WORLD MARITIME UNIVERSITY
Malmö, Sweden

ULTRA LARGE CONTAINER SHIPS

Technical implications and solutions for the design of the vessels and the port terminal facilities

By

FRAGKOULIS EVANGELOS

Greece

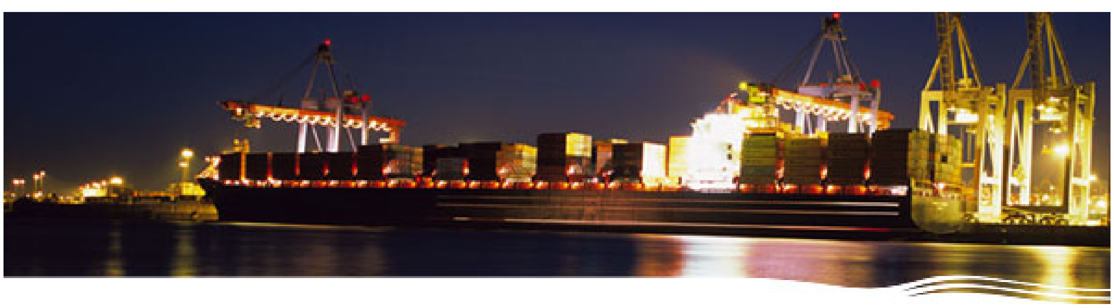
A dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MARITIME AFFAIRS

2006



Declaration

I certify that all the material in this dissertation that is not my own work has been previously identified, and that no material is included for which a degree has previously been conferred to me.

The contents of this dissertation reflect my own personal views and are not necessarily endorsed by the University.

(Signature):..

(Date):...

Supervised by: Jan Åke Jonsson

World Maritime University

Assessor:

Institution / Organization:

Co - assessor:

Institution / Organization:

Acknowledgements

First appreciation that has to be sent is of course to HELMEPA (Hellenic Marine Environment Protection Association) and more specifically to Capt. Dimitris Mitsatsos, since he was the one that honored me to have the scholarship and gave me the opportunity to study nine months in this University and enhance further on my knowledge.

I would like to express my sincere gratitude to my project supervisor Jan – Ake Jonsson for his constant assistance and valuable support over the last months. His expertise and dedication in this field was an invaluable source of knowledge and motivation for me.

Furthermore it is a fact that my appreciation has to be extended to Dr. Stina Göransson. Her help and support during the concluding stages of this project has been extremely valuable. Her appearance and constant support the latest months has changed my attitude and my motivation as well. I owe to her some of my best memories from Sweden ……

Additionally, I would like to express all my love to my parents, Fragkouli Konstantina and Fragkoulis Michail Superintendent Engineer. They always worked hard to make sure I got the best.

At last i would also like to send all my appreciation and respect to all of those that have been standing by my side and helped me during these nine months here in Sweden. Some of those are: Andreas, Anand (the one that gave me the idea of this dissertation), David, Umesh and Vipin (two father figures for me), Elin and off course all my colleagues from the MA class of 2006. I wish the best for them, and furthermore the bond created here to continue existing in the future.

Dedication

I would wish to take this opportunity and dedicate this thesis to Miss Christina Athanasiadi, a very good friend of my parents that unfortunately lost the fight against the cancer………….

She was a perfect mother and a very good and close friend, I will always remember her and have her inside my heart and my thoughts………

Abstract

Title of Dissertation: **ULTRA LARGE CONTAINER SHIPS**

Technical implications and solutions for the design of the vessels and the port terminal facilities

Degree: **M_{sc} Maritime Administration**

The dissertation is a study of the Ultra Large Container Ship concept. It is mainly concentrated into two categories:

1. The ship design itself
2. The port facilities

At first a clear definition of what is a ULCS is given. After clarifying exactly the notion of the ULCS in depth analysis of the technical implications relating to structural, powering, propulsion and safety implications is conducted.

Additionally further analysis is performed presenting all the implications that the dedicated container port terminals are facing. In this case all the difficulties of the container terminals are explained, from the sea land access, to the in- port traffic regulation and the in-land access.

Concluding at the end of this treatise having been able to have an in depth overview of what has to be changed in order to have an efficient operation of the ULCS, some solutions and innovative ideas are given. It might be highly possible that in the future some of those ideas will be materialized.

Table of Contents

List of Figures

List of Abbreviations

ULCS: Ultra Large Container Ship
TEU: Twenty Equivalent Units
CGT: Certified Gross Tonnage
DWT: Dead Weight
OECD:
KW: Kilo Watt
MW: Mega Watt
FEA: Finite Element Analysis
IMO: International Maritime Organization
AC: Alternate Current
CFD: Computational Fluid Dynamics
LCB: Longitudinal Center of Gravity
FPP: Fixed Pitched Propeller
CRP: Contra Rotating Propeller
DCT: Dedicated Container Terminal
AGV: Automated Guided Vessel
IT: Information Technology
FCT: Floating Container Terminal
HSC: High Speed Craft
ULCC: Ultra Large Crude Carrier
ABS: American Bureau of Shipping

Introduction

During the late decade the trend of moving cargo with containers has been growing. Furthermore, since the demand the size of the ships transporting them is increasing as well. As a result there have been speculations about creating vessels that can carry 12000, 15000 even 18000 TEU (The Malacca – Max concept). This design generation of container ships which have a capacity of 10.000 and more are considered to be Ultra large container ships or else ULCS.

Due to my naval architecture and marine engineering background I believed that Ultra Large Container Ship is a very challenging issue in terms of its design. A lot of Structural, powering, hydrodynamic, propulsion and safety problems have to be overviewed. Major purpose of this dissertation is to go through all the possible implications that can be found when designing an ULCS and analyze them in detail. In addition some solutions will be provided as well.

From the other side of the coin port terminal facilities have to change as well. A ULCS is not that useful if the port interface is not changed. Large container vessels need large container port terminals with the required cargo handling requirements and in port traffic regulation.

All the problems and required changes that port terminals have to undergo in order to adapt to the new design era will be examined in depth and solutions to those implications will be discussed.

The important question and reason for this treatise was how the ship design and the port facilities have to change in order to be able to have a ULCS operating efficiently to the container industry market. Is it technically possible to built a vessel as big as an ULCS that is able to carry 18.000 TEU?, can she sustains the loads experienced from such a payload?, can the powering requirements be satisfied?, are such structures safe enough?, can the gantry cranes handle the increased container throughput?, is this increment affecting the in port traffic or the is it creating a lot of traffic congestion to the surrounding urban areas?

All these questions and even more details will be discussed further down in this dissertation, the issue of the ULCS will be examined and finally some conclusions will be drawn, concerning the possibilities to see in the future a ULCS operating around the seven oceans of the world.

Chapter 1: General Information about Container Industry

1.1 History of container industry

Container industry has been introduced in the maritime industry as a replacement to the already existing general cargo transportation. It was one way to achieve a more efficient, safer, larger and technically more sophisticated transportation of commodities of high value that cannot be shipped in bulk.

The concept of carrying cargo in containers was first developed in the United States of America in the mid – 1950s with the major objective of reducing time in ports, cutting the cost of cargo handling, preventing pilferage and, furthermore, achieving more efficient and profitable ship and port operations. In April 1956, in New Jersey, 58 trailer vans were placed onto the deck of a specially adapted World War II tanker, named IDEAL X, which is considered to be the first Containership (Figure 1).

Figure 1: M/V Ideal X, the first Containership.

This ship design was a result of an intermodal strategy devised by Malcolm P. McLean, and it is considered to be the beginning of modern containerized trade.
The first ship designed to carry only containers was in 1956, her name was "Maxton", a converted tanker, which could carry 60 containers as deck cargo.

The first containership in Europe was set down by the "Fairland" at Bremer Überseehafen on the 6th of May 1966, in Germany. Quickly other shipowners from Europe and Japan realized the advantages of the containers, and as a result they began to invest in the construction of these specialized ships named as containerships.

Since then the container industry has been growing at a steady speed. At the start of the 21st Century, and until now, the world containership fleet consists of seven generations, which can be summarized in the figure below.

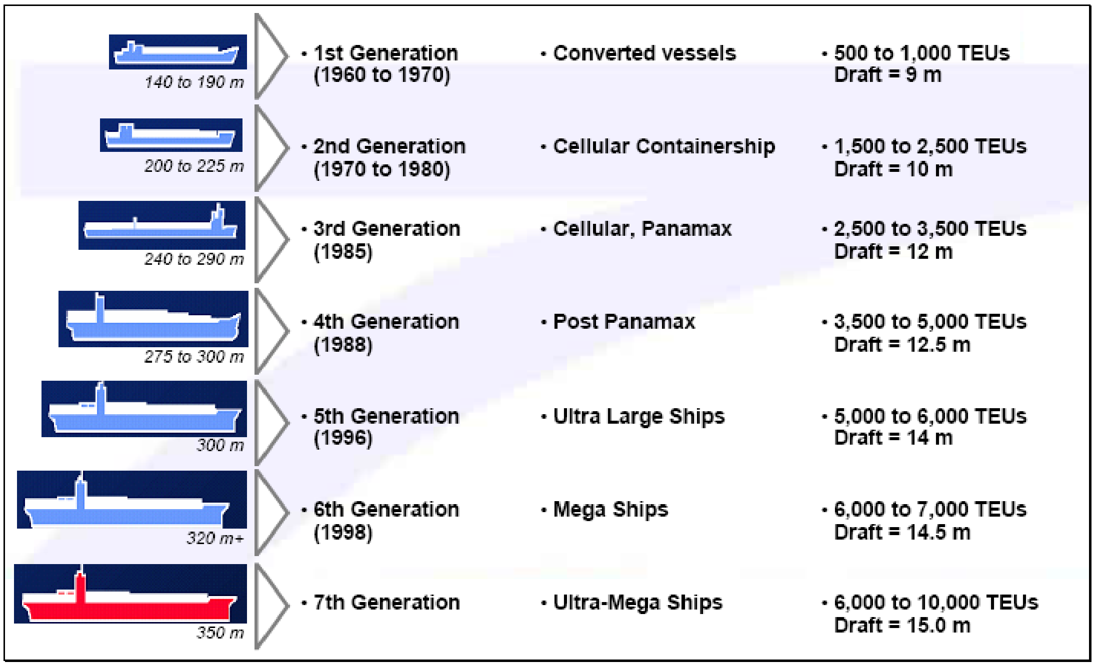


Figure 2: The Five Containership generations

A brief timeline of the container history and design is provided below.

