Stephen Bruno Marine Power & Propulsion Final Project Due: 06DEC2024

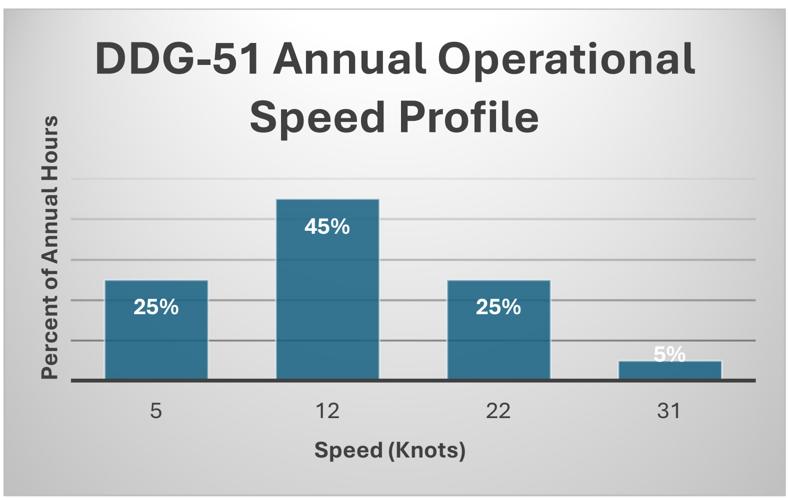
Abstract

Alternative propulsion plant designs for the Arleigh Burke (DDG-51) class destroyers were investigated to improve fuel efficiency. The original configuration consists of four LM2500 marine gas turbines, which use 15183 metric tons for propulsion annually at an average specific fuel consumption of 296 g/kWh. The new design consists of a Rolls Royce MT30 gas turbine and 20V 8000 M91L diesel engine on each shaft. Annual propulsion fuel consumption drops to 11493 metric tons annually with 226 g/kWh average consumption. This installation would add approximately 66 metric tons of weight, a 0.72% increase in the DDG-51's nominal displacement. Completing this retrofit would require significant alterations to the main reduction gears but may benefit from existing Navy logistics infrastructure used to support Rolls Royce engines on other platforms.

Introduction

The purpose of this study is to determine an alternative engine configuration for the Arleigh Burke (DDG-51) class destroyers for reduced fuel use. Figure 1 shows the ship spends significant time at off-design speeds, leaving significant room for improving fuel economy.

Table 1 DDG-51 Operational Speed Profile



Decreasing overall fuel usage was the primary determinant in selection. An initial high-level analysis of alternatives was conducted, from which the team determined to limit options to only the replacement of the prime movers. Replacing the Ship Service Gas Turbine Generators (SSGTGs) with an integrated power system (IPS) was not considered, nor was reconfiguring the Controllable Pitch Propeller (CPP), as both were likely to decrease overall efficiency and increase fuel consumption for the 4-speed operational profile. The Reduction Gear system would be touched as little as practicable. The team focused on reviewing available Marine Gas Turbine and Diesel Engine options, with heavy consideration given to commercial support availability and compatibility with the Navy's existing logistics architecture. Lastly, selected engines were required to fit in the compartments without modification to the structural bulkheads.

Selection Process

Original Configuration Annual Fuel Consumption

Required brake horsepower for each speed of the operational profile was identified from provided characteristic documentation, summarized in Appendix A. Plant configurations were then selected which loaded the propulsive engines. The original plant configuration consists of four 22MW General Electric LM2500 Gas Turbines, coupled to a reduction gear two per shaft. For conservative estimates of cost savings, it was assumed the DDG 51 would be operating in the most economical condition, which for three of the operational speeds involves transiting on a single shaft with a single engine; the brake horsepower for these plant conditions were raised by 15% to account for inefficiencies related to applied rudder angle.

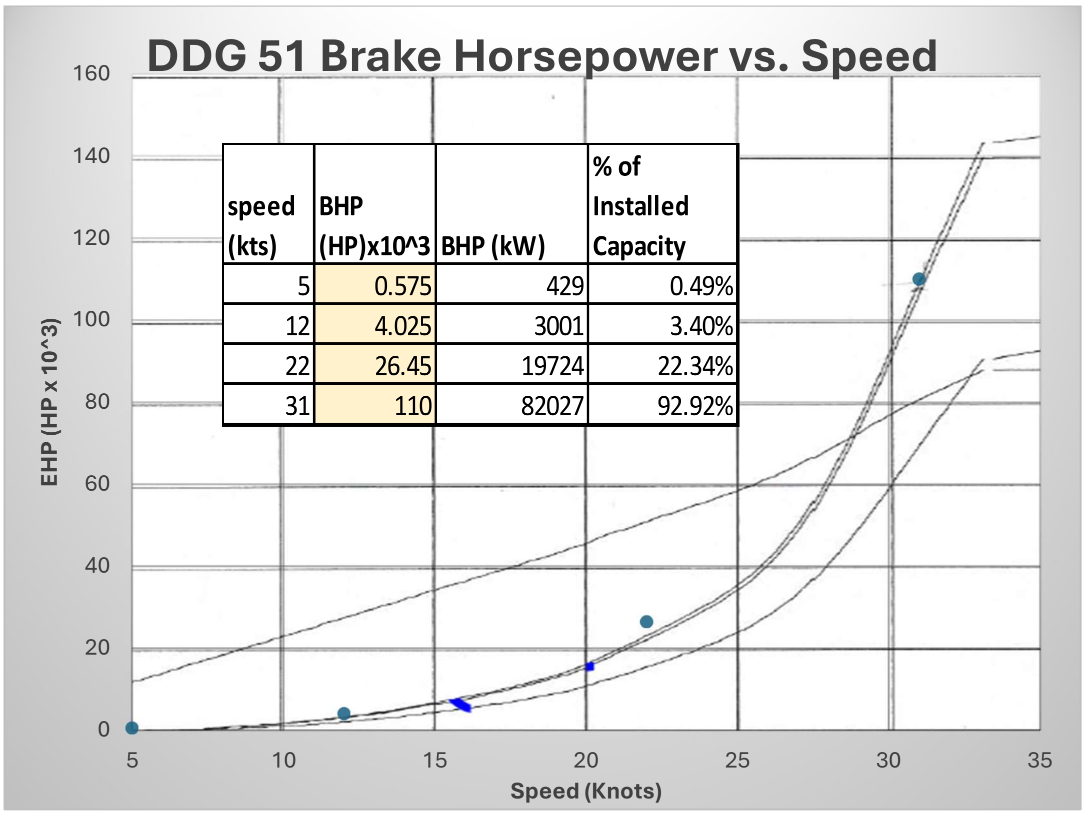


Figure 1 DDG 51 Horsepower Curve

From these values' engine loading, specific fuel consumption, and fuel mass flow for each engine at each operating condition were determined. Additionally, the electrical load was calculated for completeness. These values are summarized in table 2 and table 3. The full table of calculations is included in Appendix B.

