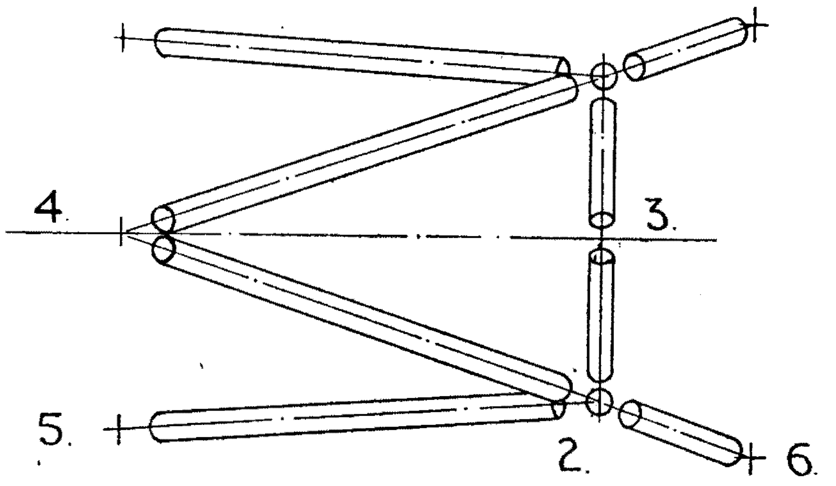


FIG. 1

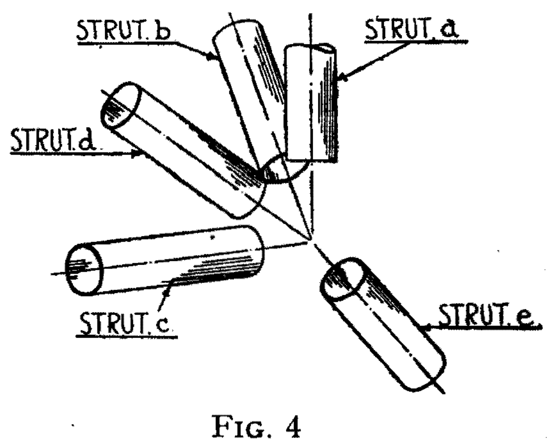


FIG. 4

Length $e=\sqrt{m^2+n^2+o^2}$

True angle strut e to horizontal $=\text{Sin } M=\dfrac{m}{e}$

,, ,, *between struts a & e* $=\phi=90^\circ+M$

,, ,, ,, *Line x–x & e* $=\text{Sin } Q$

$$=\frac{\sqrt{m^2+n^2}}{e}$$

True angle between struts c & e $=\text{Cos. } P$

$$=\frac{d^2+e^2-p^2}{2.\,d.\,e}$$

p = *line joining* 5 *to* 6.

The Origin of the Mustang

THE following resumê of the manner in which the best American single-seater fighter was designed and developed has been issued by the Ministry of Supply. We print it substantially as it was received as a historical record.

To the record of Anglo-American enterprise, which has jointly developed radar, new explosives and secret weapons of all kinds from the original inventions, can be added the story fo the North American Mustang. A triumph of foresight, combined with the complete marriage of British and American aeronautical experience, the Mustang has steadily developed into one of the outstanding fighter aircraft of the war. With the addition of jettisonable fuel tanks (provided by the hundred thousand from British factories) Mustangs helped to make possible the mass raiding of enemy territory by U.S.A.A.F. bombers. It has been developed to the stage where it is a very worthy companion of that amazingly long-lived aeroplane, the Spitfire.

Conception of the Mustang started in April 1940, when Britain asked North American Aviation Inc. to undertake a contract for the best fighter they could design. North American had developed their organization largely from the capital obtained from British orders for Harvard trainers during 1938. It was arranged that North American should develop a new type, making a start, however, under an agreement with Curtiss Wright, from certain new data obtained by the latter in their experimental work.

The subsequent collaboration worked admirably. North American executives and designers produced the first model of the Mustang in a remarkably short time with the help of the encouragement and data provided by the British Air Commission's Technical Staff—who supplied the latest operational knowledge from the R.A.F.

Even in the prototype stage the Mustang quickly showed signs of being a really promising fighter particularly owing to certain special design features of which the North American Company were the pioneers. Although the U.S. Army were not interested in this type at that stage, a Mustang production line was built up on the basis of United Kingdom dollar contracts.

The Mustang was originally designed for the Allison engine, which was then coming into production and making great strides. The Rolls-Royce Merlin was already in full operational service and it seemed to the British authorities to offer the means of immediately taking even greater advantage of the aerodynamic efficiency of the North American design. However, owing to overall dimensional limitations, the designers found they could not fit the Merlin to the Mustang airframe at that time. Later, when the first Mustang was delivered to Britain the Rolls-Royce Company fitted the Merlin engine, and the results were so auspicious that all the modification data was at once sent to the North American Company, who readily accepted the results and applied them to further development of the airframe in order to embody the Merlin engine.

In another direction a great combined enterprise was taking shape to get the Merlin engine into quantity production in America. Aided by the efforts of Mr. Knudsen, the Packard Motor Co. tooled up a production line—for which the British carried two-thirds of the capital cost of the initial facilities and, of course, provided all the necessary Rolls-Royce design data and sent a special team of engineers to collaborate with Packard's throughout the venture. Merlin production at Packard is now one of the outstanding features of aircraft engine production in North America. As soon as the merits of the Merlin-engined Mustang were established, the U.S.A.A.F. adopted the type, and ordered large numbers. As a result of whole-hearted team work, an aircraft had been produced which could out-match any comparable type in quantity production by the enemy.

As the President stated in his Seventeenth Report to Congress on Lend-Lease Operations: "Most of the outstanding scientific developments of this war are the results of joint research and planning". The President spoke of British contributions to a "joint stockpile of brains". It is appropriate in this connexion to recall that, apart from the complete pooling of technical data which made possible the Mustang it was partly due to the considerable sums which the United Kingdom was then in a position to lay out at the North American and Packard Works, that this great venture was got under way. By spending roughly half of her available gold and dollar resources to finance her aircraft programme in the United States, Great Britain, as events proved, enabled the gigantic air programme of America to reach its peak well ahead of what would otherwise have been possible.

The Geometry of a Structural Joint

(Concluded from previous page)

In Fig. 1:

Line a represents strut 1—2
,, b ,, ,, 1—3
,, c ,, ,, 1—5
,, d ,, ,, 1—4
,, e ,, ,, 1—6

Line x—x is horizontal through the centre-line of joint 1, parallel to the centre-line of the structure.

Using joint 1 as a datum, the joints 2, 3 and 4 are the same height above its centre. Joint 2 is vertically above, while 3 and 4 are located on the centre line of the structure.

Let f = distance from centre line of structure to 1.
g = ,, from 1 to 4 and 5.
h = ,, down from 1 to 5.
j = ,, out from 1 to 5.
m = ,, down from 1 to 6.
n = ,, out from 1 to 6.
o = ,, from 1 to 6.

Given the above data, the required information could be worked out direct, but the author has found the problem is easier to visualize if sketches as shown in Figs. 2 and 3 are drawn.

It is seen that for the purpose of reducing the problem to that of simple trigonometry, parallelepipeds are imagined to be constructed around the struts with the centres of the joints situated in the corners.

College of Aeronautics

THE following have been appointed to be the Board of Governors of the College of Aeronautics for post-graduate instruction in Aeronautical Science and Engineering, which, as announced in the House of Commons in October last, is being created in accordance with the recommendations of the Committee presided over by Sir Roy Fedden, whose report was issued last year:—

Chairman—

Air Chief Marshal Sir Edgar Ludlow-Hewitt, G.B.E., K.C.B., C.M.G., D.S.O.

Members—

Dr. W. Abbott, O.B.E., H.M.I.
Mr. H. Burroughes
Sir Roy Fedden, M.B.E.
Mr. J. Ferguson, H.M.I.
Brig.-Gen. Sir Harold Hartley. K.C.V.O., C.B.E., F.R.S., M.C.
Sir William Hildred, C.B., O.B.E.
Sir Melvill Jones, O.B.E., A.F.C., F.R.S.
Dr. E. B. Moullin, M.A.
Mr. J. D. North
Sir Frederic Handley Page, C.B.E.
Mr. E. F. Relf, C.B.E., F.R.S.
Dr. H. Roxbee-Cox
The Lord Selkirk
Air Marshal Sir Ralph Sorley, K.C.B., O.B.E., D.S.C., D.F.C.
Sir William Stanier, F.R.S.
Rear-Admiral T. H. Troubridge, C.B., D.S.O.
Mr. W. E. F. Ward.

Invitations are being extended to the Governments of the Dominions and India who may wish to associate themselves with the College to appoint representatives on the Board of Governors.

Preliminary steps are now being taken with a view to opening the College some time in the course of next year in temporary accommodation to be provided at Cranfield, pending the provision later of permanent premises.

Books Received

Soaring Flight. By Terence Horsley. 303 pages, illustrated. [Eyre and Spottiswoode. 16*s*.]

Aluminium Alloy Extruded Sections: Notes on Design and Manufacturing Tolerances. Illustrated pamphlet. [Aluminium Development Association. *Free*.]

Research. Pamphlet. [Advisory Bureau for Research, 70 Victoria Street, S.W.1. 1*s*. 5*d*. post free.]

Report of Conferences on Standardization of Screw Threads and Cylindrical Fits. [Combined Production and Resources Board. *Free*.]

Standards Review. Vol. 2, No. 1. Quarterly periodical. [British Standards Institution. 2*s*.]

The de Havilland Aeronautical Technical School: Prospectus. Pamphlet. [The de Havilland Aircraft Co. Ltd. *Free*.]

Charts for Turn and Manœuvreability Computations of an Aircraft. By G. A. Mokrzycki. Pamphlet, illustrated. [Author, 2720 Fourth Avenue, San Diego 3, Cal. *Free*.]

Gas—in Industry at War. By H. R. Hems. [Institution of Gas Engineers. *No price stated*.]

Design of Wood Aircraft Structures. (ANC-18). 247 pages. illuslrated. [U.S. Govt. Printing Office, Washington. No price stated.]

Making a Mark. 78 pages, illustrated. [Edward Pryor & Son Ltd., Sheffield 5f.]

Carburation. By C. H. Fisher. Second Edition. 358 pages, illustrated. [Chapman & Hall. 21s.]

Wing Tips for Tailless Aeroplanes

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

Introduction

THE study of the flight of birds has provided and will still provide much valuable information for the progress of human flight. Many suggestions for the improvements of wings by the use of special wing tips owe their existence to the observation of nature. In spite of such suggestions, free-flight experimentation —as far as published work goes—is still rather rare and restricted in scope. This reluctance may be due to practical design considerations (handling) as well as to the necessity of making the conventional aileron as efficient as possible; it may also be caused by the impression that experiment in this direction is not worth the effort.

Admittedly, for a conventional aeroplane of mediocre aerodynamic efficiency, not much can be hoped for in the way of improvement by the adoption of a special wing tip. But when it comes to a struggle for the last ounce of aerodynamic efficiency, nature can be made to concede to us: research along the lines indicated may well become a paying proposition. This is especially the case with the Flying Wing where, moreover, the demands for stability and controllability are apt to interfere seriously with the aerodynamic performance and the practical adaptability.

The conventional aileron is also greatly to blame for the reluctance to shape the tips of a wing in a more efficient manner. The history of the plain wing with positively raked tips (i.e., leading edge shorter than the trailing edge) provides a good example of this.

Importance of Tip Shape

E. W. Lanchester very early recommended such raked tips for higher efficiency as they were able to suppress or delay the pressure equalization at the ends of the wing. A wind-tunnel investigation made by O. Foeppl in 1910[1] on the basis of Lanchester's recommendations in fact proved beyond doubt that positive rake gave either higher lift (at equal incidence) or better lift/drag ratios up to moderate incidences, in comparison with square or rounded wing tips, and that this holds particularly well for cambered aerofoil sections. Saenger's experiments, to which further reference is made later, also confirm this result. N. A. V. Piercy found[2] that with suitably shaped raked tips (Alula type), cored vortices were not present in the downwash at incidences of normal flight, and that this meant a direct saving of drag of the order of 10 per cent and more.

The influence of the induced drag on the performance is not negligible. For a good practical aerofoil section (R.A.F. 34), the lift/drag ratio, i.e. the characteristic governing the thrust required and the gliding angle, is at infinite span (two- dimensional flow) at its best about 80, at the Reynolds numbers at present in use.[70] The same aerofoil section in a wing of aspect ratio 6 (a common value to-day), gives an optimum L/D ratio of only 22.

However, the latter optimum occurs at smaller incidence (4·5 deg. against 7 deg. for the optimum for the wing of infinite span). Referred to equal lift (4·5 deg. of the finite-span wing) which does not mean equal incidence for both wings because of the change in the slope of the lift curve $(dC_L/d\alpha)$ due to the induced downwash, the L/D ratio of the infinite-span wing would be only about 50. For high-speed flight, this difference of $50-22=28$ would be the actual loss in L/D due to the induced drag. A part of this loss may be made up by a suppression of the marginal vortices.

For economical flight at minimum sinking speed which takes place at higher C_L values, the loss sustained by the induced drag is more substantial. Hence a recovery of part of this loss is more a direct contribution to economical flight than to performance at maximum speed.

The influence of wing-tip shape on stability is also of importance. Lanchester suggested in 1910 that square wing tips would be of great benefit for the lateral stability although by this expedient, an increase of drag would result (*cf.* R. & M. 59 of 1911, p. 103). It is experimentally established to-day, that square tips indeed improve the roll-damping at and near the stall, and since in 1910, aeroplanes flew usually very near the stall, Lanchester's suggestion was a very sound one, besides proving how far in advance of his time his aerodynamical insight must have been in those days. Mervyn O'Gorman, then Superintendent of the R.A.F. at Farnborough, did not follow Lanchester's suggestion, for the reason that "Nature had provided no bird with square wing tips". Thus the modern elliptical wing tip was created at Farnborough.

D. H. Williams[3] investigated the rolling and yawing moments of half-wing models having tips of different shape. He observed that an abruptly swept-forward tip was beneficial for the rolling moment beyond the stall. On the same occasion, the tip shape suggested by H. Hocke[4] was experimented with. This tip is tilted upwards about an axis which forms an angle with the plane of symmetry of the wing (intersecting either in front or behind the wing). According to Williams, the Hocke tip is neither beneficial nor harmful. Hocke claimed that his upwards tilted tip would improve the stability especially in circling flight; adjustment in flight by changing the angle of upwards deflexion was intended.*

D. L. Bacon[5] measured the pressure distribution over moderately raked tips. With positive rake, two regions of low pressure are apparent on the upper surface of the wing near the tip, one at the leading edge which is apparently caused by the core of the marginal vortex, and the other near the extreme end of the tip. A downward displacement of an aileron at such a tip greatly accentuates the intensity of the second low-pressure region, and thus reacts unfavourably on the hinge moments of the aileron.

More recently, J. Valensi has experimentally investigated the marginal vortices formed at different tip shapes by the means of the smoke-thread method (Lit. 76). Unfortunately, the effects of wash-out and sweep were not included in this valuable research.

Uncommon Tip Shapes

The Zanonia category referred to in the historical survey†, may be described as a plain wing to which tips of the significant shape are fitted. This was indeed the design employed by the original Focke-Wulf aeroplanes which came under the Zanonia category, though belonging otherwise to the conventional Pénaud type. Great merits have been claimed for wing tips of this class, especially in connexion with lateral stability and freedom from autorotation when stalled (though it was evident that the elevator

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(1) O. Foeppl, *Z.F.M.* 1911, p. 83.
(2) *J. Roy. Ae. S.* 1923, p. 500 and p. 511.
(3) R. & M. 1665.
(4) Germ. Pat. Spec's. Nos. 476,877 and 528,215; Brit. Pat. Spec. No 299, 212 of 1927.
(5) N.A.C.A. Techn. Rep. No. 161.
(6) *Z.F.M.* 1930, p. 444.
(7) *Flugsp.* 1920, p. 477 ; Brit. Pat. Spec's. No. 13,331 of 1910 and No. 24,179 of 1911.
(8) Germ. Pat. Spec. No. 403,173.
(9) ,, ,, ,, ,, 238 543.
(10) ,, ,, ,, ,, 290,149.
(11) ,, ,, ,, ,, 400.877.
(12) Brit. Pat. Spec. No. 17,150 of 1908.
(13) Germ. Pat. Spec. No. 486,052.
(14) *Flight*, July 1929, p. 611.
(15) C. Wieselsberger, *Z.F.M.* 1914, p. 225.
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(20) viz. Jordan, *Lufo*, Vol. 16, 1939, p. 196.
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(22) Aircraft Engineering 1937. p. 31.
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(26) "Les Lois Experimentales de L'Aviation", Paris 1912, p. 242.
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(29) R. & M. 1577, p. 5 and fig. 7.
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(31) C. H. N. Lock, *Flight*, Aug. 1936, p. 229.
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(37) G. Richter, *Lufo* Vol. 16, 1939, p. 112.
(38) Germ. Pat. Spec. No. 509, 764.
(39) N.A.C.A. Tech. Rep. No. 613 ; R. & M. 1772 (1937).
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(52) e.g., Goett. No. 234, Tech. Ber. Vol. II, p. 437 and diagr. 210.
(53) e.g., Durand No. 7 section, *viz.* "Charattiche Aerodinam. di Ali", Fasc. ix, Rome 1925, p. 7, No. 769.
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(68) *Cf.*, S. Goldstein and Fluid-Motion Panel of the A.R.C., Modern Developments in Fluid Dynamics, Oxford 1938, Vol. II, p. 466.
(69) Ackeret, *Z. d. V.D.I.* 1926, p. 1155.
(70) R. & M. 1706.
(71) *Flight*, April 1924, p. 206.
(72) A. Baumann, Mech. Grundlagen d. Flugzeugbaues, Munich, 1913, Vol. II, p. 37.
(73) Aérophile, Sept. 1909, p. 395.
(74) Germ. Pat. Spec. No. 443, 116 of 1923.
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(76) J. Valensi, "Applicat. de la Méthode des Filet de Fumée . . ." *Public Scientif. du Minist. de l'Air*, No. 128, Paris 1938.
(77) Germ. Pat. Spec. No. 397, 131 of 1919.
(78) J. Ackeret, "Bemerkungen zu zwet neueren Schriften von G. Lilienthal," ***Z.F.M.***, 1924, p. 242.

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* The sideloads produced at such tilted-up tips have been calculated (on the basis of minimum induced drag) by Mangler.[66] As to the efficiency of shutter tips for control purposes, older American wind-tunnel tests[67] may be indicative.

† *See* "Tailless Aircraft and Flying Wings", by A. R. Weyl, Aircraft Engineering, Vol. XV, Dec. 1944, p. 341.

control was not powerful enough to stall the aeroplane completely). It was stated[6] that wing tips of such shape (Fig. 00) gave also a high aerodynamic efficiency to wings of low aspect ratio. Such tips are distant relations to the Diffuser Tip which will be discussed further below.

In connexion with the wing-tip problem, the *annular wing* already referred to may be mentioned.

Aerodynamically, such a wing system has no tips, but it is yet of finite span, i.e. subject to induced drag. It would seem that the lift-generating circulation about the front part of the circle continues into the lateral parts, and that marginal vortices in the common sense may form only at the rearwards parts. If this is so, the existence of such continued circulation (over the dorsal surface from outward to inward) must favourably affect the rolling moment due to side-slip (L_v), and this effect may continue up to large angles of incidence, because of the superposition of the circulatory motion with the relative airflow. At the same time, the rearward aerofoil part of the annulus will have a diminished lift, not only because of the downwash, but possibly due to the influence of the continued circulation at the lateral parts; this would also result in eddy formation. Based on this assumption, the longitudinal and the lateral stability of such a wing system seem assured. There is also a possibility that the induced drag is somewhat decreased, as compared with a circular aerofoil of equal span. Tilghman Richards has communicated[71] pressure-distribution tests from which it is evident that the centre-of-pressure travel may be made stable with such aerofoils.

Slotted Wing Tips

When discussing the autorotation of isolated wing systems, attention was drawn to the possibility of excluding this phenomenon by the use of lattice wing tips, and devices suggested by F. S. Barnwell and W. Schmidt were mentioned in this connexion.

Lattice wing tips are related to multiple-slot wing tips for which priority may well be claimed by the birds. If, why, and to what extent, birds exploit the slot effect of such tips during certain flying conditions (hovering flight and landing) does not yet appear to be fully understood, but that their wings are equipped with slot-like devices is generally established.[75]

The human mind bent on imitating nature blindly, very often without any attempt to understand the implications of nature's arrangements, has, of course, not let the slotted wing tip pass by unnoticed. The Wolfmueller-Geest sailplane of 1909 which had bird's shape had a gull wing and multiple-slat tips.[7] In 1921, Dornier and Diemer secured a patent for a wing tip consisting of a number of adjustable slat elements.[8]

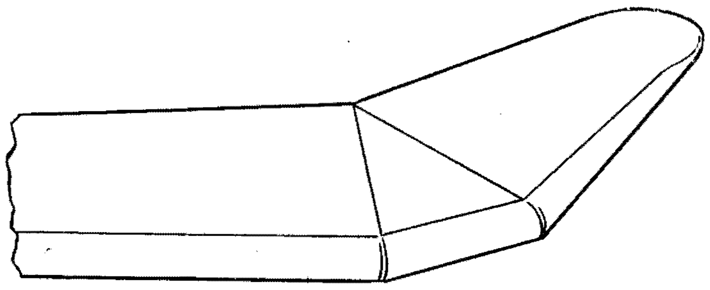

FIG. 1.—*Hocke wing tip*, 1927

A slotted wing tip prevents the separation of the air flow over the tip at an incidence at which the rest of the wing is stalled. Control organs fitted to such tips may hence retain their effect at and beyond the stall. But the same effect can be achieved by wash-out toward the tips. Greater lift cannot be expected to occur at such wing tips, since the development of high pressure differences is obviated by pressure equalization around the tips, and the only result would be a marked increase of the induced drag. Nevertheless, with tailless aeroplanes, the slotted tip might be of value to such stable wing systems which secure stability by having the higher specific lift near the wing tips, i.e. for the Buzzard category (swept-forward plan shape). Here the slotted tip may be advantageously employed in connexion with either wing-tip discs or other devices discouraging pressure equalization at the tips.

For the Flying Plank and for the Arrow category, the multiple-slat tip scarcely promises advantages. Also, it is not a device to render a wing system safe against autorotation, since a slotted wing still retains a range of incidences within which autorotation can develop.

A different kind of tip slot intended to suppress marginal vortices wos suggested by A. Baumann in 1923. A nearly chord-wise running slot was provided very near to the actual tip through which air should be exhausted (Lit. 74).

A device of perhaps more importance is formed by narrow aerofoil shaped elements arranged with a spanwise slot between them which can be singly swivelled in flight about axes which are normal to the wing surface. The elements can thus be folded together backwards, not unlike a fan. Spreadable wing tips of this kind permit a decrease in wing area and span. They can form a control device as well as one for stability and performance. In design, they are, however, rather complicated, though structurally by no means beyond the range of practical construction.

In 1909, the French motor car firm of Mors secured a patent for a wing tip consisting of a triangular sail which could be reefed in flight.[9] No slots were provided. The first fan-like spreading tip with slots between the aerofoil elements formed the interesting feature of the Austrian Ludwig Schmidtl monoplane in 1913. A quarter of the semi-span was taken up by these tip elements. Unilateral adjustments of a tip effected control in roll, while simultaneous spreading or folding back was intended as assistance to the elevator.[10] A somewhat similar, but structurally more advanced idea formed in 1921 the object of a patent by A. P. Thurston and the Bristol Aeroplane Co.[11] Here, however, the aim was not to vary the wing area and the span to an appreciable extent. When the tip elements were spread out, they assumed a greater incidence than that of the fixed wing part. In 1932, the spreading wing tip was reinvented by Custosa and the Italian Air Force made some experiments with it.