- **1956** - SS Ideal X becomes the pioneer of container shipping when she makes the first sailing from Port Newark, NJ on Sea-Land's US inter-coastal service.
- **1959** - Paceco delivers the **first** A-frame **container crane** to Matson Navigation.
- **1966** - The converted general cargo vessel SS Fairland of Sea-Land inaugurates the **first transatlantic container service** from New York to Grangemouth and Rotterdam with around 400TEU on board.
- **1967** - **The first purpose-built deep-sea container carrier**, Atlantic Container Line (ACL)'s 700TEU Atlantic Span, is delivered.

- **<u>1968</u>** - The first ever fully cellular purpose-built boxship, the United States Lines-owned, 1,200TEU American Lancer, is delivered in May.
- **<u>1968</u>** - Nippon Yusen Kaisha (NYK)'s Hakone Maru (700 TEU) becomes **Japan's first containership.** She undertakes the first transpacific fully containerized service in September between Tokyo and Los Angeles.
- **<u>1968</u>** - Manchester Challenge is delivered in October this year to Manchester Liners for service between the UK and Canada. Built by Smith's Dock in the UK, she is the **first European owned transcontinental container ship**.
- **<u>1969</u>** - The first fully containerized service between Europe and Australasia is launched by the UK-based liner consortium Overseas Containers Limited (OCL).
- **<u>1969</u>** - The **term TEU** or twenty-foot equivalent unit is coined by shipping journalist Richard Gibney.
- **<u>1971</u>** - The first fully containerized liner service between **Europe and Asia** is launched by the Trio Consortium. Trio comprises major shipowners from three countries; NYK and Mitsui OSK of Japan, Hapag and Norddeutscher Lloyd of Germany and the UK-based Ben Line and Overseas Containers Ltd.
- **<u>1972</u>** - Delivered in March, NYK's 2,228TEU Kurama Maru becomes the first containership to be built to **full Panamax dimensions**.
- **<u>1984</u>** - Nelcon delivers the first post-Panamax ship-to-shore crane to Europe Combined Terminals (ECT), Rotterdam.
- **<u>1988</u>** - American President Lines (APL) takes delivery of the **first ever post-Panamax containership**, the 4,300TEU President Truman, which is built by Howaldtswerke-Deutsche Werft of Hamburg.
- **<u>1995</u>** - The first vessel capable of loading in **excess of 5,000TEU**, the 5,344 TEU OOCL California, is delivered by Mitsubishi Heavy Industries in August.
- **<u>2002</u>** - Patrick's Fisherman Islands' facility in Brisbane, Australia, becomes the world's first automated straddle carrier terminal.
- **<u>2003</u>** - The first boxship in **excess of 8,000TEU** capacity, the 8,063 TEU OOCL Shenzhen, is delivered by Samsung Heavy Industries in April.
- **<u>2005</u>** - As we celebrate 50 years of containerization, the biggest containership plying the world's oceans is the **9,383TEU Costamare-owned** Cosco Guangzhou, chartered to Cosco,

- **2006** – Speculations that Maersk – Sealand has built secretly the first containership of the so-called Ultra Large Container Ships (ULCS) having a capacity of 13000 TEU.

1.2 Container fleet development

To get a broader view of the container industry, it is useful to present a review of the container fleet development over the last years and, in the meantime, introduce to this treatise the most important containership companies and Alliances created until now.
As already mentioned, over the last years it has been a common trend for the container fleet to grow. In more detail [1], from the period of 2001 – 2005 the world container fleet grew on an annual basis by 11.3%, and in addition to that, the number of containers rose by 5.9% and the total deadweight tonnage by 9.4%. Such statistics can be observed in the following figure.

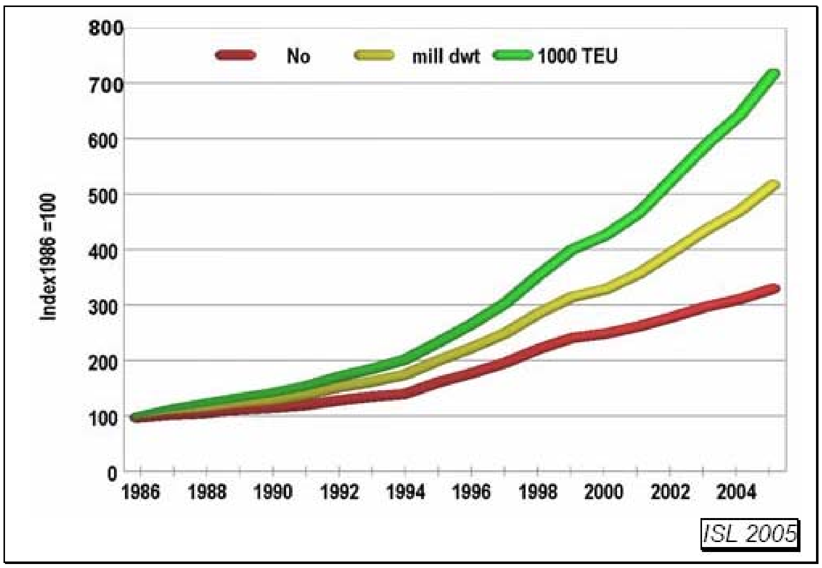


Figure 3: Container fleet development 1986 – 2005

By observing figure 3, it is obvious that the container shipping sector and the container transportation demand has been increasing, resulting in an augmented supply of container vessels to the market. At some point this can also prove the continuing growth of the vessels size in TEU capacity (see Figure 4). Bigger vessels mean more efficient operation and less cost. This issue will be further discussed in the following chapters of this thesis.

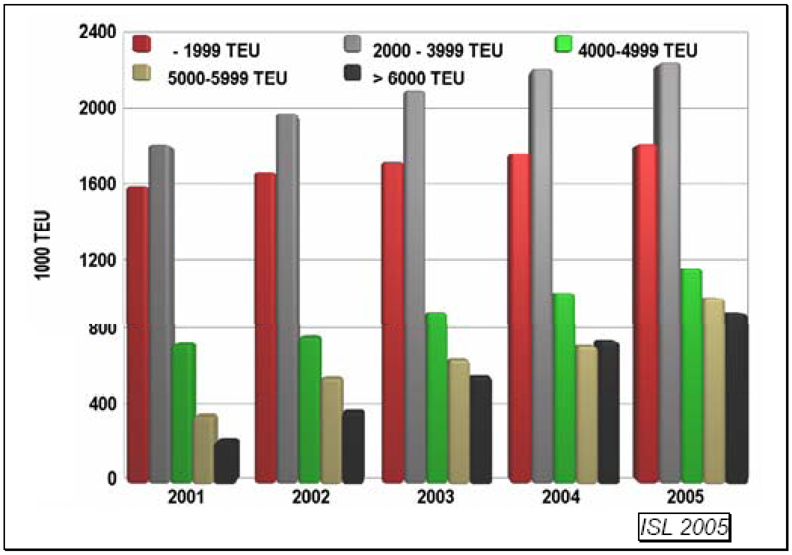


Figure 4: Container Fleet development by TEU – size

Container fleet can be classified based on the ownership patterns as well. The biggest container shipping company is Maersk Sealand. Other major companies are those of MSC and New World Evergreen as well as the CHKY alliance, the Grand Alliance and the CMA – CGM alliance. Figure 5 provides further information about the growth of those companies and alliances in 2004 and 2005.

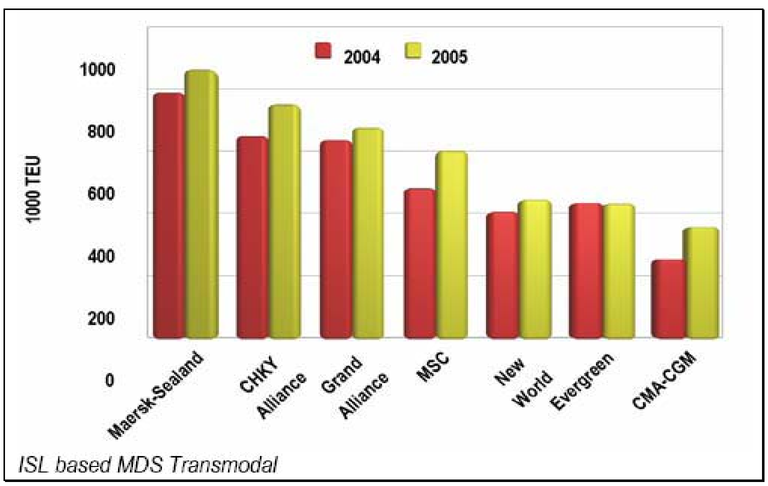


Figure 5: TEU capacity of top ranking containership operators.

