MARAN GAS MARITIME INC.

Gas Fuelled LNG Carriers: Challenges and Opportunities, effect on efficiency and emissions

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Safe ships - Clean seas - Commercial efficiency

Contents

Introduction

ANGELICOUSSIS SHIPPING GROUP

THE FLEETS

DRY BULK CARGO

average years of age: 8.1

CRUDE OIL TANKERS

average years of age: 10

LNG Carriers

average years of age: 4.4

	No.	DWT (MT)	Cubic Capacity (m3)
Operating	48	8,241,584	-
On Order	0	0	-
Sub-Total	**48**	**8,241,584**	**-**
Operating*	38	9,904,550	-
On Order	4	1,275,400	-
Sub-Total	**42**	**11,179,950**	**-**
Operating	11	963,911	1,691,280
On Order	15 LNG	1,393,308	2,543,020
Sub-Total	**26**	**2,357,219**	**4,234,300**
TOTAL	**116**	**21,778,753**	**4,243,300**

<u>Fleet as at Aug 2014</u>

* 6 under management / 8 Bare Boat out



The "Golden Age"

- The WORLD LNG Fleet:
  - 384 operating ships: 269 steam ships, 115 diesel ships
  - 120 on order, including:
    - TFDE
    - MEGI
    - Steam Re-Heat
    - FSRU
    - FLNG
- Almost all areas of LNG ship design are being examined:
  - Size
  - Propulsion / Hull & Propeller Design
  - BOR / Tank Design / Cargo Handling
  - Operations & Automation

The 3 "C's"

✓ Challenge

✓ Cooperate

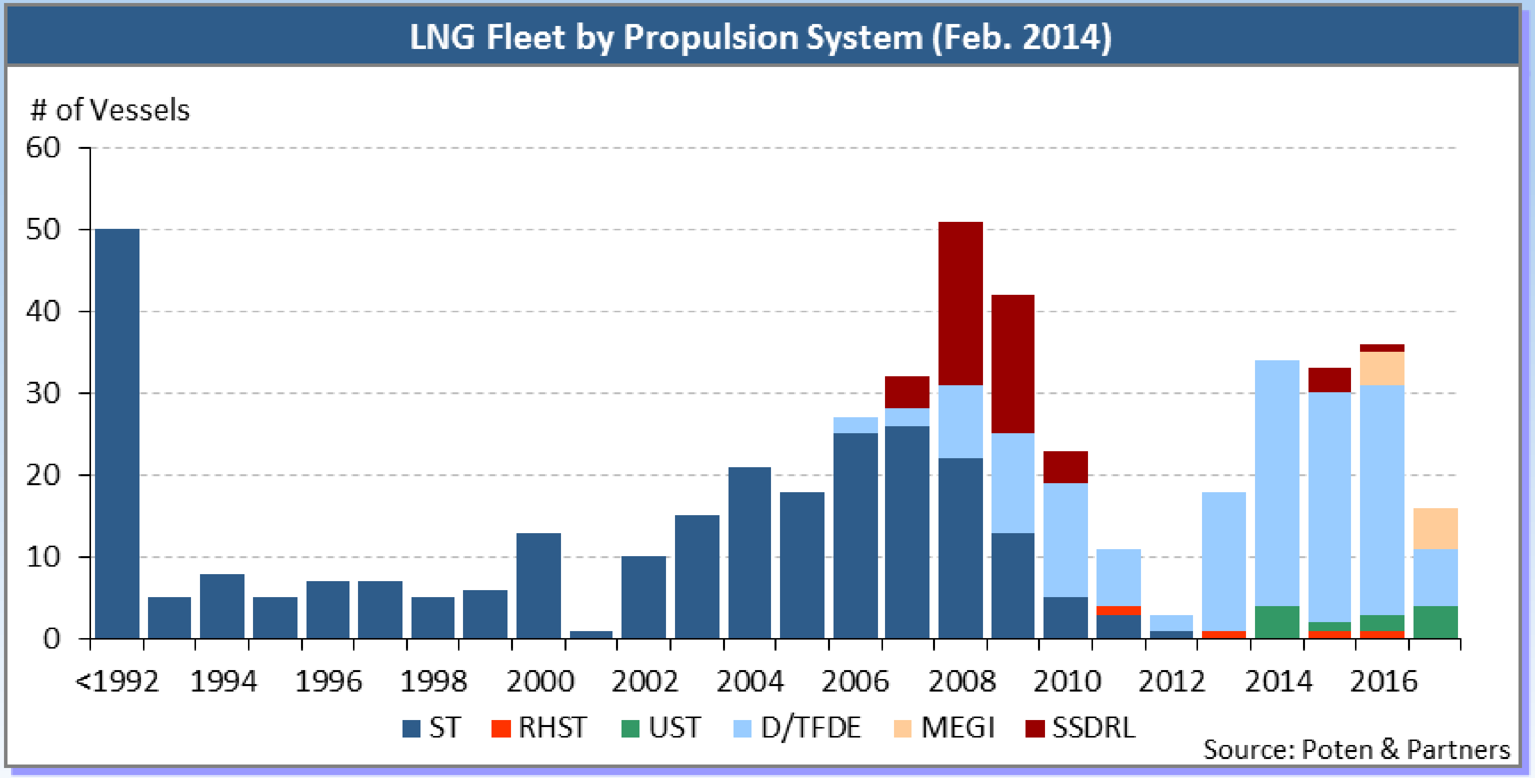
✓ Collaborate

To optimize the ship design, the Ship Owner, Shipyard and Vendors must work together!

…And be prepared to work hard!

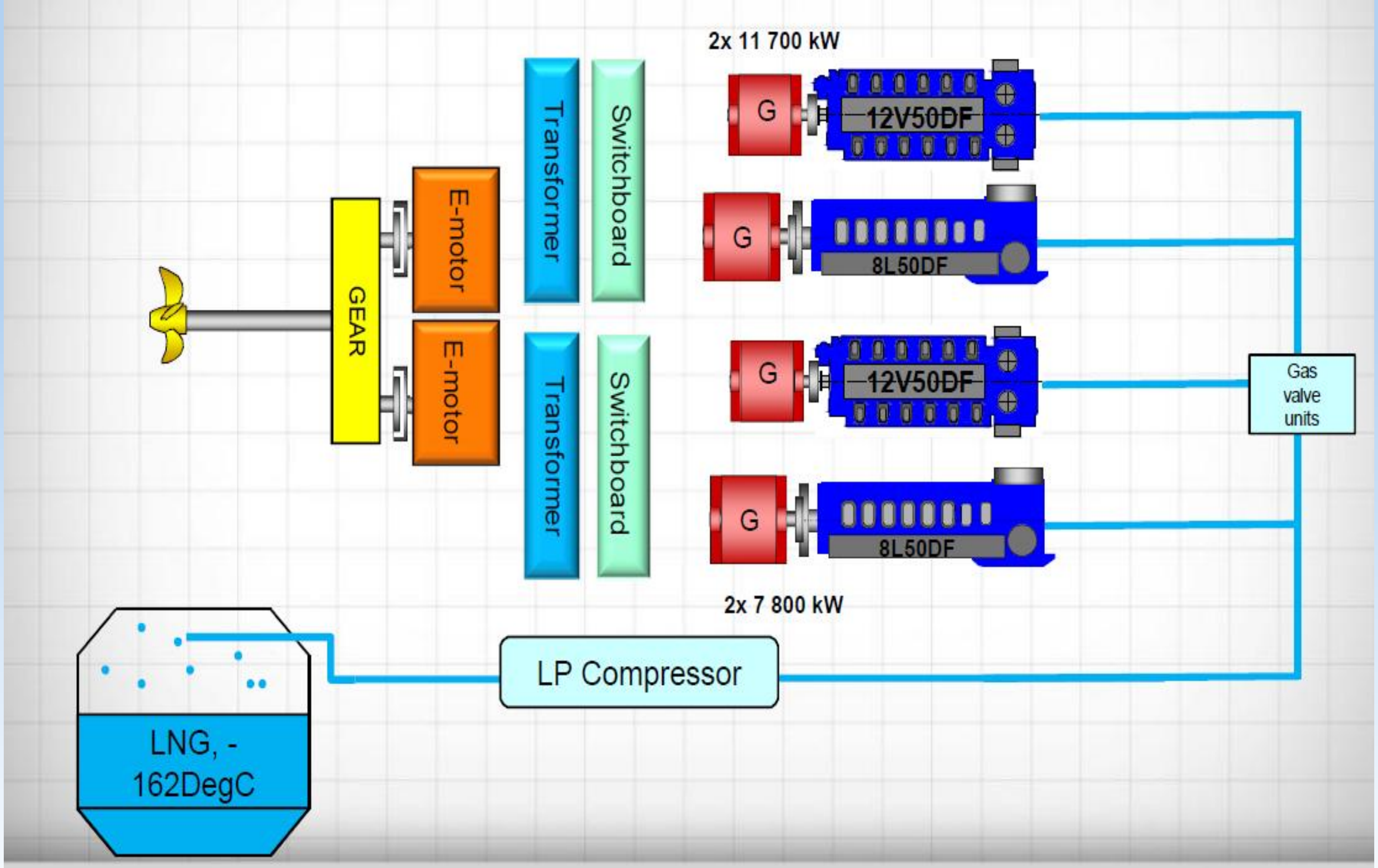
Propulsion

- The trend from steam propulsion to diesel can be seen in the graph below:



