Optimizing fuel efficiency through techno-economic modelling of ship concepts including hybrid designs

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How can you assess the actual business cases of different conceptual vessel designs? What technical design solutions will work best for various ship segments and operating profiles? What benefits can new technology such as batteries or hybrid propulsion offer? In this article we will provide some insights to these questions through project examples. We also give a few lessons learned through our Research & Development in this field.

During the phase of vessel early design development, uncertainties and risks are plentiful, but this is also the time when the most important decisions affecting cost, fuel efficiency and environmental performance are made.

In recent years, DNV GL have developed in-house computer modelling tools for technical and economic analysis of ship design concepts. The new tools are focused on propulsion and machinery systems, complementing existing tools such as hull CFD software. The tools allow modelling of any propulsion/machinery systems, simple or complex, with the purpose of comparing various designs. Normally the tools are used for minimising fuel consumption and maintenance costs or to size various system components to achieve optimal configurations.

Obvious systems to analyse are complex systems such as LNG systems, steam systems, hybrid propulsion including electro-mechanical systems with or without batteries, and more.

A hybrid power and propulsion system is a system where the captain (or the control system) can choose the most efficient way of producing power for a given operation. Engines and power systems are usually designed for an optimal operating point. In the vicinity of this optimal point, fuel consumption is at its lowest.

The term "hybrid arrangement" is a broad definition and may include amongst others: two engines of different power size in a "father and son" configuration; direct mechanical engine-propeller transmission with a shaft alternator for electricity-production, either in a simple power take-off or combined power take-off and power take-in; or a battery-engine combination, to give some examples.

A case example will illustrate how this may come into use: in this case, the client and DNVGL were working together in developing the outline specification for a new series of vessels. The challenge provided was to assess the technical and economic implications of relevant conceptual arrangements. Initially, the operating profile was developed. In doing this, data of sufficient quality is required. Normally, the vessel draft-speed operating profile is developed and for pure hull/hydrodynamic studies this is satisfactory. However, for the purpose of machinery and system arrangement modelling, detailed engine load profiles are needed for the main engine as well as the auxiliary engines. In this project, vessel AIS tracking data was coupled with performance data logged onboard. The AIS data was systemised and coupled with geographical data in order to produce an estimate for time spent in ECA zones. It is common that the performance data logged onboard includes discrepancies in date and time entries. To be useful, the data must be washed and systemised.

Through a multidisciplinary approach, modelling the combined effect of hull hydrodynamics with propeller hydrodynamics, a series of propeller alternatives for the main hull parameters were shortlisted. The advantage of this is that it enables selection of the best total combined hull/propeller efficiency, and providing the propeller shaft speed as input to further design development.

The next step was to match the propeller with propulsion engines, and to draft the alternative concept arrangements. Working with different engine and equipment suppliers, DNVGL obtained input for the suppliers' systems to our techno-economic models of the power system configurations. Efficiencies and the initial operational data for the propulsion drive train equipment were developed: engine, shafting, propeller efficiency, generators, electric motors etc. The fuel types to be used for the further work was also defined and developed. To allow relevant interpretations, the original base case was modified to be compliant with upcoming environmental regulations for ECA operation. Hence, SOx scrubber technology as well as NOx cleaning technology was added to the base case. Shaft generator with combined power-take-off (PTO) and power-take-in (PTI) were modelled. Such generators, frequently referred to as PTI/PTOs, may produce electricity from the main engine shaft, and thus benefiting from the better fuel economy of the main engine compared to the auxiliary engines. The electric generator may also be "reversed" taking the function of an electric motor. In doing this, the auxiliary engines can provide boost power to the propeller via the electric grid. Such a design may be attractive, depending on the vessels operational profile, see further discussions below.

The numbers of auxiliary engines were varied, with fewer aux engines for the hybrid cases compared to the base case. This underscores one of the main advantages of hybrid systems; the flexibility offers high utilisation of the engines. In reducing the total number of engine cylinders, maintenance cost is also reduced. Two fuel types were modelled; LNG compared to heavy fuel with SOx scrubber and NOx reducing measures.

One of the interesting options developed was derived through the detailed study of the operating profile. Recognizing how little time was actually spent around the vessel's top speed, a hybrid solution including PTO/PTI with smaller main engines was modelled. The top speed is usually a contract specified speed, however seldom used in daily operation. The contract speed can still be reached by peak power from the auxiliary engines through the PTI. Since the main engine gets support from the auxiliary engine in reaching the vessel top speed, the main engine can be reduced in size or de-rated. Also fewer aux gen-sets are needed in this configuration. While this reduces the capex, the smaller (or de-rated) main engine with PTO/PTI provide better fuel economy at the normal vessel speeds which also reduce the opex.

