Abstract

In common with all responsible equipment operators the Royal Navy continues to seek ways to reduce ownership costs. In the particular case of gas turbines, over the last few years, this has taken the form of investment to achieve improvements in fuel efficiency. This route now ceases to offer large scope for improvement. The Royal Navy has therefore carried out an Investment Appraisal into the likely cost benefits which would result from improved life and reliability. The result of this study was to demonstrate a net present value cost advantage from entering into a joint venture development programme with Rolls-Royce to uprate and improve the Marine Spey SM1A.

Introduction

A recent study of warship propulsion configurations carried out for the Royal Navy confirmed that gas turbines remain the most cost effective option for boost power. The cost of this high technology ownership however is relatively high and only those who need the inherent flexibility and high power that a simple cycle gas turbine offers can afford to join the club. Having chosen gas turbines high fuel costs can be expected because whilst the Specific Fuel Consumptions (SFC) of second generation engines are considerably better than their predecessors the fuel efficiency of all modern simple cycle engines is poor compared to competing less compact, prime movers with little scope for improvement. Ever conscious of costs the Royal Navy has therefore concluded that the best route for reducing ownership costs is by improvements in life and reliability. In order to put this theme into perspective however it is worth considering the background.

Background

The Royal Navy has chosen the Rolls-Royce (RR) Spey SM1A Marine Gas Turbine to power the next generation of warships. SM1As have been selected to replace the 2 Olympus TM3B in Type 22-07 (HMS BRAVE), due to be accepted in 1985, in the later Type 22s, and for Type 23 Batch 1. SM1As have also been chosen by the Japanese as cruise engines in a class of DDGs, with a four SM1A fit in their M Class Frigates and most recently by the Dutch navy as boost gas turbines in their M Class Frigates.

SPEY SM1A NAVAL ORDERS

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<th>Navy</th>
<th>Ship Type</th>
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<tr>
<td>UK</td>
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<td>NETHERLANDS</td>
<td>M FRIGATE</td>
<td>2 SPEY DIESEL</td>
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Table 1

The development programme for the marinised Spey was approved in 1977 and full development completed in 1982. This was followed by life extension activities which included both protracted running at Ansty on development engines, and the commissioning of the first RN Spey at the Royal Aircraft Establishment (Pyestock) in March 1983 for a 3,000 hours endurance trial. Both of these programmes were set up to better guarantee successful introduction of the SM1A into both the RN and Japanese Navies in mid 1985. The current maximum continuous power rating of the engine is 12.75 Megawatts (MW) with a capability for 14MW 'sprint' at a high life usage rate. The Declared Overhaul Life (DOL) of the engine at entry into service is comparable to those now achieved by Tyne and Olympus with a target to double this value.
The SM1A was chosen as a replacement for the Olympus to capitalise on an existing aero technology in order to obtain better SFCs (20% better than Olympus), longer life and improved reliability. The goal has always been to achieve the greatest operational effectiveness from propulsion machinery. In the past the drive has been concerned primarily with ensuring adequate life and reliability. Now that these qualities have been achieved however the emphasis has been switched to reducing ownership costs.

Financial managers are well aware that the consideration of initial purchase, maintenance and operating costs are all equally important when assessing TLCs. In the case of gas turbines particularly the fuel bill can more than outweigh the totality of hardware, overhaul and maintenance costs hence the drive for fuel efficiency can be understood. However, after 40 years of refinement the simple cycle gas turbine offers only limited scope for improvement. Although there will always be high technology refinements that can be made, the majority will give a relatively small improvement in performance (of the order of 1 or 2%) at a high cost. On the other hand overhaul and repair costs, at some 20% the total cost of ownership, can be significantly reduced, the life of a young engine can be doubled and the premature removal rate halved if a significant early investment is made.

Experience has established that low-key development of the design of an engine continues throughout its service life to overcome any design shortcomings which may come to light and to improve its safety, life and reliability. Much of this activity is in support of the policy to extend engine life and by this means the DOLs of Tyne and Olympus gas generators have been doubled during their first 12 years in service. A piecemeal approach has been adopted, whereby engines are sampled and modifications introduced, leading to a series of extensions in overhaul life, usually in 500 hour stages at approximately 2 yearly intervals.

It has already become evident that many of these improvements, significant though they may be, are being incorporated too late in the engine's careers for useful cost savings to be enjoyed. For example, a modification package to extend the DOL of Tyne engines has recently been completed after a lengthy design and trial period. Time has eroded the arguments in favour of this modification package however and the operational advantages of its adoption must now be weighed against the fact that the number of spare Tyne engines will soon rapidly increase as the early gas turbine frigates and destroyers are withdrawn from service. Certainly this particular investment is unlikely to fully pay off and from this type of example stems the Royal Navy's current drive to realise the full potential of the new engine early in its life in order to maximise post design support investment return.

