Improved Hull Designs for Energy Saving, Better Efficiency and Environment Protection

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With the increase in global population, the demand for natural resources has also risen drastically. Fossil fuel is expected to last another 30-40 years only. Another main concern is emissions from industries and transport systems.

We should introduce the concept of sustainable development in future ship designs. Almost all emissions from ships are reduced when less energy is consumed (1). According to an IMO study on greenhouse gases, it was found that there is potential for improvement in the existing technologies such as more efficient engines and propulsion systems, improved hull designs and larger ships. This simply means improvement through technical and design based measures that can reduce fuel consumption and emissions. It was also found that reductions could be obtained through operational measures such as lower speed, voyage optimisation, etc. (2).

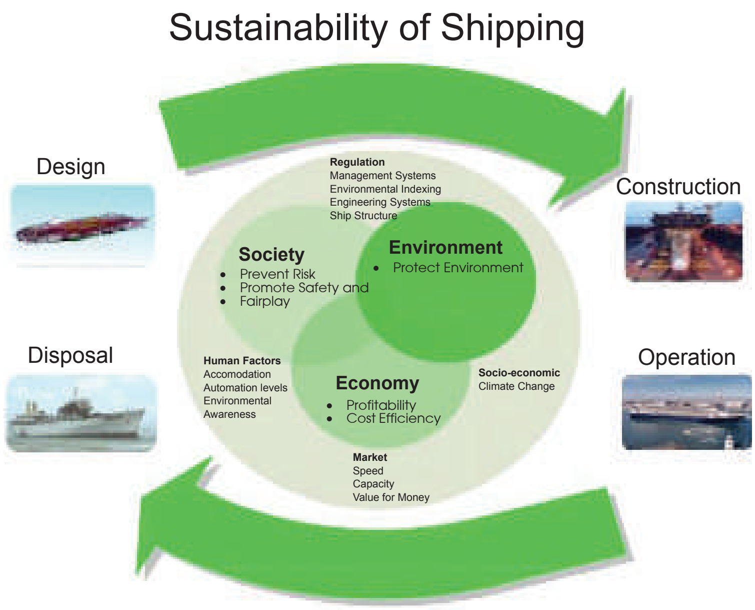

Figure 1: Sustainability of shipping

Although ship vessels are the most fuel-efficient mode of transport, the industry has been tasked to reduce its greenhouse gas emissions. One of the technical measures that had resulted from this was Energy Efficiency Design Index (EEDI), which was mandatory for new vessels built from January 1, 2013, as per IMO. The intention was to provide a new building standard, assuring that ship designs achieved a certain level of efficiency and decreased carbon emissions. It represents the energy efficiency of a ship's design, indicates the ratio between environmental impact (CO_2 emission per transportation work) and economic benefit and provides a benchmark against which a ship's efficiency may be evaluated (2).

We are designing eco-friendly ships so that future generations can enjoy natural resources to the fullest. Nature is a gift to mankind and we have a responsibility to protect it. Hence, sustainable development is necessary to safeguard our planet. Sustainability includes three elements (people, planet and profit) and has three pillars (economic, social and environmental). The shipping industry should be safe and secure, environmentally responsible, reliable and efficient in operation.

Figure 1 shows the lifecycle of shipping, from design to construction and operation and disposal. It is important to note that efficient shipping is only possible if we balance the three aspects of sustainability, i.e. economic responsibility, society and concern for environment. The design is the first step and optimisation of the hull design will play a major role in reducing resistance and emitting less greenhouse gases.

Designing a ship is a complex process. There are various enablers to be considered when designing a ship, including economy, technology, accidents, environment, security people and cultures. A design spiral is widely used and this forms a structured format for efficient and innovative ship designs as shown in Figure 2.

