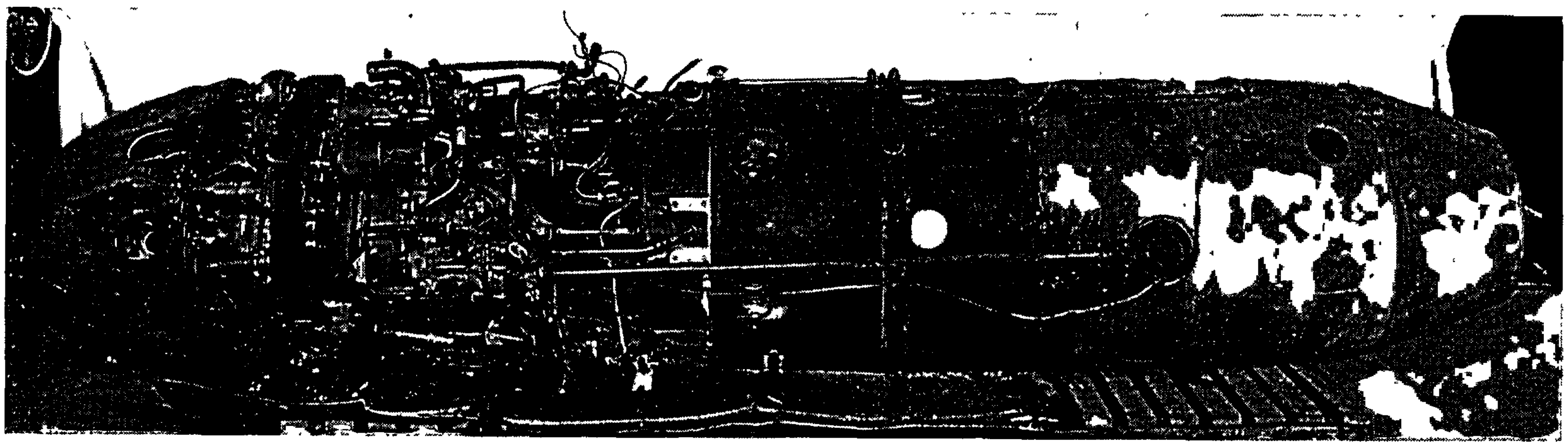


FIG. 2.—*View looking down on engine. Length excluding bullet tip* 152 *in.; maximum nacelle diameter,* 34 *in.; diameter of skin over combustion chambers,* 30 *in.; dry weight of uncowled engine,* 1,690 *lb.*

The Junkers Jumo 004 Jet Engine.*

INTRODUCTION

NOW that the Air Ministry has released information on German power plants it is possible to give a detailed description and critical examination of the Jumo 004 jet engine. Most of the work of examination, including the repair and testing of an engine, was done some months preceding the final collapse of Germany. In this article it is hoped to supplement the information already given in the technical press.

GENERAL DESCRIPTION

A photograph of a complete unit is shown in Fig. 2 and the general arrangement is given in Figs. 1 and 3. The sectional arrangement of Fig. 1 is made to show as many of the constructional details as possible and should not be considered as a true plane section of the engine. A fairly detailed description, starting from the intake and following through to the exhaust, will now be given.

Nose Cowling and Intake Casting

In the outer nose cowling there is an annular petrol tank, as shown in Fig. 4, which is divided into two sections. The small upper tank (capacity about $\frac{3}{4}$ gal.) feeds petrol to the two-stroke starter motor and the larger tank (capacity about $3\frac{3}{4}$ gals.) supplies petrol, on starting, to the main fuel jets in the combustion chambers.

The inner cowling houses the two-stroke starter motor which is attached to the inner portion of the compressor intake casting. It is gravity fed from the small tank in the outer cowling. The form of the inner and outer cowling is such that the passage area remains roughly constant up to the inlet guides, apart from the restriction caused by the four faired struts in the intake casting. The area of the entry passage is approximately 220 sq. in.

Between the petrol tank and the intake casting is the oil tank with integral oil cooler. This tank, which has a capacity of about 3 gals., is split into two parts by a dividing wall running close to the inner surface and the arrangement is such that the inner annulus acts as an oil cooler. Warm oil is fed into the top of the inner annulus and flows round the intake to the bottom of the annulus, and then into the tank proper.

The main compressor intake casting can be seen in Fig. 5. The inner portion of the entry casting is attached to the outer part through four faired struts and houses the front compressor bearing and the bevel gears. The general arrangement of auxiliary drives can be seen from the G.A. (Fig. 1). The drive from the compressor is taken to the bevel gears and starter dog through a small spindle with a cup-shaped splined end which fits over the splines on the end of the compressor stub shaft. Each bevel is supported by roller and ball races and the driving shafts fit into the internally-splined stub shafts of the bevels. These shafts transmit the drives to the main gear box and the oil pumps, the driving shaft for the main gear box passing through the upper faired strut and that to the oil pumps through the lower strut. No drives are taken from the side struts, although these could easily be arranged if required.

The front compressor bearing is made up of three ball thrust races mounted in steel liners and carried in a hemispherical light alloy housing. The pressure of a number of springs between the cover plate and this housing keep it in contact with the female portion which is part of the intake casting. Rotation of the inner housing relative to the outer housing is prevented by a stud attached to the end cover. In the bearing proper, the outer races of each bearing are mounted in separate sleeves, with the sleeves fitting one inside the other while the inner races are mounted in another sleeve which fits on the compressor shaft. With this arrangement, it is possible to pre-load the bearings on assembly to ensure that the thrust is evenly divided between the three and, on dismantling the engine, the compressor rotor can be withdrawn from the inner sleeve, leaving the bearing assembly intact.

The bearing assembly is shown in Fig. 6 and carries an end thrust of about 5,000 lb. at max. engine r.p.m. at sea level. The three bearings are identical; 65 mm. i/d, 120 mm. o/d and 23 mm. wide. They are of the "Duplex" type (double angular contact arrangement in a single row bearing) with split outer races and a one-piece cage. The cages (bronze or brass on some engines, aluminium alloy on others) are located in the outer races, and have cylindrical pockets. Four equi-spaced radial slots in the adjacent faces of the split outer races are provided for lubrication purposes. Outer race location of the cage is a departure from British practice. One probable advantage is that if initially out of balance, subsequent wear will tend to produce a balanced cage. However, differential thermal expansion, between cage and race, necessitates a substantial clearance between the cage and outer race.

Additional details are given below:—

Number and size of balls	15 0·6248 in. dia.
Cage clearance on outer race	0·0135in. to 0·0175in. on diameter
Clearance of balls in cage pockets	0·014 in. to 0·015 in. on diameter
Diametral bearing clearance	0·0015 in.
Axial bearing clearance	0·008 in.
Outer race in housing	0·0015 in. slack
Inner race on sleeve	0 to 0·0002 in. slack

All surfaces of the outer and inner sleeves have a polished black surface layer, thought to be an oxide layer produced by a treatment such as Bruno fixing. Its purpose is probably to pre-

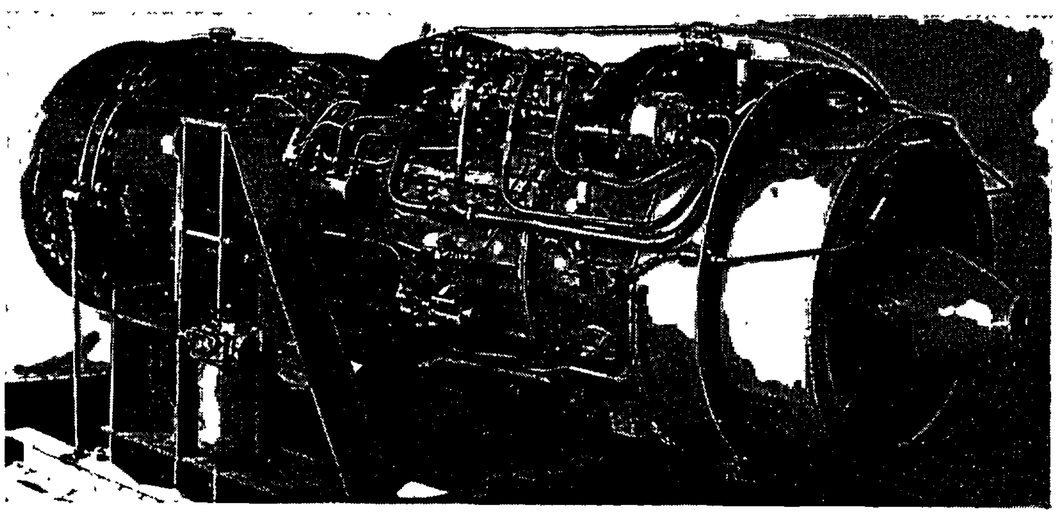


FIG. 4.—*Engine mounted on test frame with nose cowling and exhaust system removed*

* By the Research Department, Power Jets (R and D) Ltd., Pyestock.

