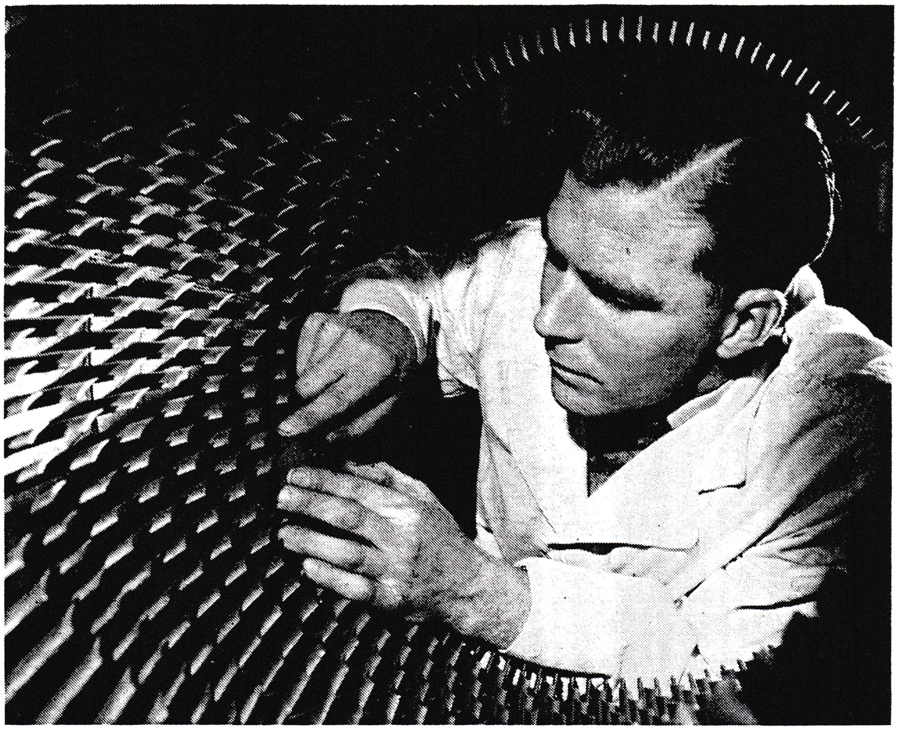


LEFT—Blades have raised the most difficult problems in development of the Orenda jet engine at Avro. John Howlett, engine fitter, is shown scraping and deburring a stator blade.

—*National Film Board Photo.*

The Orenda Story—

COMPLEX PROBLEMS SOLVED IN ORENDA DEVELOPMENT

By D. W. KNOWLES

Chief Development Engineer
Gas Turbine Engineering Division
A. V. Roe Canada Ltd.

THE EARLY development running of the Orenda showed that the engine lived up to expectations from the performance standpoint, the predicted thrust being obtained with design speed and jet pipe temperature at an early point. Starting was excellent, and acceleration reasonable.

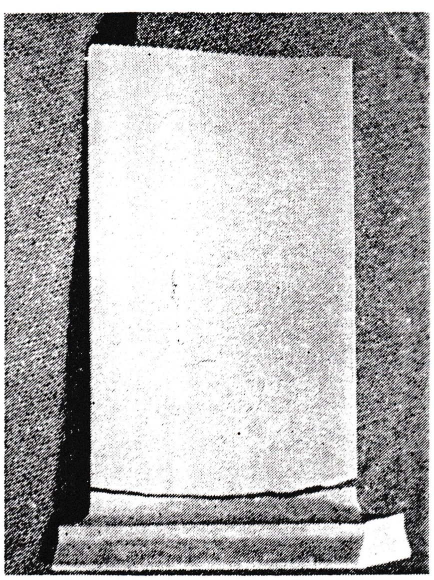


FIG. 1—Fatigue crack in a 10th-stage rotor blade. When made of steel, the blade proved satisfactory.

