Two efficient ferry concepts

AUTHOR: Oskar Levander, Head of Conceptual Design, Ship Design, Wärtsilä Ship Power

There is an increasing need for ferries to increase their competitiveness. A key aspect of cost reductions is to improve energy efficiency and new designs can help in reaching this target.

This article will look at two different ferry types representing opposite ends of the size spectrum, and compare how energy efficiency has been tackled in each case. One of the ferries is a short route ferry for day crossings, while the other is a large cruise ferry providing attractive onboard facilities for overnight passengers.

The smaller ferry represents a low cost solution, featuring an innovative hull form design and novel propulsion machinery. Nevertheless, the systems are all simple and have few components. The larger cruise ferry, on the other hand, is equipped with many new features representing the most advanced technology available today.

Size matters

Size has a big impact on the transport efficiency of a ship. The larger the vessel, the more efficient it is. Low speed means low energy consumption. These maxims apply also to ferries. However, when it comes to evaluating transport efficiency, ferries are somewhat trickier than pure cargo vessels and there are different opinions on how it should be done. In a tanker or container vessel, the payload is rather obvious. But a cruise ferry, for instance, carries not only ro-ro cargo, but also a complete "hotel" for the passengers. Should only the weight of the passengers be considered as payload? Or should it include the entire superstructure and all the various hotel functions?

In resolving this issue, many suggest that it is better to use the volume (gross tonnage) of the ships as the measurement, rather than payload weight or deadweight. The IMO (International Maritime Organization) has also considered this principle in its proposal for a CO_2 index. This index, and its rather complicated formulas, is still under discussion, but the main principle can be simplified by including only a few main parameters - installed power divided by gross tonnage and speed. This gives a unit of energy per transported ship size and distance [kWh / (GT * nm)]. →

Fig. 1 – This 58,000 gt cruise ferry represents state-of-the-art efficiency.

If this power efficiency factor is plotted for existing ferries, a clear trend emerges – larger vessels get lower energy consumption values. Furthermore, it can be seen from Figure 2, that ferries with higher Froude's numbers (dimensionless length to speed ratio) usually end up above the mean trend line, and the slow ones below. So, even if speed is a parameter within the formula, slow vessels still come out better.

Making ferries extremely large is, of course, not always feasible or even possible. There may be limited transport demand, and restrictions in ports and fairways for the size of ships that can be accommodated.

It should be noted that the simplified power efficiency factor does not give a complete picture of energy efficiency, since savings in hotel power demand, waste heat recovery, operating at reduced speed, and other means for saving fuel are not accounted for.

Froude number:
The Froude number is a dimensionless number indicating the relation between a vessel's length and its speed, expressed as: $Fn = \frac{v}{\sqrt{g * L}}$

where v=speed [m/s],
g=acceleration due to gravity [m/s^2] = 9.81 m/s^2, L=waterline length of vessel [m]

