Aircraft Engineering

K·E 965

SPECIAL HEAT-RESISTING STEEL FOR ALL TYPES OF INTERNAL COMBUSTION ENGINE VALVES, VALVE HEADS, INSERTS, RING SEATINGS AND TURBULENCE HEADS. K.E. 965 Valve Steel has more world records to its credit on land, sea and in the air than any other Valve Steel and is acknowledged by leading Engine Builders to be ideal for Valves, etc. working at high temperatures. At 900° Cent. this Steel gives the exceptionally high tensile value of 17·2 tons per square inch and at 800° Cent., 25 tons per square inch. It does not harden under any conditions and is therefore never brittle. It resists erosion to a remarkable degree. Also complete range of K.E. Valve Steels.
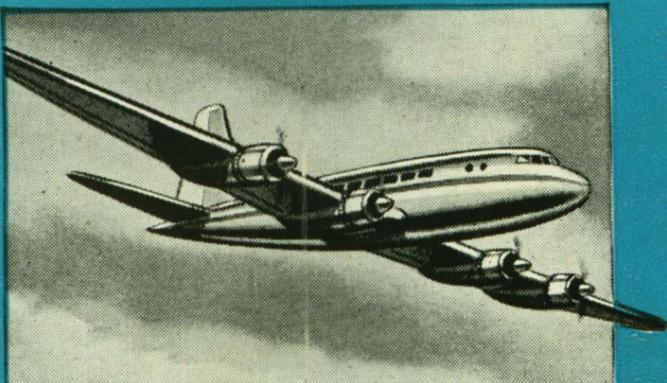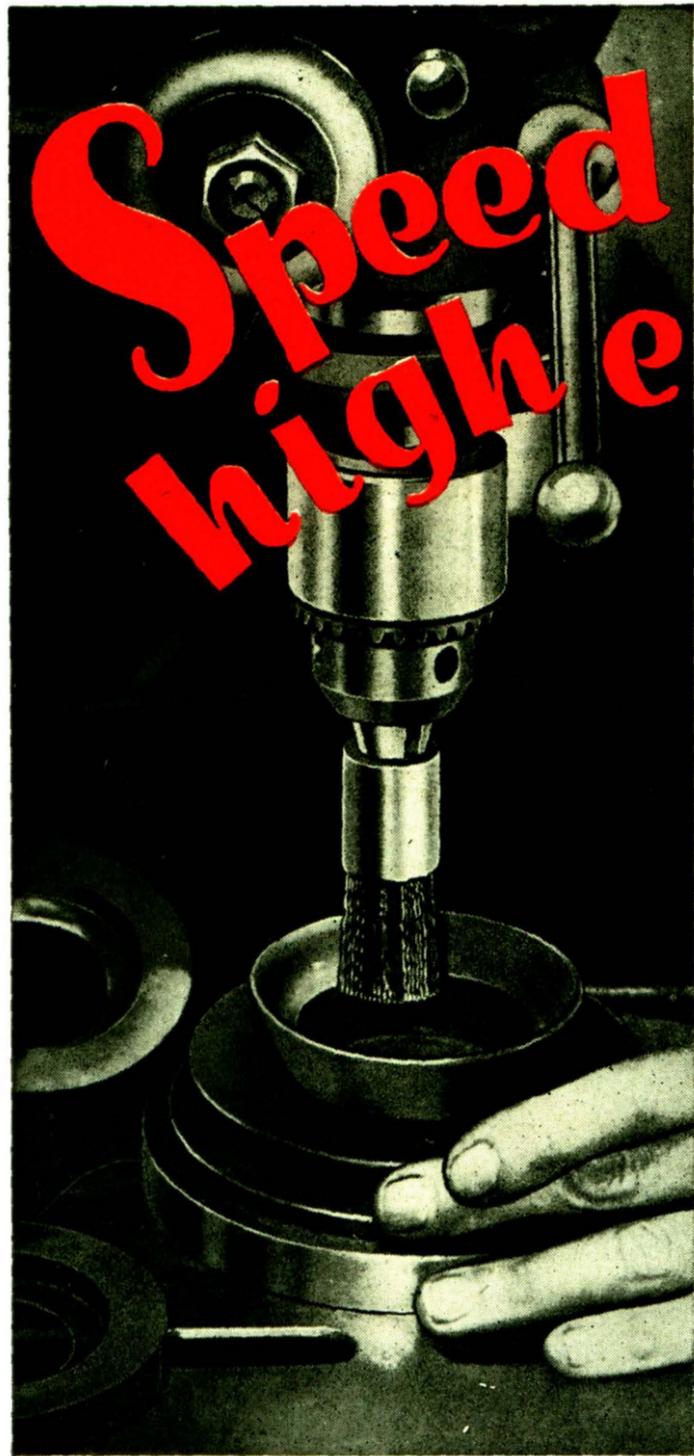
We also specialise in the manufacture of all types of Precision Ground Steels to the finest limits to meet the needs of modern automatic production.

K·E SPECIAL STEELS FOR VALVES.

TEST PIECES PULLED HOT AT 600-900°C.

COBALT CHROME — 965
241 CHROME SILICON
232 SPECIAL STAINLESS
1029 SILICON CHROME
STAINLESS STEEL

34·5 TONS PER □″ TENSILE AT 700°C

25 TONS PER □″ TENSILE AT 800°C

17·2 TONS PER □″ TENSILE AT 900° CENT.

MAXIMUM STRESS — TONS PER SQUARE INCH.
MAXIMUM STRESS — KILOGRAMMES PER SQUARE MILLIMETRE.

TEMPERATURE — DEGREES CENTIGRADE.
SOAKING 30 MINUTES.

KAYSER ELLISON & CO. LTD.

LET

SILENTBLOC

SAFEGUARD:-

INSTRUMENT PANELS
SWITCHGEAR UNITS
SENSITIVE RECORDERS

Distorted readings, damage to instrument and defects in switchgear, arising from the destructive force of vibration are eliminated when

SILENTBLOC ANTI-VIBRATION MOUNTINGS

form part of the design.

SILENTBLOC Anti-vibration Mountings present in a standard range of components a compact and convenient method of defeating all the serious effects of vibration.

Their unqualified success is due to the years of experience which have influenced their construction and to the feature exclusive to SILENTBLOC— viz. the method of pre-loading the specially designed rubber insert whereby the mounting is permitted to support the maximum load and to provide in a unit volume of rubber the greatest capacity for absorbing vibration.

Misani

SILENTBLOC LIMITED — VICTORIA GARDENS, LADBROKE ROAD, NOTTING HILL GATE — LONDON, W. 11. TELEPHONE PARK 9821 (4 LINES)

A branch of metallurgical science of great importance today is the study and manufacture of materials able to resist high temperatures. Most of the successful metals, of which Inconel and the Nimonic series of alloys are famous examples, contain nickel. Where your engineering problems involve high stresses and high temperatures ask for the advice of the pioneers in the manufacture of these nickel-containing materials, Henry Wiggin & Company Ltd., Wiggin Street, Birmingham, 16.

DWA1
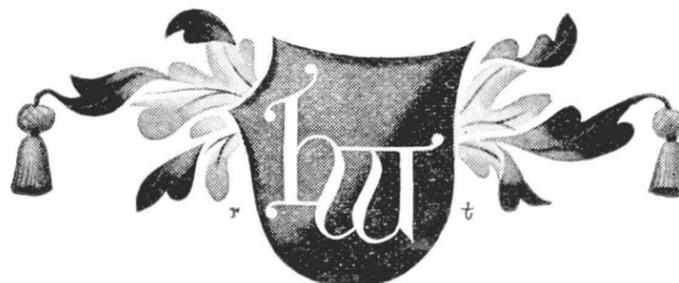
The Colossus of Rhodes

The Colossus of Rhodes was an immense bronze statue, over 100 ft. high, of Helios the Sun-God. It was set up in about 289 B.C. but fifty-six years later fell during an earthquake.

How surprised the ancient Greeks would be if they could see the extent to which engineering has developed since those far off days. Even the small components, which go to make up a highly complex engine, are fascinating in themselves. Terry's presswork, vital to almost every engine, has taken over ninety years to develop to its present standards of strength and accuracy. Each part is designed especially for the job for which it is required, and Terry's design hundreds of parts every year and produce them in millions. For expert advice on presswork, the leading firm to consult is Terry's.

TERRY'S FOR PRESSWORK
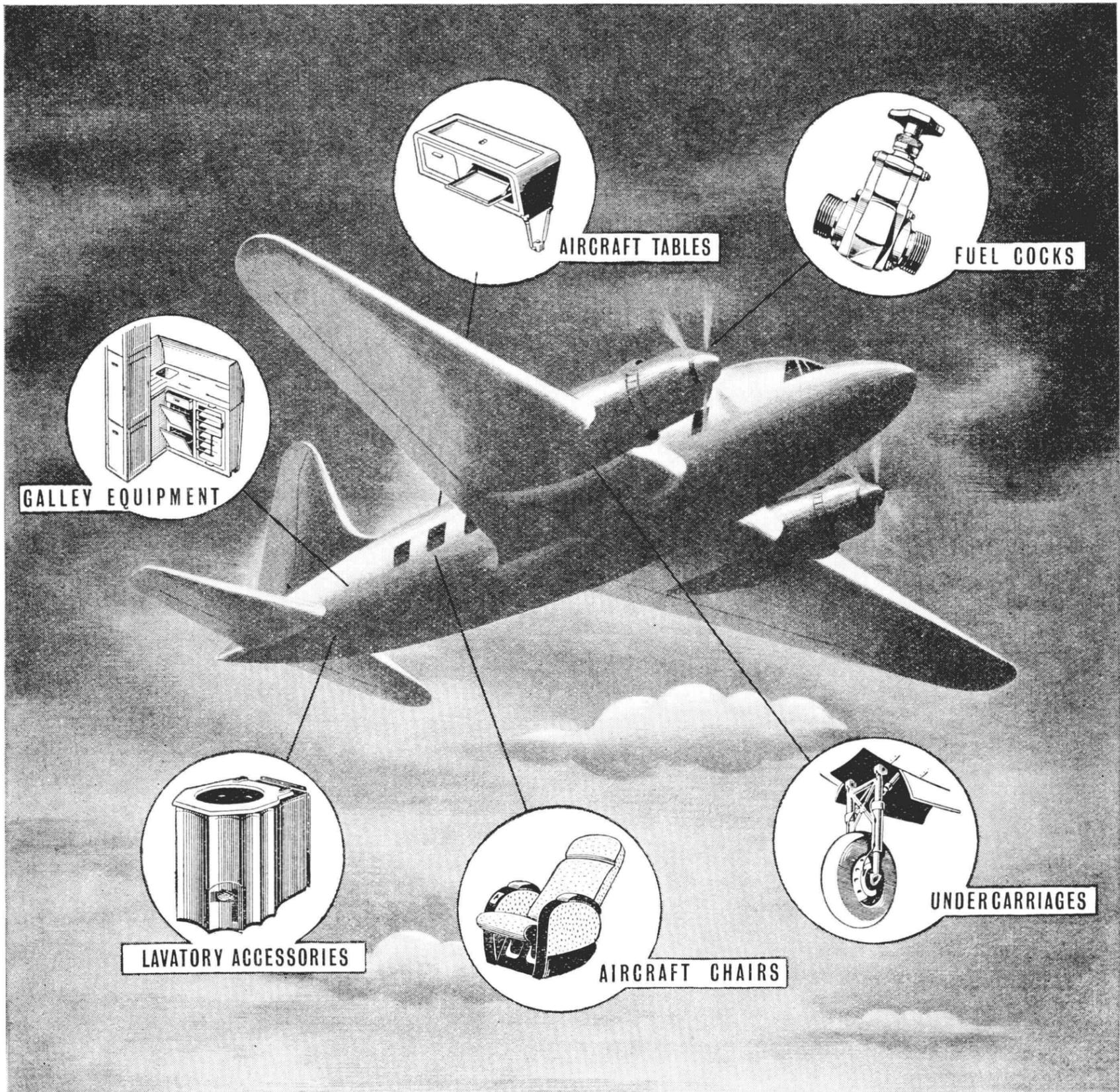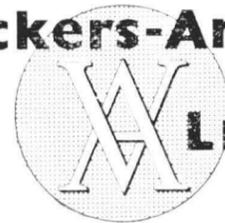
GOD FORGIVE YOU FOR GALLOPING WHEN TROTTING'S NOT A SIN   (*Scottish Proverb*)

If that were the reaction to the industrial developments of the last decade or two there'd be very little sympathy for Reynolds. Light alloys have been known for quite a while but only in recent years have they really come into their own.   Since the Reynolds Companies were founded, we have galloped (God forgive us) so fast that our extrusions, tubes, sheet and strip have become household words in many industries.   They still provide numerous opportunities wherever lightness and strength are required to gallop in double harness.

Reynolds
ALUMINIUM   AND
ALUMINIUM   ALLOYS
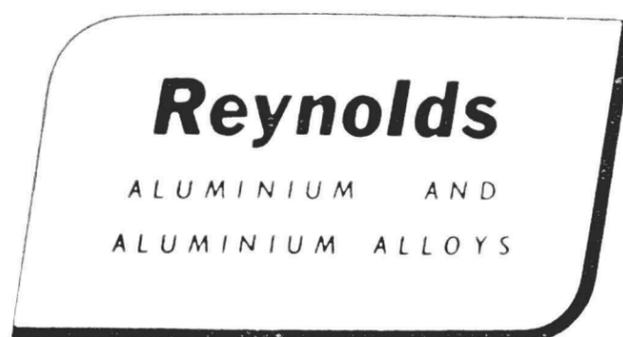
EXTRUSIONS, TUBES, SHEET & STRIP TO ALL A.I.D., B.S./S.T.A., AND B.S. SPECIFICATIONS

REYNOLDS ROLLING MILLS LTD. ⓉⒾ **REYNOLDS LIGHT ALLOYS LTD.**

Hay Hall Works, Tyseley, Birmingham.   Telephone: Acocks Green 3333

MEMO

"Bristol" used Tecalemit airframe lubrication throughout on their new Type 171 Helicopter
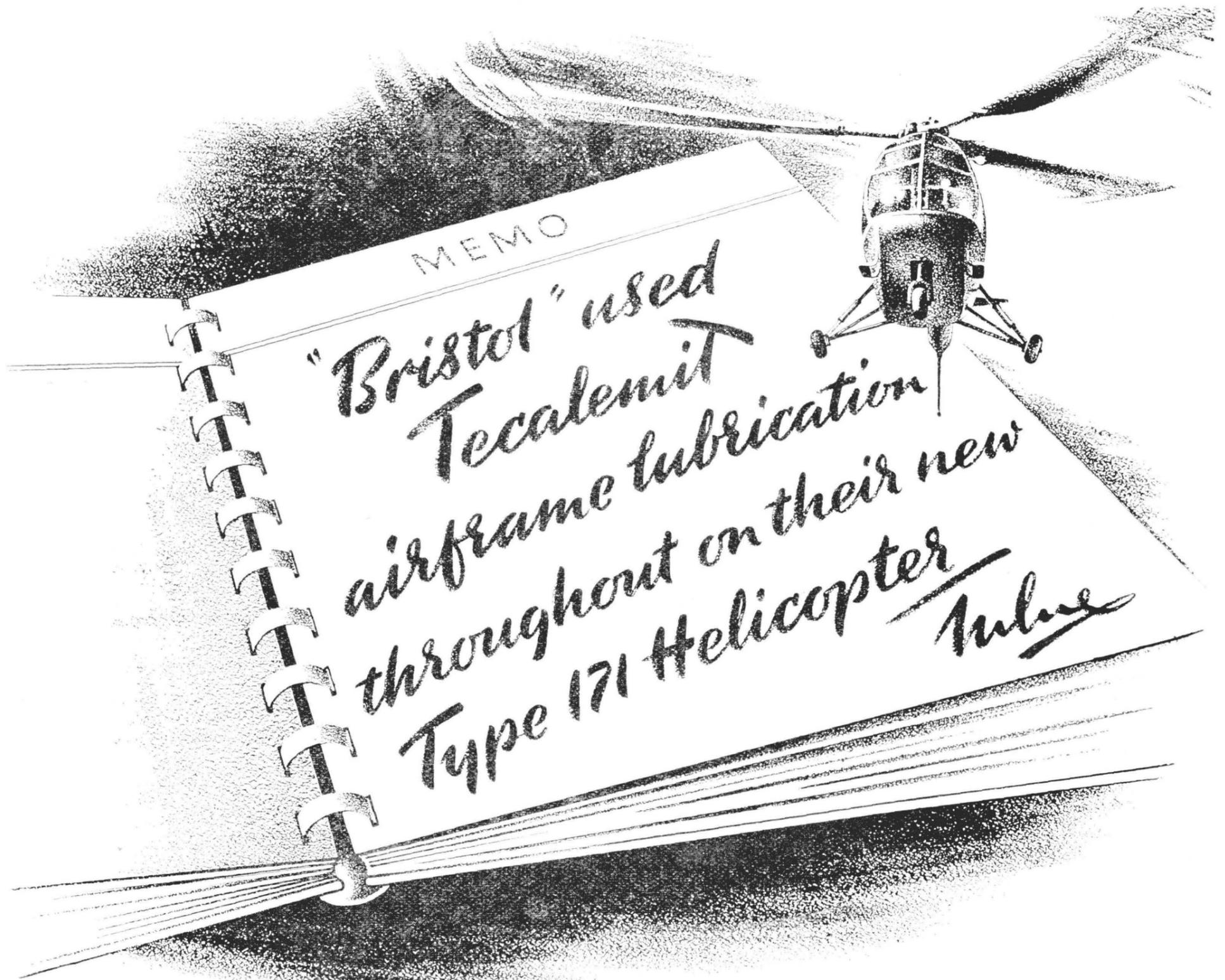
TECALEMIT
LIMITED

In addition to airframe lubrication systems which are fitted by all British Aircraft Manufacturers, Tecalemit Specialised Aviation products include Fuel and Oil Filters, 'Micro' Metering Oil Pumps and Fluid Flow Meters and Filters for Test House installations, together with compressed air and lubrication ground equipment.

TECALEMIT LTD., GREAT WEST ROAD, BRENTFORD, MIDDX.
PHONE: EALING 6661 (16 lines)   GRAMS: TECALEMIT, PHONE, LONDON

T.189c

This firm raised Cain . . .
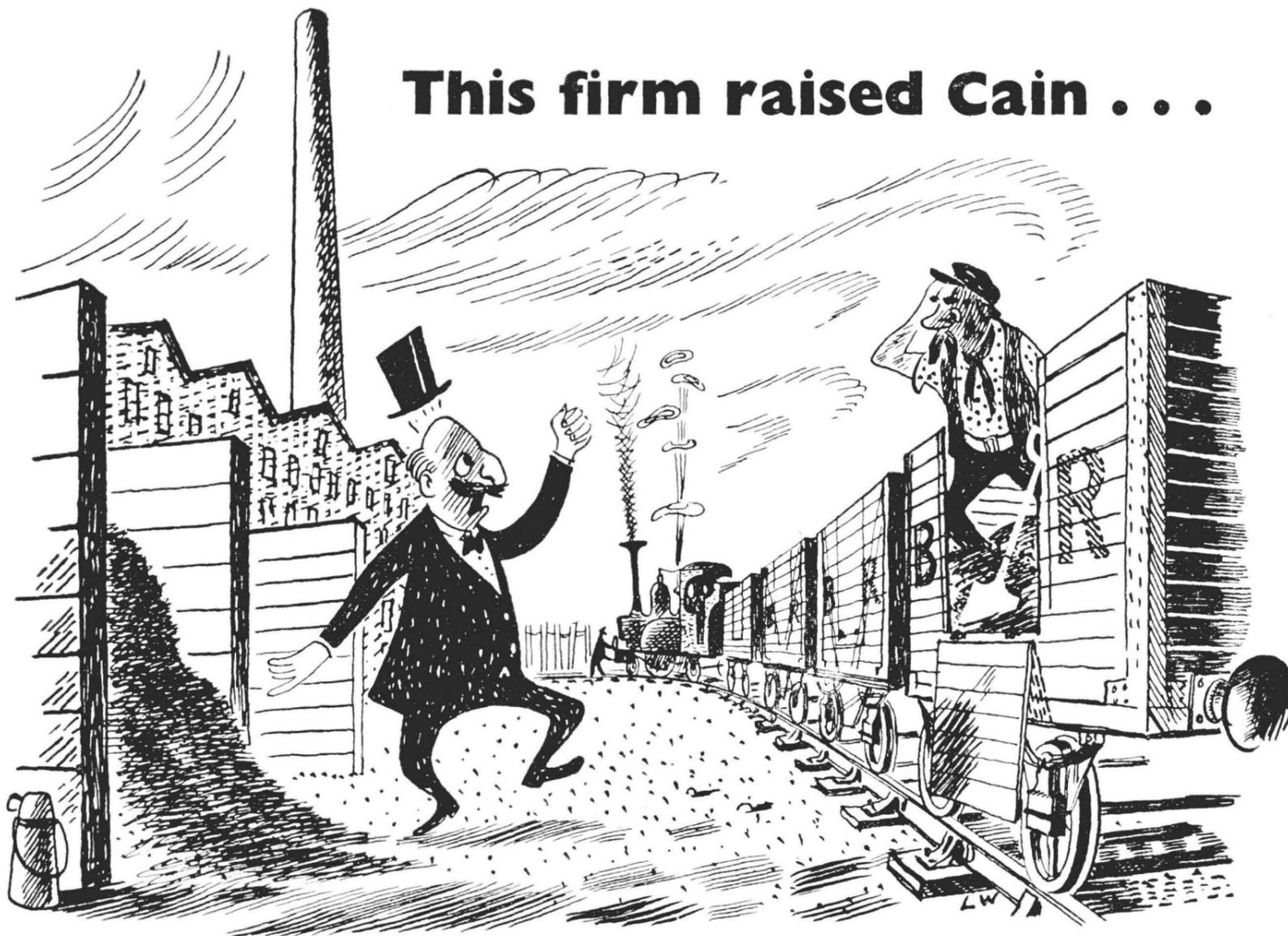
but the slacks raised steam!

A certain firm had always used good graded coals for boiler fuel, although there was no apparent reason why ord'nary boiler slacks should not be used. But when these were supplied, complaints of inability to raise steam followed post-haste.

The Ministry's Stoker Demonstrator was sent to invest'gate. He found that the flues had not been cleaned for five years and were so choked up that, even with graded coal, there was hardly sufficient draught! Cleaning the flues cured the trouble.

Of cou se *you* wouldn't make such a mistake, but wouldn't it be a good idea just to check over your plant? It is the simple errors that are so often overlooked—whether they are old legacies of the past that have been allowed to continue, or newer bad habits that have crept in unnoticed.

Why not call in the Ministry's Fuel Enginee.? His services are free, and, while you are under no obligat on to accept his advice, you would do well to consider it carefully. Even if your house *is* in order, it is nice to know it!

	REGION	ADDRESS	TELEPHONE
	Northern	Government Buildings, Ponteland Road, Newcastle-on-Tyne, 5	**Newcastle 28131**
	North-Eastern	Century House, South Parade, Leeds, 1	**Leeds 30611**
	North-Midland	Castle Gate House, Castle Gate, Nottingham	**Nottingham 46216**
	Eastern	Shaftesbury Road, Brooklands Avenue, Cambridge	**Cambridge 56268**
YOUR	London	Mill House, 87/89, Shaftesbury Avenue, W.1	**Gerrard 9700**
	South-Eastern	95, High Street, Rochester	**Chatham 3487**
REGIONAL	Southern	Whiteknights, Earley, Reading	**Reading 61491**
	Wales	27, Newport Road, Cardiff	**Cardiff 9234**
FUEL	South-Western	12/14, Apsley Road, Clifton, Bristol, 8	**Bristol 38223**
	Midland	Temporary Office Buildings, Hagley Road West, Birmingham, 17	**Bearwood 3071**
OFFICE	North-Western	Burton Road, West Didsbury, Manchester, 20	**Didsbury 5180-4**
	Scotland	145, St. Vincent Street, Glasgow, C.2	**Glasgow City 7636**
	Scotland	51, Cockburn Street, Edinburgh, 1	**Edinburgh 34831**
	Scotland	1, Overgate, Dundee	**Dundee 2179**

ISSUED BY THE MINISTRY OF FUEL AND POWER

Down to 1·8 for the Duplex Shock-absorber
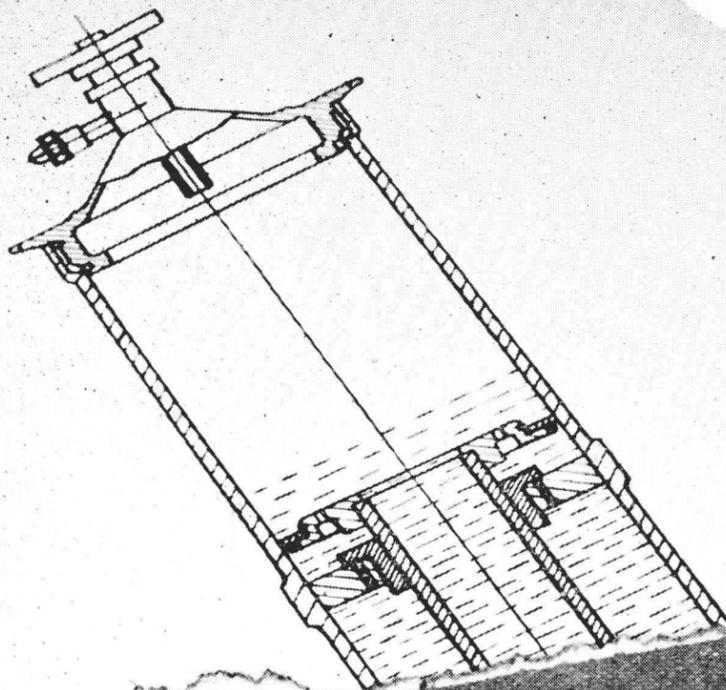
8.2.3 For the braked conditions of Case 4 the unfactored shall be taken as

$$R_2 = W_2 \frac{l_m + 3H\frac{D_B}{W_2}}{l_n + l_m}$$

where W_2 ... maximum take-off weight of aeroplane
l ... horizontal distance of c.g. from nose wheel
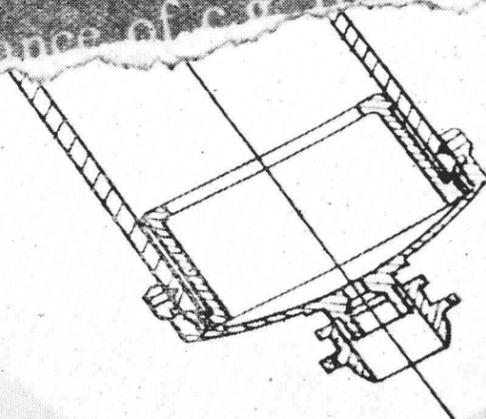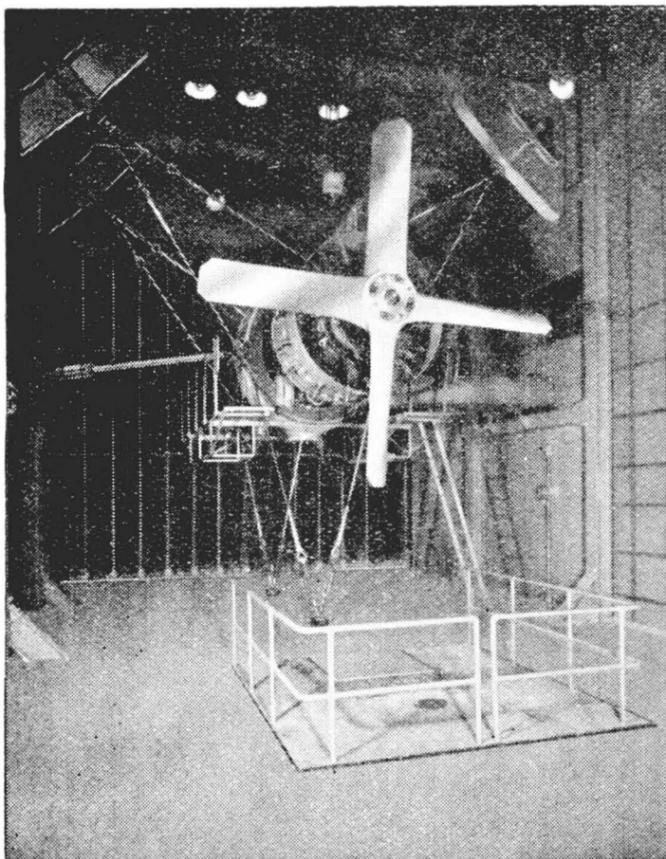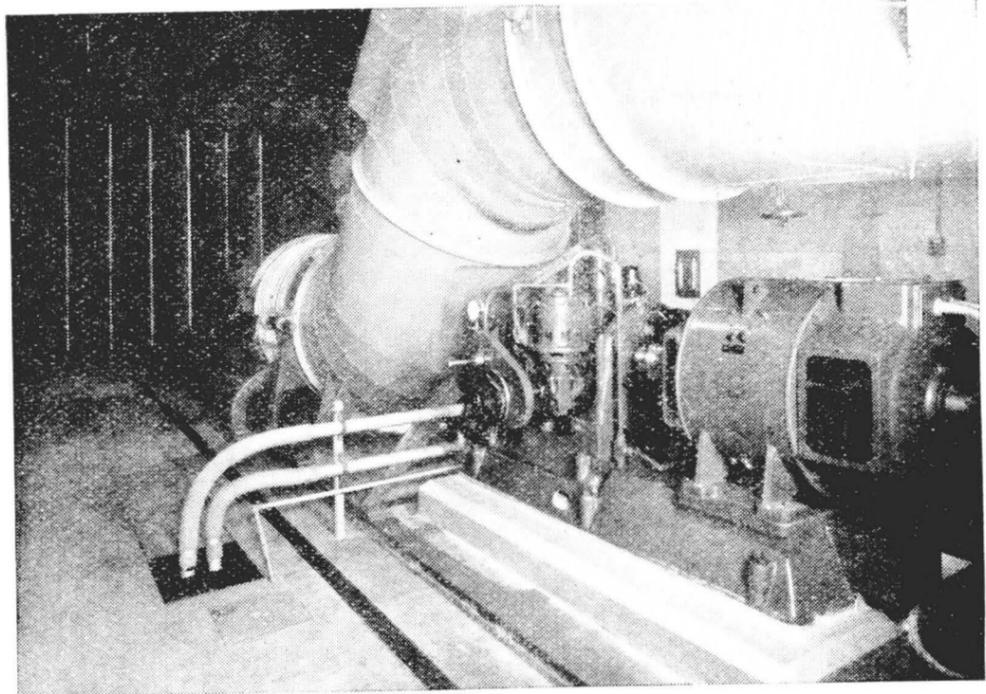
SIP HYDROPTIC 'B'

at MESSRS. J. L. JAMESON LTD.
PRECISION   ENGINEERS
EWELL   SURREY

BORING, FACING & DRILLING OPERATIONS TO A·I·D LIMITS INVOLVING COMPOUND ANGLES ON THE GEAR BOX FOR THE PROTOTYPE CIERVA HELICOPTER*

* Called The Air Horse, this machine is said to be the largest of its type in the world. It is a 24-seater and has three rotors, powered by a Rolls-Royce Merlin engine.

SEE OUR EXHIBIT
MACHINE TOOL & ENGINEERING
EXHIBITION
AUG. 26—SEPT. 11
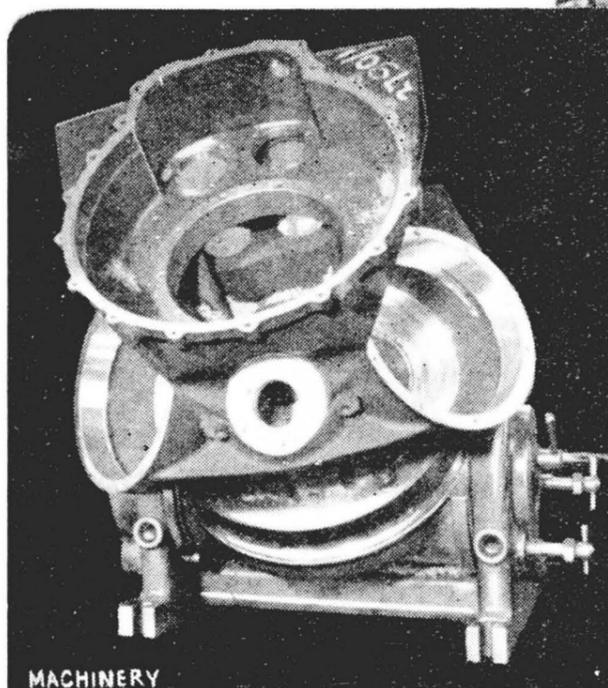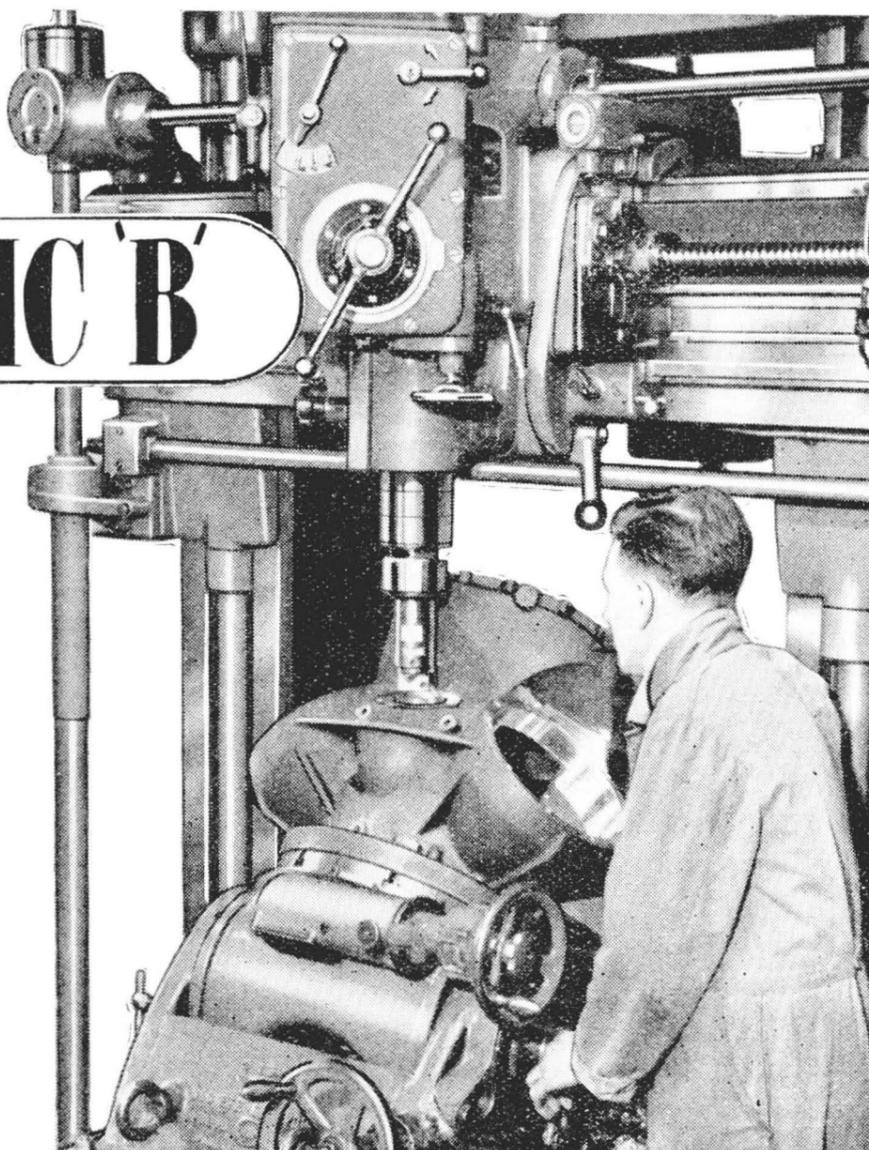
The Hydroptic "B" enables milling, boring, facing, and drilling operations to be carried out to the highest standards of accuracy. All settings made optically on scales accurate to 0.00005in. Table is hydraulically actuated. Controls are simplified so that the machine can be easily and efficiently operated.

MACHINERY

SOCIÉTÉ GENEVOISE LIMITED 5-6 BRETTENHAM HOUSE, LANCASTER PLACE **LONDON W.C.2**
Telephone: TEMPLE BAR 2126-7   Telegrams: SOGENIQUE RAND, LONDON

CONTENTS

BOOKS

AN INTRODUCTION TO AERODYNAMIC COMPRESSIBILITY. By J. Black. Price 18s. 0d. (19s. 0d. post free).

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

REPRINTS—The following reprints from AIRCRAFT ENGINEERING are available:

SHEET METAL FORMING IN THEORY AND PRACTICE. Price 2s. 6d. (2s. 8d. post free).

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

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

QUALITY CONTROL. By H. S. Phillips. Price 9d. post free.

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

NOTES ON THE GOBLIN JET ENGINE. Price 6d. post free.

UNDERCARRIAGE RETRACTION MECHANISMS. By H. G. Conway. Price 1s. (1s. 2d. post free).

RATE OF ROLL OF AEROPLANES. By W. T. Thomson. Price 6d. post free.

MECHANICAL SEALS FOR SHAFTS. By F. E. Burger. Price 6d. post free.

REPAIR OF THE D.H. MOSQUITO. By A. J. Brant. Price 1s. post free.

MANUFACTURE OF THE DOVE LIGHT TRANSPORT. Price 1s. post free.

DEVELOPMENT OF THE SHOOTING STAR. Price 1s. 6d. post free.

USEFUL CONVERSION FACTORS FOR THE SLIDE RULE

Multiplication factors for the conversion of British into Metric units and vice versa, printed in red and black on stout card with a cord for hanging. Price 6d. post free.

INDEX TO ADVERTISERS

QUIS CUSTODIET IPSOS CUSTODES? *

✳ You were on the Science side at School? Well, no doubt that was your parents' fault. Anyway we'll translate it for you. It means "Who inspects the inspector?"

At Holroyd we keep a constant and vigilant eye on our "watchers". Each gauge, micrometer, every instrument we use for testing is itself tested regularly. So when a test instrument says that something is 2 tenths of a "thou" out, you may be sure it *is* 2 tenths and not 3 or 1. And you may also be sure that it will be put right before it gets past the Holroyd Watchdogs.

The photograph illustrates the routine inspection of gauges used in our works, by comparison with a master set on a comparator. Inspection of all gauges, micrometers, etc., takes place at definite intervals and a record is made of every check.

HOLROYD GEARS

PASS THE TESTS and so do the test instruments

JOHN HOLROYD AND COMPANY LTD · MILNROW · LANCASHIRE

CRC. 122

FLAMEPROOF HOSE FOR TEST

NATURE OF TEST ....

TEMPERATURE .... 1000° C
INTERNAL PRESSURE ... 300 lb. p.s.i
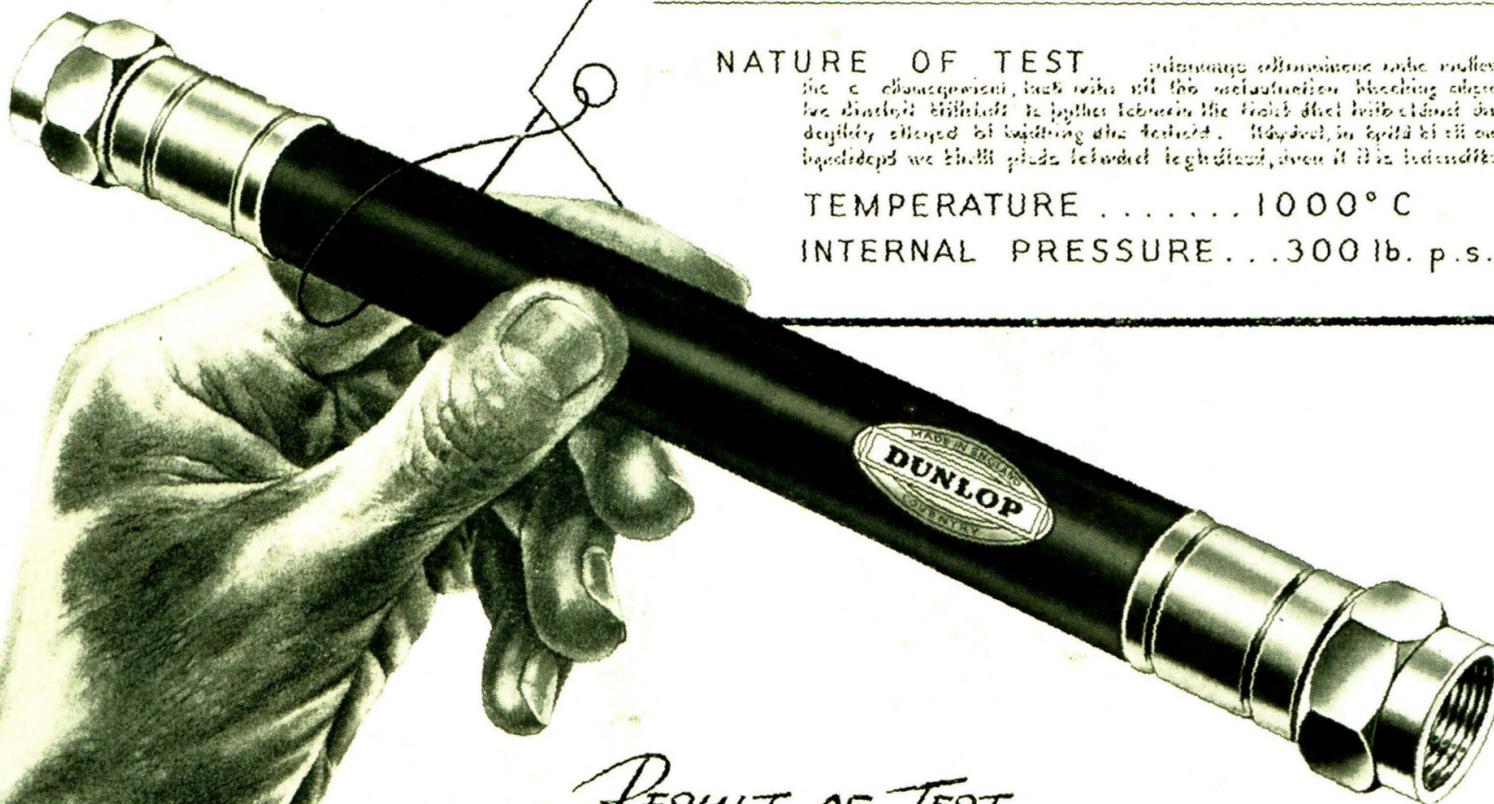
Result of Test

After 90 minutes, no sign of failure or leakage

DUNLOP RUBBER COMPANY LIMITED

DUNLOP *Flameproof* **HOSE ASSEMBLY**

AVIATION DIVISION, COVENTRY
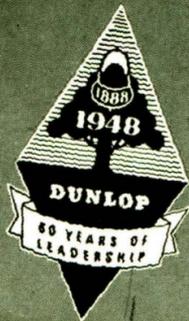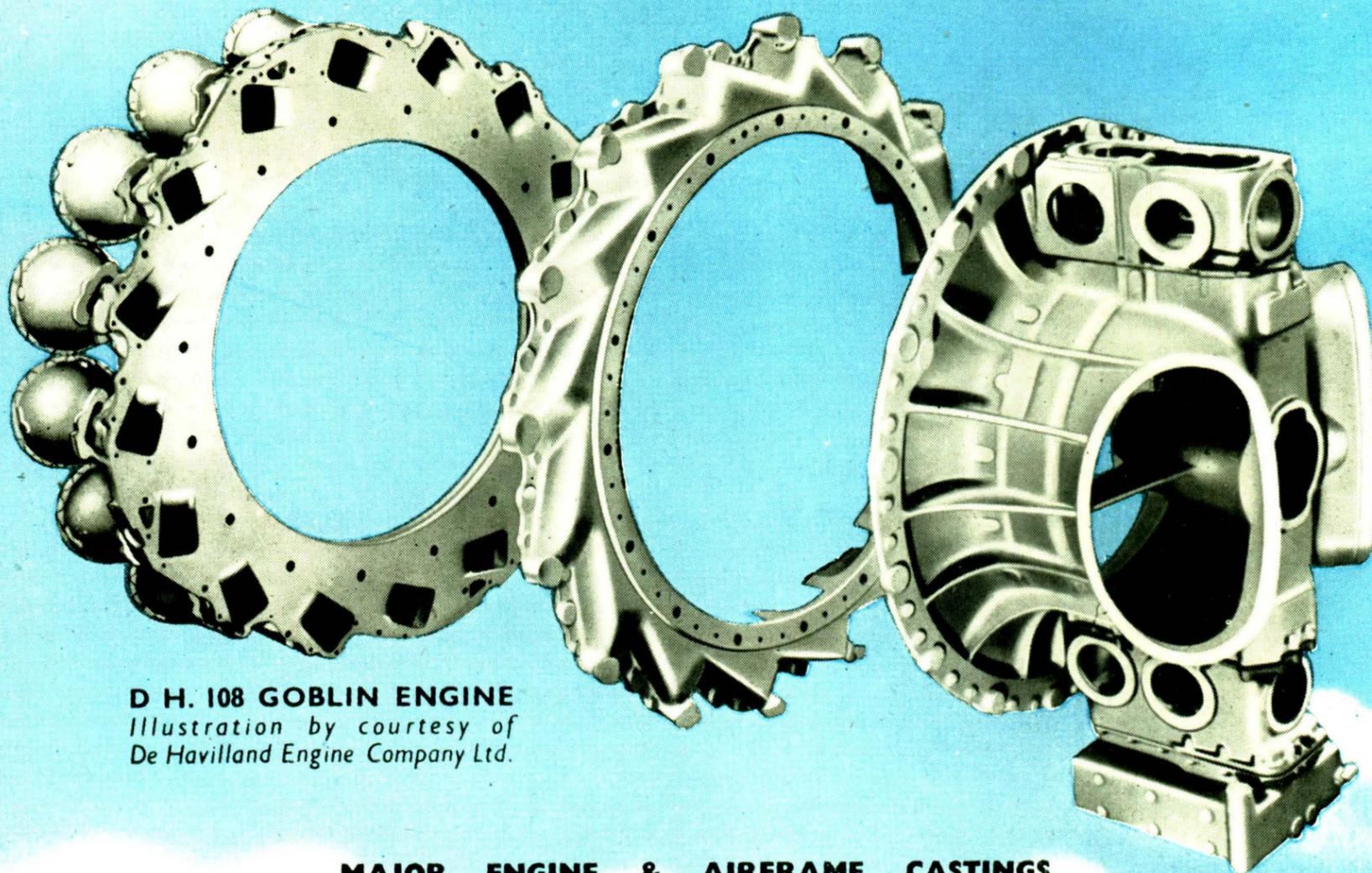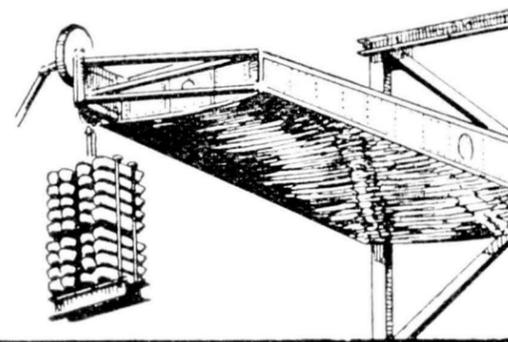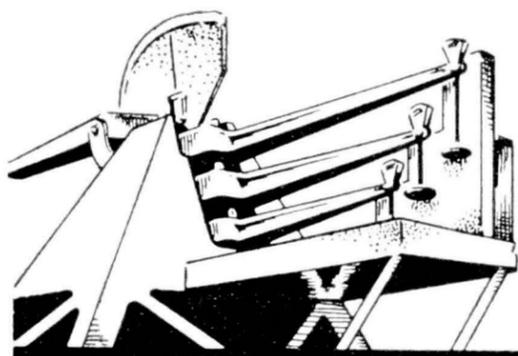
Tribute to a Pioneer

TO those who have grown up with aeronautics the name of GENERAL CROCCO is almost a legendary one, and he is in historical fact contemporary with the WRIGHT BROTHERS since his investigations into the subject date from the very beginnings of the century, as is evidenced by the fact that he took out his first patent on the control of aeroplanes in 1903. He followed this in the ensuing year with a famous paper on the stability of airships read before the Académie des Sciences, and one on the theory of aeroplane flight; while the catholicity of his early interests is further shown by his association with RICALDONI in a series of experiments with airscrews mounted on a hydroplane, for the construction of which he was partially responsible, on Lake Bracciano in 1907. When it is recalled that in 1906 he was concerning himself with the phenomena of auto-rotation in connexion with helicopters, the breadth of his outlook on aeronautical problems, and his astonishing prevision, is manifest. For many years he was, of course, chiefly known for his association with a series of ingeniously designed semi-rigid airships produced by the Italian Government, but his interest in heavier-than-air flight throughout his career found outlet in innumerable articles. In recent years he has been particularly associated with the allied phenomena of stratospheric and supersonic flight; as witness his paper entitled 'Flying in the Stratosphere', which we had the privilege of publishing in AIRCRAFT ENGINEERING in July 1932.