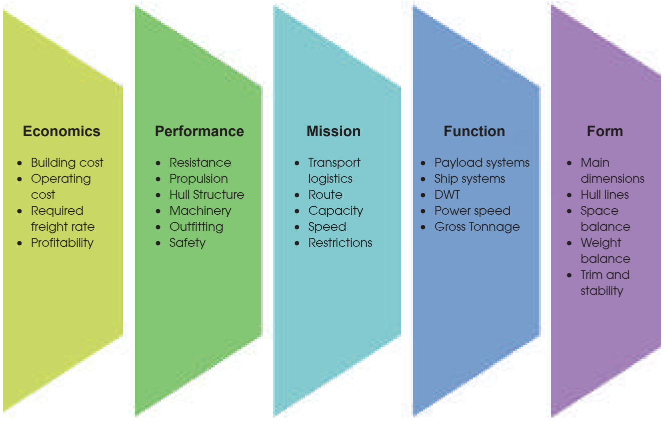

Figure 2: System based ship design spiral (Lavender, 2009)

The hull of a ship is divided into three main parts: Fore, Parallel Middle Body and Aft. Modifications can be done in the Fore and Aft parts to improve the design of the ship. The lines plan drawing of a ship is important in knowing the shape of the hull and providing information on hydrostatic data. In modern ships, new technologies have been used to improve efficiency.

DEVELOPMENTS IN SHIP HULL

Presently, there are modifications being done to the dimensions of a ship and hull forms to reduce the total weight and enable the ship to move faster and consume less fuel. Increasing the length while reducing the beam and maintaining the draft, displacement and block coefficient (Cb) constant typically yields improvements in hull efficiency, provided additional ballast is not needed to maintain adequate stability. A higher length/beam ratio tends to reduce wave making resistance, while the reduced beam/draft ratio tends to reduce wetted surface and therefore the frictional resistance (3). Hull form optimisation is mostly done in the Fore and Aft. The modifications in hull designs will greatly improve design efficiency. The improvement areas include:

- Fore body optimisation
- Aft body optimisation
- Propeller wake optimisation

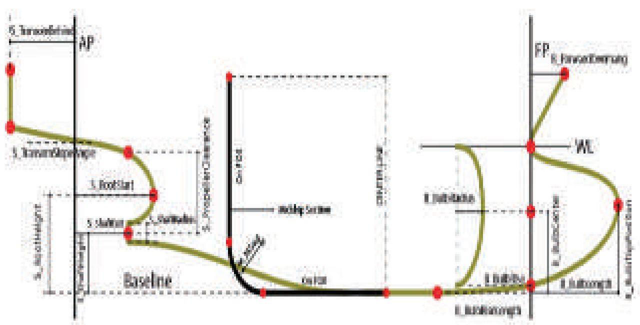

Figure 3: Exposed parameters for Aft and Bow parts of the ship and Midship section (Duvigneau et al., 2013)

Figure 3 describes the three main parts of a hull: Fore, Middle and Aft. It also determines the basic outline of measurements for optimising the hull.

1. FORE BODY OPTIMISATION

A properly designed bulbous bow reduces wave making resistance by producing its own wave system that is out of phase with the bow wave from the hull, creating a cancelling effect and overall reduction in wave making resistance. The flow is more horizontal, reducing eddy effects at the forward bilge. Physical factors considered in bulb optimisation include volume, vertical extension of the center of volume, longitudinal extension and shape (4).

Improving bulb characteristics is a complex process. We should know what kind of bow matches with the design. There are different types of bulbous bow design like the pear shaped bow, Goose neck type bow, V shaped hull etc. These modifications can be done using advanced computer software by fairing the B-spline and checking the pressure variations towards the hull.

A bulb with a reverse pear-shaped section is primarily effective at the design condition. Pear-shaped bulbs work best for drafts below the design draft. A V-shape may be introduced at the base of the bulb to mitigate slamming impact loads. Faster, more slender vessels favour larger volume and forward extension of the bulb. Goose-neck bows and stretched bulbs are particularly effective when draft and speed vary over a small range (5). The characteristics of the bulbous bow must be carefully balanced with the shape of the entrance and the transition towards the forward shoulder and bilge. Bulbs are most effective at certain Froude number (speed-length ratio) and draft. Changes in speed and draft significantly change the wave created, such that reductions in draft or speed can actually lead to increases in wave making resistance. Maersk Lines reports fuel savings of over 5% by modifying the bulbous bow (Figure 4) of a shipyard design which was optimised to the design draft. Hence, it provided a more favourable performance over the anticipated operating profile of drafts and ship speeds.

