DESIGN ANALYSIS OF

Messerschmitt Me-262 Jet Fighter

Part II — The Power Plant

By JOHN FOSTER, JR., *Managing Editor, "Aviation"*

First complete engineering study ever published on jet power plant reveals, in addition to fundamental principles of jet propulsion, the design and production compromises made necessary by limitations of materials.

As is the case with the airframe of the Me-262, the Junkers Jumo 004 axial flow gas turbine jet power plant is a compromise between design desire and available materials and production facilities.

Outstanding evidence of compromises resulting from lack of materials is the fact that more than 7% of the air taken in is bled off for cooling purposes. Despite this, however, most engines were found to have a service life of about only 10 hr., against a "design life" of 25 – 35 hr. Additional compromises are evident in the design, which shows that the production engineer – undoubtedly hampered by lack of both plant facilities and adequate skilled labor – has been as important a factor in its construction as was the designer.

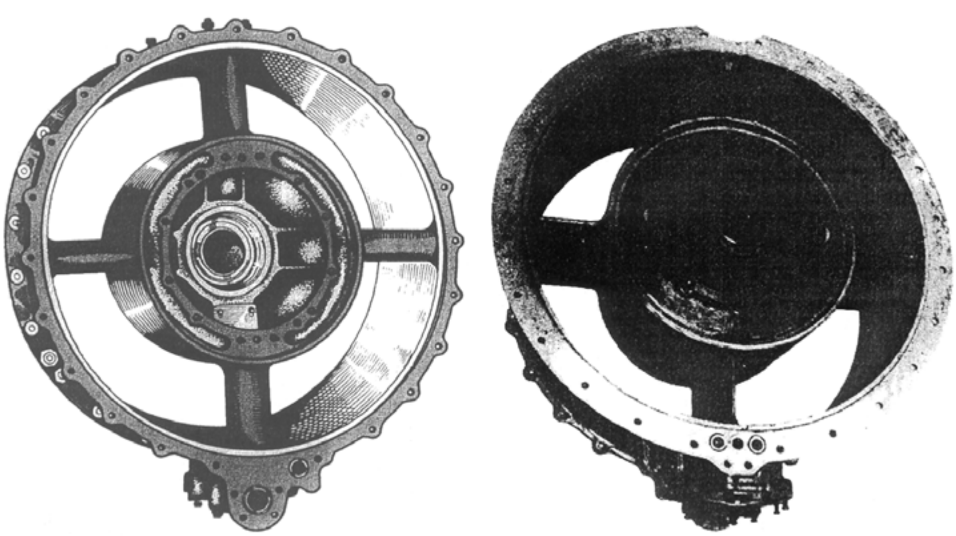
But the Germans had made real progress in overcoming materials difficulties, for just after they capitulated that development of a new alloy of excellent heat-resistant qualities had made it possible to get up to 150 hr. service in actual flight tests, and up to 500 hr. on the test stand.

A large unit, the 004 is 152 in. long from the intake to the tip of the exhaust; 30 in. in dia. at the skin around the six combustion chambers, with maximum diameter of the cowling reaching 34 in.

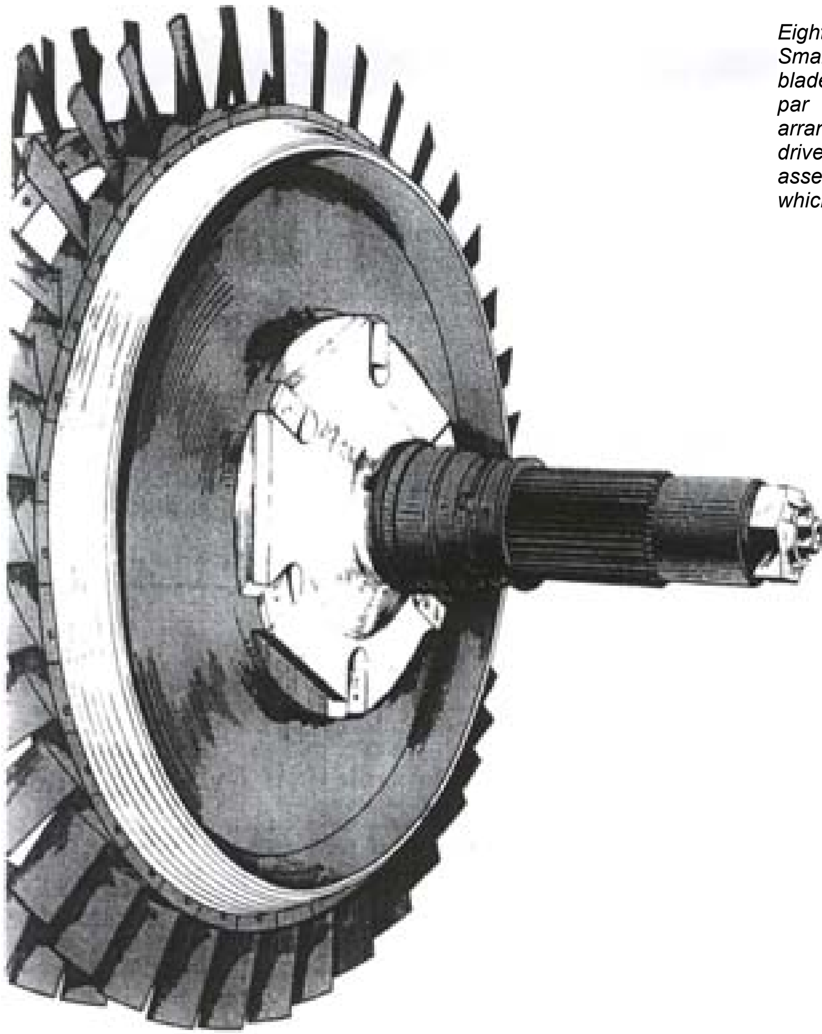
The circular nose cowling is double skinned, the two surfaces being welded together near the leading edge and held in position by riveted channel shaped brackets. Diameter at the intake end is 20 in., the outer skin increasing to 31½ in., the inner to 21½. Inside the cowling is an annular gasoline tank which is divided into two sections, the upper being of ¾-gal. capacity feeding fuel to the starting engine, the lower of 3¼-gal. capacity, feeding starting fuel to the combustion chambers.

The nose cowling attaches by eight screws in captured nuts to the annular-shaped combination oil tank and cooler. Having 3-gal. capacity, this tank has a baffle close to the inner surface so that as warm oil is fed in from the top it is cooled as it flows around to the bottom of annulus and the tank proper.

The oil tank, in turn, is attached by 23 bolts on a flange to the aluminum alloy intake casting. This unit comprises the outer ring, with flanges on both front and rear faces,



Front of Junkers Jumo 004 intake casting (left), with oil lines at bottom. Holes in outer flange are for attaching oil and starting-fuel tank assembly. Twelve studs on inner ring hold bevel gear assembly, from which drives for accessories and oil pumps extend through vertical streamlined fairings. Right: Aft face of intake casting, with front compressor bearing held in place by round plate attached to ten studs. Bolt holes in outer flange are for attachment to compressor stator casting.



Eighth compressor disk and rotor showing: Small retaining screws set in roots of blades; serrated ring around which is bled par of cooling ari; and slot-and-lug arrangement for transmitting torque from drive shaft to disk faces. Entire compressor assembly is held together by tie rod, end of which protrudes from shaft end.

four hollow streamlined spokes, and the inner ring.

Moving back to the front of the unit, though, we find inside the nose cowling a fairing which looks just like a propeller spinner, increasing in size to 12 in. at the intake casting, leaving approximately 220 sq. in. intake area. This spinner houses the starting engine, a two-cylinder two-cycle horizontally opposed gasoline engine which develops 10 hp. at 6,000 rpm. The starting engine has its own electric starting motor; and, for emergency, extending out to the front of the spinner is a cable starter similar to those found on outboard boat engines. The engine is 12½ in. long, 10 in. wide, 8¼ in. high, and weighs 36 lb.

The starter engine is bolted to six studs in the bevel gear casting, which contains bears to drive the accessories. Each of these gears is carried by ball and roller bearings, with the drive shafts fitting into internally splined stub shafts on the bevels. There are two drive shafts extending through two of the hollow fairings of the intake casting, one going up to the accessory case which is mounted atop the intake casting, the other extending down to the main oil pumps, which are set inside the lower part of the intake casting.

The bevel gear casting, also of aluminum alloy, is bolted to twelve studs set in a flange in the front face of the intake casting.

The rear side of the intake casting's inner ring is cup-shaped, housing the front compressor bearing. This unit is comprised of three thrust races – each with 15 bearings – mounted in steel liners set in a light hemispheric-shaped housing which is kept in contact with the female portion of the intake housing by the pressure of ten springs held in place by a plate bolting to the intake casting. The outer bearing races are mounted in separate sleeves which fit on the compressor shaft.

This design not only allows for preloading the bearings during assembly to ensure even distribution of thrust, but the bearing assembly can be left intact during disassembly simply by withdrawing the compressor shaft from the inner sleeve.

Next in the fore-to-aft sequence ins the aluminum alloy stator casting, which is built in top and bottom halves held together longitudinally by eleven 3/8-in. bolts through flanges on each side, with attachment to the intake casting by 24 3/8-in. bolts through a heavy flange. Running the entire length of the bottom half of the casting are three .7-in dia. passages, one serving as part of the oil line leading to the rear compressor and turbine bearings, one connecting oil sumps (which are located in both intake and main castings), and one serving as part of the oil return line from a scavenge pump set in the rear turbine bearing housing.

Just aft of the fourth compression stage in both halves of the stator casting is a slot, inside of which is a ring with a wedge-shaped leading edge pointing upstream and set to leave a .08-in. opening to bleed off air for part of the cooling system (which will be discussed later in a separate section.)

Like the stator casting, the stator rings, which consist of inner and outer shroud rings and stator blades, are built as subassemblies, then bolted in place and locked by small tabs.

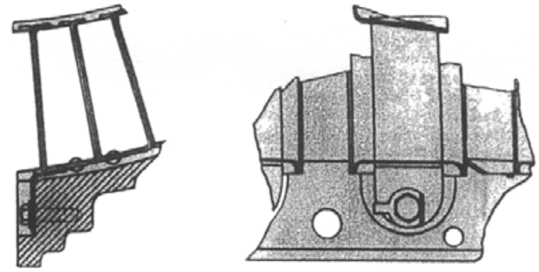
Considerable variation, both in materials used and methods of construction, was found in this section. In early production units, for example, the inlet guide vanes and first two rows of stator blades were of stamped aluminum with airfoil profiles; and in assembly, ends of the blades had been pushed through slots in the shroud rings and brazed in place. In other early engines, the third stator row varied both in material and method of attachment. In some cases it would be of aluminum, but without airfoil; in others it would be of steel with the ends turned to form flanges which were spot welded to the shroud rings. The remainder were stamped sheet steel, zinc coated.

