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Contents

Advances in the Development of the Compact Gas Turbine for Offshore Platforms

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SYNOPSIS

The various applications of gas turbines offshore can broadly be divided into two categories: electrical generation, which concerns the provision of electricity for platform production and hotel services, and mechanical drive, the provision of shaft power for pumping and compression, water injection, gas reinjection and LNG refrigeration. In both categories the incorporation of exhaust waste heat recovery systems to optimise total energy usage is becoming increasingly common. The severe financial penalties associated with a break in hydrocarbon production make it imperative that the operation continues in all weathers, twenty-four hours a day. Therefore the major items of topside equipment, on which production depends, must be designed to withstand the rigours of such environments and demonstrate the very highest levels of reliability. Of all these items of equipment, there is none whose operation is more critical to production and safety than the power plant. This paper examines the reasons behind the dominance of the aero-derivative gas turbine for such applications and selects for discussion some of the many aspects which need special consideration during the topside conceptual design phase. In particular, the need to minimise weight and size is emphasised, as are the needs both to concentrate on material selection and for compliance with the various National and International design standards. To conclude, the paper looks to the future and considers those areas of gas turbine design which, with almost two decades of offshore experience to fall back on, lend themselves readily to further refinement and improvement.

INTRODUCTION

Ever since compact, aero-derived gas turbines were first employed in land-based industrial service almost 30 years ago, they have become increasingly recognised as being ideal for the ever-widening range of industrial and marine applications and environments. Rolls-Royce's experience of operating in harsh marine environments stretches back even further, with the two first gas turbines going to sea in 1953.

Offshore platforms operate in some of the most hostile environments imaginable. In the North Sea wind speeds of 135 miles per hour are not unheard of, and the platform structures must be capable of withstanding waves 30 metres high. In these conditions the atmosphere become saturated with salt concentration and the ambient temperatures can range from +27 to –12 °C. To make matters worse the air may also be contaminated with platform generated drilling dust.

Elsewhere in the world ambient temperature ranges can be as high as 50 °C (in the Gulf) with humidities up to 100%.

Figure 1 shows that the aero-derivative concept of gas turbine, which was pioneered by Rolls-Royce, is now totally dominant in this market, having completely ousted the heavyweight gas turbine since 1980. Its success is attributable to a number of significant factors:

1. Its capital cost is highly competitive.
2. Inherently it has a high power-to-weight ratio.
3. It gives a very small set footprint, which is important where space is at a premium.
4. The gas generator, and indeed the complete gas turbine generator/mechanical drive set, is very easily transported.
5. Starting power requirements are very low and as a result only a battery pack is required, doing away with the conventional and cumbersome diesel engine starting systems.
6. It can start from cold and run up to full power very rapidly (within three minutes if necessary).
7. It now has a proven background of high availability and reliability, which is a measure of its ability to give power on demand.
8. For many operators the most important factor, and the key to high availability, is the ease with which the aero-derived gas turbine can be maintained. The fact that a gas generator can be removed and replaced with a spare in eight hours or less means that essential maintenance can be carried out on a gas generator whilst the set from whence it was removed remains available for operation.

B. N. Howe graduated in 1976 with an Honours Degree in Mechanical Engineering from the University of Bristol. He joined Rolls-Royce direct from University on a two-year graduate training scheme during which he completed a diploma in management studies at the Lanchester (now Coventry) Polytechnic. Following a period as a Development Engineer concentrating on gas turbine combustion and fuels he transferred into marketing initially as a Sales Engineer. In 1979, he moved into the front line as Regional Manager responsible for India and the Far East, rising to become head of Industrial Marketing, a post which he has held since 1984.

APPLICATIONS

The applications for gas turbines offshore fall into two categories:

1. Electrical generation, to provide electricity for platform production and hotel services.

2. Mechanical drive, to provide shaft power for pumping and compression, water injection, gas reinjection and LNG refrigeration.

Each set can be assembled and fully tested onshore as a single-lift unit which can be floated out on a barge and lifted into position on the platform.

The principle packages of which these sets are comprised are:

(a) Prime mover package
(b) Auxiliaries package
(c) Air intake package
(d) Exhaust package
(e) AC generator package
(f) Control package

Each of the above packages is shipped as a complete tested unit with, where necessary, an integral baseplate and acoustic weather-proofed enclosure.

For mechanical drive applications, Rolls-Royce supplies industrial gas generators or gas turbine driver units to original equipment manufacturers for incorporation within packages of their own design.

