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Rolls-Royce MT30 design, certification, launch and growth

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ABSTRACT

In 1999, Rolls-Royce decided following marine market studies to design and certify the MT30. This self-funded Rolls-Royce project includes team members from within the company: Marine Gas Turbines (GT) for the gas turbine design/certification, Ulstein turbines for the GT package and Marine automation for the controls. The MT30 builds on the successful Rolls-Royce marine gas turbines: the Proteus, 501/571, Olympus, Tyne, Spey and WR-21, all of which use core elements from the aero engine family. The MT30 is the largest marine gas turbine and is the first marine engine to be based on state-of-the-art aero Trent technology; and is designed to suit the requirements of the next generation of surface combatant ships, liners, fast ferries and freighters. Changes to the aero components have been kept to a minimum to take advantage of the large commercial engine production base and also profit from the aero engine technology based on accrued reliability. The current phase of the MT30 certification is endurance (cyclic) testing. Initial testing commenced in September 2002 and is taking place at the Rolls-Royce Bristol site, UK.

BACKGROUND

The MT30 is the latest evolution of the Rolls-Royce Trent aero engine family that have accumulated more than five million flying hours since entry into service in 1996.

Designed for the 21st century

During 1999 to 2001 the initial design of the MT30 was certified using a combination of analytical and rig/model tests. The results of these have been used to validate the design or, where necessary, provide direction for design changes. The MT30 has been designed from concept through to detail design with maintainability being of prime importance. The design phase is now completed, the components have been manufactured and the first two engines have been built. The MT30 brings the very latest aero gas turbine technology to the marine market. The Trent 800 was selected as the preferred parent as it offered the best combination of power, efficiency, life, proven reliability and could be developed within a reasonable cost and time scale. The engine delivers efficiency and reliability with a market leading power-to-weight ratio and reduced operating and through-life costs.

Designed with 50 to 60 per cent fewer parts than other aeroderative gas turbines in its class, the MT30 has a maximum installed continuous rating of 36MW (48,945 PS) up to ambient temperatures of 32°C, and maintains operating efficiency for powers down to 25MW (33,990 PS). The MT30 can be configured for either mechanical or electrical drive.

Heritage

The MT30 shares 80 percent component commonality with its successful aero parent the Trent 800, see Fig 1, which has now evolved into an engine family of six since its entry into service in 1996. A total of 40 customers have placed firm and option orders for almost 1700 Trents which have won over half the available engine business on new generation wide body aircraft from Airbus and Boeing.

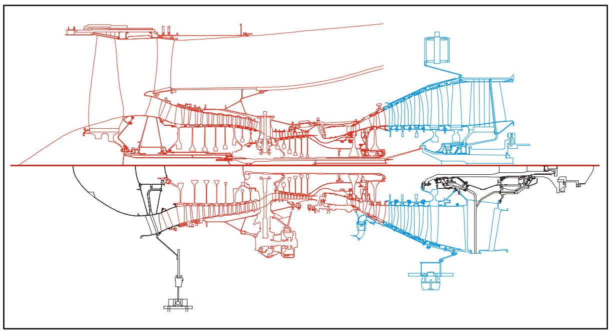

Fig 1 MT30 derivation from Trent 800

DESIGN

The design of an aero derivative marine engine maximises retention of the aero engine power density and reliability to ensure trouble free operation. The MT30 is a twin-spool, high-pressure ratio gas generator. Design changes are strictly limited to what is necessary to adapt the engine to its new environment. Compact and lightweight, the MT30 features an eight stage variable geometry Intermediate Pressure Compressor and a six stage high-pressure compressor. The four-stage free power turbine is derived from the Industrial Trent, with bearings and support based on the WR-21 gas turbine design. Proven components are used throughout, incorporating the latest blade cooling technologies. Key rotating parts are protectively coated for service in the marine environment to reduce maintenance and deliver long periods between service intervals. Engine mounted and driven accessories (HP fuel pump, lubrication feed and scavenge pumps, starter and centrifugal breather) providing a compact self contained system.

