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The use of Waterjets and Dual Fuel engines in fast ferry applications

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ABSTRACT: Over the past 15 years the fast ferry market requirements have slightly changed, forced by external factors. Economy and environment seem in conflict with high service speeds. A lightweight fast ferry with Dual Fuel engines and waterjets can be a solution to take advantage of the benefits each of these technologies can offer. In the paper an overview of the changed requirements will be given. Furthermore a comparison between the use of gas turbines and DF diesel engines is made, indicating the windows of optimal use. A comparison between propellers and waterjets is made for the use with Dual Fuel engines, focusing on the application window and the technical fit to Dual Fuel engines, to complete the analysis of the drive train. Based on these investigations a concept is presented and discussed. The impact on the operation model and infrastructure are described as part of this.

1 INTRODUCTION

Time is money, and as a paradox, saving time can also cost money. In the maritime industry a lot of thoughts and evaluations are taken into consideration in order to balance both time and cost. This paper discusses a specific segment: the fast ferry market, which evolved around the reduction of transit time compared to conventional ferries. How has the segment evolved? And what developments are going on to improve the business? This paper will highlight a new development that can help to reduce the operational expenses on typical fast ferry routes.

First a brief analysis of existing fast ferry routes is presented, where a link is made to the fleet that operates it. From this, a typical route is determined which will be used in a further analysis, in a case study.

Next the new configuration will be presented: the combination of a waterjet mechanically driven by a dual fuel LNG engine and also the technical features will be discussed.

Finally an economic analysis will be made comparing the new setup with alternatives.

2 FAST FERRY MARKET REQUIREMENTS

2.1 Fast ferry speed ranges today

To create an overview of the current ferry routes, an investigation of fast ferries equipped with Wärtsilä waterjets was done. The website *marinetraffic.com* was used to locate the vessels around the globe and to obtain real time speed on the actual routes. For the information about the routes the published schedules of the operators were collected. Only ferries that carry both cars and persons (RoRo/Pax) are considered, passenger only ferries are not taken into the investigation.

The vessels considered have been built between 1991 and 2013. The speeds that used are the maximum cruising speeds. This is not the maximum recorded speed, but the highest speed that has been sustained for a period of time during the crossing. The following conclusions can be drawn from the investigation. The older ships have a lower service speed when compared to the speed they were originally designed for. Recently delivered vessels operate close to the vessel design speed. This is logical, as the recent vessels have been selected for the route they are currently operating on, hence the profile fits the vessel. Old vessels typically do not operate on their original route anymore, and the current use depends on many more factors. Nowadays high speed vessel designs fit specific routes in order to maximize profitability of these maritime vectors.

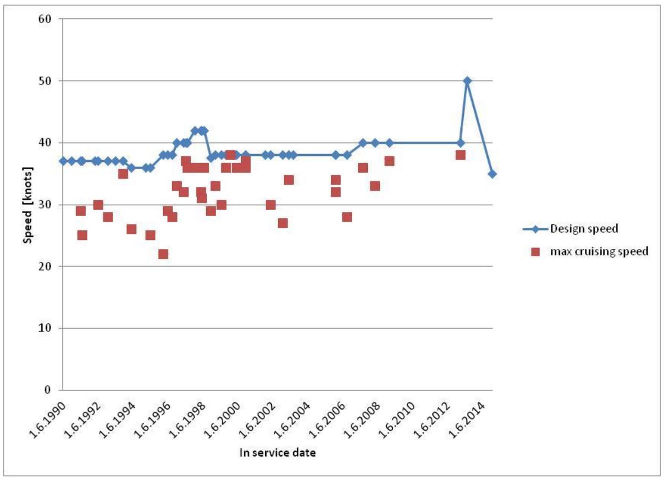


Figure 1: Design/Cruise speed trends

This graph also shows that the current maximum cruising speed is lower than the original design speed on average.

The current operating speed of the vessels (maximum cruising speed) is 32.1 knots on average.