The engine showed a slight instability in the region of 70% of full speed, however, this was not a limitation on test bed running. Oil consumption was very high. Tenth-stage stator blades showed a regrettable tendency to come off in quantities, and turbine blades developed cracks at the tip near the trailing edge.

Oil consumption continued to give trouble on most succeeding engines, but their performance in this respect was extremely erratic. Before this problem could be tackled it was necessary to get a proper adjustment of bearing oil flows, cooling air flows and air flow to pressurized glands. When these were corrected to give satisfactory bearing conditions the oil consumption still remained high.

Initial attempts to localize the oil loss were misleading but it was finally traced to the turbine bearing area. Several months were taken up in trying different sump and scavenge arrangements, new seal designs and flinger rings. Finally checks made with a very accurately calibrated oil system showed that the scavenge flow was equal to that supplied to the bearing.

The only clue seemed to be that oil loss was small at lower speeds or until the engine had been running for some time. About the same time an adequate bearing test machine became available. The rear-bearing assembly operated with negligible loss on the test rig. A thorough check of the detailed design was then made as the evidence seemed to point to a temperature effect and this was confirmed for the only difference between rig and engine conditions was the relative temperature of the components.

The trouble was apparent when it was discovered that a steel sleeve supporting the bearing, which was an interference fit and often permitting casting, was not sealing one of the oil drillings in the casting. Under operating conditions the casting had a greater thermal expansion than had been anticipated thus relieving the intereference fit and often permitting oil to escape. The end of the oil drilling was plugged and after confirmatory tests it was announced, with some embarrassment, that the oil consumption problem was solved.

During the course of development, the rest of the oil system behaved very well. There were no aeration difficulties. Very little effort was re-

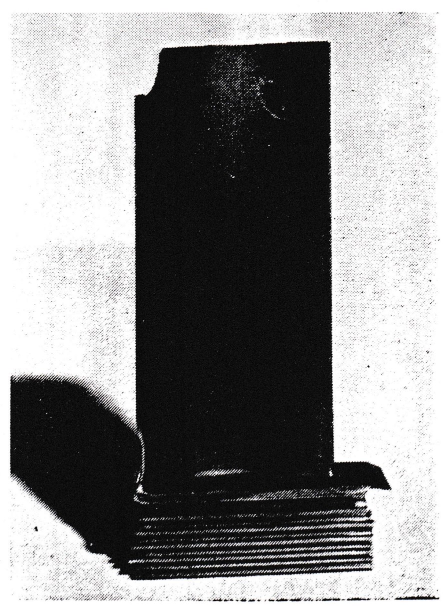
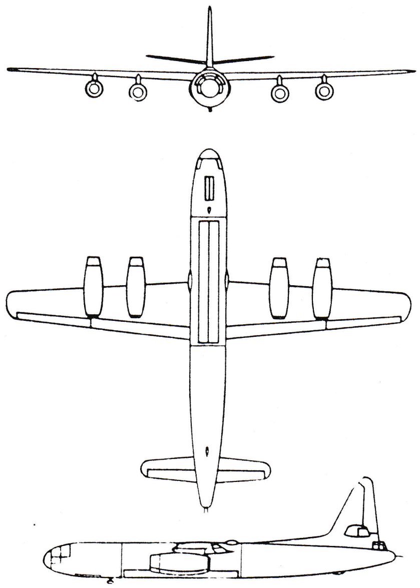


FIG. 2—"The turbine blade cracks originated in the tips near the trailing edge . . ."

RED AIR POWER
(First of a Series)



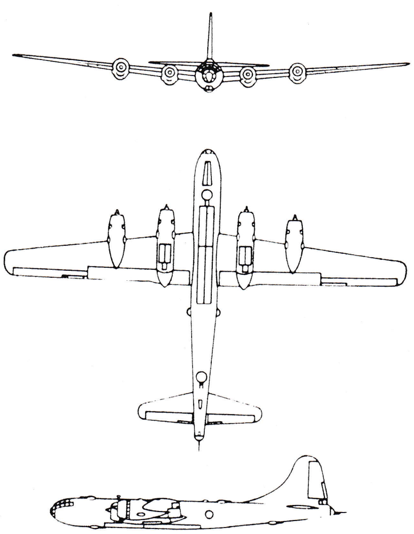
ILYUSHIN IL-16

DESCRIPTION: High mid-wing monoplane powered by four Jumo 004 axial-flow turbojets and developed from Heinkel He 343.