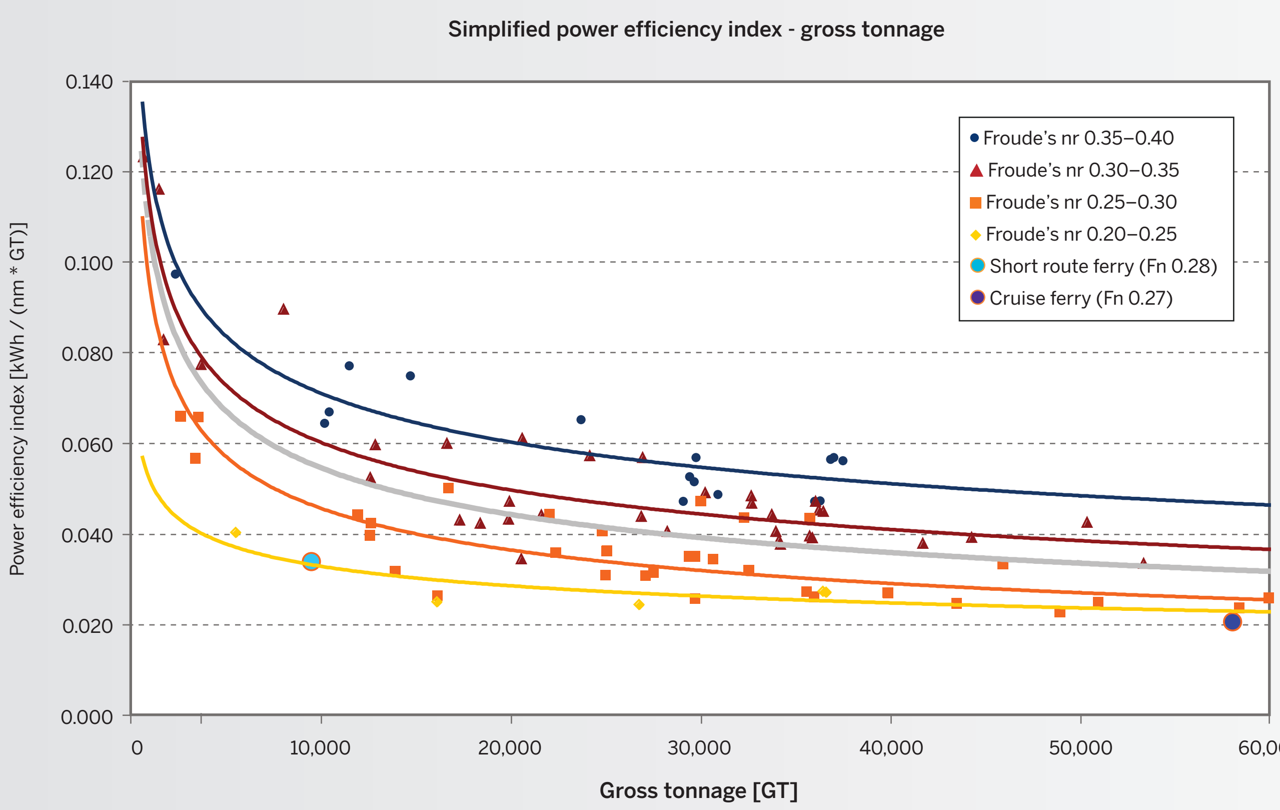
Optimizing speed

Even though low speeds will yield lower energy consumption and reduced fuel costs, the slowing down of ferries is seldom viable. In order to keep their passengers happy, ferries need attractive itineraries with convenient departure and arrival times. In many cases, they are also competing with other forms of transport, and speed is, therefore, an essential factor in keeping the passengers and trucks onboard. Slowing down will also reduce the amount of transported cargo and passengers per time, and more ferries might be needed on the same route. Selecting the right speed thus becomes a critical success factor for new ferry projects.

Hull form

Speed and displacement are the two dominating factors affecting the power demand of a ship. Conventional ferries often operate at Froude numbers between 0.25 and 0.35. These relatively high hull speeds for displacement type vessels make hydrodynamic optimization particularly

Fig. 2 – The trend indicates that large and slow vessels have a lower power efficiency index.



important. In order to reach the lowest possible resistance, the block (and prismatic) coefficient of such vessels should be low. Careful optimization of the main dimensions is of the utmost importance during the initial stages of ferry design. Lengthening the hull gives a lower block coefficient and Froude number and thereby reduced wave resistance. Added beam and draft can also result in a lower block coefficient and produce positive effects in some cases. Too low L/B ratios should, however, be avoided.

The effective length can also be increased by adding a ducktail, which is quite popular in ferries. Other stern features, such as trim wedges and interceptors, can also yield good results, especially at high Froude numbers.

The two ferry designs developed have hull forms where the waterline length has been maximized within the overall length of the vessel. They are also longer than competing vessel designs. For example, the length of the short route ferry is stretched 5–10 m compared to a conventional ferry of the same size. Already a 5 m length increase, gives a 14% effective power (hull resistance) saving at service speed and 20% saving at trial speed. Furthermore, in order to offer very low added resistance in heavy seas, the bow has been designed to have a fine waterline entry angle and a vertical stem profile with low flare angles.

Even though added length is easy to justify from a power saving point of view, it is sometimes difficult to realize in practice. There are restrictions on the size of vessels in many ports, and ships should be able to turn in the port basin and fit alongside the quay. Draft is sometimes limited by the fairways leading into port. However, since the benefits of longer vessels are so clear, naval architects should ask if these limits are carved in stone or if they can be changed. Investing in improved port facilities could perhaps be more lucrative than investing in too much engine power.

Turn-around time in port

It is not only investments in bigger ports that can be interesting; development of the port infrastructure can also pay itself back quite quickly. Speeding up port time is almost always beneficial, and the shorter the turnaround time in port is, the slower the ship can sail while still maintaining the same departure frequency. A 10 minute saving can, for example, produce annual fuel savings of 3% for a typical ferry. A bigger time saving of half an hour can result in 10% savings.

Both ferry concepts aim at achieving good cargo handling. The cruise ferry is designed to have a dedicated shore based link span also for the upper car deck, which→

Fig. 3 – Block coefficients of passenger vessels.