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The annular combustors are similar to the aero parent and designed to burn commercially available distillate fuel to DMA standard, ensuring the MT30 meets all current and anticipated legislation on emissions and smoke.

The Engine Management System (EMS) provides fully integrated alarm; monitoring and control functions for the packaged gas turbine, including independent engine over-speed protection. An integral back-up power supply ensures continued safe control should the ships main supply be interrupted. Modern databus technology provides improved reliability through simplified wiring and a reduced number of connectors, with main processors and power supplies located in a cabinet on the outside of the package enclosure. The system is designed for operation in unmanned machinery spaces, control and monitoring provided by remotely mounted dedicated touch screen panels supporting easily interpreted graphics. Alternatively, control functions can be directly integrated into ship level machinery control systems, communicating to the EMS through a dual redundant databus.

The MT30 can be configured with an axial intake plenum (for funnel installations) or compact rotatable radial intake for machinery space installation. The exhaust collector can also be rotated for machinery space (or funnel) installation.

Lightweight

With the gas turbine change unit (including power turbine) weighing just 6,200kg and a total module weight, including enclosure, of 22,000kg dependent on options) the MT30 offers the best power-to-weight ratio in its class.

A packaged module

The MT30 design incorporates all engine auxiliaries onto the package, leaving the shipbuilder to provide the starter energy (hydraulic or air), plus fuel, water and electrical connections see Fig 2. It can be installed in a single lift at the shipyard.
Engineered as a modular package the MT30 permits installation in a single lift and has a variety of intake and exhaust configurations to suit ship design requirements. This concept ensures the unit arrives on site with the engine factory tested and ready for quick, low risk installation and commissioning.
The fully packaged module can be supplied for direct drive or power generation - complete with alternator and its own acoustic enclosure. The enclosure can be configured to meet machinery space noise specifications down to 85dB(A) at one meter.

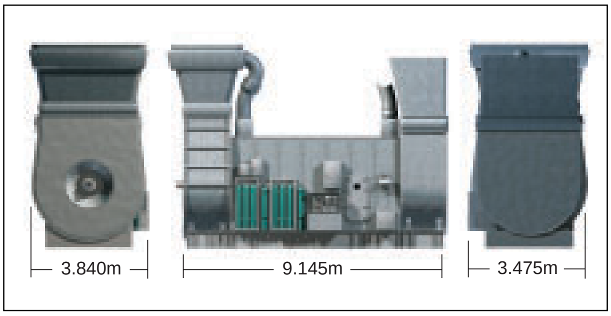

Fig 2 MT30 - Mechanical Drive Package dimensions

PERFORMANCE

The MT30 provides the marine market with significant improvements in power density – a continuous rating of 36MW at 32ºC net of installed losses and overall package size and weight comparable with that of a 25MW industry standard engine. Innovative package design yields 25% improvement in power density enabled by the twin spool design and state-of-the-art aero based technology. Rated power will be maintained through engine life, subject to the engine being operated and maintained in accordance with recommendations. The MT30 achieves a thermal efficiency exceeding 40% at rated power and maintains high efficiency throughout the top 30% of its power range, enabling applications at powers below 36MW to be efficiently addressed, as shown in Fig 3. There is no limitation on running time at idle.