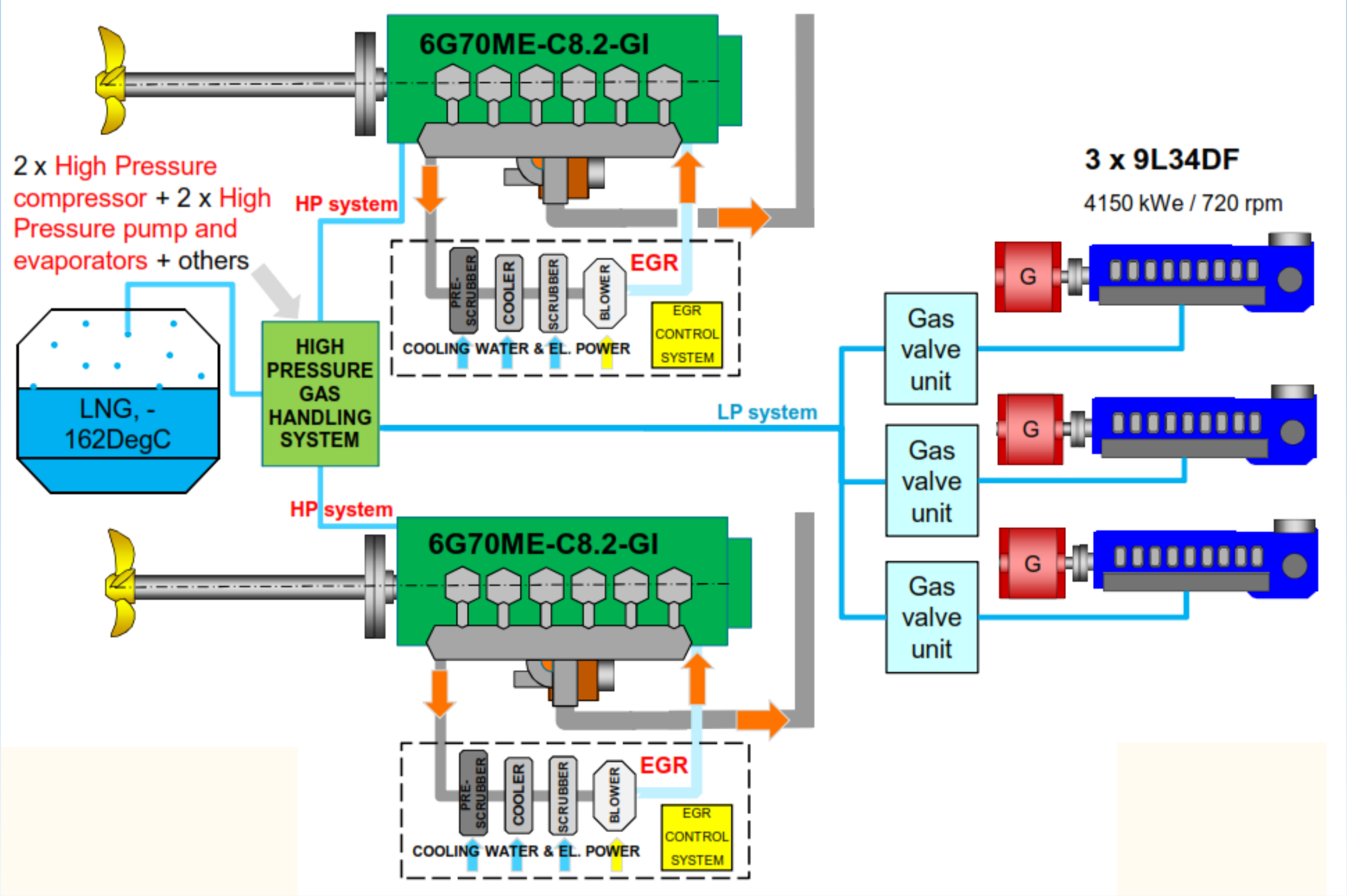
Propulsion

DFDE



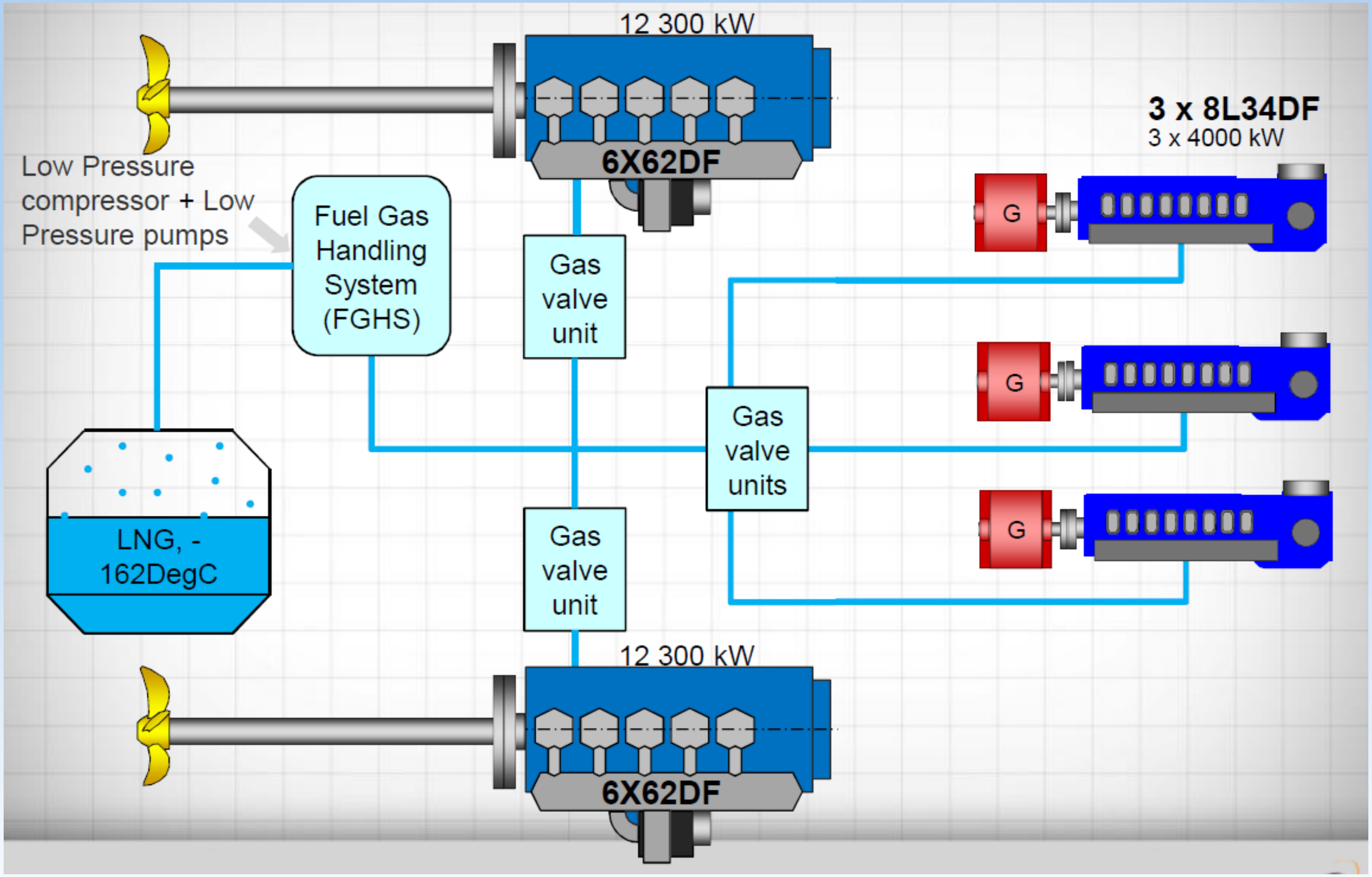
Propulsion

ME-GI



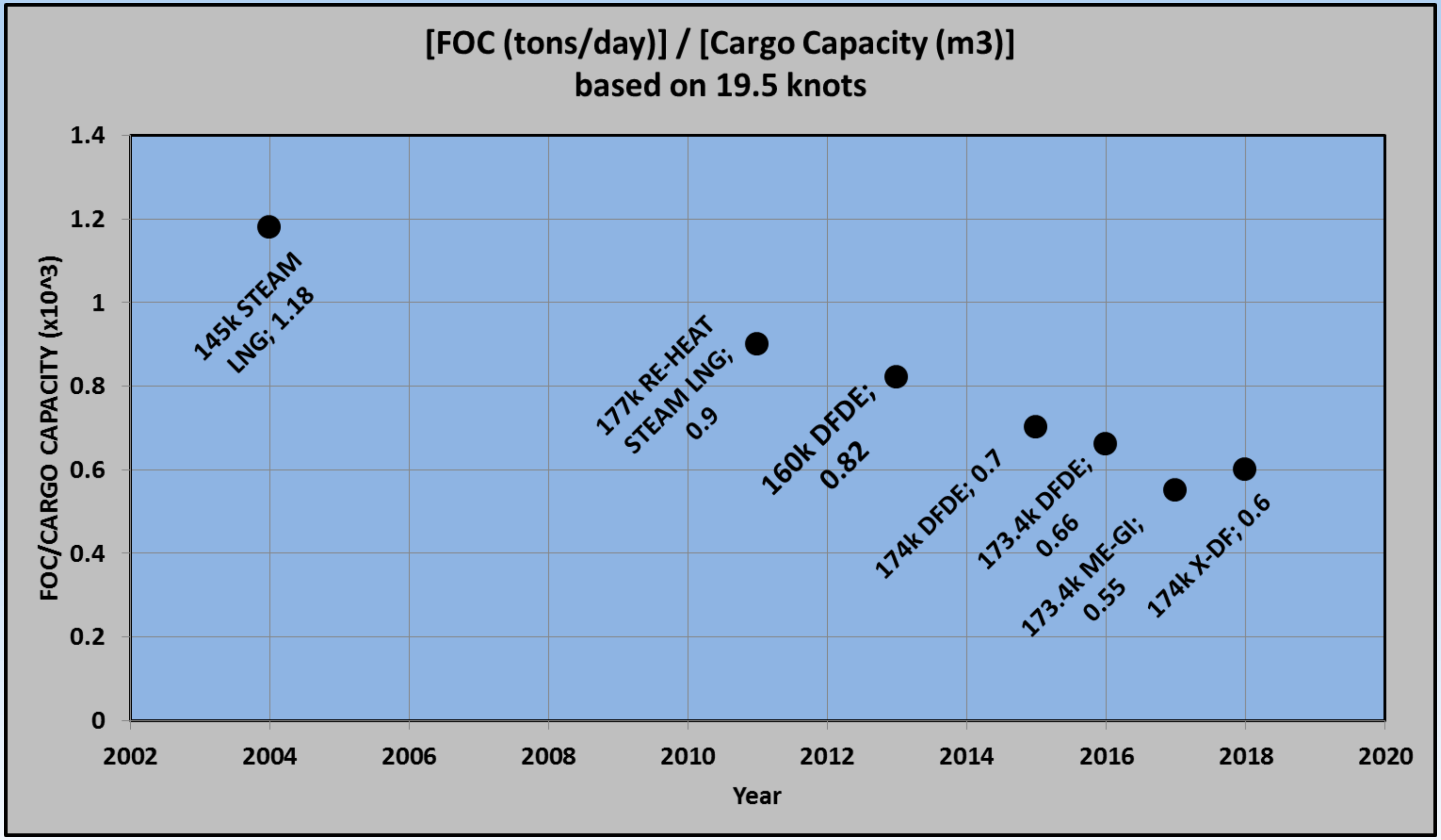
Propulsion

X-DF



Propulsion

This graph shows the combined effect of propulsion type and vessel size on fuel efficiency per cubic meter.



Propulsion

TFDE vs. 2-Stroke Gas Injection

Not a clear answer yet, and it may be that different applications yield different solutions.

Simple Comparison of TFDE vs. 2 Stroke Gas Injection

	DFDE / TFDE	MEGI	X-DF
EFFICIENCY	GOOD	BEST	CLOSE TO ME-GI
RELIABILITY	HIGH REDUNDANCY, MORE COMPLICATED CONTROL SYSTEM	HIGH RELIABILITY	HIGH RELIABILITY
CAPEX*	SAME	SAME	SAME
OPEX	MORE	LESS	LESS
EMISSIONS REGULATIONS NOX	COMPLIES ON GAS	NEED SCR	COMPLIES ON GAS
EXPERIENCE	SUFFICIENT	VERY SMALL	NO EXPERIENCE
FLEXIBILITY IN OPERATIONS	MORE	LESS - but reliquefaction plant provide more commercial flexibility	LESS – but complies with Tier III Nox on Gas.

*depending on exact configuration

Propulsion

Comparison for a 174K twin screw LNG Vessel with propulsion power at each shaft of 10,700 KW – all engines are tri-fuel.

Item	TFDE	ME-GI	Wartsila 2-Stroke