Only 15 operators control approximately 65% of all fully cellular container ships and 75% of the global TEU Capacity. As already pointed out, the largest is Maersk – Sealand, operating a capacity of 849.000 TEU, which is equal to 12.8% of the total world fleet capacity. Moreover, nine of the top 15 operators are involved in alliances. From figure 5, it can be observed that 28.7% of the total container capacity is occupied by the three alliances mentioned above: CHKY alliance, Grand Alliance incl. Grand Americana and New world Alliance. The companies mentioned above, with the addition of the two remaining individual ones, MSC and Evergreen own a market share of 57% of total TEU capacity in the world container shipping.

Another division of the container fleet can be achieved by flag states. In more detail, more than one third of the container tonnage is registered under the open registry flags of Panama and Liberia. The Panama share is at 22% of total TEU Capacity and Liberia is at 14.6%. The third biggest is Germany, which has a fleet of 0.6 million TEU.

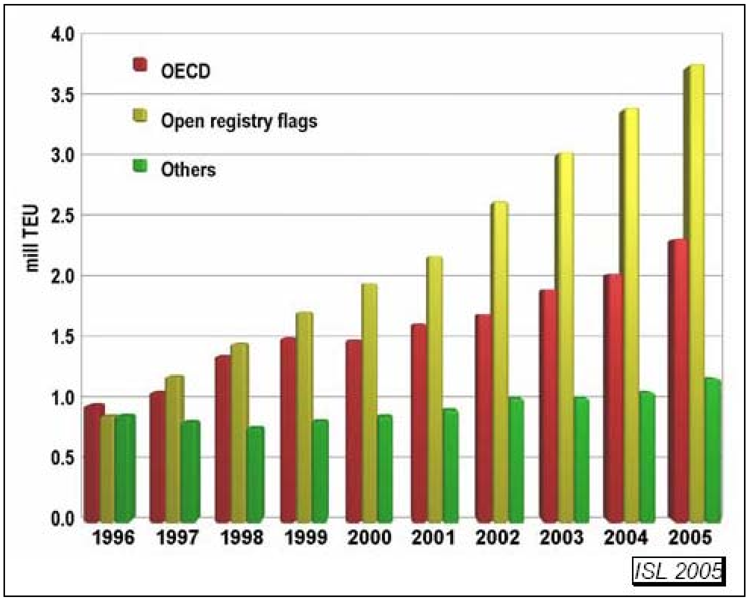


Figure 6: Container fleet development by country groups.

The percentage of the container ships registered for OECD countries is estimated at 32%. It has to be mentioned though that the same percentage in 1991 stood at 44.3%. This fact obviously demonstrates the rise and strength of the open flag registries or the so-called “Flags of Convenience”. It is a sign that ship owners having been in a tough competition with each other, and in trying to maximize their profit they have gone to the solution of flying open registry flags, which can ensure them better profit earnings and a lot of tax saving.

To conclude this section, a general comment about the world container fleet is that over the years the has been a continuous expansion of the size and the numbers of the vessels operating in this area (figure 7), as a result of the increased demand of the market.

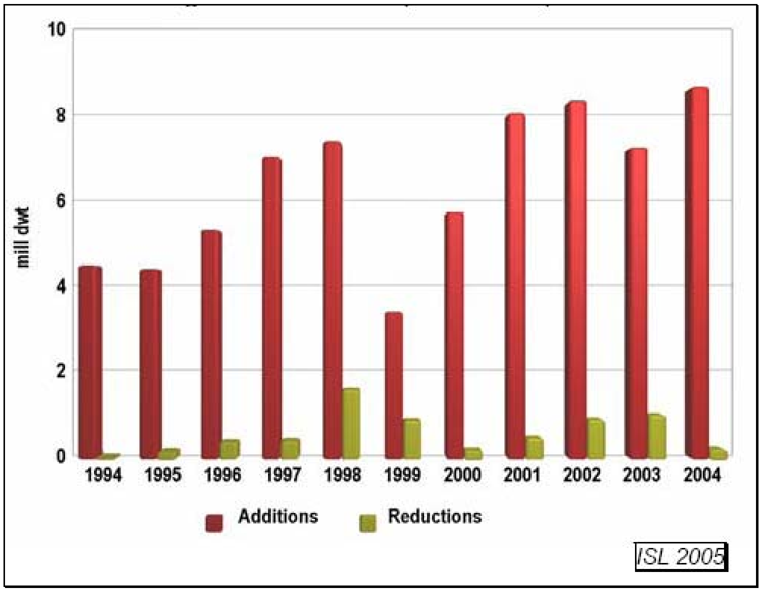


Figure 7: Container fleet additions & reductions

1.3 Container port development

Since this thesis is mainly concentrated upon the interaction between containerships and container ports, it is appropriate to present some information about the latest figures and statistical analysis of the container port development.

Based on the statistics by ISL Market analysis (June 2005) [1], there were 71major operating container ports in 2004 (34 in Asia/Oceania, 30 in Europe, and 17 in America).

In more detail, 64% of the world container traffic was in the region of Asian ports. Europe had a share of 20.6% and America 15%. (See Figure 8)

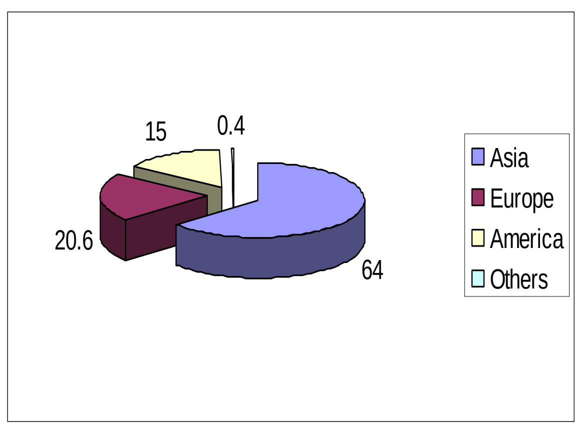


Figure 8: World container port traffic

The two top ranking container ports are situated in Hong Kong and in Singapore. The third ranking port is Shanghai, which has achieved a growth of 29.1% succeeding a traffic volume of 14.6 million TEU during the year 2004.

Moving to Europe, the three biggest ports are the port of Rotterdam and Hamburg (increased port traffic of 16.4% and 14.1 respectively). Other big container ports are Bremen / Bremerhaven, the French Le Havre, and Antwerp of Belgium, which decreased their combined market share considerably as a result of the relative raise in the ports of Rotterdam and Hamburg.

In the Mediterranean Sea, the top five ports are Gioia Tauro, Algeciras, Valencia, Barcelona and Genoa. In total, these ports have encountered an 8.8% increase in port volume. This growth is mainly determined by the three Spanish ports Algeciras, Valencia and Barcelona, which have had an increase of 16.7%, 7.6%, and 15.7% respectively.

As far as the US ports are concerned, they have shown a steady increase in port traffic over the years, especially the ports of Long Beach, Los Angeles and New York – New Jersey (Figure 9). Other major American ports that should be taken into consideration are those situated in Houston (plus 20.4%) and in Seattle (plus 19.6%).

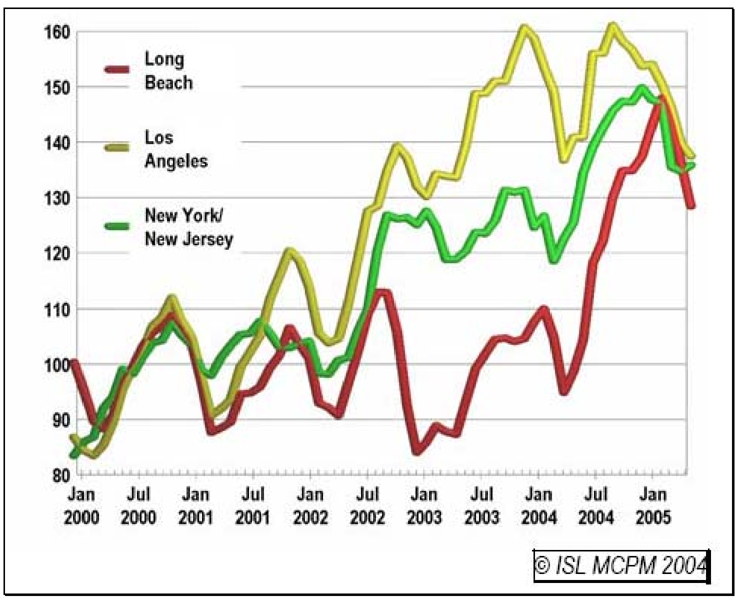


Figure 9: Container Traffic of major North American ports.

At this point, it is worth mentioning that the growth of the North American ports is directly connected with the performance of those in the Far East since strong relationships have been created between these two regions of the globe. Over 90% of the ingoing and outgoing traffic of the North American ports is directly connected with the Far East.

To conclude this research, one general remark can be done with regard to container port development.As in the case of the containerships, the increased demand results in an increased annual growth of the port container traffic. The figure below (taken from Drewry Consultants Ltd. October 2005 [2]) can easily illustrate this trend.