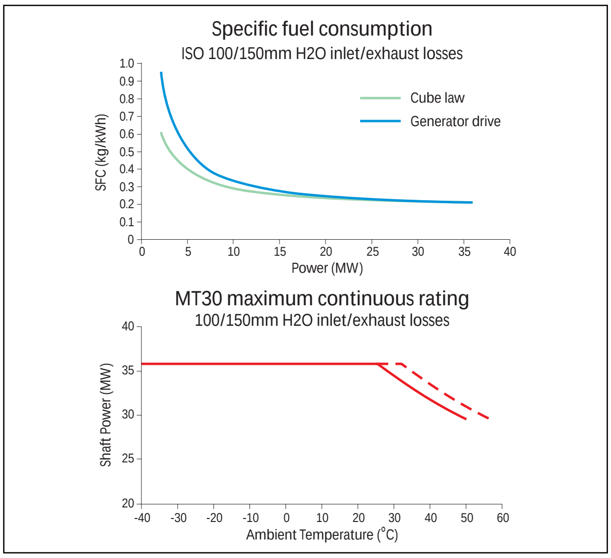

Fig 3 MT30 power rating and sfc curves

TEST PROGRAMME

The MT30 Integrated Project Team was formed in July 2000, and the marine engine ran for the first time in 2002 in a new, dedicated, yet flexible, test facility in Bristol, UK. Illustrated in Fig 4. Capable of testing gas turbines against either a cube (propeller) law or synchronous (generating set) law, the new test facility can be simply modified to allow testing at 37.8°C (100°F) by utilizing the waste heat generated by the load banks to heat the inlet air. This innovative approach ensures that the engine can be tested strictly in accordance with the Mil specifications rather than the "usual" approximation, derived from running the engine at higher powers to attain the appropriate internal temperatures.

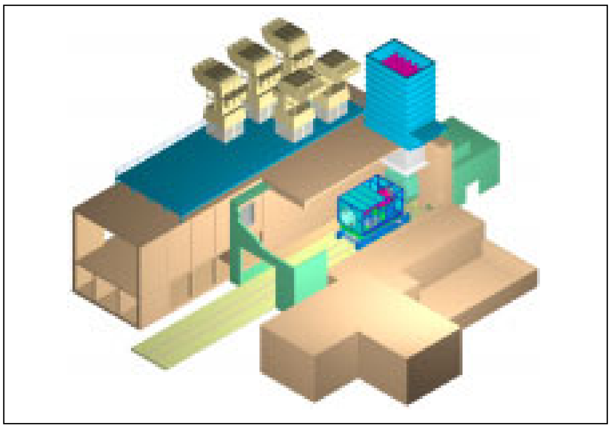

Fig 4 The new Rolls-Royce marine gas turbine test facility

MT30 - test plan

The certification testing for the MT30 has two complete engines hardware sets for testing, the engines have been assigned the notation "D1" for the first unit shown in Fig 5 and "D2" for the second unit.

Fig 5 MT30 following build

D1 engine build

This has been constructed with an interim hardware standard, the baseline objectives set as follows: facility commissioning, baseline performance, controls integration, thermal, oil & air system verification, package design data acquisition, DnV Type Test dress rehearsal.

The success of D1 on test has been so significant that objectives were extended and introduced: Cyclic endurance test (1,000 start-stop cycles total), further controls optimisation, shock response- modal mapping. The engine is now undergoing full strip and customer layout.

D2 engine build

The construction of this engine has been completed and is currently undergoing endurance (cyclic) testing, this is the Certification hardware standard, the baseline test objectives have been set as follows: final performance, thermal, oil & air system verification, also Certification controls functionality demonstration. This testing will calumniate in the Det Norse Veritas (DnV) Certification Type Test due to be completed late 2003, with commercial marine engines available for delivery to shipyards from the early part of 2004.

Further type testing is being planned to achieve American Bureau of Shipping (ABS) (United States Navy defined Mil standard endurance testing) type approval. This qualification testing phase is programmed to be complete in early 2004 with strip, inspection and ABS approval being finalised towards the middle of the year.

Summary - D1 engine test running completed

Functional testing

The total number of hours run- 132, cycles achieved- 109 start-stop cycles, time above 36 MW circa 20hrs

Endurance testing

The hours run- 126, cycles achieved- 757 start-stop endurance cycles, time at full power- 38 hours.

Combined functional and endurance

A very significant achievement for the first run of a new engine type. For the D1 engine the total hours run are 258, total start-stop cycles accrued, 866.

Performance & control testing

The MT30 Steady state performance testing conducted the following activities: facility checkout and calibration, overall engine performance, component performance, cube-law curve and constant speed load conditions (synchronous 3,600 rpm).