Table 2 Original Configuration Propulsion Loading

Port Shaft								STBD Shaft							
Turbine 1				Turbine 2				Turbine 3				Turbine 4			
Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	SFC (g/kWh)	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)
429	1.9%	592.5	334	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
3001	13.6%	450.7	3200	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
19724	89.4%	246.6	6391	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
20507	92.9%	243.9	1314	20507	92.9%	243.9	1314	20507	92.9%	243.9	1314	20507	92.9%	243.9	1314

Table 3 Original Configuration Annual Fuel Summary

Speed (Knots)	Total M_Fuel (M_T)	Avg SFC (g/kWh)
5	334	592
12	3200	451
22	6391	247
31	5258	244
Propulsion Subtotal	15183	296.3
Electrical Subtotal	4641	344.6
Total	**19823**	**307.6**

Notably fuel burned at 22 knots and 31 knots accounts for over two thirds of the total annually fuel burned; these operational points are the team's main focused for improving efficiency. Due to the exponential increase in required power from 22 kts to 31kts, the ideal solution would involve having a lower power and higher power engine per shaft.

Data Collection / Initial Filtering

41 Engines were considered, and are listed in Appendix C. Each engine is from one of three companies: Rolls Royce, Wartsila, and General Electric. These companies were selected due to their readily available technical data, product quality, and for their existing relationship providing equipment to the U.S. and allied navies. The most difficult data to acquire was specific fuel consumption, which other brands that may have otherwise been considered did not have readily available during data collection.

Due to size limitations, some models were unable to be used. Length was determined to be the major geometric limiting factor; usable space after accounting for a minimum 3-foot access buffer was determined to be 28.5 feet and 30 feet for the forward and aft main engine rooms, respectively. Additionally, the limited engine room and decision not to look at integrated propulsion necessitated that no more than 4 engines be selected to fit in existing space.

Engine combination within size limitations were compared for the best fuel efficiency at the 22kt and 31kt speeds. To account for realistic load conditions, it was assumed each engine would operate at no higher than 90% load at 22kts, and no higher than 95% load at the max speed of 31 kts.

To facilitate different plant configuration comparisons, polynomial trend lines were applied to Specific Fuel Consumption curves for constant speed simple cycle gas turbine and high-speed diesel engines. The equations of these lines were used for rapid computation of different configurations.

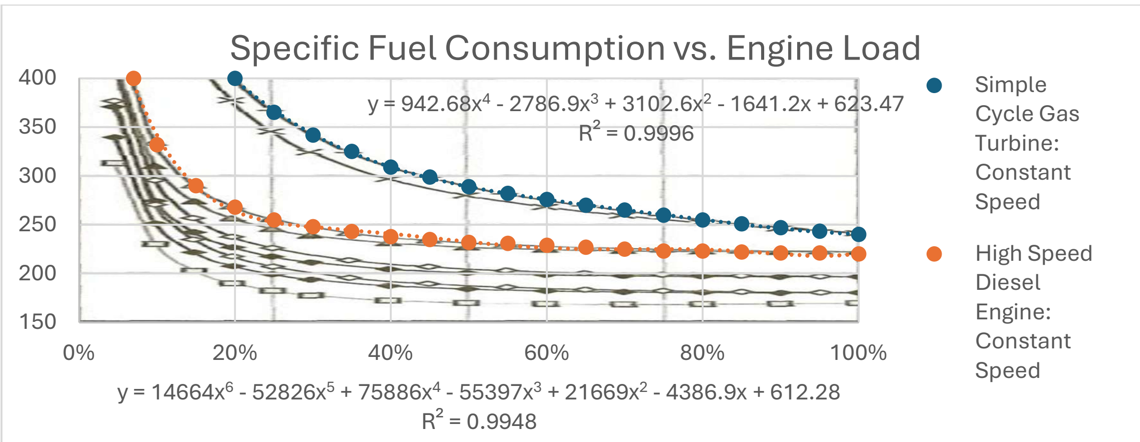


Figure 2 Specific Fuel Consumption vs Engine Load. Line Equations were modified by plus (Engine specific max power SFC) minus (Graph nominal max power SFC, 240 for GT and 220 for High Speed Diesels) to make a specific curve for each considered engine.

Final selection consisted of picking the engine with the best efficiency while meeting the power requirements of the 22kt speed profile, followed by choosing the partner high power engine to meet the max speed requirement in a CODAG configuration.

Results & Discussion

Machinery Selection

Figure 3 Rolls Royce MT-30 Gas Turbine (Left) and MTU 20V 8000 M91L Diesel Engine

The Rolls Royce MT30 marine Gas Turbine, and Rolls Royce (MTU) 20V 8000 M91L Diesel Engine were selected for a CODAG arrangement. Their Technical Data sheets are provided in Appendix D. These engines lower the average specific fuel consumption by 71 g/kWh over the DDG-51's operational profile. The 20V 8000 M91L was the first engine selected, as out of all the options it provided the best efficiency while meeting the power requirements of the 22 kt speed profile. While the GE LM2500+G4 and LM6000PC were close competitors, their maximum power was too low and too high (respectively) when paired with the RR 20V 8000 M91L in a CODAG configuration.

Table 4 New Configuration Propulsion Loading

	Port Shaft								STBD Shaft							
	Rolls Royce MT30				Rolls Royce 20V 8000 M91L				Rolls Royce MT30				Rolls Royce 20V 8000 M91L			
speed (kts)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)
5	0	0.0%	0.0	0	429	4.3%	439	247	0	0.0%	0.0	0	0	0.0%	0	0
12	0	0.0%	0.0	0	3001	30.0%	227	1609	0	0.0%	0.0	0	0	0.0%	0	0
22	0	0.0%	0.0	0	8575.5	85.8%	202	2271	0	0.0%	0.0	0	8576	85.8%	202	2271
31	31514	87.5%	248.1	2055	9500	95.0%	197	492	31514	87.5%	248	2055	9500	95.0%	197	492

Plant configuration consists of the 20V 8000 M91L engine providing propulsive load on a single shaft at 5 kts and 12 kts, two shafts at 22 kts, and in combination with the MT30 on each shaft at max speed. Notably, the 22 kt profile plant configuration changes to utilizing two shafts, which removes the additional 15% rudder resistance in addition to the SFC savings. Additionally, this selection increases the installed brake horsepower by 4%, allowing the ship to obtain an additional half knot at max speed, or account for weight additions as the ship ages. Full calculations are in Appendix E.

Table 5 New Configuration Annual Fuel Summary

speed (kts)	Total M_Fuel (M_T)	Avg SFC (g/kWh)
5	247	438.9
12	1609	226.7
22	4542	201.5
31	5095	236.4
Propulsion Subtotal	11493	225.6
Electrical Subtotal	4641	344.6
Total	**16134**	**259.8**

Installation

One of each engine will be installed on each shaft, replacing the existing LM2500s. These engines increase the weight from the existing plant by 66 metric tons, approximately 0.72% of ship's overall nominal displacement.

Modifications are needed to each reduction gear, as the RR 20V 8000 M91L rotation speed is significantly lower than the LM2500's 3600 RPM. Re-gearing at least one side of the reduction gear is necessary to allow for CODAG operations. Additionally, the MT30 is longer than the LM2500 by 2.3 feet, requiring the reduction gear in that space be shifted aft approximately the same distance to fit the larger engine. General engine characteristics and the update arrangement overlayed over existing arrangement can be found in table 6 and figure 4 - 5 below.