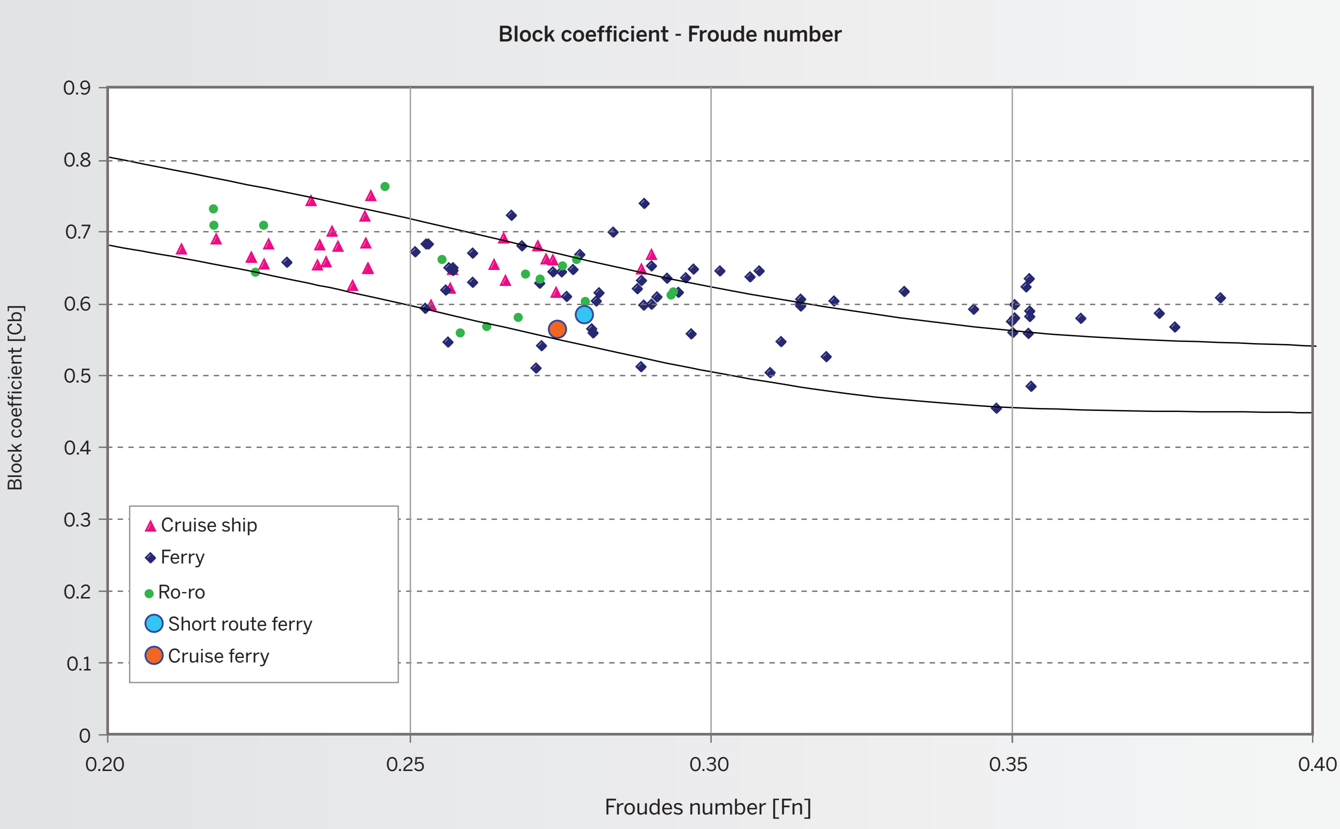


Fig. 4 – Short route ferry with fine entry angle at the bow.

together with straightforward cargo flows in port, will aid in the loading process. Internal ramps between the main and upper decks of the ship, are not as efficient as land based ramps that load directly at both levels. No lower hold is used, as this would slow down cargo handling. The lane-meters in the lower hold are often less than 10% of the total capacity in conventional ferries.

The smaller ferry has only a single RoRo deck, so there is no need for double ramps. At the same time, the bow ramp has been moved to the starboard side, thereby eliminating the need for a bow visor and it is possible for a stronger and slimmer bow form to be used. Smaller waterline entry angles will give lower resistance, and the narrow bow shape will significantly reduce added resistance in rough seas.

Automated mooring systems are another way of reducing port time. Such systems are particularly appropriate for ferries with fixed routes and a limited number of ports.

Speeding up the manoeuvring time is also important for short turnaround times. Efficient tunnel thrusters, both in the bow and stern, enable good manoeuvring characteristics. Azimuthing thrusters or pods would yield even better steering capabilities and both new concepts have at least one steerable propulsor. Despite the benefits, steerable thrusters have so far not been applied to any large extent in existing ferries.

Propulsion

Both new concepts have opted for a propulsion solution combining a single centre shaft line with one or more Optipull pulling thrusters.

The short route ferry has one pulling thruster directly behind the centre propeller forming a contra rotating propeller (CRP) couple. The CRP concept offers improved propulsion efficiency by recovering rotative losses and benefits from the wake field behind the centre skeg.

The cruise ferry has a Wing Thruster configuration with two Optipull pulling thrusters, one on each side of the central propeller. This concept also offers improved propulsion efficiency, thanks to the lower propeller loadings and beneficial wake for the centre propeller, resulting in high levels of hull efficiency. The propellers on the pulling thrusters experience clean wake fields, and the blades operate close to their design condition throughout the full revolution, thus giving good propeller efficiency.

However, the biggest advantage that the two concepts have over conventional twin screw propulsion, is the reduction in resistance when the twin shaft lines are replaced by a centre skeg propeller and pulling thruster(s). As the appendages in a conventional ferry can represent up to 20% of the vessel's resistance, big savings can be made by avoiding open shaft lines. The CRP concept in particular will offer significantly lower resistance, thereby yielding a power saving potential of up to 8–15% .

