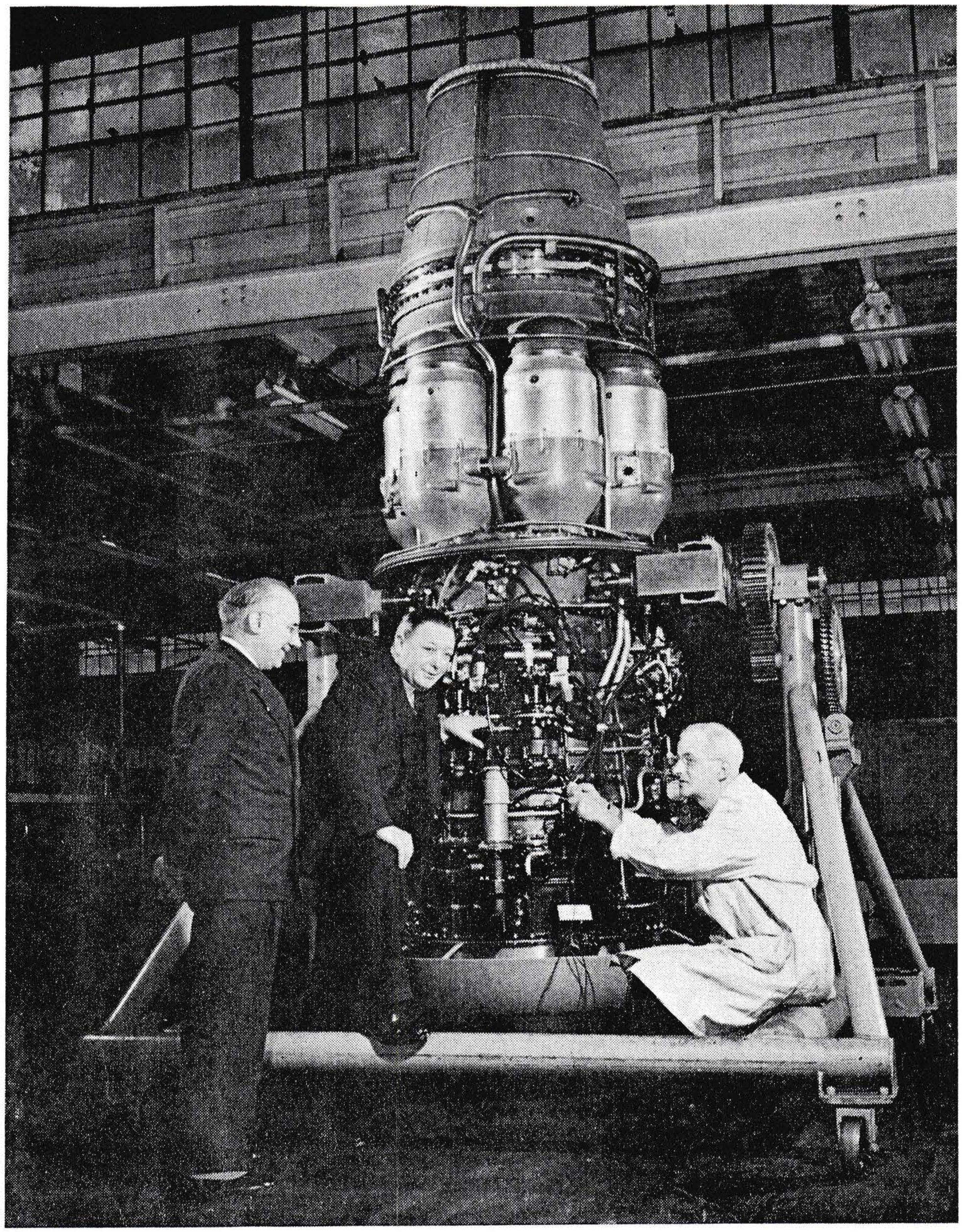
MANUFACTURING THE AVRO ORENDA JET ENGINE

New Horizons of Accuracy In Production as Canadian Gas Turbine Graduates From Experimental Stage

By
J. E. NESBITT
Gas Turbine Division
A. V. Roe (Canada) Ltd.



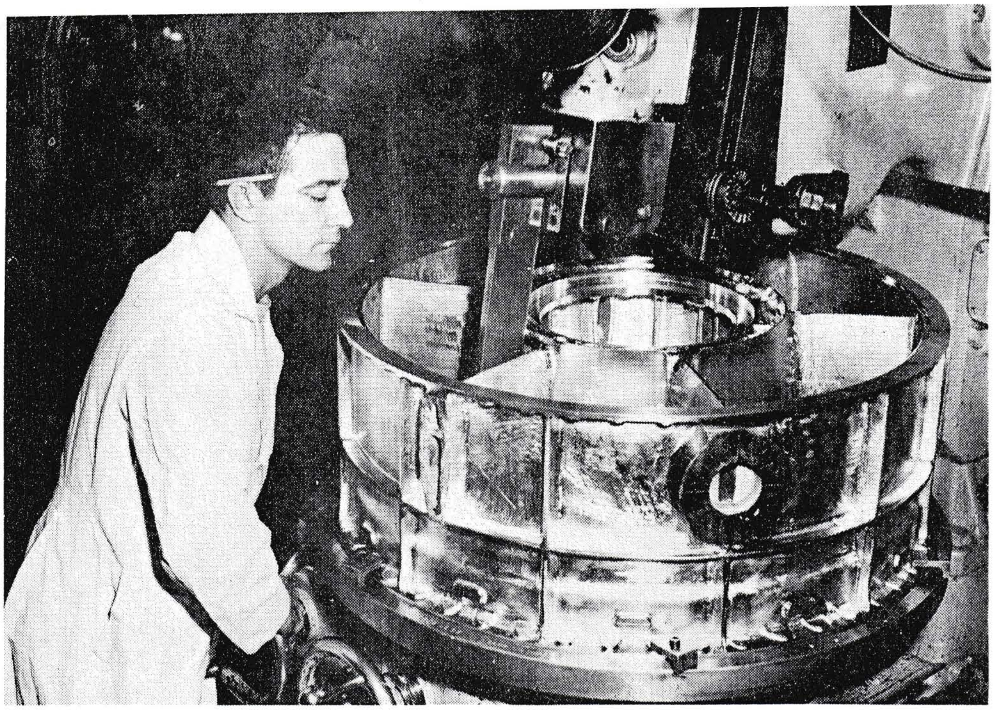
Sir Roy Dobson, C.B.E., J.P., F.R.Ae.S (centre), president of Avro Canada, examines the Orenda with Walter N. Deisher, general manager (left) and Stanley Anderson. (To the great Iroquois tribe, Orenda was the ultimate source of all power—the impersonal being from which supernatural beings in turn derived their power.

JET PROPULSION of aircraft is achieved simply by directing a stream of rapidly expanding gases of sufficient force to overcome the inertia of the aircraft, in a manner which will propel the aircraft in the required direction. There are at present three types of jets—the rocket, the ram, and the gas turbine. For many reasons not important here it has become apparent that the gas turbine is the most practical jet for today's need and that the axial flow gas turbine, such as the Avro Orenda, offers the best possibilities for development.