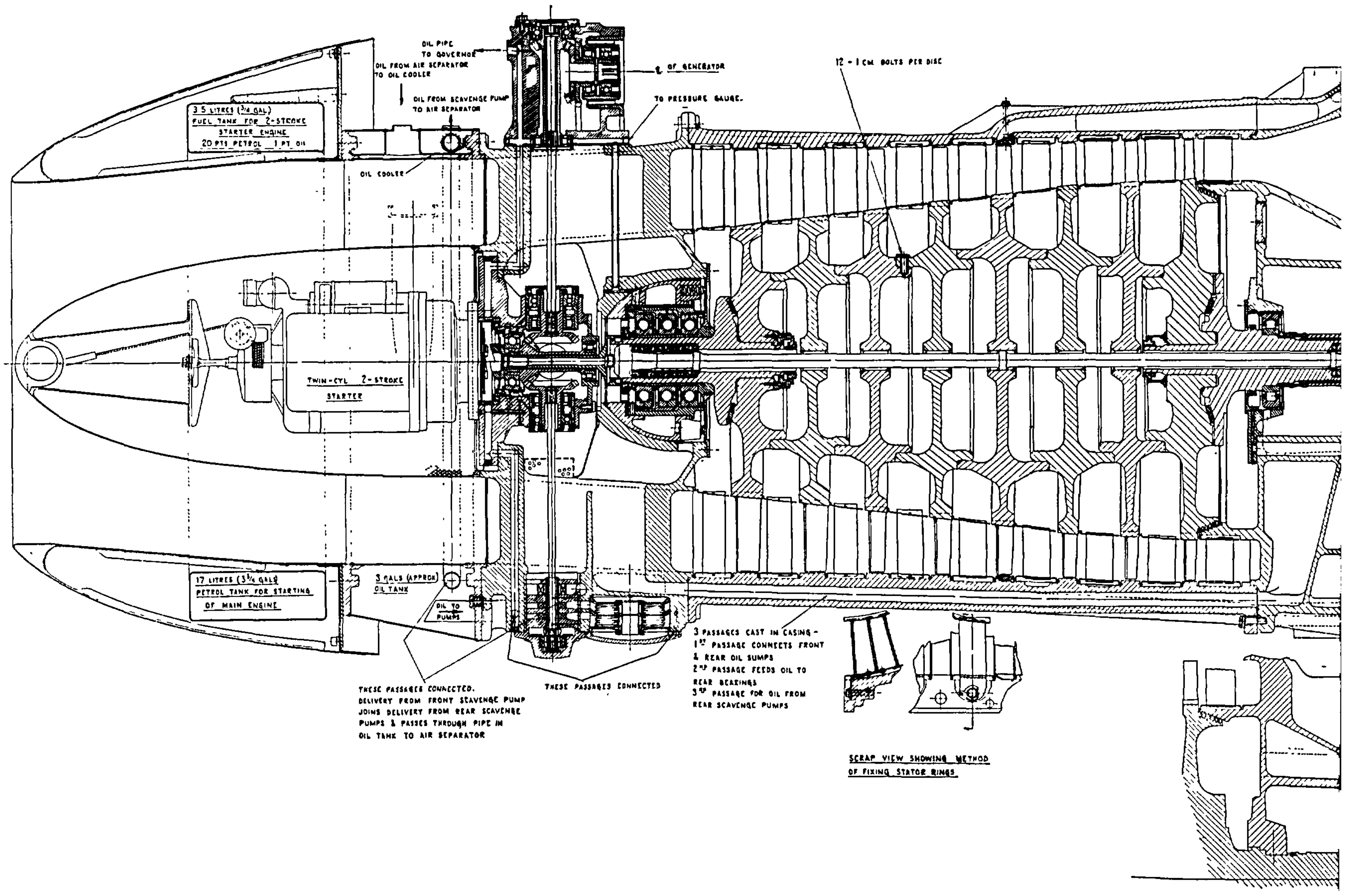


FIG. 1 (*abo*

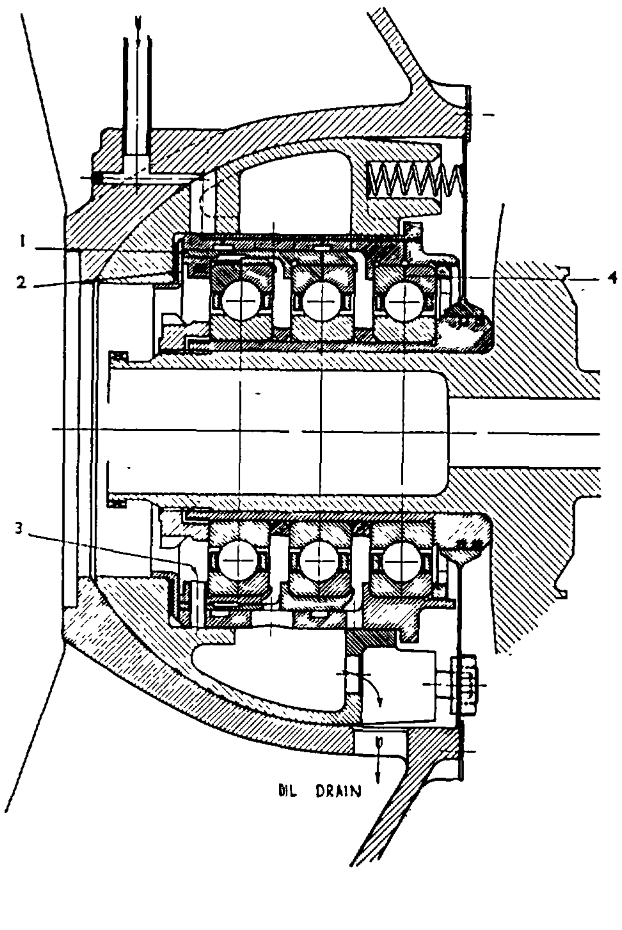
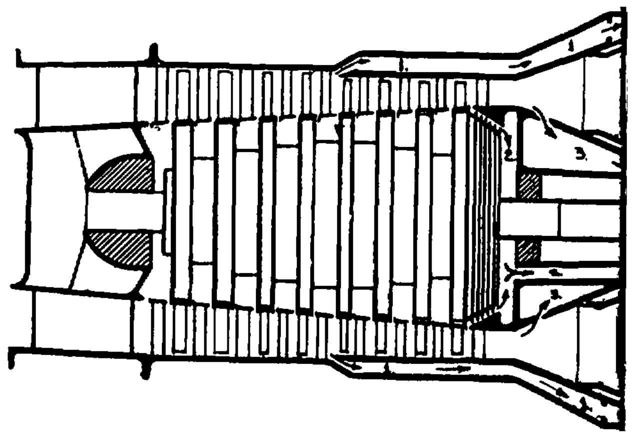
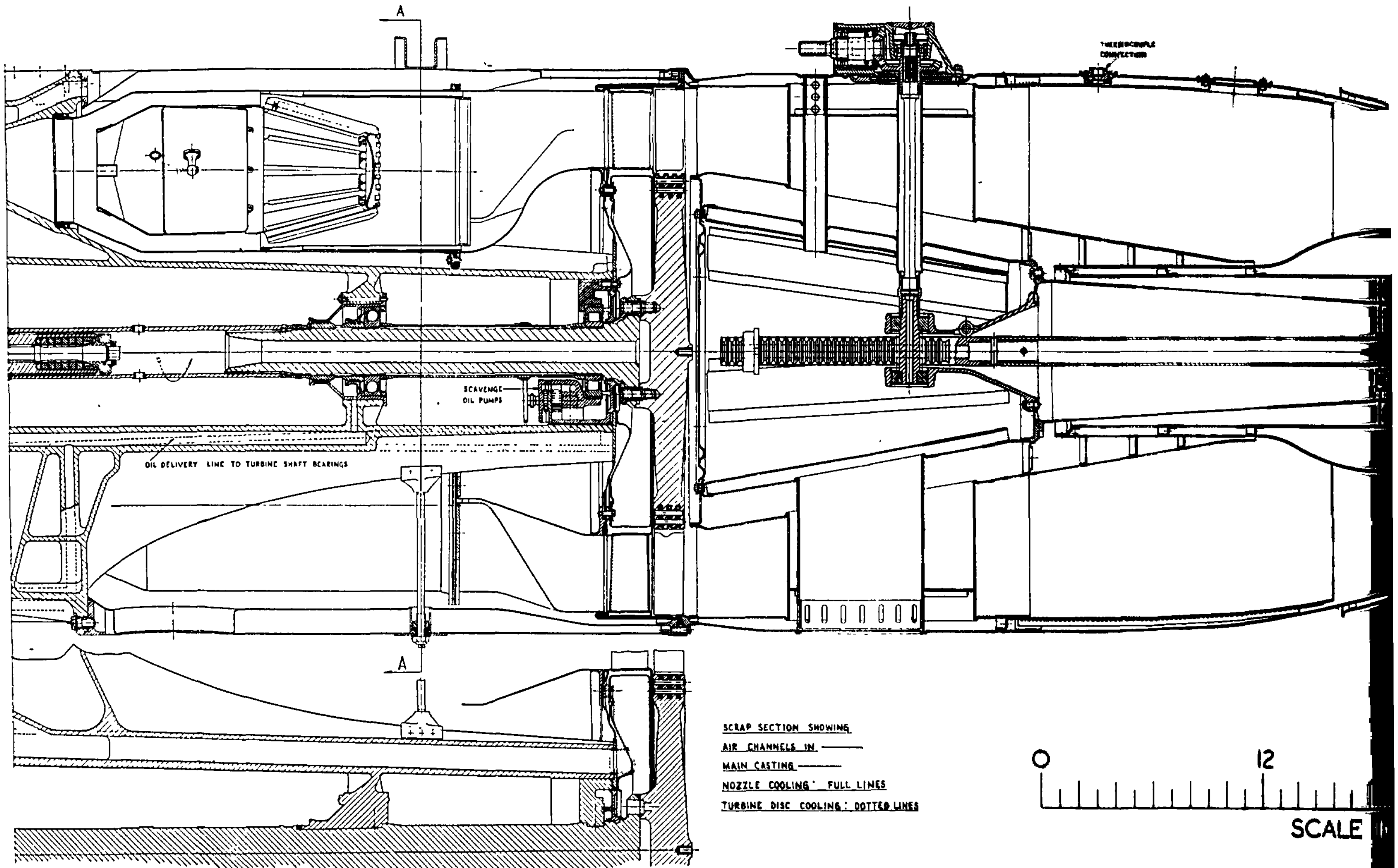