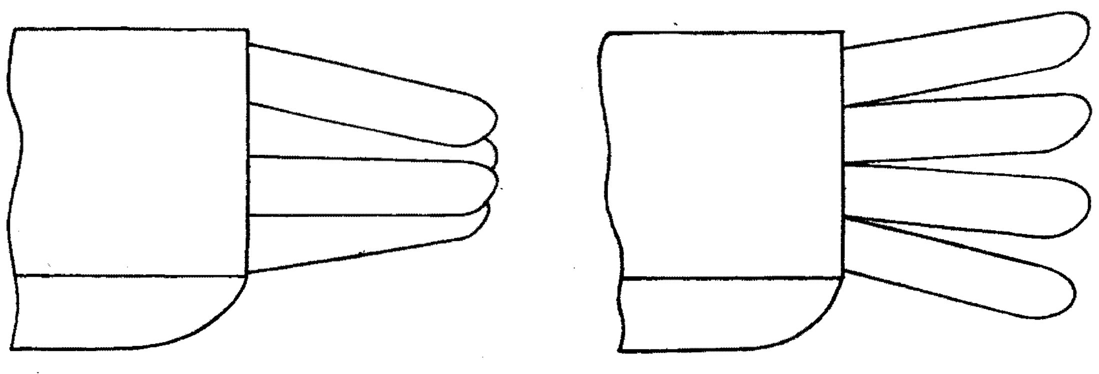

FIG. 3(*a*).—*Slotted wing tip of A. P. Thurston and the Bristol Aeroplane Co. according to a* 1921 *patent. When the elements are fanned out* (*as shown on the right*), *their incidence is greater than that of the fixed wing*

Movable Tips

Swivelling "contractible" wing tips which can be extended forward and folded backward were a feature of the tailless project of José Weiss in 1908.[12] Weiss wished to achieve a variable wing area; he claimed to have discovered that the speed of an aeroplane depended solely on its wing loading, the airscrew thrust being without influence.

As another possibility, the sliding tip deserves mention. Apart from the use of such devices at telescoping wings (e.g., Makhonine), the sliding tip can be a means of control. As such, it was anticipated in 1910 by Al. Pfitzner, an Austrian collaborator of G. H. Curtiss, who constructed a biplane at which the control in roll was effected by the outboard or inboard sliding of the wing tip. Though it is not obvious that such an arrangement could be of advantage for a modern design, its efficiency can scarcely be doubted.

As aerodynamically forming parts of wing tips, rotatable ailerons may be considered. In general, they are unsymmetrically shaped aerofoils which are obliquely mounted on a vertical axis at the structural tip of the wing. When turned about the axis, the aerofoils form either drag or lift producing elements, and it is fairly easy to secure an aileron control giving favourable yawing moments. The rotatable aileron seems to have been introduced by A. Baumann in 1912(72) and realised in a more effective form by K. N. Pearson in 1927,[13] and was successfully tried on a conventional light aeroplane.[14] It is not improbable that the incorporation of a similar control device in a diffuser tip could be utilized with advantage on a tailless aeroplane.

Diffuser Wing Tips

In the historical survey* reference was made to the diffuser-type wing tip, and emphasis was laid on the possibility that this might solve

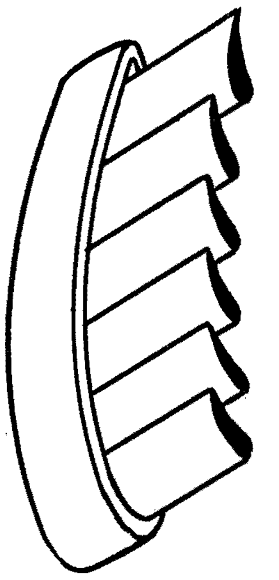

FIG. 2.—*Principle of slotted wing tip*

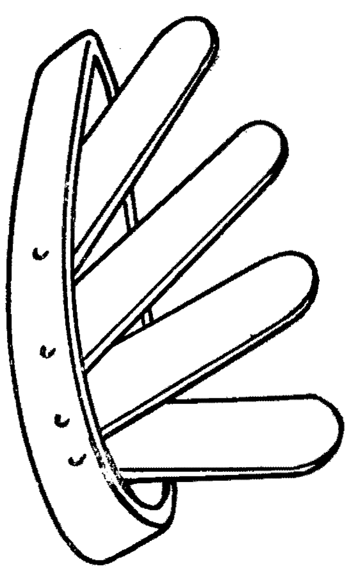

FIG. 3.—*Principle of Schmidtl wing tip*

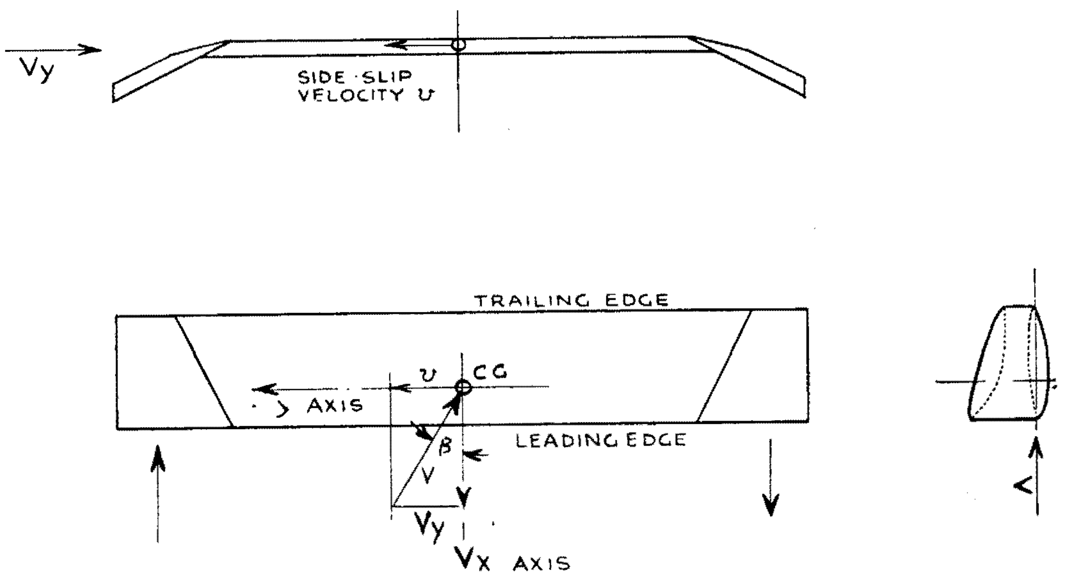

FIG. 4.—*Elementary diffuser wing tip*

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* *Loc. cit.*

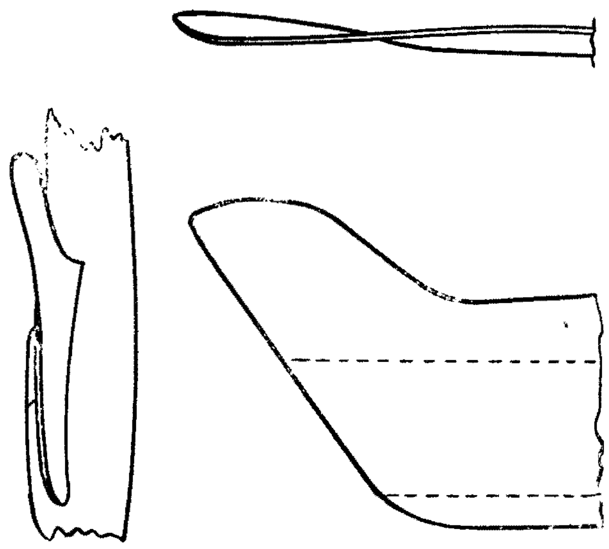

FIG. 5.—*Zanonia wing tip of a* 1912 *monoplane*

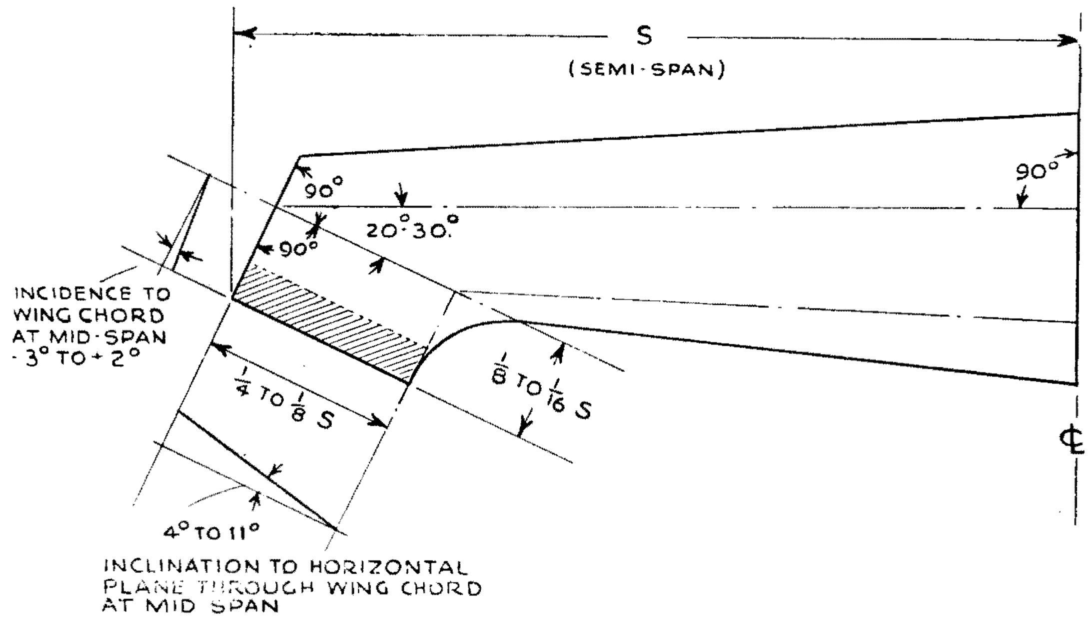

FIG. 6. —*Typical Zanonia wing tip: Focke-Wulf wing according to a* 1930 *patent which was actually utilized on transport and training aeroplanes of this firm*

many of the problems which still govern the development of tailless aeroplanes.

A diffuser as understood in turbine and blower engineering, is a device which generally converts velocity energy (i.e. the kinetic energy of a flowing fluid or gas) into pressure energy; it is based on Bernouilli's law (without taking thermo-dynamics into account and as long as frictional losses within the boundary layer and mixing losses may be neglected)*. The classification of diffuser wing tips for all "negative wing tips" (as J. W. Dunne termed such devices) embracing the wide category of tilted-down and distorted wing tips, may perhaps not be deemed entirely adequate, since their action cannot be accurately described by stating that velocity energy is transformed into pressure energy; more appropriately, they would be described as devices which diffuse vorticity from a lift-producing wing into the undisturbed air flow at the tips of a wing. However, as a general designation for the whole variety of shapes and effects, it might serve its purpose, till a more appropriate term is found.

Superficially, the ordinary diffuser tip has much in common with the gull wing, i.e. with a wing having anhedral in its outer portion, while the inner portion has positive dihedral. Gull wings of this kind have, for aerodynamic reasons, often been employed with high-performance sailplanes, while their adoption for aeroplanes is usually dictated by purely structural considerations.

In normal flight the air at the side of a lift-generating wing has an ascending component. Lanchester referred as early as 1907 to up-currents which are generated beyond the tips due to the finite span of the wing; he also stated quite correctly that a flow of air around the wing tips from the under surface of the wing (positive-pressure region) to the upper surface (negative-pressure region) forms a sort of vortex fringe. Such equalization of pressure is a loss of energy expended for obtaining lift and a diminution of the lift which is theoretically available in two-dimensional flow.

Part of this "induced" drag can be avoided, i.e. wasted energy recovered, by the adding of appropriate wing tips. Lanchester who realized this, suggested his "capping planes"; he also recommended raking the wing tips so that the trailing edge of the wing becomes greater than its leading edge. Both devices are indeed effective but, for various reasons, are not practical.

In 1914, C. Wieselsberger calculated[15] the strength of the ascending component of the air beyond the wing tips on the basis of the horse-shoe vortex system; he also proved the economy of flight in V-formation (which migrating birds had already found out many thousands of years ago), thus giving a clear indication that the energy recoverable from this ascending component is by no means negligible. V. Parseval, in 1921, estimated the energy which is carried away by marginal vortices and drew attention to the suction effect at the tips which deteriorates the lift/drag ratio near the tips.[16]

The equalization of pressure which occurs at wing tips causes the air flow at the wing surfaces to assume directions which have components normal to the plane of symmetry of the wing ("spanwise" flow). The deflexions are, for straight flight, of course, zero at the centre of the wing, while to port and starboard of the centre line, the deflexion of the air flow is increasing towards the tip (local disturbances of the flow neglected).

On the upper (dorsal) surface, where at incidences of lift, a negative pressure predominates, the air flow has a spanwise component which is directed inward, i.e. from the tips toward the centre. On the lower (ventral) surface, the air flow is deflected toward the tips. Near the tips, the air flow relative to the direction of flight (seen from above) is no longer in accord with the theory of two-dimensional flow, and conventional methods based on two-dimensional theory break down. This relates also to the common aerofoil theory of the induced drag;[17] the only way of theoretical treatment remaining is the very elaborate general vortex-sheet method given by V. M. Falkner.[18]

The energy represented by such span-wise flow components is wasted. The flow deflexions caused by the pressure gradient on the wing surface result, for a given lift, in drag which is additional to the profile drag (caused by skin friction and form drag). This additional (induced) drag increases with the square of the lift:—

$$C_{D_i} = \frac{C_L{}^2 \cdot S}{\pi \cdot b^2} \text{ (for elliptical lift distribution over the span)}$$

Apart from this loss and judging solely on the evidence of wind-tunnel experiments, span-wise flow components appear rather insignificant for the aerodynamical characteristics of wings, except at incidences near the maximum lift and for wings having pronounced sweep-back. There are, however, reasons to suspect the general validity of this common and convenient conclusion. Aerodynamcists agree that wind-tunnels tend to interfere with the three-dimensional flow of the boundary layer at wings of finite span.[68]

Wings at which span-wise flow components are impeded, for instance by rib webs protruding from the wing surface (e.g., the Kon. E. III monoplane of Rethel[19]) have proved outstanding flying qualities which might have had their cause in a fuller lift distribution and in decreased induced drag. Span-wise flow components may also well improve the behaviour at the stall[20] by directly affecting the transition vortex. Full scale observations, especially those made by W. E. Gray[21] and research by H. B. Irving[22] have established the importance of span-wise flow components on the dorsal surface upon the behaviour of the boundary layer. To-day, the fact is accepted that the separation of the boundary later from the upper surface of a wing (stall) is involved with span-wise flow.

Moreover, measurements of the pressure distribution over wing-tip discs have proved that such flow components are not at all negligible.[23] The recoverable or utilizable flow energy seems commonly underestimated. Wings at which high-lift devices are operating, give special scope for arrangements utilizing the wasted flow energy.

On thick cambered aerofoils of rectangular plan shape, E. N. Fales found[24] a pronounced span-wise flow along the dorsal surface. He concluded from his wind-tunnel experiments on boundary layer flow, that a change in flow over the cylindrical upper surface involving transition from a pronounced spanwise direction to normal direction with increasing incidence is responsible for the improved lift/drag ratios at higher incidences, and that this phenomenon is peculiar to thick aerofoil sections which have their maximum camber unusually far back. This conclusion is, as will be shown later, debatable. Fales' flow photographs also disclose a slight span-wise deflexion of the flow along the lower surface within the range of the boundary layer. Unfortunately, this evidence cannot be deemed quite conclusive since the experiments were made in the presence of a central shield which may have favoured premature separation at its joint with the aerofoil, by forming an adverse pressure gradient.

Pronounced three-dimensional flow is the cause of the abnormal characteristic (reduced induced drag, delayed stall with very high maximum-lift; absence of aurorotation) which are particular to aerofoils of very small aspect ratio. In this respect, the shape of the wing tips has proved to be of primary importance for the aerodynamical qualities of the wing.[25]

Al. Sée has claimed that "side-wind" components (side-slip) are essential, for the soaring of birds by way of assisting span-wise flow.[26] His theory of the "*vent louvoyant*" dates actually from 1908 and contains the assumption of a drag reduction caused by an angle of yaw. This theory is now assisted by Budig's "oblique-attack" effect to which further reference is made below. L. Bréguet has refuted Sée's theory of soaring on the ground that this would imply a continuous deviation from the original course.[27] Budig's contentions were then still unknown.

With wings with a sweep (either forward or back), span-wise deflexion of the air flow is enforced by the plan shape. With a swept-back wing, for instance, the flow suffers deflexion toward the tips, on the upper surface as well as on the lower one. This deflexion is superimposed on that causing the induced drag and, as a result, on the upper surface of a swept-back wing, the directions of both causes of flow deflexion are opposed to each other, while on the lower surface, both flow deflexions are in the same sense, giving a pronounced flow component directed toward the tips. On the upper surface of such a wing the resulting flow deflexions are undecided. When the sweep-back is very pronounced, there will be a spanwise com-

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* The counterpart of this conception is a nozzle.

ponent directed toward the tip, at least at small angles of incidence, while at large angles of incidence and with less pronounced angles of sweep, the component due to pressure equalization will prevail. This superposition of two flow-deflecting effects explains why the common horse-shoe vortex theory of induced drag does not hold for aerofoil shapes with sweep. It also explains the deviations of the actual lift distribution over the span from that calculated by the ordinary methods (employing the conception of a lifting vortex line).

Span-wise deflexion of the airflow of wings is also influenced by the distribution of incidence along the span (twist). The higher the local lift at or near the tips, the more pronounced will be the span-wise components caused by the marginal vortices. Wash-in (Buzzard category) can hence be expected to give decided three-dimensional flow. Wing tips producing down-lift while the rest of the wing generates up-lift, might greatly decrease the dissipative pressure equalization around the tip, and may thus give a somewhat decreased induced drag, on the expense of net lift.

Since tailless aeroplanes generally have some effective sweep and twist, they will obviously exhibit marked span-wise deflexions of the air flow over the wings. Span-wise flow components decrease the effective circulation which produces the lift; they thus imply loss of flow energy. The marked three-dimensional flow at swept-back wings also accounts for their low values of maximum lift.

Few measurements have hitherto been published giving the amount of span-wise flow of swept-back wings. All are consistent. G. T. R. Hill mentions wind-tunnel tests on a model of the Pterodactyl I[28], in which flow deflexions of 3 deg. at top speed (small lift coefficient) and of 15 deg. at stalling angle (maximum lift) were measured on the lower surface well inboard of the (floating) tips. The effective sweep-back angle was approximately 23 deg. The direction of the span-wise flow component was toward the tip. Similar observations on the Pterodactyl IV gave about 13 deg. deflexion on the lower surface near the tips at the stalling angle[29]. Again, the effective sweep was approximately 23 deg. Such large span-wise flow components fully account for the high drag caused by wing-tip disks on swept-back wings. The disks on the Pterodactyl IV had their own drag doubled when fitted to the wing.

On the dorsal surface near the tip of a swept-back wing, the superposition of the deflexion caused by the shape, with the pressure-gradient deflexion results in practical cases often in a slow outward-flow component appearing just forward of the trailing edge. This causes, at incidences at which the pressure gradient reaches certain values, regions of flow disturbance with ensuing local separations of the boundary layer; eventually a premature stall takes place and controllers near the tips are much affected[30].

At and near the stall, transverse-flow components are of primary importance for the behaviour of the boundary layer. The effect of local accelerations on the flow is greatly accentuated[31] and it should be realised that, for this very reason, the Lanchester-Prandtl theory does not hold in the range of high lifts. The theory does not consider that the vortices shed at or near the tips are inter-twisting very close to the trailing edge[32].

M. Koehler[33] made wind-tunnel investigations at and near the stall during non-steady motions, measuring the flow directions. The model wings had rectangular plan shape with square-cut tips; they were with and without wash-out. The effective Reynolds number approximated 0·22 x 10^6. For unstalled conditions Koehler found the aerofoil theory in fair agreement with the experiment. When the flow approached separation, however, considerable span-wise flow was observed, either caused by the pressure gradient or, with a wing in rolling motion, because of inertia forces. When the wing rolled, parts of the boundary layer of the inner aerofoil sections were transported towards the tips and prevented, by energizing it, a break-down of the flow there, thus delaying the separation of the boundary layer from the surface. Even the Coriolis acceleration may assist to prevent separation at the critical transition condition*.

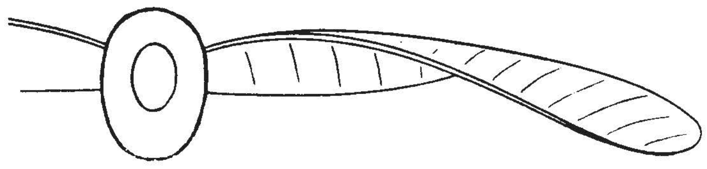
FIG. 7.—*The Geest wing of* 1907

Fortunately, progressive engineering science traces secondary phenomena which are causing losses, in order to utilise wasted energy to some good purpose. The exhaust turbine from which the gas turbine has sprung, is a perfect example of this tendency in technical development.

It is logical to apply the same principle to span-wise flow components on aeroplane wings. *A priori*, it would seem possible to derive from this wasted flow energy, forces and moments which are beneficial to stability, trim or control. Also it might be conceivable by conduction or restriction of span-wise flow to delay stalling phenomena near the tips. Both these possibilities lead to the consideration of diffuser wing tips.

The observation of soaring birds shows that their wings assume an attitude with downwardc tilted tips. Moreover, these wing tips seem to be the main device by which control and trim are effected during the soaring. E. J. Marey, in about 1880, appears to have been the first to try the effect of such tips on paper gliders[34]. K. Steiger-Kirchhofer to whom we have already referred, also came from the observation of soaring gulls to the conception of diffuser tips. J. W. Dunne arriving at the same solution, emphasized the yawing stability secured by this device and made the first successful full-scale application. Another full-scale application was made by Horatio Barber on his Valkyrie tail-first monoplanes in 1910; it remained an experimental feature.

Wald. Geest, the German experimenter, derived his diffuser-wing shape[65] also from studies on bird flight. He arrived at the importance of this shape for tailless aeroplanes in 1906 by noticing a gull flying merrily with the tail feathers removed. He secured in 1907 patents for a wing the surface of which was bent from inward to the tips with simultaneous twist so that the inner part had positive and the outer part negative incidence. A variation of the aerofoil sections along the span was also provided. Conventional aeroplanes provided with this diffuser wing built and tested before 1914 gave very promising performances, and if their difficulties in construction (bent and twisted spars), rigging and transport could have been overcome, the Geest wing would not only have been in extensive practical use, but would have given cause for a thorough study of the diffuser wing tip.

Early in 1913, Dunne's "negative wing tips" raised considerable interest in the circle of British aeronautical engineers. A. E. Berriman[35] agreeing with Dunne, expressed the belief that with the aid of such devices, lateral stability could be achieved. He pointed out that "downward pressure" (i.e., down-lift) on the tips was characteristic, and that "sensitive longitudinal stability of the weathercock order" (i.e. static longitudinal stability) was also essentially achieved. Yawing control should be effected by warping the tips, the inside wing having its negative incidence accentuated, since the addition of a vertical rudder would be unnecessary and ineffective. Berriman suggested that the natural state of a bird's wing might not be one with a permanently negative angle of incidence, and that, in general, its camber seemed to be washed out towards the tips. "It seems probable that Nature's design has succeeded in combining efficiency with security. . . . The flexible tip, it would seem, may automatically come into action as a virtual fin to make recovery from side-slip more sensitive."

Hankin seems to emphasize that for soaring in light winds, "negative" tips give security,

A theory of the "negative wing tip" considering the stability in horizontal gust on the basis of Bryan's method, was put forward by J. H. Hume-Rothery[36]. According to this investigation, the "negative" tip makes the rolling and yawing stability quite independent of each other. Hume-Rothery realized that tilted-down tips must be compensated for because of their anhedral effect, by some dihedral in the main part of the wing. F. Wenk's original patent of 1919 (Lit. 77) contained all characteristic features of the diffuser tip, though an explanation of its action was not offered. From this the Weltensegler tailless airplane was derived.

L. Bréguet tried to prove, in 1925, that the M-shape of the wings of soaring birds (seen from the front), is essential for the exploitation of horizontal pulsations of the wing, in dynamic soaring. Without the gull shape, he maintained, the internal energy of the wind cannot be utilized.

Anhedral of the wing system caused by a diffuser tip needs consideration, since it has often been the predominant feature. Dihedral gives static stability in roll (L_v, rolling due to side-slip). Anhedral of the tips seems to imply a tendency for the wing to "dig in" when side-slipping. Thus the advantage of purely tilted-down tips is by no means obvious. For gull wings, the moderating influence of the wing bend on the effective dihedral can be calculated[37]. A closer investigation, however, indicates that the contribution to the stability in roll by tilted-down wing tips is not quite so straightforward to assess. Effects of oblique air flow will influence the aerodynamic forces in side-slips; thus one partial effect of side-slip may well cancel the other with the result that—in spite of apparent anhedral—the stability in roll is not markedly deteriorated by tilted-down tips, especially in a wing having effective sweep-back.