The purpose built Bristol testbed was successfully calibrated and the engine and component performance established for comparison with pre-test predictions.

Transient performance testing conducted for start optimisation, rapid accelerations under cube law and constant speed load conditions, also abnormal event simulation, including Blow off Valves-open, loadshed and emergency shutdown events

Successful optimisation of basic operability functions and gathered vital data for final optimisation of protection functions.

Mechanical testing

The MT30 mechanical tests conducted: component and engine vibration surveys, deliberate seeded HP and LP systems out-of-balance running, static shaker excitation of whole engine vibration modes, hot shutdown and delayed restarts.

The MT30 confirmed behaviour under normal, deteriorated and abnormal conditions, and did not exhibit lockup after shutdown at any point in the test cycle. The testing also confirmed:

- Thermal analysis of the secondary air system validation and the structural thermal paint and thermocouple surveys.
- Ground analytical models and support read-across of design work from aero Trent.
- Systems, oil system pressure, temperature and flow surveys, engine heat rejection and package ventilation.
- System performance for calibration of pre-test predictions.

Certification

MT30 will be certified first to DnV Rules for gas turbines. Engine D2 will conduct the formal, witnessed Type Test. Engine D1 has successfully completed an internal dress rehearsal for the DnV Type Test: starting, mechanical running and performance.

Endurance cycles

The MT30 has an operating schedule laid down and designed to accrue damaging thermal and mechanical cycles as quickly as possible. This tests the mechanical durability of coatings and structural components. The engine was also run with handling bleeds locked open to generate temperatures equivalent to a half-deteriorated engine. Prior to the final endurance trial the D1 engine has already accrued 750 such cycles - equivalent to ~3,000hrs of cruise ship operations.

Fig 6 shows an example of the short endurance cycle:

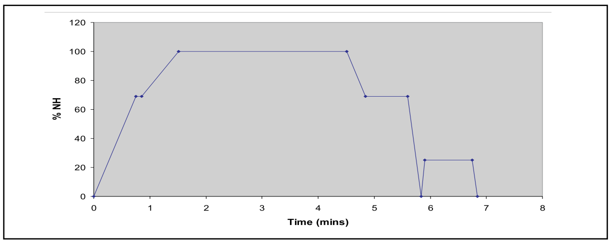

Fig 6 A typical short performance cycle

D2 engine - planned testing
Combustion and turbine Thermal paint run – intrascope read, Dummy pass-off test (DNV requirements), Controls testing, e.g. starting, load shed etc, Performance analysis/turbine mapping, Strain gauge dynamics, Power Turbine Output shaft thrust monitoring, Air/oil, Exhaust gas Emissions/smoke analysis, Noise survey, Water wash technique development, Contaminated fuel testing, Heated intake performance evaluation.

Test summary- overall progress as of April 2003

Engine D1 has completed all of its pre-test objectives together with several additional objectives added as a result of good progress- also largely met.

D1 has also completed a very significant amount of running- very good achievement for a First of Type engine on a brand new facility demonstrating the robustness of the machine. The D1 engine remains on schedule to be available for rebuid and pass to test as D1 part 2 on the due date.

The second engine D2 remains on track to complete its scheduled testing on the due date.

OPPORTUNITIES AND APPLICATIONS

Both naval and commercial marine propulsion systems are increasingly seeking more power from fewer prime movers. In naval systems, the move to electric propulsion for larger escorts and the introduction of single boost gas turbines for smaller escorts has allowed the reduction in number of installed prime movers, while retaining the required redundancy.

Frigates, Destroyers, Auxiliaries/Amphibs, Carriers –
Mechanical and electric drive. MT 30 provides the most power dense package at the highest available unit power ratings. This capability lends itself to changes in propulsion system configurations.

Developing 36MW from a single lightweight gas turbine provides a significant opportunity for change in today's Corvette and Frigate propulsion systems.