However, one drawback associated with CRP is that there is only a single steering device. A small extra rudder is, therefore, added to the short route ferry to comply with the safe return to port requirements.

This issue is not, however, relevant for the Wing Thruster concept as there are two steering thrusters. Despite this, the cruise ferry still features an optional rudder, which in this case is located behind the centre propeller. This rudder is used for steering at high speeds when the thrusters are not the most efficient means of steering. Turning the thrusters alters the incoming flow to the propellers and directs the thrust vector to the side, thus causing the ship to lose speed. A rudder is, therefore, a more efficient steering device at high speeds. When the speed is low the situation is different, since the steerable thrusters will then be able to generate much higher side forces, which is important during manoeuvring.

The centre rudder should ideally be of the Energopac type. The torpedo shape behind the propeller will improve propulsion efficiency and reduce pressure pulses from the propeller. →

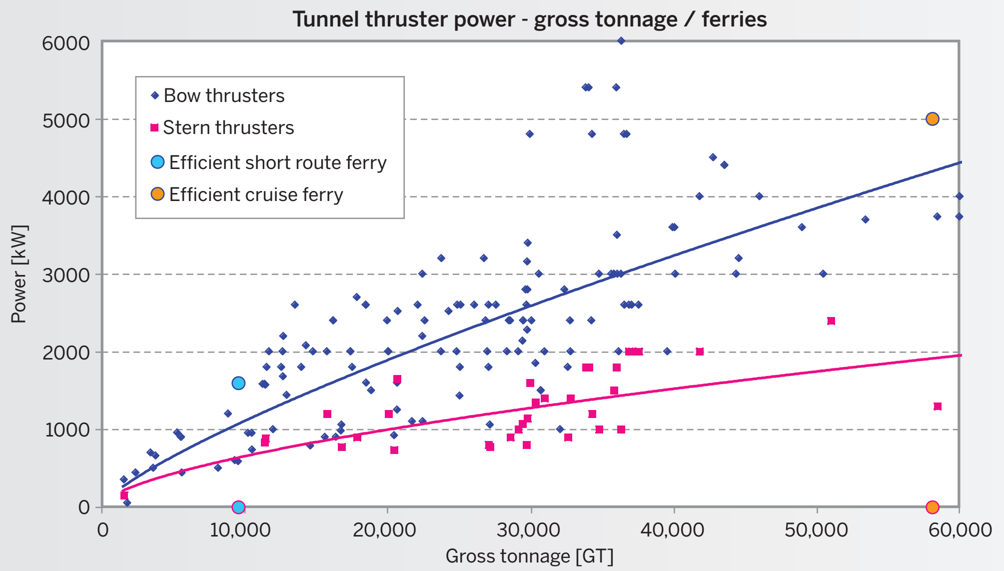


Fig. 5 – Bow and stern thruster power for existing ferries.

Fig. 6 – CRP propulsion with an Optipull pulling thruster. A small rudder is added for open water steering and steering redundancy.

Fig. 7 – Cruise ferry with Wing Thruster propulsion, including the Energopac rudder. LNG tanks are located on the open aft deck.

Machinery

Both propulsion configurations are ideally suited for combined diesel-electric and diesel-mechanical (CODED) machinery.

Use of a diesel-electric power plant allows high efficiencies at low vessel speeds and during manoeuvring. The load of the engines can be optimized by starting and stopping the engines according to the power plant principle, and variable speed thruster drive saves power during slow speed operation and manoeuvring. The centre propeller is used as a mechanical booster, giving low transmission losses when engaged at high transit speeds. Mechanical booster propulsion offers lower investment costs than a full electric propulsion setup.

This combination of electric and mechanical propulsion is especially suitable for ferries on routes with both low speed operation in restricted areas, and relatively high speeds when allowed. Such conditions result in an operating profile which includes a wide variety of operating modes, making optimization much more challenging. A flexible machinery arrangement is efficient at many different power output levels, and is therefore a preferable solution.