Table 6 Selected Engine Characteristics

Engine Characteristic	Rolls Royce MT30	RR 20V 8000 M91L
Quantity	2	2
Brake Horsepower (kW)	36000	10000
sfc Max (g/kWh)	210.8	299
RPM	3600	1150
L (ft)	28.5	21.8
W (ft)	11.6	6.7
H (ft)	10.1	11.1
Weight (lb)	66000	109348

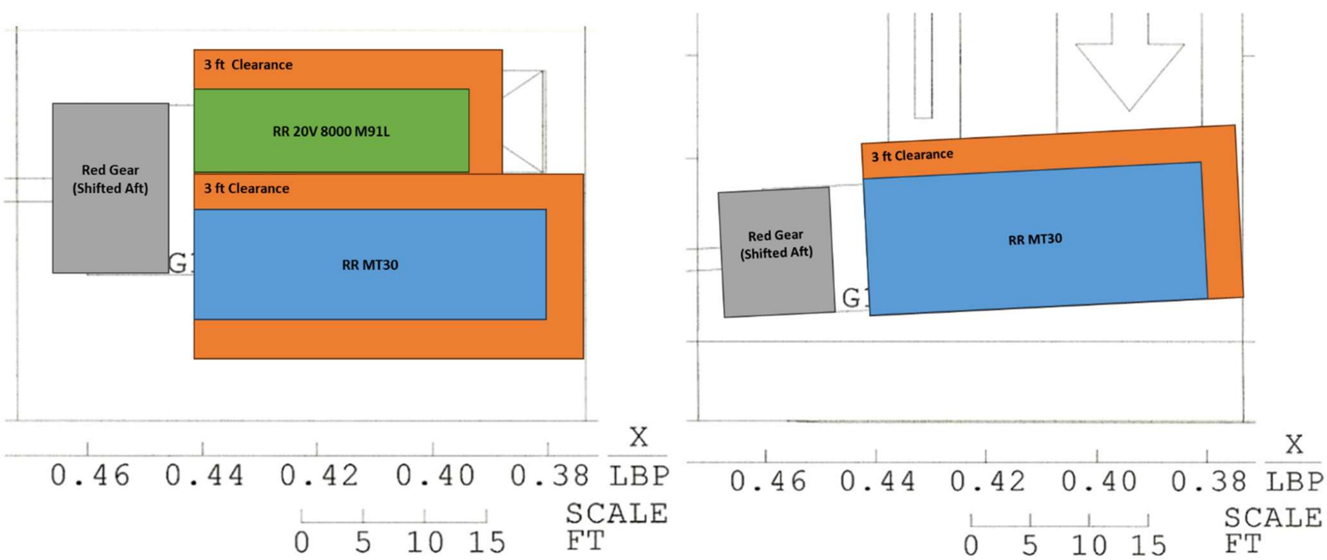


Figure 4 New Configuration Arrangement, Forward Engine Room. Top-down view (Left) and Profile view (Right)

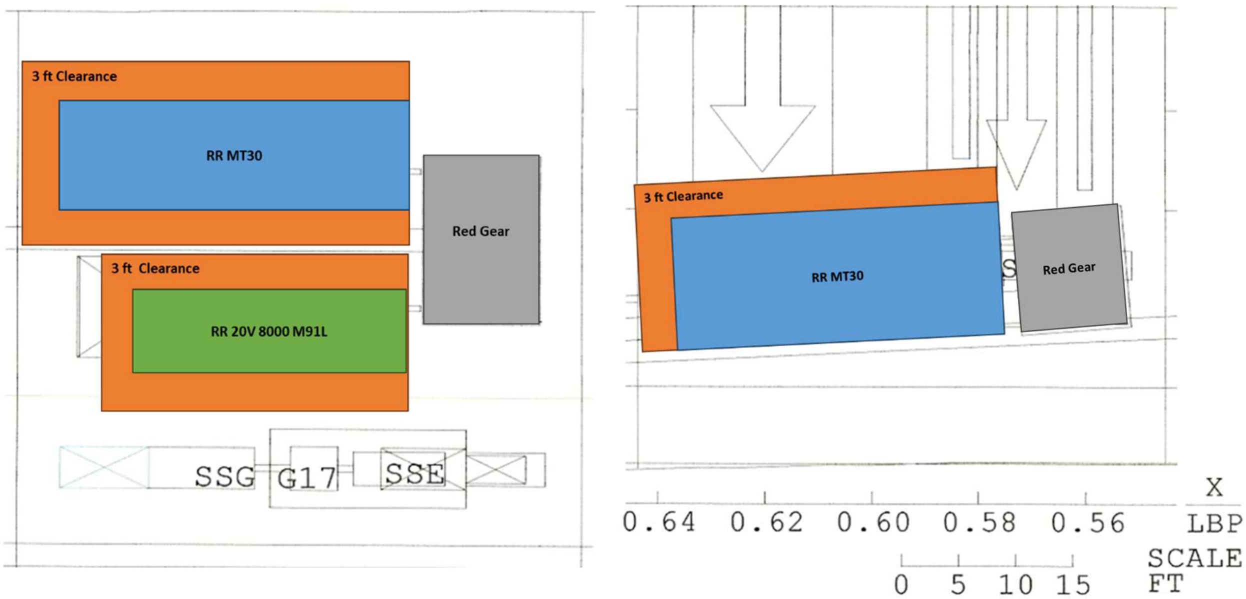


Figure 5 New Configuration Arrangement, Aft Engine Room. Top-down view (Left) and Profile view (Right)

Discussion

Reliability/Maintainability/Availability

Rolls Royce engines are relatively reliable in the marine industry. These engines are installed in naval vessels around the world, including in the U.S. Navy and U.S. Coast Guard. They are also readily available, with the MT30 already in use in the U.S. Navy's Littoral Combat Ships (LCS) and Zumwalt class destroyers. Given the issues both the classes of ship have had, the DDG-51 may be able to benefit from excess spare part inventory for the RR MT-30. Additionally, if any LCS or Zumwalt ships were prematurely decommissioned, their MT-30s could be pulled and provided for the DDG-51 configuration change.

The DDG-51 crew would require new training during the configuration change; however, these schools already exist for the other U.S. Navy and Coast Guard crews using these engines, preventing the need to stand up a one-off course. Diesel engines tend to be less complex and easier to maintain than comparable gas turbines, so there may be some maintenance savings compared to the original configuration.

Costs

Reconfiguring the DDG-51 is an expense endeavor. Procuring and installing new engines would require significant depot level time, though there could be some cost savings if engines were taken from LCS's as mentioned above. Maintenance costs will also likely increase, as Rolls Royce engines and service are more expensive, and their complex nature often requires flying out their technical representatives to access proprietary drawings. There would be a cost to either dispose of the LM2500 or refurbish them to act as spares for legacy DDG-51s and US Coast Guard national security cutters.

These costs would be offset by the significant fuel savings following the transition. Further analysis needs to be conducted to determine if the return on investment would be realized within the ship's remaining service life.

Survivability & Signature

DDG-51's survivability decreases slightly. While losing any single main engineering compartment has the same impact as in the original configuration, having unequally powerful engines paired on each shaft means a loss of the larger engine would have a disproportionate effect on the ship's combat maneuverability. In contrast, in the original configuration the loss of any one LM2500 impacts the ship's maneuverability equally. This is slightly counteracted by the ship's increased installed HP, which could allow the ship to obtain an extra 0.5 – 1 knot of speed at 95 – 100% power.