But the spread is quite large. The newer vessels (acquired for their current route) typically have higher cruising speeds. The average maximum cruising speeds for the ships delivered the last 10 years is 34.6 knots.

2.2 Fast ferry routes

Fast ferries operate today in a limited number of areas, wherever they can grant sufficient profitability. The majority of these areas (in our investigation) are in Europe, as follows:

- Mediterranean Sea (e.g. Greece islands, Strait of Gibraltar)
- North Europe (e.g. English Channel)

Note: since these areas are (or could be in the near future) ECA (Emission Control Area) zones, particular attention to the emissions should be taken into consideration. Fortunately, these zones also happen to have a more advanced LNG infrastructures (more details about LNG will be given separately in Chapter 3.3).

2.3 *Typical routes*

The typical length of a route varies between 10 to more than 100 nmi. It should be noted that the shorter routes (less than 30 nmi) are typically part of a multi-stop journey; these are not point to point routes. Exceptions are the routes across the Strait of Gibraltar, which are less than 20 nmi. Statistically, on those routes the average speed is lower than longer routes at the same cruise speed, which can be partly explained by the relatively long harbour time compared to the distance.

Based on the selected database, the route length and time is averaged at 54.1 nautical miles (nmi) and 2 hours, and a calculated trip average speed of 26.7 knots (= route length/schedule time).

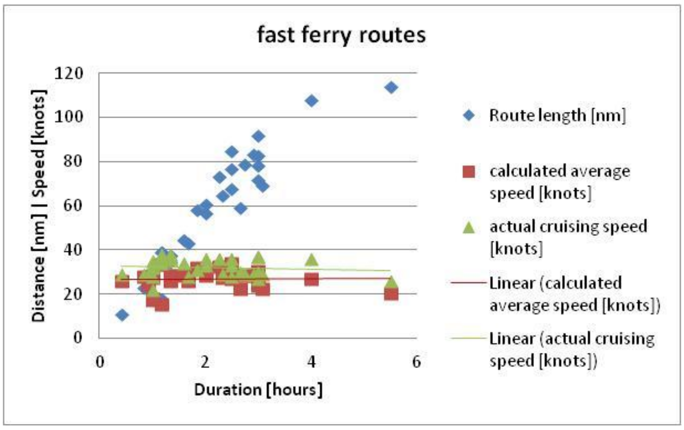
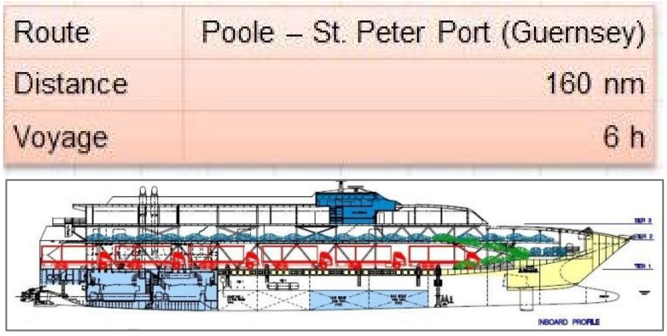


Figure 2: Fast ferry routes database

2.4 Selected case study

For the selection of a typical route for our case study the maximum cruising speed should be around 33 knots, route length to be more than 50 nmi, calculated average speed around 26 knots. The route taken is going from Poole (UK) to the island Guernsey. This route is approximately 80 nmi long, and scheduled to take 6 hours in the total round trip of 160 nmi. This will be further detailed in Chapter 5.



Route	Poole – St. Peter Port (Guernsey)
Distance	160 nm
Voyage	6 h

Figure 3: Typical fast ferry (RO/Pax) General Arrangements

Figure 4: Selected route (case study)

3 NEW MARKET DRIVERS

3.1 Fuel price

The shipping industry is facing new challenges: rising fuel prices and stringent environmental regulations drive the changes.

The development of the actual fuel prices nowadays is strongly influencing the decision on which technology equipment to install on board of a vessel (see graph of price level per fuel type).

