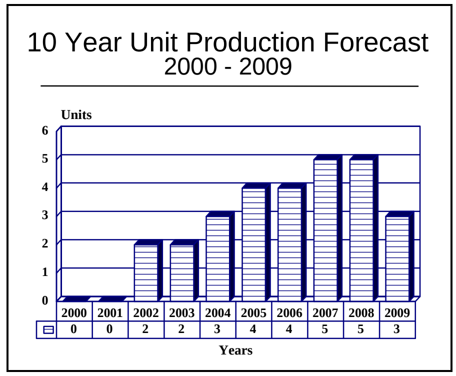
WR-21 - Archived 7/2001

Outlook

- Regenerative gas turbine intended to replace Spey, LM-2500
- Political opposition in US to development; GE clear favorite
- Arleigh Burke market thus considered virtually closed
- Hopes pinned mostly on Britain's Type 45 destroyer
- UK possibly retrofitting older (Type 23, 42) ships as well



Orientation

Description. Two-spool, simple-cycle, axial-flow aero-derivative marine gas turbine powerplant with intercooling and recuperation of intake and exhaust air.

Sponsor

US Department of Defense
US Navy
Naval Sea Systems Command (NAVSEA)
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USA
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UK Ministry of Defence
UK

French Defense Department
France

Contractors

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Electronic Sensors and Systems Division
Marine Systems
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Sunnyvale, California (CA) 94088-3499
USA
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(prime; engineering, systems integration)

AlliedSignal
Systems & Equipment Group
Los Angeles, California (CA)
USA
(intercooler, recuperator heat exchanger cores)

DCN International
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(testing)

Rolls-Royce Plc
Industrial Power Group
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Ansty, Coventry CV7 9JR
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(gas generator, power turbine sections)

Status. Advanced development, prototypes completed.

Total Produced. No production engines have been built thus far. Prototypes are in test use.

Application. This report refers only to marine uses of this system. All other applications are the subject of a comprehensive report in our *Gas Turbine Forecast*.

Platform. Currently, it appears the strongest candidate for using this engine is the British Type 45 destroyer. Other suitable platforms might be retrofits on older ships, perhaps with the possible addition of some Japanese installations.

In France, the likely future platform is the destroyer formerly known as the tri-national CNGF Project Horizon.

Price Range. The maritime WR-21 gas turbine system is estimated to cost US$8.85 to 9.25 million (in 2000 US dollars).

Technical Data

	Metric	US
Characteristics		
Length:	2940 mm	115.7 in
Diameter:	1240 mm	48.8 in
Weight:	2600 kg	5732 lb
Marine Power:	19,686 kW	26,400 shp
Output, Generator Terminals:	27,240 kW	
Heat Rate:	10,050 kJ/kWh-LHV	9,525 Btu/kWh-LHV
Exhaust Flow:	330,700 kg/h	729,000 lb/hr
Exhaust Temperature:	487°C	909°F
Fuel Flow:	5,604 kg/h	12,355 lb/hr

Design Features. The design features of the WR-21 include the following main components:

Intake. Annular intake with bullet-nose. The nose fairing is formed from light sheet alloy and is of double-skin construction to allow passage for hot air anti-icing. Variable inlet guide vanes of stainless steel are also anti-iced.

Low Pressure Compressor. The fan used in the aircraft version is removed and the former intermediate compressor (IPC) becomes the LP compressor. This consists of seven stages of titanium alloy blades, dovetailed into a drum made up of interlocking discs. Stages 1, 6 and 7 are 12 percent chromium steel, the others stages are 100 percent titanium. The Stage 1 stator and rotor blades are redesigned from the aero version for aerodynamics and strength. The casing is machined from aluminum alloy.

High Pressure Compressor. Six stages, of which blades in Stages 1-3 are of titanium alloy, Stage 4 of chromium-cobalt steel, Stages 5-6 of Nimonic 901. Discs of Stages 1-2 of titanium alloy, Stage 3 of chromium-cobalt steel, and Stages 4-6 of IN901. Casing and stator blades are of 12 percent chromium corrosion-resistant steel. ISO base rating speed is 9,100 rpm. Electrical generation base rpm is 9250. Total pressure ratio is from 19:1 to 20:1.

Combustor. Single fully annular combustion chamber with steel outer casing and Nimonic 263 liner. Eighteen airspray burners with atomizers. Dual Lucas high-energy ignition units with General Motors Corp AC Rochester Division plugs in burners #8 and #12. A gaseous fuel system is supplied by Rolls-Royce in Canada.