Bow flare also influences motion and added resistance in waves. A V-shaped rather than U-shaped flare is generally preferred, as it can reduce motion without adding resistance. The increased resistance in heavy seas due to a pronounced flare is currently not fully understood and consequently, rarely considered during the design process. However efforts are on-going to find out more (5,14).

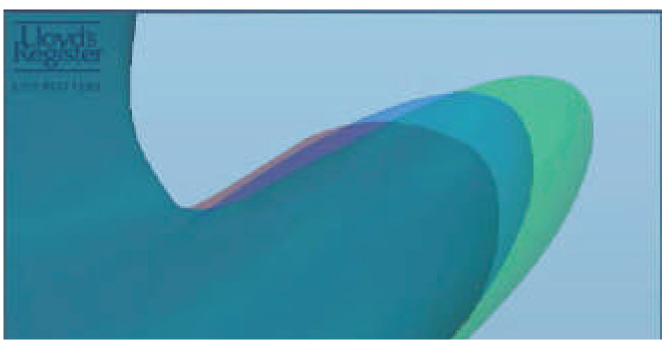

Figure 4: Bulbous bow variations (Lloyd's Register)

According to Lloyd's Register, variations in the bulbous bow can give fuel saving of 3 tons per day for a feeder container ship. In the figure above, the colour blue indicates the original shape, red gives the worst results and green is considered to give best results (6).

1.1 Modern Bow Designs

Using advanced technology, many well-known companies have put a lot of emphasis on developing efficient hulls. One of the advances in forward hull design is done by Ulstein Design companies which has come up with the concept of X-bow hull design (Figure 5). This introduces a larger and smoother volume distribution in the Fore, allowing for submersion. Combined with a sharper bow shape, the typical challenges of conventional bow shapes are solved. The shape of the hull has been optimised with a view to high top speeds, low resistance and reduced fuel consumption. Great emphasis is also placed on the crew's safety and comfort (7).

The key benefits of this type of hull design are:

- Elimination of slamming and bow impact.
- Soft entry in waves.
- Less spray.
- Low acceleration levels.
- Reduced vibration levels.
- Increased comfort and available crew rest time.
- Safer workplace due to smoother motions and protection provided by hull.

Figure 5: X-bow hull

Another improvement in the forward part of hull design was done by Rolls Royce which had been patented this year. The design features a bow with a vertical stem for smooth entry into the water. When it encounters a wave, the hull shape pierces through the water rather than rides over the top, while the bulb contours the shape of waves along the ship's side to reduce wave resistance. The straight flare in the bow design also minimises speed loss and slamming during operation.

2. AFT BODY OPTIMISATION

Aft body optimisation includes efforts to mitigate stern waves, improve flow into the propeller and avoid eddy effects. A properly designed stern can reduce the aft shoulder crest wave as well as the deep wave trough and stern waves. Improving the nature of the stern flow can lead to greater propulsive efficiency. But the aft body optimisation is a bit tricky when compared to forward part because of the presence of appendages such as the rudder, propeller etc.

Single screw sterns forward of the propeller may be V-shaped, U-shaped or bulb types. The trend today is towards the bulb shape, as the improved wake reduces cavitation and vibration. This is one of the environment friendly designs as these days, pram type stern hulls are used to shift the Longitudinal Centre of Buoyancy (LCB) aftwards, enabling smoother forward shoulders and lower waterline entrance angles which reduce resistance (8).

Three types of aft ship hull shapes can be distinguished:

i. Extreme pram type aft ships
ii. Variations of a moderate pram type with a moderate stern bulb
iii. Aft ship shapes featuring a moderate tunnel (originated from inland waterway vessels with draught limitations) (9).

Of the three types of aft ship hull shapes, the third is most efficient and the latest in operation because it can accommodate a propeller with a larger diameter. The tunnel shape ensures a steady flow into the propeller even in heavy seas, reducing propeller racing and providing sustained good thrust as shown in Figures 6 and 7.