APPROXIMATE DIMENSIONS: Span, 65 ft.

ESTIMATED PERFORMANCE: Maximum speed, 520 mph; Cruising speed, 400 mph; Range 1,500 miles.

DESIGNATION: unconfirmed.



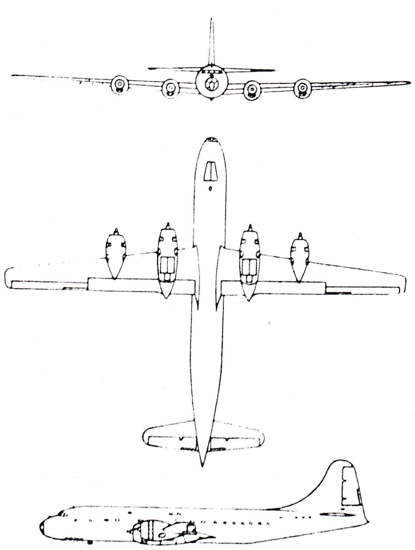
TUPOLEV TU-4

DESCRIPTION: Mid-wing monoplane strategic bomber, a "pirated" copy of the Boeing B-29. Powered by four 2,100-hp ASh-90 radial engines (copies of Wright R-3350).

DIMENSIONS: Span, 141 ft. 3 in.; Length, 99 ft.; Height, 27 ft. 9 in.; Wing area, 1,739 sq. ft.

APPROX. PERFORMANCE: Max. speed, 350 mph; Range, 4,000 miles.

ARMAMENT: Probably eight 12.7-mm machine guns in four turrets and one hand-operated 23-mm cannon in tail.



TUPOLEV TU-70

DESCRIPTION: Low-wing all-metal monoplane transport, powered by four 2,100-hp ASh-90 radial engines. As a commercial transport it will carry crew of five and 72 passengers. As a military transport, carries crew of three and 110 troops.

APPROX. DIMENSIONS: Span, 141 ft. 3 in.; Length, 120 ft.; Height, 30 ft.; Wing area, 1,739 sq. ft.

APPROX. PERFORMANCE: Maximum speed, 315 mph; Range, 2,500 miles.

A "CANADIAN AVIATION" Feature

quired to get adequate venting arrangements for oil tanks and sumps, although pressurization of the oil tanks produced spectacular results at times before the problem was cured.

The failures of 10-stage stators were initially traced to fatigue cracks which were the result of intercrystalline corrosion. Other blades in the engine also were found to be subject to this form of attack. The material used in the later stages of the compressor was changed to a similar material which was more resistant to this kind of corrosion.

However, the failures, although not as frequent, continued to give trouble, appearing now as ordinary fatigue cracks FIG. 1. A study of the resonance conditions of the blade showed that it was being excited by the 10th rotor in the second flexural mode. Strain gauge tests indicated that the blade would be strong enough if made in steel. The change proved to be a satisfactory solution.

The turbine blade cracks FIG. 2, originated in the blade tips near the trailing edge. As originally designed the blade had a feather edge which was provided to prevent serious damage in case of tip rubs which might occur due to the small clearances used. A survey of the nodal patterns of the vibration modes occurring in the running range showed that the second complex mode FIG. 3 had an area of high bending stress extending right to the tip.

