The 18MW Rolls-Royce Spey Marine Gas Turbine

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THE PURPOSE OF THIS PAPER

This paper aims to discuss the factors which led to the selection of the Spey as a marine gas turbine, and the market forces which have led to the conception of an advanced cycle version of the gas turbine at even higher power and efficiency. The operational characteristics of warships using Spey units are compared with those of ships using other propulsion systems. While this paper stands on its own, it can also be regarded as the first part of a series of two; the second part, to be published in Beijing during the September 1985 ASME Gas Turbine Exposition, will deal with further possible uprating of the Spey to about 22 MW using intercooling and heat exchange to improve its thermal efficiency to about 43%.

INTRODUCTION

There is rarely, if ever, a truly new gas turbine introduced today. Rather, there are families of engines using, as far as possible, common components in the interest of achieving both reduced development risks and the economies of scale which result from longer production runs. Examples from the Rolls-Royce "stable" are the RB 211 aero engines, of which there are 7 different marks, covering a thrust range from 37,400 to 53,000 lbs., with others planned, and the Rolls-Royce Spey, which unit is also offered in 7 different aero marks. The Spey's marine derivatives are now following in their aero parent's footsteps, and are developing into a series of units having different applications but high commonality. These derivatives also have applications in the industrial power generation and gas and oil pumping fields. The Spey aero family is shown in table 1, while the marine and industrial offshoots are shown in table 2.

THE SPEY AERO FAMILY

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>THRUST IN LBS</th>
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</thead>
<tbody>
<tr>
<td>101</td>
<td>11020</td>
</tr>
<tr>
<td>807</td>
<td>11020</td>
</tr>
<tr>
<td>511-B</td>
<td>11400</td>
</tr>
<tr>
<td>250/251</td>
<td>11995</td>
</tr>
<tr>
<td>512/14 DM</td>
<td>12550</td>
</tr>
<tr>
<td>TF61</td>
<td>15000</td>
</tr>
<tr>
<td>202 &amp; 203</td>
<td>20515</td>
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</table>

TABLE 1

THE SPEY INDUSTRIAL & MARINE FAMILY

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>POWER</th>
<th>PURPOSE</th>
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<tbody>
<tr>
<td>1900</td>
<td>11.9 MW</td>
<td>G &amp; O PUMPS</td>
</tr>
<tr>
<td>1903</td>
<td>18MW</td>
<td>MARINE</td>
</tr>
<tr>
<td>1907</td>
<td>18MW</td>
<td>POWER GEN.</td>
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</table>

TABLE 2

SPEY SMAA POWER SELECTION

Rolls-Royce led the navies of the world into gas turbine propulsion with the introduction in 1953 of the H.M.S. GREY GOOSE. This unit, which was intercooled and regenerative and very advanced for its place in history, was swiftly followed by the outstandingly successful 3.5 MW (4500HP) Proteus gas turbine which powered the 55 knot BRAVE Class Fast Patrol Boats, and convinced the Royal Navy that gas turbine propulsion offered such attractive qualities that it should also be used for major warships. The British Type 21 and Type 42 Frigate and destroyer classes followed, both powered by the now very well known Olympus and Tyne GOGOG machinery (see figure 1), and other major navies have followed this lead.
After the Olympus and Tyne developments were almost complete, Rolls-Royce had sufficient engineering effort available to tackle a new major naval project. In collaboration with the Royal Navy, the various prospective aero parents were identified, but the required power of the new unit first needed to be established. This demanded study of the warships built in recent years, and the propulsion powers which they had used. The Royal Navy's WHITBY, ROTHESAY and LEANDER family of frigates of around 2500 tonnes had a major influence. 41 of these vessels had been built for the Royal Navy, while a further 35 had been built for or by other countries. These ships had steam machinery of about 11MW (15000 HP) on each of two shafts, and it was felt that the increasingly severe financial restraints on navies would guarantee that there would be a considerable market for ships of about this size in future. Hence an 11 MW gas turbine looked attractive, and the aero Spey offered a variety of options on which a marine unit could be based. In the event, the TF41 aero Spey was selected, because it promised the achievement of the required 11.5MW power at a lower maximum cycle temperature than any of the other units, with the obviously very attractive scope for uprating in due course. Thus was born the Spey SM1A (see figure 2), and the choice of power and efficiency has been vindicated by the many orders taken for the engine even before it enters service.

