GE Marine 6L250 EPA Tier 3 Development

Task #3 Report

for:

New Technology Research and Development Program

582-11-13470-2019

Submitted by:

GE Transportation

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Abstract/Executive Summary

This project involves the prototype build and engine performance testing of US Environmental Protection Agency (EPA) Tier 3 compliant marine engines. In particular, it is a goal of this project to release a Tier 3 compliant engine ahead of the January 1, 2014, compliance deadline.

This task in particular consisted of the performance testing of one 6L250 prototype engine in the diesel engine test lab at General Electric's facility in Erie, Pennsylvania. The testing consisted primarily of performance, emissions, and power capability testing in order to develop three standard power ratings for the EPA Tier 3 6L250 engine. This testing provided the data needed to complete performance design reviews and provide the inputs to the controls team necessary to develop software builds.

Introduction / Background

The GE family of inline engines is US Environmental Protection Agency (EPA) Tier 2 certified. This project seeks to modify the current inline engine design such that it is capable of meeting the more stringent EPA Tier 3 guidelines. Given that the EPA guidelines on Tier 3 marine engines only apply to engines with a rated load of less than 2000 kilowatts, the inline engines are the engines in GE's portfolio that are subject to the Tier 3 regulations.

Project Objectives / Technical Approach

From the Grant Activities (Scope of Work):

> *"1.1. The objectives for this work are:*
>
> *1.1.1. Certify a marine 4-stroke six and eight cylinder engine rebuild kit to American Bureau of Shipping (ABS) class standards and EPA Tier 3 marine emission standards ahead of the 2014 EPA regulatory deadline."*

This report in particular is in regards to the performance development testing of the 6L250 EPA Tier 3 certified engine platform in the GE diesel engine test facility in Erie, Pennsylvania.

Tasks

Task 3: Performance test 6L250 prototype engine

From the Grant Activities (Scope of Work):

> *"2.3. Task Statement: The PERFORMING PARTY will performance test one 6L250 prototype engine."*
>
> *"2.3.1. The PERFORMING PARTY will complete all performance testing on one 6L250 engine and performance design reviews for the 6L250 engine configuration, ensuring that it meets all of the specification requirements."*
>
> *"2.3.1.1. The performance testing will include varying the timing and operation of the engine to maximize the benefit of the Tier 3 emissions package."*
>
> *"2.3.1.2. The performance development will be used to develop various ratings for each engine configuration. The developed ratings will include, but are not limited to the following:*
>
> *a) 6L250, 900RPM, 2009hp*
>
> *b) 6L250, 1000RPM, 2232hp*

c) 6L250, 1050RPM, 2344hp"

"2.3.1.3. For all ratings, the four EPA listed duty cycles will be developed, as follows:

-B1 – Fixed Pitch Propeller Variable Speed,

-B2 – Controllable Pitch Propeller or Diesel Electric Main,

-B3 – Variable Speed and Load Auxiliary Engine, and

-B4 – Diesel Engine Auxiliary."

Performance testing and performance design reviews

Performance testing of the 6L250 prototype engine is complete for all the required engine ratings and applicable duty cycles. Design reviews have been held and approved for each of the three engine ratings. The conclusion of the performance testing was to generate a set of operating parameters for each rating of the 6L250 that would enable it to meet EPA Tier 3 emissions standards while minimizing fuel consumption and maximizing power capability. The conclusion of the reviews was to update the engine interface control documentation to include these new configuration parameters which will serve as inputs to the next task of developing engine control software.

Slight changes have been made to the engine power ratings since the signing of the initial Tier 3 L250 development contract. The performance testing and design reviews were performed for the following engine ratings:

a) 6L250, 900 RPM, 2035 hp
b) 6L250, 1000 RPM, 2261 hp
c) 6L250, 1050 RPM, 2374 hp

These power ratings were increased slightly to better align the rated power with current and future commercial offerings of marine engines in this power range.

Additionally, the 'B3 – Variable Speed and Load Auxiliary Engine' duty cycle has been eliminated from the scope of this program. With the new emissions regulations, the B3 Duty Cycle is no longer applicable to GET engines. GET engines will still operate in all of the currently served markets using the remaining three duty cycles. As a result, the 6L250 prototype was developed to be emissions compliant for the following duty cycles:

- B1 – Fixed Pitch Propeller Variable Speed,
- B2 – Controllable Pitch Propeller or Diesel Electric Main,
- B4 – Diesel Engine Auxiliary.

For each engine rating, the performance test process consisted of 3 major steps:

d) Turbocharger matching test
e) Power potential testing

f) Specific fuel consumption and emissions testing

Turbocharger matching

Matching the turbocharger to the engine consists of testing multiple internal components at various sizes on the engine (i.e. compressor wheel, turbine stage inlet nozzle, compressor stage outlet diffuser). This validates the thermodynamic modeling done in the design phase and confirms the right ‘match’ that will produce ideal engine boost pressure, exhaust temperature, in-cylinder peak pressure, and turbocharger rotating speed. The testing also ensures that the turbocharger operates with air flows safely away from any risk of ‘surging’, which can damage turbo components and cause engine deration. This process was completed for each of the three engine ratings and required roughly 2-3 weeks to complete each time. An example of one of the turbocharger compressor maps that was generated as a result of the testing is displayed in Figure 1 below.