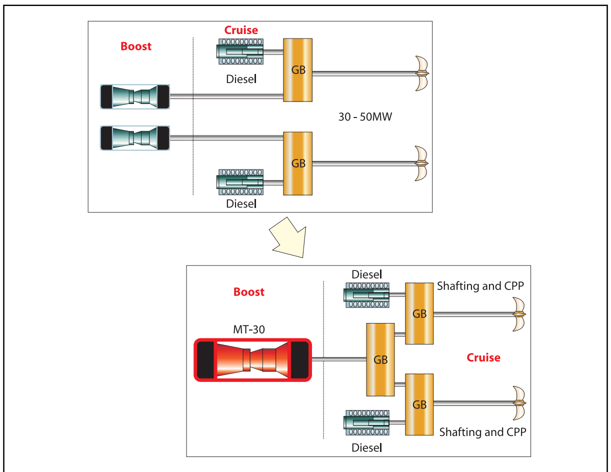

Fig 7 Trends in Frigate CODOG/CODAG Systems

Frigates usually employ twin gas turbines to achieve speeds in excess of 28 knots via twin shafts. The most popular option has been Combined Diesel Or Gas Turbine (CODOG) using two 20MW gas turbines. . Recently some ships have adopted a single gas turbine Combined Diesel And Gas Turbine (CODAG) system. Whilst this configuration reduces the number of gas turbines to just one it does lead to a complex multi-speed gearbox in order to combine the power of the torque limited cruise diesels, to that of a limited-power gas turbine. The power available from a single MT30 allows a simple CODOG system with only one Gas Turbine. This is illustrated in Fig 7.

Whilst the cross-connecting gearbox is larger than the twin gas turbine system, it does allow a single diesel to drive the two shafts. This will lead to a useful improvement in annual fuel consumption together with reduced maintenance costs as most naval combatants spend significant time at or around 25% of maximum power.

Similar changes to the propulsion system configuration options also become available for larger naval combatants. Some examples are illustrated in Fig 8, which shows COGOG, CODOG and a hybrid electric drive option.

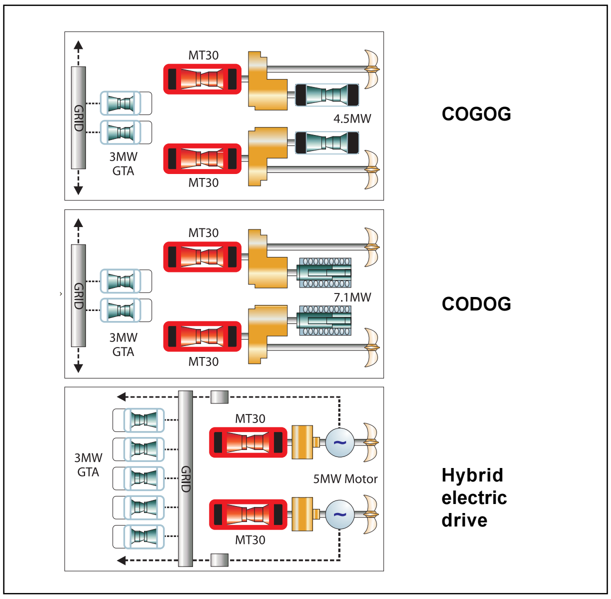

Fig 8 Modern propulsion system options

Whilst the 70-80MW offered by a twin mechanical drive MT30 system is sufficient for large combatants such as Cruisers and Aircraft Carriers, many navies are now moving towards all-electric drive for these ships. Conflicting requirements for these propulsion systems are to optimise the flexibility offered by electric transmission with the desirability of minimum prime movers. MT30 is being considered for a number of large naval combatants. Fig 9 illustrates one of the MT30 options for the United Kingdom's new conventionally powered Aircraft Carrier (none nuclear).

Cruise liners

Electric or mechanical drive propulsion is a target target opportunity for the MT30. These ships generate revenue from passengers and hence from passenger cabins, they are also required to sail into some of the world's most environmentally sensitive areas. All gas turbine power offers significant benefits over reciprocating engines in both power density and emissions and are therefore ideally suited to these ship types.

