THE APPLICATION OF GAS TURBINE ENGINES TO SMALL CRAFT

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ABSTRACT

There is a set of factors which influence the way small craft are sustained and operated in the Royal Navy: the increasing difficulty in using petrol at sea; the increasing need for faster craft with more powerful engines; the desire to reduce the engine upkeep support burden in the field and the desire to ensure that high performance fast craft have high availability combined with suitable propulsion and military performance. To meet these challenges, the emergence of Gas Turbine (GT) engine technologies may enable alternative propulsion drives to be considered. Small GTs are now available which offer: high performance for acceleration and sustained high power; long times between overhauls; high power to weight ratios and acceptable fuel consumption. This paper shows how the introduction of small GTs may contribute to the solution of some of the operating issues.

Background

This paper presents the results of a study by BMT Defence Services Limited which was funded by the UK MoD gas turbine section of the Marine Propulsion Systems Integrated Project Team. The study has been driven by a set of factors which influence the way small craft are operated in the Royal Navy and the emergence of technologies which may enable alternative propulsion drives to be considered. The following factors are affecting current usage:

a) the increasing wish to reduce the use and storage of petrol at sea;

b) the increasing need for small fast craft to have high availability together with the necessary propulsion and military performance;

c) the desire to reduce the engine upkeep support burden in the field;

d) the maturity of GTs made by small workshop organisations;

e) the availability of marinised helicopter engines.

Petrol at Sea

The carriage of petrol onboard ships is strictly controlled to ensure the fuel does not present a fire hazard to the ship and its crew. Petrol is stored in jettisonable stowages on the weather deck and consequently there is a limited amount that can be carried before temporary stowages affect the deck area which is allocated for other operations. The petrol store on deck is also an easy target for asymmetric threats. Due to the issues surrounding petrol and the issues of logistics, the world's military seek to remove it from the battlespace.

Accordingly, the UK MoD is looking into ways in which current petrol-driven craft can be alternatively powered as part of a trend towards the adoption of Single Fuel Policies [Ref. 1]. The USN have investigated the concept of a common fuel and specifically, avcat would appear to be the candidate, subject to lubricity issues for some transfer pumps.

More Powerful Engines

The trend towards naval operations in the littoral environment has led to an increase in the use of small craft for troop movements and logistics support of all kinds. The threat of small arms fire makes speed a priority and when the loads being carried are increasing to limit the number of round trips. Therefore, there is an increased set of expectations from the propulsion system. At sea when operating between ships, there is also a need for safe operations in a wide range of sea states and this often translates through to a need for more thrust and controllability and a more powerful engine with good low speed torque properties.

Upkeep Support

The support of small craft overseas requires the deployment of staff with specialist skills and their dedicated set of tools and spares. The hard use of small craft engines in hot climates can reduce their time between services and make the logistics of spares support an onerous burden. Alternatives which lead to a reduced need for invasive support would lead to a higher availability for the small craft deployed.

Small Fast Craft

There is a continuous effort to ensure the overall performance of small fast craft is of the highest standard. Such craft need to have low weight, high operational availability together with high speed and low signatures. Such targets place a high emphasis on the use of low-risk proven equipment but still require outstanding state-of-the-art performance.

GTs from Radio-controlled Aircraft

The growth of the small radio-controlled airplane market in North America has been further enhanced by the growth of the small GT business which is supplied by small workshop organisations. These GTs are becoming increasingly reliable and their maturity has led some suppliers to become involved in units for UAVs with power ratings up to 150hp. However the radio-controlled market offers volume and this will continue to allow such suppliers to develop better products.

Summary of Background

There are strong push and pull effects which may provide a sustaining trend towards the adoption of GTs for the propulsion of small performance craft. The availability of small and lightweight GTs burning avcat (F44) or diesel distillate fuel oil (F76) and the need to reduce the use of petrol-based engines both make the adoption of such GTs an attractive proposition.

To address these effects, the potential for GT-driven OBM and inboard engine in the range 50hp through to 1200hp were investigated.