A Pleasant Memory

In view of his eminence, judge then of our gratification (as our French friends might say) when we were a few months ago honoured by his calling on us with the suggestion that we should publish a translation of three papers he had read before the Accademia Nazionale dei Lincei. The somewhat delayed outcome of this visit (which we recall with vivid pleasure of a conversation carried on with an exceptionally courteous gentleman in a strange admixture of, if we may say so, faulty French on both sides, a little English and still less Italian) is the article on 'Passing Through the Sonic Barrier' which appears in this issue. It is written in the delightful literary style which seems to have been almost the monopoly of Italian scientists from the time of LEONARDO DA VINCI onwards, a very large measure of the charm of which has been retained in the admirable translation by MR LIONEL MOTE, who has an unusual flair for reproducing the style of a foreign original in idiomatic English; more particularly perhaps when he is dealing with Italian.

We do not think the article has lost any of its interest through the elapse of two years since the first of the original papers was written, because, as with all his work, GENERAL CROCCO is dealing with the stuff of which fundamentals are made.

An Intriguing Project

Now that Americans have successfully survived flight at a speed beyond that of sound, though in what precise circumstances and in what attitude has not yet been divulged, the theories and suggestions in regard to control and economics in supersonic flight are becoming of more than purely academic interest. For this reason the glimpse into the future, which here appears as Part III of the consolidated article, of the intriguing possibility of flight without, as the author delightfully puts it, 'the assistance' of wings is of considerable importance. The present writer may be pardoned for taking a special interest in this discussion on account of the fact that some years ago he was severely taken to task, in the course of the discussion following a lecture on the subject of speed, for venturing the opinion that in the ultimate development it was a little difficult to be sure where the aeroplane ceased to exist as such and became merely a projectile. Leaving aside that debatable question, we do not remember having previously read a serious examination of the problems of controlling and economically utilizing an aircraft which depends for its lift as well as its power on a turbo-jet engine.

While yielding place to others more competent than ourselves to examine the fundamental soundness or otherwise of GENERAL CROCCO'S reasonings, we are content to point out that in all his long career, though notable for his foresight and advanced ideas, he has never shown himself purely a visionary, and many of his early theories, which received little acceptance at the time when he originally propounded them, have since become the commonplaces of knowledge.

A Splendid Idea

The possibilities are at least, it will be admitted, fascinating to contemplate. As GENERAL CROCCO himself well puts it, the fact that it does not appear possible at the present stage to adopt completely the theoretical project outlined of the reduction of the aircraft to a simple fuselage containing the jet engine, this difference between the practical and the theoretical does not make less interesting the possibilities outlined. One consummation at any rate that we feel is devoutly to be wished—as our readers will have gathered from what we wrote last month—is envisaged in the author's pregnant phrase summing up one aspect of his simplified aircraft: 'There is, therefore, no need for aerodromes either for take-off or landing.'

We feel that those of our readers who are not aware of the fact will be glad to know that in LUIGI CROCCO there is a successor ready to follow in his father's footsteps who has already started to make his name, since he was before the war author of several reports in the well-known series of 'Atti di Guidonia', and there appeared in these columns only last month a summary of a report from his pen on the characteristics of gas turbines.

THE S.B.A.C. DISPLAY SEPTEMBER 7—12

The Editor and staff of AIRCRAFT ENGINEERING will be pleased to welcome readers at STAND NO. 117 in the WEST EXHIBITION HALL at Farnborough, where we hope to renew old acquaintances and to make new ones among the members of the Aircraft Industry at home and abroad. As it is always difficult on these occasions to make contact with one's friends, we shall be happy to place ourselves at the service of those who may require a rendezvous and wish to leave messages.

Passing Through the Sonic Barrier[*]

Three Papers Presented at Meetings of the Accademia
Nazionale dei Lincei, on April 18th, 1946, and
January 11th, 1947, by G. A. Crocco

Part I The Jet Propulsion Engine

IN a study of high-speed flight presented to the Accademia dei Lincei in 1926 (G. A. Crocco, *The Possibilities of Super-Aviation*, February 7th, 1926) an outline was given of the problem of 'super-aviation', i.e. flight in excess of the speed of sound and made economical by operating in the stratosphere. Then in 1931 (G. A. Crocco, *Aerodynamic Bodies of Negative Resistance*, Rendiconti Lincei, June 12th, 1931), a jet-reaction engine in which the external air was entrapped was described as representing a possible solution of this problem; the principle was indicated diagrammatically as long ago as 1931 by Lorin.

In a similar jet engine, which utilizes the pressure of the entrapped air and provides subsequent cooling in order to increase the jet velocity, the efficiency increases with the flying speed; at supersonic speeds it becomes equal to or even greater than that of the normal engine-airscrew combination.

The main difficulty in the operation of such an arrangement, which is without mechanical moving parts, was produced by the low efficiency at low speeds, it being always necessary to associate it with an auxiliary engine-airscrew combination for starting and take-off.

Today this difficulty has been overcome by the adoption of a turbine-compressor combination which, by supplying the necessary pressure for take-off so that the jet unit becomes autonomous, makes it unnecessary to provide aircraft with auxiliary engines and airscrews.

It follows that when a certain flying speed is reached, the pure athodyd may replace the turbo-jet unit.

In the present note it is intended to study this important problem and to indicate the theoretical possibilities of flight at supersonic speeds.

From this point of view a mathematical treatment of the turbo-jet and athodyd will be developed, with the introduction of some simplifying limiting assumptions.

It will be assumed that the air velocity in the combustion chambers is negligible at the burners, that the increase in temperature τ due to the ram effect and the increase θ due to the effect of the mechanical compression in the compressor are both adiabatic, and that the value θ and the kinetic efficiency of the ducts are constant. It will also be assumed that in providing the power required by the compressor, the turbine will be subject to a decrease in temperature exactly equal to θ and finally that the pressure at the final discharge nozzle will be equal to the ambient pressure.

Let, therefore, T_0, V_0 and ρ_0 be the external absolute temperature, air velocity and pressure respectively; T_1, ρ_1 the temperature and pressure due to the ram effect, T_2, ρ_2, the temperature and pressure reached after the compressor, T_3 the temperature reached after the increment ΔT supplied by the burners at pressure $\rho_3 = \rho_2$, T_4, ρ_4 the temperature and pressure at the exit from the turbine and finally T_5, V_5, $\rho_5 = \rho_0$ the temperature, air velocity and pressure at the exit from the jet-pipe, all measured in degrees centigrade and in kg. per sq. metre.

The intermediate air velocities V_1, V_2, V_3 are assumed negligible in comparison with V_0. Assuming that the thermal effects produced by the temperature rise τ due to the deceleration and that θ due to the compression in the compressor are superimposed, however they are distributed over the fixed and rotating parts of the ducts, we may write $T_1 = T_0 + \tau$; $T_2 = T_0 + \tau + \theta$; $T_3 = T_2 + \Delta T$; $T_4 = T_3 - \theta$ and we may deduce T_5 from the adiabatic equation $T_5 T_2 = T_3 T_0$, assuming the ratios between the pressures ρ_0 and ρ_2, and ρ_4 and ρ_0 to be equal.

If then, g, is the acceleration of gravity, E, the mechanical equivalent of heat, C_p the specific heat at constant pressure, we may deduce the exit velocity V_5 for this simplified jet system from

$$\frac{V_5^2}{2gEc_p} = \frac{T_3(\tau+\theta)}{T_0+\tau+\theta} - \theta = \frac{\Delta T(\tau+\theta)}{T_0+\tau+\theta} + \tau; \quad \ldots\ldots(1)$$

from which the duct losses ϵV_0^2 must be deducted, assuming that no shock is produced in the intake nor at any point in the duct itself. The effect of shock waves in the intake will be mentioned later.

Equation (1) gives the exit velocity $V_5 = U_0$ for a turbo-jet engine operating under static conditions ($V_0 = O$, $\tau = 0$) for which

$$\frac{U_0^2}{2gEc_p} = \Delta T \frac{\theta}{T_0+\theta}; \quad \ldots\ldots\ldots(2)$$

where a total efficiency coefficient will be introduced to account for losses in the ducts.

Equation (1) also gives the exit velocity for an athodyd ($\theta = 0$).

$$\frac{(V_5)_A^2}{2gEc_p} = \tau + \Delta T \frac{\tau}{T_0+\tau}. \quad \ldots\ldots\ldots(3)$$

In all these expressions τ is calculated from $V_0^2 = 2gEc_p \cdot \tau$.

It is now proposed to introduce into the general equation (1) the condition $V_5^2 - V_0^2 = V_0^2$ which defines the coefficient σ of the kinetic increment which will be useful for the calculation and comparison of jet engines. Then accounting for the losses in the ducts ϵV_0^2 and referring to the expression for τ we may then write (1) in the non-dimensional forms.

$$\sigma + \epsilon = \frac{\Delta T}{\tau} \frac{\tau+\theta}{T_0+\tau+\theta}; (\sigma+\epsilon)_A = \frac{\Delta T}{T_0+\tau}; \quad \ldots(4)$$

where the first applies generally to the turbo-jet and the second to the athodyd ($\theta = 0$).

Both of these equations, which apply for the case of shockless entry, permit the calculation of the thrust of a jet engine, when τ is not zero, the loss factor ϵ is known and the mass flow per unit time into the intake can be suitably estimated.

For this reason and given the scope of the present work, the calculation will be limited to speeds not less than that of sound in the ambient air, and it will be assumed that the mass flow can be expressed by the product of the density of the ambient air ρ, the velocity V_0, and the frontal area of the intake which will be known as the intake area ω_0. This intake area ω_0 will be defined on the assumption that the mass flow at the intake is $\rho\omega_0 V_0$. This mass is then assumed equal to the calculated exit flow, the additional mass of the fuel being ignored.

Now, for the hypotheses which form the basis of the foregoing calculation and which imply that the speed of sound is not exceeded in any part of the engine, the intake area ω_0, for shockless entry, will be assumed to be variable, or better, controllable by varying the velocity V_0; and it will be assumed to be followed by a reduced section ω_1 where the local speed of sound is reached and is proportional to the frontal area A of the entry into the compressor rotors (assumed to be constant) and where the Mach number established by the designer is never exceeded. If, however, M_0 and M_a are the Mach numbers corresponding to the air velocity in the intake ω_0 and in the impeller entry A, and the ratio of the specific heats is $K = 1.4$, the ratio between the variable intake ω_0 and the fixed entry A must be

$$\frac{\omega_0}{A} = \frac{M_a}{M_0}\left(\frac{1+0,2M_0^2}{1+0,2M_a^2}\right); \quad \ldots\ldots\ldots(5)$$

which makes it possible to calculated the intake flow necessary for each flying speed.

If, on the other hand, it is supposed that ω_0 is a constant, restricted area of the ducting and that the air enters as a result of a frontal shock wave, then in such a case the pressures downstream are calculated by the laws of shock waves (L. Crocco, 'The Singularity of Supersonic Flow', *Aerotecnica*, No. 6, Vol. XVII, June 1937) and the calculation of the exit velocity of the air is rendered more difficult. It is, however, possible to return to equation (1) and introduce a parameter δ defined by

$$\delta = \frac{(1+0,2M_0^2)(7M_0^2-1)}{4,3M_0^2}; \quad \ldots\ldots\ldots(6)$$

for $K = 1.4$, and to write in place of (4)

$$(\sigma+\epsilon)\tau = \Delta T\left(1 - \frac{\delta T_0}{T_0+\tau+\theta}\right) + (1+\delta)T_0; \quad \ldots(7)$$

applicable for the case of intake shock. In this case, however, the simplification of the design aspect gives rise to greater complication from the theoretical viewpoint.

Being given the definition of the intake area ω_0, which is the key to the possibilities of the jet engine, we may express the thrust F by

$$F = \rho\omega_0 V_0(V_5 - V_0) = \rho\omega_0 V_0^2 \cdot C_t; \quad \ldots\ldots(8)$$

TABLE I

M_o	τ gradi C	TURBOREATTORE				AUTOREATTORE			
		T_2-T_0 gradi ass.	ΔT	σ	C_F	T_2	ΔT	σ	C_F
1	15	165	610	5.64	1.57	270	1230	4.55	1.35
1.2	65	185	590	4.00	1.24	290	1210	4.07	1.25
1.5	101	221	551	2.61	0.90	326	1174	3.50	1.12
2	180	300	475	1.11	0.55	405	1095	2.60	0.90
2.5	280	400	375	0.76	0.33	505	995	1.87	0.79
3	405	525	250	0.33	0.10	630	870	1.26	0.51
4	720	840				945	550	0.59	0.26

where the thrust coefficient C_F, for the condition defining the increase in kinetic energy σ is given by

$$C_F = -1 + \sqrt{1+\sigma}; \quad \sigma = C_F(2+C_F); \quad \ldots\ldots (9)$$

while the lift coefficient which relates the weight of an aircraft Q to the wing area may be replaced by a new coefficient indicated by ψ which relates it to the defined intake area ω_0. Use will be made of this in the third part of this study.

The foregoing considerations extend the notion of the athodyd to jet engines in which the mechanical and thermal effects are combined; but they remain valid only at supersonic speeds.

In the subsonic range we may consider only operation under static conditions, that is for $V_0 = 0$, making use of known results of tests which imply that the air velocity through the entry A should have a value of about one quarter of the exit velocity U_0, taking the efficiency into account. Thus we have, with good approximation, and assuming that $A = \omega_0$,

$$F_0 = \rho\,\omega_0\,\frac{U_0^2}{4}; \quad \ldots\ldots\ldots\ldots (10)$$

while the velocity U_0 for the maximum peripheral velocity allowed by the mechanical strength of the rotating parts is of the order of something more than 600 metres per second in bench tests.

In this theoretical consideration it is not, however, possible to give a precise law for the conversion of the static thrust to that for $M_0 = 1$.

An important observation must be made at this point about the increase in temperature ΔT on which the increase in kinetic energy σ and the thrust coefficient C_F depend. This temperature rise ΔT is, in fact, limited only by the maximum temperature attainable in the combustion chamber. When this maximum temperature is established according to the design of the engine, the increase ΔT diminishes rapidly with increasing flying speed, and consequently the temperature due to compression by the ram effect, until it reaches zero. Thus σ and C_F diminish and finally reach zero.

There is, however, a distinct difference between the case of the turbo-jet and the athodyd. In the first case the value ΔT is included in the maximum temperature which can be supported by the turbine blades, for which we may write

$$T_0 + \vartheta + \tau + \Delta T = \boxed{T_c} \quad \ldots\ldots\ldots\ldots (11)$$

where $[T_c]$ is, at present, about 1,000 deg. absolute. On the other hand, in the athodyd which may contain no metal parts in the combustion chamber, the ΔT value may be greater, not only because $\theta = 0$, but also because the maximum temperature permissible for the refractory walls may reach figures in excess of 2,000 deg. In this case

$$T_0 + \tau + \Delta T = \boxed{T_A} \quad \ldots\ldots\ldots\ldots (12)$$

It is interesting to determine for what value of τ, that is for V_0, the athodyd may provide the same increase in kinetic energy σ as the turbo-jet, in spite of the absence of the mechanical effect, and thus the same propulsive force in the case when $T_A = T_c$. Then it must be that

$$\boxed{T_c}\frac{\tau+\vartheta}{T_0+\tau+\vartheta} - \vartheta = \boxed{T_A}\frac{\tau}{T_0+\tau}$$

from which it is deduced, assuming $[T_A]=[T_c]$, that

$$\tau^2 + (2\,T_0 + \vartheta)\,\tau - T_0\left[\boxed{T_c} - (T_0 + \vartheta)\right] = 0;$$

which defines τ. For $T_c=1,000$ deg., $T_o=225$ deg. (stratosphere), $\theta=120$ deg. we obtain $\tau=191$ deg., which is verified for a velocity of 610 m/sec., or more than double the speed of sound in the stratosphere, which may be taken as 300 metres per second.

Below this value $\tau=191$ deg., a turbo-jet with the value $\theta=120$ deg. will give a greater thrust than the athodyd with the same maximum temperature $[T_c]=1,000$ deg., but since $[T_A]$ may always exceed $[T_c]$ in an athodyd, suitably constructed, it follows that equality of thrust may be obtained even at lower speeds. Thus at a speed of 450 m/sec., $[T_A]=1,210$ deg. will suffice to be equivalent to $|T_c|=1,000$ deg. and at 360 m/sec., $|T_A|=1,480$ will be sufficient. Up to this last value of V_o which is hardly one fifth more than the speed of sound in the stratosphere, it will thus be possible, with suitable arrangements, to replace the turbo-jet by the athodyd, and to retain the advantage at greater speeds.

Table 1 illustrates this advantage in a comparison of a turbo-jet with shockless entry and $T_c=1,000$ deg. and an athodyd in which $[T_A]=1,500$ deg. The comparison is valid for the stratosphere where it is assumed that $T_o=225$ deg. The losses were evaluated on the basis of $\epsilon=0.1$. The mechanically produced temperature rise is $\theta=120$ deg.

It is evident from the table that, for the same intake area and altitude, the thrust of the athodyd, under the thermal conditions described and for a Mach number of $M_0=3.5$, is more than three times that of the corresponding turbo-jet. For $M_0=4$ the athodyd is still efficient whereas the turbo-jet becomes impossible to operate. Combinations of the two types may have advantages.

It will, therefore, be interesting to evaluate the resistance to be encountered by jet engines at these supersonic velocities in order to consider their operation in flight. It is proposed to do this in Part II.

Part II—Resistance at Supersonic Speeds

In the first part of this study, theoretical considerations were indicated which permit the calculation of the magnitude of the thrusts supplied by jet-propulsion engines adapted to pass through the sonic barrier.

Now it is proposed to evaluate the resistances opposed to these thrusts.

We shall continue to use the lift and drag coefficients employed for subsonic flight, C_P and C_r, defined by

$$P = C_P\,\rho\,S\,V^2 \quad ; \quad R = C_r\,\rho\,S\,V^2; \quad \ldots\ldots (13)$$

where P is the lift and R the total drag of the aircraft, in kilograms, S the wing area in square metres and V the velocity in m/sec.

For the calculation of C_P and C_r the method of the first approximation indicated by Ackeret and developed by Prandtl and Busemann ('Aerodynamic Lift at Supersonic Speeds', Volta Conference of the Accademia d'Italia, 1935) will be used and we recall that the basic principle of 'super-aviation' (G. A. Crocco, 'Flying in the Stratosphere', AIRCRAFT ENGINEERING, July 1932) consists in increasing the altitude of flight until the maximum flying speed coincides with the most economic speed. This takes place when the so-called penetration resistance, which for a given velocity V_0 is proportional to the density ρ of the air at the altitude of flight, is equal to the resistance to lift which is inversely proportional to this density. From this is derived a value for ρ which defines the economical altitude, i.e. that of the minimum drag for a velocity V_0.

In supersonic flight the lift coefficient may, in the first approximation, be expressed by $C_P = s\cdot\alpha$ where α is the angle of incidence of the wing, in radians, and is assumed to be small ($\sin\alpha\simeq\alpha$; $\cos\alpha\simeq1$) and s is a coefficient of the lifting capacity to be discussed later. Thus the lift resistance takes the form $R_s = s\alpha^2\rho SV^2$ while the penetration resistance is produced by the fuselage drag which, in the first approximation, is quadratic (Th. von Karman, Resistance in Compressible Fluids, Volta Conference of the Accademia d'Italia, 1935) plus the frictional drag of the wings which is also, in the first approximation, quadratic (Busemann, loc. cit.), plus the wave resistance of the wings which also depends on the coefficient s and which can be written $hs\rho SV^2$. The coefficients s and h are given by

$$s = \frac{2}{\sqrt{M_0^2 - 1}} \quad ; \quad h = \frac{4}{3}\delta^2; \quad \ldots\ldots (14)$$

where M_0 is the Mach number relating to the velocity V_0 at the altitude of flight and δ the relative thickness of a biconvex circular aerofoil profile, i.e. the ratio between the thickness and the chord of the wing.

The penetration resistance will thus have the form $R=(r+hs)\rho SV^2$ where r is the sum of the fuselage and the frictional resistances and $r+hs$ may be called the supersonic penetration coefficient.

In order that the weight of the aircraft, Q, in view of the smallness of

the angle α, may be maintained in horizontal flight, $Q = P = sa\rho SV^2$, the total drag will take the expression, to the first approximation,

$$R = R_P + R_S = \left(r + hs + \frac{C_p^2}{s}\right)\rho SV^2; \quad \ldots\ldots (15)$$

which reproduces, in different terms, that already given in the works quoted and which has a minimum value for the values of C_P and ρ defined by

$$C_p^2 = s\,(r + hs) \quad ; \quad \rho V_0^2 = \frac{Q}{SC_p}; \quad \ldots\ldots (16)$$

which allow the thrust to be made equivalent to the minimum resistance of flight, which is twice the penetration resistance.

To obtain this equality in horizontal flight it will be sufficient to equate the weight with the lift and the thrust with the drag, expressing them with the coefficients of Part I with respect to the engine and with those of this part where the aircraft is concerned. We thus obtain an equality of the non-dimensional coefficients.

$$\psi\,\omega_0 = C_p S \quad ; \quad C_F\,\omega_0 = C_r S; \quad \ldots\ldots (17)$$

independently of $_P$, S and V_0.

In particular, the second equation in (17) for the economical altitude, will give

$$C_F\,\frac{\omega_0}{S} = 2\,(r + hs); \quad \ldots\ldots (18)$$

from which it results that, the minimum resistance of the aircraft being determined by the coefficients r, h, s, and the unit thrust C_F of the jet engine by the maximum temperature condition in the combustion chamber, the ratio ω_0/δ between the intake area of the jet engine defined in Part I, and the wing area is also known. This will be referred to as the intake/wing-area ratio and it will be observed that, in contrast to the consideration of reciprocating engines, this overcomes the problem of the power of the jet engine. It will be sufficient to calculate this ratio to solve any problem.

As an interesting numerical example, let us study the C_F values calculated in Part I for the turbo-jet when $[T_C] = 1,000$ deg. Kelvin and for the athodyd when $[T_A] = 1,500$ deg. K and relate them to the values of $(C_r)_{min} = 2(r+hs)$ of a hypothetic supersonic aircraft with a wing loading $Q/S = 260$ kg. per sq. m. with a biconvex circular aerofoil of a relative thickness $\delta = 0.05$, and where therefore $h = 1/300$. Considering a fuselage of the type described by Karman (loc. cit.) with a maximum cross-section equal to one seventh of the wing area with a coefficient 0.056 and assuming the value of 0.003 given by Busemann (loc. cit.) for the friction, a value $r = 0.011$ is obtained.

We then have the approximate values given in Table II for various Mach numbers from 1 to 4 at stratospheric altitudes where $T_0 = 225$ deg. and the velocity of sound is 300 m./sec. The table shows the lifting capacity coefficients s, the optimum C_p values, the minimum drag C_r equal to $2(r+hs)$, the drag-lift ratios C_r/C_p, the densities ρ at the respective economical altitudes, and the corresponding altitudes, and finally the coefficients C_F and the reciprocals of the intake/wing area ratios S/ω_0 for the turbo-jet and athodyd at the maximum temperatures of 1,000 and 1,500 respectively.

The table indicates the smaller values of the ratio ω_0/δ required by the athodyd at large Mach numbers in comparison with those required by the turbo-jet, which would not appear to be capable of operation at $M = 4$. It can also be concluded that, assuming a maximum temperature in the combustion chamber, the practical possibility of a supersonic aeroplane depends on the solution of a dimensional design problem.

Further it is possible to evaluate the fuel consumption. In this respect, if $\rho g\omega_0 V_0$ is the amount of air entering, in kg./sec., which is heated to ΔT deg. C with a specific heat c_p assumed constant, the calories required per second will be $\rho g\omega_0 V_0 c_p\Delta T$. Dividing by QV_0 we shall obtain the calories required per kg. of aircraft weight per metre travelled. The increase in temperature ΔT will be expressed by equation (4) of Part I where, instead of τ, the value deduced from $2gEc_p\tau = V_0^2$ will be used so as to give

$$gc_p\Delta T = \frac{(\sigma + \epsilon)V_0^2}{2E}\left(1 + \frac{T_0}{\tau - \theta}\right)$$

Remembering that the weight Q can be expressed by $\rho\omega_0 V_0\psi$ and assuming that the calorific value of the fuel is equal to 10,000 calories, the consumption, in k.g. of fuel per kg.-metre travelled, is obtained as a non-dimensional expression. This can then be converted to kg. of fuel consumed per ton-kilometre C.

TABLE II

M_0	s	C_p	C_r	C_r/C_p	$\varepsilon \times 100$	l km	Turbo $[T_C] = 1000°$ C_F	S/ω_0	Auto $[T_A] = 1500°$ C_f	S/ω
1	—	—	0.05	—	—	—	1.57	51.5	1.35	27
1.2	3	0.25	0.042	0.168	0.85	20.5	1.24	29.5	1.25	29.7
1.5	1.78	0.174	0.034	0.195	0.75	21.5	0.90	26.5	1.12	32.8
2	1.155	0.131	0.030	0.229	0.55	23.0	0.55	18.3	0.90	30.0
2.5	0.887	0.112	0.028	0.250	0.42	25.0	0.33	11.6	0.70	25.0
3	0.708	0.097	0.0265	0.273	0.32	27.0	0.16	5.8	0.51	18.9
4	0.516	0.081	0.0255	0.315	0.22	29.0	—	—	0.26	10.2

This will give

$$C = \frac{100}{E}\,\frac{\sigma + \varepsilon}{2\psi}\left(1 + \frac{T_0}{\tau + \theta}\right) \quad \ldots\ldots (19)$$

as the fuel consumption of a supersonic aeroplane propelled by turbo-jet, from which the corresponding expression for an aircraft propelled by athodyd is obtained by making $\theta = 0$. The speed of the aircraft is implied by the symbols adopted.

In the preceding expression the second term can be calculated as

$$\frac{\sigma + \varepsilon}{2\psi} = \frac{C_r}{C_p}\left[1 + \frac{1}{2}\left(C_F + \frac{\varepsilon}{C_F}\right)\right], \quad \ldots\ldots (20)$$

easily obtained from the expressions in σ and ψ; this shows that in determining the minimum consumption, it is necessary to take account of the intake/wing-area ratio implied in the coefficient C_F. In fact, if equation (20) is differentiated with respect to C_p, assuming C_F to be known, a minimum condition is obtained which is not satisfied by (16), that is by $C_p^2 = s(r+hs)$ already determined in the assumption of C_F. It will, however, easily be recognized that the effect of C_F and thus of the intake/ wing-area ratio is not very great, and that when this may be made use of by the designer, the expression for the optimum value of C_p may be easily adjusted.

Applying (19) and (20), for which the values C_r/C_p and C_F are obtained from the table already given, and the values for τ and θ from the table in Part I, we obtain, as an example of the order of magnitude of the consumption at $M_0 = 2$ for a turbo-jet engine, a value of 129 grams per ton-kilometre, and at $M_0 = 3$ for an athodyd, a value of 136 grams per ton-kilometre. These values are not very different from those obtained for subsonic aircraft under cruising conditions, which often exceed 100 grams.

In conclusion, supersonic flying speeds are shown not only to be possible, but economically practicable, provided that the calculated intake areas can be realized and that artificial cooling can be arranged for the cabins, which are surrounded by a boundary layer at a temperature τ (L. Crocco, 'Rend. Acc. Lincie', Vol. XIV, No. 2; Aerotecnica, 1932, Vol. XII, p. 181) as was demonstrated in 1931 ('Flying in the Stratosphere', loc. cit.).

This possibility gives no information, however, on the crucial point of supersonic flight which remains the actual crossing of the sonic barrier; i.e. the passage through the transition range between subsonic and supersonic speeds, now known as the transonic range.

The difficulties foreseen in this zone, which can be included between $M_0 = 0.8$ and $M_0 = 1.2$, were explored in 1935 at the Volta Conference on High Speed Flight held by the Accademia d'Italia. It was then seen that within this zone there is a considerable increase in resistance, which afterwards diminishes, an indeterminable loss of lift, which afterwards recovers, and a dangerous instability of equilibrium which also returns later to normal.

The transonic range has been studied below $M_0 = 1$ experimentally with models, and above, theoretically, but the results of the two considerations cannot be reconciled because neither the experimental method itself, nor the mathematical theory of the first approximation, is perfect.

The only reliable information available of the transonic range is obtained from ballistics and is based on trajectories which show a maximum resistance at the altitude corresponding to the speed of sound, which, in the case of the pointed-nose shell, exceeds the resistance for $M_0 = 3$ by only 85 per cent. The theory itself leads one to expect the existence of a maximum value for slender bodies of revolution; this does not however
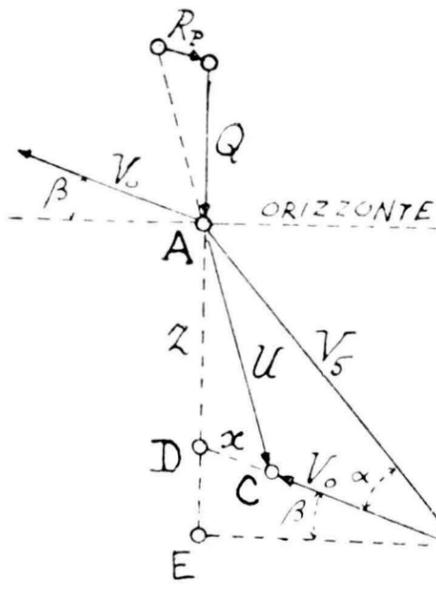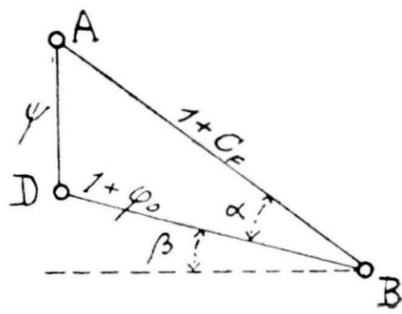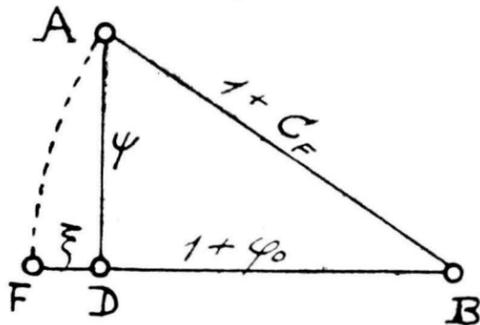
Fig. 1

Fig. 2

Fig. 3

seem to apply to aerofoil profiles which, at both sides of the speed of sound, seem to produce resistances asymptotical to infinity. This uncertainty can only be overcome theoretically as was assumed by Relf in his lecture to the Royal Society of London ('Recent Aerodynamic Developments', *Flight*, June 6, 1945), and as we propose to do here, adopting a finite value of 0·05 for C at the speed of sound, or double that calculated for $M_0 = 3$.

With this assumption the preceding table, for $M_0 = 1$ corresponding to the maximum C_F value obtainable with a turbo-jet engine, gives an intake/wing-area ratio of 1 : 31·5 which is more favourable than that required by an athodyd for $M_0 = 2$. Thus the transonic resistance of an aeroplane would appear capable of being overcome from the point of view of the drag.

There remains, however, the unknown value of the lift. In fact the loss of lift demonstrated experimentally, may be illustrated by drawing a graph of the coefficient s which is its derivative with respect to the angle of incidence and has, therefore, the significance of a 'lifting capacity'. While the linearized theory of Prandtl would give to s an infinite value just below or above the speed of sound, as if there should be a maximum around $M_0 = 1$, this maximum is reached in experiment relatively well before the speed of sound, at about $M_0 = 0.8$, and soon afterwards the lifting capacity s falls towards zero in all the practical work so far carried out at subsonic speeds and rises again at supersonic speeds (see Relf, *loc. cit.*, and Field-mann, 'The Effects of Compressibility', *Interavia*, April 1946, p. 60). It appears that the lifting capacity of the wings falls to zero before the speed of sound is reached, and the duration, and the extent of the collapse of the lift which ensues, cannot yet be stated exactly. From this point of view, the transonic problem changes its aspect; it is, metaphorically, less the scaling of a barrier than the jumping of a ravine.

There is one attitude of flight for which the necessity for lift is eliminated —the vertical dive. In this attitude, using the maximum vertical component of the weight of the aircraft, the force required to overcome resistance is obtained without the necessity for lift. This has been attempted by daring pilots, with varying success; some have lost their lives. Then there is the third difficulty mentioned earlier, the instability of equilibrium. This is due to a concomitance of various causes, all connected with the formation of the transonic shock wave at the rear, upper part of the wing. The aircraft becomes suddenly nose-heavy and will not respond to the controls, the wings are surrounded by a turbulent zone and the wave moves along the upper surface in an unpredictable manner. There exist special balancing devices but they are not yet in current use. Under these conditions the crossing of the sonic barrier, even ignoring the sudden reduction in lift, becomes a dangerous aerobatic operation and the problem of supersonic flight is waiting for the science of aerodynamics to open the door.

Part III contains an indication of a method, which is believed to be novel, of crossing this barrier. Since the wings are the sole cause of the difficulty, the possibility will be demonstrated of flight without wings.

Part III—The Lift-Producing Jet Engine

The concept of a lifting, aero-thermo-dynamic body introduced in 1931 in a communication of the 'Accademia dei Lincei' (*Rendiconti*, June and September 1931) will be developed in this part, and the definition will, in consequence, be modified.

In the two preceding parts, we have formulated a jet-engine (*Rendiconti*, 1946, Vol. I, No. 10, p. 1006) as a propulsive mechanism intended to overcome the resistances (*Rendiconti*, 1946, Vol. I, No. 11, p. 1155) opposing the penetrating and lifting components of a supersonic aeroplane. As such we have outlined its application to the passage through the sonic barrier and to the attainment of supersonic speed; after the suppression

of the airscrew and the replacement of the reciprocating engine by the compressor-turbine combination, we have foreseen the probability that this type of engine will also be replaced by the athodyd.

At this point it is necessary to consider a new possibility—that of suppressing the wings, as such, of an aeroplane.

The apparent paradox in this suggestion can be explained by recalling that wings, in their function of producing lift, are essentially organs which deflect the air, and which support the aircraft by deflecting downwards in unit time a certain mass of air so as to use the consequent variation in the vertical component of the momentum.

If, therefore, a jet engine, which takes in air at the front and discharges it at increased speed to produce thrust, also deflects the air downwards, it will produce a lifting force in addition to the thrust.

In this case the lifting function of the wings may be transferred to the power unit, and the aircraft may be reduced, in principle, to a simple fuselage, more or less inclined, without airscrew or wings, and containing a jet engine providing thrust and lift.

Any other device, capable of the same kinetic effect, may be used to produce lift together with thrust. With suitable deflectors at the rear, lift could be obtained from an airscrew and with the required change in trim the vertical motion and lift could be assured by means of a rocket as was proposed early in the study of this combination.

Here the novelty lies in the possibility of using a type of engine already in practical use and of employing it to eliminate the difficulties of crossing the sonic barrier.

It is proposed to consider this possibility from the theoretical viewpoint without reference to the problems of design or production.

Assume that, in general, V_0 is the absolute speed of advance of the aircraft in still air, and is equal and opposite to the relative entry velocity of the air into the intake; further that V_5 is the exit velocity of the air from the jet, after deflexion through the angle α without loss. Let β be the angle of trim, i.e. the angle between the speeds of advance and the horizontal.

Assume that the two speeds are represented by the two vectors V_0 and V_5 (FIG. 1) meeting at the centre of gravity A of the aircraft. Let Q be the weight of the aircraft, R_p the penetration resistance of the inclined fuselage containing the jet engine; i.e. the only force resisting the motion of the aircraft.

To obtain equilibrium in motion it will be necessary that the resultant of the two velocities V_5 and V_0 be a vector U directed downwards in the direction of the resultant of the external forces Q and R_p and that this resultant be balanced by the force Φ generated by the jet engine.

If, however, as in the preceding part, we make the mass of air entering the intake equal to $\rho \omega_0 V_0$, then the deflected force of reaction which must balance the resultant will be $\Phi = \rho \omega_0 V_0 \cdot U$. Then dividing the velocity U into a vertical component z and another x in the direction of flight, there must be equilibrium of the respective components.

$$ Q = \rho \omega_0 V_0 z \quad ; \quad R_P = \rho \omega_0 V_0 x. \quad \dots \dots (21) $$

We then assume that R_p refers to the maximum cross-section of the Ω fuselage and that the intake ω_0 defined in the preceding part, represents a design constant. The reason why this is not in agreement with the definition of ω_0 is that the conclusions are no longer general but are limited to a predetermined flying speed.

From the preceding assumption, it follows, if C_p is the drag coefficient of the fuselage, that $C_p \Omega = \phi_0 \omega_0$, i.e. we introduce a new coefficient ϕ_0 which can be considered under the same conditions as before, as a design constant and will facilitate a numerical calculation of the lifting jet-engine.

Let ABC in FIG. 1 be the triangle of the velocities V_5, V_0 and U. Complete it by drawing the vertical to meet the horizontal through B at E and produce the side BC to D on the vertical. Then AD is the component z of U and CD the component x.

In the right angled triangle ABE we then have the relationship

$$ V_5^2 = (V_0 + x)^2 + z^2 + 2 z (V_0 + x) \sin \beta; \quad \dots (22) $$

which can be made non-dimensional by using the definitions of the coefficients σ, C_F and ψ, and by incorporating the equation (21) and the preceding definition of the fuselage coefficient ϕ. We then have

$$ V_5^2 - V_0^2 = \sigma V_0^2 \; ; \; F = C_F \rho \omega_0 V_0^2 \; ; \; Q = \psi \rho \omega_0 V_0^2 $$
$$ R_P = \phi_0 \rho \omega_0 V_0^2 \; ; \; z = \psi V_0 \; ; \; x = \phi_0 V_0; \quad \dots (23) $$

and suppressing the common factor V_0^2, (22) becomes

$$ \sigma = \psi^2 + \phi_0^2 + 2 \phi_0 + 2 \psi (1 + \phi_0) \sin \beta \quad \dots \dots (24) $$

Since from (9) we can obtain $1+\sigma = (1+C_F)^2$, equation (24) may also be written

$$1 + \sigma = (1 + C_F)^2 = \psi^2 + (1 + \varphi_0)^2 + 2\psi(1 + \varphi_0)\sin\beta; \qquad \ldots\ldots\ldots\ldots (25)$$

and in this form will be considered as the general non-dimensional equation of the dynamics of lifting jet-engines.

Equation (25) can be expressed geometrically as the triangle ABD in FIG. 2 in the same way as that in FIG. 1; the sides can be given values as shown in the diagram assuming that $V_0 = 1$.

In this first study we have to consider horizontal flight which will give the notions corresponding to this unusual form of lift. Putting $\beta = 0$ in equation (25) we obtain the expressions

$$1 + \sigma = (1 + C_F)^2 = \psi^2 + (1 + \varphi_0)^2 \quad ; \quad \tan\alpha = \frac{\psi}{1 + \varphi_0}; \qquad \ldots\ldots\ldots\ldots (26)$$

which are applied to FIG. 3 and allow it to be completed at BF by the segment on BA so as to obtain the differential segment ξ which can be expressed as

$$\xi = 1 + C_F - (1 + \varphi_0) = C_F - \varphi_0. \qquad \ldots\ldots\ldots (27)$$

This equation gives an interesting indication of the lifting efficiency of the jet-engine.

Multiplying the terms by the expression $\rho\omega_0 V_0^2$ and recalling equation (8) we may deduce the value of the force F of the jet-engine considered as acting horizontally, as a function of the actual resistance to penetration R_p to be overcome and of the fictitious resistance to lift R_s which defines the lifting efficiency. Then

$$F = R_P + R_S \quad ; \quad R_S = \xi \cdot \rho\omega_0 V_0^2; \qquad \ldots\ldots\ldots (28)$$

where it must be emphasized that the force F is itself a fictitious force equal to $C_F\rho\omega_0 V_0^2$ which is useful for purposes of calculation and comparison with the force required from an aircraft fitted with a purely propulsive jet-engine, whereas the actual force Φ developed by the lifting jet-engine is equal to $\rho\omega_0 V_0 U$.

To ascertain the lifting efficiency defined above and to give ξ its optimum value, we have to resolve a problem of minimum values. It is necessary, in fact, to find the value of the force F with respect to the weight of the aircraft, for which the ratio F/Q has a minimum value.

Referring to equation (23) which defines the coefficients representing F and Q, that is C_F and ψ, we have to find the minimum value of the ratio C_F/ψ.

Taking the square root and dividing by ψ equation (25) gives

$$\frac{C_F}{\psi} = -\frac{1}{\psi} + \sqrt{1 + \frac{(1 + \varphi_0)^2}{\psi^2}} \,; \qquad \ldots\ldots\ldots (29)$$

which, with the assumption made for ϕ_0 considered constant with respect to ψ in the differentiation, gives

$$\frac{\partial}{\partial\psi}\left(\frac{C_F}{\psi}\right) = +\frac{1}{\psi^2} - \frac{1}{\psi^3}\frac{(1 + \varphi_0)^2}{\sqrt{1 + \frac{(1 + \varphi_0)^2}{\psi^2}}} = 0\,; \qquad \ldots\ldots (30)$$

from which we deduce

$$(\psi)_{opt} = (1 + \varphi_0)\sqrt{\varphi_0^2 + 2\varphi_0}\,; \qquad \ldots\ldots\ldots (31)$$

and corresponding with such values

$$1 + C_F = (1 + \varphi_0)^2 \;;\; (C_F)_{opt} = \varphi_0^2 + 2\varphi_0 \;;\; (\tan\alpha)_{opt} = \sqrt{C_F}\,; \qquad \ldots\ldots\ldots (32)$$

and finally

$$\left(\frac{C_F}{\psi}\right)_{min} = \frac{\sqrt{\varphi_0^2 + 2\varphi_0}}{1 + \varphi_0} \quad ; \quad (\xi)_{opt} = \varphi_0(1 + \varphi_0)\,. \qquad \ldots\ldots (33)$$

From this we deduce that the resistance to lift approaches, although it

does not equal, the resistance to penetration, as it does in the case of the lifting wing, so that we have $(\xi)_{opt} = \phi_0(1 + \phi_0)$.

We may also conclude that the optimum values of ψ, C_F and α are determined independently of the velocity and altitude. Assuming that ω_0 is given, then it must be deduced from the expression in ψ, that for each flying speed there is a corresponding altitude for the best economy and maximum thrust for the jet engine.

It must be observed that these conclusions concerning ψ, C_F, and α are based on the previous determination of the intake area ω_0 which gives a constant ϕ_0 value, which we must now justify.

In this connexion, reverting to the take-off conditions of the lifting jet-engine, we have assumed that the weight of the aircraft can be supported without the assistance of wings, until $V_0 = 0$. In this case the expressions so far adopted do not apply and we must return to equation (10) of Part I which gives the static thrust F_0 of a jet engine, that is for $V_0 = 0$ which gives $4 F_0 = \rho\omega_0 U_0^2$.

According to this equation the maximum exit velocity of the air taken in by the compressor depends on the temperature rise or on the maximum peripheral velocity which can be supported by the impeller and this velocity V_0 is beginning to reach values of 600 metres per second in jet engines already in use. Assuming therefore that the air at the exit could be deflected to a vertical direction, i.e. so that $\alpha = 90$ deg., while maintaining the velocity mentioned, and that in such a case $F_0 = Q$, the maximum value of the ratio Q/ω_0 is then determined for take-off, $\rho = \rho_0$ so that

$$\left(\frac{Q}{\omega_0}\right)_{max} = \frac{\rho_0 U_0^2}{4} = 11250. \qquad \ldots\ldots\ldots (34)$$

Q/ω_0 will be called the intake loading by analogy with the wing loading, but a maximum value will not be assumed because a margin must be available for the acceleration of the aircraft. Thus, in agreement with the values found for the intake ratio in the case of the use of wings, where on the average $S/\omega_0 = 30$ for a wing loading of 260 kg./sq.m., we may assume the value

$$\frac{Q}{\omega_0} = 30 \cdot \frac{Q}{S} = 7800.$$

With such a value for the intake loading, which will serve to develop a numerical example of equations (32), the non-dimensional coefficient ϕ_0 cannot yet be determined because it is necessary to ascertain the maximum cross-section of the fuselage which is not in constant proportion to the weight of the aircraft. The equations derived so far are, thus, intended to be exact for a given aircraft, taken for reference, and for a given speed, but they are approximate for similar aircraft of approximately the same size. We have, therefore, assumed a weight of 7,800 kg. to which would correspond a total intake area of one square metre representing two or more jet engines, and for this weight we have assumed a maximum cross-section of 3 square metres. Accepting the Karman coefficient indicated in Part II, this would give ϕ_0 a value of $\phi_0 = 0.165$.

We then obtain the optimum values for the minimum thrust

$$(C_F)_{opt} = 0.357 \;;\; (\psi)_{opt} = 0.695 \;;\; \left(\frac{C_F}{\psi}\right)_{min} = 0.51 \;;\; (\alpha)_{opt} = 31°\;;$$

which will make it possible to define the altitude of flight and the consumption for any supersonic speed.