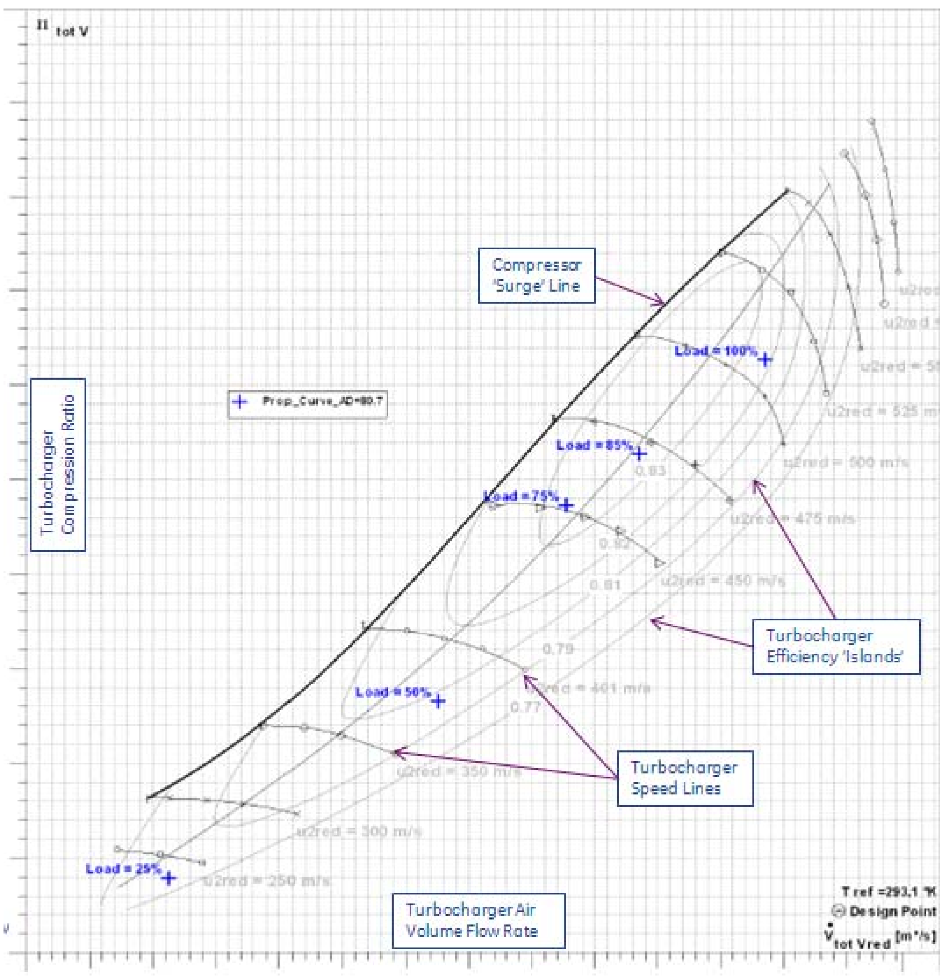

Figure 1: Turbocharger Compressor Map, 1050 rpm Rating

Power Potential Testing

Once the turbocharger is matched, the next step was to test the power capability of the engine. For each customer application there is a separate nominal propeller curve that the engine must match. Each has a different peak load as well as minimum torque constraints in the mid-speed range. The engine must also be capable of reaching 110% load at rated speed for Marine Class Society acceptance. Therefore, GE's current practice is to match all of these applications by rating the engine to maintain constant engine torque across the entire speed range >= 550 rpm. This capability must be validated upon matching the turbocharger with consideration for pre-turbine temperature, in-cylinder pressure and turbocharger speed limits. Fuel injection timing can also be varied to optimize the power curve for maximum boost pressure within these limitations. This testing was performed for each of the three engine ratings on the 6L250 and required ~ 2 days of testing per rating. Examples of the power potential curves generated for each engine rating as a result of the testing are provided in Figures 2-7 below.

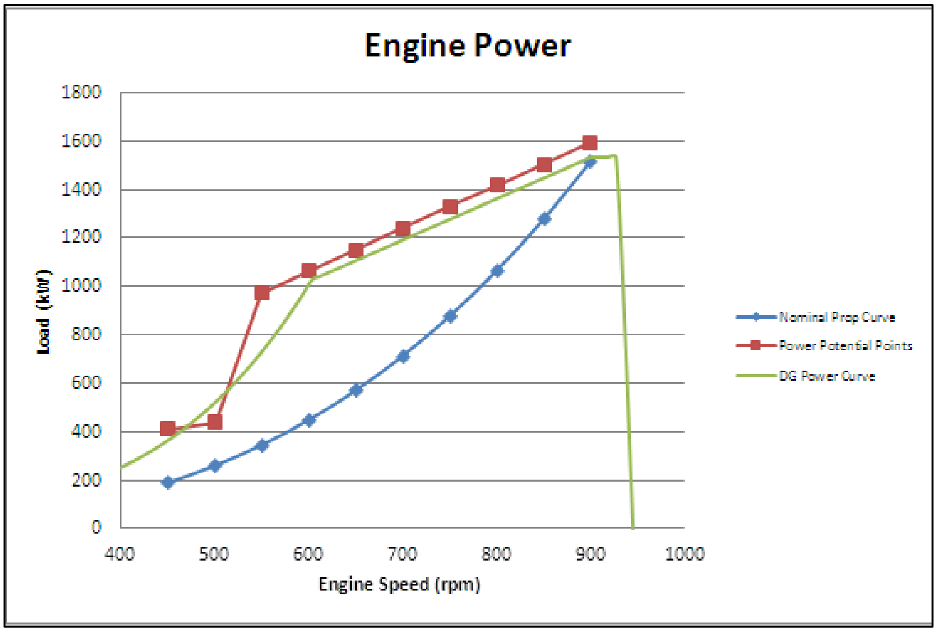

Figure 2: Engine Load Potential Results, 900 rpm Rating

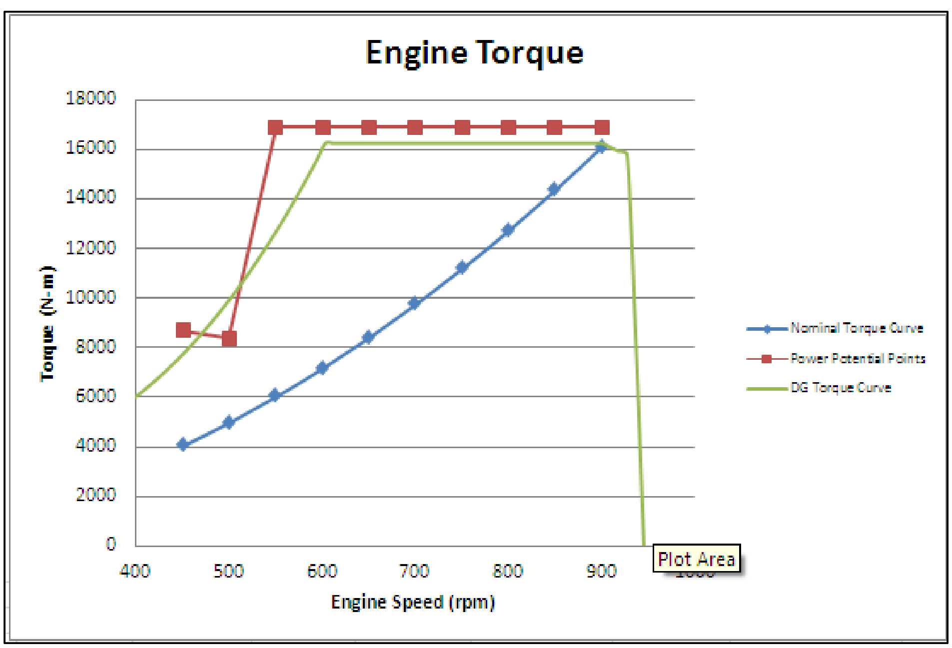

Figure 3: Engine Torque Potential Results, 900 rpm Rating (Blue = Nominal Fixed-Pitch High-Torque propeller curve, Green = GE Design Target, Red = Tested Actual)