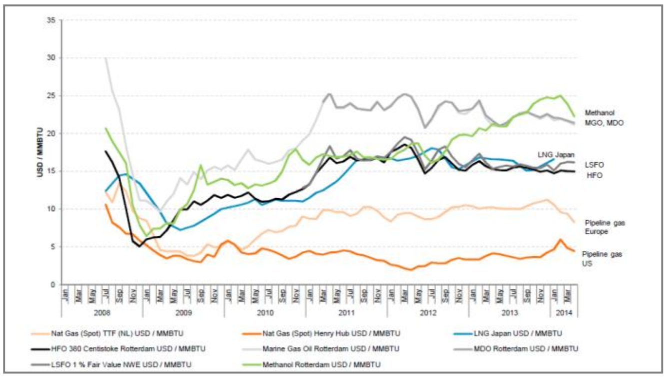


Figure 5: Fuel prices trend

3.2 New environmental legislations

In parallel, the upcoming environmental regulations (NOx, SOx, PM), lead the shipping industry to design installations and retrofits that already perform within the emission level imposed. The established Emission Control Area (ECA zone) is nowadays applied to the North Sea, the Baltic Sea, the English Channel, and an area stretching for 200 nautical miles from the USA and Canadian coastlines. However, it is possible that in the future these areas will extend also to Mediterranean Sea, Americas, Singapore, Australia, Japan and/or South Korea.

Figure 6: ECA zones

In order to achieve the levels mentioned in IMO Tier III which apply to the above mentioned areas, primary and secondary emission reduction measures can be employed. Primary measures include internal engine configurations (such as, exhaust gas recirculation, Low-NOX combustion, Miller timing), as well as the use of less polluting fuels, such as diesel or gas. Secondary measures include the use of scrubbers and NOX catalyst reducers (SCR).

3.3 LNG infrastructures and bunkering

The available infrastructure of the LNG today, allows bunkering the actual LNG existing World Fleet with the following modality:

- Tanker truck
- Containers lifted onboard
- Trailers loaded onboard
- Land based storage tank
- Tanker ship / barge

4 WATERJET AND DF ENGINE MATCHING

4.1 The DF engine: technology and advantages.

The Wärtsilä dual-fuel engine is the ultimate ‘fuel flexibility’ solution. It is a four-stroke low pressure gas engine that also runs on light fuel oil (LFO) or even heavy fuel oil (HFO), and can smoothly switch over from gas to LFO/HFO and vice versa during engine operation. The Wärtsilä dual-fuel engines are available in a power range from 0.8–17.5 MW having a speed range from 500–1200 rpm. During the switchover to gas, the fuel oil is gradually substituted by gas. In the event of a gas supply interruption, the engine converts from gas to fuel oil operation at any load instantaneously and automatically, without power interruption. Furthermore, the separate liquid fuel system makes it possible to switch over from MDO to HFO and vice versa. The fuel switch from liquid to gas operation mode can be made on operator’s command. This operation flexibility is a real advantage of the dual-fuel system. The natural gas is supplied to the engine through a gas valve unit, where the gas is filtered. The DF engine today is a solid, proven and reliable technology, with more than 1,000 engines operating in diversified application and with more than 10,000,000 running hours accumulated in the field.

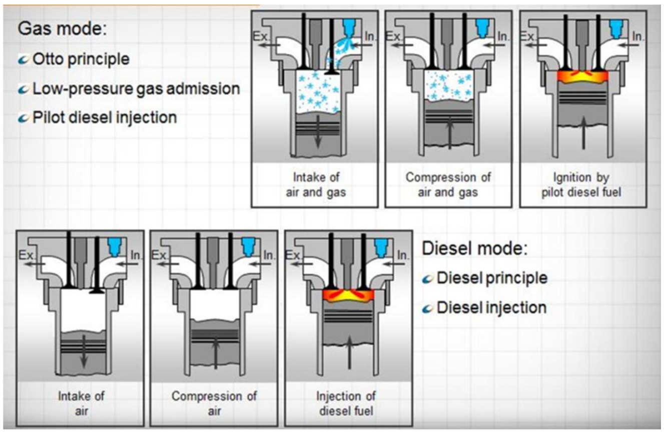


Figure 7: Gas/Diesel mode in a DF engine

The main advantages of this engine technology bring the following installation benefits:

