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DESIGN DATA SHEET

CALCULATION OF SURFACE SHIP ENDURANCE FUEL REQUIREMENTS

DEPARTMENT OF THE NAVY
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A major consideration in the design of any Naval ship or craft is its ability to meet the endurance requirements established by the Chief of Naval Operations. This Design Data Sheet outlines the procedure to determine the minimum necessary fuel tankage for non-nuclear surface ships.

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1. APPLICABLE DOCUMENTS

1.1 General. The documents listed in this section are specified in the main body of this document. This section does not include documents cited in the Appendices.

1.2 Government documents.

1.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE STANDARDS

DOD-STD-1399-301	-	Interface Standard for Shipboard Systems, Section 301, Ship Motion and Attitude

(Copies of this document are available online at https://assist.daps.dla.mil/quicksearch/ or https://assist.daps.dla.mil.)

1.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NAVAL SEA SYSTEMS COMMAND (NAVSEA) DESIGN DATA SHEETS (DDS)

DDS 051-1	-	Prediction of Smooth-Water Powering Performance for Surface-Displacement Ships
DDS 310-1	-	Electric System Load and Power Analysis for Surface Ships

(Copies of these documents are available from Commander, Naval Sea Systems Command, ATTN: SEA 05S, 1333 Isaac Hull Avenue, SE, Stop 5160, Washington Navy Yard DC 20376-5160, or by email at commandstandards@navy.mil with the subject line “DDS request”.)

1.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS (SNAME)

T&R Bulletin 3-28	-	Marine Gas Turbine Power Plant Performance Practices
T&R Bulletin 3-49	-	Marine Diesel Power Plant Practices

(Copies of these documents are available from the Society of Naval Architects and Marine Engineers, 601 Pavonia Avenue, Jersey City, NY 07306 or online at www.sname.org.)

1.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2. INTRODUCTION

A major consideration in the design of any Naval ship or craft is its ability to meet the endurance (see 3.1) requirements established by the Chief of Naval Operations. This Design Data Sheet outlines the procedure to determine the minimum necessary fuel tankage for non-nuclear surface ships.

A ship's tankage must be sized to meet all specified endurance conditions: surge to theater, economical transit, and operational presence. These conditions represent three different operational scenarios for a ship. Economical transit minimizes the consumption of fuel under normal transits. Surge to theater requires a ship to rapidly travel a specified distance, (such as to an operational area) without having to refuel. Operational presence requires a ship while deployed to remain on station for a specified period of time.

The mobility requirements of these scenarios in conjunction with sustained speed requirements can drive the choice of prime movers and their ratings. Historically, the U.S. Navy has specified only the "economical transit" condition for an endurance speed of 20 knots[1]. Assuming sustained speed requirements can be met, a lower endurance speed of 16 knots could result in a Combined Diesel (electric) and Gas Turbine (electric) plant. An operational presence profile heavily weighted for low speeds with high mission electrical loads will favor selecting power plants with a high degree of load sharing among the prime movers such as an Integrated Power System (IPS) solution. For auxiliary and amphibious warfare ships with a lower sustained speed (see 3.4), diesel or diesel electric plants will likely be selected.

This document uses metric units with the exception of distance which is measured in nautical miles, ship speed which is measured in knots, and temperature which is measured in degrees Fahrenheit. Conversion factors (see 3.20) are provided to convert the units used to traditional units (long tons, pounds, and horsepower).

This document is organized in a task oriented approach. The General Requirements section details the input and outputs of the Endurance Fuel Calculation Process. These inputs and outputs are defined in the Definition section. The Specific Requirements section provides details on the method to calculate the process outputs based on the inputs. The calculation method is demonstrated in two examples provided in the appendices. Appendix A is an example set of calculations for a ship with a mechanical drive plant and Appendix B is an example set of calculations for a ship with an Integrated Power System plant. Note that the examples in Appendix A and B are fictitious; they do not represent any existing ship, existing ship system, or any particular ship concept.

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[1] The endurance calculation method previously used differs somewhat from the method to calculate endurance fuel requirements in this document. The differences are primarily in the assumptions used for the electrical load calculations.

3. DEFINITIONS

3.1 Endurance. Endurance refers to the metrics used by the Chief of Naval Operations used to determine the minimum amount of burnable fuel the ship must carry. Endurance is specified by one or more of the following metrics: surge to theater distance, economical transit distance, and operational presence time. The tankage is sized to have sufficient capacity to achieve all of the specified endurance metrics.

3.2 Endurance fuel load. Endurance fuel load is the full load of ship's fuel (metric tons) for which tankage must be provided to meet its endurance requirement.

3.3 Surge to theater distance. Surge to theater distance is the minimum distance (nautical miles) which a ship can sail without replenishment and using all of its burnable fuel (excluding cargo and aviation fuel), at sustained speed, deep water, and full load displacement, with a ship service operating condition corresponding to a cruise with self defense capability.

3.4 Sustained speed. Sustained speed (knots) is the customer specified speed that the ship shall at least maintain when corrected to full load displacement, normal trim, and clean bottom in deep, calm, 75 °F water, and 80 °F (for gas turbine 100 °F) air at a shaft power that is 80 percent of the design full power shaft power.

3.5 Economical transit distance. Economical transit distance is the minimum distance (nautical miles) which a ship can sail without replenishment and using all of its burnable fuel (excluding cargo and aviation fuel), at a specified endurance speed, deep water, and full load displacement, with a ship service operating condition corresponding to a cruise with self defense capability.

