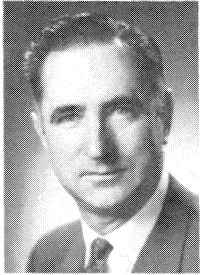


GAS TURBINES—HIGH EFFICIENCY COMBINED WITH EASE OF MAINTENANCE

by
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Born in England, George Barker graduated from Bennet College Sheffield in 1939. He served in the Royal Air Force (1940-1947), where he completed the Royal Air Force Engineer Officers Course in 1946. After working with British Overseas Airways as Flight Engineer (1947-1953), he then joined Rolls-Royce (Canada) Limited, where he is presently Vice President, Marketing. He is also a Director of Rolls-Royce (Canada) Limited.

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He is a member of Canadian Aeronautics and Space Institute; Director—Canadian Gas Association; Chairman—Canadian Gas Association (Transmission Equipment Division). He is also a member of the Management Committee (Manufacturers' Section), and the Canadian Gas Association.

1. INTRODUCTION

The advent of jet propulsion as a form of prime mover during World War II spearheaded a tremendous surge in gas turbine technology which continues unabated today. As each new specification is issued for a gas turbine, the common requirements are longer life, greater reliability, and lower fuel consumption. These specifications have been met progressively and today the gas turbine is a highly reliable and efficient piece of equipment.

This advanced technology has now been applied to industrial and marine installations providing potential for:

- high efficiency
- ease of maintenance
- reliability
- low maintenance costs

This paper is intended to be of a practical nature and will deal with specific hardware. Throughout the paper reference will be made to:

The Industrial Avon: an industrial version of the first generation aero Avon engine.

The Industrial RB.211: an industrial version of the second generation aero RB.211 which powers the Lockheed 1011.

The Industrial Spey: an industrial version of the second generation aero Spey which powers the Trident, BAC 1-11, LTV.A7, Grumman Gulfstream II and other aircraft.

The Industrial Avon has proven that aero derived industrial gas turbines are capable of achieving extremely high levels of availability and reliability, and has demonstrated the ability to operate in excess of 30,000 hours without overhaul or hot section inspection. This operating experience has been used extensively in the design of the advanced technology Industrial RB.211 and Industrial Spey.

2. IMPROVED THERMAL EFFICIENCY

Since October 1973 there has been considerable emphasis on the need for utilizing fossil fuel in the most efficient manner. This emphasis was long overdue and its need had been recognized by many industry leaders for some years. Figure 1 indicates that Canada is able to supply its own fuel needs at the present time but demand will exceed supply in 1980. Other parts of the world are facing a more critical fuel supply situation.

It is clearly necessary to improve the efficiency with which fossil fuel is converted to useful energy

- (a) to reduce or control costs,
- (b) to conserve natural energy resources for the future.

There are several means of improving the thermal efficiency of gas turbines.

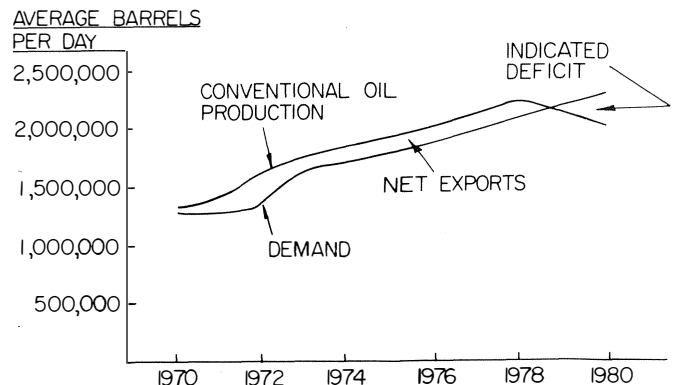


Figure 1. Canadian Petroleum—Reserves and Demand.

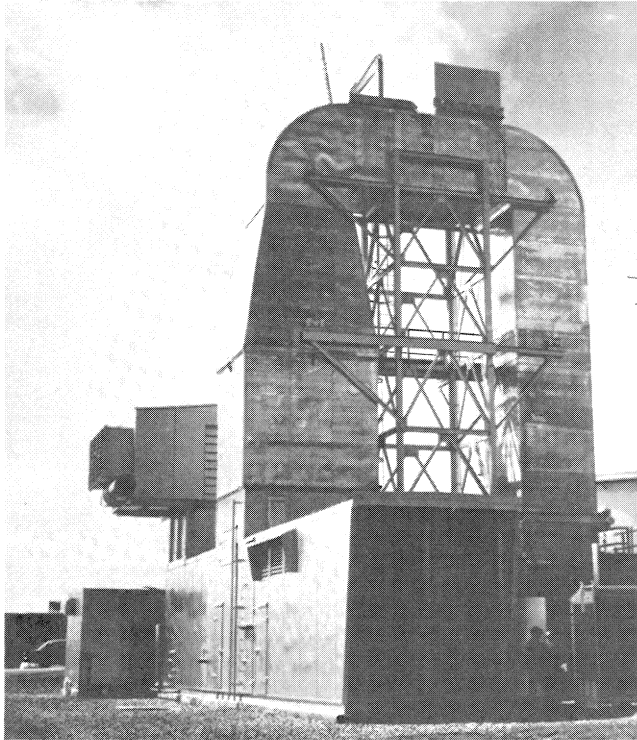


Figure 2. Typical Waste Heat Recovery Installation.

Figure 2 shows an installation using waste heat recovery (combined cycle). This set has been in operation for about five years. Figure 3 is a schematic of a waste heat recovery gas turbine. In this installation exhaust gases from the gas turbine at about 1000° F. are passed through a heat exchanger (boiler) and the resultant steam is used to drive a steam turbine. This system is effective in improving thermal efficiency from about 26% to perhaps 40% depending on the cycle.

It has the disadvantages of:

- (a) being expensive,
- (b) being heavy and requiring special installation and maintenance equipment.

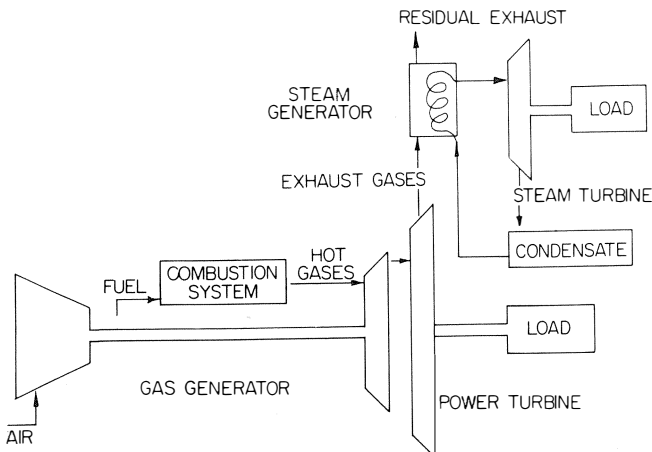


Figure 3. Schematic of Waste Heat Recovery.