The full range of Rolls-Royce gas generators offered and their shaft output coupled to a typical power turbine are shown in Table I.

Air sampling programmes and samples taken from engine drains have shown that the typical offshore platform has an environment which combines a harsh marine atmosphere and in some cases high sulphur content fuels with a typical polluted industrial environment.

Contaminants from oil processing facilities, flare stacks and machinery exhausts, together with wind blown salt-spray from waves breaking on platform structures can be drawn into engine air intakes presenting highly erosive/corrosive conditions to engine components, especially those in the hot gas path. These conditions can be countered by:

1. Material changes and addition of anti-corrosive coatings.
2. Improvements to air intake filtration.
3. Improvements to fuel supply systems both in storage tanks and by improving filtration to the engine.

Materials

The major development programmes have been aimed at new materials and surface coatings throughout the engine to combat erosion and corrosion.

Some of the most extreme erosion/corrosion problems were experienced on the early hovercraft engines and this experience, together with the work done for marine propulsion gas turbines, has been invaluable in the development of engines for offshore power sets. Typical early changes were:

1. Lightweight magnesium alloy casings, which were highly susceptible to salt water corrosion and could under certain failure conditions lead to fire risks, were replaced by aluminium alloys.
2. Blading materials with better anti-corrosive properties were needed. In general, this required a material with a higher chrome content, which also had to be balanced against the required material strength.
3. For added protection against corrosion in the marine atmosphere various surface treatments were developed, including pack aluminising processes for hot gas path components such as turbine blading and sermetal coatings in lower temperature areas of the engine.

Intake systems

The engineering of the intake system for an offshore gas turbine generating set is a collection of individual design requirements. The various requirements that have to be dealt with are:

1. An intake air distribution at the compressor inlet face which ensures satisfactory compressor operation throughout the envisaged range of duties, yet is of minimum size and weight.
2. Adequate filtration to protect the engine not only from the salt in the intake air, but also from the less obvious natural particulates (oil, carbon and drilling dust), whose level varies from platform to platform depending upon function and location.
3. Operation in icing conditions, bringing the need to incorporate anti-icing protection, and possibly filter by-pass doors, which will give dependable service under abnormal circumstances.
4. Minimal maintenance requirements.

Table I: Rolls-Royce gas turbines and their shaft output

	Efficiency (%)	*ISO base rating* (shp)
Spey	34.1	16 400
Avon	30.6	20 700
RB211	34.7	30 550
Olympus	31.4	38 600

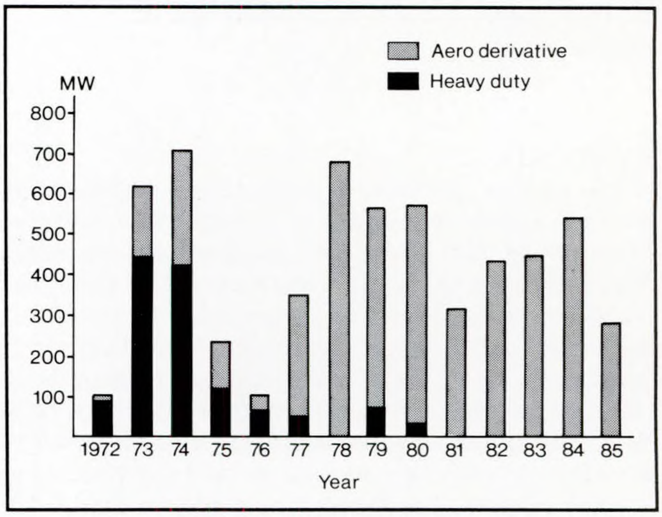

FIG. 1: International offshore market for gas turbines of 10 MW and above

Figures 2 and 3 show the typical intake design for a single-lift unit destined for the North Sea. Two significant features of this are:

1. The anti-icing 'piccolo' tubes which inject air heated by a heat exchanger in the exhaust duct. An alternative source of hot air is the engine compressor delivery air.
2. The compact, three-stage, high-velocity filter system.

The incorporation of by-pass doors is a matter of customer preference, depending as it does upon a judgement of the importance of continued operation, given blocked filters, against the possible detrimental effects on the gas turbine of consuming unfiltered air. In the event that the decision is taken in favour of by-pass doors then the motorised variety must be considered to be mandatory. The reliability of non-motorised systems is inadequate for the intake of an offshore unit where access to restore a door to operation in bad weather is extremely difficult.

