Competing Manufacturers of MARINE GAS TURBINES

A Special Descriptive Market Analysis

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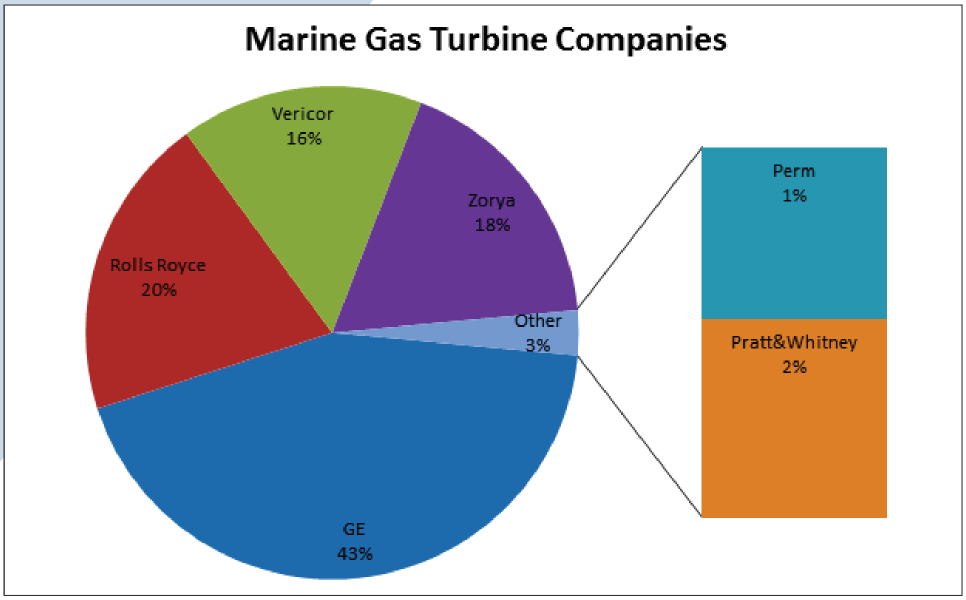
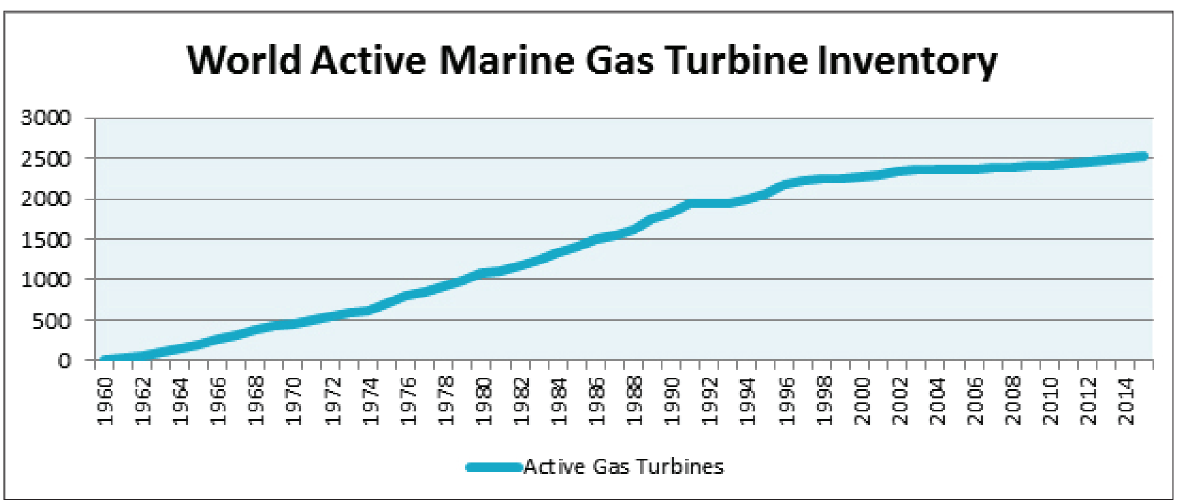
FORECAST INTERNATIONAL

Preface

This market assessment of the marine gas turbine sector is based on the Forecast International Industrial and Marine Gas Turbine Database, a comprehensive listing of more than 41,150 gas turbine installations, of which 3,916 (9.51 percent) are marine gas turbines used for propulsion and 933 (2.27 percent) are gas turbines used for onboard power generation. The Industrial and Marine Gas Turbine Database is a unique reference source that contains details of every propulsion gas turbine that has ever been installed in a warship.



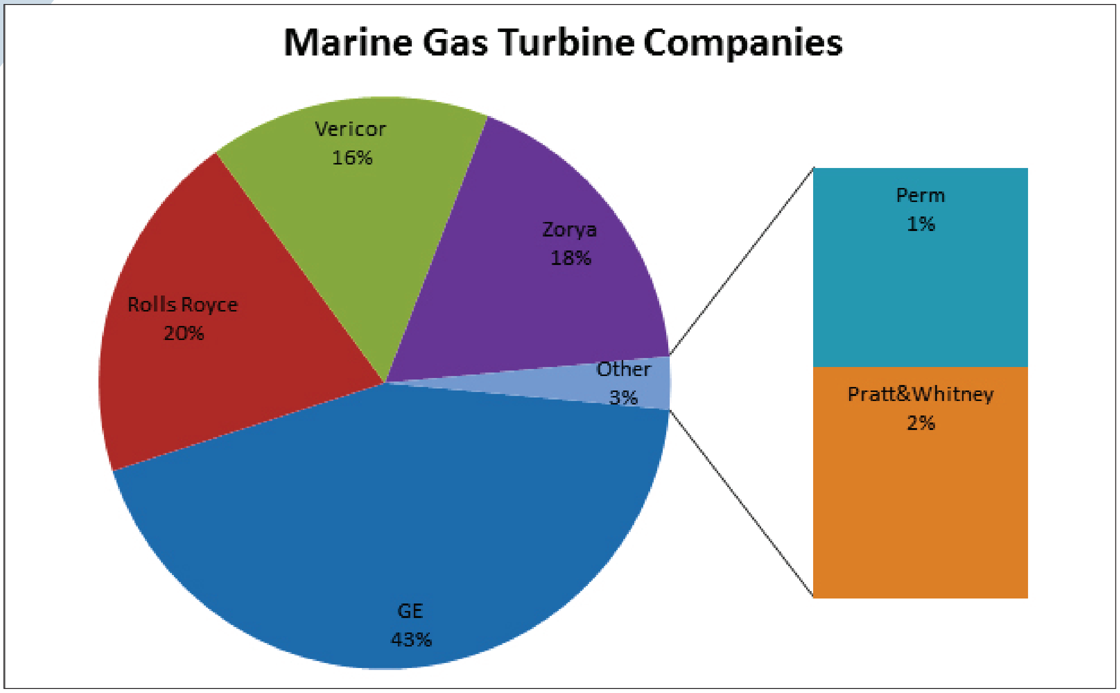
The status of these gas turbines is defined as being retired, operational or planned. Retired gas turbines are defined as those whose platform has been decommissioned. These turbines may not have been scrapped; most navies operating gas turbine-powered ships maintain a pool of replacement engines and turbines from decommissioned ships. The turbines are added to the pool, probably replacing older or inferior units. Operational gas turbines are those where the platform in question is still in service. Planned units are those for ships whose construction has been authorized but where the platform in question has not yet been commissioned.