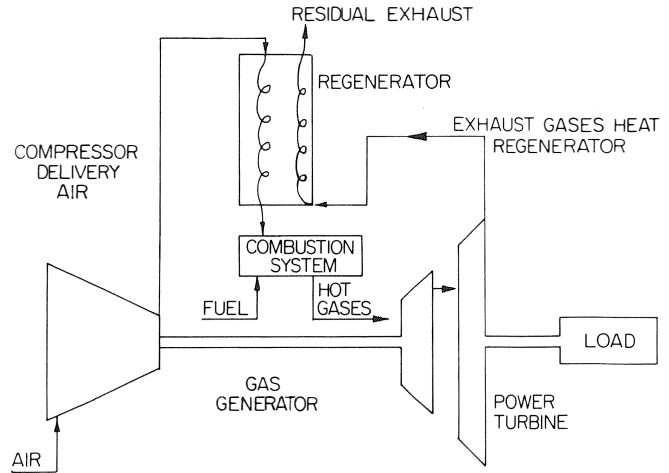


Figure 4. Schematic of Regenerative Cycle.

- (c) using water and steam with attendant problems of leaking, freezing, etc.

A typical regenerative cycle gas turbine is shown in figure 4. In this installation heat from the exhaust gases is transferred to compressor delivery air effectively making use of heat energy which would otherwise be discharged to the atmosphere. The system is effective in raising thermal efficiency from 26% to 34% but has the disadvantages of:

- (a) being expensive,
- (b) being heavy and requiring special installation and maintenance equipment,
- (c) requiring a large building to house the plant,
- (d) being limited by turbine entry temperature,

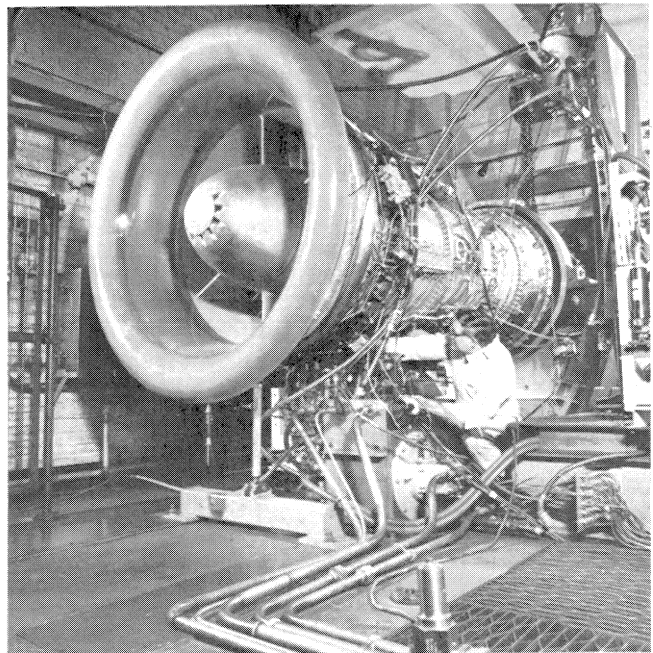


Figure 5. Industrial RB.211 Gas Generator.

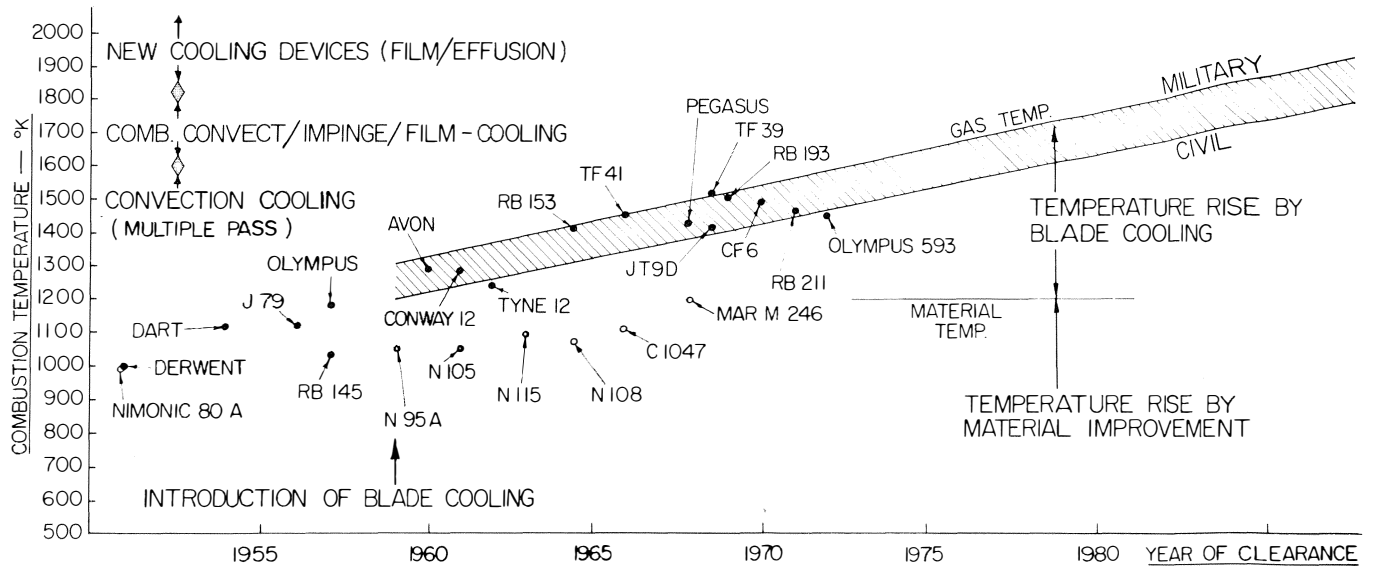


Figure 6. Increases in Combustion Temperatures.

(e) only being effective on low pressure ratio units.

An alternative to the waste heat recovery and to the regenerative approach is a simple cycle gas turbine based on advanced technology as shown in figure 5. The turbine temperature is about 1950° F., the pressure ratio is 20:1 and the thermal efficiency with a sensible power turbine would be about 34% to 34.5%.

The next logical step is to match waste heat recovery to an advanced technology gas turbine to obtain 46% thermal efficiency. This is quite feasible and 46% thermal efficiency must be attractive to operators.

The question might be asked “How far can this approach be taken?”. There is clearly a point of diminishing returns.

Figure 6 shows the historical increase in flame temperature permitted by:

(a) metallurgical improvements, and

(b) improved air cooling.

The greatest advance in flame temperature has been obtained by improved air cooling techniques. The limit to the increase in flame temperature is imposed by the desired longevity and reliability of the turbine section. The Industrial RB.211 uses a 1950° F. flame temperature to achieve a design life of 100,000 hours.

Figure 7 combines increased flame temperature and pressure ratio to show the diminishing returns achieved by increasing pressure ratio. This carpet plot indicates that greater gains in efficiency can be obtained from increasing the flame temperature than from increasing the pressure ratio.

Figure 8 shows, in simplified form, how an aero RB.211 is modified to become an Industrial RB.211. The single stage fan, the fan shaft, and the three stage turbine are deleted to leave a two shaft generator. The high pressure shaft carries a six stage axial compressor driven by a single stage turbine. The low pressure shaft carries a seven stage axial compressor driven by a single stage turbine. This results in a compact gas generator with a minimum of moving parts.