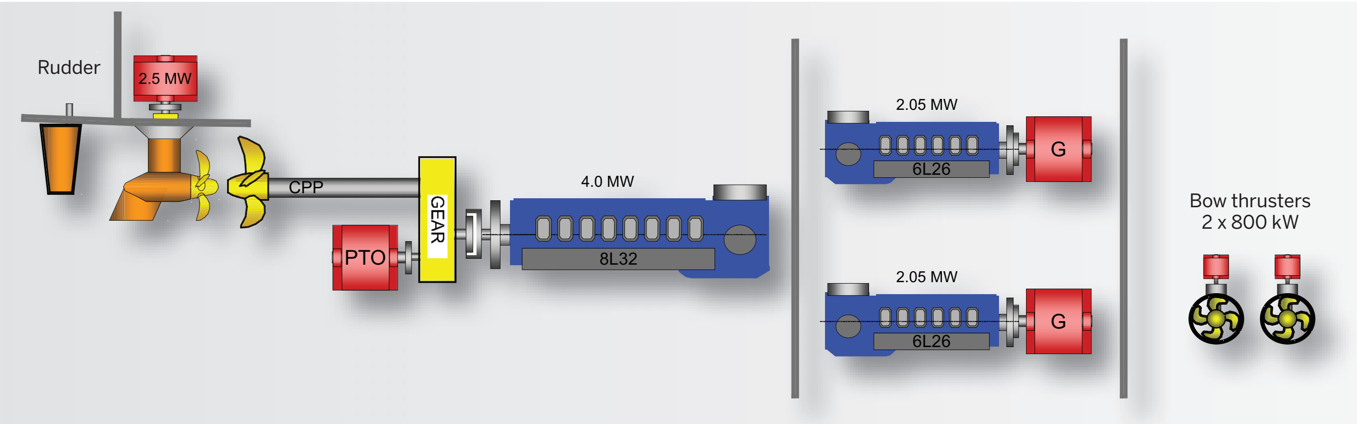


Fig. 8 – A simple version of CODED machinery and CRP propulsion for the short route ferry.

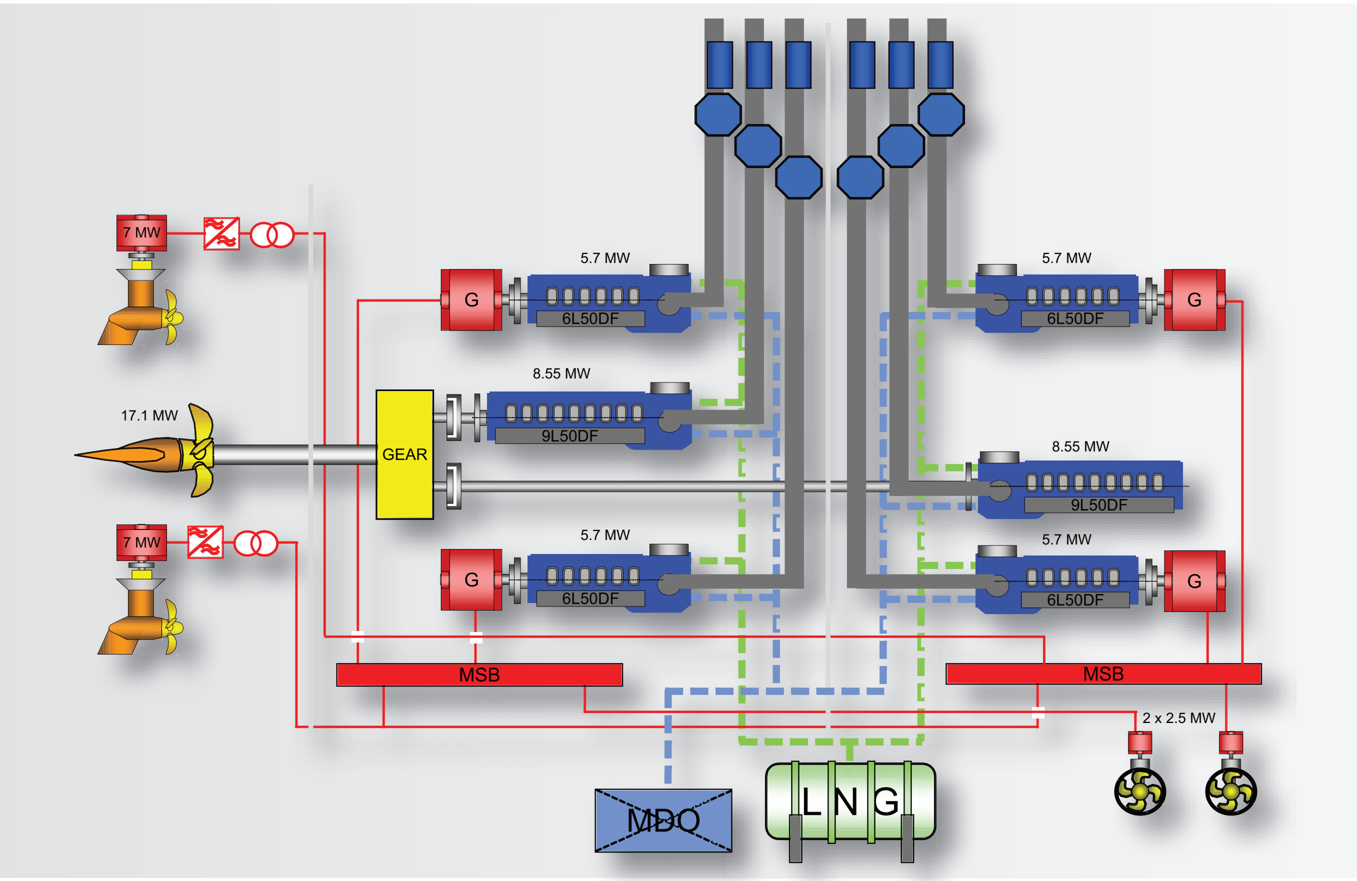


Fig. 9 – The cruise ferry has CODED machinery with six dual-fuel engines.