So that for $M_0 = 2$, from $Q = \psi\rho\omega_0 V_0^2$ and assuming $Q/\omega_0 = 7800$ and $(\psi)_{opt} = 0.695$ we obtain $\rho V_0^2 = 11200$; which, assuming a velocity of sound of 300 m./sec., in the stratosphere gives an air density, at the economical altitude, of $\rho = 0.0311$ which is reached at about 12 kilometres. Similarly for $M_0 = 3.5$, i.e. somewhat less than 3800 km./hour, the altitude would be approximately 21 km.

The consumption of a lifting jet-engine is calculated according to the expressions applying to the normal jet-propulsion engines. For $M_0 = 2$, assuming $\epsilon = 0.1$, we have $\left(\frac{\sigma + \epsilon}{2\psi}\right)_{opt} = 0.686$ which for a turbo-jet, with the thermal data given in the preceding Parts, gives a consumption of 278 grams per ton-km.

At $M_0 = 3.5$, the athodyd would have a consumption of 227 grams for $[T_A] = 1,500$ deg.

It will, of course, be possible to reduce these consumptions if greater intakes can be used, until they reach the same order of magnitude as those required by supersonic winged aircraft.

Let us consider the minimum velocity permitted by the equation given, i.e. that for $M_0 = 1$. For this velocity the expression $\rho V_0^2 = 11200$ would give $\rho = 0.125 = \rho_0$, which means that the crossing of the sonic barrier must be made at zero altitude. The formula, as written however, does not apply numerically to the case when $\rho = \rho_0$ because the temperature ratios are different from those calculated. Moreover the velocity of sound cannot logically be accepted as a cruising speed but only as temporary speed. This then requires a reserve of thrust for acceleration, and for climbing to the desired altitude. We cannot, however, assume optimum values and
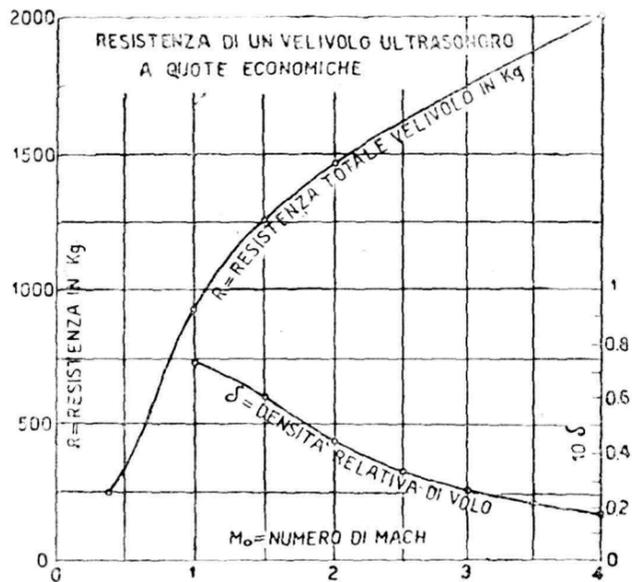
Fig. 1.—The drag of a supersonic aeroplane at economic altitude
Top curve R = total drag of aeroplane in kg.
Bottom curve δ = relative density of air
Ordinate R = drag in kg.
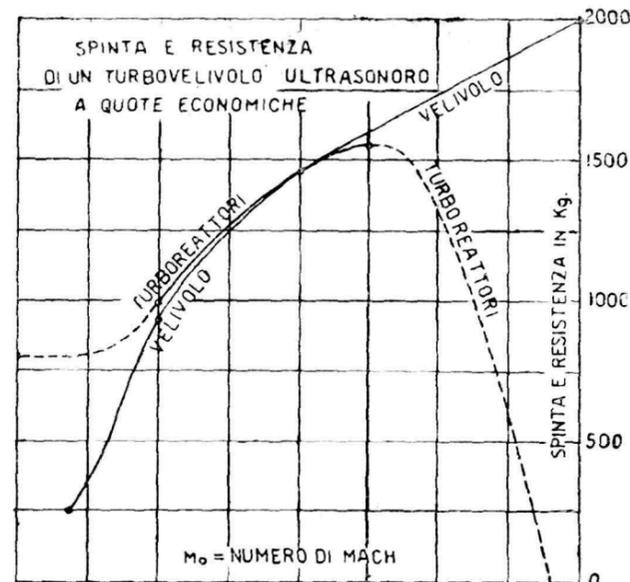Abscissa M_0 = Mach number

Fig. 3.—Thrust and drag of supersonic turbo-jet driven aeroplane at economic altitude
Turboreattori = turbo-jet engines
Velivolo = aeroplane
Ordinate = thrust and drag in kg.
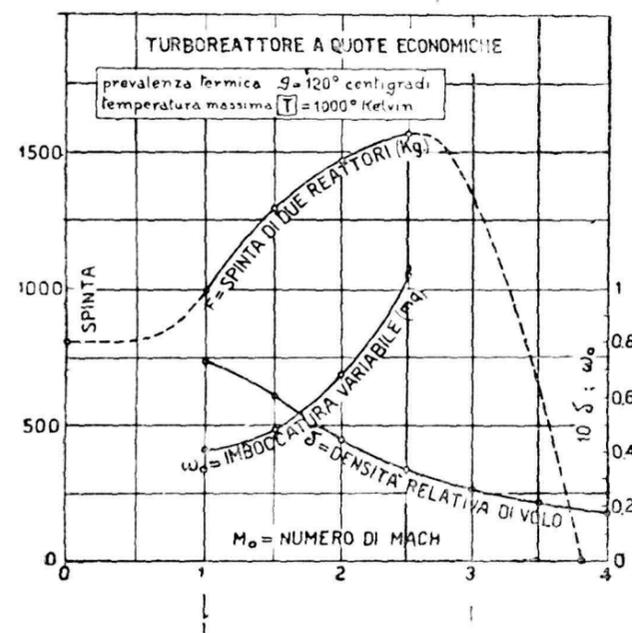Abscissa M_0 = Mach number

Fig. 2 (left).—Turbo-jet engine at economic altitude
Temperature rise through compressor
$\theta = 120°$ C.
Maximum temperature [T] = 1,000° K
Top curve F = thrust of two engines in kg.
Short curve ω_0 = variable intake area in sq. m.
Bottom curve δ = relative density of air
Ordinate Thrust
Abscissa M_0 = Mach number

Fig. 5 (right).—Intake area and power of a turbo-compressor at a constant velocity of 600 m./sec. at increasing altitudes
Left Ordinate = thousands of horse-power
Right Ordinate = intake area in sq. metres
Abscissa $\Delta = \frac{1}{\delta}$ = rarefaction of air at various altitudes
Livello del mare = sea level
Quota economica = economic altitude
Top curve = intake area
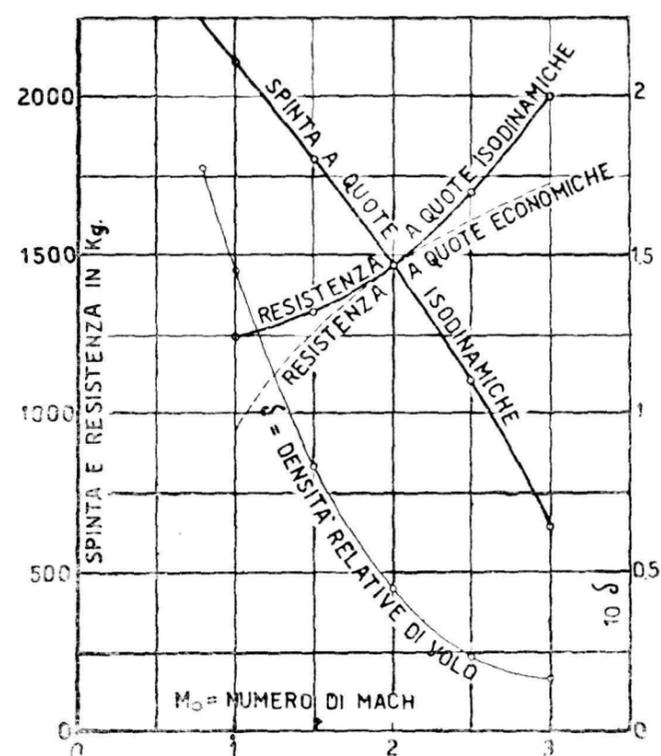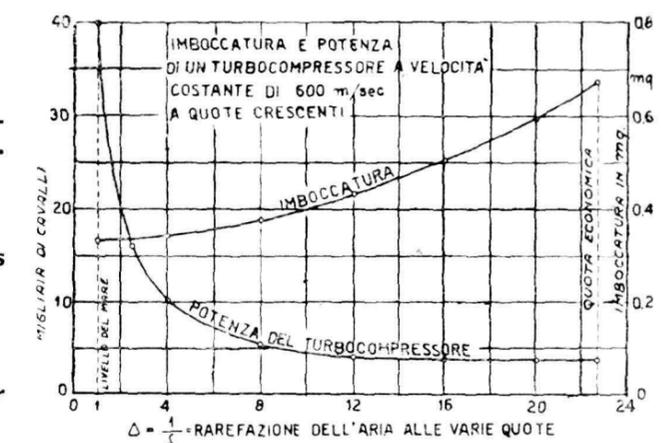Bottom curve = power of turbo-compressor unit

Fig. 4.—Left Ordinate = thrust and drag in kg.
Abscissa M_0 = Mach number
Curves from top (reading down line for $M_0 = 1.5$)
Thrust at isodynamic altitude
Drag at isodynamic altitude
Drag at economic altitude
δ = relative density of air

minimum thrusts for such speed but must expect the maximum available C_F value from the turbo-jet. It is, then, necessary to perform a step-by-step calculation applying the process of acceleration and climb to various altitudes until the maximum altitude and speed are reached, as is done for winged aircraft. The ψ value necessary for each altitude and speed is determined from $\psi = \frac{7800}{V_0^2}$ and the required C_F from equation (25) for a pre-determined trim angle β. The C_F value available, calculated from (9) for each altitude and speed, can be obtained from the difference, divided by ψ, the value of the available acceleration. The calculation is similar to that adopted to evaluate the climbing times of winged aircraft; it also permits an evaluation of the total consumption required to pass through the sonic barrier and to reach the velocity required.

A similar calculation will evaluate the times, velocities and consumptions for the operations of deceleration and descent, This will show how, by passing from the athodyd to the turbo-jet under the appropriate conditions and by gradually reducing the thrust, it is possible to return to subsonic speeds, until finally by adjusting the angles α and β the aircraft can be landed at horizontal and vertical speeds of practically zero. There is, therefore, no need for aerodromes either for take-off or for landing.

In conclusion, the lifting jet-engine, in the scheme outlined, lends itself in theory to the crossing of the sonic barrier without particular danger or difficulty or complicated control operations. It can allow very great supersonic speeds, of the order of 4,000 km. per hour although the consumptions then exceed those assumed, but not yet proved in experiment, for supersonic winged aircraft.

There will, of course, be differences between the theory and its realization in practice. Above all it will be necessary to reduce the specific weight of the turbo-jet; that is the weight per unit thrust. This weight falls, today, between one half and one third of the static thrust, i.e. of the weight of the aircraft to be supported by lifting jet-engines. Accounting for the necessary margin for the weight of the fuselage, the controls, fuel supply and useful load, the specific weight of the engines should be reduced, at least, to one quarter of the static thrust.

This is not all. This theoretical project depends entirely on the operation of the engine, i.e. on the continual availability of the thrust required. What would happen if the thrust failed on landing? This might occur in the athodyd if the combustion or the fuel supply failed or in the turbo-jet by failure of the rotating parts.

With winged aircraft, the total failure of the engines necessitates gliding flight, which forms the key to the safety of landing. In aircraft with lifting jet-engines, a number of power-units will be used to reduce the probability of total failure, and there is the advantage that rotating parts are less likely to fail than reciprocating mechanisms. We may also count on the unfailing progress of the turbo-jet engines, their safety devices, and fuel and ignition systems.

In the case of a landing with extinguished jet engines, it will not be possible to count on the same gliding flight as is afforded by the lifting wing. There is, nevertheless, with the lifting jet-engine, the possibility of gliding flight as may be deduced from (25) by making $\sigma = 0$ and evaluating the angle of descent β and the velocity V_0 corresponding to predetermined minimum conditions. Such a glide would, however, be too steep and rapid, even for a forced landing.

We may conclude that it does not appear possible, at the present stage of this study, completely to adopt the theoretical project outlined, i.e. the reduction of the aircraft to a simple fuselage containing the jet engine. As well as for reasons of lateral equilibrium, it will be necessary to provide a number of jet engines, and high-lift devices at the junction between the fuselage and the engines, which, together with a fuselage designed to give some lift, will provide enough lift for a forced landing. This difference between the practical and theoretical aspects of the project, which it would be premature to discuss at length, does not make less interesting the possibilities outlined in this study or those which may be produced as a result of particular developments which we reserve the right to discuss later.

Part IV—Design Considerations and Experimental Comparisons

In this part we shall return to the problem of exceeding the speed of sound with winged aircraft, discussed in Part II, with the object of presenting the calculations in concrete form and of comparing them with the results of recent subsonic experiments.

For this purpose we refer to the relationship given by equation (5) of Part I between the conventional intake ψ_0 and the total frontal cross section A of the entry to the compressors, of which the proof was omitted for the sake of brevity. This relationship is based on the ideal hypothesis that a current of air entering a compressor passes adiabatically and continuously from the speed of advance V_0 to that V_a with which it enters the impellers at A, where a predetermined maximum Mach number M_a will not be exceeded. Starting with the intake ω_0 (for which let M_0 be the Mach number, c_0 and T_0 the velocity of sound and the external temperature), and passing through a reduced section ω_1, where the local sonic velocity c_1 is reached and the temperature is T_1, the air arrives at the cross-section A where the prescribed Mach number M_a with respect to the local speed of sound c_a, depending on the local temperature T_a, is reached.

The hypothesis is concerned with the continuity of the flow

$$\omega_0\,\rho M_0\,c_0 = \omega_1\,\rho_1\,c_1 = A\rho_a\,M_a\,c_a , \quad \ldots\ldots\ldots (35)$$

where ρ, ρ_1, ρ_a are the corresponding air densities, but ignores, for supersonic speeds, the suction effect of the compressor in determining the temperature.

Then in equation (35) for $K=1\cdot4$ we may put

$$\begin{cases} \left(\dfrac{c_a}{c_1}\right)^2 = \dfrac{T_a}{T_1} = \dfrac{1+0,2}{1+0,2\,M_a^2} \quad ; \quad \dfrac{\rho_a}{\rho_1} = \left(\dfrac{T_a}{T_1}\right)^{\frac{1}{K-1}} : \\[3mm] \left(\dfrac{c_a}{c_0}\right)^2 = \dfrac{T_a}{T_0} = \dfrac{1+0,2\,M_0^2}{1+0,2\,M_a^2} \quad ; \quad \dfrac{\rho_a}{\rho_0} = \left(\dfrac{T_a}{T_0}\right)^{\frac{1}{K-1}} ; \end{cases} \quad (36)$$

and obtain, still for $K=1\cdot4$,

$$\frac{\omega_1}{A} = M_a\left(\frac{1+0,2}{1+0,2\,M_a^2}\right)^3 \quad ; \quad \frac{\omega_0}{A} = \frac{M_a}{M_0}\left(\frac{1+0,2\,M_0^2}{1+0,2\,M_a^2}\right)^3 \quad (37)$$

The second of these two relationships is the same as equation (5) of Part I while the first leads to the assertion, implied in Part I, that the reduced section ω_1 is in constant ratio to the entry A to the impellers.

If now, for the practical purpose envisaged by this Part, we assumed that $M_a=0\cdot5$ (somewhat more than that deduced by other writers) we obtain in round figures

$$\frac{\omega_1}{A} = 0,75 \quad ; \quad \frac{\omega_0}{A} = 0,432\,\frac{\left(1+0,2\,M_0^2\right)^3}{M_0} ; \quad \ldots\ldots (38)$$

which, although being less approximate may be extended to the subsonic zone. We thus obtain the equation $\omega_0=A$ approximately for $M_0=0\cdot5$ which thus represents the lower limit of application, from which point the ratio between ω_0 and A falls to 0·75 for $M_0=1$ and then rises again. For $M_0=2$ it reaches 1·25. The intake area ω_0 is, therefore, said to be variable.

In order to be able to assume a constant value, suitable to define the dimensions of the impellers, it is useful to take the entry cross-section A itself, which from the practical design point of view is connected with the impeller diameter D. A useful relationship, when we are concerned with two jet-engines, is $A=2\cdot0.32\,D^2$ which allows D to be calculated when A is determined by the cruising speed required from a given subsonic aircraft.

Adopting the value of the constant A instead of the variable ω_0 in the expressions for the mass flow at the intake in unit time, $m=\rho\omega_0 V_0$, and for the total thrust of the engines of a given aircraft $F=mc_F V_0$, where C_F is derived from the calculation in Part I, we obtain the new equations,

$$m = 0,432\,Ac_0\,\rho\left(1+0,2\,M_0^2\right)^3 ; \quad \ldots\ldots (39)$$

$$F = 0,432\,Ac_0^2\cdot\rho\left(1+0,2\,M_0^2\right)^3\cdot C_F\,M_0 ; \quad \ldots\ldots (40)$$

which give rise to interesting deductions.

In fact, if the Mach number M_{0E} is established for which the thrust of two jet engines must balance the drag of a supersonic aircraft, defined by its drag coefficient C_r, then it is possible to determine A and therefore D from the equation

$$\frac{A}{S} = \frac{C_r\,M_{0E}}{0,432\,C_F\left(1+0,2\,M_{0E}^2\right)^3} : \quad \ldots\ldots\ldots (41)$$

in which C_r can be deduced from Part II in the case of flight at the economic altitude.

As a concrete example, given that $M_{0E}=2$ for which $C_F=0\cdot55$ and at

the economic altitude $C=0\cdot03$ we obtain $A=0\cdot0437\,S$. Thus for an aircraft with a wing loading of 260 kg./sq., and of 6,500 kg. weight which would correspond to $S=24\cdot6$ sq. m. the result is $A=1\cdot07$ sq. m. and for the ratio quoted between A and D we obtain $D=1\cdot29$ m. in round figures for each of the two jet engines. At the economic altitude, corresponding to minimum drag and for which $\rho_E=0\cdot0055$ the thrust required from the two engines is 146 kg. which gives an effective output of 11,700 thrust horse power if, naturally, the assumptions made are fulfilled.

It is interesting to compare this result with the known data of the world speed record won by Gloster-Meteor fighter aircraft in September 1946 at an average speed of 991 km./hour.

The weight of this aircraft is about 6,400 kg. and the two turbo-jets develop, in flight, a total thrust of about 3,800 kg. corresponding to an effective output of 14,000 thrust horsepower.

This power output is, however, in excess of that calculated for the example of the supersonic aircraft and even when a comparison is made with the probable effective power outputs absorbed, in any case, by the turbine-compressor units the conclusion will be reached that the power required in the example given is less than that needed for the compressors of the Gloster-Meteor.

The diameter of the impeller of the compressor for the supersonic aircraft, $D=1\cdot29$, is in fact a little more than twice that of the compressor in the Gloster-Meteor.

From this comparison it would appear that a scaling-up of the present turbo-jet engines is required for them to propel a supersonic aircraft at the economic altitude at a speed corresponding to a Mach number of 2. The practical problem becomes that of building high altitude turbo-jet engines of comparable power but of twice the dimensions.

It appears useful to accompany this interesting conclusion with a graphic representation of the drag of the supersonic aeroplane treated in the example at the economic altitude (FIG. 1) and of the total thrust at the same altitude, of the two turbo-jet engines which should overcome this resistance corresponding to a Mach number of 2 (FIG. 2). The diagrams show the relative density at the economic altitude, and the intake area of each of the two engines calculated for $A=1\cdot07$ sq. m., that is for $D=1\cdot29$ m., for each engine.

The two curves have then been superimposed (FIG. 3) in order to draw another deduction. FIG. 3 shows that, with the data prescribed, the curve of the total thrust of the two jet-engines, which is equal in theory to the drag of the aircraft for a Mach number of two, coincides with the drag curve except for a slight excess up to a Mach number of 1. Thus in the interval between 1 and 2 the two values are balanced for any speed.

An aircraft, powered in the manner described, which, after having exceeded the speed of sound, should attain the successive flying speeds at the economical altitude, would have no reserve for acceleration or for climbing; in practice it could not, therefore, attempt to pass the sonic barrier.

The conditions are changed completely if, while estimating the economic altitude for the Mach number of 2, the economic altitudes are renounced for the lower velocities, adopting instead the criterion of maintaining the minimum altitude allowed by the maximum power for which the compressor is designed.

In general, it is useful to define this power by the mass flow at the intake m, and the temperature rise θ of the compressor defined in Part I. The power required by the compressor in shaft horse-power π_c can then be derived from the equation

$$75\,H_C = m\cdot g\,EC_p\cdot\vartheta ; \quad \ldots\ldots\ldots\ldots (42)$$

while the useful output π_s in thrust horsehorse power is given by

$$75\,H_S = m\cdot C_F\,V_0^2 . \quad \ldots\ldots\ldots\ldots (43)$$

An interesting ratio is then obtained between the power required by the compressor and the effective output, for supersonic speeds

$$\frac{H_C}{H_S} = \frac{\vartheta}{2\,C_F\,\tau} ; \quad \ldots\ldots\ldots\ldots\ldots (44)$$

where τ is given by the relationship $V_0^2=2gEc_p\tau$ indicated in Part I.

Equation (44) gives a minimum value of the ratio for an M_0 value of approximately 2.

If now we calculate the power required by the compressor for cruising at a Mach number of 2, by using equations (42) and (39), and we assume the condition of flying at the altitudes equivalent to the power input to the compressor, that is altitudes for which the product $m\theta$ remains constant, which for $\theta=$ constant means that the mass flow m is constant, it will be sufficient to fulfil the conditions deduced from (39)

Painting by Eric Fraser, F.S.I.A.

TRADE WINDS No 7

HAKLUYT'S PROUD DEDICATION

Under the far-sighted and spirited encouragement of Queen Elizabeth, English commerce expanded apace. Venice had abandoned the struggle and Antwerp was involved in the Wars of the Spanish Netherlands; Amsterdam and the rebel Dutch had not yet established themselves.

The pioneering spirit of the English, fast becoming an unrivalled tradition throughout the world, was effectively summed up in 1589 by Hakluyt in the proud dedication of his "Voyages."

"Which of the Kings of this land before her Majesty, had their banners ever seen in the Caspian sea? Which of them hath ever dealt with the Emperor of Persia as her Majesty hath done, and obtained for her merchants large and loving privileges? Who ever saw, before this regiment, an English Ligier in the stately porch of the Grand Signor at Constantinople? Who ever found English Consuls and Agents at Tripoli in Syria, at Aleppo, at Babylon, at Bakara, and, which is more, who ever heard of Englishmen at Goa before now? What English ship did heretofore ever anchor in the mighty river of Plate? Pass and repass the unpassable (in former opinion) strait of Megellan, range along the coast of Chili, Peru and all the backside of Nova Hispania, further than any Christian ever passed, traverse the mighty breadth of the South Sea, land upon the Luzones, in despite of the enemy, enter into alliance, amity and traffic with the Princes of Maluccas, and the isle of Java, double the famous Cape of Bona Speranza, arrive at the isle of St. Helena, and last of all return home richly laden with the commodities of China, as the subjects of this now flourishing monarch have done?"

The Servicing of Hydraulic Equipment

Comprehensive Notes on the Maintenance Duties and Problems that face the Mechanic

By H. G. Conway, F.R.Ae.S.*

INTRODUCTION

THESE notes have been prepared because it is a fact that there is no publication available to the ordinary aeroplane mechanic which gives him the essential information which will guide him in the overhaul and maintenance of hydraulic equipment. There are only one or two books which even touch on the subject other than the official (and very excellent) R.A.F. publication, A.P. 1803.

The scope of the notes extends to the basic principles of hydraulic maintenance and the important features and defects of those parts (valves, seals, pipes, etc.) which are the essential constituents of any hydraulic component or installation.

While the author does not pretend to be a qualified mechanic he can at least claim to have direct personal knowledge of the subject and to have dismantled (and reassembled!) every component or constituent referred to. The recommendations made can, therefore, be claimed to be based on actual practice rather than drawing office theory.

FLUIDS AND RUBBER

Fluids

Aeroplane hydraulic systems use two main types of hydraulic fluid, the one consisting of a castor oil mixture, the other a light mineral oil. There is a third type of synthetic fluid just being introduced in the U.S.A. known as Silicone fluid, but this it not yet in operational service.

Castor or vegetable oil base fluids are used because they have little or no swelling effect on natural rubber. Mineral oils, however, require special synthetic rubber mixes as they cause rapid deterioration of natural rubber. The deleterious effect of castor base fluids on some synthetic rubbers is not inappreciable although not so serious as the reverse case just mentioned. For this reason it is absolutely essential not to mix hydraulic fluids nor to allow rubber glands to come into even momentary contact with the wrong fluids.

The main types of castor base fluids are as follows:

(i) British—D.T.D.391 (Lockheed)
Castor oil—cellosolve mixture; standardized R.A.F. hydraulic system fluid during wartime, now replaced by D.T.D.641. Characteristic colour—BLUE.

D.T.D.641
Similar to above but with rather better low temperature performance; the current standard R.A.F. castor base hydraulic fluid. Characteristic colour—BLUE.

D.T.D.388 (Lockheed)
Castor oil-isopropyl alcohol mixture; standardized R.A.F. castor base fluid for shock absorbers and rather thicker than D.T.D. 641. Characteristic colour—ORANGE.

(ii) American—Lockheed Blue—similar to D.T.D. 391 and suitable for hydraulic systems. Characteristic colour—BLUE.

* Technical Director, British Messier Ltd., Gloucester.

(iii) French - Messier Violet
Castor oil-alcohol mixture for hydraulic systems, equivalent to D.T.D.391. Characteristic colour—VIOLET.

Messier Green
Castor oil-alcohol mixture more viscous than the Violet fluid and specially for shock absorbers. Characteristic colour—GREEN.

The main types of mineral oil are as follows:

(i) British—D.T.D.585
A very light mineral oil suitable for hydraulic systems and shock absorbers; standardized on all modern R.A.F. and civil aircraft. Characteristic colour—RED.

D.T.D.44
An earlier version of D.T.D.585 now obsolete for hydraulic systems although still used on certain special types of equipment as a lubricating oil.

D.T.D.44 - paraffin mixture
Used on some gun turrets during the war but now replaced by D.T.D.585.

(ii) American—AN-VVO-366B
This is identical and interchangeable with D.T.D.585.

Most of these fluids are stable and do not deteriorate appreciably in service. With castor base fluids it sometimes happens that after many months some of the alcohol or equivalent evaporates and the fluid becomes more viscous. As this will upset the system the tank and pipe lines should in this event be emptied and new fluid added. Any serious change of viscosity can be noticed by comparing two drops of fluid, one old and the other new, as they run along a piece of glass.

Rubber

As already mentioned castor base fluids alone are suitable for use with natural rubber and mineral oils require synthetic rubber. It is not easy to tell the difference between glands made in natural and synthetic rubber although the latter usually have a characteristic smell.

In order to appreciate the serious effect of mineral oil on natural rubber it is recommended that the simple test be made of immersing a spare natural rubber ring in a small tin of oil such as D.T.D.585 for about twenty-four hours. After this time the ring can clearly be seen to have swollen appreciably and is obviously useless.

Synthetic rubbers are usually made of Neoprene, Perbunan or Hycar materials. These are not in general suitable for use with castor base fluids, although the common G.R.S. material has occasionally been used as a direct natural rubber substitute.

Cleaning Fluids

A matter of prime importance is the solvent to be used when cleaning hydraulic components or systems. With natural rubber and castor base fluids, petrol or paraffin must *not* be used anywhere near the components. Apart from the direct effect of either on the rubber (worse than

mineral oils) it is very difficult to remove all traces of paraffin before assembly. A paraffin wash should not be used for this reason. The correct cleaning fluid is alcohol, purchased if necessary in the form of methylated or surgical spirit. Failing this, or in addition, a wash in the hydraulic fluid itself, particularly at final assembly, is convenient.

With mineral base fluids and synthetic rubber petrol and paraffin may be used for washing the components, although neither should be left in contact with the synthetic rubbers for any length of time; a wash in the fluid itself is preferred.

Greases

With mineral oil systems, ordinary light grease of the anti-freeze type can be used where necessary, e.g. on jack piston rods. With castor base systems such grease must not be used if any risk is run of the grease contacting the natural rubber. While castor base greases are known, they are not generally available; jack piston rods, for example, should be 'greased' with hydraulic fluid or pure castor oil (D.T.D. 72), if available.

CLEANLINESS IS PARAMOUNT

Benches

Cleanliness during maintenance and the avoidance of dirt or swarf is of such importance that it is best to approach the problem as a fanatic.

The ordinary dirty bench with dirt, swarf and filings embedded in it will not do. A clean, new and preferably polished bench top is necessary. Failing this spread two or three sheets of white paper (e.g. old drawings) all over the bench.

The usual vice with rough jaws and covered with filings also will not do. Clean it thoroughly and use soft aluminium, copper or fibre jaws.

A clean bench and vice, a clean set of tools, and clean hands and overalls are required because, when dismantling a part, it may be a tiny piece of swarf from inside that you are looking for; when reassembling it, a tiny piece from the bench or falling off your overalls may get in the part and interfere with its performance.

Temporary Storage of Parts

When a component is dismantled and left for a time before reassembly a good way to stop it collecting dust and dirt is to store it in a small tin of hydraulic fluid. When eventually lifted out the parts will be perfectly clean. Long tubes such as jack cylinders should be stuffed with rag. Piping should have its ends taped.

PIPING

Pipe Cutting

A good hydraulic engineer *never* cuts a pipe with a hacksaw as this is certainly the best method of filling it with swarf. The proper procedure is to use a tube cutter which can be bought for a few shillings and should be the indispensable possession of a conscientious mechanic. FIG. 1 illustrates a typical pipe cutter. This tool is rotated round the pipe screwing up the roller cutter meanwhile, until the pipe breaks off, leaving a clean swarfless cut. Some tube cutters have a wedge shaped scraper which can
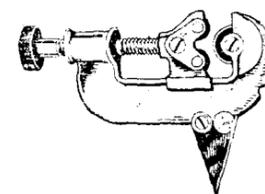

Fig. 1.—A typical tube cutter

TABLE I.—TABLE OF MINIMUM BEND RADII OF HYDRAULIC PIPING, ALL MATERIALS

Nominal Pipe Dia. in.	Minimum Bend Radii inner wall.—in.	
	With filler or pipe bender (3D)	By Hand (6D)
	·4	·8
	•6	1•2
	·8	1·5
	1·0	2·0
	1·2	2·5
	1·5	3·0
	1·5	3·0
	2·0	4·0
	2·0	4·0
	2·5	—
	3·0	—
	3·0	—

TABLE II.—PIPE DIAMETER WALL THICKNESS AND SAFE MAXIMUM WORKING PRESSURES
(based on a burst factor of 3)
TUNGUM PIPE O.D. INS. (DTD. 323)

Thickness S.W.G.	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4
16	*	*	*	*	*	*	*	*	*	3,900
18	*	*	*	*	*	*	3,800	3,300	3,000	2,800
20	*	*	*	*	3,600	3,100	2,800	2,400	2,200	2,000
22	*	*	4,000	3,300	2,500	2,400	2,100	1,900	1,700	1,600
24	*	*	3,100	2,500	2,100	1,900	1,600	1,500	1,300	1,200

STEEL PIPE O.D. INS. (DTD. 503)

Thickness S.W.G.	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4
16	*	*	*	*	*	*	*	*	*	4,000
18	*	*	*	*	*	*	3,900	3,500	3,100	2,800
20	*	*	*	*	3,300	3,300	2,900	2,500	2,300	2,100
22	*	*	3,700	3,400	2,400	2,500	2,200	2,000	1,800	1,600
24	3,600	3,600	2,800	2,500	2,000	1,900	1,700	1,500	1,400	1,300

* = over 4,000 lb./sq. in.

be used to remove the edge left inside the pipe by the cutter action; this edge can normally be left as it will not affect performance in any way and if it is scraped off, more swarf may be produced.

A conscientious mechanic without a tube cutter will file the pipe all round with a triangular file, not quite through, then break it off clean. If a hacksaw must be used, choose a miniature one with a six-inch blade and make quite sure that the pipe is blown through clean afterwards. It cannot be too strongly emphasized, however, that a hacksaw is the wrong tool to use.

Pipe Bending

On modern high pressure hydraulic systems the pipes are of small diameter and can generally be manipulated by hand. TABLE I give the recommended minimum bend radii for all pipe materials, including steel and tungum. To facilitate bending, particularly on the larger sizes, a tube bender of the type illustrated in FIG. 2 will be found extremely useful and not particularly expensive; with these, pipes can be bent round a particular radius in a few moments.

Heat should not be applied when bending aircraft pipes as the material may be weakened. Fusible material which is used to fill up the pipe prior to bending should *not* be used in the field as it is virtually impossible to remove the fusible filler completely without steam pressure and complicated pull-through operations.

Pipe Installations

The installation of piping in an aircraft is determined by the makers and the service mechanic is generally concerned only with replacements which will be made similar to the original. TABLE II gives information on suitable piping which can be used in the absence of other information. A word of warning, however, is necessary in connexion with straight pipes; it may happen that the new pipe is slightly shorter than the original and tightening up may actually overstress the end pipe connexions unless the remainder of the piping or components are suitably loosened to allow the pipe connexions to be pulled home.

Before installing any pipe, make particularly sure that it is clean inside, as nothing causes such unserviceability as dirt in the pipes. Blow the pipe through off the shop airline and if possible

TABLE III
TABLE OF PIPE–CLIPPING RECOMMENDATIONS

Nominal Pipe Dia. in.	Distance between supports.—in.		
	Per Douglas Aircraft Co.		Alternative, all materials
	Aluminium Alloy	Steel	
	9·5	11·5	12
	12	14	12
	13·5	16	15
	15	18	18
	16·5	20	18
	—	—	24
	19	23	24
	—	—	24
	22	25·5	24
	24	27·5	30
	—	—	30
	26·5	30	30

Fig. 2.—A tube bender

2 OR 3 TURNS OF ADHESIVE TAPE OR SYSTOFLEX

STRIP OF COPPER FOIL

BONDING STRIP CLAMPED UNDER BOLT

Fig. 4.—The method of bonding pipe clips

Fig. 3.—Dunlop bonded rubber pipe clip

pull through a fluid-soaked cloth on the end of a wire (but be careful that all the cloth comes through!). Then tape the ends of the pipe until the last moment of assembly.

When removing a pipe or component always tape the open pipe ends which are left in position.

Pipe clipping is normally determined by the aircraft designer, but TABLE III gives information on good practice on this matter. The pipe must be bonded to the aircraft, if not at each clip, at least at regular intervals. A convenient rubber faced pipe clip with automatic bonding is illustrated in FIG. 3. Where ordinary metal clips are used, the joint should be prepared with a few layers of tape or Sistoflex between the clip and

TABLE IV.—FLEXIBLE HOSE BEND RADII

Bore of Hose	Minimum straight from end of ferrule before bend—in.	Minimum Bend Radii—in.
	2	4
	2	5
	2	6
	3	6
	3	8
	3	8

the pipe, wound round the pipe with a strip of copper foil or gauze touching the pipe; the copper is then clamped under the clipping bolt. FIG. 4 illustrates this method.

FLEXIBLE PIPES

Hydraulic system flexible pipes are generally of the high burst pressure steel cored type, although cotton braided types are also used for lower pressure systems.

The important point to observe is that the hose should not operate in torsion as the steel cored types are torsionally rigid and twisting is bad for the cotton braided types.

While the installation runs of these pipes are generally fixed by the designer of the aircraft, the service mechanic should know what is the correct method. To avoid torsion 'the end fittings must be in, and move in the same plane'. FIG. 5 illustrates the right and wrong methods. TABLE IV gives recommended bend radii, etc., for the average high pressure steel cored hose as used on the modern 2,500 lb./sq. in. hydraulic system.

Very little can be said regarding hose in service as if failure occurs it is generally due to a defective pipe, assuming installation is correct. It sometimes happens that very slight leak occurs between the layers of the hose causing a blister to form on the outside of the pipe. It will be found that these can be punctured (cover with a cloth to avoid spurting oil) and that generally the hose is still serviceable as the leak may seal up.

PIPE CONNEXIONS
Types

Pipe connexions for modern high pressure hydraulic systems fall into two categories—expansion and compression types. Brazed or soldered connexions are not suitable for hydraulic work.

An expansion joint is one where the end of the pipe is flared out at 30 deg. or 90 deg. included angle and the end of the pipe clamped between the pipe joint parts.

A compression joint uses an olive which is slipped over the pipe and squeezed down on to the pipe when the joint is made.

A flared joint requires special flaring equipment, but if not properly tightened up will only leak.

An olive joint can be made with no special tools at all, but if not properly made will allow the pipe to blow out.

Flared Joints

The standard British A.G.S. and American A.N. joints are of the flared type, the former at 30 deg. and the latter 90 deg. FIG. 6 illustrates the features of these two joints.

A standard flaring tool is illustrated in FIG. 8.

(A) PIPE FOULS

(B) BEND TOO SHARP

(C) HOSE ENDS DO NOT MOVE IN SAME PLANE

MOTION OF JACK

Fig. 5.—Installation of flexible hose

SLEEVE

90° FLARE

NUT (OR WITH EXTENSION REPLACING SEPARATE SLEEVE)

USUALLY TAPER THREAD ASSEMBLE WITH SEALING COMPOUND

FLARING
FLARE SHOULD NOT PROJECT OUTSIDE SLEEVE NOR OVERLAP SLEEVE CONE

PIPE   SLEEVE

Fig. 6 (above and right).—A.G.S. and A.N. pipe joints—flaring dimensions

90° FLARING TOOL ROTATE WHILST STRIKING LIGHTLY

SPLIT BLOCK CLAMP IN VICE

USE SPARE SLEEVE AS GAUGE OF FLARING DIAMETER

NOTE: IN AN EMERGENCY USE THE PEEN END OF A SECOND BALL-PEEN HAMMER

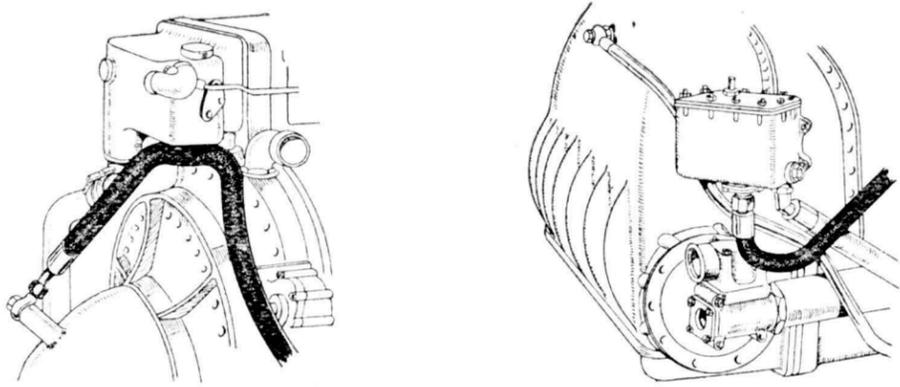In this, the pipe is clamped by a split collet and the wedge expander screwed in as it is rotated to flare out the joint. The end of the pipe should be drawn in to the end of the collet before clamping up, but no further.

Olive Joints

The standard French joint is illustrated in FIG. 7 and requires no special tools to enable it to be made. Care must be taken that the pipe projects through the olive properly and it is wise to dismantle the joint once made for inspection; final tightening up must be adequate and with hard pipe an appreciable torque should be applied.

SEALS

Types of Seal

The materials from which seals are made have already been discussed. Soft rubbers (50-60 shore) are used for static seals, but harder material (70-90 shore) is usually used on moving or 'dynamic' seals to improve wear resistance. The latter is less resilient and should not be stretched excessively.

FIG. 9 illustrates the main types of seal in current use on aircraft hydraulic equipment including those on shock absorbers. The simple types are made entirely from natural or synthetic rubber, but some are reinforced with layers of linen fabric to increase mechanical strength.

The important point about any seal is that it must fit the parts it seals with interference, either by direct compression as on the simple rubber types or by bending some part of the lip of the seal. The seal must be properly in contact with the walls it is sealing so that when the oil pressure is applied to it, the seal is squeezed on to the parts and the oil does not leak past.
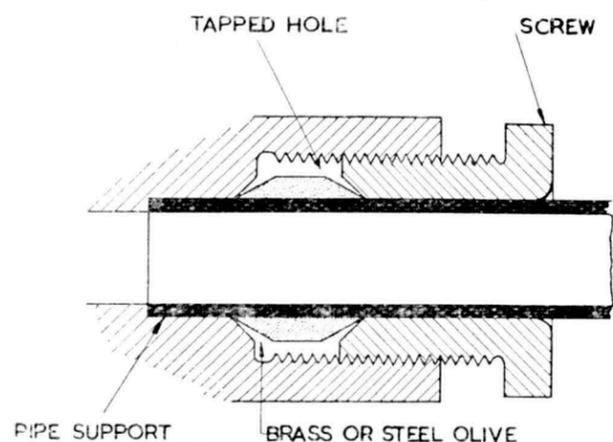
Storing Seals

Rubber seals are affected by sunlight and should be stored properly in boxes in a reasonable atmosphere. They should be stored dry. Old stock should be inspected for signs of ageing.

Removing and Fitting Seals.

Simple types of seal can be removed without difficulty using a small blunt-pointed screwdriver, care being taken not to damage the edges of the ring groove, nor to stretch the ring excessively. Other types of seal have to have their housings, etc., dismantled to allow removal.

When assembling components fitted with rubber rings or seals, a good lead or radius is necessary to enter the seals; the seals, of course, should be lubricated. The lead or radius is particularly necessary when the parts are screwed together as rotation on a sharp edge will cut the ring. Make sure the radius is adequate and polish if necessary before assembling any component, using a scraper and then very fine emery paper.

Use is sometimes made of special seal entry tools; these may be useful for U or lip seals, although an adequate radius is equally effective. The special entry tool is disliked because of its very nature as a special tool for one job only.

It is strongly recommended that the mechanic when reassembling a pair of parts with a seal between them makes a trial assembly, then removes the inner part to examine the seal. It is very difficult to tell if the seal has been cut unless the mechanic knows the feel of correct assembly and a trial assembly will enable him to get this feel.

VALVES

The valves which form one of the most important essentials of any hydraulic equipment and are found in almost every component are usually of one of the following types: slide valves, rotary valves or poppet valves. The first two types rely on initial factory accuracy being maintained in service, but the last type can usually be repaired if it becomes unserviceable.
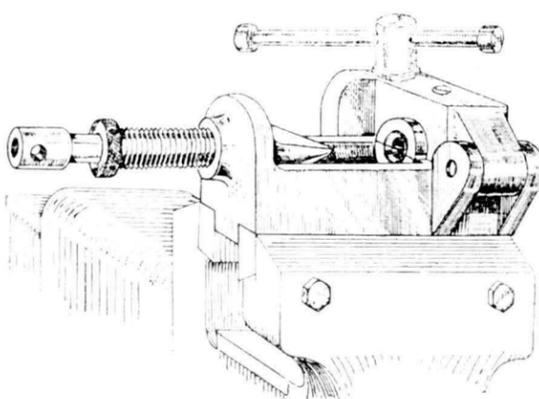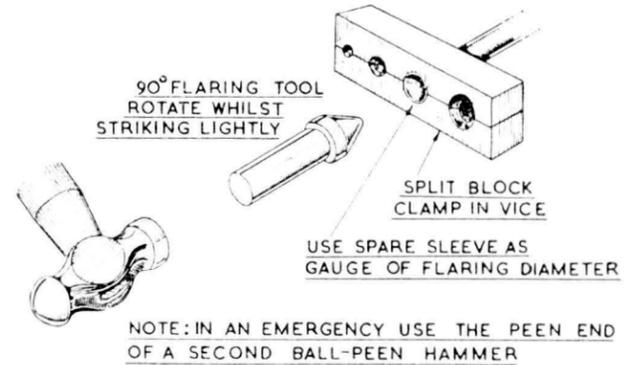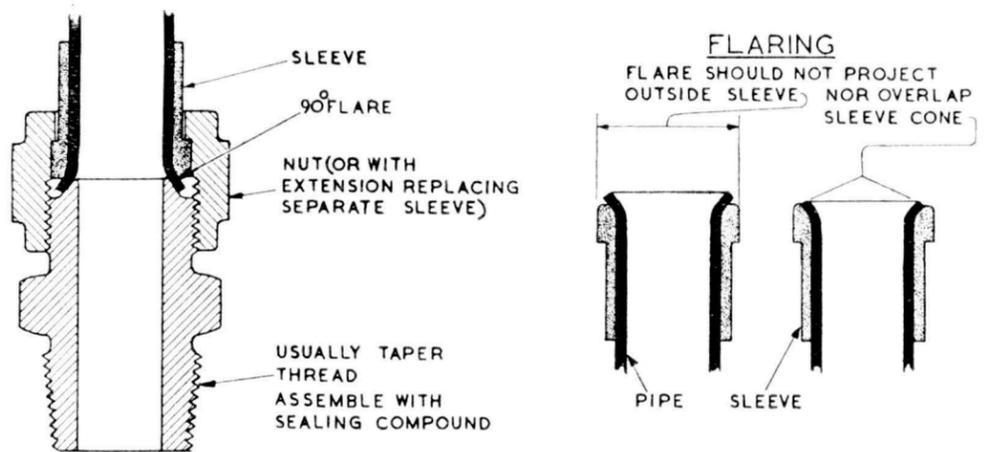
Slide Valves

In these, a plunger or slide carrying grooves slides axially in a cylinder in which it fits extremely closely, the fit between the parts being sufficiently close to prevent leakage or at any rate limit it. The fit is usually obtained by lapping the two parts together.

Very little can be done to rectify defects on slide valves. If they become jammed with dirt or swarf, it may be possible to remove the slide and polish off the mark left by the swarf with metal polish. Emery will remove too much metal from the fine fitting surface to be practicable. The degree of leak proofness achieved depends on the make of valve, but usual practice is to limit leakage between one port and another to a few drops a minute. Before deciding, however, that such a valve is worn or defective it should be ascertained what is the appropriate permissible leakage as some valves are satisfactory up to several ccs. of fluid per minute. If a slide valve leaks excessively, however, there is nothing that can be done about it other than replacement or returning it to the makers for the fitment of an oversize slide.

Rotary Valves

These are either of the disk or barrel type. The first has a disk which rotates with a very close fit on a flat surface of the valve body in which are drilled ports; the disk also has ports or grooves so that the desired porting is obtained as the disk rotates. The barrel type is similar except that the 'disk' is a cylinder rotating in an-

TAPPED HOLE   SCREW

PIPE SUPPORT   BRASS OR STEEL OLIVE

Fig. 7.—French Messier connexion

Fig. 8.—A pipe flaring tool

A   B

C   D

E   F

Fig. 9.—Types of hydraulic seal

Fig. 10 (left).—Types of poppet valve—(a) unguided ball, (b) guided ball, (c and d), outside guided poppet, (e) stem guided poppet

Fig. 11.—Defects in poppet valves

other cylinder, the rotation of the rotor bringing ports into correspondence with those on the body.

