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MIL-STD-2189(SH)
SECTION 200-1
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MILITARY STANDARD

DESIGN METHODS FOR NAVAL SHIPBOARD SYSTEMS

SECTION 200-1

CALCULATION OF SURFACE SHIP ENDURANCE FUEL REQUIREMENTS

AMSC N/A FSC 1990

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND

Washington, DC 20362-5101

Design Methods for Naval Shipboard Systems
Calculation of Surface Ship Endurance Fuel Requirements

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FOREWORD

Purpose. The purpose of this standard is to set forth design methods for shipboard components or systems as designated in the title.

CONTENTS

1. GENERAL AND SCOPE

1.1 General. The procedures established by MIL-STD-2189 are applicable. This section and the basic standard are to be considered as an integral single document.

1.2 Scope. This standard contains the requirements for determining the minimum necessary fuel tankage for conventionally powered steam, diesel, or gas turbine ships or craft of the U.S. Navy.

2. REFERENCED DOCUMENTS

Not applicable.

3. DEFINITIONS

3.1 Endurance. Endurance is the theoretical distance which a ship can travel utilizing all of its burnable fuel (excluding cargo), at a specified speed, under ambient air and seawater conditions, in deep water, at full load displacement.

3.2 Design endurance power. Design endurance power is the shaft horsepower at the specified endurance speed, as indicated by the latest available speed-power curve applicable to the ship or craft. This curve may be either one prepared in the early design stages and based on predicted performance of the ship or craft, or one based on actual self-propelled model basin test results. It normally includes a correlation allowance (ΔC_f) of 0.0005, which represents the equivalent of freshly applied vinyl paint on surface ships. While the 0.0005 value is a reasonable approximation for the majority of endurance calculations, this factor is not a constant, applicable to all designs. Where a different correlation allowance is used, a correction is applied to allow for the different roughness. An accepted method for determining this correction is shown on figure 1.

3.3 Average endurance power. Average endurance power is the design endurance power increased by 10 percent. This increase is an allowance for adverse sea conditions and average bottom fouling over a 2-year period.

3.4 Average 24-hour electric load. Average 24-hour electric load is the average anticipated electric load, without growth, over a 24-hour period, with the ship or craft operating at the specified endurance speed under ambient air and seawater conditions.

3.5 Calculated all-purpose fuel rate. Calculated all-purpose fuel rate is the specific fuel rate in pounds per shaft horsepower-hour based on the total fuel consumption for propulsion machinery, ship service generators, and other services, with the ship or craft operating at the specified endurance speed under ambient air and seawater conditions. PRAIRIE MASKER systems are considered in operation 50 percent of the time for ships so fitted. For steam plants the calculated all-purpose fuel rate is the figure resulting from the heat balance calculations. For a diesel or gas turbine propelled ship or

craft, it is necessary to calculate the consumption of each service separately to arrive at the calculated all-purpose fuel rate.

3.6 Ambient conditions. Ambient conditions for use in determining the calculated all-purpose fuel rate are 100-degree Fahrenheit (°F) temperature and 40-percent relative humidity of air to the fuel-consuming services.

3.7 Specified fuel rate. Specified fuel rate is the calculated all-purpose fuel rate increased by a correction factor to allow a tolerance for measurement inaccuracy (torsion meter and shaft modulus) during ship acceptance trials, and for minor machinery design changes made during the construction period. This factor, used as a multiplier, is 1.04 if the average endurance power is one-third or less of the rated full power of the propulsion plant, 1.03 if between one-third and two-thirds, and 1.02 if between two-thirds and full power.

3.8 Average endurance fuel rate. Average endurance fuel rate is the specified fuel rate increased by 5 percent. This is an additional increase to allow for plant deterioration over a 2-year period.

3.9 Endurance fuel (burnable). Endurance fuel (burnable) is the actual fuel, in (long) tons, required to meet the specified endurance.

3.10 Tailpipe allowance. Tailpipe allowance is a factor applied as a divisor to the endurance fuel (burnable) to allow for the unavailable fuel remaining in the tanks but below the tailpipes. If the majority of tanks are broad and shallow, the factor is 0.95; if narrow and deep, it is 0.98.