3.6 Operational presence time. Operational presence time is the minimum time in hours that a ship can conduct specified missions with a given speed-time profile, with a ship service operating condition corresponding to the specified missions, without replenishment, and using all of its burnable fuel (excluding cargo and aviation fuel).

3.7 Ambient condition profile. The ambient condition profile consists of a number of temperature/relative humidity ambient conditions and an associated percentage of time spent operating in the particular ambient condition.

3.8 Electric plant load analysis. Electric plant load analysis (EPLA) is used to calculate the ship service loads in the specified operational condition over the ambient condition profile. The EPLA includes margins and service life allowance. DDS 310-1 describes how to prepare an EPLA.

3.9 Electrical generation, conversion, and distribution efficiencies. Electrical generation, conversion, and distribution efficiencies are used to convert the ship service load (and propulsion load for electric propulsion) into load sustained by the prime movers. The efficiencies should account for all losses associated with the electrical generation, conversion, and distribution. The efficiencies are typically a function of power. If the specific fuel curve for an electrical generator set includes the generator efficiency, then the generator efficiency is not required to be known independently.

3.10 Electric and propulsion plant concept of operations. The electric and propulsion plant concept of operations is used to determine which prime movers are online, how propulsion power is shared among the propulsors, and for determining how power is shared among the prime movers for given operational conditions and loads. In early stages of design, the electric and propulsion plant concept of operations is included as part of the study guide (see 3.19). In later stages of design, it typically is a stand-alone document.

3.11 Propulsion speed-power curve. Propulsion speed-power curve is used to determine the shaft power (kW) required by each shaft (measured at the output of the propulsion motor or reduction gear) to achieve a given speed. This curve is calculated for smooth, deep water at full load displacement with appropriate margins and service life allowance. See DDS 051-1 for details for predicting smooth-water power performance for surface-displacement ships. The propulsion speed-power curve includes corrections to account for losses associated with shaft bearings and shaft seals. In many cases, the shaft speed (rpm) is also needed as a function of ship speed to properly determine either the propulsion motor module efficiency or the prime mover specific fuel consumption (mechanical drive). For ships with controllable pitch propellers, the pitch schedule directly impacts the shaft speed curve.

3.12 Propulsion motor module efficiency (electric drive). Propulsion motor module efficiency is used to convert the propulsion power (kW) measured at the output of the motor to electrical power at the input of the motor drive (including transformer, if applicable). The efficiency should account for all losses associated with the propulsion motor module including those losses associated with thrust bearings if incorporated into the motor design. The efficiency is typically a function of power.

3.13 Reduction gear efficiency (mechanical drive). Reduction gear efficiency is used to convert the propulsion power (kW) measured at output of the reduction gear to the power (kW) at the output of the attached engine. The efficiency should account for all losses associated with the reduction gear including thrust bearings and couplings. The efficiency is typically a function of power. For early stages of design, T&R Bulletin 3-49 and T&R Bulletin 3-28 may be used to estimate reduction gear efficiency.

3.14 Prime mover specific fuel consumption curves. Prime mover specific fuel consumption (kg/kWh) curves are used to calculate the amount of fuel burned per hour (kg/h) for each prime mover for a given load (kW). The prime mover specific fuel consumption curves may require correction factors to account for conditions such as higher than normal exhaust backpressure, higher temperatures, and attached pumps. For electrical generator sets, the specific fuel consumption curve may include the generator efficiency. In later stages of design, or earlier if known, the specific fuel consumption curves should reflect the impact of the ambient condition profile.

Where available, use manufacturer guidance to interpolate between constant SFC lines on fuel consumption contour plots. If such guidance is not provided, use the SFC value of the closest contour line; if equally distant to two contour lines, use the higher SFC value. Where the difference between the SFC values of the two bounding contour lines is not small, interpolating between the contour lines is also permissible.

3.15 Plant deterioration allowance. The plant deterioration allowance accounts for increased fuel consumption as the equipment ages.

3.16 Sea state and fouling factor. Sea state and fouling factor accounts for additional drag to the ship's hull due to average fouling and sea state. The impact of sea state is determined for a specified operating area, in head seas, at the high end of sea state 4 as defined in the latest revision of DOD-STD-1399-301 using the propeller coating, bottom coating, and cleaning methods intended for the ship. The sea state and fouling factor may be a function of speed.

3.17 Tailpipe allowance. The tailpipe allowance accounts for the additional fuel required in a tank that cannot be used because it is below the fuel system suction and due to the effects of suction vortexes.

3.18 Deep water. Deep water is greater in depth than the length of the ship.

3.19 Study guide. A study guide is a planning document intended to align customer expectations with work accomplished in a technical study. Among many other items, study guides include the general approach for conducting the study and a list of key study assumptions.