The Industrial and Marine Gas Turbine Database is being constantly maintained and updated, with new installations entered as the requisite orders are placed. Also, as installations are decommissioned, the appropriate database entries are amended to reflect this status. They are not, however, deleted. Ships have been known to be recommissioned after being withdrawn from service. They may be returned to their original roles, although this is becoming increasingly rare as the concept of reserve fleets falls into disuse. More commonly, a decommissioned ship may be sold to a new user. To avoid duplication, the Industrial and Marine Gas Turbine Database lists ships under their last active user. Land-based gas turbine power generation systems are often mothballed but maintained so that they can be returned to service in the event that more modern plants go off-line for any reason or there are unexpected surges in power demand.

Descriptive Market Analysis

The startling thing about the marine gas turbine market is just how few companies are actually involved in it. During the 1980s, the major players absorbed the minor ones and the industry consolidated to just six players. Of these, Pratt & Whitney and Perm provide mostly aircraft engines for use on hovercraft and other air cushion vehicles. This is a very limited niche market, accounting for only 3 percent of the number of gas turbines supplied to the marine market. Vericor owes its position to its provision of gas turbines for the U.S. Navy Landing Craft, Air Cushion (LCAC) program. However, the follow-on program to the LCAC, the Ship-to-Shore Connector, will use Rolls-Royce MT7 gas turbines, suggesting that Vericor will not be participating in the future marine gas turbine market to the same extent. Thus, the key players in the marine gas turbine market are GE, Rolls-Royce and Zorya-Mashproekt. GE is the undoubted market leader with nearly half the market, while Rolls-Royce and Zorya-Mashproekt split the rest between them.



Notes: Vericor was formerly Avco Lycoming, which was acquired by MTU as a wholly owned subsidiary. Perm is a Russian company that primarily builds aero turbines.

To some extent, this concentration of the market into a few key suppliers is disguised by the fact that licensed production accounts for a significant number of gas turbines. Rolls-Royce and GE both have licensees in Japan, and GE has also licensed the LM2500 to Italy, India, Norway and Korea. Zorya-Mashproekt has sold production licenses to India and China. In computing the market share of the primary companies listed above, production by licensees is included within the totals.

GENERAL ELECTRIC

General Electric Company is one of the largest and most diversified industrial corporations in the world. GE traces its beginnings to Thomas A. Edison, who established his Electric Light Company in 1878. In 1892, Edison General Electric Company and Thomson-Houston Electric Company merged to form General Electric Company.

From the time of General Electric's incorporation in 1892, the company has developed, manufactured, and marketed a wide variety of products for the generation, transmission, distribution, control, and utilization of electricity. Over the years, development and application of related and new technologies have considerably broadened the scope of GE's activities and those of its affiliates. The company's products include lamps, motors, locomotives, major appliances for the home, industrial electronic products and components, electrical distribution and control equipment, power generation and delivery products, nuclear power support services and fuel assemblies, and commercial and military aircraft jet engines. It also produces engineered plastics, silicones, and cutting materials, as well as a wide variety of high-technology products used in aerospace, defense, and medical diagnostic applications. General Electric employs about 307,000 people worldwide.

Marine Turbine Programs

GE LM500

The General Electric LM500 is an industrial and marine gas turbine produced by GE Aviation. It is a derivative of the General Electric TF34 aircraft engine. The first LM500 engine was delivered to Esso Australia Ltd, in Sale, Australia, in 1981. The engines performed flawlessly in all applications, and run time between major overhauls far exceeded original expectations. In the late 1980s, the engine became difficult to market due to declining natural gas prices and the engine's higher cost versus competitive, less efficient engines. Current versions of the LM500 deliver 6,000 shp (4.47 MW) with a thermal efficiency of 31 percent at ISO conditions. It has been used in various applications, such as in the Flyvefisken-class patrol vessels and in fast ferries.

GE LM1500

The LM1500 is an industrial and marine gas turbine derivative of the General Electric J79 aircraft engine series. Many J79-derived engines have found uses as gas turbine power generators in remote locations, in applications such as the powering of pipelines. The LM1500 delivers 10,000 shp (7,420 kW) with a thermal efficiency of 33 percent at ISO conditions. The LM1500 product line is no longer a current offering from OEM (original equipment manufacturer) packagers. S&S Turbine Services Ltd is currently the sole facility holding all the necessary fabrication jigs for full Level IV overhaul of these units, as well as certified and calibrated test cell equipment specifically designed for testing of these units with corrected data to land-based and marine ISO conditions.

