Endurance Fuel Calculations

Electric Power Load Analysis (EPLA)

Revision of 8 August 2026

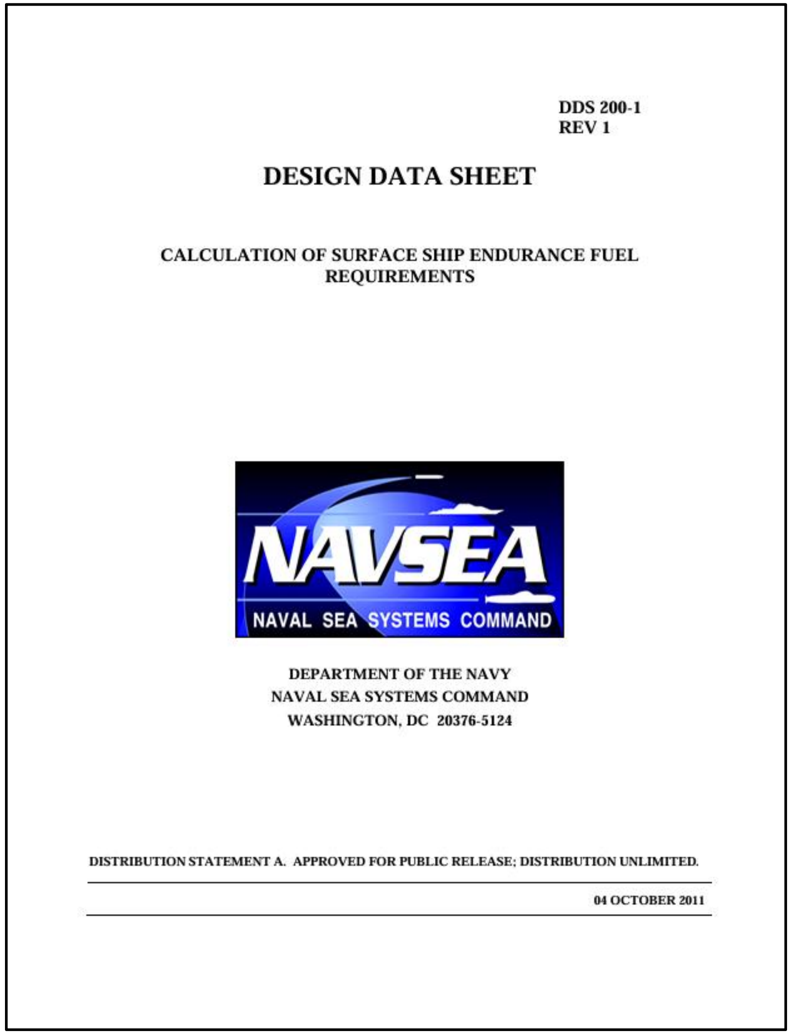
Dr. Norbert Doerry

Essential Questions

What information is needed to perform an Endurance Fuel Calculation?	Understand
How does one obtain the information needed to perform an Endurance Fuel Calculation?	Understand
What are the results of an Endurance Fuel Calculation used for?	Understand
How is an Endurance Fuel Calculation performed?	Apply

Introduction

- Endurance Fuel Calculation are used to determine the size of the fuel tanks
- Size of fuel tanks depends largely on
  - How far one wants to go (or how much time one wants to go)
  - How fast one wants to go
  - What operational condition one is in while going
- DPC 200-1 (formerly DDS 200-1)
  - Defines procedure for calculating endurance fuel requirements
  - Applicable to naval ships, but may be adapted to commercial ships


DDS 200-1
REV 1

DESIGN DATA SHEET

CALCULATION OF SURFACE SHIP ENDURANCE FUEL REQUIREMENTS

NAVSEA
NAVAL SEA SYSTEMS COMMAND

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20376-5124

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Owner's (Service) Requirements

- Economical Transit
  - Economical transit distance (nm)
  - Endurance speed (knots)
- Surge to Theater
  - Surge to Theater Distance (nm)
  - Sustained speed (knots)
- Operational Presence
  - Operational mission
  - Speed-time profile (knots vs % time)
  - Operational presence time (hours)

Operational Condition: Cruise with self-defense

Operating area may also be specified or use default: North Pacific

One with largest fuel requirement used for determining fuel tank capacity

Ambient condition profile may also be specified or use default:

(1) 25% 10 °F with 95% relative humidity
(2) 50% 59 °F with 95% relative humidity
(3) 25% 100 °F with 40% relative humidity

Ship design details needed

- Electric Power Load Analysis (EPLA)
- Generator set, conversion equipment efficiencies
- Electrical Power System Concept of Operations (EPS-CONOPS)
  - Includes generator set scheduling table
- Propulsion System Concept of Operations (PS-CONOPS)
  - Includes propulsion scheduling table
- Propulsion speed-power curve
- Propulsion system efficiency data
- Generator set and propulsion prime mover specific fuel consumption curves
- Plant deterioration allowance (default 1.05)
- Sea state and fouling factor (default 1.10 for early-stage design)
- Tailpipe allowance (tanks: broad and shallow 0.95; narrow and deep 0.98)
  - Fuel suction cannot completely empty the fuel tank