3.20 Conversion factors.

a. 1 metric ton = 0.984206528 long tons

b. 1 horsepower = 0.745699872 kilowatts

c. 1 pound = 0.45359237 kilograms

4. GENERAL REQUIREMENTS

4.1 Endurance fuel calculation inputs. The data needed to perform the endurance fuel calculations can be divided into the following two categories:

a. Service requirements

b. Design details

4.1.1 Service requirements. At least one of the following endurance set of metrics must be specified for a given ship design:

a. Economical transit
   (1) Economical transit distance (see 3.5) (nautical miles)
   (2) Endurance speed (if not specified, use 16 knots)

b. Surge to theater
   (1) Surge to theater distance (see 3.3) (nautical miles)
   (2) Sustained speed (knots)

c. Operational presence
   (1) Operational mission
   (2) Speed – time profile (knots vs. % time)
   (3) Operational presence time (see 3.6) (hours)

Additionally, the customer may specify the following:

d. Ambient condition profile (see 3.7) with the following temperature/relative humidity profile defaults:
   (1) 25% 10 °F with 95% relative humidity
   (2) 50% 59 °F with 95% relative humidity
   (3) 25% 100 °F with 40% relative humidity

e. The operating area for calculating sea state and fouling factor (see 3.16): Default is North Pacific

4.1.2 Design details. The following information from the ship design is needed:

a. EPLA (see 3.8)

b. Electrical generation, conversion, and distribution efficiencies (see 3.9)

c. Electric and propulsion plant concept of operations (see 3.10)

d. Propulsion speed-power curve (see 3.11)

e. Propulsion motor module efficiency (electric drive) (see 3.12)

f. Reduction gear efficiency (mechanical drive) (see 3.13)

g. Prime mover specific fuel consumption curves (see 3.14)

h. Plant deterioration allowance (see 3.15). If not specified, or if the applicable Technical Warrant Holder has not approved a different value, the default value is 1.05.

i. Sea state and fouling factor. For early stages of design, the default value of 1.10 is used for every speed. For later stages of design, the sea state and fouling factor should be determined for the intended operating area.

j. Tailpipe allowance (see 3.17). If the majority of the tanks are broad and shallow, the factor is 0.95; if narrow and deep, it is 0.98. In later stages of design, the tailpipe allowance can be calculated from the actual geometry of the tanks.

4.2 Endurance fuel calculation outputs. The output of the endurance fuel calculation is the required full load of ship's fuel (metric tons) for which tankage must be provided to meet endurance requirements.

5. SPECIFIC REQUIREMENTS

5.1 Economical transit burnable fuel load. The economical transit burnable fuel load (metric tons) is determined by the following equation:

$$\frac{\text{Calculated Economical Transit Fuel Rate (kg/h)} \times \text{Economical Transit Distance (NM)} \times \text{Plant Deterioration Allowance}}{\text{Endurance Speed (knots)} \times 1000}$$

If the economical transit distance is not specified, then the economical transit burnable fuel load is zero.

The calculated economical transit fuel rate (kg/h) is the total amount of fuel consumed (kg) per hour by all prime movers to achieve the 24-hour average ship service endurance electric load averaged over the ambient condition profile and the average endurance power (for propulsion). This rate must account for the efficiency of any power generation, power conversion, or power distribution systems elements.

The ambient condition profile is used primarily to calculate the ship service electrical load. While specific fuel consumption (SFC) of prime movers is also a function of the ambient condition profile, it usually varies to a lesser degree than the electrical load. To simplify calculations, the prime mover SFC for the worst ambient condition in the ambient condition profile is often used for all conditions in the ambient condition profile.

The 24-hour average endurance ship service electric load (kW) is the average anticipated ship service electrical load (including margin and service life allowance but not electric propulsion) expected over a 24-hour period for the ship service operating condition corresponding to a cruise with self defense capability (Condition III Wartime Cruising for surface combatants) for each ambient condition specified in the ambient condition profile. Propulsion related ship service loads are calculated for the average endurance power. The 24-hour average ship service endurance electric load is obtained from the EPLA.

The average endurance power (for propulsion) is obtained by applying any required efficiency factors to the product of the sea state and fouling factor and the power derived from the propulsion speed power curve at the endurance speed. For mechanical drive ships, it is important to ensure that efficiency factors associated with bearings and reduction gears are included. For electric drive ship, efficiency factors associated with bearings, motors, and motor drives must be incorporated.

The specific method for calculating the calculated economical transit fuel rate (kg/h) is highly dependent on the details of the power and propulsion architecture and the electric plant and propulsion plant concept of operations. The general process is to:

a. Determine the amount of power (kW) provided by each online prime mover for the economical transit condition. The average endurance power (for propulsion) and the 24-hour average endurance ship service electric load are apportioned to each prime mover in accordance with the electric plant and propulsion plant concept of operations.

b. For each prime mover, determine the specific fuel consumption (kg/kWh) when providing the power calculated in step (a) from the prime mover specific fuel consumption curves.

c. For each prime mover, calculate its fuel rate (kg/hr) by multiplying the specific fuel consumption (kg/kWh) by the power it provides (kW).

d. Sum the fuel rates for all prime movers to obtain the calculated economical transit fuel rate (kg/h).

5.2 Surge to theater burnable fuel load. The surge to theater burnable fuel load (metric tons) is determined by the following equation:

$$\frac{\text{Calculated Surge to Theater Fuel Rate (kg/h)} \times \text{Surge to Theater Distance (NM)} \times \text{Plant Deterioration Allowance}}{\text{Sustained Speed (knots)} \times 1000}$$

If the surge to theater distance is not specified, then the surge to theater burnable fuel load is zero.

The calculated surge to theater fuel rate (kg/h) is the total amount of fuel consumed (kg) per hour by all prime movers to achieve the 24-hour average ship service sustained electric load averaged over the ambient condition profile and the average sustained power (for propulsion). This rate must account for the efficiency of any power generation, power conversion, or power distribution systems elements.