3.11 Endurance fuel load. Endurance fuel load is the fuel load in tons obtained by dividing the endurance fuel (burnable) by the tailpipe allowance. It is the full load of ship's fuel for which tankage will be provided to meet the ship's endurance requirement. It does not include the additional 5 percent in equivalent tank volume which is provided to allow for expansion of fuel. For a compensated fuel system, see 4.2.

4. GENERAL REQUIREMENTS

4.1 Procedure. After calculation of the average endurance fuel rate, fuel requirements shall be determined by the following formulas:

(a) Endurance fuel (burnable), tons =

$$\frac{\text{Endurance} \times \text{average endurance power} \times \text{average endurance fuel rate}}{\text{Endurance speed} \times 2240}$$

(b) Endurance fuel load, tons =

$$\frac{\text{Endurance fuel (burnable)}}{\text{Tailpipe allowance}}$$

A sample calculation is shown on figure 2.

4.2 Compensated fuel system expansion allowance. In calculating endurance fuel load for a ship fitted with a compensated fuel system, an allowance of less than 5 percent may be provided to allow for expansion of fuel; however, this allowance shall be determined on a case basis.

5. DETAILED REQUIREMENTS

Not applicable.

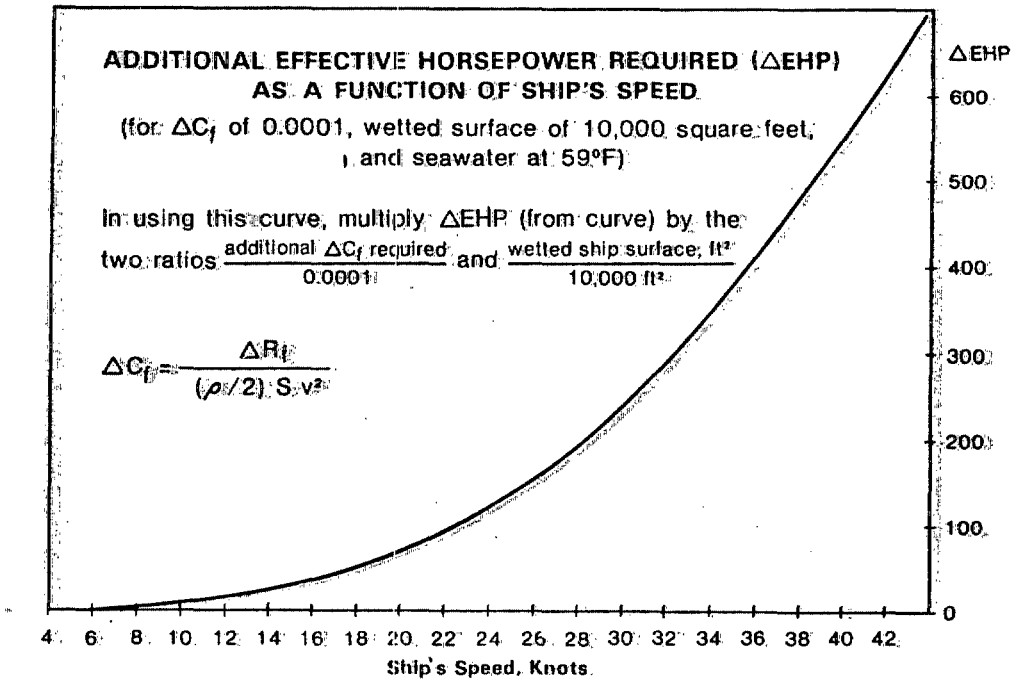
6. NOTES

6.1 Intended use. This standard is intended to establish the endurance requirements for Naval ships or craft.

6.2 Subject term (key word) listing.

Diesel powered
Energy consumption
Gas turbine
Steam powered

Preparing activity:
Navy - SH
(Project 1990-N074)



Sample calculation: To find the added effective horsepower (EHP) required for a guided missile cruiser (CG) at 30 knots when increasing ΔC_f from 0.0006 to 0.0008.