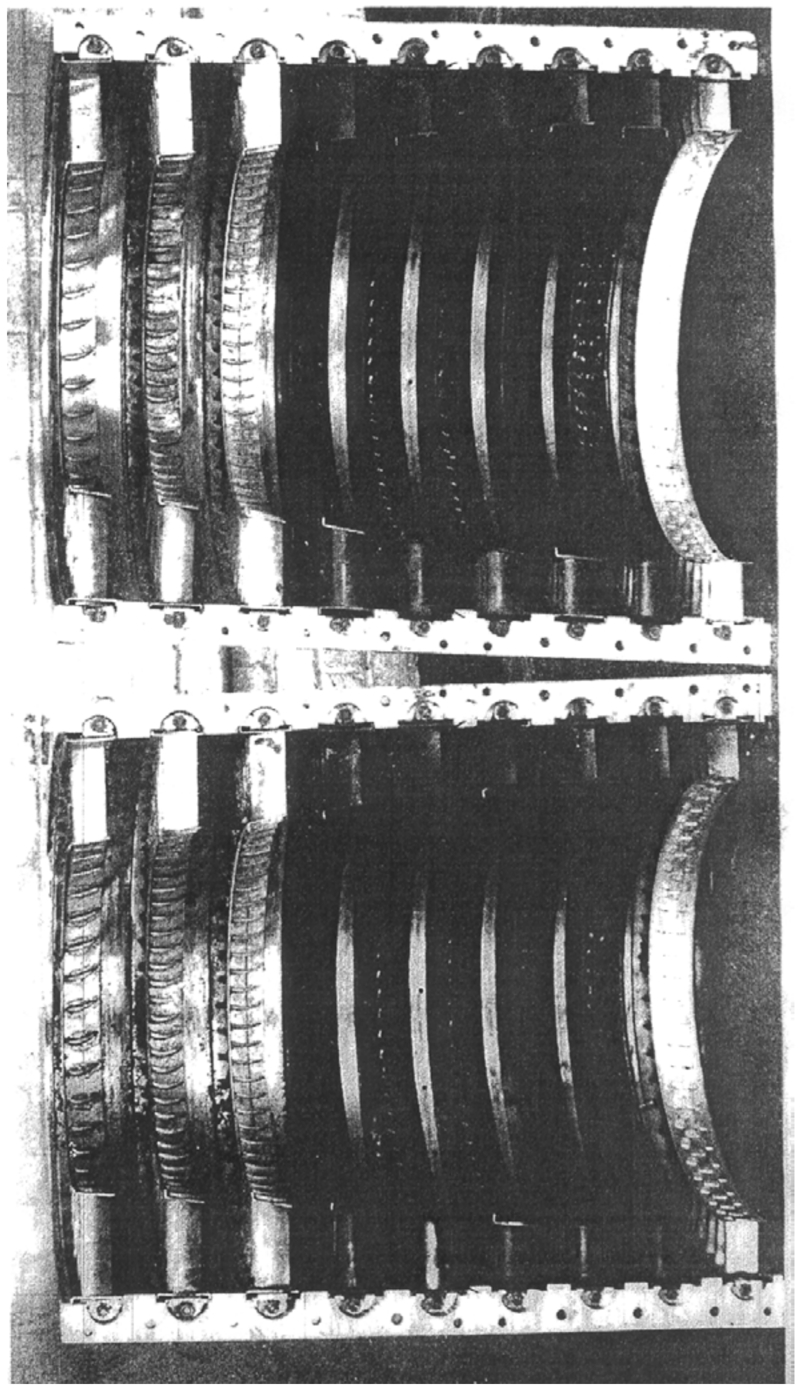
One late-production engine examined showed a combination of all the variations, with the inlet guide vanes and first two rows of stator blades of stamped aluminum, and the rest steel, indicating the Germans may have been swinging over from aluminum to steel exclusively. Apparently all the steel blades had been enameled, but this protective coating on the last row, where temperatures reached approximately 380 deg. C., appeared to have been burned off.

Methods of attaching blades to shroud rings also varied. On the inlet guide vanes and first two rows, the ends of the blades had been pushed through slots in the shroud rings and brazed in place; the 3rd, 6th, and 7th rows had a weld all around the blade end; the 4th, 5th, and 8th row blade ends had been formed into split clips which were spotwelded to the shroud rings.

The outer shroud rings are channel shaped with an angle bracket riveted to each end, this bracket in turn being bolted to a stud set in the casing just inside the mating flange. Inner shroud rings are flanged along the leading edge, with the exception of the 7th row, which is channel shaped.

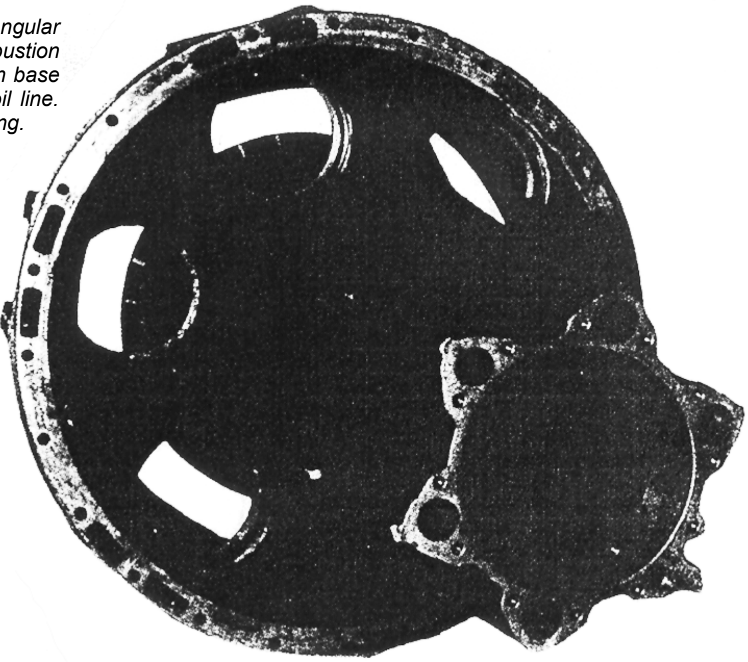
Except for the inlet guide vanes and the last row of stator blades, which act as straighteners, stator blades are arranged as impulse blading – they are set at nearly zero stagger and simply serve as guides to direct the airflow into the rotor blades.

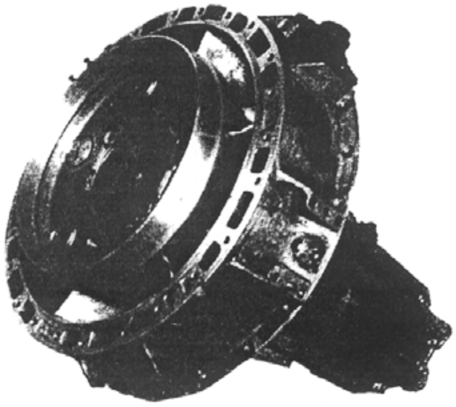




Top and bottom halves of stator casting. These sections are bolted together longitudinally, with flange on front end bolting to intake casting, that on aft end to main casting. Light colored blades are aluminum, darkere are enameled mild steel. Germans were evidently changing over from aluminum to steel blades throughout stator at war's end. Sketches at top show method of attaching stator blades.

Rear view of main casting showing rectangular cooling air passages and the six combustion chamber inlets. Five larger cored passages in base of ribs are cooling air passages, smaller is oil line. Aft turbine bearing fits in rear end of this casting.



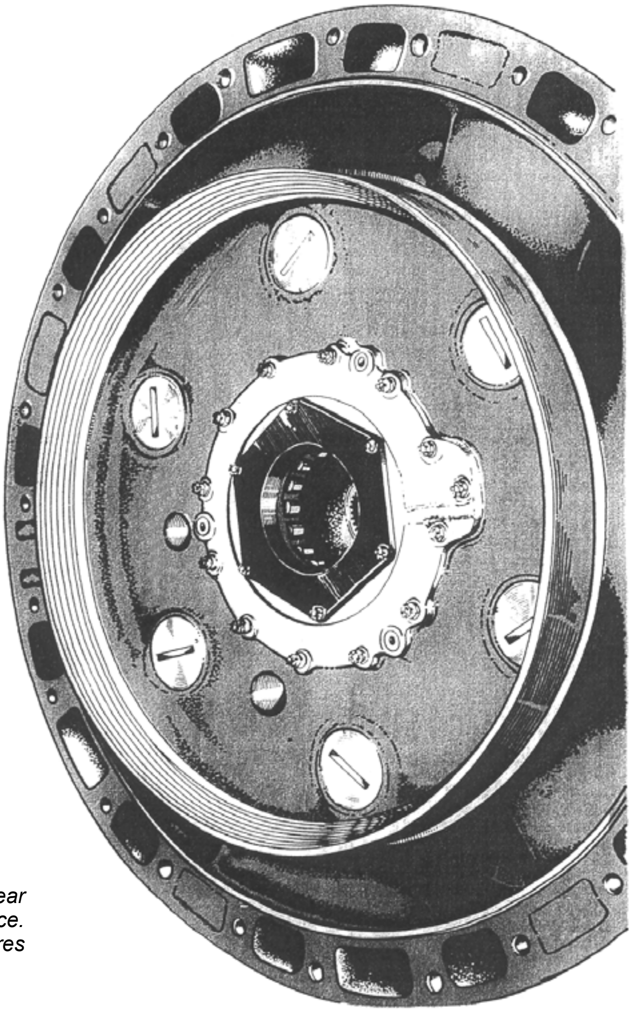


Three-quarter front view of main casting which supports entire engine. At top is engine attachment fixed to one of six possible pickup points spaced around unit. Rectangular openings infront outer rim are cooling air passages, and air inlets from compressor to combustion chambers are between faired struts between chambers and serrated ring. Air passing betrween th serrations and those on last compressor disk is also used for cooling. Studs around center core are for attaching aft compressor bearing housing.

The compressor rotor is made up of eight aluminum disks held together by twelve bolts each through shoulders approximately at mid-diameter, with the entire unit being pulled together by a 38.75-in. long, .705-in. dia. tie rod which has been estimated to have a stress of some 40,000 psi., with a force to pull the assembly together figured at about 16,000 psi.

Diameters of the disks increase from the low to high pressure ends as follows: Stage 1, 13.86 in., Stage 2, 14.68 in., Stage 3, 15.61 in., Stage 4, 16.44 in., Stage 5, 17.18 in., Stage 6, 17.85 in., Stage 7, 18.24 in., and Stage 8, 18.34 in.

To carry the compressor bearings there is attached to each end disk a steel shaft with an integral disk carrying a round-faced washer. This shaft goes through the disk and is



Closeup of front of main casting showing rear compressor bearing and housing in place. Large screws seal off passages left by cores used in making casting.

tightened by a nut so that the face of this washer (rounded to facilitate alignment) bears against the disk face. The flange on the rear shaft has six slots around its outer edge, into which fit projections on the rear disk. Thus torque is transmitted from the turbine to the rear compressor disk, and from there on to the other disks by the bolts previously noted as fastening the disks together, the torque being transmitted to the compressor unit around the faces, rather than through a central shaft.