Defects in rotary valves are of the same type as in slide valves and the service mechanic can rarely do anything about excessive leakage. In the case of flat disk valves it may be possible to relap the flat surfaces on a surface plate with very fine emery but this is unlikely.

Poppet Valves

The main types of poppet valve are shown in FIG. 10. The commonest type is the unguided ball valve (a) although it is the least reliable. Type (b) is a guided ball; types (c) and (d) are poppets guided on the outside and type (e) is the mushroom poppet guided on its stem. There are numerous other variations of these types such as flat pastille valves, and rubber seated valves.

Defects in Poppet Valves

The plain unguided ball valve is not now used on the best equipment because it becomes marked in service, turns round and then allows the mark to lie across the valve seat. This defect is illustrated in FIG. 11 which also shows the main defect of the guided cone poppet—that of a lack of concentricity between the cone or seat and the guiding diameter, again allowing a leak when the valve turns round. This, however, is usually taken care of in manufacture, whereas the defect in the ball valve may occur any time in service.

Correct Seating Technique

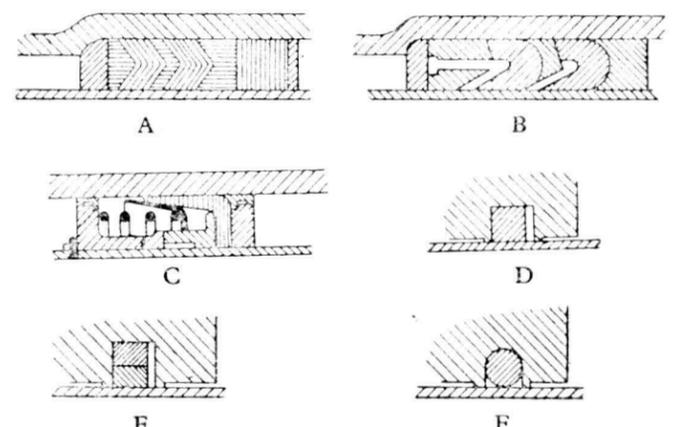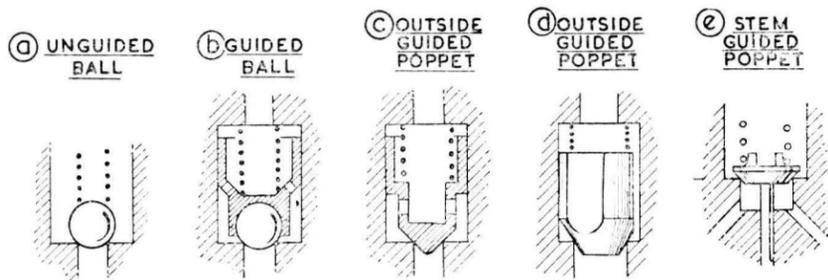The prime features of a good hydraulic poppet valve seat, apart from its truth already referred to, is that the seat shall be extremely narrow in width, in fact as near a knife edge as possible. This is so that the pressure loading between the valve and seat shall be high enough to crush the seating surface firmly and make a leak-proof joint; also it has been found that a narrow seat is less likely to trap particles of swarf.

A ball should be seated on to a newly made seat which has been machined with a clean sharp edge by tapping *squarely* the ball with a hammer and a soft drift; repeated light blows are better than one heavy one. The seat should have the appearance of a bright even ring of about 0.010 in. width if seated properly. A marked ball should be replaced.

In the original manufacture of guided poppet valves, the seat should have been prepared carefully as for the ball valve; the poppet cone should have been ground true with the guiding diameter. To remove minor imperfections from the cone face, even from a new valve and certainly fro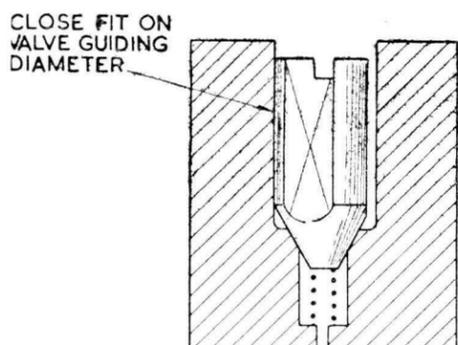m a worn one, a dummy lapping block of the type shown in FIG. 12 should be made up in cast iron and used with fine lapping paste. The usual lapping technique used in internal combustion engine valves and which will be familiar to most aeroplane mechanics should be used—that is, the oscillation back and forth over a small angle, the valve being turned round a quarter of a turn or so after eight or ten oscillations, the process being continued until the valve is lapped in. The small spring shown in the illustration helps to lift the valve between rotation; a screw-driver slot in the valve is obviously necessary.

When the valve cone has been lapped true on the dummy block it should be wiped clean and rubbed on to its seat on the component, etc. It is preferable to seat the valve without using lapping compound on the body and if after lapping in dry, a bright, thin, even seat marking is obtained on the poppet, the sealing under pressure will probably be satisfactory and should be tried. If not adequate, lap the two parts together with the finest possible lapping paste or, better, powder; a very light, short lap is preferable and great care should be taken to clean off all remains of the paste or powder. It must be emphasized, however, that if the parts are right before assembly, paste lapping should not be necessary.

While it should be possible to lap true a worn or pitted poppet with a lapping block, rectifying a defective seat is not so easy. This will involve the use of a special cutter or reamer unless the services of a skilled lathe turner are available. FIG. 13 illustrates the best types of seat rectifying cutters. Type (a) which opens out the valve throat diameter is the best type but is difficult to make; type (b) which cuts the flat face of the seat is easier to make but is liable to chatter in use; if a lathe is available it may be easier to machine the flat seat face, skimming lightly to remove the old seat.

FIG. 14 illustrates an operation which is possible only with very small valve throats (not exceeding $\frac{1}{8}$ in. diameter). In this a drill is used to open out the valve throat, the drill being guided by carefully made pilot bush which fits the guiding diameter and the drill closely. A sharp well-ground drill must be used.

Testing Valves

After lapping or seating a valve it should be tested with low pressure air (50-100 lb./sq. in.) with the valve parts absolutely dry. The valve should be opened and closed a few times and the absence of air leakage noted with a soap or 'spit' bubble across a convenient port or hole. This is by far the best and most searching test on any poppet valve and passing it will guarantee a reliable valve in service. If air equipment is not available a hydraulic test, first at low pressure and then the full valve design pressure, must be made. The valve should not leak at all; holding the pressure for about two minutes is a usual criterion.
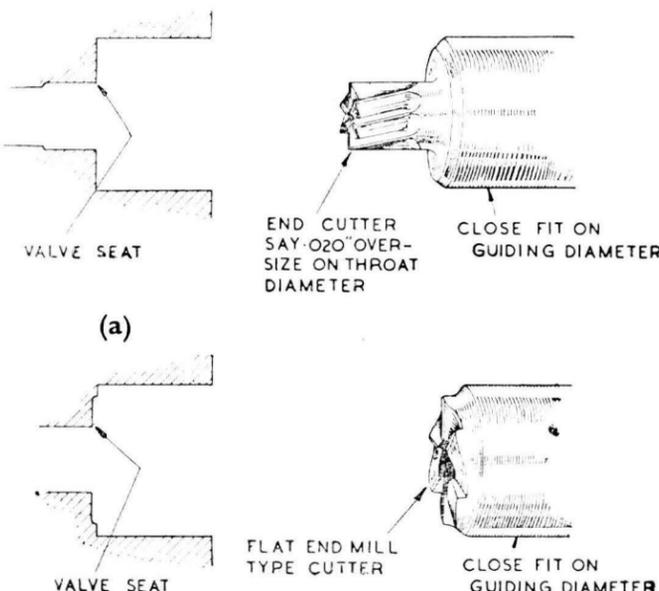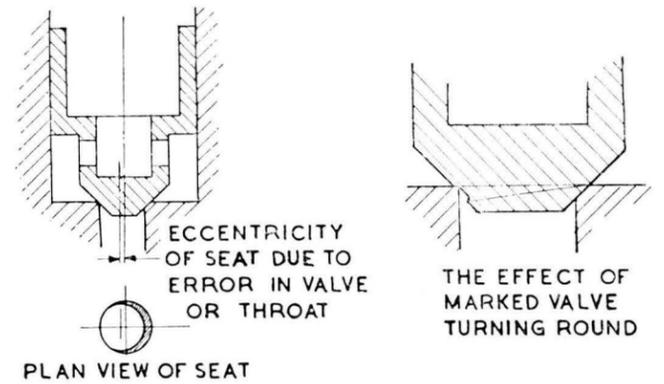
GENERAL NOTES ON SERVICING OF HYDRAULIC COMPONENTS

Jacks

The exact method of dismantling a jack depends on its construction, but usually the correct procedure is to remove the piston rod gland housing end, allowing the piston and rod to be removed with the gland housing still on the rod. Remember that the jack may be partially full of oil which will run out when it is opened up. TABLE V illustrates the S.B.A.C. range of standard hook spanners which will be found to suit most slotted nuts of the type common on jacks. Spanners to these dimensions can be made up for particular nuts by the enthusiastic mechanic by hard work with a hack-saw and a file.

Jack cylinders or piston rods must not be clamped in a vice in any way other than in split wood blocks as illustrated in FIG. 15. The importance of this in avoiding distorted tubes cannot be over-emphasized.

In certain cases when dismantling jacks and the like it may be necessary to rotate the cylinder while an end fitting, etc., is clamped in a vice. This involves the use of a strap spanner, probably 'home-made', but care must be taken that the handle does not indent the cylinder.

The most likely cause of unserviceability of a jack is worn glands. Piston rod glands may be worn due to wear or the scoring of the piston rod although as this is usually chrome plated, this is not very likely. In the case of undercarriage jacks, leakage of engine oil on to piston rods sealed with natural rubber glands is a prolific cause of failure. Scored piston rods should be repolished not by circumferential polishing

Fig. 12.—Lapping block for poppet valves

Fig. 13.—Seat rectifying cutters (a and b)
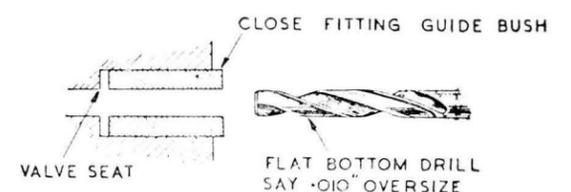
Fig. 14.—Drill piloting bush for opening out small valve throats
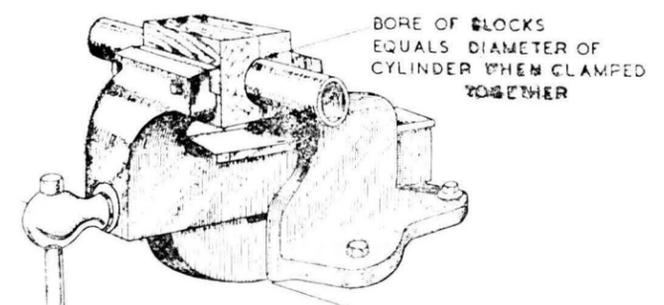
Fig. 15.—Accumulator or jack cylinder, held in split wood blocks

EACH SPANNER IS INTENDED TO COVER THE RANGE BETWEEN ITS NOMINAL DIAMETER & THE NEXT SIZE LARGER—IE·A 3·2"DIA SPANNER IS SUITABLE FOR ANY SIZE FROM 3·2"DIA. TO 3·3"DIA.

IT SHOULD BE NOTED THAT APART FROM THE VARIATION OF DIAMETER, SEVERAL SPANNERS CAN BE MADE FROM THE SAME BLANK. 18 BLANKS ONLY ARE NEEDED FOR THE SIZES 12, 15, 19, 22, 25, 28, 31, 34, 37, 40, 43, 46, 49, 53, 57, 61, 65 & 70.

SPANNER SHOULD BE CALLED UP AS FOLLOWS :—R.S. 181/DIA IN 1/10 OF AN INCH THUS R.S. 181/32 IS A SPANNER SUITABLE FOR ANY DIAMETER BETWEEN 3·2" AND 3·3".

USE MILD STEEL PLATE CYANIDE HARDEN AT HOOK

T· THICKNESS

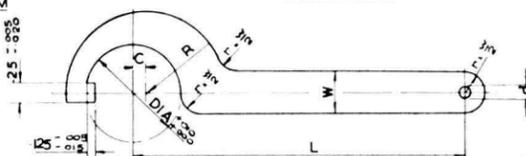| DIA	C	R	W	L	T	d
1·1	20	1·00	·55	3·75	·187	·199
1·2	15	1·00	·55	3·75	·187	·199
1·3	30	1·20	·65	4·5	·187	·199
1·4	20	1·20	·65	4·5	·187	·199
1·5	20	1·20	·65	4·5	·187	·199
1·6	35	1·45	·75	5·25	·187	·199
1·7	30	1·45	·75	5·25	·187	·199
1·8	25	1·45	·75	5·25	·187	·257
1·9	20	1·45	·75	5·25	·187	·257
2·0	35	1·65	·80	5·75	·25	·257
2·1	30	1·65	·80	5·75	·25	·257
2·2	25	1·65	·80	5·75	·25	·257
2·3	35	1·85	·85	6·25	·25	·257
2·4	30	1·85	·85	6·25	·25	·257
2·5	25	1·85	·85	6·25	·25	·257
2·6	40	2·05	·90	7·0	·25	·257
2·7	35	2·05	·90	7·0	·25	·323
2·8	30	2·05	·90	7·0	·25	·323
2·9	40	2·20	·95	7·75	·25	·323
3·0	35	2·20	·95	7·75	·25	·323

DIA	C	R	W	L	T	d
3·1	30	2·20	·95	7·75	·25	·323
3·2	40	2·35	·95	8·5	·25	·323
3·3	30	2·35	·95	8·5	·25	·386
3·4	30	2·35	·95	8·5	·25	·386
3·5	42	2·55	1·00	9·25	·25	·386
3·6	37	2·55	1·00	9·25	·25	·386
3·7	32	2·55	1·00	9·25	·25	·386
3·8	42	2·70	1·00	10·0	·25	·386
3·9	37	2·70	1·00	10·0	·25	·386
4·0	32	2·70	1·00	10·0	·25	·386
4·1	45	2·90	1·05	10·75	·25	·386
4·2	40	2·90	1·05	10·75	·25	·386
4·3	35	2·90	1·05	10·75	·25	·385
4·4	45	3·05	1·10	11·5	·25	·385
4·5	40	3·05	1·10	11·5	·25	·385
4·6	35	3·05	1·10	11·5	·25	·385
4·7	50	3·30	1·20	12·25	·25	·385
4·8	45	3·30	1·20	12·25	·25	·385
4·9	40	3·30	1·20	12·25	·25	·385
5·0	60	3·55	1·30	13·25	·25	·385

DIA	C	R	W	L	T	d
5·1	55	3·55	1·3	13·25	·25	·386
5·2	50	3·55	1·3	13·25	·25	·52
5·3	45	3·55	1·3	13·25	·25	·52
5·4	65	3·80	1·4	14·25	·25	·52
5·5	60	3·80	1·4	14·25	·25	·52
5·6	55	3·80	1·4	14·25	·25	·52
5·7	50	3·80	1·4	14·25	·25	·52
5·8	65	4·00	1·4	15·25	·25	·52
5·9	60	4·00	1·4	15·25	·25	·52
6·0	55	4·00	1·4	15·25	·25	·52
6·1	65	4·00	1·4	15·25	·25	·52
6·2	65	4·20	1·4	16·25	·25	·52
6·3	60	4·20	1·4	16·25	·25	·52
6·4	55	4·20	1·4	16·25	·25	·52
6·5	50	4·20	1·4	16·25	·25	·52
6·6	70	4·25	1·45	17·50	·25	·52
6·7	65	4·45	1·45	17·50	·25	·52
6·8	60	4·45	1·45	17·50	·25	·52
6·9	55	4·45	1·45	17·50	·25	·52
7·0	50	4·45	1·45	17·50	·25	·52

Fig. 16.—Spanner dimensions

Fig. 17.—A simple static test bench

5000 LB SQ IN GAUGES

STRONG COARSE GAUZE SCREEN

NON RETURN VALVE

CONNECTIONS FOR TESTING

ALL PIPING IN STEEL OR TUNGUM
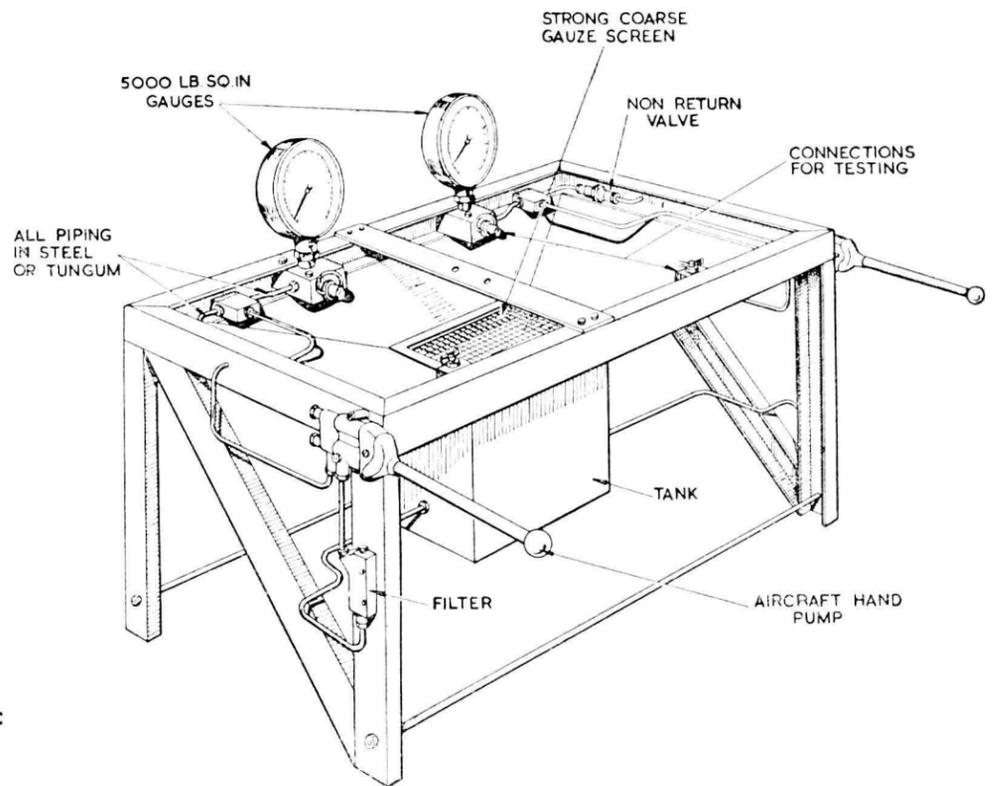
TANK

FILTER

AIRCRAFT HAND PUMP

but longitudinal 'stroking' with very fine emery paper, first dry and then oiled. The longitudinal action is important to keep any marks in an axial direction where they will have least effect on the glands. The degree of polish achieved, however, must be very high. Cylinder scratches, particularly on light alloy cylinders, are much harder to deal with. If it were vital to repair a scored cylinder when a replacement was not available a temporary repair could be made by polishing the score with very fine oiled emery paper used on the end of a suitably shaped stick. The difficulty is to see the results of the polishing without an internal inspection lamp; the reflection of light produces very deceptive results, daylight being preferable to artificial light. A dental mirror or its equivalent will enable a proper inspection of the score to be made. It will not be possible to polish out all of a score or scratch by such methods, but the important point is to smooth off the edges so that the rubber glands at least will not be cut.

The piston if scored can be cleaned up lightly with fine emery; it is important, however, not to remove excess metal and in many cases not to damage the sharp edge of the gland grooves since these are usually kept sharp to support the edge of the seals and prevent nipping of the edges of the rubber. For the same reasons pistons should be handled carefully to prevent burring of the seal lands.

The piston clearance on jacks will not concern the mechanic as the jack is unlikely to have worn in the normal sense of the word; modern high pressure systems have a piston clearance of about 0.001-0.008 in. The clearance and ovality of the cylinder can be measured with long feeler gauges, the piston passing lightly to avoid scratches or distortion. A clearance of more than 0.010 in. will cause high seal wear at 2,500 lb./sq. in. operating pressure.

When a jack is reassembled it should be pressure tested at both (or all) connexions holding the normal maximum working pressure for two minutes without leakage. It should be pumped back and forth two or three times. It will be tested again after installing on the aircraft.

Accumulators

Piston accumulators can be treated exactly as for the jacks mentioned above. Pistonless accumulators hardly need any maintenance. In order to avoid possible explosion under air pressure—which can be very dangerous—all accumulators *must* be hydraulically tested with an ample pressure *before* air testing or inflation. The dangers of a pneumatic failure cannot be over emphasized.

Pumps

The dismantling and maintenance of engine-driven pumps is a specialized side of hydraulic equipment servicing which is outside the scope of these notes because information cannot be generalized and must refer to particular designs of pump. Engine pumps, however, are more liable to wear and loss of pumping efficiency than to the types of derangements that are common with other hydraulic equipment. While a competent mechanic can take them to pieces, he rarely can do anything to repair the unit when it is dismantled, other than replacing the essential pumping elements. In addition, most pumps are intended by their makers only to be serviced at the factory or major depots where proper test equipment is available.

Hand pumps, however, are well within the scope of the hydraulic mechanic. Most defects are those already dealt with—seal failures, valve leaks, scored cylinders, although in the latter case polishing the bore is not recommended and the whole cylinder should be replaced. On test, a hand pump should be able to generate and hold without any leakage at least 1.5 times its rated maximum pressure (e.g. 3,750 lb./sq. in.). The only other test of importance is that of the suction valve. Since a good suction lift is essential for good performance, the pump should be able to lift about 20 in. of mercury (i.e. about – 10 lb. /sq. in.) and hold it for at least two minutes. As vacuum gauges are not normally available the mechanic should rig up on a piece of wood a glass U-tube, the arms of the U being about 30 in. long; this can be half-filled with mercury and one branch connected to the hand pump by a rubber tube. The difference in level of the two branches when the pump is operated should reach 20 in. on the good pump, assuming the suction valve has a normal amount of fluid on it; a dry valve may have difficulty. If the pump will not create such a suction, it may not be due to a defective valve but to the strength of the suction valve spring, which causes a loss in pressure through the suction valve; since the absolute limit of suction pressure is about 30 in. of mercury, any loss due to this spring will limit the suction head.

Selectors

From the servicing point of view, selector defects are mainly obvious mechanical ones or seal and valve troubles already dealt with above. In certain designs the valve operating rocker may wear or bed in and limit the valve lift. The mechanic should know that on an ordinary ball or poppet valve the lift of the valve should be at least 30 per cent of the valve throat diameter.

Relief Valves

Apart from seal and valve troubles, the important point to check is the correctness of the opening pressure, rectifying it by whatever shim or screw adjustment is appropriate; and also to verify that the valve holds pressure right up to opening pressure and does not tend occasionally to open prematurely. Irregular performance is almost certain to be due to a bad valve seat.

FILLING THE SYSTEM—PRIMING AND BLEEDING

Priming consists in pumping the fluid from the tank down each pipe line and filling the various components. Bleeding consists in eliminating air from the system, and, as modern systems are largely self-bleeding, is often carried out at the same time as priming.

The correct process of priming and bleeding a typical system is as follows :

(a) Fill the tank, and keep topping it up.

(b) Slacken the hand pump delivery connexion and pump until oil appears; then retighten. This primes the hand pump which can then be used for all other circuits except the engine pump.

(c) Inflate any accumulators in the system.

TO SYSTEM

PRESSURE GAUGE

AIRCRAFT HAND PUMP

FILTERS

SAFETY VALVE

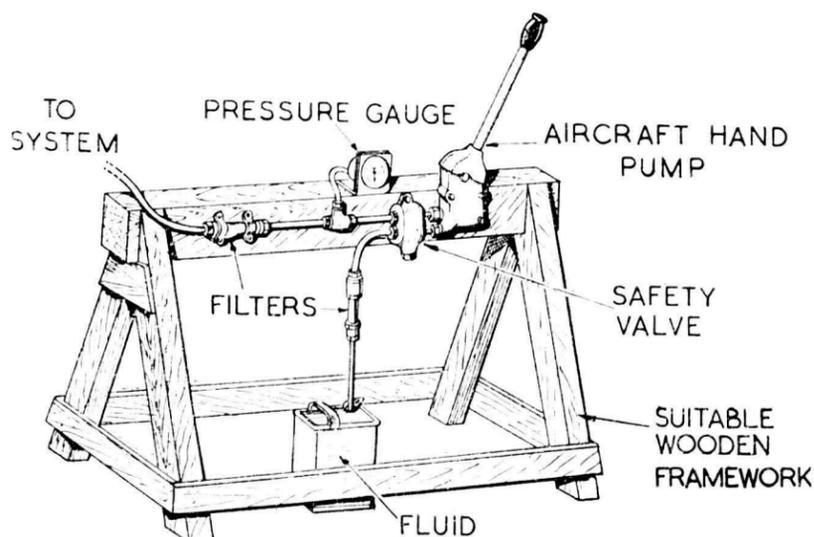SUITABLE WOODEN FRAMEWORK

FLUID

Fig. 18.—A hand pump portable test rig

(*d*) Slacken off the most remote pipe connexion on, say, the undercarriage up line and after appropriate selection get an assistant to hand pump until oil flows freely; then tighten up. Repeat on all circuits of the whole system. Where a single line feeds two jacks, bleed at the division of the pipe line first, and then at each jack end connexion.

(*e*) In the case of undercarriages, uncouple the jack from the retraction gear; operate these jacks (or the flaps or doors without uncoupling), in and out a few times.

(*f*) Rebleed the remote jack end connexions or bleeder screws, if fitted, to remove any residual air. If a good flow of oil is pumped, air will not collect in the top corners of pipes but will be swept down to the undone connexion.

The system should now be ready for engine test and the bleeding of the engine pump delivery circuit if necessary. The operation of the pump and cut-out, etc., should then be checked by operating the flaps 10-12 times.

Hydraulic brake systems should be treated as above except that as there is a greater vertical drop in the pipe lines, more care is needed to get rid of air. The following is recommended:

(*a*) On power brake systems, bleed about half a pint of oil from each brake bleeder screw, using a rubber tube dipping into a glass jar of fluid, an assistant pumping rapidly on the hand pump.

(*b*) On direct foot pedal brake systems where bleeding is extremely important, the bleeding process used on motor cars is not effective and it is much better to bleed by pumping oil into the brake, out the lines and up into the reservoir or brake pump units. This ensures that the air is carried upwards. However, in this case, any air in the system can be felt as sponginess on the pedal.

TEST RIGS AND GEAR

There are three items of test gear which are essential or desirable for general hydraulic servicing. First is a simple static test bench (FIG. 17) fitted with a hand pump sucking from small reservoir, and delivering preferably through a shut-off cock to a component being tested; a pressure gauge in the line is essential. The component should be laid in the tray of the bench, any fluid dripping back through the tray back to the tank. This bench is essential to any servicing work.

FIG. 18 illustrates a typical simple portable hand pump rig which is essential for filling, test-

ing, etc., on the actual aircraft and enables components to be operated *in situ*. (It is also extremely useful for servicing oleo-pneumatic undercarriage shock absorbers.)

The third item of equipment is more complicated and is important only in a large servicing organization. It is an electric motor-driven engine pump rig to enable full scale retraction tests to be made. This involves, however, an 8-10 h.p. motor, a belt drive to step the pump up to the correct spead, a tank and automatic cut-out, and some means to allow fluid to return from the aircraft system to the pump rig tank. This type of equipment is not desirable for simple maintenance work, and requires designing for each particular aircraft.

TROUBLE TRACING

Line Diagrams

It is essential for any mechanic who is trying to trace a fault in a hydraulic system to have a thorough understanding of the operation of the system. Assuming that he has been instructed in the general principles of hydraulic systems, it is necessary for him to understand clearly the details of the system on the particular aircraft he is dealing with.

The handbooks of many aircraft illustrate the
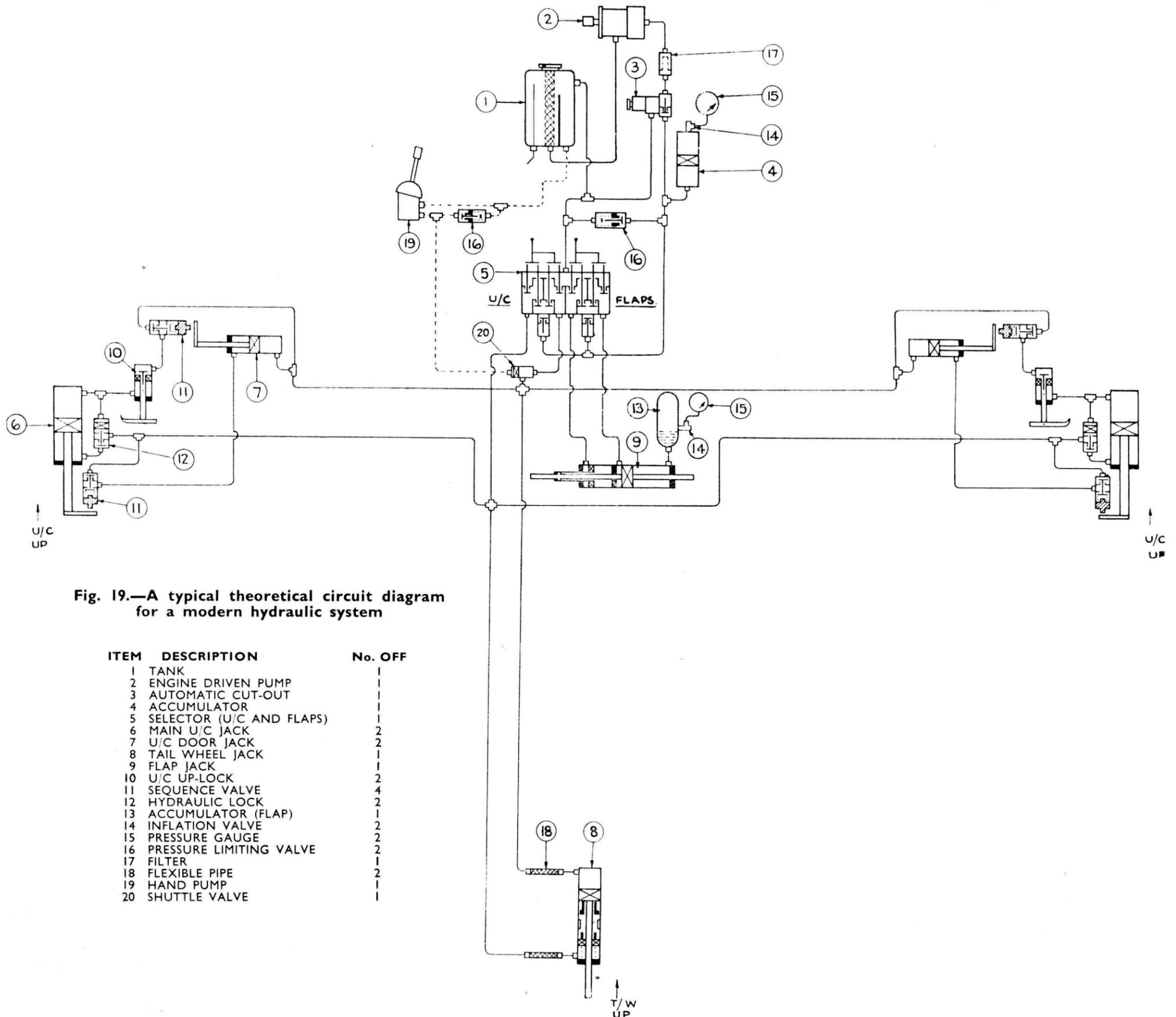
Fig. 19.—A typical theoretical circuit diagram for a modern hydraulic system

ITEM	DESCRIPTION	No. OFF
1	TANK	1
2	ENGINE DRIVEN PUMP	1
3	AUTOMATIC CUT-OUT	1
4	ACCUMULATOR	1
5	SELECTOR (U/C AND FLAPS)	1
6	MAIN U/C JACK	2
7	U/C DOOR JACK	2
8	TAIL WHEEL JACK	1
9	FLAP JACK	1
10	U/C UP-LOCK	2
11	SEQUENCE VALVE	4
12	HYDRAULIC LOCK	2
13	ACCUMULATOR (FLAP)	1
14	INFLATION VALVE	2
15	PRESSURE GAUGE	2
16	PRESSURE LIMITING VALVE	2
17	FILTER	1
18	FLEXIBLE PIPE	2
19	HAND PUMP	1
20	SHUTTLE VALVE	1

hydraulic system with block diagrams representing the outside of the components; it is very difficult to visualize in these cases how the system operates without reference to sectional drawings of the components.

The best practice is to depict the system with a line diagram using theoretical symbols as in a radio circuit, except that the symbols should as far as possible illustrate diagrammatically the actual operation of the component—i.e. if it has poppet valves it should be shown as such, and so on. FIG. 19 illustrates a typical theoretical circuit diagram of a modern hydraulic system; a complicated one has been chosen deliberately to demonstrate how involved trouble tracing may be.

If the mechanic finds any difficulty in understanding or following such diagrams he should draw out for himself the system into its various essential circuits; viz. the pump and pressure circuit, the undercarriage circuit, the flap circuit, the bomb door circuit, etc. This will enable him to understand the whole system in stages.

DIAGNOSIS

Fortunately, many of the major troubles can be traced fairly easily by systematic deduction. For example, if the undercarriage will not retract, it is probably due to (a) inadequate pressure (a worn pump, leaking cut-out or relief valve), traced by fitting a pressure gauge; (b) a defective jack (leaking piston seals); (c) abnormal back pressure in the jack return line (a blocked pipe, or worn selector not allowing full valve opening). Such defects will be easily traced by systematic thought and analysis and a study of the circuit diagram.

Certain special aspects, however, must be mentioned. Aircraft are not now commonly fitted with a main hydraulic system pressure gauge. For maintenance work such a gauge, if reliable, is invaluable, and if not fitted the mechanic should connect a service gauge in between the pump and selectors when tracing faults.

This gauge can give invaluable information as to the general state of the system. If not properly understood, however, its reading can cause considerable confusion as due to pipe losses, pressure waves, restrictors, etc., the pressure recorded on the gauge during operation of the system may not necessarily be that at the jack or at the pump. The cut-out pressure of an automatic cut-out in the system may, due to the position chosen for the gauge, be recorded as plus or minus 100 lb./sq. in. of the true pressure when using the engine-driven pump. Using the hand pump the cut-out may read appreciably higher, but the engine pump result should be used as a basis of checking.

If the normal gauge pressures for operation in the air and on ground are noted and recorded, the gauge readings under particular circumstances will indicate a fault. A typical set of readings would be retraction in the air 1,900 lb./sq. in.; ground test retraction 2,100 lb./sq. in.; peak pressure during ground test at end of retraction just before cutting out 2,500 lb./sq. in.; dropping at once to 2,400 lb./sq. in. and settling at 2,300

lb./sq. in.; cut in at 2,000 lb./sq. in. It is possible, however, that when checking the cut-out with the hand pump, the pressure may rise above the pressure reached with the engine pump, the difference being possibly as much as 100 lb./sq. in.

Another use of the pressure gauge in the pump line is to check the inflation pressure of the main system accumulator, or the gauge on this unit if fitted. By emptying the accumulator slowly by operating some part of the system the point at which the slowly descending needle on the gauge suddenly drops away, indicates when the accumulator piston bottoms and thus the inflation pressure.

The effects of air in the system are not often serious, and in fact may not be noticed. Where accurate positioning of a jack is important as on undercarriage doors, for example, a large amount of air may cause undesirable irregular motion. In the case of direct operated brakes, air will cause sponginess in the pedals or lever and prevent the brakes being applied fully. This can be diagnosed easily, however, by the elasticity of the system.

Back pressures, usually in the tank return line when the undercarriage is lowered, may cause peculiarities in a system not designed against them. Cases have been known where such back pressures from the undercarriage moved the flaps, or the opening of the bomb doors on the ground tended to unlock the undercarriage. These effects occur if the selector valves do not stay shut when there is a back pressure in the tank line, but allow the pressure to be applied to some other part of the system.

New Recording Test Equipment

Some Details of the Avimo Photo-Acoustic
Apparatus for Obtaining Light and Sound Measurements

New Developments in the Recording of Oscillograph Traces

It is well known that high-speed mechanical or electrical variations can be translated by a standard commercial oscillograph into visible traces on a fluorescent screen. The impermanence of the traces, however, makes difficult any accurate study of the inter-relationship of several phenomena and makes impossible any subsequent checking; and attempts have been made with varying success to photograph these traces by means of standard cameras.

Traces Recorded Side by Side

During the late war, Avimo Ltd. of Taunton, Somerset, designed special cameras which gave much more satisfactory results and recorded, side by side, on continuous film or paper, traces from any standard type of oscillograph. The number of traces which could be so recorded was, however, limited in practice by the fact that the space between the screens necessitated moving the camera back so far that the traces were reduced eventually to an impracticable scale. To provide a record on a

Fig. I.—Avimo 15-channel camera which records 15 oscillograph traces side-by-side. A similar device is used with the photo-acoustic unit

practical scale where a number of traces are required to be shown side by side. Avimo now have in production a series of recording cameras with built-in cathode ray tubes—the latter so arranged that their traces are photographed through a mirror. In this way, as many as 15 traces, plus a timing interval, may be recorded on a scale adequate for practical purposes.

Specially Designed Equipment

A camera of this type has been incorporated in a photo acoustic recording unit, which has been designed and made to the special requirements of the Ministry of Supply (FIG. 1).

The apparatus consists essentially of an Avimo 6-channel camera with built-in cathode ray tubes, and 6 photo-cell microphone pick-ups—the latter being suitably placed round a target within a radius of 2,000 ft. The camera, with electronic amplifiers and control equipment, is housed in a van and is connected to the pick-ups by cables.

Each pick-up transmits, in the form of electrical energy, both the light intensity throughout the duration of the flash and the sound of the flash—thus enabling, for example, the distance of the flash to be determined.

How the Photo Acoustic Recording Unit Works

The reactions of the pick-ups are recorded in the form of linear traces on the six 1½-in. cathode ray tubes (V.C.R. 522), which are built into the camera. The maximum length of trace on each tube screen is 1 in. which is reduced to 10 mm. on the film. Provision is made for the use of standard 70 mm. perforated film or paper in 100 ft. lengths, wound on metal spools, and a microscope is provided which permits the viewing of the traces while recording is in progress. The cathode ray tubes are each mounted in a mu-metal shield, so arranged that the light from the tube heaters has a minimum effect on the film, and it is possible—by an adjustment which is not affected by normal vibraton and handling, so to orientate each tube in its mounting that the traces lie on *one straight line* on the record, at right angles to the direction of
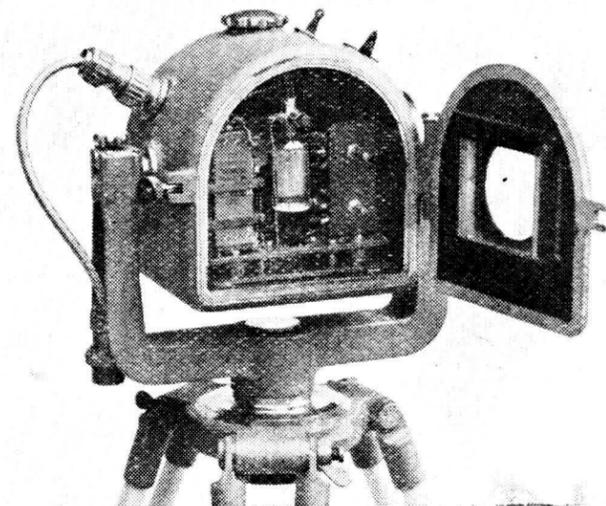

Fig. 2.—Avimo photo-cell microphone unit, part of the apparatus designed specially for the M.O.S. to obtain light and sound measurements

film travel. A range of six film speeds is obtainable, approx. 1, 2½, 5, 10, 25 and 50 in./sec.

The Pick-up Unit

The photo-cell microphone pick-up (FIG. 2) may be thus briefly described:

The door carries a 1/16 in. opal glass screen mounted in front of a glass colour filter cell which contains a suitably coloured solution to serve as a correction filter for the photo-cell spectral response.

Inside the housing is the following apparatus:

1. G.E.C. type K.M.V. 6-vacuum photo-cell, with 110 V.H.T., adjustable.
2. Carbon microphone.
3. Mullard Type D.A.C. 32 as cathode follower.
4. Potentiometer to act as the pre-set microphone attenuator.
5. Potentiometer to act as the pre-set microphone attenuator and capacitor to act as high frequency compensation.
6. Siemens square dry cell.
7. Post office type 3,000 relay with one pair of make contacts, coil resistance 20,000 ohm for switching cathode follower filament.
8. Container for Silica-Gel (to avoid misting of window).

The pick-up is mounted on an anti-vibration chassis with telescopic legs, so that the height of the unit may be varied.
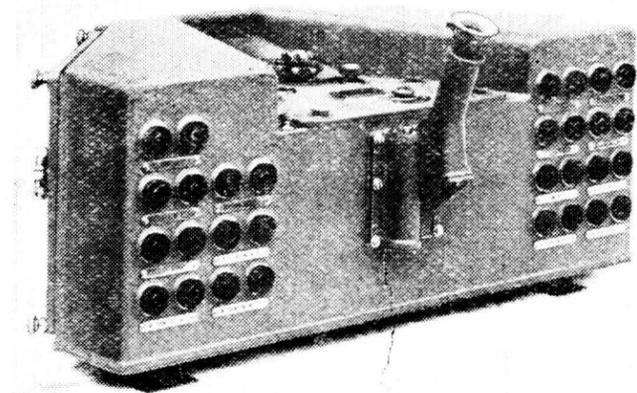
Thermodynamic Properties of Combustion Gases

A Simplified Basis for the Calculation of Gas Turbine Efficiencies in which all the Variables are Related to the Properties of Air by means of Determined Constants

By J. Kestin, Ph.D., D.I.C., Dipl. Ing., A.M.I.Mech.E.[*]

REFERENCES TO LITERATURE

(1) Finniecome, J. R. New Temperature—Total Heat—Entropy Chart for Gases with variable Specific Heats. *Proc. I. Mech. E.*, Vol. CLV (1946), pp. 117-124. W.E.P. No. 17.

(2) Heck, C. H. R. The New Specific Heats. *Mech. Eng.* Vol. LXVI (1940), pp. 9-12. Discussion and addenda *ibid.* Vol. LXVI (1941), pp. 126-135.

(3) Keenan, J. H. Thermodynamics. John Wiley & Sons, New York. 1941.

(4) Keenan, J. H. and Kaye, J. Thermodynamic Properties of Air. *Journ. Appl. Mech.* Vol. X (1945), pp. A128-A130.

(5) Keenan, J. H. and Kaye, J. Thermodynamic Properties of Air. John Wiley & Sons, New York. 1945.

(6) Lutz, O. and Wolf, F. J. S.—Tafel fur Luft und Verbreunungsgase. Julius Springer, Berlin. 1938.

(7) Lutz, O. Use of Charts for Flow Discharge Calculations. *L.F.F.* Vol. XVII (1940). No. 8 and T.M. 972.

(8) Pinkel, B. and Turner, L. R. Thermodynamic Data for the Computation of the Performance of Exhaust-Gas Turbines. N.A.C.A. Report. (Feb. 1944).

(9) Rosin, P. and Fehling, R. Das I,t—Diagramm der Verbreunung. *Z.V.D.I.* Vol. VII (1927), p. 383, and separate publication of the V.D.I. (1929).

(10) Rosin, P. and Fehling, R. The It—Diagram for complete and imperfect combustion. *J. Inst. Fuel*, Oct. 1942, p. 20.

(11) Rosin, P. Total, recoverable and returnable heat in combustion gases. *J. Inst. Fuel*, Vol. XIX (1945), p. 53, *corr.* Vol. XIX (1946), p. 191.

(12) Schmidt, E. Einfuhrung in die technishe Thermodynamik, 3rd ed. Julius Springer, Berlin. 1945. Transl. into English by Kestin, J. Thermodynamics. Principles and applications to engineering. Clarendon Press. To be published shortly.

(13) Schmidt, E. Das J,t—Diagram ein neues Hilfsmittel zur Berechnung von Gasturbinenprozessen. *Schriften d. deutsch Akad. d. Luftfahrt.* Vol. VIIB (1942). pp. 77-91.

(14) Spiers, H. M. Technical data on fuel. London, 1945.

(1) Introduction

THE calculation of gas turbine efficiencies on the basis of the real properties of the working medium is a laborious process. Such a calculation involves the determination of the composition of the combustion gases for a series of air fuel ratios, and the evaluation of a number of thermodynamic properties at various temperatures and pressures, such as the enthalpy (total heat), entropy, specific heats, etc. These properties are calculated from the tabulated properties for the component gases with the aid of the rules for mixtures.

Recently published data on the specific heats of gases[†] obtained from spectroscopic measurements from a rational basis for such calculations. The composition of the combustion gases is evaluated from the known composition of the fuel and the assumed air ratio, i.e. the ratio of the actual quantity of air to that necessary for theoretical, stoichiometric, combustion. The air ratio is usually very large in gas turbine calculations and the combustion can be assumed complete. Moreover, since temperatures in a gas turbine working fluid rarely exceed 2,700 deg. F. no dissociation phenomena need be taken into account.

The fact that calculations pertaining to combustion gases can be appreciably simplified has been recognized by several investigators. Rosin and Fehling[9,10,11] presented a graphical method for the calculation of the temperature of combustion based on a single graph and established a number of simple formulae correlating the various quantities to be calculated with the calorific value of the fuel. Lutz and Wolf[5,7] introduced an enthalpy—entropy chart, which covers a wide range of combustion gases at the cost of an appreciable complication of the drawing. This chart is basically an enthalpy—entropy diagram for 1 kilogram-molecule of air, but the authors have demonstrated that thermodynamic changes of combustion gases can also be followed with its aid. For a combustion gas lines of constant entropy become oblique, the angle of inclination being dependent on the composition of the gas. Furthermore, the enthalpy scales must also be suited to the composition of the combustion gas.

Finniecome[1] has published a simpler, but essentially similar chart, except that he designed it for a specific fuel (86·46 per cent carbon, 13·50 per cent hydrogen, and 0·04 per cent sulphur), determined the slope of the oblique isentropes in terms of the weight of fuel to air ratio and drew the chart for 1 lb. of gas.

Pinkel and Turner[8] have developed a method which permits calculating gas turbine cycles by the use of two effective values of the ratio of specific heats, γ, related to the value of γ at the start of the process and to the pressure ratio. The calculation of γ at the start of the process involves the use of a number of temperature functions.