Dual-fuel

The cruise ferry is designed for operation on LNG with marine diesel as back-up. The machinery is based on six Wärtsilä 50DF dual-fuel engines, of which two are driving the centre propeller via a twin-in single-out reduction gear. The remaining four engines are driving the generators. The engines are divided into two separate compartments to comply with safe return to port requirements.

The use of LNG significantly reduces the vessel's emissions, with CO_2 cut by ~25% and NO_X emissions by 85%. In addition, there are virtually no SO_X emissions and the particle levels are reduced significantly as well. But lower emissions are not the only advantages of LNG. Energy demand is also reduced, and the low temperature of LNG can be used for cooling in the air-conditioning (AC) systems, thus reducing the need to run AC compressors. The savings potential is estimated at ~1.1 MW of cooling power, which corresponds to ~275 kW in electric power assuming a COP (coefficient of performance) factor of 4. Furthermore, there is no need for an HFO tank or trace heating, thereby reducing the use of the oil fired boiler.

Wind power

When trying to improve energy efficiency in ships, thoughts soon turn to harnessing some of the free energy from the surrounding elements. Wind is the most feasible of these options and there are many means of using wind power, the oldest, but still relevant method, being to use sails. Flettner rotors and kites have also emerged as potential options for creating forward thrust from wind. Another approach is to use some kind of wind turbine to produce electric energy. The benefit of the latter is that it also works when the ship is standing still in port, but is perhaps less ideal in head winds.

A ferry is a rather challenging ship type for wind power. The speed of the vessel is usually high, which means that headwinds become the apparent wind direction. The sail device must, therefore, work well at small angles of attack. A slower vessel will have more side and downwind encounters. The other typical feature of a ferry is that the legs are short, and there might be many turns and changes in the heading. This means that the sail device must be adjusted frequently.

Taking these special requirements into account, the Flettner rotor seems to be the most promising sail device. The Flettner rotor, named after its inventor Anton Flettner, is a vertical cylinder that is rotated around its axis by a motor. As the wind blows past the rotating cylinder, high pressure on one side is formed with a corresponding low pressure area on the opposite side. This pressure difference will generate a thrust force perpendicular to the wind's direction. There is also a drag force. The forward components of these forces will result in thrust to drive the ship ahead.

The advantage of the Flettner rotor, compared to a sail or kite, is that the rotor works at rather small angles of attack and is simple to turn on and off. The rotor is also more efficient than a sail. A Flettner rotor can have a lift coefficient (C_L) of around 10, while normal sails are just above 1. This means that the rotor can generate about ten times more thrust with the same "sail" area. The speed of the rotor is adjusted by controlling the electric motor driving it, and when the wind speed or direction changes, the rotational speed and direction is adjusted automatically to give optimal thrust. If the wind power is no longer needed, the rotor is simply stopped. No need to lower any sails. It is a very simple and easily adjusted device needing no additional crew.

The Flettner rotor was first applied in a ship in the 1920's. It was tried a few times in different ships, but no big breakthrough occurred since the era of sailing ships was coming to its end at that time. Now, once again, it is becoming a hot topic as energy costs are rising, and there is a need to reduce the CO_2 footprint.

The cruise ferry concept features four Flettner rotors to produce extra thrust. Three of the rotors are integrated into the funnel and one is part of the forward mast structure. The exhaust pipes are fed through two of the aft rotors. The idea has been to introduce rotors without changing the side profile of the vessel too much. The rotors are relatively small in comparison to the overall ship size. However, according to an assumed operating profile and actual wind data for the route, they are estimated to produce an average thrust gain of 10%. Their contribution is larger at lower speeds, while at high speeds it is correspondingly reduced.

The wind power suggested for these ferries is not intended for primary propulsion, as it was for old sailing ships, but rather as a means of reducing fuel consumption.

Solar power

The cruise ferry design also features solar panels to produce electric energy from sunlight. About 800 m^2 of panels have been located on the sloped sides of the AC rooms on the top deck. Unfortunately, today's solar panels will not produce very much power in a ship operating in northern Europe, and an annual average power of 11 kW was calculated for the ferry. This is not very much for this type of ship, but in the future when solar panel technology becomes more efficient and cheaper, it can become more interesting, especially for ships operating in sunnier climates.

Waste heat recovery

One potential area for improving the energy balance in a ship is to apply waste heat recovery (WHR) systems for the machinery. This has been done successfully in container vessels, and is now also being considered for a wider range of ship types, ferries being one. In ferries, surplus energy is available in the exhaust and engine cooling water when operating at high power. Unlike cruise ships, ferries bunker fresh water in port and seldom produce water onboard, so the waste heat is not needed for these systems. The waste energy should ideally be converted into electric power to give more flexible use.