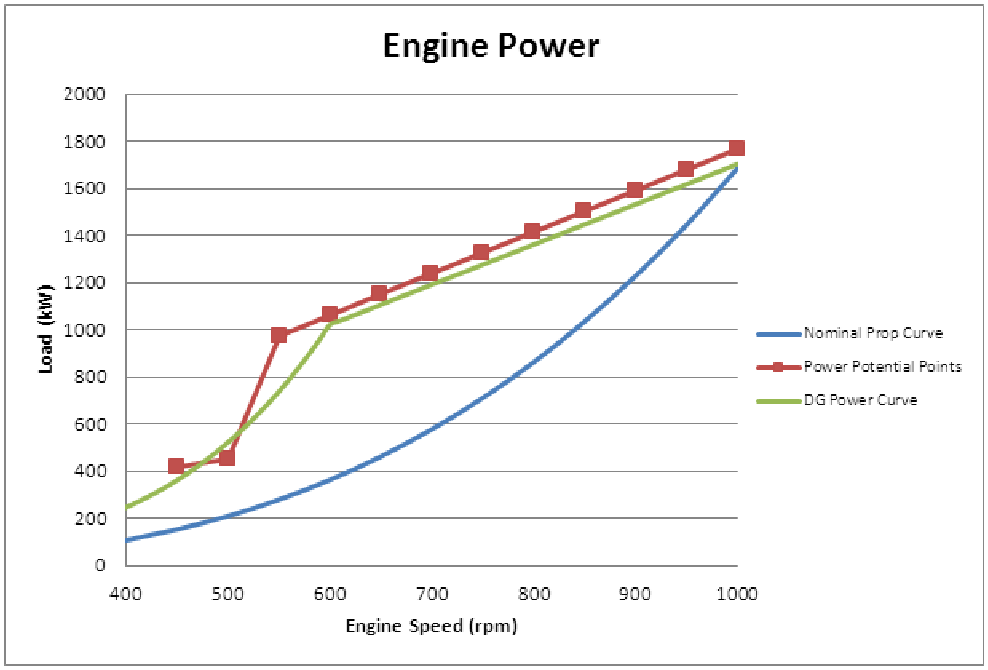

Figure 4: Engine Power Potential Results, 1000 rpm Rating

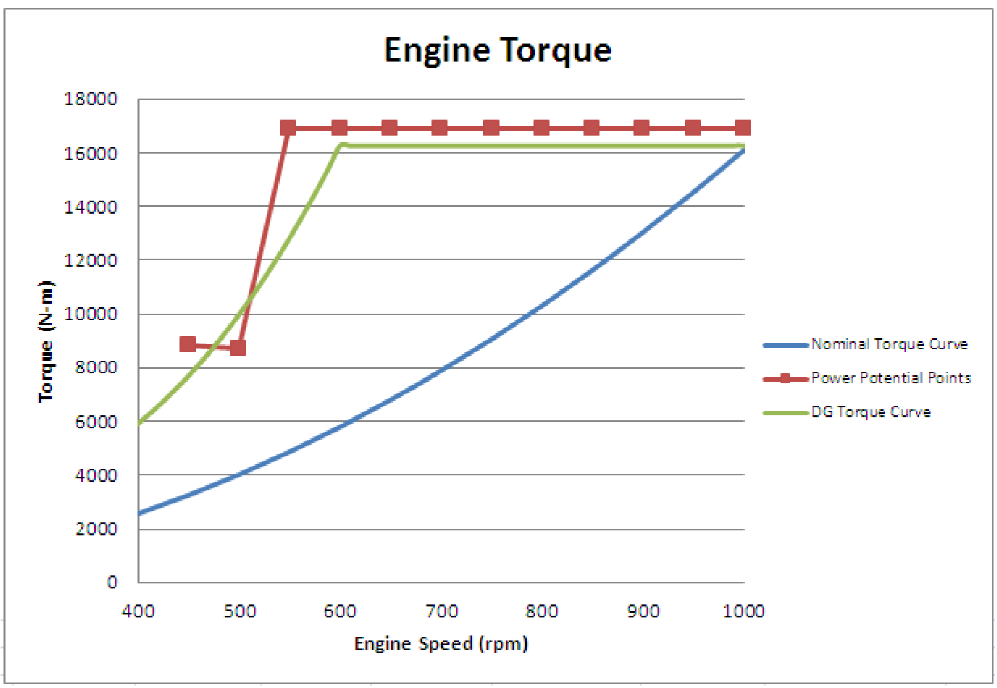

Figure 5: Engine Torque Potential Results, 1000 rpm Rating (Blue = Nominal Fixed-Pitch High-Torque propeller curve, Green = GE Design Target, Red = Tested Actual)