GE LM1600

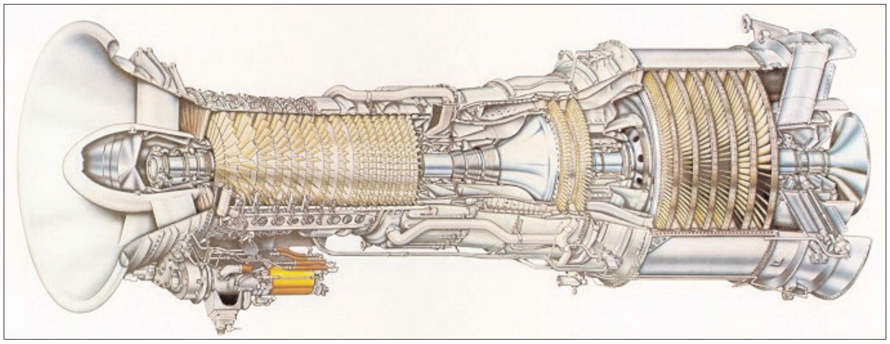
This is a simple-cycle, three-shaft, axial-flow, aviation-derivative industrial and marine gas turbine. More specifically, the LM1600 is a derivative of the General Electric F404 aircraft engine series. The LM1600 delivers 20,000 shp (14,920 kW) with a thermal efficiency of 37 percent at ISO conditions. Applications include mechanical drives, including compressor drives for pipeline, platform, and process operations; electrical generator drive and cogeneration duty; and marine propulsion. A dwindling order book portends an early end to the production life-cycle of this engine.

GE LM2500

The LM2500 is a twin-spool, axial-flow, aeroderivative industrial gas generator and marine gas turbine designed for marine propulsion, industrial and electric utility power generation (including cogeneration duty), and various mechanical drives. The LM2500 is a derivative of the General Electric CF6 aircraft engine. The LM2500 is available in three versions:

- The LM2500 delivers 33,600 shp (25,060 kW) with a thermal efficiency of 37 percent at ISO conditions. When coupled with an electric generator, it delivers 24 MW of electricity at 60 Hz with a thermal efficiency of 36 percent at ISO conditions.
- The improved, third-generation LM2500+ version of the turbine delivers 40,500 shp (30,200 kW) with a thermal efficiency of 39 percent at ISO conditions. When coupled with an electric generator, it delivers 29 MW of electricity at 60 Hz with a thermal efficiency of 38 percent at ISO conditions.
- The latest, fourth-generation LM2500+G4 version was introduced in November 2005 and delivers 47,370 shp (35,320 kW) with a thermal efficiency of 39.3 percent at ISO conditions.

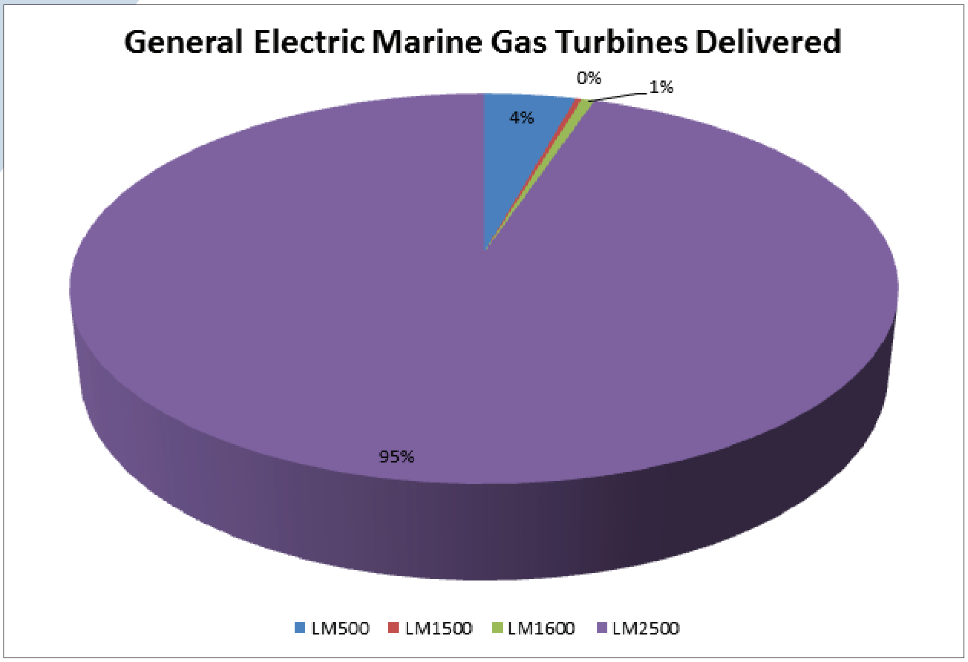
The LM2500 is license-built in Japan by Ishikawajima-Harima, in India by Hindustan Aeronautics Ltd (HAL), and in Italy by Avio (now a wholly owned GE subsidiary).



LM2500 Gas Turbine
Source: General Electric Power Systems

GE LM6000

The LM6000 is a simple-cycle, very high-efficiency, aeroderivative two-shaft industrial gas turbine capable of driving equipment from either front- or rear-output shafts. The LM6000 is derived from the CF6-80C2 aircraft turbofan. Applications include industrial and utility power generation in cogeneration and combined-cycle configurations, mechanical drives, and marine propulsion. The LM6000 provides 54,610 shp (40,700 kW) from either end of the low-pressure rotor system, which rotates at 3,600 rpm. This twin-spool design with the low-pressure turbine operating at 60 Hz, a common electrical frequency, eliminates the need for a conventional power turbine. Its high efficiency and installation flexibility make it ideal also for a wide variety of utility power generation and industrial applications, especially peaker and cogeneration plants. The machines are used as replacement units for older gas and steam turbines. Production of the LM6000 machine began in 1992.