The DDG-51's signatures may change a marginal amount. The noise signature of diesel engines tends to travel further than gas turbines, creating a larger acoustic signal for combatant submarines to pick up on. However RR MTU engines are generally high performing with less vibrations, which may counter this effect. Temperature wise, the DDG-51 would have a lower heat signature while operating on the diesel engines due to their generally lower exhaust temperatures but may have a higher signature from the more powerful MT-30 turbine when operating at max speed. Further analysis would be needed to determine the net effect over the ship's operational profile.

Emissions

Toxic emissions are greatly reduced in the new configuration. At each speed in the ship's operational profile, specific fuel consumption is lower than the original configuration, which an average reduction of 70.7 g/kWh of fuel per year. This reduction in fuel use has a proportional reduction in CO_2 and SO_x, which are primarily related to how much fuel is burned. NO_x is overall lowered as well, though the specific rate of production in g/kWh for diesel engines is higher than gas turbines. The 20V 8000 M91L is IMO tier II complaint by default but can be outfitted with Selective Catalytic Reduction to obtain tier III compliance.

Conclusions

The primary selection criterion for this project was to reduce annual fuel consumption. Reliability, availability, and maintainability were additionally considered as key elements of selection. The selected Rolls Royce MT-30 gas turbine and 20V 8000 M91L are an optimal solution, reducing annual propulsion fuel use by 24%, from 15183 metric tons to 11493 metric tons. Further review would be needed to determine the true feasibility for installation.

If different criteria were applied, it is likely a different configuration would be ideal. In this project the operation speed profile was provided only at four distinct speeds, which favors having direct drive engines optimized for those speed points. If the operational speed profile was instead a continuous distribution across all speed between bare steerage and max, it is likely that an IPS solution would be a stronger contender, as these systems tend to be more efficient over a wide range of speeds. Another alternative scenario is if reducing lifecycle cost was the primary criteria. While a solution would still likely reduce fuel consumption given fuel's outsized weight on overall lifecycle costs, installation and procurement costs may have steered the selection toward engines that tempered fuel savings at the benefit of cheaper acquisition.

Lastly, due to limited time a combined diesel electric option was not considered; however, the excess power capability by the currently installed SSGTGs in all electrical loading conditions is enough to move the ship at the 5-knot operating condition. If addition time was devoted to reviewing configuration options, single 500-600 kW motor should be considered for additional marginal fuel savings at that operating point.

Main Propulsion			
Characteristic	**Symbol**	**Value**	**Unit**
Ship Displacement	Δ	9145	Tons Metric
Ship Speed (Max Sustained)	Vs_max	31	Knots
Ship resistance (Max Sustained)	R_max	3150	kN
Propeller Speed (Max Sustained)	n_p	160	rpm
Wake Fraction	w	0.02	
thrust deduction	t	0.055	
Relative Rotative Efficiency	η_R	0.985	
Shaft Efficiency	η_s	0.99	
Gearbox Efficiency	η_GB	0.98	
Lower Heating Value of Fuel	hL	42700	kJ/kg
Sea water density	ρ	1025	kg/m^3
Main engine SFC (max load)	sfc_me	0.41	lbm/(hp-hr)
	sfc_me	0.249	kg/kW-hr
Main Engine Max Power (kW)	P_Max	22070	kW
Total Installed HP		88280	kW

Electrical Generation			
Characteristic	**Symbol**	**Value**	**Unit**
Ship Service High Speed Diesels	N# SSGTG	3	
Brake power SSDG	P_B SSGTG	2500	kW
Installed SSDG Power		7500	kW
24-hr average electrical load (Cruising)	P_EL avg	2377	kW
Max Winter Battle Load (10% of underway time)	P_WBL	3574	kW
Max Summer Cruise Load (10% of underway time)	P_SCL	3075	kW
SFC of SSGTGs (Max load)	SFC_ssgtg	0.473	lbm/(hp-hr)
	SFC_ssgtg	0.288	kg/kW-hr

Ship Operating Spectrum (While Underway, 219 days (60%) per year)			
Main Propulsion	**Annual Percent**		**Speed**
25% of Underway	25%	5	kts
45% of Underway	45%	12	kts
25% of Underway	25%	22	kts
05% of Underway	5%	31	kts
Electrical	**Annual Percent**		**Speed**
Average Electrical Load	80%	2377	kW
Max Summer Cruise	10%	3075	kW
Max WBL	10%	3574	kW
Required Installed Electrical 200% Max WBL	7148	kW	
N-1 generators carry WBL, no more than 80% on 1 gen	3574	kW	
Minimum 3 Generators (N)			

Appendix A
Original Configuration Characteristics

Propulsion

					Installed	Port Shaft: Turbine 1				Port Shaft: Turbine 2				STBD Shaft: Turbine 3				STBD Shaft: Turbine 4			
Underway %	**Hrs / Year**	**speed (kts)**	**BHP (HP)x10^3**	**BHP (kW)**	**% of Installed Capacity**	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	SFC (g/kWh)	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)
25%	1314	5	0.575	429	0.49%	429	1.9%	592.5	334	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
45%	2365.2	12	4.025	3001	3.40%	3001	13.6%	450.7	3200	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
25%	1314	22	26.45	19724	22.34%	19724	89.4%	246.6	6391	0	0.0%	0.0	0	0	0.0%	0.0	0	0	0.0%	0.0	0
5%	262.8	31	110	82027	92.92%	20507	92.9%	243.9	1314	20507	92.9%	243.9	1314	20507	92.9%	243.9	1314	20507	92.9%	243.9	1314
				88280																	

Electrical

**Assume only using Gens when UW, Shorepower inport

				SSGTG 1				SSGTG 2				SSGTG 3			
Underway %	Hrs / Year	Electrical Load (kW)	% of Installed Capacity	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)
80%	4204.8	2377	32%	1189	48%	352.0	1759	1189	48%	352.0	1759	0	0%	0.0	0
10%	525.6	3075	41%	1538	62%	328.2	265	1538	62%	328.2	265	0	0%	0.0	0
10%	525.6	3574	48%	1787	71%	315.4	296	1787	71%	315.4	296	0	0%	0.0	0

Speed (Kno	Total M_Fuel (M_T)	Avg SFC (g/kWh)
5	**334**	**592**
12	**3200**	**451**
22	**6391**	**247**
31	**5258**	**244**
Propulsion Subtotal	**15183**	**296.3**
Electrical Subtotal	**4641**	**344.6**
Total	**19823**	**307.6**