Large container vessels use a WHR system that combines exhaust power turbines and steam cycles. This might not be as well suited for ferries.

The cruise ferry is designed to use a WHR system based on an Organic Ranking Cycle (ORC). This system has not yet been applied in ships, but there is some development work being carried out. The idea is to achieve good efficiency already at part load, and to be able to use low grade heat from the cooling water. The system in the cruise ferry is designed to utilize the heat from two engines, as all engines are used only for short periods of time in the assumed operating profile. It is estimated that the WHR system will be able to recover about 1 MW of energy from two engines at high load. The drawback with the ORC is the large volume of space needed for the equipment. This also limits the feasibility of this system for very large power plants. →

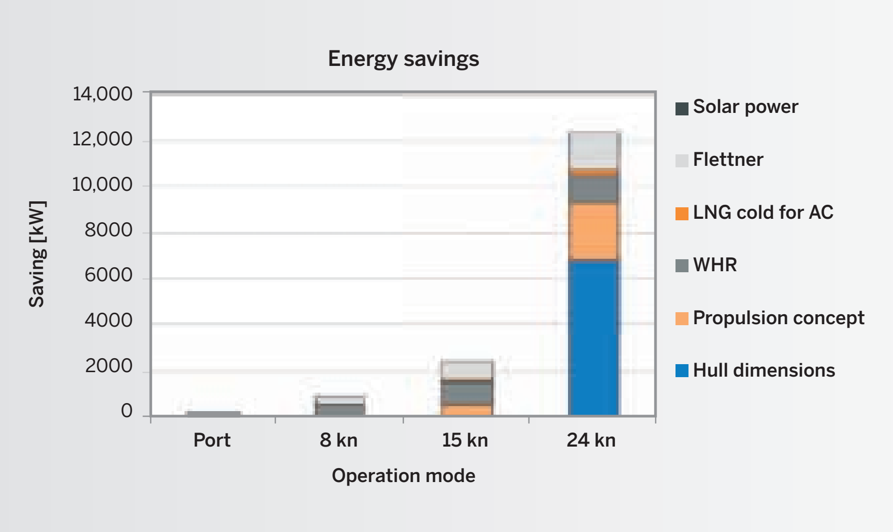


Fig. 10 – Estimated power savings for the cruise ferry. The biggest savings are derived from the hull and the propulsion concept.

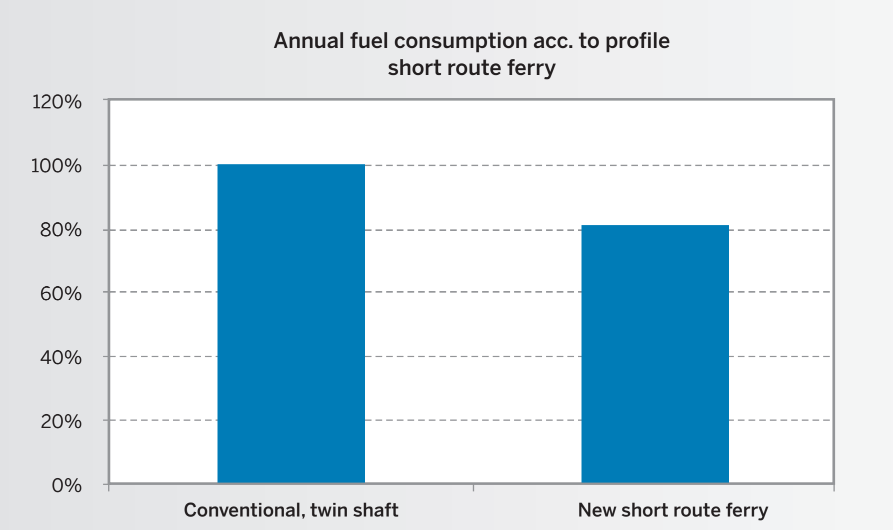


Fig. 11 – Annual fuel consumption for the short route ferry compared to a conventional 5 m shorter ferry with twin shaft lines.

Fig. 12 – Cruise ferry with Flettner rotors and solar panels.

Auxiliary power savings

Large passenger areas mean high hotel loads, and all means of reducing consumption by using energy-efficient lighting, smart HVAC (heating, ventilation and air conditioning) systems, and well designed galleys must be considered.

The large variations in demand for propulsion power during the voyage also mean that frequency-controlled pumps are an attractive option for many auxiliary systems. This is particularly true for ferries operating in climates that are significantly cooler than the maximum temperatures used when dimensioning the vessel's systems.

CONCLUSION

The two presented ferry concepts show two different approaches to the making of an efficient ferry. The smaller short route ferry has a more limited number of features, and costs are kept low. The improvements are concentrated on developing an efficient hull with a long waterline and sharp entry angles, efficient CRP propulsion, and CODED machinery in a simple arrangement with only three engines. It still saves up to 20% fuel compared to a conventional ferry.