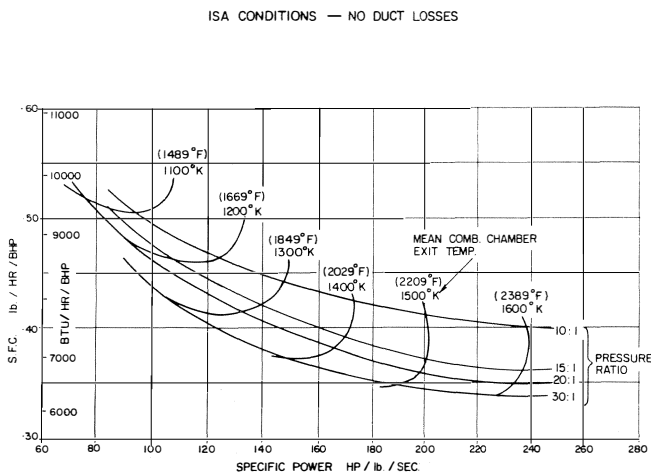


Figure 7. Gains to be Achieved from Higher Combustion Temperature and Higher Pressure Ratio.

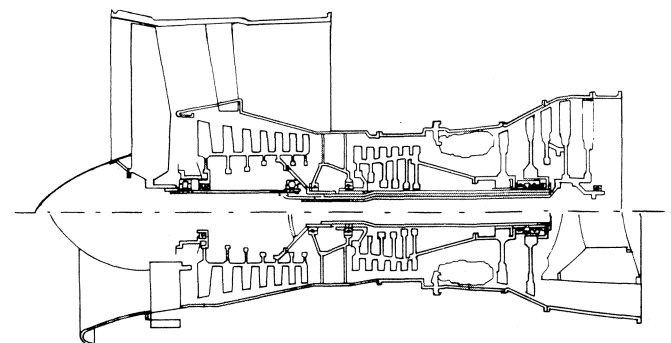


Figure 8. Principle Changes to Industrialize the RB.211.

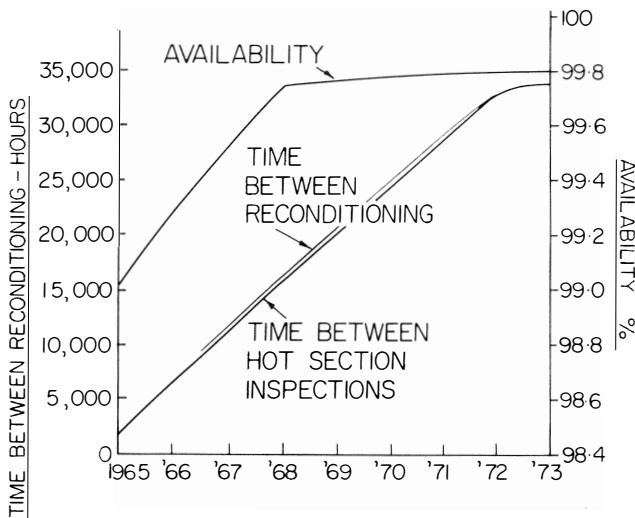


Figure 9. Industrial Avon Mk.1533 North American Base Load Operation.

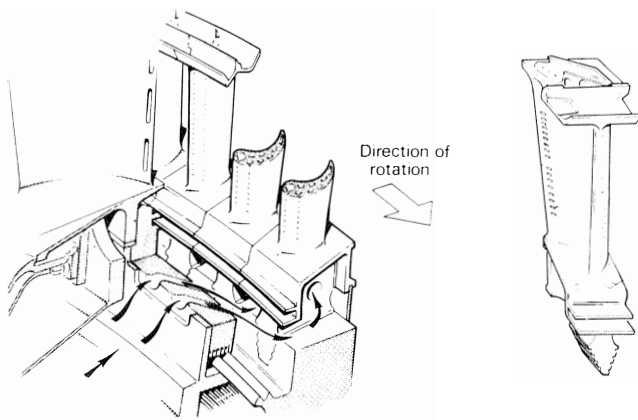


Figure 10. Industrial RB.211 Air Cooled High Pressure Turbine Blade.

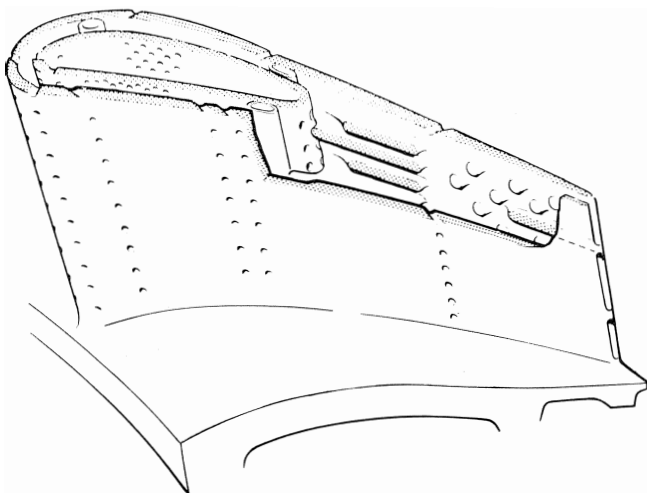


Figure 11. Industrial RB.211 Air Cooled High Pressure Nozzle Guide Vane.

The reliability of the Industrial Avon has been used as the basis for design of an Industrial RB.211 advanced technology gas turbine. Figure 9 shows the history of increase in overhaul life and increase in availability demonstrated by the Industrial Avon. It should be noted that hot section inspections have been eliminated.

It was concluded that while flame temperatures must increase, metal temperatures must remain unchanged by utilizing effective air cooling. Figure 10 shows the means of cooling a High Pressure Turbine Blade. The high pressure air is used to cool the inside of the blade and is also exhausted via small holes in the surface of the blade to form a film of air which insulates the blade from the hot gases. A similar technique is shown in figure 11 of an air cooled Nozzle Guide Vane (Stator).

All mating parts where movement occurs, essentially in the combustor area, are flame plated with tungsten carbide to combat wear at extended running times. The combustor is shown in figure 12.

All main line bearings have increased capacity to ensure trouble free operation in the manner already proven on the Industrial Avon.

Main line journal bearings are divorced from the engine carcass by an oil film, referred to as a "squeeze" film as shown in figure 13. This feature produces a pronounced reduction in carcass vibration which is expected to increase component and carcass life by a large factor.

The lubrication console and the fuel control system are mounted off the engine to provide optimum services totally divorced from engine vibration. This feature simplifies maintenance and increases reliability. The location of the lubrication console is shown in figure 14.

The combination of these features holds the promise of an advanced technology gas generator which will achieve new standards of efficiency, and reliability. Figure 15 is a cross section of the industrialized gas generator.



Figure 12. Industrial RB.211 Combustor.