As an example of a very different intake arrangement, Fig. 4 shows the self-cleaning pulse filter concept installed on units destined to meet the sandstorm conditions of the Gulf region.

Fuel supply systems

Whilst gas turbines for compressor drive are generally gas fuelled, units employed for power generation have to be capable of operation on both gas and liquid fuels. Operation

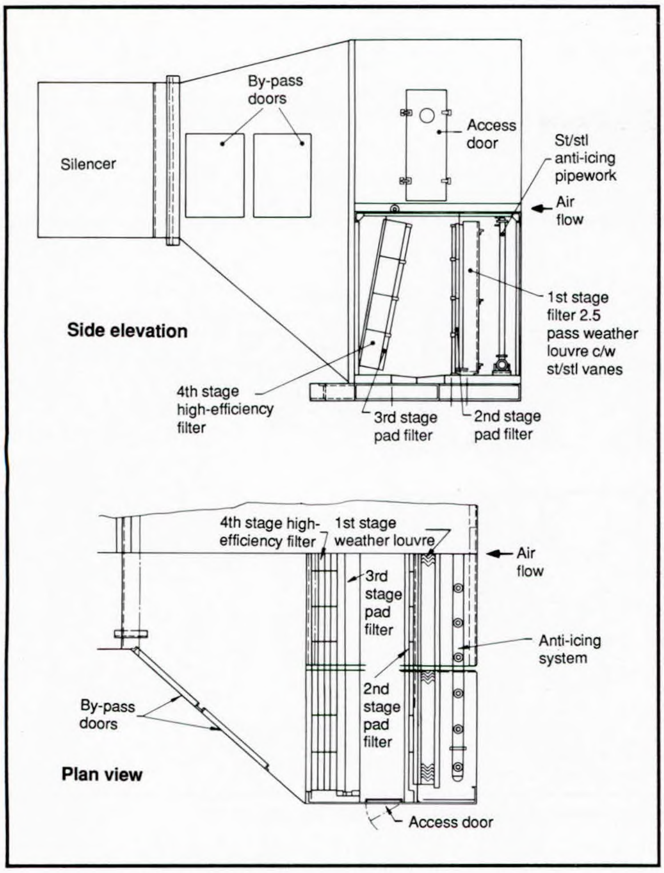

FIG. 2: Typical low-velocity filter system

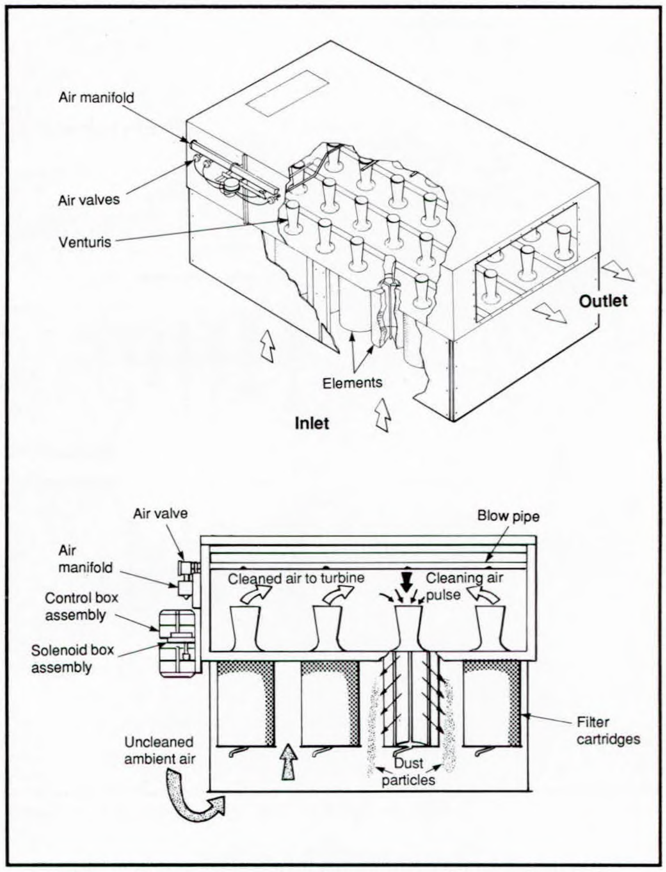

FIG. 4: Pulse clean type filter system, illustrating self-cleaning operation

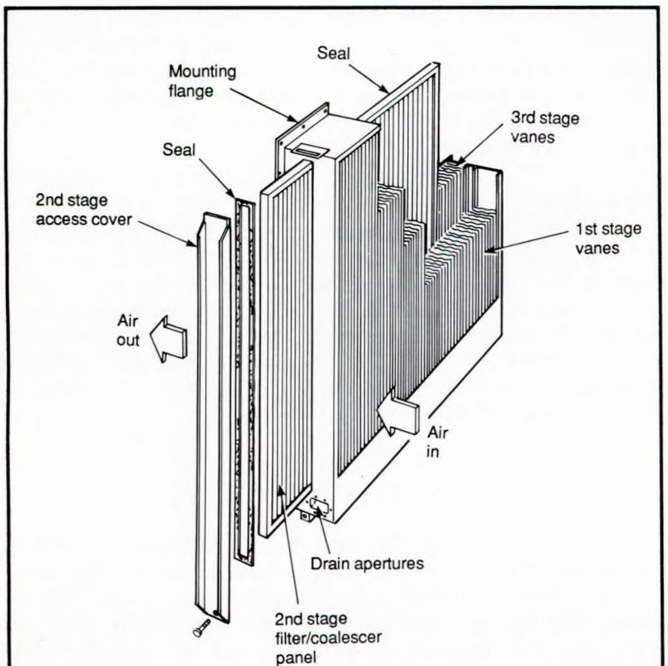

FIG. 3: Three-stage high-velocity filter system

on diesel fuel is required either as insurance available automatically should gas fuel pressure fail or, on oil platforms, to run the units when associated gas is either unavailable or is being allocated to reinjection.

However, the supply of diesel fuel can be a problem. It has to be shipped out to the platform, and then is normally stored in tanks in the platform legs. It is easy for it to become contaminated with salt water during handling and storage, and this contamination has to be removed to avoid turbine corrosion. Whilst coalescers are often adequate for this task, duplex units of large capacity are necessary to minimise the maintenance burden.

Equally, it is important that gas fuel is free from aqueous or hydrocarbon droplets, and adequate gas-drying must be built into the supply line. The gases available as turbine fuel are increasingly, for economic reasons, the residue from a gas upgrading process. They may therefore have a substantial inert fraction and correspondingly low calorific value, or possibly high calorific value because of the proportion of higher hydrocarbons.

All of Rolls-Royce's industrial gas generators now have dual-fuel capability, allowing operation on, say, distillate oil and natural gas either uniquely or in combination to a maximum mixture of 90% + 10%. Combustion systems have now been developed for most of the machines to allow operation on medium and low calorific value gases, light liquids such as naphtha and selected heavy fuels after treatment.

SECOND GENERATION GAS TURBINES

The original aero-derivative type machines (typified by the single spool compressor Avon) are now being superseded by the new breed of engines which in general have higher pressure ratios, higher temperatures and hence higher efficiencies than their predecessors. The RB211 gas turbine is one example of this new generation.

The industrial RB211 is derived from the aero RB211 (37 400 to 58 000 lb thrust) which was launched into service in 1972 and has now accumulated over 23 million flying hours in TriStar Boeing 747 and 757 aircraft. With the introduction