Main Engines	2 x 12 V 50 DF 2 x 8 L 50 DF Elec motor =10,700 kW out @ 68.8 RPM	2 x 5G70ME - GI NCR = 10,700 kW 65.5 RPM	2 x 72 DF (derated) NCR = 10,700 kW (85.6% MCR) 65.5 RPM
Auxiliary Generators	N/A	4 x 4-stroke ~3,200 kW DF	4 x 4-stroke ~3,200 kW DF
Gas Pressure	6 Bar	300 Bar	16 Bar
Re-Liq Plant	No	Yes (Brayton or JT)	No
Tier III	Yes – in gas	Needs SCR or EGR	Yes – in gas Need SCR or EGR in oil mode
Operation	Otto Cycle	Diesel Cycle	Otto Cycle

Propulsion

Overall Daily Consumption Comparison for a 174K twin screw LNG Vessel

ENGINES MODE	ME-GI	TFDE	X-DF
HFO @ 19.5kn	100%	122%	105%
HFO @ 16kn	100%	113%	106%
HFO @ 12kn	100%	112%	105%
However an LNG vessel will very seldom sail on HFO only mode, even in ballast condition.			
ENGINES MODE	ME-GI	TFDE	X-DF
MIX MODE @ 19.5kn	100%	114%	105%
MIX MODE @ 16kn	100%	96%	103%
MIX MODE @ 12kn	100%	97%	101%
ENGINES MODE	ME-GI	TFDE	X-DF
GAS ONLY @ 19.5kn	100%	104%	102%
GAS ONLY @ 16kn	100%	104%	103%
GAS ONLY @ 12kn	100%	92%	101%

In some cases, better overall consumption.

Very close to ME-GI.

Propulsion

Areas for Improvement of Propulsion Efficiency

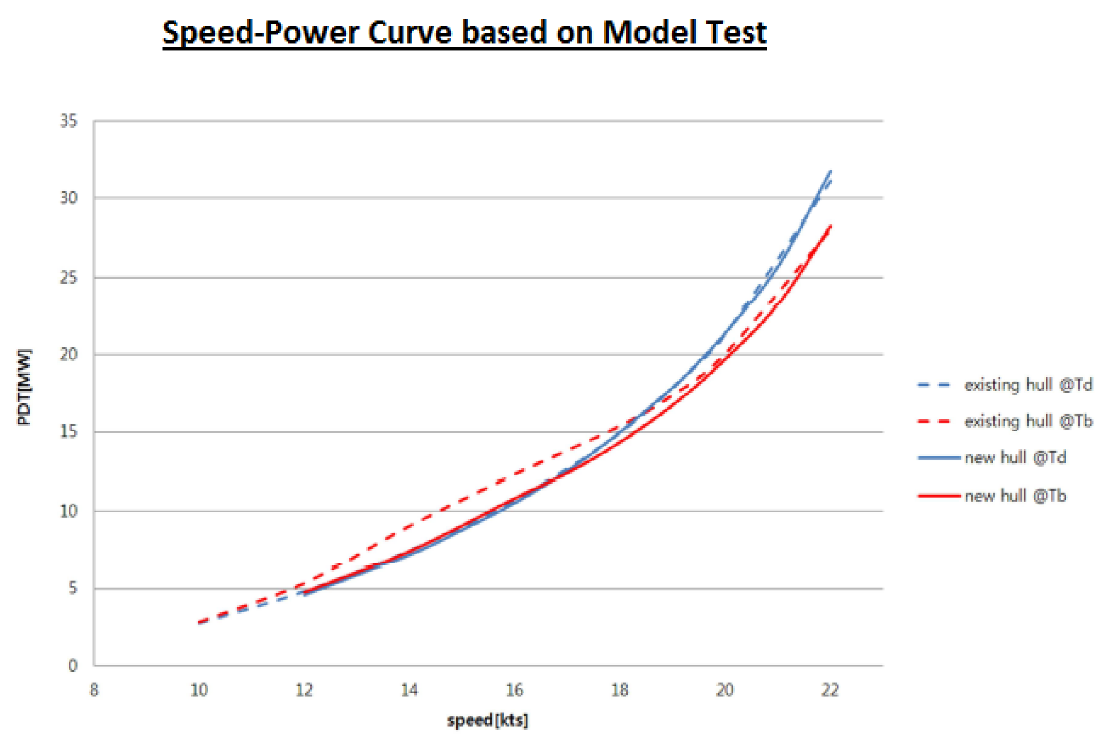
Possible Gains in Propulsion Efficiency for particular project