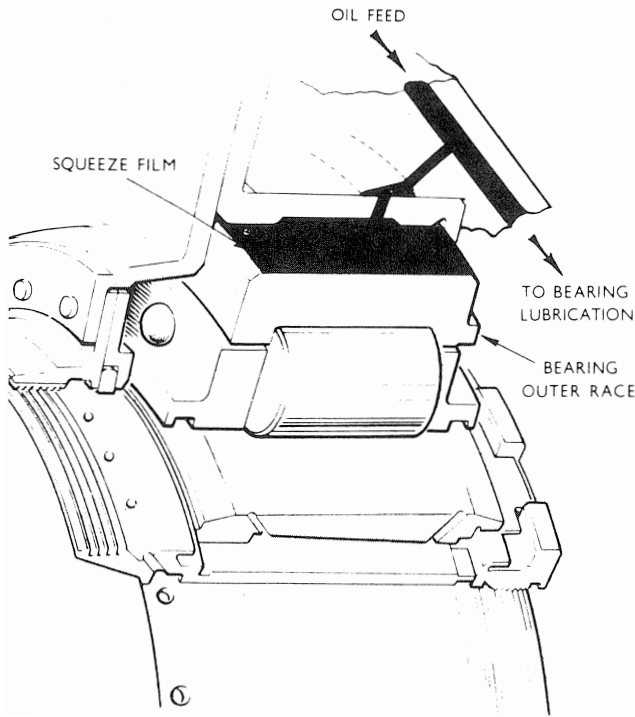


Figure 13. Typical Squeeze Film Bearing.

3. EASE OF MAINTENANCE

The advance of technology frequently brings complications in its wake. As gas turbines become more powerful and more expensive it becomes increasingly important to avoid stoppages for routine maintenance; to avoid unscheduled stoppages by anticipating problems; and to reduce routine maintenance man hours to a minimum. It

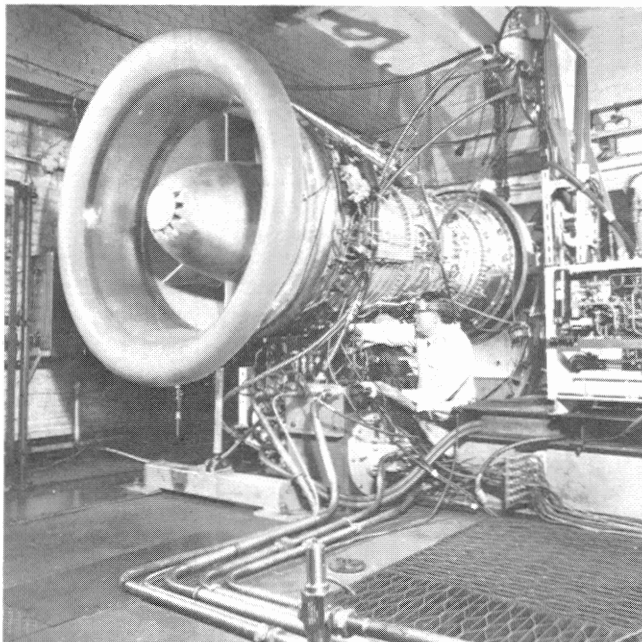


Figure 14. Floor Mounted Lubrication Console.

is believed that these criteria can be achieved by appropriate attention to the requirements during the design stage. Figure 16 details the Industrial RB.211 modular construction concept which holds great promise for simplified maintenance and reduced inventory of spare units.

Figure 17 shows the combustor which has been designed to eliminate the need for hot section inspections by careful attention to the design and the application of tungsten carbide to mating parts where movement or fretting is possible.

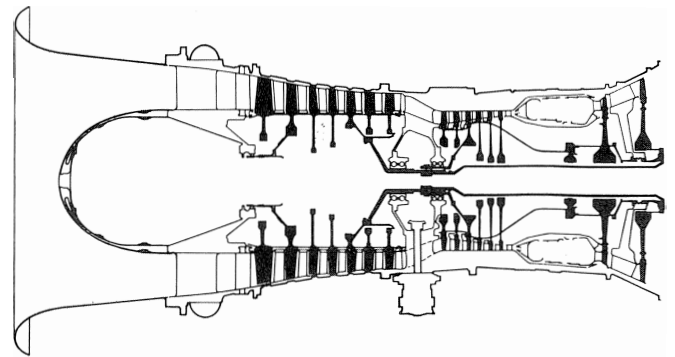


Figure 15. Industrial RB.211 Gas Generator.

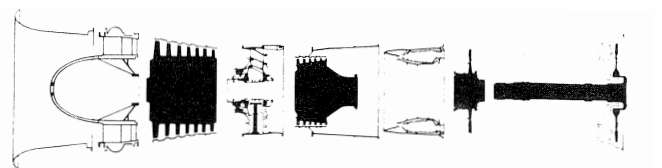
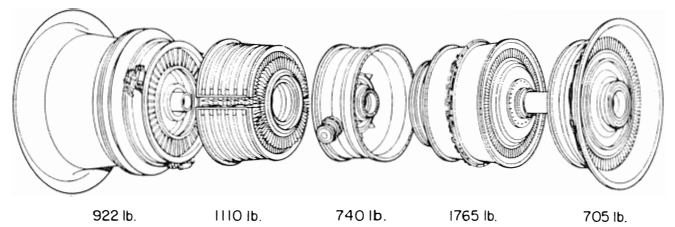


Figure 16. Industrial RB.211 Modular Construction.

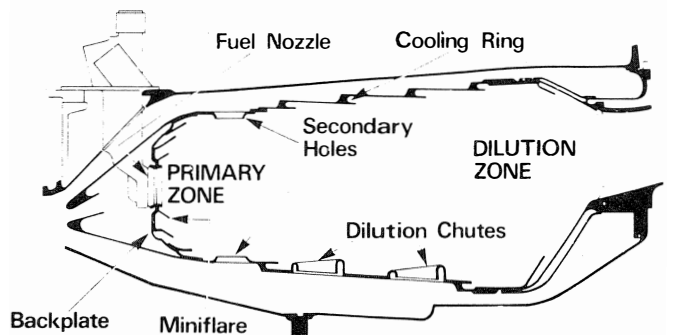


Figure 17. Industrial RB.211 Combustion System.