The guidelines for uprating the unit were:

a. that the new maximum cycle temperature should be well within the aero experience of Rolls-Royce,
b. that the maximum possible commonality should be maintained with the existing SM1A components,
c. that the opportunity should be taken during any redesign to introduce cost reduction features,
d. that the uprating should be achieved by a combination of increasing the mass flow and raising the maximum cycle temperature in order to obtain the optimum power increase while minimising the aerodynamic changes needed,
e. that the new unit, when achieving 18MW should have a life no less than that of the SM1A at its 12.75MW rating.

Inherent in c. above was the need to ensure that if any new Rolls-Royce aero unit contained components which could be common with the uprated Spey components, then the opportunity would be taken to merge the designs if this could be achieved without unacceptable penalties for either application.

UPRATING DESIGN PRINCIPLES

The extent to which the SM1A could be uprated depended partly upon the limitations of existing SM1A components which, in the interest of economy, should not be redesigned, and partly upon limitations which might be imposed by technology on components which

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**TABLE 3**

<table>
<thead>
<tr>
<th>NAVY</th>
<th>SHIP TYPE</th>
<th>MACHINERY</th>
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</thead>
<tbody>
<tr>
<td>UK</td>
<td>TYPE 22-07</td>
<td>2 SPEY 2 TYNE CCAG</td>
</tr>
<tr>
<td></td>
<td>TYPE 22-11 et seq</td>
<td>2 SPEY 2 TYNE CCAG</td>
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<tr>
<td>JAPAN</td>
<td>DD</td>
<td>2 SPEY 2 TM3B CCAG</td>
</tr>
<tr>
<td>NETHERLANDS</td>
<td>M FRIGATE</td>
<td>2 SPEY CCAG</td>
</tr>
</tbody>
</table>

**FIG. 2** SM1A marine propulsion module.

(SM1A units have been sold or ordered until the time of writing, mid 1984.) 5 classes of warships in 3 different navies have the Spey committed as their power plant. (See table 3)
were in any case to be redesigned. The considerations affecting each of the major SM1A components are now discussed briefly in turn.

a. Low Pressure Compressor
Two possibilities existed, namely either to add a zero stage or to retain the existing 5 stages but to modify the blading design and to allow the compressor to run at higher speed. An increase in mass flow of up to about 15% was possible while retaining 5 stages. On balance, it was thought that the retention of the existing bearing centre distance on the low pressure compressor was very desirable, and thus the 5 stage solution was adopted.

b. High Pressure Compressor
It was determined at the outset that the existing high pressure compressor design would be suitable for up to about 20% increase in air mass flow.

c. Combustion
While the existing fuel pumps, being identical to those on the much larger Olympus engine, would be suitable for any proposed uprating, the combustors would need to be checked for satisfactory combustion at all powers up to the new maximum selected.

d. High Pressure Turbine
It was known that improved cooling arrangements would be needed for the high pressure turbine blading for any significant uprating.

e. Low Pressure Turbine
No changes were needed.

f. Power Turbine
Up to an increase in mass flow of about 15%, a reduced capacity 1st stage nozzle would be needed; above 15%, increased nozzle capacity would be needed; at much higher mass flows, aerodynamic changes to the two rows of blading would be needed. Thus there was an obvious preference for 15% increase in mass flow in order to minimise the changes needed in the power turbine area.

g. Ancillary Items
The only item judged as possibly needing significant change was the intake cascade bend, but calculation showed that this would only be necessary if the air mass flow were to be increased by more than 20%.

While there would obviously be other minor matters to be considered as the design proceeded in detail, the above were the controlling factors, and of major significance was the fact the power turbine could remain aerodynamically unchanged if the air mass flow were to be increased by 15%. Investigation was therefore made of the implications of such a mass flow increase, and it was found that the associated HP first stage stator outlet temperature was well within current Rolls-Royce experience, and was therefore acceptable. A check on the overall brake power which would result from the unit showed 18 MW (24,200 SHP), which would nicely meet the requirements of most ships being actively discussed. Furthermore, turbine hot end life at this power was estimated to be the same as for the SM1A at its 12.75 MW rating, and thus entirely suitable for use as a maximum cruising rating. There is, of course the implication of a maximum sprint rating at some power higher than 18 MW, but it was judged prudent not to declare it at this stage, but rather to wait until the prototype development unit had first run and the predictions for it had been confirmed in practical tests.