FIG. 6 (*left*)—*The compressor thrust bearing*

1. *End faces of sleeves ground flush*
2. *Face of inset ridged*
3. *Three taper pins 5·5 mm. dia.*
4. *Mating faces of outer races relieved at four positions*

FIG. 13 (





(*above*)—*General arrangement of Jumo 004 engine*

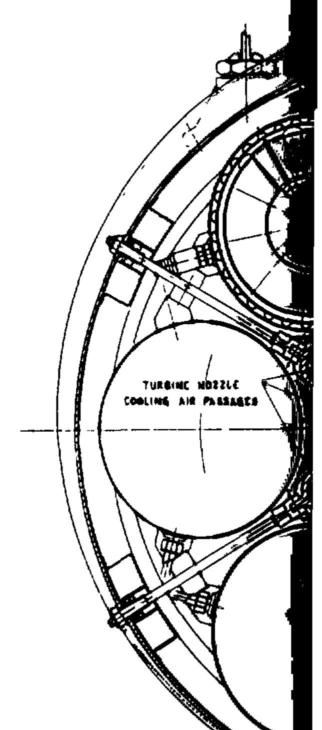
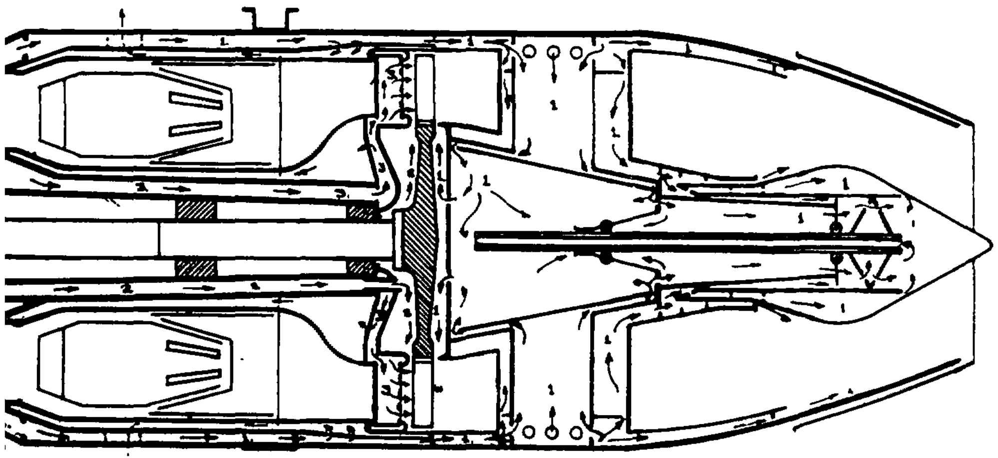


FIG. 3 (*right*)—*Section A-A through the main casting and the combustion chamber*

13 (*below*)—*Diagram of the cooling air system*



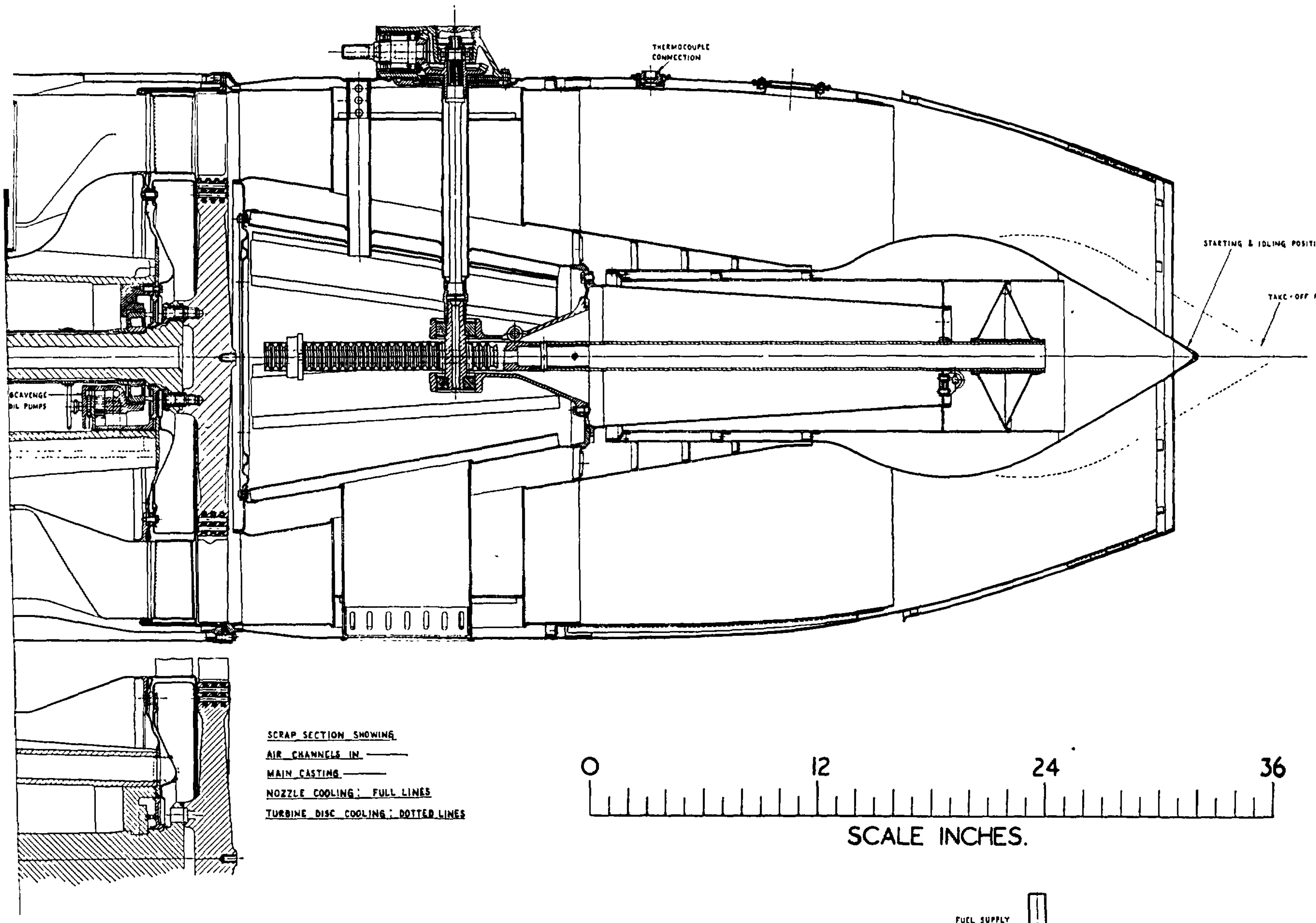
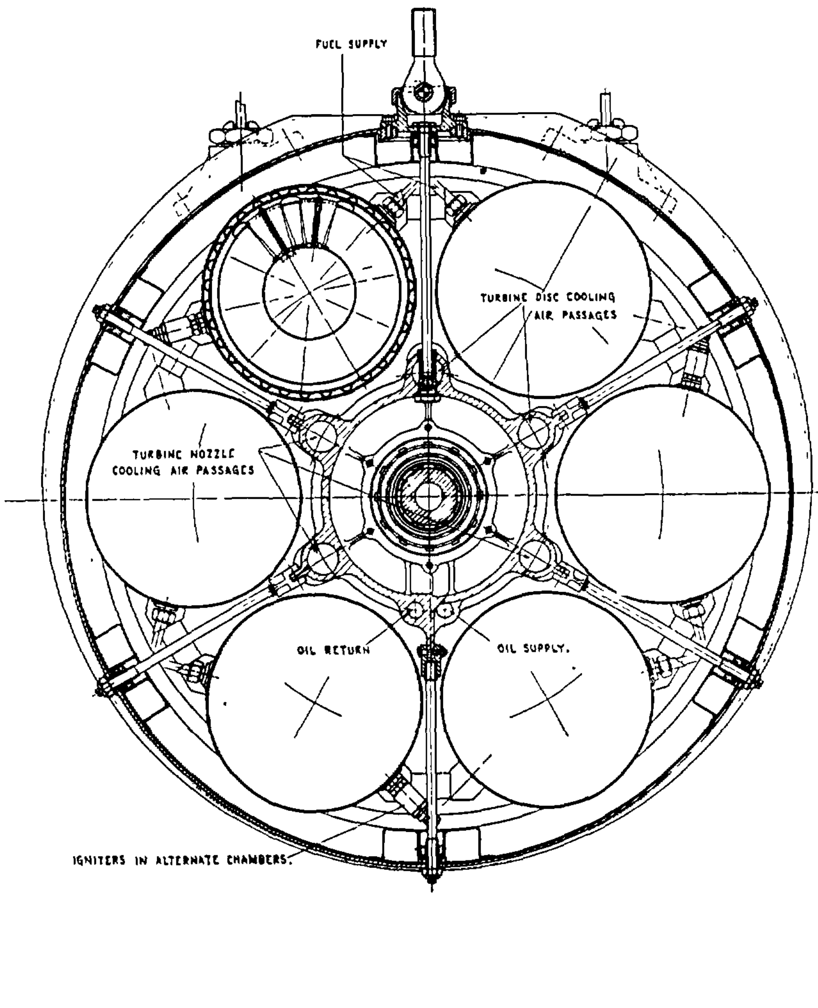
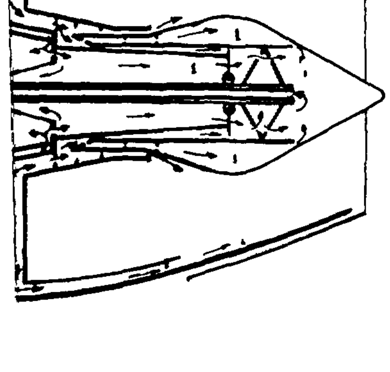


