Ship Requirements

Norbert Doerry

August 10, 2025

1. Introduction

As with any other engineered system, the design of shipboard power systems should be based on a well-articulated set of requirements. Doerry and Amy (2020) identified the following key ship-level requirements on the design of a naval ship's electrical power system and propulsion system:

- Flexibility
- Sustained speed
- Endurance
- 'Compromised Mobility' Speed
- Survivability
- Low Observable Mode
- Operating and Support Costs

Two more requirements can be added to the list above:

- Emissions
- Special Loads

Other lower-level requirements are identified by Doerry et al. (2022).

Commercial ships also share many of the requirements in addition to customer requirements for classification society classification symbols based on the intended use of the vessel. Examples of these classification symbols for the American Bureau of Shipping (ABS) include:

✠ AMS	Vessel machinery, boilers and systems have been constructed and installed under ABS survey.
✠ ACC	Vessel has means to control and monitor propulsion and machinery spaces from a continuously manned central control and monitoring station.
✠ APS	Vessel fitted with athwartship thrusters.
CR	Cyber Resilience.
✠ DPS-X	Dynamic Positioning System (DPS) where X is from {0, 1, 2, 3} and refers to different levels of DPS redundancy.

RX	Redundancy of propulsion system, where X is either 1 or 2 and refers to the level of redundancy. Additional qualifiers may be added to the notation {+, -S, -S+}

A complete list of ABS notations and symbols is published by ABS at https://ww2.eagle.org/. Each notation/symbol has a specific set of requirements that must be met.

Additional requirements come from government regulations (Code of Federal Regulations in the United States) and international treaties such as the International Maritime Organization (IMO) International Conventions for the Safety of Life as Sea (SOLAS) and International Convention for the Prevention of Pollution from Ships (MARPOL). Customers may also specify their own preferences for equipment and architectures in the contract; these preferences are often intended to promote commonality within their fleet.

2. Key requirement

2.1. Flexibility.

Flexibility is the ability to adapt a ship's systems to evolve over the ship's life to achieve new objectives. Because of the continuous evolution of warfare systems and tactics, naval ships can be expected to need more flexibility than single-purpose commercial ships. Within the commercial realm, international environmental regulations (MARPOL) are also evolving; owners and ship designers should consider the ramifications of future changes to these regulations when selecting architectures and equipment. Usually, the goal of flexibility is to enable the ship to affordably maintain relevancy (profitability) over its design service life. Historically, flexibility has been provided in the form of service life allowances. Service life allowances by themselves however, have not always proven adequate.

2.2. Sustained speed

For naval ships, sustained speed is the speed that must be attained (or surpassed) when the propulsion system is operating at 80% of its rated power with the ship having a clean, full load displacement, and in calm water. The 80% factor is used to account for having a fouled bottom and higher sea states.

For commercial ships, the term service speed is often used instead of sustained speed. The power needed to propel the ship at the service speed with a full load displacement, clean bottom and calm water is calculated. The propulsion system continuous rating is obtained by applying margin to this power. This margin consists of two parts: a sea margin to account for conditions other than calm water; and an engine margin to improve fuel efficiency and provide operational flexibility to enable the ship to operate at higher than the service speed when needed. The customer can determine the values to use for these two margins. Typically, but not always, a sea margin of 15% and an engine margin of 10% is used. Combining the typical values for these two margins is equivalent to the service speed being 79% of the continuous rating of the propulsion system.

2.3. Endurance

Endurance requirements determine how long a ship can operate at sea. For power and propulsion, the most relevant endurance metric is the required capacity of the ship's fuel tanks (burnable fuel). For many ships, the endurance fuel requirement has been specified in terms of the distance a ship must be capable of achieving at a particular endurance speed. For naval ships, this endurance speed is in the form of an economical transit speed; usually a value between 16 and 20 knots has been used. For commercial ships, the service speed has been typically used.

Since 2011, two additional metrics have been defined for naval ships: Surge to theater distance based on the sustained speed; Operational presence time base on an operational speed profile. See DPC 200-1 for more details.

2.4. 'Compromised Mobility' Speed

For naval ships, the allowable degradation in the ship's mobility following exposure to a threat is a major driver in the design of the propulsion system. This degradation may be expressed in terms of a minimum speed the ship must be able to attain following damage. The definition of the threat defines the extent of expected damage, and the minimum speed determines the residual capability required.