Acceptance Criteria

Although the stated drivers and technology enablers may permit the introduction of GTs into small craft, there requires to be a set of acceptance targets for specific financial viability or performance superiority. In general, the following are considered to be the tests to be met:

a) The GT solution results in a reduction in through life costs;

b) The GT leads to a useful increase in top speed for the same fuel capacity;

c) The GT solution leads to a large range for the same total weight of fuel and propulsion machinery.

These tests were used to assess the feasibility of GT solutions in a set of diesel engine (DE) /petrol-driven craft currently in RN service or planned for RN service.

STUDY TERMS OF REFERENCE

In mechanical drive systems, there is always a need for a shaft drive from the engine to a type of propeller or waterjet. Consequently only those GTs which are turbo-prop or turbo-shaft were considered.

The study initially reviewed the gas turbine market for the identified power range and catalogued the available data from web sites and from specific requests to gas turbine suppliers. The data set was filtered to identify those engine sets which had the best characteristics for marine propulsion as applied to a candidate set of in-service boats.

A number of different types of GT were considered:

a) Radio-controlled model aircraft;

b) Helicopter engines;

c) Industrial engines.

There are several suppliers world-wide of GTs for radio-controlled aircraft. The makers of such engines range from hobbyists to small design and manufacturing concerns. UK suppliers were consulted

Those helicopter engines which are used in hobby boats and one-off novelty boats (usually in North America) are usually now out of production and were not actively supported by a world-wide organisation. This left GTs which are actively supported and in production. At one end of the scale were the workshop GT-makers of whom Microjet Engineering manufactures models up to 150hp (Figure 1). At the other end of the scale were helicopter engines which are in use today and which lie in the required power range for the conceptual Fast Combat Craft i.e. between 1000 and 1200hp.

Fig. 1 Microjet Engineering Turboshaft Engine

PLATFORMS IN USE

Petrol Driven Craft

The results of the performance assessments are presented in Table 1. The assessments are based on the authors' own interpretation of the performance of a typical candidate GT and serves to indicate the trends rather than an accurate set of performance results.

The main petrol-driven craft are the 40hp Gemini's and the 75hp Avon Sea Riders currently embarked on UK frigates and destroyers. The other craft have inboard diesel engines and alternative GTs were identified and their performance comparators examined.

The results shown in each column are explained below:

a) The ratio of the specific fuel consumption (Sfc) at full engine power Maximum Continuous Rating (MCR), for the GTs over the reciprocating engine.

b) The GT's weight including its built-in gearbox as percentage of original engine weight;

c) The increased speed in knots due to the reduction in weight and/or increase in power due to the use of the GT;

d) The increased range as a multiple of the original if the difference in weight between the GT and the original engine is made up with extra fuel;

e) The range at top speed as a percentage of the original top speed with original fuel capacity

Table 1 Summary of results for typical GTs installed in small craft

Platform, Engine & Rating	Alternative GTs rating	A: Sfc Ratio at full power	B: GT's weight as % of original engine	C: Speed increase in knots	D: Range increased as a multiple of original range.	E: Range at top speed as % of original
Gemini 1 x 40hp	1 x 70hp	2.5	46	0.5	1.4	83
Avon Sea Rider, 1x 75hp	1 x 70hp	2.5	50	1.6	2.5	42
Pacific 24 RIB. 1 x 370hp	1 x 504hp	1.17	20	6.0	3.0	99
Rigid Raiding Mark III 2 x 230hp	2 x 240hp	1.74	50	1.0	1.1	58
LCVP Mark V. 2 x 450hp	2 x 593hp	1.22	26	2.0	1.4	33
LCVP Mark V. 2 x 450hp	2 x 1157hp	1.24	30	8.0	1.4	84
Fast Patrol Launch 2 x 740hp	2 x 750hp	1.56	9	1.0	5.0	66
Fast Combat Craft 2 x 1000hp	2 x 986hp	1.21	19	1.0	1.1	84

The calculated results in Table 1 show for a wide spread of platforms that the introduction of GTs into small craft which currently employed either inboard or outboard drives has the following effects:

a) GTs have a worse fuel consumption and this ratio increases for low powers.

b) The weight of the GT compared to its petrol/diesel equivalent is much reduced and for OBM this can be used to good effect for manual handling.

c) The speed increase of the craft due to the reduced weight of the machinery is negligible.

d) If the engine weight saving can be translated into the increased fuel capacity then the range can be much extended. The smaller the craft the more likely there will be issues surrounding the provision of space for such fuel and the increased weight balance of the craft as the fuel is expended.

e) If the weight made available due to the engine weight difference is not exploited with additional fuel, the higher specific fuel consumption of the GTs will lead to a reduction in the original range of the craft at top speed.