FIG. 3 (*right*)—*Section A-A through the main casting and the combustion chamber*





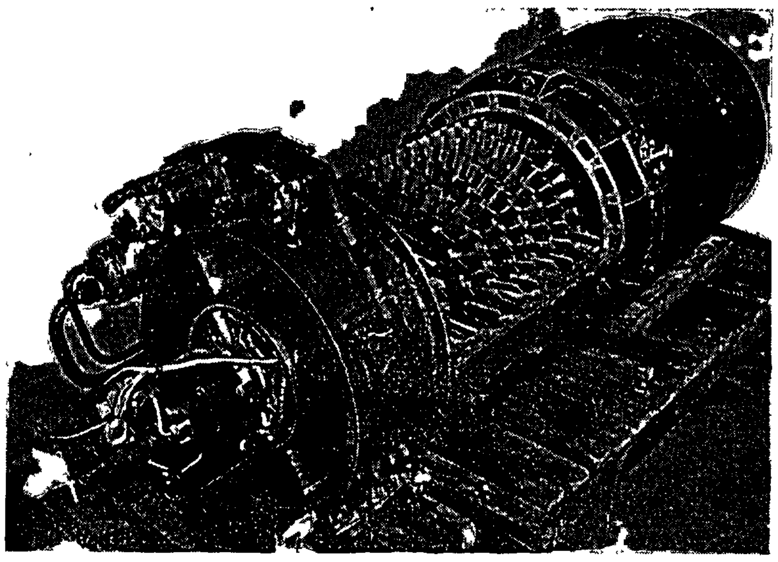


FIG. 5 (left).—*Engine with nose cowling, petrol tank and oil tank, upper portion of compressor casing, and exhaust system removed*

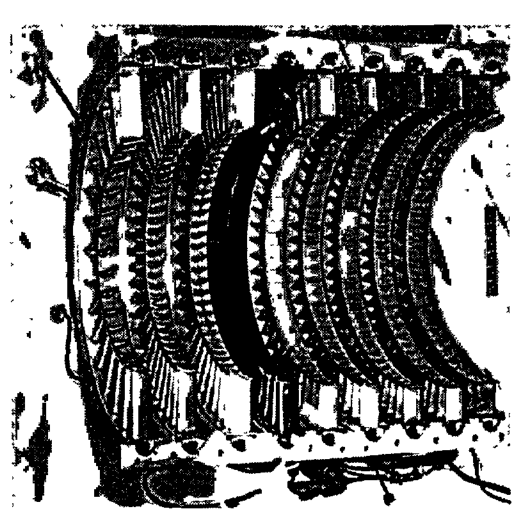


FIG. 7*a* (right).—*Upper half of stator casing showing bleed off at fourth stage*

vent fretting (of which there were no signs on the bearing examined) and to reduce friction between the outer sleeves.

Compressor and Central Casting

Bolted to the intake casting is the compressor stator casing for the eight stage disk compressor. This is an aluminium casting made in two halves and a picture of the upper half with the stator rings in position is shown in Fig. 7*a*. The internal diameter over the first blade row is 21·5 in. and over the last row 22·6 in.

At the bottom of the lower half of the stator casing are three passages about 0·7 in. diameter running the whole length of the casting. One is an oil feed to the turbine bearings and rear compressor bearing; one an oil return from the scavenge pump mounted in the rear turbine bearing housing; and the third connects the oil sump in the main casting with the oil sump in the intake casting.

The stator rings are also built in two halves and attached to the compressor casing as shown on the G.A. and in Fig. 7*a*. The inlet guide vanes and the first two rows of stator blades are of light alloy with an aerofoil profile. For attachment, the ends of the blades are pushed through slots in the shroud ring and brazed into place. Apart from the third row, the subsequent rows of stator blades are made from bent steel sheet, with a zinc coating for protection against corrosion. They are attached by three tabs at each end which pass through slots in the shroud rings and are then bent over at right angles and spot welded. For the third stator row, shown black in Fig. 7*a*, the type of blade and method of fixation appears to vary. On some engines this row has been similar in construction to the first and second stator rings, although the blades were of bent light alloy sheet and not of aerofoil section. On the latest engines received, the blades were of steel, the ends of the blades being turned over to form flanges which were spot welded to the shroud rings. It is now known that the Germans had some failures of this stator ring, due to vibration, when light alloy blading was used.

Inserted in the stator casing over the fifth row of rotor blades is a ring providing a slot, pointing upstream, through which the outer boundary layer is bled off to cool the exhaust system. This can be seen in the G.A. and in Fig. 7*a*. The width of the slot is 0·08 in., that is about 3 per cent of the blade height.

The compressor rotor consists of eight light alloy disks fastened together by spigots and screws about half way up each disk and pulled together by a central tie rod. The disks increase in diameter from the low pressure to the high pressure end of the compressor. Attached to each end disk is a steel shaft to carry the bearings. Integral with each shaft is a disk or flange carrying a steel washer; the shaft passes through the end rotor disk and is pulled up by a nut so that the face of the washer bears up against the face of the disk as shown in the G.A. The washer face bearing against the stub shaft flange is rounded to help alignment. The flange on the rear stub shaft is slotted to receive six projections on the end disk: this dog and claw arrangement transmits the torque from the turbine to the compressor and disk. From disk to disk the torque is transmitted via the studs fastening the disks together.

From measurements made on the extension of the tie rod, the force pulling the whole assembly together is estimated at 8 tons, giving a stress in the tie rod of about 20 tons/sq. in. The length of the tie bolt between the end nuts is 38·75 in. and the diameter 0·705 in. At each end there are a number of steel rings which act as a heavy spring. The spring rate of the bank of washers is rather doubtful but is of the order of 200 tons/in. These were probably fitted to permit of a reasonable turn on the nut when tightening.

On the periphery of the disks the blade roots are dovetailed into staggered grooves and fixed into position by a grub screw on each root.

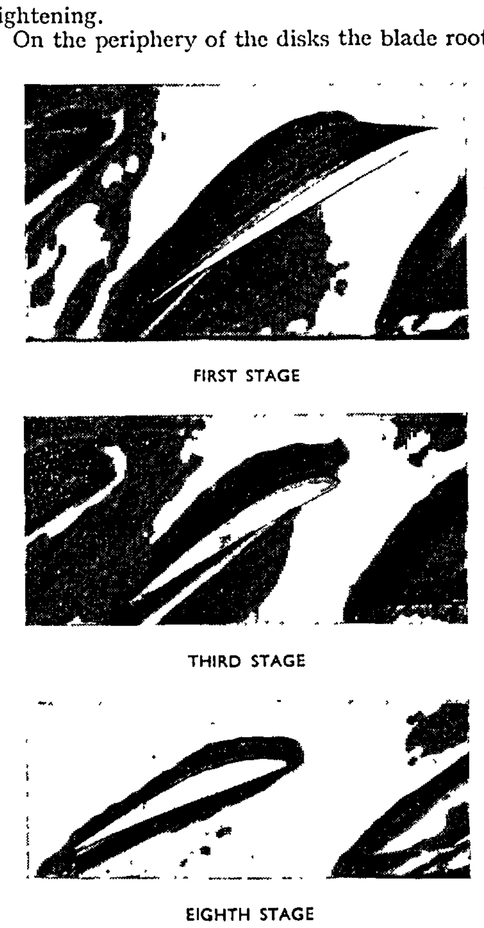


FIG. 7*b*.—*Compressor rotor blade profile*

Some details of the stator and rotor blading are given in Table I. The tip stagger of the rotor blades remains fairly constant over the first six stages, but is increased in the last two stages. The blade chord decreases in steps through the compressor, the width of the disk heads decreasing accordingly. The rotor blade profiles can be roughly divided into three groups, the first two stages, the third, and the remaining stages. The types of tip profile are illustrated in Fig. 7*b*.

The aerodynamic design of the compressor is such that all the stage pressure rise occurs across the rotor blades and, apart from the inlet guide vanes and last row of stator blades which act as straighteners, the stators are arranged as impulse blading, that is they are set at approximately zero stagger angle and just act as guides to redirect the air into the next row of rotor blades. This design is not the best for efficiency but permits of a simple construction for the stator blades and does not call for fine axial clearances between the stator shroudings and the disk rims. The axial clearances between the stator shroud rings and the disks lie between 0·1 and 0·15 in., while the axial distances at the root between the edges of the rotor and stator blades are from 0·5 to 0·6 in.

As expected, the performance is not particularly good and from engine test measurements the efficiency appears to be between 75 and 80 per cent. The pressure ratio at max. r.p.m. on the test bed is about 3·1 and the mass flow about 43 lb./sec.

The design is such that the axial velocity of the air is about 420 ft./sec. at entry to the compressor and 260 ft./sec., leaving the compressor. The low leaving velocity does away with the necessity of having a diffuzing passage between the compressor and combustion chambers.

The high-pressure end of the compressor stator casing is bolted to an aluminium casting —shown in Fig. 8 (*a*)—which can be considered as the backbone of the engine. It carries the rear compressor bearing, the two turbine bearings, the turbine nozzles and the combustion chamber assembly. Also, the three pick up points whereby the engine is mounted to the aircraft are attached to this casting. As shown in Fig. 8 (*b*) two come on to the outer part of the casting between the compressor and combustion chambers, and the third is fixed to a steel rod bolted to the casting roughly half way between the two turbine bearings.

The air passage in the forward end of the casting may be considered as the diffuzer, except that in this engine there is no change in passage area between the compressor exit and the entry to the combustion chambers, but only a change in passage shape from an annulus, to the six circular entries of the combustion chambers.

