Operating Conditions and Profiles

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September 1, 2025

1. Introduction

When performing a number of types of analyses, knowing what equipment is part of the ship and how that equipment is interconnected is necessary, but not sufficient. Often, an understanding of how the ship and its systems are intended to be used by the operator at various times is also needed; one method of modeling how the ship is intended to be used is to define operating conditions, operating profiles, and associated relationships.

Variations of operating conditions and profiles are used in the ship design process to ensure power generation and distribution equipment is properly sized (DPC 310-1and IEEE 45.1), to ensure fuel tanks are properly sized (DPC 200-1), and to estimate the amount of fuel consumed in a year (DPC 200-2). While the ship is operational, custom operating conditions and profiles may be employed to estimate fuel usage on a particular voyage or deployment. While this document concentrates on the use of operating conditions and profiles with naval ships, analogous methods apply to commercial ships.

With some variation, a ship normally operates in one of a set of operational conditions (also known as ship states). Each operational condition describes which loads are online, and the amount of time each load is on. If a load can have different operating states with significantly different power demands, then the amount of time in each operating state is needed. Depending on the type of analysis, the set of operational conditions may vary somewhat. For example, in determining the required rating of power system components, an electric power load analysis (EPLA) is conducted using at a minimum, the following operational conditions:

1. Anchor
2. Shore
3. Cruising
4. Functional (Can have more than one)
5. Emergency

Additional operating conditions may be defined if needed to determine the required rating of specific equipment.

The list of operational conditions used for endurance fuel calculations are:

1. Cruise with self defense capability (Cruising)
2. Mission (Functional)

An example of the list of ship states that may be used in annal fuel calculations could include:

1. Inport – shore (Shore)
2. Inport – anchor (Anchor)
3. Underway – peacetime cruising
4. Underway – wartime cruising (Cruising)
5. Underway – Anti-Submarine Warfare (ASW) operations (Functional)
6. Underway – Anti-Air Warfare (AAW) operations (Functional)
7. Underway – Anti-Surface Warfare (AsuW) operations (Functional)
8. Underway – Surveillance operations (Functional)
9. Underway – Theater Ballistic Missile Defense (TBMD) station (Functional)

The definition of each operating condition / ship states generally does not include propulsion power. In mechanical drive ships, the propulsion power demand is usually assumed to be distinct and separate from the ship service power demand. In integrated power systems (IPS) and hybrid electric drive systems (HED), propulsion power is linked to the ship service power demand. Depending on the type of analysis, the propulsion loads associated with each operating condition / ship state may be needed. The propulsion loads are often defined in terms of a table of ship speeds and percentage of time the ship operates at that speed while in the corresponding operating condition / ship state; this table is often called a speed-time profile.

For each type of analysis, the analyst should clearly document assumptions for which ship systems are online, and if necessary, the equipment operating mode. These assumptions may be documented through means such as a study guide, technical report, or as a model within a model-based systems engineering (MBSE) environment.

While the operating condition / ship sates indicate which loads are online and offline, in real operations, the operator has considerable flexibility in deciding how to configure and operate the ship systems. Hence an operating conditions / ship states is really an estimate of how the ship will function when in service on a particular voyage.

Annual fuel calculations generally require a higher-level definition of how the customer intends to employ the ship in any given month (or other similar time interval); these definitions are called "operational modes." Ship states are not directly used because ships are seldom operating in the same ship state / operational condition for a full month. Operational modes are linked to ship states via a ship state participation tables which lists the faction of time that each ship state is applicable for a given operational modes. Possible examples of operational modes for naval ship include:

1. Presence and training at home
2. Presence overseas
3. Theater Ballistic Missile Defense (TBMD) operations
4. Lesser contingencies
5. Major Combat Operations (MCO)
6. Maintenance and modernization

The operational modes are aligned with how long-range schedules are developed for naval ships. In a ship deployment and employment profile, one of the operational modes is assigned to each month of the ship's design service life. This deployment and employment profile impacts not only cost estimates, but also reliability estimates. It is also possible to create multiple deployment and employment profiles to understand the variation in cost and reliability due to possible variations in the deployment and employment profile.

2. Application of operational conditions and profiles

Operational conditions and profiles are used somewhat differently for each type of analysis. The set of operational conditions and profiles used for each type of analysis should be large enough (but no larger) to enable producing accurate answer for achieving the analysis goals.

If the goal of the analysis is to determine ratings of power system equipment, then operational conditions should be created to find the worst plausible case that impacts the rating. The objective typically is to determine, at a minimum, the required rating of generators, switchboard bus bars, bus tie ampacity, transformer ratings, power electronic converter ratings, and shore power connection ratings. Other considerations include avoiding lightly loading generator sets for operational conditions that are likely to happen relatively often. The limiting operating condition for one power generation and distribution piece of equipment may differ from the limiting operating condition for other power generation and distribution equipment.

For endurance fuel calculations, the operational condition names are defined to be Cruise with self-defense capability and Mission. These operational conditions are used to calculate the 24-hour average endurance ship service electrical load, the 24-hour average sustained ship service electric load, and the 24-hour average mission ship service electric load profile. The endurance speed, sustained speed, and speed-time profile are used to define the propulsion requirement. As indicated previously, it is still up to the analysts to determine and document what equipment is online and offline for each of the operational conditions.

For annual fuel calculations, sufficient operating conditions are defined to cover ship operations over an entire year; the different operating conditions should have significantly different fuel usage implications. Additionally, sufficient operating modes are defined to enable assigning one to every month of the ship's service life in a ship deployment and employment profile; they should align with how the customer actually schedules the ship's employment. A ship state participation table provides a mapping between the ship states / operating conditions and the operating modes. See DPC 200-2 for additional details and examples.

3. Creating operational conditions and profiles

Ideally, the operational conditions and profiles would be developed as part of a rigorous MBSE process. This MBSE process would provide traceability of the operational conditions and profiles

to the ship requirements; changes to the ship requirements could flow to changes in the operational conditions.

This level of MBSE may not be performed in the earlier stages of design, if at all. The limited time and resources available in concept studies may delay the use of MBSE until Preliminary Design.

In the early stages of design, operational conditions and profiles can be developed by analogy to other ships. Through digital twin technologies, it is now possible to determine what equipment is online for a particular operating condition of an in-service ship. This data can be used to help refine the definitions of what equipment is online for a particular operating condition for new design or modified repeat design ships with similar missions.

As a last resort the load factor tables in DPC 310-1 and IEEE 45.1 incorporate assumptions as to how a "typical" ship will operate for a given operational condition.

4. Implications of operational conditions and profiles on design

Each of the different uses for operational conditions and profiles, and their associated load estimates, can significantly impact the design and cost of a ship. If the load estimates are too low, the ship may not meet its requirements, or require extensive and expensive changes to meet the requirements. If the load estimates are too high, expensive and unnecessary capacity may be designed into the system. Of particular importance is if the load estimates indicate a need to use more expensive and volume intensive medium voltage generation and distribution when in fact the loads experienced in service indicate that a low voltage generation and distribution system would be adequate. Similarly, if the load estimates indicate that a low voltage generation and distribution system would be adequate, but the loads experienced in service indicate that much higher loads, then the cost and operational limitations necessary to mitigate the limits of low voltage distribution capacity could be prohibitive.

5. 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