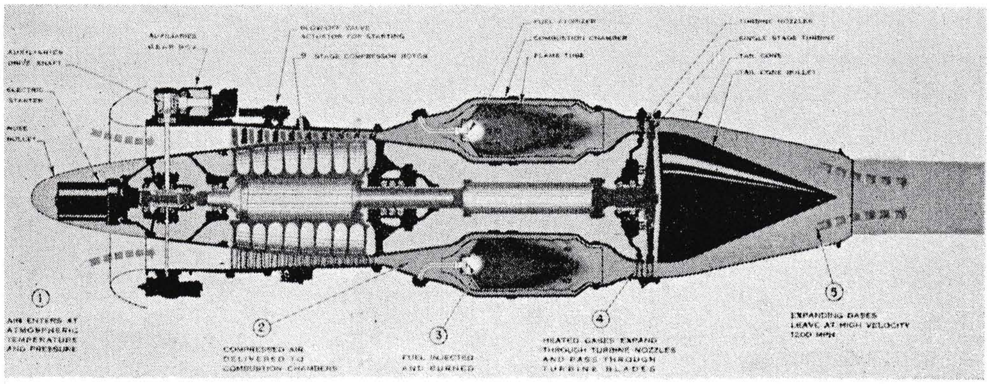
Functioning of gas turbine engines depends on four main components—a compressor, expanding air from which produces the jet stream, a combustion system to boost the rate of expansion, a turbine to drive the compressor and a tail cone to produce an effective jet stream. The compressor in the axial flow engine is made up of rows of rapidly rotating blades spaced by rows of stationary blades in a passage which becomes progressively smaller. The Orenda has more than 1,000 blades. The turbine in the Orenda is made up of a single row of blades driven by the jet stream just forward of the tail cone and mounted on the rim of a disc which is directly coupled to the compressor shaft and thus drives the compressor.

The problems in manufacturing gas turbines arise from the main factors which control design. These factors are three closely related ratios which we will call Power-Weight, Weight-Strength and Strength-Temperature. Examining these in order will give a clear picture of general production difficulties.

The power-weight factor is common to all aircraft engines and is



Left: Fig. 3—Compressor intake casting in vertical shaper.



Above: Fig. 2—Diagram of operation of Avro jet engine. This section shows the earlier smaller Chinook engine.

now generally familiar. Obviously an aero engine becomes better if its weight drops as its power increases. Power-weight has two main design effects: all possible useless material is trimmed from every part and the lightest possible material is used in every case. These effects present the first manufacturing troubles, for as material is trimmed from parts they become more intricate and thus much harder to cast and machine, and much harder to hold as machining goes on. Also lighter materials cannot stand the holding and cutting pressure in regular use. Further, the accuracies and finishes required in gas turbine parts are generally considered practically impossible, even by today's standards.

Weight-Strength

The weight-strength factor is a direct offspring of power-weight and should be easily understood, for it must be obvious that while weight reduces strength must not, and, indeed, must increase in proportion to power. Thus strength becomes doubly important. Weight-strength is a prime consideration in all airframe and engine design, but in gas turbines the problem is greatly intensified. It must be remembered that the gas turbine engine, while giving speed and power utterly impossible from reciprocating engines has actually only one moving part and this part weighing many times as much as the crankshaft of a reciprocating engine and traveling at many times its speed must do all the power-producing work of the engine. This part, the compressor and turbine rotor assembly or simply rotor, is made up of hundreds of smaller parts, each one made and fitted so accurately that the entire assembly will be as one piece and in perfect balance, for unbalance produces vibration, and vibration can tear an engine to pieces in a matter of moments.

The weight-strength factor has effect on every single part of the engine, for while the rotor parts must produce their mighty power, the static parts must contain and direct this power while their weight must still be at a minimum. The manufacturing difficulties resulting from weight-strength are mostly evident in the decreased machinability resulting from increased strength and the extremely high standards of accuracy and finish which must be

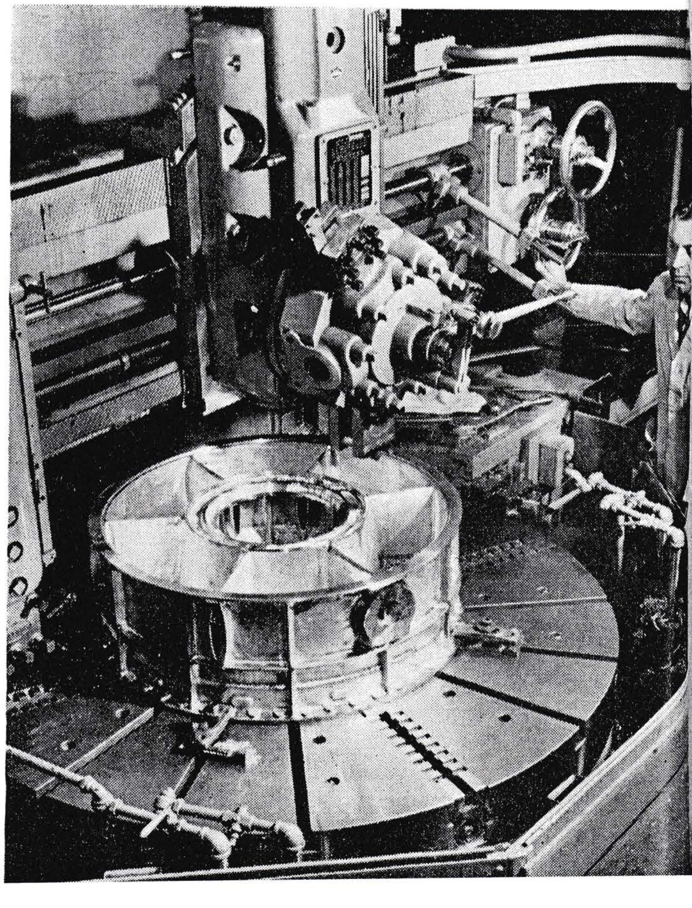


Fig. 4—Turning compressor intake casting in Bullard Man-au-Trol.

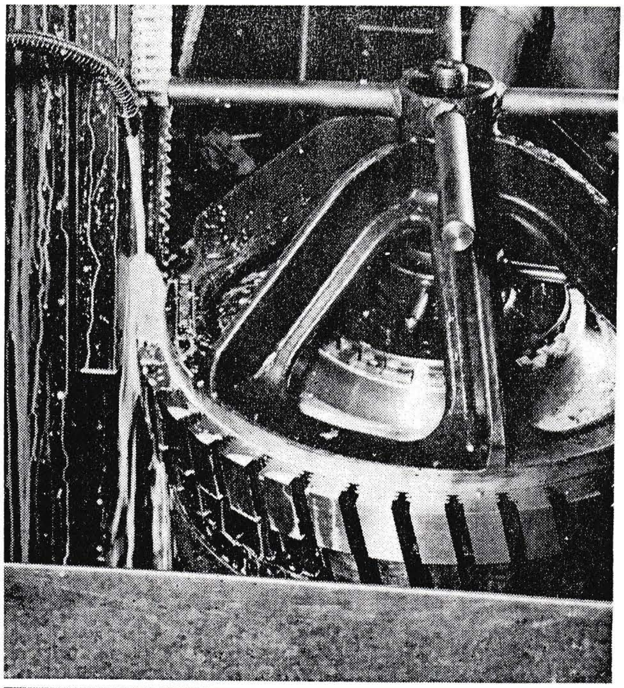


Fig. 8 — Broaching fir-tree slots in compressor disc.