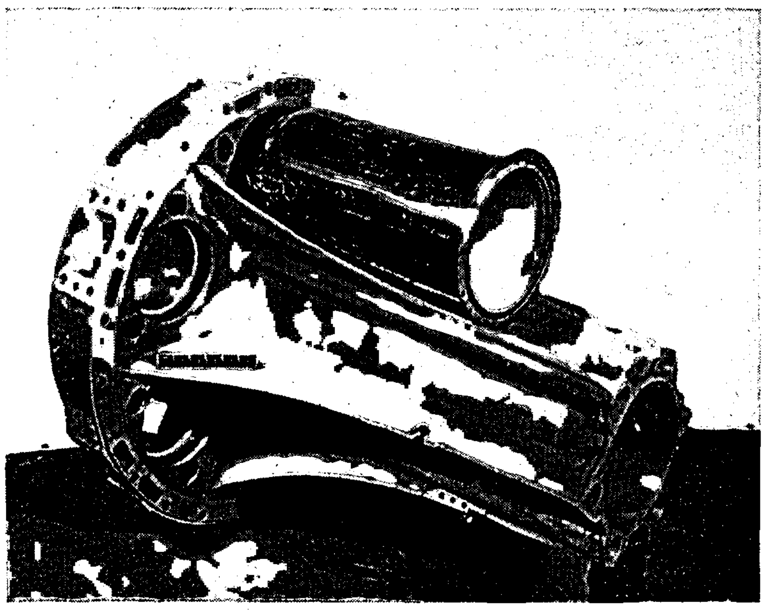


FIG. 8a.—*Central casting*

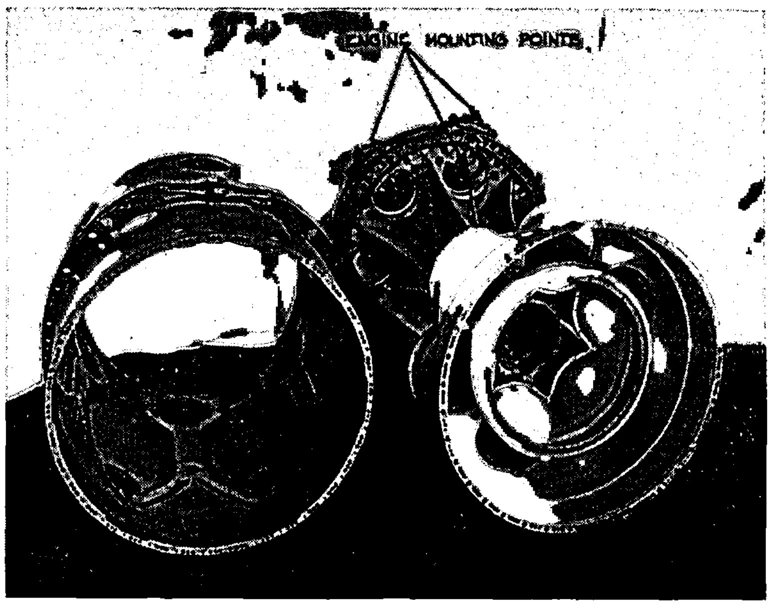


FIG. 8b.—*Central casting, turbine inlet ducting and outer casing*

Combustion Chamber and Turbine Nozzle

From the compressor, the air is delivered at a velocity of about 250 ft./sec. (at full r.p.m.) to six circular straight-through-flow combustion chambers disposed round the central casting. Fig. 9 shows a photograph of the various items making up a combustion chamber.

Briefly, a combustion chamber consists of a mild steel outer air casing (approximately 19 s.w.g.), of overall length 20·6 in. and max. diameter 8.60 in. Inside this, at the discharge end, is fitted an 11 in. long aluminized mild steel liner (metal thickness approx. 20 s.w.g. with coating thickness 0·2 mm.) spaced from the air casing by a corrugated sheet so that cooling air can pass between the liner and the air casing. Supported from the air casing is the flame tube which can be considered to be made up of two parts, namely the cylindrical entry section of 22 gauge mild steel sheet coated with a black enamel, and the aluminized mild steel stub pipe assembly carrying a dished circular baffle plate 4 in. in diameter. The stub pipe assembly consists of ten chutes welded to a 7·1 in. diameter ring at the forward end, and to the baffle plate at the rear end. To help force air down the stub pipes, small semi-circular baffles are riveted to the forward ring which is, in turn, riveted to the enamelled entry section. The cans are fitted with interconnectors and one sparking plug in every other can. The weight of one complete can is 19 lb.

Air for the primary combustion of the fuel passes through a six-vane swirler and fuel is injected upstream into the swirling primary air from a fixed component spray nozzle. Mixing with secondary air is brought about by the baffle and by the airstream through the stub pipes. The hot gases are forced out between the stub pipes into the cold air stream flowing over the stub pipes.

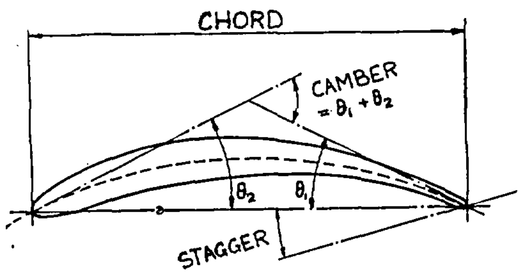
From atmospheric rig tests the combustion efficiency under full speed ground level conditions is estimated to be in the 90 to 92 per cent region and the pressure loss 2·6 lb./sq. in. This pressure loss is about 5·9 per cent of the compressor delivery pressure.

The standard fuel used is a grade known as J2 and it is found to be a predominately naphthenic fuel with a distillation range 115–298 deg. C. With the fixed component spray nozzle, atomization is poor under starting conditions, although on the rest rig (fuel pressure 30 lb./sq. in.) instantaneous ignition was obtained with the above fuel for air flows greater than 1·0 lb./sec. per can. Ignition with petrol was instantaneous under all conditions, and thus, to ensure satisfactory ignition on starting, petrol is first fed through to the burners by a small booster pump.

At the entry end, the combustion chambers are supported in the light alloy casting, and to cater for thermal expansion are free to slide in the casting. Rubber ring seals are fitted to avoid excessive air leakage. The flanges on the air casings at the discharge end are fixed by studs to the turbine inlet ducting.

Surrounding the whole of the combustion chambers is a mild steel metal skin of 16 s.w.g.

TABLE 1.—COMPRESSOR BLADE DETAILS



	CASING DIAMETER INS	TIP CLEARANCE INS	MEAN BLADE DIAMETER	MEAN BLADE HEIGHT	NUMBER OF BLADES	CHORD INNER INS	CHORD OUTER INS	PITCH/CHORD MID. DIA	STAGGER INNER DEGREES	STAGGER OUTER DEGREES	MAX. THICKNESS INNER INS	MAX. THICKNESS OUTER INS	THICKNESS/CHORD INNER %	THICKNESS/CHORD OUTER %	θ_1 APPROX INNER DEGREES	θ_1 APPROX OUTER DEGREES	θ_2 APPROX INNER DEGREES	θ_2 APPROX OUTER DEGREES
INLET GUIDE			17·43	3·89	32	1·23	1·23	1·39	+11¼	+16¼	·196	·196	15·9	15·9				
1ST ROTOR	21·52	0·03	17·66	3·80	27	1·95	1·91	1·08	-51½	-59½	·203	·095	10·4	5·0	11	4	21	10
" STATOR			17·97	3·63	63	1·32	1·32	·68	+5¼	+3¾	·212	·212	16·1	16·1				
2ND ROTOR	21·72	0·03	18·17	3·49	27	1·94	1·89	1·11	-51	-60	·188	·092	9·7	5·0	9	6	20	11
" STATOR			18·55	3·34	61	1·40	1·40	·68	+3	+6	·112	112	8·0	8·0				
3RD ROTOR	22·00	0·03	18·77	3·16	38	1·34	1·23	1·20	-55¼	-61¼	·179	·102	13·4	10·7	12	8	28	28
" STATOR			19·12	3·00	59	1·40	1·40	·73	-4¼	-1¾	·055	·055	3·9	3·9				
4TH ROTOR	22·22	0·04	19·29	2·85	38	1·33	1·23	1·24	-56	-60	·152	102	11·4	9·4	12	8	26	21
" STATOR			19·45	2·75	60	1·37	1·37	·74	-7½	-4½	·055	·055	4·0	4·0				
5TH ROTOR	22·20	0·04	19·65	2·47	38	1·30	1·22	1·29	-56½	-60½	·157	·118	12·1	9·8	12	9	21½	17
" STATOR			19·75	2·40	60	1·39	1·39	·74	-3	-3	·055	·055	4·0	4·0				
6TH ROTOR	22·45	0·04	20·11	2·26	38	1·30	1·23	1·32	-58	-60½	·151	·112	11·6	9·1	13½	9	21	23
" STATOR			20·24	2·24	71	1·39	1·39	·65	0	-3	·055	·055	4·0	4·0				
7TH ROTOR	22·65	0·04	20·40	2·16	38	1·24	1·15	1·47	-63½	-66½	·144	·120	11·6	10·4	10	7	22	24
" STATOR			20·45	2·20	71	1·37	1·37	·68	0	-2	·055	·055	4·0	4·0				
8TH ROTOR	22·69	0·04	20·47	2·13	38	1·21	1·14	1·45	-66½	-67¼	·154	·112	12·7	9·8	10	6	24	27
" STATOR			20·38	2·24	56	1·43	1·43	·80	-8	-8	·055	·055	3·8	3·8				

