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The WR-21 Intercooled Recuperated Gas Turbine Engine – Integration Into Future Warships

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ABSTRACT

The WR-21 is an advanced cycle gas turbine designed to meet the requirements of both conventional propulsion and Integrated Electric Propulsion (IEP) systems. The WR-21 will not only meet the high power prime mover requirements of future warships but also offer an efficient cruise/boost engine in one package. For Navies who use the traditional two engine 'cruise' and 'boost' fit, the engine gives ship designers the freedom to procure, install and maintain one engine to power the vessel over its entire operating profile in place of the two engines. Compared directly to the use of simple cycle high power engines, the WR-21 provides significant fuel savings which, besides reducing costs, offers operational advantages in ship range, speed, an time on station. Warship operators will also have a new freedom to configure the warship propulsion plant to return unprecedented Platform Life Cycle Cost reductions in peacetime while retaining operational capability in time of conflict.

The Royal Navy is the first user of the WR-21 Intercooled and Recuperated (ICR) gas turbine engine in its Type 45 Air Defence destroyer (**Figure 1**). The vessel is a 7500 tonne monohull, fitted with an IEP plant comprising two WR-21 Gas Turbine Alternators (GTAs) rated at 21 MWe, 4.16KV. These GTAs in combination with a pair of 2 MWe diesel generators will provide electrical power to two 20 MWe electric propulsion motors and the ship's non-propulsion consumer electrical distribution system. Any combination of generator set can provide any consumer with electrical power.

This paper details how the WR-21 will power the Royal Navy's Type 45 Destroyer and provides examples of the engine's potential for use in other warship classes.

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Figure 1 – The Type 45 Air Defense Destroyer (Artist's Impression)

NOMENCLATURE

Abbreviation or Symbol	**Meaning**
CODLAG	Combined Diesel Electrical and Gas Turbine
COGAG	Combined Gas Turbine and Gas Turbine
COGOG	Combined Gas Turbine or Gas Turbine
DG	Diesel Generator
EEC	Electronic Engine Controller
FADEC	Full Authority Digital Electronic Engine Controller
FW/SW HX	Fresh Water / Salt Water Intercooler Heat Exchanger Skid
FRPP	Fire and Repair Party Post
GTA	Gas Turbine Alternator
HP	High Pressure
ICR	Intercooled and Recuperated
IEP	Integrated Electric Propulsion
IFEP	Integrated Full Electric Propulsion
ILS	Integrated Logistic Support
ISO	International Standards Organization Standard Day Conditions (15°C, 101.3 kPa atmospheric pressure)

KVA	Kilo Volt Amps
LOP	Local Operating Panel
LOM	Lubrication Oil Module
LORA	Level of Repair Analysis
MMI	Man Machine Interface
MMS	Main Machinery Space
MV	Medium Voltage
MWe	Mega Watts of Electricity
NGMS	Northrop Grumman Marine Systems
NPT	Power Turbine Speed (rpm)
pf	Power Factor
PMS	Platform Management System
RCM	Reliability Centred Maintenance
RN	UK Royal Navy
RR	Rolls-Royce
SCC	Ship Control Centre
Type 45	Type 45 Air Defense Destroyer
VAN	Variable Area Nozzle
US	United States
WW	Water Wash

INTRODUCTION

The WR-21 ICR gas turbine engine has been selected for service in the Royal Navy Type 45 Area Defense Destroyer (Type 45). It's selection is a landmark in visionary acquisition that has the potential not only to considerably minimize the life cycle expenditure for the Royal Navy in its future classes of Surface Combatants, but also to significantly enhance the operational capability of all its ships in every theatre. The selection is in line with the Royal Navy's Marine Engineering Development Strategy[1], which encourages the adoption of advanced cycle, modern gas turbine engines to avoid escalation in life cycle costs caused by stagnation in marine engineering operation and maintenance practices and obsolescence of equipment.