Fully 95 percent of the marine propulsion gas turbines delivered by GE or its licensees are LM2500s of varying types. The LM1500 is long out of production and its support is in the hands of small aftermarket companies. The LM1600 has reached the end of its production life, while the LM500 achieved a limited degree of success as a power unit for fast attack craft but has never moved outside that niche.

The LM6000 appears to have achieved the most success as a power unit for offshore oil applications. Currently there are 14 LM6000 gas turbines operating in marine installations, such as on floating production storage and off-loading (FPSO) vessels in the harsh North Sea environment. These engines had accumulated over 260,000 fired hours in service by 2003. In April 2015, the LM6000 PC and PG models received Lloyd's Register's Design Appraisal Document to the Marine Naval Vessel Rules (NVR). Brien Bolsinger, vice president, Marine Operations, GE Marine, said at the time, "The LM6000 already has a reliable track record in marine and industrial service, logging more than 21 million operating hours. Over 1,110 PC models are used for land-based power generation, driving LNG compressors, and on marine floating production storage and offloading ships, offshore platforms, and power barges." It is notable that naval marine propulsion applications for the LM6000 appear conspicuous by their absence.

So, it appears that GE Marine is still largely dependent on the LM2500 for the bulk of its income. It is a machine that has been available for a long time, but continues to sell well. The 46,000-shp/34.3-MW LM2500+G4 offers more than a 12 percent increase in power compared with its predecessor, over a wide range of conditions. This latest upgrade gives customers additional horsepower in virtually the same engine envelope. The newest model can operate in both simple-cycle and combined-cycle modes, and will quickly be available in both standard and DLE combustion models, capable of burning natural gas, fuel oil, or both in a dual-fuel capacity. The LM2500+G4, in combined-cycle mode relative to the LM2500+, will have more power, plus a 0.8 percent heat rate advantage. Yet, for all that, the LM2500 is a dated gas turbine and it faces rivals that have the benefit of evolved design technology.

ROLLS-ROYCE

Rolls-Royce was established in 1904 in Manchester, England, when C.S. Rolls and Henry Royce joined forces to produce and market the latter's automobiles in the United Kingdom. The company moved to Derby in 1908, and during World War I became involved in the production of aircraft engines for the Royal Fighting Corps. In the ensuing years, Rolls-Royce produced a wide variety of piston engines, and during World War II the company handled the lead development of the Whittle gas turbine engine. After the war ended, Rolls-Royce continued to refine its capabilities in both aero and industrial/marine gas turbine engines.

During the 1960s, Rolls-Royce began development of the RB211 turbofan engine. The RB211 design featured the use of a new carbon-fiber material – Hyfil – that was lighter than aluminum and stronger than steel. However, protracted and costly development of the Hyfil resulted in substituting Hyfil components with those made of titanium. The subsequent redesign, labor, and material costs escalated rapidly, culminating in the company declaring bankruptcy in 1971. At that time, the restructured, nationalized Rolls-Royce Ltd concern was formed, with Rolls-Royce Motors Ltd restructured as a separate public company. Rolls-Royce Motors Ltd is currently a company of the Vickers plc group.

In 1995, Rolls-Royce expanded its presence in its largest market, the U.S., through the acquisition of Allison Engine Company. The acquisition gave Rolls-Royce a firm base from which its engines could compete for U.S. military programs. In November 1999, Rolls-Royce completed the purchase of Vickers plc, further enhancing its global position in marine power systems. The company divested Vickers Defence Systems in late 2002. Rolls-Royce employs approximately 55,200 worldwide.

Marine Turbine Programs

Marine Proteus

Originally developed by the Bristol Aeroplane Company, Proteus was the first successful marine gas turbine. It was originally developed to power the abortive Brabazon airliner and Princess flying boat, but with the failure of those programs, it was adopted for small naval patrol craft, hovercraft, and electrical generating sets. The Proteus was a two-spool, reverse-flow gas turbine. Because the turbine stages of the inner spool drove no compressor stages, but only the propeller, this engine was classified as a free turbine. During development, there were severe problems with compressor blades, turbine blades, and bearings failing at even low power output levels. These issues, not uncommon for gas turbines of that era, led to doubts about its use on aircraft, and a marinized version of the engine was used to power the Royal Navy's Brave-class fast patrol boats, and subsequently in many fast patrol boats of similar design built for export by Vosper. These were among the fastest warships ever built, achieving over 50 knots on flat water. The Swedish torpedo boat Spica and her sisters were also powered by the Proteus, which was used on the SR.N4 Mountbatten-class cross-Channel hovercraft. In this installation, four "Marine Proteus" engines were clustered in the rear of the craft, exhausts pointed rearward. In the mid-1960s, Proteus development was stopped in favor of the more reliable Tyne.

Proteus developed up to 4,450 shp with a fuel consumption of 273 Imp gal/hour.

Tyne

Designed in 1954, the RB109 Tyne was initially designed for a power of 2,500 shp, but when first run in April 1955 the engine far exceeded expectations and was soon being type-tested at 4,220 shp. A single-stage HP turbine drives the nine-stage HP compressor. A three-stage LP turbine drives the six-stage LP compressor. The combustor is cannular. Usually paired with the Olympus gas turbine, the Tyne was a remarkably successful little engine once engineering officers got enough experience with it to accept that a box that small could actually generate enough power to safely maneuver a ship. In 1970, 24 shipsets of Tyne and Olympus gas turbines were ordered for future Royal Navy ships. The Tyne went through a series of improvements that steadily boosted its output power.

The last Tyne gas turbine in Royal Navy service was powered down for a final time in April 2012, ending 40 years of service. The trusty Tyne, though, remains in service with many navies worldwide.

Olympus

The Rolls-Royce Marine Olympus is a marine gas turbine based on the Rolls-Royce Olympus aircraft turbojet engine. The first Marine Olympus was built in 1962 for the German Navy. In 1962, BSEL was contracted to provide the gas generator, and Brown Boveri was contracted to provide a two-stage long-life marine power turbine. Test-running of the next Marine Olympus began in 1966. The power turbine was of a single stage operating at 5,600 rpm utilizing wide-chord blades. Beginning its sea trials in 1968, the Turunmaa, a 700-ton corvette of the Finnish Navy, was the first Olympus-powered warship to enter service, some six months before entry into service of HMS Exmouth, the first British ship that had been refitted to trial the propulsion system for the Royal Navy.