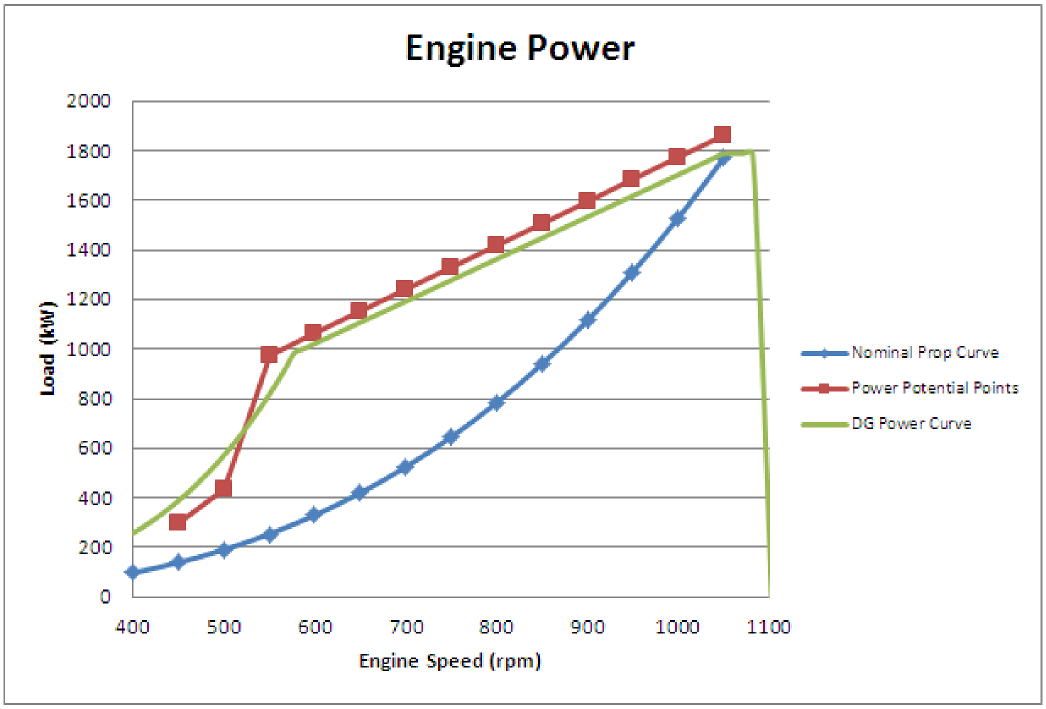

Figure 6: Engine Power Potential Results, 1050 rpm Rating

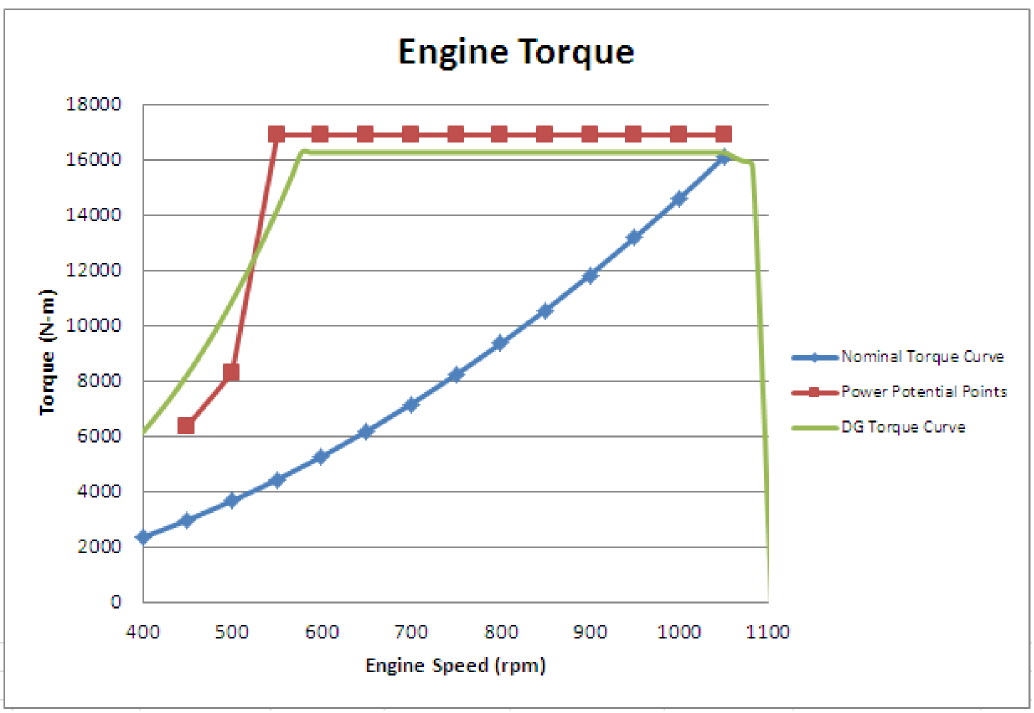

Figure 7: Engine Torque Potential Results, 1050 rpm Rating (Blue = Nominal Fixed-Pitch High-Torque propeller curve, Green = GE Design Target, Red = Tested Actual)

Specific fuel consumption and emissions testing

Fuel consumption and emissions testing were completed for all 3 engine ratings on the B1, B2, and B4 duty cycles on the 6L250. The process consists of varying fuel injection timing at each point on the duty cycle until an operating point is found that minimizes fuel consumption while passing EPA Tier 3 emissions with a factor of safety margin. Each point on the duty cycle is weighted as a percentage of the allowable value for NOx + HC and PM. After the optimum fuel injection recipe was found, the NTE (not-to-exceed) points were completed as well with timing variations. The final step was to build a combined fuel injection recipe for all duty cycle, NTE, and power potential points that meet the emissions requirements. This testing required ~2 weeks for each engine rating. An example of the resulting 1000 rpm rating power and fuel data sheets is attached in Appendix A. The EPA Tier 3 Marine emissions limits are displayed below per Part 1042.

Table 1: EPA Tier 3 Duty Cycle Emissions Limits, Part 1042

Paremeter (grams per kilowatt-hour)	EPA Limit
NOx + HC	7.00
CO	5.00
PM	0.34

Performance Design Reviews

"Formal Design Reviews" were held for each of the three engine ratings for the 6L250. These reviews were conducted to present the data proving EPA Tier 3 emissions compliance, confirm that the engine will operate safely within the mechanical and thermal limits of the engine components for all duty cycles, and to ensure that all the correct technical requirements are provided to the controls team via the engine ICD (interface control document). Each review took ~3 days to prepare for and complete. All necessary follow-on reviews have been completed.

Schedule

From the Grant Activities (Scope of Work):

> *"2.3.3. Schedule: The PERFORMING PARTY shall complete this task within 17 months of the signed Notice to Proceed Date as issued by TCEQ."*

The Notice to Proceed Date was agreed upon as July 11, 2011. Performance development testing began in the test cell on March 1, 2012. All three engine ratings were completed with all associated reviews held and approved by October 31, 2012.

Deliverables

From the Grant Activities (Scope of Work):

"2.3.4. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to pictures of the completed prototype engine, and completed performance level design reviews for all desired engine ratings *and configurations."*

Pictures of completed prototype engine

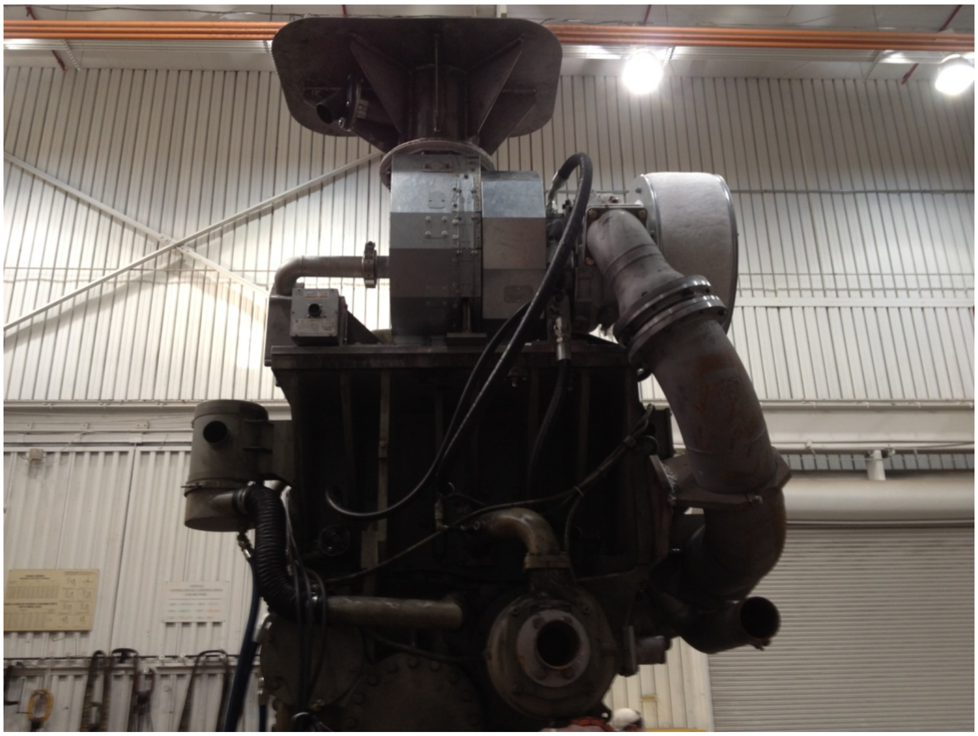

Figure 8: Front view of prototype 6L250 engine configured for performance testing

Figure 9: View of new turbocharger installed on the prototype 6L250 engine

Completed performance level design reviews

The goals of the performance design reviews were to review and approve the fuel consumption and emissions data, present the fuel injection recipe and operating strategy, and present the data showing that this strategy will run the engine safely. First, the duty cycle and NTE test data was presented to demonstrate EPA Tier 3 emissions compliance. Then the power potential data was also shown to demonstrate that the engine will meet the loading requirements of each customer application. Next, a scorecard was reviewed that tracks each of the performance parameters and mechanical limits for the engine rating against their target values, i.e. duty-cycle emissions, pre-turbine temperatures and peak cylinder pressures at overload conditions, specific fuel consumption, etc. The reviewers must approve the safety margins of these parameters before the engine ratings can be released. Finally, the changes to the engine control interface document were reviewed line-by-line to ensure that the updates proposed to the engine software release are accurate. This process was followed for all 3 engine ratings, and each review was approved so that software development could begin.