Energy-saving Solution	Expected gain	Model tests	Sea Trials
Twin-Skeg	0.5%	CONFIRMED	CONFIRMED
PBCF	1-2%	CONFIRMED	CONFIRMED
3-Bladed propeller	1-2%	CONFIRMED	-
Pre-Swirl Stator	2%	CONFIRMED	CONFIRMED
Z-twisted rudder	1.5%	CONFIRMED	-
Rudder position optimization	0.5-1%	NOT CONFIRMED	-
Rudder angle optimization	0.5%	CONFIRMED	CONFIRMED
CLT propeller	1-2%	NOT CONFIRMED	-

** Note: The above gains in propulsion efficiency cannot be necessarily added up. The application of one "energy-saving solution" may exclude or reduce the benefit of another one; energy-saving estimates from different measures are not cumulative.

Hull Design

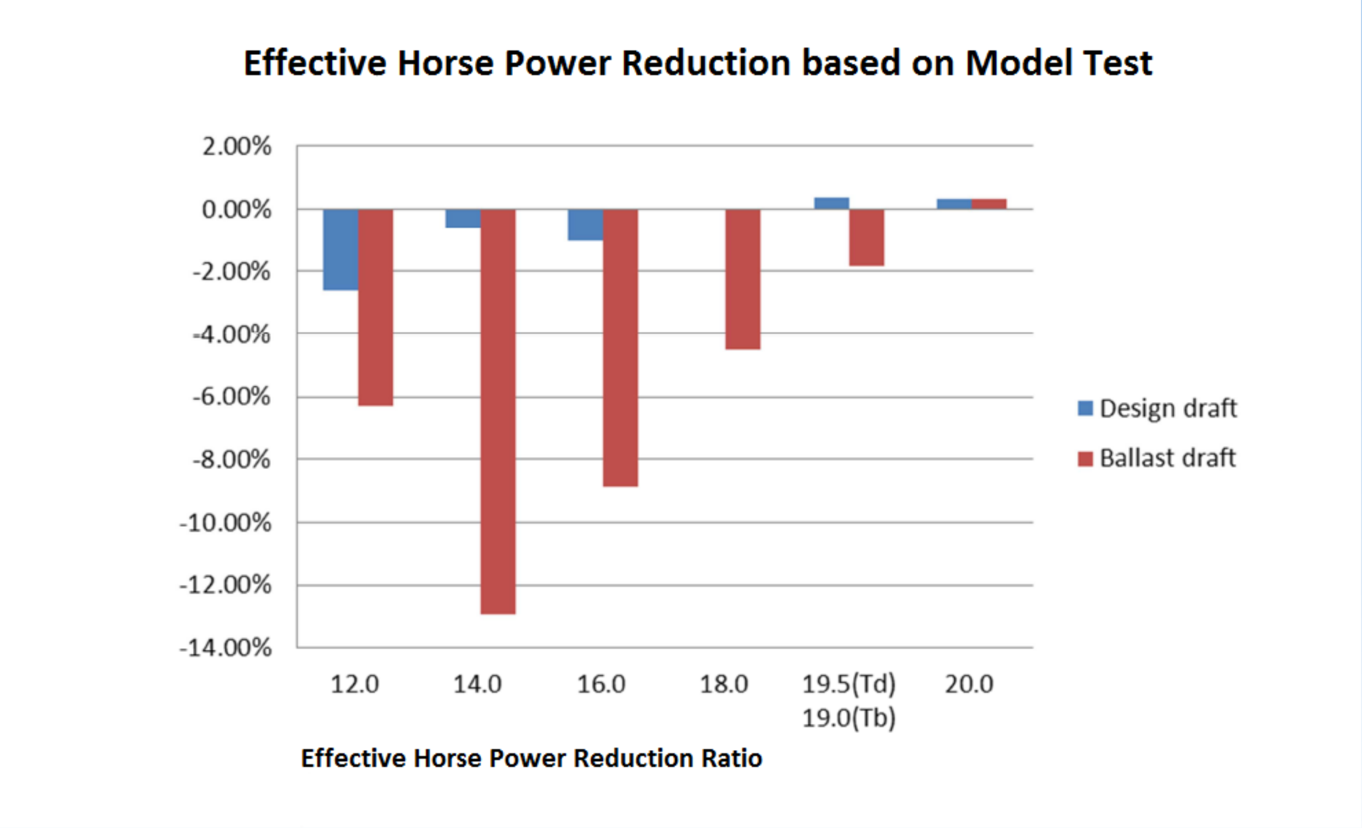
In the case below, the vessel's initial hull design met the spec for the design speed. However, after further testing, it was realized that it could be improved to achieve better fuel performance at slower speeds, particularly in ballast.



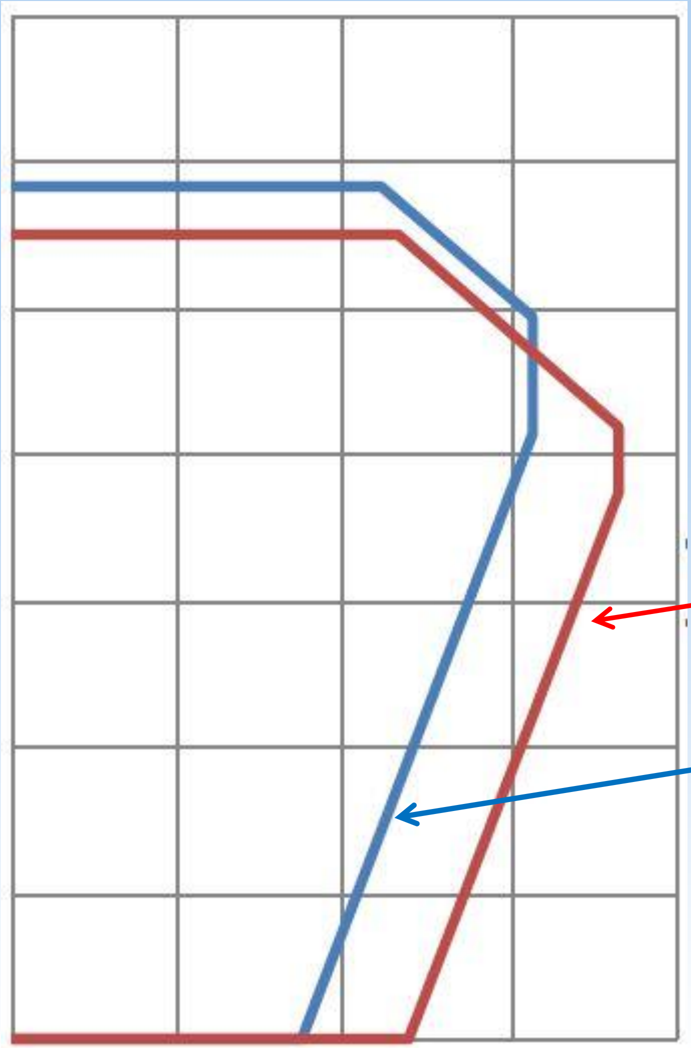
Speed-Power curve

Hull Design

Seen below are the reductions in effective horse power achieved over the full operating speed range, for both laden and ballast conditions, with the new vessel hull design.