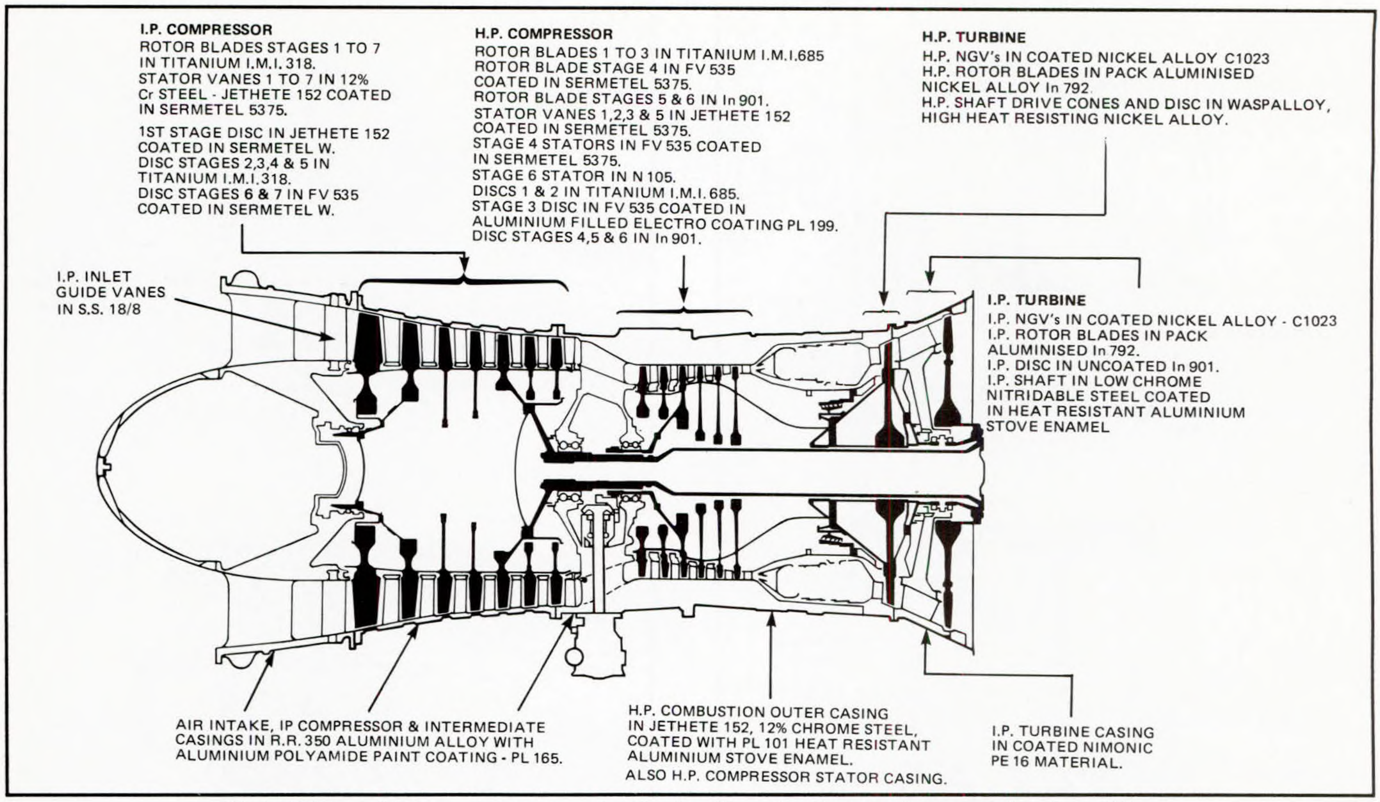

FIG. 5: RB211 - 24C gas generator — dual-fuel turbine showing standard materials for offshore

of the -524 varient the industrial RB211 inherited the uprated HP turbine in 1976 and improvements to the compressors followed in later engines.

To ensure satisfactory operation in an offshore environment the following marinisation programme was initiated.

Gas generator material and coating changes

With future applications in the marine environment in mind, during the redesign of the engine for industrial use further changes in material and coatings were incorporated to improve corrosion resistance and life. The present materials are shown in Fig. 5.

IP compressor

The intake casing, previously made in Jethete for aero use, the compressor casing and intermediate casing are all aluminium alloy coated with polyamide paint for improved corrosion resistance.

The compressor rotor stage 1, 6 and 7 discs are 12% chrome steel coated in Sermetal W, whereas in aero engines the stage 1 disc was uncoated titanium and the sixth and seventh stage discs had a heat resistant stove enamel coating. In common with aero engines, disc stages 2, 3, 4 and 5 are uncoated titanium.

All seven stages of rotor blades are titanium and stages 1 to 4, originally aluminium in aero use, have been changed to give increased life. All seven stages of stator vanes are now Jethete and coated in Sermetal 5375. The stage 1 to 4 aluminium stator shrouds are now coated with polyamide paint.

HP compressor

No material changes have been made to the HP compressor, but corrosion resistant coatings have been applied to the steel components. These components, the fourth stage rotor blade and stator vane stages 1 to 5 are now coated in Sermetal 5375.

HP turbine

Changes from aero engines have been carried out on the rotor blades only. These blades have been changed from Mar M 002 material to In 792 nickel alloy and as before they are pack aluminised. The new standard of blading for the -24C dual-fuel gas generator incorporates coated and super polished rotor blades and a change to C1023 for the HP NGVs with the same surface treatment.

IP turbine

Changes have been limited to pack aluminising of the C1023 nickel alloy NGVs and replacement of pack aluminised Mar M 002 with pack aluminised In 792 for the rotor blades, as for the HP turbine. In the -24C these materials will be changed to coated and super polished In 792 rotor blades and coated C1023 IP NGVs to enhance further the corrosion resistance of both components and improve production methods on the IP NGV.