Viewing angles of borescopes

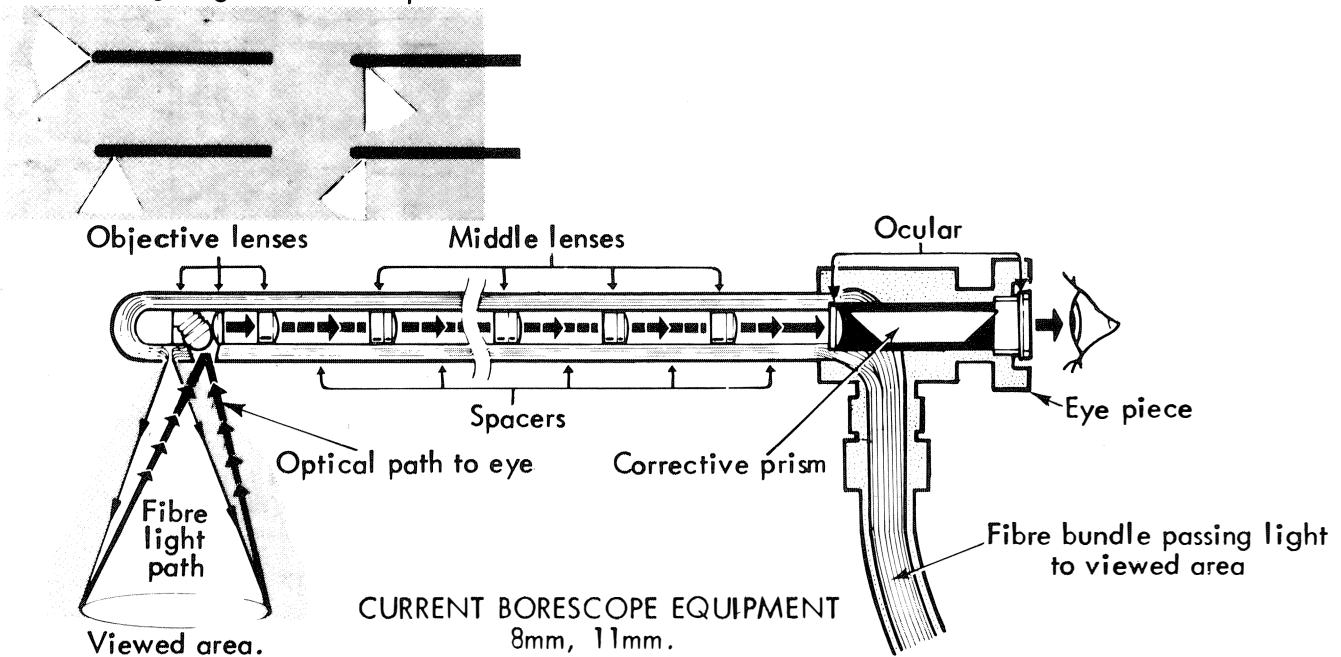


Figure 18. Fibreoptics Boroscope.

Large savings in maintenance man hours can be achieved if it is possible to inspect the inside of the gas generator. Figure 18 shows a fibre optics borescope which is a very useful tool if provision has been made in the gas generator design for its use. In the Industrial RB.211 all major moving parts can be viewed with a borescope by one man in one to two hours as shown in

figure 19. In addition, photographs of the condition revealed by the borescope can be taken for detailed study, and for record purposes. Examples of such photographs are shown in figures 20 & 21. The advantages of this capability will be immediately apparent to those engaged in gas turbine maintenance.

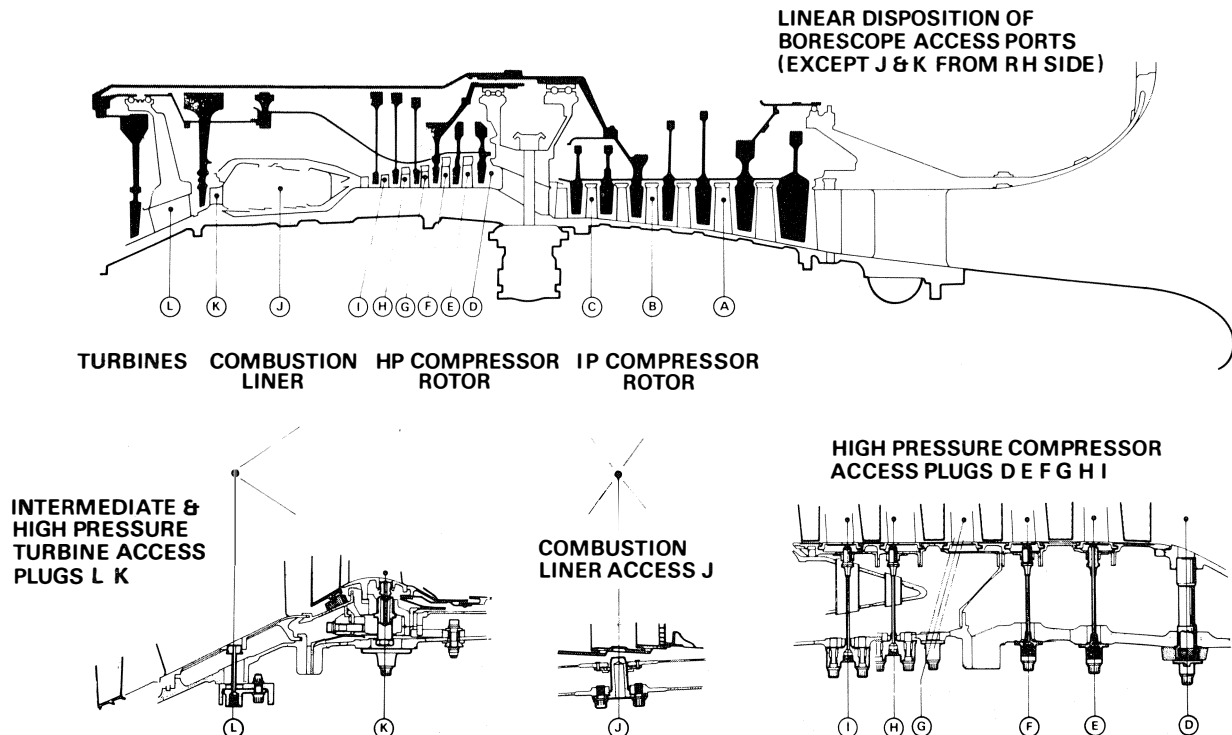


Figure 19. Ports for Boroscope Examination.

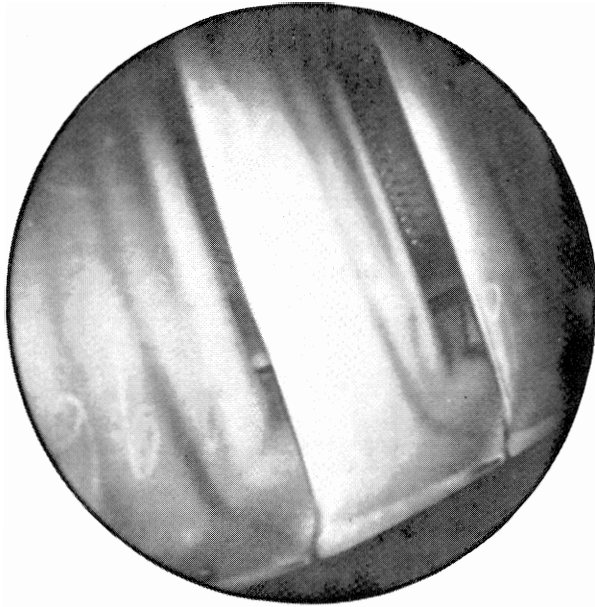


Figure 20. Boroscope view of High Pressure Turbine.



Figure 21. Boroscope view of Combustion Equipment.