The 24-hour average sustained ship service electric load is the average anticipated ship service electrical load (including margin and service life allowance but not electric propulsion) expected over a 24-hour period for the ship service operating condition corresponding to a cruise with self defense capability (Condition III Wartime Cruising for surface combatants) for each ambient condition specified in the ambient condition profile. Propulsion related ship service loads are calculated for the average sustained power (for propulsion). The 24-hour average ship service sustained electric load is obtained from the EPLA.

The average sustained power (for propulsion) is obtained by applying any required efficiency factors to the product of the sea state and fouling factor and the power derived from the propulsion speed power curve at the sustained speed. For mechanical drive ships, it is important to ensure that efficiency factors associated with bearings and reduction gears are included. For electric drive ship, efficiency factors associated with bearings, motors, and motor drives must be incorporated.

The specific method for calculating the calculated surge to theater fuel rate is highly dependent on the details of the power and propulsion architecture and the electric plant and propulsion plant concept of operations. The general process is to:

a. Determine the amount of power (kW) provided by each online prime mover for the surge to theater transit condition. The average sustained power (for propulsion) and 24-hour average sustained ship service electric load are apportioned to each prime mover in accordance with the electric plant and propulsion plant concept of operations.

b. For each prime mover, determine the specific fuel consumption (kg/kWh) when providing the power calculated in step (a) from the prime mover specific fuel consumption curves.

c. For each prime mover, calculate its fuel rate (kg/hr) by multiplying the specific fuel consumption (kg/kWh) by the power it provides (kw).

d. Sum the fuel rates for all prime movers to obtain the calculated surge to theater fuel rate (kg/h).

5.3 Operational presence burnable fuel load. The operational presence burnable fuel load (metric tons) is determined by the following equation:

$$\frac{\text{Calculated Operational Presence Fuel Rate (kg/h)} \times \text{Operational Presence Time (h)} \times \text{Plant Deterioration Allowance}}{1000}$$

If the operational presence time is not specified, then the operational presence burnable fuel load is zero.

The calculated operational presence fuel rate (kg/h) is the average amount of fuel consumed per hour by all prime movers across the specified speed time profile using the 24-hour average ship service mission electric load profile and the average mission power profile (for propulsion). This rate must account for the efficiency of any power generation, power conversion, or power distribution systems elements.

The 24-hour average mission ship service electric load profile is the curve of the average anticipated ship service electrical load (including margin and service life allowance but not electric propulsion) expected over a 24-hour period for the ship service operating condition corresponding to the specified missions for each ambient condition specified in the ambient condition profile versus the speeds in the specified speed-time profile. The 24-hour average ship service mission electric load profile is obtained from the EPLA.

The average mission power profile is the design mission power profile multiplied by the sea state and fouling factor and appropriate efficiency factors to obtain the power delivered by each propulsion prime mover (mechanical drive) or propulsion motor (electric drive). The design mission power profile is the propulsion shaft horsepower for each shaft as indicated by the latest available speed-power versus the speeds in the specified speed time profile. For mechanical drive ships, it is important to ensure that efficiency factors associated with bearings and reduction gears are included. For electric drive ship, efficiency factors associated with bearings, motors, and motor drives must be incorporated.

The specific method for calculating the calculated operational presence fuel rate is highly dependent on the details of the power and propulsion architecture and the electric plant and propulsion plant concept of operations. The general process is to:

a. Determine the amount of power (kW) provided by each online prime mover for each speed in the speed-time profile. The propulsion load and ship service electric load are apportioned to each prime mover in accordance with the electric plant and propulsion plant concept of operations.

b. For each prime mover, determine the specific fuel consumption (kg/kWh) when providing the power for each speed in the speed-time profile calculated in step (a) from the prime mover specific fuel consumption curves.

c. For each prime mover, calculate the fuel rate profile (kg/h) as a function of speed in the speed-time profile by multiplying the specific fuel consumption (kg/kWh) by the power it provides (kW) at the given speed.

d. For each prime mover, calculate its average fuel rate (kg/h) by taking the weighted average of the fuel rate profile, weighting each fuel rate in the fuel rate profile by the percentage of the time the ship operates at the given speed.

e. Sum the average fuel rates for all prime movers to obtain the calculated operational presence fuel rate (kg/h).

5.4 Endurance fuel load. Endurance fuel load (see 3.2) is the fuel load (metric tons) obtained by dividing the design burnable fuel load by the tailpipe allowance. It does not include an additional 5 percent in tank volume which must be provided to allow for expansion of fuel. For a compensated system, an allowance of less than 5 percent may be provided if approved by the appropriate Technical Warrant Holders. Tank volume must also account for internal structure; internal structure typically uses about 2 percent of the tank volume.

The endurance fuel load does not include fuel required for the operation of aircraft, boats, other vehicles, or carried as cargo.

The design burnable fuel load (metric tons) is the maximum of the economical transit burnable fuel load, the surge to theater burnable fuel load, and the operational presence burnable fuel load.

5.5 High speed ships. The propulsion speed power curve for many high speed ships (particularly those with uncompensated fuel systems) are very sensitive to displacement in that as fuel is burned, displacement and drag can be significantly reduced. In these cases, assuming full load displacement for the economical transit burnable fuel load and surge to theater burnable fuel load cases is highly conservative. In these cases the procedure for calculating the economical transit burnable fuel load and surge to theater burnable fuel load may be modified to account for the reduction in ship drag as fuel is consumed. However, since the Navy typically does not allow ships to come close to burning all of its available fuel, the ship should be able to achieve half of its economical transit distance while expending no more than half of its design burnable fuel load. Likewise, the ship should be able to achieve half of its surge to theater distance while expending no more than half of its design burnable fuel load. The operational presence burnable fuel load calculations should continue to use full load displacement.