For commercial ships, the degradation in the ship's mobility following an accident is often defined in terms of required redundancy. The customer can specify the desired level of redundancy in terms of required classification society notations and symbols. The minimum level of redundancy required for a particular type of ship is usually defined in regulations or SOLAS.

2.5. Survivability

For naval ships, the customer should explicitly state in the ship's requirements, the expected residual capability a ship should have or be able to restore following exposure to a threat. Mission critical equipment (MCE) are elements of mission critical systems that are required to operate through emergency conditions. It is important that the customer clearly state the mission critical systems and associated threats within the ship's operational requirements.

For commercial ships, survivability is generally specified in terms of the capability following damage due to accidental collision, grounding, flooding, or fires. These requirements are usually specified in regulations and in SOLAS.

2.6. Low Observable Mode

Naval ships may be required to reduce their acoustic, thermal, and electromagnetic signatures as part of efforts to reduce ship's susceptibility to detection, tracking, targeting, and homing weapons. These reduced signature requirements can have a significant impact on the design of the ship's power and propulsion systems.

Commercial ships may also have signature requirements based on their intended use. Cruise ships for example, are increasingly seeking to reduce waterborne acoustic emissions in order to be able to operate in environmentally sensitive areas. Similarly, research ships may have signature requirements base on the types of scientific research conducted.

2.7. Operating and Support Costs

Fuel, manpower, and maintenance are some of the major operating and support cost drivers for a ship. Usually, customers desire to minimize operating and support costs while meeting all other requirements. These costs are a function of how the customer intends to operate and maintain the ship. The definition of ship operating conditions, ship system concepts of operation, and maintenance strategies can have a significant impact on power and propulsion system design. Similarly, the design and operation of the ship's power and propulsion systems themselves have a significant impact on fuel consumption, manning, and maintenance costs.

2.8. Emissions

MARPOL Annex VI Prevention of Air Pollution from Ships limits sulfur oxide and nitrogen oxide emissions and establishes mandatory measures to reduce greenhouse gas emissions. Annex VI is having a tremendous impact on the selection of fuels and associated prime movers as well as measures incorporated in the power and propulsion systems to improve efficiency.

2.9. Special and Large Loads

The power systems for naval ships in particular are having to supply power to large and dynamically challenging loads such as high-power radars, electronic warfare systems, and electric weapons. For many of these loads, the concept of operations describing how the operator intends to use them in relationship to other large loads (and propulsion) can be a significant driver in power and propulsion system design. See McCoy (2015) for additional insights.

2.10. Derived Requirements

The design of the ship's power and propulsion system are also heavily influenced by design decisions for other aspects of the ship design. Equipment selected to meet other requirements have their specific electrical power requirements (including maximum allowable power interruption time for Quality of Service calculations); naval architectural concerns can limit where power and propulsion equipment is located; the choice of hull form and appendages determines the amount of propulsion power required to achieve a given speed; and zone boundaries determine which equipment are located within each zone and the subsequently, the amount of power that must be provided.

3. Impact of key requirements on power and propulsion system design

The key requirements listed in the previous sections can have a significant impact on both the basic architecture of the power and propulsion systems, as well as specific implementation details. Three basic architectures comprise the majority of ships currently in service: mechanical drive; hybrid electric drive; and integrated power systems (IPS). In a mechanical drive system, prime movers (typically diesel engines or gas turbines) are directly connected to the mechanical drive train (normally consisting of a reduction gear, shafting, and propeller). Electric power for ship service (hotel) loads is generated by a completely different set of prime movers. In a hybrid electric drive system, an electric propulsion motor is integrated into either the reduction gear or shafting of an otherwise mechanical drive ship; at low power levels, the dedicated propulsion motors are turned off and power for both the ship service loads and the propulsion motor is provided by a common set of prime movers / generators. Hybrid electric drive can significantly reduce fuel consumption at low speeds. If the ship service loads can rival propulsion loads for one or more of the ship's operating conditions, it may be more economical to use an IPS where propulsion motors are connected to a common power distribution system for both propulsion and ship service electrical power. Doerry and Fireman (2006) and McCoy (2015) provide details on the impact of requirements on the design of IPS ships. The choice of power system architecture may be influenced by customer preference or other system requirements as described below.

3.1. Flexibility

Naval ships have historically used service life allowances to provide additional capacity in power generation and power distribution to serve loads that will be installed when the ship is in service. Service life allowances by themselves may not be adequate if the future loads are anticipated to be very large, or require special types of power. In these cases, modularity or other flexibility methods may be useful to provide the capability for incorporating changes to increase capacity or provide special power to these loads, but necessarily providing the capacity or special power at delivery; changes are only incorporated in the power system when the loads themselves change.