Royal Navy/Rolls-Royce Feasibility Improvement Study

During engine development the SM1A was run on a simulated ship operating profile up to 14MW. While actually rated for continuous operation at 12.75MW, the higher power was used to aggravate any design shortcomings and accelerate their presentation. As a result of this running the engine showed itself to be fully capable of increased duty. The SM1A currently sits somewhere between the first and second generation of engines with high thermal efficiency and pressure ratio but with modest turbine entry temperatures. In order to achieve a full second generation status the turbines need to be uprated for continuous higher duty and this potential is the cornerstone of future development activities.

In 1983 the Royal Navy and Rolls-Royce entered into a joint Feasibility Improvement Study to examine the potential of the SM1A for further development. This study was funded on an equal share basis and was designed to assess:

- The potential methods of achieving better fuel efficiency and the likely improvements, associated technical changes, risks and costs which would be required to achieve this.
- The requirements for introducing a 14MW continuous rating.
- The potential for further uprating.
- The benefits in terms of overhaul life and reliability when operating the uprated engine at the current rating.
- The potential for introducing cost saving and improved maintainability in conjunction with the uprating redesign.

The study concluded that, whilst a 1% improvement in fuel economy can be achieved, it would be at the expense of an increase in complexity and a reduction in life and reliability that would be unacceptable. It recognised however that there is considerable scope for improving upon the present laborious and piecemeal approach to improvements in life and reliability described in the last section. This argument was based on the fundamental principle that a higher powered engine run at lower power inherently wears less and lasts longer than a lower powered engine run at high duty. It became apparent that a single programme to uprate the engine to 18MW would serve the interests of both Rolls-Royce and the Royal Navy, on the one hand providing more power and on the other reduced cost of ownership from increased life and reliability. The uprated engine is designated SMIC.

Rolls-Royce undoubtedly see the 18MW SMIC as a vehicle to gain increased market penetration into the highly competitive marine gas turbine field. As long as it can be shown that the through life cost savings resulting from increased reliability and overhaul life outweigh the Royal Navy's share in development costs, then they too have a good proposition. That the Royal Navy would end up with an uprated engine is not to their disadvantage. Although in the trade-off between life and power the current arguments favour life, in the Fleet of the future the balance may well change. An 18MW engine will allow designers and planners far greater flexibility when attempting to find the balance between ships' speed, life and reliability; this itself will change dependent upon the nature of ship duties.

SMIC Investment Appraisal

In order to quantify Through Life cost savings an Investment Appraisal (IA) was carried out to compare initial capital costs and operating costs of ships fitted with either 2 SM1A or 2 SMIC engines. The technique adopted was to:

- use a Logistic Support Computer Simulation Model to establish the required SM1A/SMIC populations up to the end of current build programmes.
- estimate the total net through life service and hardware costs using the engine populations established above and calculated overhaul and repair costs during SM1A/SMIC operation. All costs were discounted back...
to 1984 to show the net present value (NPV) savings resulting from the adoption of SMIC.

It is essential in any IA to validate fully all starting point assumptions. Some of the data used is classified and so cannot be presented in this forum. The major inputs into the IA were:

- Ship build programmes - current and long term predictions.
- Ship operating profiles - programmed up time and down time.
- Gas turbine usage - predicted engine usage rates.
- Discount rate of 5% per year was used (see para 15 below).
- Development cost of 18 MW SMIC - capital and hardware investment.
- Operating fuel costs - from manufacturers SFC curves.
- Engine power - maximum continuous rating of the SMIC engine.
- Interchangeability - a design constraint.
- Hardware costs - new production, overhaul, repair and SMIA to SMIC retrofit.
- Retrofit policy - which and when.
- Effect of increased spares holding - additional spares required during transition period.
- Effect on repair and overhaul facilities - additional facilities required during transitional period.

Although the IA techniques are quite straightforward they introduce the concept of discounting. The mechanics of discounting are relatively simple. £1 invested now to reduce spend over n years must attract a saving of £(1.05)^n to break even. This is nothing to do with inflation. In order to fund development programmes Governments have to borrow money from investors at a premium. In the UK this is normally 5% per annum and it is this premium which demands a minimum net present value (discounted) return. Discounting becomes significant in through-life calculations for a ship propulsion engine population because of the long calendar period involved. A 5% per annum premium will erode by 75% a saving made 30 years hence and this has a dramatic effect on projected costs.

The direct function of the IA was to calculate total hardware and service costs for the SMIA and to compare these with calculated hardware and service costs with the uprated engine (SMIC) introduced after 5 years of development. The method of calculating hardware and service costs was to carry out a number of separate calculations for a given number of hulls and an engine population with its associated mean DOL and Premature Removal Rate (PRR). The output of these calculations in terms of total numbers of overhauls and repairs were then used to estimate total through life service costs. These costs were then discounted and directly compared to provide through life cost savings. The calculation methodology is shown below.