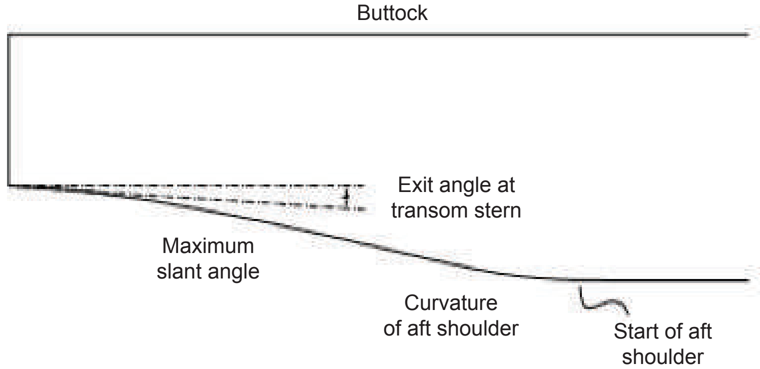

Figure 6: Aft hull seen from starboard side includes slant angle, exit angle and start of aft shoulder (Tregde, 2003)

Figure 7: Moderate tunnel shaped aft ship (J.j.nieuwenhuies, D. 2002)

When the hull is properly improved, it will reduce resistance, which means less power will be required to propel the ship. This will also help reduce emissions from the engine and increase the overall efficiency of the ship.

2.1 Propeller Rudder Interaction

The efficiency of a ship also depends greatly on propulsive efficiency. There have been on-going studies on propellers and rudders for a long time. With developing technology, engineers and designers at Rolls Royce have come up with a unique and interesting technology of propeller and rudder integration to satisfy the demands of energy efficient design. It is named as Promas Lite (Figure 8).

Behind a normal propeller hub, a strong low pressure vortex (hub vortex) acts on the propeller hub, increasing drag and reducing propeller thrust. In the Promas Lite, a special hubcap fitted to the propeller streamlines the flow onto a bulb that is added to the rudder, effectively reducing flow separation immediately after the propeller. The result is an increase in propeller thrust as previously wasted energy is recovered from the flow. In addition, the bulb on the rudder streamlines the flow aft of the rudder, further reducing drag. The hubcap is mounted outside of the propeller hub and acts purely as a hydrodynamic fairing. No special hub design is needed, so cost and technical complexity are kept to a minimum (10). Benefits of this design include:

- Reduced fuel consumption – improvements of 5-15% are possible, depending on the vessel's operating profile.
- Reduced environmental impact – corresponding reduction in emissions with lower emission taxes, wake wash and noise.
- Short payback period – depends on vessel operating hours, but the return on investment is usually less than two years.
- Increased propulsive efficiency – integrated rudder and propeller design, reduced pressure pulses for improved comfort.
- Simple and quick installation – can normally be fitted within a week
- Lower maintenance costs – reduced engine loads means less oil consumption and potentially reduced engine wear.

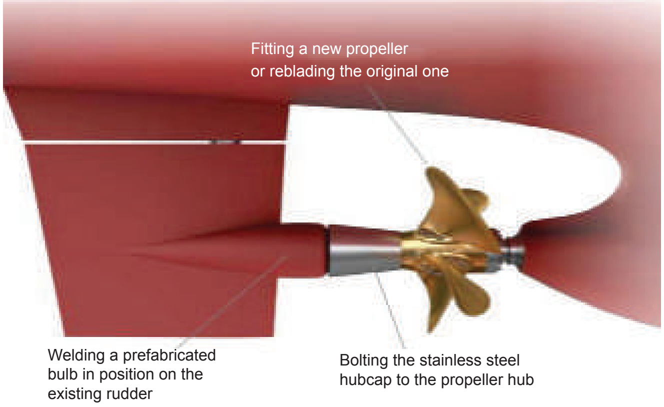

Figure 8: Promas Lite, propeller rudder interaction by Rolls Royce (Rolls Royce Marine)

ANALYSIS OF HULL OPTIMISATION AND FUEL SAVINGS

Table 1 was taken from a report by Lloyd's Register. According to this, when the hull of a ship is optimised, it affects the trim of ship ahead and aft. If we carefully distribute the weight along the length of ship and produce a stable trim, there will be reduced resistance and savings on fuel consumption. This optimisation was done on various types of ships and it was found that there were confirmed savings on fuel greater than 1-2% and improvements in ship speed. Resistance was minimised and fuel consumption was reduced as less power was needed to propel the ship. At the same time, overall efficiency was increased.