Commercial ships have historically not provided significant flexibility for future change; the assumption has been that the ship is designed to fulfill a specific function, and that function is likely not to change significantly over its service life. With future MARPOL limitations on emissions, power systems on commercial ships may have to evolve to meet these changing requirements; flexibility to incorporate future equipment and technologies may be required for these ships to achieve their design service life while remaining profitable.

Doerry (2014) provided additional guidance for power system design in the context of ship modularity, flexibility, and adaptability.

3.2. Sustained Speed

The propulsion power required to achieve the sustained speed requirement has a significant impact on the design of the propulsion system, and may significantly impact the electrical power system for integrated power systems and hybrid power systems. With a few exceptions, mechanical power rating of a propeller is normally limited to about 50 MW; the power rating usually is set at or below about 35 MW per shaft. Single-shaft propulsion systems are typically more efficient than twin-shaft propulsion systems; they usually require less installed propulsion power. However, other requirements, such as survivability, may lead to twin-shaft designs. Ships that normally operate at their sustained / service speed are typically mechanical drive because the losses associated with propulsion for a mechanical drive ship are typically lower at these higher propulsion loads than for electric propulsion. Ships that normally operate at speeds much lower than their sustained / service speed, such as naval ships, may benefit from the significantly lower losses at the associated power level in the prime movers associated with IPS and hybrid electric drive.

3.3. Endurance

Shipboard power and propulsion systems are usually optimized to minimize fuel consumption under the endurance conditions. For naval ships, the endurance speed is typically well below the sustained speed. Fuel efficient prime movers and supporting architectures are often chosen to enable efficient operation at endurance speeds; Less efficient, but lighter and less costly prime movers (typically gas turbines) are added to plant line-ups to achieve the sustained speed requirement.

Commercial ships that operate most of their time at their service speed are optimized to be fuel efficient at that speed; fuel efficiency at lower speeds may be less of a priority.

3.4. ‘Compromised Mobility’ Speed

The ‘Compromised Mobility’ speed has a significant impact on the design of the propulsion system for naval ships. If low enough (typically 14 knots or below), it may be achieved with a forward drop down propulsor; in this arrangement, the main propulsion may be concentrated aft to reduce shaft line lengths, enhance producibility, and free up valuable ship volume for other purposes. Otherwise, twin propulsion shafts are typically employed with the main propulsion units separated by at least two watertight bulkheads.

The ‘Compromised Mobility’ speed for commercial ships is typically a derived result from the redundancy requirements required by customer preference, regulation or class rules.

3.5. Survivability

Survivability requirements for naval vessels influence power distribution architecture choices to ensure continuity of power for mission critical loads that are not directly impacted by threat-induced damage, and quick restoration of power to undamaged mission critical loads in areas that are directly impacted by damage. Larger ships typically employ a zonal architecture to provide zonal survivability. In zonal survivability, damage in any two adjacent zones does not cause a loss of power continuity to loads in the undamaged loads. Compartment survivability provides for restoring power to undamaged mission critical loads by providing multiple sources of power and possibly a connection to a casualty power system. Additional guidance is provided by Doerry (2005) and Doerry (2007).

Mechanical drive naval ships are able to power all loads with at least one generator set out of service. The generator sets are typically separated to ensure sufficient generation survives following damage to power remaining loads. IPS ships are able to power ship service loads plus sufficient propulsion to achieve the ‘Compromised Mobility’ speed with any one generator set out of service.

Certain passenger ships are required by SOLAS to have “Safe Return to Port” provisions. These provisions are similar to zonal survivability implementations.

3.6. Low Observable Mode

With the incorporation of sufficient energy storage, IPS and hybrid electric drive ships could operate at low speeds without any prime movers online. In this mode of operation, the large infrared signature of the engine exhausts can largely be eliminated. Structure borne noise from operation of the prime-movers can also be eliminated when operating on energy storage. The reduced infrared and acoustic signatures may reduce the ship’s susceptibility to detection, targeting, and threat weapon homing.

The reduction in structure borne noise may also be of benefit to some commercial ships that operate in environmentally sensitive areas.