In the present paper all calculations are related

List of Symbols

A	volume of air per 1 lb. of fuel
$\bar{C}_p$	molar specific heat at constant pressure
$\bar{C}_v$	molar specific heat at constant volume
$\bar{C}_1, \bar{C}_2$	correction functions for $\bar{C}_p$ [eqns. (20), (20a) and (20b)]
$\bar{H}$	enthalpy (total heat) per mol of gas
$\bar{H}_1, \bar{H}_2$	correction functions for $\bar{H}$ [eqns. (21) and (21a)]
P	pressure
P_o	pressure at reference state
$\bar{R}$	universal gas constant
$\bar{S}$	molar entropy
T	absolute temperature
T_o	absolute temperature at reference state
$\bar{U}$	molar internal energy
$\bar{V}$	molar volume
$\bar{V}_o$	molar volume at reference state
V_g	volume of gases per 1 lb. of fuel
x	volumetric (molar) fraction
γ	ratio of specific heats
Γ	correction function for γ [eqn. (16)]
κ	characteristic quantity dependent on the gas composition [eqn. (25)]
λ	air ratio
Φ_p	entropy function [eqn. (8)]
Φ_v	entropy function [eqn. (9)]
Φ_1, Φ_2	correction functions for Φ_p [eqns. (22), (22a)]

Suffixes

1	referring to combustion gas with theoretical air quantity
air	referring to air
O_2, N_2, etc.	referring to the respective gas

to the properties of air which are comprehensively listed in Keenan and Kaye's Tables[5]. Each calculation requires the determination of one constant, κ, which depends on the molar (volumetric) composition of the combustion gas. It will be proved that the difference between the property of the combustion gas and the corresponding value for air at the same temperature is a function of κ only [eqns. (17), (20b), (21) and (22)]. Thus a general set of corrections, which depend on temperature alone could be established for each property in question, that is for the molar specific heat at constant pressure $\bar{C}_p$, for the molar enthalpy $\bar{H}$ and for the molar entropy function

$$\Phi_p = \int_{T_0}^{T} \frac{\bar{C}_p}{T} dT.$$

These corrections are listed in Tables 5 and 6 and are represented in the form of graphs in FIGS. 7, 8, 9 and 10.

(2) Assumptions

(i) It is now generally agreed that for all practical purposes it is sufficiently accurate to assume the validity of the perfect gas law[‡]

$$P\bar{V} = \bar{R}T \qquad \qquad (1)$$

where $\bar{V}$ denotes the molar volume and $\bar{R}$ is the universal gas constant, the value of which is

$$\bar{R} = 1 \cdot 986 \ \text{Btu./lb.mol deg. F} \qquad (2)$$

(ii) It can be proved[§] that the specific heats of a substance conforming to (1) is a function of one variable only, namely temperature. Furthermore, provided (1) is assumed we have the very well known formulae, which are listed here for the purpose of easy reference:

$$\bar{C}_v = \bar{C}_p - \bar{R} \qquad \qquad (3)$$

$$\gamma = \frac{\bar{C}_p}{\bar{C}_v} \qquad \qquad (4)$$

$$\bar{H} = \int_{T_0}^{T} \bar{C}_p dT \qquad \qquad (5)$$

$$\bar{S} = \int_{T_0}^{T} \frac{\bar{C}_p}{T} dT - \bar{R} \ln \frac{P}{P_o} \qquad (6)$$

$$= \int_{T_0}^{T} \frac{\bar{C}_v}{T} dT + \bar{R} \ln \frac{\bar{V}}{\bar{V}_o} \qquad (7)$$

The integrals

$$\Phi_p = \int_{T_0}^{T} \frac{\bar{C}_p}{T} dT \qquad \qquad (8)$$

and

$$\Phi_v = \int_{T_0}^{T} \frac{\bar{C}_v}{T} dT \qquad \qquad (9)$$

will be termed *entropy functions*. Consequently:

$$\bar{S} = \Phi_p - \bar{R} \ln \frac{P}{P_o} \qquad \qquad (6a)$$

$$= \Phi_v + \bar{R} \ln \frac{\bar{V}}{\bar{V}_o} \qquad \qquad (7a)$$

Furthermore,

$$\bar{U} = \bar{H} - \bar{R}T \qquad \qquad (10)$$

and, by virtue of (3)

$$\Phi_v = \Phi_p - \bar{R} \ln \frac{T}{T_o} \qquad (11)$$

* Polish University College, London.

† See references 2. 42. 5, 8 and 1.

[‡] See reference 5, p. 56.

[§] See reference 3, p. 96 or reference 12.

[‖] Throughout this paper we propose to omit the superfluous heat equivalent of mechanical energy, assuming that all quantities have been reduced to one system of units.

(iii) The suffix *o* in the above equations denotes an arbitrary reference state. It should be pointed out in this connexion that the lack of uniformity in selecting reference states is deplorable. The author favours the Centigrade scale and N.T.P., however the excellent set of tables prepared by Keenan and Kaye uses the Fahrenheit scale and a reference temperature of 400 deg. F. abs. Since the present work is intended for use in conjunction with that set of tables, the Fahrenheit scale has been retained. It was, however, found impracticable to retain the same reference temperature, as the sources from which the values of specific heat were taken did not indicate values below 540 deg. F. abs. It was, therefore decided to assume a reference state characterized by

$$\text{and} \quad \left. \begin{array}{l} P_o = 14 \cdot 696 \text{ lb./in.}^2 \\ T_o = 540 \text{ deg. F. abs.} \end{array} \right\} \quad \ldots \ldots \ldots \text{(12)}$$

It will emerge later that the selection of the reference pressure does not influence the prepared tables. The selection of the reference temperature, admittedly quite arbitrary, does influence the values given in the tables, but is of no conse-

TABLE I.—MOLAR (VOLUMETRIC) COMPOSITION OF ATMOSPHERIC AIR (KEENAN AND KAYE)

Component	Percentage by volume
Nitrogen N_2	78·03
Oxygen O_2	20·99
Argon A	0·98

quence from the point of view of actual calculations in which only differences of enthalpy, internal energy, etc., are important.

(iv) As mentioned earlier incomplete combustion and dissociation were left out of consideration.

(v) It was found more convenient to calculate with molar quantities. In order to relate the quantities to 1 lb. of gas it is necessary to divide by the molecular weight, and in order to expedite its calculation the nomograph in FiG. 1 has been prepared.

(vi) It should be noted from the formulae given in *(ii)* that all thermodynamic properties of a gas can be calculated if the dependence on

temperatures of *one* only, for example $\bar{C}_p$, or γ is known from experiment.

(3) Sources and data

The molar (volumetric) composition of air has been assumed, as given by Keenan and Kaye, TABLE I.

Comprehensive data on the values of the specific heat at constant pressure of gases were published by Heck, Pinkel and Turner and Schmidt[2,8,12]. These data have been plotted on a large graph for the purpose of comparing them, and it was found that the values for oxygen, carbon dioxide and nitrogen agreed very closely. The values for water vapour at low pressures published by Pinkel and Turner were appreciably higher than those indicated by Heck, but they agreed very well with Schmidt's values. It was, therefore, decided to employ Heck's values for oxygen, carbon dioxide and nitrogen. The values for water vapour were taken from Pinkel and Turner's paper in the range of 600–2,700 deg. F. abs. In the range 2,700–4,500 deg. F. abs. interpolated values from Schmidt's metric table were taken. All these data are collected in TABLE II.
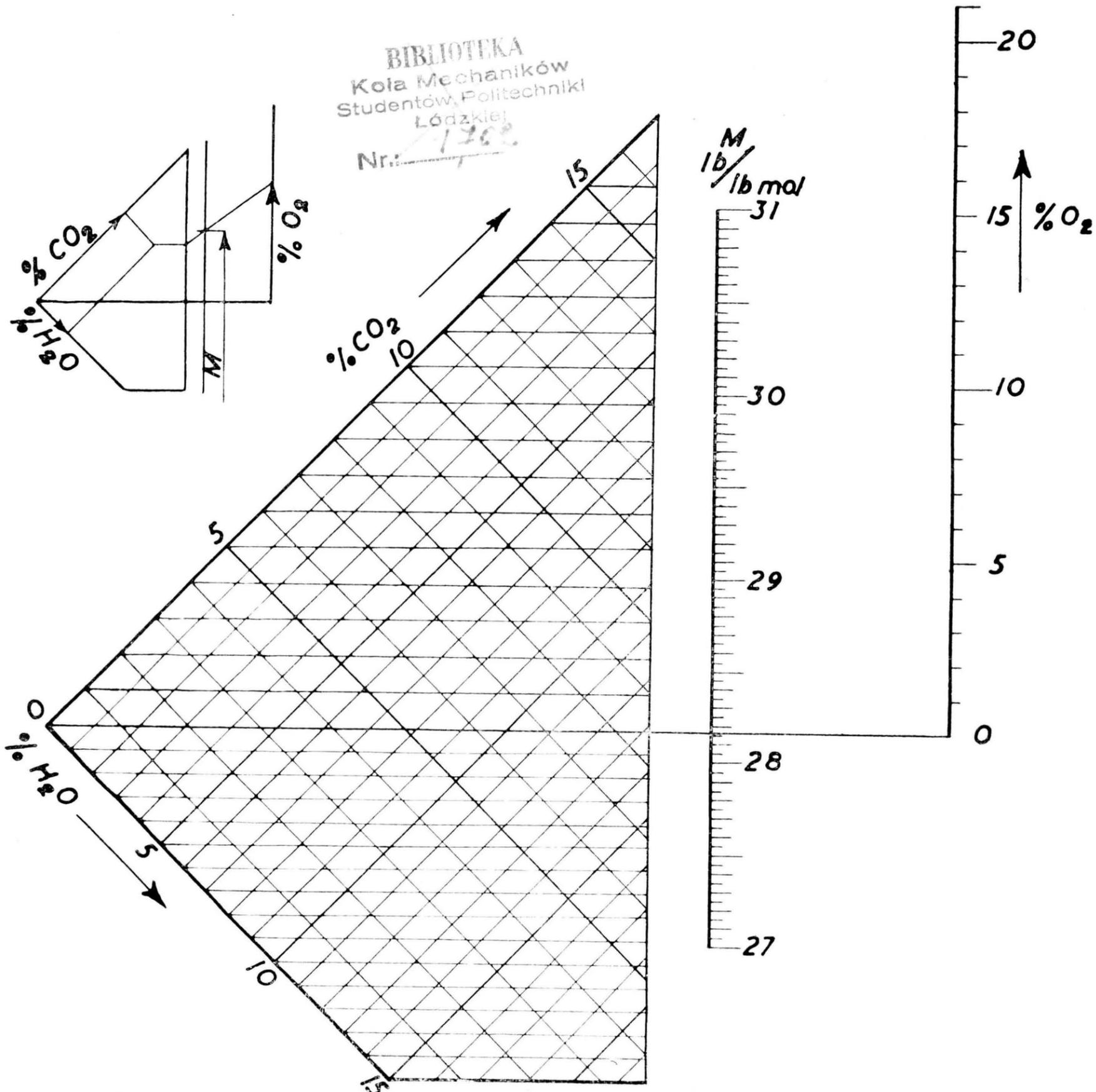
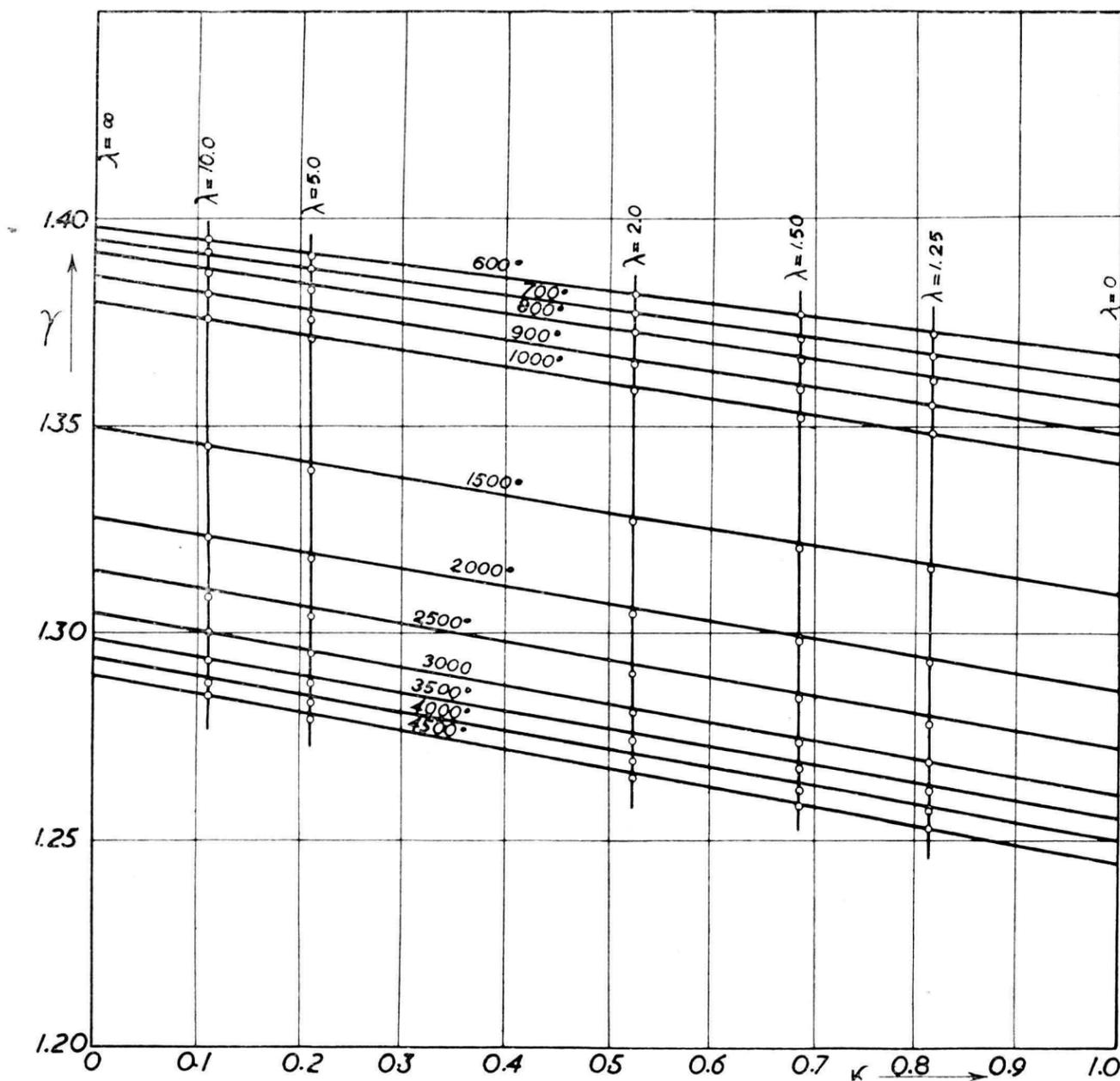Fig. 1.—Nomograph for the calculation of the molecular weight of a mixture

The specific heat of argon was assumed constant and equal.

$$\bar{C}_{pA} = 4 \cdot 967 \text{ Btu./lb.mol deg. F.} \quad \dots \quad (13)$$

The assumed molecular weights were taken from Heck's paper and are collected in TABLE III.

(4) The ratio of specific heats for standard fuel

At first let us concentrate on one representative fuel and let us examine the variation of the ratio of specific heats γ with temperature and air ratio λ. We shall find that, by introducing a function of λ, which we shall denote by κ it will be

possible to represent γ by a single equation of a form which lends itself easily to integration. We shall then demonstrate that the variation in the composition of the fuel can be allowed for by a suitable choice of the function κ and by relating it to the volumetric composition of the combustion gas rather than to the air ratio. Thus our results will become valid for all gas turbine fuels encountered in practice. The idea of such a procedure is due to Lutz and Wolf.

The composition of the 'standard' fuel has been selected as 85 per cent carbon and 15 per cent

TABLE III

Substance		Molecular weight M lb./lbmol
Carbon	C	12·010
Hydrogen	H₂	2·016
Nitrogen	N₂	28·016
Oxygen	O₂	32·000
Argon	A	39·950
Air (calculated)		28·969

TABLE II—Molar Specific Heats, $\bar{C}_p$, in Btu/lb.mol. deg. F.

deg. F. abs.	CO₂ (1)	H₂O (2)	N₂ (1)	O₂ (1)	Air (4)
600	9.283	8.074	6.968	7.075	6.970
700	9.788	8.167	6.986	7.174	7.005
800	10.251	8.285	7.019	7.297	7.057
900	10.679	8.425	7.071	7.434	7.127
1000	11.049	8.567	7.140	7.570	7.208
1100	11.392	8.715	7.216	7.700	7.295
1200	11.695	8.876	7.300	7.822	7.387
1300	11.970	9.039	7.389	7.931	7.480
1400	12.218	9.204	7.482	8.030	7.573
1500	12.445	9.375	7.571	8.119	7.660
1600	12.650	9.544	7.657	8.201	7.744
1700	12.832	9.721	7.740	8.275	7.825
1800	13.005	9.891	7.821	8.341	7.903
1900	13.159	10.068	7.899	8.399	7.975
2000	13.298	10.235	7.971	8.452	8.042
2100	13.425	10.399	8.036	8.501	8.103
2200	13.541	10.559	8.094	8.548	8.158
2300	13.648	10.718	8.148	8.591	8.210
2400	13.747	10.867	8.199	8.631	8.259
2500	13.839	11.015	8.247	8.669	8.303
2600	13.923	11.155	8.292	8.705	8.346
2700	14.002	11.291	8.334	8.740	8.387
2800	14.075	11.420	8.373	8.774	8.424
2900	14.142	11.535	8.410	8.807	8.459
3000	14.205	11.649 3)	8.444	8.840	8.494
3100	14.264	11.757 3)	8.475	8.872	8.523
3200	14.317	11.865 3)	8.504	8.903	8.552
3300	14.369	11.967 3)	8.531	8.935	8.581
3400	14.417	12.071 3)	8.557	8.966	8.607
3500	14.460	12.154 3)	8.581	8.998	8.633
3600	14.501	12.255 3)	8.604	9.029	8.656
3700	14.539	12.340 3)	8.625	9.059	8.679
3800	14.575	12.417 3)	8.646	9.089	8.703
3900	14.610	12.492 3)	8.665	9.118	8.725
4000	14.644	12.566 3)	8.684	9.148	8.746
4100	14.677	12.637 3)	8.701	9.177	8.765
4200	14.708	12.705 3)	8.717	9.206	8.784
4300	14.739	12.772 3)	8.733	9.234	8.801
4400	14.768	12.838 3)	8.747	9.262	8.818
4500	14.797	12.903 3)	8.761	9.290	8.834

(1) Heck   (2) Pinkel and Turner   (3) Schmidt (interpolated)   (4) Keenan and Kay

Fig. 2.—The variation of γ with temperature, T, and air ratio, λ, for standard fuel A (C = 0·85, H₂ = 0·15)

TABLE IV—The Variation of $\bar{C}_p$, $\bar{C}_v$ and γ with temperature, T, and air ratio, λ, for standard fuel A (C = 0.85, H₂ = 0.15)

T	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ	$\bar{C}_p$	$\bar{C}_v$	γ
600	7.396	5.410	1.367	7.315	5.329	1.372	7.261	5.275	1.377	7.192	5.206	1.382	7.061	5.075	1.391	7.016	5.030	1.395	6.970	4.986	1.398
700	7.487	5.501	1.361	7.396	5.410	1.367	7.333	5.347	1.371	7.255	5.269	1.377	7.107	5.121	1.388	7.057	5.071	1.392	7.005	5.021	1.395
800	7.586	5.600	1.355	7.486	5.500	1.361	7.417	5.431	1.366	7.332	5.346	1.372	7.169	5.183	1.383	7.114	5.128	1.387	7.057	5.073	1.392
900	7.697	5.711	1.348	7.589	5.603	1.355	7.516	5.530	1.359	7.421	5.435	1.365	7.247	5.261	1.376	7.187	5.201	1.382	7.127	5.142	1.386
1000	7.815	5.829	1.341	7.700	5.714	1.348	7.622	5.636	1.352	7.523	5.537	1.359	7.336	5.350	1.371	7.273	5.287	1.376	7.208	5.223	1.380
1100	7.934	5.948	1.334	7.813	5.827	1.341	7.786	5.800	1.342	7.625	5.639	1.352	7.433	5.447	1.364	7.365	5.379	1.369	7.295	5.310	1.374
1200	8.054	6.068	1.327	7.929	5.943	1.334	7.843	5.857	1.339	7.734	5.748	1.346	7.528	5.542	1.358	7.458	5.472	1.363	7.387	5.400	1.368
1300	8.177	6.191	1.320	8.046	6.060	1.328	7.955	5.969	1.333	7.841	5.855	1.339	7.626	5.640	1.352	7.553	5.567	1.357	7.480	5.493	1.361
1400	8.300	6.314	1.314	8.162	6.176	1.322	8.068	6.082	1.327	7.948	5.962	1.333	7.726	5.740	1.346	7.650	5.664	1.351	7.573	5.585	1.355
1500	8.416	6.430	1.309	8.273	6.287	1.316	8.176	6.190	1.321	8.052	6.066	1.327	7.812	5.834	1.339	7.741	5.755	1.345	7.660	5.675	1.350
1600	8.528	6.542	1.304	8.381	6.395	1.310	8.279	6.293	1.316	8.151	6.165	1.322	7.910	5.924	1.335	7.828	5.842	1.340	7.744	5.759	1.345
1700	8.634	6.648	1.299	8.484	6.498	1.306	8.378	6.392	1.311	8.244	6.258	1.317	7.996	6.010	1.331	7.911	5.925	1.335	7.825	5.840	1.340
1800	8.739	6.753	1.294	8.582	6.596	1.301	8.473	6.487	1.306	8.336	6.350	1.313	8.078	6.092	1.326	7.991	6.005	1.331	7.903	5.916	1.336
1900	8.839	6.853	1.290	8.675	6.689	1.297	8.563	6.577	1.302	8.424	6.438	1.308	8.158	6.172	1.322	8.067	6.081	1.327	7.975	5.988	1.332
2000	8.932	6.946	1.286	8.765	6.779	1.293	8.651	6.645	1.298	8.503	6.517	1.305	8.230	6.244	1.318	8.137	6.151	1.323	8.042	6.055	1.328
2100	9.018	7.032	1.282	8.846	6.860	1.289	8.727	6.741	1.295	8.577	6.591	1.301	8.297	6.311	1.315	8.201	6.215	1.320	8.103	6.116	1.325
2200	9.096	7.110	1.279	8.919	6.933	1.287	8.798	6.812	1.292	8.645	6.659	1.298	8.357	6.371	1.312	8.258	6.272	1.317	8.158	6.174	1.322
2300	9.171	7.185	1.276	8.990	7.004	1.284	8.865	6.879	1.289	8.707	6.721	1.296	8.413	6.427	1.309	8.312	6.326	1.314	8.210	6.226	1.319
2400	9.242	7.256	1.274	9.056	7.070	1.281	8.929	6.943	1.286	8.768	6.782	1.293	8.466	6.480	1.307	8.363	6.377	1.311	8.259	6.272	1.317
2500	9.308	7.322	1.272	9.118	7.132	1.278	8.988	7.002	1.284	8.824	6.838	1.290	8.515	6.529	1.304	8.410	6.424	1.309	8.303	6.317	1.315
2600	9.370	7.384	1.269	9.177	7.191	1.276	9.045	7.059	1.281	8.878	6.892	1.288	8.562	6.576	1.302	8.455	6.469	1.307	8.346	6.362	1.312
2700	9.429	7.443	1.267	9.232	7.246	1.274	9.098	7.112	1.279	8.926	6.940	1.286	8.606	6.620	1.300	8.497	6.511	1.305	8.387	6.399	1.310
2800	9.485	7.499	1.265	9.284	7.298	1.272	9.146	7.160	1.277	8.974	6.988	1.284	8.647	6.661	1.298	8.536	6.550	1.303	8.424	6.437	1.308
2900	9.535	7.549	1.263	9.335	7.349	1.270	9.192	7.206	1.276	9.016	7.030	1.282	8.686	6.700	1.296	8.574	6.588	1.301	8.459	6.472	1.306
3000	9.584	7.598	1.261	9.377	7.391	1.269	9.237	7.251	1.274	9.057	7.071	1.281	8.723	6.737	1.295	8.609	6.623	1.300	8.494	6.507	1.305
3100	9.628	7.642	1.259	9.420	7.434	1.267	9.278	7.292	1.272	9.097	7.111	1.279	8.758	6.772	1.293	8.642	6.656	1.298	8.523	6.537	1.303
3200	9.671	7.685	1.258	9.459	7.473	1.266	9.316	7.330	1.271	9.132	7.146	1.278	8.789	6.803	1.292	8.672	6.686	1.297	8.552	6.568	1.302
3300	9.711	7.725	1.257	9.498	7.512	1.264	9.352	7.366	1.270	9.166	7.180	1.277	8.817	6.831	1.291	8.701	6.715	1.296	8.581	6.595	1.301
3400	9.750	7.764	1.256	9.533	7.547	1.263	9.387	7.401	1.268	9.199	7.213	1.275	8.849	6.863	1.289	8.729	6.743	1.295	8.607	6.623	1.300
3500	9.784	7.798	1.255	9.568	7.582	1.262	9.418	7.432	1.267	9.228	7.242	1.274	8.877	6.891	1.288	8.756	6.770	1.293	8.633	6.647	1.299
3600	9.819	7.833	1.254	9.600	7.614	1.261	9.451	7.465	1.266	9.260	7.274	1.273	8.903	6.917	1.287	8.781	6.795	1.292	8.656	6.672	1.298
3700	9.851	7.865	1.253	9.630	7.644	1.260	9.479	7.493	1.265	9.287	7.301	1.272	8.928	6.942	1.286	8.805	6.819	1.291	8.679	6.695	1.297
3800	9.882	7.896	1.252	9.659	7.673	1.259	9.506	7.520	1.264	9.314	7.328	1.271	8.952	6.966	1.285	8.828	6.842	1.290	8.703	6.718	1.296
3900	9.910	7.924	1.251	9.685	7.699	1.258	9.532	7.546	1.263	9.339	7.353	1.270	8.974	6.988	1.284	8.850	6.864	1.289	8.725	6.738	1.295
4000	9.937	7.951	1.250	9.712	7.726	1.257	9.558	7.572	1.262	9.363	7.377	1.269	8.997	7.011	1.283	8.872	6.886	1.288	8.746	6.759	1.294
4100	9.965	7.979	1.249	9.737	7.751	1.256	9.583	7.597	1.261	9.387	7.401	1.268	9.018	7.032	1.282	8.892	6.906	1.288	8.765	6.778	1.293
4200	9.989	8.003	1.248	9.762	7.776	1.255	9.606	7.620	1.261	9.409	7.423	1.268	9.038	7.052	1.282	8.911	6.925	1.287	8.784	6.796	1.292
4300	10.014	8.028	1.247	9.784	7.798	1.255	9.629	7.643	1.260	9.429	7.443	1.267	9.057	7.071	1.281	8.930	6.944	1.286	8.801	6.814	1.292
4400	10.037	8.051	1.246	9.806	7.820	1.254	9.649	7.663	1.259	9.449	7.463	1.266	9.075	7.089	1.280	8.948	6.962	1.285	8.818	6.831	1.291
4500	10.059	8.073	1.245	9.829	7.843	1.253	9.671	7.685	1.258	9.470	7.484	1.265	9.093	7.107	1.279	8.965	6.979	1.285	8.834	6.849	1.290

Fig. 3.—The variation of γ with κ and T (standard fuel A)

Fig. 4.—Definition of Γ

TABLE VI

Temp. deg. F. abs.	$\bar{C}_1$	$\bar{C}_2$	$\bar{H}_1$	$\bar{H}_2$	$\bar{q}_1$	$\bar{q}_2$
600	0.389	0.030	22.38	1.71	0.03749	0.00300
700	0.433	0.037	63.48	5.06	0.10070	0.00815
800	0.478	0.045	109.03	9.16	0.16148	0.01362
900	0.507	0.047	158.28	13.76	0.21946	0.01903
1000	0.537	0.055	210.48	18.86	0.27443	0.02451
1100	0.568	0.061	265.73	24.68	0.32710	0.02992
1200	0.601	0.067	324.18	31.06	0.37797	0.03549
1300	0.625	0.071	385.48	37.96	0.42701	0.04101
1400	0.646	0.075	449.03	45.26	0.47412	0.04641
1500	0.665	0.078	514.58	52.91	0.51936	0.05169
1600	0.684	0.081	582.03	60.86	0.56291	0.05682
1700	0.704	0.085	651.43	69.16	0.60497	0.06185
1800	0.739	0.092	723.58	78.01	0.64623	0.06691
1900	0.757	0.096	798.38	87.41	0.68666	0.07199
2000	0.775	0.099	874.98	97.16	0.72594	0.07699
2100	0.809	0.107	954.18	107.46	0.76457	0.08201
2200	0.824	0.110	1035.8	118.31	0.80257	0.08706
2300	0.839	0.113	1119.0	129.46	0.83954	0.09201
2400	0.850	0.115	1203.4	140.86	0.87549	0.09686
2500	0.861	0.118	1288.9	152.51	0.91043	0.10162
2600	0.878	0.121	1375.9	164.46	0.94455	0.10631
2700	0.889	0.123	1464.2	176.66	0.97791	0.11091
2800	0.900	0.126	1553.7	189.11	1.01045	0.11544
2900	0.912	0.128	1644.3	201.81	1.04224	0.11989
3000	0.940	0.136	1736.9	215.01	1.07363	0.12437
3100	0.952	0.138	1831.5	228.71	1.10465	0.12886
3200	0.958	0.140	1927.0	242.61	1.13497	0.13328
3300	0.965	0.141	2023.1	256.66	1.16457	0.13760
3400	0.971	0.142	2119.9	270.81	1.19346	0.14182
3500	0.978	0.144	2217.4	285.11	1.22174	0.14597
3600	0.984	0.145	2315.5	299.56	1.24931	0.15003
3700	0.991	0.147	2414.2	314.16	1.27638	0.15403
3800	0.998	0.148	2513.7	328.91	1.30296	0.15797
3900	1.005	0.150	2613.8	343.81	1.32900	0.16184
4000	1.012	0.152	2714.7	358.91	1.35453	0.16566
4100	1.019	0.153	2816.2	374.16	1.37963	0.16943
4200	1.025	0.154	2918.4	389.51	1.40426	0.17313
4300	1.048	0.161	3022.1	405.26	1.42863	0.17683
4400	1.055	0.163	3127.2	421.46	1.45283	0.18055
4500	1.063	0.165	3235.1	437.86	1.47666	0.18424

hydrogen by weight, and we shall refer to it as fuel A.

The values of γ have been calculated for a number of air ratios ranging from theoretical ($\lambda = 1$) to $\lambda = 10$. Evidently, the values of γ for air as given by Keenan and Kaye on p. 36 of their book correspond to $\lambda = \infty$. The theoretical composition of the combustion gases for each λ (that is disregarding dissociation) has been calculated. The values of $\bar{C}_p$ were calculated by applying the general expression for gaseous mixtures.

$$\bar{C}_p = \Sigma\ x_i\ \bar{C}_{pi} \quad \dots \dots \dots \dots \quad (14)$$

the summation extending over all the component gases. The values of $\bar{C}_v$ were then found by (3) and the ratio of the two, γ, was finally calculated. The results are collected in TABLE IV and plotted in FIG. 2.

It is evident from the graph, and it was verified analytically, that the curves are almost identical in shape—that is they are nearly equidistant vertically. It is, therefore, natural to perform a change of variables and to select a derived function of λ for the ordinates, such as would transform the curves of constant temperature into straight lines. We shall denote this new variable by κ, so that

$$\kappa = f(\lambda) \quad \dots \dots \dots \dots \dots \quad (15)$$

The precise form of this function will be determined later, but it is now evident that we are free to choose two arbitrary values for it. It is convenient to stipulate

$\kappa = 1$ when $\lambda = 1$ (theoretical fuel-air mixture)

and

$\kappa = 0$ when $\lambda = \infty$ (atmospheric air).

The straight lines of constant temperature are plotted in FIG. 3. They have varying inclinations but the salient feature of the graph consists in the fact that to each value of λ there corresponds one value of κ, irrespective of temperature, the lines of $\lambda = $ const. being nearly straight and vertical. In other words the change of variables effected by the still undetermined function (15) straightens out all curves *simultaneously* within close limits of accuracy. The function (15) can be determined from FIG. 3, but it has been found more expedient to correlate κ with the volumetric compositions of the gas, and we shall revert to this point later.

We are now in a position to represent the variation of γ with κ and T by one simple formula, for let Γ denote the maximum difference in γ at one given temperature, FIG. 4, or the difference between γ_{air} for air ($\kappa = 0$) and γ_1 ($\kappa = 1$) for the theoretical mixture, that is

$$\Gamma = \gamma_{air} - \gamma_1 \quad \dots \dots \dots \dots \quad (16)$$

Thus for any intermediate κ

$$\gamma = \gamma_{air} - \kappa \Gamma \quad \dots \dots \dots \dots \quad (17)$$

as seen from FIG. 4. In the above equation γ_{air} and Γ are functions of temperature. The former was listed in TABLE II ($\lambda = \infty$) and the latter has been calculated by eqn. (16) from TABLE II, and is given in TABLE V.

TABLE V—THE VALUES OF Γ IN TERMS OF T

T°F abs.	600	700	800	900	1000	1100	1200	1300
Γ	0.031	0.034	0.037	0.038	0.039	0.040	0.041	0.041

T°F abs.	1400	1500	1600	1700	1800	1900	2000	2100
Γ	0.041	0.041	0.041	0.041	0.042	0.042	0.042	0.043

T°F abs.	2200	2300	2400	2500	2600	2700	2800	2900
Γ	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043

T°F abs.	3000	3100	3200	3300	3400	3500	3600	3700
Γ	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044

T°F abs.	3800	3900	4000	4100	4200	4300	4400	4500
Γ	0.044	0.044	0.044	0.044	0.044	0.045	0.045	0.045

(5) The specific heat $\bar{C}_p$

The specific heat $\bar{C}_p$ can be expressed in terms of γ in the following way:

$$\bar{C}_p = \frac{\gamma}{\gamma - 1}\ \bar{R} \quad \dots \dots \dots \dots \quad (18)$$

In particular, the specific heat for air is

$$\bar{C}_{pair} = \frac{\gamma_{air}}{\gamma_{air} - 1}\ \bar{R} \quad \dots \dots \dots \dots \quad (18a)$$

hence

$$\bar{C}_p = \bar{C}_{pair} - \frac{\gamma_{air}}{\gamma_{air} - 1}\ \bar{R} + \frac{\gamma}{\gamma - 1}\ \bar{R}$$

Substituting (17) and simplifying, we obtain

$$\bar{C}_p = \bar{C}_{pair} + \frac{\kappa \Gamma}{(\gamma_{air} - 1)^2} \cdot \frac{1}{1 - \dfrac{\kappa \Gamma}{\gamma_{air} - 1}} \cdot \bar{R} \ . \ . \quad (19)$$

Now, the value of $\dfrac{\kappa \Gamma}{\gamma_{air} - 1}$ in the denominator of the second fraction is small in comparison with unity. In the extreme case for $\kappa = 1$ and e.g. for $T = 4,500$ deg. F. abs. $\gamma_{air} = 1.290$ and $\Gamma = 0.044$, hence $\dfrac{\kappa \Gamma}{\gamma_{air} - 1} = 0.152$. With values of $\kappa < 1$ which are the rule in gas turbine calculation it will be even smaller. We are, therefore, justified in expanding (19) into a series, retaining the first two terms.

Thus

$$\bar{C}_p = \bar{C}_{pair} + \kappa \frac{\Gamma \bar{R}}{(\gamma_{air} - 1)^2} + \kappa^2 \frac{\Gamma^2 \bar{R}}{(\gamma_{air} - 1)^3} \quad \dots \quad (20)$$

Substituting

$$\bar{C_1} = \frac{\Gamma \bar{R}}{(\gamma_{air}-1)^2} \text{ and } \bar{C_2} = \frac{\Gamma^2 \bar{R}}{(\gamma_{air}-1)^3} \quad \ldots\ldots (20a)$$

we have

$$\bar{C_p} = \bar{C}_{pair} + \kappa \bar{C_1} + \kappa^2 \bar{C_2} \quad \ldots\ldots\ldots\ldots (20b)$$

where $\bar{C_1}$ and $\bar{C_2}$ are functions of temperature alone. In this manner we have succeeded in separating the functions of temperature and air ratio, or combustion gas composition, as we did in the expression for γ. The values of $\bar{C_1}$ and $\bar{C_2}$, calculated from (20a), are given in TABLE VI.[*]

(6) The enthalpy and the entropy function

Equation (20b) can now be integrated and both the enthalpy $\bar{H}$ and the entropy function $\bar{\Phi}_p$ can be expressed by formulae, similar to the one for $\bar{C_p}$, since κ is a constant in the process of integration. Thus by (5)

$$\bar{H} = \bar{H}_{air} + \kappa \bar{H_1} + \kappa^2 \bar{H_2} \quad \ldots\ldots\ldots\ldots (21)$$

where

$$\bar{H_1} = \int_{T_0}^{T} \bar{C_1} dT \text{ and } \bar{H_2} = \int_{T_0}^{T} \bar{C_2} dT \quad \ldots\ldots (21a)$$

are again functions of temperature alone.

In a similar way, by (8) we obtain

$$\bar{\Phi}_p = \bar{\Phi}_{pair} + \kappa \bar{\Phi}_1 + \kappa^2 \bar{\Phi}_2 \quad \ldots\ldots\ldots\ldots (22)$$

where the function of temperature $\bar{\Phi}_1$ and $\bar{\Phi}_2$ are given by

$$\bar{\Phi}_1 = \int_{T_0}^{T} \frac{\bar{C_1}}{T} dT \text{ and } \bar{\Phi}_2 = \int_{T_0}^{T} \frac{\bar{C_2}}{T} dT \quad \ldots\ldots (22a)$$

The values of the auxiliary functions $\bar{H_1}$, $\bar{H_2}$, $\bar{\Phi}_1$ and $\bar{\Phi}_2$ have been calculated step by step and are given in TABLE VI.

The values for air, namely $\bar{H}_{air}$ and $\bar{\Phi}_{pair}$ are listed very accurately and for very small temperature increments in Keenan and Kaye's tables.[5]

(7) The specific heat $\bar{C_v}$, the internal energy $\bar{U}$ and the entropy function $\bar{\Phi}_v$

It is suggested that the most convenient method of calculating $\bar{C_v}$ is by the use of eqn. (3). The internal energy $\bar{U}$ is best calculated by eqn. (10) and the entropy function $\bar{\Phi}_v$ may be quickly evaluated from eqn. (11) with the aid of the table of values of $R \ln N$ appended (TABLE VII).

(8) Thermodynamic properties of other combustion gases

Similar calculations to the ones described above have been performed for two more fuels. The composition of fuel B was 80 per cent carbon and 20 per cent hydrogen, and that of fuel C was 92 per cent carbon and 8 per cent hydrogen by weight. It was discovered that the detected regularity of behaviour still held true and that the values of the auxiliary functions Γ, $\bar{C_1}$, $\bar{C_2}$, $\bar{H_1}$, $\bar{H_2}$, $\bar{\Phi}_1$, and $\bar{\Phi}_2$ could be retained without change.

The function (15) was then determined for each of the three selected fuels and the result is plotted in FIG. 5.

The graph leads to the conclusion that the deviations among the functions are small and it is natural to suppose that a satisfactory correlation may be achieved by relating κ to the volumetric composition of the combustion gas. We shall assume, with Lutz and Wolf, a linear relation of the type

$$\kappa = X_1 x_{CO_2} + X_2 x_{H_2O} + X_3 x_{N_2} \quad \ldots\ldots\ldots (23)$$

[*] By putting $\kappa = 1$ we have $\bar{C_1} + \bar{C_2} = \bar{C}_{p1} - \bar{C}_{pair}$ where $\bar{C}_{p1}$ is the specific heat of the theoretically correct combustion gas. This equation served as a check on our calculation and the result proved to be correct within 2·5 per cent.
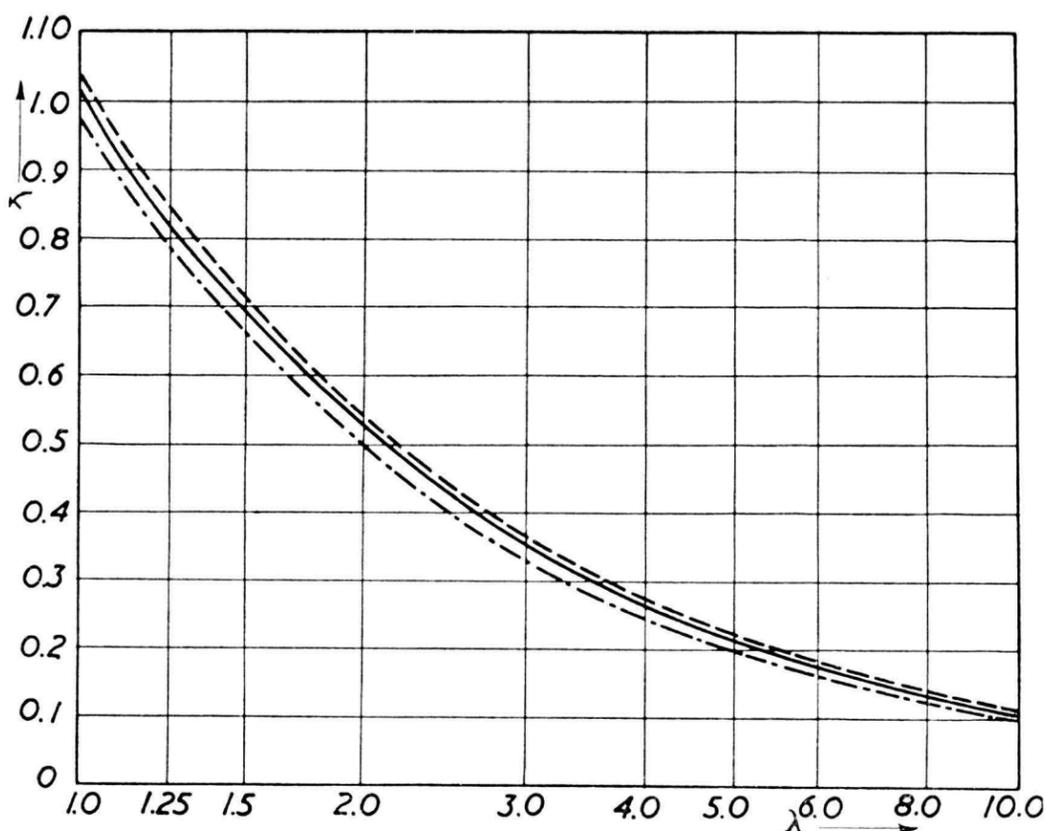
Fig. 5.—The function $\kappa = f(\lambda)$ for the three representative fuels

———— fuel A	C—0·85	H₂—0·15
.... fuel B	C—0·80	H₂—0·20
—·—·— fuel C	C—0·92	H₂—0·08

TABLE VII. $\bar{R} \ln N$ in Btu/lb.mol. deg. F. $\bar{R} \ln (10^n N) = \bar{R} \ln N + 4.57296 n$.

