Developing a propulsion scheduling table

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January 18, 2025

1. Introduction

An important element of a Propulsion System Concept of Operation (Propulsion-CONOPS) is a propulsion scheduling table. This table indicates for a given range of propulsion load, the online status of propulsion prime movers and propulsion motors, and for those propulsion prime movers and propulsion motors that are online, the method to determine how much mechanical power is provided by each propulsion prime mover and propulsion mover, and the amount of power consumed by each propulsor. Table I is a simple example of a propulsion scheduling table for an Integrated Power System (IPS) with two shafts and two motors per shaft. Two motors, which may share a common housing, operating on the same shaft offer the opportunity for increased efficiency when less than 50% propulsion power is required. The table indicates which propulsion motors are online, and for those that are online, how propulsion power is shared.

Propulsion plant line-ups where there is only one prime mover / propulsion motor online per shaft are often called "split plant." If all prime movers / propulsion motors are online on all shafts, the propulsion plant line-up is often called "Full Power."

Propulsion plants can include "combined plants" that integrate different types of propulsion prime movers, or propulsion prime movers and electric propulsion motors. These propulsion plants may have additional propulsion plant line-ups with ship unique names.

Each operational condition of the ship may have its own scheduling table. Operational conditions where the ship must maneuver or take station alongside another vessel may call for all available propulsion motors and propulsion prime movers to be online for any speed (Full Power).

Table I: Propulsion scheduling table for an IPS system with 2 motors per shaft (Doerry and Parsons 2023)

	Propulsion motor 1	Propulsion motor 2	Propulsion motor 3	Propulsion motor 4
Rating (MW)	15	15	15	15
$0 <$ Total propulsion ≤ 30 MW	1/2 Power	Offline	Offline	1/2 Power
$30 <$ Total propulsion ≤ 60 MW	1/4 Power	1/4 Power	1/4 Power	1/4 Power

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2. Discussion

For the cruise operational condition (and perhaps other operational conditions), fuel economy is typically the highest priority when constructing a propulsion scheduling table. In deciding which propulsion prime movers or propulsion motors to employ, the losses and fuel rates associated with each option should be calculated and the configuration with the best fuel economy should be chosen.

Constructing the propulsion scheduling table can be straight forward for simple propulsion systems, such as those where 1 or 2 prime movers or motors are dedicated to powering each shaft and all shafts share power equally to provide mechanical power to identical propellers. In these cases, the propulsion scheduling table will almost always be very similar to Table I. The propulsion scheduling table for combined plants may be more complex.

In some cases, it may be desirable to shift from one prime mover / propulsion motor per shaft to two prime movers / propulsion motor prior to reaching the rated power of the single unit. An example would be if the prime mover / propulsion motor is controlled to regulate the shaft speed rather than the shaft power. Since the amount of power required to maintain a regulated shaft speed will vary with time, especially in higher sea states, the average power should be less than the rated power. Regulating shaft speed may be desirable if a ship is operating alongside another vessel, such as during underway replenishment. Shaft speed is typically linearly related to the ship's speed; adding or subtracting an rpm can facilitate keeping station on the other vessel. Other times, the prime mover / propulsion motor may be operated in constant power mode; here the switch from one to two prime movers / propulsion motors may occur at the rated power of a single unit. Power regulation typically places the lowest mechanical stresses on the power and propulsion system. In certain situations, such as when ice breaking or when travelling through water with debris, it may prove beneficial to regulate torque; the potential for damage to the propeller is reduced as the power to the shaft is automatically reduced if the propeller slows due to hitting ice or debris.

At low speeds, the "trail shaft" propulsion plant line-up can be more economical than powering both shafts. When operating in trail shaft, one shaft is not powered and left to freewheel. All power is provided on the other shaft. Because the propeller providing power is no longer operating at the design advance coefficient J, its open water efficiency is no longer the same as if both shafts are powered. Similarly, the wake fraction and thrust deduction factor are also likely to change. The trailing shaft propeller and rudder action to steer a straight course also provide additional drag. On the other hand, most motors (and associated drives) as well as propulsion prime movers, have no load losses and fuel rates; there is a penalty associated with turning a motor, gas turbine, or diesel engine on. If the additional losses associated with the propellor operating in trail shaft are less than losses associated with having additional gas turbines, diesel engines, and motors online, then operating in trail shaft is beneficial. Usually, but not always, trail shaft operation is not more economical with mechanical drive diesel configurations and electric propulsion configurations. Trail shaft operation has been found to be economical in certain gas turbine mechanical drive configurations as shown in Figure 1. Understanding the speed ranges where trail shaft operation is economical requires a significant study of the propulsion system. Note that in Figure 1 the fuel rates of the electrical power generators are included; at low ship speeds, more fuel is consumed to generate electricity than used to propel the ship. The differences between the curves are due to the propulsion plant line-up.

Operating at trail shaft may be limited by shaft, reduction gear, and propeller maximum torque ratings. Both power and torque should be examined to determine when it is necessary to shift from trail shaft to split plant.

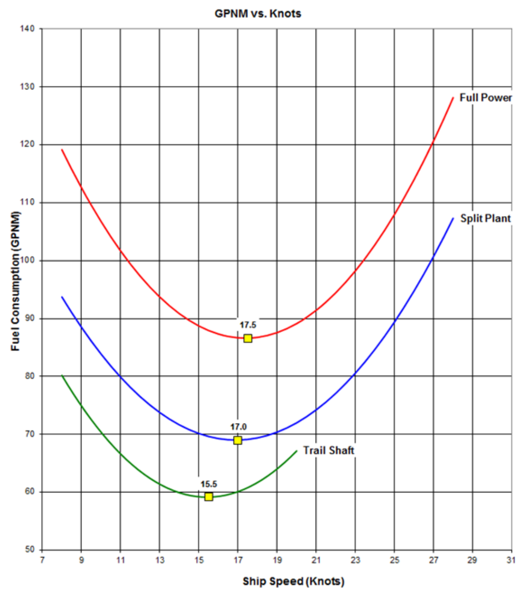

Figure 1: Fuel Consumption for Trail Shaft, Spit Power, and Full Power for DDG 51 Class ships (NAVSEA SL101-AA-GYD-00)

3. References

Doerry, Norbert, and Mark A. Parsons, "Modeling Shipboard Power Systems for Endurance and Annual Fuel Calculations." J Ship Prod Des (2023;): doi: https://doi.org/10.5957/JSPD.07230016

NAVSEA Technical Publication – Shipboard Energy Conservation Guide, SL101-AA-GYD-010 Revision 5. 19 July 2016.