High Pressure Turbine. A single axial stage drives the HP spool. Blades are held into discs by fir-tree roots. Blades and nozzle guide vanes are cooled by convection and film cooling.

Low Pressure Turbine. The LP design is similar to the intermediate turbine in the aircraft variant, the three-stage turbine which drives the fan stage also eliminated in the industrial variant. A single axial stage drives the LP spool via the inner coaxial shaft. Air-cooled nozzles guide vanes. Discs, blades and vanes of various nickel-based alloys.

Accessories. Start is by a gas generator-mounted air/gas driven starter motor (complete with a speed-sensing unit): an engine-mounted hydraulic starter can be fitted as an option. Gaseous fuel system for industrial operation. A floor-mounted console contains the fuel control system, oil pumps, and filters. Various ducting, silencing, and filtration means are also available.

Operational Characteristics. The Westinghouse/Rolls-Royce WR-21 marine gas turbine is a two-spool gas turbine unit developed directly from the three-spool RB.211 aviation turbofan which powers such aircraft as the Boeing 747, 757 and 767 and the Lockheed L-1011. The conversion to a marine variant was accomplished by removing the fan and its associated turbines, by engineering changes to the first stage blades and vanes of the LP (formerly IP) compressor, and by the installation of duplex ball thrust bearings.

Following the removal of the fan, no additional compressor stages were incorporated to replace the boost effect of the fan. As such, the marine RB.211 runs at a lower pressure ratio and mass flow than does the aero RB.211 engine core at sea level conditions. The thrust bearings are grouped together in the inner compressor casing – no inter-shaft bearings are fitted.

Vibration is suppressed by the use of the Squeeze Film technique, which provides a high-pressure film of oil between the bearing track and engine casing. The two rotors are fully independent and run at their own optimum speeds. A floor-mounted console contains the fuel control system, oil pumps, and filters. Various ducting, silencing, and filtration means available.

Variants/Upgrades

RB.211 ICR. The RB.211 ICR is an Inter-Cooled, Recuperated gas turbine powerplant member of the RB.211 family. WR-21 is part of the same family of engines, representing a further development of the RB.211.

British documentation initially referred to this engine as a Rolls-Royce/Westinghouse program, US documentation as Westinghouse/Rolls-Royce. This discrepancy was later resolved and the style Westinghouse/Rolls-Royce adopted.

Program Review

Background. RB.211 is a fully marinized shipboard propulsion developed from the Rolls-Royce RB.211 for naval warship and large commercial bulk carrier installations. In January 1992, the US Navy's Naval Sea Systems Command awarded Westinghouse Electric Corp's Marine Division a four-year contract for US$160.2 million for the design, development, fabrication and testing of two intercooled, recuperated (ICR) gas turbine powerplant systems in support of the US Navy's Advanced Surface Machinery Systems (ASMS) Program. Westinghouse's Marine Division, AiResearch, will be the ICR prime contractor in a team with CAE in Canada and Rolls-Royce.

Rolls-Royce, as a major subcontractor, is responsible for the gas turbine design, test and performance. CAE is responsible for the controls, and AiResearch for the recuperator and intercooler. If all of the contract options are exercised, Rolls-Royce's share would increase to US$120 million from the current US$67 million. During 1992, the designation of the engine was changed to WR-21.

The US Navy requirements for surface combatants call for: a power base of 26,400 bhp (19,686 kW) with no physical change or reduction in power capacity; an SFC curve equal to a thirty percent reduction in propulsion fuel usage, emphasizing part load usage; the unit must fit within the footprint of the US Navy's current-generation gas turbine engine, GE's LM-2500; the power turbine output speed, direction, and relative position must be maintained. Life-cycle costs, maintainability, reliability, and noise levels are all more stringent than on existing designs.

The ICR prototype will be rated at approximately 26,400 bhp/19,686 kW, offering a 30-percent fuel savings at Navy operating conditions. The engine is expected to grow to 29,000 bhp (21,625 kW), though a production version could be designed to produce anywhere from 20,000 to 40,000 hp (14,914 to 29,828 kW). The system incorporates an intercooler between the LP and HP compressor systems and a recuperator to recover heat energy from the exhaust gases. In the prototype, the LP compressor, HP compressor and LP turbine are from the RB.211-535E aero engine, while the HP turbine comes from the RB.211 524G/H aero engine and the power turbine is adapted from the Trent aero engine's LP turbine with the addition of a variable area nozzle. The combustor is derived from the Spey marine and Tay aero engines.