The TM1 and TM2 variants comprised a power turbine baseplate carrying the turbine and the gas generator mountings, and differed significantly only in the construction of the power turbine structure, which was a steel casting on the TM1 and a fabrication on the TM2. All TM1 and TM2 installations were fitted with an A-rated gas generator. The TM3 comprised a similar power turbine baseplate plus a gas generator enclosure, an air intake enclosure, and many support services, including ventilation and fire extinguishing systems. All TM3 installations were fitted with a B-rated gas generator.

During its period in service, the power output of the Olympus rose from 19,500 shp to 28,000 shp. Specific fuel consumption of the Olympus is 0.817 lb/(lbf·h).

The Olympus entered service as a peak-demand industrial power generator in 1962 when the Central Electricity Generating Board (CEGB) commissioned a single prototype installation at its Hams Hall power station. By 1972, the CEGB had installed 42 Olympus generating sets. Olympus engines are also used to provide backup power in case of a loss of grid electrical power at some of Britain's nuclear power stations. Many sets were exported, and many found use on offshore platforms. By 1990, more than 320 sets had been sold to 21 countries, many of which remain in service.

Spey

The Rolls-Royce Marine Spey is a marine gas turbine based on the Rolls-Royce Spey and TF41 aircraft turbofan engines. The Spey was designed to fill the gap in power between the Olympus (approximately 28,000 bhp) and the Tyne (6,000 bhp).

The SM1 module is a complete marine propulsion package offered for naval surface vessels. It comprises a Marine Spey gas generator, an acoustic enclosure, a cascade air inlet bend, ancillary systems, electrical power points, and fire protection systems, all mounted in a fabricated steel baseplate. It incorporates its own local control facility and can be connected to alternative remote-control systems from the ship control center. The package includes heat and noise insulation, a self-contained ventilation system, and nuclear-biological-chemical (NBC) protection.

The Spey SM1A is the basic model of the Marine Spey. It is rated at 17,100 shp. The Spey SM1C gas generator is an uprated version of the SM1A; it is currently rated at approximately 26,150 shp. This model incorporates the latest technology from the Tay aero engine. The gas turbines on many SM1A ships were replaced by the SM1C variant, although the ability of the gearing in those ships to absorb the extra power is unclear. The Marine Spey has largely replaced the older Olympus as the high-output component of a ship's powertrain. Throughout the 1980s and 1990s, the Spey was the primary rival to General Electric's LM2500. The Spey is no longer in production.

WR21

In January 1992, the U.S. Navy, Naval Sea Systems Command (NAVSEA), awarded Westinghouse Electric Corp's Marine Division (Sunnyvale, California) a four-year, $160.2 million contract for the design, development, fabrication, and testing of two intercooled recuperated (ICR) gas turbine powerplant systems. The then-Westinghouse Marine Division, AiResearch, and CAE in Canada teamed with Rolls-Royce as prime contractors on the ICR powerplant. Rolls-Royce was responsible for the gas turbine design, test, and performance. CAE was responsible for the controls, and AiResearch for the recuperator and intercooler. In 1992, the powerplant was designated the WR21.

The U.S. Navy requirement was for a power base of 26,400 bhp (19,686 kW) with no physical change or reduction in power capacity, and a specific fuel consumption (SFC) curve equal to a 30 percent reduction in propulsion fuel usage, emphasizing part load usage. Also, the unit had to fit within the footprint of the U.S. Navy's (then) current generation gas turbine engine, GE's LM2500, and the power turbine's output speed, direction, and relative position had to be maintained. The Marine ICR powerplant's life-cycle costs, maintainability, reliability, and noise levels were all more stringent than the existing designs at the time.

The ICR prototype offered a 30 percent fuel savings at Navy operating conditions. The system incorporates an intercooler between the LP and HP compressor system, and a recuperator to recover heat energy from the exhaust gases. In the prototype, the LP compressor, HP compressor, and LP turbine were from the RB211-535E aero engine, the HP turbine came from the RB211-524G/H aero engine, and the power turbine was adapted from the Trent aero engine's LP turbine, with the addition of a variable-area nozzle. The combustor was derived from the Spey marine and Tay aero engines. The WR21 is intended for future naval vessels and for refit into existing vessels, including those powered by the LM2500 and the LM2500 "Plus." The turbine itself was designed primarily by Rolls-Royce, with significant marine engineering and test facility input from DCN. The WR21 is the first aeroderivative gas turbine to incorporate a gas compressor intercooler and exhaust heat recovery system technologies that deliver low SFC across the engine's operating range. It offers a reduction in fuel burn of 30 percent across the typical ship operating profile.

The only current application for the WR21 is the Type 45 destroyer, and the engine is being replaced in marketing terms by the Trent MT30.

Trent MT30

Announced in March 2002, the Rolls-Royce Marine Trent MT30 gas turbine machine brings state-of-the-art Trent aero-engine technology to the cruise industry. The new engine model is available for service in either mechanical or electrical genset applications for both commercial and naval marine markets. The Marine Trent MT30 boasts a power rating of 36 MW (ISO, no loss). The Marine Trent MT30 has a two-spool compressor design that offers reduced start times, good balance retention, and no lockup problems, resulting in good operational flexibility. The Marine Trent MT30 has an 80 percent commonality with the Trent 800 aero engine. It can be replaced within 12 hours of engine cooldown. It is easily transportable by land, sea, or air for module separation on the dockside or at the repair and overhaul base.