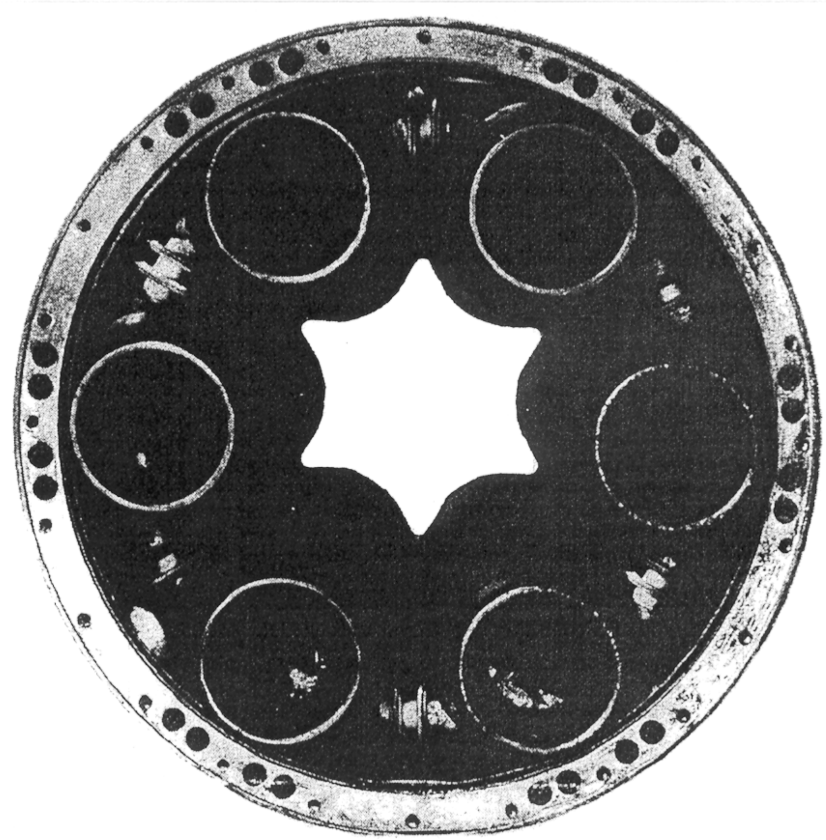
Compressor rotor blades, of which there are 27 in the first two stages, 38 in the rest, are all stamped aluminum with machined roots fitting into pyramid shaped slots in the rotor disk. Through the aft face of each blade root, directly under the blade trailing edge, is a small screw set longitudinally and extending into the disk.

Tip stagger of the blades is about the same through the first six stages of compression, but increases in the last two. Chord of the blades decreases through the eight stages as follows: 1.95 in., 1,94; 1.34; 1.33; 1.30; 1.30; 1.24; and 1.21.

Blade profiles in the first two stages are very similar (possibly even designed to the same section), while the third stage has a thicker section. Stages 4, 5, and 6 have thinner sections (here, too, possibly the same), with about the same chord as Stage 3, while the last two stages, though set at greater pitch and having slightly narrower chord, have generally similar camber and profiles.

Clearances between the rotor blades and the stator casting are .103 in. over the first three stages and .04 over the remaining five. Axial clearances between rotor disks and inner stator shroud rings range from .1 to .15 in., and axial clearances at roots between rotor and stator blades are .5 and .6 in.

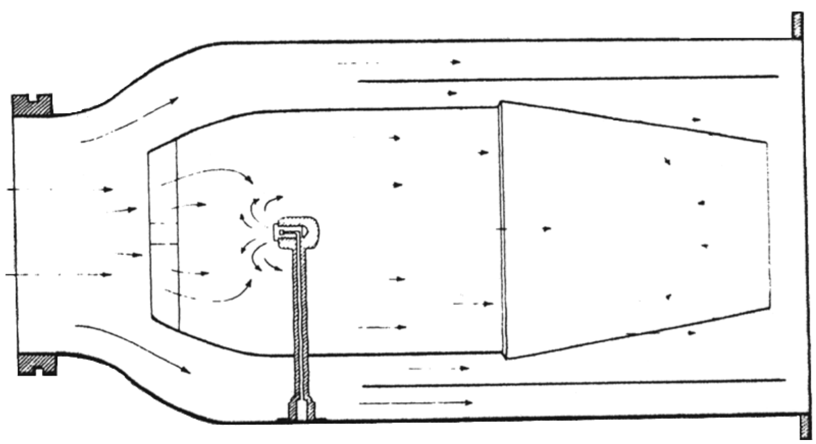
Backbone of the 004 is a complex aluminum casting which, in addition to providing the three engine attaching points, supports the compressor casing – through 25 bolts – the entire combustion chamber assembly, the turbine nozzle, the aft compressor bearing, the two turbine bearings and, through the combustion chamber casing, the entire exhaust system.



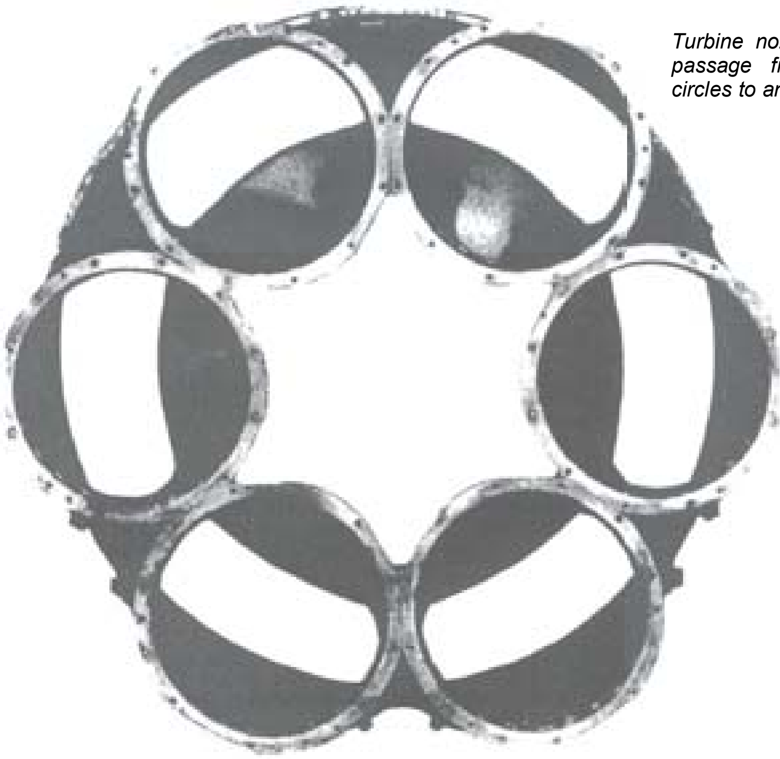
Head-on view of combustion chamber casing with combustion chambers and ignition interconnectors and plugs in place. Every other chamber has ignition pluig.

Moreover, in the base of each of the six ribs supporting the combustion chambers, there are cored passages, five of which carry cooling air, one carrying lube oil. And, while the air passage area remains constant between the compressor and combustion chambers, the main casting changes the shape from annular to circular at the entrance to the chambers.

In the front of the casting, at the tip of the last stator row, is an 18-3/8-in. die. ring with a serrated inner



Exploded view of combustion chamber showing main components. At left is outer casing, mad of mile steel; center is flame tube, showing swirler at front, fuel nozzle, ignition plug connection (on side) and stub pipe assembly; and at right is aluminized steel liner with corrugations to carry cooling air along inside of casing.

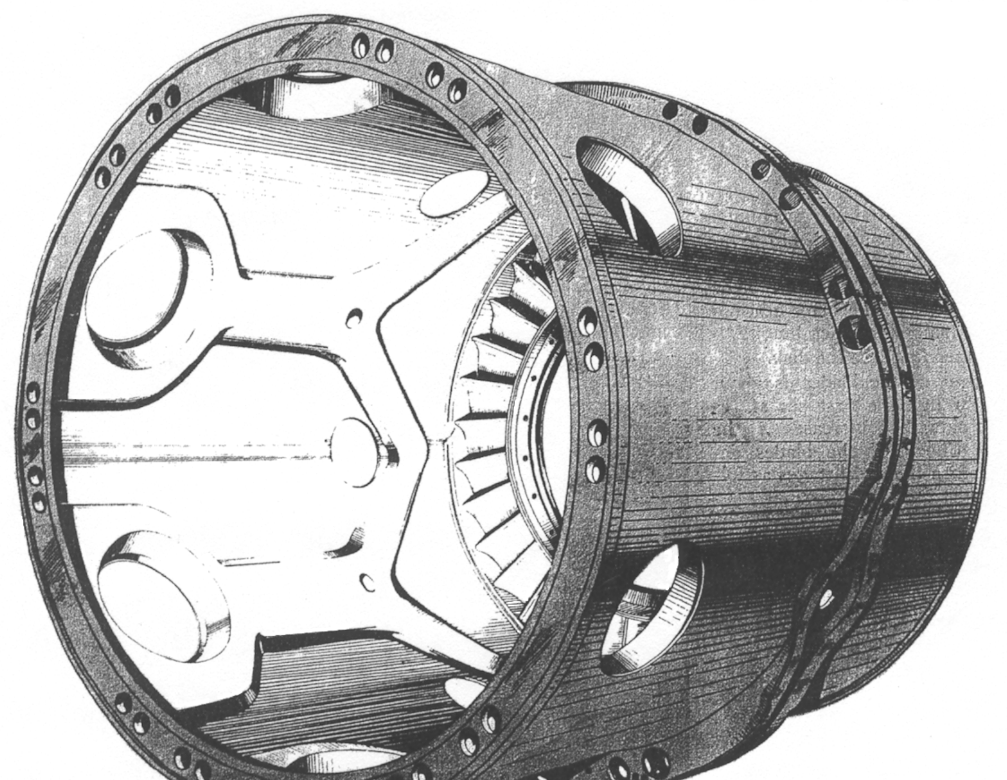


Turbine nozzle inlet ducting which changes air passage from indvidual combustion chamber circles to annular shape before entering nozzle.

surface fitting closely to serrations on the aft face of the last compressor disc. Air bleeding through the serrations is carried aft through cored holes in the casting to cool there front face of the turbine disk and, on hollow-bladed turbines, to cool the blades themselves.

Just outside and in back of this ring are the fairings which divide the air and direct it into the individual combustion chambers. These fairings, in turn, are surrounded by a 28-in. o.d. ring with 25 bolt holes for attaching the compressor casing. Besides the bolt holes there are 18 openings, six of which carry the air bled off from the compressor on aft for exhaust system cooling, and twelve smaller ones which take cooling air around the combustion chambers.