The WR-21 is intended either for future naval vessels, or for refitting into existing vessels. The engine was committed to Flight IIA class DDG-51 Arleigh Burke destroyers, as well as to the 21st Century Battle Fleet Combatants (SC-21) and Arsenal Ship programs. Westinghouse and Rolls are proposing the WR-21 as a retrofit for the GE LM-2500 aboard CG-47 Aegis cruisers and AOE-6 replenishment ships. Compared to the GE LM-2500's 11,300 hour mtbr and 0.552 sfc, the WR-21 offers an anticipated 24,000 mtbr and 0.378 sfc.

The WR-21 moved to a demonstration/validation phase in FY1995. In the US Navy's FY1996 budget, however, the ICR effort reverted from demonstration/validation status to advanced development status, extending the development period for the engine (full-scale development was scheduled to run from June 1994 to December 1999). Assembly of the first advanced development model commenced in the first quarter of 1994. A second prototype, running concurrently with the first at the Test and Evaluation Establishment in Pyestock (near Farnborough) in England, was also to complete performance testing by the end of 1995.

Problems were experienced with the recuperator in January 1995 and the test schedules were rearranged. The recuperator bypass trials were subsequently scheduled to be finished ahead of time, in order to minimize the overall delay on the program. An improved recuperator was expected for the tests in October '95.

Completion of the first 500 hour test, which had been scheduled for October 31, 1996, was considered to be the first critical milestone of the test program. (No information is available as to whether that has been accomplished.) A production readiness review was scheduled for October 1997, by which time a 3,000 hour endurance test with a production standard engine was to have begun. It turns out that this schedule has been slipped, however, since the final development test phase was not begun until late October 1999.

Four development machines were to be refurbished for shipboard trials during 1999, although the US Navy had indicated earlier that it would have liked two machines ready for shipboard trials in 1997. The 3,000 hour test continued in 1998, while ship integration and shock testing were due to start at the DDG-51 land-based test site at the Carderock Naval Surface Warfare Center (CDNSWC) at the Philadelphia Naval Base. Nevertheless, as indicated above, the program was marred by delays and the final development test did not become activated until in the fourth quarter of 1999.

There was significant political opposition to the WR-21 program during 1995 and early 1996; strong political support was given to the rival General Electric LM2500R. Engineering changes made in the WR-21 during this period also made replacement of the LM-2500 engines (already in service) with the WR-21 all the more unlikely.

The WR-21 marine gas turbine machine is also under serious consideration for the Vosper Thronycroft Stealth Warship design, tentatively designated *Sea Wraith*, in a CODLAG arrangement.

Meanwhile in the US, the WR-21 (ICR) program was dealt a setback by the US Navy and Congress. While questions of technical problems were surfacing, the main difficulty was perceived to be in the amount of time it would take for the program to pay off. Though the WR-21 would save $650,000 per ship annually in fuel costs, the Navy estimated that, at an ICR acquisition cost of $49.5 million per ship (development costs included), it would take 76 years to reach a break-even point for the total amount invested in the program.

At the time, the US Navy was attempting to determine when to begin testing of the WR21 in an installation, but, because the program has reverted from demonstration/validation status to advanced development status, when this testing will occur is unclear. It is now evident that the machines will not be installed aboard any of the remaining DDG-51 class Aegis destroyers or fast transports at all, but would be available for the US Navy's planned DD-21 new destroyer class early in the this century.

The WR-21 utilizes the most up-to-date technology from Rolls-Royce's aero engines, placing it at the leading edge of turbine technology for the year 2000 and beyond. The installation is being sold on the premise of saving the operator money on both fuel and maintenance.

The RB211 machine easily meets the needs of an energy-conscious industry, thanks largely to its high thermal efficiency. Emissions of NOx are also reduced with the RB211 Dry Low Emissions (DLE) system, a technology that has proven itself on the Industrial RB211, where it has reached more than 15,000 hours in service. NOx emissions reduction of 25 ppm or lower are currently desired by most highly industrialized nations, and Rolls' system meets these requirements, as do those of Rolls' competitors, General Electric, Siemens and ABB.

Funding

Funding of the WR-21 program was at an annual level of roughly US$45 to 50 million in the US defense budget, in fiscal years 1995 and 1996.

At that time, the Navy also recommended withdrawal from the program but later reversed the decision thanks to the persuasion by the UK and France, since they had made a public announcement to join the international development team. However, the US Navy noted that even with UK's contribution, the program was still underfunded by at least US$95 million over the subsequent four to five years. The unofficial perception in the USN has been that the

Americans have borne the brunt of the program's development costs, and that the other partners have not contributed their fair share.