Stephen Bruno

Marine power Propulsion
Final Project

Due: 06DEC2024

Type	Manufacturer	Model	RPM	Max Power (kW)	Efficiency	SFC (g/kWh)	Feet Length
Diesel	Wartsila	W_8V31	750	5200	50%	169.4	20.1
Diesel	Wartsila	W_10V31	750	6500	50%	169.4	22.2
Diesel	Wartsila	W_12V31	750	7800	50%	169.4	25.2
Diesel	Wartsila	W_14V31	750	9100	50%	169.4	27.3
Diesel	Wartsila	W_16V31	750	10080	50%	169.4	29.4
Diesel	Wartsila	6L26	900	1950	45%	187	24
Diesel	Wartsila	8L26	900	2600	45%	187	26.7
Diesel	Wartsila	9L26	900	2925	45%	187	29.0
Diesel	Wartsila	12V26	900	3900	45%	187	27.4
Diesel	Wartsila	16V26	900	5200	45%	187	32
Diesel	Wartsila	6L26	1000	2040	45%	188	24
Diesel	Wartsila	8L26	1000	2720	45%	188	26.7
Diesel	Wartsila	9L26	1000	3060	45%	188	29.0
Diesel	Wartsila	12V26	1000	4080	45%	188	27.4
Diesel	Wartsila	16V26	1000	5440	45%	188	32
Diesel	Rolls Royce	16V 4000 M93L	2100	3440	37%	230	11.4
Diesel	Rolls Royce	16V 4000 M93	2100	3120	38%	224	11.4
Diesel	Rolls Royce	20V 4000 M73	1970	3200	40%	213	12.9
Diesel	Rolls Royce	20V 4000 M73L	2050	3540	40%	212	12.9
Diesel	Rolls Royce	20V 4000 M73L	2050	3600	40%	212	12.9
Diesel	Rolls Royce	20V 4000 M93	2100	3900	40%	213	13
Diesel	Rolls Royce	20V 4000 M93L	2100	4300	38%	220	13
Diesel	Rolls Royce	16V 1163 M74	1250	4800	40%	210	14.9
Diesel	Rolls Royce	16V 1163 M84	1280	5200	40%	210	14.9
Diesel	Rolls Royce	16V 1163 M94	1325	5920	40%	211	14.9
Diesel	Rolls Royce	20V 1163 M74	1280	6000	41%	208	17.2
Diesel	Rolls Royce	20V 1163 M84	1280	6000	41%	208	17.2
Diesel	Rolls Royce	20V 1163 M94	1325	7400	40%	210	17.2
Diesel	Rolls Royce	16V 8000 M71L	1150	7280	43%	196	18.7
Diesel	Rolls Royce	16V 8000 M91L	1150	8000	43%	198	198
Diesel	Rolls Royce	20V 8000 M71	1500	8200	44%	190	21.8
Diesel	Rolls Royce	20V 8000 M71L	1500	9100	45%	189	21.8
Diesel	Rolls Royce	20V 8000 M91L	1150	10000	42%	199	21.8
GT	Rolls Royce	MT7	15000	4600	32%	260	5.1
GT	Rolls Royce	MT30 - 36MW	3600	36000	40%	210.8	28.5
GT	Rolls Royce	MT30 - 40MW	3600	40000	40%	210.8	28.5
GT	General Electric	LM2500	3600	22070	36%	233	26.2
GT	General Electric	LM2500+	3600	26630	36%	233	26.2
GT	General Electric	LM2500+G4	3600	30460	36%	233	26.2
GT	General Electric	LM500	7000	4570	31%	269.5	23.4
GT	General Electric	LM6000PC	3600	46123	42%	202.7	16.1

Size Borderline
Size Exceeds Available Space

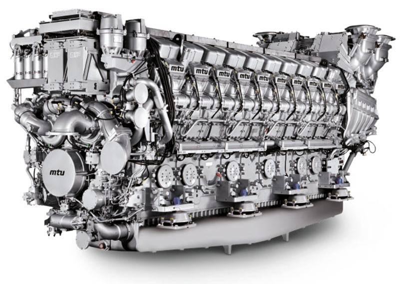
Sources:	General Electric	https://www.geaerospace.com/military-defense/marine
	Wartsila	https://www.wartsila.com/marine/products/engines-and-generating-sets/diesel-engines
	Rolls Royce (DE)	https://www.mtu-solutions.com/na/en/applications/commercial-marine/system-solutions/engines.html
	Rolls Royce (MT30	https://www.rolls-royce.com/products-and-services/defence/naval/gas-turbines/mt30-marine-gas-turbine.aspx

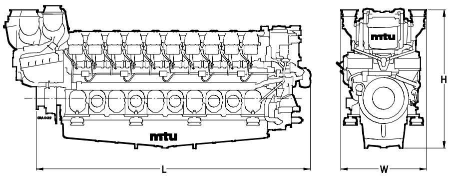
Appendix C
Prospective Engine Data

Marine

DIESEL ENGINE 20V 8000 M91L

for fast vessels with low load factors (1DS)





Optional equipment and finishing shown. Standard may vary.

Engine	Dimensions (LxWxH) mm (in)	Mass, dry kg (lbs)
M93	6645 x 2040 x 3375 (261.6 x 80.3 x 132.9)	49600 (109348)
		Mass, wet kg (lbs)
		51965 (114563)

Typical applications: OPVs, Corvettes, Frigates, Destroyers and Landing Ships with naval requirement and large yachts with high acoustic requirements respectively

Engine type		**20V 8000 M91L**
Rated power ICFN	kW	10000
	(bhp)	(13410)
Speed	rpm	1150
No. of cylinders		20
Bore/stroke	mm (in)	265/315 (10.4/12.4)
Displacement	l (cu in)	347.4 (21200)
Optimization of exhaust emissions*		IMO II

* IMO - International Maritime Organisation (MARPOL)

A Rolls-Royce solution

Fuel consumption *		20V 8000 M91L
at rated power	g/kWh	199
	l/hr	2397,6
	gal/hr	633.3

* Tolerance +5% per ISO 3046, Diesel fuel to DIN EN 590 with a min L.H.V. of 42800kJ/kg (18390 BTU/lb)

Standard equipment	
Starting system	Air starter motor, 15 bar; press. reduct. station 40/15 bar, coolant preheating system
Oil system	Lube oil pump, automatic filter with backflushing, centrifugal oil filter, lube-oil heat exchanger, lube oil priming pump, lube oil level monitoring/replenishment system, switchboxes for lube oil replenishment and priming pumps
Fuel system	Fuel delivery pump, fuel duplex filter with diverter valve, “common rail” fuel injection system with high-pressure pump, pressure accumulator and electronically fuel injection with cylinder cutout system, jacketed HP fuel lines, leak-off fuel tank level m onitored, fuel hand pump, fuel pre-filter with water separator, fuel recooler
Cooling system	MTU-split-circuit coolant system, coolant-to-raw water plate core heat exchanger, centrifugal raw water pump with priming system, coolant circulation pump, coolant expansion tank
Combustion air system	Engine coolant temperature-controlled intercooler, sequential turbocharging with 4 water-cooled turbochargers, on-engine set of combustion-air filters
Exhaust system	On-engine exhaust manifolds, exhaust bellow
Mounting system	Highly resilient mounts for high acoustic requirements and/or shock requirements to NATO Standards
Power transmission	Torsional and offset compensating couplings
Engine management system	Engine control and monitoring system (MDEC), interface to remote control and monitoring system, local operating panel (LOP)
Interfaces	Flexible joints (hose lines, rubber bellows)