Hull Design & Cargo Tank Design

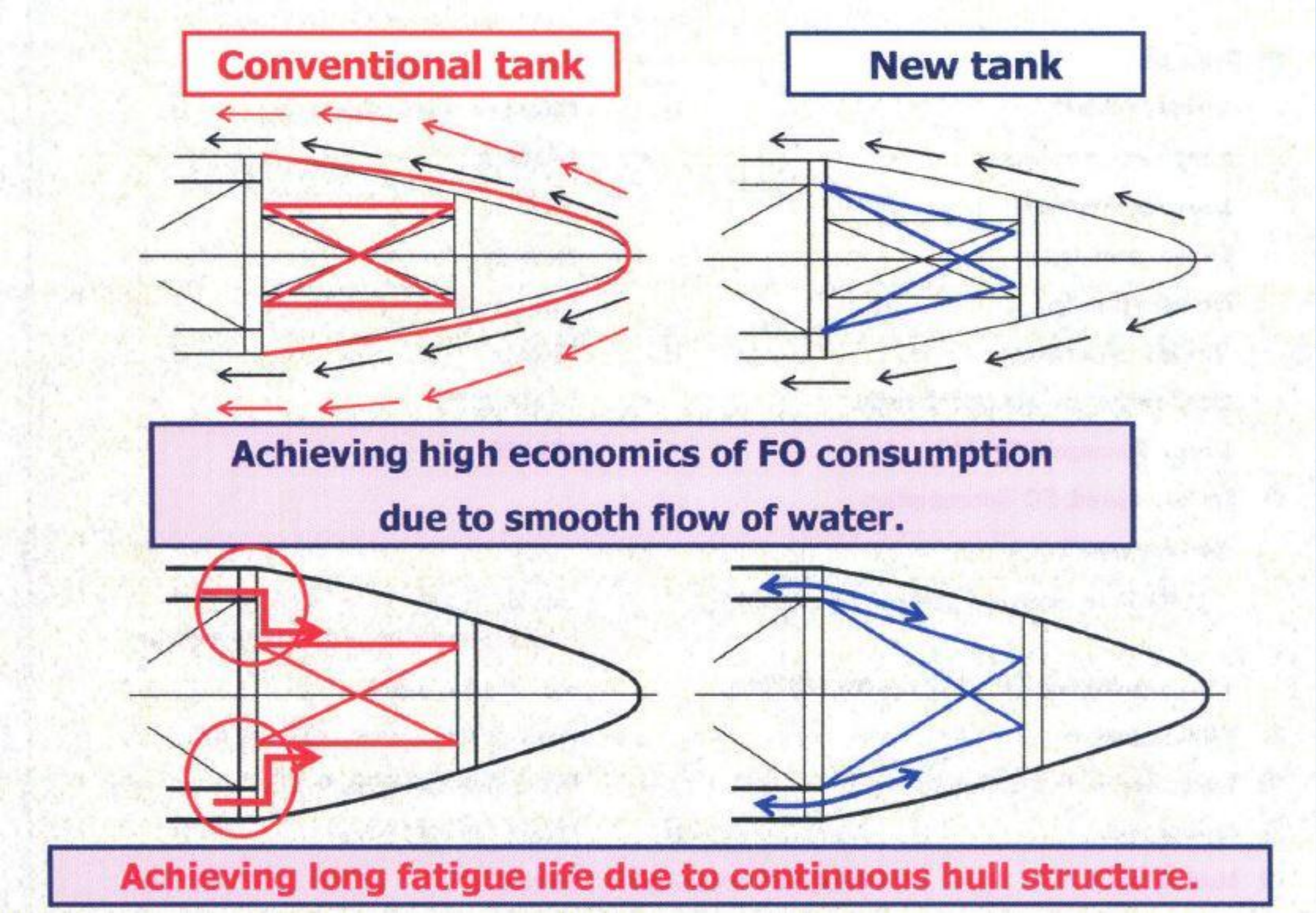


The Mark II design has some limitations at the fore body. GTT and the shipyards have worked to improve the tank shape and hull lines.

The red line is the original cross section of the number 1 tank and the blue line represents the cross section of the new design.

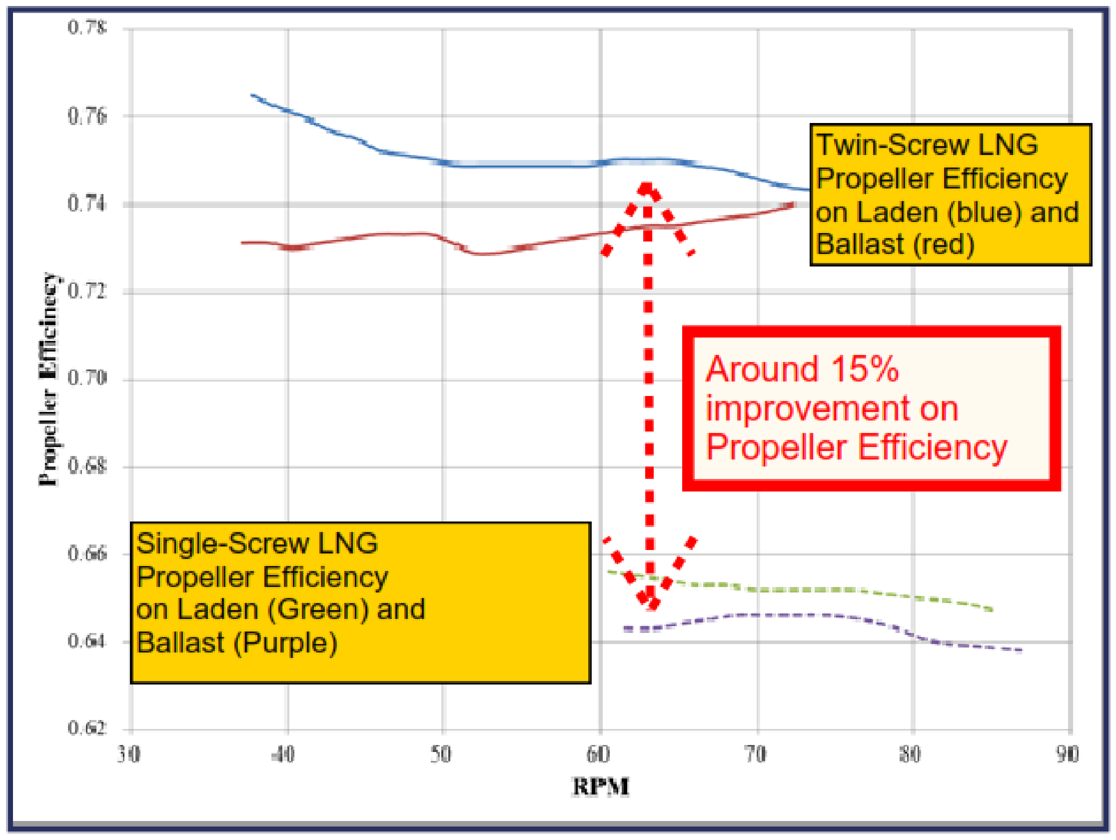
Hull Design & Cargo Tank Design

Imabari Shipyard and GTT have designed a trapezoidal number 1 Mark III cargo tank forward.



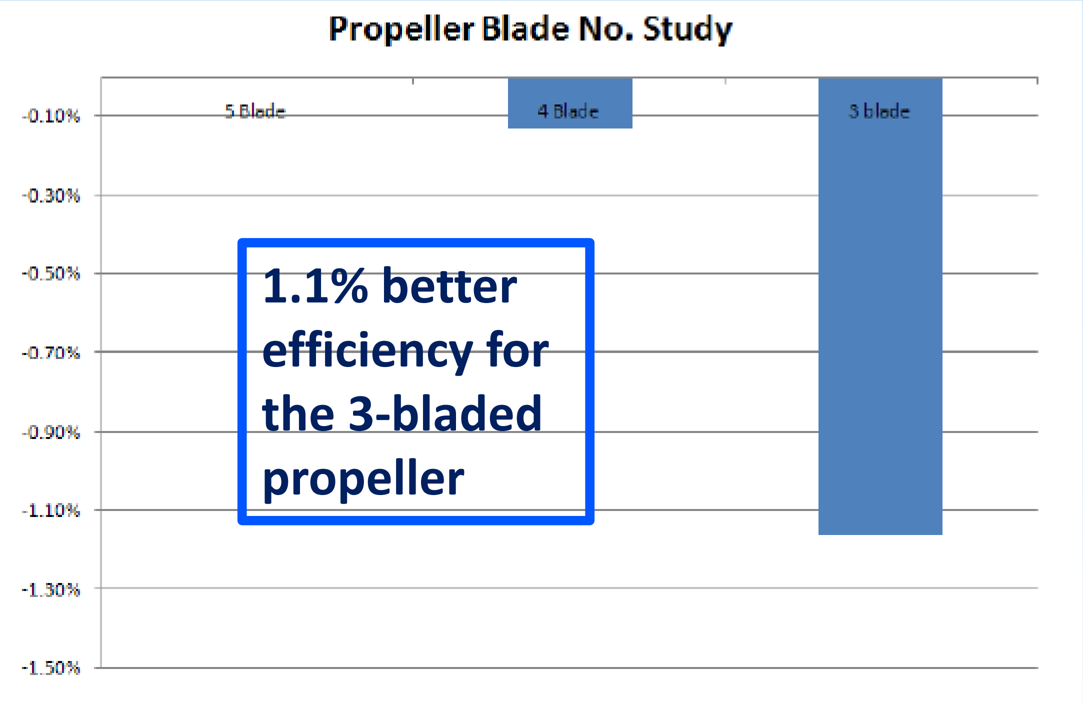
Propeller Design

The below shows the propeller efficiency improvement of a twin-screw LNG compared to a single-screw LNG of same size.