3.7. Operating and Support Costs

The desire to minimize operating and support costs usually leads to the following design features of the ship electrical power and propulsion systems:

a. The number and type of prime movers is minimized to the extent that other design objectives are met. Minimizing the types of prime movers simplifies logistics and the number of skilled mariners needed to maintain them. Minimizing the number of prime movers reduces the total maintenance burden.
b. The ratings and type of prime movers used are designed to enable efficient operation at power levels consistent with the ship’s concept of operation / projected speed-time profile. If much of the time is spent at the service speed, then mechanical drive propulsion systems

are often the most economical. If the ship's concept of operation includes operational conditions where the ship's service loads are high while the ship speed is low, and where the ship's service loads are not as high while the ship speed is high, then IPS configurations are often advantageous. IPS and hybrid drives are often cost effective if a significant portion of the speed / time profile is spent at speeds well below the sustained / service speed.

c. Single shaft propulsion is usually more efficient than twin-shaft propulsion. Other design considerations however, may preclude the employment of only a single shaft.
d. Counter-rotating propellers are usually more efficient than a single propeller on a shaft. The perceived complexity of counter-rotating propellers, and lack of industry support, has typically led to designs using only a single propeller on the shaft.
e. Azimuthing propulsors (pods) can be more efficient than traditional shafted propellers and are often used in cruise ship and ice breaker IPS applications.
f. Energy conservation efforts, such as the use of LED lights and modern, efficient heating, ventilation and air conditioning (HVAC) equipment can reduce the electrical power load demand onboard ship.

3.8. Emissions

Emissions are having and will continue to have a significant impact on power and propulsion system design. Historically, prime movers compatible with heavy fuel oil (HFO) have been used due to the low cost of the fuel. However, the use of HFO is decreasing due to its high sulfur content making it incompatible with achieving MARPOL requirements. In response to the MARPOL requirements, the commercial marine industry increasingly used distillate fuels or blends of distillate fuels with heavy fuel oil such as Marine Diesel Oil (MDO) and Intermediate Fuel Oil (IFO). The use of distillate marine diesel fuels, including low sulfur variations and bio-diesel blends, has been increasing. Not all engines are compatible with low sulfur fuels; the sulfur is useful for lubricating moving parts.

As emission requirements continue to become stricter, ships with alternate fuels are being constructed. Engines employing liquified natural gas and electrical power and propulsion systems using ammonia as a transport fuel are currently being produced. Some ferries and other special purpose ships employ electrical energy storage exclusively; the ships recharge whenever they are in port.

Naval ships typically use NATIO F76 fuel (also known as Naval Distillate Fuel) for both power generation and ship propulsion. Naval prime movers are usually compatible with JP-5 which is the primary jet fuel used in naval aviation; ships usually store JP-5 for embarked helicopters and fixed wing aircraft and can consume the JP-5 if necessary.

The type of fuel that is intended to be used has a significant impact on the choice of available prime movers. The choice of prime movers and fuel type in turn may require further exhaust scrubbing equipment (Exhaust Gas Cleaning System (EGCS)) to meet MARPOL requirements. While an EGCS adds cost and weight to the ship, the ability to use lower-cost high sulfur fuels may make this option financially attractive.

3.9. Special and Large Loads

Some ships have special loads that require large amounts of power of a specific type and quality of service. The nature of these special loads can significantly impact the architecture and design of the ship's electrical generation and distribution systems. Other large loads may only exist when in port (such as cranes for offloading cargo) or when the ship is operating at less than its sustained speed (such as some types of electric weapons). In this latter case, the total installed power onboard the ship can be minimized by using an IPS or hybrid electric drive.

3.10. Derived Requirements

One important derived requirement that influences the design of the electrical power system is the total amount of electrical load per operating condition. If the total amount of electrical load onboard the ship is large enough (greater than about 6 MW), the most economical electrical distribution system tends to incorporate a medium voltage (greater than 1000 volts) electrical generation system for the generators and large loads, and low voltage distribution (less than or equal to 1000 volts) to the smaller loads.

Quality of service requirements influence the selection of power ratings of the various generator sets and the business case for the incorporation of energy storage. Quality of service requirements can also influence the choice of fault protection strategy; the use of faster fault protection can result in the reclassification of uninterruptible loads to short-term interrupt loads. Similarly, the incorporation of faster starting generator sets can result in the reclassification of short-term interrupt loads to long-term interrupt loads. Increasing the relative proportion of long-term interrupt loads provides more flexibility in selecting the rating of generator sets to achieve other design objectives.