Moreover, with birds, the wing tips are not simply tilted downwards. The axis of curvature of the plane of the wings is not in the direction of flight, but intersects the plane of symmetry of the wing in front of the leading edge. J. W. Dunne was probably the first to realise this; he incorporated this oblique tilt in his "negative wing tips". Also, it does not seem to have escaped Steiger's attention, and it forms the principle of the Geest wing.

Characteristics of Diffuser Tips

Diffuser-type tips are thus not simply tilted-down tips; their characteristics are

(*a*) deflexion of the plane of the wing tip against the plane of the wing, in combination with:—

(*b*) axis of the deflexion of the plane of the wing tip arranged under such an angle to the plane of symmetry of the aeroplane that the two axes of deflexion of both tips intersect forward of the leading edge of the wing. This results in a twisting distortion of the wing at the tip.

In characterizing the significant features of a wing tip of the diffuser type, it is inessential whether the angle of deflexion is a proper angle (i.e. axis of deflexion lying within the plane of the wing) or if it is the result of a gradual bend in the wing (axis of deflexion lying below the plane of the wing). Also, the axis of deflexion may or may not be parallel to the plane of the

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* An effect which may be of some importance for slow-roll manœuvres and also for the phenomenon of self-recovery from a spin, after or during the first rotation, with certain aeroplane types.

wing. Thus an immense variety of wing tips of the diffuser type is possible. Only a few of these shapes have been experimented with up to now.

The angle of skew which the axis of tip deflexion forms with the plane of symmetry of the aeroplane is aerodynamically essential. At first sight, it might appear that this feature amounts to not much more than a washing-out twist of the wing. It seems, however, nearer to the truth to assume that by means of the skew, the effect obtained for lateral stability, corresponds to that of a toed-in fin disk located at the wing tip (to which we have referred already, viz. "Stability of Tailless Aeroplanes", AIRCRAFT ENGINEERING, April, 1945, p. 107).

A diffuser-type tip which seems to deviate somewhat from the shapes outlined in our definition, but which is in principle equivalent, is the "hollow half-cone" fitted to the ends of an otherwise normal wing, as experimented with by R. Schul[38].

Consider a plain wing provided with a primitive diffuser tip in a side-slip to starboard (Fig. 4), i.e. flying under an angle of yaw β. The angle of yaw $\beta = sin^{-1} \frac{v}{V}$ is thus positive, the starboard wing is leading and the port wing trailing. The velocity V of the resultant air flow can be resolved into two components, one of velocity U parallel of the plane of symmetry, and the other of velocity V_y with a span-wise direction. In our assumption, the transverse flow component V_y is positive—being from starboard to port. It affects the wing tips differently: at the leading wing (starboard), it decreases the effective angle of incidence, while at the trailing tip, the effective incidence is increased. The rolling moment resulting from this tends to depress the leading wing. In accordance with the standard system of body axes used, the moment is positive, hence

$$L_v = \frac{\partial L}{\partial \beta} > o$$

i.e., the tip makes the wing unstable in roll, due to anhedral effect, and the wing thus equipped would appear to have the tendency to "dig in" when side-slipping, unless the wing part outside the tip can, due to effective dihedral, neutralize this tendency.

This simple consideration of the stability in roll is, however, far from being complete. First of all, it neglects influences such as those due to boundary-layer flow at or near the tips. The span-wise movement of boundary-layer material toward the trailing wing is obviously of some importance on the lift there and hence on the rolling moment. Possibly the boundary layer is thickening near the trailing tip on the dorsal surface of the wing, and partial separation will decrease the lift force. Further, the tilted tip facing the relative wind forms a heavily cambered aerofoil section which gives relatively large lift forces even at negative geometric angles of incidence, besides large drag and span-wise components within the boundary layer on it, will make premature separation unlikely. A separation of the boundary layer on the leading wing will, if at all, occur in parts only, which are inboard, while at the trailing tip, stalling phenomena may set in early at the tip itself (contrary to corresponding disturbances produced by the marginal vortices of a plain wing with square-cut straight tips).

Other less explored effects (e.g. the "oblique attack") may be contributing to an extent which really seems to be worth some painstaking research and the application of appropriate theoretical methods, before the characteristics of diffuser tips could be considered as known.

But even without such detailed knowledge, it does not seem unreasonable to assume that the deficiency in rolling stability as induced by a diffuser tip is, at the least, small and in any case smaller than the anhedral alone would lead one to believe.

In general, however, diffuser tips are used with wing systems which possess some effective dihedral in the inner part (though Dunne and some other tailless experimenters have made no use of this feature). As a sort of countermeasure, Dunne placed the centre of gravity of his monoplane very low beneath the aerodynamic centre of the wing.

In the wing system considered above, the drag in side-slip is obviously unequal at both wing tips. The leading tip presents a large frontal area to the relative air flow ,the drag of which (heavily-cambered section) must be in excess of that of the trailing tip. The yawing moment N resulting from this drag difference tends to turn the wing into the relative wind, hence:—

$$\frac{\partial N}{\partial \beta} < O, \text{ i.e. positive weathercock stability.}$$

But again that is only part of the story. The drag on the leading tip depends largely upon the relative incidence, far more than the, in comparison, smaller drag component caused by the trailing tip. The weathercock stability will thus greatly vary with the incidence. And when we assume the existence of the "oblique-attack" effect claimed by Budig giving negative drag components at large angles of side-slip, then a diffuser tip may even give zero or negative weathercock stability, i.e. yaw the aeroplane so that it is flying with the relative wind. Dunne presumed that the Zanonia seed-leaf (as opposed to his "negative" tips) had this quality.

The whole problem is moreover complicated by the scale effect. With cambered sections, and the effective tip sections in side-slip are always cambered, the scale effect is much evident when the effective incidence becomes negative. According to British and to N.A.C.A. tests[39], large variations of the down-lift occur in a critical range of Reynolds numbers between $0{\cdot}45$ and $1{\cdot}8$ x 10^6, so that differences can be expected to occur between high speed and landing speed, and with small and slow tailless aeroplanes and models. For experiments with scaled-down tailless aircraft this should be borne in mind. It may not only affect the longitudinal stability and the trim, but also the yawing stability.

In general, model experience indicates, that diffuser tips tend to keep an aeroplane on its original course, i.e. that the weathercock stability is either zero or very small, while a Zanonia type wing tends to turn against the relative wind. It was stated that Northrop had to reduce the tilt of his diffuser tips, because the weathercock stability in flight had become excessive, in comparison to model experiments.

When a wing with diffuser tips yaws, i.e. turns about its z-axis in a positive sense (port wing advancing), the leading tip (port) will commonly experience more drag and increased down-lift, in comparison with the trailing tip. Thus damping in yaw

$$N_r = \frac{\partial N}{\partial r}$$

and a reduced value of the derivative of the rolling moment due to yawing

$$L_r = \frac{\partial L}{\partial r}$$

can be expected. The latter property is, as mentioned before, conducive to comfort and steadiness in flight. Both qualities are largely responsible for the steadiness of the flight path which is exhibited by glider models provided with diffuser-type wing tips.

Another stability derivative which may be influenced by a diffuser wing tip, is the yawing moment due to rolling

$$N_p = \frac{\partial N}{\partial p}$$

It is also conceivable that the roll damping L_p is not only beneficially influenced at incidences below the stall, but that it might not change its sign for some range of incidences above the stall, i.e. that a diffuser tip could render a wing safer against an inadvertent spin. How far freedom from auto-rotation could be achieved by appropriate shapes of diffuser tips, would certainly be worth an investigation, as possibilities in this direction seem to exist.

Diffuser tips may also have effect on the rotary derivative of the pitching moment due to pitching

$$M_q = \frac{\partial M}{\partial q}$$

When discussing the longitudinal stability of isolated wing systems*, we found that the damping in pitch (M_q) made the main difference in the flying qualities of the tailless aeroplane, as compared with conventional types. We then pointed out that any improvement of the aerodynamic damping would be beneficial for the problem of the flying wing. The diffuser wing tip might bring about such an improvement. It would seem that the span-wise flow component induced by this device is tending to increase the mass of air which will be set in motion by a pitching oscillation of the wing. Admittedly, this effect may also express itself as an apparent increase in the moment of inertia about the lateral axis[40]. But if the diffuser tip itself is considered, it would appear obvious that, in pitch, its air damping qualities will differ greatly when the angle of incidence of the wing is increased to that when it is decreased. This unilateral damping assisted by the air flow at the tip and unaffected by the phenomena of unsteady lift permit one to suppose that the diffuser tip will be beneficial for the aerodynamic damping in pitch.

Due to its inherent wash-out, the diffuser tip also influences the static longitudinal stability; in the extreme case, it is possible to render any, in itself unstable wing into a longitudinally stable system by fitting appropriate diffuser tips.

From this it is evident that a diffuser tip exerts a profound bearing on the stability qualities of an isolated wing system, and that this influence is far greater than that which can be expected from an equivalent ordinary wash-out or anhedral. It can therefore be assumed that it forms an excellent device for tailless aeroplanes and flying wings, and its adoption at modern Northrop tailless aeroplanes is evidence that designers begin to awake to this fact.

Suitability of Diffuser Tips

With every stability device two main aspects deciding adoption present themselves to the designer: the effect on performance and the structural implications. For the diffuser tip, the structural disadvantages are obviously those that to a purely lift-generating wing, tips are added which do not conform to the plain constructional lines of this wing and which may be subject to considerable forces and moments of their own. Compared with wing-tip disks, such structural disadvantages do not seem great; moreover, parts of diffuser tips may well replace control surfaces or trimming tabs otherwise necessary, so that it will on the whole be reasonable to assume that for tailless aeroplanes, from the structural point of view, the designer might well favour the device.

Aerodynamically, the diffuser tip is, of course, an element which by itself causes drag and, in the general case, also down-lift. But since it can take the place of wing-tip disks (fins and rudders) and also that of wing twist (as required for longitudinal stability), the deficiency in performance caused by it, can be considered to be tolerable. Beyond this, however, the diffuser tip could even become superior in performance to all other devices applicable to isolated wing systems. The utilization of span-wise flow components may well permit the achievement of stability and trim without the expense of additional drag.

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* Viz. "Stability of Tailless Aeroplanes", AIRCRAFT ENGINEERING, March, 1945, p. 79.

When considering the possibilities of wing tips of the diffuser type, the application of boundary-layer suction methods at such tips should not be overlooked. Ordinary (closed) diffusers can obtain a greatly improved efficiency, by making in this way, the flow adhere to the walls[69]. Accordingly, with shaped wing tips, the sucking away of the boundary layer would possibly help to suppress the periodic shedding of vortices (which is a direct result of premature separation of the boundary layer from the tip surfaces forming expanding passages). The marginal vortices are not only dissipative, but also cause, as a reaction upon the wing, induced vibrations in the structure, and may impair the steadiness of the flight, too, when shed by an elaborate wing tip.

Moreover, such manipulation of the boundary layer at shaped wing tips might constitute a practical form of aerodynamic control. The suction energy required would not be prohibitive, and the mechanical complications might well be tolerable with large Flying Wings.

The Rams-Horn Vortex and Related Phenomena

When surveying the problem of diffuser wing tips, it is worth while to recall former (generally overlooked or forgotten) research on bird flight which, though originally based on mistaken assumptions, seem to have yielded results which may have some bearing on the subject.

Wings of soaring birds show aerofoil sections with rather thick, rounded leading edges and pronounced camber which forms a concave lower surface. Phillips[41] and Goupil have based the conception of the "dipping" leading edge on observations with such aerofoil sections. Phillips conceived that the air flow in front of a lifting wing has an ascending tendency.

A. Goupil experimented in 1883 with a large bird-like monoplane glider of 20 ft. span in in natural wind and claimed to have observed the appearance of "negative drag" on virtue of its cambered thick aerofoil section (Lit. 73).

In 1896, L. Hargrave investigated flow phenomena on heavily cambered aerofoils[42]; he observed and described the formation of a standing vortex in the cavity of the lower surface when experimenting in flowing water to which ochre had been added. He concluded from this discovery that this vortex must have something to do with sustentation in flight such as is exhibited by soaring birds.

Fr. Ahlborn, the Hamburg school teacher, who has already been mentioned as the father of the Zanonia wing, checked up on Hargrave's observation in 1901 and experimented with a corresponding aerofoil in a water tank; he obtained flow photographs[43] which clearly showed the presence of this vortex in the cavity.

In 1911–12, Gustav Lilienthal (brother of the great pioneer of flying) conducting experiments in natural wind, not only observed a pronounced span-wise flow along the concave lower surface of bird-like wings, but gave a clear description of the character of the vortex formation which he termed "Widderhorn-Wirbel" (rams-horn vortex)[44].

Lilienthal had made his flow observations in free wind on complete bird models of 13 ft. span, having a maximum wing chord of 2·64 ft.; the section camber amounted to one-tenth of the chord. The flow direction was indicated by tiny flags mounted on thin needles, hence not dissimilar to the modern Haslam method of silk tufts. Lilienthal also noticed that the flow over the smooth upper surface was approximately undeflected in plan, i.e. was following the direction of the wind, and that this also applied to that part of the lower surface which was near the bird-like fuselage; beyond this relatively narrow region, the airflow was directed more or less toward the tips. The spiral shape of the tip-ward progressing vortex gave cause for the name.

Unfortunately, Lilienthal drew somewhat precipitate conclusions from his observations. He stubbornly contended that the vortex formation gave to the bird wing a negative drag, and that this phenomenon was responsible for the soaring flight of birds. Living in a country of experts where amateurish views are severely frowned upon, the pugnacious discoverer of the rams-horn vortex and his discovery went into oblivion.

Commenting later upon Lilienthal's contentions, J. Ackeret (of the Goettingen Circle) agrees that there is a large stationary vortex in the aerofoil cavity, but emphasises that this vortex formation is purely dissipative (Goett. 462 aerofoil section compared with Goett. 535 section. He doubted if the plan shape of Lilienthal's bird wing could render "rams-horn vortex" sections more useful for flying, and he also disclaimed the possibility of diminishing the induced drag by the aid of such devices (Lit. 78).

Years afterwards (in 1921), P. Idrac[45] investigated in a wind tunnel at St. Cyr the wing of a vulture which had Hankin's patagial depression at its lower surface behind the leading edge. He observed normal flow over the dorsal surface with a regional deflexion toward the centre of the body, while at the lower surface, the flow was strongly deflected toward the body, after having been normal when flowing over the first third of the chord; this deflexion was restricted to the boundary layer region. This inwards deflexion in or near to the boundary layer may have been caused by the extending passage formed at the wing body-joint.

Friedrich Harth, the tenacious pioneer of soaring flight, who experimented with bird-like aerofoil sections, did not believe in the benefits of the rams-horn vortex. In his view[46], the air being deflected by the wedge-like leading edge, impinges on the concave lower surface, instead of forming a cylindrical vortex.

Nearly 20 years afterwards, the existence of Lilienthal's rams-horn vortex was experimentally confirmed in a wind-tunnel investigation made by E. Saenger at the Aerodynamic Laboratory of the University of Vienna[47].

Saenger argued that the induced drag is caused by eddies which originate from the equalization of pressure at the wing tips, and that an appropriate deflexion of the flow at the tips might suppress, at least partially, the formation of these dissipative vortices. He also assumed that the profile drag which is mainly surface friction, might be reduced by the effect of a rotating air mass underneath a wing, similar in action to that of a roller bearing. In his view. the birds obtained far better lift/drag ratios than ordinary aerofoils, by the use of devices of such a character.

If one adopts G. Lilienthal's conception of the rams-horn vortex (Fig. 9), the following flow phenomena becomes apparent: a streamline entering at the lower surface separates from the wing surface at or near the point when the section curvature becomes concave, since the centrifugal forces acting upon the flow particles, will prevent it adhering to the surface in the cavity. That this actually takes place is beyond question, and A. Betz refers (in one of his patents on boundary-layer suction) expressively to boundary layer separation under such circumstances[48]. Due to friction of this separated air layer (free vortex layer) with the dead air enclosed within the cavity, the latter will begin to rotate, i.e. forms a vortex in the cavity which has a span-wise axis. This also is in agreement with observations other than those by G.

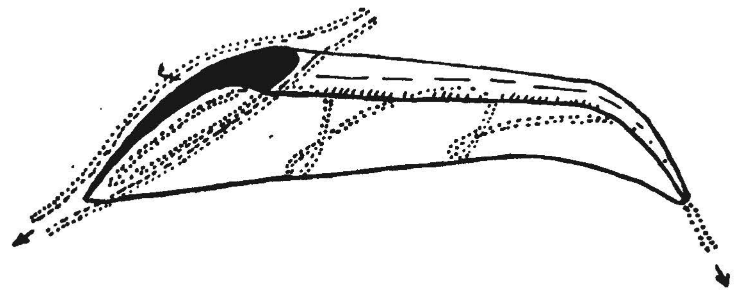


FIG. 8 (*left*).—*The "Rams-horn" vortex*

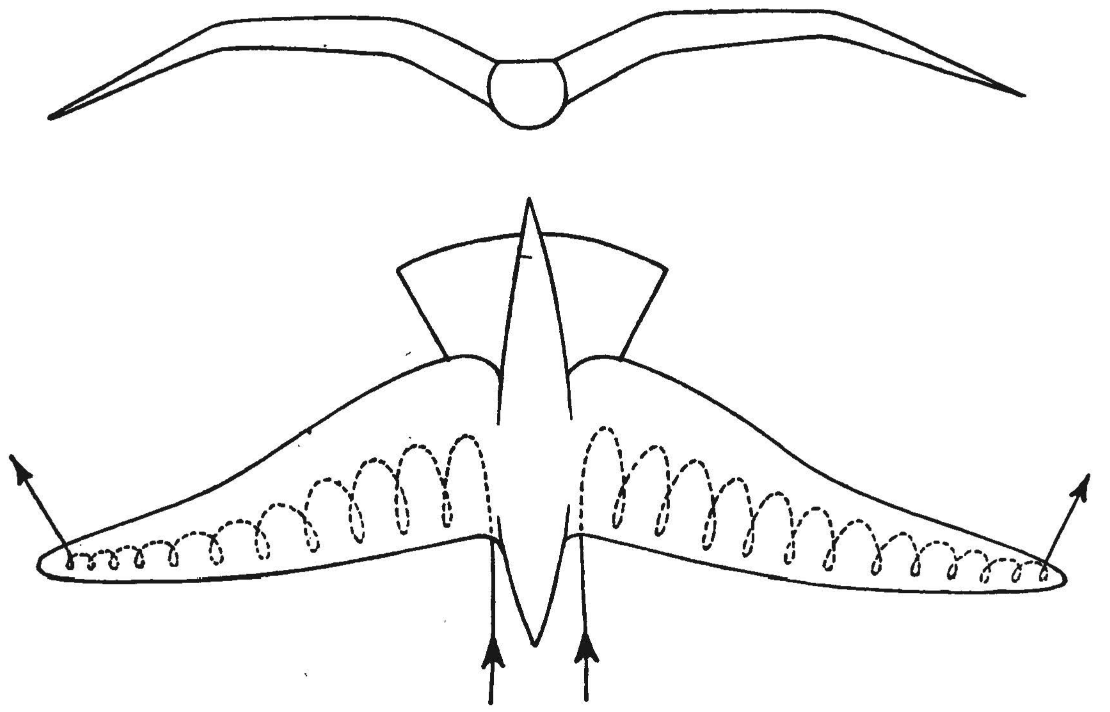


FIG. 9.—*The "Rams-horn vortex" as observed in 1911 by Gustav Lilienthal. He investigated the air-flow on the lower surface of this model of a bird in natural wind*

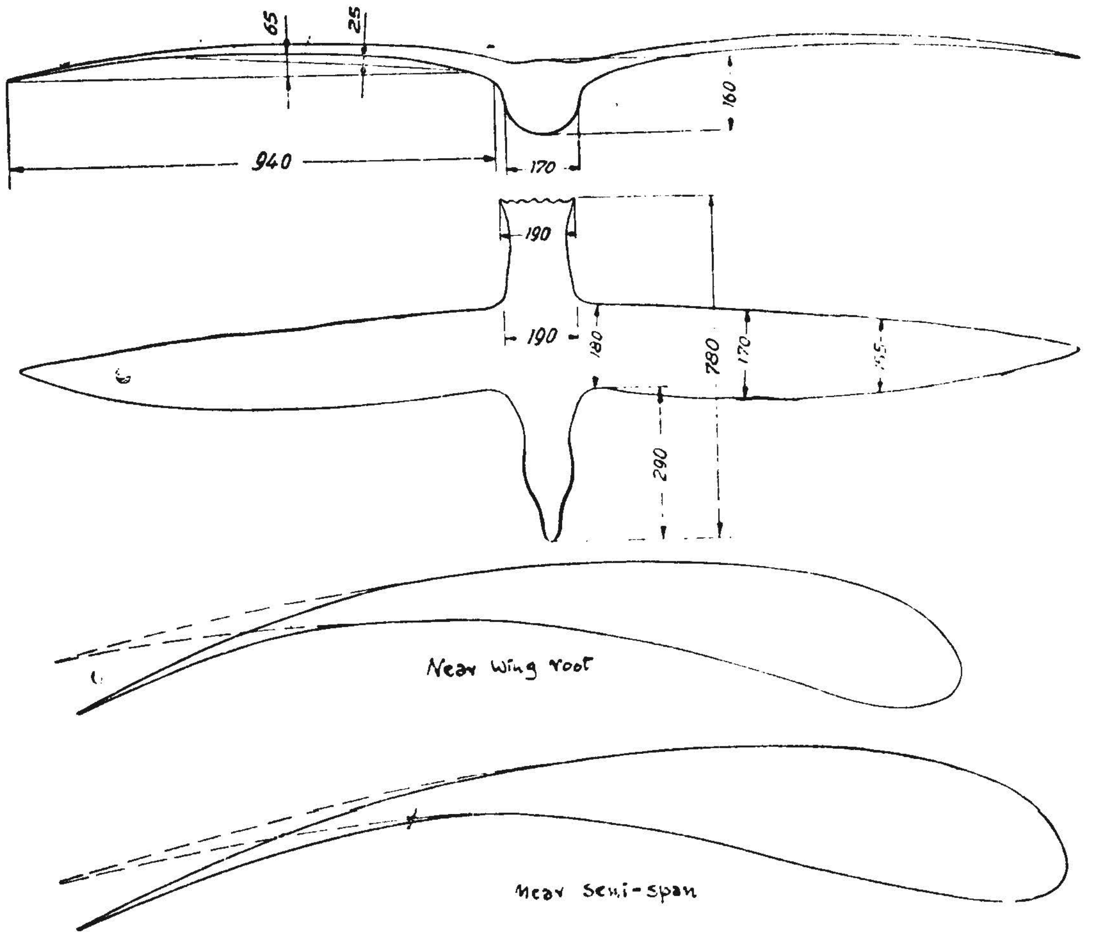
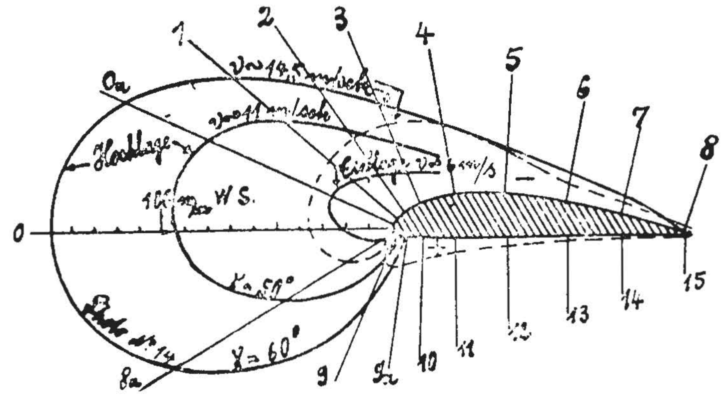
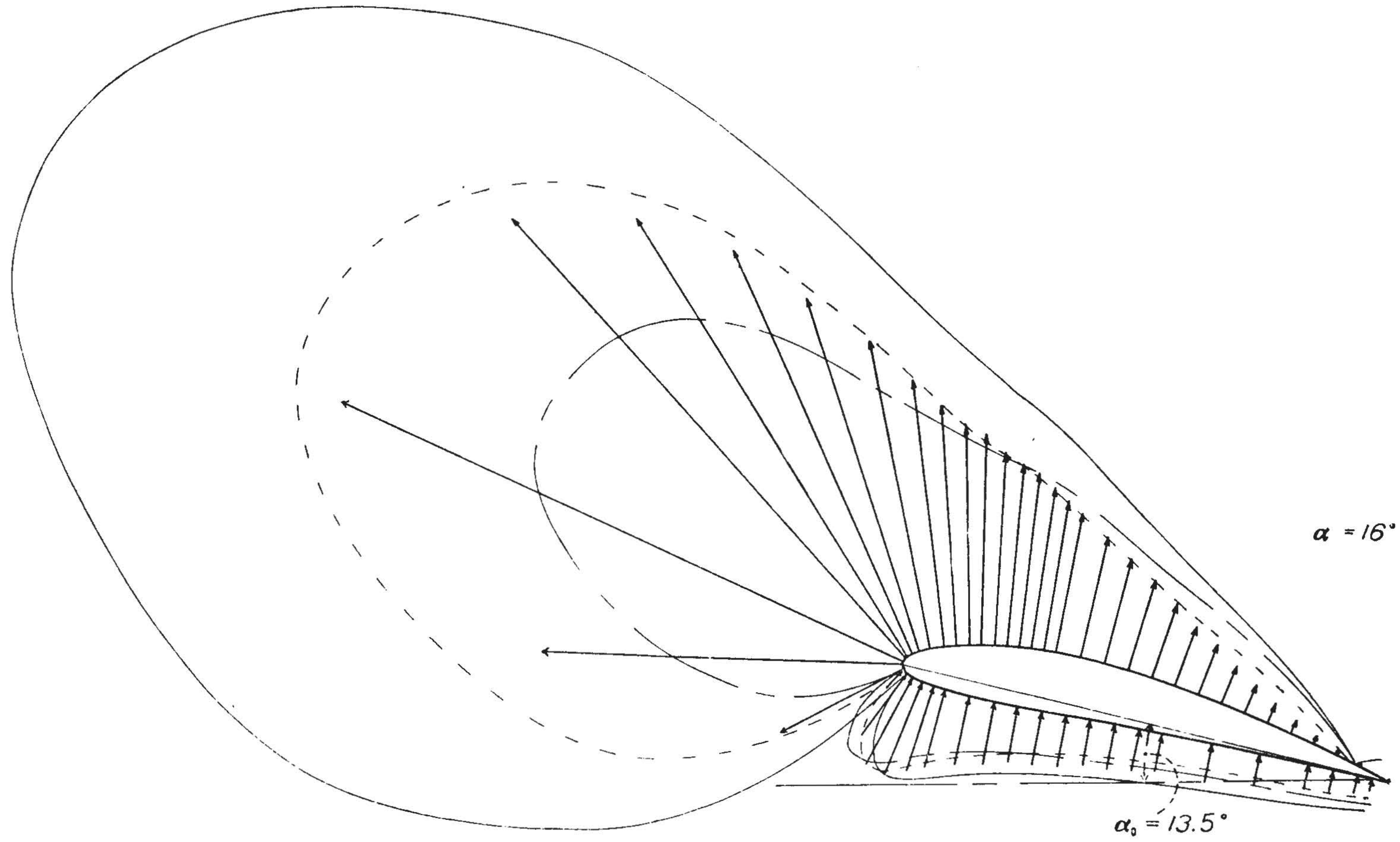