FIG. 3 Variation of specific fuel consumption with power.

SMY SM1C PREDICTED PERFORMANCE

The new Spey unit has been designated SM1C, the "C" indicating a higher rating than "A". (Another Rolls-Royce project considers an intermediate rating to which the suffix "B" has been allocated.) The specific fuel consumption of the unit has been estimated and is shown in figure 3 and this information has been used for calculating ship performance shown below. Also shown in this figure for comparison are the specific fuel consumptions of the Tyne and Olympus and also the RB211, if fitted with a typical power turbine. This latter unit is representative of the performance to be expected of large second generation gas turbines.

In figure 4 is shown the estimated marine rating of the SM1C and also the current marine rating of the SM1A, plotted against ambient temperature for no loss conditions.

FIG. 4 Variation of power turbine output with air intake temperature, SM1C standard.
SHIP PERFORMANCE

Figure 5 shows the power-speed relationship of a typical frigate of about 2500 tonnes standard displacement. This is to be used for comparing the performance achieved with different engine arrangements. Figure 6 shows the wartime operating profile which has been assumed for the frigate, and which has been used to estimate typical mission fuel consumptions.

Figure 7 shows fuel flow against ship speed for the frigate, for the Tyne, Olympus, RB211 and the Spey SMIC. From these figures have been estimated the fuel consumptions to be expected for four different machinery installations. In each of these, the two propeller shafts are completely separate. Thus it has been assumed for the purposes of fuel consumption calculations that single shaft operation, with the other shaft trailing, is carried out whenever possible to conserve fuel. In the CODOG arrangements, the cruising diesels are of the high speed type, and have been taken as of 3.82 brake MW installed power, in order to compare directly with the Tyne cruising gas turbine, which is also of this power. The maximum cruising speed is taken as that possible with both cruising engines in use, driving their separate propellers.

From the above table it can be seen that the Spey engine, with its very high efficiency at typical frigate operating speeds, offers a very significant
reduction in fuel consumption over the other CODOG options, albeit with a small reduction in maximum speed. The cruising speed is, of course, the same for all CODOG options. Because a gear change is not easy to incorporate in a main reduction gearbox of high power, CODAG arrangements are generally unattractive. With gas turbines, however, their powers can be added without the need for gear ratio changes and hence COGAG is possible. The COGAG arrangement in Table 4 is actually the machinery installation which is being fitted in the British Type 22 Batch 3 vessels. It offers the well known advantages of the all gas turbine plant and high maximum speed, but with a fuel consumption which is inevitably higher than that of the best of the CODOG options.

THE LONGER TERM FUTURE

The SM1C, as currently conceived, offers the possibility of intercooling and regeneration (or recuperation, as some prefer to call it) to achieve a further uprating to about 22 MW, associated with a very significantly increased thermal efficiency. At maximum power, this is predicted to be about 43%, and it will also be possible to make a dramatic improvement in part load efficiency. The effect will be similarly dramatic upon ship performance and fuel consumption: cruising engines, whether gas turbines or diesels, will not be necessary, because the part load efficiency of the new unit is so high. This could well open up new markets for the marine gas turbine. These developments, now well on in the design stage, will be the subject of a paper to be prepared for a later ASME meeting.

CONCLUSIONS

SM1A Stretch Potential

The SM1A, with intent, had significant potential for uprating, and a development programme aimed at an 18 MW SM1C availability in 1989 is in hand. The SM1C will, in its turn, also be capable of development, up to 22 MW, by means of intercooling and regeneration, with higher efficiency.

SM1C Efficiency

The SM1C unit has very high efficiency in the high usage power bracket of the typical frigate, and its use in preference to other available gas turbines will show significant fuel savings, but with slightly lower maximum ship speed.

Noise

The COGAG installation offers the lowest noise signature while avoiding the need for complex noise isolating mountings. Some operators, however, prefer CODOG systems to economise in fuel. In such installations, it is possible to use the gas turbines during prolonged anti-submarine operations, and this is already practised in some navies. Because the SM1C is more efficient at low powers than the other large gas turbines with which it is compared, there is less penalty in using it during prolonged anti-submarine operations than is the case with the other gas turbines.