Cracks started in the thin feather edge and were propagated along the line of high stress. As the behavior of turbine shroud ring under operating conditions was established it was possible to employ satisfactory tip

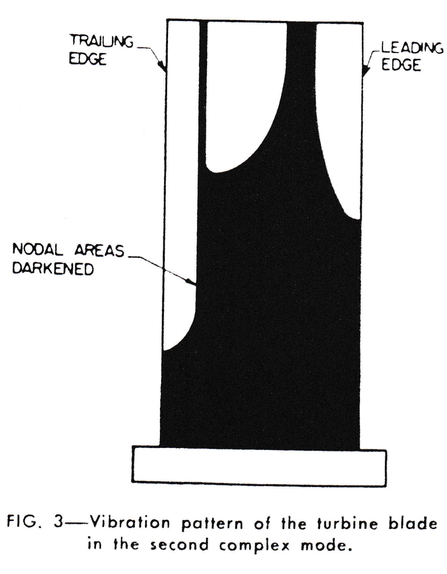


FIG. 3—Vibration pattern of the turbine blade in the second complex mode.

clearances without the danger of rubs. Since the need for the feather edge had disappeared it was deleted in order to strengthen the blade tip. This proved to be an effective remedy.

As more running hours were accumulated, further difficulties began to crop up. Almost all engines were inclined to heavy rubbing of the 10th stage peripheral seal with complete loss of its effectiveness. This was thought to happen on running down from high speeds when the pressure behind the 10th stage disc decreased rapidly but a high pressure could remain momentarily between the ninth and 10th discs causing the disc to flex and the stepped sealing ring to foul its gland. The interstage cavity was vented through the 10th stage disc, which cured the trouble.

Considerable work was involved in the development of the flexible thrust ring of the centre-bearing assembly. This feature was incorporated in the design to look after angular misalignment resulting from flight manoeuvres. A similar design had been used on the Chinook engine and proved to be an excellent method of obtaining the required degree of angular flexibility.

As originally designed, the rings were of soft rubber with slotted steel corner braces. They suffered considerably from extrusion of the rubber around the edges of the corner braces, through the slots in the corner braces and from the unbraced corners FIG. 4. The resulting collapse of the ring permitted the compressor to move forward and foul the stator assembly.

(Continued on page 48)

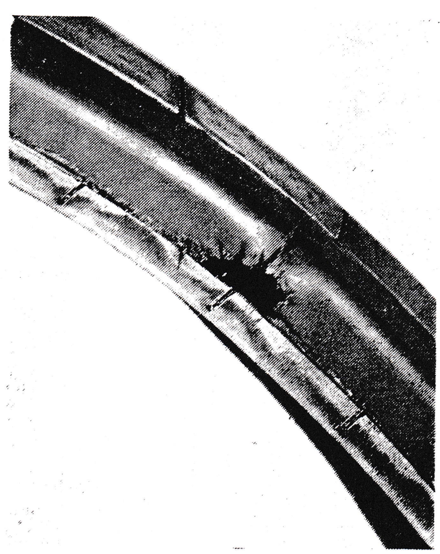


FIG. 4—Failure of the centre bearing thrust ring, as shown here, was one of the problems overcome in development of the Orenda.

DEVELOPMENT OF THE ORENDA

(Continued from page 24)

This was partially remedied by placing a strip of tape between the corner brace and the rubber. A further variation consisted of binding the ring with nylon tape. However, it was difficult to cure the ring to the required dimensions even under pressure as the tape binding tended to make the ring oval after curing. Under operating conditions the ring would assume the rectangular shape intended with reduction of its axial dimension and compressor fouling could still occur.

The problem was finally solved by using a composite ring with a hard exterior and soft core without binding which did not alter dimensionally during operation.

The front-bearing seal went through several stages of development to produce a satisfactory design. The seal in question is introduced behind the front bearing of the compressor rotor to prevent lubricant from escaping into the cavity immediately in front of the first rotor discs. This space is at a depression of 1.5-2 psi. as it is connected to the compressor air passage ahead of the first stage rotors. The bearing area is at atmospheric pressure.

The original seal was a carbon ring held in place against a cast-iron rubbing surface by a single helical spring with a pressurized gland on the shaft as a further seal. This arrangement did not work well as the single helical spring did not bear evenly on the carbon ring. The result was uneven heavy wear of the sealing surfaces.