**Through Life Hardware Costs**

These are provided from the logistic support computer simulation model. Inputs to the model are:

- Predicted ship build programme and required Gas Turbine Change Unit (GTCU) delivery dates.
- Estimate of DOL with calendar time.
- Estimate of PRR with calendar time.
- Overhaul and repair line turn-around times.
- Discount rate of 5% per annum.
- Cost of GTCUs.

Given the above information the model predicts the required GTCU buying-in programme in order to maintain a minimum acceptable spare holding of GTCUs and from this total non-discounted hardware costs can be determined.

**Through Life Service Costs**

The calculation uses the following inputs:

- Number of hulls.
- Number of engines per ship.
- Gas turbine usage (hours per year).
- Total ship operating life (hours).
- Mean declared overhaul life.
- Mean premature removal rate.

The assumption that all engines which fail, having achieved more than 75% of the DOL, are sent for overhaul rather than repair.

- Cost of repair.
- Cost of overhaul.
- Ship build programme.
- Discount rate of 5% per annum.

From the above it is possible to calculate numbers and non-discounted costs of repairs and overhauls. Both hardware and service costs must now be discounted back to find the Net Present Value (NPV). In order to do this hardware and service costs rate of spend must first be established. This is achieved using the ship build programme and derived hulls per calendar year profile as shown below.
Part of any IA is to carry out sensitivity analysis to show the effect of varying assumptions for underachieving performance targets. In the IA GTCU usage rates and the number of hulls were varied as shown on the graph below.

Fig 2 Hardware and Service Cost Expenditure Profiles

From the above curve it is possible to estimate the percentage of total expenditure during the three phases, growth, steady state operation and retirement. These can now be translated into raw and NPV spend profiles for both hardware and service costs as shown below.

Fig 3 Variation of Net Present Value Saving with GTCU Usage Rate for Different Hull Populations

Quite clearly in the hypothetical case above there is a break even point in terms of number of hulls and GTCU usage rate. In this instance however, providing a minimum GTCU usage is maintained even the worst case shows a modest net return on investment. In the case of the Royal Navy similar returns on investment have been demonstrated.

Route to Longevity

It may appear at first sight that the Royal Navy's and Rolls-Royce's ambitions differ markedly. The Royal Navy needs long life and high reliability and Rolls Royce require high power and both expect these qualities from the same engine. Fortunately the two ambitions are complementary and can be achieved by a single development programme. The drive for reduced cost of ownership has pushed the Royal Navy along the uprating path. The concomitant improvements in life and reliability from running the uprated engine at low powers provide the route to longevity.

In common with all new engines, early operation of SM1A is bound to throw up problems and design changes to overcome any shortcomings will be incorporated in the SMIC development programme to enable early achievement of long life. Without the SMIC development programme in the normal course of events the Royal Navy would have to fund Post Design Support (PDS) to overcome any design shortfalls of the SM1A. Currently the intention is for the RN and RR to enter into a joint venture, jointly funded contract so it is for consideration that the RN investment in the 18MW development programme is a more attractive option.
The Through Life Approach

The through life hardware and service costs calculated in the IA are an attempt to manage financially the SM1A Spey programme using an unsophisticated model. The Royal Navy already uses far more sophisticated Design Through Life Cost models in the cradle to grave management of weapon systems. This model is now being adapted for SM1A and SMIC. Once the model has been set up it will be possible to optimise between the engine population in terms of numbers, reliability, life and overhaul and repair turn round times. The trade offs can easily be seen. If an engine has a very high reliability it will not need to be repaired often. If on the other hand it breaks down often but has a minimal repair turn round time few spare engines will be required. The Royal Navy is confident that an increase in life and reliability will pay the greatest dividends but, with limited resources, it cannot afford to ignore second order considerations and a balance needs to be found.

Having taken the first step there is no doubt that the shift towards improved life and reliability will provide substantial returns both in terms of reduced cost of ownership and increased operational flexibility. Operational flexibility is not an aspect that has been addressed in this paper and is difficult to quantify. However, if the number of engine removals can be halved and the ships on average have greater engine life remaining at any given time, the operational advantage can clearly be seen. It will take some years before The Royal Navy sees any return from this new philosophy but the time has long since passed when an operator can afford to limit his ambitions to short term gains.

Conclusions

It was concluded that given the limited scope for improvement in fuel efficiency of simple cycle gas turbines, improvements in life and reliability provide the greatest return on investment in terms of reduced cost of ownership.

It was concluded that a single uprating programme for SM1A provides the greatest scope for reduced cost of ownership this from improved life and reliability associated with running the uprated SMIC engine at low powers.

It was concluded that even when account was taken of the 5% per annum government premium on investment, there was still a net present value saving from the anticipated improved life and reliability of the Marine Spey SMIC.

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