CONCEPTUAL DESIGNS

At an early stage in the topside planning of a new production platform, various major decisions have to be taken on the platform power supply requirements. These will be determined by the quantities of oil and gas flowing from the field, and the main duties will be a mix of oil pumps, gas compressors (possibly including high-pressure reinjection units) and injection water pump. Secondary duties will be platform utilities, well drilling, topside process equipment, cooling water pumps etc.

A further, growing requirement is the wish to recover turbine exhaust heat for process and hotel services, or for turbine intake anti-icing.

If intake air filtration requirements are a major consideration for a particular project, then the space taken by the filter housing can be a determining influence on the platform configuration.

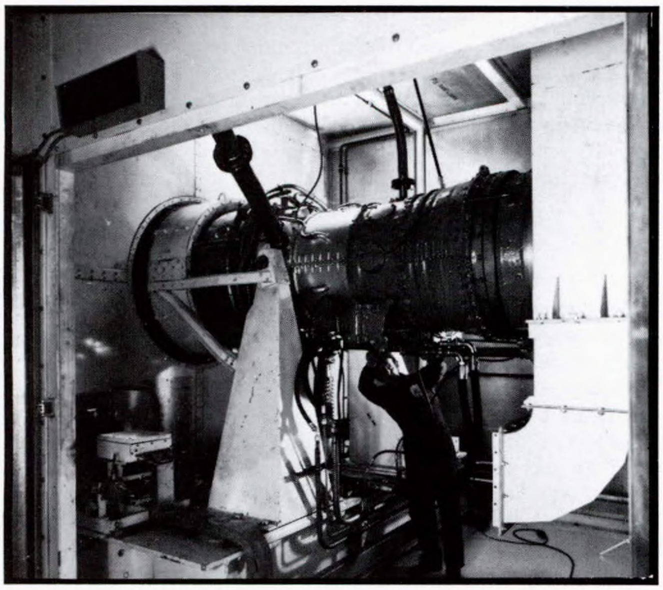

FIG. 6: Working on a gas generator inside the module

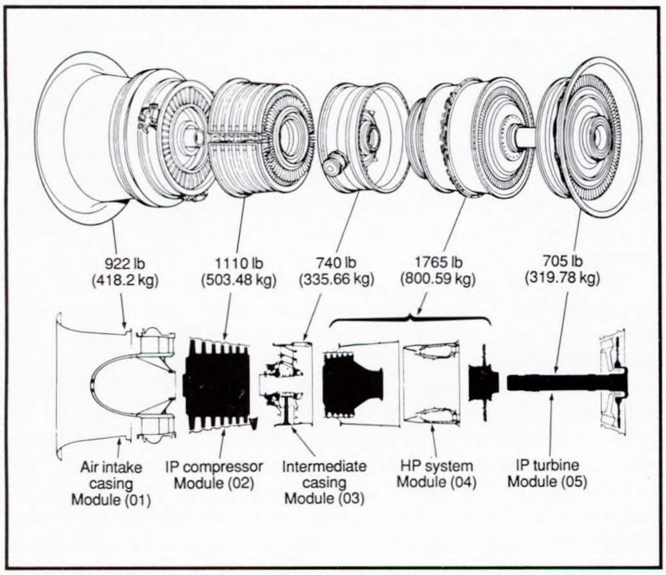

FIG. 7: Modular construction of RB211 gas generator

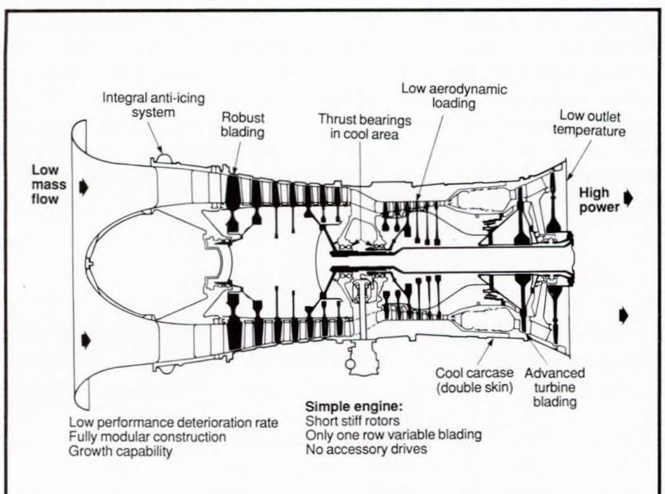

FIG. 8: Major features of the RB211 gas generator

These fundamental decisions will influence topside equipment layout. Whereas gas turbine driven compressors will be located in an optimum position to suit their role in the process flow, a decision to go to an 'all electric' platform allows the topside designer to put the generating sets almost anywhere, with the preference generally being for an outdoor, upper deck location.