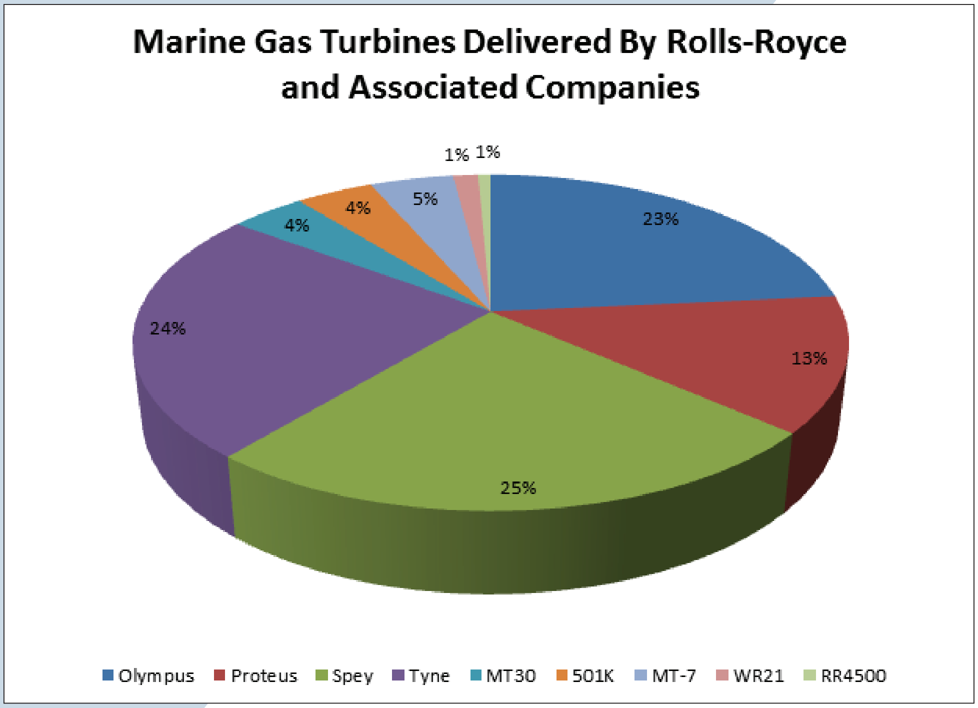
In addition to the U.S. Navy's DD(X) and LCS efforts, the MT30 Marine Trent machine has been selected for the U.K. Queen Elizabeth-class aircraft carriers and is believed to be the preferred power source for the new Type 26 frigates.

In September 2002, the Spanish shipbuilder and designer Izar and Rolls-Royce announced plans for a new European High Speed Cargo Vessel as a cost-effective, short-sea shipping alternative to road transport in Europe. The monohull EHSCV was to have been powered by two Rolls-Royce MT30 gas turbines driving Rolls-Royce Kamewa waterjets. A severe downturn in the container shipping industry means that this design has gone nowhere and is defunct. In general, proposals for very fast merchant ships are usually non-viable since their narrow, yacht-like hulls are suited only to high-speed operation and they are inefficient when run at conventional speeds. The MT30 has received design approval from the Norwegian verification agency Det Norske Veritas (DNV), certifying the engine at 36 MW to meet DNV's rules for classification of high-speed light craft and naval surface vessels. It has also received American Bureau of Shipping (ABS) certification, a U.S. Navy requirement for operational use.

MT7

The MT7 is a member of the successful AE family of aero engines that has accumulated over 48 million operating hours and shares proven common core architecture with the AE 1107C Liberty aero engine that powers the unique Bell/Boeing V-22 Osprey tiltrotor aircraft. Rolls-Royce has delivered over 4,500 AE family engines, a heritage that allows MT7 to draw upon well-established methods and processes and a supply chain that delivers hundreds of engines annually. Delivering power of 4 to 5 MW, the MT7 is a compact powerplant with excellent fuel efficiency and performance retention. MT7 is well suited to a variety of system configurations, offering ship designers and builders increased flexibility in terms of propulsion system layout, and can be configured for either mechanical or electrical drive. As such, it has been specified for the U.S. Navy's Ship-to-Shore Connector.

The twin-shaft axial design of the MT7 comprises a 14-stage compressor followed by an effusion-cooled annular combustor, a two-stage gas generator turbine, and a two-stage power turbine. The cold-end-drive engine features six stages of variable compressor vanes, a dual-channel Full Authority Digital Engine Control (FADEC) system, modular construction, and an "on-condition" maintenance capability. Proven components are utilized throughout the engine, with key parts protectively coated to resist sand erosion and salt corrosion to ensure optimum performance in the most challenging of marine environments. Fuel and oil systems are fully integrated on the engine assembly, making the unit compact and lightweight, yet powerful.



As evidenced by the pie chart, Rolls-Royce has a much more diversified product portfolio than General Electric and has exploited advancing gas turbine design technology to the fullest. It is making major inroads into General Electric's once-solid monopoly of U.S. Navy gas turbine supply. With the success of the MT30 in securing contracts at the high end of the power spectrum and the emergence of the MT7 as a viable contender at the low end, Rolls-Royce has revitalized its product line. This will continue to be the case if the developing use of integrated full electric propulsion (IFEP) emphasizes the value of the MT7 as a ship service generator that contributes its output to the electricity pool of the ship.

Zorya-Mashproekt

Zorya-Mashproekt is a Ukrainian company founded in the early 1950s. It designs, manufactures, and supplies gas turbines for industrial and marine applications. The group's product range includes power generation plants, engines, gearings and gearboxes, marine propulsion plants, steam injection plants, and power generation units. The company also offers maintenance and repair services. Zorya-Mashproekt is based in Mykolaiv, Ukraine.

In 2015, the Ukrainian government proposed that a number of state-owned companies be denationalized and sold to private investors; however, Zorya-Mashproekt was explicitly excluded. This reversed a previous statement made in August 2014 that suggested up to 40 percent of the shares of Zorya-Mashproekt could be sold to private investors.