Figure 22 shows a magnetic chip detector. These are plugs located in each lubrication oil line and can be checked for any metal accumulation without stopping the gas turbine. This permits a quick and effective check of the condition of the main line bearings and internal gearing. Should metal particles be found on a chip detector, it will be apparent which module (section) of the gas generator is in distress and suitable action can be taken with a minimum of cost and labour.

The Industrial RB.211 is particularly amenable to control by trend analysis. Figure 23 shows an existing installation in a remote area where Trend Analysis would be a particularly useful maintenance tool.

While mechanical equipment is made by man, which is likely to be for a long time, problems will occur. When faced with major maintenance it should be possible to complete the task with a minimum of manpower, in the minimum period of time, with the minimum of equipment. For example, if metal is found on a chip detector it should be possible to change the offending module on site.

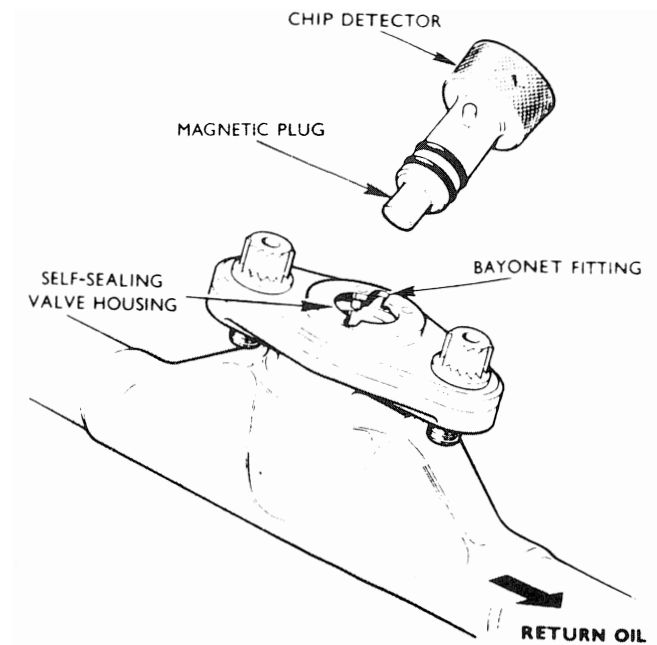


Figure 22. Magnetic Chip Detector.



Figure 23. Remote Monitoring by Trend Analysis.

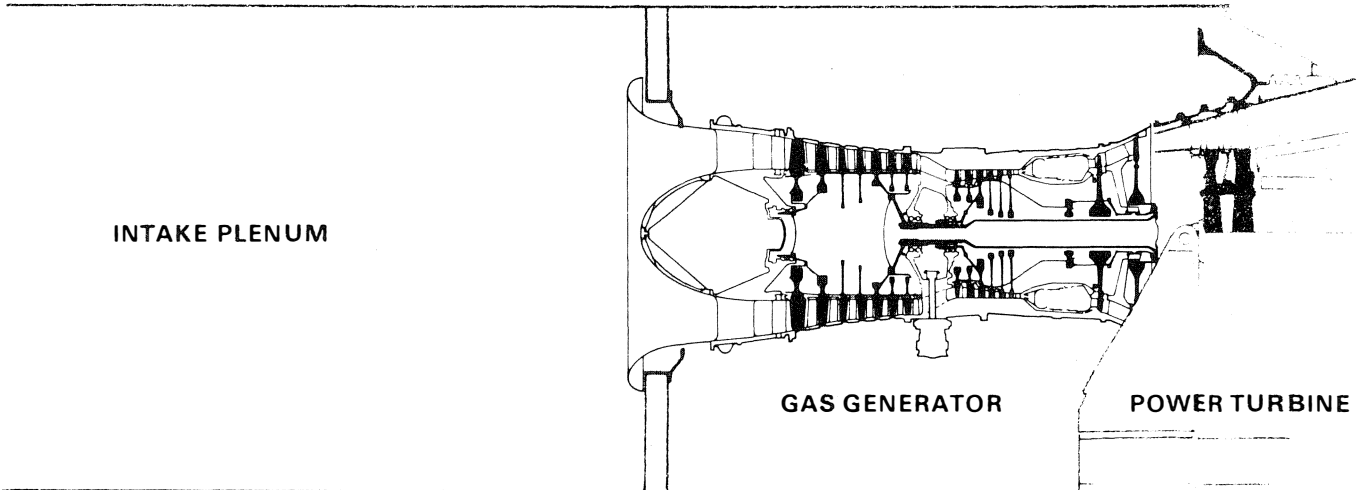


Figure 24. Simplicity and Accessibility of Modern Gas Generator.

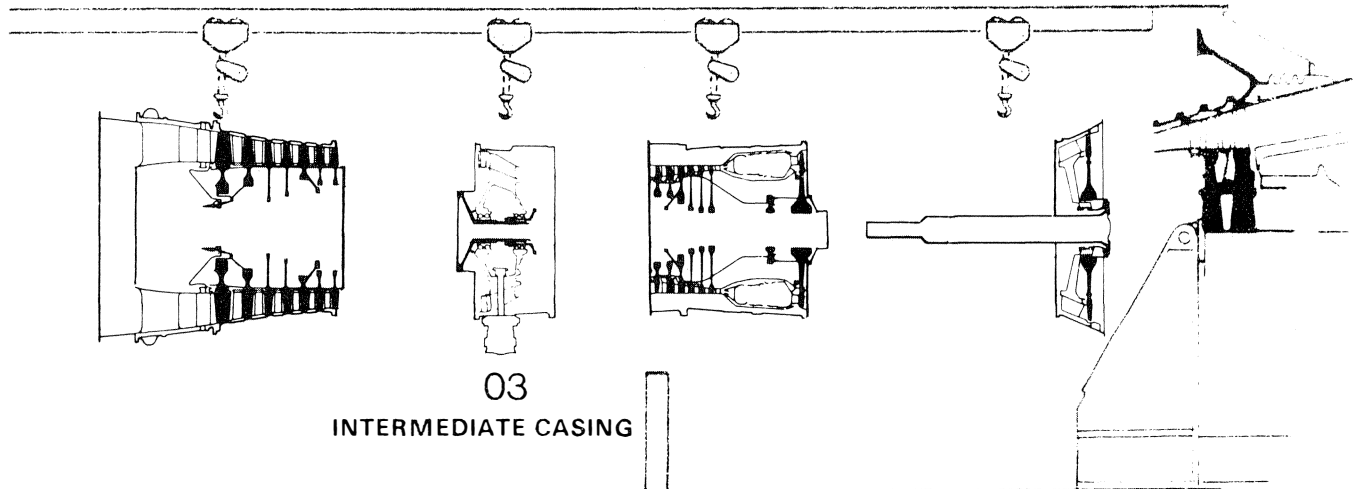


Figure 25. Industrial RB.211 can readily be Changed on Site.

Figures 24 & 25 show how the Industrial RB.211 is fully modularized. Each module can be changed in two working shifts by a three man crew. The heaviest module weighs only 1765 lbs. The gas generator can be changed readily in four hours and as it weighs only 5250 lbs. special handling equipment is unnecessary. Figure 26 details the elapsed times necessary to change modules or the gas generator. It will be evident that the advantages of modular construction and low component weight are particularly important in remote and inhospitable areas.