- Fuel flexibility
- Application flexibility
- Proven and reliable dual-fuel technology
- Long overhaul intervals
- Low exhaust gas emissions
- Fuel economy over the entire range
- Low gas feed pressure
- Embedded automation system

4.2 DF engine: operational area in gas mode

When operating in gas mode the operational window for the engine is narrow, especially when a large amount of power is needed. This operating window (the white area in Figure 8) is limited by the possibility of knocking on one side and by the misfiring on the other side. The engine automation controls keep a tight grip this, in order to optimize the performance.
Figure 8 schematically shows the operating area of a DF engine in gas mode.

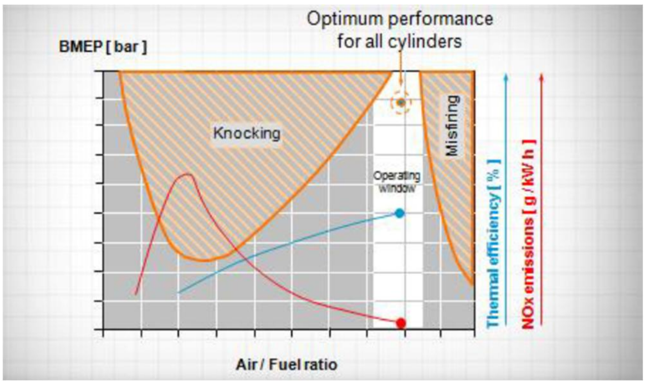


Figure 8: Operating area of a DF engine in gas mode.

Large variations in load can cause the point of operation to go out of the sweet spot (optimal performance range). In the extreme case of overload, it may lead to the switch-over to diesel fuel, MDO or HFO (in which case the engine still continues to deliver the same power and speed as on LNG).

4.3 Waterjets and FPP power absorption

The characteristics of a Wärtsilä waterjet are compared to those of a FPP (Fixed Pitch Propeller). A waterjet impeller has a similar physical appearance and geometry as a fixed pitch propeller, but the effect on engine load is quite different.

Figure 9: Wärtsilä waterjet impellers

The difference is caused by the location of the propulsors and the hydrodynamic properties of the propeller / impeller. A propeller extends below the hull; a waterjet operates inside an inlet duct. Changes in ship speed are therefore directly felt by the propeller. The effect on the waterjet of such changes is however minimal.

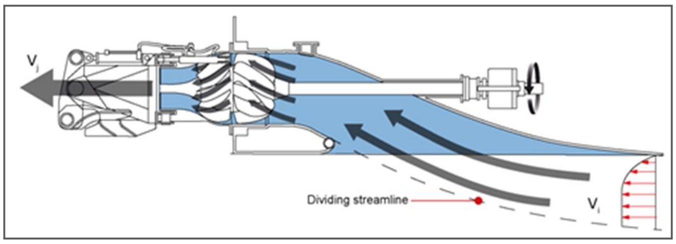


Figure 10: Water flow into a Wärtsilä waterjet

A propeller causes a variable load on the engine which deviates from the well-known (cubic) propeller curve. The load depends on the resistance curve of the vessel but also fouling of the hull. Waves also have a direct influence on the engine load.

These factors have a minimum influence on the performance of a waterjet: here the power absorption closely follows the cubic propeller curve regardless of the mentioned external factors. Changes in resistance due to wind, waves, fouling etc. have minimal (<2 %) influence on the *power-rpm diagram* relation of the jet and hence on the engine power demand.

Figure 11 shows a normalized *power vs engine rpm*: the red line is the limit for temporary operation; the blue line is the limit for continuous operation. It follows the typical third power law.