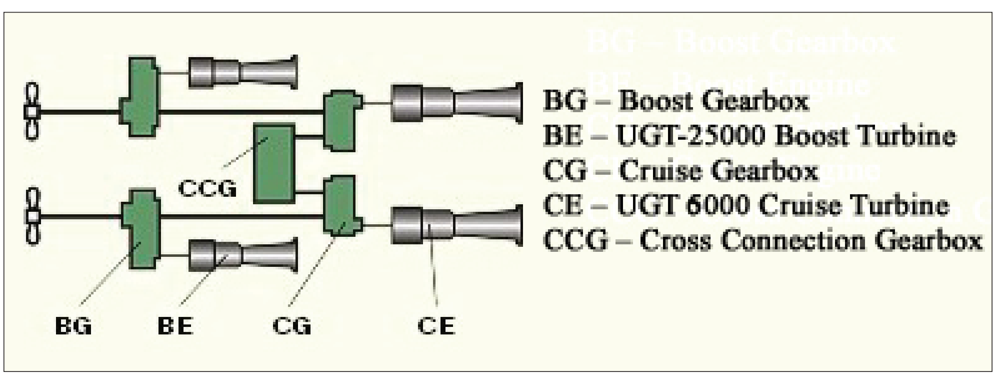
As part of its transition from operating within the confines of the Soviet Union to becoming a key part of the economy of an independent Ukraine, Zorya-Mashproekt needed to cut the time taken to meet customer demands and lower its design and production launch costs. Zorya-Mashproekt met these challenges by investing in modern computer-aided design/computer-aided manufacturing equipment. This included the acquisition of an advanced CAD system for modeling complex 3-D parts, such as cast-cooled turbine blades, and for working with large 3-D assemblies. This also allowed the establishment of a computer-aided NC (numerical control) programming process and the ability to identify errors in part and assembly design as early as possible in the development process.

This new system was first used for a new product line in 2011, when the company's research board decided to develop a new-generation 35-MW gas compressor unit drive to meet customer demand and expand market share. The pressure of competing with Western companies meant that the new system had to be available within two to three years. Delivery beyond three years could easily render a new product obsolete before its launch. This objective was achieved using 3-D modeling of complex parts and assemblies involving long development cycles; these included turbine and compressor blades, cast combustion chamber parts, engine piping parts and assemblies, and auxiliary systems. The system also needed to support concurrent engineering, and needed to be able to make changes quickly. Further, it needed to offer revision control for multiple configurations, along with end-to-end product development support, as well as provide associative part geometry within a single environment. With this equipment, Zorya-Mashproekt was equipped to compete with General Electric and Rolls-Royce on equal terms, albeit with a product line that emphasized different aspects of the performance spectrum.

One problem that is endemic to trying to analyze the use of machinery originating within the old Soviet

Union is the bewildering number of designations that get applied to each and every system. It is not uncommon for a given piece of equipment to have up to a dozen designations. Often, much time is spent trying to comprehend the significance of these differing designations, and success is elusive. It seems as if there is a rationale behind these designations, but the system derived from that rationale has changed several times without any one system completely replacing its predecessors. As a result, the designations are the result of a complex maze of overlapping systems.

A few things are clear. The modern gas turbines produced by Zorya-Mashproekt are referred to as the UGT series (UGT apparently simply standing for Ukrainian Gas Turbine), with "UGT" followed by a number that is the listed output of the gas turbine in question measured in kilowatts. Thus, the UGT 25000 is a Ukrainian Gas Turbine rated at 25,000 kW. So far, so good, although some anomalies exist even within this simple system. The problem comes when that gas turbine is put in a ship. One thing is clear. Reference is often made in published sources to gas turbines whose designation is a single letter followed by a single number (for example, M9 used in the Project 1155 class destroyers). It is now apparent that this is not a gas turbine designation but the designation applied to the whole machinery layout of the ship, including the gas turbines, diesels, ship service generators, emergency generators, gearing and shafts. The "output" listed for this system is the total output rating of all the power generation units included within it.



Propulsion Plant Configuration M9
Source: Zorya-Mashproekt

Between the UGT and M designations are a whole series of other designations applied by the Soviet Navy. Usually these begin with a D followed by a single suffix letter (e.g., DT or DI). The meaning of these suffixes is unclear, although in Soviet terminology, I meant an export system and K referred to one in which a fundamental fault had been corrected. E could indicate a turbine used primarily to drive an electrical generator. It is unknown whether this system is still used by the Russian Navy.

This two-letter combination is followed by a pair of numbers. These do not refer to dates or power outputs, so their meaning is unclear.

Marine Turbine Programs

UGT 3000

This is a three-shaft gas turbine used as a marine propulsion unit. It consists of an axial eight-stage LP compressor and a nine-stage HP compressor. The combustion chamber is a can-annular nine-liner counter-flow chamber. Compressor turbines are axial single-stage engines. The power turbine is an axial three-stage engine. The turbine starts up by means of a single AC electric starter of 30-kW continuous power. The rated output of the UGT 3000 is 3,360 kW with an efficiency of 29 percent.