Subsequently a carbon-ring seal supported by a multiplicity of small springs was adopted. At this time it was decided to delete the gland as an unnecessary complication. The new seal worked well on rig tests but was erratic on the engine. It was thought that the differential thermal expansion of the rotor and stator casing was causing the trouble by permitting the sealing surfaces to move apart. This was checked by introducing wear plugs near the seal which showed that little differential expansion was taking place. When this was established a large number of seals were examined and it was discovered that the spring rate and travel of seals as supplied was varying considerably from specification. When these were brought under closer control the trouble disappeared.

One of the more difficult problems did not become apparent until almost a year of testing had been done and engines had logged about 2,000 hours of operation. Then a single seventh-stage rotor failed followed by several more within a short period, some on engines with relatively few hours of running FIG. 5. Failures continued to occur in apparently random fashion thereafter. Such failures appear as fatigue cracks.

This trouble will serve to show the many steps which are often necessary to get a satisfactory solution to development difficulties in aircraft engines. They are the result of the high vibratory stresses induced in the blade by the coincidence of one of the natural frequencies of the blade with an exciting force such as that caused by the passage of the blade through the wakes of the preceding row of blades.

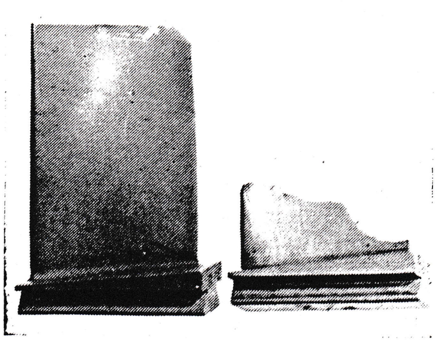


FIG. 5—Fatigue crack in seventh-stage rotor blade of Orenda during development. This problem was solved after considerable research.

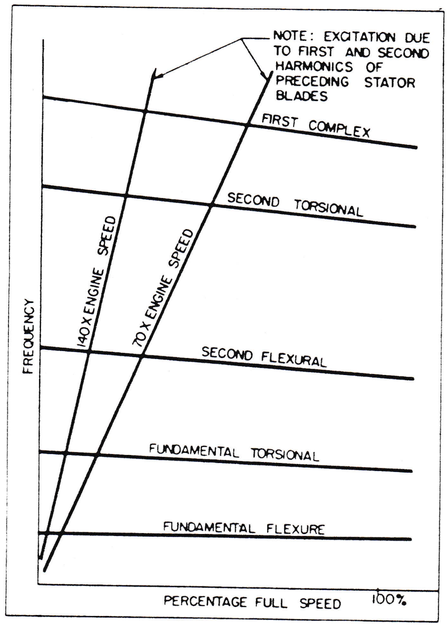


FIG. 6—Interference diagram for seventh-stage rotor blade.

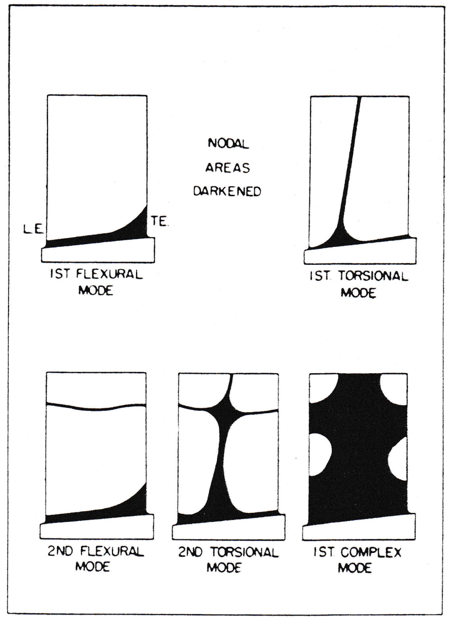


FIG. 7—Vibration patterns for seventh-stage rotor blade.