The US Navy now covers the related technologies, and presumably the development costs of this particular program as well, under budget items designated as "Integrated Power Systems," "Shipboard System Component Development," and "Advanced Surface Machinery." [The related Acquisition Strategy comments, from February 2000 on RDT&E Project Justification, include a notion "ICR is a candidate system for DD-21".] The latter program was funded at US$29 in 1999 and was reduced to 26 million in the fiscal 2000. It was reduced to US$5.6 million in 2001, presumably since the program is approaching production. Money awarded for FY00 represented an increase by US$7 million over the funds requested by the administration, signaling the program's perceived value and urgency.

Recent Contracts

Contractor	Award ($ Millions)	Date/Description
Northrop Grumman	365.0	*December 1991* — US Naval Sea Systems Command (NAVSEA) contract to a team led by Northrop Grumman, for the design, development and testing of two prototype marine ICR engines, using Rolls-Royce's RB211-535 Trent as its core. Westinghouse's share of the deal came to US$160 million and Rolls-Royce's to US$67 million.
Westinghouse Electric	160.2	*January 1992* — Four year contract from NAVSEA for the design, development, fabrication and testing of two ICR systems (USN ASMS).
Lockheed Martin	50	*1996* — Full-scale advanced development of a modular off-the-shelf power system for future USN combatants.

Timetable

Month	Year	Major Development
Jan	1992	Westinghouse, Rolls-Royce win marine GT ICR system contract
Jun	1994	Full-scale development begins
Jul	1994	Light-off of marine prototype WR-21 at UK MoD's T&E facility in Pyestock
Jul	1995	US Congress proposes end to ICR program
Aug	1995	France signs MoU for joining the development team
FY	1996	WR-21 returns to advanced development from dem/val in USN RDT&E budget
	1997	Two development models prepared for delivery to US Navy
Jan	1999	Eighth (of ten) system test completed successfully
Apr	1999	UK pulls out from tri-national Project Horizon, goes ahead with own Type 45
Oct	1999	Final test phase begins at Northrop Grumman. US Congress adds US$7 million to ICR Engine Cost Improvement Program
May	2000	Design Review 5 completed, followed by final production qualification test
	2001	Possible order from UK expected
Thru	2009	Continued production of WR-21 projected

Worldwide Distribution

At present, no gas turbines of this type are in service. This is a tri-national program involving the US, the UK and France, countries which are also expected to become the main users of the finished product. Japan is another potential user country once large-scale production begins.

Forecast Rationale

The British Royal Navy has been a long-time user of Rolls-Royce turbines. Since the Common New Generation Frigate (CNGF) Project Horizon has now been cancelled, it is less certain what engine will be chosen for the ships, which will now be built more individually by the UK, France and Italy. It is probable, though, that at least the British will stick to the WR-21 in their platform of choice, now called Type 45. Up to 12 ships are foreseen there, with two turbines per ship. It is difficult to imagine that any other engine would be chosen for this position.

Additional systems may be ordered as retrofit items for Type 22 and Type 23 frigates during the early years of the next decade. WR-21 systems could also be ordered for the new carrier replacement program presently known only as CV(F). These latter orders all would fall just outside the forecast period but, if they materialize, will rapidly inflate the total in the next few years.

In the US, however, Westinghouse/Rolls-Royce faces strong competition for scarce funding from General Electric's Marine and Industrial engine division LM-2500 machine, which already powers many US Navy vessels. The US Navy seems predisposed to tapping GE for naval propulsion, and W-RR may be a performance/price opponent held up by the USN, to keep GE on acceptable price and performance target. It appears that Westinghouse/Rolls-Royce will have to compete largely in countries other than the US for military contracts, or break waves in the developing commercial fast-ferry/cargo market.

As for the other countries, France and Italy are each believed to be building two ships. Of these, Italy is less likely to go with the WR-21. The GE connection through Nuovo Pignone is so strong there that the use of an LM2500 is quite possible. In France, the decision is more ambiguous and could, in fact, go either way. Nevertheless, the participation of France in the WR-21 project at least in some form may mean adding another feather to the cap of this new design. It would seem logical that the French would pick this new, less emitting and less fuel-hungry engine for their all-new warship, since they participated in the engine's development and have no political baggage with regard to other OEMs such as GE.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR PRODUCTION

			High Confidence Level			Good Confidence Level			Speculative			
Designation	**System**	**Thru 99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**Total 00-09**
WR-21	MARINE GAS TURBINE ENGINE (UKRN)	2	0	0	2	2	3	4	4	5	5	3	28