NAVAL FORCES
INTERNATIONAL FORUM FOR MARITIME POWER

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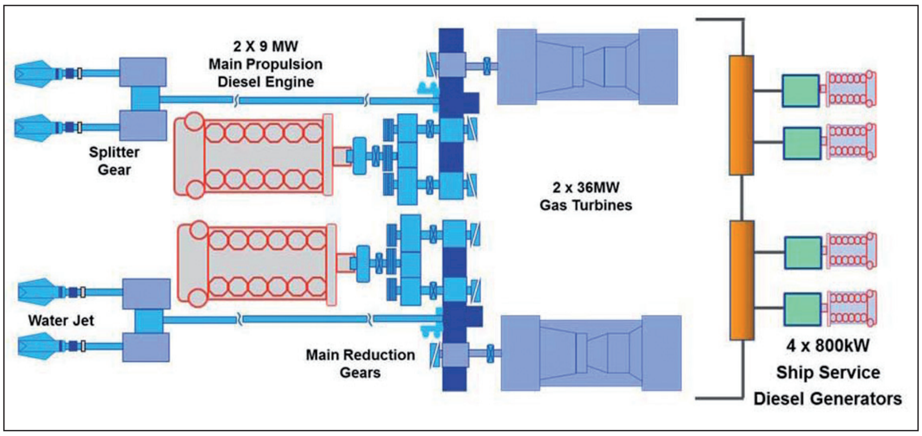
THE COST OF SPEED

Today's sophisticated weapons systems, complete with fire-and-forget missile technology and proliferation of both manned and unmanned aircraft at sea, call into question the value of speed.



NAVSEA example of design space exploration using a dynamic contour profiler.
(All photos: Courtesy of GE Marine)

IRON TRIANGLE

To help gain insight into the influence that speed has upon a 3,500 tons frigate, three conceptual mechanical drive configurations are compared. Results reveal a 40-knot ship requires almost three times more power than 30-knot ship, and that a more lightweight, power dense propulsion system can enhance mission payload by over 200 tons. While a high-speed vessel may be justified based on mission requirements, it can lead to inefficient ship design, which has less combat lethality. These comparisons highlight the benefits of having a family of gas turbines with wide power ranges, to allow naval architects to best match the iron triangle of speed, endurance, and mission payload. As opposed to a single power class, **GE Marine's** gas turbine solutions range from 6,000-70,275 shaft horsepower (shp)/4.5-52MW. These varying engine sizes offer design flexibility in diesel engine selection and smaller power increments to enable more efficient loading of prime movers.

ENDURANCE

For the US Navy, endurance cannot be sacrificed given the transoceanic nature of geopolitical interests, thus dictating a required minimum cruising range of 3,500nm (6,480km). Yet many Navies set cruising range requirements at 6,000nm (11,110km) for endurance purposes which oftentimes indirectly yields longer on-station time for independent operations. There is little advantage to 'getting to the fight' quickly if on-station time truncates the mission. In most Navies, endurance for self-deploying or independently operating vessels compels designers to conceive larger ships. These must accommodate the fuel and supplies necessary to transit long distances while still having a useful mission payload. To that end, high speed requires high power and that means bringing and burning lots of fuel.

PAYLOAD

Navies are also payload-centric. In fact, a surface combatant's primary focus is defined by the ship's suite of weapons, sensors and unmanned systems. Payload is important to modern navies given that operational requirements dictate many vessels be capable of independently conducting multiple missions such as Anti-Submarine Warfare (ASW), Anti-Air Warfare (AAW), and Surface Warfare (ASuW). Naval architects focus on the available space and weight – or design space – for fitting the mission payload aboard the ship. Available space is largely a function of vessel size, hull form, cost constraints, maximum speed, and endurance range. Reduced payloads limit self-defence and striking capabilities. Upcoming changes to the Littoral Combat Ship (LCS) programme attest, as the US Navy has hinted that it may be willing to sacrifice ship speed in the interest of enhancing weapons payload and lethality. In the end, the true purpose of a warship is to deliver ordnance on target.

40 KNOTS REQUIRES NEARLY 270% INCREASE IN POWER

The speed-power relationship for a 3,500 tons surface combatant with a conventional clean monohull design can be defined by a nominal cubic load curve. The fundamentals of the cubic load curve dictate that doubling speed requires eight times more power. Speed-power profiles can be derived from past profiles of similar surface combatants (of a given displacement), or from smooth-water performance predictions and other hull test data. Naval architects develop these predictions using ship models of similar hull form, appendage, and propulsor configurations to estimate the necessary shaft power to propel across a range of desired speed. The profiles are not perfect, but can provide a reasonable starting point for engine matching and machinery plant options.