The Type 45 will employ two WR-21 ICR gas turbine engines in the first IEP system to go to sea in a Destroyer. The use of modern Platform Management Systems, coupled with taking advantage of the full range of control functionality available in digital control environment means that there is much greater freedom to optimize the operation and maintenance of all the Ship's machinery. An IEP propulsion plant also allows the Royal Navy to harness the benefits of fewer installed prime movers and a smaller complement to further drive out life cycle costs.

This paper briefly describes the WR-21 engine and how it is being integrated into the Type 45. It also outlines the engine's use in the Royal Navy's Electric Ship Technology Demonstrator programme, the operational and support advantages this engine offers, and its potential use in other warships and propulsion system configurations.

WR-21 ENGINE

The WR-21 is an advanced cycle (intercooled and recuperated) gas turbine system developed specifically to power the next generation of warships. Its main design targets included increased thermal efficiency, reduced signature, increased reliability, and ease of maintenance, all leading to reduced cost of ownership. It has been developed with funding from the US, British and French Governments. The prime contractor in the design and development programme has been Northrop Grumman Marine Systems (NGMS) with Rolls-Royce as the major subcontractor responsible for the design of the gas turbine. In addition Honeywell are subcontracted for the design and supply of the intercooler, Ingersoll Rand Energy Systems (IRES) for the recuperator, and CAE for the EEC.

The ICR propulsion system package is designed to occupy the same footprint as existing power plant installations and to deliver high levels of reliability, maintainability and component life. The latter attributes being carried forward from the excellent in-service experience of the modular aero engine parent. The general layout is shown in **Figure 2**.

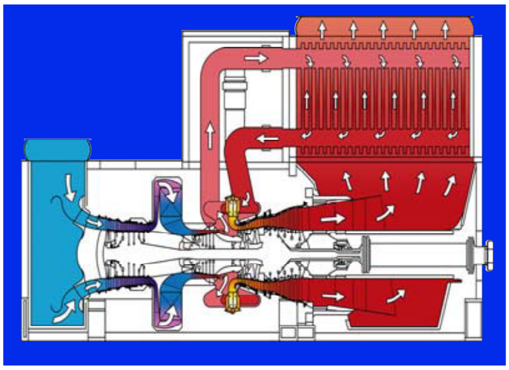


Figure 2 – General Layout

The WR-21 achieves its significant fuel saving over existing simple-cycle engines by using heat exchangers and power turbine entry VANs. The cycle is shown in **Figure 3**. The intercooler lowers the HP compressor entry temperature, which reduces the outlet temperature, increasing recuperator effectiveness and reducing HP spool work. The recuperator recovers waste energy from the gas turbine exhaust prior to the air entering the combustion chambers thus reducing fuel burn. The VANs, which are fully open at full power and progressively closed as power reduces, improve engine part load efficiency by maintaining the high exhaust temperature at part powers. This allows the recuperator to be used to full effect giving the characteristic flat fuel consumption of the WR-21 shown below in **Figure 4**.