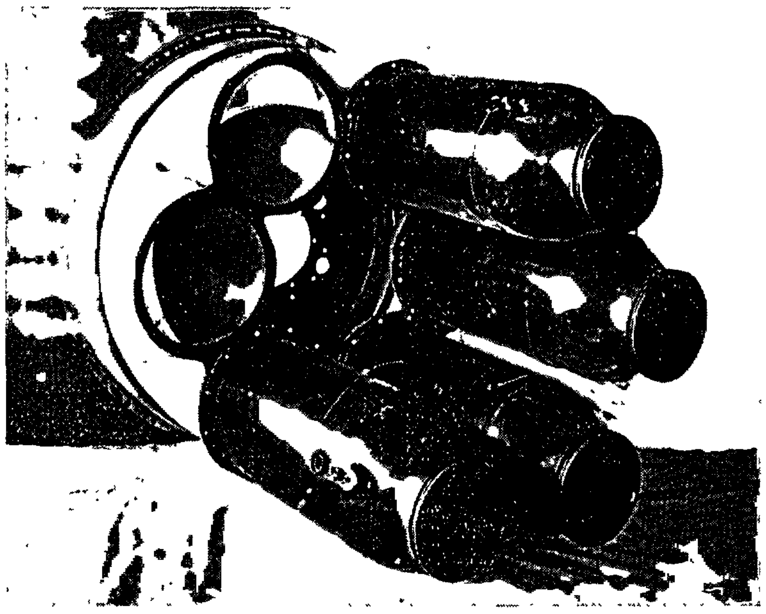


FIG. 8c.—*Turbine inlet ducting and combustion chambers*

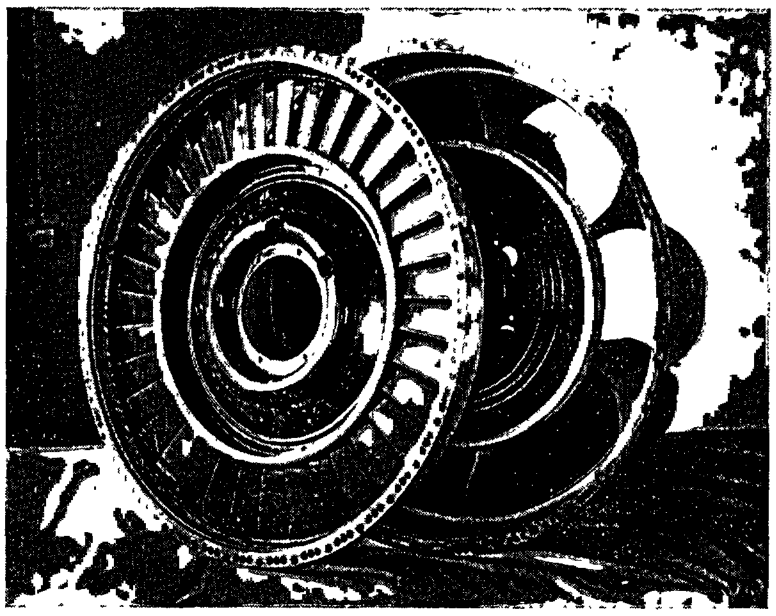
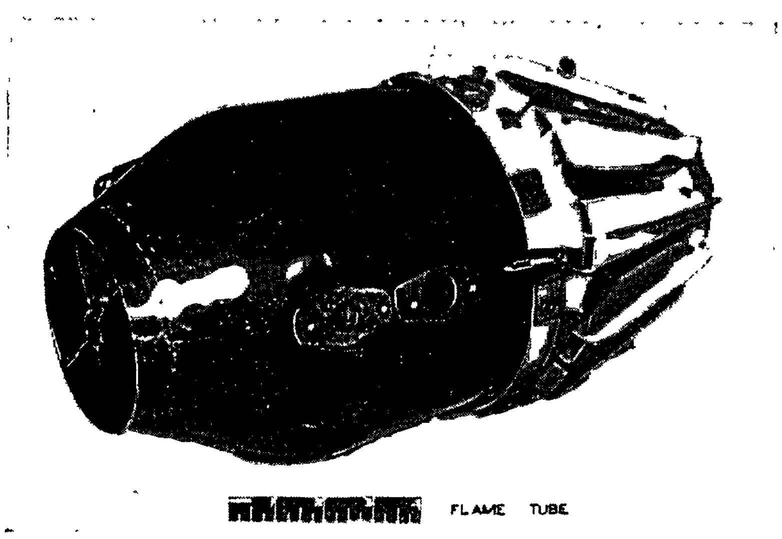


FIG. 8d.—*Turbine nozzles and inlet ducting*



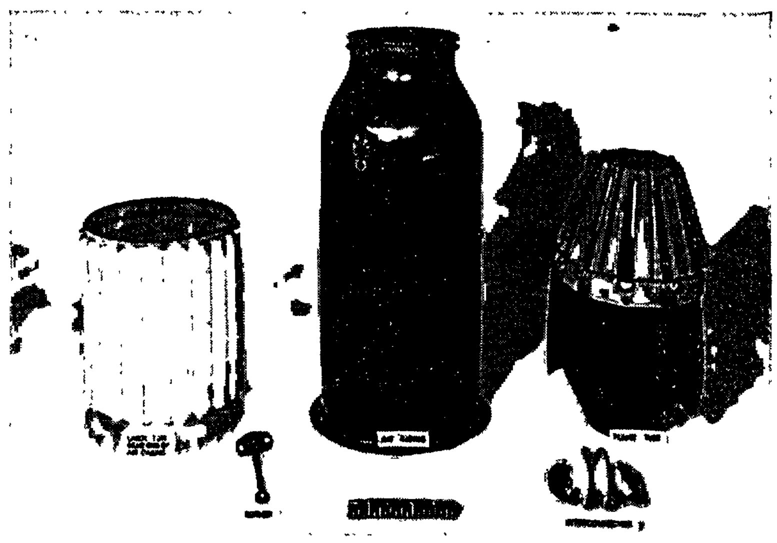
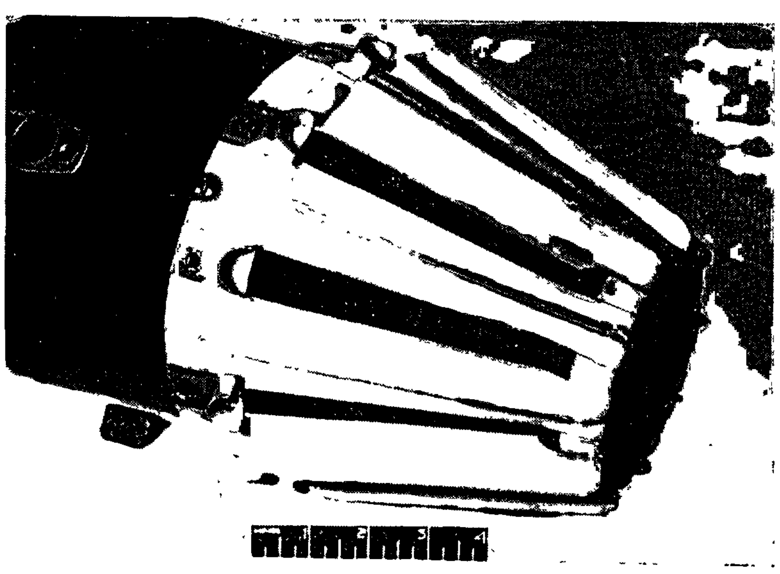
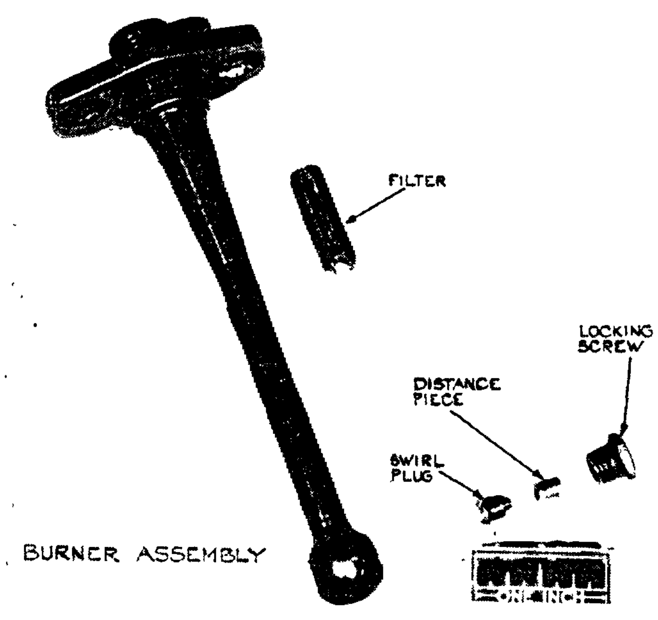


FIG. 9 (*above and below*).—*Four views of the combustion chamber, assembled and dismantled, showing component parts in detail*





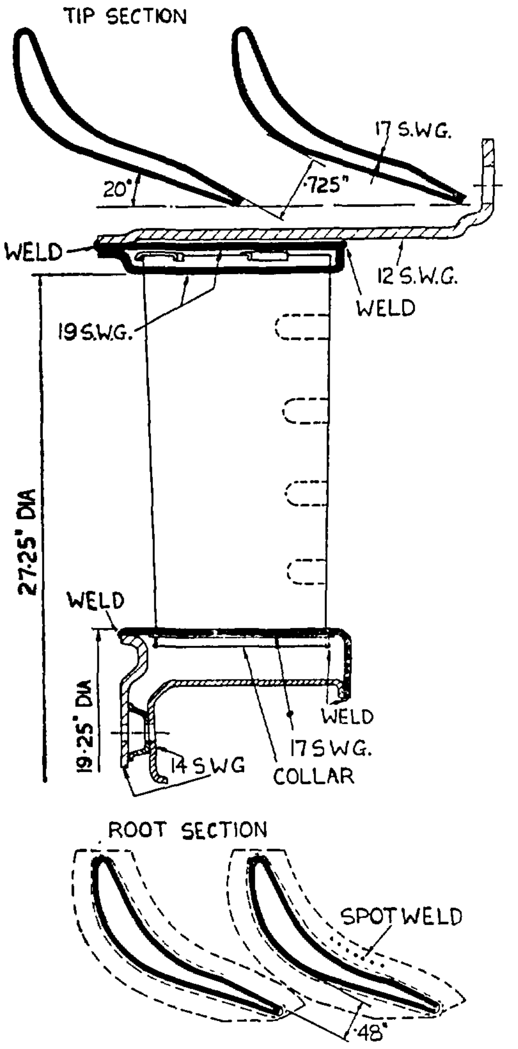


FIG. 10.—*Turbine nozzle assembly* (*shaded parts in mild steel*)

(Fig. 8*b*) which has fairly heavy flanges welded to each end. Holes in this skin allow access to the burners and sparking plugs. At the forward end, the flange is fixed by studs to the central casting, while the rear flange is joined, again by studs, to three other flanges. These are:—

(1) The flange on the outer part of the turbine inlet ducting.