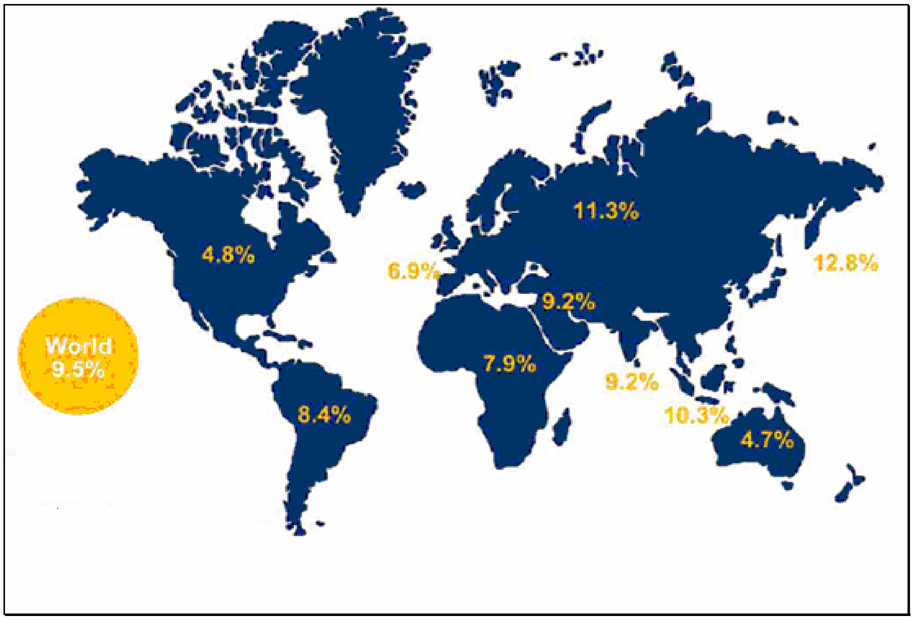


Figure 10: Average annual growth in container port traffic.

1.4 Container shipbuilding development

A final sector of the container industry that has to be analysed in this chapter is the shipbuilding development over the last years. Having a clear understanding of the orderbook capacity of the shipyards is very helpful in assessing the future market potential of the container industry.

Based on the latest statistical analysis about the marine market [1], the new orders for container ships in 2005 increased in terms of deadweight (8%). From the shipbuilding side of view, containerships dominate in relation to other types of vessels (e.g. tankers, bulk carriers, passenger ships). Their 2005 cgt share of the world orderbook is estimated at 32%, which translates into 1100 vessels and 54 million DWT.

With the help of the following two figures (11, 12), it is easily observed that the rate of production of newbuilds is constantly increasing. Moreover, the majority of new ships entering into business are of the large TEU capacities (Figure 12 42% of the newbuilds are of 6500 TEU and greater), demonstrating once again the tendency of this market, which is to continuously build new ships, due to the increased demand, and in addition to raise the average capacity of those vessels.

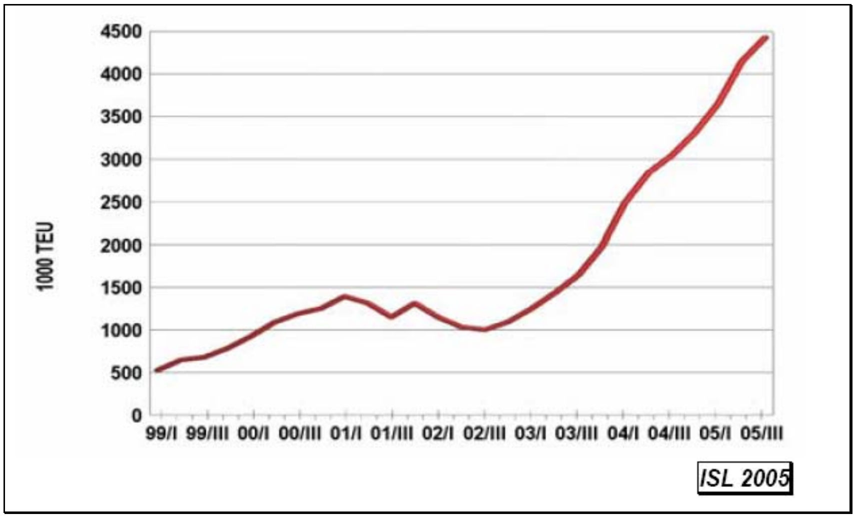


Figure 11: Quarterly Containership order book development

Once again, the potential of introducing Ultra Large Container Ships in the future is very likely to happen.

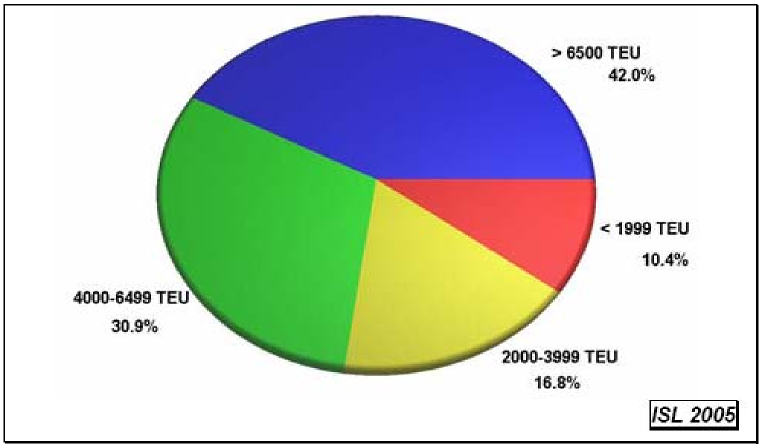


Figure 12: Containership order book by TEU size (as of July 2005)

Chapter 2: Design limitations and problems of the ultra large containership design

2.1 Introduction

This chapter constitutes a very central part of the treatise, as it discusses what limiting factors and problems ultra large containerships are facing. Chapter two will give a broad overview of the technical problems this type of vessel has to overcome in order to be materialised and operate efficiently.

Further down, the most important technical implications will be discussed and analyzed, and, in addition to that, some innovative solutions and ideas will be demonstrated. There are four major categories of problems:

1. Structural considerations
2. Powering requirements
3. Propulsion and hydrodynamic implications
4. Safety considerations

To start this technical analysis, the term ultra large container ship has to be defined exactly, what are the main dimensions and what the carrying capacity is.

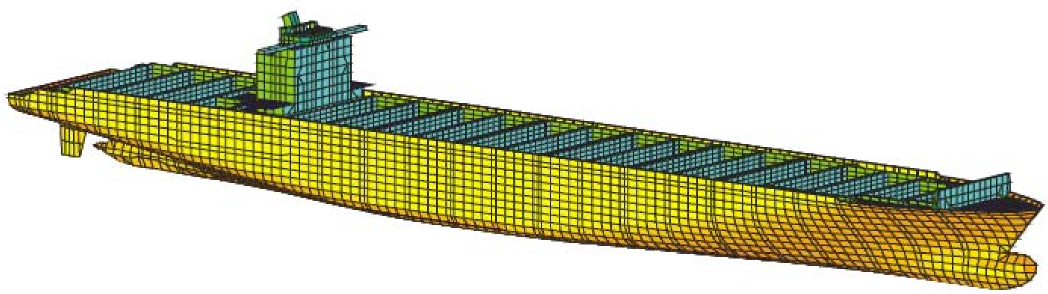


Figure 13: A ULCS design

2.2 Profile of Ultra Large Container Ship

An ULCS is a vessel that has a capacity of more that 10000 TEU. The actual range of TEU capacity is from 10.000TEU till 18.000TEU. Latest designs unveiled; by classification societies are showing three categories of ULCS.

1. The 10.000 TEU capacity
2. The 12.000 TEU capacity
3. The 18.000 TEU capacity, well known as Malacca-max design, having a maximum draught of 21 meters.

10.000TEU Capacity

This category is the first and the smallest (in terms of capacity) classified ULCS. The figure below gives a computerised representation of a containership of such capacity, and it is provided by Wärtsilä.

Figure 14: Design of a 10.000 TEU vessel (Source: Wartsila)

Main particulars of this vessel are the following:
Length: 360 meters
Breadth: 49 meters
Scantling Draft: 15, 5 meters
Powering requirement: 80, 08 MW
This vessel can carry inside the cargo hold, 17 containers across and 19 across on the deck. In contrast to the conventional smaller containerships, this design can be either single or twin skeg and, in addition to that, the superstructure is not usually placed at the aft of the ship.
Further details about the structural and powering configurations available will be presented further on.

12.000 TEU Capacity

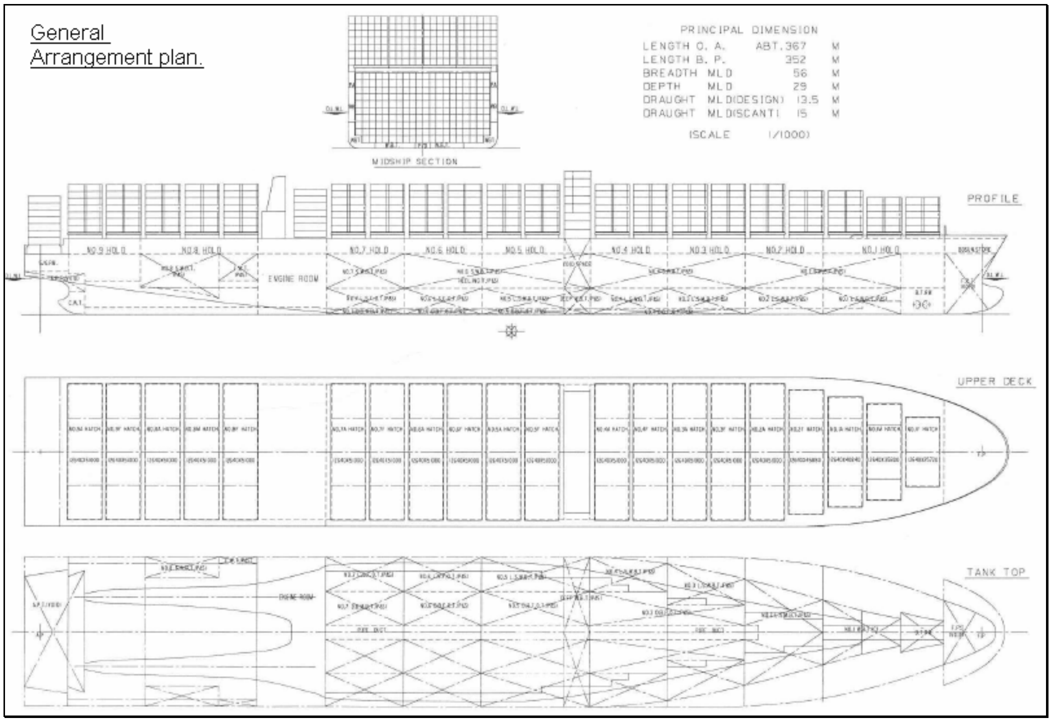


Figure 15: General Arrangement of a 12.000TEU vessel

The figure above demonstrates one typical general arrangement plan of a 12.000TEU vessel. Main particulars of that vessel are the following:

Length: 352 meters

Breadth: 56 meters

Scantling Draft: 15 meters

Powering requirement: of about 82 MW

This design has been taken by the latest research project of Germanischer Lloyd. Other classification societies, of course, have their own designs, but the differences between them are considered to be minor.

