Ship Operational Conditions and Mission Profiles

Examples

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1. Introduction

Document D_000009 provides a detailed introduction to operational conditions and profiles. This document focuses instead on the application of operational conditions and profiles to endurance fuel calculations (operational presence) and annual energy usage calculations using the examples in DPC 200-1 and DPC 200-2 respectively.

2. Endurance fuel calculations – operational presence (DPC 200-1)

DPC 200-1 provides two worked examples for conducting endurance fuel calculations. This document focuses on the operational presence calculations in DPC 200-1; DPC 200-1 also includes calculations for economical transit and surge to theater.

The goal of endurance fuel calculations is to determine the endurance fuel load that the ship is required to carry in its fuel tanks.

2.1. Example 1: mechanical drive use case

2.1.1. Service requirements:

The operational presence speed-time profile is provided in Table I. The operational presence time is 240 hours and the default ambient condition profile as depicted in Table II is used.

Table I: Operational presence speed-time profile

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

Table II: Default ambient condition profile

Percent of time	Temperature (°F)	Relative Humidity
25%	10	95%
50%	59	95%
25%	100	40%

2.1.2. Design details

Electrical power is provided by two of three 3000 kW gas turbine generator (GTG) sets. The generator set scheduling table has only one configurating consisting of two GTGs online at all times. Document D_000001 provides guidance for developing a generator set scheduling table.

The ship service electric load for the Condition III and Mission operational conditions as calculated from the EPLA (see DPC 310-1, IEEE Std 45.1 and IEEE Std. 45.3) are shown in Table III. The electric load depicted includes margin, service life allowance, and power system efficiency; these powers are those that must be provided by the GTGs.

The ship has a propulsion configuration consisting of a twin shaft mechanical drive driven by up to four 15 MW propulsion gas turbines (MTG); two propulsion gas turbines and a reduction gear per shaft. The propulsion system may be operated in one of three modes: Trail shaft with one MTG driving one shaft and the other shaft freewheeling; split plant with one MTG online on each of the two shafts; and full plant with all four MTGs online. The propulsion scheduling table and speed-power curve is depicted in Table IV; power is measured on the propeller shaft. Document D_000002 provides guidance for developing a propulsion scheduling table.

Specific fuel consumption (sfc) data for the MTGs are provided in Table V and are provided for the GTGs in Table VI. Power is measured at the shaft output of the MTG, and at the generator output terminals for the GTGs. The reduction gear is assumed to have a constant efficiency of 0.975. See Doerry and Parsons (2023) for additional guidance with respect to MTG sfc, GTG sfc as well as reduction gear efficiency.

The default plant deterioration allowance of 1.05 is used along with a sea state and fouling factor of 1.10 for every speed. Use 0.95 Tailpipe allowance for broad and shallow tanks.

Table III: Ship service electric load

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

Table IV: Propulsion scheduling table and 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

Table V: Propulsion gas turbine (MGT) sfc curve

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

Table VI: Gas Turbine Generator (GTG) sfc curve

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

2.1.3. Calculations

Table VII shows the calculations for determining the fuel rate for propulsion. The speed and profile % time are taken from Table I. The propulsion power is from Table IV. The Average Mission Power Profile is the Propulsion Power multiplied by the Sea State and Fouling Factor. The number of MGT online is from Table IV. The Power per MGT is is

Average Mission Power Profile divided by the Number of MGT Online and Reduction Gear Efficiency. The MGT SFC is interpolated from Table V. When interpolating SFC curves, it is best to convert the SFC curves to fuel rate, interpolate based on the fuel rate, then covert back to SFC. See Doerry and Parsons (2023) for details. The Weighted Fuel rate is the Fuel Rate multiplied by the Profile % time.

Analogous calculations for the electric plant are shown in Table VIII.

The calculated operational presence fuel rate is the sum of the Total Propulsion Fuel Rate and the Electric Plant Fuel Rate: 2858 kg/h + 1210 kg/h = 4068 kg/h

The operational presence burnable fuel load is equal to the Calculated operational fuel rate (4068 kg/h) times the Operational presence time (240 hours) times the Plant deterioration allowance (1.05) divided by 1000 kg/metric ton which equals 1025 metric tons.