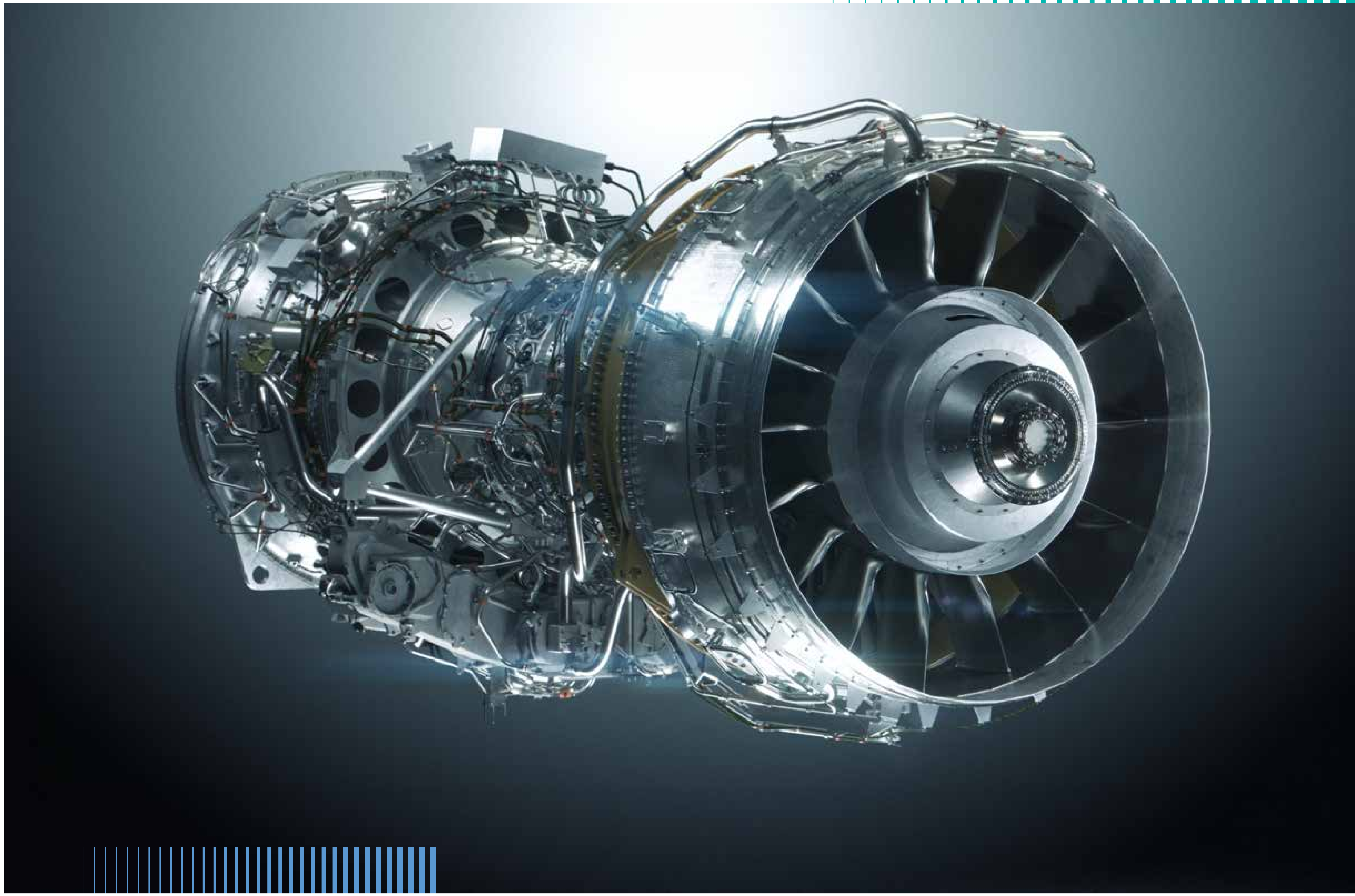
Optional equipment	
Starting system	Compressed air tanks
Monitoring/Control system	Monitoring and control system MCS-5, remote control system RCS-5
Gearbox option	Various gearbox models
Flywheel/housing	SAE 0 flywheel housing “wet”, SAE 1 flywheel housing “dry”, SAE 1 flywheel housing “wet”
Accessory drives	Battery charging alternator, 28VDC, aux. PTO’s for hydr. pump drives and compressors

Reference conditions:
> Intake-air temperature: 25°C (77°F)
> Ambient air pressure: 1000 mbar
> Altitude above sea level: 100 m (328 ft)
Customization possible. Engines illustrated in this document may feature options not fitted as standard to standard engine.

Subject to change. | 3236371 | Edition 01/19 | ESM 2019-10.

MT30

Powering the world's future fleets



2008 marked the entry into service for the MT30 powering the US Navy's first Littoral Combat Ship, USS Freedom. The propulsion system features twin MT30 engines and two diesel engines driving waterjets in a sophisticated combined diesel and gas turbine (CODAG) mechanical arrangement. MT30 has demonstrated excellent performance in service, powering the ship to speeds in excess of 40kts.

MT30 alternator packages provide the power for the US Navy's all-electric Zumwalt-class destroyers and the Royal Navy's new aircraft carriers. The Italian Navy's future flagship, the Landing Helicopter Dock, will be powered by two MT30s.

Drawing on the high-power density attributes, single MT30-based hybrid propulsion system powers the Republic of Korea Navy's new Daegu-class frigates and selected for their new Ulsan-class frigates as well as the Royal Navy's innovative Type 26 City-class. MT30 sits at the heart of BAE System's Global Combat Ship design as selected for the Royal Australian Navy's new Hunter class and the Royal Canadian Navy's Canadian Surface Combatant programmes. The Japanese Maritime Self Defence Force's new 30FFM frigates will also be powered by MT30 in a single gas turbine CODAG configuration.

Now selected for over seven ship types, MT30 has become the gas turbine of choice for many of the World's advanced naval programmes.

© LOCKHEED MARTIN

The MT30 entered service in 2008 powering the US Navy's monohull Littoral Combat Ship, giving it a top speed in excess of 40 knots.

Modern, state-of-the-art gas turbine technology for the marine market delivering...

- 36MW or 40MW flat rated to 38°C.
- Excellent performance retention with no power loss between overhauls.
- Member of the aero Trent family providing excellent reliability and optimised spares availability.
- Self-contained, single lift package.
- 40% thermal efficiency.
- Modular design for simplified engine maintenance.
- Low emission levels.

Designed to meet stringent reliability and maintainability goals

Excellent performance retention

Maximum power and efficient fuel consumption throughout life:

- Turbine operates at 70°C below design limits
- Short and robust structure maintains gas path tolerances

Operational flexibility

There are no operational limitations on re-starting of the engine. After normal or emergency shutdowns, the engine can be restarted at any time. The free power turbine allows a wide range of matching of output speed to spool speed. This allows the MT30 to operate a range of cube law power curves and output through a wide range of drive configurations. This also gives excellent speed control characteristics and frequency recovery for sudden load changes in generator applications.