The wetted surface of the CG is 32,000 square feet. From the curve Δ EHP = 236 at 30 knots.

Then, added EHP (at 30 knots)

$$= (236) \times \frac{(0.0002)}{(0.0001)} \times \frac{(32{,}000)}{(10{,}000)}$$

$$= (236) \times (2) \times (3.2)$$

= 1510 horsepower, answer.

Caution: Note that this curve gives the additional EHP required. To obtain the required additional SHP, the result must be divided by propulsion coefficient at speed in question.

Symbols used above:

ΔC_f	=	Correlation allowance, treated as an increase in the coefficient of frictional drag.
ΔR_f	=	Increased frictional drag, pounds
ρ	=	Density of seawater, pound-second^2 per foot^4 (= 1.9905 slugs per foot^3 at 59°F).
S	=	Wetted surface area of ship, square feet
v	=	Speed of ship, feet per second.

FIGURE 1. Calculation to correct for changes in wetted surface roughness.

Design _____
Prepared by _____
Checked by _____

		Examples	
		Steam	Diesel or gas turbine
(1)	Endurance required, nautical miles	3,000	1,200
(2)	Endurance speed, knots	15	6
(3)	Full load displacement, tons	3,000	400
(4)	Rated full power, SHP	50,000	700
(5)	Design endurance power at (2) and (3), SHP	3,000	150
(6)	Average endurance power, SHP: (5) X 1.10	3,000 X 1.10 = 3,300	150 X 1.10 = 165
(7)	Ratio, average endurance power to rated full power: (6)/(4)	0.066	0.24
(8)	Average endurance, brake horsepower (BHP): (6)/transmission efficiency	---	165/0.95 = 174
(9)	Average 24-hour electric load, kilowatts (kW)	500	30
(10)	Calculated propulsion fuel rate at (8), lb/(BHP-hr)	---	0.479
(11)	Calculated propulsion fuel consumption, pounds/hour: (10) X (8)	---	0.479 X 174 = 83.3
(12)	Calculated ship service generator fuel rate at (9), lb/(kW-hr)	---	0.690
(13)	Calculated ship service generator fuel consumption, pounds/hour: (12) X (9)	---	0.690 X 30 = 20.7
(14)	Calculated fuel consumption for other services, pounds/hour	---	15.0 (heating)
(15)	Total calculated all-purpose fuel consumption, pounds/hour: (11) + (13) + (14)	---	83.3+20.7+15.0 = 119.0
(16)	Calculated all-purpose fuel rate, lb/(SHP-hr): (15)/(6) or heat balance	1.00	119.0/165 = 0.721
(17)	Fuel rate correction factor based on (7).	1.04	1.04
(18)	Specified fuel rate, lb/(SHP-hr): (16) X (17)	1.00 X 1.04 = 1.04	0.721 X 1.04 = 0.750
(19)	Average endurance fuel rate, lb/(SHP-hr): (18) X 1.05	1.04 X 1.05 = 1.09	0.750 X 1.05 = 0.788

FIGURE 2. Sample surface ship endurance calculation.

	Steam	Diesel or gas turbine
(20) Endurance fuel (burnable), tons: (1) x (6) x (19)/[(2) X 2240]	$\frac{3,000 \times 3,300 \times 1.09}{15 \times 2240} = 321$	$\frac{1,200 \times 165 \times 0.788}{6 \times 2240} = 11.6$
(21) Tailpipe allowance factor	0.98	0.95
(22) Endurance fuel load, tons: (20)/(21)	321/0.98 = 328	11.6/0.95 = 12.2

References for source data:

Design endurance power _____
Transmission efficiency _____
Calculated propulsion fuel rate _____
Calculated ship service generator fuel rate _____
Calculated fuel consumption for PRAIRIE MASKER _____
Calculated fuel consumption for other services _____
Heat balance _____
Full load displacement _____

FIGURE 2. Sample surface ship endurance calculation. - Continued

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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
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3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR
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b. ADDRESS *(Street, City, State, ZIP Code)*	☐ MANUFACTURER
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5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
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