Economical Transit burnable fuel load

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

(Units are metric tons)

- Calculated Economical Transit Fuel Rate (kg/h)
  - Sum of fuel rates for propulsion and ship service electrical generation prime movers.
  - Propulsion power from each propulsion unit determined from speed power curve of online propulsion units and from propulsion scheduling table.
  - Ship service power provided by each generator set determined from 24-hour average ship service endurance electric power averaged over ambient condition profile (from EPLA) and generator scheduling table.
  - Fuel rates for each prime mover determined from prime mover sfc curves.

Surge to Theater burnable fuel load

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

(Units are metric tons)

- Calculated Surge to Theater Fuel Rate (kg/h)
  - Calculated in analogous way as the Calculated Economical Transit Fuel Rate (kg/h)

Operational Presence burnable fuel load

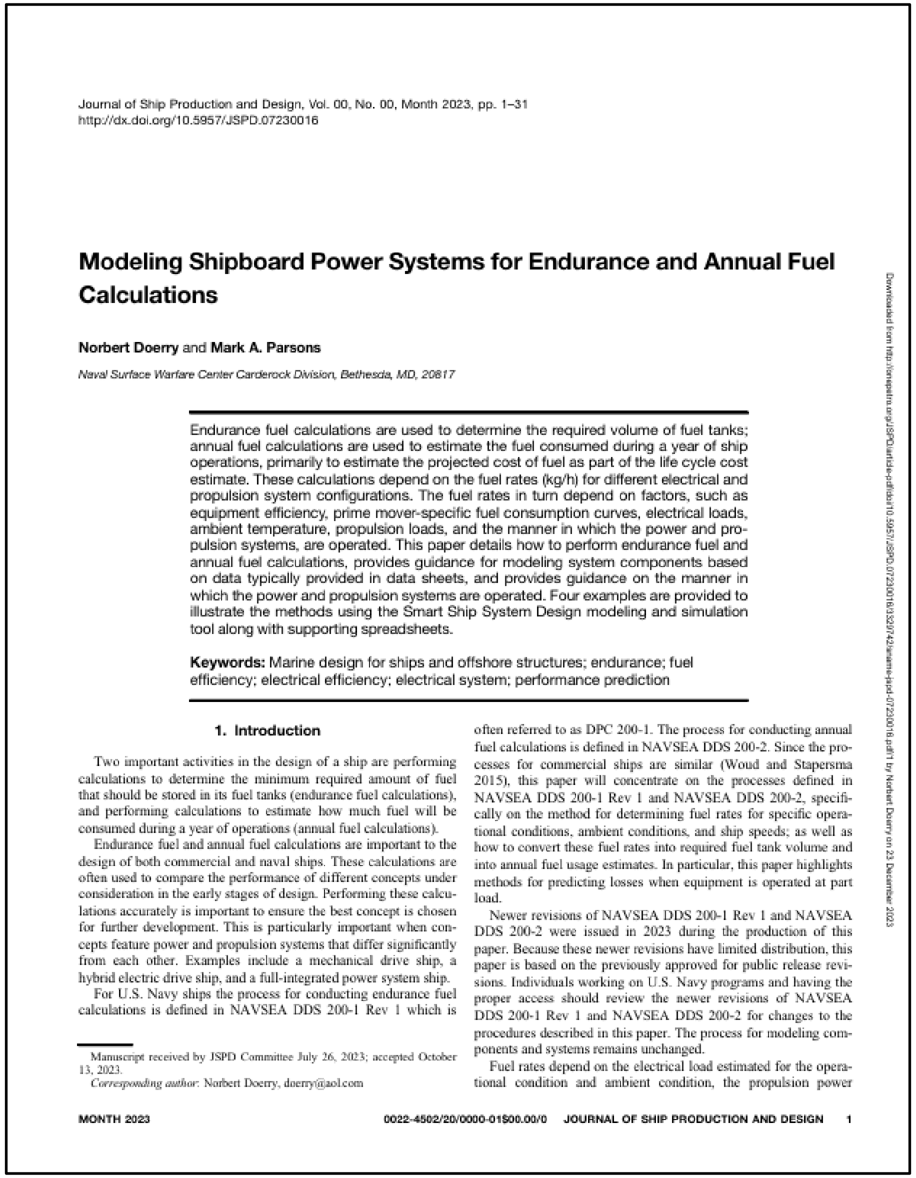
$$\frac{\text{Calculated Operational Presence Fuel Rate (kg/h)} \times \text{Operational Presence Time (h)} \times \text{Plant Deterioration Allowance}}{1000}$$

(Units are metric tons)

- Calculated Operational Presence Fuel Rate (kg/h)
  - Sum of fuel rates for propulsion and ship service electrical generation prime movers averaged using the percent of time for each speed in the operational profile.
  - Propulsion power from each propulsion unit determined from speed power curve of online propulsion units and from propulsion scheduling table for each speed in the operational profile.
  - Ship service power provided by each generator set determined from 24-hour average ship service endurance electric power averaged over ambient condition profile (from EPLA) and generator scheduling table.
  - Fuel rates for each prime mover (for each speed in the operational profile) determined from prime mover sfc curves and the amount of power provided by each prime mover.