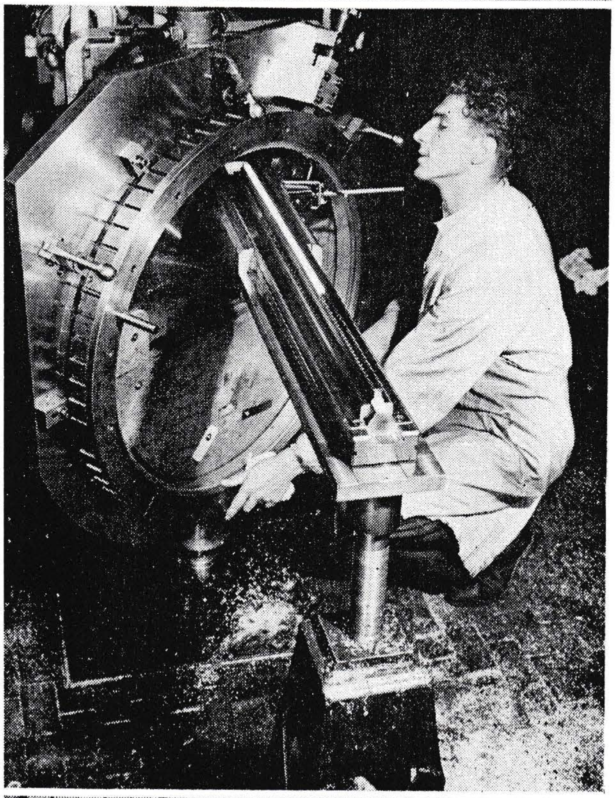


Fig. 7—Broaching internal slots for blades in compressor stator ring.

maintained. A simple compressor rotor disc which must fit as accurately as a tiny instrument part must often sustain loads of close to half a million pounds, yet these discs are made of aluminum alloy and run as thin as .150 in. in the web. Obviously even an imperceptible finish imperfection finish on a part could have disastrous results.

Strength-Temperature Factor

WE HAVE SEEN how the weight-strength factor introduces new manufacturing standards, but we have not yet taken into account the fact that many parts of the gas turbine engine must operate in temperatures which would render even the strongest ordinary materials so soft and plastic that they would soon fail under the stresses imposed. This problem shows up in the strength-temperature factor, for, as is well known, the rule in metals is that as temperature increases strength decreases, while the opposite effect is required in gas turbines. This has brought about the development of a whole new range of materials with truly amazing characteristics.

To point up the strength-temperature effect let us consider the turbine blades—these blades which sometimes travel well beyond the speed of sound at ordinary temperatures, are run red-hot, and yet must be able to stand pressures that from centrifugal force alone amount to many thousands of times their own weight. Further to this, the materials from which these blades are made must be readily forgeable for manufacturing purposes. Impossible as it sounds, this has been achieved. The manufacturing troubles brought in by strength-temperature are mostly in the cutting and forming of the new metals, for these metals which

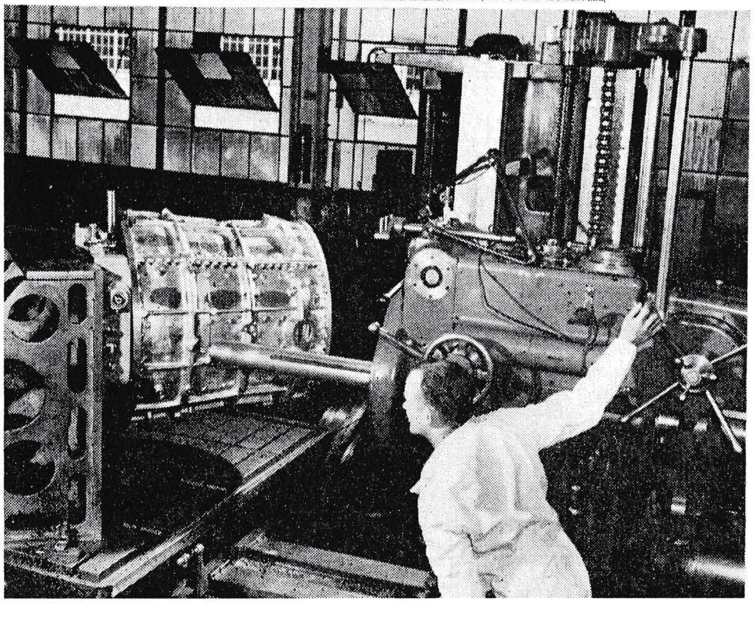


Fig. 5—Boring compressor stator housing in Air-Gage tracer lathe.

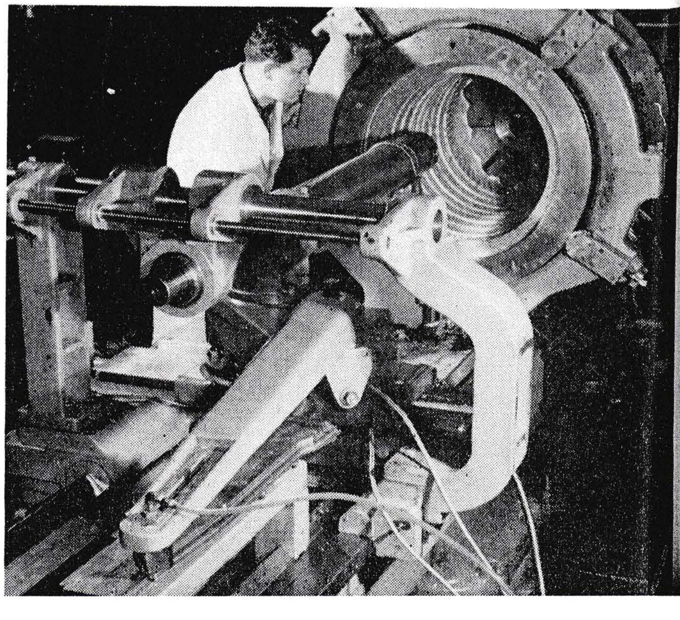
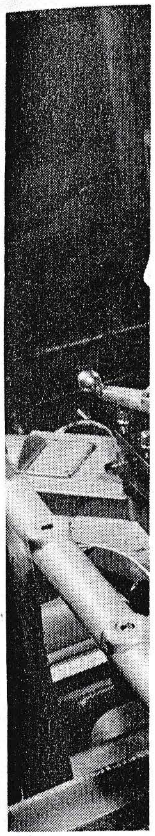


Fig. 6—Universal horizontal boring machine drilling bosses in assembled compressor housing.