Discussion/Observations

Objectives vs. Results

All desired objectives have been met for this portion of the grant objectives. All performance testing for all engine ratings, configurations, and duty cycles has been completed and the required performance design reviews have been completed and approved.

Critical issues

The only critical issue encountered thus far has been with regard to schedule, due to lab resource availability with competing test programs. The impact of this risk has been minimized by increasing work through the off-shifts and overtime.

Technical and commercial viability of the proposed approach

All aspects of this project to date are deemed achievable and technically viable. Some activity is still to be undertaken to develop a serial production ready version of the hardware, however this task can be viewed as a modification of the prototype component designs, and is seen as on track with respect to the GE design guidelines.

Scope for future work

Future work is to involve the compliance certification of the engine with the applicable governing bodies. For this task, much of the work performed will be leveraged for the 8L250 system design.

Intellectual Properties/Publications/Presentations

All information provided in this Task Deliverable Report is the property of GE Transportation. It has been supplied in accordance with the agreed upon terms of the NTRD contract as proof of Task completeness.

The commercialization process of the GET EPA Tier 3 L250 engine has begun in 4Q 2012. The new brochure, released this quarter, is provided in Appendix B.

Summary/Conclusions

The elements of this part of the grant activity focused on the performance and emissions testing and formal design reviews of the EPA Tier 3 6L250 Prototype engine in the test cell facility in Erie, PA. All tasks specified in this deliverable report have been completed. Technical information, figures, charts, and test results have been provided as proof of the successful development of 3 engine ratings for the prototype 6L250. The remaining scope of this grant activity include the certification testing/submission and software release of the 6L250 engine, along with the performance development, testing, and certification of the 8L250 prototype engine.

Contact Information

For further information about this project please contact:

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Appendices

Appendix A: Power and Fuel Data Sheets

GE Engine Power Torque and Fuel Data

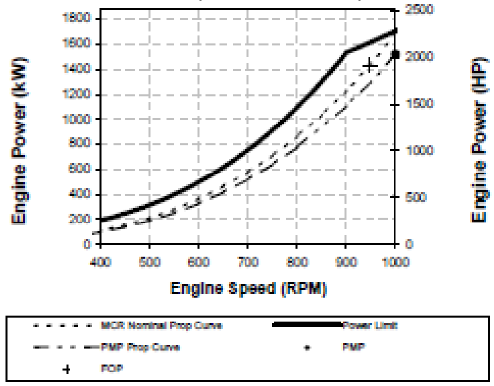
Engine Model:	**GE 6L250MDB**
Application:	**Marine Fixed Pitch Propeller**
Emissions:	**US EPA Tier 3 (40 CFR Part 1042)** **IMO Tier II**
Duty Cycle:	**E3**
MCR Power:	**1686kW / 2261hp**
MCR Speed:	**1000RPM**
Bypass:	**Yes**
Wastegate:	**No**

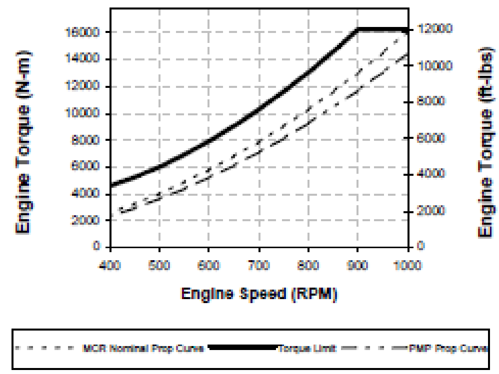
Engine Power, Torque, and Fuel Data

Engine: 6L250MDB FPP
1686kW/2261hp @ 1000RPM

Type: 4 Stroke, Electronic Fuel Injection (EFI)
Aspiration: Turbocharged & Intercooled
Fuel Type: No. 2 Diesel: ASTM D-975
Emissions Standard: US EPA Tier 3
Reference conditions: per ISO 3046, raw water temp 27°C (81°F)

MCR Speed	RPM	1000	Arrangement		Inline
MCR Power	kW (hp)	1686 (2261)	Cylinders Volume	liter (in³)	15.7 (958)
Bore	mm (in)	250 (9.8)	BMEP (at mcr)	bar (psi)	21.47 (311.4)
Stroke	mm (in)	320 (12.6)	Mean Piston Speed	m/s (ft/min)	10.7 (2106)
No. of Cylinders		6	Compression Ratio		16.8 : 1





Speed	Power Limit		Speed	Torque Limit	
RPM	kW	bhp	RPM	N-m	ft-lbs
1000	1703	2284	1000	16261	11994
950	1618	2169	950	16261	11994
900	1533	2055	900	16261	11994
850	1301	1745	850	14617	10781
800	1095	1469	800	13074	9643
750	914	1225	750	11634	8581
700	755	1012	700	10296	7594
650	617	827	650	9064	6686
600	499	669	600	7940	5856
550	399	535	550	6925	5108
500	315	423	500	6025	4444
450	247	332	450	5246	3870
400	193	258	400	4597	3391

Nominal Propeller Curve Fuel Consumption

Speed	% MCR Load	Power (kW)	Power (bhp)	BSFC (g/kW-hr)	BSFC (lbs/hp-hr)	Fuel Burn (l/hr)	Fuel Burn (gal/hr)
1000	100	1686	2261	196.7	0.325	374.3	99.0
910	75	1265	1696	199.9	0.331	285.3	75.5
800	50	843	1131	204.0	0.337	194.1	51.3
630	25	422	565	211.2	0.349	100.5	26.6

Engine Match Points Fuel Consumption

Speed	% MCR Load	Power (kW)	Power (bhp)	BSFC (g/kW-hr)	BSFC (lbs/hp-hr)	Point Description
1000	90	1517	2035	195.9	0.324	Prop Match Point (PMP)
947	85	1433	1922	203.3	0.336	Fuel Optimization Point (FOP)

1) Reference conditions for the continuous output ratings according to ISO 3046-1:2002E, ISO8665 are: Total Barometric Pressure 1.0 bar (14.5 psi), Air Temperature 25°C (77°F), Relative Humidity 30%, Charge Air Coolant Temperature 25°C (77°F). The output is also available at a low temperature system air coolant temperature of maximum 38°C (100.4°F), and an air temperature of maximum 45°C (113°F). For higher temperatures, the output ratings must be reduced according to the rules stated in ISO 3046/I.
2) Steady state smoke is limited to 20%.
3) Data is representative of a typical engine with all engine driven pumps attached. All values are ISO 3046-1 Standard Corrected (reference value for fuel lower heating value of 42700 kJ/kg), fuel corresponds to ASTM D975 S5000 and DMX value corresponding to ISO 8217 and tolerance is +5%. Any additional pumps will increase SFC by 1% each.
4) Specifications are subject to change without notice

Definitions

Maximum Continuous Rating (MCR):
Maximum speed and load conditions at which the engine is capable of operating continuously for an unlimited number of hours per year; between the normal maintenance intervals stated by GE, under stated ambient conditions, and with the maintenance prescribed by GE having been carried out.