One method to calculate the economical transit burnable fuel load (and the surge to theater burnable fuel load) for these high speed ships is:

a. Divide half the economical transit distance (surge to theater distance) into a number of segments (typically 5 to 10).

b. For the first segment, assign the ship a displacement equal to the full load displacement.

c. Develop the speed power curve for this displacement and calculate the corresponding economical transit burnable fuel load (surge to theater burnable fuel load) for the first segment.

d. For the second segment, subtract from the displacement used during the first segment, the weight of the fuel consumed during the first segment to obtain the second segment displacement.

e. Develop a new speed power curve for this displacement and calculate the corresponding economical transit burnable fuel load (surge to theater burnable fuel load) for this segment.

f. Repeat steps (d) and (e) for all remaining segments.

g. Add up the economical transit burnable fuel load (surge to theater burnable fuel load) for all the segments.

h. Multiply the result by 2 to obtain the economical transit burnable fuel load (surge to theater burnable fuel load).

Another simpler method for these high speed ships is:

a. Calculate the economical transit burnable fuel load (surge to theater burnable fuel load) using the speed power curve associated with full load displacement. (see 5.1 and 5.2)

b. Recalculate the economical transit burnable fuel load (surge to theater burnable fuel load) using the speed power curve associated with full load displacement – 25 percent of the economical transit burnable fuel load (surge to theater burnable fuel load) calculated in step (a).

c. Use the economical transit burnable fuel load (surge to theater burnable fuel load) calculated in step (b) in the calculation of the design burnable fuel load.

5.6 Special cases for economical transit. Some ships may be able to traverse the economical transit distance using less fuel with a speed greater than the specified endurance speed. With customer approval, a more optimal speed above the endurance speed may be used for the economical transit burnable fuel calculations.

Ships potentially may be able to achieve the stated endurance speed on average using less fuel by using a speed time profile where a portion of the time is spent above the endurance speed and a portion of the time is spent below the endurance speed. With customer approval, a speed, percent time profile that results in an average speed equal to or greater than the endurance speed, may be used for the economical transit burnable fuel calculations if it results in a smaller economical transit burnable fuel load.

APPENDIX A. MECHANICAL DRIVE USE CASE

A.1 Service requirements:

a. Economical transit distance: 5000 NM

b. Endurance speed: 16 knots

c. Surge to theater distance: 2000 NM

d. Sustained speed: 30 knots

e. Operational presence speed-time profile:

Speed (knots)	% Time
5	20%
10	30%
15	25%
20	15%
25	8%
30	2%

f. Operational presence time: 240 hours

g. Ambient condition profile: Default

A.2 Design details:

a. Electric plant load analysis:

Temperature (°F)	Condition III Electric Load (kW)	Mission Electric Load (kW)
10	3000	4800
59	1800	3200
100	2400	4000

Includes margins, service life allowance, and power system efficiencies. Assumes electric load is independent of ship speed.

b. Electric and propulsion plant concept of operations: The electric plant consists of three 3000 kW gas turbine generator (GTG) sets. Two GTGs are online at all times. Power is shared evenly among all online GTGs.

The propulsion plant consists of two shafts with two 15,000 kW main gas turbines (MGT) on each shaft with a reduction gear. Available configurations are trail shaft with one MGT online, split plant with one MGT on each shaft, and full plant configuration with two MGTs on each shaft. The most economical configuration is used for a given speed. Power is shared evenly among all online MGTs.

c. Propulsion speed power curve:

Speed (knots)	Port Shaft (kW)	Starboard Shaft (kW)	Propulsion Configuration
5	217	0	Trail Shaft
10	1733	0	Trail Shaft
15	5850	0	Trail Shaft
16	7100	0	Trail Shaft
20	6933	6933	Split Plant
25	13542	13542	Full plant
30	23400	23400	Full plant
32.3	29250	29250	Full plant

Design propulsion power for smooth, deep water at full load displacement with margins and service-life allowance. Measured at low speed output of the reduction gear.

d. Reduction gear efficiency (assume constant): 0.975

e. Prime mover specific fuel consumption curves:

(1) MGT specific fuel consumption (SFC):

Power (kW)	SFC (kg/kWh)
1500	0.60
3000	0.48
6000	0.34
9000	0.30
12000	0.27
15000	0.26

For power levels below 1500 kW, use a constant fuel rate (kg/h) calculated at 1500 kW. Power is measured at the coupling between the output of the MGT and the high speed input to the reduction gear.