Having decided that a design to suit this exposed upper deck location is required, various other design principles follow:

First, an integrated, single-lift unit, fully load tested onshore, is most sensible. The cost of assembly and commissioning work offshore is many times the cost of the same work onshore and is to be avoided. Since the topdeck location eliminates interference from platform bracing steelwork, such an approach is entirely permissible. Furthermore, this concept minimises the number of design interfaces with other platform equipment.

Secondly, the significant static and dynamic distortions of the platform steelwork caused by deadweight loads, platform settlement, operating loads, solar heating, wind, and wave effects must have minimal influence on the machinery in order to avoid misalignment resulting in vibration or bearing problems. The units may therefore need to be structurally uncoupled from the platform steelwork, which can be achieved through a three-point mounting.

Thirdly, a three-point mounted unit must be designed to be strong and stiff in itself, in bending and torsion, since it will still be under the influence of normal, and abnormal, operating loads and wind gusts, and cannot rely on its foundation for any rigidity, as a land-based installation would. Whatever the mounting arrangement, the unit has to be able to accept the loads involved in lifting, transportation and installation on the platform.

For units which are not going into topdeck installation, a wider variety of decisions may have to be made. It is quite possible, for example, that platform bracing steelwork will prevent units being delivered as total assembles, and a degree of work on the platform has to be accepted. Once this decision has been taken, separate attachment of the major sub-assemblies to the platform structure may well save total weight, but in this case some flexible jointing between the sub-assemblies may be necessary.

Another option for the top deck designer is to build the equipment onshore into major modules of up to 2000 tonnes each. In such cases, the equipment will neither be exposed to the weather nor suffer the premium costs associated with offshore assembly work, and unit design may be very similar to those for land-based equipment.

It may be possible to use separate sub-bases for turbine driven equipment, should local module structural stiffness be adequate to maintain the alignment that can be accepted by the flexible drive couplings connecting the driving and driven equipment.

DESIGN FOR MAINTENANCE

Whilst the aero-derivative engine needs a minimum of maintenance, it remains necessary from time to time to remove components from various locations on the generating set for repair or replacement. Figure 6 shows the ease of working on the gas generator inside the module. Should complete gas generator removal be necessary, it can readily be transferred into its transportation cradle using the lifting rail unit inside the enclosure.

Alternatively, the RB211 comprises five easily removable modules which are completely interchangeable with similar new or reconditioned modules which have been factory balanced. Modules can be replaced in a small maintenance space, with only a hoist and a few special tools being necessary. Module connections are made by self-centring couplings thus eliminating the need to rebalance assemblies.

A considerable saving can be achieved for fleet operators who need only stock selected spare modules instead of a number of spare gas generators. An appreciation of the different rates of wear on modules means that the optimum life can be achieved from the gas generator or fleet of engines. In addition to this, an appreciable saving on the cost of the overhauls can be made by returning individual modules to be reconditioned or repaired instead of returning the complete gas generator. In this way each module can be used to its maximum extent before being returned for individual overhaul.

The modular construction of the industrial gas generator is as follows. The build up of these modules is shown in Fig. 7, and Fig. 8 shows the major features of the gas generator.

Module 01

This is the air intake casing module which houses the nose bullet assembly, the intake support vanes and the variable inlet guide vanes.

Module 02

This module, the IP compressor module, comprises the IP compressor stator casing and rotor.

Module 03

This is the intermediate casing module and houses the fully assembled IP rear and HP front compressor stubshafts and location bearings together with the starter drive and starter motor mounting.

Module 04

This module, the HP system module, is commonly referred to as the 'hot section module' and houses the HP compressor, the combustion system and the HP turbine. The HP compressor is attached to the HP turbine, in common with the IP spool, by a self-centralising coupling.

The combustion system interposed between the HP compressor and turbine has an annular combustion chamber housed within combustion chamber outer and inner casings which provide for the passage of cooling and dilution air. This annular design of combustion chamber provides a clean aerodynamic extension to the HP compressor outlet, minimises the area to be cooled, gives good temperature distribution and avoids interconnector problems. Fuel is delivered by means of 18 dual-fuel spray nozzles.