Around the outside of this ring, extending back to a heavy flange to



Mild steel double-skinned casing which surrounds combustion chambers. Note holes in front ring which carry cooling air into ducts between the two skins. Access holes lead to combustion chamber ignition plugs and interconnectors. Heavy transverse ring around outside of casing carries tier rod braces into main casting and also serves as attachment for aft engine pickup point.

which the combustion chamber casing bolts, are twelve raised longitudinal ridges arranged in pairs. These have machined faces having four bolt holes and two aligning pins serving s the forward engine pickup points. With six such pickup points, the engine was designed for a wide variety of mountings. In the case of the Me-262 plates with collared nuts were fastened to the two on either side of the topmost unit.

Overall length of the main casting is 37¼ in., with the previously mentioned ribs tapering down from the aft face of the ring structure to the central longitudinal member which has an 8¾-in. dia. ant the aft end.

The aft compressor bearing, having 16 rollers, is set in the front of the main casting inside the serrated ring, the housing being attached to the casting by 14 bolts.

The turbine thrust bearing is set inside the main casting, with the centerline of the balls 24-3/8 in. back of the front edge of the serrated ring, and the main turbine roller bearing is bolted into the rear end.

Each of the six combustion chambers is built up of three major components having a combined weight of 19 lb. First, there is a mild steel outer casing, of 5¾ in. dia. at the entering end flaring out to 8-5/8 in., and having a length of 20-5/8 in. The front end has a collar with a rubber sealing ring which is pushed up against the aft face of the main casting to take care of air leakage and to compensate for the difference in casting and combustion chamber expansion.

Fitting inside the front end of this casing is the flame tube, which has two main components – the entry section and stub pipe assembly. The fore part of the entry section flares out somewhat as does the outer casing, and at the front end has a six-blade swirler. This unit is made of 22 gage mild steel with a black enamel coating. The stub pipe assembly is made up of ten flame chutes welded to a ring (which is welded by brackets to the rear end of the flame tubes and to a 4-in. dished baffle plate at the rear. To help direct air into the chutes, ½-in. circular baffle plates are riveted to the forward ring. Material of this unit is mild steel with an aluminized finish.

Front view of turbine nozzle assembly showing rear turbine bearing and diaphragm plates in place. Cooling air enters two holes seen just below bearing, goes up between diaphragm plates and through nozzle roots, then out through openings in trailing edges. Note36 bolt holes (in aouter rear flange) for attaching assembly to combustion chamber casing, also 36 series-of-three holes for carrying exhaust system cooling air.

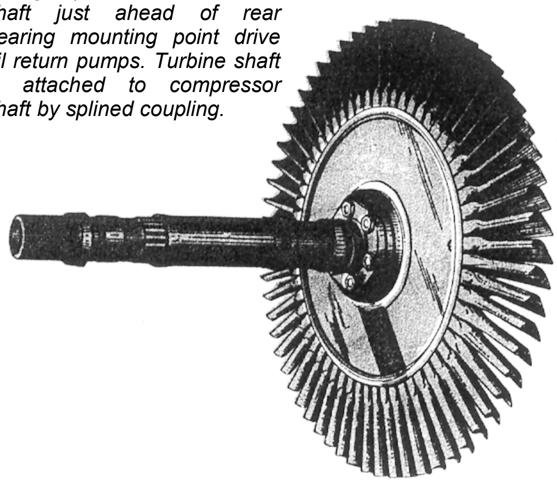
Third major component of the combustion chamber is an 11-in. long 20-gage aluminized steel liner having a corrugated outer skin which permits cooling air to flow inside the outer casing. This liner fits into the aft end of the casing. The aft ends of the combustion chambers are bolted around flanges to a ring of six rings which fits over there rear end of the main casting.

Ignition interconnectors between chambers are of but 15/32 in. dia., and starting plugs are provided in three of the six chambers. These elements, as are the fuel plugs, are enclosed in streamlined fairings.

Surrounding the combustion chambers is a 16-gage mild steel double skinned casing having flanges welded at both ends – that at the front end attaching by studs to the main casting; that at the rear attaching to the turbine inlet duct outer flange, the nozzle ring assembly flange, and the exhaust casing flange. Besides the bolt holes in the front flange, there are 24 of similar size, twelve leading to six ducts of 22-gage steel which carry the air bled from the fourth compressor stage through the combustion chamber casing, and twelve directing air around the combustion chambers. These ducts also help stiffen the skin, as it takes the weight of the entire exhaust system.

Six large hand holes are cut in the casing just behind the flange. These give access for making minor adjustments to burners and the three ignition plugs.

A little more than halfway aft around the combustion chamber casing is a heavy collar comprised of two channel shaped members, and inside the casing at this ring are six tie rids, connecting it to the main casting. Any one of these six units can serve as the aft engine pickup point; in the case of the Me-262 it is



Hollow blade turbine assembly. Cooling air is forced inside flange near hub and up behind sheet spotwelded to disk, then through blade roots, and out through tips. Gear teeth cut on shaft just ahead of rear bearing mounting point drive oil return pumps. Turbine shaft is attached to compressor shaft by splined coupling.

Detail sketch of turbine disk showing method of attaching hollow blades. Groove in disk stub is filled with special high temperature silver-based brazing flux, blade is then pinned in place, and entire unit heated. Two small holes on ends of disk stubs direct cooling air through blade roots.

the top one.

Ducting from the combustion chambers to the turbine nozzle changes the air passage from the six circles to annular shape. Attached to the combustion chambers by bolts, this 19-gage aluminized mild steel unit is made in two parts, the rear of which is welded to a heavy flange. Studded to this flange from the inner shroud ring of the turbine nozzle assembly are two mild steel diaphragm plates. These, in turn, are studded to the rear end of the main casting, and so support the inlet ducting and turbine nozzle ring. On the rear of the outer turbine inlet ducting a light flange mates with a flange on the rear of the combustion chamber casing. Thus the turbine inlet ducting, to which the combustion chambers are attached, is supported partly the diaphragms, and partly by the skin.

Maintenance crews really take a beating as the result of the final design, for it is a major operation to get at the combustion chambers. First, the variable-area nozzle operating shaft must be removed so that the complete exhaust system assembly can be taken off. Then, unless special equipment is available, the engine must be placed upright on the turbine disk and burner pipes and ignition leads disconnected from the combustion chambers. Then the compressor casing-main casting joint can be broken and the whole front end lifted off. Next the rear compressor bearing assembly, torque tube, and locking ring can be removed and the main casting assembly removed – when the nut on the front end of the turbine shaft is unscrewed. The rear diaphragm plates can then be removed and the turbine inlet ducting and combustion chamber assembly lifted off. Then the front diaphragm plate is removed and the turbine inlet ducting, with the combustion chamber assembly, lifted out of the casing. At this point, as one sweating engineer who did the job declared, "Now, Bub, y'can take out the individual combustion chambers."

An unusual feature of the 004's design is the use of hollow turbine nozzle blades through which cooling air is fed from the compressor via the main casting and supporting diaphragm plates. The two-part outer nozzle shroud ring is made of mild steel and both parts are welded to a ring that is joggled and flanged to mate with flanges through 36 bolts on the inlet ducting and the aft flange of the combustion chamber casing. In addition to the bolt holes the flange has 36 sets of three holes for cooling air passage.

The 35 nozzles are made of austenitic sheet steel, .045 in. thick, bent to shape around a 1/16-in. radius to form the leading edge. Between the sheets at the trailing edge are spotwelded four wedge shaped spacers, 1 in. long and tapering from 1/8 to .020 in., leaving a .020-in. gap down the trailing edge through which the cooling air escapes.

In assembly, the blade tips are closed, pushed through slots welded to the outer shroud ring, and the roots are pushed through slots in the inner shroud ring and spotwelded in place on the inner surface of the ring.

To this ring, in turn, is welded a heavy, mild steel flange and second flanged ring, the two flanges picking up with the diaphragm plates which support the assembly from the rear of the main casting.

Two types of 61-blade turbines are used. Originally both blades and disks were solid, later hollow blades and lighter disks were introduced at a saving of approximately 40 lb.

The solid disks were of hardened chrome steel, taking stresses of about 15 tons at maximum rpm. Cooling is effected by spilling air bled back through the main casting against the disk face then up over the blade roots and out between the blades.

The 12¼-oz. solid blades are

forged from an austenitic steel containing 30% nickel, 14% chrome, 1.75% titanium, and .12% carbon, corresponding closely to "Tinidur," a Krupp alloy known before the war, and are attached by three machined lugs drilled to take two 11-mm. rivets each. Maximum centrifugal blade stresses have been estimated at 18,000 psi., and gas bending stresses at 2-4,000 psi. Study of the solid blades indicates that the roots didn't get much above 450 deg. C., due to the cooling air flow up from the disk, but near the center it appears the temperatures got up to about 750 deg. C. This applies to service models, not those previously mentioned as having given the longer flight and test-stand life.

Disks for hollow blade turbines are of lighter material than the solid types and have attached, across the front face, a thin sheet flared out near the center. This picks up the cooling air and, via ridges on the disk, whirls it out toward the blade roots where it goes through two small holes drilled in the disk rim up through the blade and out the tip.

Made of the same material as the solid blades, the hollow type are formed by deep drawing a disc through a total of 15 operations. In assembling the turbine, the blade roots are fitted over grooved stubs on the disk rim. Two small holes on each side take locating pins to hold the blades in place during assembly, but they take no stresses.

With a silver-base flux in the grooves, the entire unit is put in an oven at 6-800 deg. C., warmed for 20 min., then heated to about 1,050 deg. C. in 40 min., then cooled in still air at room temperature before hardening in a gas or air oven.

Later production units have two rivets in the blade trailing edges near the tips, a modification made necessary by cracking caused by vibration.

The turbine is attached by six studs to a short shaft carried no two bearings housed in the main casting. The front bearing is a single-race ball thrust, the rear a single-race roller type, and both are cooled by oil only Connection of the turbine and compressor is vi a heavy, internally splined coupling.

The exhaust cone is made up of aluminized mild steel, and consists of two major components: outer fairing is double skinned, with cooling air bled from the compressor flowing between the skins to within 15-3/4 in. of the exit where the inner skin ends. Outside the other skin from there to the end is another skin, flared at the leading edge to scoop in cooling air. It is attached by spot welded corrugations.