Using the projected speed-power relationship, design engineers can consider various machinery arrangements for a proposed surface combatant. Depending upon the ship's primary mission and its associated operating profile (i.e. how much time the vessel is projected to operate at different speeds), a navy may further stipulate general propulsion plant configurations. These mechanical drive, hybrid or integrated electric systems can include arrangements such as:

– Combined Gas Turbine and Gas Turbine (COGAG);
– Combined Diesel and Diesel (CODAD);
– Combined Diesel or Gas Turbine (CODOG);
– Combined Diesel and Gas Turbine (CODAG);
– Combined Diesel Electric and Gas Turbine (CODLAG).

Fuel efficiency and power density can significantly influence design choices. Yet, in all of these configurations, the amount of installed engine power will largely be influenced by maximum speed for short term operation, and to some degree cruising (or economical) speed, for longer transit operations.

Prime movers should be selected to best match the demands of the iron triangle. As always, the ship design team must also account for the propulsion plant, since an optimal prime mover match can improve the ship's cruising range

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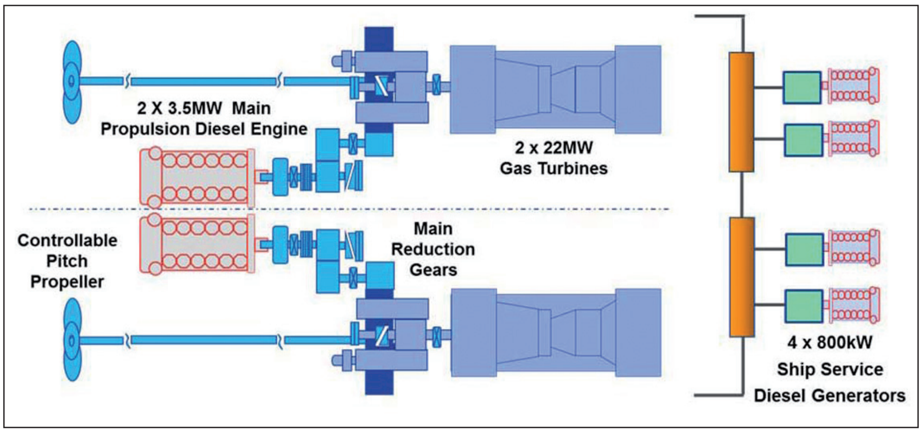
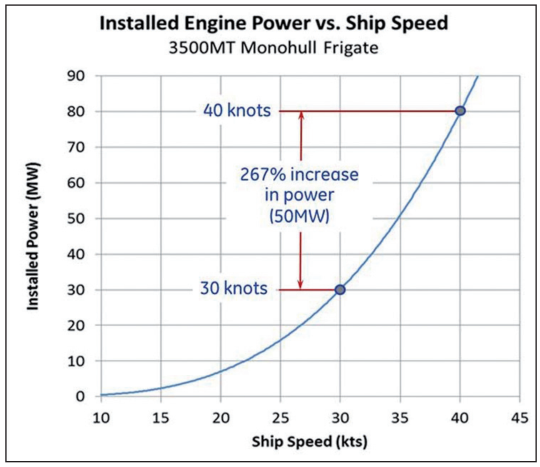
Reader note: In the diagram "Installed Engine Power vs. Ship Speed" and several other references throughout the article, the actual increase in power is nearly 170%.



Example of mechanical drive cubic load curve. Note the dramatic increase required in power to generate vessel speeds above 30 knots. This illustrates the profound influence that the selection of a propulsion plant configuration and prime movers has on the speed-power relationship: nearly a 270% increase in power will be needed to reach the 40 knot speed.



and/or increase mission payload. This allows maximum space, weight, and cost allocation to each critical systems.

CONCEPTUAL PROPULSION PLANT CASE STUDIES

To illustrate the effect speed has on propulsion plant design, three conceptual propulsion plant mechanical drive configurations were developed that achieve the different maximum speeds of 29, 32, and 40 knots. Four 800kW diesel generators supply electrical power for ship service requirements. To simplify matters, 4% gear and shaft losses (i.e. power delivered to the propeller) and 7% shipyard design margin (i.e. effective power) were assumed. Although more detailed transmission loss and design margins come into play for a thorough analysis of power requirements, this approach provides a snapshot of the maximum and cruising speed capabilities of the three propulsion plant configurations. Case comparisons are presented as follows:

Case 1 represents a 40-knot option, featuring 90MW of installed power in a CODAG arrangement; main combining and splitter gears accommodate four steerable/ reversible water jet propulsors;

Case 2: 51MW CODOG with controllable pitch propellers; it represents a 32-knot option with 51MW of installed power in a CODOG arrangement. A conventional main gear allows for either the gas turbines or main propulsion diesel engines to drive the power train. The propulsors are controllable pitch propellers;

Case 3 represents a 29-knot option with 33MW of installed power in a CODOG arrangement; a main gear allows the gas turbines or the propulsion diesels to drive both controllable pitch propellers simultaneously.