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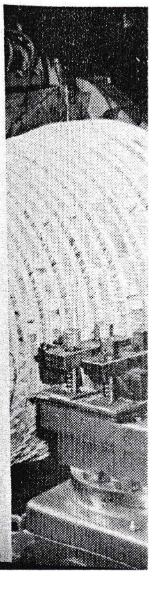


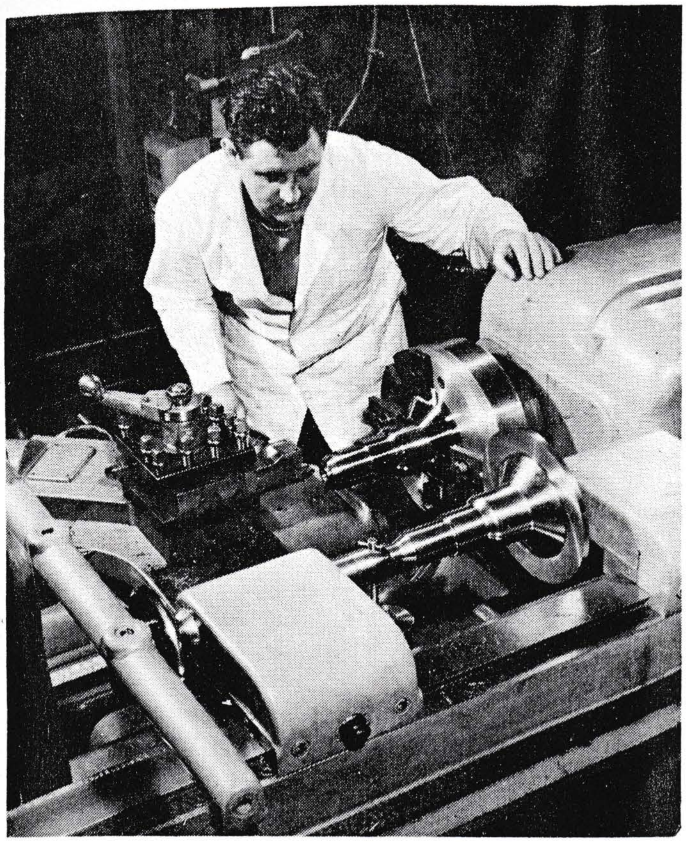


Fig. 9—Tracer lathe copying shaft coupling element from a master. Requirements of accuracy and finish are most exacting.

retain their strength at high temperatures are almost unworkable at low temperatures. In fact some of our present materials are so tough that they cannot be economically cut and must be precision cast and then ground. Strength-temperature, therefore, has required the establishment of radical techniques and may eventually result in a new conception of all standard metalworking practice.

EXPERIMENTAL DIVISION SHOPS

The gas turbine experimental shops at Avro Canada employ probably the largest body of highly skilled mechanics in the country and contain, as well as all types of the latest machine tools, many machines developed by Avro for operations peculiar to gas turbines. To best consider the tools and techniques used in making these engines it will be as well to detail the sections into which they are divided for design and control of manufacture. (Blades and vanes will not be taken in their assemblies, as they are a section in themselves.)

THE COMPRESSOR intake is essentially a casting of magnesium alloy and consists of two concentric rings joined by six hollow struts of airfoil section. The outer ring is about 34 in. in diameter by about 12 in. long. The passages between the rings and struts form the air intake, while the inner ring houses the front bearing, power take-off and the starter. Through the hollow struts pass the power take-off shafts as well as oil and electrical connections.

Beyond extremely close machining tolerances, particularly as to concentricity, the intake casting presents no great manufacturing difficulties although the annular faces of the air passages, which are worked out (fig. 3) on a Pratt and Whitney vertical shaper, require very close attention. All turning on this casting is done (fig. 4) on a Bullard vertical turret lathe, while horizontal boring mills and radial drills complete the work. The air passage is faired in by hand to give smoothest possible airflow.

It might be as well to mention at this point that while the major engine castings present varying degrees of machining difficulty, one thing they have in common is their extreme complexity to the patternmaker and foundryman. While the techniques developed to overcome these problems are of great interest, unfortunately they are not within the scope of this article. Light Alloys Limited of Renfrew, Ont., and the Aluminum Co. of Canada have done notable work in producing these castings.

The compressor is made up of two main components, the stator and the rotor. The stator also forms the casing for the compressor assembly.

Fig. 10 — Turning blade tips in special Bertram lathe fitted with Turchan follower.

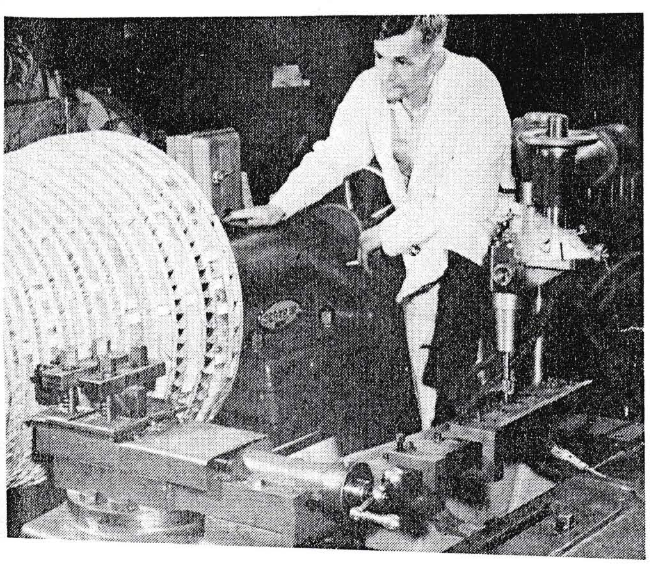
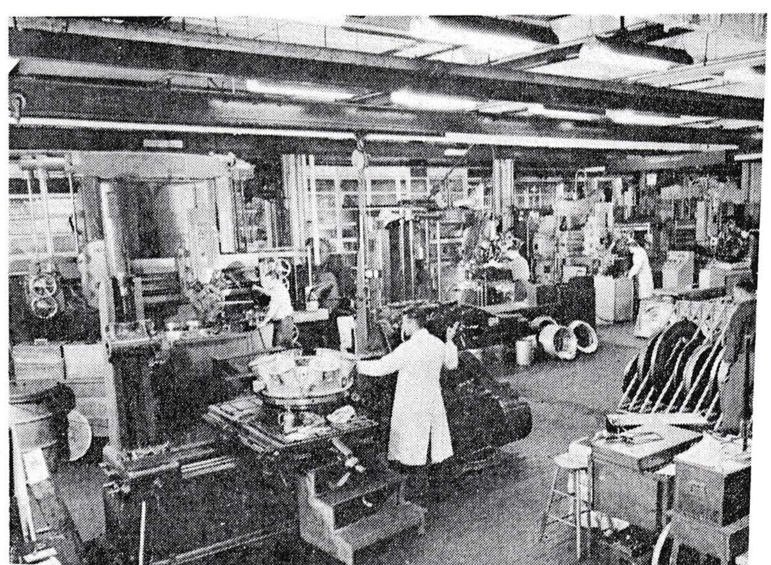


Fig. 11 — In foreground, diffuser casting in horizontal boring machine.