(2) The flange on the nozzle ring assembly—through this support is provided for the nozzle tips.

(3) The flange welded to the exhaust casing and supporting the entire exhaust system.

In addition, the outer skin is attached to the central casting about half-way along its length by six long bolts. To one of these is attached the third pick-up point shown in Fig. 8*b*.

Attached to the metal skin are six ducts, of 22 s.w.g., which carry cooling air, bled off from the fourth stage of the compressor, through to the exhaust system. These ducts also help to stiffen the outer skin so that this can take the whole weight of the exhaust system.

The assembly of the combustion chambers, turbine inlet ducting and turbine nozzle ring is shown in Figs. 8 (*a*), (*b*), (*c*) and (*d*). The inlet ducting to the turbine is made from aluminized mild steel sheet of 19 s.w.g. and is attached, at the forward end, to the combustion chambers as shown. It is made in two parts and the rear end of the inner part is welded to a fairly substantial flange. Fixed to this by a number of studs, is a flange from the inner shroud ring of the turbine nozzle assembly (which carries the nozzles) and two mild steel diaphragm plates. These plates, in turn, are fixed by studs to the rear end of the central casting and so support the inlet ducting and the nozzle ring. On the rear outer part of the turbine inlet ducting, a light flange picks up with the flange on the rear of the skin surrounding the combustion chambers (mentioned in the previous paragraph). Thus the turbine inlet ducting, to which are fixed the combustion chambers, can be considered to be supported from the central casting, partly through the diaphragms attached to the rear of the casting, and partly through the skin surrounding the combustion chambers.

Turbine and Exhaust

The general design of the turbine appears to follow that of normal steam turbine practice. The nozzles have a comparatively low efflux angle ($17\frac{1}{2}$ deg. from $\sin^{-1} \frac{\text{opening}}{\text{pitch}}$, including the cooling air slot) and the blades are given some overlap, i.e. the blade height is made slightly greater than the nozzle height.

The mean diameter of the turbine is 23·1 in., that is only a few inches greater than that of the last compressor stage. This means that the mean circumferential blade speed is relatively low and to get the necessary work out without too much swirl in the exhaust gases the turbine must work with only a small amount of reaction at the mean diameter (this is estimated at 20 per cent). Assuming free vortex design, the reaction at the blade roots would be −18 per cent. This low reaction gives an end thrust on the rotor sufficiently low to be taken on one ball thrust race and also enables cooling air to be drawn up over the blade roots. The general design, that is amount of reaction, form of nozzles and turbine plates, is such that high efficiency is unlikely. To some extent this is confirmed by the final engine performance. Although separation of compressor and turbine efficiency is not possible when working back from the final engine performance, the figure obtained for turbine efficiency on assuming a compressor efficiency of 80 per cent is only 80 per cent. German tests made on a turbine alone also show that the turbine efficiency is only about 80 per cent.

One novel feature of the turbine design is the use of hollow turbine nozzles which are fed with cooling air from the compressor delivery. The nozzle is formed from sheet non-magnetic manganese-steel 0·045 in. thick, bent round and welded at the trailing edge over shaped spacing pieces. The spacing pieces are such that a gap 0·028 in. wide is left at the trailing edge.

The method of fixing the nozzles in the nozzle ring is shown in Fig. 10. The root of the finished blade is pushed through a slot in an inner shroud ring. A collar is gas welded on to the open end of the nozzle and this collar is then spot welded to the underside of the shroud ring. To this shroud ring is welded a heavy mild steel flange and a second ring, flanged as shown in the sketch. The two flanges pick up with the two diaphragm plates supporting the nozzle assembly and the turbine inlet ducting from the rear end of the central casting. The top of the nozzle is closed and passes through a slot in an outer shroud ring. Two small clips, welded to the tip of the nozzle, help to locate it while allowing for some radial expansion. This outer shroud ring is covered by a further ring and both are welded to a much thicker ring joggled and flanged to pick up with the flanges on the inlet ducting and outer casing.

The material of the nozzle blade is a chrome-manganese steel (18 per cent Mn., 9 per cent Cr.), and further particulars of this material are given later. It appears that the steel used would probably not be adequate for service without air cooling because of its relatively low scaling resistance.

The number of nozzle blades is 35, the total nozzle throat area is 84 sq. in. (with tolerance given as +3 sq. in.) and the form of nozzle passage is shown in Fig. 10.

Most of the engines received have been fitted with 61 solid turbine blades similar to the one

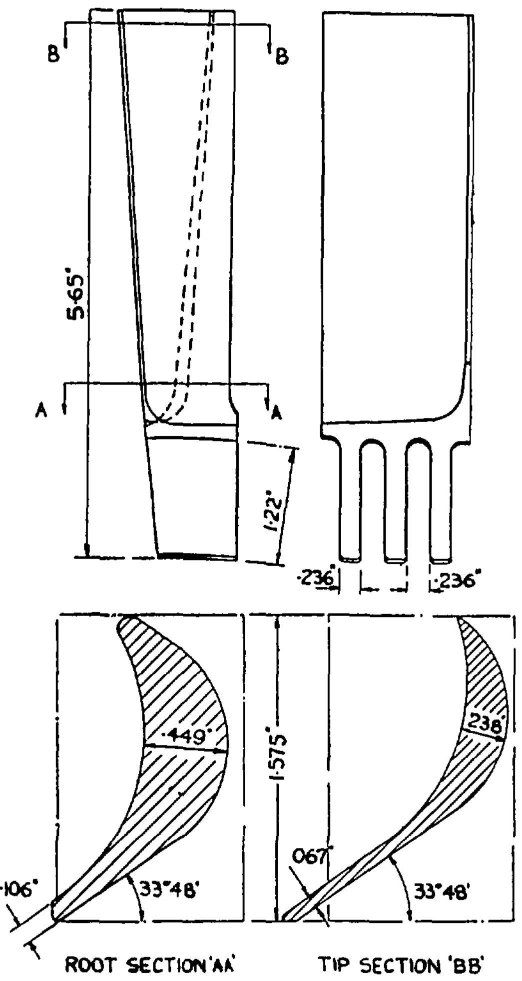


FIG. 11*a*.—*Solid turbine rotor blade*

shown in Fig. 11*a*. These are machined from a forging and have a forked type blade root fixed by two rivets to the turbine disk. Dimensions of the blade are given in the figure. From this it will be seen that the blades are of heavy construction and little attention has been paid to refinements such as the thickness of the trailing edge. The weight of one blade is $12\frac{1}{4}$ oz.

The blade roots and tips appear to have been running fairly cool (probably not in excess of 450 deg. C.) which is largely due to the cooling air flow over the blade roots and the nature of the temperature distribution from the combustion chambers. The centres of the blades appear to be subject to a higher temperature (probably about 700 deg. C.) and the material has probably little reserve of strength over the service requirements. The blade stresses, are actually fairly low; maximum centrifugal blade stress is 9 tons/sq. in. and gas bending stress between 1 and 2 tons/sq. in.

The solid disk is made from a hardened chrome steel (2·8 per cent chrome) and dimensions are given in Fig. 12*a*. The disk stresses are fairly high—about 15 tons/sq. in. at full r.p.m. The use of these heavy solid blades was an interim measure and the latest engine received was fitted with hollow blades of the type shown in Fig. 11*b*. The material used is the same as that of the solid blades and the weight (6·1 oz.) is only half that of a solid blade.

The disk used for the hollow blades is rather lighter than that used with the solid blades, and dimensions are given in Fig. 12*b*.

It is known that vibration trouble has been experienced with the hollow blades and the blades split down the tip of the trailing edge. To overcome this the trailing edge towards the tip of the blade is reinforced by two rivets.