While each conceptual configuration serves as a feasible solution for a 3,500 tons surface combatant, the variance in both maximum and cruising speed capabilities translates into significant increases in cost and weight. These increases have a marked effect upon mission payload in terms of affordability and capability.

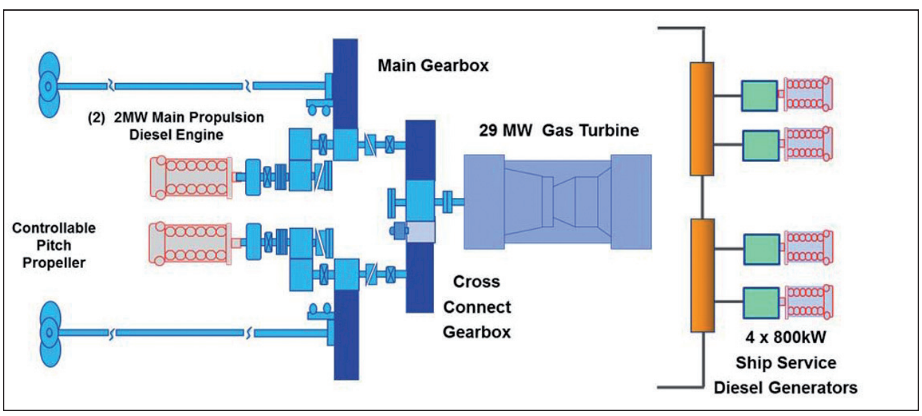
ENHANCED PAYLOAD WITH COMPACT POWER PLANT

Machinery weight is an important design consideration because it has an intrinsic relationship on payload and speed. By reducing machinery and installing the lightweight CODOG propulsion system (similar to that of Case 2 or 3), the mission payload may be enhanced by more than 200 tons. Machinery volume cannot be ignored, especially in smaller surface combatants. However, to simplify the discussion, weight was addressed as the most critical factor. Estimates for machinery weight were developed using these three plant configurations, as well as similar propulsion plant arrangements from past studies. The weight summaries of main machinery components clearly demonstrate that the combined diesel and gas turbine architectures for all three cases significantly increase in weight as installed power increases. This has an attendant effect upon the available weight dedicated to mission payload and fuel capacity.

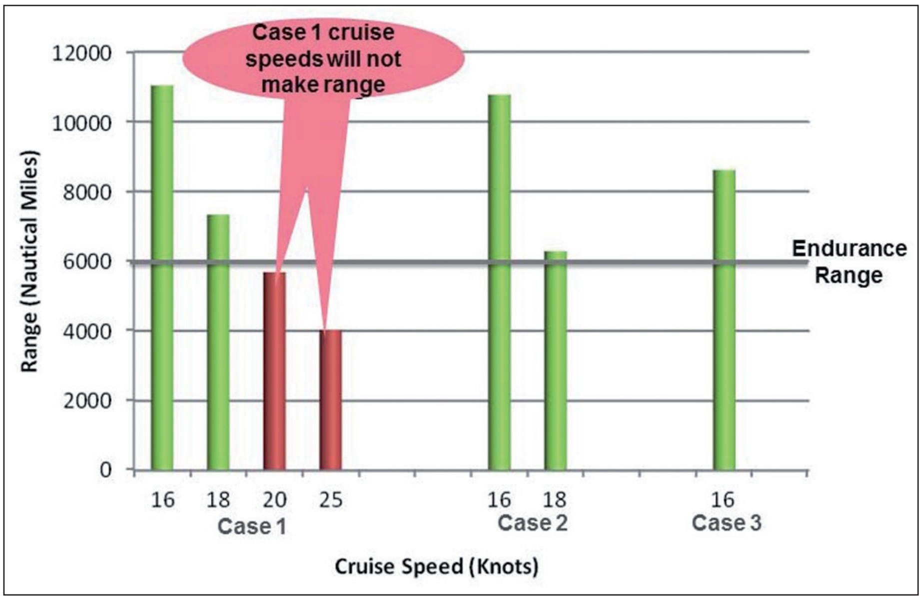
To help understand this relationship, weight allocations for fuel and mission payload capacity were derived using typical percentages for surface combatants. A good rule of thumb for fuel allocation is 15% of total weight distribution, with mission payload nominally accounting for 11% of total weight distribution. Assuming the baseline fuel load, cruising ranges were calculated using fuel consumption attributes of both the propulsion engines and ship service generators at various ship speeds. Cruising ranges fall off precipitously with higher speeds on the larger diesel engines. In fact, as illustrated for Case 1, at speeds above 19.5 knots, the 9MW diesel engine is unable to attain 6,000nm (11,110km) – the common cruising range for small surface combatants.