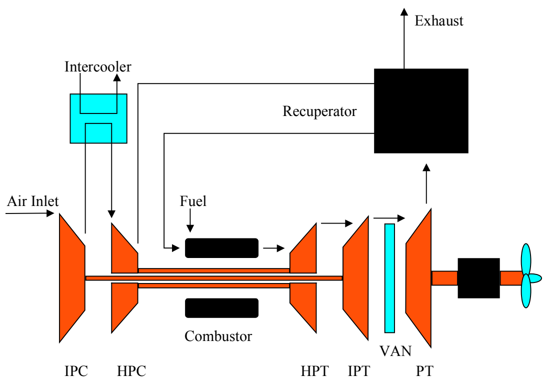


Figure 3 - Principle of Operation

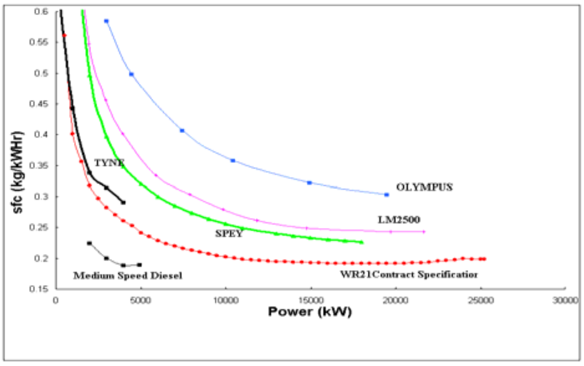


Figure 4 – WR-21 Fuel Consumption Compared to Simple Cycle

WR-21 GTA INSTALLATION IN TYPE 45 DESTROYER

The WR-21 GTA set being delivered to the Type 45 Destroyer consists of the WR-21 ICR core engine and heat exchangers fitted in a maintenance optimised engine enclosure. This is close coupled to a 21 MWe alternator on joined bedplates that effectively form a common machinery raft. The engine support auxiliary systems, supplied separately on one or more off engine skids are: The EEC, LOM, the FW/SW HX, a WW skid and alternator auxiliary requirements. The mechanical components are shown in **Figure 5.**

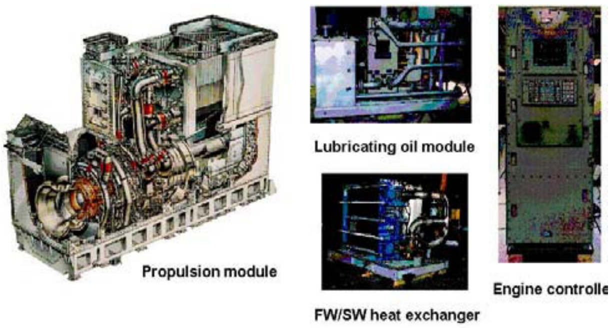


Figure 5 – WR-21 Mechanical Components

The two sets of WR-21 GTAs per Type 45 will feed a High Voltage 4.16 KV bus. Also feeding this 4.16 KV bus are two Wartsila 2MWe diesel generators. This generating capacity supplies the ship service electrical load via link converters and the two 20MWe advanced induction motors via Pulse Width Modulated Converters. A schematic diagram of the system is shown in **Figure 6.**

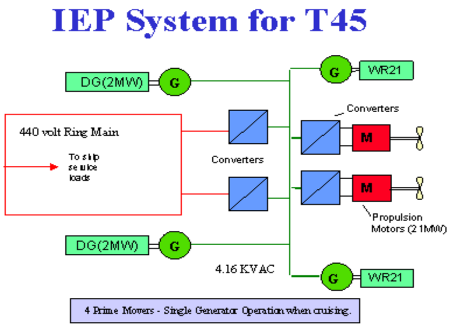


Figure 6. – Schematic Diagram of the T45 IEP System

The WR-21 offers the shipbuilder all the upkeep and easy removal advantages of a modern third generation marine gas turbine with a modular construction (inherited from its aero parents, the highly reliable and well-proven RR RB211 and Trent engines). The engine is capable of modular exchange in the machinery space to an optimum level of refinement that will be determined in the economic LORA, which form a key component of the engine Integrated Logistic Support Study.

The maintenance optimised engine enclosure also allows the engine to be removed from the enclosure sideways or forwards into the MMS. Importantly this precludes engine removals being constrained to take place through engine air intake trunking. Sideways removal was evolved for the RN's second generation of marine gas turbine engines (RR Spey), as a direct result of lessons learned in earlier installations and to avoid the increased cost, time and technical risk of intake removal.

The WR-21 ICR GTA installation for Type 45 is a versatile package that will offer high reliability for low life cycle costs. It represents perhaps the best propulsion architecture to truly take advantage of the WR-21's cycle efficiency as a 'cruise' and 'boost' engine in one package. It allows the implementation of a flexible and robust power system, based upon only four prime movers. In addition, the warship's diesel generator capacity does not to extend beyond the current harbour and low speed operation requirement.

PLATFORM ISSUES

A significant warship platform life cycle cost driver is the Men and Women borne in the ship. Marine Engineering department complement sizes are driven by the warfighting requirement and requirements of machinery operation and maintenance. The evolution of modern machinery systems has allowed the RN to drive down the Marine Engineering Department complement sizes from Steam Powered Leander Class Frigates (65 men) through the introduction of gas turbine propulsion plants. Successive reductions have occurred in Type 42 Destroyers and Type 21/22 Frigates (50 persons) and the adoption of digital control systems and Combined Diesel Electric and Gas Turbine (CODLAG) propulsion plants in the Type 23 Frigate (35 persons).