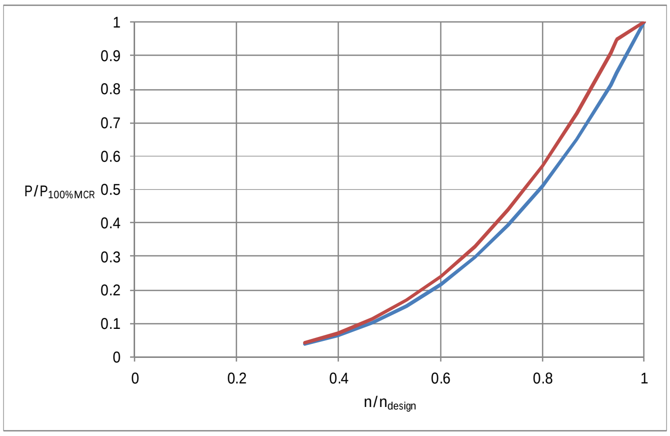


Figure 11: normalized power/rpm diagram for engine.

When the power lines are plotted in a normalized graph of rpm against ship speed, we see a clear distinction between the FPP (Figure 12) and the waterjet (Figure 13). The lines for the waterjet are parallel and flat, while for the FPP they are curved upward and approach each other towards higher ship speeds. When the engine curve is drawn in the FPP graph, it is noticeably steep as can be seen in Figure 12. The engine curve cannot be drawn in the waterjet graph, as the lines for absorbed power and n/n_{design} coincide.

For the FPP, Figure 12 shows that with decreasing ship speed (e.g. higher waves, or other external cause), the propeller has a lower rpm where the same power is absorbed.

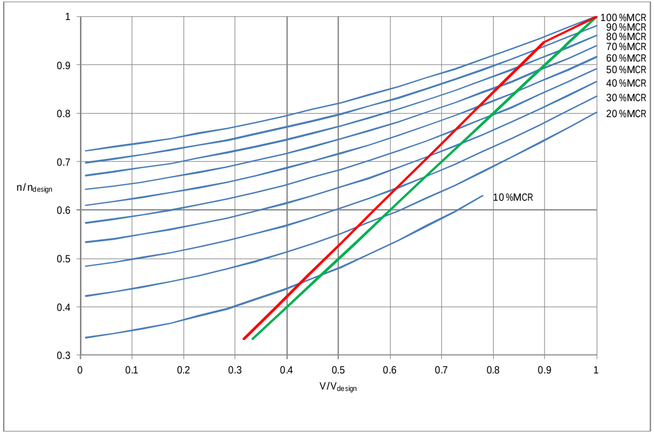


Figure 12: normalized rpm/ship speed diagram with engine curve for FPP.

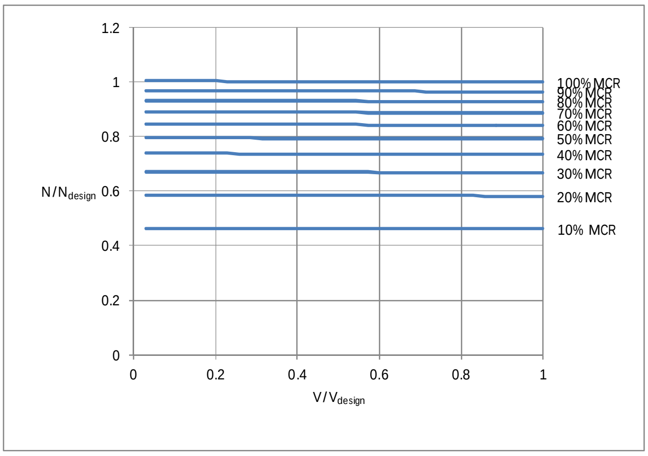
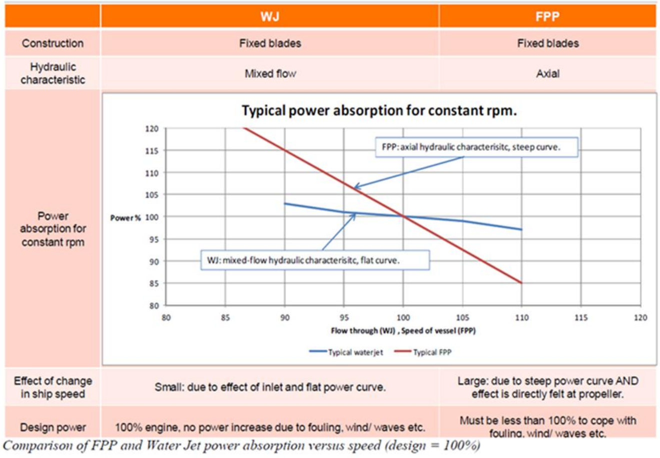