	0	1	2	3	4	5	6	7	8	9	Diff. 1	2	3	4	5
1.0	0.0000	0.0199	0.0393	0.0588	0.0778	0.0969	0.1158	0.1345	0.1529	0.1712	20	38	58	75	93
1.1	1893	2073	2250	2427	2602	2776	2947	3118	3287	3456	18	34	52	70	87
1.2	3621	3785	3950	4110	4272	4431	4590	4747	4903	5056	16	32	48	64	79
1.3	5211	5362	5513	5664	5813	5960	6107	6252	6397	6540	14	30	44	60	73
1.4	6683	6824	6965	7104	7241	7380	7515	7652	7785	7920	14	28	42	56	68
1.5	8053	8184	8315	8446	8576	8705	8832	8959	9084	9209	12	26	38	52	64
1.6	9334	9457	9581	9704	9825	9946	1.0065	1.0184	1.0303	1.0421	12	24	36	48	60
1.7	1.0537	1.0635	1.0770	1.0895	1.1000	1.1113	1.1226	1.1340	1.1451	1.1562	12	22	34	46	58
1.8	1674	1783	1892	2001	2111	2218	2325	2430	2538	2643	10	22	32	44	54
1.9	2748	2851	2955	3058	3161	3263	3364	3465	3566	3666	10	20	30	42	52
2.0	3765	3864	3964	4061	4158	4256	4353	4448	4545	4641	10	20	30	40	48
2.1	4734	4829	4923	5016	5109	5203	5294	5386	5477	5568	10	18	28	38	46
2.2	5660	5749	5838	5928	6055	6142	6232	6319	6406	6494	8	18	26	36	44
2.3	6579	6665	6752	6837	6923	7006	7092	7175	7258	7342	8	18	26	34	42
2.4	7425	7507	7590	7671	7753	7834	7916	7995	8077	8156	8	16	24	32	40
2.5	8235	8315	8394	8472	8551	8629	8706	8784	8861	8938	8	16	24	32	40
2.6	9014	9091	9167	9242	9318	9393	9467	9542	9616	9689	8	16	22	30	38
2.7	1.9765	1.9836	1.9910	1.9983	2.0057	2.0128	2.0199	2.0271	2.0344	2.0414	8	14	22	30	36
2.8	2.0486	2.0557	2.0627	2.0698	0768	0837	0907	0976	1046	1115	8	14	22	28	36
2.9	1183	1252	1320	1387	1455	1522	1590	1657	1723	1790	6	14	20	28	34
3.0	1856	2470	3101	3711	4305	4881	5439	5983	6513	7029	58	115	173	232	288
4.0	2.7532	2.8022	2.8501	2.8968	2.9425	2.9871	3.0308	3.0735	3.1152	3.1562	46	89	135	179	222
5.0	3.1963	3.2356	3.2743	3.3121	3.3492	3.3855	4215	4566	4912	5252	36	73	109	145	183
6.0	5585	5913	6235	6552	6866	7174	7478	7776	8070	8360	32	62	91	123	153
7.0	8646	8928	9206	9480	9750	4.0015	4.0278	4.0538	4.0794	4.1049	26	54	79	107	131
8.0	4.1297	4.1545	4.1787	4.2030	4.2266	2502	2735	2963	3192	3416	24	46	70	93	115
9.0	3637	3857	4073	4288	4500	4711	4919	5124	5328	5529	22	42	64	85	105
10.0	4.5730														
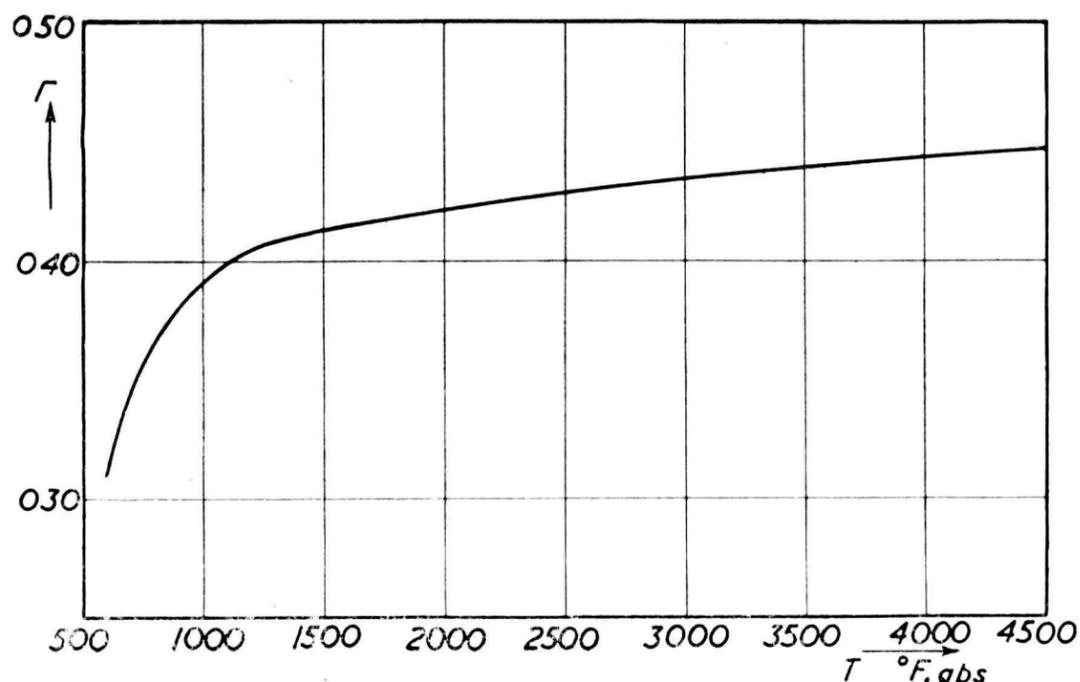
Fig. 7.—Γ in terms of temperature

Fig. 6.—Nomograph for the calculation of κ from eqn. (25)
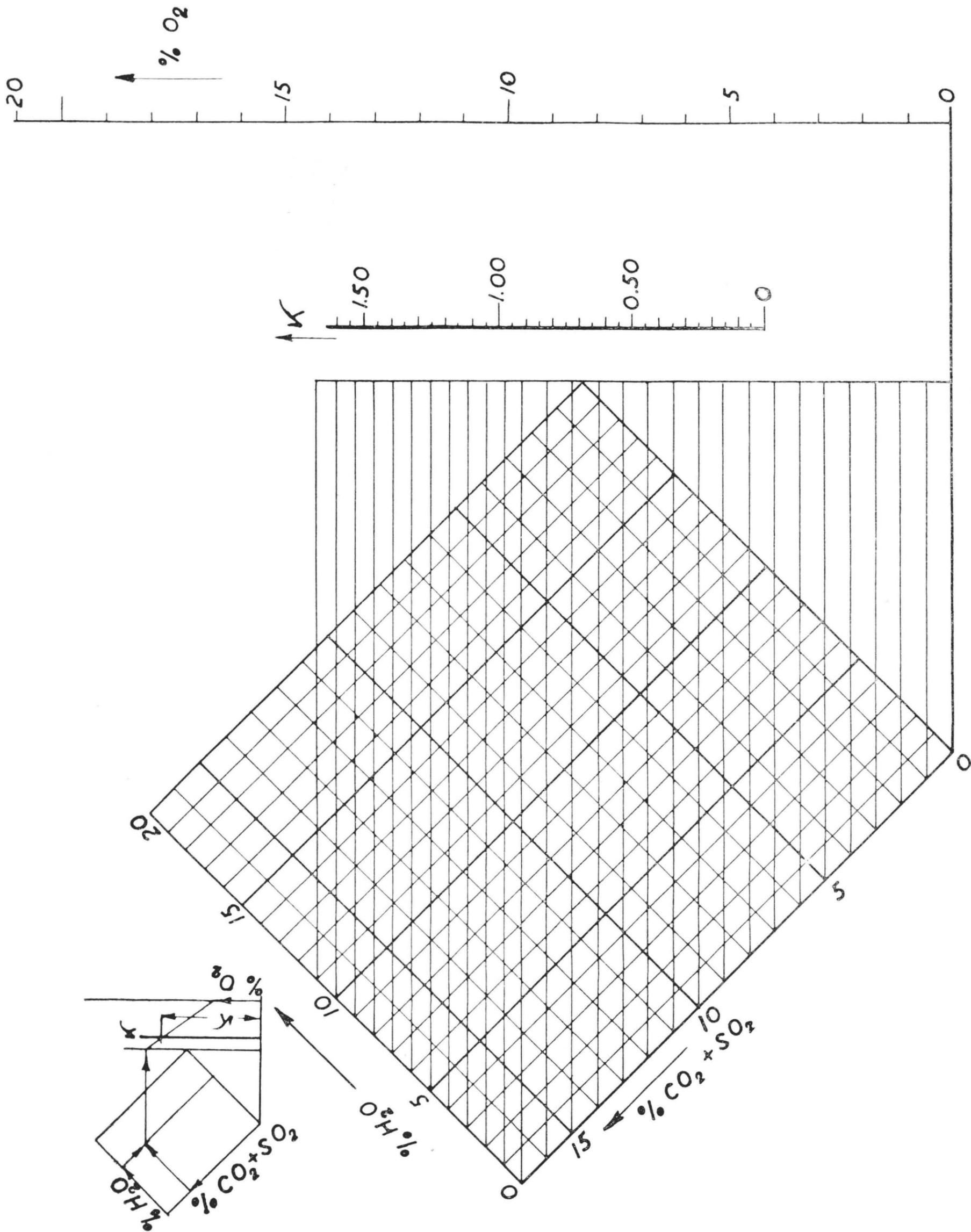
Fig. 9.—$\overline{H}_1$ and $\overline{H}_2$ in terms of temperature

Fig. 8.—$\overline{C}_1$ and $\overline{C}_2$ in terms of temperature

where

$$x'_{N_2} = x_{N_2} + x_A$$

The sulphur dioxide content, if any, can be added to that of carbon dioxide. From the data in hand we can write down a series of equations (23), with four unknowns, exceeding them in number. The interesting fact is that the values of the four unknowns X_1, X_2, X_3, and X_4, calculated from different sets of four simultaneous equations differ very little and it is sufficient to adopt the following mean values:

$$\left.\begin{aligned} X_1 &= 6 \cdot 96 \\ X_2 &= 4 \cdot 69 \\ X_3 &= 0 \cdot 70 \\ X_4 &= 2 \cdot 63 \end{aligned}\right\} \quad \ldots\ldots\ldots(24)$$

Thus

$$\kappa = 6 \cdot 96(x_{CO_2} + x_{SO_2}) + 4 \cdot 69 x_{H_2O} - 0 \cdot 70(x_{N_2} + x_A) + 2 \cdot 63 \ldots\ldots(25)$$

A nomograph, similar to the one for the calculation of the mean molecular weight of a mixture has been prepared for the calculation of κ.

The formulae deduced in sections (4), (5), (6) and (7) are seen to hold for all three fuels. It is estimated, on the basis of numerous sample calculations that the range of fuels may be extended to include those with 0·70 carbon to 0·95 carbon as well as the percentage of sulphur which is normally encountered. The deviation in $\overline{C}_p$ detected in the course of these calculations did not exceed 0·8 per cent.

It may be pointed out here, that owing to the

Fig. 11.—Values of κ_1 and M_1 for the theoretical combustion gas in terms of the fuel composition $(c+h=1)$. Values of A_1 and V_{g_1} in ft.³/lb. fuel at N.T.P. can be read off the two linear scales

Fig. 12.—Composition of the theoretical combustion gas in terms of the fuel composition $(c+h=1)$
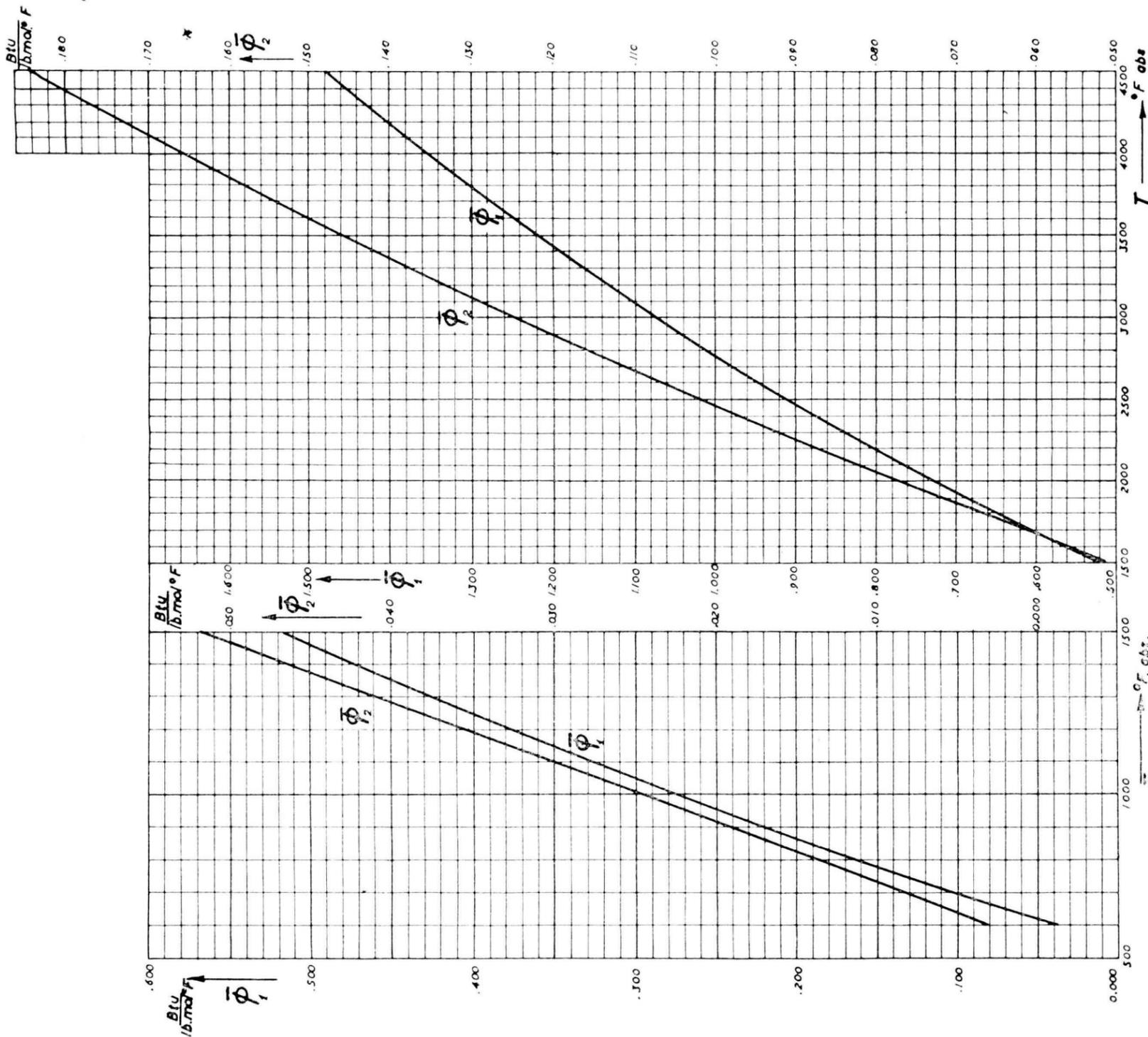
Fig. 10.—Φ_1 and Φ_2 in terms of temperature

fact that κ has been correlated with the volumetric composition of the fuel it will not assume the value $\kappa=1$ for the theoretical combustion gas of all fuels, as it does in the case of fuel A^*. For example for fuel B $\kappa_1=1\cdot032$, and for fuel C $\kappa_1=0\cdot970$.

A set of graphs giving the seven correction functions is appended and it is obvious that for small values of κ the term containing κ^2 may be disregarded.

(9) Acknowledgments

The author wishes to express his thanks to Mr S. Janusz for his assistance in the performance of calculations and to Mr F. Zagiel for his help with the drawings and corrections.

---

* Actually, owing to the approximations in the calculation of the factors X in Eqn. (23), the value for the theoretical combustion gas from fuel A is $\kappa=1\cdot010$.

APPENDIX

Examples

(1) When performing gas turbine calculations it is convenient to relate all quantities to a unit mass of fuel, since the thermodynamic properties of the quantity of gas which then results are linear functions of the air ratio, λ. This fact has been utilized by E. Schmidt in his H, λ diagram*. In fact any combustion gas is best regarded as a mixture of the theoretical gas with the excess air, provided combustion is complete, as assumed in this paper.

In order to apply the present approximate method it is necessary to calculate the volume of the combustion gas V_g, its molecular weight M, and its composition, from which the coefficient κ can then be deduced. The volume of the combustion gas, resulting from the combustion of 1 lb. of fuel is the sum of the volumes of the theoretical combustion gas, V_{g1} and of the excess air $(\lambda-1) A_1$, A_1 denoting the theoretical quantity of air in ft.^{3}/lb. fuel at N.T.P. Hence

$$V_g = V_{g1} + (\lambda - 1)A_1 \quad \dots \dots \dots \dots (25)$$

The molecular weight of the gas is

$$M = \frac{(\lambda-1)A_1}{V_g}[M_{air}] + \frac{V_{g1}}{V_g}M_1 \dots \dots (26)$$

* Refs. 13 and 12 (transl.), section 95.

The values of κ_1 and M_1 for the theoretical gas for a range of fuel containing from $c = 1$ to $c = 0.70$ carbon by weight (the other component being hydrogen, so that $c + h = 1$), are given in FIG. 11. Since, under our assumptions, V_{g1} and A_1 are linear functions of c, namely

$$\begin{aligned}
A_1 &= 142 \cdot 24\,(2 \cdot 979 - 1 \cdot 979c) \\
&= 423 \cdot 73\,(1 - 0 \cdot 664c) \\
\text{and} & \\
V_{g1} &= 142 \cdot 24\,(3 \cdot 604 - 2 \cdot 604c) \\
&= 512 \cdot 63\,(1 - 0 \cdot 723c)
\end{aligned} \right\} \quad \dots \dots (27)$$

it is sufficient to add two linear scales, from which these values can be simply read off. The values of V_{g1} and A_1 can be also conveniently calculated by the method of Rosin* from the known calorific value of the fuel.

The volumetric composition of the combustion gas can be easily calculated from the known composition of the theoretical combustion gas. The latter has been plotted in FIG. 12 for the same range of fuels as before. We can, namely, write:

oxygen (part by volume) $\dfrac{(\lambda-1)\,A_1 \times 0 \cdot 2099}{V_g}$

carbon dioxide (part by volume) $\dfrac{V_{g1}}{V_g}x_{1CO2}$

nitrogen (part by volume)

* Refs. 11 and 12 (transl.), section 73 and 74.

$$\frac{\lambda A_1 \times 0 \cdot 7901}{V_g} = \frac{V_{g1}}{V_g}x_{1N2} + \frac{(\lambda-1)A_1 \times 0 \cdot 7901}{V_g}$$

water vapour (part by volume) $\dfrac{V_{g1}}{V_g}x_{1H2O}$

(2) In order to obtain an estimate of the accuracy of the present method we shall calculate some thermodynamic properties of three fuels and compare them with their accurate values, as calculated from the rule for mixtures. We shall assume theoretical combustion, for which, as shown earlier, the error is greatest.

a. Motor benzole*

Composition (by weight)
- carbon c = 0·9165
- hydrogen h = 0·0805
- sulphur s = 0·0030

Composition of combustion gas:
- carbon dioxide $x_{CO2} = 0 \cdot 159$ (incl. sulphur dioxide)
- water vapour $x_{H2O} = 0 \cdot 083$
- nitrogen $x_{N2} = 0 \cdot 758$

Characteristic quantity, eqn. (25),
$$\kappa = 0 \cdot 965.$$

Results are given in TABLE VIII.

b. Diesel oil†

Composition (by weight)
- carbon c = 0·863
- hydrogen h = 0·128
- sulphur s = 0·009

Composition of combustion gas
- carbon dioxide $x_{CO2} = 0 \cdot 137$ (incl. sulphur dioxide)
- water vapour $x_{H2O} = 0 \cdot 120$
- nitrogen $x_{N2} = 0 \cdot 743$

Characteristic quantity, eqn. (25),
$$\kappa = 0 \cdot 996.$$

Results are given in TABLE IX.

c. Ethyl alcohol‡

Composition (by weight)
- carbon c = 0·375
- hydrogen h = 0·125
- oxygen o = 0·500

Composition of combustion gas:
- carbon dioxide $x_{CO2} = 0 \cdot 116$
- water vapour $x_{H2O} = 0 \cdot 230$
- nitrogen $x_{N2} = 0 \cdot 654$

Characteristic quantity, eqn. (25),
$$\kappa = 1 \cdot 428.$$

Results are given in TABLE X.

* Ref. 14, p. 257.
† Ref. 14, p. 260.
‡ Ref. 14, p. 257.

TABLE VIII.—THERMODYNAMIC PROPERTIES OF THE THEORETICAL COMBUSTION GAS FROM MOTOR BENZOLE, AT ATMOSPHERIC PRESSURE

Temperature °F abs.	Ratio of specific heats γ			Specific heat $\bar{C}p$ Btu/lb.mol°F			Enthalpy $\bar{H}$ Btu/lb.mol		
	approx.	accurate	% error	approx.	accurate	% error	approx.	accurate	% error
600	1·369	1·365	+0·29	7·374	7·428	−0·73	431	444	−2·92
1,500	1·311	1·305	+0·46	8·381	8·496	−1·35	7,515	7,598	−1·09
2,500	1·273	1·269	+0·32	9·248	9·365	−1·27	16,364	16,610	−1·48

TABLE IX.—THERMODYNAMIC PROPERTIES OF THE THEORETICAL COMBUSTION GAS FROM DIESEL OIL, AT ATMOSPHERIC PRESSURE

Temperature °F abs.	Ratio of specific heats γ			Specific heat $\bar{C}_2$ Btu/lb.mol°F			Enthalpy $\bar{H}$ Btu/lb.mol		
	approx.	accurate	% error	approx.	accurate	% error	approx.	accurate	% error
600	1·368	1·366	+0·15	7·388	7·418	−0·40	432	444	−2·70
1,500	1·309	1·307	+0·15	8·406	8·455	−0·58	7,536	7,569	−0·44
2,500	2·272	1·270	+0·16	9·282	9·346	−0·68	61,414	16,563	−0·90

TABLE X.—THERMODYNAMIC PROPERTIES OF THE THEORETICAL COMBUSTION GAS FROM ETHYL ALCOHOL, AT ATMOSPHERIC PRESSURE

Temperature °F abs.	Ratio of specific heats γ			Specific heat $\bar{C}_2$ Btu/lb.mol°F			Enthalpy $\bar{H}$ Btu/lb.mol.		
	approx.	accurate	% error	approx.	accurate	% error	approx.	accurate	% error
600	1·355	1·361	−0·44	7·588	7·491	+1·29	445	448	−0·67
1,500	1·295	1·317	−1·67	8·729	8·551	+2·08	7,822	7,643	+2·34
2,500	1·255	1·263	−0·63	9·780	9·532	+2·60	17,131	16,820	+1·85

Don't sew it up

It is unfortunate when a design is so tight that there is no chance of increasing the bearing capacity to suit extra loading imposed on the machine as it is developed.

It is doubly unfortunate when, due to factors not fully realised by the draughtsmen, the bearings are not quite man enough for the duties for which the machine is primarily intended.

The wisest course is to consult us before the design is sewn up; as bearing specialists we have a lot of accumulated knowledge and it is all at your disposal.

FBC
TRADE MARK

ball and roller bearings

FISCHER BEARINGS COMPANY LTD., WOLVERHAMPTON. Associated with British Timken Ltd.
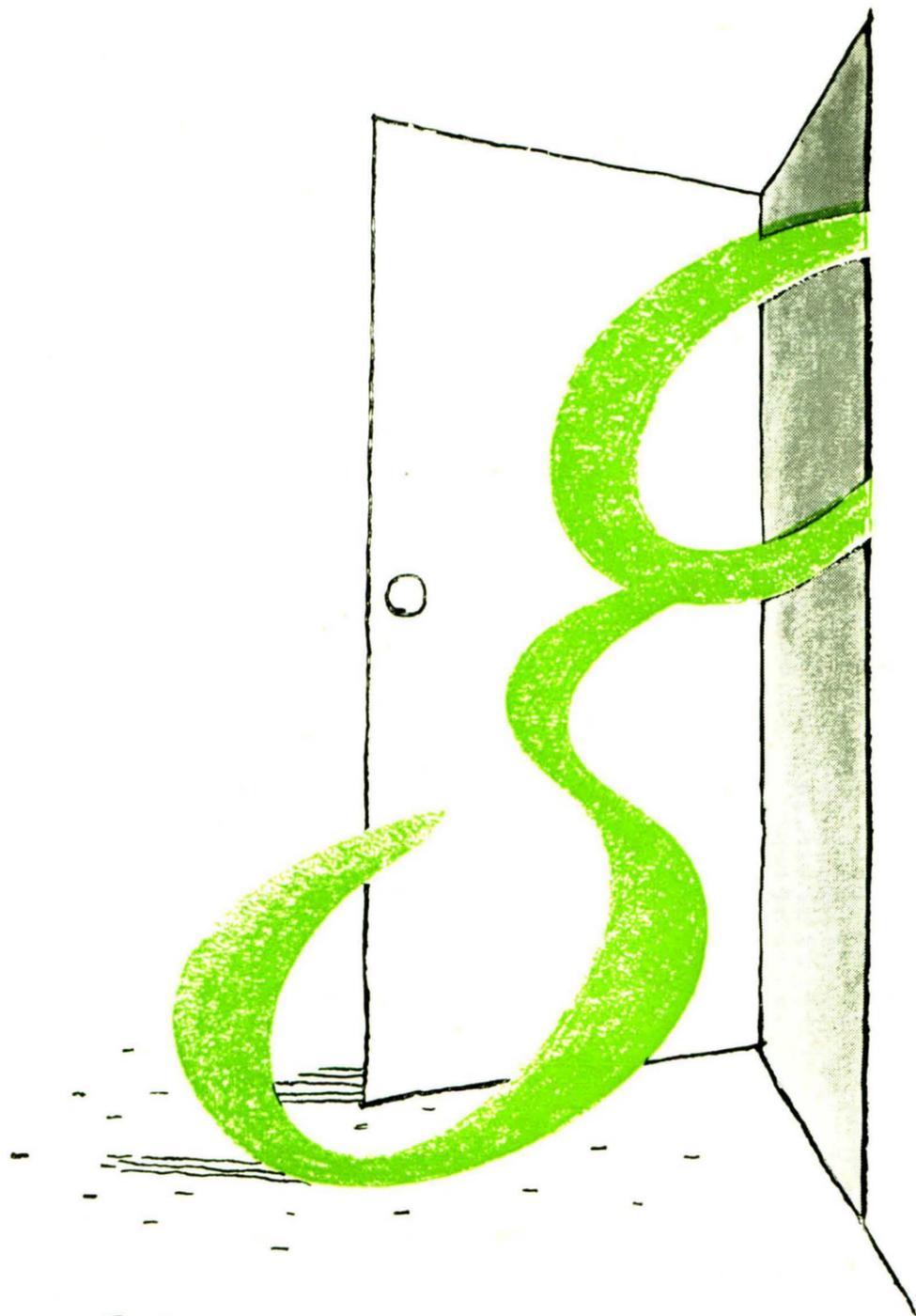
on his way out

When did **g** for GRAVITY come in? Long before Sir Isaac Newton identified him, **g** was up to his favourite game of confusing strength with weight. It was **g** who prompted the knights of old to wear sheet-iron union suits. It was **g** who built bedsteads like barns and barns like castles and castles like mountain ranges. There seemed no alternative *then*. The only way of escape from the burden of gravity is to find a material which is strong and light as well. Nowadays we . . . .

. . . make light work of *g* it with

HIGH DUTY ALLOYS

The Machine Tool and Engineering Exhibition

Advance Notices of Some of the Equipment Displayed After a Lapse of Fourteen Years

THE Machine Tool and Engineering Exhibition which is being held in Olympia, London, from August 26 to September 11, is the revival of an event which last took place in 1934. In those days the British machine tool industry was very small compared with what it has grown to be during the 14 years' interval, particularly under the stimulus of war. The number and range of machine tools to be seen are therefore of incomparably more interest than on the last occasion, and the exhibition should be visited by all concerned with the production side of the aircraft industry.

We give below a pre-view of some of the important items of equipment of which we have received details from the firms exhibiting. As we go to press well in advance of the date on which the show opens we cannot hope to cover more than a fraction of the many varieties of machine tools and other engineering equipment displayed, and we trust that firms whose descriptions of their exhibits arrived too late for inclusion will accept this explanation of the omission.

The exhibits of **Birlec Ltd.**, Tyburn Road, Erdington, Birmingham, 24, are restricted to photographs and special models of their most important electric furnaces for gas carburizing, copper brazing and induction heating. The display has been arranged to bring the advantages of gas carburizing, which has already been described in AIRCRAFT ENGINEERING, to wider notice than it yet has achieved and also to show the more generally known Birlec furnaces, including the standard continuous belt conveyor type with controlled atmosphere, that is used for annealing.

Since their name was changed from Muir Machine Tools Ltd., during an extensive re-organization, the firm of **David Brown Machine Tools Ltd.**, Huddersfield, has not shown before at any exhibition. Specializing in making machine
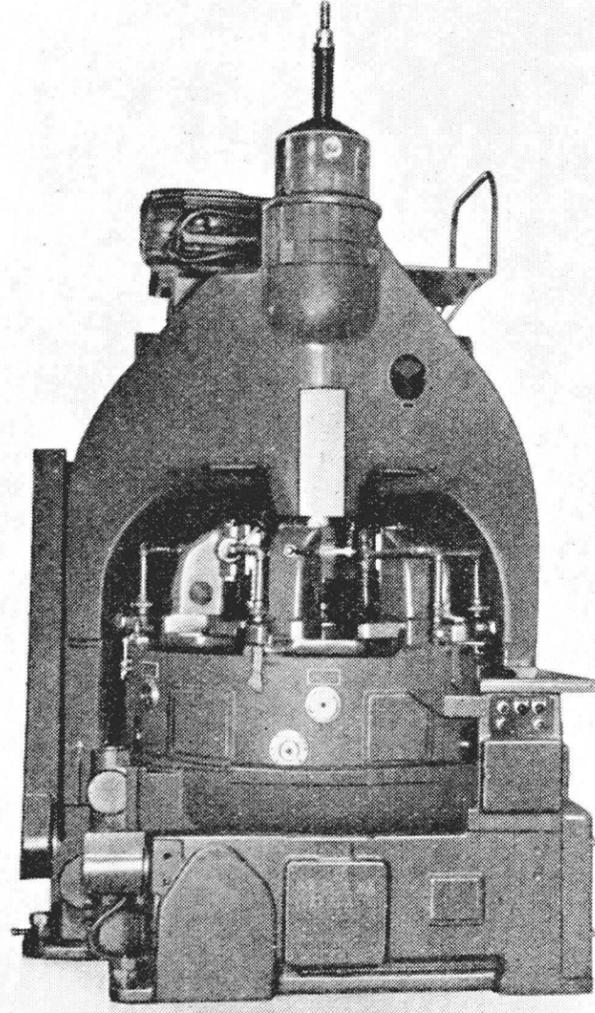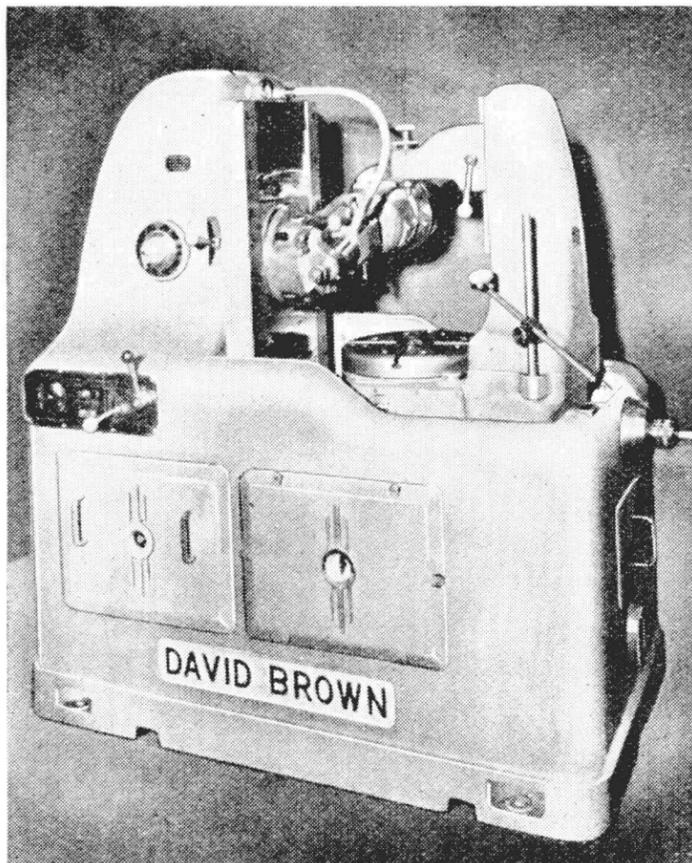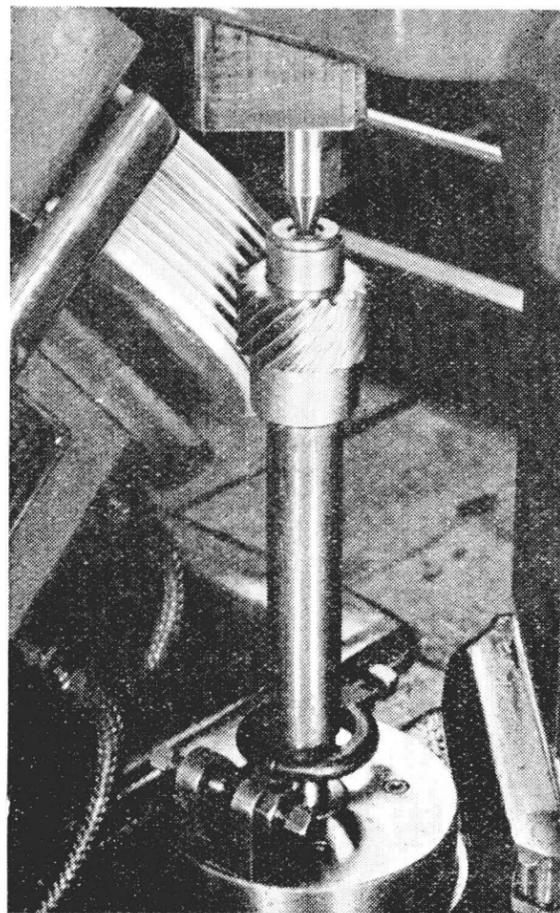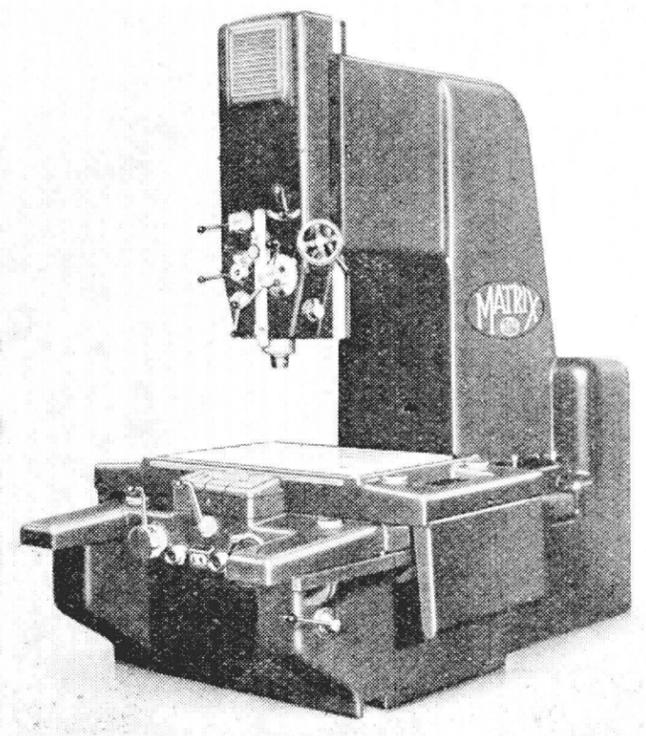
tools that not only work, but look well, they are showing examples from their familiar range of moving table hobbing machines, their new S25 gear shaving machine, the MT15 hobbing machine, also a first appearance, and other equipment including the No. 12 Relieving Lathe.

Specialists of 50 years' standing in the manufacture of collets, **Crawford and Co. (Tottenham) Ltd.**, Witney, Oxfordshire, are exhibiting an exceptionally wide range of these accessories for capstans, centre lathes, automatics and millers. A new product on show will be a tungsten carbide steady bush for automatic lathes.

The range of **Matrix** machine tools and of **Matrix** gauges, measuring instruments, jigs, fixtures, etc., are shown on the stands of the **Coventry Gauge and Tool Co. Ltd.**, and **British Engineers' Small Tools and Equipment Co. (BESTEC)** respectively. The former shows the No. 50 Optical Jig Boring Machine, the No. 40 Gear Grinder of exceptional speed and accuracy, and the No. 51 Thread Milling Machine that was specially evolved to meet the requirements of working screwed plastic components.

The firm of **Alfred Herbert Ltd.** are showing on no less than four Stands; on Stands 1 and 12 are exhibited machines of British, American and Swiss manufacture for which the firm acts as agents, on Stand 14 are tools of their own manufacture, while on Stand 217 are shown small tools and measuring equipment. The equipment is too varied to be listed in full, as this is one of the largest individual exhibits, but among the most interesting equipment on view are the Herbert Carbicut Lathe for turning spindles and shafts with carbide tools; the No. 7 and No. 8 Pre-optive Combination Turret Lathes, the latter being the largest capacity turret lathe to have the Herbert Preoptive Headstock and capable of taking bar work of $3\frac{3}{4}$ in. dia. and chuck work up to 20 in. dia.; the new No. 3 Hexagon Turret Lathe; the No. 5A Auto Lathe for heavy duty automatic chucking; and the No. 47V Vertical Milling Machine. Among the tools for which Alfred Herbert Ltd. have the agency are the Heald Automatic Centreless Internal Grinding Machine, the Fellows 6-spindle Planetary Gear Shaper, the New Britain Double-ended Tool Rotating Automatic and 6-spindle Automatic, the Gordon P13 Three-dimensional Pantograph, the Devlieg Precision Jigmil, and the Edgwick Di-mill. The measuring equipment includes a number of the Adam Hilger projectors and other devices, Watts, Cooke and O.M.T. inspection instruments

Fig. 1.—Fellows 6-spindle planetary gear shaper

Fig. 2.—The re-designed David Brown Machine Tools MT15 hobbing machine

Fig. 3.—The Coventry Gauge and Tool No. 40 gear grinder set up for a steeply helixed wheel

Fig. 4.—The Coventry Gauge and Tool Matrix No. 50 optical jig borer
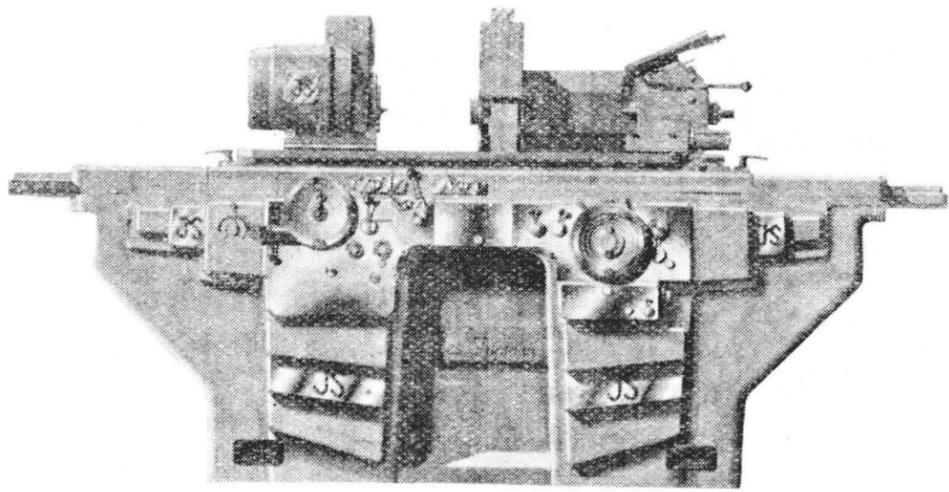
Fig. 5 (above).—The Jones and Shipman 10 in. by 27 in. hydraulic
precision grinder
Fig. 6 (right).—Self-energizing thread rolling on a Wickman 5-spindle
automatic
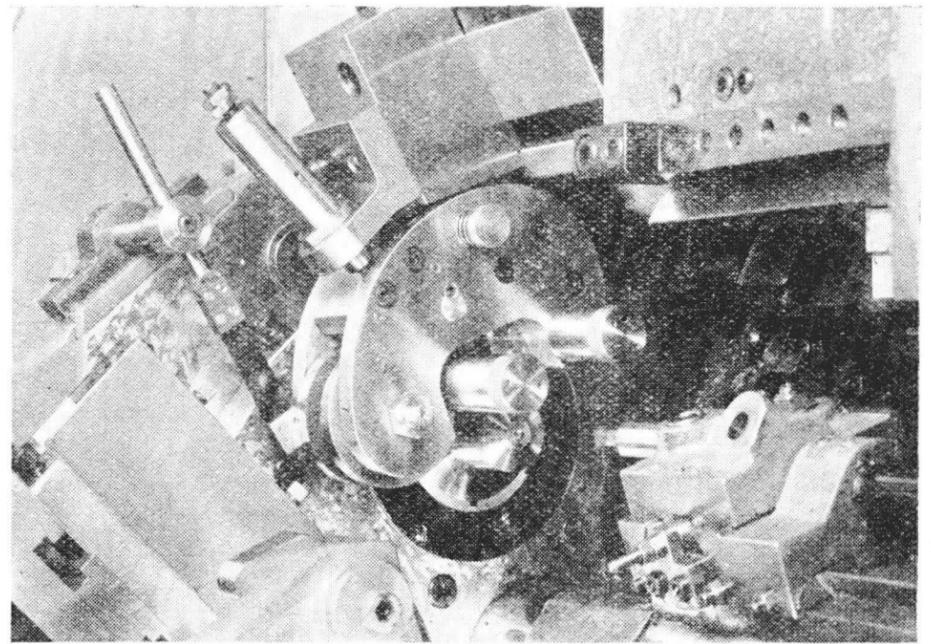
and both Avery and Edgwick hardness testers. The range of accessories and small tools is also extensive and interesting.

E. H. Jones (Machine Tools) Ltd., The Hyde, London, N.W.9, whose Export Organization produces an interesting monthly booklet called 'Modern Times', have had the excellent idea of issuing a special edition describing the equipment they are exhibiting. Again, this firm occupies five large stands with its many exhibits and includes British, American and European equipment—actually more than seventy separate items are on view. Of the more particular items the C.V.A. Jigs & Moulds Ltd. No. 8 Automatic is a machine that has largely replaced tools formerly obtained from the U.S.A., diamond laps are represented by the new Offen Micro-Lap, while among subsidiary items a New Style Toolmakers' Vice, new Master Vee Blocks and additions to the Offen range of Boring Heads are of interest. An unusual item is the Makonus Multi-Tool, a pocket device that can be made up with four blades to suit general engineering, woodworking or the electrical trade. Other machine tools of particular note are C.V.A. British-built versions of the Kearney and Trecker 2D Rotary Head Miller and Model E Plain and Universal Milling Machines, the C.V.A. 10-ton Dieing Press, the Halifax Bench Lathe, Bullous Pneumatic Drill Jigs and Compound Rotary Table, together with several C.V.A. and Sigma machines that are being exhibited for the first time.

The firm of **A. A. Jones and Shipman Ltd.,** Narborough Road South, Leicester, are exhibiting fourteen machines, all but four of which are from their standard range. The new machines are a 10 in. by 27 in. Plain Spindle Grinder, a 10 in. by 27 in. Spindle and Internal Grinder, an 8 in. by 24 in. Universal Precision Grinder and a 10 in. by 36 in. Spindle and Internal Grinder. Among small tools the firm's comprehensive range is on view including new Parting-Off and Side-Tool Holders and their Unigrip Machine Vice.

Acknowledged to be one of the leading designers of grinders **Arthur Scrivener Ltd.,** Tyburn Road, Birmingham, exhibit a number of automatic grinders. A number of these machines have already been described fully in AIRCRAFT ENGINEERING, and it is sufficient to recall here some of the types. The fully automatic No. 2 Centreless Grinder with automatic rotary hopper, the new Herbert-Scrivener Centreless Thread Grinder, and the general purpose No. 1, Model D small centreless grinder are on show. In a separate class there is the No. 1 Scrivener Profile-turning Lathe which is used for camshafts and similar copying work.

The British branch, **Société Genevoise Ltd.,** 5/6 Brettenham House, W.C.2, of the famous Swiss firm exhibit a number of their precision machines. The Hydroptic 7 and 8 Jig Boring and Milling Machines with optical settings are shown with their accessories, as also is the No. 2H Jig Borer, which appears in a revised form. Measuring equipment is represented by the MUL-100 Universal Measuring Machine, the MU-214B Universal Measuring Apparatus and the MUL-250 Shop Gauge Measuring Machine which have been chosen to represent the firm's experience, over eighty years, of metrology. Two comparators are also shown, the AP-6 and AP-10 Profile Projectors, of which the former can be used for photographic copying as well as ordinary comparison checking. Among accessories produced by the firm are high precision boring tool holders for their own boring machines and a range of their Type L adjustable holders is on view.

A member of the Fairey Aviation group of companies, **Weatherley Oilgear Ltd.,** of Heaton Chapel, Stockport, Cheshire, are showing several interesting machines. There is the range of injection and compression moulding machines for plastics, of which 4, 8 and 16 oz. injection machines are available, with 32 oz. and 50 oz. machines in the offing, while both 100-ton and 200-ton downstroking push-button controlled automatic presses are available. A feature of these machines is the special Oilgear Hydraulic operation. Sheet metal working machinery is represented by the W.O.L. 6-ton Hydraulic Bench Press, as an example of the 4, 6 and 8 ton sizes, the 25-ton P.R. Straightening Press, while the 80A Press Brake and the 200-ton Double-Acting Hymulti Press are under development. Yet a third activity, broaching, is covered by the exhibition of the XL-6 and XL50A Horizontal Broaching Machines, the XM-30×48 Cyclematic Broaching Machine, the XP-10×30 Vertical Broaching Machine (two machines being shown, one set up for automatic multiple broach handling and the other for full three-way working) and the XD-20×54 Double Slide Vertical Surface Broaching Machine. In addition to the
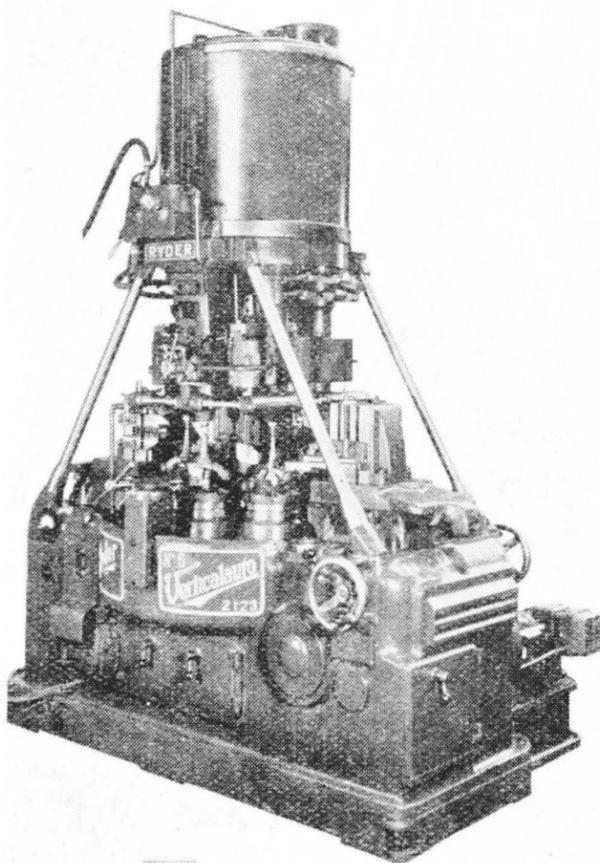
Fig. 7.—The Ryder No. 6 Verticalauto
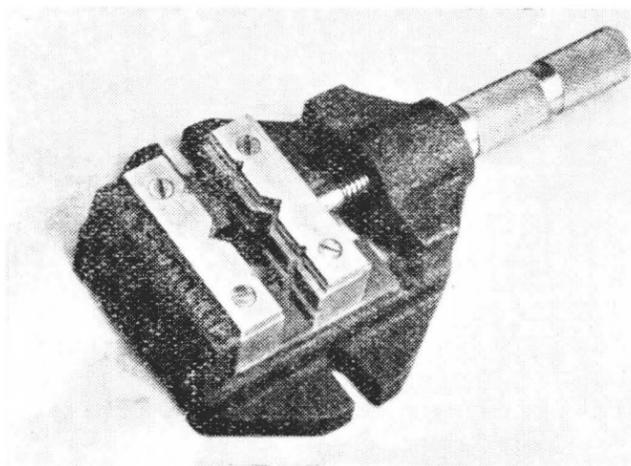
Fig. 8.—The J. & S. Unigrip machine vice
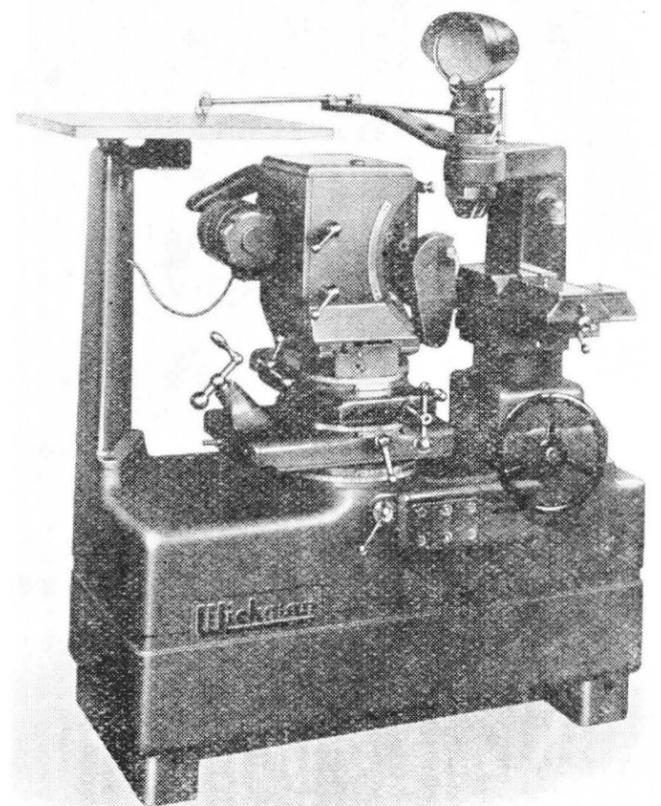
Fig. 9.—The Wickman optical profile grinder

Research Reports and Memoranda

Under this heading are published regularly abstracts of all Reports and Memoranda of the Aeronautical Research Council, Reports and Technical Notes of the United States National Advisory Committee for Aeronautics and publications of other similar Research Bodies as issued

FRANCE

PUBLICATIONS SCIENTIFIQUES ET TECH-NIQUES DU MINISTERE DE L'AIR

RAPPORTS

Magasin C.T.O., 2 Rue de la Porte d'Issy, Paris, XV

No. 213. Scientifiques de la Couche Limite Laminaire. (The Scientific Methods of the Laminar Boundary Layer.) By A. Oudart. (500 Frs.)