If the operational presence burnable fuel load is larger than the economical transit burnable fuel and the surge to theater burnable fuel load (in the DPC 200-1 example, this is not the case) then the Endurance fuel load is equal to the design burnable fuel load (1025 metric tons) divided by the tailpipe allowance (0.95) which equals 1079 metric tons.

Table VII: Propulsion fuel rate (kg/h)

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

Table VIII: Electric plant fuel rate (kg/h)

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

2.2. Example 2: integrated power system use case (DPC 200-1)

2.2.1. Service requirements

The service requirements are the same as for Example 1.

2.2.2. Design details

The propulsion plant consists of two shafts, each with a propulsion motor module (PMM). Propulsion power is equally shared between the two PMMs.

The electrical power system has two 3 MW gas turbine auxiliary turbine generator sets (ATGs) and three 24 MW gas turbine main turbine generator sets (MTGs). At least two generator sets are on at all times. Power is shared among online generator sets such that the ratio of the load provided to their rating is a constant.

Table IX depicts the generator set scheduling table. The process for creating a generator set scheduling table is detailed in document D_000001.

The ship service electrical loads are identical to Example 1 and are depicted in Table III.

The speed power curve and PMM efficiency are depicted in Table X. See Doerry and Parsons (2023) for guidance in estimating PMM efficiency.

The specific fuel consumption for the MTG is as depicted in Table XI. The ATG specific fuel consumption is identical to the GTG from Example 1 and is depicted in Table VI.

The plant deterioration allowance, sea state and fouling factor, and tailpipe allowance are the same as for Example 1.

Table IX: Generator Set Scheduling Table

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

Table X: Speed Power Curve and PMM efficiency

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

Table XI: 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

2.2.3. Calculations

Table XII, Table XIII, and Table XIV demonstrate the calculations for each of the temperatures in the ambient condition profile. The propulsion electric load is the Total Propulsion Shaft Power multiplied by the sea state and fouling factor and divided by the PMM efficiency. The propulsion electric load and the ship service electric load are added to obtain the total electrical load. The fuel rates for the MTGs and ATGs are obtained by interpolating the SFC rates based on the power allocated to each generator set. See section 2.1.3 for details on calculating SFC rates. The weighted fuel rate for a given speed is the portion of the time at that speed times the fuel rate at that speed. The weighted fuel rates are summed to provide the operational presence fuel rate for a given temperature. As depicted in Table XV, the operational presence fuel rates for the different temperatures are combined using the ambient condition profile to determine the Calculated operational fuel rate.

The operational presence burnable fuel load is equal to the Calculated operational fuel rate (3150 kg/h) times the Operational presence time (240 hours) times the Plant deterioration allowance (1.05) divided by 1000 kg/metric ton which equals 794 metric tons.

If the operational presence burnable fuel load is larger than the economical transit burnable fuel and the surge to theater burnable fuel load (in the DPC 200-1 example, this is not the case) then the Endurance fuel load is equal to the design burnable fuel load (794 metric tons) divided by the tailpipe allowance (0.95) which equals 836 metric tons.

Table XII: Operational presence calculations for 10 °F

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

Table XIII: Operational presence calculations for 59 °F

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

Table XIV: Operational presence calculations for 100 °F

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

Table XV: Operational presence fuel rate calculations

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

3. Example 3: Annual energy usage calculations (DPC 200-2)

DPC 200-2 includes a fictional example for estimating the fuel consumed by a ship over its service life considering two operational tempos (OPTEMPOs) intended to provide a low and a high estimate.

3.1. Operational mode development

The operational modes should be based on how the ship is intended to be operated from the perspective of the fleet owner; each operational mode should have a significantly different fuel consumption rate. The set of operational modes should be sufficient to apply to every day of the ship's service life. For this fictional ship the operational modes are identified to be:

- Maintenance and modernization
- Predeployment training
- Deployment
- Major combat operations (MCO)

3.2. Ship state development

Where possible, the ship states should align with the ship operating conditions used in the EPLA. Where such alignment is not possible, a new ship operating condition that aligns with the ship state should be created and an EPLA performed. For this example, the ship states identified are:

- Inport – shore (24-hour average for "shore" operating condition)
- Underway – economical transit (24-hour average for "cruising" operating condition)
- Underway – surge to theater (24-hour average for "cruising" operating condition)
- Underway – mission (24-hour average for "functional" operating condition)

When inport, the ship does not operate propulsion equipment.