Table 1: Trim Optimisation (Lloyd's Register)

TRIM OPTIMISATION	DESIGN YEAR	FOC IMPROVEMENT EXPECTED / CONFIRMED IN OPERATION
VLCC	2006	<1% confirmed Saving abt. $250k/year
ULCS 13K Teu	2007	<1% confirmed Saving abt. $700k/year
PCTC	2005	1 – 2% confirmed
87K Dwt Bulk Carrier	2004	Speed-up experienced
Feeder Container		Speed-up experienced
MT Tanker		Speed-up experienced
32k dwt Bulk Carrier		0.2 knots increase on average speed for same FOC
General Cargo	2013	0.4 knots increase speed at 14 knots

1. EXAMPLES OF HULL OPTIMISED SHIPS

If we analyse Table 2 and 3, we can see that optimisation of the hull not only helps save fuel but also protects the environment. The results are based on Lloyd's Register survey, which is one of the best classification societies involved in ship design for years.

Table 2: Integrated hull form optimisation (Lloyd's Register)

Delta Marin B DELTA 39k DWT Bulk Carrier for CNCO Delivered in 2013	
INNOVATIVE SOLUTION	Integrated Hull Form Optimisation
PERFORMANCE	• FOC of 18.5 t/day @ 4554kw • EEDI 21% below required limit • High Cargo Volume • Shallow Draft • High Deadweight Design

Table 2 shows a bulk carrier delivered in 2013 with this integrated hull form optimsation. Its performance showed that it had high cargo volume and a great reduction of CO_2 content i.e. EEDI of 21% below required limit. If this technology is applied to most ships in future, we will be able to produce highly efficient, eco-friendly ships.

Table 3 also describes a bulk carrier with optimisation in its super structure and propeller that also amounted to savings of at least 3% in fuel consumption and EEDI of 12% below required limit. These two ships have proved to be efficient and environment friendly.

Development of the hull form is important to minimise the weight of the structure as this is related to resistance and fuel consumption.

Table 3: Optimisation of hull and propeller (Lloyd's Register)

VICTORIA STEAMSHIPS 95k dwt BC Flettner Rotors & Aerodynamic Accommodation	
INNOVATIVE SOLUTION	Optimisation of Hull (Superstructure and Propulsion) by Lloyd's Register, Nakashima and Flettner Rotors
PERFORMANCE	• Up to 3% FOC savings against 22 knot headwind • "Saving 700 kw" • EEDI about 12% below required limit • 15 t/day @ 10.5 knots!

2. METHODS TO IMPROVE ENERGY

Here are some methods that will improve present fuel efficiency and ship efficiency systems.

a. Optimisation of Ballast and Trim-The Ballast, cargo and bunker distribution. The relationship between these is fundamental to give a ship optimal position in the water, a crucial consideration for optimisation of fuel efficiency. If these operations are carefully carried out on board, it can save up to 4% fuel (11).

b. Optimisation of Propeller/Hull interface can also save up to 4% fuel.

c. Lightweight construction lessens the weight of the ship, leading to a reduction in the propulsive energy required and savings in fuel.

d. Alternative fuel engines can also help save fuel and protect the environment.

e. Air Lubrication System (Figure 9). The frictional resistance of the hull can be significantly reduced by the introduction of a thin layer of air pumped in between the hull and water. This can save up to 15% fuel and increase ship efficiency (12).