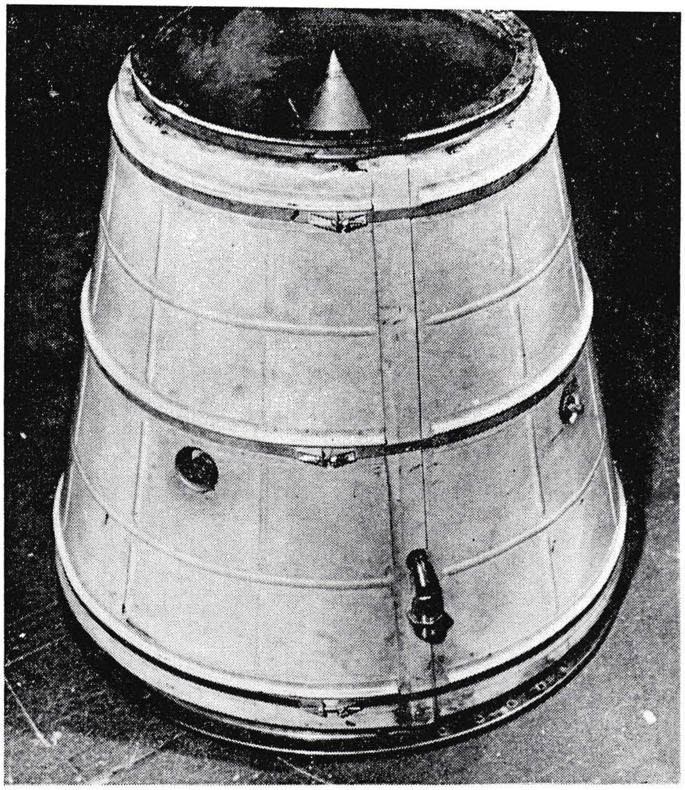


Fig. 14 — Tail cone assembly introduces new requirements of accuracy to sheet metal work.

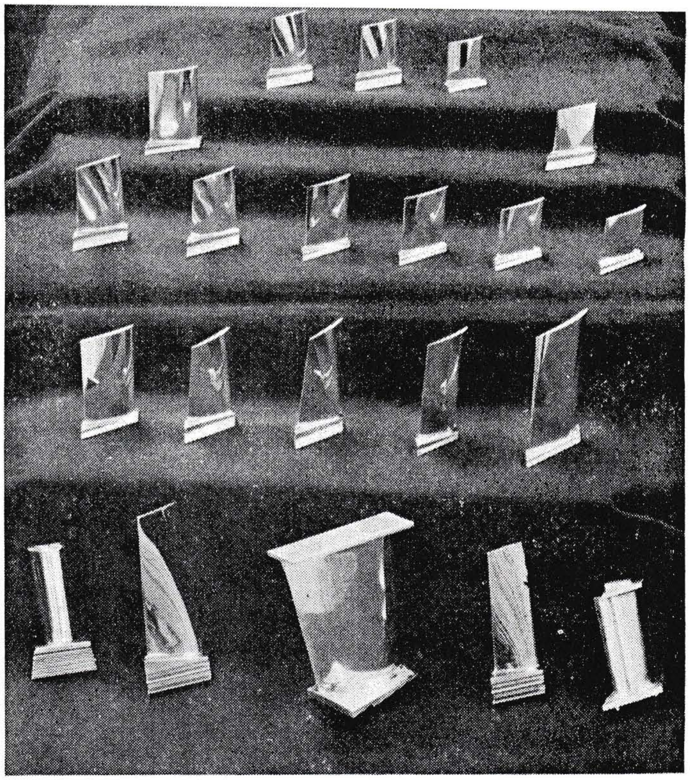


Fig. 15 — Variety of aluminum blades and vanes that go to make up a gas turbine compressor.

Compressor Stator

THE STATOR CASE consists of two semicylindrical magnesium alloy castings which are fitted together after the joint and end faces are squared up on a horizontal boring mill. The conical cylinder thus formed is then bored on a Monarch Air-Gage tracer lathe (fig. 5) in a series of concentric steps and angles as well as three deep grooves which form air passages to bleed off excess and cooling air. After this boring operation the stator returns to the horizontal boring mill for machining of various exterior bosses (fig. 6) and mounting pads.

The casing is then ready to receive the blade rings and spacers, which are of aluminum alloy. The spacers are plain rings while the blade rings have a number of dovetailed slots through their inner faces to hold the dovetail roots of the stator blades. These slots are broached in a special fixture (fig. 7) on a horizontal broaching machine. After the rings are fixed in the casing the entire assembly is set up on the Monarch tracer lathe and the airflow contour machined on the passage formed by the inner faces of the rings. The blades are now mounted in the rings and after pouring wax between the blades to support them the blade tips are machined to the contour of the inner air passage, again in the tracer lathe.

Compressor Rotor

THE COMPRESSOR rotor consists of discs separated by spacing rings and mounted on three drums which are joined end-wise to form a shaft. With the exception of the last stage disc all these parts are of aluminum alloy. The last stage disc and the stub shafts, which are mounted on the drum ends, are of alloy steel. The discs are broached through their outer rims (fig. 8) to receive the rotor blades, this operation being done on a vertical broach. The rotor discs, being among the most vital members of the engine, have presented an interesting manufacturing problem, particularly as to accuracy of form and finish on the webs. At present the aluminum discs are turned on large turret lathes by means of special formers, while the steel disc is being turned on a Bullard vertical turret lathe with an electronic tracing unit. Other methods are now in

Fig. 12 — The gas turbine rotor on its shaft.

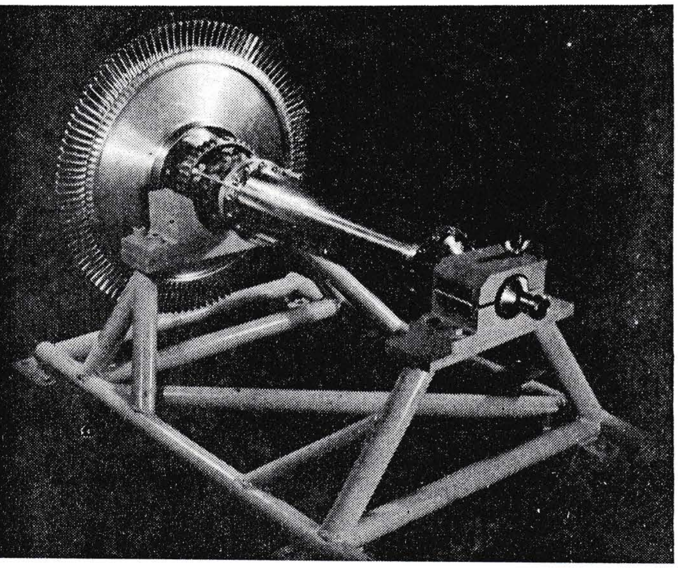
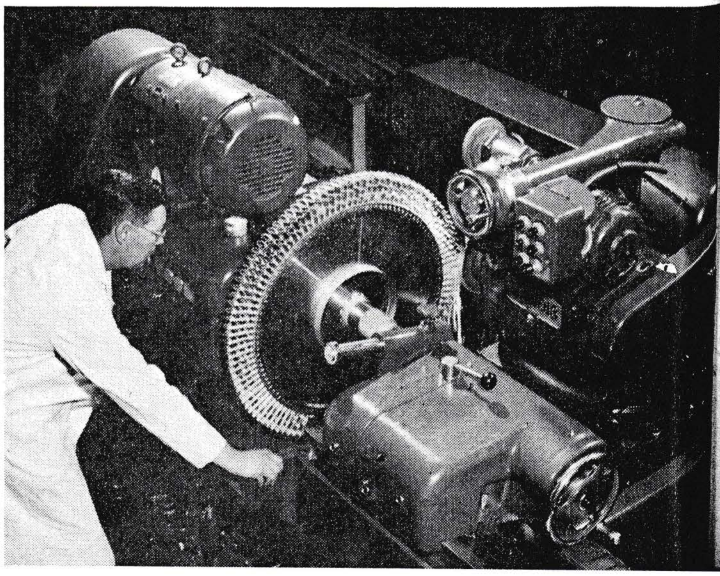


Fig. 13 — Grinding turbine rotor blade tips.