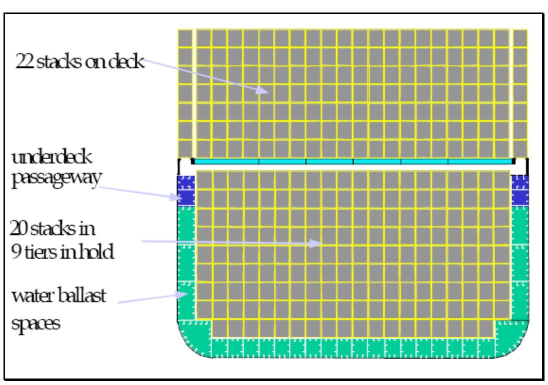


Figure 16: Detailed midship section

Based on the midship section above it is observed that 20 stacks of containers can be loaded inside the cargo hold, while 22 stacks of containers can be loaded outside the cargo hold, on top of the hatch cover. According to the general arrangement plan the accommodation deck house is moved further forward and separated from the machinery spaces. The reason for doing so, and various other alternatives of where to locate the deck house and why, will be further described later in this chapter.

18.000TEU Capacity

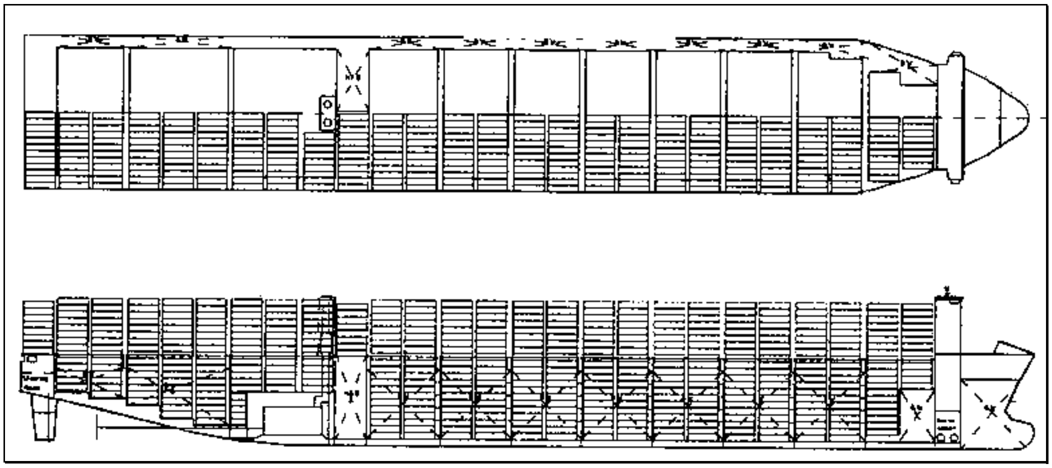


Figure 17: The Malacca max design (Source: Delft University)

This containerhip design, the so-called Malacca – max, is of the open top design and double hull as well. To achieve this capacity 26 blocks of 40-ft containers are stowed 20 wide below deck and 24 wide above deck. A particular feature of this design is that the double hull spacing is five meters wide in order to withstand the excessive torsion loads that a ship of such dimensions will experience.

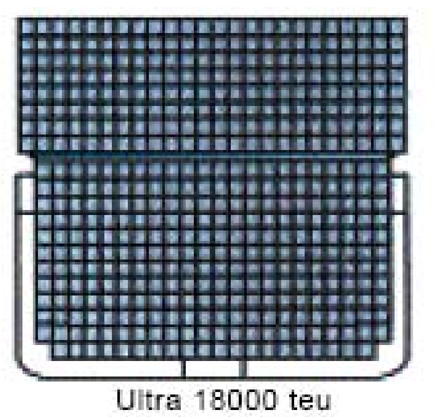


Figure 18: Midship section

Speaking of dimensions, the main particulars of this design project, created by Delft University in Holland, are the following:

Length: 400 meters

Breadth: 60 meters

Draught: 21 meters

Powering requirements: 116, 6 MW

Again, this design has to present various differences in terms of structural configurations and powering plants, which will be analyzed in the next following pages.

2.3 Structural considerations of ULCS

The continuous increase in the size of container vessels creates a lot of structural challenges and problems for the ship designers. Having designs of Ultra Large Container Ships of the capacity range from 12.000 to 18.000, TEUs pushes the designs to areas where little direct service experience exists. For that reason, a careful scientific approach has to be employed to ensure that the structure designed will be safe and rigid during the ship operation. In this regard, the author will explain and show the main concerns of structural engineers about the dangerous areas onboard the vessel that need to be taken under special consideration.

Deck Structure

Generally, a vessel can be considered as a box girder. Ships like bulk carriers or tankers that have largely closed cross section (hatch opening at such designs are small maybe 40% of the total deck area), have better characteristics in terms of torsion and bending tolerance. Containerships, on the other hand, are well known for their big deck openings and their large hatches. In consequence, there is only a small area for deck that can be used to contain the main hull girder strength of the vessel. This creates a lot of design headaches, particularly with respect to torsion

To overcome those problems, special attention should be given in the design and structural arrangement of the double hull spaces. At this area special torsion boxes are created and furthermore the transverse and longitudinal stiffening is placed in such a way to ensure that the vessel can resist the loads experienced during her voyage. Of course, to find the optimum structural arrangement, various computational analyses are used, such as the Finite Element Analysis. With this tool the best available configuration can be achieved ensuring that no extra, unwanted weight from stiffening is used and, at the same time, that the ship is safe.

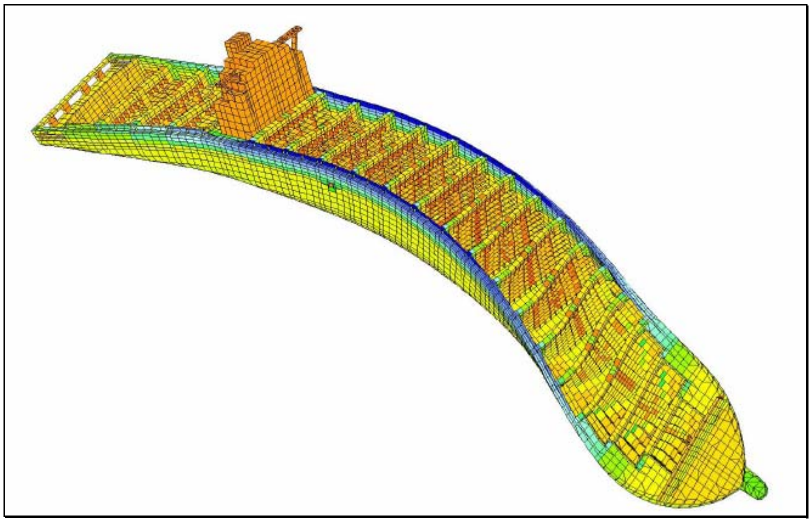


Figure 19: Finite Element Analysis to ULCS

Some of the results of using these sophisticated soft wares are the creation of innovative structural arrangements, such as the continuous hatch coamings or the inboard longitudinal girders. Moreover, to resist the loads counteracted, hull thickness up to 78 mm and high tension steel material has been used.

Hatch corners

Hatch corners in all the types of vessels are a very critical area of concern. It is the exact point where the longitudinal and transverse structures meet each other (see the two figures provided below). As it can be understood this is a very dynamic point experiencing a combination of bending moments, shear forces and torsionally induced stresses. With regard to containership, this particular area is even more dangerous since the hatch openings of the cargo holds are large to be able to accommodate the maximum number of containers.

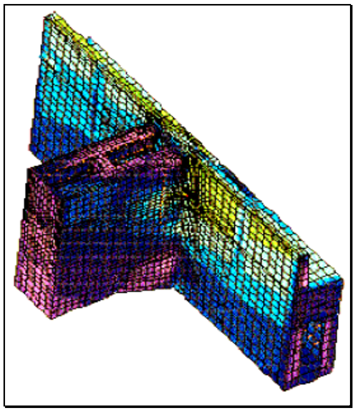


Figure 20: FEA on hatch corner

As far as the ULCS designs are concerned, this opening is considered to be of a large scale; hence naval architects are facing a great deal of problems with this area. To find out the required amount of thickness plating needed and where design features can be modified to increase its strength, Finite Element Analysis (FEA) is used.

To conclude the issue of the hatch corners, the figure below provides the major areas of consideration. These areas include the distortion of hatch openings at the hatch coaming top, the hatch corners at the level of the strength deck and the hatch corners at the level of the second deck.