The first step is a precautionary one taken in the design stage. The fundamental flexural and torsional critical frequencies of all blades are calculated. A check is then made to determine that these are not in resonance with known exciting frequencies within the engine operating range. As it is very difficult to calculate the frequencies of higher modes of vibration which could cause trouble these are found experimentally when the first blades are manufactured. From this information an "interference diagram" is plotted for each blade.

A typical diagram is shown in FIG. 6. The frequency of various exciting forces is plotted against engine speed and the critical frequencies of the blade are also plotted. At the speed where the lines cross the blade will be in resonance with the exciting frequency.

At the time the blade frequencies are determined the vibrational pattern of each mode is studied and recorded to assist in the identification of any failures. It is usual to do about 150 tests of this type for an engine such as the Orenda. A set of vibration patterns is shown in FIG. 7. The lines and dark areas indicate nodes.

As the failures being considered were somewhat sporadic and as there was a great spread between the lengths of running time which produced failures it was suspected that the material might be at fault.

(Continued on page 62)

the FAI, BOAC, BEA, and there is a comprehensive list of the Commonwealth and Foreign air lines which operate to the U. K. together with air charter companies of the U. K. and Commonwealth.

There is a full list of all the civil airports in the U. K. giving length of runways and conditions of usage, and a list of Air Transport licence holders and other holders of civil licences. There are lists of institutions, clubs, and societies, with flying and gliding clubs in the U. K. and Commonwealth, and all aviation periodicals of the Commonwealth countries. Two hundred and fifty pages are devoted to the names and addresses of all firms in or associated with the aircraft industry. This year's list is enhanced in value as it includes the industries of the Commonwealth countries outside Great Britain of which Canada is the largest, with five aircraft constructors, and 47 ancillary firms who occupy between them five pages — Geoffrey Dorman.

DESTINY OF CANADAIR TOP INDUSTRY RATING

(Continued from page 15)

the war years Mr. Notman was on loan to the Dept. of Munitions and Supply as a consulting specialist and co-ordinator of ordnance.

Robert A. Neale, vice-president, manufacturing, is a production expert and specialist in business management. Mr. Neale's manufacturing experience includes production of a number of leading United States aircraft, including the B-17 and B-29. Over 18 years with Boeing Aircraft Company, he was director and operations manager of 11 of the company's plants on the Pacific Coast from 1943-47.

Responsible for design and research development at Canadair is William K. Ebel, vice-president, engineering.

A graduate of Heidelburg College and Case Institute of Technology, Mr. Ebel also holds doctorates in engineering and science. For 25 years he was with the Glenn L. Martin Company, becoming their vice-president of engineering in 1941, and was later director of engineering for Curtis-Wright. Mr. Ebel is responsible for the design of many types of aircraft, ranging from the 83-ton Mars flying boat to jet aircraft, and has also worked on the design of guided missiles.

Peter H. Redpath, vice-president sales, combines practical flying experience with a solid background in administration. A veteran transport pilot, Mr. Redpath was 13 years with Trans-World Airways in various flying and administrative capacities. Also an expert on navigation, he has written several books on the subject. In 1946 Mr. Redpath became vice-president of operations for the Swedish Air Line (ABA) and later vice-president of the combined Scandinavian Air Lines System (SAS).

SOLVE MANY PROBLEMS DEVELOPING ORENDA

(Continued from page 48)

Consequently, a survey was made of the physical properties of the batches of material from which the failed blades had been made and these were compared with the properties of batches which did not produce any failures. This threw little light on the situation.

Since the experimental engines had been used for a variety of tests a survey of the running history of all engines was made by plotting the operating time in each 100 rpm. speed range. It was not possible to draw any conclusions from a comparison of histories of engines which had failed blades and those which had not. The study was narrowed down to a comparison of histories 10 hours, five hours and one hour prior to failure with the idea of establishing speed ranges which caused failure. This also proved abortive.