Power Limit Curve:
Maximum power capability of the engine at a given operating speed.

Torque Limit Curve:
Maximum torque capability of the engine at a given operating speed.

Specific Fuel Consumption:
The amount of fuel consumed by the engine in mass flow per unit of power output or units of g/(kW*hr) or lb/(bhp*hr).

PMP:
GE suggested speed and load point for proper propulsion system matching

FOP:
Engine operating conditions under which minimum specific fuel consumption is achieved

FPP-HT:
A vessel where the engine is used to power a fixed pitch propeller that does require extended max torque from the engine (examples: tug boats, tow boats, dredge pumps)

FPP:
A vessel where the engine is used to power a fixed pitch propeller that does not require extended max torque capabilities from the engine

CPP / EPP - VS
A vessel where the engine is used to power a controllable pitch or elecctrically powered propeller that operates at variable speeds

CPP / EPP - CS
A vessel where the engine is used to power a controllable pitch or elecctrically powered propeller that operates at constant speed

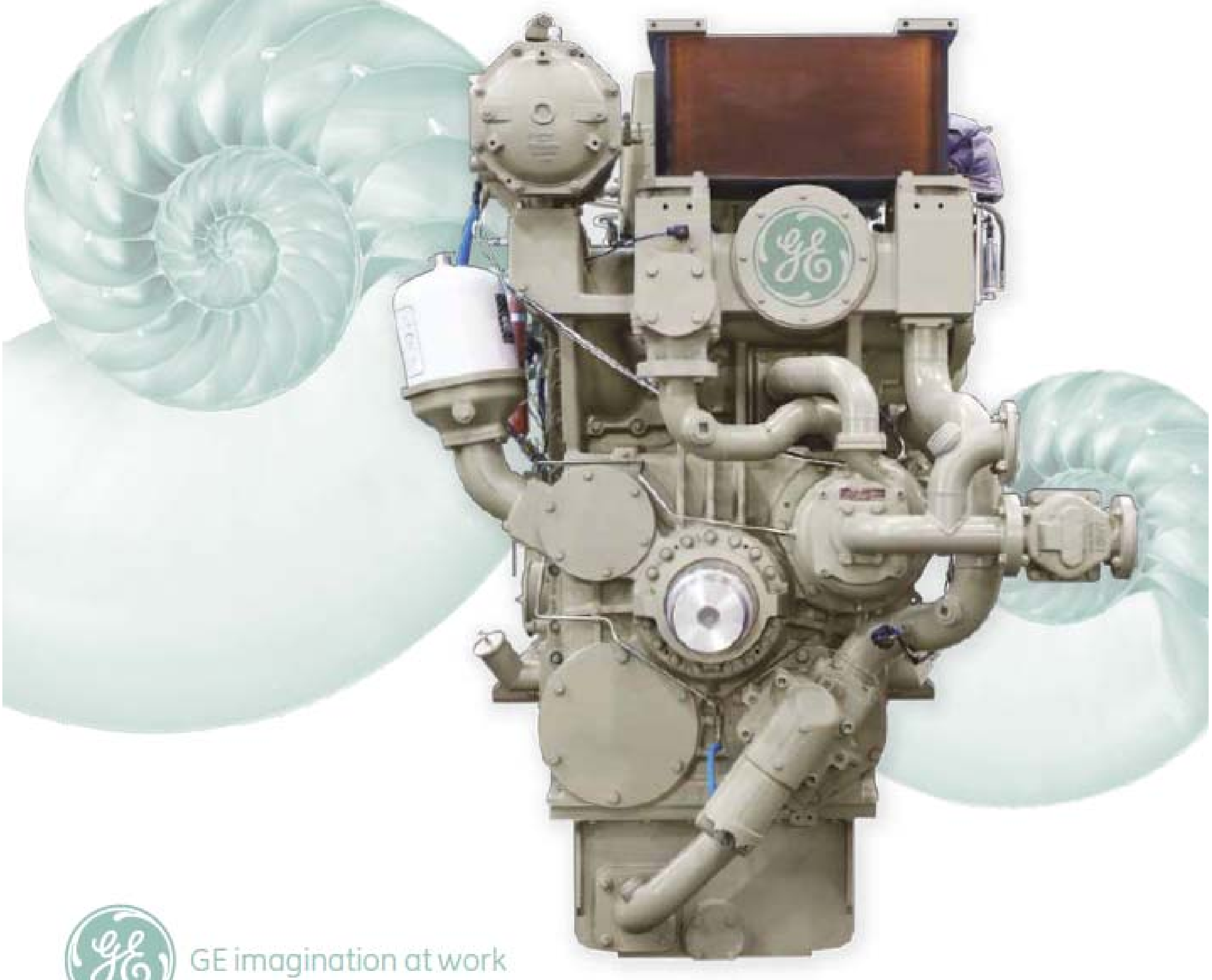
GEN
A marine based engine used to power auxiliary devices