FIG. 10.—*Wing shape and wing sections of a grey albatross. The dotted lines indicate the presumed deflexions under air load in soaring flight. Measurements in millimetres.* (*From "Flugsport"*)





FIGS. 11(a) and 11(b).—*Pressure distribution (vector diagrams) under "oblique attack" and according to the hydrodynamic theory*

On the left, Budig's measurements under oblique attack. Tests made in natural wind (48 *ft./sec.*) *with a full-scale rectangular wing of Goett.* 387 *section. γ is the angle of side-slip; in addition, the wing is tilted at* 30 *deg. to the horizontal. The angle of incidence is* 14·5 *deg.*
"Hochlage"=high end of the tilted wing; "Tieflage"=low end.
The dotted lines represent measurements in the Goettingen wind tunnel at normal attack, but otherwise corrected to the conditions of the test.

On the right, theoretical pressure distribution of potential flow for an N.A.C.A. 4412 *aerofoil section at an incidence of* 16 *deg* (*from R. M. Pinkerton, N.A.C.A. Tech. Rep.* 563). *The full and the dotted lines represent flow without viscosity of an aerofoil of infinite span. The broken dotted line refers to a lift equalling that of an aerofoil at an incidence of* 16 *deg., i.e. corresponding to an incidence of* 13·5 *deg. of the theoretical lift. The vectors* (*arrows*) *give the actually measured pressures in the centre line of the aerofoil for a test at a Reynolds number of approximately* 3 x 10^6.

Lilienthal on bird-like wings.* Now Lilienthal claimed that this vortex, by way of its centrifugal force, contributed to the lift. Even, if such effect were present at all, it will be negligibly small. Lilienthal also contended that, when the surface within the cavity was rough, energy from this vortex gave, by losing part of its kinetic energy, thrust to the wing, i.e. at least decreased the profile drag materially. This also is mere speculation and seems scarcely probable. The vortex shifts axially in a span-wise direction. This is so because of the pressure gradient along the span. Its span-wise translational velocity increases toward the tip. At the tip, the translating and rotating vortex air encounters, at a bird's wing, the tilted-down parts; it is deflected downward and thus causes a lift force as reaction. Finally, the vortex leaves the nozzle-shaped tip with a velocity which is still greater than that of the surrounding air; hence it is able to suppress the formation of eddies at the tips.

Saenger assumed that all these partial effects, with the exception of the last one, would only result in an increase of the profile drag, due to increased vorticity and increased surface friction. His tests with aerofoils having rectangular shape and bird-like cambered sections confirmed this. Indeed, a very large number of aerofoil sections having concave lower surfaces are known to exhibit peculiarities and abrupt changes in the air flow which are consistent with the view that, below certain characteristic angles of incidence which lie at small or medium lift coefficients, something like the flow phenomenon described above takes place on the lower surface. These aerofoil sections, have, in general, a thick and bent-down nose (Phillips Entry) which things rapidly toward the trailing edge, and an accentuated camber which reaches its maximum aft of the 50 per cent station of the chord. Examples of such aerofoil sections are the Goettingen sections 232, 252, 263, 370, 393, 394, 395, 396, 400, 448, 450, 461, 462, 464, 652; Eiffel 36; Durand 10; N.A.C.A. 97, 4409, 4412, 6712, etc. Moreover, normal aerofoil sections with high-lift devices of the plain-flap type may exhibit similar peculiarities when the flap is operating, while in slotted wings an opposite effect seems to be present[49]. From a comparative test (Goett. 481 and 481A) it is evident that when the cavity on the lower surface is filled, the drag at small incidences improves greatly, while the maximum lift suffers (camber effect), and while the drag at incidences near the stall is somewhat deteriorated. At the characteristic incidence of flow transition in such aerofoils, the pitching moment is also affected, indicating a variation in the pressure distribution around the section (Goett. 464).

A span-wise ridge along the lower surface behind the leading edge does not seem to be essential for the discontinuity effect. But to judge from the Goettingen tests published, genuine Joukowsky sections seem remarkably free from the change in flow. This might indicate that the variation of section thickness from nose to tail is linked with the behaviour of the flow. Centrifugal forces acting on boundary-layer material are presumably of great importance upon the formation of the vortex.

Aware of the possibilities of changing the fundamental characteristics of a wing by varying the lower surface, L. Bréguet suggested[50] covering the cavity of the concave lower surface by an elastic fabric and connecting the space between the wing surface and this elastic envelope with the outer atmosphere by a duct opening forward against the relative wind, so that the entrance slip is parallel with the wing chord at zero-lift angle of incidence. Thus at small incidences, a concave lower surface is formed, while at large incidences, a convex lower surface becomes effective.

Most decidedly, the phenomenon is particularly sensitive to scale effects N.A.C.A. tests on the influence of the Reynolds number [51] leave no doubt about that. The early Goettingen tests were made at Reynolds numbers of 79,000, the later ones at those of 440,000. Both indicate the presence of the vortex formation in aerofoils having square tips. The N.A.C.A. tests seem to limit the range of the effect down to below 170,000.

Further, it seems that, at very low Reynolds numbers the effect as expressed in the polar diagram may actually be reversed[52] and even discontinuities of the lift curves may well appear[53].

The result of the presence of the vortex is that the lift/drag ratio experiences an abrupt improvement at a characteristic incidence; at this incidence, moreover, two distinct values of drag seem possible. Below this characteristic incidence, the drag is much increased. The deflexion of a flap forming the trailing edge has apparently no profound influence, and also leaves the characteristic angle unchanged, an indication that this angle depends on the nose shape. Downward deflexion of the flap accentuates the change of flow. In extreme cases (Goett, 652[54]), the drag at the characteristic incidence can drop to as little as 35 per cent of its original value.

Saenger's tests established that with plain aerofoils having such sections and square tips, a standing vortex is formed in the cavity which rotates in a sense which is opposite to that of the lift-producing circulation. It was not observed that the vortex shifted in its axial direction. At the tips the usual equalization of pressure took place and normal marginal vortices were shed. The characteristic incidence was about 8 deg.

By the addition to this wing of positively raked, tapered and downward-tilted tips, an axial shift of the vortex toward the tips took place, especially at negative incidences. The characteristic incidence decreased to 1¼ deg. for a pointed and to 6 deg. for a blunt tip. The latter was, however, in general superior to the pointed one, especially at larger incidences. In the range of the optimum incidence (maximum lift/drag ratio), which was just above the characteristic incidence of flow change, the vortex was less in appearance. No span-wise flow was observed beyond the tips. An accentuation of the tilt of the tips improved the flow there. Span-wise stiffeners running within the cavity of the lower wing surface did not seem to affect the flow characteristics to a noticeable extent.

Saenger's tests were made at a Reynolds number of approximately 132,000, i.e. well within the range mentioned above. At equal incidences, the profile drag of the three arrangements investigated does not differ greatly, while the lift coefficient is 70 per cent greater with the diffuser tip as compared with the plain rectangular aerofoil.

R. Schul also claimed in favour of his diffusor tip that it gave not only improved stability, but also a decreased formation of marginal vortices, hence an increased lift and a decreased drag.

In wing systems having an effective sweep-back, an intensified action of the rams-horn vortex can be expected, since the flow component due to sweep-back encourages the span-wise shift of the vortex. This might explain the aerodynamic superiority of sailplanes such as the Weltensegler which have a bird-like shape.

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* The presence of such a vortex formed behind a dipping leading edge was also observed by L. Prandtl who published excellent flow photographs of it, viz., "The Generation of Vortices in Fluids of Small Viscosity." *Journal of the Roy. Aer. Soc.*, 1927, p. 727, fig 15.

The "Oblique-Attack" Effect

Quite a different phenomenon of transverse flow was observed and studied by F. Budig, an independent aerodynamical experimenter.

In 1916, while investigating in flight the pressure distribution on the ailerons of experimental biplanes, by the means of multiple manometres, he noticed the profound and detrimental influence of side wind (side-slip) upon the control efficiency of the ailerons. Overbalancing and dead-centre action became apparent. About 10 years after this, Budig found occasion to investigate the matter further and he then discovered what he termed the "oblique-attack" effect. This refers solely to flow over the dorsal surface of a wing when it is exposed to a side-wind[55].

The discovery claimed by Budig was not the first observations of this kind. For instance, F. H. Wenham mentions, in 1866, that he found the fluid force exerted on a plate moved transversely to a flow of water to be greater than that experienced when the plate remained motionless in the fluid stream[56].

According to Budig, a wing under an angle of yaw experiences a span-wise deflexion of the air upwards of the stagnation point at the leading edge. This deflexion is responsible for a profound change in the air flow over the upper surface. The deflexion may be caused by side-slip, by sweep-back, or by a wing tip having positive rake. A rectangular wing under an angle of bank and of yaw is particularly susceptible to the effect.

The result of the air deflexion at the leading edge is, Budig claims, a spreading out of the streamlines over a wider region of the dorsal surface and thus, without separation of the airflow from the surface, the formation of abnormally high negative pressures at that part of the leading edge which is facing the relative wind (i.e., in a side-slip, the leading wing). This abnormal low-pressure region not only increases the lift but, due to the forwards inclination of the resultant aerodynamical force acting at that region, also decreases the drag to an extent, that it may become negative for the wing part concerned.

As, according to Budig, the "oblique attack" prevents separation, the negative pressures at the exposed leading edge may grow considerably with incidence even far beyond such incidences, at which normally stalling would set in[57]. Otherwise, at small angles of incidence, the effect is far less accentuated.

Wind-tunnel tests made in closed-jet tunnels by the Goettingen Laboratory have shown no agreement with the experimental observations of Budig. This is not necessarily evidence for the non-existence of the "oblique-attack" effect, since, by their nature, wind-tunnels are apt to suppress phenomena of span-wise flow, and disagreements of wind-tunnel tests on yawed wings with the results of experiments in flight and with theoretical calculation are known to exist. Budig has made his experiments on full-scale wings in the natural wind over land (aerodrome surface) and water at Reynolds numbers which would seem to be comparable with conditions of slow flying. He has also made tests in water. His experimental installations were actually approved by the German Research Institute for Aeronautics (DVL), subject to inaccuracies caused by gustiness and ground influence; moreover the DVL then stated authoritatively that the negative-pressure phenomena observed seemed "entirely in agreement with experiences gained elsewhere"[58]. Large-scale investigations made in a French wind-tunnel at Chalais-Meudon by Rebuffet seem to confirm Budig's observations[59]. Considerable negative drag (i.e., a thrust force) was measured at 29 deg. incidence under 45 deg. of side-slip.

Experiments made by Haller in Zurich proved the existence of an "oblique-attack" phenomenon on vertical surfaces situated above a tailplane[60], by which an aerodynamical force increasing a spinning motion of the aeroplane is produced. Previously, Budig had already pointed out that oblique-attack played a large part in spinning.

The pressure distribution under oblique attack at or near the leading edge as observed by Budig, agrees in shape and magnitude closely with the theoretical pressure distribution which can be calculated on the basis of potential flow with the help of Bernouilli's equation[61]. It would thus appear conceivable that the oblique-attack effect could make up for the influence of viscosity in the boundary layer. From the boundary-layer theory it follows that by removing the boundary layer (for instance, by sucking it away) flow patterns can be achieved which closely approach those of genuine potential flow. O. Schrenk has pointed out[62] that it is, for this, not necessary to remove the entire boundary layer, and that a sort of "relay action" has been proved to exist. If so, one possibility is that the oblique-attack as observed, could be the result of periodic vorticity over the wing parts affected. As E. G. Richardson has stated again, such periodicity is not identical with a turbulent boundary layer[63], but the final effects are not dissimilar. This refers particularly to the delay of boundary layer separation from the surface, thus giving higher lift values and less drag at higher incidences. Even the contention of a negative drag by Budig is consistent with the assumption of periodicity in the boundary layer. That mere vibration of a wing may raise the maximum lift considerably, must be considered a fact; it has been experimentally confirmed by wind-tunnel experiments of M. Denis at St. Cyr[64], and observations in flight are in agreement. Even the Katzmayr (Knoller-Betz) effect points in that direction and seems, with its periodic fluctuations in the boundary layer pattern, related to the oblique effect.

On the other hand, when evaluating the observations of Budig, it must not be overlooked that, since Budig made his experiments in natural wind which fluctuates in direction and velocity, phenomena of non-steady lift (hysteresis effect) due to inertia of the boundary layer may have influenced the somewhat baffling results. At the time that Budig staked his claims for an aerodynamic discovery (1930), phenomena of flow inertia and of non-steady lift arising therefrom had not yet been sufficiently explored. With regard to the discrepancy between his measurements and the Goettingen tests, Budig contended that it might well be that, for the oblique-attack effect, the law of dynamic similarity (Reynolds number) does not hold; he argued that great velocity of airflow might decrease the angle of deflexion at the leading edge, and this angle decides the magnitude of the negative pressures.

On the strength of his discovery, Budig believed that obliquely-cut wing tips would be helpful to make auto-rotation impossible. Spinning trials on certain transport aeroplanes with tips resembling those of the Zanonia type, have indeed given some strength to this contention, though the case is one of considerable doubt, since lack of elevator power may also have contributed to the results. Budig also recommended the *M*-shape of wings (in front view) and of wing-like parts. In a side-slip, with wing tips of this shape, in Budig's view, the leading tip will not only be free from separation of the flow, i.e. from loss of lift due to stalling, but will, on the contrary, experience higher lift and diminished drag. Thus a stabilizing effect takes place.

Nearly all discoverers and experimenters of diffuser wing tips have also employed the tips for control purposes and/or trim: Dunne fitted curved controllers to both wing and tip; Schul suggested that control devices are best fitted to the ends of his "hollow cones"; Kupper attached not only controllers but splitting air-brake rudders to the diffuser tips of the tailless MU.5 sailplane; Huettmann employed tilting of the entire tip for control; Northrop used the same idea, but employed in addition controllers fitted to the wing tip.

One of the greatest advantages of diffuser tips for stability and control is that they will not be fundamentally affected by the stall of the lift-generating part of the wing. Though it has yet to be established if and how far a complete separation of flow at great incidences can be delayed by the effect of a diffuser tip, it seems fairly obvious that control by way of such tips will have an advantage by remaining less impaired at and beyond the stall of the aeroplane.

It will also seem that the diffuser tip is not only an interesting subject to explore for aerodynamical research, but a device which is of so much promise for practical application that it deserves more interest and study than it has received in the past.

Professional Publications

Concluded from p. 253)

The Society of Automotive Engineers

S.A.E. JOURNAL (*MONTHLY*)

Vol. 53, No. 7, July 1945.

"Engine Oil Foaming." H. A. Ambrose & C. E. Trautman.

"Relation of Vapor Lock to Temperature—V/L Characteristics of Gasolines." E. W. Aldrich, E. M. Barber & A. E. Robertson.

"Oil System Problems at High Altitude." W. L. Wheeler.

"Prediction of Engine Cooling Requirements." W. M. S. Richards & F. H. Erdman.

"Electronic Analysis of Airplane Hydraulic Braking Systems." D. B. Gardener.

Vol. 53, No. 8, August 1945.

"Making the Cockpit Practical for the Pilot." G. F. Beal.

"The Valuation of Better Fuels." E. A. Ryder.

"Co-ordination of Supercharger Speed to Manifold Pressure." J. Dolza.

The Institution of Production Engineers

JOURNAL (*MONTHLY*)

Vol. XXIV, No. 6, June 1945.

"Plastics in Engineering." E. M. Elliot.

The Engineering Institute of Canada

THE ENGINEERING JOURNAL (*MONTHLY*)

Vol. 28, No. 6, June 1945.

"The Principles Involved in a Modern Concept of Airline Operation." J. T. Bain.

"The Engineering Selection of an Airline Aeroplane." J. T. Dyment.

"Future Aspects of Radio and Communication in Air Transportation." S. S. Stevens.

"Recent Developments in the Field of Materials and Processes." P. E. Lamoureux.

Vol. 28, No. 7, July 1945.

"Evaluation of Aeroplane Metals." J. A. Van den Brock.

The Royal Aeronautical Society

JOURNAL (*MONTHLY*)

Vol. 49, No. 415, July 1945.

"Hydraulics for Aircraft." R. H. Bound.

"Some Notes on Vibration Analysis." R. J. Manley.

Vol. 49, No. 416, August 1945.

"Control Surface Design in Theory and Practice." R. B. Morgan & H. H. B. M. Thomas.

Micro-Deformation under Tension and Compression Loads of Thin Aluminium Alloy Sheets for Aircraft Construction. By Georges Welter. (Ecole Polytechnique University of Montreal).

This paper presents test results on the stress characteristics for micro-elastic and micro-plastic deformations as well as the modulus of elasticity of thin aluminium alloy sheets in tension and compression. The sheets were analysed for seven different angles to the direction of rolling and cold-stretching as well as over the whole width. The investigation, which consisted in submitting the specimens to tension stresses, succeeded by compression, showed results which are of interest to the designer and constructor of modern monocoque structures. A new gripping device for tension tests and a special device for compression tests on single thin specimens have been developed.

Research Reports and Memoranda

AUSTRALIA

AUSTRALIAN COUNCIL FOR AERONAUTICS

Report ACA-8. Ducted Fans: Approximate Method of Design for Small Slipstream Rotation. August, 1944. By G. N. Patterson.

This report describes a second method* of designing airscrew type fans with straighteners. The first method of design aimed particularly at obtaining a high efficiency and it was assumed that all other design factors could be chosen to suit this main condition. In practice, however, some of these factors are frequently fixed by other considerations and the problem then becomes that of determining a design which will give good efficiency under those conditions. It was considered necessary, therefore, to develop a second method of design which would be more direct in practical cases of this type.

The second method of design is based on a large and relatively constant lift/drag ratio along the blade compared with constant efficiency at all radii in the first method. Also the straightener loss coefficient is to be small compared with the coefficient of pressure rise at which the fan operates. An approximate expression for the slipstream rotation factor has been developed, which has made possible the integration of the thrust and torque grading equations (as in the case of the first method). The overall characteristics of a fan designed to operate in a given duct can, therefore, be calculated without first carrying out a detailed blade design, thus considerably facilitating the choice of a suitable fan for a given practical case. The method is direct in that no successive approximations or graphical methods are required and the detailed design need only be done once after the basic design factors are fixed and the resulting overall torque, thrust, power and efficiency have been found to be satisfactory.

Report ACA-9. Ducted Fans: Effect of the Straightener on Overall Efficiency. September, 1944. By G. N. Patterson.

The conditions set out in Reference 1 which lead to the design of a fan-straightener unit of high efficiency have been extended by an examination of the part played by the straightener. The best operating condition for the straightener blade element has been determined and applied to the case of the N.P.L. straightener. The problem of design for high efficiency is then summarized in three final conditions which show the designer how to obtain the maximum efficiency possible with a fan-straightener unit, the theory being subject to the same basic assumptions as in Reference 1.

The results of the above investigation show that high efficiency in a fan-straightener unit corresponds to an increase of pressure (Δh) through the unit of about the same order as the initial dynamic head in the annulus in which the unit operates (i.e., $k = \Delta h / \frac{1}{2}\rho U^2 = 0(1)$). This means that in ducts where the total pressure rise (ΔH) is large compared with the dynamic head ($\frac{1}{2}\rho U^2$), a number of fan-straightener units (or stages) must be used if high efficiency is to be maintained.

In many practical installations a value of the fan operating coefficient (k) considerably in excess of 1·0 is unavoidable and the problem is to use the minimum number of stages while retaining a high efficiency. The conditions at high values of k (i.e. at large slipstream rotation) have, therefore, been investigated to determine the variation of efficiency with increase of slipstream rotation. Owing to the lack of complete information on interference in straighteners designed for large angles of rotation, qualitative results alone have been obtained for this case. However, the general effect of blade interference is indicated, and it is shown that the chief obstacle to high efficiency at large slipstream rotation (i.e. for $k >> 1$) is the high solidity of the straightener.

Since high overall efficiency has been retained throughout this investigation as an overriding design requirement, the problem of straightener design for high values of k, i.e. for large slipstream rotation, was not carried beyond the qualitative results given in this report. It became clear that the reason for the high solidity of the straightener (and the associated interference losses) was simply that it was the limiting case of a contra-rotating fan operating in the worst condition from a solidity point of view. It became evident that two contra-rotating fans would be more efficient at large k since the second fan could be designed (*a*) to remove the large rotation without an excessive solidity, and (*b*) to give a larger pressure rise than that through a straightener. The author decided, therefore, to leave the investigation of straighteners at the point indicated in this report and make a detailed study of ducted contra-rotating fans. This forms the subject of the fourth report of this series.

Report ACA-10. Ducted Fans: High Efficiency with Contra-Rotation. October 1944. By G. N. Patterson.

This report is the fourth of a series on the subject of ducted fans. Previous work had indicated that high efficiency could be obtained with a fan-straightener combination, but only for a relatively low pressure rise through the unit. At higher pressure rises, the efficiency was reduced by interference effects in the straightener due to the larger amount of rotation in the slipstream. Further investigation showed that if the straightener were replaced by a second fan rotating in a direction opposite to that of the first fan and designed so that it removed the slipstream rotation introduced by the latter, then it would be possible to reduce the interference effects and so obtain an appreciably higher pressure rise while retaining the same high efficiency.

The theory of ducted contra-rotating fans is given in this report along with two methods of design. It is shown that very high efficiencies are possible with a contra-rotating system and that these high efficiencies can be attained at larger pressure rises than in the case of a fan-straightener combination.