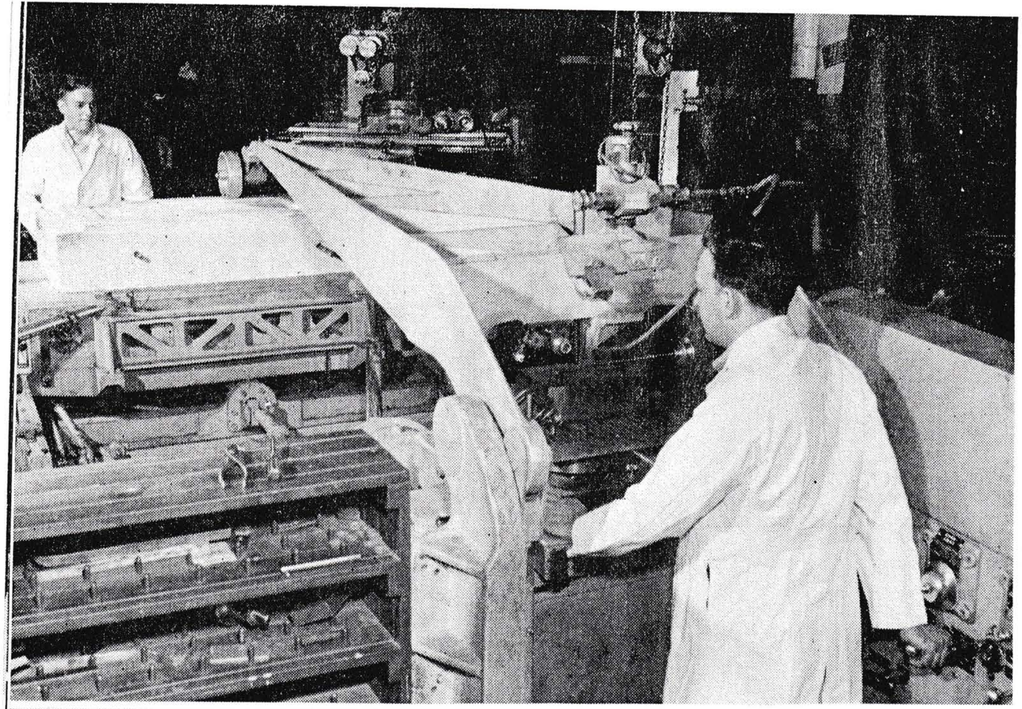


Fig. 16 — Pantograph duplicating machine (Avro Canada patented design) for grinding cavities in blade forging dies.

the planning stage and will be soon under experiment.

The front and rear stub shafts which are more or less bell-shaped are contoured (fig. 9) on an American hydraulic tracer lathe, while the airflow contour on the rotor body, which forms the inner air passage of the compressor, is formed on the Monarch tracer lathe. The rotor blade tips which are contoured to fit the outer air passage are machined on equipment developed by Avro for this purpose. This blade-tipping machine was made by cutting the centre section from a Bertram 36-in. engine lathe (fig. 10) and setting this section on a base somewhat out from the centre line of the lathe, thus making a large fixed gap lathe. This separate section, of course, carries the saddle of the lathe and to this is fitted a Turchan hydraulic following unit to trace in the required contour.

Diffuser Casting

THE CENTRE, or diffuser, casting is of high-strength aluminum alloy as it is the "keystone" in the build-

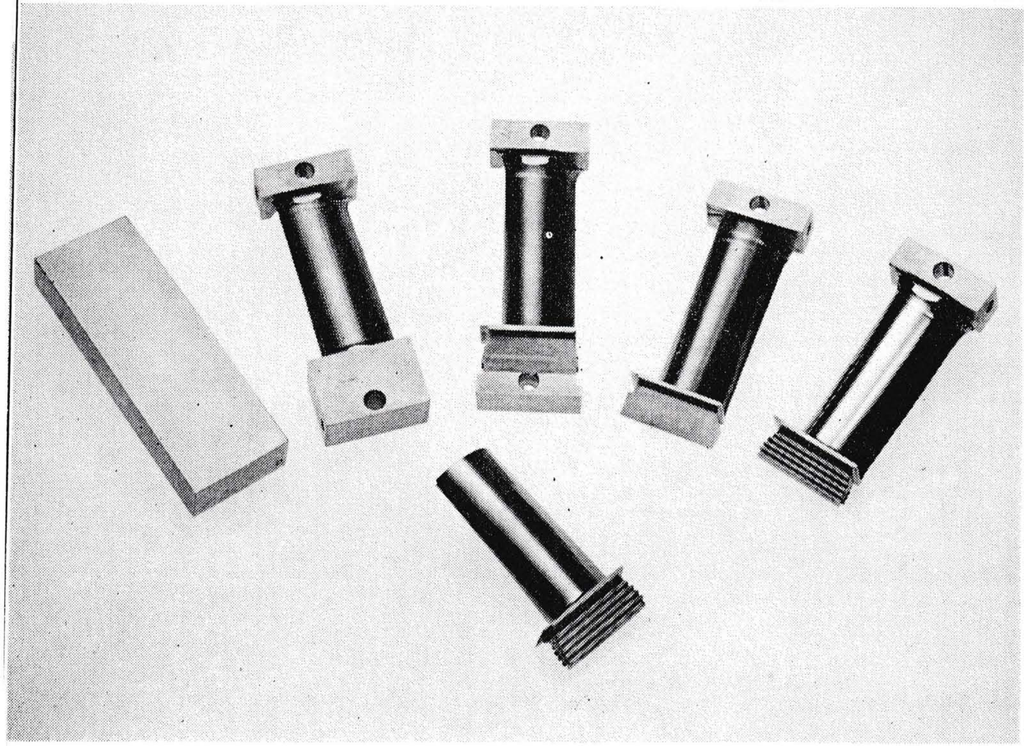


Fig. 17 — Stages in manufacture of turbine blades from bar stock.

up of the engine. It is similar to the intake casting in character, that is two concentric rings form the air passage while the inner ring houses the centre bearing, but it has the addition of six horns on the aft face which diffuse air to the combustion chambers. Most of the manufacturing difficulties on this part arise from the intricacy of the casting and its mate, the centre bearing housing. As in the other major castings the vertical turret lathe, horizontal boring machine (fig. 11) and radial drill perform most of the machining, with the addition of some jig boring and engine lathe work on the bearing housing.

Backbone Casting

The backbone casting is simply a slim cylinder of aluminum alloy, expanding slightly at each end to allow for spigotting to its related components. As with the centre casting, no great difficulties are met in manufacturing this component.