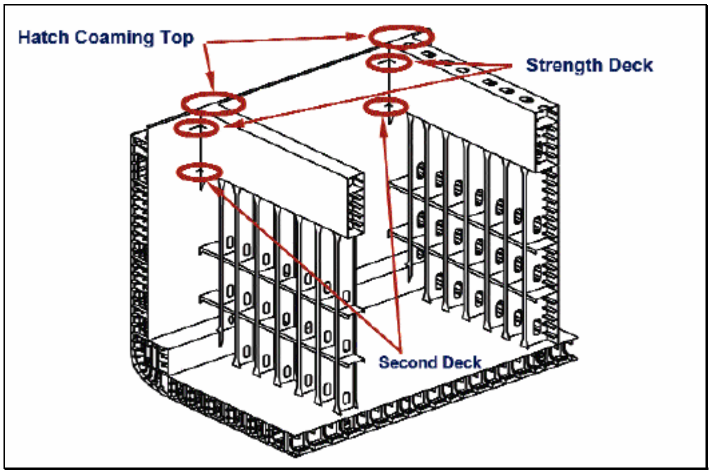


Figure 21: Important hatch corner areas (Source: ABS)

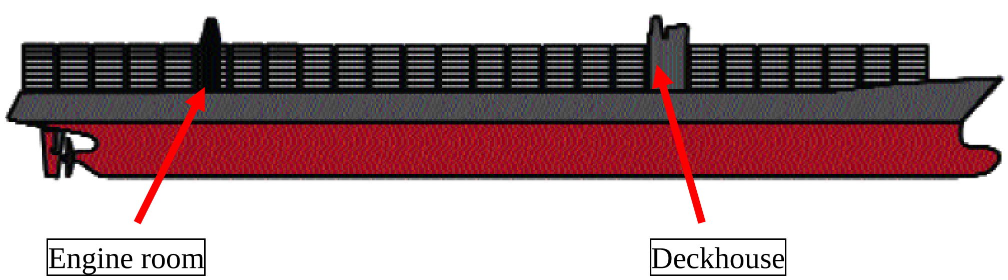
Location of deck house and engine room

Another very serious structural consideration for the ULCS is the location of the engine room and the deck house. Until now, in all the containerships created (the latest biggest is of 9600 TEU capacity), the deck house has been located exactly on top of the engine room area. Going though to designs above 10.000 TEU, the vessels become larger and the open area of the deck is expanded as well. This relocation can be easily seen above in the presentation of the various designs of ULCS published until now.

The exact final position of the deckhouse is dependant upon various factors, these are:

1. The most important and basic reason was the IMO visibility criterion that requires that the water surface 500 meters forward of the bow must be visible from the bridge. There is no requirement for visibility aft.

2. Capacity of TEU. As the deck house is moved forward to satisfy point number one, the capacity of the vessel is increased since more parallel middle body area is used.
3. Crew comfort. The limiting factor to have the deck house completely forward is the comfort of the people working onboard the vessel. The sea-keeping characteristics of the vessel will create unpleasant feelings to the crew, something which is unwanted.
4. Furthermore, the deckhouse should be located at an area where it can help control the hatch opening distortions and stresses. The deck house should be placed in the location where structural continuity and integrity is secured.
5. One final comment about the exact location of the deck house is that the dynamic response of the structure due to the excitation of the propeller has to be taken into consideration. Vibration is a major issue in each ship design, hence the deck house has to be placed where it could not be affected by the global vibration characteristics of the vessel.



Bow structural considerations

The bow structure of the containerships has been very critical from the early design of this type of vessels. These considerations have been even more pronounced since the introduction of the ULCS era.

One of the major problems is the dynamic loads from bow flare impact and the green water loads on the fore end.

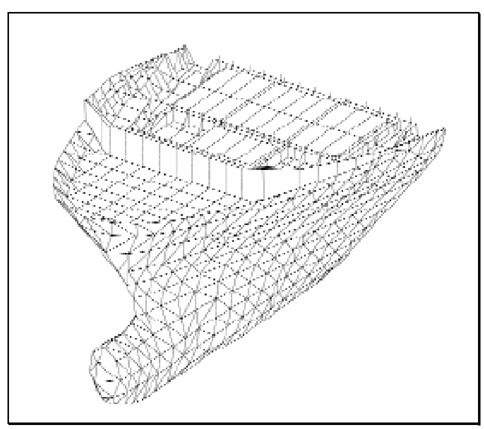


Figure 22:FEA at the bow region of a ULCS

Container ships are vessels which are considered to have very fine hullforms in order to achieve high speed (at the range of 25 knots). Designers of ULCS should understand and give special attention that the bow flare angle should be at the required degree angle. Angles greater of 40º are particularly challenging and it might result into structural deficiencies at the very early stages of the ship operation.

For that reason Finite element analysis should be used in order to investigate what are the areas of high stress concentration, and thus enforce them. With such a method, various loading and head seas conditions are tested and, furthermore, the worst case scenario, in terms of environmental and loading conditions, is used as the required strength standards of the ship designed.

Another very important issue for the design of the forward part of the ULCS is the green seas effect. Green water is the one that comes onboard the vessel due to environmental conditions (head seas for example). These green waters can cause a lot of damage to the cargo due to the fact that most of the times they have strong dynamics, creating structural failures to the lashings of the containers. There have been cases where containers have been lost to sea due to this adverse phenomenon.

As a result, special protection should be given in the design of the bow region and the forecastle deck of the ULCS, in order to avoid contact of the green waters with the first rows of containers stacked onboard the vessel.

For that reason, in all of the ULCS designs it is observed that forward of the first row of containers there is a breakwater erected for this very purpose. In addition to cargo protection, this breakwater arrangement protects the crew operating on the deck as well.

Finally it has to be pointed out that due to the green waters, the bow design should be enforced structurally in order to withstand the loads experienced from green head waves hitting the vessel.

These points are very important. In previous designs they existed as well, but in the case of the ULCS, since the vessel dimensions are stretched to the limit (having a length of 400 meters and a beam of 60 meters is the limit), the loads experienced are much greater and therefore more dangerous.

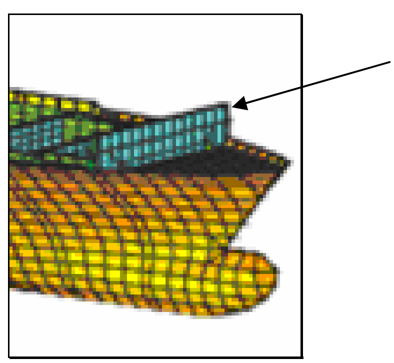


Figure 23: Breakwater arrangement

Aft structural considerations

Evolving to the ULCS era, the aft structural configuration changes as well. It will be further discussed later, but it has been seen from the design profiles presented above that ULCS can be either single skeg or double skeg. This change, in addition to the extreme dimensions achieved (in terms of length and breadth), has created the problem of aft slamming. Slamming may occur at the aft sections of the ship, due to the fact that those designs are having a very flat bottom, especially the twin screw configurations.

This has created a lot of structural problems since the local pressure at those areas is at very high levels. In global terms this phenomenon creates an increased sagging moment which again should be avoided. The impact loads, from aft slamming, are highly concentrated in a very short period as well. As already mentioned, those impact forces may result in damage of local structure and emphasize structural vibration throughout the hull, often referred to as whipping. For that reason during the design stage, at any cross section of the vessel, complete analysis of the hull girder requires prediction of combined wave and whipping responses. Sophisticated computer soft wares as well as model testing help defining the hull girder loads.

Vibration

One final area that is very important and directly related to the structural arrangement of the ULCS is vibrations. The problem with vibrations, and especially in ULCS which are very large structures, is that they have multiple sources. Some of them are:

- Wave action, especially slamming
- Propeller induced pressure fluctuations
- Operation of main diesel engine
- Operation of the auxiliary machinery on the engine room

Having vessels with a length of a ULCS means that structure is more flexible. This flexibility is translated into lower hull girder frequencies and, depending on the nature of the dynamic loading, a ULCS might experience high vibratory levels during operation. That is why the vibration characteristic of a vessel should be examined before the start of her construction, because having such problems after the completion of the ship is a very costly and undesirable problem. To overcome such complications, modern analytical tools can be used. Under this function, modeling of the dynamic forces is achieved. Simulation and model tests are valuable instruments as well.

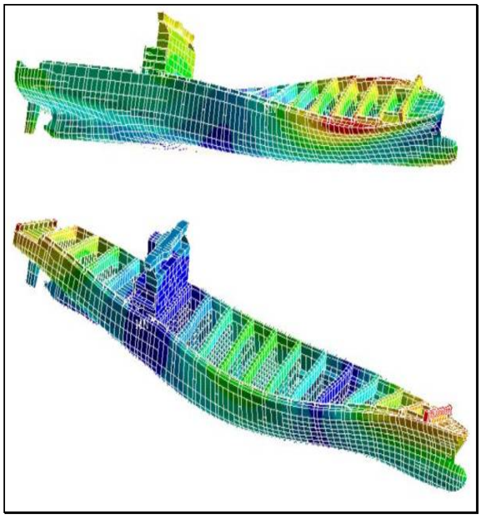


Figure 24: Torsional Vibration Analysis (Source Germanischer Lloyds)

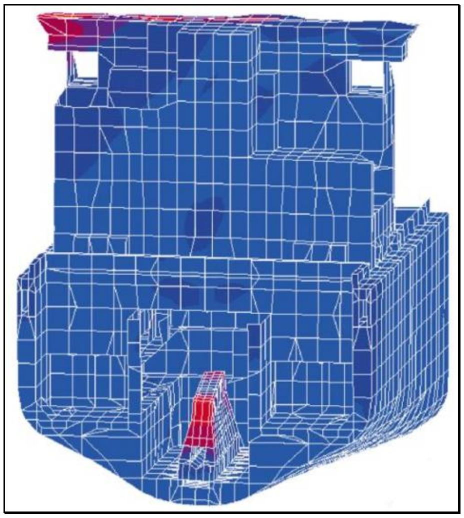


Figure 25: M/E and deckhouse vibration analysis (Source Germanischer Lloyds)

2.4 Powering requirements about ULCS

Powering requirements for ULCS have been very demanding as a result of their size and their required high service speed. The necessary output power range starts at 80 MW to 116 MW. These values of delivered power are massive and hence special attention should be given to the selection of the engine used to propel such a vessel.

