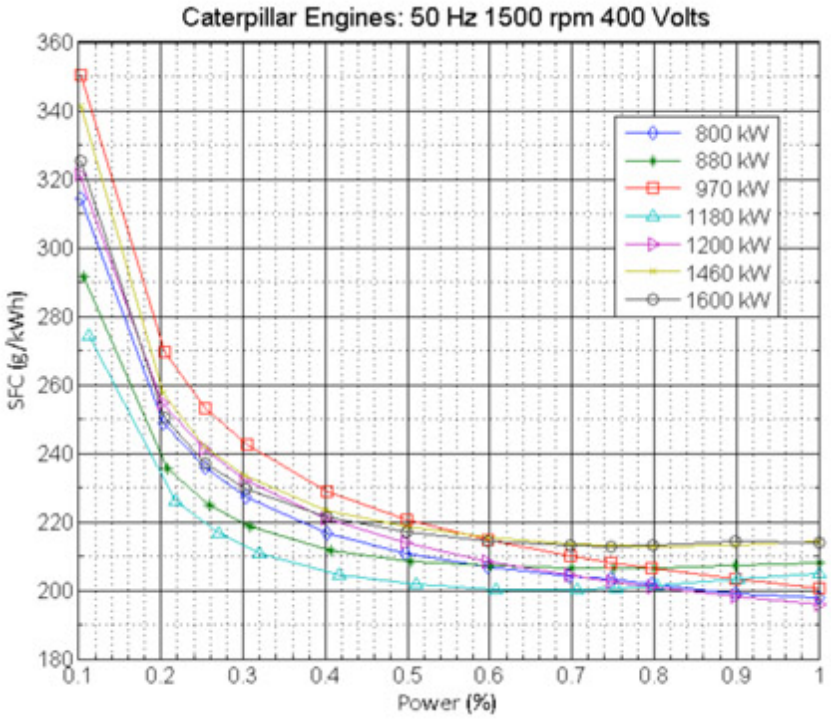
Diesel Generator Set Optimization for Marine Transportation

Introduction

It is well known that for a given use profile, the number of specific motors and generators on a ship can be optimized. The formal optimization can consider such factors as purchase cost, fuel economy, maintenance logistics, size, and weight. In addition, it has been shown that the choice of granularity, i.e., the number and power rating of the component systems, affects the maximum fuel efficiency that can be obtained for a given use profile. Once the granularity has been selected, the control system can then be set to achieve maximum efficiency with the set of installed units.

A fundamental reason for this dependence on granularity is summarized in Figure 1, which is provided by Caterpillar on their website.



This figure summarizes the specific fuel consumption as a fraction of its full power for diesel generator sets from a particular manufacturer, Caterpillar. The general nature of the curves is driven by fundamental physics and so they are not particularly different for other manufacturers. The key feature for this discussion is that lightly loaded machines are much less efficient than are more heavily loaded units. Moreover, the increase in specific fuel consumption with a decrease in load tends to be much larger below about half load than above half load. Thus, it is obvious that some granularity should provide a benefit in fuel economy.

Specific Investigation for 100 m Class Vessel

To present the effects of diesel generator set selection, a 100 m class passenger vessel was selected. A typical mission profile was identified which included varying power levels needed for the vessel's anticipated modes of operation. Since operating modes and power levels will vary with ship type and use, diesel generator set granularity must be assessed on a case-by-case basis.

Model Number	Electrical Power Rating (kW)
3508B	800
3512B	880
3512B	970
3516B	1180
3512B	1200
3516B	1460
3516B	1600

This analysis was limited to available Caterpillar data and focused on the seven diesel generator systems shown in Table 1. With this set of choices, there are 470 combinations that will yield power levels between 5200 kW and 6200 kW, which is the power range of interest. For each of these possible combinations, the resultant power, volume, and mass were tabulated. In addition, for each combination, the annual fuel consumption was estimated based on an anticipated ship use profile.
It is likely that the most important observation from this data is that for the 470 cases, the maximum fuel consumption is about 8.5% larger than the lowest fuel consumption. While this difference may be large enough to be significant in driving decisions, it must be recognized that the annual use profile is estimated, and not likely known to this precision. Variations in the use profile could change the annual fuel consumption of many combinations by several percent leading to a different order.

Table 2 highlights the fact that the power, volume, mass, and annual fuel consumption are not minimized simultaneously. The table shows which combinations of diesel generator sets yield the lowest value of:

1. annual fuel consumption
2. volume
3. mass
4. installed power

When several combinations yielded the same mass or installed power as a minimum, the one selected was the one that also proved the best fuel efficiency.

Table 2. This table lists the combinations of diesel generator sets that independently provide the minimum values of each of the four tracked variables, i.e., annual fuel consumption, volume, mass, and installed power.

			Gen-set Combinations						# of Diesel GenSets	Size and Performance			
Combination with:	Combination Number	3508B 800 kW	3512B 880 kW	3512B 970 kW	3516B 1180 kW	3512B 1200 kW	3516B 1460 kW	3516B 16000 kW		Power (kw)	Volume (m^3)	Mass (kg)	Annual Fuel Consumption (m^3)
Lowest fuel consumption	1	2	-	1	-	3	-	-	6	6170	56.70	36560	4978.37
Lowest volume	48	7	-	-	-	-	-	-	7	5600	46.03	36512	5015.45
Lowest mass	217	-	-	1	-	1	-	2	4	5370	50.41	29122	5078.72
Lowest installed power	253	2	3	1	-	-	-	-	5	5210	52.02	41051	5085.84
						Maximum Percentage Delta Relative to Minimum Baseline				+18.43	+23.18	+40.96	+2.16

Of these four parameters, it is likely that the two most relevant are expected to be fuel consumption and volume. Fuel consumption is a major contributor to operating costs and production of pollution, so it must be minimized. Volume is always a critical factor on a ship. Mass is less likely to be important as the mass in question is below the waterline. This means that any mass reduction would be compensated by an increase in ballast. Finally, the demand for installed power is likely to grow over the life of the vessel, so it is probably not prudent to minimize installed power.

Table 2 leads to several observations. First is that the smallest and lightest combinations tend to cluster near the most fuel efficient end of the spectrum. Consequently for these choices, the fuel consumption differs by only about 2%. This difference is unlikely to be significant, as mentioned above, because of the imprecision of the knowledge of the annual use profile. While the mass varies significantly, it is unlikely that reducing this mass reduces overall ship mass due to ballast requirements.

The volume variation is greater than 20%. While this appears to be large enough to be important, a critical factor affecting volume has been omitted from this analysis. The analysis only considers the volume of the diesel generator sets themselves. Another critical contributor to the required volume is the ducts for intake and exhaust air. The volume required cannot be estimated, however, without a complete ship layout, as these ducts generally pass through all decks above the engine room.

The duct volume situation is highlighted by the fact that the minimum volume solution uses seven diesel generator sets. It is expected that the needed exhaust volume for seven diesel generator sets would be larger than for a smaller number of units because the diesel engine performance is very sensitive to back pressure. This consideration suggests that a minimum number of individual units may be desirable to reduce unnecessary space being devoted to intake and exhaust ducting. Some granularity is required, however, for fuel efficiency.

Moreover, within the seven Caterpillar units to choose from, a minimum of four are needed to meet the minimum power requirement. A potential ancillary benefit arises with the four diesel generators combination, which consist of two sets of two identical engines. This commonality may lead to lower overall repair and maintenance costs. This is listed as a potential benefit as data were not available to estimate its significance.