Appendix B: GE L250 EPA Tier 3 Brochure

GE Marine

Clean, lean marine

GE's L250 EPA Tier 3 inline diesel engine



GE imagination at work

GE's marine-class engines

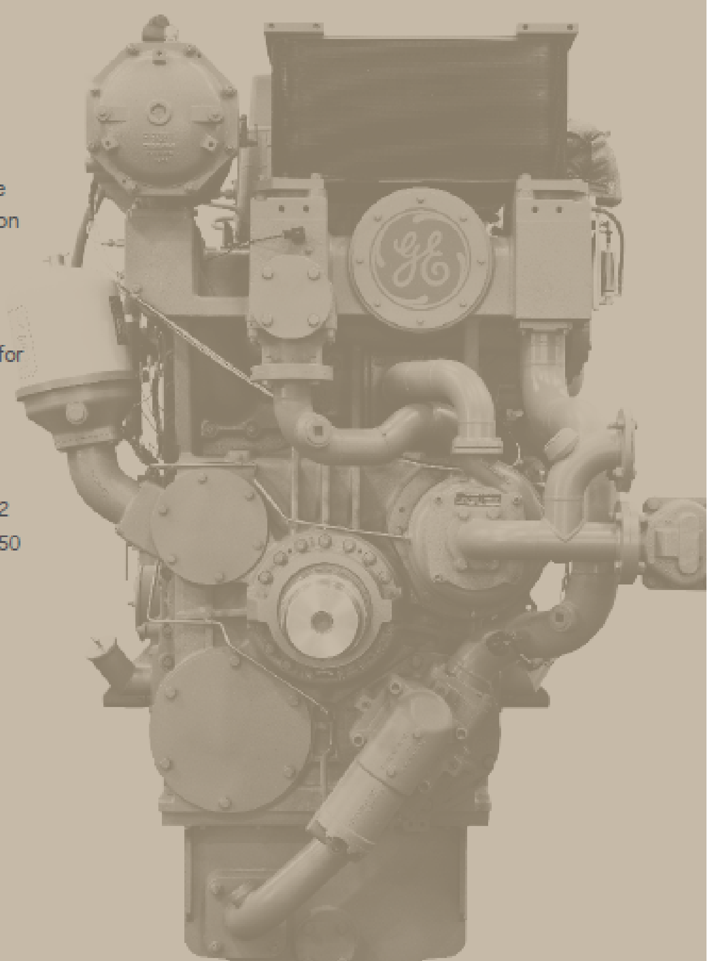
A history of proven performance

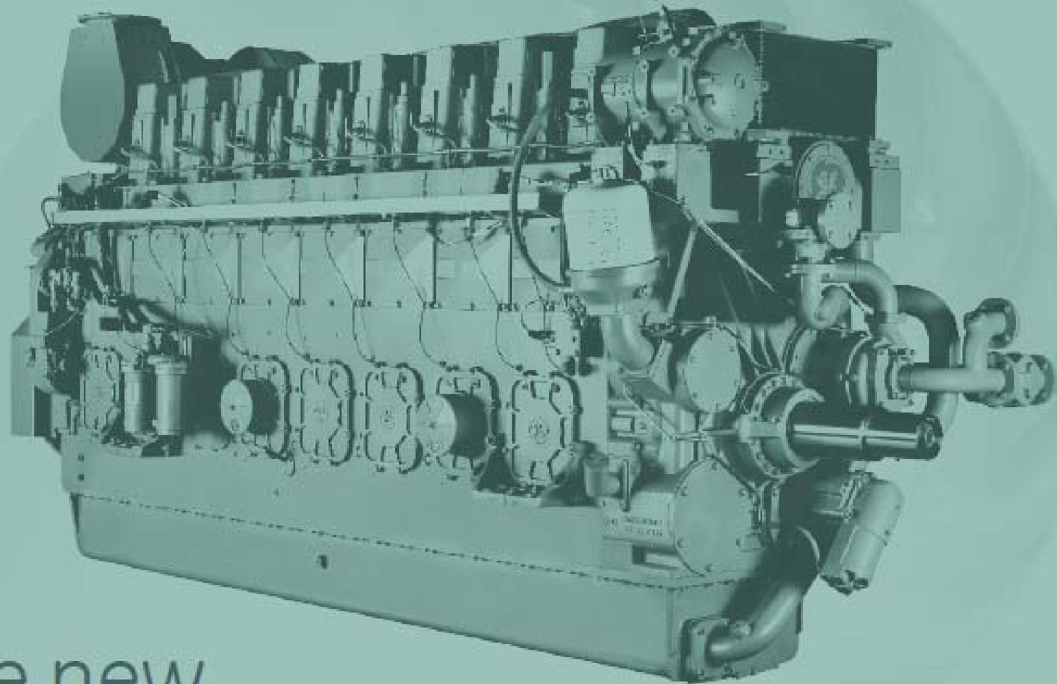
GE Transportation has been serving the transportation industry for more than a century. For nearly 50 years, we have designed and built high-performance diesel engines and have become one of the largest manufacturers of medium-speed engines in the world.

GE Marine, a division of GE Transportation, is one of the world's leading manufacturers of marine products that help tackle the most important challenges facing the marine industry today through integrated solutions, breakthrough technologies and process innovations. You can rely on GE's experience, innovation and proven performance to help you succeed. We've invested millions to ensure our engines comply with the latest emission standards through technological advancements that will exceed your expectations. The L250 engine series is just one example of our dedication to a sustainable environment and supporting our customers with GE's efficient, reliable and economic diesel engines. Where applicable, the L250 engines meet EPA Tier 3 emission standards without the need for exhaust after treatment.

Along with the new L250 EPA Tier 3 engine, GE's family of medium-speed engines include 8-, 12- and 16-cylinder V configurations, all of which are EPA Tier 2 and/or IMO Tier II certified with future plans for our L250 and V250 engines to meet EPA Tier 4 and IMO Tier III emission levels.

With more than 15,000 engines operating worldwide in some of the most challenging industrial environments, GE's medium-speed engines are dependable, long-lasting, durable and efficient. From tugboats in Turkey and fishing vessels in Peru to offshore construction vessels in Norway and ferries in Texas, GE's marine engines are supported by an extensive global parts, distribution and service network.





The new

L250 EPA Tier 3 inline diesel engine

GE's new L250 inline diesel engine offers a streamlined design that is fuel-efficient and delivers continuous power from 1,518 to 1,999 kW. The L250 is specifically engineered for marine applications with its accessories mounted on the engine for maintenance ease and offers a full-power PTO option.

The L250 is marine-class compliant and meets U.S. EPA Tier 3 emission requirements (certified to EPA Tier 2 during 2013) — a proactive approach to fuel savings and emissions reduction natural to GE. Depending on the application and duty cycle, the L250 offers an average 12% fuel savings when compared to the V228 engine.

The engine, available in 6- and 8-cylinder models, also offers ease of re-power as its narrow inline footprint takes in mind marine engine room constraints where space is at a premium. The narrower frame uses a similar footprint as competitive engines for minimum design change.

GE designed the L250 engine based on the successful V250 engine platform using the Six Sigma Quality design process. Together, with flexible installation and maintenance options, proven parts performance and support from GE's worldwide distribution network, the L250 offers customers reliability and limited downtime.

→ FUEL-EFFICIENT

→ EPA TIER 3 EMISSIONS-COMPLIANT

→ COMPACT POWER

→ NARROW FOOTPRINT

→ EASY TO MAINTAIN

L250 components — Marine class. Inline design.

Sturdy mainframe

The L250's mainframe is a rugged one-piece iron casting which provides excellent vibration-dampening characteristics and long-term stability to minimize line bore distortion. Further strength and rigidity are added by bolting main bearing caps both vertically and horizontally. The lube oil gallery and passages are cast or drilled into the frame to provide lubrication to all vital engine areas with no pipe or hose connections within the frame, to help eliminate leaks or loss of lubrication.

Turbocharger

The L250 uses a new, high-efficiency, radial flow and water-cooled turbocharger to achieve EPA Tier 3 emissions without sacrificing engine performance. Depending on duty cycle and application, response time and fuel efficiency have improved over the L250 Tier 2 engines and fuel consumption improved 5% to 6% at 85% of MCR.