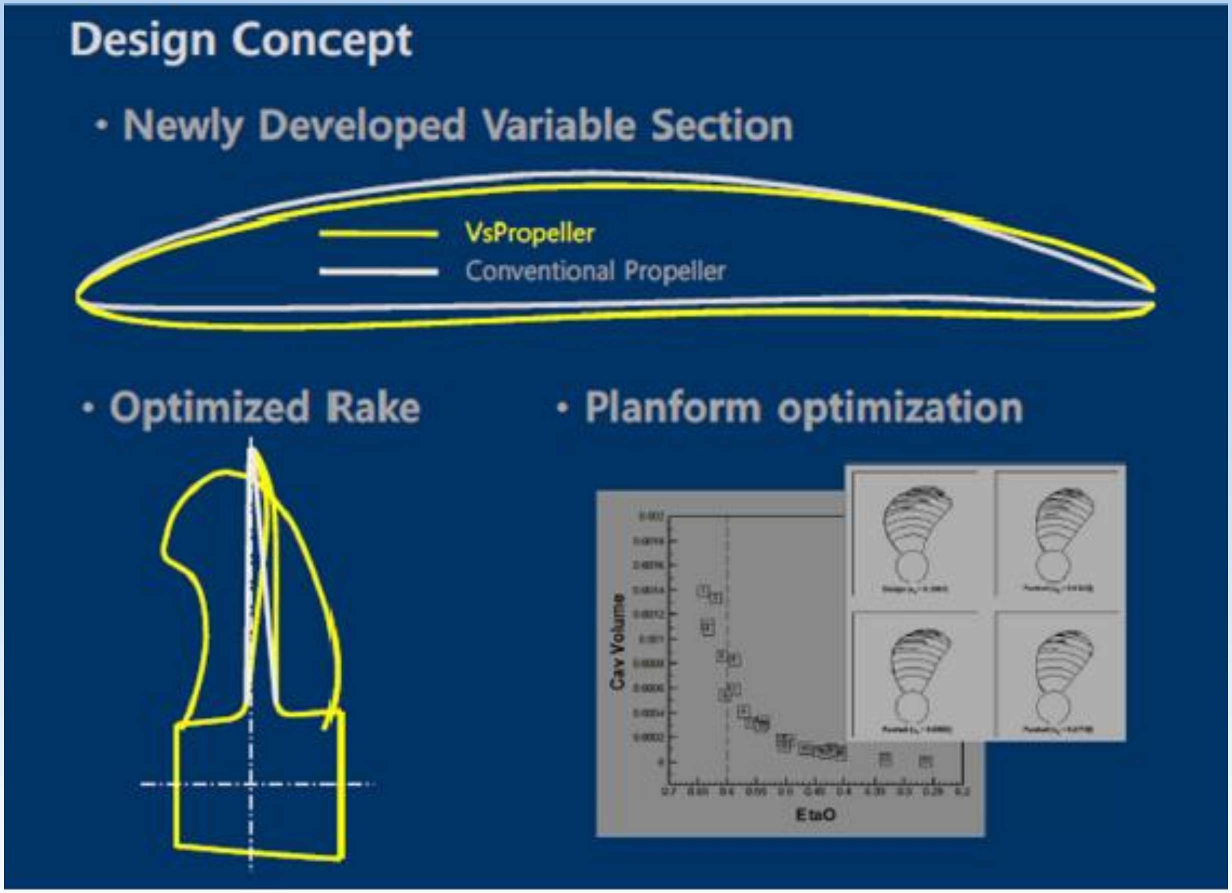
Propeller Design

The below shows the propeller efficiency improvement (1.1%) of a twin-screw LNG according to the number of blades (5-bladed, 4-bladed and 3-bladed)



Propeller Design

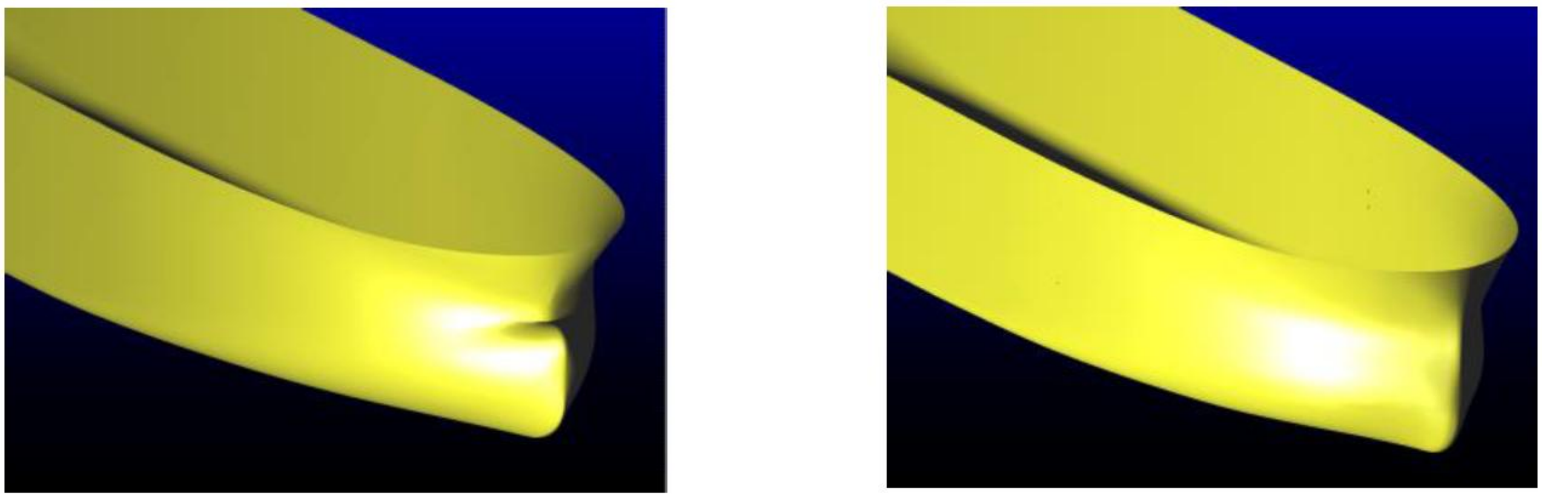
For a 3-bladed propeller, extra redesign studies improved the efficiency by around **1,3%.**



Bulbous Bow

Focusing only on improving hull design / performance on calm waters can be totally misleading and promised gains in power may never materialize in practice..

One example is the Bulbous Bow.



* Bulbous Bow   * No bulb Bow

Bulbous Bow

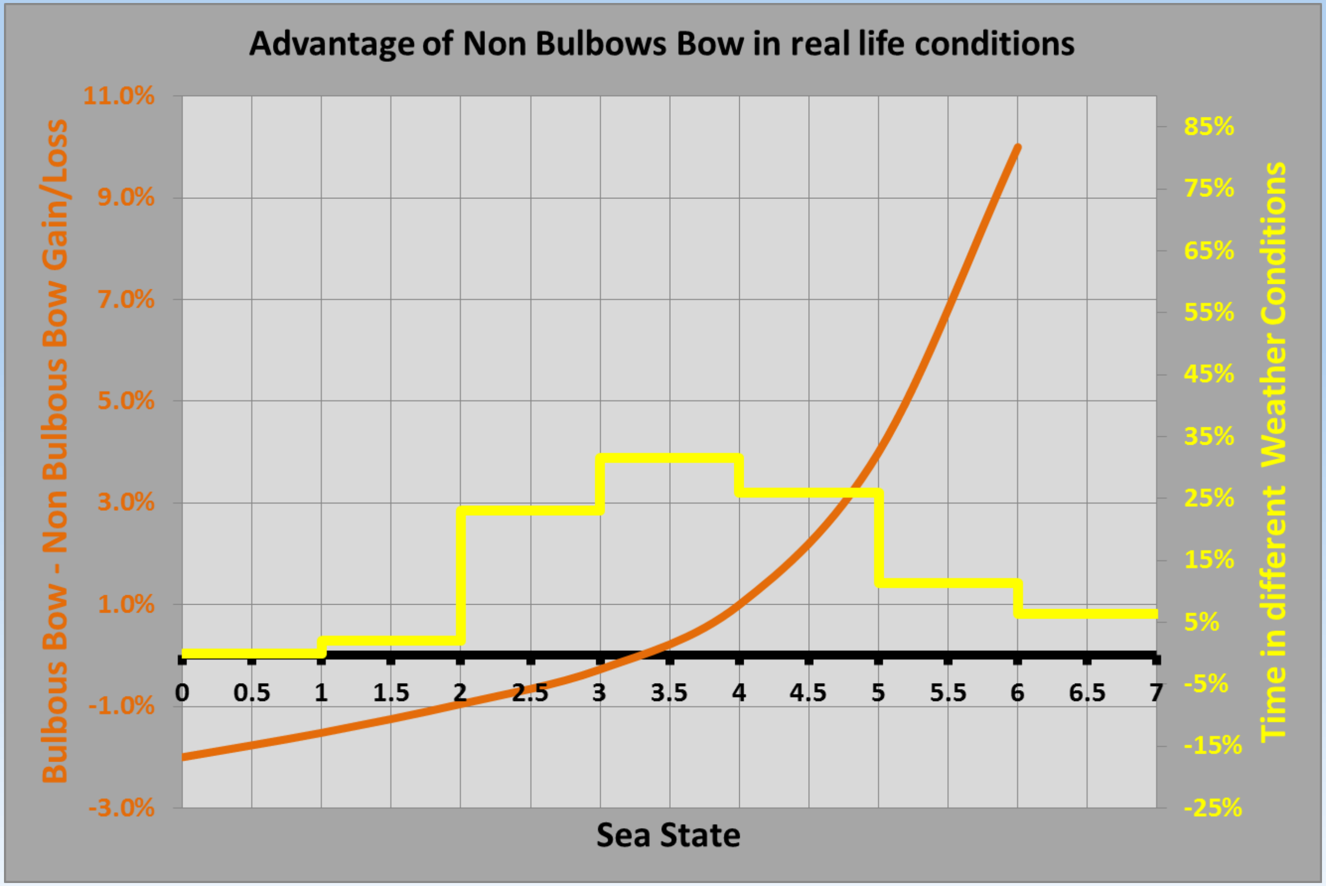
A VLCC with Bulbous Bow Design can save up to
2% of power @ SS0
compared with a Non-Bulbous Bow design.