As the WR-21 provides an efficient cruise and boost engine and the Type 45 IEP system contains only 4 prime movers, the Marine Engineering Department compliment may be further reduced. This reduction in compliment will go hand in hand with a review of machinery operating practice. The role of engineering watchkeeping personnel during peacetime high seas cruising above the established merchant manning levels of one technician with sight of alarms and warnings and one mechanic rounds man will be examined.

OPERATIONAL ADVANTAGES

The Type 45 Destroyer IEP system, utilising the WR-21 GTA, is a major advance in naval propulsion/power systems and should deliver a considerable number of benefits to the Royal Navy, including:

- Significant cost of ownership savings
- Fewer installed prime movers
- Enhanced propulsion/power system flexibility
- A robust and modern prime mover offering fleet-wide savings for decades to come
- Reduced engineering complement
- Reduced shore support

WR-21 OPERATION IN THE ESTD

The Electric Ship Technology Demonstrator (ESTD) is a joint programme between the UK and France which looks to de-risk Integrated Full Electric Propulsion (IFEP) technology so that it becomes an attractive option for future ship propulsion system prime contractors. The schematic of ESTD is at **Figure 7**. Broadly speaking it includes a half ship set of equipment with representative Power Generation and Distribution systems linked by two static power converters. The WR-21 GTA, rated at 21MWe, is the high power source. The 20 MW Propulsion Motor drives a dynamic four-quadrant load, enabling the system to be demonstrated throughout the complete operating envelope. The zonal distribution system, with the inclusion of both zonal and bulk energy storage, completes the picture. The supporting aims of ESTD are:

- To identify and de-risk IFEP system integration issues, including system stability, fault identification and protection and harmonic distortion levels.

- To validate equipment and system software models to reduce or eliminate need for shore testing of future warship power/propulsion systems.

- To generate ILS data.

- To assess signature issues.

- To inform future platform baseline designs and provides supporting evidence for technology pull-through.

- To support the development of power and propulsion requirements for future warships.

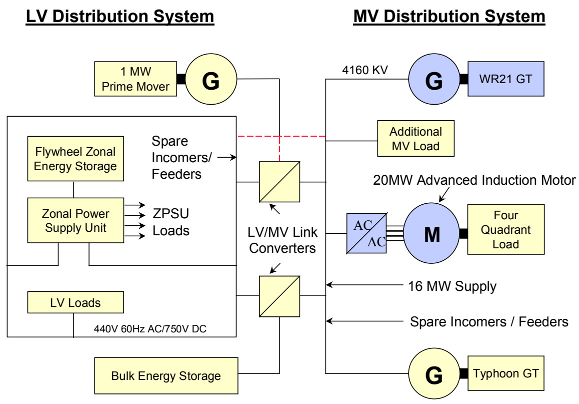
Inclusion of some Type 45-specific equipment will also allow the facility to be used for Shore Integration Testing (SIT) for Type 45 systems once the majority of ESTD testing has been completed.

Planned trials potentially affecting the WR-21 are:

- Short circuit MV with WR-21 operating as the only alternator
- Auto-synchronisation failure during paralleling of WR-21 and Typhoon (5MW) GTA
- Short Circuit MV system at full load
- Crash stop MV system at full load
- De-excitation of one alternator with 2 alternators on load
- WR-21 GTA Trip on full load

These trials are currently underway and are due to complete in mid 2003. Further trials, dependant on the outcome of the first phase of trials, will take place late 2003/early 2004.

Figure 7 – ESTD System Layout



WR-21 POTENTIAL USE IN OTHER WARSHIPS AND PROPULSION SYSTEMS

WR-21 provides a power dense package at a high unit power ratings. This capability lends itself to many propulsion system configurations.

Developing 25.61 MW (34,820 PS) ISO no loss from a single lightweight gas turbine provides a significant opportunity for today’s Corvette and Frigate propulsion systems.