Crankshaft and engine drive train

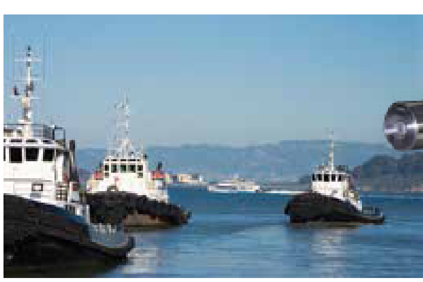
The crankshaft is press-forged, high-quality alloy steel. Oil passages drilled in the crankshaft allow oil delivery to connecting rod bearings and pistons. A flywheel with ring gear for the starting motor is bolted directly to the crankshaft flange.

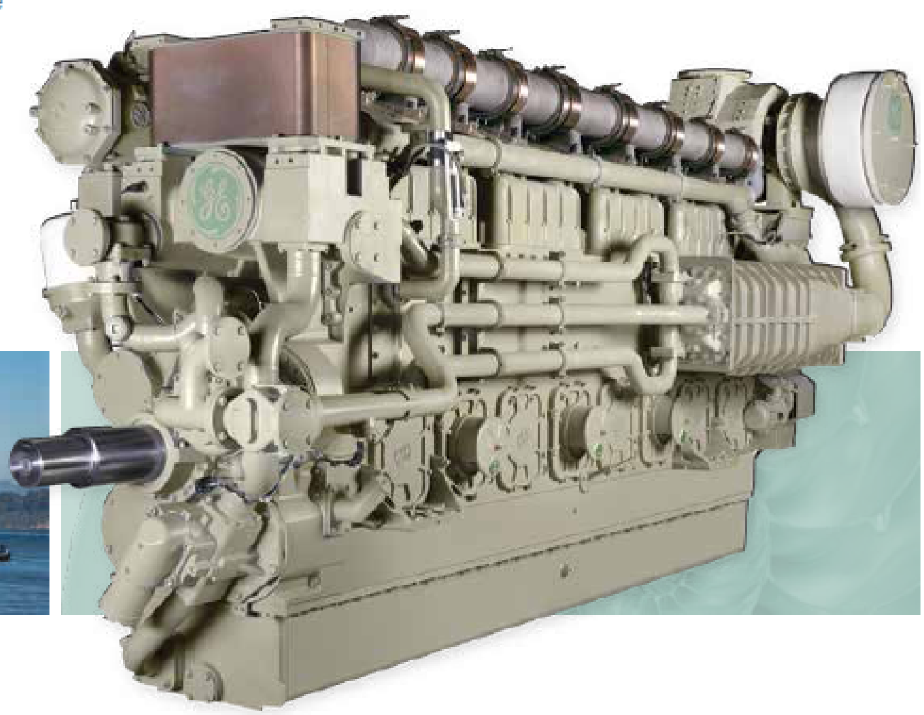
One-piece liners

The stiff, one-piece, mid-stop liner has an integral external water jacket that removes the possibility of water leaks. An anti-polishing ring provides a durable running surface, improving lube oil consumption and liner life. The top one-third of the liner is cooled.

Power assemblies

The L250's power assemblies are designed to meet the high-pressure demands of the engine while adhering to strict reliability requirements and an easy-to-maintain assembly concept. Unitized cylinder assembly enables quick change-outs and increased engine uptime. Each assembly is mounted directly to the mainframe and includes liner assembly, cylinder head, intake and exhaust valves, valve linkage and a high-pressure fuel-injection pump and nozzle. This design enables excellent flow paths for combustion, lower fuel consumption and reduced emissions. Design improvements will result in a significant reduction in lube oil consumption over L250 Tier 2 engines.





Exhaust manifold

The exhaust manifold provides increased transient response and better efficiency under pulse and constant pressure operation. It is modularized with identical piping and bellows sections for all of the cylinder assemblies. The bellows sections help lower the thermal and vibration-induced stresses on the exhaust system.

Intercooler and air-intake manifold

The L250's combustion air-intake system includes one intercooler mounted on the mainframe between the turbo outlet and air manifold inlet. This allows for lower fuel consumption, emissions and exhaust temperatures. For servicing, the intercooler can be removed without dismantling other engine components.

Pistons

Our pistons are ruggedly designed to accommodate the high-peak firing pressure requirements of L250 engines. The pin and skirt components are also designed to yield better piston lubrication and guidance as it travels within the liner. The design helps minimize oil consumption and blow-by as well as lengthen oil life.

Connecting rod assembly

The forged-steel connecting rods are exceptionally strong and exhibit high stiffness, which is beneficial during the engine's lifetime. Large bearing widths with optimized oil grooves also help improve oil-film thickness and pressure, allowing for optimum performance and lower friction losses.

Advanced EFI

Designed for greater efficiency at varying speeds and loads, the L250's electronic fuel injection features precise fuel control, increased pressure capability and refined timing. Optimization of the cam profile, injection start, injection volumes and flows, and control algorithms have produced a relatively simple system, proven reliable through extensive validation.

Camshafts

The camshafts on the L250 are made of sectional carbon steel forgings joined by dowel-bolted flanges, a design that simplifies component removal and replacement. Individual sections of the camshaft, rather than the entire camshaft, can be serviced or replaced.

L250 EPA Tier 3 inline diesel engine specifications

	6L250	8L250
Engine data		
Number of cylinders	6	8
Stroke cycle	4	4
Cylinder arrangement	inline	inline
Bore	250 mm (9.84 in)	250 mm (9.84 in)
Stroke	320 mm (12.60 in)	320 mm (12.60 in)
Compression ratio	15.7	15.7
Power output at 900 rpm		
Maximum continuous rating*	1,518 kw (2035 hp)	1,998 kw (2679 hp)
Power output at 1,000 rpm		
Maximum continuous rating*	1,687 kw (2261 hp)	N/A
Power output at 1,050 rpm		
Maximum continuous rating*	1,771 kw (2374 hp)	N/A
Engine dimensions		
Length	5,095 mm (200 in)	5,985 mm (235 in)
Width	2,032 mm (80 in)	2,032 mm (80 in)
Height including sump	2,962 mm (116 in)	2,962 mm (116 in)
Crankshaft center line to sump	940 mm (37 in)	940 mm (37 in)
Crankshaft center line to mounting feet	308 mm (12 in)	308 mm (12 in)
Exhaust diameter	457 mm (18 in)	457 mm (18 in)
Dry weight	15,909 kg (35,000 lbs)	19,090 kg (42,000 lbs)

*Maximum continuous rating (MCR):

Maximum speed and load conditions at which the engine is capable of operating continuously for an unlimited number of hours per year: between the normal maintenance intervals stated by GE. under standard ambient conditions and with the maintenance prescribed by GE having been carried out. Engine overload is limited for U.S. EPA Tier 3 (40 CFR Part 1042) regulations.

Dimensions and weights are approximate and include all engine mounted accessories.

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