When underway – economical transit, the design propulsion power is 7.1 MW, equally split between the two shafts.

When underway – Surge to theater, the design propulsion power is 46.8 MW, equally split between the two shafts.

When underway – mission, the ship employs the speed profile depicted in Table XVI.

Table XVI: Speed profile for underway – mission ship state

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

3.3. Design details

The fictional ship has design service life of 15 years; year 1 is assumed to be 2015. A single year-long modernization overhaul is required midway through its service life.

The fictional ship employs an integrate power system. The ship service load, determined from the EPLA is presented in Table XVII. Power generation consists of two Auxiliary Turbine Generators (ATGs), each with a 3 MW rating and three Main Turbine Generators (MTGs), each with a 24 MW rating. At least two generator sets are online at all times as indicated by the generator set scheduling table depicted in Table XVIII. Power is shared such that the power provided by each generator set divided by its rating is the same for online generator sets. The propulsion speed power curve and propulsion scheduling table is depicted in Table XIX. The MTG sfc curve is depicted in Table XX and the ATG sfc curve is depicted in Table XXI.

For a plant deterioration allowance, use a default 1.05. For a sea state and fouling factor, use a default 1.10 for every speed. Use the default ambient condition profile depicted in Table II.

Table XVII: Ship service load for each ship state

Temperature (°F)	Inport - Shore (kW)	Underway - Economical Transit (kW)	Underway - Surge to Theater (kW)	Underway - Mission (kW)
	Shore Power	Generators	Generators	Generators
10	1000	3000	3000	4800
59	500	1800	1800	3200
100	900	2400	2400	4000

Table XVIII: Generator set scheduling table

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

Table XIX: 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

Table XX: MTG sfc curve

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

Table XXI: ATG sfc curve

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

3.4. Ship state participation table development

As depicted in Table XXII, the ship state participation table relates the ship states to the operational modes. The operational modes are associated with the rows, and the ship states are associated with the columns. For each operational mode, the columns represent the fraction of time the ship is in each ship state. As such, the values in each row should sum to 1.0.

The ship state participation table should ideally be based on historical data. Unfortunately, the data isn't always readily available; in these cases, the modeler should use expert judgement to establish the table values. If possible, sensitivity analysis should be performed to determine the sensitivity of the final calculated values to assumptions embodied in the ship state participation table.

Table XXII: Ship state participation table

	Inport – shore	Underway – Economic al Transit	Underway – Surge to Theater	Underway – Mission
Maintenance and Modernization	0.9	0.05	0.0	0.05
Predeployment Training	0.6	0.2	0.0	0.2
Deployment	0.1	0.2	0.0	0.7
MCO	0.05	0.15	0.05	0.75

3.5. Ship deployment and employment profile

The ship deployment and employment profile assigns the fraction of time spent in each of operational modes for each year in the ship's service life. It is not unusual to explore multiple ship deployment and employment profiles to explore the range of fuel consumption possible over the ship's service life. In this example, two profiles were developed. In practice, one may consider developing many more. If historical data is available, then the development of Markov chains as detailed by Doerry and Koenig (2017) may enable the production of many ship deployment and employment profiles that are statistically similar to the historical data.

Variations of Markov chains are also possible. One alternate method applies a pdf to the length of time in each operational mode and sets the diagonal elements of the transition matrix to 0 to prevent transitioning to the same operational mode; one always transitions to a different operational mode. This technique is useful if each of the operational modes has a characteristic length that has some variation, but is different from the other operational modes.

For this fictional ship, two ship deployment and employment profiles were used: one represents a low operational tempo; and the other represents a high operational tempo. These profiles are depicted in Table XXIII.