A study of the calculation of the boundary layer and the essential hypotheses underlying it. After an introductory chapter dealing with the equations adopted, the author discusses the theory according to Schmidt and Schroeder, the boundary layer of a flat plate and the Blasius problem, heat exchange and the problem of Pohlhausen, the integration condition of Kármán and the equations produced by Pohlhausen, the laminar boundary layer on an angular object and the thermal boundary layer. After the author's conclusions, an appendix gives some general equations in orthogonal curvilinear co-ordinates.

PUBLICATIONS DU GROUPEMENT FRANÇAIS POUR LE DÉVELOPPEMENT DES RECHERCHES AÉRONAUTIQUES

RAPPORT TECHNIQUES

L'Office National d'Études et de Recherches Aéronautiques, 3 Rue Leon-Bonnat, Paris.

No. 33. Étude d'une Méthode de Résonance pour la Mesure de la Transmission des Vibrations Sonores à travers une Cloison et de leur Reflexion. (Study of a Resonance Method for the Measurement of the Transmission of Sound Vibrations through a Partition, and of their Reflexion.) By P. Liénard.

A description in some detail of the development of apparatus for the determination of the acoustic properties of materials. The apparatus consists of two resonant tubes mounted in-line, the material to be tested being placed between them. In each tube there is produced a system of waves formed by the superimposition of a progressive wave on a stationary wave. A study of these waves permits the measurement of the coefficients of reflexion and transmission of the material used in the partition.

No. 34. Étude Statistique de la Turbulence Fonctions Spectrales et Coefficients de Corrélation. (Statistical Study of Turbulence. Spectral Functions and Correlation Coefficients.) By F. N. Frenkiel.

The author defines the differences between the various correlation coefficients and turbulence spectra before studying the relationships between them. The second chapter recalls some experimental results and studies the means of representing them by empirical equations. The following chapters contain an examination of the representation of correlation curves and spectra, and comparison is made with previous measurements. The fifth chapter concerns the application of a series of polynomials, according to Hermite, to the representation of the law of correlation and of the spectrum proposed by de Fériet.

U.S.A.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORTS

Secretary, N.A.C.A., Washington, D.C.

These reports are reprints of papers originally issued by the N.A.C.A. to provide rapid distribution of advance research results to authorized persons during the war period. They are here merely listed as it is impossible to find space for printing summaries. The first number is the serial number under which they are filed by the British Ministry of Supply. The second number (within brackets) is the N.A.C.A. reference number. Any of them is available on loan from the Editor.

N.A.C.A. T.I.B. 1506 (A.R.R. E5J03). Performance Comparison of Two Deep Inducers as Separate Components and in Combination with an Impeller. By William K. Ritter, Ambrose Ginsburg and William L. Beede.

N.A.C.A. T.I.B. 1507 (M.R. Aug. 1941). Static Characteristics of Curtiss Propellers having Different Blade Sections. By Blake W. Corson, Jr. and Nicholas Mastrocola.

N.A.C.A. T.I.B. 1508 (M.R. No. E5A04). Suitability of Ethers as Aviation Fuel Compoents. The Knock-Limited Performance of Several Ethers Blended with an F-28 Fuel. By Henry E. Alquist and Leonard K. Tower.

N.A.C.A. T.I.B. 1509 (A.R.R. E5128). Preliminary Investigation of Deep Inducers as Separate Supercharger Components. By William K. Ritter and Irving A. Johnsen.

N.A.C.A. T.I.B. 1510 (C.B. No. E5K21). The Effect of two Inlet-Duct Designs on Turbine Efficiency. By Elmer E. Trautwein and David S. Gabriel.

N.A.C.A. T.I.B. 1511 (M.R. July 1942). Investigation of Means for Extending the Range of Several Bombers to 6,000 Miles. By H. S. Ribner and S. M. Harmon.

N.A.C.A. T.I.B. 1512 (M.R. No. L5L03). Analytical Investigation of the Stability of an F8F Dropping Model with Automatic Stabilization. By Doris Cohen.

N.A.C.A. T.I.B. 1513 (A.C.R. No. E5H31). Knock-Limited Power Outputs from a C.F.R. Engine Using Internal Coolants. II Six Aliphatic Amines. By Donald R. Bellman, W. E. Moeckel and John C. Evvard.

N.A.C.A. T.I.B. 1514 (M.R. No. L5G31). Longitudinal-Trim Tests of a 0-59-Scale Model of the Curtiss-Wright XP-55 Airplane. By George F. MacDougall, Jr., and Leslie E. Schneiter.

N.A.C.A. T.I.B. 1515 (M.R. July 1942). Generalized Selection Charts for Bombers Powered by One, Two, Four and Six 2,000-horse-power Engines. By M. J. Brevoort, G. W. Stickle and Paul R. Hill.

N.A.C.A. T.I.B. 1516 (M.R. March 1942). Power-on Longitudinal-Stability and Control Tests of the 1 8-Scale Model of the Brewster F2A Airplane Equipped with Full-span Slotted Flaps abd a New Horizontal Tail. By John G. Lowry and Thomas A. Toll.

N.A.C.A. T.I.B. 1517 (M.R. No. L4K09). An Investigation of the Mutual Interference Effects of a Tail-Surface-Stern Propeller Installation on a Model Simulating the Douglas XB-42 Empennage. By Walter A. Bartlett, Jr., and Alfred A. Marino.

N.A.C.A. T.I.B. 1518 (M.R. June 1944). Static-Thrust and Torque Characteristics of Single- and Dual-Rotating Tractor Propellers. By Jean Gilman, Jr.

N.A.C.A. T.I.B. 1519 (M.R. April 1944). Tests of N.A.C.A. 65(216)-420 and 66(218)-420 Aerofoils at High Speeds. By Joseph L. Anderson.

N.A.C.A. T.I.B. 1520 (M.R. March 1942). The Aerodynamic Tests of Three Edo Floats for the SB2U-3, OS2U-2, and XSB2C-2 Seaplanes N.A.C.A. Models 106-K, 107-K, and 125-AH. By Robert B. Liddell.

N.A.C.A. T.I.B. 1521 (M.R. Feb. 1943). Wind-Tunnel Investigation of a Revised Horizontal Tail Surface for the Grumman TBF-1 Airplane. By John W. McKee and Robert B. Liddell.

N.A.C.A. T.I.B. 1522 (MR. No. L5H29). Calculation of the Aileron and Elevator Stick Forces and Rudder Pedal Forces for the Bell XP-83 Aeroplane (Project MX-511) in Spins. By Ralph W. Stone, Jr., and Leslie E. Schneiter.

N.A.C.A. T.I.B. 1523 (M.R. Feb. 1944). Tests of a 1 17-Scale Model of the XBDR-1 Aeroplane in the N.A.C.A. Gust Tunnel. By Thomas D. Reisert.

N.A.C.A. T.I.B. 1524 (M.R. No. L5112). An Investigation of the Ranger V-770-8 Engine Installation for the Edo Xose-1 Aeroplane I Cooling. By Robert N. Conway and M. Arnold Emmons, Jr.

N.A.C.A. T.I.B. 1525 (A.C.R. April 1938). Aerodynamic Characteristics of a 4-Engine Monoplane Showing Effects of Enclosing the Engines in the Wing and Comparisons of Tractor- and Pusher-Propeller Arrangements. By Abe Silverstein and Herbert A. Wilson, Jnr.

N.A.C.A. T.I.B. 1526 (M.R. No. L5K21). Free-Spinning, Longitudinal-Trim, and Tumbling Tests of 1 17·8 Scale Models of the Cornelius AFG-1 Glider. By Ralph W. Stone, jnr. and Lee T. Daughtridge, Jnr.

N.A.C.A. T.I.B. 1527 (M.R. Oct. 1941). Wing-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with an 18.05 per cent Chord Maxwell Slat and with Trailing-Edge Flaps. By Clarence L. Gillis and John W. McKee.

N.A.C.A. T.I.B. 1528 (M.R. No. L5L18). Ground-Stand Cooling Investigation of a R-2600-22 Engine in a P.B.M.-3D Nacelle. By Robert C. Spencer, F. William Petring, and William R. Prince.

N.A.C.A. T.I.B. 1529 (M.R. No. A5J12). Aerodynamic Characteristics of a ¼-Scale Powered Model of a High-Speed Bomber with a Dual Pusher Propeller aft of the Empennage. By James A. Weiberg and Alfred W. Schnurbusch.

N.A.C.A. T.I.B. 1530 (M.R. No. L5A04a). Measurement of Flying Qualities of a Douglas A-26B Aeroplane, (A.A.F. No. 41-39120). III-Stalling Characteristics. By S. A. Sjoberg, H. L. Crane and H. H. Hoover.

N.A.C.A. T.I.B. 1531 (M.R. April 1943). Flying Qualities and Stalling Characteristics of North American AP-51 Aeroplane. By Maurice D. White, Herbert H. Hoover and Howard W. Garris.

N.A.C.A. T.I.B. 1532 (M.R. No. L5C19). Flight Tests of a Rudder With a Spring Tab on an F6F-3 Airplane (B.U.A.E.R. No. 04776). By Walter C. Williams.

N.A.C.A. T.I.B. 1533 (M.R. Sept. 1944). Tests of a 0.30-Scale Semispan Model of the Douglas XTB2D-1 Airplane Wing and Fuselage Combination in the N.A.C.A. 19-Foot Pressure Tunnel, I. Full-span Flap and Air-Brake Investigation. By C. Dixon Ashworth, Stanley H. Spooner and Robert T. Russell.

N.A.C.A. T.I.B. 1534 (M.R. Oct. 1942). A Flight Investigation of the Stability of a Towed Body. By W. H. Phillips.

N.A.C.A. T.I.B. 1535 (M.R. March 1942). Wind-Tunnel Tests of Wickwire-Spencer Propeller. By E. Floyd Valentine and Nicholas Mastrocola.

N.A.C.A. T.I.B. 1536 (A.R.R. No. 5I128). Fatigue Strength of Flush-Riveted Joints for Aircraft Manufactured by Various Riveting Methods. By G. A. Maney and L. T. Wyly.

N.A.C.A. T.I.B. 1537 (R.B June 1942). The Fatigue Strengths of Some Wrought Aluminum Alloys. By G. W. Stickley.

N.A.C.A. T.I.B. 1538 (M.R. No. L5112b). An Investigation of the Ranger V-770-8 Engine Installation for the Edo XOSE-1 Airplane. II Aerodynamics. By Mark R. Nichols and John S. Dennard.

N.A.C.A. T.I.B. 1539 (M.R. Aug. 1943). Flight Measurements of the Effect of Various Amounts of Aileron Drop on the Low-Speed Lateral-Control Characteristics of an Observation Airplane. By William N. Turner and Betty Adams.

N.A.C.A. T.I.B. 1540 (M.R. April 1944). Comparison of the Compressive Strength of Panels With Alclad 24S-T81 Sheet or With Alclad 24S-T86 Sheet Riveted to Alclad 24S-T84 Hat Section Stiffeners. By Robert A. Weinberger, Carl A. Rossman and Gordon P. Fisher.

N.A.C.A. T.I.B. 1541 (M.R. Dec. 1941). Pressure-Distribution Measurements of a Low-Drag Aerofoil with Slotted Flap Submitted by Curtiss-Wright Corporation. By I. H. Abbott.

N.A.C.A. T.I.B. 1542 (A.C.R. May 1942). The Development of Satisfactory Flying Qualities on the Douglas Dive Bomber Model SBD-1. Through Flight Testing Successive Modifications in Control-Surface Area, Hinge-Line Location, and Aerodynamic-Balance Nose Shape. By L. E. Root.

N.A.C.A. T.I.B. 1543 (M.R. No. L6C13). Tests of a 1 7-Scale powered Model of the Kaiser Tailless Airplane in the Langley Full-Scale Tunnel. By G. W. Brewer and E. A. Rickey.

N.A.C.A. T.I.B. 1544 (M.R. Sept. 1944). Aerofoil Section Data from Tests of 10 Practical-Construction Sections of Helicopter Rotor Blades Submitted by the Sikorsky Aircraft Division, United Aircraft Corporation. By Neal Tetervin.

N.A.C.A. T.I.B. 1545 (C.B. April 1942). Construction of Finned Aluminium Muffs for Aircraft-Engine Cylinder Barrels. By Langley Memorial Aeronautical Laboratory.

N.A.C.A. T.I.B. 1546 (A.R.R. E5I123). Performance Effect of Fully Shrouding a Centrifugal Supercharger Impeller. By William K. Ritter and Irving A. Johnsen.

N.A.C.A. T.I.B. 1547 (M.R. No. L5K12a). Wind-Tunnel Investigation of Alternative Propellers Operating Behind Deflected Wing Flaps for the XB-36 Airplane. By Emanuel Boxer.

N.A.C.A. T.I.B. 1548 (M.R. No. L5C29a). Full-Scale-Tunnel Performance Tests of the PV-2 Helicopter Rotor. By Eugene Migotsky.

N.A.C.A. T.I.B. 1549 (C.M.R. No. L4J11). Ditching Tests with a 1 11-Size Model of the Army B-25 Aeroplane in N.A.C.A. Tank No. 2 and on an Outdoor Catapult. By George A. Jarvis and Margaret F. Steiner.

U.S.A.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
TECHNICAL NOTES
Secretary, N.A.C.A., Washington, D.C.

Distribution of the extremely limited number of N.A.C.A. Technical Notes allocated to Great Britain is effected through the Ministry of Supply, who are only able to spare us copies on loan for a brief period. In view of this, and the extreme pressure on our space, there seems to be no object in giving a summary of the contents of each note, as they are not available for study by readers in this country, and we therefore merely give a list of titles as a matter of record.

No. 1332. A Rapid Compression Machine Suitable for Studying Short Ignition Delays. By W. A. Leary, E. S. Taylor, C. F. Taylor and J. U. Jovellanos.

No. 1469. Tensile, Fatigue, and Creep Properties of Forged Aluminium Alloys at Temperatures up to 800 deg. F. By L. R. Jackson, H. C. Cross and J. M. Berry.

No. 1486. Stress Distribution in a Beam of Orthotropic Material Subjected to a Concentrated Load. By C. B. Smith and A. W. Voss.

No. 1506. An Application of Falkner's Surface-Loading Method to Predictions of Hinge-Moment Parameters for Swept-Back Wings. By Arthur L. Jones and Loma Sluder.

No. 1517. Wind-Tunnel Investigation of an N.A.C.A. 0009 Airfoil with 0·25- and 0·50-Airfoil-Chord Plain Flaps Tested Independently and in Combination. By M. Leroy Spearman.

No. 1519. The Buckling of a Column on Equally Spaced Deflectional and Rotational Springs. By Bernard Budiansky, Paul Seide and Robert A. Weinberger.

No. 1528. Tests of a 45 deg. Sweptback-Wing Model in the Langley Gust Tunnel. By Harold B. Pierce.

No. 1537. Apparent Effect of Inlet Temperature on Adiabatic Efficiency of Centrifugal Compressors. By Robert J. Anderson, William K. Ritter abd Shirley R. Parsons.

No. 1538. Analysis of Accuracy of Gas-Filled Bellows for Sensing Gas Density. By Edward W. Otto.

No. 1539. Measurements of the Pressure Distribution on the Horizontal-Tail Surface of a Typical Propeller-driven Pursuit Aeroplane in Flight. III—Tail Loads in Abrupt Pull-up Push-Down Manoeuvres. By Melvin Sadoff and Lawrence A. Clousing.

No. 1540. The Effect of Tip Modification and Thermal De-Icing Flow Air on Propeller Performance as Determined from Wind-Tunnel Tests. By W. H. Gray and R. E. Davidson.

No. 1541. The Effect of Wing Bending Deflexion on the Rolling Moment Due to Sideslip. By Powell M. Lovell, Jr.

No. 1542. Effect of Rotor-Blade Twist and Plan-Form Taper on Helicopter Hovering Performance. By Alfred Gessow.

No. 1543. Effect of Chord-wise Location of Maximum Thickness on the Supersonic Wave Drag of Swept-Back Wings. By Kenneth Margolis.

No. 1544. Strength of Thin-Web Beams with Transverse Load Applied at an Intermediate Upright. By L. Ross Levin.

No. 1547. Tank Tests of Three Types of Afterbodies on a Flying-Boat Model with Basic Hull Length-Beam Ratio of 10·0. By Charlie C. Garrison and Eugene P. Clement.

No. 1548. The Damping to Roll of Triangular, Trapezoidal, and Related Plan Forms in Supersonic Flow. By Arthur L. Jones and Alberta Alksne.

No. 1549. Effect of Yaw at Supersonic Speeds on Theoretical Aerodynamic Coefficients of Thin Pointed Wings with Several Types of Trailing Edge. By W. E. Moeckel.

No. 1554. Application of the Linearized Theory of Supersonic Flow to the Estimation of Control-Surface Characteristics. By Charles W. Frick, Jr.

No. 1562. Calibration of Altimeters under Pressure Conditions simulating Dives and Climbs. By Daniel P. Johnson.

TECHNICAL MEMORANDA (TRANSLATIONS)
Secretary, N.A.C.A., Washington, D.C.

No. 1167. Calculations and Experimental Investigations on the Feed-Power Requirement of Aeroplanes with Boundary-Layer Control. ('Rechnerische und experimentelle Untersuchung zur Frage des Forderleistungsbedarfes von Flugzeugen mit Grenzschichtbeeinflussung.' Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Forschungsbericht Nr. 1618. Göttingen, April 27, 1942.) By W. Kruger.

Calculations and test results are given of the feed-power requirement of aeroplanes with boundary-layer control. Curves and formulae for the rough estimate of pressure-loss and feed-power requirement are set up for the investigated arrangements which differ structurally and aerodynamically. According to these results the feed power for three different designs is calculated at the end of the report.

No. 1169. Description of Russian Aircraft Engines. 'AM 35' and 'AM 38', ('Beschreibung der russischen Flugmotoren 'AM 35' und 'AM 38.' Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 690. Deutsche Versuchsanstalt f. Luftfahrt E. V., Inst. f. Triebwerk-Gestaltung, Motoren-Prüffeld, Berlin-Adlershof, ZWB, Aug. 1, 1942.) By H. Denkmeier and K. Gross.

Only excerpts which describe the Russian developed swirl throttle have been translated and are presented here.

No. 1170. Report on Rocket Power Plants Based on T-Substance. ('Bericht über die R-Triebwerke auf Grundlage des T-Stoffes.' R-Antribee, Schr. d. D. Adak. d. Luftfahrtforschung, Heft 1071, Nr. 82, 1943, pp. 63-89.) By Hellmuth Walter.
Nature of T-Substance.

In the search for an energy source independent of air for the propulsion of underwater craft, attention was early concentrated on T-substance (hydrogenperoxide). It was possible to convince the O.K.M (N.A.C.A. comment: Navy High Command) very quickly of the importance of this material. In 1934, the first experiments were undertaken.

A difficulty was at once presented by the limited concentration that had been obtained. At first only 60 per cent T-substance could be supplied; this amount was later increased to as much as 85 per cent. Decomposition and combustion experiments conducted on the grounds of the C.P.V.A. in Kiel-Dietrichsdorf led to the first practical information as to the technical feasibility of the use of T-substance. New perspectives soon developed because a method of concentrated energy production had been found here, which was capable of many applications. The idea of using this energy for the propulsion of missiles either in guns or as rockets suggested itself and appropriate proposals, which quickly led to the construction of the first experimental devices, were made to the official quarters concerned.

In January 1937, the first flight of a DVL aircraft with T-substance auxiliary propulsion took place at Alimbsmühle in the presence of Colonel Udet, who piloted the third flight. In June 1937, the first T-substance rockets were fired (Altenwalde). Then in rapid succession take-off auxiliary, main propulsion, and other rocket drives were brought out in experimental versions.

No. 1171. Laboratory Report on the Investigation of the Flow Around Two Turbine-Blade Profiles Using the Interferometer Method. ('Versuchsbericht über die Untersuchung der Strömung um zwei Turbinenschaufelprofile mit Hilfe der Interferenzmethode.' Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 2096, Luftfahrtforschungsanstalt Hermann Göring E. V., Inst. f. Motorenforschung, Braunschweig, Germany, ZWB, May, 31, 1944.) By K. von Vietinghoff-Scheel.

The interferometer method (reference 1) enables making visible the differences in density and consequently the boundary layers that develop when a flow is directed on the profile. Recognition of the points on the profile at which separation of flow occurs is thus possible. By means of the interference photographs the extent of the dead-water region may be ascertained. The size of the dead-water region provides evidence as to the quality of the flow and allows a qualitative estimate of the amount of the flow losses. Interference photographs thus provide means of judging the utility of profiles under specific operating conditions and provide suggestions for possible changes of profile contours that might help to improve flow relations. Conclusions may be drawn concerning the influence of the blade-spacing ratio, the inlet-air angle, and the connection between the curvature of the profile contour and the point of separation of the flow from the profile surface.

In addition, interference photographs also make possible ascertainment of the distribution of pressure and velocity over the blade. Such quantitative evaluation of the interference photographs was not undertaken in regard to the present experiments.

No. 1172. Preliminary Report on the Fundamentals of the Control of Turbine-Propeller Jet Power Plants. ('Vorläufger Bericht über die Grundlagen der Regelung von PTL-Triebwerken.' Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 1272. Deutsche Versuchsanstalt f. Luftfahrt, E. V., Inst. f. motorisches Arbeitsverfahren und Thermodynamik, Berlin-Adlershof, WZB, June 9, 1944.) By H. Kühl.

On the basis of the investigations so far completed on the behaviour of turbine-propeller jet power plants under various operating conditions, in which the influence of the propeller characteristics is of considerable importance, the most important aspects of a control system for turbine-propeller jet power plants are deduced. A simple possible means for its concrete realization, which is also applicable to jet power plants, is presented by means of examples.

No. 1173. Pressure Distribution Measurements on a Turbine Rotor Blade Passing Behind a Turbine Nozzle Lattice. ('Druckverteilungsmessungen an einer sich hinter einem Turbinendüsengitter vorbeibewegenden Turbinenlaufschaufel.' Berichte der Gittertagung in Braunschweig, Institutf. Motorenforschung der Luftfahrtforschungsanstalt Hermann Göring, März 27 u. 28, 1944, Br.B. Nr. M325 44g, pp. 95-100.) By Hausenblas.

As a turbine rotor turns, the blades traverse the wake zones of the nozzle vanes. A periodic fluctuation of the pressure distribution around the circumference of the rotor blade is therefore caused. It was desired to investigate quantitatively this effect. At the same time, the magnitude of the force acting upon one profile of the rotor-blade lattice at various positions of this lattice relative to the nozzle lattice was to be determined.

No. 1174. Analytical Treatment of Normal Condensation Shock. ('Analytische Behandlung des geraden Kondensationsstosses.' Heeres-Versuchsstelle, Peenemünde, Archiv Nr. 66 72, März 30, 1942.) By Heybey.

The condensation of water vapour in an air stream has the following consequences:

1. Acquisition of heat (liberated heat of vaporization.)
2. Loss of mass on the part of the flowing gas (water vapour is converted to liquid.)
3. Change in the specific gas constants and of the ratio k of the specific heats (caused by change of gas composition.)

A discontinuous change of state is therefore connected with the condensation; schlieren photographs of supersonic flows in two dimensional Laval nozzles show two intersecting oblique shock fronts that in the case of high humidities may merge near the point of intersection into one normal shock front. The discussion here deals with normal shock fronts only; it is assumed that the velocity vector may be considered as being at right angles to the shock front (one-dimensional theory).

No. 1175. Fundamental Aerodynamic Investigations for Development of Arrow-Stabilized Projectiles. ('Die grundsätzlichen aerodynamischen Untersuchungen zur Entwicklung pfeilstabiler Geschosse.' Schriften der Deutschen Akademie der Luftfahrtforschung, Nr. 1059 43, 1943, pp. 33-71.) By Hermann Kurzweg.

The principle of arrow-stabilized performance has been applied to a large number of calibers which were stabilized by various means. Most promising was the development of a subcaliber wing-stabilized projectile with driving disc (Triebspiegel) where rigid control surfaces extend beyond the caliber of the projectile into the free stream. The stabilization of full-caliber, wing-stabilized projectiles with fins within the caliber is considerably more difficult. A completely satisfactory solution for the latter has not been found yet.

No. 1177. Wind-Tunnel Investigations on a Changed Mustang Profile with Nose Flap Force and Pressure-Distribution Measurements. ('Windkanaluntersuchungen an einem abgeänderten Mustang-Profil mit Nasenklappe. Kraft- und Druckverteilungsmessungen.' Zentrale für wissenschaftliches Berichtswessen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Untersuchungen und Mitteilungen Nr. 3153, Göttingen, September 22, 1944.) By W. Krüger.

Measurements are described which were taken in the large wind tunnel of the A.V.A. on a rectangular wing 'Mustang 2' with nose flap of a chord of 10 per

cent. Besides force measurements the results of pressure-distribution measurements are given and compared with those on the same profile 'without' nose flap.

No. 1178. Investigation of the Operating Properties of the Leakage Current Anemometer. ('Untersuchung der Betriebseigenschaften des Vorstromanemometers.' Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) —Berlin-Adlershof, Untersuchungen und Mitteilungen Nr. 1203. Aachen, February 4, 1944.) By Wilhelm Fucks.

Freedom from inertia, erosion of electrodes, and reaction make the leakage current particularly appropriate for the measurement of flow velocities in gases. Apparatus previously described has now been improved by reducing the size of the electrodes by one one-thousandth, as is necessary aerodynamically, and by increasing the magnitude of the current from 1000 to 10,000 times; the latter result was obtained by use of mercury high-pressure lamps set up at the one focal point of an ellipsoidal reflector with the cathodes arranged at the other focal point or by use of suitable X-ray radiation. Families of calibration curves were taken with a number of vivid tests conditions of the greatest variety and the operating properties of the instrument were widely elucidated by calculation of the sensitivity to fluctuation; this was done at first for operation at stationary conditions only; due to the freedom from inertia the instationary conditions were thus also given. Accordingly, the leakage current anemometer ought to be appropriate for investigations of turbulence.

TECHNICAL REPORTS
Government Printing Office, Washington, D.C.
1944

Report No. 786. Performance of Blowdown Turbine Driven by Exhaust Gas of Nine-cylinder Radial Engine. By L. Richard Turner and Leland G. Desmon. (15 cents)

An investigation was made of an exhaust-gas turbine having four separate nozzle boxes each covering a 90 deg. arc of the nozzle diaphragm and each connected to a pair of adjacent cylinders of a nine-cylinder radial engine. This type of turbine has been called a 'blowdown' turbine because it recovers the kinetic energy developed in the exhaust stacks during the blowdown period; that is, the first part of the exhaust process when the piston of the reciprocating engine is nearly stationary. The purpose of the investigation was to determine whether the blowdown turbine could develop appreciable power without imposing any large loss in engine power arising from restriction of the engine exhaust by the turbine.

The engine power was decreased a maximum of 1 per cent by the presence of the turbine at the lowest turbine-outlet pressure as compared with the engine power delivered with a conventional collector ring discharging to an equal exhaust pressure. No engine-power loss was imposed by the presence of the turbine with turbine-outlet pressures greater than 20 inches of mercury absolute. The engine air-flow rate was not affected by the presence of the turbine. At an engine speed of 2,000 r.p.m. and an inlet-manifold pressure of 33·5 inches of mercury absolute, the turbine power varied from 9 per cent of engine power with a turbine-outlet pressure of 28 inches of mercury absolute to 21 per cent of engine power with a turbine-outlet pressure of 7·5 inches of mercury absolute.

Report No. 787. A Theoretical Investigation of the Rolling Oscillations of an Airplane with Ailerons Free. By Doris Cohen. (15 cents)

An analysis is made of the stability of an aeroplane with ailerons free, with particular attention to the motions when the ailerons have a tendency to float against the wind. The present analysis supersedes the aileron investigation contained in N.A.C.A. Report No. 709. The equations of motion are first written to include yawing and sideslipping, and it is demonstrated that the principal effects of freeing the ailerons can be determined without regard to these motions. If the ailerons tend to float against the wind and have a high degree of aerodynamic balance, rolling oscillations, in addition to the normal lateral oscillations, are likely to occur. On the basis of the equations including only the rolling motion and the aileron deflection, formulae are derived for the stability and damping of the rolling oscillations in terms of the hinge-moment derivatives and other characteristics of the ailerons and aeroplane. Charts are also presented showing the oscillatory regions and stability boundaries for a fictitious aeroplane of conventional pro-

portions. The effects of friction in the control system are investigated and discussed.

If the ailerons tend to trail with the wind, the condition for stable variation of stick force with aileron deflexion is found to determine the amount of aerodynamic balance that may be used. If the ailerons tend to float against the wind, the period and damping of the rolling oscillations are found to be satisfactory (in a mass-balanced system) so long as the restoring moment is not completely balanced out. Unbalanced mass behind the hinge, however, has an unfavourable effect on the damping of the oscillations and so shifts the boundary that close aerodynamic balance may not be attainable. It is found that friction may retard somewhat the damping of the aileron-free oscillations but in no case causes undamped oscillations if the ailerons are otherwise stable.

Report No. 788. On the Plane Potential Flow Past a Lattice of Arbitrary Airfoils. By I. E. Garrick. (15 cents)

The two-dimensional, incompressible potential flow past a lattice of aerofoils of arbitrary shape is investigated theoretically. The problem is treated by usual methods of conformal mapping in several stages, one stage corresponding to the mapping of the framework of the arbitrary line lattice and another significant stage corresponding to the Theodorsen method for the mapping of the arbitrary single wing profile into a circle. A particular feature in the theoretical treatment is the special handling of the regions at an infinite distance in front of and behind the lattice. Expressions are given for evaluation of the velocity and pressure distribution at the aerofoil boundary. An illustrative numerical example is included.

Report No. 789. On the Flow of a Compressible Fluid by the Hodograph Method. I—Unification and Extension of Present-day Results. By I. E. Garrick and Carl Kaplan. (20 cents)

Elementary basic solutions of the equations of motion of a compressible fluid in the hodograph variables are developed and used to provide a basis for comparison, in the form of velocity correction formulae, of corresponding compressible and incompressible flows. The known approximate results of Chaplygin, von Kármán and Tsien, Temple and Yarwood, and Prandtl and Glauert are unified by means of the analysis of the present paper. Two new types of approximations, obtained from the basic solutions, are introduced; they possess certain desirable features of the other approximations and appear preferable as a basis for extrapolation into the range of high stream Mach numbers and large disturbances to the main stream. Tables and figures giving velocity and pressure-coefficient correction factors are included in order to facilitate the practical application of the results.

Report No. 790. On the Flow of a Compressible Fluid by the Hodograph Method. I—I Fundamental Set of Particular Flow Solutions of the Chaplygin Differential Equation. By I. E. Garrick and Carl Kaplan. (20 cents)

The differential equation of Chaplygin's jet problem is utilized to give a systematic development of particular solutions of the hodograph flow equations, which extends the treatment of Chaplygin's into the supersonic range and completes the set of particular solutions.

The particular solutions serve to place on a reasonable basis the use of velocity correction formulae for the comparison of incompressible and compressible flows. It is shown that the geometric-mean type of velocity correction formula introduced in Part I has significance as an over-all type of approximation in the subsonic range.

A brief review of general conditions limiting the potential flow of an adiabatic compressible fluid is given and application is made to the particular solutions, yielding conditions for the existence of singular loci in the supersonic range.

The combining of particular solutions in accordance with prescribed boundary flow conditions is not treated in the present paper.

GREAT BRITAIN
AERONAUTICAL RESEARCH COUNCIL
HM Stationery Office, London

R. & M. No. 2171. Heat Flow Measurements. November, 1946. By Ricardo & Co. (3s.)

Heat flow is one of the most serious limitations in the design of high-duty engines; it, is, therefore, desirable to have as much information as possible on the subject. A fair amount is known about the total heat loss from an engine cylinder under various work-

ing conditions, but there is not much information as to the local intensity of heat flow at individual points in the cylinder. In the case of the poppet-valve four-cycle engines, the zones of intense heat flow, and at least a rough estimation of their degree of intensity, are known from mass experience extending over many years, but this does not yet apply in the case of the sleeve-valve engines, and still less, in that of two-cycle sleeve-valve engines. The most comprehensive figures are those obtained by Professor Eichelberg, but most of these, and of other such data, were obtained on large engines, and there is practically nothing applicable to aero-engine work.

To measure a local heat flow one must do one of two things:

(i) Thermally isolate the spot under investigation from the rest of the engine, and cool it with an independent supply of coolant whose heat pick-up can be measured.
(ii) Measure the local temperature gradient in the metal and calculate the heat flow from the gradient and the conductivity of the metal.

The first method is rarely, if ever, practicable, and one is thus forced to use the second. The conductivity can, of course, be determined by a laboratory test on the material (though the published data shows some surprising discrepancies).

The problem is thus reduced to that of measuring the temperature gradient in the cylinder wall. For this Eichelberg used fixed thermo-couples located at different depths in the wall; this is practicable with the thick cylinders of large engines, but becomes very difficult in the case of the thin cylinders of aero-engines. For these it is much easier to use a traversing thermocouple which slides in a small hole drilled in the cylinder wall, and this method was used in the present case.

R. & M. No. 2172. Effect of various Factors on Heat-flow in Four-cycle Petrol Engines. November, 1946. By H. R. Ricardo. (1s. 6d.)

This report is based on the results from several hundred heat balance tests on a very large number of four-cycle, spark-ignition engines of many different types and sizes and under widely varying conditions. To reduce the results to a useful common denominator it is best to take a given cylinder and to consider how the total gross heat flow to the walls of the cylinder will be affected by such changes as varying the mixture strength, the throttle opening, supercharging, ignition timing, etc., and where possible to express such variations in terms of percentage, taking as unity the heat flow from that cylinder when operating with wide open throttle at atmospheric pressure, at the chemically correct mixture strength and with optimum ignition advance. The chemically correct mixture strength is taken as unity because, in all cases, and on all fuels tested, the gross heat flow to the jackets is at a maximum at this mixture ratio.

Again, since the mechanical efficiency of the various engines tested has varied widely, it seems best to express the power output in terms of indicated mean pressure, and here again, the indicated mean pressure obtained when the engine was operating under the optimum conditions under atmospheric pressure, as described above, has been taken as unity. Although this report is only concerned with high-duty aero-engines, and the results quoted were obtained from high-speed, high-performance engines, it is interesting to note that the results obtained from relatively low-speed or low-performance engines, do, in fact, fall closely into line.

R. & M. No. 2175. The Buckling of a Flat Rectangular Plate upon Axial Compression and its Behaviour after Buckling. II. Conditions for Permanent Buckles. October, 1945. By H. L. Cox. (2s.)

The conditions under which a flat rectangular plate under compression in its own plane may become permanently buckled are estimated.

Attention is directed mainly to the case of a plate of which all four edges are held straight; the effect of complete or partial freedom of the edges parallel to the direction of loading to wave is briefly discussed. The criterion of elastic failure applied is the value of a local maximum shear stress; application of the criterion of local maximum shear energy (the Mises criterion) or of the criterion of true maximum local shear stress is mentioned. General formulae are developed for the stress system at any amplitude of buckle under any degree of lateral constraint; but detailed results are given only for the case when the plate is completely free to expand laterally.

The least satisfactory feature of the present analysis is the rather artificial criterion of elastic failure adopted in default of means to apply the usual criteria. Until this defect shall have been overcome there seems

little point in extending the analysis to other cases. At the same time this extension in respect of lateral restraint is straightforward. The effect of freedom of the unloaded edges to wave is very difficult to assess, but it is unlikely to be considerable. The effect of torsional restraint at these edges is likely to be marked, but again analysis presents great difficulties.

R. & M. No. 2176. Formulae for the Computation of the Functions Employed for Calculating the Velocity Distribution about a Given Aerofoil. May, 1945. By E. J. Watson. (2s.)

In order to determine the velocity distribution about an arbitrary aerofoil, it is necessary to evaluate the functions ψ', ϵ and ϵ' (in the notation of aerofoil theory) when ψ is given numerically. If the values of ψ are specified at $2N$ points equally spaced about the circle into which the aerofoil is transformed, the formulae obtained here may be used to calculate these functions at the same points. Formulae are also given for calculating the integrals of ψ and ϵ, since these have application to the design of aerofoils by Thwaites' numerical method.

The simplicity of the formulae for ψ', ϵ and ϵ' enables the effect on the velocity distribution of a local change of shape readily to be determined by making N large.

The formulae are collected and a table of the coefficients for the case $N = 20$ is given.

R. & M. No. 2177. Free Streamline Suction Slots. February, 1946. By E. J. Watson. (4s. 6d.)

In this report the theory of free streamlines is applied to the design of suction slots, or similar entries to ducts. Although suction slots are intended for boundary layers, where potential flow does not apply it is hoped that the slot shapes obtained here may provide a basis for experiment. These slots may be compared with those derived empirically by Fage and Sargent, but contain one novel feature in that there is, in general, a step between the flat boundaries at either side of the slot. The figures show a series of slots covering a range of slot angles and of ratios of stream velocity to slot velocity, and the co-ordinates of these slots are given in the Tables. The formulae by which these slots are calculated are collected in the Appendix.

R. & M. No. 2178. The Theory of Flat Panels Buckled in Compression. June, 1945. By W. S. Hemp. (2s.)

This report is based upon the two non-linear differential equations of the theory of the large deflexion of plates. An approximate solution is outlined and the necessary analysis is developed. Formulae are developed for the initial slope of the post-buckled load-strain curve and the results are applied to special cases of simply supported edges and clamped edges. The 'semi-energy' method previously used for analysis of this problem is criticized and the assumptions and conclusions are summarized.

R. & M. No. 2179. Effect of Variation of Airscrew Tip Speed and Drag Critical Speeds at Two Forward Speeds. August, 1943. By R. C. Pankhurst. (6s.)

The variation of airscrew efficiency with tip speed has been calculated by the method of R. & M. 2035 for forward speeds of 0·6 and 0·75 times the velocity of sound and for a wide range of horsepower, blade lift coefficient and solidity, using the compressibility-drag data of Part II of R. & M.2020.

R. & M. No. 2180. Wind-tunnel Tests on High-lift Devices. December, 1939. By H. M. Lyon and J. E. Adamson.

An investigation of high-lift devices was initiated in connexion with Fleet Air Arm requests for a low landing speed combined with a high wing loading to give a high top speed and carrying capacity in spite of the limitations in size. Model tests were made with high-lift devices designed to give maximum lift coefficients of not less than 3·0.

R. & M. No. 2181. Note on the Influence of Spanwise Flow on Lift Distribution. March, 1946. By W. P. Jones. (9d.)

The influence of spanwise flow on the lift distribution for a thin flexible wing of any plan form is considered. By the use of Euler's equations for incompressible, inviscid flow, it is shown that the lift distribution is not appreciably affected, provided that the displacements of the wing are small.

R. & M. No. 2182. On Fundamental Sets of Solutions of the Equations of Lateral Motion, and the Rapid Calculation of General Solutions. May, 1945. By K. Mitchell.

The lateral motion of a symmetrical aeroplane slightly disturbed from steady flight is determined, to the first order of small quantities, by the solution of a system of six simultaneous linear differential equations with constant coefficients, in which the inhomogeneous terms, representing control forces or the effects of gusts, may be arbitrary functions of time. In virtue of the general properties of such equations, as is well known, their most general solution can always be written down in a form involving definite integrals. Calculations of such theoretical expressions can be very tedious, and it is now shown that the most general solution can be much more simply obtained, by processes of addition, multiplication, and integration, from a set of three fundamental solutions. A large number of such sets of fundamental solutions has already been obtained by means of the differential analyser, and the application to these of the methods of this report will make possible a large range of more special response calculations, some of which may well develop into important matters of routine.

R. & M. No. 2183. A Note on Compressible Flow in a Tube of Slightly Varying Cross-section. December, 1945. By G. N. Ward.

Non-uniform compressible flow in a tube is investigated using the approximate linearized equation for the velocity potential. It is found that for supersonic flow, stationary oscillatory disturbances result from initially non-uniform conditions and these persist down the tube. For subsonic flow in a straight tube no oscillatory disturbances occur and any initial non-uniformity is damped out downstream in general. A method of calculating the supersonic flow in a tube of slightly varying cross-section is indicated.

PASSING THROUGH THE SONIC BARRIER

$$\rho \left(1 + 0,2 \, M_o^2 \right)^3 = \rho_E \left(1 + 0,2 \, M_{oE}^2 \right)^3 ; \quad \ldots \ldots (45)$$

in which ρ_E is the air density corresponding to the economic altitude calculated for the Mach number reached in cruising M_{oE}.

It is proposed to call 'isodynamic altitudes' those altitudes corresponding to the values of ρ deduced from (45)

Assuming $M_{oE} = 2$, $\rho_E = 0·0055$, the mass flow at the intake becomes 4·44 or approximately 45 kg. which gives a balancing thrust of $F_E = 4·44 \, C_F V_{oE} = 1,465$ kg. already calculated.

Similarly the thrust supplied by the two jet-engines at the isodynamic altitudes may be calculated for the other speeds of flight, as was done in FIG. 4, which shows the relative densities corresponding to the isodynamic altitudes.

We must now evaluate the corresponding drag values of the aircraft, which are shown to be somewhat greater than those at the economic altitudes because they are derived from (15) and from the second part of (16) in Part I,

$$C_r = r + hs + \frac{C_p^2}{s} \quad ; \quad C_p = \frac{Q/S}{\rho V_o^2} ; \quad \ldots \ldots (46)$$

without regarding the condition of the minimum value $C_p^2 = s(r+hs)$.

The values of the aircraft drag thus calculated for the isodynamic altitudes are also included in FIG. 4 and show an excess of thrust over drag which appears more than sufficient to supply the reserve for acceleration and climbing, i.e. for the practical crossing of the sonic barrier and for the easy attainment of the economic cruising altitude.

We may therefore enunciate the following conclusion: whereas the economic altitudes are suitable for supersonic cruising speeds because they demand, for any velocity, the minimum thrust, consumption and power input to the compressor, the isodynamic altitudes, at which the power supplied to the compressor is kept constant, appear to be indicated in order to reach the cruising speeds and for crossing the sonic barrier. It may also be demanded whether the economic altitude must be rigidly observed or whether in practice a lower altitude might be more successful. It is known that for a given cruising speed V_E, the economic altitude gives the minimum thrust, minimum consumption and for (44) the minimum power input to the compressor. This, however, requires an intake area nearly double that at sea level.

If in equation (46) we assume, for a given speed V_E, that

$$C_p = \frac{Q/S}{\rho V_E^2} = \frac{Q/S}{\rho_0 V_E^2} \Delta = \Delta \mid Ks ; \quad \ldots \ldots (47)$$

where ρ_0 is the density at sea level, Δ the rarefaction of the air or the inverse ratio of the relative density and K is a constant defined by the equations in (47), we obtain for the second part of (17) of Part II, and indicating by ω_0 the intake area at sea level

$$C_F \frac{\omega}{S} = r + hs + K\Delta^2 \quad ; \quad C_F \frac{\omega_0}{S} = r + hs + K \quad ;$$

$$\frac{\omega}{\omega_0} = \frac{r + hs + K\Delta^2}{r + hs + K} \quad \ldots \ldots \ldots \ldots (48)$$

from which, since K is negligible compared with $r + hs$ and where $K\Delta_E^2 = r + hs$ for the economic altitude, the intake area ω_E is almost exactly double the value of ω_0.

Equations (47) and (48) permit, then, the determination of the value of the intake area ω for any other altitude defined by the rarefaction Δ.

The corresponding power absorbed by the compressor may, by analogy, be written

$$75 \, H_C = \rho_0 V_E E \, c_p \, g\vartheta = 75 \, H_{CE} \frac{\omega}{\omega_0 \Delta} ; \quad \ldots \ldots (49)$$

and calculated for any value of Δ after the calculation of the corresponding ratio of the intake areas.

These calculations are illustrated in FIG. 5 which suggest that the extreme value represented by the economic altitude be renounced for cruising and that lower altitudes be adopted, where the intake area is reduced, and where the dimensions of the jet engine required are less although the power absorbed by the compressor and the cruising consumption become somewhat greater than the economic minimum. Thus, for example, for a rarefaction half of the maximum for the aircraft considered, we obtain an intake area and a power input to the compressor equivalent to twenty-five per cent in excess of their minimum values.

The solution of the compromise to which this final consideration leads may be left to the technical experts, it being sufficient for us to have shown its practical importance.

Trade Announcements

Under this heading are published monthly news of recent professional appointments, industrial developments and business changes, etc.

Air Survey Company in India

Air Survey Co. Ltd., a subsidiary company in the Fairey Aviation Co. Ltd. group of companies, announces the formation of a new subsidiary company in Pakistan and the revision of the name of its long-established subsidiary company in India.

The name of Indian Air Survey & Transport Ltd. has been changed to Air Survey Company of India Ltd.

At Karachi, a new subsidiary of Air Survey Co. Ltd., has now been formed with the title of Air Survey Company of Pakistan Ltd.

The Air Survey group of companies now consists of: Air Survey Co. Ltd., Air Survey Company of India Ltd., Air Survey Company of Pakistan Ltd., Aero Surveys Ltd. (Vancouver), Aerographic Surveys Ltd.

B.C.S.O. (London)

The British Commonwealth of Nations Scientific Liaison Offices (London) have been opened on the third floor of Africa House, Kingsway, W.C.2. This is one of the measures to facilitate co-operation in the civil aspects of science within the Commonwealth decided on by the British Commonwealth Scientific Official Conference held in London in 1946. For a number of years several of the Commonwealth countries have maintained scientific liaison offices in London, and these, together with the ones about to be established, will now have their headquarters in Africa House. Each of these offices will continue to operate as in the past, retaining complete independence of action, but the convenience of occupying adjacent premises will facilitate co-operation between them on matters of common interest. For ease of reference to the group of independent offices as a whole the title given above has been chosen, with the abbreviation B.C.S.O. (London) for common use. The offices taking part in the scheme are the Scientific Liaison Offices of Australia, Canada, Central African Council, India, New Zealand, South Africa and the United Kingdom. Pakistan and the Commonwealth Agricultural Bureaux will be represented and the Overseas Liaison Division of the U.K. Department of Scientific and Industrial Research will work in Africa House.

In Washington the scientific liaison offices of the Commonwealth countries are associated under a similar scheme.

Handley Page Ltd.

Mr G. C. D. Russell has been appointed Secretary of Handley Page Ltd., having acted in this capacity during the past six months.

Hawker Aircraft Ltd.

The appointment of Mr William Humble as Sales Manager has been announced by Hawker Aircraft Ltd., following the resignation from the Company of Mr F. H. M. Lloyd.

Mr T. D. M. Robertson has been appointed General Manager of Hawker Aircraft Ltd., Mr J. T. Lidbury becoming Secretary.