Figure 13: normalized rpm/ship speed diagram with engine curve for Waterjet.

These considerations lead us to the following comparison WJ/FPP power absorption:



	WJ	FPP
Construction	Fixed blades	Fixed blades
Hydraulic characteristic	Mixed flow	Axial
Power absorption for constant rpm	Typical power absorption for constant rpm.	
Effect of change in ship speed	Small: due to effect of inlet and flat power curve.	Large: due to steep power curve AND effect is directly felt at propeller.
Design power	100% engine, no power increase due to fouling, wind/ waves etc.	Must be less than 100% to cope with fouling, wind/ waves etc.

Comparison of FPP and Water Jet power absorption versus speed (design = 100%)

Figure 14: Comparison WJ/FPP power absorption.

When comparing the graphs it becomes very clear that the waterjet power absorption is independent from the ship speed. This leads us to a logical conclusion: a waterjet is a propulsor that has inherently small load variations, making it an ideal matching with a DF engines.

5 OPEX FOR A CASE STUDY

5.1 Dual Fuel advantages

The investigation presented so far in this article clearly points to LNG being a very attractive option, both from the point of view of cost and environmental compliance. The combination of the 4 Stroke (4S) Dual Fuel engine technology applied to the Waterjet allows several and remarkable benefits if we are comparing with an equivalent Gas Turbine (on LNG) installed:

- Greater efficiency at different loads
- Load and Speed guaranteed in any condition
- Redundancy
- Lower emission level

5.2 Opex comparison with different options

In the proposed case study, the analysis assumes a Fast Ferry with design speed 36 kn and with an installed power required of about 30MW (divided over four power trains achieved by 4 Wärtsilä main engines W16V34DF type, 8MW each). The round trip analysed consists of a voyage of 160 nmi, while the average vessel maximum cruise (service) speed is about 34 kn. The trip is broken down in the operation profile as shown in Figure 15, which relates to the average calculated trip speed of 26.7 knots.

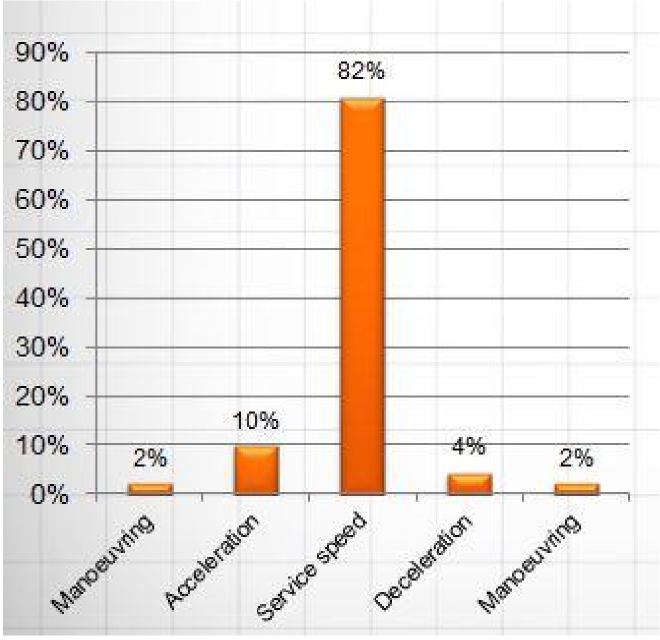


Figure 15: Operation profile

As we are considering different machinery types installed to fulfil the emission ECA requirements, the analysis is focused on the following machinery concept applied to this case:

- 4 Stroke High Speed Engine with SCR abatement technology device
- Gas Turbine
- 4 Stroke Dual Fuel Engine

Based on these assumptions, the DF engine has the most convenient footprint both for the energy consumption and for the total fuel cost, as it is shown in Figure 16.