Combustion System

THE COMBUSTION system consists mainly of the combustion chambers and the nozzle box. These are made from high-temperature alloys and are mostly fabrications of press-

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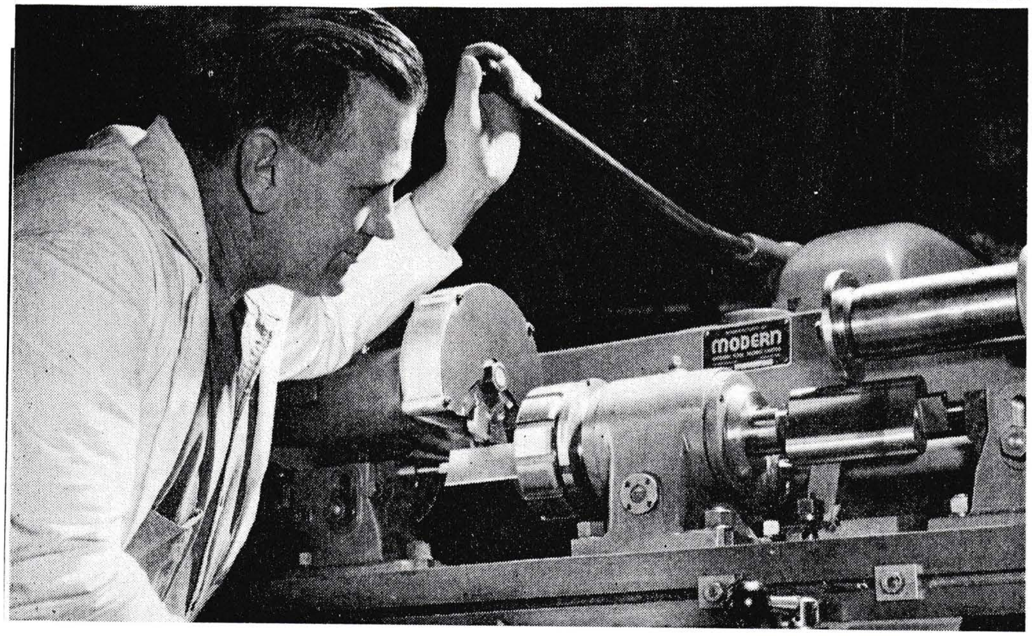


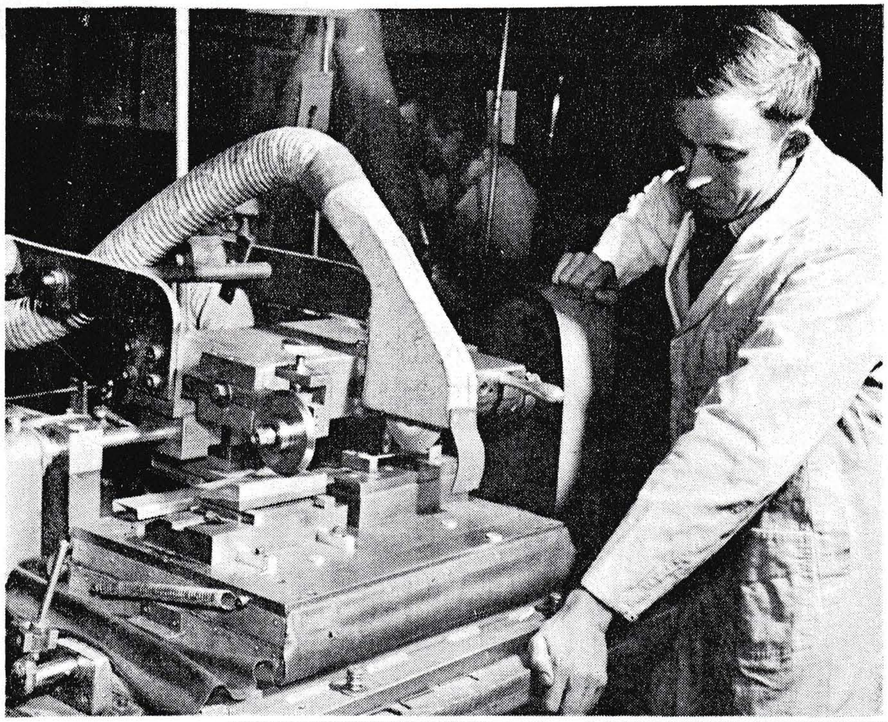
Fig. 19 — Special attachment in Modern milling machine for profiling blades.

ings and castings, and present a great many difficulties in manufacturing. Up to now most of these parts have been obtained from Joseph Lucas of England, but in a short time the entire system will be made at Avro. Those parts which are made at Avro have given rise to some very interesting problems in metal-cutting technique, though very little special equipment has been involved. The carbides are used extensively on these materials and experimentation has constantly been carried on to improve results. An imposing mass of data has been gathered and this will probably form the basis for re-examination of all standard metal-working practice for it has been found that the generally accepted standards of machinability, rate of stock removal and finish, fall significantly short of what can be achieved in actual practice when put to the test.

TURBINE

THE TURBINE (fig. 12) is made up of a number of parts, but the major component is, of course, the disc which is probably the most exacting single part to manufacture in the entire engine. This disc is machined from a large well-worked forging of a special Timken alloy, the stub shaft being included on the forging. Some 240 lb. of material are removed during machining. All turning is done on a vertical turret lathe with the help of special camming and other tools, but the chief necessity on this job is extreme care and patience from the mechanics concerned, both in grinding the cutting tools and machine setup and operation, for the slightest slip on this part would be disastrous.

After turning, the "fir tree" slots are broached in the rim of the disc. This "fir tree" is used generally throughout the industry and has been the subject of a tremendous amount of discussion and research. It is in the form of a V with a number of serrations on each side giving a silhouette similar to that of the tree for which it is named. In the United States it is generally known as the "Christmas tree" form. This form constitutes an envelope over the root of the turbine blade, which is similarly formed, the inner faces of the serrations taking the bearing of the blade. The elements of this form are held to extreme limits of accuracy and require the utmost vigilance in manufacturing. After broaching the disc is splined and threaded on the stub shaft, some milling operations are performed and the stub shaft is silver-plated, while the air seal lands are chrome-plated.



Above: Fig. 20 — Grinding blade contour in Avro duplicator.