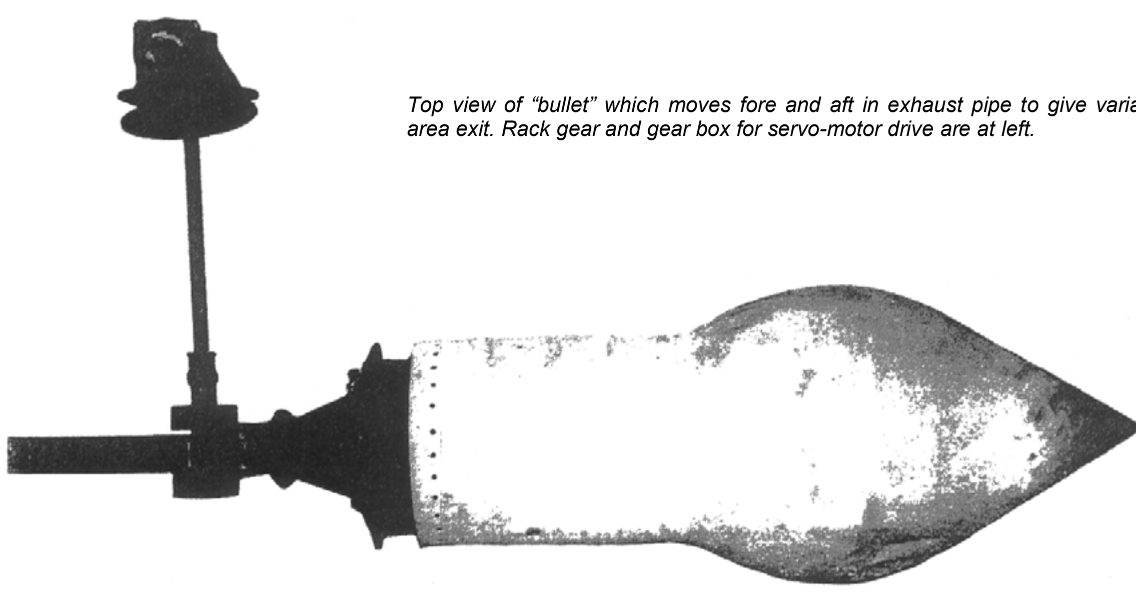
Attached to the outer fairing by six faired struts is the inner fairing, tapering from 19½ in. at the turbine end to 9¾. This unit houses a rack gear – driven by a shaft entering through one of the struts – which moves a "bullet" extending from its aft end. Actuating this bullet over its maximum travel of approximately 7-3/8 in. varies the exit area between 20 and 25%. It is set in retracted position for starting to give greater area and help prevent over-heating, then moved aft to decrease the area and give greater velocity for takeoff and flying. The movement is accomplished by a gear-type servo motor set near the accessory housing and connected by a long torque tube to gears set on the exhaust housing over one of the struts leading into the previously-mentioned rack gear.

Originally the unit was supposed to operate automatically over small ranges at extremely high speed and altitudes to give maximum efficiency, but on some engines examined the necessary lines had been blanked off. The two-position operation is obtained through a mechanical linkage with the throttle so that the bullet moves aft at between 7,000 and 7,500 rpm.

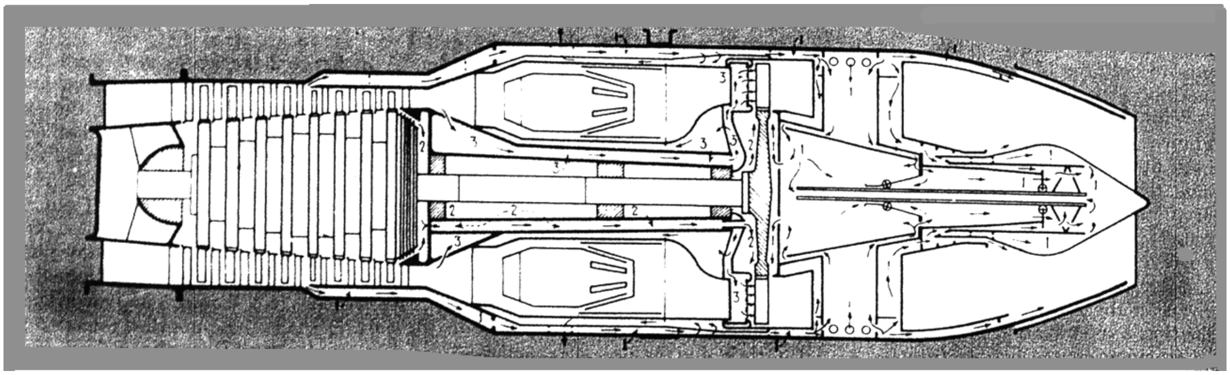
Since the necessary cooling system played a very important part in both the design and construction of the 004, it is felt best to note it briefly as a separate part of the study. It consists of three major stages, as follows:

1. Air bled off after the 4th compression stage.
2. Air taken off just after the last compression stage.
3. Air bled off between the compressor and combustion chambers.

In Stage 1 the air is picked up by



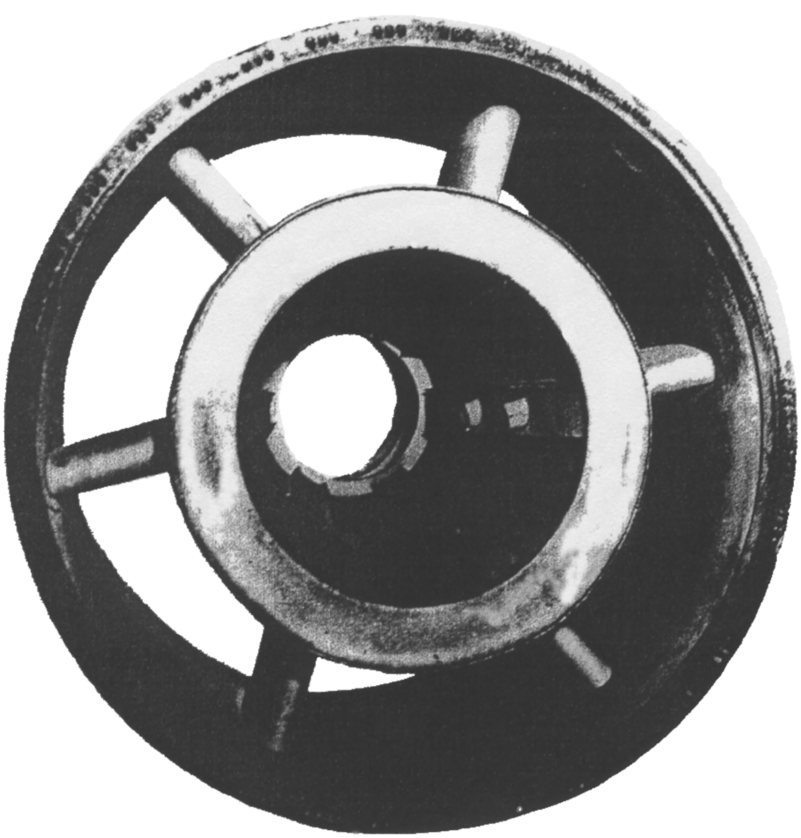
Top view of "bullet" which moves fore and aft in exhaust pipe to give variable area exit. Rack gear and gear box for servo-motor drive are at left.



Schematic diagram of cooling system, which takes well over 7% of total air intake. Stage 1 air, bled off after fourth compression stage, cools exhaust system. Stage 2 cooling air taken through serrations on last compressor disk, is directed through main casting to cool turbine disk and, on units with hollow turbine blades, through the blades themselves. Stage 2 air, taken off between compressor and combustion chambers, is carried through main casting to cool turbine nozzles. Not course of cooling air in and out of "bullet."

the ring after the 4th compressor row and is directed into six cored passages in the stator casting, then at the combustion chamber casing it is divided so that some of the air goes through six ducts in the combustion chamber casing skin, some goes inside the casing and around the chambers themselves. That which goes into the ducts continues aft and, through small holes in the flanges, between the double skin of the exhaust cone outer fairing. Majority of the air goes straight on aft to the end of the inner skin, but some is taken through the six struts connecting the inner fairing into that unit to cool the rack gear and bullet.

Front end of exhaust cone showing cooling air holes in outer falnge and faired struts supporting inner structure which houses rack gear for moving "bullet" to give variable area exit. Note cooling air inlets at root of strut at right.



In Stage 2 the air goes through the serrations between the compressor and the main casting, into two of the six cored passages in the casting back to the turbine. Here, on the original engines, it was spilled against the face of the turbine disk and moved out to escape between the turbine blades. On engines with hollow blades, however, the air is ducted across the space between the two diaphragm plates supporting the turbine disc where it is picked up by ridges and forced up through the turbine blade roots out through the blade tips.

Stage 3 cooling air, bled off between the compressor and combustion chambers, is ducted through three passages in the main casting to the space between the turbine nozzle-supporting diaphragms, then up through the turbine nozzle vanes and into the slip-stream through the trailing edges of the vanes.

It is estimated that Stages 1 and 3 take approximately 3% each of the total air movement, and that Stage 2 probably takes at least half as much; thus better than 7% of the available flow is taken off because of a lack of higher heat-resistant alloys. Additional performance penalties are evident in the fact that ducting is necessary, complicating both the weight and production pictures.

Air is not the only cooling medium, for the lubricating system too is employed. In this system, two gear pumps circulate lube oil to the front compressor bearing assembly, the accessory-drive bevel gears, and the accessory gears. Another supplies oil to lubricate and cool the rear compressor and both turbine bearings, the latter two being sprayed and splashed, respectively.

The two main pumps, mounted beneath the engine and driven from the bevel gears through a nose casting strut, deliver 190 gal./hr. each. The two-part scavenge unit is built into the turbine bearing housing and is driven by a gear cut into the sleeve which serves to return oil to the cooler. In level flight, one part of the unit, a 300 gal./hr. puma, returns oil through one of the cored passages in the main casting, then through a passage in the stator casting to the pump in the bottom of the intake casting. In climbs, the other part, a 90 gal./hr. gear pump, picks up the oil and feeds it into a common return line to the air-oil separator. Oil is returned from the main pump to the separator by a 300-gal./hr. driven by the same shaft as the delivery pumps.

Two types of fuel are used on the 004: gasoline for starting and J-2 brown coal "crud" for running. The gasoline is carried in the lower part of the annular tank set in the nose cowling, and is automatically cut off after ignition at about 3,000 rpm. This is fed by an electrically driven pump delivering 80 gal./hr. at 28 psi. Near the end of the war it was found that centrifugal crude oil was also used as operating fuel.

The main single-stage electrically-driven gear type pump has a maximum delivery of 500 gal./hr. at 1,000 psi. at 3,000 rpm.

Most interesting of the accessories is the all-speed governor, a 17-lb. unit consisting basically of a centrifugal governor, oil pump and spill and throttle valves. In operation, oil goes through a passage to the pilot piston and is distributed to outer faces of either the spill or follow-up piston, depending on movement of the flyweights. Both the pistons move at the same time, adjusting the fuel spill to counteract changes in engine speed. The distance between the spill and follow-up pistons varies according to the flow of oil through the passages so that the spill piston action is a step-by-step operation controlled by the follow-up which returns to normal position after each step. A throttle valve is linked with the governor cam so that when the throttle is advanced the fuel flow increases and response is immediate. The governor then takes over and adjusts the engine speed to a predetermined value set by the position of the cam.