Diesel engines operating at reduced power normally attain better cruising ranges, which may allow for reduced fuel weight and a corresponding increase in the mission payload. However, fuel load reductions may not be

90MW CODAG with water jets.



Cruising range for various speed.



operationally feasible if they constrain the range the ship is able to travel at maximum or sustained speeds (or sprint speed). Case 1 cannot reduce fuel load below 500 tons if a 1,000nm (1,850km) sprint range is required, whereas the other more austere plants require less than 325 tons of fuel to sprint 1,000nm. By fixing displacement and fuel load and applying the reduced weight of the propulsion plant arrangements for Cases 2 and 3, an estimate can be made of the additional mission payload available for the lower-powered plant arrangements. Mission payloads increase for Case 2 by 184 tons (or to >16% of total displacement) and for Case 3 by 215 tons (or to 17% of total displacement). The fuel load for Cases 2 and 3 may be reduced because the fuel tonnage required for both cruising and sprint ranges is well within design margin thus adding more payload capacity.

SPEED AND ACQUISITION COST

Today's advanced sensor and weapons suites on-board surface combatants require complex integration schemes, influencing capital cost and operational requirements. Thus, a greater portion of the ship's cost and technology risk resides in the topside systems. The propulsion system and its auxiliaries typically account for about 11-15% of the total cost of the ship. Pricing for major propulsion drive train components such as the prime movers, gears, shafts, and propulsors is a function of installed power. Therefore, a decision to invest significant funding into high power/high speed propulsion systems must be carefully weighed against the cost trade-offs for these topside systems. Not surprisingly Case 1, by virtue of its higher power requirement, is the most expensive system – almost double that of Case 3.

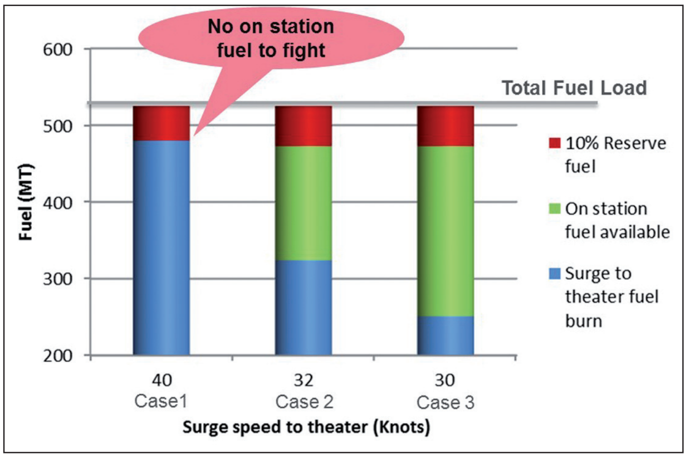
PAY ONLY FOR POWER NEEDED

As these case comparisons clearly illustrate, the proper sizing of a ship's power to best match its mission profile is critical for Navies – especially when trying to satisfy demands of the speed-endurance-payload iron triangle. GE's marine gas turbines provide flexibility for prime mover selections in all of the combined diesel and/or gas turbine propulsion plants. These lightweight, power dense gas turbines are sized for a wide range of ship applications including patrol boats, corvettes, frigates, destroyers, cruisers, supply and amphibious ships, and aircraft carriers.

CONCLUSION

The need for speed is an alluring catchphrase. But with speed comes the associated 'cost', both in terms of acquisition and mission capability. From an acquisition standpoint, a ship speed increase from 30-40 knots results in almost a 270% increase on propulsion power required, doubling the cost of the propulsion plant. Money saved with a more modest, capable propulsion system can be devoted to topside weapon and sensor technologies. From a mission capability perspective, the larger propulsion plant reduces available mission payload by around 200 tons. A properly-sized propulsion plant using GE's LM marine gas turbines that match to the mission profile will help provide a balanced solution for the speed-endurance-payload triangle. In the end, the propulsion plant exists to effectively and reliably transit the crew to the objective area such that the combat system can exert sustained influence when, like John Paul Jones, the intent is "to go in harm's way." **NAFO**

Surge to theatre fuel comparison.



Enhanced mission payload capacity.