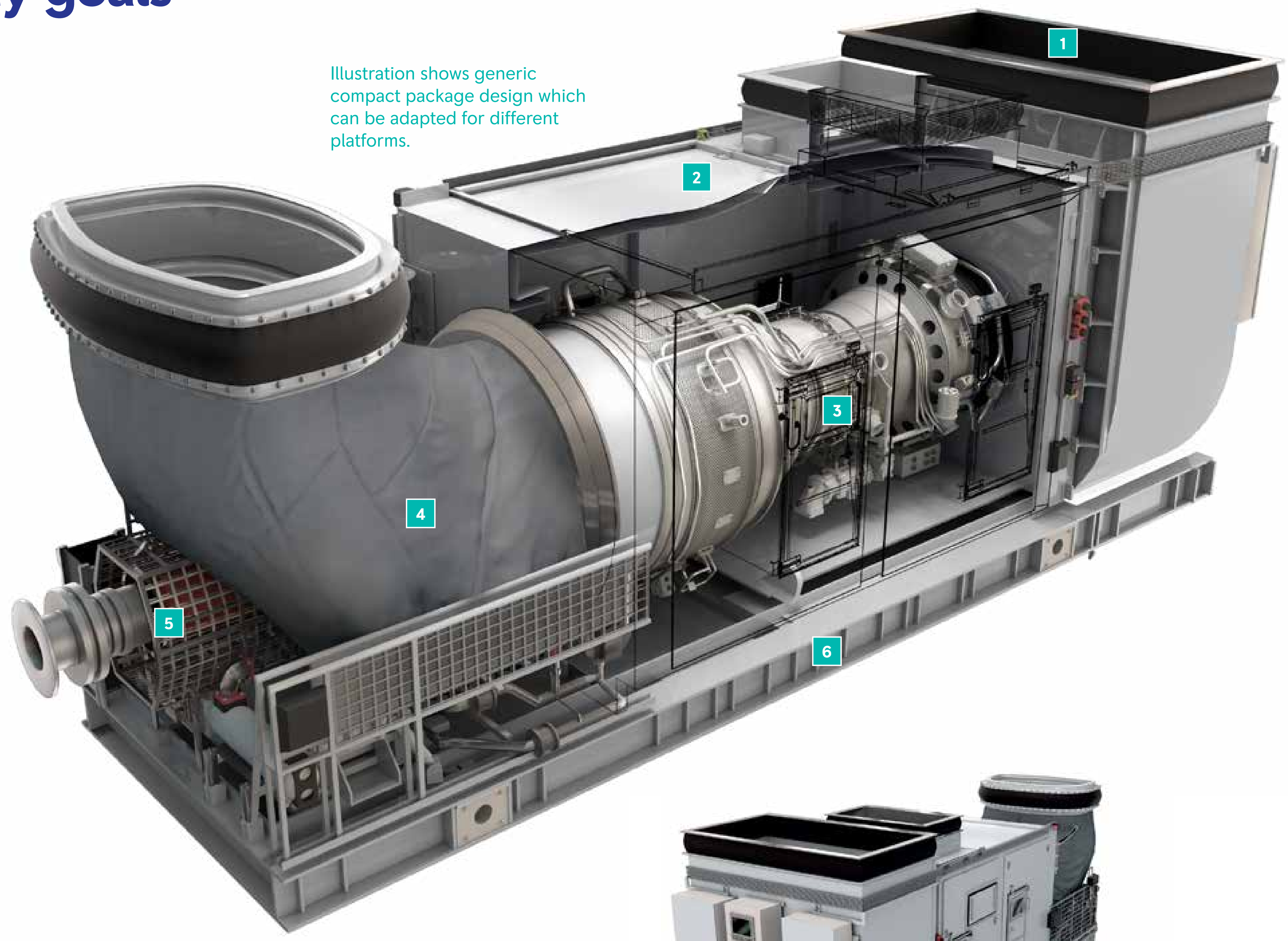
Type approvals

- ABS – Type approved at 36MW and 40MW
- Lloyds Register – Type approved at 36MW and 40MW for ship and naval ships

The MT30 features

- High-pressure ratio gas generator with free power turbine
- Low vibration unit, resiliently mounted
- Fully Integrated Digital Control and Monitoring system
- Electric or hydraulic start

Illustration shows generic compact package design which can be adapted for different platforms.



All engine accessory systems are incorporated in the engine baseplate to simplify installation for the shipbuilder.

Key components

1 Air inlet

- Compact low-loss radial design

2 Engine acoustic enclosure

- Allows ventilation and thermal management of GTCU externals
- Integral fire protection system
- Optimised for system accessibility and maintainability
- Maximum external noise is designed to be 85db(A) at 1m

3 Gas turbine

- Derived from the Rolls-Royce
- Trent engine family developed for today's widebody jets
- Modular construction
- Robust, four-stage power turbine derived from Trent 800

4 Exhaust collector

- Low-loss design for optimum performance

5 Output shaft

- 3,600 rpm – alternator drive
- 3,300 rpm – mechanical drive

6 Baseplate

- Steel construction, supporting all accessory systems
- Single assembly permits installation of the gas turbine and enclosure in the ship with a single lift.

Integrated Control System

- Provides integrated control and monitoring of the gas turbine and accessory support systems.

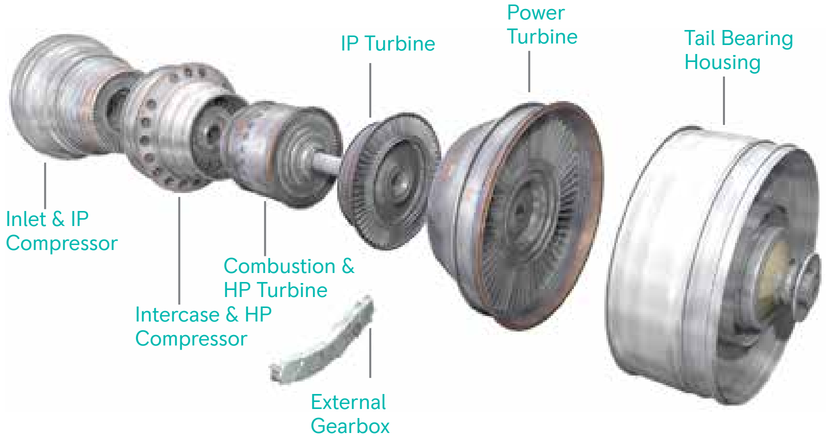
Designed for 21st century vessels, the MT30 provides maximum maintenance flexibility with minimum shipboard resources

Reliability Centred Maintenance studies were a feature of the engine design which together with an inherently low maintenance design has resulted in a condition based maintenance philosophy with scheduled on-board maintenance limited to less than two hours per week – a significant advantage in meeting modern navies' lean crew requirements.
The acoustic engine enclosure design optimises on-board maintenance procedures, providing space and access for ships staff to complete more complex maintenance tasks without removing the engine.

In the event that engine removal is required it can be achieved by removal through either the air intake or via the side of the enclosure, depending upon customer requirements. Both methods employ a removable rail system to safely guide the engine which can be installed inside the package when required. The engine removal system is designed to achieve complete engine exchange in less than 48 hours, however in practice the exchange has been carried out successfully in less than 36 hours.

The engine successfully completed its 1,500 hours ABS endurance test in 2005 taking less than 6 months. This was achieved at 38°C or above for the entire duration of the test. This is the first gas turbine to have successfully completed this arduous test programme in these actual conditions, reinforcing confidence that the MT30 will deliver world-leading times between overhaul.