At the same time a Non-Bulbous Bow design can save up to
10% of power @ SS6
compared with a Bulbous Bow design.

So the decision should be based on a Techno-Economical study rather than a purely hydrodynamic one.

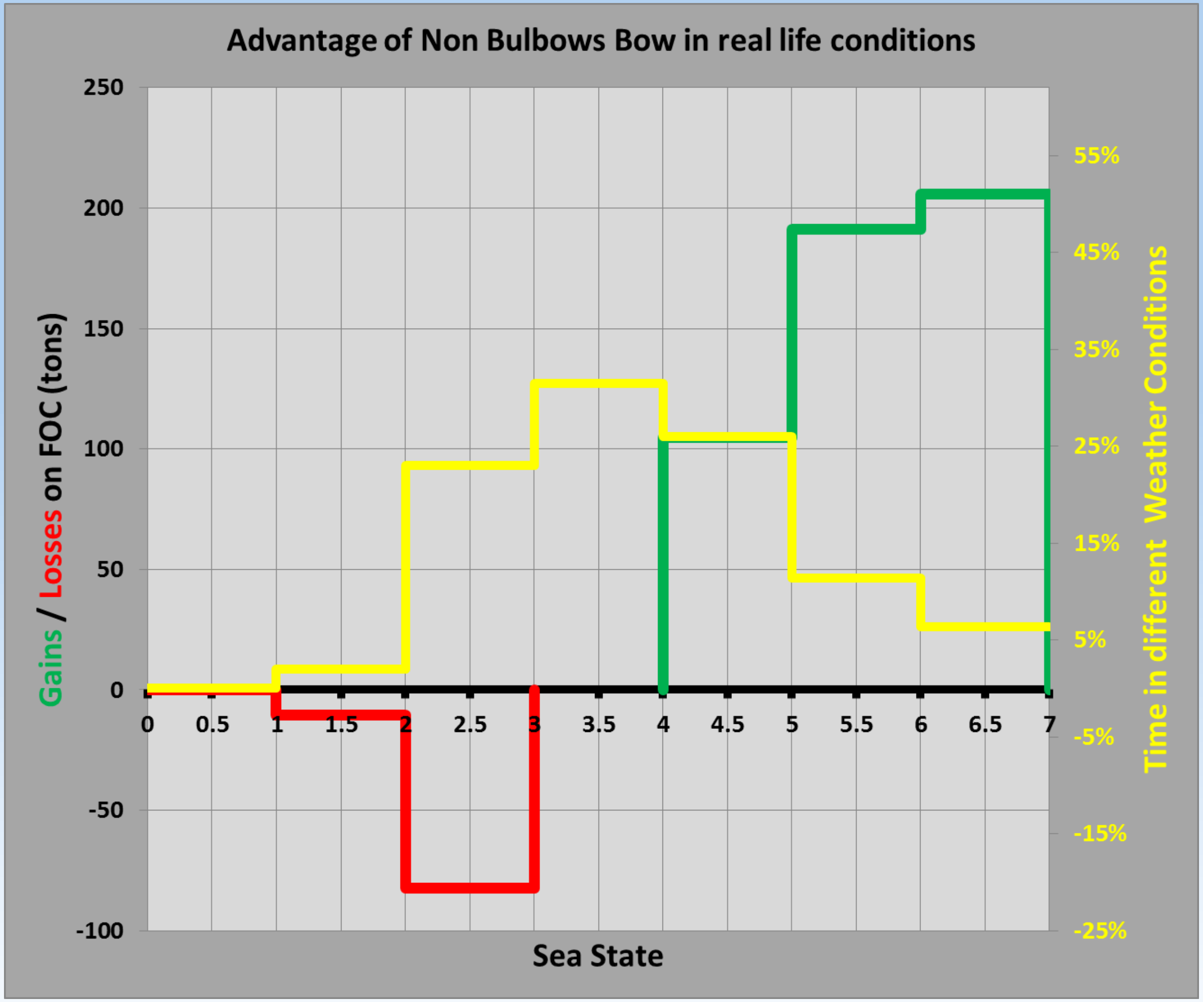
Bulbous Bow

The below tables are based on average figures from 5 VLCC of Maran Tankers



Bulbous Bow

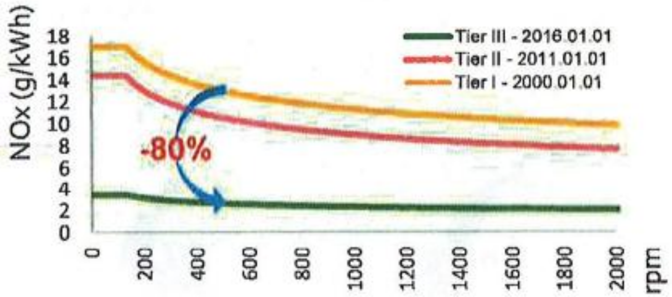
Around 400 tons (for 5 vessels and 640 days sailing) are saved,
OR
0.625tons per day per vessel
saving.



Emissions

◆ NOx (Depends on ship construction date)

Construction Date	Inside NOx ECA	Outside NOx ECA
Before 2000	Uncontrolled	Uncontrolled
2000 to 2010	Tier I (17.0 g/kWh)	Tier I
2011 to 2015	Tier II (14.4 g/kWh)	Tier II
After 2016	Tier III (3.4 g/kWh)	Tier II



◆ SOx / Fuel Sulphur (all ships)

Construction Date	Inside SOx ECA	Outside SOx ECA
Before May 2005	Uncontrolled	Uncontrolled
May 2005 ~ July 2010	1.5%	4.5%
July 2010 ~ 2014	1.0%	3.5%
After 2015	0.1%	0.5%



Emissions

HFO ONLY @ 19.5kn						
Type of Emissions	DFDE		ME-GI			X-DF
	tons/day		tons/day		tons/day	
SOx	2.4473	20% higher than ME-GI because of higher overall consumption	2.0190	Lowest because of better overall consumption	2.0970	Slighly higher (4%) than ME-GI
NOx	0.936	Lowest because of Tier III compliance.	4.4394	At least 4 times higher because of nn compliance with Tier-III. Also Nox emissions from Auxiliary Engines not	0.9983	Slighly higher (6%) than DFDE
CO2	382	20% higher than ME-GI because of higher overall consumption	315	Lowest because of better overall consumption	328	Slighly higher (4%) than ME-GI

GAS ONLY @ 19.5kn						
Type of Emissions	DFDE		ME-GI			X-DF
	tons/day		tons/day		tons/day	
SOx	0.0083	Practically zero, depends only on the sulfur content of the pilot fuel.	0.1722	20 times higher than DFDE because of HFO being used as pilot for the engines and as fuel for the aux.boilers	0.1084	13 times higher than DFDE because of Aux. Boilers HFO consumption
NOx	0.972	Lowest because of Tier III compliance.	4.4851	At least 4 times higher because of nn compliance with Tier-III. Also Nox emissions from Auxiliary Engines not	1.0343	Slighly higher (6%) than DFDE
CO2	259	Slighly higher (4%) than ME-GI	247	Lowest because of better overall consumption	251	Slighly higher (2%) than ME-GI

Operations & Automation

Trim Optimization:

Model test have shown that for certain hull designs, the effect of 1 to 2 meters of trim by the bow can reduce the power required significantly.