There are various scenarios about what types of engines that can be used, and what is their cylinders number. Moreover, there have been suggestions about using AC drives or even steam turbines.

All the scenarios will be analysed further down and at the end of this chapter some innovative ideas will be presented (Steam injection etc.). Such ideas came up due to the continuing increasing of the fuel prices, which create a lot of expenses to the ship owners. Major target of those is to increase the fuel efficiency of the main engines and as a result reduce the fuel oil burned to move the ships around the globe.

12 Cylinder Vs 14 Cylinder engines

For the Ultra large containership designs, and especially for those with TEU capacities from 10.000 to 12.000, there is a great flexibility upon the engine selection. Key role for this decision is the use of twin screw or simple screw configuration.

In terms of powering, having a twin skeg design means that the maximum power needed can be split up on two propellers, meaning that the engines that will be used are the ones that have been in operation in many years, hence there are no problems with those since they have been used and tested well.

The problems and the concerns arise when single skeg is used to such big vessels. Under this occasion there is only one shaft, meaning that the power have to be transmitted by one engine via one propeller shaft to the propeller in order to move the vessel. As a result, the engine design has to be stretched to the extreme.

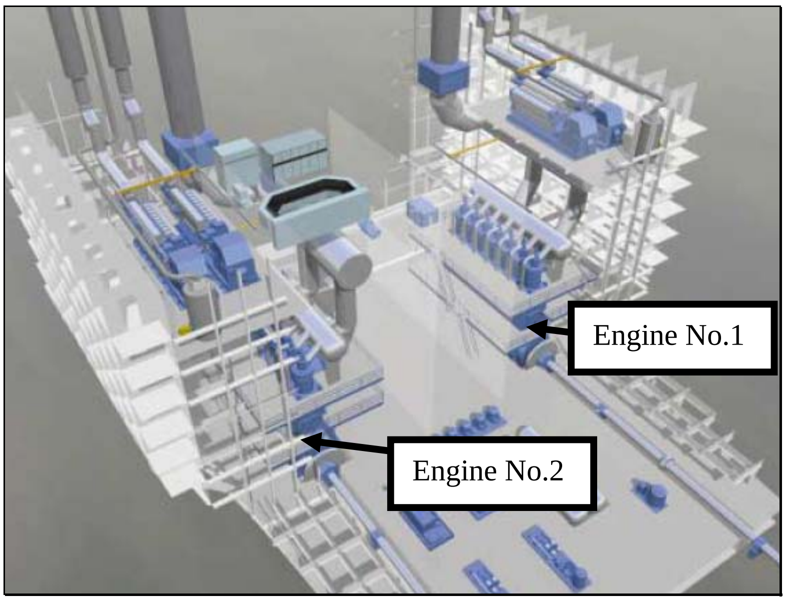


Figure 26: Twin engine configuration.

For this scenario, and always for the designs of 10.000 and 12.000 TEU, two options can be used.

One option is to use a 12 cylinder engine, like the ones used until now, but the bore diameter will be increased from 960 mm to 1.080 mm.

The other alternative is to use a 14 cylinder engine with the standard bore diameter which has been used until now (960mm).

There are various advantages and disadvantages for both solutions:

1. First of all, by using a 12 cylinder engine instead of a 14 cylinder, space minimization is achieved, since this engine has two cylinders less and hence is a more compact design with smaller dimensions. For example, the 12 cylinder K108ME-C from MAN B&W has a length of 27 meters approximately, whereas the 14 Cylinder K98ME from the same maker has a length of 29 meters.
2. Moreover, having a 12 cylinder engine automatically means that two cylinders are omitted. This of course has a direct effect to the operational costs. By saving two cylinders, maintenance cost is reduced considerably.
3. Furthermore, the 12 cylinder engine with bigger bore diameter has higher maximum power output (83, 4 MW), compared to the 14 cylinder engine, which has a typical power output of 80.08MW which is the exact required for a 10.000 TEU vessel.
4. On the other hand, the 14 cylinder engine has the same engine dimensions (bore, stroke etc), same engine rpm; same piston speed and the same mean effective pressure of 18.2 bar as the majority of the two stroke main engines have until now. This is a major advantage, since the operating conditions of the main engine have been tested and used thoroughly and hence all the possible problems and malfunctions that will be observed during operation can be fixed fast, since the required repair action is known.
5. The above point is the major disadvantage of using engines with bigger bore diameter. This alteration completely modifies the dimensions and the operating conditions of the engine. That results into unknown situations which mean that very good modelling and testing should be done before installing such applications onboard the vessels.
6. Other problem with the 12 cylinder engine is the practicality. There is no problem with the strength of the components nor with the cooling of the combustion chamber. The major practicality limitation is the crankshaft and the production of the main crank pin, crosshead bearing, cylinder liner and piston rings. Customizing and building such parts might create problems in terms of maintenance and extra cost. So it might be the case that the cost of installing a 12 cylinder engine with bigger bore diameter will be higher from the 14 cylinder engine.

Bearing in mind all the above points it is up to the ship owner's judgment about what type of engine that will be used. Both solutions have their benefits and drawbacks concerning installation and operation.

In the case of ultimate ULCS design (18.000 TEU) the powering requirements is the maximum ever wanted. It is clearly understood that a single engine producing a power output of 116, 6 MW is impossible to be designed and produced and used in operation efficiently.

For that reason, the Malacca max design is using twin screw propulsion which means that the power output is transferred via two shafts, hence the power experienced in each shaft is of 58.3 MW. As a result, two engines are needed with a power output of 58, 3 MW each, which is a common main engine used for the operation of post Panamax container ships.

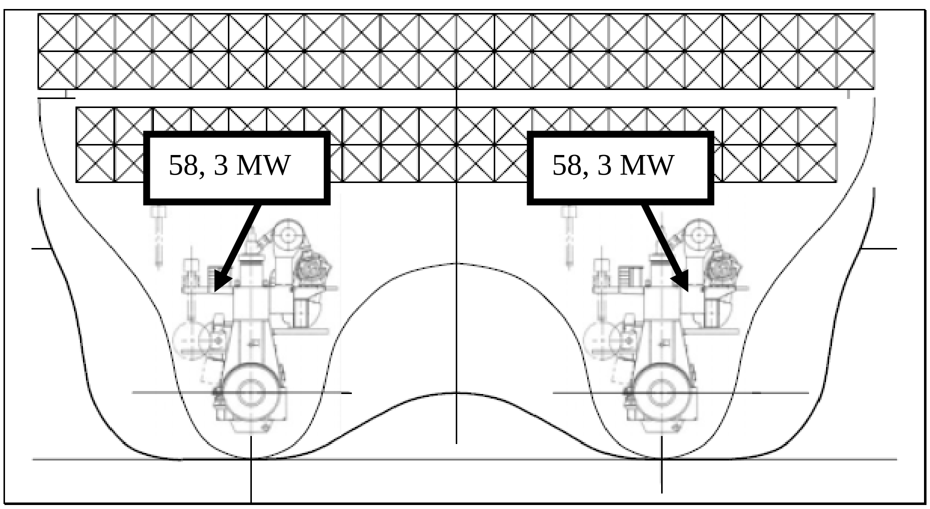


Figure 27: Powering arrangement in Malacca max design

Consequently, in this situation 14 cylinder engines are not needed, nor are 12 cylinder engines with expanded bore diameter. The usual 12 cylinder with the common diameter can be used.

At this point it should be emphasized that instead of diesel engines other powering configurations can be used for such designs, such as diesel electric power plant. Such selections are mainly related with the propulsion design used. For example, in the case where azimuth pod propulsion is used it would have been an option to use generators instead of transmitting the power to the pods mechanically. Such issues will be further discussed in the next chapters.

Heat recovery Plant

The heat recovery plant is an innovative idea created by various engine manufacturers. With this system the exhaust gases from the main engine are used to create an extra amount of power.

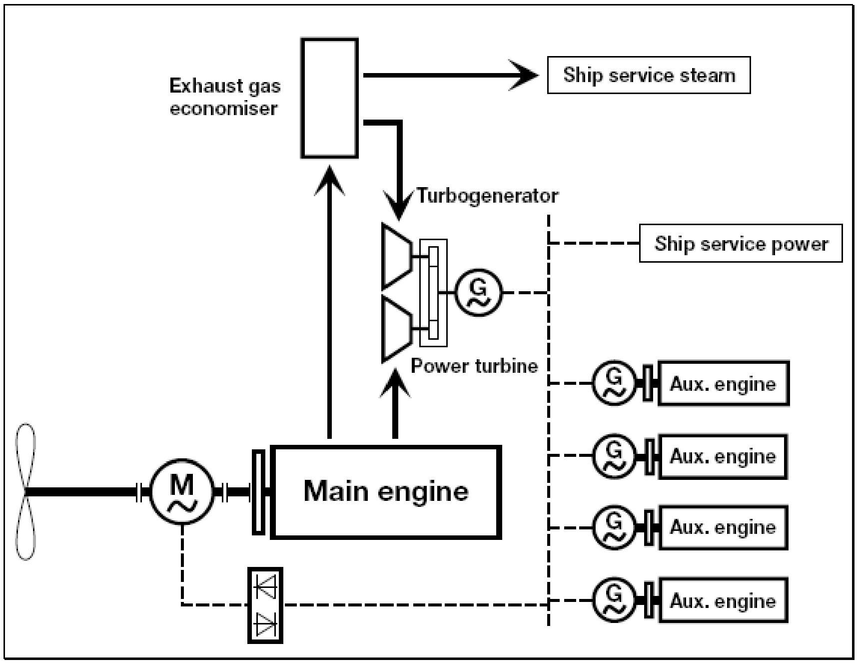


Figure 28: Heat recovery plant operation (Source: MAN B&W)

The major operation of the heat recovery plant is that steam is supplied by a dual – pressure exhaust gas economiser to a turbo generator set, which also incorporates a power turbine fed with exhaust gas branched from the engines manifold.