ACKNOWLEDGEMENT

• In addition to the staff of the Foreign Equipment Branch, Technical Data Laboratory, ATSC, *AVIATION* extends heartfelt thanks to Col. R,L, Wassell, Chief Special Research Branch, Power Plant Laboratory, ATSC; Lt. Col. P.F. Nay, Assistand Chief; Maj. R.I. Berge, Administrative Officer; Capt. W.C. Gerler, Project Engineer; and Mr. A.T.Miller, Chief Technician.

General Data

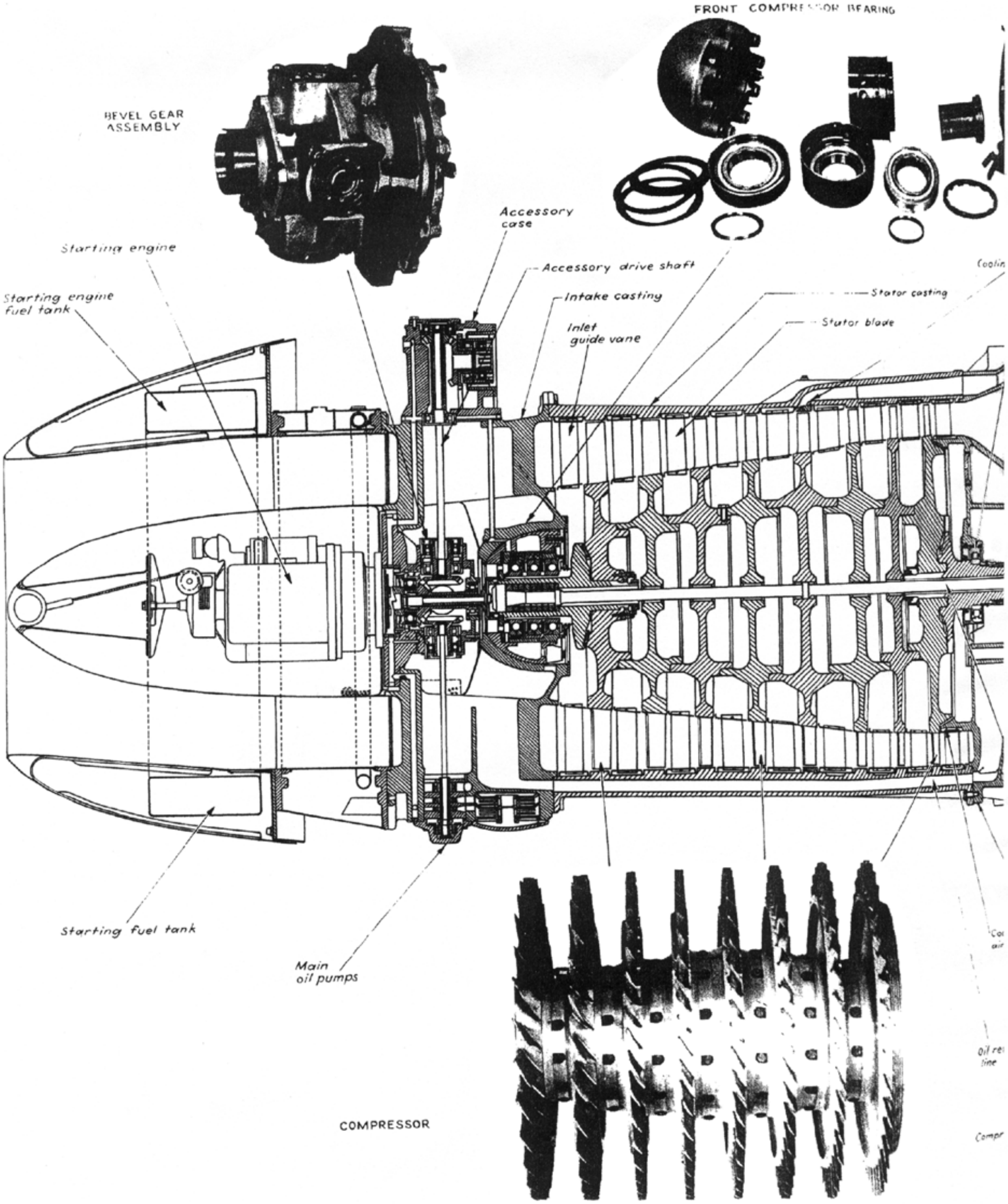
Wt. (without cowl)	1,669 lb.
Wt. (with cowl)	1,775 lb.
Specific wt.	.85 lb
Thrust	1,970 – 1980 lb.
Pressure ratio	3:1
Fuel consumption	2,720 – 2,745 lb./hr.
Maximum speed	8,700 rpm.
Idling speed	3,080 rpm.
Idling speed fuel consumption	614 lb./hr.
Length	152 in.
Maximum dia.	34 in.
Frontal area (cowled)	6.4 sq. ft.

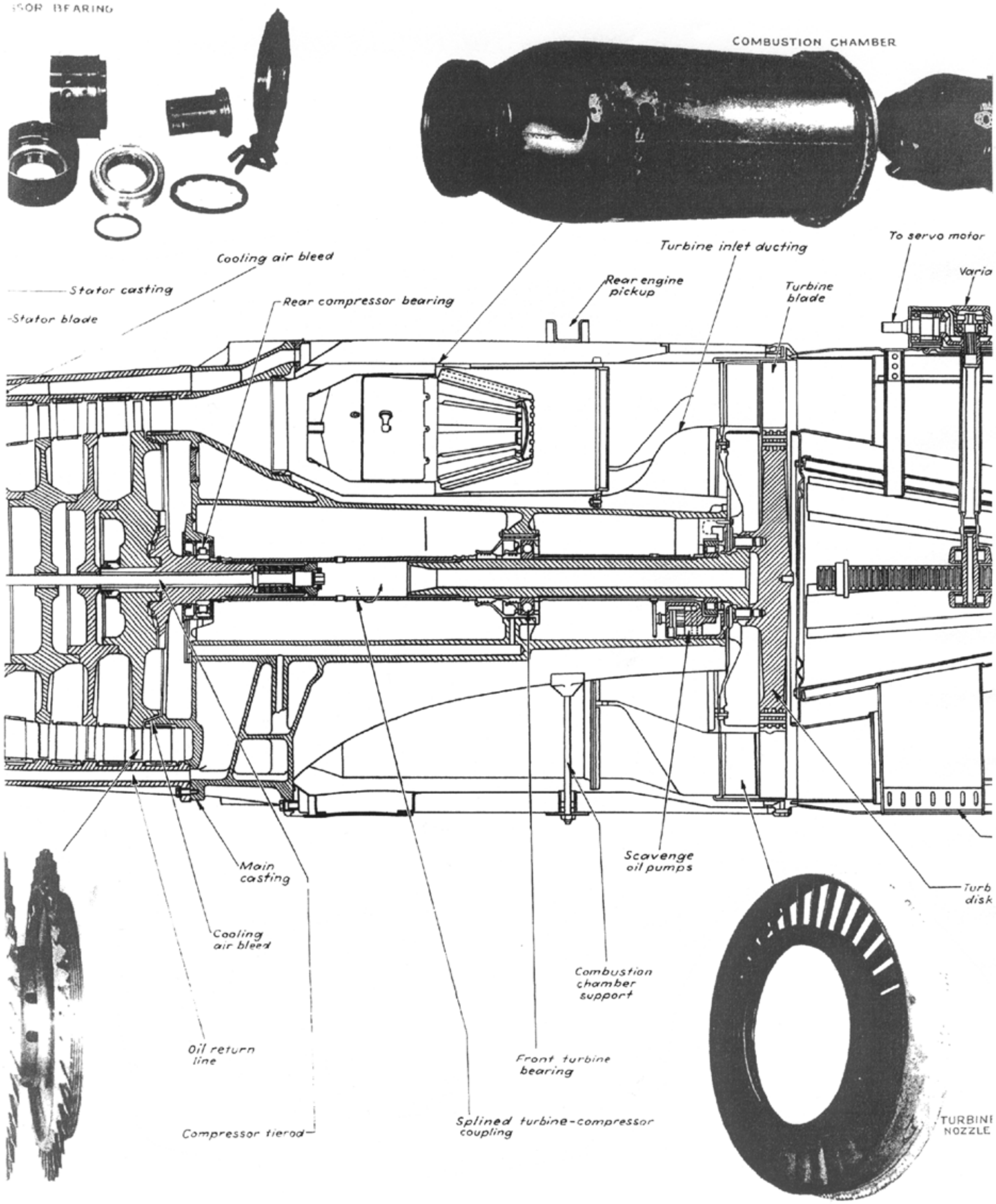
Number of Blades, Compressor

	Stator	*Rotor*
Inlet guide	32	. . . .
1	61	27
2	61	27
3	59	38
4	61	38
5	61	38
6	71	38
7	71	38
8	57	38