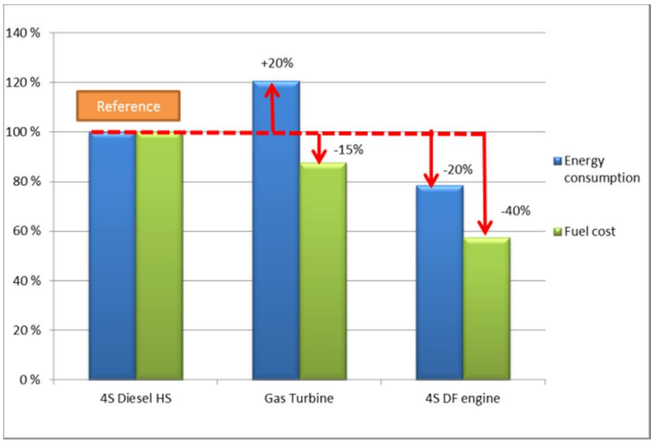


Figure 16: Comparison Diesel/gas turbine/ DF options

These given benefits enable large savings in terms of Opex. The DF solution can bring savings up to -40% in fuel cost/year compared to a 4S Diesel HS engine installation, or up to -25% fuel cost/year, compared to a Gas Turbine solution. The highest efficiency of the DF engine applied also allows a drastic reduction in term of LNG tons required per round trip, compared to an equivalent Gas Turbine. This factor reduces the total volume of the LNG to be stored on board; for the same vessel a reduction over 30% of volume can be considered for a DF solution, compared to the equivalent Gas Turbine application. Furthermore the total efficiency of the ship (ratio between the energy content in fuel and energy demand) show a clear benefit with the DF solution, allowing an improvement up to + 15% of the total efficiency compared to a Gas Turbine solution, with the same installed power. A possible general arrangement footprint with a DF application with Waterjet is schematized in Figure 17 (*source: INCAT*)

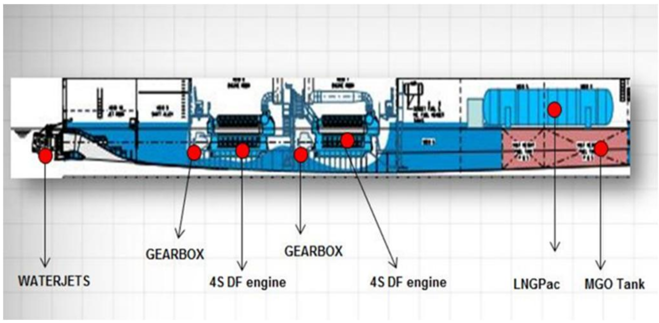


Figure 17: Layout for WJ and DF engines with LNG system

5.3 *Other factors*

In this article the focus has been kept on the Opex costs and technical feasibility of the power train. Moreover, further detailed analysis could have been done by considering other factors, such as the initial capital expenses (Capex), the availability of LNG infrastructures, dead-weight and related pay-load capacity and so on. All in all, these factors can only be analysed in more complex calculations, by involving also operators, yards and suppliers.

5.4 *Conclusions*

As conclusion of this study we can infer that the Dual Fuel solution clearly can be a valuable and reliable solution for the fast ferry market, especially if it is applied as a prime mover for a Waterjet installation. The DF engine / Waterjets matching is particularly favourable and technically feasible.

5.5 *Acknowledgements*

For this paper several internal Wärtsilä sources and resources have been consulted. The authors wish to thank for this support. Also the following external sources have been consulted:

Clarkson World Fleet register (2014) *Vessel database*

Marinetraffic.com (2014) *Routes and vessels analysis*

Incat.com.au (2014) *Courtesy INCAT vessels database*