4. Establishing key requirements

Many of the key ship-level requirements are determined during ship concept design. The principal products of ship concept design are a set of operational requirements for the ship, an assessment of the utility of a ship that meets the set of operational requirements, and cost estimates for procuring and sustaining a ship that achieves the set of operational requirements. Ship design concepts are developed, not typically as a final product of concept design, but rather a demonstration that it is possible to create a ship that meets the operational requirements (feasibility); and as a means for establishing a representative cost for achieving the set of operational requirements. Cost estimating processes currently can generate cost estimates for a ship design concept, but cannot generate cost estimates directly from a set of requirements. Cost estimates for a set of requirements may be based on a single representative ship design concept, or may be derived from a group of ship design concepts, all of which meet the set of requirements. Because it is very difficult to determine if a single ship design concept is truly representative of the many ship designs that meet the set of requirements, deriving cost estimate from a group of ship design concepts is preferred. See Doerry (2015) for one method of deriving a representative cost based on diversity.

In concept design, multiple sets of requirements, often called "capability concepts" are compared with respect to feasibility, cost, and effectiveness. At the end of concept design, the customer will choose the set of requirements (capability concept) to move forward with in preliminary design. Ideally all major requirements would be fixed at this time; unfortunately, this is not always the case and the design of the ship power and propulsion system may have to account for this uncertainty in requirements.

Brown (2020) expands upon the many methods and techniques employed in ship concept design.

5. Impact of time of requirements establishment on power and propulsion system design

Ideally, all requirements that significantly impact the design of the power and propulsion systems would be finalized at the end of concept design and prior to the start of preliminary design. Unfortunately, this is not always possible.

There are at least two ways to address uncertain or changing requirements during the design phase: Design robustness, and design flexibility. In design robustness, additional capability is provided in the design to account for the full range of uncertainty in the requirements. This additional capability is often in the form of design margins on equipment capacity. Design flexibility allows for the economic modification of the power system design. Design flexibility can be in the form of space, weight, and services allocations for power system equipment that may or may not be needed. It can also be in the form of allowing easy substitution of equipment (a power converter for example) with equipment of a higher rating; interfacing cables, cooling systems, etc. should be designed to be able to accommodate or be easily modified to accommodate the higher rated equipment.

Changing requirements when the ship is in service are also addressed by either robustness or flexibility whenever possible. If the requirement changes were not anticipated during the design phases, considerable modification to the shipboard installation may be required.

6. References

ABS, "List of ABS Notations and Symbols," American Bureau of Shipping, March 2025.

Brown, Dr. Alan J., *Design of Marine Engineering Systems in Ship Concept Design*, The Marine Engineering Series Edited by Michael G. Parson, SNAME, Alexandria VA, 2020 ISBN 978-1-7923-0964

Doerry, CAPT Norbert, "Zonal Ship Design", presented at the ASNE Reconfiguration and Survivability Symposium, February 16-17, 2005, Atlantic Beach FL. Also published in ASNE Naval Engineers Journal, Winter 2006, Vol. 118 No 1, pp 39-53.

Doerry, CAPT Norbert H., and Howard Fireman, “Designing All Electric Ships,” Proceeding of the Ninth International Marine Design Conference, Ann Arbor MI, 16-19 May, 2006.

Doerry, CAPT Norbert, "Designing Electrical Power Systems for Survivability and Quality of Service" presented at ASNE DAY 2007, Arlington, VA, June 25-26, 2007. Also published in ASNE Naval Engineers Journal, 2007, Vol. 119 No 2, pp 25-34.

Doerry, Dr. Norbert H., "Electrical Power System Considerations for Modular, Flexible, and Adaptable Ships" presented at ASNE EMTS 2014, Philadelphia, PA, May 28-29, 2014.

Doerry, Dr. Norbert, "Measuring Diversity in Set-Based Design," Presented at ASNE Day 2015, Arlington VA, March 4, 2015.

Doerry, Dr. Norbert, and Dr. John Amy, Jr., "Key Requirements for Surface Combatant Electrical Power System and Propulsion System Design," presented at Advanced Machinery Technology Symposium, ASNE AMTS, Virtual Conference, October 6-7, 2020.

Doerry, Norbert, Andrew Johnson, Edward Ammeen, and Katherine Beaumont, "Design Activity Modeling, " SNAME Maritime Convention 2022, Houston TX, Sept 27-29, 2022.

McCoy, Timothy J., "Integrated Power Systems - An Outline of Requirements and Functionalities for Ships," in Proceedings of the IEEE, vol. 103, no. 12, pp. 2276-2284, Dec. 2015.

Naval Sea Systems Command, “Calculation of Surface Ship Endurance Fuel Requirements,” DPC 200-1.