Report ACA-11. The Torsion of Solid and Hollow Prisms in the Elastic and Plastic Range by Relaxation Methods. November, 1944. By F. S. Shaw.

The problem of the torsion of a uniform prism has not been found tractable by exact mathematical methods for many of the members common in engineering practice. To overcome this, recourse has been had to two methods of solution, (*a*) experimental, and (*b*) approximate numerical, usually depending upon the use of finite differences. Of the former the membrane analogy is probably the most useful. This paper gives examples of the use of the latter method as devised by Christopherson and Southwell, and known as relaxation methods. By freely borrowing ideas from the membrane analogy, it has been found possible to use the relaxation methods for solving problems in the plastic as well as in the elastic range of the material. Problems involving multi-connected boundaries are also capable of solution. Problems treated in this paper include:—

(*i*) simply-connected boundary—a commercial rolled steel joist section;
(*ii*) multiply-connected boundary—a splined shaft;
(*iii*) multiply-connected boundary, plastic behaviour—hollow rectangular section.

The accuracy of the relaxation methods is discussed, and some comparisons are made with known solutions. In general, it seems that accuracies involving errors of the order of 1 per cent may reasonably be expected.

It is shown that the method may be extended to cater for non-isotropic materials, in particular wood.

A set of numerical tables for assistance in computation is included.

Report ACA-12. The Buckling of Flat Plywood Plates in Compression. December, 1944. By R. C. T. Smith.

The buckling of isotropic plates under edge thrust has been treated exhaustively for various loading cases and boundary conditions. Timoshenko gives an account of some of these problems. Non-isotropic plates have not, however, been dealt with thoroughly in spite of their frequent occurrence in practice as stiffened or corrugated metal or as plywood. Apart from a few elementary problems and Seydel's investigation of a simply supported orthotropic plate under shear few exact solutions are known.

H. W. March has recently given approximate solutions of several problems in the buckling of plywood without paying much attention to the boundary conditions. His aim is to estimate the effect of varying the elastic constants, grain directions, etc.

Further exact solutions are desirable because of the large effect of the boundary conditions on the buckling load. One such problem is solved here for three different sets of boundary conditions. A restricted type of anisotropy (orthotropy) is assumed in which the plate possesses two axes of elastic symmetry at right angles. Such anisotropy is possessed by normal plywood. A short discussion of the elastic behaviour of wood and plywood is given in Part I and the equation appropriate to the buckling of plywood under edge thrust is derived.

The problem is that of finding the buckling load of an orthotropic rectangular plate under uniform compression in one direction only. The three cases considered are:

In Part II: Ends clamped, sides simply supported.
In Part III: Ends simply supported, sides clamped.
In Part IV: All edges clamped.

Exact solutions are obtained for the first two, but an approximate method (the Rayleigh-Ritz procedure) is used for the third.

The results bear a simple relation to those for isotropic plates, and agree, apart from a small correction term, if the bending stiffness in the "isotropic" formula is replaced by the geometric mean of the stiffness in the two principal directions, and if the ratio of sides is multiplied by a factor depending on the ratio of these stiffnesses.

Flat plywood panels have been tested under the first set of edge conditions, and a brief comparison is given finally between these results and theoretical values.

GREAT BRITAIN.

AERONAUTICAL RESEARCH COMMITTEE

(*H.M. Stationery Office, London*)

R. & M. No. 1918. Natural Frequencies of Vibration for a Wing Carrying Wing Engines. July 15, 1940. By G. C. J. Dalton, F. S. Shaw and R. V. Southwell. (4*s*.)

A paper (R. & M. No. 1917) dealing with calculations of natural frequencies for a particular engine mounting was presented to the Oscillation Sub-Committee at its meeting on 9th February, 1940. Somewhat before that date Dr. Pugsley sent data for another problem of the same kind; namely, masses and stiffness figures for a particular design of wing, carrying wing engines and attached to a fuselage which he proposed should be treated as rigid. The Sub-Committee work on this second problem is described in the present note. The data (in effect) reduce the wing to a system having 6 degrees of freedom: we have determined its six natural frequencies, together with the associated modes, (1) when both wings vibrate in phase, so that the fuselage, which is free to move, pitches but does not roll, and (2) for anti-phased vibrations which roll but do not pitch the fuselage.

R. & M. No. 1922. The Stabilization of Struts by Lateral Support. January 31, 1941. By H. L. Cox. (2*s*. 0*d*.)

It is shown in R. & M. 1923 that the weight of the most economical strut necessary to transmit a compressive load P over a distance l is a function of the "structure loading coefficient," P/l^2, and of the properties of the material. At low values of structure loading coefficient this minimum weight may considerably exceed the weight of material which would be necessary if buckling of the strut could be prevented. Accordingly, it may be possible to reduce the *total* weight of the structure by bracing the strut laterally to any points of support which may be available. The possibility of saving weight in this way obviously depends on the value of the

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* The method was described in this series under the title Ducted Fans ; Design for High Efficiency, Report ACA-7. (See AIRCRAFT ENGINEERING, April 1945, p. 111).

structure loading coefficient and on the disposition round the strut of the possible points of support. The present note discusses the conditions governing this possibility.

Two cases are considered, that of a strut free to deflect laterally in any plane and that of a strut constrained to deflect in one plane only and the bearing of the results on the problem of a bent beam is discussed. The use of lateral ties to stabilize struts at low values of structure loading coefficient may result in a considerable saving of weight, even in cases where the length of the ties considerably exceeds that of the strut. In the case of an unrestrained strut, weight may be saved by bracing provided that the ratio of the length of each tie to the length of the strut is less than a quantity given by a simple formula.

R. & M. No. 1923. Structures of Minimum Weight. November 30, 1943. By H. L. Cox and H. E. Smith. (6*s.* 0*d.*)

An attempt is made to set up standards of optimum efficiency for certain simple structures on a basis of minimum weight.

The dimensions of a structure are divided into two groups, the values of one group being specified *ab initio*, the values of the other being variable to meet the loading conditions specified. It is shown that the number of variables in the latter group is reducible to the number of possible modes of failure, and a logical procedure for fixing the values of these variables so as to make the total weight of structure the least possible is developed. It is shown that this minimum weight depends on the qualities of the materials of construction, and on the " structure loading coefficient." The nature of this dependence is established for examples of tie-bars, struts, wide struts, grid frameworks and stiffened panels.

The conclusions are summarised in several formulae and diagrams. Whereas the specific weight (weight per unit length divided by the load) of a tension member is an increasing function of its structure loading coefficient, that of a compression member is a decreasing function of this parameter.

R. & M. No. 1929. Two-dimensional Supersonic Aerofoil Theory. January 21, 1944. By M. J. Lighthill. (3*s.* 6*d.*)

The previous work on the theory of sharp-nosed aerofoils in a supersonic stream is connected and summarized, and a proof is given of the behaviour of such a stream flowing past a smooth surface which authors from Ackeret (1925) onwards have assumed. Practical methods and tables are given which will help the forces on such an aerofoil to be calculated exactly, except in so far as the effects of viscosity are ignored. Their exact results are compared with certain convenient approximations.

R. & M. No. 1930. The Conditions Behind the Trailing Edge of the Supersonic Aerofoil. January 31, 1944. By M. J. Lighthill. (2*s.* 0*d.*)

In " Two-Dimensional Supersonic Aerofoil Theory," R. & M. 1929, by the same author, discussion in detail of the conditions behind the trailing edge of a supersonic aerofoil was omitted. The omission was made because the conditions do not affect the forces on the aerofoil, and because they would suffer more than any other characteristics of the flow from the effects of viscosity.

Some importance is attached to the conditions behind the trailing edge of a wing as the tailplane is situated there, and the present paper advances a non-viscous theory. It also considers the shape of the shock-waves far behind the aerofoil and finds them to be approximately parabolic.

R. & M. No. 1931. Some Experimental Determinations of the Apparent Additional Mass Effect for an Aerofoil and for Flat Plates. October 27, 1941. By C. Scruton. (2*s.* 0*d.*)

Values of the true structural moments of inertia of model and full-scale wings and control surfaces are required frequently for flutter investigations. An accurate calculation of these is not often practicable but they may be determined from oscillation experiments in air if the effect of the air on the motion is known.

The effect on the motion of a body due to the energy imparted to the surrounding air is conveniently regarded as an addition to the inertias of the body. It is variously described as " the apparent additional mass effect " and " the virtual mass effect."

Experiments to determine these quantities have been confined almost exclusively to tests on flat plates whilst theoretical considerations have led to solutions in only a few cases. W. P. Jones in R. & M. 1953 has obtained theoretical values for thin plates of finite span moving in a perfect fluid. The effect of frequency of oscillation on the quantities, due to viscosity, is commonly neglected in both experimental and theoretical work, but where it has been considered, e.g., in the case of the sphere, its effect is not large except for very slow oscillations and rapidly decreases with increase in frequency.

Part 1 of this report describes briefly an attempt to measure the additional inertia corresponding to pitching oscillations of an aerofoil at various frequencies. The accuracy obtained by the method was not satisfactory.

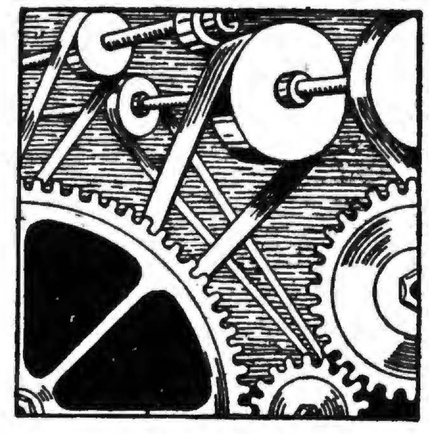
Part 2 demonstrates, with the use of rectangular flat plates, a very simple method for the experimental determination of the additional mass effect for flat bodies. The method requires no elaborate apparatus, gives good accuracy, and is suitable for determinations on aerofoils and control surfaces.

List of Selected Translations

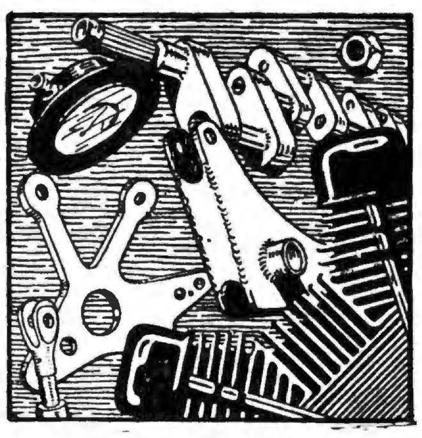
APPLICATIONS for the loan of copies of translations mentioned below should be addressed to the SECRETARY (R.T.P.3) MINISTRY OF AIRCRAFT PRODUCTION, LONDON, S.W.1, and copies will be loaned as far as availability of stocks permits. Suggestions concerning new translations will be considered in relation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

LIST No. 84

Translation No. and Author	*Title and Reference*
	Aero Engines
(2526) TANZLER, H. U.	*Rotary Displacement Type Compressors for Scavenging Small Two-Stroke engines.* (A.T.Z. Vol. 46, No. 2, Jan. 25th, 1943, pp. 31-36.)
	Aerodynamics
(2525)	*The Role of Rheological Analogies in Certain Aerodynamical Problems.* (Extract of letter to be read by Prof. Peres.)
	Aircraft and Accessories
(2530)	*Me.262. Possible Purposes of Employment.* (Supplement to description of the aircraft dated 10.8.43, pp. 23106-23213.)
	Aircraft (De-icing)
(2533)	*Report on Temperature Measurements on the Wing of a He.177 with Hot Air De-icing System.* (Aeronautical Laboratory, Göttingeen Inst. for Low Temperature Research Branch Station.)
	Armaments
(2538)	*Testing Programme for Airborne Weapons.* (German Report 1.)
	Electrical Apparatus
(2532) RAMM, R. ... BATH, F. ...	*Measurements with the Copper Oxide Rectifier.* (Veroff a.d. Geb. Nachrichtentech, Vol. 6, Pt. 1, 1936, pp. 51–68.)
	Electronics
(2529) MEINKE, H.	*Co-axial line Elements which produce no Disturbing Fields at High Frequencies.* (H.F.T., Vol. 61, No. 5, May 1943, pp. 145–151.)
(2535) WUNDERLICH, R.	*Covering the Working Method of a Cathode Follower Amplifier.* (Elketr. Nachr. Techn., Vol. 19, 1942, pp. 63, etc.)
	Materials
(2534) KIRNER, J.	*On Some Interesting Observations on the Case-Hardening of Steel, particularly with regard to the effect of Nitrogen.* (Z.f.g. Huttenk. Metallurgie, 1911, No. 3, pp. 72–77.)
(2536)	*Specification for Steel Castings Report No. 1.* (Issued by Aircraft Industry Economic Group, Berlin, Materials Test Section.)
	Materials (Tropicalization)
(2524)	*Construction and Operation of Climatic Testing Chambers for Communication Equipment.* (E.T.Z., Vol. 64, No. 37–38, pp. 507–510.)
(2539) SCHULZE, W. M. H.	*The Influence of Climate on Material Stressing under Tropical Conditions.* (Z.f. Fernmeldew, Vol. 27, Nos. 1, 2 and 3, Jan. 1943, pp. 1–10, 21–28, 35–40.)
	Meteorology
(2540) FINDEISEN, W.	*Do Condensation Nuclei Originate at the Surface of the Sea?* (Meteorologische Zeitschrift, Oct. 1937, pp. 377–379.)
	Miscellaneous
(2528) SAMTLEBEN, A.	*The Utilization of the Ammonia and Hydrogen Sulphide from Coke Oven Gas.* (Communication from the Laboratory of the Large Gas Works Control, Germany.)
	Plastics
(2531) STAUDINGER, H.	*High Polymer Compounds. Communication 60. (1) The Relationship between the length of Chain Molecules and (2) the Specific Viscosity of their solutions.* (Ber. Dtsch. Chem. Ges. Berlin, Vol. 65, 1932, pp. 267–279.)
	Workshop Methods
(2537) HANSEN, W. H.	*Brazing under a Protective Gas Atmosphere in the Electric Resistance Furnace.* (Metallwirtschaft, Vol. 21, No. 11–12, 1942, pp. 154–162.)



Production and Maintenance Section



A.C. Power and Aeroplane Accessories[*]

By J. D. Miner

It is slightly over two years since the U.S.A.A.F. asked some of the leading electrical manufacturers of the country to undertake the development of a wholly new alternating-current electrical system for aircraft. While some of the details are not ready for publication, enough can be revealed to make this an opportune time to review the progress which has been made, and to evaluate the significance of this highly publicized development.

Fundamentally, the object of an A.C. system for aeroplanes is weight economy through the use of higher voltages than now appear practical for direct-current systems. Preliminary studies of A.C. electric systems started long before the war. Navy experience with high-power radio equipment had demonstrated as early as 1930 that A.C. power equipment was far more reliable than D.C. equipment for supplying high plate voltages of the order of 1,000 to 2,000 volts. The use of dual generators providing variable-frequency alternating current for radio and direct current for the power system is common practice on U.S. Navy aeroplanes, and is a compromise between D.C. and A.C. systems which is adaptable to many aeroplanes of moderate size.

For very large aeroplanes a higher system voltage than the present 27-volt value is essential. Searching for ways to increase system voltage, the U.S.A.A.F. authorized two experimental aeroplanes equipped with A.C. systems in the middle 1930's. The Boeing XB-15 was equipped with a single-phase, 800-cycle system, and the Douglas XB-19 was equipped with a 120-volt, 400-cycle, three-phase system. System capacities were relatively small, the power supply for each aeroplane being a pair of small auxiliary-engine-driven alternators, and the installations were far short of the elaborate systems now being developed.

The XB-19 was test-flown on June 27th, 1941, some four years after test flights of the earlier XB-15. Operation of the electric equipment on the XB-19 demonstrated the superiority of poly-phase power for motors and for parallel operation of alternators, as contrasted with previous experience with the single-phase system. Before December 7th, 1941, alternating-current-powered aeroplanes were interesting experiments, but with the advent of war they assumed new significance. Perfected A.C. systems, according to the more enthusiastic engineers at Wright Field, would mean that the electric system would no longer be a limiting consideration in determining the maximum size of an aeroplane.

During the dark days of 1942, Japan rapidly acquired all the air bases between Pearl Harbour and Australia. As the war developed, it began to appear high time to start developing an electric system which would overcome the limitations inherent in existing low-voltage systems; that is, by going to something of the order of the 230-volt industrial practice.

Long range aeroplanes must necessarily be high-altitude aeroplanes; and it was quickly decided that high-voltage direct current at high altitudes was a gamble that could not be risked, partly because of the unknown hazards of low arcing voltages and partly because of the known hazards of excessive brush wear at altitudes above 30,000 ft. With this decision made, and a controversy initiated that is still raging, the Electrical Branch of the Equipment Laboratory at Wright Field set up an A.C. engineering unit and attacked the problem of an A.C. electric system in earnest.

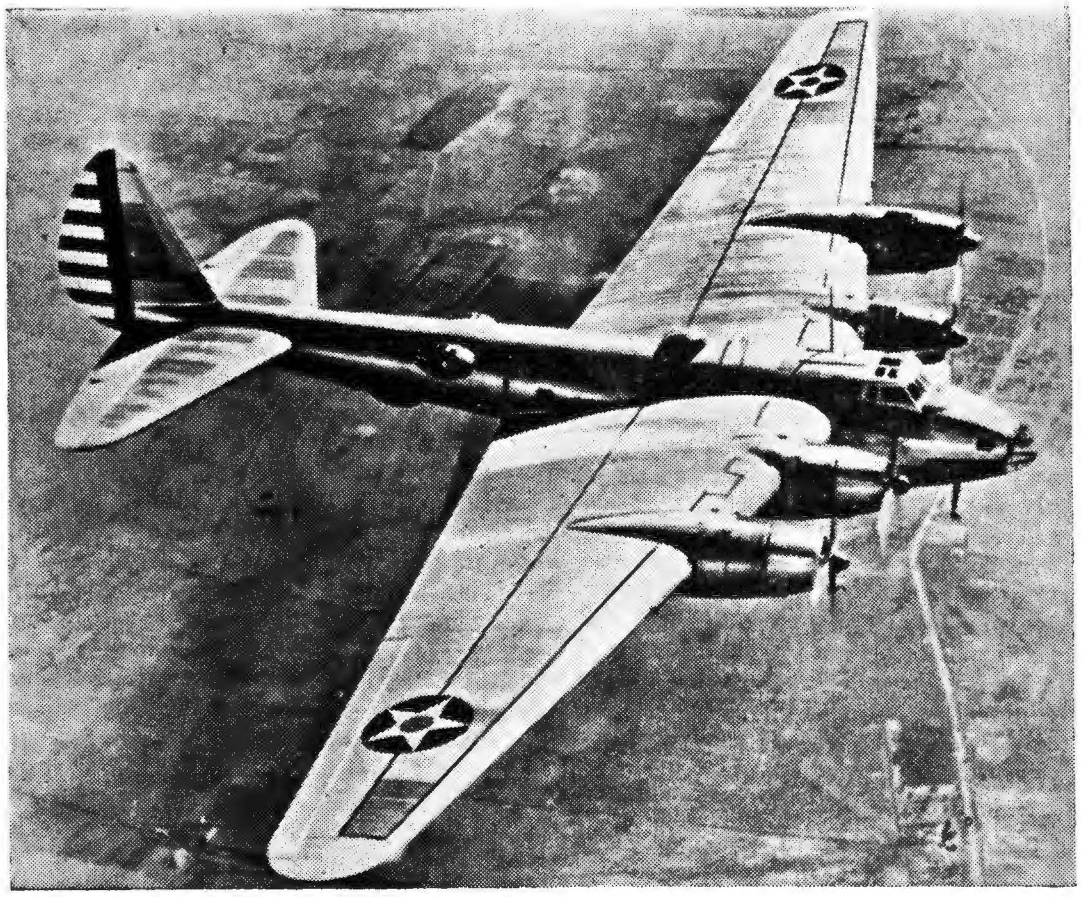


FIG. 1. — *The Boeing XB-15, first test flown on October 15th, 1937, was the first aeroplane in the world to carry a full 110-volt alternating current electrical system. Two auxiliary petrol power plants drove the generator supplying current to the electrically-operated parts*

Conferences with selected manufacturers began in December, 1942, and tentative specifications were gradually whipped into shape. Basic elements of the system have been fixed since a general meeting called at Wright Field on January 18th, 1943. System characteristics are as follows:—

Volts, line-to-line ...	208 at generator 200 at load centres
Volts, line-to neutral	120 at generator
Frequency	400 ± 20 cycles per second
Neutral	grounded

Basic generating units are main engine driven alternators rated 40 kva. at 75 per cent power factor. They are designed for parallel operation when suitable speed-controlled drives are provided. Four such units provide 120 kw. (160 kva.) and require distribution lines rated approximately 440 amps. By contrast, the familiar "24-volt" system, operating at 27 volts, would require copper to carry 4,400 amperes. For long conductor spans, where regulation rather then thermal capacity determines the size of conductor required, the single 27-volt conductor would require 17 times the copper that is required for all three of the 208-volt conductors.

Motors are of course poly-phase. They are operated grounded neutral so that they will develop partial ratings with one line shot away, and will continue to run at light load with two lines show away, although they will not re-start under the latter condition.

Availability of A.C. systems does not mean that all large aeroplanes will or should use them. In selecting the system best suited to a particular aeroplane, many factors must be considered; the size and electric power requirements of the aeroplane being two of the most important factors. Functionally, an aeroplane is a device for carrying pay load from point A to B, and systems must be studied primarily to determine the overall effect they will have on pay-load capacity. Installation weight, fuel consumption, and, for a military aeroplane, the probability of its reaching its destination, must all be considered in determining this. Although a military aeroplane must be designed to meet certain specific tactical requirements, like any other type, once it is designed, it will lift a certain gross load. The combined weights of the aeroplane, equipment, fuel, and pay load must not exceed the total lift. Fuel consumption for operating equipment may be of far more consequence than the equipment weight for operation over extreme ranges.

Reliability is fully as important as weight. Pay-load capacity achieved at the cost of reliability is not a good investment; capital would be expended faster than the fictitious high rate of return could ever justify. Where possible, of course, the designer will provide the spares necessary to assure the return of the aeroplane even though some vital device fails because of enemy action or because of its inherent weakness. The weight of this reserve equipment must be subtracted directly from pay-load capacity. Remaining deficiencies in reliability must be made up by supplying additional aeroplanes and crews.

Conversely, an improvement in reliability cuts down losses. "All-electric" aeroplanes, according to the U.S.A.A.F., are much less vulnerable to combat damage than are hydraulically equipped ones. This is one of the reasons for the military importance of electric systems, since the transition from hydraulic to electric operation of actuators and accessories is a major factor in the expansion of electric power requirements on large aeroplanes. The only other

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[*] The writer, who is manager of the Design Engineering Department of the Westinghouse Electric Corporation, Lima, Ohio, U.S.A. acknowledges the assistance of H. J. Braun, H. E. Keneipp, and C. G. Veinott, all of the Aviation Engineering Department, particularly for furnishing curves and other basic data upon which this article is based.

factor of comparable magnitude is the great increase in the use of radar devices. The B-29, although equipped with a 24-volt, D.C. system, is considered the first all-electric aeroplane, and has the largest capacity of any aeroplane regarding which information has been released.*

Neither comparative reliabilities of 24-volt and 120-volt D.C. equipment, nor the comparative reliabilities of 120-volt D.C. and 208-volt A.C. equipment have yet been established by operating experience, although some experimental and much theoretical evidence is available on these subjects. In general, the absence of brushes and commutators on motors will increase reliability, and it is generally admitted that circuit interruption problems will be less with alternating current than with direct current at comparable voltages.

Closely related to reliability is the factor determining the time an aeroplane will be grounded for maintenance. This factor may be evaluated as the pay-load utilization factor. An aeroplane does not carry out its function of delivering pay load while a service crew is struggling with its electric equipment; or with any other equipment for that matter. As the intricacy of the equipment increases, the time for ground maintenance is very likely to increase in proportion. Some of the equipment proposed for A.C. power systems is admittedly much more intricate than equipment now being used for 24-volt systems. Too much should not be made of this point, as 24-volt equipment is also growing more intricate as new requirements develop.

Although actual service will tell the final story, some predictions regarding maintenance have been made for actual or anticipated designs on the basis of such general considerations as the number of parts involved, the necessity for abnormally accurate tolerances, likelihood of excessive temperatures, vulnerablity to combat damage, and ability to withstand abuse and improper operation. Evaluated on this basis, constant-speed drives and synchronizing controls appear likely to require somewhat greater maintenance and a somewhat higher standard of technical ability to operate them than do any components of the existing 24-volt systems. Motors for use with A.C. systems, on the other hand, will require considerably less maintenance than D.C. motors now require.