Lambert Pharmacal Company

A new factory was opened on June 1st by the Lambert Pharmacal Company, at Victoria Road, South Ruislip, Middlesex, for the manufacture of Listerine antiseptic and other Listerine products.

Licensed Aircraft Engineers

Squadron-Leader Edward C. Rogers has been compelled by ill-health to resign from the position of General Secretary to the Society of Licensed Aircraft Engineers.

Captain Peter F. Murray assumed the responsibilities of General Secretary from June 7th, 1948.

Mr Lionel Lodge

The death has been announced, at the age of 65, of Mr Lionel Lodge, managing director of Lodge-Cottrell Ltd., of Birmingham, and a director of Lodge Plugs Ltd., of Rugby. Mr Lodge was the fourth son of the late Sir Oliver Lodge, and it was for the commercial development of some of Sir Oliver's patents relating to electrical precipitation and the purification of air that he formed the company which later became Lodge-Cottrell Ltd.

United Steel Companies Ltd.

Mr C. E. Edwards has been appointed Sales Manager of the Appleby Frodingham branch of the United Steel Companies Limited.

TRADE PUBLICATIONS RECEIVED

Bakelite Progress, Spring 1948
Bakelite Ltd., 12 Hobart Place, S.W.1]
The Makonus Multi-Tool
The Wells Safeguard Power Press Improved Roll Feed Device
[E. H. Jones (Machine Tools) Ltd., The Hyde, N.W.9]
About Ourselves, 1904–1947
Compact Power
[Brook Motors Ltd., Empress Works, Huddersfield]
Titanine Aircraft Finishes
[Titanine Ltd., Colindale, N.W.9]
The Midsaw Universal Woodworker
Precision Metal Cutting Machines
[The Midland Saw & Tool Co. Ltd., Pope Street, Birmingham]
Spraytex Fabrics by Spray Gun
[Spraytex (Manchester) Ltd., 168 Oxford Road, Manchester]
Cork for Insulation
[British Cork Mills Ltd., 167 Victoria Street, S.W.1]
The Rivnut and Phillips Recess Screw
[Linread Ltd., Cox Street, St Paul's, Birmingham, 3]
T.B. Power Presses
[Turner Bros. (Birmingham) Ltd., Galvanic Works, Cliveland Street, Birmingham, 19]
Athyweld
[Edgar Allen & Co. Ltd., Imperial Steel Works, Sheffield, 9]

MACHINE TOOLS

(*Concluded from p. 244*)

foregoing equipment assembly presses, cold heading presses, and a section and tube stretching machine will be on view.

Over sixty machines, exhibited on three Stands, represent the firm of **A. C. Wickman Ltd.,** Coventry, who show their well-known range of Multi- and Single-Spindle Automatics, a new series of Grinding and Lapping Machines, together with the latest versions of Applied Frequency Heaters, Cornelius Electronic Comparators and Wimet Tungsten Carbide. The company is also the sole agent for the following British machines: Webster and Bennett Boring and Turning Mills, Chatwood Hob Grinders, Neven Grinding and Lapping Machines and Diamond Wheels, which are also shown. Machines are also exhibited from the following Continental and American firms for which A. C. Wickman are agents: the Swiss firms Henry Hauser Ltd., Schanblin Ltd., Essa, Lambert and Safag; the Swedish Lidkoping and U.V.A.; and the American Pines, Davenport, H.P.M., Le Blond, Warner and Swasey, Brandes, Yoder and Carlton. Of particular interest is the Wickman Optical Profile Grinder, for carbide tools, split dies, gauges, templates, etc., working on a 50 to 1 pantograph system. The Model 8B and 14C Grinding and Lapping Machines are very up-to-date machines for servicing tungsten carbide tools. The well-established Hauser Jig Boring and Jig Grinding Machine, Type 2SB, is also on view. The **Thomas Ryder & Son Ltd.,** No. 6 Verticalauto, for which A. C. Wickman Ltd. are sole agents, is an interesting new machine that is shown on its maker's Stand, No. 101.

Wild-Barfield Electric Furnaces Ltd., Watford, Herts, are precluded by the size of their equipment from showing more than photographs and models of most of their products, but they do show their Model M94 twin tube laboratory muffle, the Model TRT1010 forced air circulation toolroom tempering furnace, and the Model HTP4 high temperature furnace, various radio frequency appliances. The Eternite Casehardening Compound and the Shell-Wild-Barfield quenching oils are exhibited to show the accessories to the furnaces.

Trade Reviews

Under this heading are published from time to time brief reviews of a selection of the Trade Publications received for notice

The Specification of Meehanite Metal. [*The International Meehanite Metal Co. Ltd., 66 Victoria Street, London, S.W.1*]

This pocket booklet sets out the properties, characteristics and uses of the high duty irons covered by the trade name of Meehanite. Generally these materials are not of great interest to aeronautical engineers, although their special properties make them suitable for high quality jigs and fixtures and for the bodies of milling cutters and other toolroom uses.

Bostik Adhesives for Industry. [*B.B. Chemical Co. Ltd., Ulverscroft Road, Leicester*]

This is a catalogue of the more common Bostik products and includes, among other items, careful instructions on how to use the Blue Label Glazing Compound tube—but does not solve the problem of how to keep the nozzle clean for re-use between applications.

Standard Specifications and Typical Analyses—Metals, Metallic Alloys, Carbides. [*Murex Ltd., Rainham, Essex*]

A useful pocket reference booklet giving the essential data on the manufacturers' products, ferrous alloys, metal powders and metallic carbides.

J.M.C. Electrical Resistance Materials. [*Johnson, Matthey and Co. Ltd., 73 Hatton Garden, London, E.C.1*]

This booklet by one of the principal makers of resistance material in the world (they provide the wire for nearly all the strain gauges used in this country) is absorbingly interesting. The uses and characteristics of the various wires are described and, at the end, there is a useful nomogram relating the resistance in ohms per yard with resistivity and wire diameter.

Marconi Radio Communications and Navigational Equipment
Airborne Automatic Direction Finder, Type AD7092
Airborne Beam-Approach Receiver, Type AD 86
Lightweight Airborne Transmitter, Type AD 97
Lightweight Airborne Receiver, Type AD 108
Voltage Regulator Units for Aircraft Radio Stations
Universal Racking System for Aircraft Radio Equipment
[*Marconi's Wireless Telegraph Co Ltd., Marconi House, Chelmsford*]

The titles of these seven booklets explain their contents; the first is a general illustrated description of the range of equipment, while the others are more detailed descriptions of the items. In particular, the navigational sets, AD 86 and AD 7092, are described and illustrated very fully.

The Installation and Maintenance of Smiths Instruments. [*Smiths Aircraft Instruments Ltd., Cricklewood, London, N.W.2*]

This publication consists of a large quarto folder containing a series of leaflets on the many instruments in the Smiths range. Each leaflet is a miniature manual with an illustrated description, installation instructions and maintenance notes on the instrument concerned. The folder is provided with an index and an amendment list so that an up-to-date record of the contents can be kept. Originally issued with about half of the proposed contents, new leaflets are added as they are completed.

Although Smiths Aircraft Instruments Ltd. hope eventually to be able to issue copies to all licensed aircraft engineers, supplies are at present restricted to firms and applications must be made on behalf of a user and not by individuals.

U.S. Patent Specifications

These details and drawings of patents granted in the United States are taken, by permission of the Department of Commerce, from the 'Official Gazette of the United States Patent Office'. Printed copies of the full specification can be obtained, price 10 cents each, from the Commissioner of Patents, Washington, D.C., U.S.A. They are usually available for inspection at The British Patent Office, Southampton Buildings, Chancery Lane, London, W.C.2.

2,433,830. Endless Track Landing Element and means for Mounting the same on Aircraft. George Herbert Dowty, Cheltenham, England. Application November 25, 1944. Serial No. 565,116. Section 1, Public Law 690, August 8, 1946. Patent expires November 23, 1963. 6 Claims. (Cl. 244—100.)
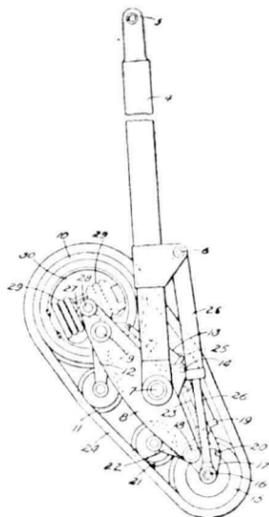
2,433,932. Fuel Combustion. Arthur J. Stosick, Pasadena, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif., a corporation of Delaware. Application March 11, 1944. Serial No. 426,065. 9 Claims. (Cl. 52—5.)
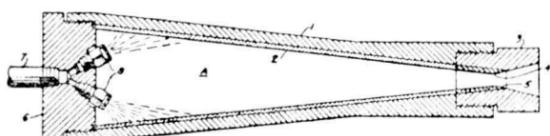
2,433,943. Operation of Jet Propulsion Motors with Nitroparaffin. Fritz Zwicky, Pasadena, Frederick J. Ewing, Altadena, James M. Carter, Highway Highlands, and Arthur J. Stosick, Pasadena, Calif., assignors to Aerojet Engineering Corporation, Azusa, Calif., a corporation of Delaware. Application March 11, 1944. Serial No. 526,064. 12 Claims. (Cl. 60—35.6.)
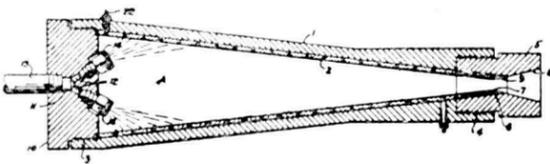
2,434,029. Interferometer Apparatus for Quantitatively Determining Fluid Pressures in Wind Tunnels. William Ewart Williams, Pasadena, Calif. Application April 1, 1944. Serial. Serial No. 529,154. 1 Claim. (Cl. 88—14.)
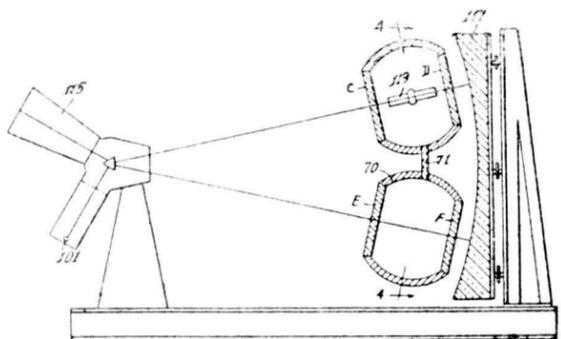
2,434,134. Cooling Means for Internal-Combustion Turbine Wheels of Jet Propulsion Engines. Frank Whittle, Rugby, England, assignor to Power Jets (Research and Development) Limited, London, England. Application November 24, 1942. Serial No. 466,805. In Great Britain December 19, 1939. Section 1, Public Law 690, August 8, 1946. Patent expires December 19, 1959. 8 Claims. (Cl. 60—35.6.)
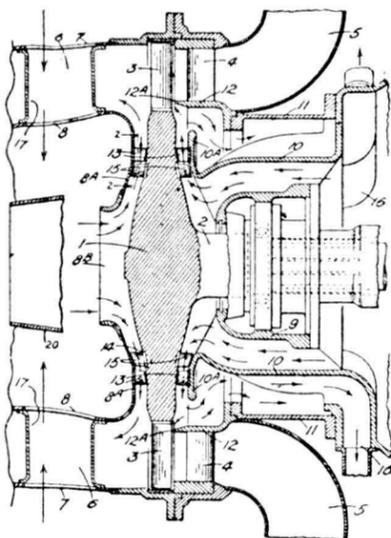
Owing to the difficulties of keeping pace with the patents of aeronautical interest taken out in the United States of America within the limitations of space available we have decided in future to print only the title and other essential details of each patent with the relevant drawing, without the explanatory text. We feel that the latter is as a rule so abbreviated that it contains little further information than can be gained from a study of the drawing. In any case, recourse must be had to the full Specification if complete knowledge of the claims made is to be gained and the drawing gives a sufficient indication of whether this further investigation is desirable

2,434,319. Pusher Installation for Turbine-driven Propellers. Andrew Kalitinsky, Eagleville, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware. Application January 30, 1945. Serial No. 575,338. 2 Claims. (Cl. 253—39.)
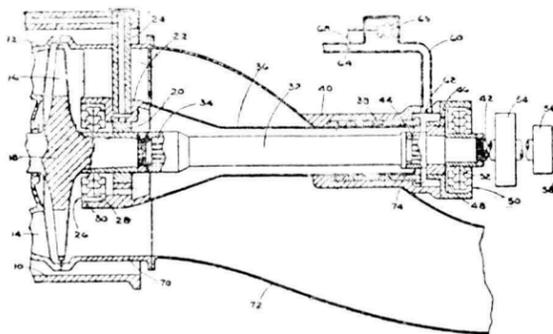
2,434,323. Sliding Compressor Cylinder. Walter A. Ledwith, Manchester, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware. Application July 6, 1945. Serial No. 603,494. 7 Claims. (Cl. 230—56.)
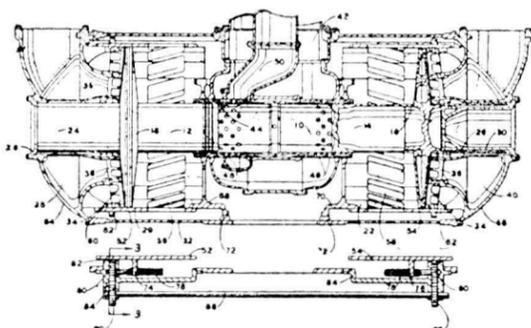
2,434,341. Wing Flap Actuating Mechanism. Emil Anderson, Briarcliff Manor, N.Y., assignor to Electrolux Corporation, Old Greenwich, Conn., a corporation of Delaware. Application September 2, 1943. Serial No. 500,883. 3 Claims. (Cl. 244—42.)
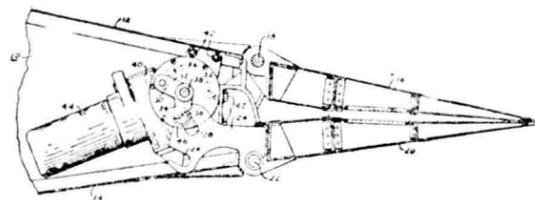
2,434,379. Apparatus and Method of Stretch Pressing Metal Sheets. Frank W. Wiesner and Alexander Coulter, Baltimore, Md., assignors to The Glenn L. Martin Company, Middle River, Md., a corporation of Maryland. Application December 16, 1944. Serial No. 568,454. 3 Claims. (Cl. 153—48.)
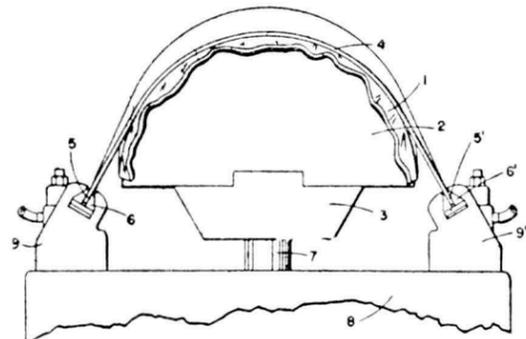
2,434,777. Power Plant comprising a Gas Turbine and an Internal-Combustion Engine Compressor serving as a Gas Generator Thereto. Robert James Welsh, Rugby, England, assignor to the English Electric Company Limited, London, England, a British company. Application December 3, 1943. Serial No. 512,836. In Great Britain September 30, 1942. 1 Claim. (Cl. 60—13.)
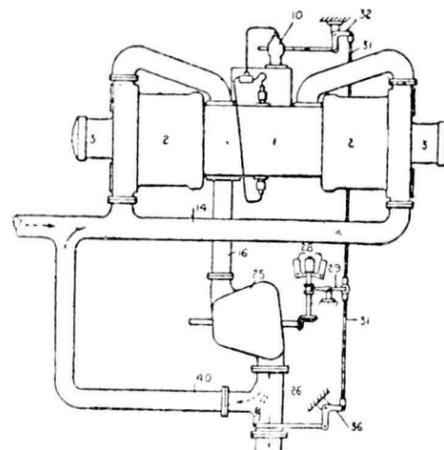
2,434,901. Turbine Cooling. Richard S. Buck, Glastonbury, and Andrew Kalitinsky, Eagleville, Conn., assignors to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware. Application August 23, 1944. Serial No. 550,873. 6 Claims. (Cl. 60—41.)
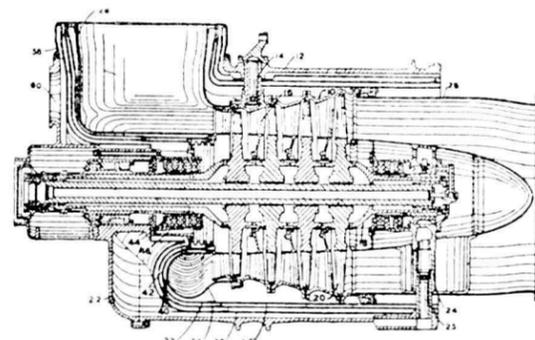
2,435,168. Aeroplane Engine Nacelle. Dalton B. Suggs, Fort Worth, Tex., assignor to Consolidated Vultee Aircraft Corporation, San Diego, Calif., a corporation of Delaware. Application November 20, 1944. Serial No. 564,392. 3 Claims. (Cl. 123—171.)
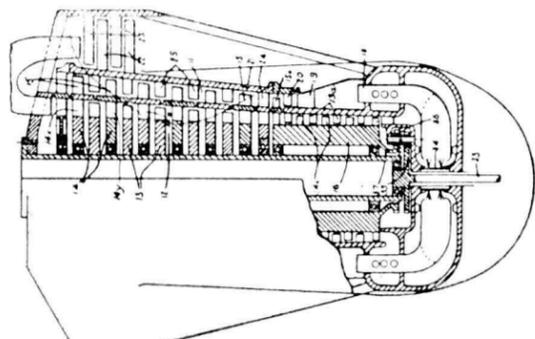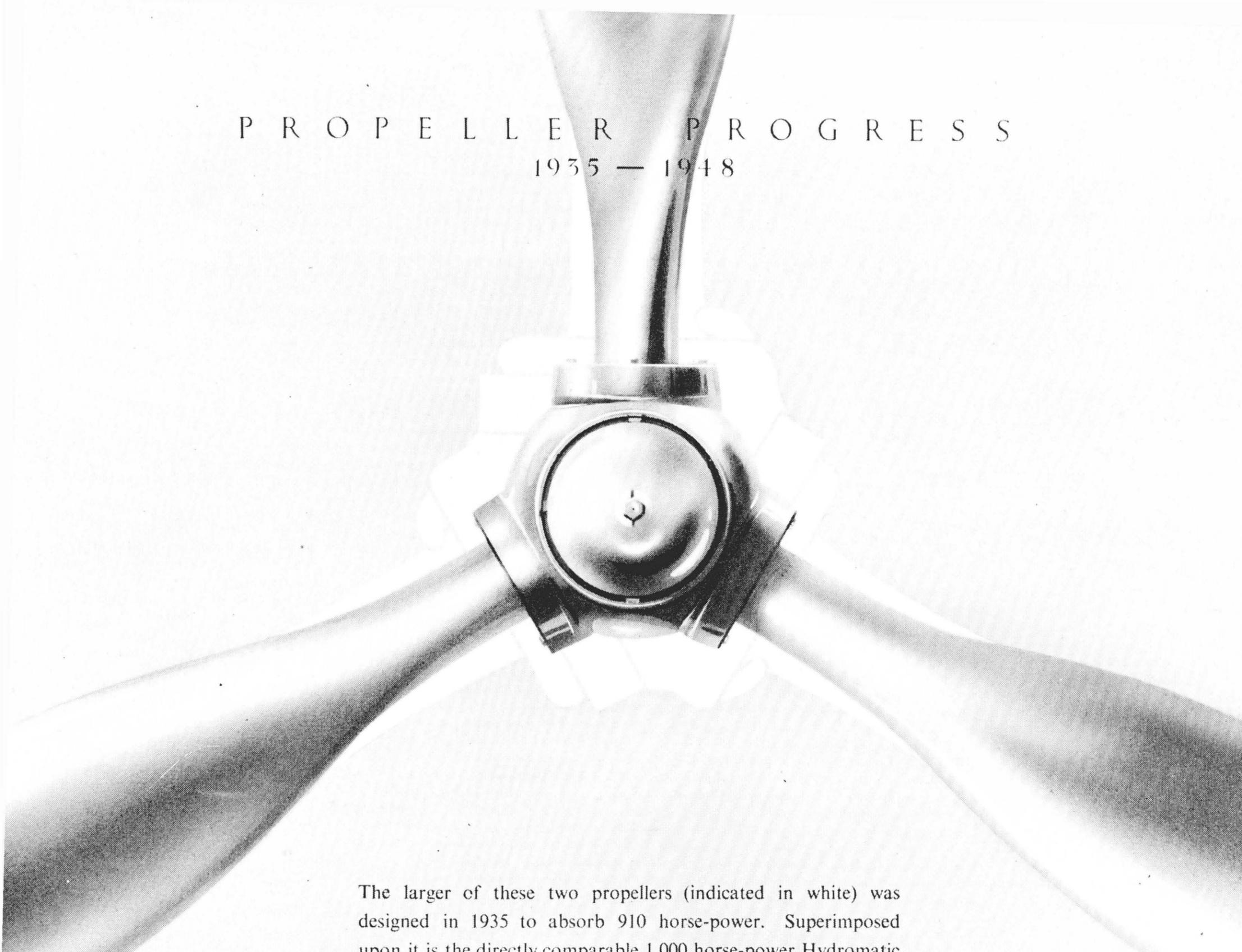
PROPELLER PROGRESS
1935 — 1948

The larger of these two propellers (indicated in white) was designed in 1935 to absorb 910 horse-power. Superimposed upon it is the directly comparable 1,000 horse-power Hydromatic propeller of to-day, suitable for piston or turbine application. In thirteen years the weight has been reduced by 37 per cent and the hub frontal area by 43 per cent, while a two-pitch mechanism of 20 degrees' range has given place to constant-speed, feathering and braking operation with a pitch range of 120 degrees. From current development in materials, in blade form and in refinements of actuation, equally valuable progress may be expected in the next decade

DE HAVILLAND
PROPELLERS

DH
PROPELLERS

"You have sent us just the men we wanted"

WRITES MR. P. H. LOWE
Chief Personnel Manager

" WE FEEL this is an opportune moment to register our sincere thanks for the very excellent service rendered by the Regional Appointments Office during the past year in submitting suitable applicants for staff vacancies of Executive type.

" By your prompt and untiring efforts to pre-select suitable qualified individuals, a great deal of valuable time has been saved, and some very satisfactory appointments concluded. You have sent us just the people we wanted. The writer will be grateful if you will convey thanks and appreciation to all your obliging staff." So writes Mr. Lowe, chief personnel and welfare manager of the Simplex Electric Co. Ltd., Birmingham.

EVERY DAY the volume of such letters grows — reaching the Appointments Offices all over the country. Employers in every category of enterprise (and those in search of *employment*, too) realize that the services of the Appointments Department are unprecedented in their scope and efficiency. There has never before been an executive employment service of this kind — which can find the right man or woman for the job in any part of the country, in a matter of days if need be.

The nation-wide Register of Applicants is available to all 14 Regional Appointments Offices, which are linked by teleprinter, to save unnecessary delays in communication. Your local Appointments Office will find the man you want if he's registered anywhere in the United Kingdom, for vacancies in the executive, managerial and administrative field.

In the three years since VE-day, more than 70,000 executive posts have been successfully filled by the Appointments Department, often at short notice.

For highly qualified technical and scientific personnel — engineers, scientists, architects, etc. — appointments are dealt with centrally, in London, by the specialist staff of the Technical and Scientific Register, York House, Kingsway, W.C.2. Temple Bar 8020.

14 linked Appointments Offices cover the Nation's potential executive manpower

Issued by the Ministry of Labour and National Service, Appointments Department, 1-6 Tavistock Square, London, W.C.1

No failure after 50,000 Pressure Cycles..
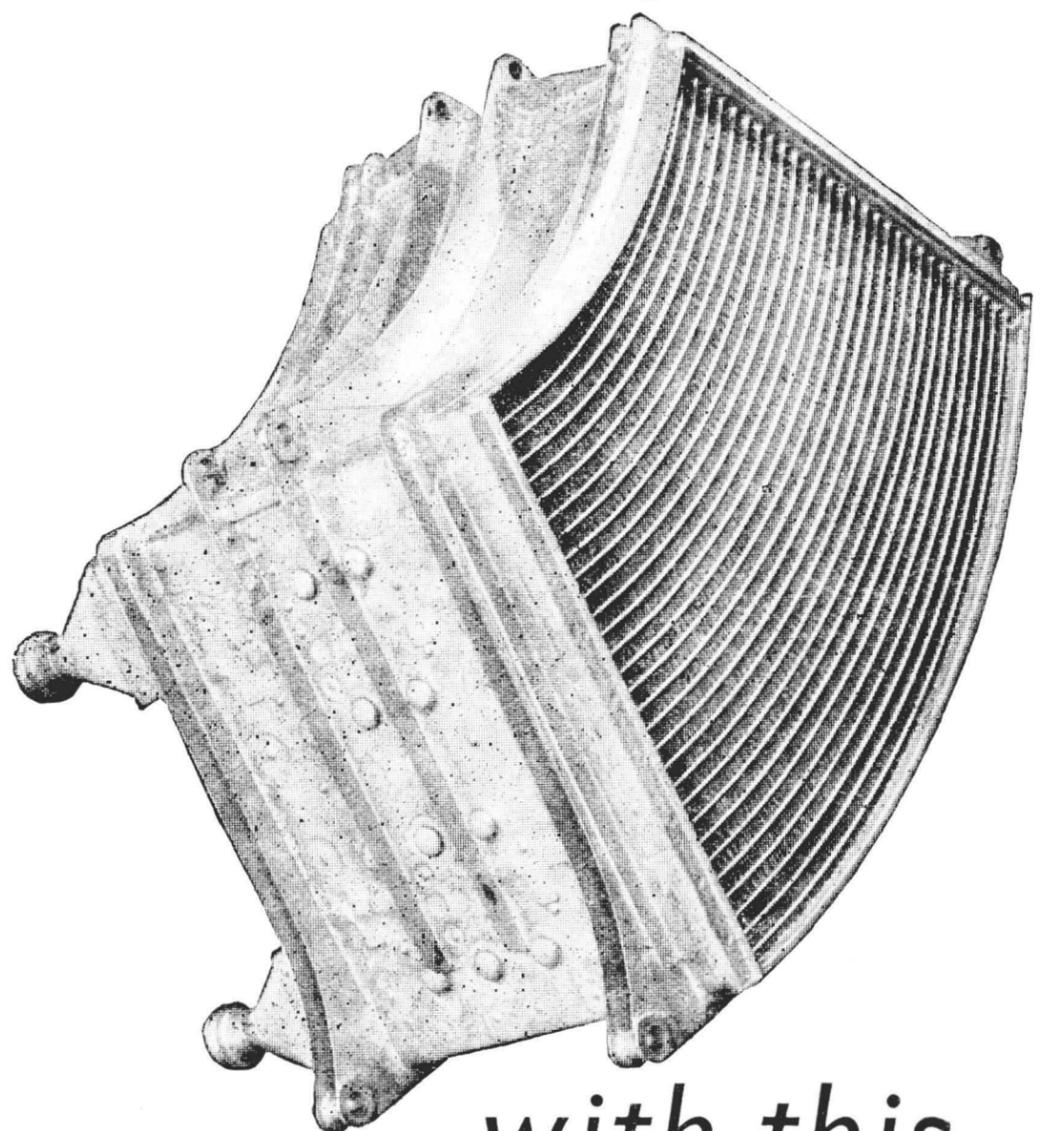
with this MAREX HEAT EXCHANGER

★ Working at pressures of up to 70 lb. per square inch at 150°C. this Merlin Intercooler Radiator gives 16% increased performance. It has silver-brazed, copper water-way tubes throughout.

For any information in connection with heat exchangers please write to:

MARSTON EXCELSIOR LIMITED
(A subsidiary company of Imperial Chemical Industries Ltd.)
DEPT. P.5, PAUL STREET, WOLVERHAMPTON

MAR.30

Synthetic RUBBER SEALING

For the retention of lubricants at high speeds and temperatures we recommend our Synthetic Rubber Oil Seals. In type and size they cover a multitude of applications, and special conditions can always be catered for. Consult us on all your sealing problems concerning oils and other fluids, chemicals and gases, and the protection of foodstuffs.

WESTON OIL SEALS

CHARLES WESTON & CO. LTD., IRWELL BANK WORKS, DOUGLAS GREEN, SALFORD 6.
PHONE: PENDLETON 2857-8-9.
BIRMINGHAM, MID. 6952, LONDON, HOL. 0414

Smee's W55

AGREED THEN GENTLEMEN—WE INSTAL 'GRAVINER'

When the aircraft operator specifies 'Graviner' he does so for the best reasons in the world—because 'Graviner' is the pre-eminent name in airborne fire-protection equipment and because it most effectively safeguards a very valuable asset. As pioneers of aerial fire-fighting techniques and inventors of the systems chosen for all British warplanes and leading airliners in the post-war period, 'Graviner' brings unrivalled experience to every new project in this specialised field.

Fully descriptive literature is available on request to Air Line Managements, Aircraft Manufacturers and Designers.

INSTIL **CONFIDENCE** – *INSTAL* **GRAVINER**

AIRCRAFT FIRE-PROTECTION EQUIPMENT

GRAVINER MANUFACTURING CO., LTD · POYLE MILL WORKS · COLNBROOK · BUCKS · Telephone: COLNBROOK 48/49

"Klingerit" GASKETS—

Conform to Air Ministry Specification D.T.D. 378A
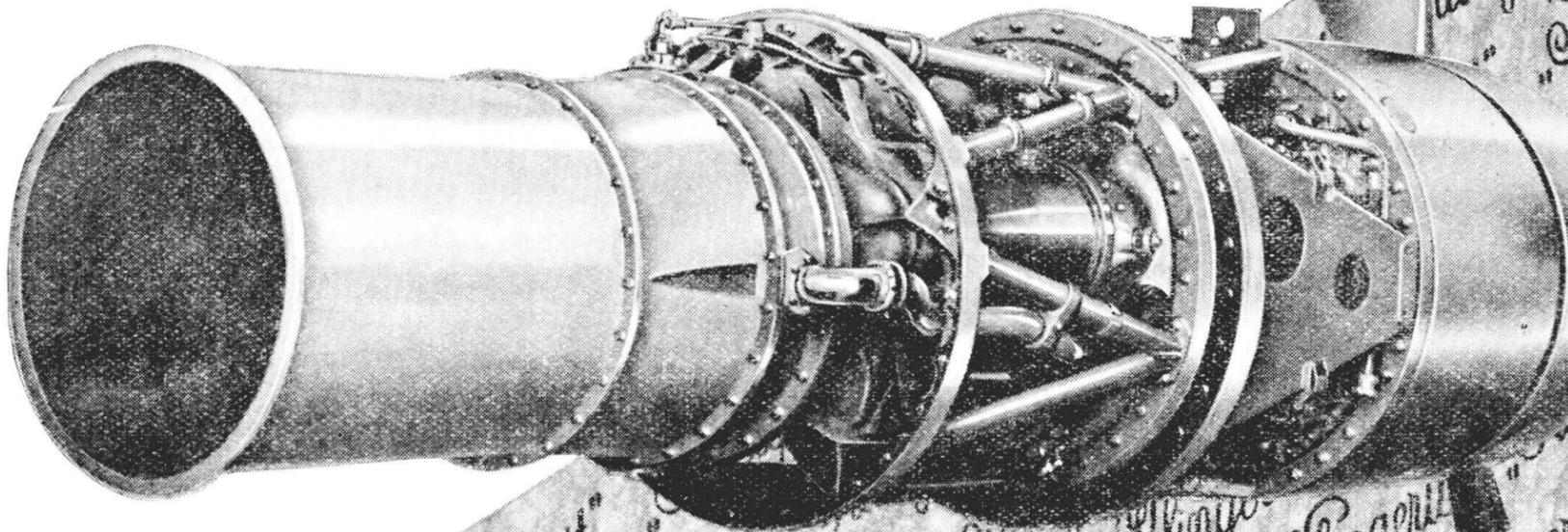
AN ESSENTIAL FITMENT ON THE NAPIER NAIAD GAS TURBINE AERO ENGINE

RICHARD KLINGER LTD · KLINGERIT WORKS · SIDCUP · KENT   *Telephone:* Footscray 3022
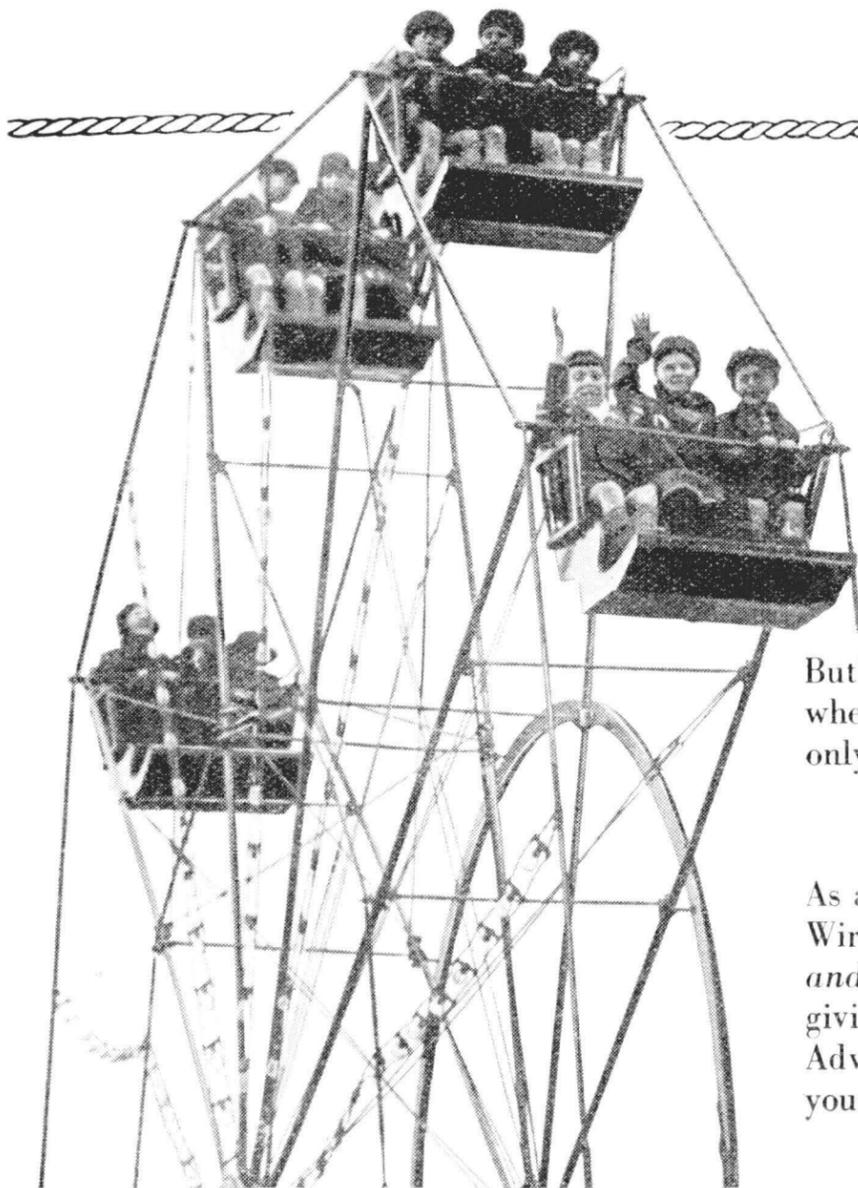
RESEARCH-LIGHT ON *Rope*

The Wheel goes round and round

Butlin's had a problem at Birmingham; the wire rope driving the giant wheel at their famous Amusement Park was averaging a life of ten days only. Our Advisory and Technical branch was called in to investigate...

and the moral comes out here

As a result of their recommendation, one of our Blue Strand Preformed Wire Ropes, spliced endless and pre-stretched, was installed last July— and *is still in use today*. Months of life as against days, and still giving perfect satisfaction; that is typical of the many ways in which our Advisory and Technical branch can both solve Rope problems and save your money.   Can we help you too?

(A typical Giant Wheel)

BRITISH ROPES LIMITED

solve your problems and supply the ropes in WIRE, HEMP OR NYLON

HEAD OFFICE **DONCASTER**   WORKS: CHARLTON, CARDIFF, LIVERPOOL, GATESHEAD-ON-TYNE AND RUTHERGLEN
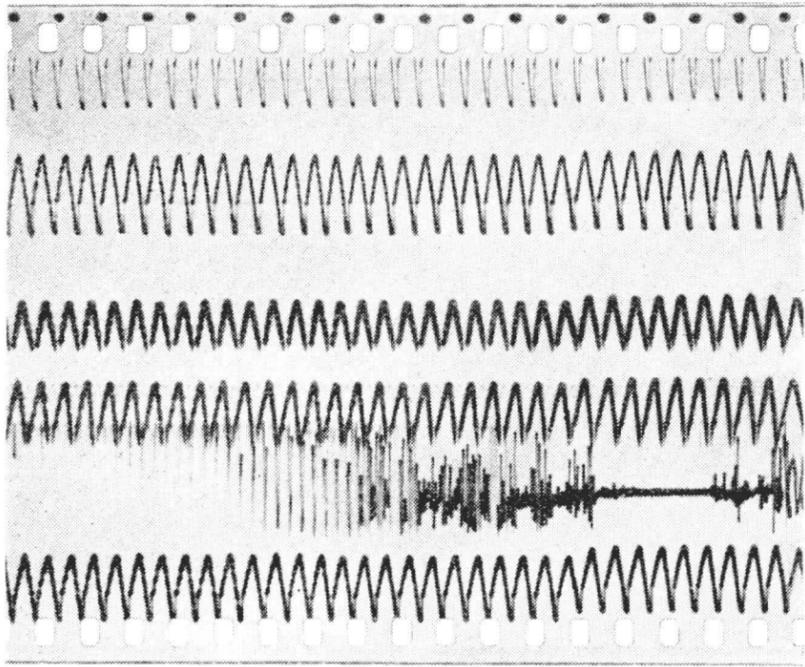
TRANSIENT EVENTS ARRESTED

The first Avimo Oscillograph was a specially built Camera designed to provide records of Cathode Ray Traces to a scale which permitted accurate measurement, side by side on continuous film, so that precise relationships could be determined.

Success in this specialized field led to demands for Cameras to record other kinds of transient events, so that within the Avimo range listed below there are, today, Instruments to meet nearly any requirement of the Research or Laboratory worker.

The wide experience gained in the course of this development is at your disposal and Avimo engineers will be glad to submit suggestions if you will state your problem.

GROUP	FUNCTION
A. Continuous Recording . .	For recording oscillograph traces on 35 mm. or 70 mm. film.
B. Single Shot	For use where phenomena are constant.
C. Combined Continuous and Single shot	Provides the functions of Groups A or B as desired.
D. Drum	For high speed drum recording of high-frequency phenomena on 35 mm. film.
E. Multi-Channel Recorders .	With built-in Cathode Ray tubes for continuous recording of up to 15 traces.
F. Instrumentation Cine . .	Provides a pictorial record of several variants over a period of time.

There is no reasonable limit to the film speeds which may be provided and recorders of Groups A, B, C and D may be used in conjunction with any standard oscillograph.

AVIMO

AVIMO LTD · TAUNTON (SOM) · ENGLAND

[ATTENTION is called to The Control of Engagement Order, 1947. The following vacancies are restricted to persons or employments excepted from the provisions of the Order. Among the latter are: employment in a managerial, professional, administrative or executive capacity.]

CROWN AGENTS FOR THE COLONIES

Applications from qualified candidates are invited for the following post:
SENIOR ENGINEER (AVIATION) required by the Tanganyika Government for 2/3 years in first instance. Salary according to qualifications and experience in scale £600 rising to £720 a year. Cost of living bonus £108 on salary of £600. Outfit allowance up to £60. Free passages and quarters. Provident Fund. Candidates, under 45, must hold a 'B' licence covering Anson I aircraft. Apply at once by letter, stating age, whether married or single, and full particulars of qualifications and experience and mentioning this paper to the Crown Agents for the Colonies, 4 Millbank, London, S.W.1, quoting M/N/18514/3D on both letter and envelope.

Classified Advertisements

Minimum (12 words or less): 4s. 0d.
Each additional word: 4d.

AIR SURVEY COMPANY OF INDIA LTD. (British Controlled) operating Dominies, require Chief Ground Engineer for employment in India. 'B' and 'D' Licences required. Leave three months every three years. Passage paid both ways. Apply, stating age, etc., to Box No. 405, AIRCRAFT ENGINEERING, 12 Bloomsbury Square, London, W.C.1.

PACKING AND SHIPPING

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

EXPORTERS TO BRAZIL AND PORTUGAL!
Portuguese Translations by Aeronautical Technician. Now translating for leading aero-engine manufacturers. Seeks further commissions. Apply M.19, Woodcote Village, Purley, Surrey. Phone: Uplands 7494.

PATENTS

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

It is desired to secure the full commercial development in the United Kingdom of BRITISH PATENTS NOS. 523,301, 523,282, 523,283, 523,300 and 524,368 which relate to 'SHOCK ABSORBERS' and 'WHEEL MOUNTINGS FOR AIRCRAFT' either by way of the grant of licences or otherwise on terms acceptable to the Patentee. Interested parties desiring copies of the patent specifications and further particulars, should apply to STEVENS, LANGNER, PARRY & ROLLINSON, 5 to 9 Quality Court, Chancery Lane, London, W.C.2.
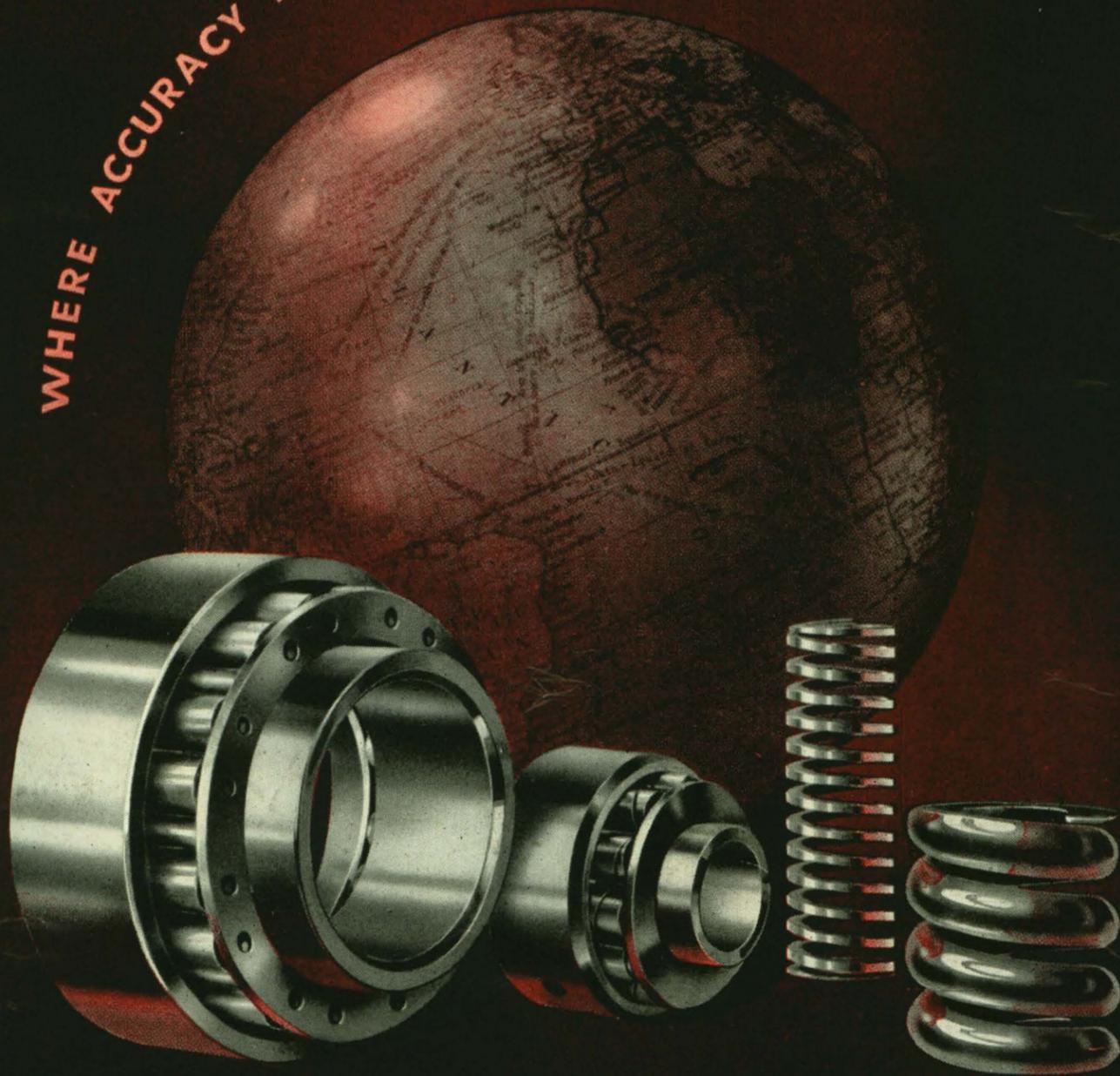
360 DEGREES SAFE!

Take a SEEGER CIRCLIP. Contract or expand it (as the case may be) to place it in position. Let it snap home. From beginning to end it retains its truly circular shape. When seated snugly in its groove, its tapered form ensures uniform pressure on the periphery, thereby providing a perfect circle of security.

SEEGER CIRCLIPS

MANUFACTURED BY
AUTOMOTIVE ENGINEERING CO · LTD · THE GREEN · TWICKENHAM · MIDDX ·
Telephone : Popesgrove 2206 (P.B.X.)   *Telegrams :* Motif, Twickenham
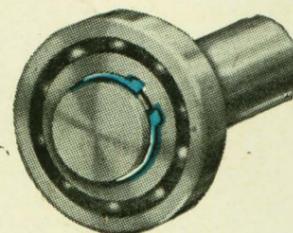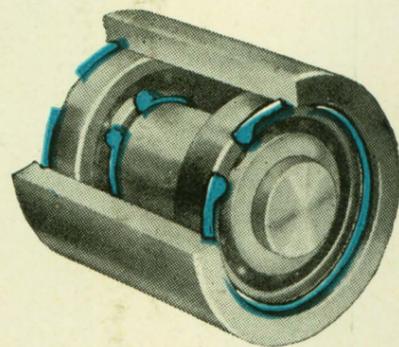
Smee's. AE 51

360 DEGREES SAFE!

Take a SEEGER CIRCLIP. Contract or expand it (as the case may be) to place it in position. Let it snap home. From beginning to end it retains its truly circular shape. When seated snugly in its groove, its tapered form ensures uniform pressure on the periphery, thereby providing a perfect circle of security.

SEEGER CIRCLIPS

MANUFACTURED BY

AUTOMOTIVE ENGINEERING CO · LTD · THE GREEN · TWICKENHAM · MIDDX ·

Telephone : Popesgrove 2206 (P.B.X.)   Telegrams : Motif, Twickenham

Smee's.   AE 51