Calculating Fuel Rates

- Specific method for calculating fuel rates depends on the details of the electrical power and propulsion architecture, the EPS-CONOPS, and the PS-CONOPS
- For details on modeling see:
  - Doerry, Norbert, and Mark A. Parsons, "Modeling Shipboard Power Systems for Endurance and Annual Fuel Calculations," SNAME J Ship Prod Des (2023)
- Also see DPC 200-1 for worked examples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Modeling Shipboard Power Systems for Endurance and Annual Fuel Calculations

Norbert Doerry and **Mark A. Parsons**

Naval Surface Warfare Center Carderock Division, Bethesda, MD, 20817

Endurance fuel calculations are used to determine the required volume of fuel tanks; annual fuel calculations are used to estimate the fuel consumed during a year of ship operations, primarily to estimate the projected cost of fuel as part of the life cycle cost estimate. These calculations depend on the fuel rates (kg/h) for different electrical and propulsion system configurations. The fuel rates in turn depend on factors, such as equipment efficiency, prime mover-specific fuel consumption curves, electrical loads, ambient temperature, propulsion loads, and the manner in which the power and propulsion systems, are operated. This paper details how to perform endurance fuel and annual fuel calculations, provides guidance for modeling system components based on data typically provided in data sheets, and provides guidance on the manner in which the power and propulsion systems are operated. Four examples are provided to illustrate the methods using the Smart Ship System Design modeling and simulation tool along with supporting spreadsheets.

Keywords: Marine design for ships and offshore structures; endurance; fuel efficiency; electrical efficiency; electrical system; performance prediction

1. Introduction

Two important activities in the design of a ship are performing calculations to determine the minimum required amount of fuel that should be stored in its fuel tanks (endurance fuel calculations), and performing calculations to estimate how much fuel will be consumed during a year of operations (annual fuel calculations).

Endurance fuel and annual fuel calculations are important to the design of both commercial and naval ships. These calculations are often used to compare the performance of different concepts under consideration in the early stages of design. Performing these calculations accurately is important to ensure the best concept is chosen for further development. This is particularly important when concepts feature power and propulsion systems that differ significantly from each other. Examples include a mechanical drive ship, a hybrid electric drive ship, and a full-integrated power system ship.

For U.S. Navy ships the process for conducting endurance fuel calculations is defined in NAVSEA DDS 200-1 Rev 1 which is often referred to as DPC 200-1. The process for conducting annual fuel calculations is defined in NAVSEA DDS 200-2. Since the processes for commercial ships are similar (Woud and Stapersma 2015), this paper will concentrate on the processes defined in NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2, specifically on the method for determining fuel rates for specific operational conditions, ambient conditions, and ship speeds; as well as how to convert these fuel rates into required fuel tank volume and into annual fuel usage estimates. In particular, this paper highlights methods for predicting losses when equipment is operated at part load.

Newer revisions of NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2 were issued in 2023 during the production of this paper. Because these newer revisions have limited distribution, this paper is based on the previously approved for public release revisions. Individuals working on U.S. Navy programs and having the proper access should review the newer revisions of NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2 for changes to the procedures described in this paper. The process for modeling components and systems remains unchanged.

Fuel rates depend on the electrical load estimated for the operational condition and ambient condition, the propulsion power

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Corresponding author: Norbert Doerry, doerry@aol.com

Calculating Required Fuel Tank Volume

- Design Endurance Fuel Load
  - Divide the largest of the three burnable fuel loads by the tailpipe allowance
- Convert to volume
  - The specific gravity of F76 fuel is about 0.84 kg/L (see DPC 200-2)
  - There are 1000 liters in a cubic meter
  - Hence specific gravity of F75 fuel is about 840 kg/m^3
- Add in allowances
  - Additional 5% volume for expansion of fuel
  - Additional volume (typically 2%) for internal structure

Special Cases

- See DPC 200-1 for special cases
- High speed ships
  - Accounts for reduction in drag as fuel is consumed
- Efficient high-speed operations
  - In some cases, ships can operate more economically at a higher speed than the economical transit speed
  - Ships that employ foils or other lifting surfaces may be in this category
- Using a profile to achieve economical transit speed on average
  - In some cases, ships can operate more economically when operating a portion of the time at a speed higher and the remaining time at a speed lower than the economical transit speed
  - Hybrid electric drive ships may be in this category