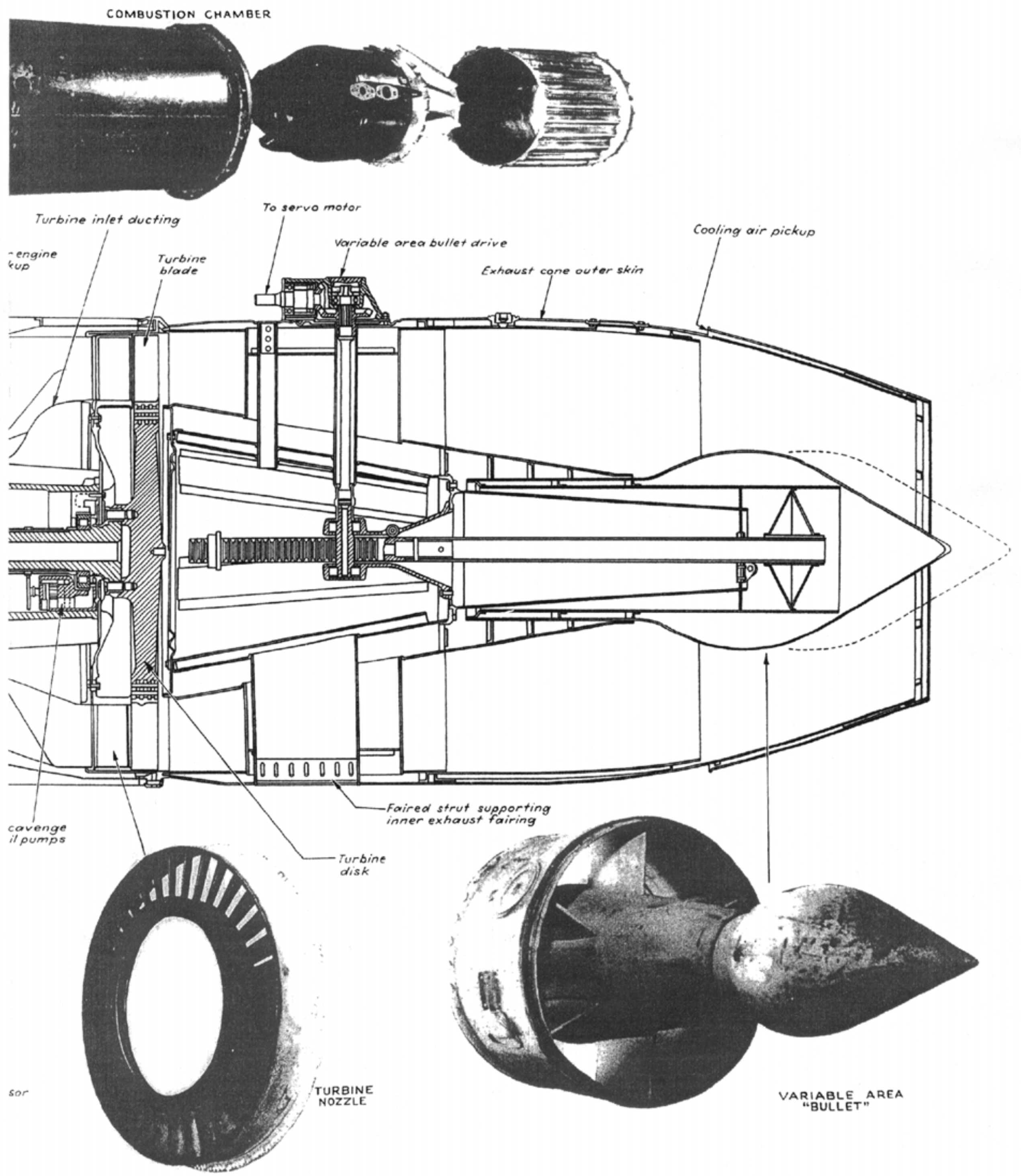
Junkers Jumo 004 Weight Table

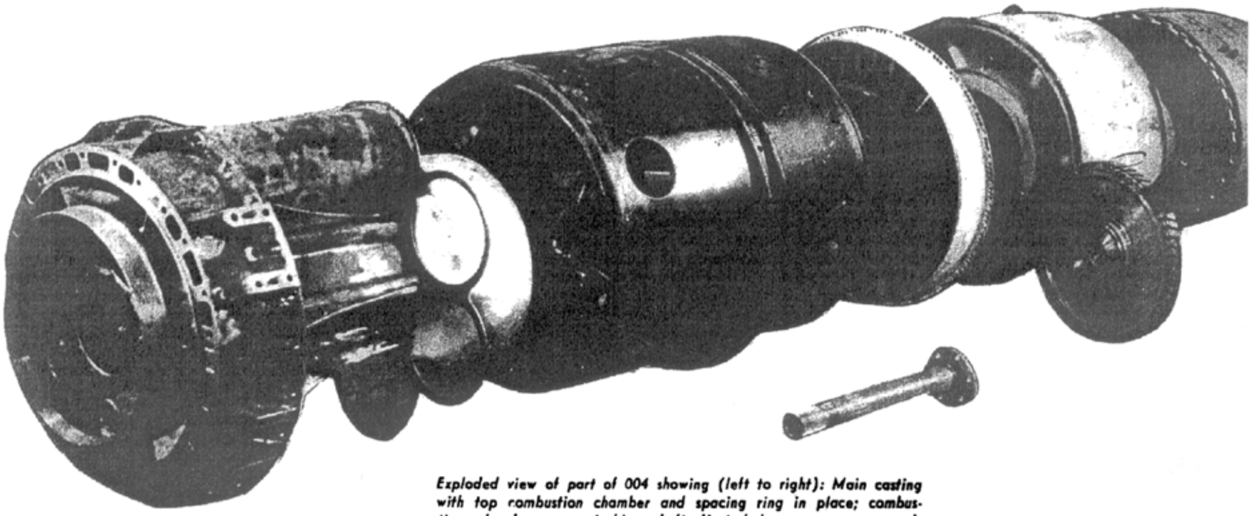
Intake	
Casting with oil pumps, filter	57 lb.
Bevel gear assembly & drive shafts	18 lb.
Gear box & drives	35 lb.
Front compressor bearing assembly	25 lb.
	135 lb.
Compressor	
Stator csting & blades	200 lb.
Rotor with stub shaft & tie rod	220 lb.
Center Section	
Main casting & fittings	163 lb.
Utter casing & fittings	100 lb.
Rear compressor bearing assembly	6½ lb.
Front turbine bearing assembly	7½ lb.
Rear turbine bearing assembly & scavenger pumps	9 lb.
	286 lb.
Combustion	
6 chambers burners, igniters, & interconnectors	116 lb.
Turbine	
Inlet ducting & joint rings	42 lb.
Nozzle assembly	43 lb.
Diaphragm plates	10 lb.
Disk & blades (solid)	151 lb.
Shaft, sleeve, fittings	30 lb.
Compressor coupling	7 lb.
Exhaust	
Bullet assembly	190 lb.
	1,430 lb.
Accessories	
Oil tank	27 lb.
Fuel pump	9 lb.
Governor	17 lb.
Tachometer	1½ lb.
Air-oil separator	4 lb.
Bullet control servo motor	17½ lb.
Drive shaft for bullet	4 lb.
Fuel filter	2 lb.
Fuel non-return valves	1 lb.
Throttle linkage	7 lb.
Misc. fittings & attachments	25 lb.
Engine mount brackets	15 lb.
	115 lb.
Starter	
Starter engine	36 lb.
Gasoline tanks & supports	20 lb.
Gasoline pump	6 lb.
Igniter coils	3 lb.
Net dry weight with starter	1,625 lb.
Accessories	
Generator fittings	36 lb.
Hydraulic pump	8 lb.
	4 lb.
Cowling	
Starter engine cowling	4 lb.
Starting fuel tank cowling	17 lb.
Remainder of cowling	85 lb.
	106 lb.
Total dry weight, completely cowled engine	1,175 lb.


FRONT COMPRESSOR BEARING
BEVEL GEAR ASSEMBLY
Accessory case
Starting engine
Accessory drive shaft
Starting engine fuel tank
Intake casting
Stator casting
Inlet guide vane
Stator blade
Starting fuel tank
Main oil pumps
COMPRESSOR

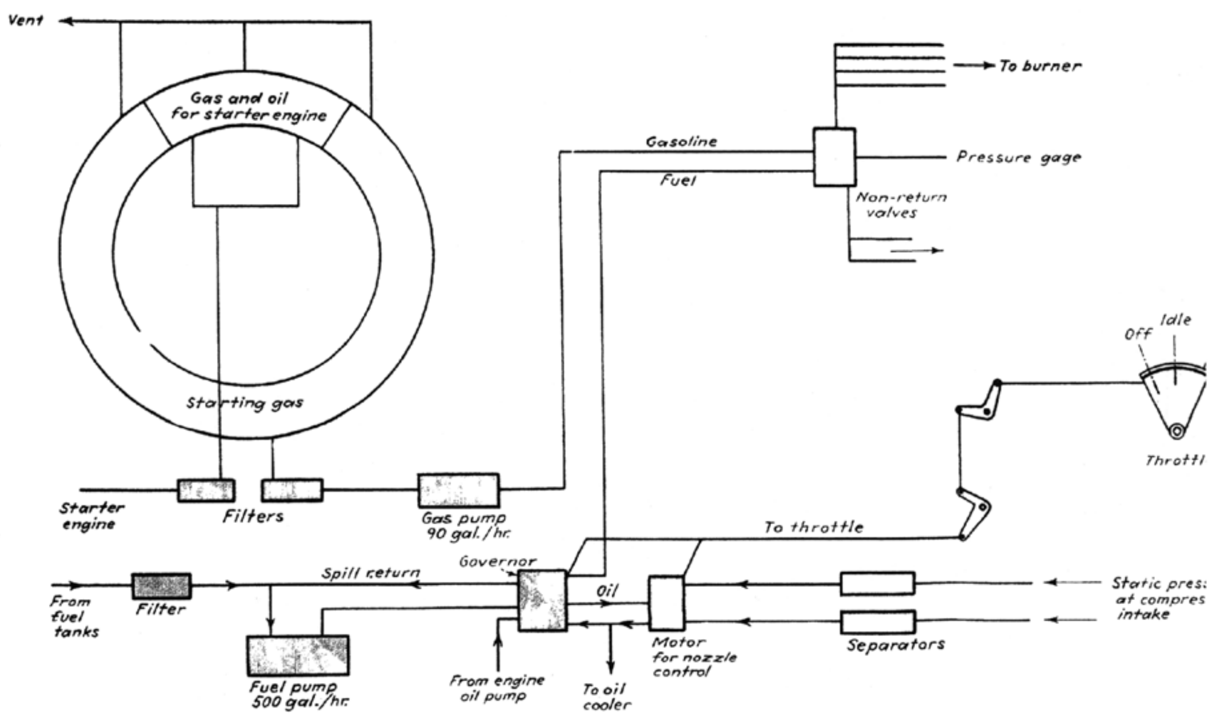


SOR BEARING
COMBUSTION CHAMBER
Cooling air bleed
Stator casting
Stator blade
Rear compressor bearing
Rear engine pickup
Turbine inlet ducting
Turbine blade
To servo motor
Scavenge oil pumps
Main casting
Cooling air bleed
Combustion chamber support
Oil return line
Front turbine bearing
Compressor tierod
Splined turbine-compressor coupling
TURBINE NOZZLE

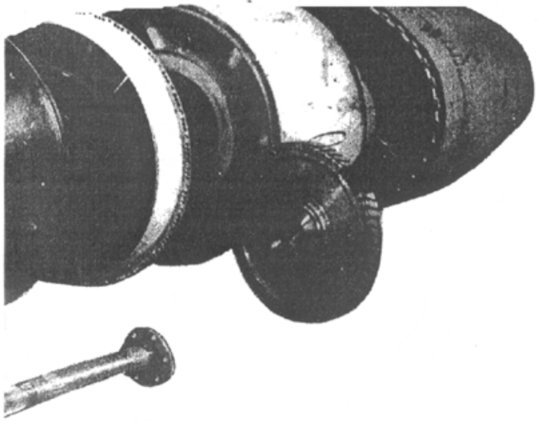

COMBUSTION CHAMBER
Turbine inlet ducting
To servo motor
Variable area bullet drive
Cooling air pickup
Turbine blade
Exhaust cone outer skin
Faired strut supporting inner exhaust fairing
Turbine disk
TURBINE NOZZLE
VARIABLE AREA "BULLET"



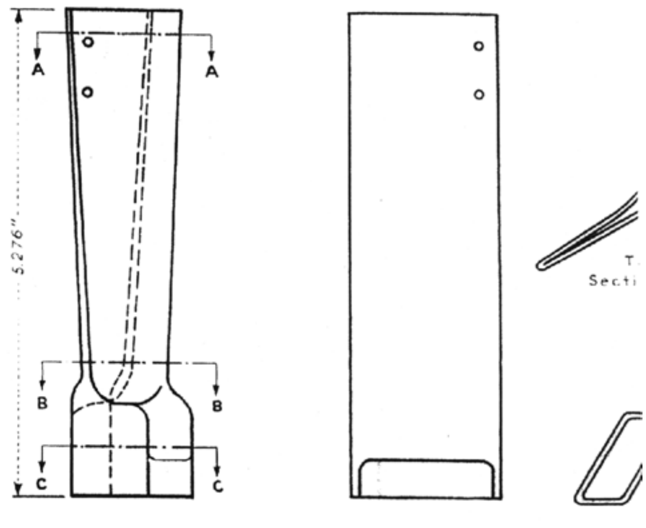
Exploded view of part of 004 showing (left to right): Main casting with top combustion chamber and spacing ring in place; combustion chamber case; turbine shaft (just below compressor case); turbine nozzle; turbine (in line with shaft), with three hollow-type blades in place; and exhaust system with tail cone pulled away to show part of exhaust "bullet" for giving variable area exit.