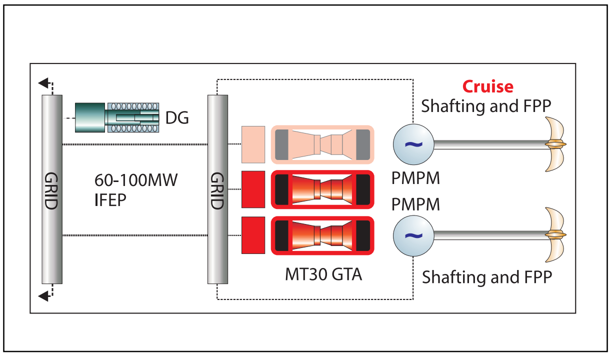

Fig 9 Options for large all-electric Combatants

For Liquid Natural Gas (LNG) tanker Carriers

Mechanical drive propulsion system weight is less important than the very compact dimensions of the power unit. Valuable cargo space can be liberated by the very small size of the turbine, compared with diesel or steam plant, offering immediate transport cost reductions by increasing payload (membrane type) or reducing the overall length of the ship (Moss type).

Fast sea fright, RORO ferries - (mechanical drive)

Where speeds are in excess of 35 knots, gas turbines offer very low weight and minimum volume. These characteristics are important to fast passenger or cargo transport ships to enable them to deliver low transport costs through increased payload and hence increased revenue: the larger and faster the ferry the more compelling is the case see figure 10. Excess machinery weight simply devours revenue-generating payload, reducing revenues and increasing transport costs.

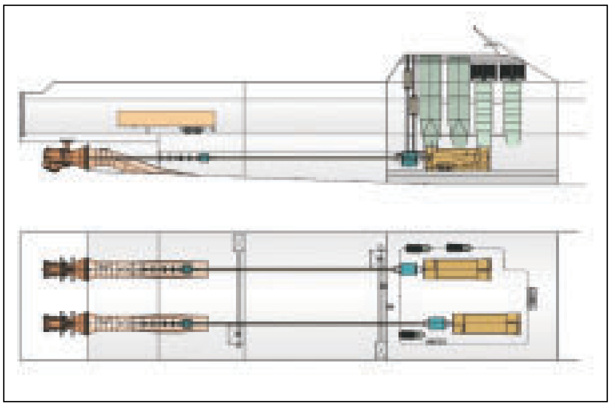

Fig 10 Fast monohull propulsion system in IZAR ship

SERVICE ENTRY

- The MT30 has been selected to power the Integrated Power System (IPS) Engineering Development Model (EDM) for the US Navy's DD(X) multimission destroyer programme see Fig 11.
  This order for the MT30 marks the company's entry into the US naval market for large gas turbines.
  Rolls-Royce will provide one 36 MW MT30 generating set to Northrop Grumman to drive the IPS EDM at the US Naval Surface Warfare Centre Philadelphia Division Land Based Test Facility (LBTF).

Fig 11 Artists impression of the DD(X)

- United Kingdom (UK) Defence Secetary anticipates that Rolls-Royce will provide propulsion systems for two new Royal Navy aircraft carriers see Fig 12.
  Rolls-Royce will now work with prime contractor BAE Systems on propulsion and through-life support issues. Final arrangements on the prime mover are yet to be made, but the propulsion system is expected to feature the MT30.

Fig 12 Artists impression of the UK future carrier

Growth Potential

- The MT30 is ideally suited for power growth to the 50 MW MT50 variant.
- The MT50 uses all of the MT30 components and adds to it the industrial LP compressor module and adds an additional stage to the Power turbine again from the industrial variant.
- The added equipment has proven reliability from its aero and industrial parentage.
- FastShip opportunity, is a high speed waterjet powered freight vessel carrier for the transatlantic and further possibilities include Trans-Pacific and Asia Pacific intra regional ports, see Fig13.