System modularity for increased availability and low cost of ownership

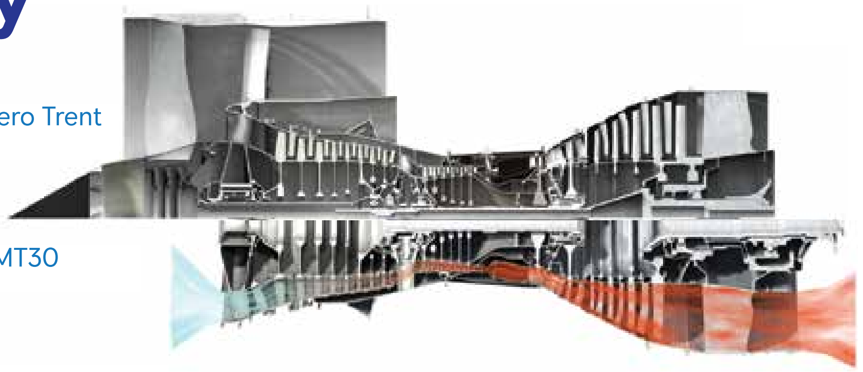


The MT30's modular design enables selected modules to be either overhauled or 'parked' to avoid unnecessary costs. Modularity also provides options to exchange modules between engines to reduce turnaround times.

Advanced design proven technology

The compact and lightweight MT30 is a twin-spool, high-pressure ratio gas generator with a free power turbine, an eight stage variable geometry intermediate pressure compressor and a six-stage corrosion protected high pressure compressor. Three stages of variable vanes and blow off valves are provided for compressor handling purposes and a continuous flow of IP delivery air is taken for bearing sealing and cooling purposes.

The four-stage free power turbine is derived from the Industrial Trent and Trent 800 and is supported on a robust bearing structure for optimum reliability. Proven components, incorporating the latest blade cooling technologies are employed throughout. Key components are protectively coated for service in the marine environment to reduce maintenance and deliver long service life. Using commercially available fuels MT30 meets all current and anticipated legislation on emissions and smoke without modification.



With the gas turbine change unit (including power turbine) weighing 6,500kg and the total module weight including enclosure and ancillary components in the order of 30,000 kg (dependent upon options) the MT30 offers a highly competitive power-to-weight ratio. To simplify installation the entire module can be installed on the base plate for a single lift, saving time and money.

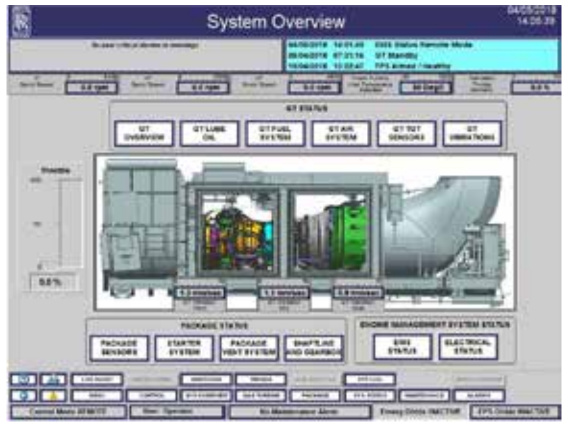
MT30 can be removed either via the enclosure side or air inlet using a removable rail system. Optimised package and tooling design allows for complete engine removal and replacement within 36 hours.

Lowest maintenance costs – less than two manhours scheduled maintenance per week

Fully Integrated Control System

The MT30 control system provides fully integrated alarm, monitoring and control functions for the packaged gas turbine, including overspeed protection. An integral back-up power supply is an option. A distributed processing architecture uses modern databus technology to provide improved reliability through simplified wiring and a reduced number of connectors, with main processors and power supplies located on the outside of the package enclosure. The system supports unmanned operation by making engine control and monitoring available over dual redundant databus and hard-wired signals for full integration into the platform control system. It can also be set to log predetermined engine/package data for optional off-board engine health monitoring and logistical support. A local control panel is provided to display all necessary engine and package parameters and enabling control of engine functions, maintenance and calibration activities.

The local control panel displays all engine parameters, enables local control and supports calibration and maintenance activities



Select from a range of support options that optimise engine availability and reduce through-life costs

A compact packaged module - simplified ship interface

The MT30 design incorporates all engine accessory systems on the baseplate, simplifying installation for the shipbuilder, which is limited to providing the starter energy, plus fuel, water and electrical connections.

Engineered as a modular package the MT30 permits installation in a single lift and capable of integrating with a range of ship intake and exhaust configurations. 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 is configured to meet customer machinery space noise specifications.

The MT30 alternator packages which powers the Royal Navy's Queen Elizabeth class aircraft carriers and the US Navy's DDG 1000 destroyers.

Support you can count on
Comprehensive support options are available for every Rolls-Royce marine gas turbine installation. We provide customers with service alternatives designed to maximise engine availability with the lowest through-life costs and manage the technical and financial risks. Our engine support programmes range from event or termbased maintenance to TotalCare packages with activities selected from a menu of support options.

A typical support package could include:
- Spares provisioning
- Customer training
- Equipment health monitoring
- 24 hour help desk
- Worldwide support teams
- Shipboard maintenance and trouble shooting assistance
- Shore based spare parts availability, replenishment and inventory management
- Engine overhaul
- Spare engine management

1. Royal Australian Navy's Hunter-class - Global Combat Ship
2. Italian Navy's Trieste - Landing Helicopter Dock
3. JMSDF's Mogami-class Multi-role Frigates (30FFM)
4. JMSDF's Aegis System Equipped Vessel
5. Royal Navy's City-class - Type 26 Frigate
6. US Navy's USS Zumwalt-class Destroyer (DDG-1000)
7. US Navy's USS Littoral Combat Ship (Freedom-class)
8. Republic of Korea Navy's Daegu-class (FFX Batch II), Ulsan-class Frigates (FFX Batch III)
9. Royal Navy's Queen Elizabeth-class Aircraft Carriers

Rolls-Royce plc
PO Box 3, Filton, Bristol,
BS34 7QE United Kingdom
Tel: +44 (0) 117 979 1234

rolls-royce.com

REF: VCOMB 3258

Rolls-Royce®

Propulsion

						Port Shaft								STBD Shaft								
						Rolls Royce MT30				Rolls Royce 20V 8000 M91L				Rolls Royce MT30				Rolls Royce 20V 8000 M91L				
Underway %	Hrs / Year	speed (kts)	BHP (HP)x10^3	BHP (kW)	% of Installed Capacity	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Load	% Load	SFC (g/kWh)	M_Fuel Annual (M_T)	Total M_Fuel (M_T)
25%	1314	5	0.575	429	0.47%	0	0.0%	0.0	0	429	4.3%	438.9	247	0	0.0%	0.0	0	0	0.0%	0	0	247
45%	2365.2	12	4.025	3001	3.26%	0	0.0%	0.0	0	3001	30.0%	226.693	1609	0	0.0%	0.0	0	0	0.0%	0	0	1609
25%	1314	22	23	17151	18.64%	0	0.0%	0.0	0	8575.5	85.8%	201.526	2271	0	0.0%	0.0	0	8576	85.8%	202	2271	4542
5%	262.8	31	110	82027	89.16%	31514	87.5%	248.1	2055	9500	95.0%	197.252	492	31514	87.5%	248.1	2055	9500	95.0%	197	492	5095
																						11493

speed (kts)	Total M_Fuel (M_T)	Avg SFC (g/kWh)
5	247	438.9
12	1609	226.7
22	4542	201.5
31	5095	236.4
Propulsion Subtotal	11493	225.6
Electrical Subtotal	4641	344.6
Total	**16134**	**259.8**