From the turbine the hot gases pass out through the exhaust system. Both the outer fairing, the inner cone, and the six struts holding the inner cone to the outer cone, are of

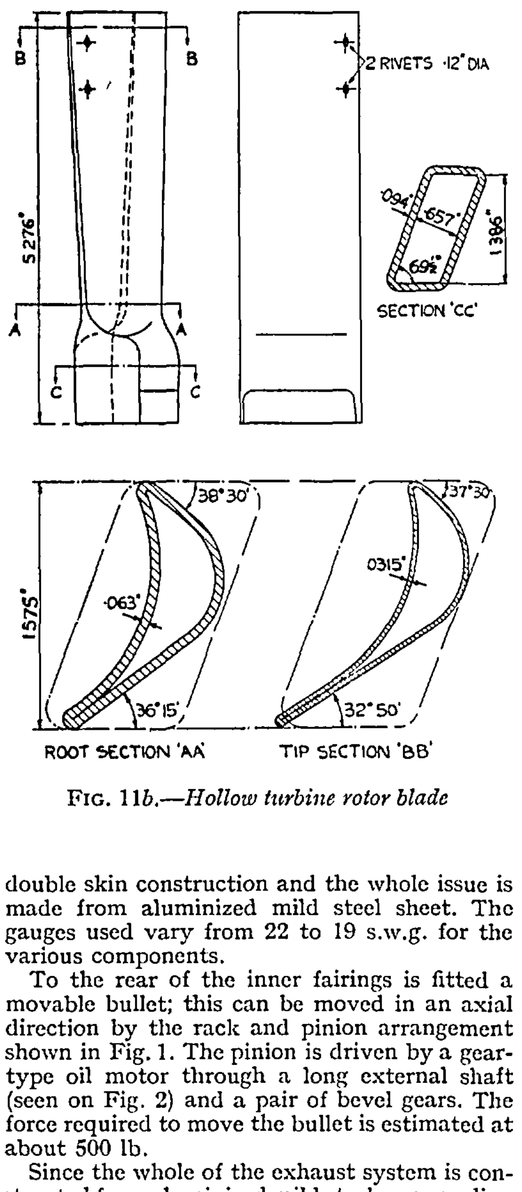


FIG. 11*b*.—*Hollow turbine rotor blade*

double skin construction and the whole issue is made from aluminized mild steel sheet. The gauges used vary from 22 to 19 s.w.g. for the various components.

To the rear of the inner fairings is fitted a movable bullet; this can be moved in an axial direction by the rack and pinion arrangement shown in Fig. 1. The pinion is driven by a gear-type oil motor through a long external shaft (seen on Fig. 2) and a pair of bevel gears. The force required to move the bullet is estimated at about 500 lb.

Since the whole of the exhaust system is constructed from aluminized mild steel some cooling is necessary.

Cooling Air System

A feature of this German engine is the extensive use of compressor air, to cool the hot metal parts. This "wastage" of compressor air detracts from the efficiency of the engine but is necessary when heat resisting materials are not available. In the British engines every effort has been made to keep up the efficiency and as the necessary heat resisting materials were more readily available cooling air has not been used to the same extent.

A diagrammatic sketch of the cooling air system is shown in Fig. 13. It can be considered to be made up of three parts:—

(1) Cooling air bled off from just ahead of the fifth compressor stage, to cool the exhaust system.

This passes through six cored ducts in the compressor stator casing and through the six ducts on the outer skin surrounding the combustion chambers (Fig. 8*b*) to the exhaust assembly. Some air escapes through tiny holes in the ducts into the space around the combustion system. In the exhaust system some of the cooling air passes down between the double skin of the outer cone and the rest passes through the six faired struts to cool the inner cone.

The bleed off is unlikely to be more than 3 per cent of the air entering the compressor.

(2) Cooling air leaking past the gland on the last compressor disk, to cool the turbine disk.

This passes through two of the cored passages at the base of the ribs in the central casting which run the whole length of the casting. It is ducted across the space between the two diaphragm plates supporting the turbine nozzles and inlet ducting from the rear of the central casting and blows out on to the turbine disk, flows up the turbine disk and over the blade roots to the exhaust. The two discharge ports in the rear diaphragm plate of the nozzle assembly can be seen in Fig. 8*d*.

The quantity of air going to cool the disk cannot be estimated since this is controlled by the gland clearances and these are not known.

(3) Cooling air bled off from the compressor delivery to cool the turbine nozzles.

After the last compressor stage, air is tapped off and ducted by way of three cored passages in the central casting into the space between the two plate diaphragms supporting the nozzle assembly from the rear of the central casting. A little air escapes through tiny holes into the space between the combustion chambers, but the majority of it passes into the hollow turbine nozzle guide vanes and out from slits in their trailing edges.

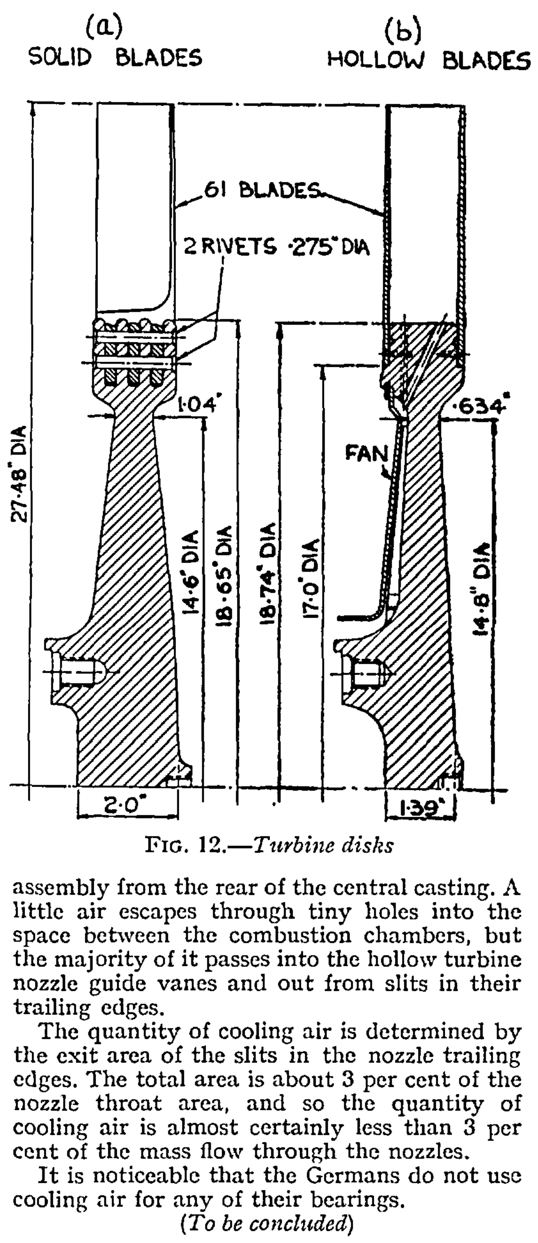


FIG. 12.—*Turbine disks*

The quantity of cooling air is determined by the exit area of the slits in the nozzle trailing edges. The total area is about 3 per cent of the nozzle throat area, and so the quantity of cooling air is almost certainly less than 3 per cent of the mass flow through the nozzles.

It is noticeable that the Germans do not use cooling air for any of their bearings.

(*To be concluded*)

Modern Aeroplane Types

The Lockheed Shooting Star

(*See p.* 354)

THE Lockheed P-80 represents in effect an adaption of the original Whittle installation in the Gloster E 28/39 with the necessary modifications to include military equipment and armament. That is to say the engine and fuel tanks are mounted in the fuselage behind the pilot and the air is led into the engine by ducts along the sides of the fuselage and is ejected through an orifice in the tail. The original air intakes in the nose of the E 28/39 have been discarded owing to the need for carrying guns, ammunition and camera in the nose of the fuselage. This design is, of course, a quite logical development and it is particularly suited to very high speeds, as the fuselage is then of the correct long narrow streamline for speeds approaching that of sound.

Comparatively few details of the Shooting Star have been released at the time of writing, but the following points are of particular interest.

A laminar-flow wing section is used with simple inset ailerons and separate flaps. The flaps run between the ailerons, and the central fuselage portion can be operated independently as an air brake.

The engine installation is simple, as with most Whittle-type units, and the makers claim that an engine change can be made in twenty minutes.

The fuel capacity has not been given, but the normal tankage is said to be sufficient for ordinary fighter duties, while the curious wing-tip drop tanks are said to give it a really long range.

The P-80 was designed for the General Electric Whittle-type engine, and it has also been fitted with the de Havilland Goblin and the Rolls-Royce Nene, both of which give it an outstanding performance.

The method of obtaining a very accurate and high-class finish is of considerable interest. The whole of the external surfaces are dressed and buffed and are then filled with zinc-chromate primer. Butt joints are filled with cement filler and flexible joints are covered with organdie mesh tape. Then a special surfacer is applied before spraying with paint and finally the entire aeroplane is baked in a special oven. Final finishing is given by light sanding and buffing followed by a special wax spray and polish. This treatment appears very elaborate and it seems doubtful if it will be practical to operate aeroplanes with this finish under active service conditions.

The armaments of the P-80 consist of six ·5-in. machine guns which are mounted in the under part of the nose, where they do not cause any flash to the pilot.

PRINCIPAL CHARACTERISTICS

Span	38 ft. 10½ in. (11·85 m.)
Length	34 ft. 6 in. (10·52 m.)
Height	11 ft. 4 in. (3·45 m.)
Empty weight (approx.)	8,000 lb. (3,620 kg.)
Gross weight (approx.)	14,000 lb. (6,340 kg.)

Books Received

The Wings of Warfare. G. D. M. Block. 133 pages, illustrated. [Hutchinson. 15s.]

Die Knickfestigkeit von Stäben und Stabwerken. J. Ratzersdorfer. 321 pages, illustrated. [J. W. Edwards, Ann Arbor, Mich., U.S.A. $8.80.]

Aircraft Engines. Vol. I. A. W. Judge. Second Edition. 492 pages, illustrated. [Chapman & Hall. 28s.]

Higher Technological Education. Pamphlet. [H.M. Stationery Office. 6d.]

The British Council Science Department. Outline of Activities. Pamphlet. [The British Council. Free.]

Ideas Have Legs. Peter Howard. 190 pages. [Frederick Muller. 7s. 6d.]

Steel and its Practical Applications. W. Barr and A. J. K. Honeyman. 156 pages, illustrated. [Blackie. 8s. 6d.]

Tables of Arc Sin X. 121 pages of tables. [Columbia University Press, New York. $3.50.]

Allied Aircraft Illustrated. Edited by Leonard Taylor. 64 pages of photographs. [Air League. 10s. 0d.]