(2) GTG specific fuel consumption:

Power (kW)	SFC (kg/kWh)
600	0.66
1200	0.42
1800	0.33
2400	0.27
3000	0.26

Power is measured at the output of the electrical generator.

f. Plant deterioration allowance: Use default 1.05

g. Sea state and fouling factor: Use default 1.10 for every speed

h. Tailpipe allowance: Use 0.95 for broad and shallow tanks

A.3 Calculations:

a. Economical transit burnable fuel load:

(1) Design endurance power (16 knots): 7100 kW trailshaft

(2) Sea state and fouling factor: 1.10

(3) Average endurance power: 7100 × 1.10 = 7810 kW

(4) Reduction gear efficiency: 0.975

(5) MGT power: 7810 / 0.975 = 8010 kW

(6) MGT specific fuel consumption (interpolated from table): 0.313 kg/kWh

(7) MGT fuel rate: 8010 kW × 0.313 kg/kWh = 2507 kg/h

(8) Electric plant fuel rate:

Temperature (°F)	24-Hour Average Ship Service Endurance Electric Load (kW)	GTG Load (kW)	SFC (kg/kWh)	Total GTG Fuel Rate (kg/h)	Profile %	Weighted Fuel Rate (kg/h)
10	3000	1500	0.375	1125	25%	281
59	1800	900	0.540	972	50%	486
100	2400	1200	0.420	1008	25%	252
				Total Electric Plant Fuel Rate (kg/h):		1019

(9) Calculated economical transit fuel rate = MGT Fuel Rate + Electric Plant Fuel Rate
= 2507 kg/h + 1019 kg/h = 3526 kg/h

(10) Economical transit burnable fuel load = (3526 kg/h × 5000 NM × 1.05) / (16 kts × 1000) metric tons
= 1157 metric tons

b. Surge to theater burnable fuel load:

(1) Design sustained power (30 knots) = 23,400 kW each shaft (full plant – 2 MGT per shaft)
= 11,700 kW each MGT

(2) Sea state and fouling factor: 1.10

(3) Average endurance power: 11,700 × 1.10 = 12,870 kW (per MGT)

(4) Reduction gear efficiency: 0.975

(5) MGT power: 12,870 / 0.975 = 13,200 kW

(6) MGT specific fuel consumption (interpolated from table): 0.266 kg/kWh

(7) MTG fuel rate: 4 × 13,200 kW × 0.266 kg/kWh = 14,045 kg/h

(8) Electric plant fuel rate:

Temperature (°F)	24-Hour Average Ship Service Endurance Electric Load (kW)	SFC (kg/kWh)	Fuel Rate (kg/h)	Profile %	Weighted Fuel Rate (kg/h)
10	3000	0.375	1125	25%	281
59	1800	0.540	972	50%	486
100	2400	0.420	1008	25%	252
			Total Electric Plant Fuel Rate (kg/h):		1019

(9) Calculated surge to theater fuel rate = MGT Fuel Rate + Electric Plant Fuel Rate
= 14,045 kg/h + 1019 kg/h = 15,064 kg/h

(10) Surge to theater burnable fuel load = (15,064 kg/h × 2000 NM × 1.05) / (30 kts × 1000) metric tons
= 1054 metric tons

c. Operational presence burnable fuel load:

(1) Propulsion plant fuel rate:

Speed (knots)	Profile % Time	Propulsion Power (kW)	Average Mission Power Profile (kW)	Number MGT Online	Reduction Gear Efficiency	Power per MGT (kW)	MGT SFC (kg/kWh)	Fuel Rate (kg/h)	Weighted Fuel Rate (kg/h)
5	20%	217	238	1	0.975	244	3.682	900	180
10	30%	1733	1907	1	0.975	1956	0.564	1102	331
15	25%	5850	6435	1	0.975	6600	0.332	2191	548
20	15%	13867	15253	2	0.975	7822	0.316	4939	741
25	8%	27083	29792	4	0.975	7639	0.318	9721	778
30	2%	46800	51480	4	0.975	13200	0.266	14045	281
								Total Propulsion Fuel Rate (kg/h):	2858

(2) Electric plant fuel rate:

Temperature (°F)	24-Hour Average Ship Service Mission Electric Load Profile (kW)	GTG Load (kW)	SFC (kg/kWh)	Fuel Rate (kg/h)	Profile %	Weighted Fuel Rate (kg/h)
10	4800	2400	0.270	1296	25%	324
59	3200	1600	0.360	1152	50%	576
100	4000	2000	0.310	1240	25%	310
					Total Electric Plant Fuel Rate (kg/h):	1210

(3) Calculated operational presence fuel rate: 2858 kg/h + 1210 kg/h = 4068 kg/h

(4) Operational presence time: 240 hours

(5) Operational presence burnable fuel load = 4068 kg/h × 240 h × 1.05 /1000 metric tons
= 1025 metric tons

d Endurance fuel load:

(1) Economical transit burnable fuel load: 1157 metric tons

(2) Surge to theater burnable fuel load: 1054 metric tons

(3) Operational presence burnable fuel load: 1025 metric tons

(4) Design burnable fuel load: 1157 metric tons (maximum of above)

(5) Endurance fuel load = Design Burnable Fuel Load / Tailpipe Allowance
= 1157 metric tons / 0.95 = 1218 metric tons

A.4 Output. The ship's tank capacity must be sized for the endurance fuel load of 1218 metric tons plus an additional 5 percent of volume for the expansion of fuel and an additional 2 percent of volume for structure.

APPENDIX B. INTEGRATED POWER SYSTEM USE CASE

B.1 Service requirements.

a. Economical transit distance: 5000 NM

b. Endurance speed: 16 knots

c. Surge to theater distance: 2000 NM

d. Sustained speed: 30 knots

e. Operational presence speed-time profile:

Speed (knots)	% Time
5	20%
10	30%
15	25%
20	15%
25	8%
30	2%

f. Operational presence time: 240 hours

g. Ambient condition profile: Default

B.2 Design details.