ADDITIONAL ISSUES

The operation of small diesel engines in small craft of all types is usually subject to restrictions with respect to the time that may be spent at the full rated power. It is not uncommon for the engines only to be permitted to operate at their rated power for 1 hour in 10 and if this is exceeded issue surrounding the life of the engine may be affected.

With GTs, the stated rated power is almost always the MCR and the engine can be operated at such powers indefinitely subject to times between overhauls. Where a GT has been introduced in place of a DE, the GT usually brings with it the scope for greater sustained time spent at wide-open throttle.

The specific issues surrounding each platform and the alternative engine will now be presented.

Gemini Inflatable

The use of a GT OBM in such a craft will enable petrol to be dispensed with and the OBM will be lighter than the current design allowing ease of manual handling.

Avon Sea Rider

The 4.7m Avon Sea Rider is driven by a 60 or 75hp petrol-driven outboard motor (OBM) and carries fuel in two separate tanks. The GT considered for the Avon Sea Rider was the 70hp HFTS 100 from Microjet Engineering of Cambridge, UK [Ref.2]. The weight of the petrol engine in the powerhead of the OBM was replaced by the weight of the GT to identify the complete weight of the OBM.

There are many issues relating to the satisfactory integration of a GT into an outboard motor for the armed forces. Although a GT OBM has been achieved by Marine Turbine Technologies (MTT) of the USA [Ref.3] this is a large GT and would not meet all the UK military requirements for post-immersion restart, non-electric start and shock and signature performance.

Pacific 24 RIB

The Pacific 24 RIB is the new seaboat for the RN and is supplied by Halmatic [Ref. 4]. The Pacific 24 has a top speed of 39 knots and a fuel capacity of 165 litres [Ref.5]. The identified replacement GT engine is the Arrius 2F (100kg) from Turbomeca which replaces the Yanmar 6LYA-STE (500 kg) rated at 370hp. The engine drives a Hamilton HJ 241 waterjet and the GT has a gearbox which could be matched to the drive. The large weight difference between the engines allows more fuel to be carried and the range and speed to be much increased.

Rigid Raiding Craft Mark III

The Rigid Raiding Craft Mark III is a high-speed troop carrier also capable of operating in a logistic role without troops. It is driven by two Yamaha stern drives each rated at 230hp. The GTs considered for this boat was the 172hp WTS124 from Williams International Inc. which was developed as a sub-system power unit for a helicopter. The GT would thus require significant development for this application.

LCVP Mark V

The LCVP Mark V can travel up to 20 knots when light and is normally powered by two 450hp inboard diesel engines driving waterjets. The Allison 250 engine in its 47M variant rated at 448kW (593hp) was chosen as an option for this craft. This engine is well proven and is widely available.

To achieve a fast transit time, the use of the 1157hp MTR390 engine [Ref. 6] in the LCVP was considered. There was an 8 knots speed from increasing the installed power and although the flat bottom shape of the LCVP means that the resistance curve would be non-linear, there would clearly be a significant speed increase.

Fast Patrol Launch

The 16m Fast Patrol Launch is driven by two MAN D2840LXE 740hp diesel engines each driving a stern drive. The GT considered as a possible option for this boat was the LTS-101 helicopter engine from Honeywell. GT engines would offer a much reduced engine weight which if replaced with additional fuel would significantly increase the range, even with the GT engine's higher specific fuel consumption.

Fast Combat Craft

The use of GTs in a conceptual 60 foot Fast Combat Craft was explored as a feasibility study to allow the comparison of GTs with high performance diesel engines. The craft is to have a top speed of 50 knots.

The propulsion arrangement comprises two high performance diesel engines each rated at 1050hp which drive two waterjets which can be used for steering and braking. The drive is assumed to be from Alternatively Arneson drives or the Power Vent System could also have been used.