So far, electric systems have been discussed rather generally as to the effect that the system may have on the aeroplane as it carries out its primary function of carrying pay load. For proper overall perspective, it is now necessary to consider the fact that all large aeroplanes carry some equipment which must be operated from direct current and some equipment which must be operated from alternating current. Solenoids and some forms of control apparatus function best when designed for direct current, whereas many instruments and all high-power radar equipment operate from alternating current. Regardless of the type of power provided for the main system, conversion equipment will be required to suit many of the devices to be operated. Where possible, of course, devices will be designed to operate from the basic power supply without the use of conversion equipment. Although an A.C. motor will weigh only about 60 per cent of that of an equivalent D.C. motor, it will not pay to install an invertor to permit the use of A.C. motors on D.C. equipped aeroplanes unless compelling reasons other than weight exist. On the other hand, radar valves require power at a D.C. potential of many thousands of volts. The lightest and most reliable method of obtaining this power is by transforming high-frequency A.C. power to a suitable voltage and then rectifying it to provide the required D.C. potential. The weight required on D.C. aeroplanes for invertors or for special alternators provided solely for radar operation is considerable, but it is negligible compared with that required for D.C. generation at the necessary voltage.

Comparison of complete electric systems is facilitated by breaking the system down into the following elements:

(*a*) prime mover,
(*b*) coupling device (with or without speed ratio),
(*c*) generator,
(*d*) excitation source,
(*e*) control and protective devices,
(*f*) distribution circuits,
(*g*) conversion devices,
(*h*) utilization devices.

These elements may be compared item for item for various systems and for all sorts of aeroplanes. An attempt has been made to indicate the salient characteristics of the components of various systems in Table I. In such a table, remarks are necessarily limited to generalities, but a great deal of detailed information is available in the technical press for those who require it. A full-size mock-up of a complete four-engine installation has been constructed at Wright Field for exhaustive tests of equipment as it is delivered.

With so much progress in developing equipment for A.C. systems already recorded, it is necessary to report that one tremendous obstacle has not yet been overcome. In *Machine Design* for June, 1941, Dr. E. E. Minor writes on the subject of "high-frequency power for aircraft" and points out the need for a constant-speed device to couple the alternator to the main engine. Not much more can be said in 1945, at least at the time of writing. The variable stroke, friction-drive device to which Dr. Minor alluded was abandoned some time ago; but there are at least three hydraulic devices which bear some promise of success, although at much higher weights than were originally contemplated. Recent developments in the gas-turbine field also suggest that an auxiliary gas turbine may be a suitable prime mover in spite of high fuel consumption, and that development of such a turbine may make it possible to abandon the long quest for a constant-speed drive.

Table I indicates that A.C. systems will be justified for high values of connected load, and for aeroplanes of large physical size with power-transmission distance exceeding 100 or possibly 200 ft. The dividing line between preference for D.C. systems and for A.C. systems is not too clearly established, and will shift somewhat according to the success in developing an alternator drive, and, as pointed out previously, according to the particular make-up of the utilization devices required on the aeroplane.

One question of paramount importance cannot be answered at this time, namely: When will the new A.C. system be in actual operation? Some of the urgency has disappeared since 1942. Then again, much of the early impetus came from the high-altitude brush problem, a major obstacle to D.C. apparatus in 1942, now almost forgotten, thanks to the work of Dr. Howard Elsey of the Westinghouse Research Laboratories and his associates. Even so, with so much of the equipment already completed, it does not appear that flight tests will be long delayed, although it is admitted that the first installations cannot be as complete as protagonists of the A.C. system would like to see them.

If this prediction is correct, it behoves the designers of aircraft accessories to be ready with A.C. versions of aircraft electrical equipment. In general, conversion of existing D.C. motor-driven devices will be relatively simple, and in most cases, the A.C. powered device will be simpler, lighter and easier to maintain than its D.C. counterpart. Often, an A.C. motor will merely be substituted for the D.C. motor, with negligible modifications of the accessory. Many designers, however, will want to take advantage of the possibilities inherent in A.C. motor application by re-designing the accessory for a higher motor speed.

The most popular speed for D.C. motors is probably 7,500 r.p.m; 11,500 r.p.m. is expected to be the most popular speed for 400-cycle motors, although conservative designers may hesitate to exceed 7,500 r.p.m. except for intermittent ratings or for continuous ratings below one horse-power. Very large motors are likely to warrant special lubrication systems which will permit operation at 11,500 or 23,000 r.p.m., speeds which are already exceeded on gas-turbine compressors and on superchargers.

The use of built-in A.C. motor parts is considerably simpler than is the case with D.C. motor parts, since no brush rigging is used. As a compromise between motor parts and complete motors, the U.S.A.A.F. are sponsoring the development of "three-quarter" motors, the bearing housing for the drive-end being part of the accessory instead of being part of the motor. This method of construction saves some weight compared with complete motors, and facilitates motor replacement compared with integral motor parts, but is being resisted by many manufacturers because it complicates problems of ventilation, factory testing, and responsibility for satisfactory operation. Standardization of three-quarter motors is considerably more difficult than standardization of complete motors, since many internal features of motor design are affected.

Care must be taken in applying any motor to recognize its speed-torque characteristics. Fear has been expressed that A.C. motors with high-ratio gear reductions may not have sufficient starting torque to overcome the drag of congealed lubricants at minimum ambient temperatures, but tests have shown that such fear is groundless if motors are properly designed.

Designers who are familiar with portable tools know that the use of high-frequency, poly-phase motors for high speeds and for high power at low weight is well established for grinders, wood-working tools, and for many other hand-held tools. Such motors have no brush and commutator maintenance problem—a serious obstacle to the production-line use of some portable tools with series-wound, universal motors.

High-power output with low weight is not the only desirable characteristic of high-speed A.C. motors. Gyroscopic instruments are already largely A.C. motor driven, although there are still many instruments using D.C. gyros. Most of these would be improved by the substitution of A.C. motors, since these motors have no brush friction, are free from carbon dust to spoil precision bearings, are easier to balance, and are much more uniform in speed than D.C. motor-driven gyros. The hysteresis-synchronous motor is particularly suitable for small gyros, as it combines accurate speed with simple construction. An interesting fact in favour of this type of motor is that it has a relatively constant impedance from locked rotor to synchronous speed.

Lighting equipment becomes very flexible when alternating current is available. Fluorescent lamps, ultra-violet instrument illumination, and filament type lamps may be employed where each is most suitable, and each type may be operated at its most favourable voltage.

Radio equipment is readily designed for A.C. operation, and, in fact, the majority of high-powered transmitters are already constructed for single-phase, high-frequency power. Radio can be operated single-phase as at present by using line-~~to-neutral~~ power, or it can be redesigned for poly-phase operation with some reduction in weight of the power-supply filter. Although a constant frequency is not necessary for the plate-voltage supply, it is frequently necessary for some devices. This is one advantage of the new system as compared with some installations where variable-frequency power is now provided by means of variable-speed alternators; another advantage is that far greater reserve capacity is available in case one or two alternators fail.

Operation of low-power radio transmitters and receivers from alternating current eliminates the need for rotating dynamotors for plate power, but also eliminates the possibility of emergency operation from battery power. Dependance for emergency power may be placed upon an auxiliary alternator set, or some emergency radio equipment may continue to be operated from the 28-volt bus.

Alternating-current motors appear to suffer by comparison with direct-current motors when variable speed is required. However, the principal use for variable-speed motors is for turret operation, and these motors must operate with precise control from zero speed to maximum speed in either direction. This is now accomplished by using direct-current, variable-voltage motors with fixed field excitation. A variable-voltage generator and generator-driving motor must be provided for each variable-voltage motor. Present systems may be used almost intact by driving the variable-voltage generators from A.C. motors instead of from D.C. motors; considerable reduction in weight is possible by driving two generators from one motor, since both generators never demand full power at the same time. Maximum motor rating occurs when azimuth and elevation speeds each equal 70 per cent of the maximum turret speed. Field excitation for the azimuth and elevation motors may be obtained from small static rectifiers, or from the auxiliary 28-volt bus.

Designers will not be entirely satisfied with this arrangement; it saves considerable weight, but probably even more can be saved by eliminating the motor generator altogether, and controlling the effective voltage at the motor armatures by means of thyratrons. Still another method of controlling speed for turrets and for general applications presupposes that the hydraulic variable-ratio drive will be developed; it will then merely be necessary to interpose a small version of this transmission between a constant-speed motor and the device to be driven at variable speed.

Many occasions arise for synchronized operation

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* It should be noted in regard to this statement that the Short Empire flying boats of 1936 were "all-electric" and that they were the forerunners of the Sunderland and Stirling.—EDITOR.

Table I—General Comparison of Various Electric Systems for Large Aircraft Generators Rated 24 to 32 Kw

Equipment	400-Cycle, 3-Phase, 208/120-Volt, 4-Wire A-C System			24-Volt Direct Current System	120-Volt Direct Current System	Dual Generator System 24-Volt, Direct Current 120-Volt, Single-Phase Var.-Freq. A-C
Prime Mover	(A) Main engine	(B) Auxiliary engine	(C) Auxiliary gas turbine	Main engine	Main engine	Main engine
(A) Weight	Light	Very heavy	Very light	Light	Light	Light
(B) Fuel efficiency	Good	Very poor	Very poor	Good	Good	Good
(C) Maintenance	Normal	Considerable	Minimum	Normal	Normal	Normal
(D) Availability	Available	Not fully developed	Not available at present	Available	Available	Available
Coupling	Variable-ratio drive	Step-up gears	Step-down gears	Double-universal jack shaft	Double-universal jack shaft	Double-universal jack shaft
(A) Weight	Probably 3-5 lb/kva	Low	Low	Low	Low	Low
(B) Efficiency	Probably 60-80%	95-97%	95-97%	Negligible losses	Negligible losses	Negligible losses
(C) Maintenance	Probably high	Slight	Slight	Negligible	Negligible	Negligible
(D) Availability	Not available	No problem	No problem	Available	Available	Available
Generator	High-speed (6000 rpm) alternator			Wide speed range (2700 to 9000rpm) large commutator complicated brush rigging	Wide speed range (2700 to 9000 rpm) moderate commutator	Wide speed range (2700 to 9000 rpm) two generators in one housing
(A) Weight	Approx. 2 lb per kva (including exciter)			Approx. 5 lb per kw	Approx. 4.5 lb per kw	Approx. 6 lb per kw
(B) Efficiency	Approx 90%			Approx. 85%	Approx. 88%	Approx. 85%
(C) Maintenance	Slight			Moderate	Moderate	Moderate
(D) Availability	Available for 40 kva at 75% pf			Not fully developed	Not fully developed	Not fully developed
Excitation	Integral d-c exciter (weight included in alternator weight)			Self-excited or separate exciter	Self-excited or separate exciter	Self-excited
Control	Complicated control required—will require trained technicians for maintenance			Simplest control	Control fairly simple—special interruption devices required	Dual control required
Speed Governor	Accurate speed control required for frequency control and for load division. Must operate more rapidly than engine speed can change			None	None	None
Voltage Regulator	Operates on exciter field. Must divide reactive power as well as control voltage. Weight 10-15 lbs			Requires a heavy-duty regulator unless an exciter is used. Weight 10-15 lb	Requires a heavy-duty regulator unless an exciter is used. Weight 10-15 lb	Requires two regulators: d-c regulator 5-12 lb a-c regulator 10 to 35 lb
Meters	Volts: Amperes: Kilowatts: Kilovars: Frequency			Volts: amperes	Volts: amperes	d-c volts, d-c amperes a-c volts, a-c amperes
Bus Connection	Synchronizing control: Frequency and voltage relays: Three-pole latched-in circuit breakers with d-c operating coils			Reverse current or differential-voltage relay	Reverse current or differential-voltage relay	Reverse current relay for d-c generator
Protective Devices	Differential phase relay: Exciter-ceiling relay: Three-phase breakers for isolation and transfer: Thermal protection. Low-frequency relay: Fuses or other circuit-protective devices			Generator fault breaker: Thermal protection: Fuses or other circuit-protective devices	Generator fault breaker: Thermal protection: Fuses or other circuit-protective devices	Generator fault breaker: Thermal protection. Fuses or other circuit-protective devices
Distribution	Parallel operation requires complicated control. Three relatively light-weight circuits are required. Fuselage used for neutral. Considerable reactive power must be circulated			Parallel operation is simple. One extremely heavy circuit required. Voltage regulation a serious problem. Fuselage used for return	Parallel operation is simple. One or two medium-weight circuits required. Some objection to use of grounded return	Parallel operation of d-c units is simple. Parallel operation of a-c units is impossible. One heavy circuit and two light circuits required
Conversion Devices	Light-weight transformers for a-c to a-c voltage transformation. Approx. 2 lb per kva. m-g sets or static rectifiers for a-c to d-c conversion Weight about 10 lb per kw, efficiency about 60% at full load.			Large inverters or additional engine driven alternators required for radio and radar. 10 to 20 lb per kva. Dynamotors for radio 25 to 150 lb per kw	Large inverters or additional engine driven alternators required for radio and radar. 10 to 20 lb per kva. Dynamotors for radio 25 to 150 lb per kw	Light-weight transformers for a-c to a-c voltage transformation. Dynamotors for low power radio. Small inverters for constant-frequency instrument circuits
Motors	Characterised by high speeds, low weight, simplicity, minimum maintenance, moderate torque. Require at least two thermal protectors. Require dc for brakes and clutches			Moderate speeds, moderate weight, high torques, moderate maintenance. Single thermal protector	Moderate speeds, weight for large motor slightly less than for 27-volt motors, high torques, moderate maintenance. Relays probably required for thermal protectors	Moderate speeds, moderate weight, high torques, moderate maintenance Single thermal protector
Radio	Operate direct			Use dynamotors or inverters	Use dynamotors or inverters	Operate from a-c or from d-c with dynamotors
Turrets	Ideal for motor on variable-voltage m-g sets. Facilitates use of electronic computers. May be suitable for thyratron drive			Slightly heavier than a-c for variable-voltage m-g sets	Slightly heavier than a-c for variable-voltage m-g sets	Slightly heavier than a-c for variable-voltage m-g sets
Instruments	Ideal for gyroscopes and synchro-tie equipment. Facilitates design of many other instruments			Usually require inverters	Usually require inverters	Usually require inverters
Control Surface Actuators	Ability to synchronize, a very important consideration			Flap controls, etc., require means for synchronising	Flap controls, etc., require means for synchronising	Flap controls, etc require means for synchronising
Lighting	Easy to use most favorable voltage			Satisfactory	Believed satisfactory	Satisfactory
Heating Devices	Satisfactory			Satisfactory	Satisfactory	Satisfactory
Cabin Supercharging	Does not appear practical because of need for speed control.			Possible but weight excessive. Power requirements would be very heavy	Possible. Weight probably higher than other methods	Possible but weight excessive Power requirements would be very heavy

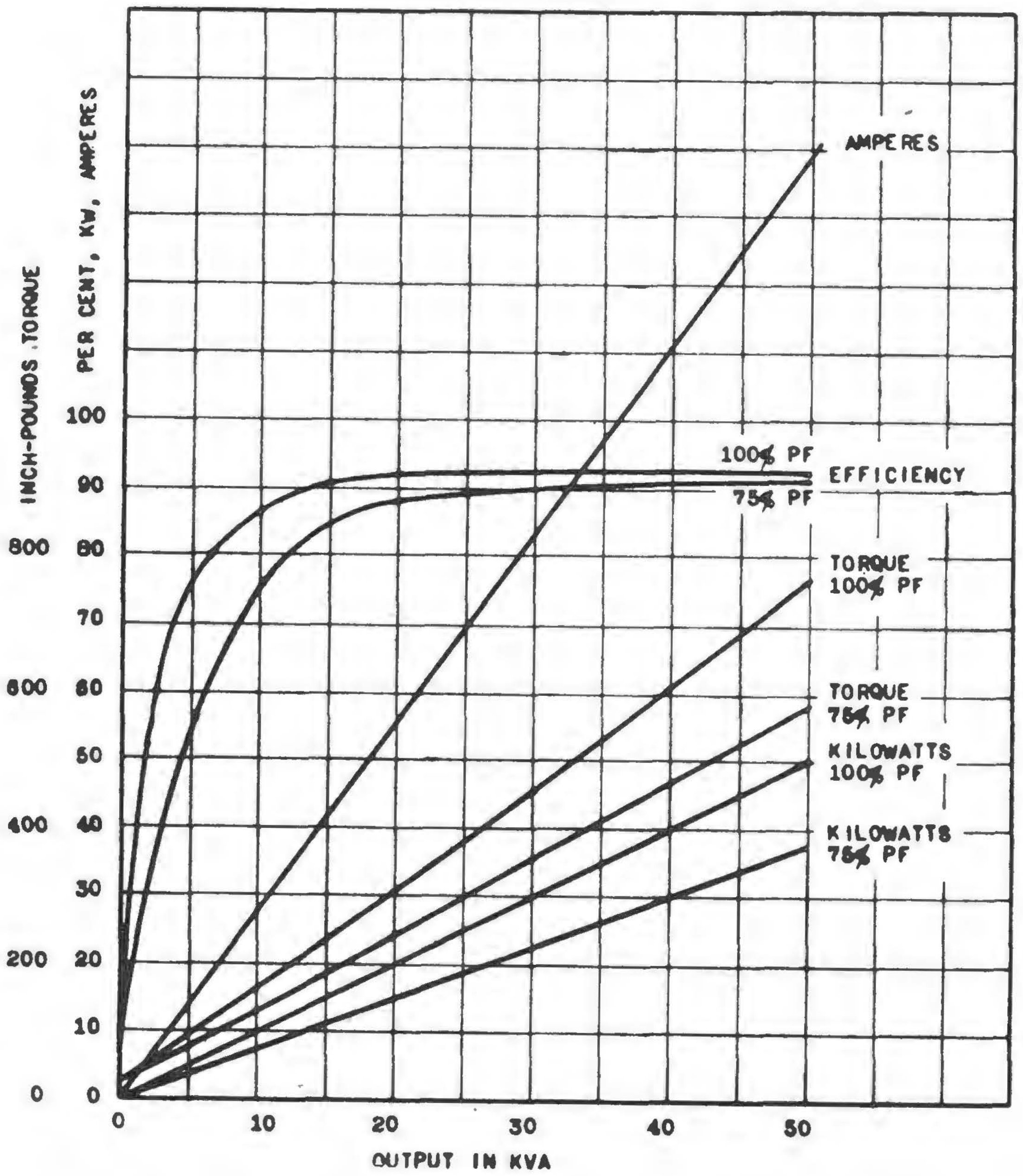

FIG. 2.—*Efficiency torque and output curves of 40-kva. alternator at 6,000 r.p.m., from dynamometer tests*

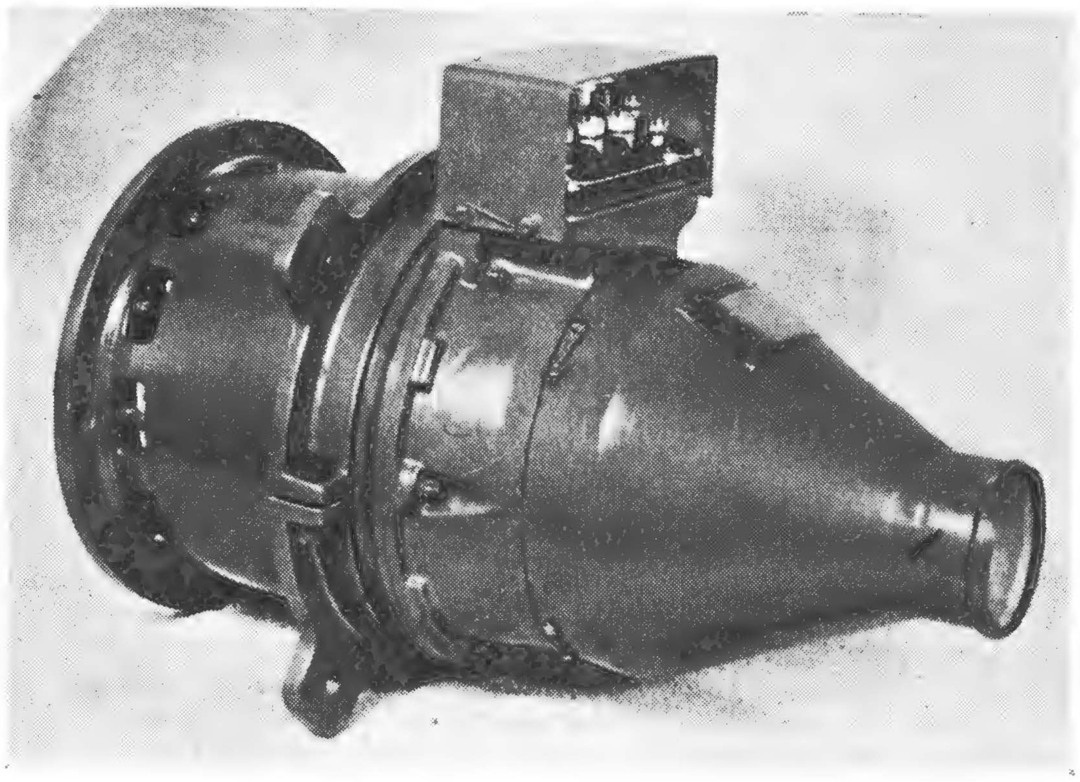

FIG. 3.—*40-kva. alternator—showing mounting flange, support brace, terminal board, and three-inch air inlet*

FIG. 5.—*A 40-kva. alternator installed for an altitude-chamber test. The voltage regulator is being adjusted by the tester. To the right of the regulator is a three-phase 208/120-volt circuit breaker with a latched-in contactor*

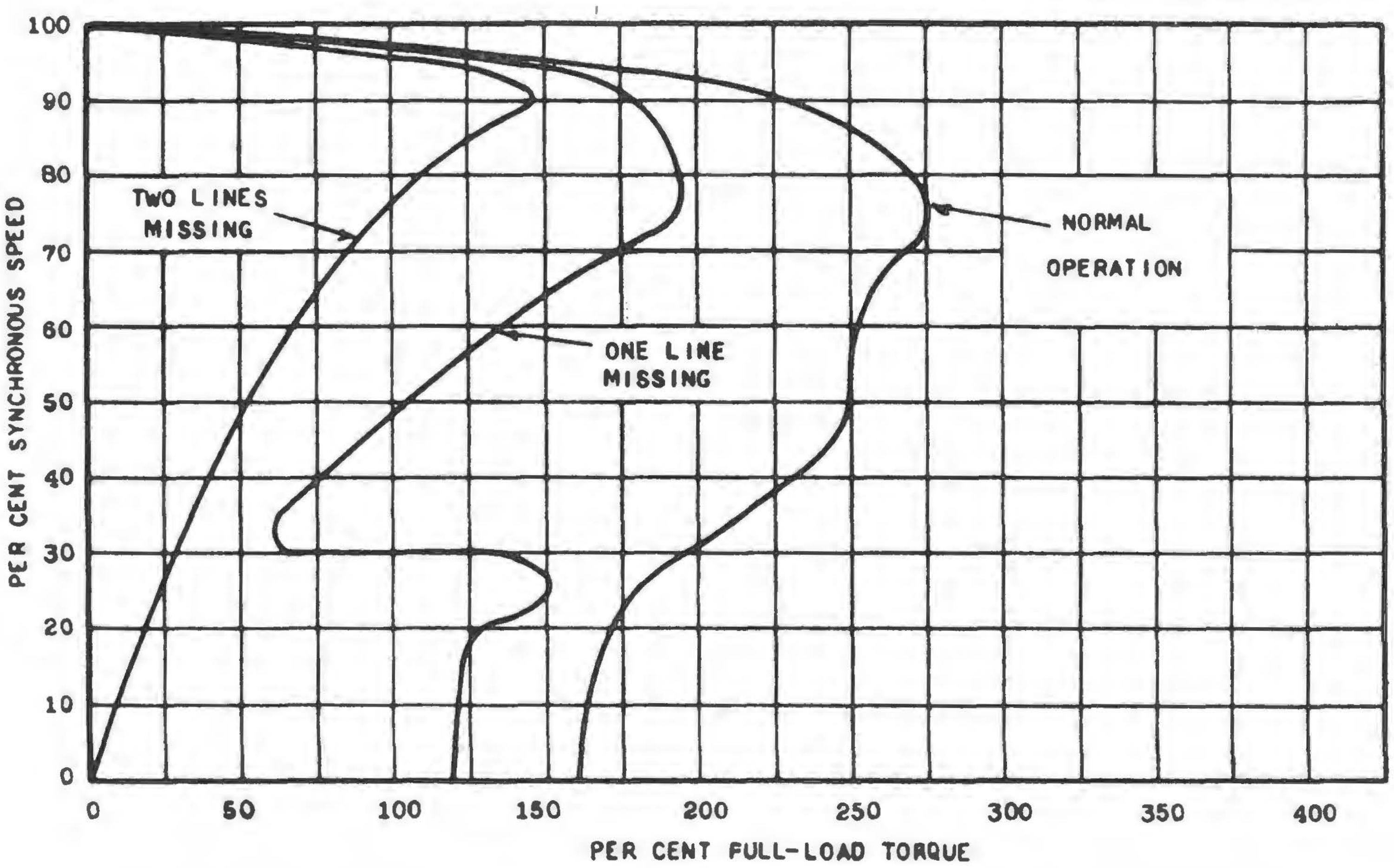

FIG. 4.—*Test speed-torque curves of a three-phase four-wire induction motor showing the effect of having one and two lines shot away*

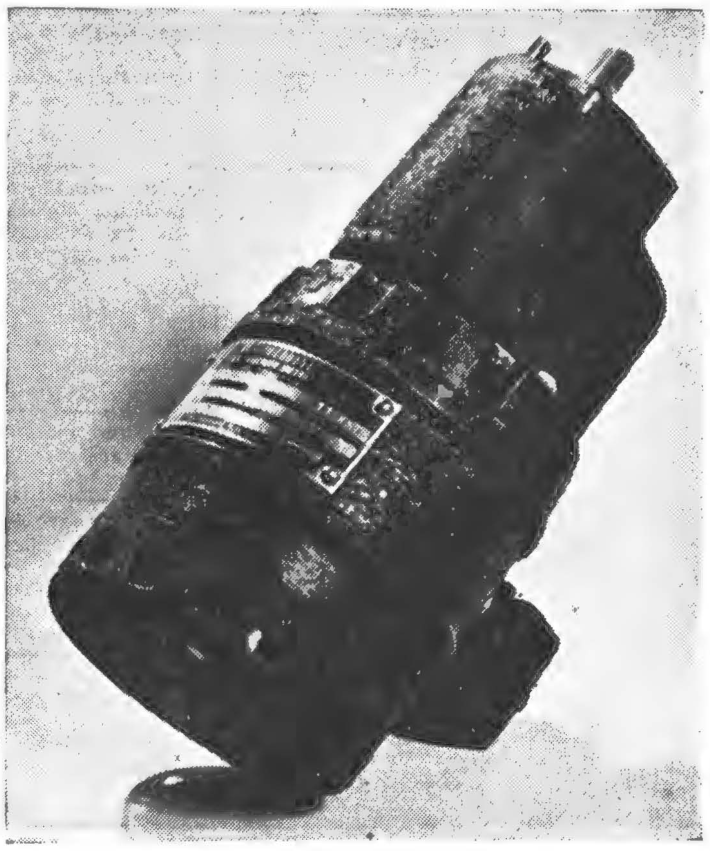

FIG. 6.—*A 400-cycle gear motor on "rotary actuator" rated 200 inch pounds at 27·5 r.p.m. and having a break-away torque of approximately 600 inch pounds. This heavy-duty unit weighs* 3 *lb.* 5 *oz.*

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44–193 Influence of Electricity on Aircraft Instrumentation, C. F. Savage, p. 802, *A.I.E.E. Trans.* Vol. 63, Nov. 1944.