Temperature (°F)	Condition III Electric Load (kW)	Mission Electric Load (kW)
10	3000	4800
59	1800	3200
100	2400	4000

Includes margins, service life allowance, and power system efficiencies. Assumes electric load is independent of ship speed.

a. Electric and propulsion plant concept of operations: The propulsion plant consists of two shafts each with a propulsion motor module (PMM) on each shaft. Propulsion power is shared equally between the two PMMs.

The electric plant consists of two 3,000 kW gas turbine auxiliary turbine generator (ATG) power generation modules (PGM) and three 24,000 kW gas turbine main turbine generators (MTG) PGMs. At least two PGMs are online at all times. Power is shared evenly (proportional to rating) among all online PGMs. (Note: Power sharing in this manner is not always optimal, but is an acceptable assumption for early stage design.)

b. Power generation configurations:

Power Low (kW)	Power High (kW)	Number MTG	Number ATG
1200	5700	0	2
5700	25650	1	1
25650	45600	2	0
45600	68400	3	0
68400	78000	3	2

c. Propulsion speed power curve:

Speed (knots)	Total Propulsion Shaft Power (kW)	Port Shaft (kW)	Starboard Shaft (kW)	PMM Efficiency
5	217	108	108	0.85
10	1733	867	867	0.89
15	5850	2925	2925	0.90
16	7100	3550	3550	0.91
20	13867	6933	6933	0.92
25	27083	13542	13542	0.94
30	46800	23400	23400	0.94
32.6	60000	30000	30000	0.94

Design propulsion power for smooth, deep water at full load displacement with margins and service-life allowance. Measured at the output of propulsion motor module (PMM). Design motor power per shaft is the electrical power measured at the input to the PMM.

d. Prime mover specific fuel consumption curves:

(1) MTG specific fuel consumption:

Power (kW)	SFC (kg/kWh)
2400	0.465
4800	0.375
9600	0.263
14400	0.233
19200	0.210
24000	0.200

Power is measured at the output of the electrical generator.

For power levels below 2400 kW, use a constant fuel rate (kg/h) calculated at 2400 kW.

(2) ATG specific fuel consumption:

Power (kW)	SFC (kg/kWh)
600	0.66
1200	0.42
1800	0.33
2400	0.27
3000	0.26

Power is measured at the output of the electrical generator.

For power levels below 600 kW, use a constant fuel rate (kg/h) calculated at 600 kW.

e. Plant deterioration allowance: Use default 1.05

f. Sea state and fouling factor: Use default 1.10 for every speed

g. Tailpipe allowance: Use 0.95 for broad and shallow tanks

B.3 Calculations.

a. Economical transit burnable fuel load:

(1) Design endurance power (16 knots): 3550 kW per shaft

(2) Sea state and fouling factor: 1.10

(3) Average endurance power: 3905 kW per shaft

(4) PMM efficiency: 0.91

(5) PMM electrical load: 4291 kW per shaft; 8582 kW total

Temperature (°F)	24-Hour Ave SS Electric Load (kW)	Propulsion Electric Load (kW)	Total Electrical Load (kW)	Nbr MTG	Nbr ATG	MTG Power (kW)	ATG Power (kW)	MTG SFC (kg/kWh)	ATG SFC (kg/kWh)	MTG Fuel Rate (kg/h)	ATG Fuel Rate (kg/h)	Total Fuel Rate (kg/h)
10	3000	8582	11582	1	1	10295	1287	0.259	0.407	2663	524	3187
59	1800	8582	10382	1	1	9229	1154	0.272	0.439	2507	506	3013
100	2400	8582	10982	1	1	9762	1220	0.262	0.417	2557	509	3066

Temperature (°F)	Total Fuel Rate (kg/h)	Profile	Weighted Fuel Rate (kg/h)
10	3187	25%	797
59	3013	50%	1507
100	3066	25%	767
Calculated economical transit fuel rate:			3070

(6) Calculated economical transit fuel rate: 3070 kg/h

(7) Economical transit burnable fuel load = (3070 kg/h × 5000 NM × 1.05) / (16 kts × 1000) metric tons
= 1007 metric tons

b. Surge to theater burnable fuel load:

(1) Design sustained power (30 knots): 23,400 kW per shaft

(2) Sea state and fouling factor: 1.10

(3) Average endurance power: 25,740 SHP per shaft

(4) PMM efficiency: 0.94

(5) PMM electrical load: 27383 kW per shaft; 54766 kW total

Temperature (°F)	24-Hour Ave SS Electric Load (kW)	Propulsion Electric Load (kW)	Total Electrical Load (kW)	Nbr MTG	Nbr ATG	MTG Power (kW)	ATG Power (kW)	MTG SFC (kg/kWh)	ATG SFC (kg/kWh)	MTG Fuel Rate (kg/h)	ATG Fuel Rate (kg/h)	Total Fuel Rate (kg/h)
10	3000	54766	57766	3	0	19255	0	0.210	0	12124	0	12124
59	1800	54766	56566	3	0	18855	0	0.212	0	11972	0	11972
100	2400	54766	57166	3	0	19055	0	0.211	0	12044	0	12044

Temperature (°F)	Total Fuel Rate (kg/h)	Profile	Weighted Fuel Rate (kg/h)
10	12124	25%	3031
59	11972	50%	5986
100	12044	25%	3011
Calculated surge to theater fuel rate:			12028