The diesel engines were assumed to be similar to engines which are used in offshore powerboating. As such engines are designed to be used for high power, low endurance applications. They are assumed to have a useful life of 1,000 hours between overhauls.

The TM 333 2B2 from Turbomeca [Ref. 7] is a candidate engine with an MCR of 986hp and a maximum intermittent rating of 1105hp which is the helicopter take-off rating (1 hour in 12). The Rolls-Royce CTS-800 is also a candidate engine [Ref. 2].

The Fast Combat Craft would achieve a 10% better range if the GTs were to be introduced, provided space could be found for the extra fuel.

PERFORMANCE CRITERIA

General

The studies have indicated trends in the dynamic performance as well as the steady state and cost aspects. These trends are described below.

Acceleration

The high torque from the GT engine at lower shaft speeds allows for the maximum available thrust to be delivered from the propulsor at low boat speeds (Figure 2). Propeller-based systems will need to consider the risk of over-torque as the maximum torque can be twice the torques at the top power point.

For a boat with the same specification of top speed and range, the GT engine solution will allow an acceleration which results in top speed in less than two-thirds the time of a diesel solution.

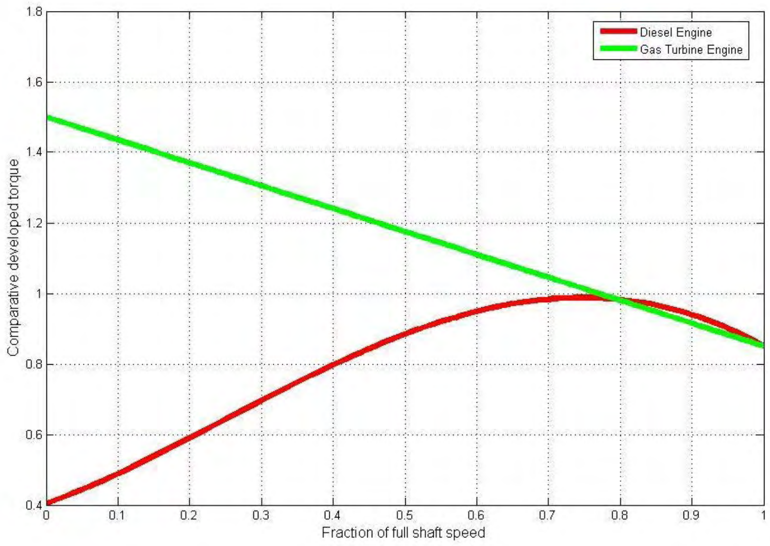

Fig. 2 Comparative Torque Curves

Top Speed

The reduced boat weight due to the difference in the weights of the different engines usually allows for a gain in top speed of at least 2 knots. The handling and the control systems will need to be adapted for the way the engine dynamics may vary with changes in engine load. The lower system inertia may lead to under and over-speeds if the control system is not suitably adapted.

Endurance

From the range of platforms studied and presented above, if the reduction in weight between the two engines is made up by additional carry-on fuel, the range of the craft is usually increased by more than 25%. The extra fuel can be added to ensure parity of the top speed range is achieved. If the range at the stated cruise speed (engine load between 50 and 70%) is to be achieved the full allowance of weight saving from the difference in engine weights may need to be consumed.

Summary

Performance

Clearly from the results presented above, for GT driven solutions to work, the weight saving of the GTs needs to be used to increase the fuel capacity of the craft. This fuel can be carried lower in the craft and may help provide greater stability than current designs. The assessments are based on the boat operating at top speed, if the engine loading is 50% then the GT's Sfc will be much worse: in other words with GTs there will be little benefit to fuel consumption in running the engine slower due to the sharp increase in Sfc below 50% load. GT solutions therefore favour high performance craft which operate at high speeds and engine loads above 50% for much of the time.

Costs

Cost model analysis has identified annual savings in running costs for all craft, however this figure is largely dependent on the assessment of planned maintenance costs. It is recognised that to realise real savings in manpower reductions is very difficult and consequently if the costs of planned maintenance are discounted, there are no overall running savings. Through life overhaul, spares and corrective maintenance costs are reduced for the GT options and for many craft, the GT will never reach its time between overhaul hours. However, the greater cost of fuel due to the significantly greater fuel consumption of the GT may outweigh this depending on the elapsed hours run per year.