As more failures occurred they were tentatively identified from the nodal pattern surveys as being caused by either second torsional mode or the first complex mode both of which occurred within the running range, but it was still not possible to explain how some engines could run several hundred hours without failure and others would fail in less than 100 hours even when the known scatter of the endurance properties of the material was taken into account. Failed blades were carefully examined for manufacturing flaws and inconsistencies such as variations in thickness and trailing edge radius without result.

As soon as it was apparent that the failures were not isolated ones a decision was made to study the problem using strain-gauge techniques. This involved the development of a slip-ring unit to transmit the minute strain gauge signals from the rotor at high speeds without electrical distortion. Several months of laboratory work and engine testing were required before an adequate slip-ring unit, proper instrumentation and reliable wiring methods were established. It was then possible to determine the relative magnitudes of the stresses in the various resonances and also the width of the resonance bands.

At the same time the problem was being attacked using more ad hoc methods by running engines to a test schedule which consisted of equal operating periods at 25 rpm. speed increments with frequent inspection of the blades through viewing ports in the compressor casing in order to determine the speed range in which failures occurred and the length of time required at speed to produce failures.

The strain gauge tests and engine running confirmed that both suspected resonances were contributing to the trouble and established a speed range which should be avoided in order to prevent fractures until a redesigned blade could be manufactured and proven. As capacity for manufacturing new blade designs was already strained, several interim solutions were tried using the existing blades. These reduced the incidence of failure considerably.

The first was a change in the number of stator blades preceding the rotors in which failures were occurring. The sixth and seventh stators originally had equal numbers of blades in each row. It was thought that this might be causing trouble as both the leading and trailing edges of the blade would receive impulses at the same time thus increasing the coupling of the exciting force.

The number of blades in the sixth stator row was increased 10% to correct this condition and to move the resonance speed away from the cruising speed range. The results of this change were beneficial as far as the seventh rotor blades were concerned. However, it had the effect of causing eighth-stage rotor failures after long operating periods.

The second interim solution was introduced when it was determined that the relative indexing of the seventh rotor row to the preceding rotor rows had an appreciable effect on blade life. As originally built the relative positions of the blades in the various rotor stages was quite random. During the special engine tests mentioned above one engine ran for several hundred hours without failure while another failed blades consistently with a few hours of running. Both engines were carefully examined for component variations, the only apparent difference being the indexing of the rotor blades. When the method of blade indexing was reversed on the two engines their blade breaking abilities did also.

This largely explained the wide variations in running time to failure. The favorable indexing was then adopted as standard for all engines. Further studies with controlled indexing variations are now proceeding using strain gauges to get quantitative information to guide future work.

The final solution of blade vibration problems requires that one of the following courses shall be adopted:—

(a) the damping action of the blade root shall be increased sufficiently to prevent the blade from being overstressed.

(b) the blade shall be strengthened to be able to withstand the vibratory stresses.

(c) the blade shall be redesigned or the exciting frequency altered so that the natural frequency of the blade does not coincide with the troublesome exciting frequency within the engine operating range.

The final method was adopted as the solution for this particular problem.

BRISTOL FREIGHTER ORDERED FOR RCAF

(Continued from page 30)

ture setting at 10,000 ft. altitude, max. continuous power is 1,215 hp.

Fuel consumption using 1,215 hp and 2,400 rpm is .441 lb/bhp/hr. in lean mixture. Drawing 722 hp and running at 1,400 rpm, fuel consumption is .411 lb/hp/hr.

Each engine is installed as a completely-cowled power plant with its own oil tank, oil cooler, gearbox and engine drive accessories. Four pins form the attachment points to the aircraft nacelle. The cowling, of the free-exit type, is fitted with hinged and detachable panels to permit rapid accessibility for servicing purposes.

Engine cooling is achieved via the annulus of the nose cowl (assisted by a fan attached to the propeller driving plate) and controlled by special cylinder-head baffles and division plates in conjunction with two fixed-exit annuli formed by the special construction of the free-exit cowl. With this form of cooling, the air stream is divided so that a proportion of air passes to the cylinder heads only and emerges through a forward annulus behind the rear cylinders. The remaining air cools the cylinder barrels