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* A.I.E.E. Technical Paper Numbers.

in two or more parts of the aeroplane. For example, corresponding wing flaps on both wings must be kept in step within close limits or the aeroplane will become uncontrollable. For most such applications, ordinary low-slip induction motors will give adequate synchronization, especially if the units are forced into exact coincidence at one or both ends of the cycle. In any case, the common system frequency may be used by the ingenious designer as a reference base for many synchronization schemes.

Designers will find a fertile field for other new devices which the A.C. power system will make possible. There will also be many applications for such well-known devices as transformers and static rectifiers. Hypersil is extensively used in aircraft transformers and has made possible some remarkable savings in weight because of its magnetic properties at high frequencies and high densities.

Finally, the A.C. equipment proper is far from completely developed. Fame and fortune await the designer who finally develops the variable-ratio drive. Much work remains to be done on speed-governing mechanisms even after the drive is available. Possibly an entirely new approach will solve the difficulty; for example, consider an electronic frequency converter which will convert variable-frequency alternating current to constant-frequency current.

Methods of providing the necessary direct current are probably less satisfactory than some future methods will be. Static rectifiers have little overload capacity and no instantaneous reserve power. Voltage regulators for them are either heavy or else sluggish in operation. Motor-generator sets avoid these difficulties, but have high imputs at light loads and require the maintenance normal to rotating equipment.

Fault protection is being studied seriously as a result of combat experience. Really selective fault-clearing devices are needed, especially for military aeroplanes; these devices should clear damaged circuits almost instantaneously, yet never take out an undamaged circuit, or take out a circuit so far from the fault that undamaged branch circuits are disconnected.

British Standard Specification

*B.S. No. S.*100.—*Testing Procedure Applicable to Aircraft Steels.*

One of the principal reasons necessitating the preparation of a separate series of specifications for aircraft purposes has been the more stringent testing requirements that are required. While there are some specifications where for aircraft purposes a closer control on the quality of the material to that laid down for general engineering purposes is laid down, this does not always apply and very often the specification requirements are the same as those laid down for the corresponding standard for general engineering purposes; the only difference being the more stringent testing conditions. This has resulted in a duplication of standards. The step has therefore been taken of preparing a document which covers the testing requirements to be followed when steel is ordered for aircraft purposes and in future it will be possible, where appropriate, for the steel to be ordered to the chemical and mechanical requirements laid down in a general engineering standard, with the proviso that the testing procedure will be in accordance with the requirements of S.100. In this way the duplication of the specifications will be obviated.

Price 1s.

Trade Publications Received

Rapid Dynamic Balancing Machine for Light Rotors, etc.

Rapid Dynamic Balancing Machines for Medium Size Rotors, etc.

Dynamic Balancing

[W. & T. Avery Ltd., Birmingham]

A List of Products

[The United Steel Companies Ltd., Sheffield]

Pyrometer Testing Furnace

[Wild-Barfield Electric Furnace Ltd., Watford]

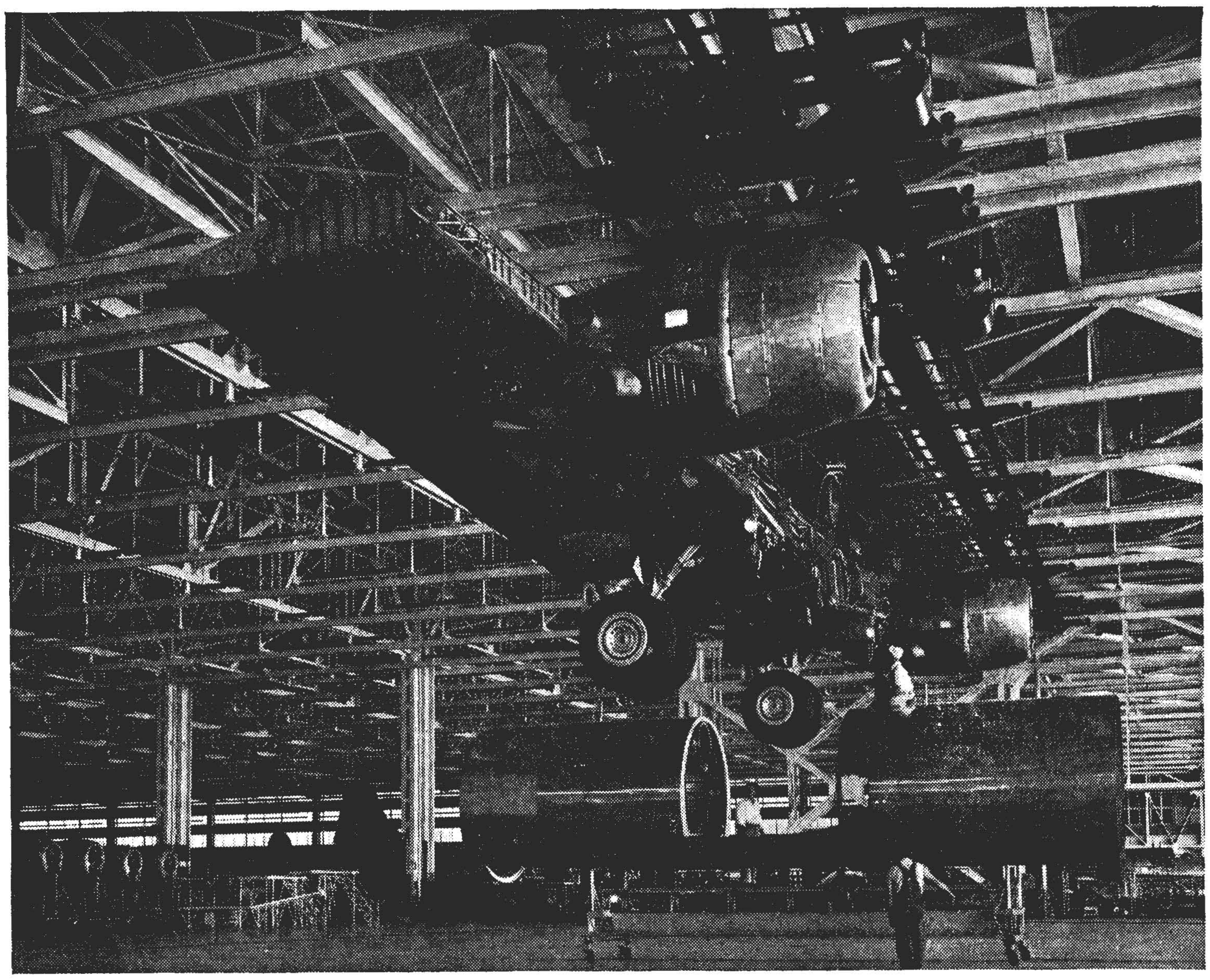


FIG. 1.—*Assembly of a completed centre-section to the central portion of the fuselage. It will be noted that not only is all possible "plumbing" already fitted to the centre-section, but both the under-carriage and the outer power plants are in place. This centre-section unit weighs about 17 tons and the lowering of it into the recess in the comparatively flimsy centre portion of the fuselage is a delicate operation*

Assembly Practice in a Boeing Factory

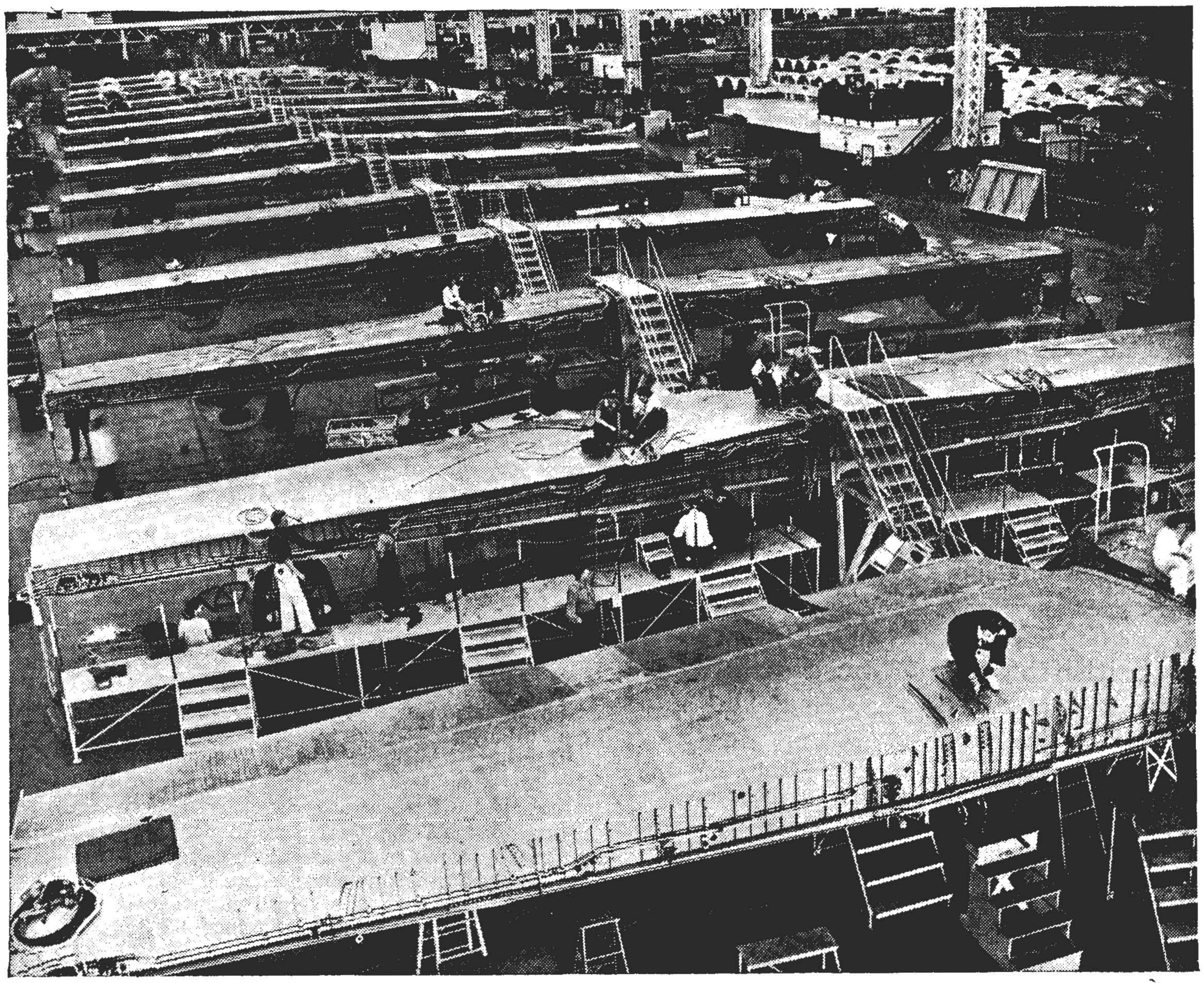


FIG. 2.—*The main plane assembly line. This general view shows how the vast centre-section unit—shown in Fig. 1—is built on a line assembly from the bare box-spar unit in the foreground to the complete component in the distance. Note the exceptionally neat workshop equipment*

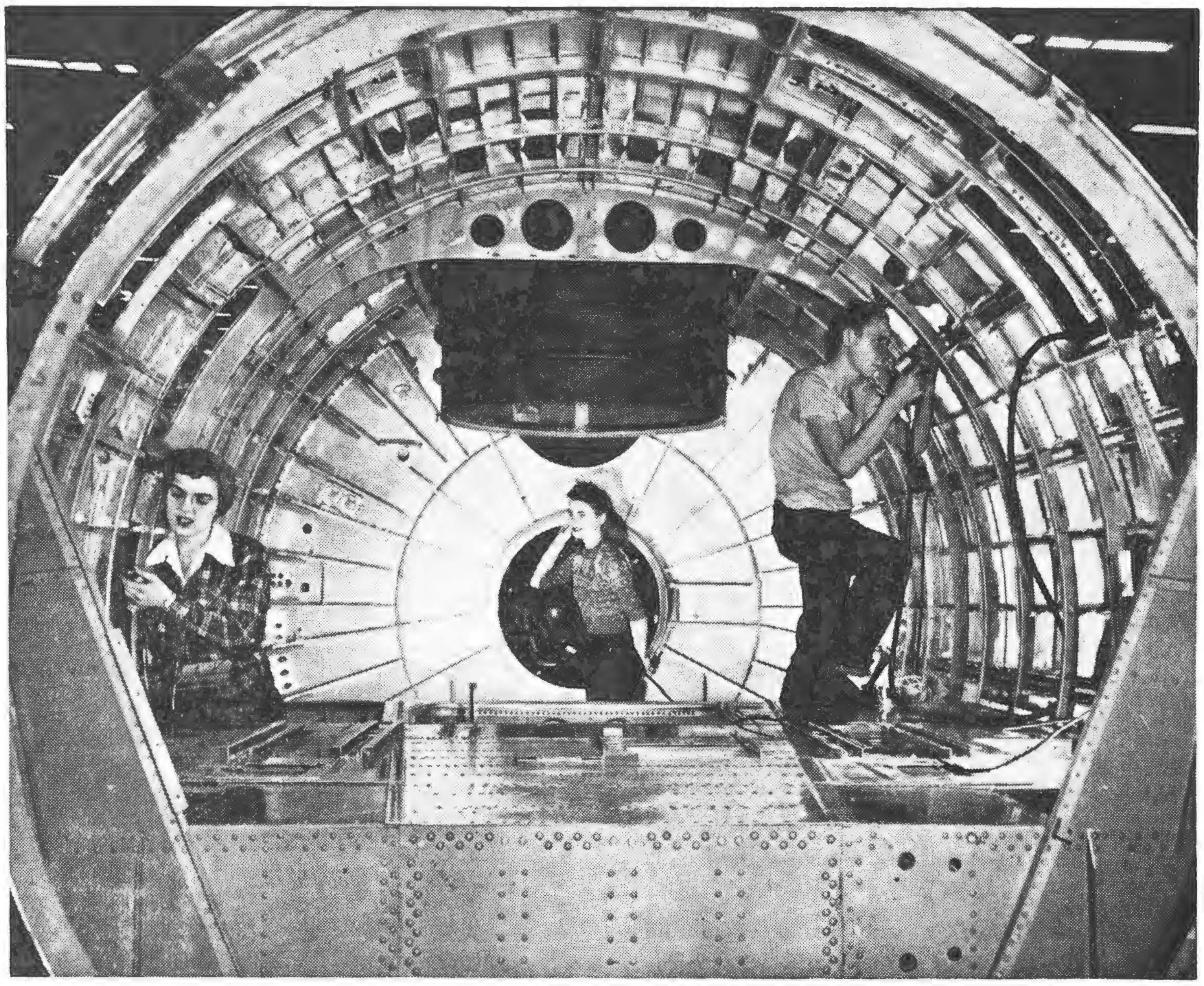


FIG. 3.—*A general view of assembly work in the pressurized portion of the B-29 fuselage. This illustration shows final riveting work in the upper barbette bay*

Pictures of the B-29 and C-97 in Production

FIG. 4.—*Weighing the C-97 (Stratocruiser). The neatness of this portable equipment for the weighing of such a large aeroplane is notable and may be studied in connexion with the article on pp.* 250–253. *It will be noted that the scales incorporate jacks, and that each unit is fitted with castors and handles for transport*

Tools for the Workshop

A Tyre-Removing Device

Beaching gear tyres for P.B.M. Mariner flying boats are being dismounted by one man in from 1 to 7 minutes as against the two men and 35 to 90 minutes previously required, at The Glenn L. Martin Company, Baltimore, Maryland, with the help of a new tool developed by K. H. Tidrick, the tool design methods engineer.

The new device consists of two pressure rings, slightly larger than the outside diameter of the wheel hub, mounted in an upright position on steel plates on a heavy girder base. One of the plates is fixed and the other movable; the fixed pressure ring having a 3-inch and the movable one a 2-inch depth.

The air is let out of the tyre to be taken off, which is rolled up on to the tool between the two pressure rings with the wheel hub centred. Pressure is applied through a horizontally mounted hydraulic jack at the centre of the movable pressure ring. The tyre is squeezed between the two rings to remove the bead from the wheel flanges on both sides of the tyre at once. The pressure is then released and four springs separate the pressure plates, permitting easy removal of the tyre from the tool. (Fig. 1).

Since the P.B.M. beaching gear is of split rim design, it is now a simple matter to unbolt the two portions of the wheel and complete the dismounting of the tyre.

As an added safety precaution, stops are provided at the four corners of the movable plate to prevent damage to the brake-drum casting through actual contact with the plates on which the rings are mounted.

Prior to the introduction of the new device, it was necessary for two men to break the tyre bead loose from the wheel flange with hammers and wooden wedges. Not only was this a time-consuming operation, but there was always a danger of damaging the tyre with the wedge. Savings achieved through the elimination of this damage are as important as those effected in man hours, since the new tool was built at a lower total cost than the value of two of these tyres.

While this new device was designed for the specific purpose of dismounting P.B.M. beaching gear tyres, it is obviously equally adaptable to any aeroplane tyre mounted on a split wheel, and should prove of value if generally adopted.

The P.V.E "Critic"

For the purpose of measurement of burnished or polished surfaces, or of those with a fine ground finish, the Pitter Gauge & Precision Tool Co. Ltd., of 39 Kingston Road, Leatherhead, have developed a portable optical surface finish analyser (for which patents are pending) which incorporates in one unit a light source, an optical system and reference lens, by means of which use is made of Interference Fringes of light for producing a series of bands, which follow exactly the minute differences present upon the surface under test; these bands being, in effect, a number of highly magnified (although distorted) pictures of the surface contours. With this method absolute accuracy of surface measurement is assured, there being no possibility of errors due to mechanical defects, or electrical faults, because the series of bands are, themselves, self-calibrating, the distance between each band depending upon the wavelength of the light being used, this dimension being practically constant for a given type of illumination under all conditions.

Consequently, although the overall magnification may be varied as may be required, the depth of surface finish may be immediately measured without reference to the variations, as the distance apart of the bands will always represent the same dimension.

The interference fringes are produced by means of a "reference" lens, the brightest and clearest fringes for highly reflective surfaces being obtained when the reference lens is coated on the side nearest the specimen under test with a reflective coating. This coating is not required, however, when examining glass or duller articles and the coating, to some extent, prevents a clear view of scratches, etc., which may be superimposed upon the background. Therefore, both coated and uncoated lenses are supplied, so that the user may have the most appropriate lens for any particular circumstances. It is recommended, however, that the coated lens be used wherever possible for photographic work, although, for ground finishes, the uncoated lens will give the best results, owing to the great difference between the reflecting powers of ground specimens and coated lenses.

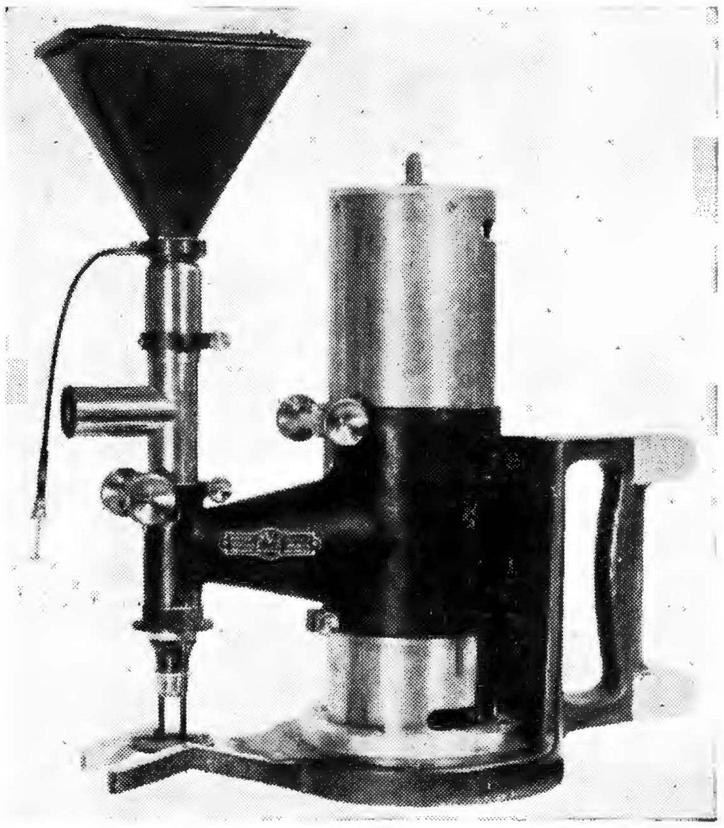


FIG. 2.—*The P.V.E. surface analyser with photographic attachment*

The illuminating source used is a sodium vapour lamp, which emits light of a wavelength of 5,896 a.u., resulting in spacing between bands for practical purposes of 0·000,012 inches. Sodium vapour lamps give off considerable heat whilst running, but the lamp-house has been so devised that the heat is dispersed without affecting the instrument, and, after several hours working, practically no increase in temperature is detectable at the eye-piece, whilst the outside of the lamp-house feels only slightly warm to the touch.