The cruise ferry features many additional features for reducing energy consumption, such as wind power, LNG, waste heat recovery, solar power, and so on. These all add to the complexity, but they also give a quick payback. Compared to a conventional ferry designed for the same mission, our estimates indicate that the new concept offers energy savings totalling more than 32%. This figure relates to the hull, propulsion and machinery, and does not include any potential energy reductions in the accommodation areas (HVAC, lighting). Neither does it include savings achieved through operational means of reducing port time, or smart operation of the vessel. The figure can, therefore, be further increased significantly.

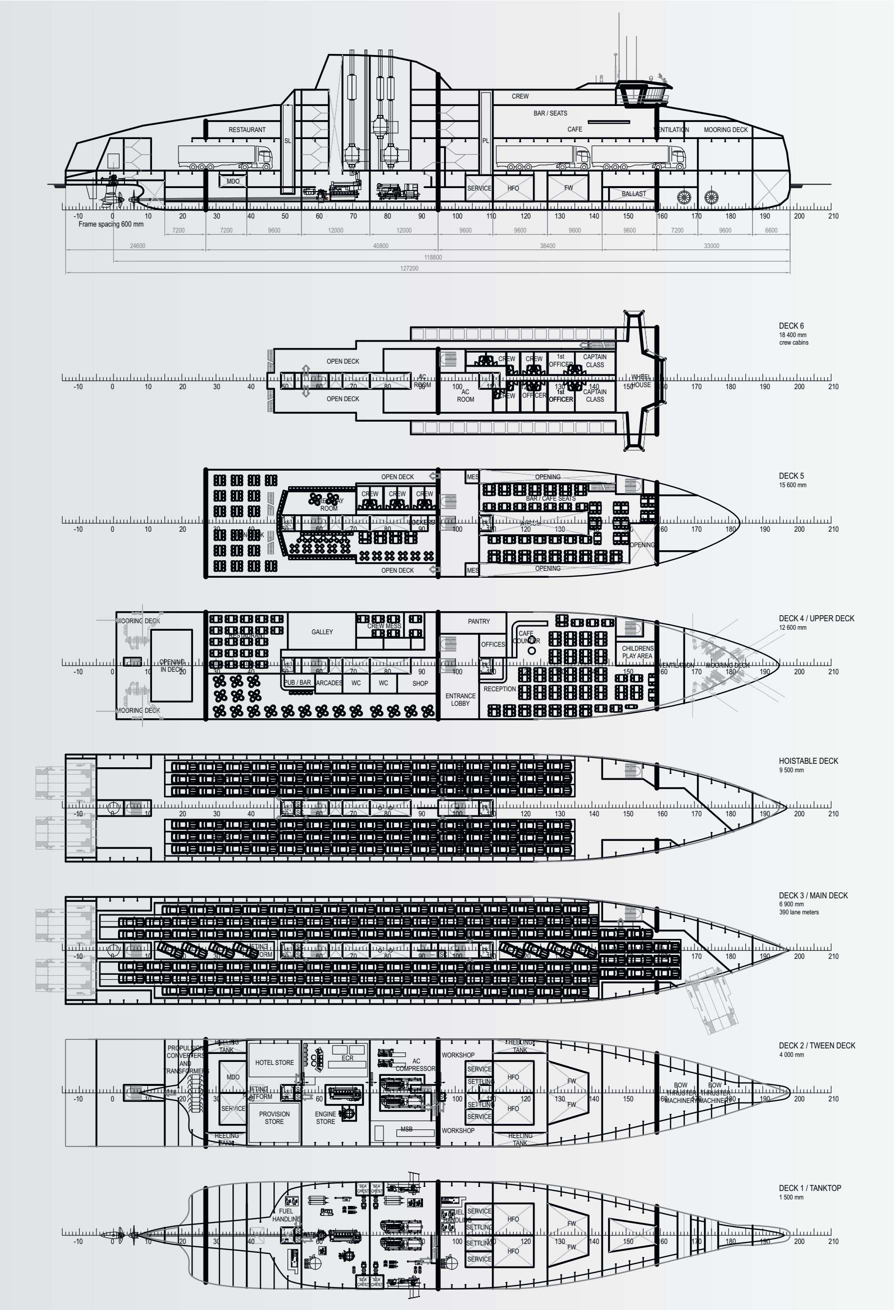


Fig. 13 – General arrangement of the short route ferry.

	Cruise ferry	Short route ferry	
Gross tonnage	58,000	9500	GT
Length overall	224	128	m
Length, bp	215	118	m
Breadth	31.2	18.8	m
Draught, design	6,8	4.5	m
Depth, main deck	9.8	6.9	m
Depth, upper deck	15.6	12.6	m
Deadweight	5000	1400	tons
Service speed	24	18.5	knots
Pax capacity	2800	900	pcs
Pax cabins	760	-	pcs
Crew cabins	190	25	pcs
Lane meters	1420	390	m
Lane meters, extra cars	820	-	m
Installed power	39,900	8100	kW