Figure 1 shows the economic results for some selected concepts, which are all compliant with ECA and NOx Tier 3 requirements. The results are anonymised for propriety reasons. The alternative concepts developed are shown with their difference in costs in million USD compared to the base case. Each line represents a specific design combination. Starting with the investment cost in year zero, the curve shows the cumulative discounted operating costs developing through the 15 year life time. The results are specific for the operating profile initially developed. The examples are made for an oil-equivalent LNG price of ca. 830 USD/ton and HFO price of 600 USD/ton.

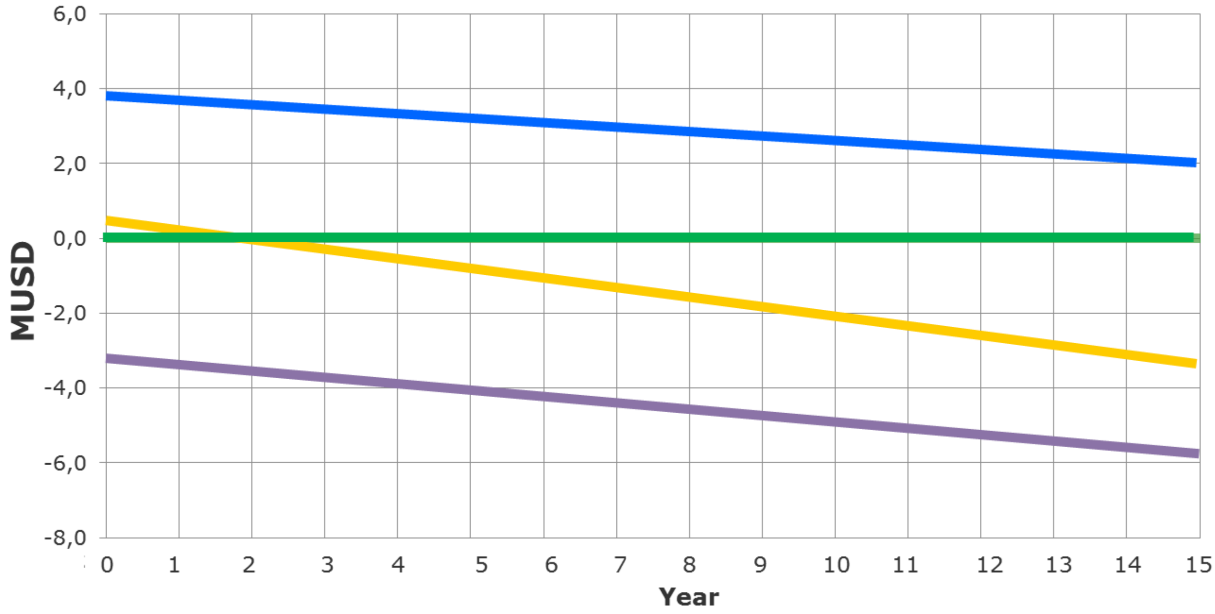

Figure 1 - Combined cumulative discounted costs (capex and opex) in MUSD, comparing different arrangement designs and emission compliant technologies. All economic figures are relative to the green line which is the base case. The results are project specific subject to the operating profile of the vessel, not valid for general statements.

A battery – engine combination differ from the other hybrid arrangements. The power load curve of batteries differs significantly from conventional engines. The torque curve of a battery-electrical motor system provide almost instantaneously full torque upon demand, as opposed to an engine which need time to ramp up speed to deliver the same torque. The effect is that a battery powered system will have a much quicker response time.

It follows from this that the biggest opportunities for savings will be attributed to ships with frequent load transients, ships with high requirement to power flexibility and response, or ships that are operating large time at low loads. Interesting opportunities also exist for ships with prime movers with special operational limitations, or ships operating in environmentally sensitive areas, but these will not be discussed further in this article.

The FellowSHIP III project has designed and integrated a 0.5 MWh battery to the existing gas engine electric propulsion and power generating system onboard the Eidesvik owned OSV Viking Lady, and measured extensively all operating parameters during all operating modes, and in changing operating conditions. DNV GL together with partners Eidesvik and Wärtsilä initiated this project in order to provide unique full scale measurements of large battery operation. Recent results show that the batteries may give significant fuel savings in all operating modes, with actual savings dependent on power system design and on operating conditions such as weather.

Through the battery measurement data gathered, DNV GL are able to model the effect of including batteries in hybrid system designs, quantifying fuel savings for different design options. The results show that the two most important factors dictating the fuel saving effect is (a) how the power system is operated and (b) weather conditions. The peak shaving effect often referred to with battery operation, denotes the fluctuating power situation where the battery is either providing the peak power, or being charged by the sudden system surplus power. The full effect of this in transit operation is rather weather dependent, with highest impact in heavy wind and sea states. In DP operating mode, the fuel saving impact of batteries is mostly dictated by whether or not the operator allow the batteries to replace gas generators, meaning that one or more generators are shut down. Depending on the nature of the DP operation, this is often regulated by the charterer requirements and classification rules. DNV GL are in the process of issuing classification rules that open up for batteries replacing diesel/gas engine generators in the power system vessels operating in DP. The rules will be available 1 July 2015, entering into force 1 Jan 2016.