Frigates usually employ twin gas turbines to achieve speeds in excess of 28 knots via twin shafts. As the most popular option has been Combined Diesel or Gas Turbine (CODOG) using two 20MW gas turbines, this presents an ideal opportunity for the use of the **WR-21**. Under the ‘cruise and boost’ in one engine concept it is possible to replace the diesel/gas turbine cruise/boost (CODOG) machinery installation typical for other warships with a single WR-21 gas turbine per shaft. The purchase and other costs associated with separated cruise diesel engines can be saved, reducing total ship cost. Additionally, the manpower intensive heavy maintenance, larger crews and increased harbour down time linked with compact naval diesels are avoided. Using a low cost single input, single output unit reduces gearbox weight, complexity and volume. Less expensive acoustic signature reduction measures can be adopted, which have less impact on ship design and hence further reduced total ship cost.

Similar changes to the propulsion system configuration option also become available for larger naval combatants. Some examples are illustrated in **Figures 8 & 9** that show COGOG & COGAG

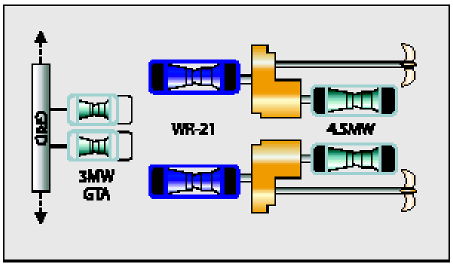


Figure 8 - Modern Propulsion System Option

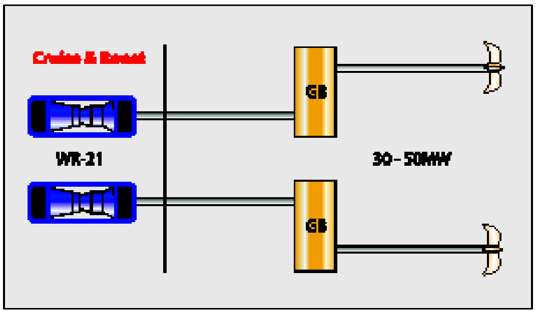
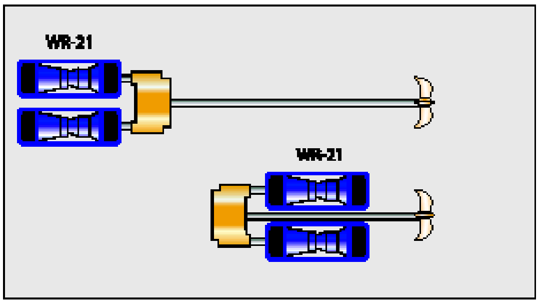


Figure 9 - Option for large Combatants

Whilst the 88.26MW (120,000 PS at JDA conditions 200 mmWG inlet loss, 300 mmWG exhaust loss & air intake temperature 30°C) offered by a four mechanical drive WR-21 system is sufficient for large combatants such as Cruisers and Destroyers (USN AEGIS CG and DDG, Korean KDX111 & Japanese DD class) and Aircraft Carriers. WR-21 has the potential to be selected for a number of large naval combatants; typical system configurations are illustrated in **Figure 10.** In the largest, all gas turbine (COGAG), warships the WR-21 will reduce propulsion fuel consumption by approximately 30%.

So far the propulsion systems looked at have had installed power densities of about 5 to 10MW per 1000 tonne of ship displacement. However a new class of fast combat ships with installed power densities of around 35 MW per ship displacement tonne are currently being designed. Here innovative hull forms such as tri-marans and catamarans as well as semi-displacement mono-hulls are being considered

Figure 10 – Typical Mechanical Drive Configuration



and require waterjets for power delivery and a very powerful and power dense propulsion system. **Figure 11** shows one options for just such an application.