Two variations of the instrument are being made at present, one for visual operation only and one for visual operation with photographic attachment for the making of permanent records of the surface under test. (Fig. 2). The instrument, being quite light, and comparatively small, may be "taken to the job" and one of the great advantages of the P.V.E. Surface Analyser is that, for large shafts, rolls or flat surfaces, the instrument may be stood or rested upon the article under examination. During machining processes the analyser may be used for taking periodic checks until the required surface is obtained, when a photograph may be taken for record purposes, or as a guarantee that the part is to specification. The instrument will also just as readily deal with smaller components, which can be laid upon an anvil or vee block, beneath the reference lens.

This instrument may be used for the checking of surface finish of convex, concave and flat surfaces by means of the various special reference lenses provided.

Spacers with Micrometer Adjustment

Fig. 3 shows the new Euco Expanding Milling Spacer, with micrometer adjustment.

The calibrated scale, which can be clearly seen, is graduated in steps of 0·0005 in. This compares with the usual type of adjustable spacer which does not permit of finer variation than steps of 0·002 in. The Euco spacer, however, is capable of even finer adjustment than its engraved scale suggests. It is, in fact, infinitely variable and, the scale being comfortably open with nearly $\frac{1}{8}$ in. between markings, no difficulty would be experienced in achieving visual accuracy down to 0·00025 in.

Adjustment is effected by turning the outer sleeve —which moves telescopically on a fine thread—and can be carried out either on or off the arbour. When the desired setting is obtained it can be maintained indefinitely by means of the set-screw, which locks the expanding device firmly in position.

These expanding milling spacers can be used either alone, or in conjunction with ordinary spacers, depending on the desired width. The present range embraces two sizes: Model 1, covering from $\frac{1}{4}$ in to $\frac{5}{16}$ in. and Model 2, extending from $\frac{13}{16}$ in. to 1 in. Both models are supplied in various diameters, to suit most arbours.

These spacers can be obtained from Euco Tools Ltd., 11 Bedford Square, London, W.C.1.

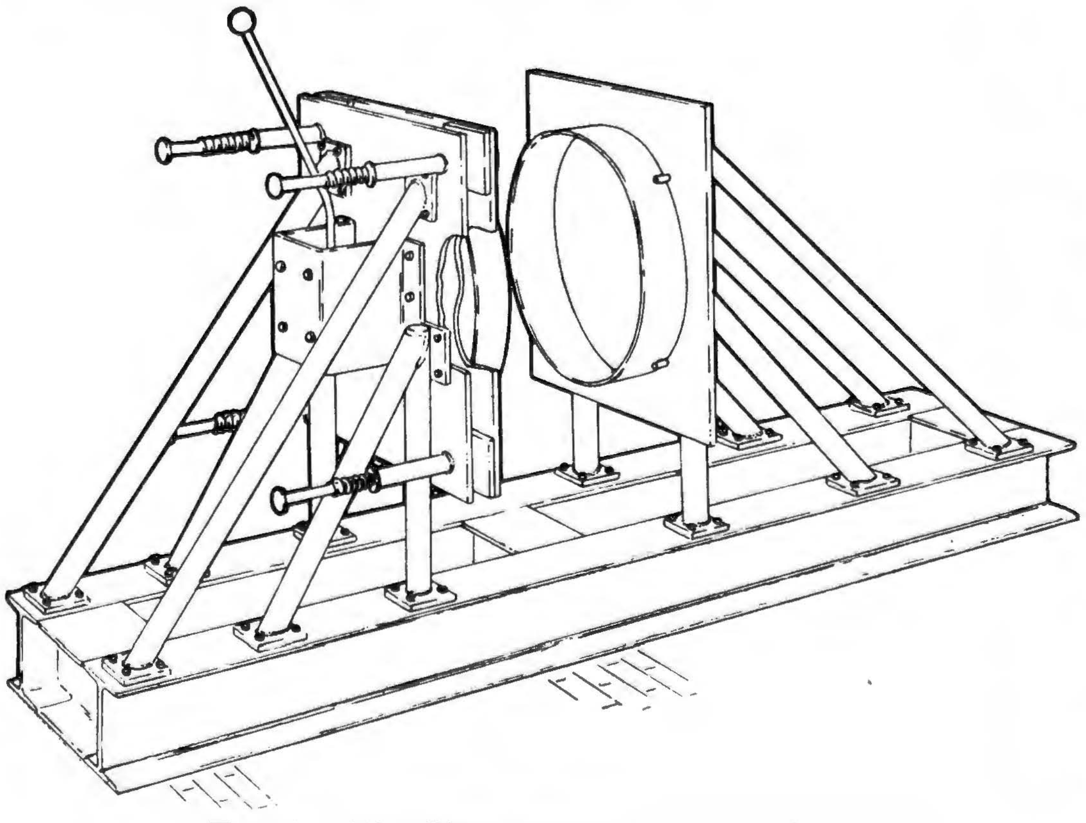


FIG. 1.—*The Glenn Martin tyre-removing set-up*

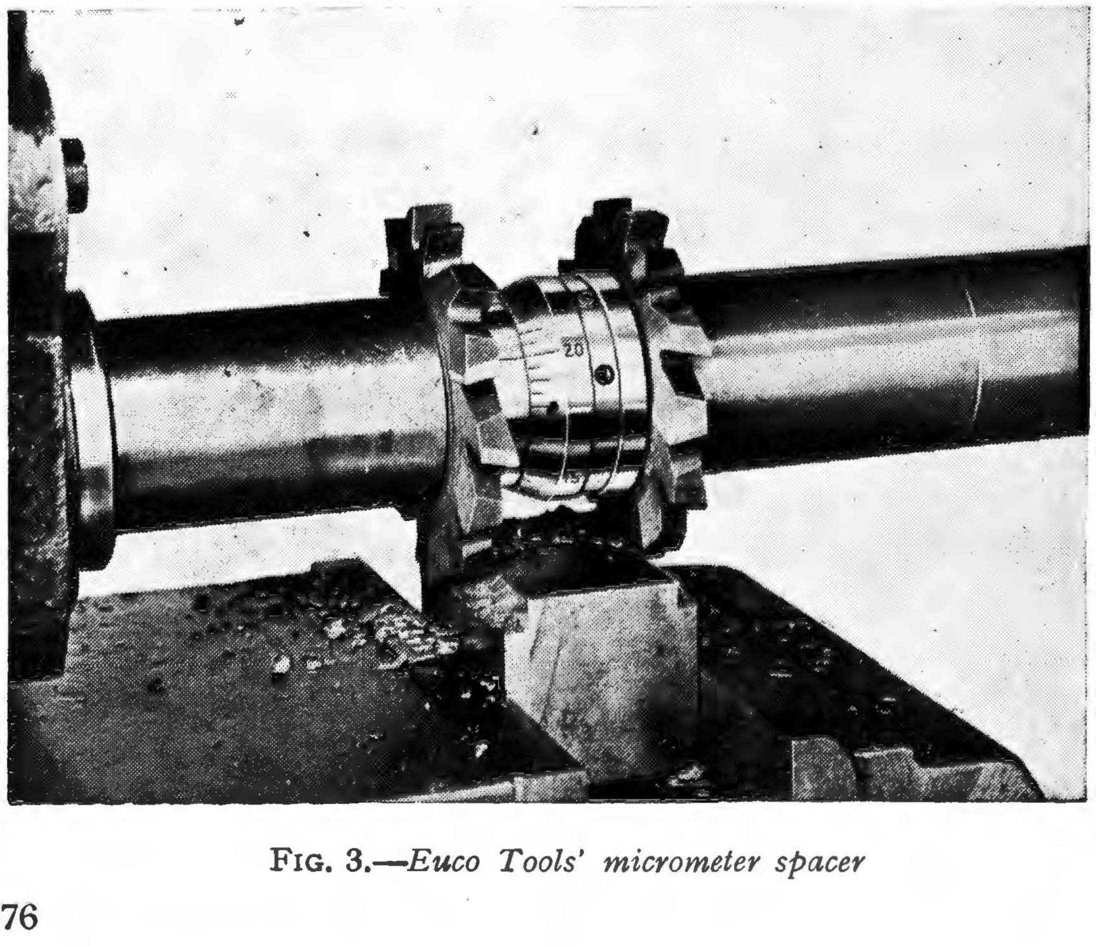
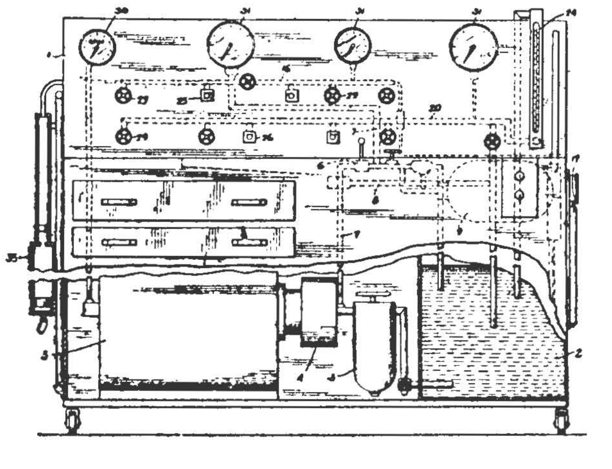


FIG. 3.—*Euco Tools' micrometer spacer*

U.S. Patent Specifications

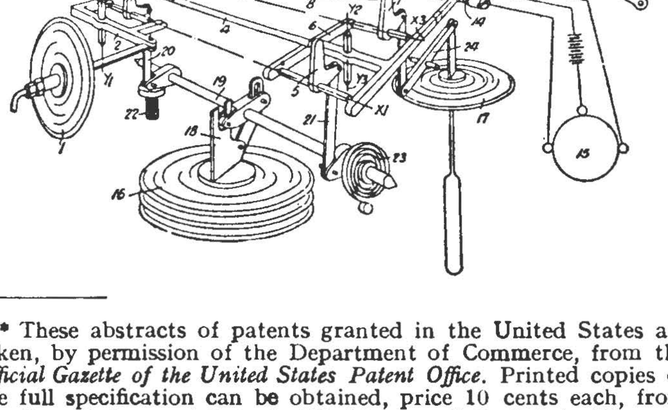


2,364,709. Portable Hydraulic Test Stand for Aircraft. Edward M. Greer, West Hempstead, Long Island, N.Y. Application June 24, 1943. Serial No. 492,084. 6 Claims. (Cl. 73—168.)

A transportable test stand for testing hydraulic appliances on aircraft which comprises a transportable frame, a reservoir for fluid under normal pressure mounted therein, three devices for supplying fluid under increased pressure; to wit, a high pressure variable flow pump associated with a motor, a low volume pressure pump adapted to be operated manually, and a hydraulic accumulator adapted to supply fluid under progressively decreasing pressure, conduits to feed fluid from said reservoir to said two first-mentioned devices, means to feed fluid under pressure from said first-mentioned to said third mentioned device, a plurality of pressure outlets in one of the outside walls of said frame, each including a self-sealing coupling, a plurality of return outlets in one of the outside walls of said frame, each including a self-sealing coupling, a free return line extending between all said return outlets and said reservoir, another return line extending between the same outlets and the same reservoir but including a flow meter, means to direct the return flow of fluid alternatingly through the first-mentioned and the second mentioned return line, and means, operable from the outside, to connect any desired number of pressure outlets to any desired number of devices.

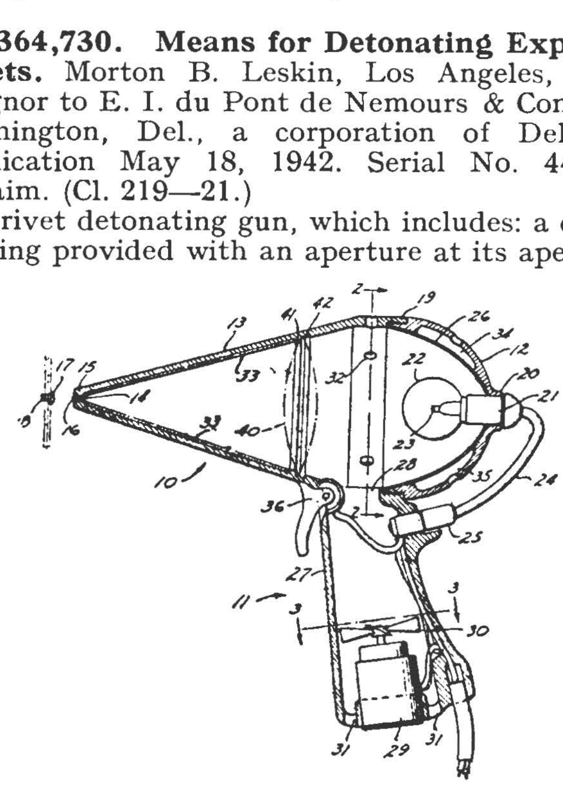
2,364,718. Automatic Control of Variable Physical Conditions. Harold William Ibbott, London, England, assignor to Negretti and Zambra, London, England. Application February 9, 1943. Serial No. 475,289. In Great Britain July 1, 1942. 5 Claims. (Cl. 74—1.)

Automatic control apparatus comprising a primary device responsive to changes in the condition to be controlled and exerting a force against resistance to its displacement which varies according to the state of said condition, mechanical linkage serving to transmit from a force-applying device resistance to said displacement, means adapted, when the force exerted by said primary device is out of balance with the resistance thereto, to vary the state of said condition in the sense of restoring balance, and at least one secondary device responsive to changes in another factor or factors required or be taken into account in the determination of the desired state of the first-mentioned condition, which latter device operates on the mechanical linkage to vary its leverage, said mechanical linkage comprising a pivoted frame about the axis of which there are opposed moments of forces, a member to apply one of these forces to the frame, said member being pivoted about an axis inclined at approximately right angles to the axis of the frame so that the distance of the line of action of the force from the axis of the frame varies when the pivoted member is rocked, the said forces being exerted by the said primary device and said force-applying device, and the said pivotal member being rocked through the agency of the said secondary device.



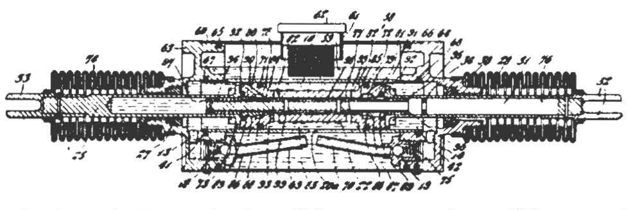
2,364,730. Means for Detonating Explosive Rivets. Morton B. Leskin, Los Angeles, Calif,. assignor to E. I. du Pont de Nemours & Company, Wilmington, Del., a corporation of Delaware. Application May 18, 1942. Serial No. 443,542. 1 Claim. (Cl. 219—21.)

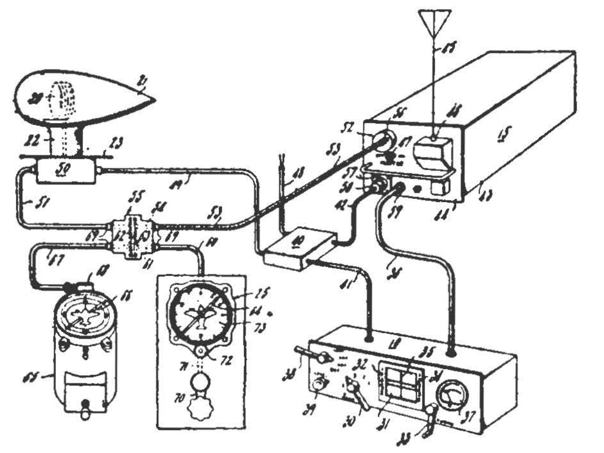
A rivet detonating gun, which includes: a conical housing provided with an aperture at its apex, and a seat for engaging a rivet head; a source of infra-red radiant energy disposed in the rear portion of said housing; a reflector in said housing for directing rays from said energy source and focusing the same on said rivet receiving portion of said cone; switch means for controlling the energization of said energy source; a handle attached to said housing and provided with a blower for directing a current of air through said housing upon the de-energization of said energy source; and switch means adapted to energize the circuit of said blower when said switch is open and to de-energize the same and energize the radiant energy circuit when said switch is closed.



2,365,247. Locking Device for Remote Control and other Force-Transmitting Systems. Quintin Healey Carlton, London, England, assignor to Automotive Products Company Limited, London, England. Application January 11, 1941. Serial No. 374,137. In Great Britain January 18, 1940. 12 Claims. (Cl. 192—8.)

A hydraulic locking device (Fig. 2) comprising a fixed cylinder having its interior divided into two compartments by a piston **22** rigidly integrated with a piston rod **25** whose inner end is in the path of movement of an operating member **32**; said piston also being integrated with a member **33** required to be operated, and further being integrated with a tubular piston rod **28** whose outer end terminates just short of, but in the path of movement of, the operating member **32**; said piston further being fitted with a pair of opposed by-pass valve members adapted to move axially into and out of engagement with corresponding annular seatings, these valve members being normally closed so as to prevent liquid flowing from one compartment to the other, and thus prevent movement of the piston in response to force applied through the member to be operated, said operating member being arranged, when moved, to open one or the other of the bypass valves so as to allow liquid to pass from one compartment of the cylinder to the other, characterized by the fact that each of the by-pass valve members is substantially cylindrical in shape, with one end normally in engagement with an annular seating on the piston, while the other end slides within a bore in said piston, the arrangement being such that the diameter of the said bore is substantially equal to the outside diameter of that area of the valve member engaging the annular seating, and the outside of the valve member between the seating and the said bore is subject to the Pressure of the liquid which is by-passed by said valve, so that the valve member, when closed, is in a balanced state as far as the said pressure liquid is concerned.



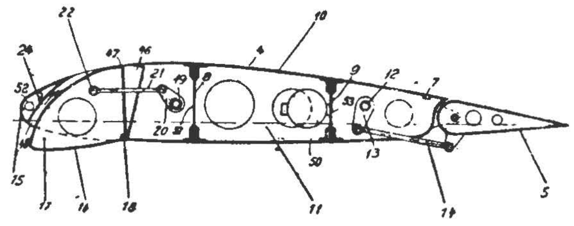


2,365,347. Radio Direction Indicator System. William P. Lear, Piqua, Ohio, assignor to Lear Avia, Inc., Piqua, Ohio, a corporation of Illinois. Original applications July 27, 1939. Serial No. 286,733, and December 28, 1940. Serial No. 372,059. Divided and this application January 18, 1943. Serial No. 472,715. 20 Claims. (Cl. 250—11.)

In combination with a rotatable directional antenna a reversible electric motor for controlling the rotation of said antenna; mechanism for manually rotating said antenna comprising a crank, a cable joining said crank with said antenna and a member normally uncoupling said crank from said cable; and an electromagnetic clutch in circuit with said motor mechanically coupling said antenna and motor when said motor is energized to rotate the antenna and normally uncoupling said motor from the antenna when the motor is de-energized.

2,365,382. Aircraft Plane. Ludwig Bölkow, Augsburg, Germany; bested in the Alien Property Custodian. Application July 30, 1941. Serial No. 404,695. In Germany August 2, 1939. 13 Claims. (Cl. 244—42.)

An aircraft plane comprising in combination a main plane, a wing nose pivoted to said main plane, an auxiliary front wing movably connected to the front face of said wing nose, means for swinging said wing nose for varying the camber of the plane, and means for selectively spreading said front wing from the front face of said wing nose to form a slot between said front wing and said wing nose.



2,365,494. Computer for Aircraft Load Distribution. Ernest W. Schlieben, Scarsdale, and William Friedman, New York, N.Y., assignors to York Research Corporation, New York, N.Y. Application January 1, 11944. Serial No. 516,626. 5 Claims. (Cl. 235—61.)

In an instrument for the determination of the horizontal position of the centre of gravity of an aircraft by means of load reactions caused by the weight of the grounded aircraft: a chart having two coordinate lines, each of said coordinate lines forming a circular arc around a different centre point and being calibrated according to values indicating the magnitude of said load reactions; two movable indicators on said chart, each associated with a different one of said coordinate lines and adapted to rotate around the centre point of its associated coordinate line and having an indicating line radially extending along each indicator, said indicating lines intersecting at each position of said indicators within the range of operation of the instrument; a runner on at least one of said indicators, said runner being adapted to slide radially on said indicator and having two intersecting hair lines, said hair lines being so arranged that the angle between them would be bisected by a line passing through their intersection and the centre point of the indicator on which said runner slides; a family of lines on an area of the chart over which the intersections

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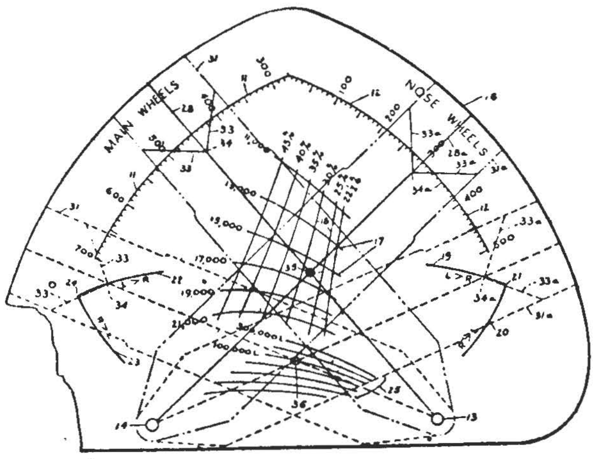
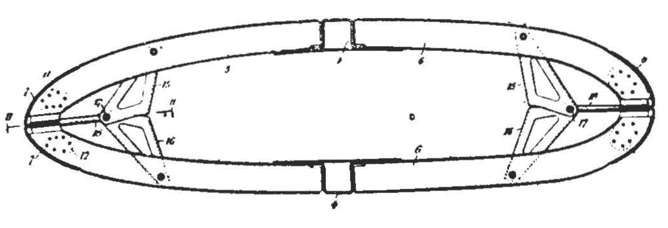
of said indicating lines move when the indicators are operated, each line of said family representing points of equal longitudinal positions of the centre of gravity of the aircraft as determined by the intersections of said indicating lines when set according to the given load reactions on said two coordinate lines; a second family of lines on said same area of the chart, each line of said second family representing values of the moments around the longitudinal axis of said aircraft as caused by said load reactions, said moments being determined by the intersections of said indicating lines when said indicators are set in accordance with the values of said load reactions, the setting of the indicators being determined by two pairs of curves on said chart within the operating area of said indicators, each pair of curves being associated with a different one of said indicators and enabling a setting of said indicators so that the angle between each indicating line and a reference line is always proportional to the difference between the values on the associated coordinate line to which the hair lines on said runners had been set.



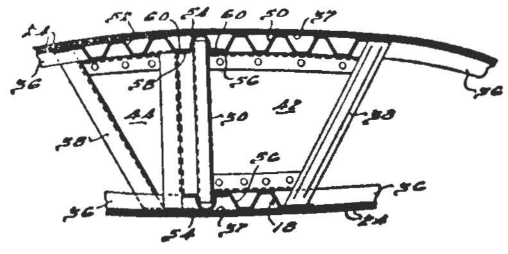


2,365,669. Aircraft Wing and other Control Surfaces of the Stressed-Skin Type. Barnes Neville Wallis, Weybridge, England, assignor to Vickers-Armstrongs Limited, London, England. Application June 8, 1942. Serial No. 446,236. In Great Britain March 28, 1941. 5 Claims. (Cl. 244—123.)

A basic structural framework for an aircraft wing or other control surface structure of the stressed-skin type comprising two longitudinal sections each forming a surface of the structure, said sections being formed as separate units, and means for rigidly connecting said sections along their longitudinal edges comprising pairs of jointed toggle members, one member of each pair being pivoted to one of said sections, a screw-threaded rod pivoted to each toggle joint, a nut threaded on said rod, and an abutment for said nut constituted at the adjoining edges of the assembled sections of the structure.

2,365,781. Spar Structure for Airplane Wings. Frank M. Smith, Dearborn, Mich., assignor, by mesne assignments, to Consolidated Aircraft Corporation, San Diego, Calif. Application May 9, 1941. Serial No. 392,679. 7 Claims. (Cl. 189—37.)

A spar structure for airplane wings comprising, in combination, a horizontally elongated vertically extending web formed from thin sheet metal and provided with corrugations extending transversely of its length, top and bottom flanges arranged with the general planes of their thicknesses transverse to the plane of thickness of said web extending longitudinally of said web and formed from relatively thin sheet metal and provided with corrugations extending in the direction of the length of said web, the upper and lower edges of said web being received within a corrugation of said top and bottom of said flanges, respectively, and being secured thereto.



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