Table XXIII: Ship deployment and employment profiles

Year	Low OPTEMPO (fraction of time) Maintenance and Modernization	Low OPTEMPO Predeployment Training	Low OPTEMPO Deployment	Low OPTEMPO MCO	High OPTEMPO (fraction of time) Maintenance and Modernization	High OPTEMPO Predeployment Training	High OPTEMPO Deployment	High OPTEMPO MCO
1	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
2	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
3	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
4	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
5	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
6	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
7	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
8	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
9	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
10	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
11	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
12	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
13	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
14	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
15	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0

3.6. Calculations of fuel consumed by ship

Once all the design data (including the EPLA) and profiles have been established, then the calculations of fuel usage follow the methods described in DPC 200-1. Initially, the fuel rates are calculated for each of the operational modes as depicted in Table XXIV.

Table XXIV Operational mode fuel rates

	Inport - Shore	Underway - Economical Transit	Underway - Surge to Theater	Underway - Mission	Calculated Operational Mode Fuel Rate (kg/h)
Fuel Rate(kg/h)	0	3070	12028	3150	
Maintenance and Modernization	90%	5%	0%	5%	311
Predeployment Training	60%	20%	0%	20%	1244
Deployment	10%	20%	0%	70%	2819
MCO	5%	15%	5%	75%	3424

As depicted in Table XXV and Table XXVI , these fuel rates are then applied to the ship deployment and employment profile to determine the estimated fuel consumed in each year and across the ship's service life.

Table XXV Low OPTEMPO fuel consumption

Year	Maintenance and Modernization (1000 kg)	Predeployment Training (1000 kg)	Deployment (1000 kg)	MCO (1000 kg)	Total Fuel (1000 kg)
1	682	2,726	12,356	0	15,763
2	682	2,726	12,356	0	15,763
3	682	2,726	12,356	0	15,763
4	682	2,726	12,356	0	15,763
5	682	2,726	12,356	0	15,763
6	682	2,726	12,356	0	15,763
7	682	2,726	12,356	0	15,763
8	2,726	0	0	0	2,726
9	682	2,726	12,356	0	15,763
10	682	2,726	12,356	0	15,763
11	682	2,726	12,356	0	15,763
12	682	2,726	12,356	0	15,763
13	682	2,726	12,356	0	15,763
14	682	2,726	12,356	0	15,763
15	682	2,726	12,356	0	15,763
				Lifetime Fuel (1000 kg)	223,415

Table XXVI High OPTEMPO fuel consumption

Year	Maintenance and Modernization (1000 kg)	Predeployment Training (1000 kg)	Deployment (1000 kg)	MCO (1000 kg)	Total Fuel (1000 kg)
1	682	2,726	12,356	0	15,763
2	682	2,726	12,356	0	15,763
3	682	2,726	12,356	0	15,763
4	682	2,726	12,356	0	15,763
5	682	2,726	12,356	0	15,763
6	682	2,726	12,356	0	15,763
7	682	2,726	12,356	0	15,763
8	2,726	0	0	0	2,726
9	682	2,726	12,356	0	15,763
10	682	2,726	12,356	0	15,763
11	682	2,726	0	20,112	22,402
12	682	2,726	0	20,112	22,402
13	682	2,726	0	20,112	22,402
14	682	2,726	12,356	0	15,763
15	682	2,726	12,356	0	15,763
				Lifetime Fuel (1000 kg)	243,331

4. References

DPC 200-1 Calculation of Surface Ship Endurance Fuel Requirements

DPC 200-2 Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy

DPC 310-1 Electric Power Load Analysis (EPLA) for Surface Ships.

IEEE Std 45.1 IEEE Recommended Practice for Electrical Installations on Shipboard – Design.

IEEE Std 45.3 IEEE Recommended Practice for Shipboard Electrical Installations – Systems Engineering.

Doerry, Dr. Norbert H. and Dr. Philip Koenig, "Framework for Analyzing Modular, Adaptable and Flexible Surface Combatants," presented at SNAME Maritime Convention, Houston, TX, October 25-27, 2017

Doerry, Norbert, and Mark A. Parsons, "Modeling Shipboard Power Systems for Endurance and Annual Fuel Calculations," SNAME J Ship Prod Des (2023)

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