Various pipelines are being planned from the Arctic, which is a remote area devoid of normal means of transport and normal amenities. Figure 27 shows the route of some of these pipelines and the geographical areas in which they will be located. Figure 28 shows a drilling station at TAGLU in the Mackenzie River Delta at "mid-night," while the rugged nature of the Arctic is shown in figure 29, Richardson Heights. Figure 30 shows an Industrial Avon site in northern Ontario.

	ESTIMATED ELAPSED TIME
GAS GENERATOR	4 - 5 HRS.
MODULE 01 - AIR INTAKE	4 HRS. 40 MINS.
MODULE 02 - I.P. COMPRESSOR	9 HRS.
MODULE 03 - INTERMEDIATE CASING	17 HRS. 50 MINS.
MODULE 04 - H.P. MODULE	13 HRS.
MODULE 05 - I.P. TURBINE	7 HRS. 30 MINS.

NOTE - THE ABOVE MODULE CHANGE TIMES ARE BASED ON A FOUR MAN CREW.

ALL MODULES MAY BE CHANGED ON SITE WITH THE ENGINE IN THE HORIZONTAL POSITION

NO HEAVY LIFTING EQUIPMENT IS REQUIRED

Figure 26. Industrial RB.211 Module Change.



Figure 27. Proposed Gas Pipelines in the Arctic.



Figure 29. Richardson Heights, Northwest Territories.

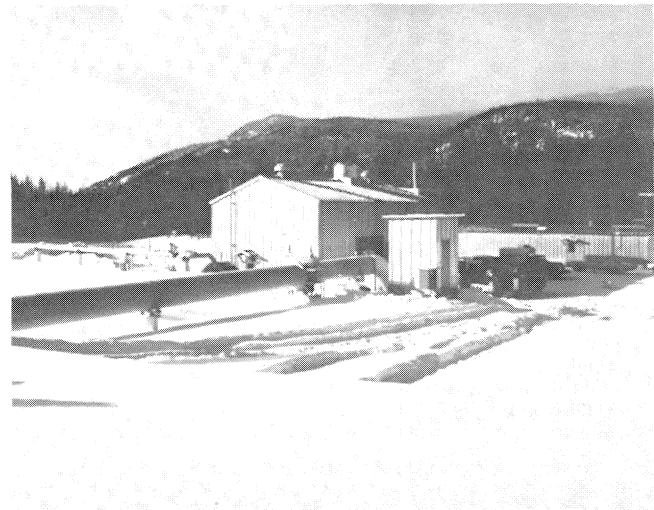


Figure 30. Industrial Avon Gas Pumping Set.

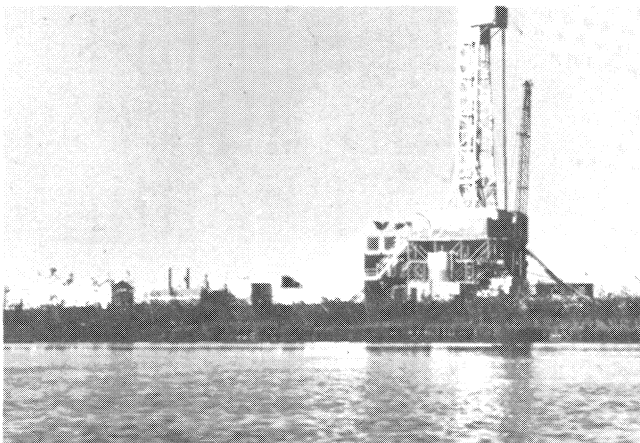


Figure 28. Drilling Rig in the Arctic and Midnight.

4. GENERAL

Figure 31 shows the rating curve of the Industrial RB.211. The ISO rating is 26,400 SHP. The output increases as ambient temperature falls and thermal efficiency improves co-incidentally. A second version of the Industrial RB.211 offers 29,000 SHP at ISO with a further improvement in thermal efficiency.

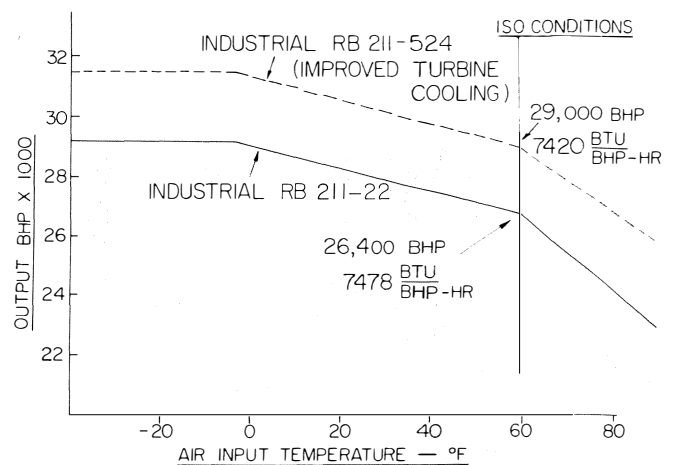


Figure 31. Rating Curve—Industrial RB.211.