Although the through life costs are a trade between reduced in-service upkeep for the GTs against its higher fuel consumption, there are also issues surrounding the timing of upkeep for the GTs and the required skill set to be able to maintain one in the field in the event of the need for unplanned maintenance.

However, the main barrier to the introduction of GTs is their high initial cost which tends to make project instigation very difficult and which can make the payback period for through life cost savings many operating years.

In addition to the specific military requirements, each platform will also be subject to proving trials as required by the MCA document [Ref.8] and SOLAS requirements [Ref.9]. For the OBM this will include operation after immersion.

Conclusions

General

The need to replace petrol in the fleet and to reduce the in-service upkeep burden are two reasons why the scope for the use of GTs in small craft was examined. Candidate GTs have been identified for a range of craft from OBM through to the inboard drives in fast craft. The range of GTs is considerable as they include those for radio-controlled models and those found in helicopters.

The rise in the general population of turbo-shaft engines is making their unit cost cheaper in real terms. However GTs are not cheap when considered against their petrol/diesel equivalents and for GTs to prevail, future cost models need to reflect the specific operational issues of in-field support and spares handling.

Outboard Motors

The assessment of GTs for propulsion in small low-powered craft indicates that they have potential to replace petrol engines. Petrol engines are used in outboard motors for Gemini craft which operate between ships at sea, for trips ashore and for other small craft operations. They also operate as crash boats for helicopter operations, consequently they need to be reliable but do not need to be fuel efficient as they only have a need for a limited range. The proposed GT is based on a radio-controlled model drive and is not fuel efficient. The GT is derived from a turbocharger and consequently has a single spool and a limited pressure ratio.

The GT offers a lighter power-head in the OBM and will enable diesel fuel to be used instead of petrol. The main issues are the limited bearing life of the candidate GT, non-electric starting, the ability to exchange engines quickly and the design of a large air flow demand into a small OBM cowl.

Starting and controls are the main potential areas for technology development as well as heat management. Integration of the GT inside the OBM cowl is not likely to be a major issue but operation after immersion may require special isolation/shut-off features. A GT-powered OBM has been developed by MTT and a Williams International unit existed as early as the 1950's. The success of such a project will depend on the ruggedisation of the GTs to the marine environment and the ability to extend its life to create a reliable product for single engined craft.

Inboard Engines

Helicopter engines have been the prime candidates for inboard engine solutions as they are already turbo-shaft designs. The shaft speed from their reduction gearbox is normally around 6,000 rev/min which is a good match for many small propulsor solutions. The engines have a high degree of fidelity as they are designed with reliability in mind to assure the safety of the helicopters. This leads to a high initial cost which may possibly be managed through the use of lease deals and the forward looking establishment of partnerships and contractor logistics support. The time between overhauls of the GTs can be as much as 5,000 hours and this is much increased over many diesel engines, some of which fail to last 1,000 hours.

GT solutions will require the transmission torque limits to be revised due to the potential for high initial torque at slow shaft speeds. The much reduced weight of the GTs is offset by their worse fuel consumption. Clearly for short range operations this is less critical but for longer range missions the engine weight saving may have to be compensated for by an increased fuel capacity. The GT solution with reduced weight and range offers a marginal top speed improvement of 1 to 2 knots but the GT solution will offer a better acceleration.

In conclusion, there is a wide range of small GTs which offer much potential for the increase of the performance of small RN craft. The acquisition costs of the GTs are the main barrier to their introduction but the need to remove petrol from RN service at sea and the attraction of higher craft speeds may serve to make their introduction a more attractive proposition.

Acknowledgements

Grateful acknowledgement is made to Microjet UAV Limited of Cambridge, UK for their permission for the use of a picture of their turboshaft engine.

The assistance and co-operation given by all the gas turbine engine suppliers contacted for the development of this paper is acknowledged with thanks.

The opinions expressed are solely those of the authors and do not reflect the opinions of the UK MoD or BMT Defence Services Limited.

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