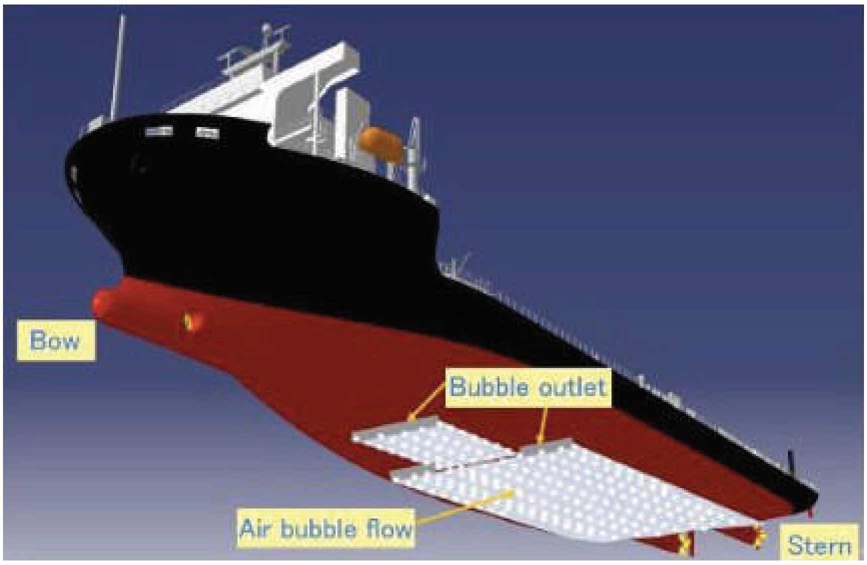

Figure 9: Ship Air Lubrication System

f. Waste heat recovery system. The heat of the engine exhaust can be captured and converted into electrical power for on-board applications, mechanical power (e.g. shaft of a steam turbine or used directly for heating. Reducing the demand on auxiliary power generators can save up to 10% fuel.

3. FUTURE SHIPS

We can expect to see environment-friendly ships being built in the future, such as the NYK Super Eco Ship 2030 (Figure 10), so named because, with its energy ef ciency, it will produce less CO_2 emissions than today's vessels. It is considered energy efficient in design because the water resistance of its hull has been reduced by cutting down on its dead weight – a simple but effective solution to increase energy efficiency and propulsion power increased through the use of energy sources such as LNG-based fuel cells, solar power and wind power. These emit little or no CO_2. It also created an in-built loading system in the hull. The independent in-built crane not only reinforces the vessel's strength but also reduces loading and unloading time by not having to rely on third-party onshore operators (13).

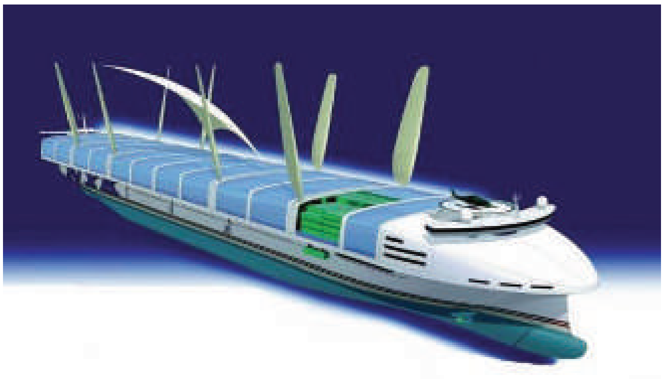

Figure 10: NYK ECO SHIP 2030 (Google)

CONCLUSION

We have presented an analysis based on hull form in order to predict the kind of ships which will be designed and developed in the future. An optimised hull design is both cost effective and environment friendly. A well designed hull can reduce resistance as well as emissions through the use of less fuel.

In terms of hull design we need to improve the fore and aft part of ship to get better efficiency. X-bow type designs are efficient as these reduce the slamming effect and are smooth in operation. A sharper bow also reduces the wave making resistance.

In terms of aft body, pram type hulls extended with a tunnel have been found to be efficient because they allow a steady flow to the propeller and produces good thrust. For good propulsion and sea keeping, it is important to have propeller rudder interaction which reduces fuel consumption and emissions. An integrated hull form optimisation also helps reduce noise and wake wash.

Other methods to reduce fuel consumption and improve overall ship efficiency have also been discussed. The ships of the future will be efficient in terms of hull profile as well as reduced emissions to meet the requirements for environment protection. We also showed the concept design of future vessel, the NYK Super Eco Ship. This heralds the beginning of a sustainable planet. ■

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