Module 05

This module, the IP turbine module, comprises the IP turbine casing, IP nozzle, HP/IP bearing support structure and IP turbine rotor assembly.

Module 06

This designation is used for convenience to cover non-modular dressing items such as air and oil pipes, the power turbine cooling pipe, anti-icing air pipe and valve, IP handling bleed valves, HP starting bleed valve starter and electrical harness etc. These are all fitted to the engine after assembly of the five modules.

Advantages of module construction

In summary, it may be seen that significant advantages are offered by module construction, including:

1. Rotating component modules being pre-balanced and having self-centring couplings eliminate the need to re-balance assembles.
2. Repairs, except in normal circumstances for module heavy maintenance, may be carried out onboard by site staff.
3. Modules may be removed without disturbance to components of mating modules or to floor mounted support systems.
4. Lower overall maintenance costs and minimum downtime for repair.
5. Savings on transportation, storage and inventory space.
6. All modules (including the complete gas generator) are air or road transportable.
7. Simple training of maintenance personnel.
8. Spare modules and special tooling required to carry out module changes can be supplied in pre-packed air transportable containers.

FUTURE DEVELOPMENTS

The existing offshore sets provide a continuous feedback of information which is used to refine current and future design practices on new installations.

However, the main guide must still be the customer specification and other installations (especially those for retrospective fitting) must have an element of being 'tailor made' as dictated by the available size slot or the rig lifting facility, eg the 60 ton limit imposed in lifting components for the recent Britoil platform.

Development is still in hand on new materials and the current trend seems to emphasise the use of ceramics for both complete components and as a high-temperature coating/barrier material to enable the use of higher temperatures with better corrosive resistance. The results so far have been encouraging, especially in application to small gas turbines, but it will be some years before ceramics become widely available, especially for highly stressed components.

A further major innovation for future sets is the extended use of electronics. The old control system of large cabinets containing stacks of electro/mechanical relays are replaced by the programmable logic control systems and microprocessors, which not only provide savings in space/weight but also give far greater reliability and easier maintenance by direct replacement.

The use of electronic systems has greatly improved the instrumentation field and together with data acquisition techniques all relevant machinery parameters can be continually assessed. With the development of 'on-line condition monitoring', the old procedures of routine inspection and servicing at set time intervals will tend to be replaced by servicing 'as required'. This will have benefits in very much reduced downtime and higher availabilities.

Existing gas turbines already emphasise the benefit of modular construction as regards ease of maintenance and change of major components, but this aspect is still being developed together with better internal inspection methods without the need for dismantling machinery, eg boroscope inspection facilities and X-ray techniques.

One of the largest single items of equipment allied to offshore gas turbine plant has been the air filtration system. Most of the recent work has been directed at improving the performance, reliability and maintenance procedures of existing systems, but a real need exists to reduce the size of future systems especially where equipment may need to be installed 'buried' in the platform. In this case, future systems will need to operate at higher air velocities and filter manufacturers are already engaged in assessment and model testing of new designs.

PLANT DUPLICATION

Because of the extensive consequences (both physical and economic) of plant failure/shutdown on a platform, operators in the past have tended to specify large contingency reserve, eg

2 x	100%	or	100%	over capacity
3 x	50%	or	50%	over capacity
4 x	33%	or	30%	over capacity

The above examples of past installations show the tendency to reduce this cushion and with tightening economic conditions this tendency will continue and operators will look for greater reliability, reduced maintenance downtime and other means to reduce cost.

During the course of a year the power level requirements on a platform varies considerably season by season. To cover these requirements economically it is possible to utilise a mix of machinery of varying power levels, but this solution must be balanced by the logistical costs associated with different machinery types.

FUTURE EQUIPMENT

Some electrical manufactures are already working on higher-frequency (above 50-60 Hz) generating equipment and an alternator of this type could for a given power be very much reduced in size and weight.

This type of high-frequency alternator directly coupled to a modern, single-shaft, aero-derivative gas turbine (ie eliminating the use of a separate power turbine and gearbox) would lead to a generating set approximately half the size and half the weight of existing gas turbine sets of the same power output.

The first initiative will probably have to come from the platform builder when he is convinced of the necessity and economic benefit and is prepared to specify all the platform electrical equipment to the new design.

Whenever that time arrives, it is certain that an aero-derivative gas turbine will be available to utilise the new technology.