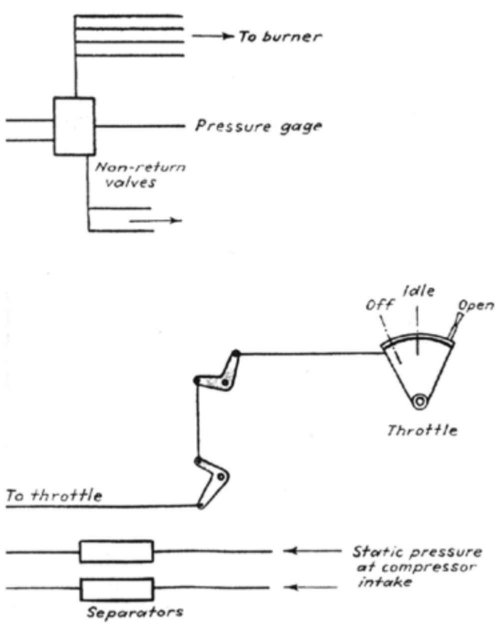
Diagrammatic layout of fuel and exit area control system.



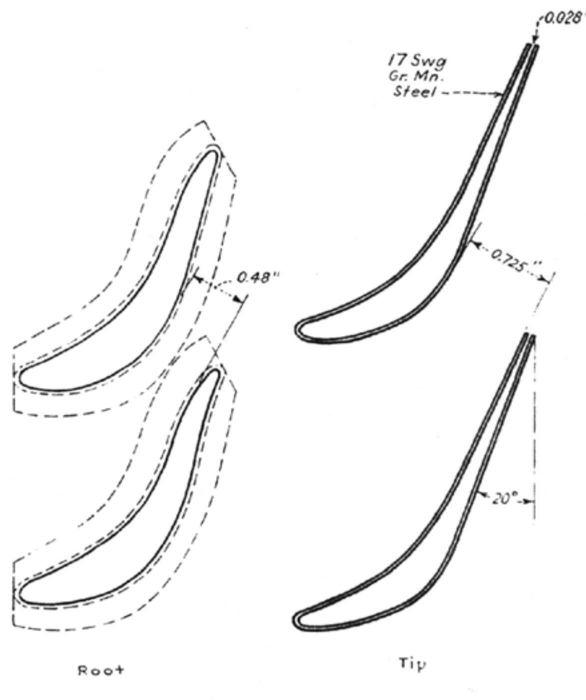
…t): Main casting
… place; combus-
…ompressor case);
…three hollow-type
…one pulled away
…iable area exit.



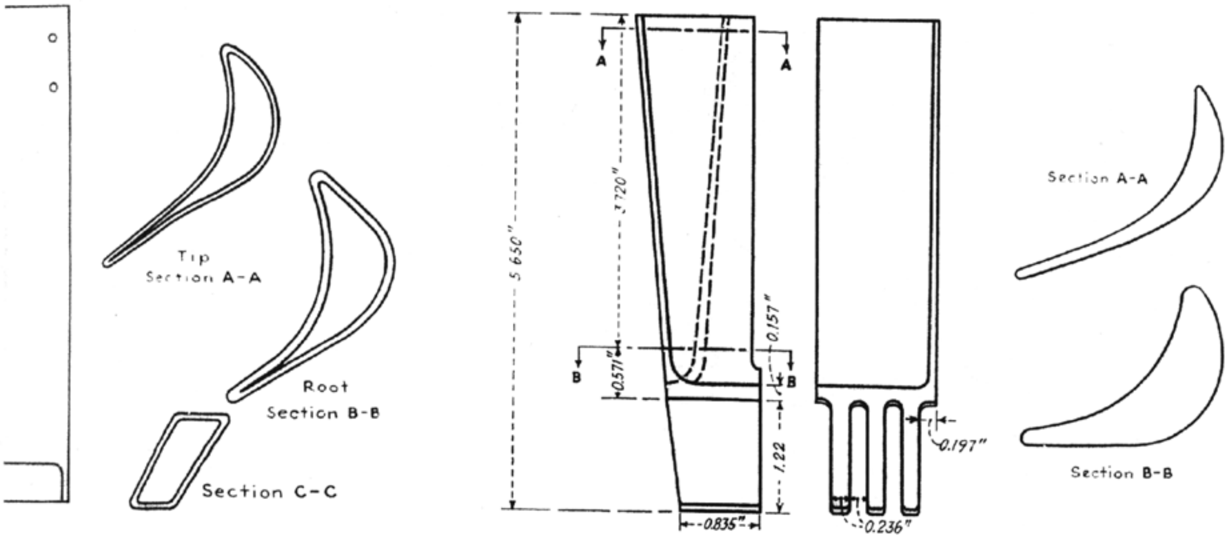
Sketches showing dimensions of hollow t…
turbine blades. Original 004s used solid b…



…ntrol system.



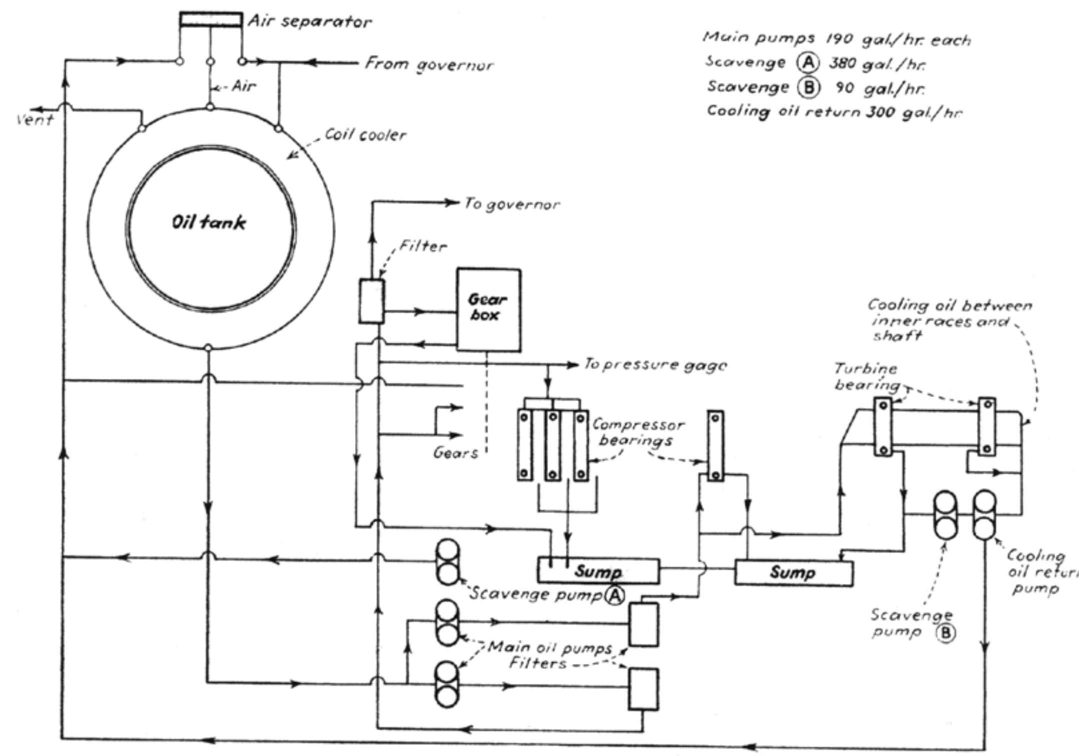
Cross sectional sketches of turbine nozzle roots (left) and tips (right). Engine has 35 nozzles, with nozzle throat area of 84 sq. in.



URBINE BLADE

Solid Turbine Blade

showing dimensions of hollow type (left) and solid type (right) odes. Original 004s used solid blades; later units used hollow type which, combined with lighter turbine disk, saved some 40 lb. in weight and gave slightly longer service, since cooled blades had longer life.



Schematic diagram of lubricating system.

Edit ors note:

This article was originally published in the October and November, 1945 issues, Volume 44, numbers 10 and 11, of *Aviation* magazine, published by McGraw-Hill Publishing Company of New York, NY, USA.

This reconstruction is derived from microfilm. The source is University Microfilms International, Publication No. 364 (*Aviation Week and Space Technology*), Reel No. 21 (January 1945 – December 1945). The source was a tightly bound volume, so that there is some distortion of the images, especially near the binding. It has not been practical to remove or compensate for all the distortions, so none of the illustrations in this reconstruction should be considered reliable sources as to fine details of shape, proportion or spatial relationship. The distortions are, in general, small, and should not detract from a general appreciation of arrangement and relationship.

The editor has attempted to represent the original layout of the article, but there are some exceptions. Limitations in the compositing tools cause a difference in the text flow relative to the illustrations, compared to the original, so that some changes have been made, to compensate partially for that effect, and the tabular data have been removed from the flow of text and brought together on a single page after the text, partly to make them more accessible, and partly to sidestep problems with page layout. In addition, the original Part II article contained a foldout. Images from that sheet have been added at the end of the article. The images have considerable overlap, so that no information is lost, even though it is not practical to reproduce the original illustrations.

This article was one in a series of design analyses published in *Aviation* during the war years, between May 1943 and November 1945. The subjects were the Bell P-39 *Airacobra*, Curtis C-46 *Commando*, Fleetwing BT-12, Douglas A-20 *Havoc*, Bristol *Beaufighter* (British), deHavilland *Mosquito* (British), North American P-51 *Mustang*, Lockheed P-38 *Lightning*, Focke-Wulf FW-190 (captured German), Boeing B-17 *Flying Fortress*, North American B-25 *Mitchell* (specifically, the B-25H and B-25J models), Mitsubishi “Zeke 32” *Hamp* (captured Japanese), Consolidated Vultee B-24 *Liberator*, Fairchild C-82 *Packet*, and Messerschmitt Me-262 (captured German), with one article dealing specifically with the Me-262's Jumo 004 jet engine. Some of the analyses were authored by senior members of the design teams at the original manufacturers, while others were written by staff editors of *Aviation* magazine.