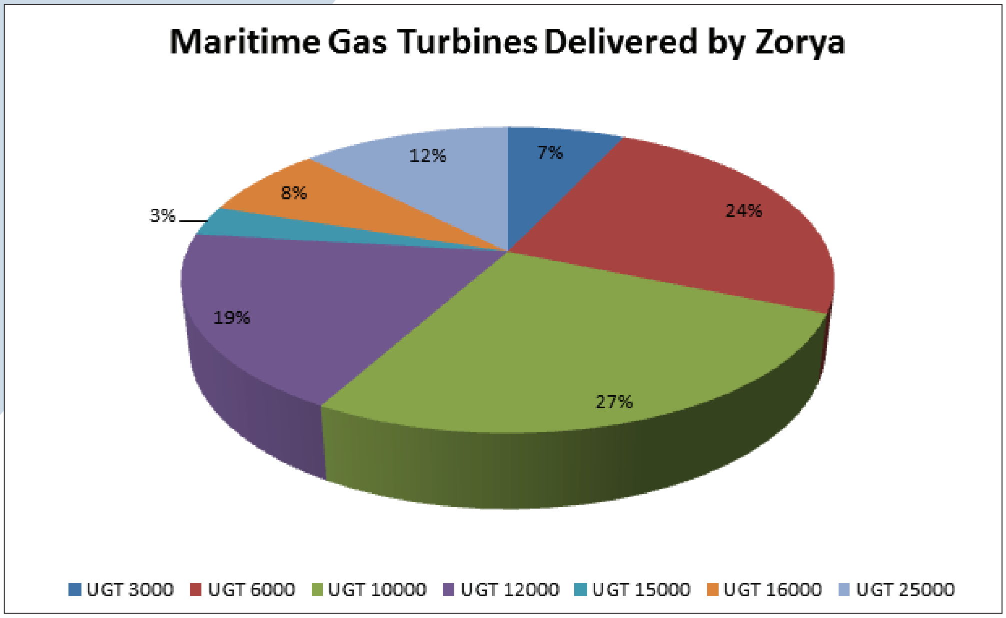
UGT 6000

The UGT 6000 is a three-shaft gas turbine with an axial eight-stage LP compressor and a nine-stage HP compressor. The combustion chamber is a can-annular 10-liner counter-flow chamber. The compressor turbines are axial single-stage LPT and HPT. The power turbine is an axial two-, three-, four- or six-stage engine, depending on the version adopted. The turbine is started up by an AC electric starter of 30-kW continuous power. Output is 7,350 kW with an efficiency of 32 percent. An advanced version of this gas turbine, the UGT 6000+, delivers 8,800 kW with an efficiency of 33 percent.

UGT 15000

The UGT 15000 is a three-shaft gas turbine using an axial nine-stage LP compressor and a 10-stage HP compressor. The combustion chamber is a can-annular 16-liner counter-flow chamber, and the compressor turbines are axial single-stage engines. The power turbine is an axial three- or four-stage engine. The turbine start-up uses two AC electric starters of 30-

kW continuous power. The UGT 15000 is available in a number of versions that deliver between 14,700 kW and 17,650 kW at an efficiency of 35.4 percent. The UGT 15000+ version delivers 20,000 kW at an efficiency of 36 percent.



The UGT 15000 appears to be the standard Zorya-Mashproekt medium-power turbine. The UGT 10000 is now only promoted as a compressor driver for gas pumping systems, while the UGT 12000 has disappeared completely from the marketplace. Both these powerplants, which dated from the earliest days of the Soviet gas turbine industry, appear to have been replaced by variants of the UGT 15000. It appears likely that the UGT 16000, another comparatively old marine gas turbine, will also be absorbed into the UGT 15000 family.

UGT 16000

The UGT 16000 is a three-shaft gas turbine with an axial seven-stage LP compressor and a nine-stage HP compressor. The combustion chamber is a can-annular 10-liner straight-flow chamber. The compressor turbines are axial two-stage engines. The power turbine is an axial two- or three-stage engine. The turbine starts up using three AC electric starters, each providing 30-kW continuous power. Rated output is 16,550 kW with an efficiency of 30 percent. This is a dated engine that is likely to be replaced by a version of the UGT 15000.

UGT 25000

The UGT 25000 is the heavyweight, high-powered engine in the Zorya-Mashproekt line. It is generally used as the boost engine for major surface combatants. The UGT 25000 is a three-shaft gas turbine with an axial nine-stage LP compressor and a nine-stage HP compressor. The combustion chamber is a can-annular 16-liner counter-flow chamber. Compressor turbines are axial single-stage engines, while the power turbine is an axial two- or four-stage engine. The turbine is started up using two AC electric starters, each with 45-kW continuous power. The UGT 25000 has a rated power output of 28,700 kW and an efficiency of 37 percent.

Zorya-Mashproekt has a well-established range of marine gas turbines that cover the needed power spectrum well. The company appears to be rationalizing its product range, eliminating older products that are no longer appropriate to the market and concentrating on establishing a position of strength in the international market. In view of the unpromising environment in which it had to operate, it has done rather well, establishing itself as a provider of solid, workmanlike products. The Zorya gas turbines are particularly favored in China and India, where their solidity and relative simplicity are well suited to the prevailing industrial environment.

Historically, Zorya's biggest – indeed only – market was the warship production of the Soviet Union. Nearly all Russian gas turbine-powered warships use machinery from this plant, the only exceptions being a few air cushion landing craft that use aero-derived gas turbines. With the outbreak of hostilities between Russia and Ukraine, the Ukrainian government has, quite reasonably, embargoed any future deliveries of marine powerplants. From the Russian point of view, this presents a major difficulty in completing its naval expansion plans. A short-term solution to this problem appears implausible, since Russia has become far too invested in the Ukrainian confrontation to back down.

The obvious solution would be for Russia to establish its own marine gas turbine construction capability, and moves to this end are now in hand. Saturn VMF, the daughter company of the Rybinsk-based NPO Saturn, is preparing to produce the first Russian-made gas turbines for the Russian Navy. The problem is that the engines currently available from that source are small units suitable for patrol craft. They do not solve the issue of powering larger warships.

The president of Russia's United Shipbuilding Corporation, Alexei Rakhmanov, summarized the problem when he said, "We hope that at the beginning of 2017, first turbines – to be more precise, first prototypes – will be through bench tests in Rybinsk, and we will be able to begin mounting them on ships we are building for the Russian Navy. Before 2017, we will have to either try to get what we have already paid for or will have to change the configuration of the ships these engines were meant for."

The implication of this statement is that the engines in question will not be available in production quantities much before 2022. Neither the Russian Navy nor export customers will be prepared to wait eight years to get their ships. Obtaining the engines from Ukraine seems improbable, since the current political situation is unlikely to make the Ukrainian government well-disposed to complying with Russian requests.

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Note: This white paper has been abstracted from a larger 80-page report entitled **"MARINE GAS TURBINES; A MARKET ASSESSMENT,"** which will be sold separately. Please contact our Sales Department for information.

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