(6) Calculated surge to theater fuel rate: 12,028 kg/h

(7) Surge to theater burnable fuel load = (12,028 kg/h × 2000 NM× 1.05) / (30 knots × 1000) metric tons
= 842 metric tons

c. Operational presence burnable fuel load:

(1) 10 °F condition:

Speed (knots)	SS Electric Load (kW)	Propulsion Electric Load (kW) 1/	Total Electrical Load (kW)	Nbr MTG	Nbr ATG	MTG Pwr (kW)	ATG Pwr (kW)	MTG SFC (kg/kWh)	ATG SFC (kg/kWh)	MTG Fuel Rate (kg/h)	ATG Fuel Rate (kg/h)	Total Fuel Rate (kg/h)
5	4800	280	5080	0	2	0	2540	0	0.268	0	1360	1360
10	4800	2142	6942	1	1	6171	771	0.343	0.591	2126	458	2573
15	4800	7150	11950	1	1	10622	1328	0.257	0.401	2756	536	3258
20	4800	16580	21380	1	1	19004	2376	0.211	0.272	4070	654	4656
25	4800	31693	36493	2	0	18247	0	0.215	0	7932	0	7830
30	4800	54766	59566	3	0	19855	0	0.209	0	12804	0	12428

Speed (knots)	Total Fuel Rate (kg/h)	% Time	Weighted Fuel Rate (kg/h)
5	1362	20%	272
10	2573	30%	772
15	3258	25%	814
20	4656	15%	698
25	7830	8%	626
30	12428	2%	249
10 °F Calculated operational presence fuel rate:			3432

(2) 59 °F condition:

Speed (knots)	SS Electric Load (kW)	Propulsion Electric Load (kW) 1/	Total Electrical Load (kW)	Nbr MTG	Nbr ATG	MTG Pwr (kW)	ATG Pwr (kW)	MTG SFC (kg/kWh)	ATG SFC (kg/kWh)	MTG Fuel Rate (kg/h)	ATG Fuel Rate (kg/h)	Total Fuel Rate (kg/h)
5	3200	280	3480	0	2	0	1740	0	0.339	0	1180	1180
10	3200	2142	5342	0	2	0	2671	0	0.265	0	1418	1418
15	3200	7150	10350	1	1	9200	1150	0.272	0.440	2505	506	3011
20	3200	16850	19780	1	1	17582	2198	0.218	0.290	3829	638	4466
25	3200	31693	34893	2	0	17447	0	0.218	0	7621	0	7621
30	3200	54766	57966	3	0	19322	0	0.210	0	12158	0	12158

Speed (knots)	Total Fuel Rate (kg/h)	% Time	Weighted Fuel Rate (kg/h)
5	1180	20%	236
10	1418	30%	425
15	3011	25%	753
20	4466	15%	670
25	7621	8%	610
30	12158	2%	243
59 °F Calculated operational presence fuel rate:			2937

(3) 100 °F condition:

Speed (knots)	SS Electric Load (kW)	Propulsion Electric Load (kW) 1/	Total Electrical Load (kW)	Nbr MTG	Nbr ATG	MTG Pwr (kW)	ATG Pwr (kW)	MTG SFC (kg/kWh)	ATG SFC (kg/kWh)	MTG Fuel Rate (kg/h)	ATG Fuel Rate (kg/h)	Total Fuel Rate (kg/h)
5	4000	280	4280	0	2	0	2140	0	0.296	0	1267	1267
10	4000	2142	6142	1	1	5460	682	0.360	0.627	1963	428	2391
15	4000	7150	11150	1	1	9911	1239	0.261	0.414	2587	513	3100
20	4000	16580	20580	1	1	18293	2287	0.214	0.281	3921	643	4564
25	4000	31693	35693	2	0	17847	0	0.216	0	7727	0	7727
30	4000	54766	58766	3	0	19589	0	0.209	0	12293	0	12293

Speed (knots)	Total Fuel Rate (kg/h)	% Time	Weighted Fuel Rate (kg/h)
5	1267	20%	253
10	2391	30%	717
15	3100	25%	775
20	4564	15%	685
25	7727	8%	618
30	12293	2%	246
100 °F Calculated operational presence fuel rate:			3295

1/ Calculated by multiplying the design motor power per shaft (kW) by the number of shafts and by the sea state and fouling factor.

Temperature (°F)	Calculated Fuel Rate (kg/h)	Profile	Weighted Fuel Rate (kg/h)
10	3432	25%	858
59	2937	50%	1469
100	3295	25%	824
Calculated operational presence fuel rate:			3150

(4) Calculated operational presence fuel rate: 3150 kg/h

(5) Operational presence time: 240 hours

(6) Operational presence burnable fuel load = 3150 kg/h × 240 h ×1.05 / 1000 metric tons
= 794 metric tons

d. Endurance fuel load:

(1) Economical transit burnable fuel load: 1007 metric tons

(2) Surge to theater burnable fuel load: 842 metric tons

(3) Operational presence burnable fuel load: 794 metric tons

(4) Design burnable fuel load: 1007 metric tons (maximum of above)

(5) Endurance fuel load = Design Burnable Fuel Load / Tailpipe Allowance
= 1007 metric tons / 0.95 = 1060 metric tons

B.4 Output. The ship's tank capacity must be sized for the endurance fuel load of 1058 metric tons plus an additional 5 percent of volume for the expansion of fuel and an additional 2 percent of volume for structure.