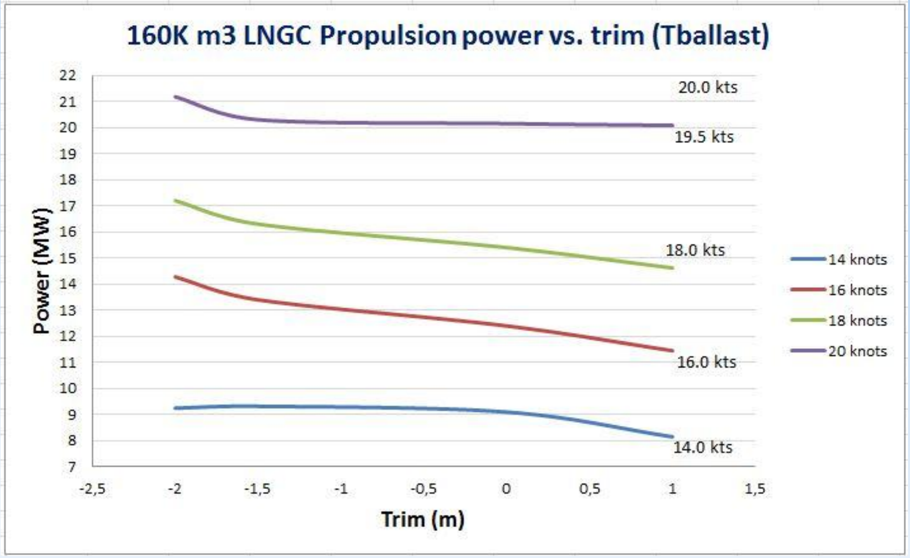
However, for LNG vessels, there are **constraints**:

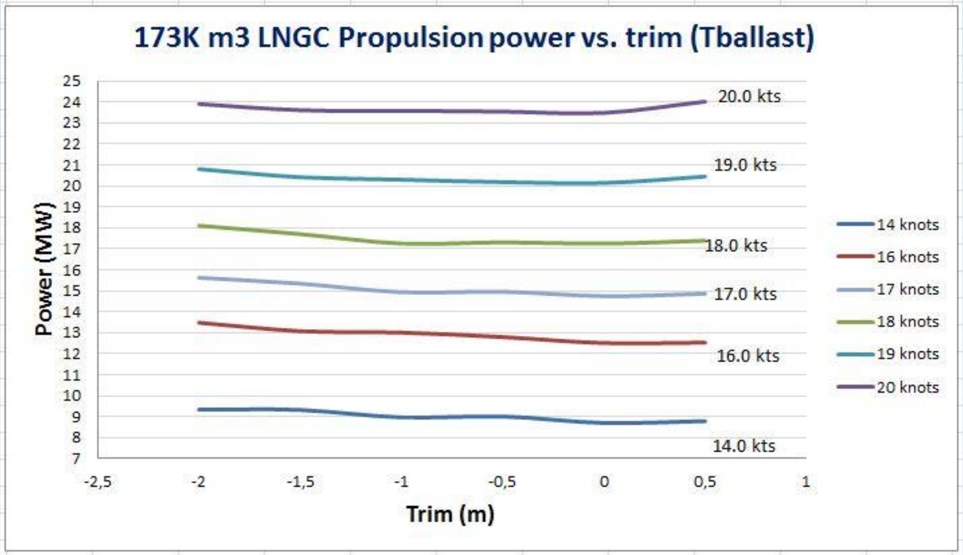
1. **In ballast** – if heel is carried then trim by the bow will not allow the fuel pumps to operate
2. **Laden** – caution needs to be exercised if trimming by the bow, so that LNG does not cover the vapor dome area.

Operations & Automation

Trim Optimization:

The following graphs show the evolution of design has helped to reduce the effect of trim.

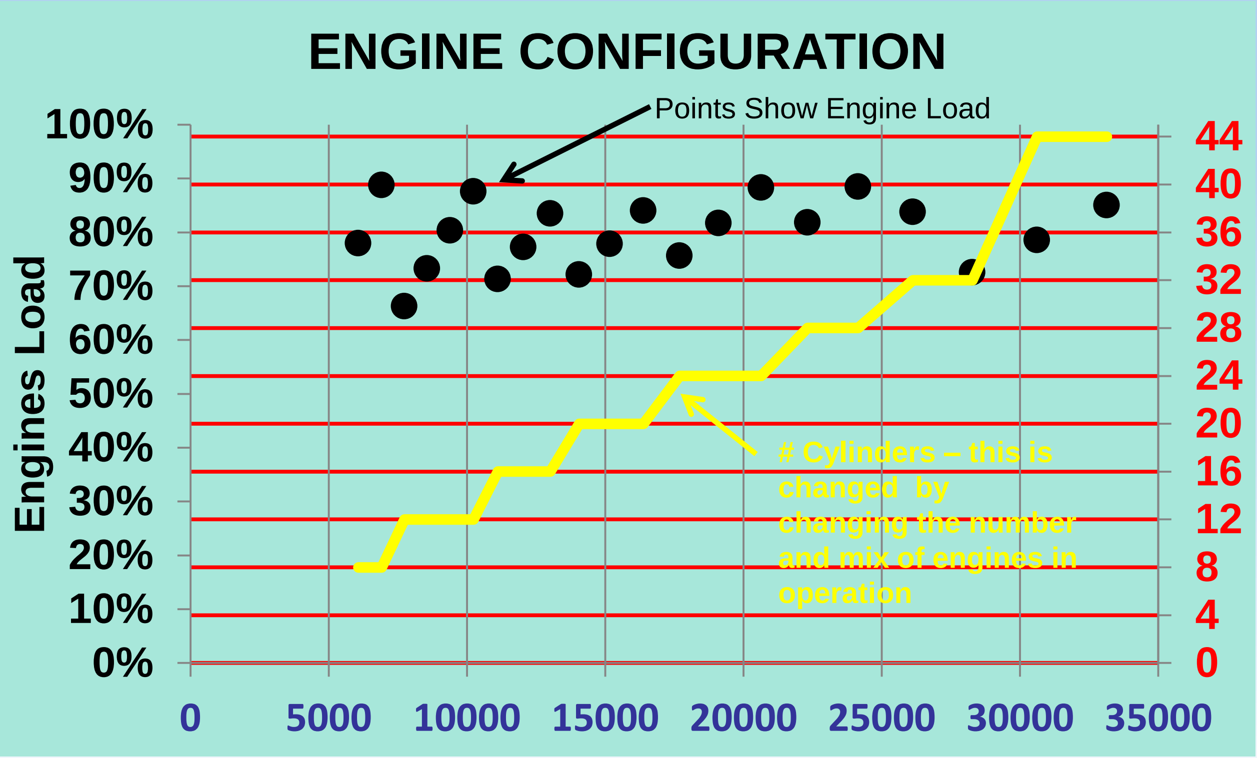




Operations & Automation

TFDE Engine Load Optimization:

It is best to match the number of engines operating with the power requirement to keep the engine load up in the efficient operating area.



Total Power - kW

Operations & Automation

TFDE Engine Load Optimization:

While the goal is to always select the mix of engines to run at the optimum efficiency, this must also be adjusted based on the amount of BOG available and the voyage instructions.

In minimum gas mode, some engines may need to be run on gas and some on heavy fuel oil to achieve the required power.

Fuel sharing mode – allowing the engine to burn a mix of HFO and BOG – has been introduced by one engine maker and is under development by the other.

Currently the adjustment of cargo tank pressure, and therefore BOG flow rate, provides the mechanism to achieve the desired engine mix to achieve efficiency.

Operations & Automation

Automation has become (<u>even more</u>) complex!

- TFDE designs require 4 main integrated control systems:
  - Main Generator Control
  - Main Electric Power Generation and Motor Control
  - Cargo Compressor and Fuel Pump Control
  - Integrated Automation System operating overall
- Within each system there are a number of safety systems and equipment permissions that must be satisfied before the equipment is allowed to run.
- Manual control is not really an option.
- Adjustment may be required for different LNG cargo compositions – a factor in expanded LNG trading operations
- Tracking of Software Settings, Upgrades, Operating System Versions is a key issue!

Conclusions

1. The pace of technical change in the LNG industry is higher than it has ever been.
2. Shipyards, Equipment Vendors and Owners need to work very closely to seek an optimum design that integrates solutions across different parts of the ship.
3. Together with improved efficiency, increased complexity is received. This is a burden for Designers, Operators and for the Service Organizations supporting the equipment.
4. The search for improved efficiency is continuing and will likely do so for many years to come – the end point is nowhere in sight.
5. Emissions has become an issue, regulations are getting stricter and stricter and LNG is for sure a way forward.

Thank you!