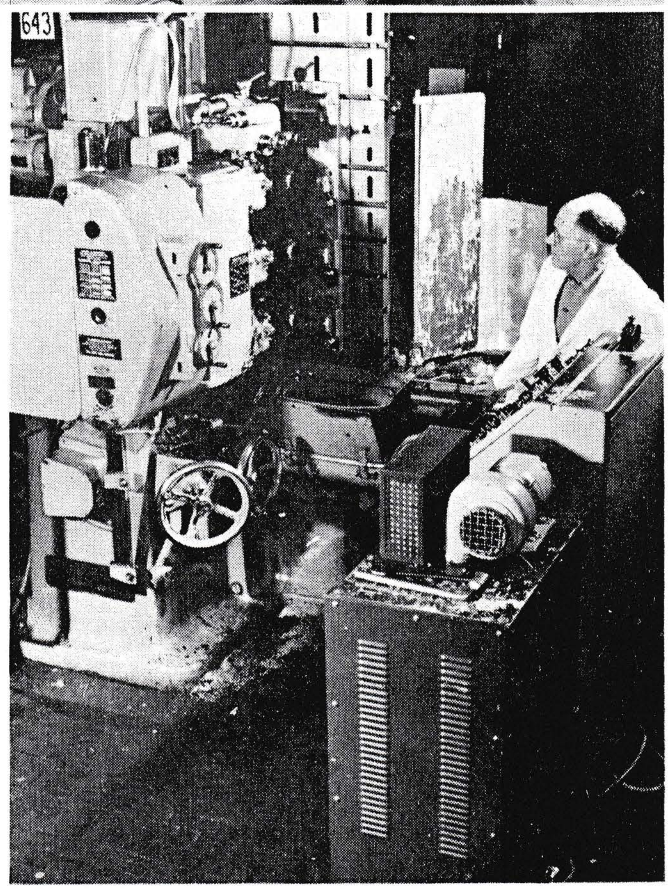


Fig. 18—Kellering three blades at one setting.

Tail Assembly

The tail assembly (fig. 14) is fabricated entirely from high-temperature alloys. It is made mostly in the sheet-metal shop and has opened up a new era in this phase of metalworking, requiring the use of tools such as height gauges and verniers hitherto unknown in this trade. This assembly consists mainly of an inner and outer cone, the outer being truncated, which form the passage leading the jet stream to the final nozzle and the jet pipe. These cones are mount-

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tion little overhead clearance is necessary, making them ideal for work beneath cross members or other obstructions.

These wrenches have different size openings at each end for greater adaptability and are available in the following popular sizes: 3/8 in. and 7/16 in., 1/2 in. and 9/16 in., and 5/8 in. and 3/4 in. Over-all lengths range from 5 5/8 in. for the smallest to 8 3/4 in. for the largest, and all of them are chrome plated.

For further information write to Snap-on Tools of Canada, Ltd., Long Branch, Ontario.

NEW LUBRICANT

The rare metal molybdenum has been used in place of, or supplementing regular lubricating oils and greases in recent years. Molybdenum is an extremely "greasy" metal, practically indestructible at high temperatures and pressures, certain forms of it having the peculiar faculty of "plating" itself firmly to any friction surface. This forms a permanent friction-supporting film which cannot be "squeezed out" by any amount of pressure, thus protecting the bearing against scoring or seizing even after all the oil has been burned out.

Molybdenum lubrication has now been made available in a form suitable for use in any conventional lubricating system, by a new development of the Lubricants Division of the Lockrey Company, College Point 1, N.Y., which is now placing on the market a new molybdenum-base lubricant called "Liqui-Moly." This can be used alone, or added directly to crank-case or other oils which carry it to the friction-surfaces, where it "plates out" on the metal, providing a permanent low-friction anti-seizing coating.

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ed together by a series of tubes which also serve the purpose of carrying cooling air to the aft face of the turbine disc. In the jet passage are four vanes of airfoil section which serve to support and space the inner and outer cones. Many other engine components are made in the sheet-metal shop, almost without exception to accuracies till now confined to the machine shop.

BLADES AND VANES

THE MANUFACTURE of gas turbine blades and vanes has presented the greatest challenge to metalworking men to appear in many years. These parts are thin sections, often of unworkable materials, held to extreme accuracies, yet almost always of nongeometrical form. Millions of dollars have been, and are being, spent throughout the world to find practical manufacturing methods and in this respect Avro is no exception, for experimentation is always going on. There are six distinct types of blades and vanes now used in the Orenda as well as a wide variety of test blades.

The inlet guide vanes are made from precision castings of aluminum alloy (fig. 15) and they are relatively simple to make. There is no machining beyond polishing done on the airfoil section. The only machining is on the roots, while the platforms adjacent to the airfoil are worked by hand in form fixtures.

All but the last stage of stator blades are somewhat similar to the inlet guide vanes in that their airfoils are only polished. They differ, however, in that they are precision forgings rather than castings. These forgings are produced by the Aluminum Co. of Canada in dies made by Avro and are held to as close as .002 in. This is radical departure from accepted forging practice and the Aluminum Co. deserves great credit for their achievements in this important work. The making of the dies for this work has required some very interesting innovations among them a 10 to 1 pantograph grinder of patented design (fig. 16) which works off a plaster master, and a special comparator for checking blade forms and cavities.

The first, second, third and last stage rotor blades and the last stage stator blades are made from stainless steel bar and are completely machined. The major steps (fig. 17) are as follows: the bar is cut off somewhat longer than the finished blade and a tooling hole is drilled and reamed in each end to locate the work for subsequent operations. The blank is gashed on milling machines to some approximation of the finished blade. The airfoil section is roughed in on a three-spindle Keller die sinker (fig. 18) and then refined again on a Keller, to which has been added an Avro-developed electronic unit to increase sensitivity and eliminate as much as possible "dwell" at points of reciprocation. The airfoil is then ground on a machine developed by Avro which works off a master form, and is then rough polished.

The blade root which, on these blades is a modified fir tree, is then crush-ground on a Thompson grinder with Avro-developed tooling. The root platform is now worked in by hand in form fixtures and the blade is finally polished and buffed to an 8 micro-inch (rms) finish as are all blades.

The remaining rotor blades are made from aluminum alloy bar, although it appears that forgings will be used in the near future. These blades follow somewhat the same course as the stainless blades excepting that Gorton profilers (fig. 20) rather than Kellers are used to rough in the airfoil, and the root, being a dovetail, is milled rather than crush-ground.

Nozzle Guide Vanes

THE NOZZLE guide vanes, which must operate in the hottest part of the engine, present a major problem in that the material used cannot be cut so that all machining is done on grinders, the airfoil and platforms being finished by polishing and buffing only. These vanes are cast by the "lost wax" method of precision casting and important advances in this technique have been made at Avro.

Turbine Blades

The turbine blades follow the same general processing as the stainless steel blades, except that they are made from high temperature alloys and have the full fir tree roots. This root is also crush-ground but on a machine made for Avro by the Coventry Tool & Gauge Co. of England which incorporates two wheels and thus grinds the entire form in one setting.

It must be realized that the foregoing only covers some representative questions in this wide new manufacturing field. No mention has been made of gears, gear boxes, splines, couplings, bearings, and such items, which space does not allow, but it is well to remember that any part which goes into a jet engine is made to specifications hitherto confined to the finest instrument work. Nor has any reference been made to the important problem of inspection and control of components in which many new techniques have been developed. Such measures as X-ray and supersonic testing have become commonplace. It is hoped, however, that this article will provide some idea of the obstacles to be met in this new industry.

In closing some mention must be made of the way in which the Canadian mechanic has played his part in helping to achieve the great success which has brought worldwide attention to Avro. It must be remembered that never before in any branch of manufacturing in this country has such an ambitious program of development and experimentation been undertaken, let alone in such a trying field. The willingness of the Canadian workman to learn and often to unlearn, his interest and enthusiasm, have been a revelation. The result of this is that in hundreds of hours of testing on Avro engines there has never been a failure traceable to poor workmanship.