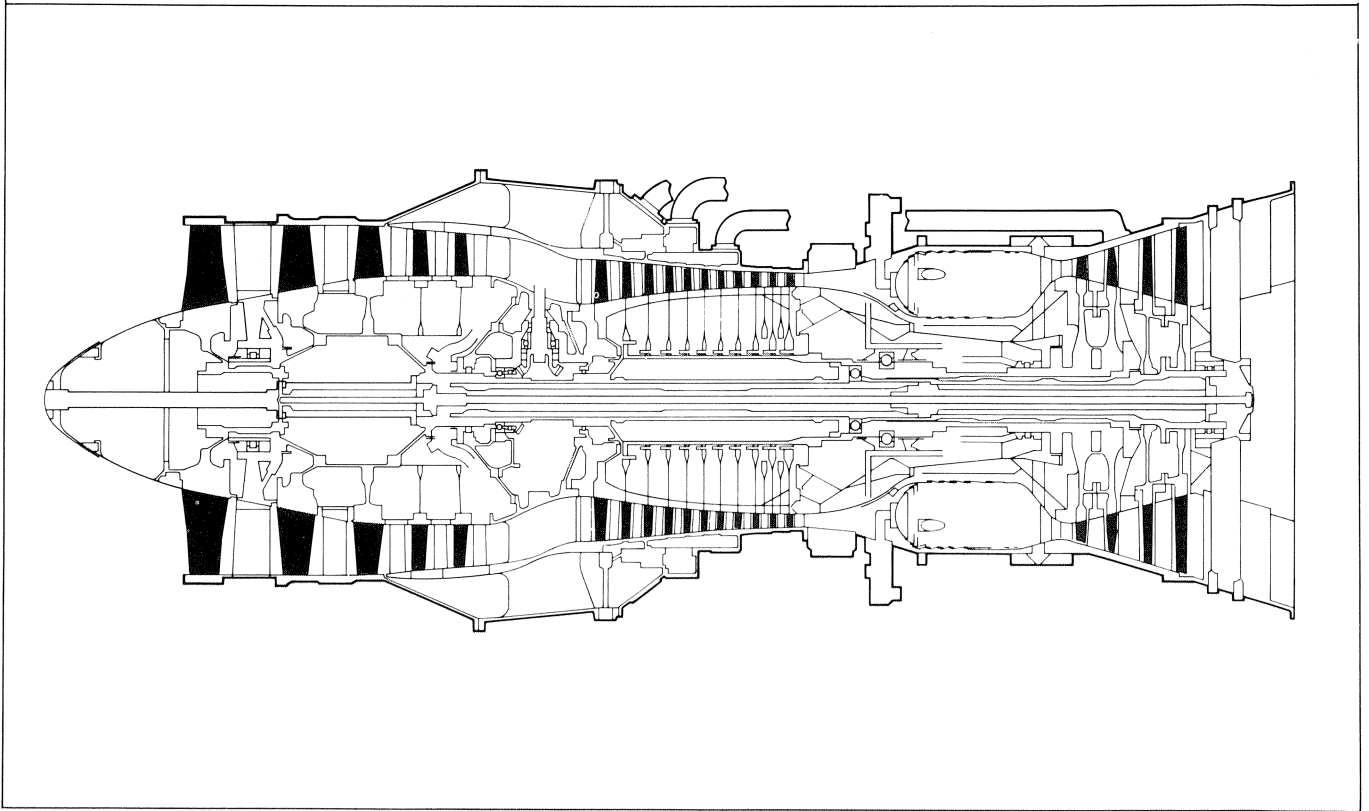


Figure 32. Industrial Spey Gas Generator.

The Industrial RB.211 has a stable companion, the Industrial Spey, which is designed to similar concepts of high efficiency, high reliability and ease of maintenance. An outline of the Industrial Spey is shown in figure 32. FIGURE 33 indicates that the Industrial Spey offers 16,000 SHP at ISO; a thermal efficiency of about 33% and considerable potential for up-rating. This gas generator weighs only 3250 lbs.

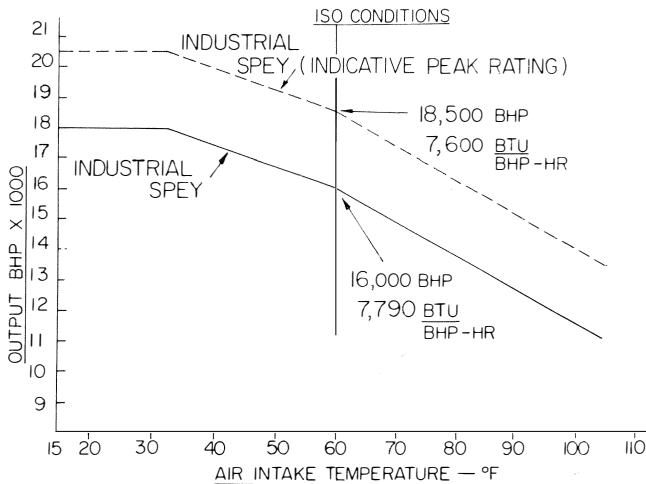


Figure 33. Rating Curve—Industrial Spey.

Figures 34 & 35 compare operating costs of first generation gas turbines and advanced technology units. The savings offered to a potential operator are impressive, amounting to:

\$125,000 per year with an Industrial RB.211

\$160,000 per year with an Industrial Spey

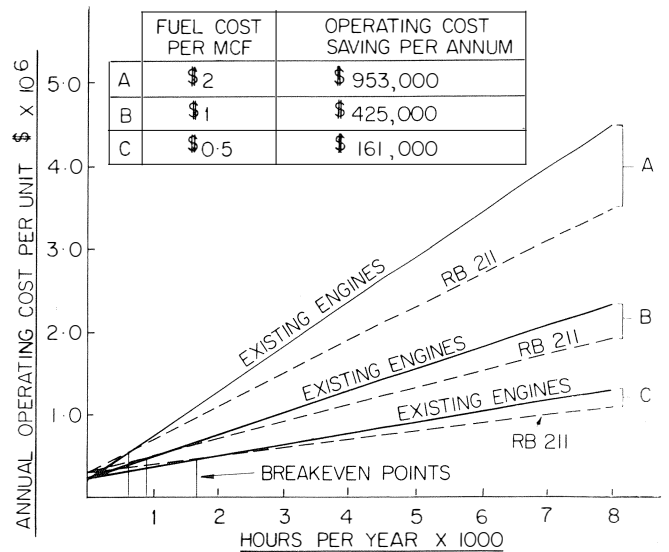


Figure 34. Annual Savings Obtainable by use of the Industrial RB.211.

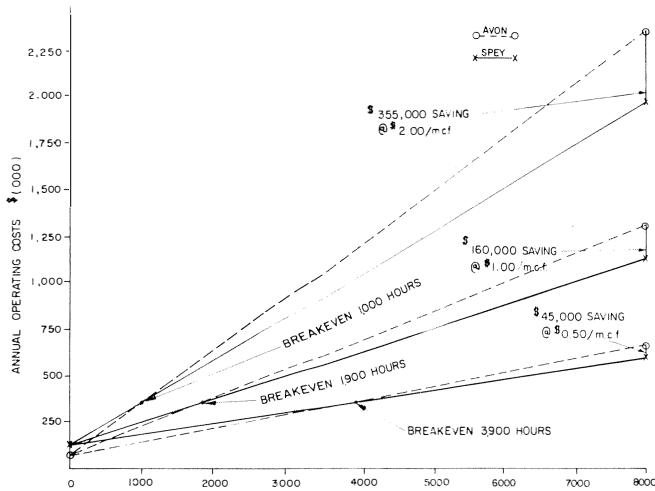


Figure 35. Annual Savings Obtainable by use of the Industrial Spey.

using a nominal figure of \$1/MCF for natural gas delivered to the consuming areas. Should gas prices increase to \$2/MCF the savings will be proportionately greater.

These figures take cognizance of:

- (a) the higher first cost of advanced technology gas turbines
- (b) a purposely pessimistic maintenance cost estimate
- (c) 13% per year amortization

The Industrial RB.211 commenced field operations in 1974 and the Industrial Spey will commence operation in the latter part of 1975.

5. CONCLUSIONS

- (a) Advanced technology can be harnessed to provide high efficiency, simple cycle gas turbines, without the complications of regeneration, waste heat recovery, etc.
- (b) Advanced technology can be applied to proven concepts to achieve even greater reliability.
- (c) High efficiency gas turbines can be designed to take advantage of new maintenance procedures which reduce manpower requirements, simplify maintenance procedures and reduce inventories of spare parts.
- (d) Advanced technology aero derived gas turbines are particularly adaptable to Trend Analysis systems which will reveal deterioration before it becomes serious.
- (e) Advanced technology aero derived gas turbines can be allied to a waste heat recovery system, resulting in a most attractive thermal efficiency of 46%.

Gas Turbine technology is a rapidly changing science; this is what makes it all so exciting—who can tell what the next decade will reveal.

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