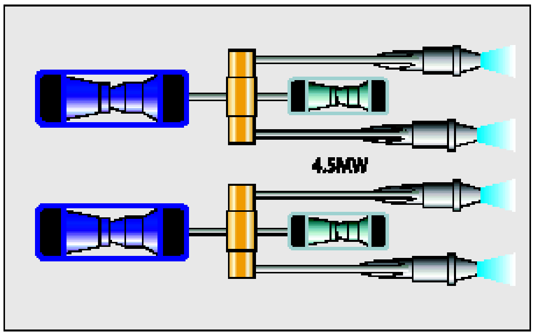


Figure 11 - Fast Combat Ship Propulsion System

WR-21 SUPPORT

A comprehensive Integrated Logistics Support Study for the WR-21 is underway. This will define the most cost effective maintenance method for the engine using contemporary techniques. Gas turbine engines will generally attract a degree of low-level planned maintenance that may sensibly be completed by Ship's Staff. The over arching maintenance philosophy for the WR-21, however, is reliability-centred maintenance via both data logging and inspection techniques. Such emphasis is placed on RCM that the engine has 10 boroscope port locations and the enclosure access design has been driven to allow ease of inspection access for both the (US) Standard and (RN) Maintenance Optimised Enclosures. Engine Boroscope locations are shown in **Figure 12**.

In the Royal Navy's experience, the primary driver of the gas turbine 'cost per fired hour' (the cost of planned and unplanned maintenance and overhaul divided by the cumulative running hours), excluding the fuel costs, is the cost of overhaul. The modular concept of the WR-21 allows overhaul costs to be reduced by the utilising the maximum the life of each module and replacing some modules in the ship. Additionally, with typical RN operations warships in the 12-18 knot speed range, this low power 'cruise' role should return long component lives. Also the WR-21 is a marine gas turbine from conception and therefore maintenance and life are assessed using marine degradation limits and has not inherited costly aero baseline maintenance requirements.

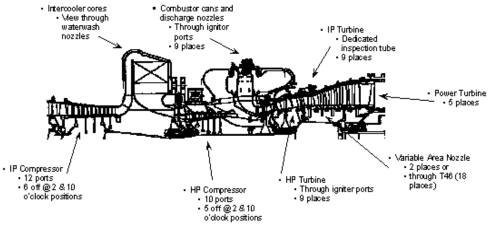


Figure 12 – Engine Boroscope Locations

The RN operates both non-modular gas turbine engines (RR Olympus and Tyne RM1-C) and modular gas turbine engines (RR Spey SM1A and SM1C). Although both require to be overhauled in a fully equipped facility, experience has demonstrated that modular gas turbines have much reduced spare engine pool size requirements due to the reduced work content and quick turn round of returned engines. The WR-21 extends this concept with pre-balanced modules allowing exchange in a controlled environment and not at a second line facility. The will allow the certain modules to be changed in the ship. This not only reduces logistics costs for transportation of modules in place of engines but also drives the number of holdings of spare engines (either as built engines or collections of modules) down even further. This reduction in spares holdings can be as much as 50% when compared to a non-modular gas generator and represents a significant cost both in procurement and storage.

CONCLUSION

WR-21 is a "state-of-the-art" marine gas turbine derived from very modern and reliable aero parents. The engine 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 efficiency throughout its operating range. 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.

The inherent advantages of the WR-21 include:

- High efficiency throughout the operating range
- Improved reliability which as a GTA enables Single Generator Operation for cruising
- Ability to operate as both the "cruise" or "boost" engine
- Reduced maintenance
- Reduced cost of overhaul through modularization
- Reduced overall cost of ownership
- Improved "naval" characteristics such as Infra-red signature and noise

The Royal Navy led the world in the introduction of marinised aero gas turbines in the COGOG propulsion systems (RR Tyne and Olympus gas turbines) of the Type 21 Frigates and Type 42 Destroyers in the 1970s. This was advanced with the hybrid electro/mechanical CODLAG systems (RR Spey gas turbines) of the Type 23 Frigates in the 1990s. The Type 45 Destroyer IEP system, with the WR-21 GTA, is the next major step in a history of world leading naval propulsion systems.

REFERENCES

1. RN Marine Engineering Development Strategy Issue 2 dated 18 Dec 95

The views expressed in this paper are those of the author and not necessarily those of the UK Ministry of Defence.