Fig 13 FastShip

- This marine transport system is targeted at a niche market opportunity between deferred air freight (3 day door-to-door) and high end (30 day door-to-door) surface shipping. The initial route is transatlantic between Cherbourg and Philadelphia, with a target 4 day (5 day assured) crossing and 6 hours turn round in port, giving 7 days door-to-door. The overall FastShip concept includes provision of special fast handling facilities at point of load/unload.
- This particular vessel design lends itself to reconfiguration to fast logistic where heavy military equipment needs to be deployed in distant places around the world in short time.
- FastShip - semi-planing monohull
  32,500 Tonnes ship, Dry 17,000 Tonnes, Cargo 10,000 Tonnes (1,432 TEU) & Fuel 4,500 tonnes.
  TEU = Twenty foot Equivalent Units - Containers
  Ship length 265 meters x 40 meters wide.
  Rolls-Royce Scope of Supply will be potentially for 25 MT50 engines, five for each vessel, see Fig 14, together with a 2 year support package for each engine.

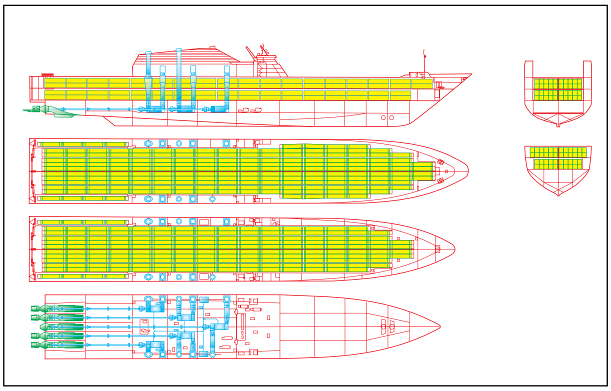

Fig 14 FastShip general arrangement

Operator's timetable, the turnaround time allocated of 6 hours per vessel per crossing, with a monthly 24 hr maintenance window, agreed additional time allocated from the 10 hr operating cycle crossing buffer plus time spent in the Delaware Estuary. A maximum of 6750 hours/engine/year and a maximum of 120 starts per annum is envisaged.

The concept design of the FastShip vessel entails 5 x 50 MW Kamewa waterjets, requiring five engines per vessel rated at 47.5 MW continuous, 50 MW restricted. nine vessels are planned for the Cherbourg/Philadelphia route. The initial contract would be for four vessels with an option for a further five vessels.

A MT50 a derivative of the MT30 will have mounting, packaging, and secondary systems to suit the FastShip installation.

SUMMARY

Rolls-Royce working with ship architects, navies, commercial operators and ship yards has given us the ability to foresee the future shape and trends within the naval and commercial marine market place is sought by all participants within the market. It is true that for many marine products and services, by the time market developments are clear it is probably too late to react. Bold product decisions and investment often create the market. However, behind these bold product decisions lies careful analysis and extrapolated predictions on which product development investment decisions are made. Such a decision and investment have lead to the introduction of the MT30 marine gas turbine supported by the analysis that the marine market requires and will continue to require more powerful gas turbines in several sectors.

This paper describes the MT30 and analyses the potential market sectors and marine propulsion systems that will benefit from its introduction.

MT30 is the only "state-of-the-art" marine gas turbine derived from a very modern and reliable aero parent through an extremely effective marinisation process. The "minimum change" marinisation programme has produced a marine derivative with 80% commonality with the aero-parent. The programme included two demonstration engines that have validated the predicted performance, established a new, flexible test facility and enabled multi-agency certification of the engine to be undertaken.

The MT30 offers ship designers new possibilities for propulsion that has a significant benefit on the performance and capability of the vessel design. It provides substantial power from a compact, power dense package and delivers class leading efficiencies. The engine also offers shipyards a simpler and quicker propulsion system to fit and for operators and navies new levels of performance and revenue generation in niche market segments. This is an engine for the 21st century.

REFERENCES

Tooke and Bricknell, - Propulsion systems and the MT30 marine gas turbine the quest for power - ASME Turbo Expo paper GT2003 38951.