The electricity generated is then applied to a shaft motor / generator for additional propulsive power. It has to be mentioned that in addition to the extra power given, this system provides better fuel consumption, reduced maintenance requirements and exhaust gas emissions, especially those of CO_2, which have been lately on target.

With such a system it has been calculated that it is possible to obtain both an electrical output of about 10% of the main engine shaft power and a reduction of the daily fuel consumption of about 8%, numbers which are very important for the shipowners when the time comes to decide to build a ULCS, which has high fuel consumption characteristics. Heat recovery plants designs can be found by major engine builders, such as MAN B&W and Wartsila. Having gone through both designs, there are not any differences that can be observed since both designs seem to have the same way of principal operation.

The diesel electric concept

In the late years it has been a common trend, in both naval and commercial operations of ships, the concept of all electric ship. Under this regime, electricity is used as a way to deliver power to the propulsion unit. This kind of installation has its negative and positive sides.

In the case of containerships, having an "all electric" notion is probably an expensive one (very high investment cost). One of the ideas that probably can be used in the future is the combination of diesel and electric, which comes out to the diesel electric concept. Under this regime the advantages of having AC drives are combined with those experiencing when having a diesel engine.

When having a combined Diesel – Electric and Diesel – Mechanical system a lot of gains in terms of hydrodynamic performance can be achieved. In addition to these gains, improvements to the total economic feasibility can be seen.

In the following paragraphs all gains and drawbacks using such a powering arrangement are presented:

1. One of the major advantages using a diesel electric machinery is that the generators sets, used for the power generation needed for the ship propulsion, can be freely arranged anywhere inside the vessels structure, since for their power transmition shaft lines are not needed. As a result, the generators can be placed in the most effective position along the containership and in that way gain a lot of space, which can be used for cargo. For example, the engines can be placed in the very aft of the ship or at the very forward gaining a lot of space in the parallel middle body areas of the vessel.
2. One more feature to be taken into account is that the design and the size of the generators have been evolving. Major goal is to create a compact design with reduced dimensions with maximum power density and reduced weight, complexity and maintenance. Such an example is the latest reveal by ALSTOM, a high power machine of 20 MW that occupies no more than three square meters and at 100% of the rated speed has an efficiency of 97%.
3. In addition, an accurately chosen diesel – electric machinery is able to operate the diesel engines at the optimum load in all operation modes. In terms of containerships this issue is quite important since during the vessel's voyage the propulsion load needed is high (due its 25 knots needed) but during port the

engine load becomes very little (due to low hotel load). With such a configuration the optimum power output is thus maintained.

4. With the diesel – electric uniform machinery can be applied. In other words, all the engines used are of the same family, which makes the spare part logistics easier and reduces the crew training demand.

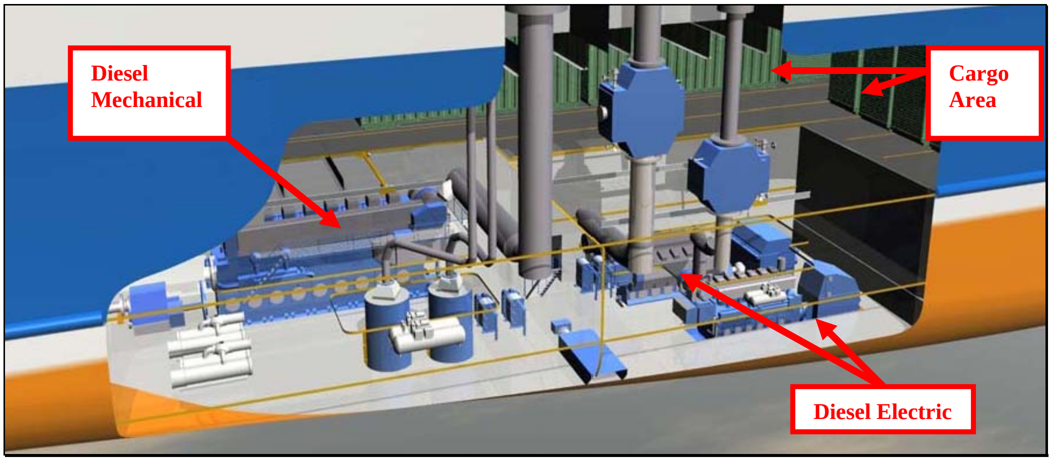


Figure 29: Combined diesel electric power plant

5. Diesel – electric machinery has lower noise and vibration levels. This feature is again quite important in ULCS since vibration in such big structures will be a problem (it has been already stated above). As a result by achieving better vibration characteristics by the machinery spaces, elimination to the global vibration problems of the structures is achieved.
6. The big drawback, as it has been already stated, is the high investment cost. What make it so high-priced are the electrical parts. Converters, transformers and motors have a great value to buy them. In rough calculations for a ULCS the increase of the ship investment cost is round about 1.5% which is a considerable amount.
7. Despite that though, the fact that better fuel consumption can be achieved, has to be taken under consideration. It is estimated that round about a 10% reduction in fuel consumption can be achieved, these exact figures depends directly upon what type of propulsion arrangement will be used. Those issues will be addressed in the next chapter which is about the hydrodynamic and propulsion challenges of ULCS.
8. Another disadvantage that has to be stated is that transmission losses can happen during the operation of the vessels. Those losses are directly associated with the electric power transmission. As a result, and in combination with the first point

stated, there is the free choice of placing the generators literally everywhere along the structure of the vessel, but on the other hand there is the problem of transmission losses. These two factors have to be taken into consideration together, and it must be checked if the losses are compensated for by the volume gained in the cargo area. This is a very important factor for the Ultra Large Container Ships.

9. Electric propulsion motors have very accurate torque characteristics over a wide range of speed. This permits the use of a fixed pitched propeller. Again, this is a very important factor for the ULCS because they use this type of propeller and not the controllable pitch type.
10. One further advantage is that emission control can be achieved. Generally, in having such a powering arrangement the fuel emissions are reduced, giving an environmental friendly profile to the vessel, a very good point in terms of marketing and public advertisement.

In more detail, and as a concluding mark, in case of the ULCS, it is known that the powering requirements are quite high, starting from 80.08 MW till 116, 6 MW. As a result, having a diesel – electric power generation plant, the power output can be divided into two parts, the mechanically and the electrically generated one. Consequently, this feature gives a great redundancy to the vessel operation, and furthermore the engine room arrangement can be in that way that cargo area optimization can be achieved and hence gain in total TEU capacity. The shipowner has to broadly ensure what are the advantages and the disadvantages, and then make his selections. The cost of installation, the cost of operation, the redundancy and the powering requirements of an ULCS form a complex building equation.

Figure 30: ALSTOM 20MW motor

Other alternatives

Ultra large containerships, due to their increased dimensions and high service speed, have a great amount of fuel oil consumption. As a result, these vessels are mainly affected by the prices of the fuel oil.

This problem that has been noticed lately with the increased price of the bunkers was that shipowners had to add an extra fee, known as Bank Adjustment Factor, in order to be able to overcome the increased bunkers cost.

If this market trend continues in future two events will be happening. The first is that the containership demand will stay at the same level or rise and the bunker demand will increase as well, hence the shipowners will face the problem of having the demand required to operate their vessel but not having the sufficient fuel oil prices. Thus, in the case where fuel oil prices go at a very high level in the future (say one and a half or two times to what they are these days), having in mind the oil shortage as the time goes by, there are various alternatives proposed for the operation of the ULCS that achieve reduction in fuel consumption by using innovative ways of producing power.

Steam Injection

The first innovative idea is the use of steam injection. Although the installation cost will be raised by 30% to 50%, it is likely that it will have a 10% reduction in fuel consumption, which means that the payback time will be roughly three to five years.

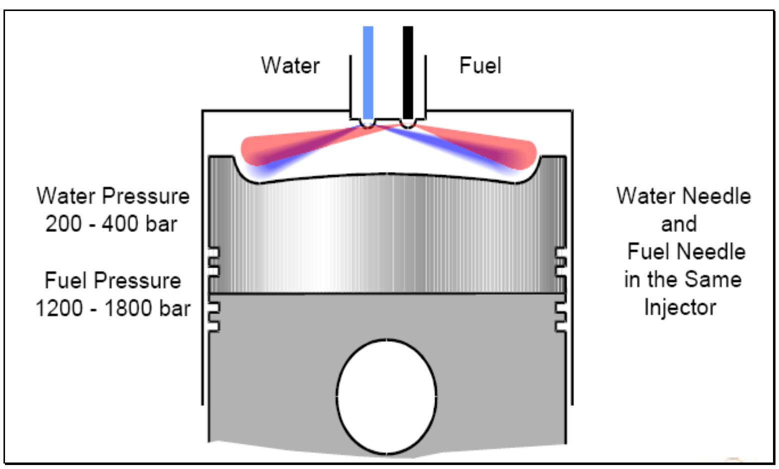


Figure 31: Steam injection (Source Wartsila).

As can be observed from the figure below, the steam is injected at the same time as the fuel from the same injector. By using such apparatus also the fuel emissions are reduced and furthermore have advanced fuel efficiency.

To have steam injection, an electronic control unit has to be installed. This unit is the one responsible for providing the required mix of steam and fuel oil for injection. The main engine manufacturers, who are experimenting with this technique, believe that the main reason for the additional costs will be such hardware additions required to run such type of engine efficiently.

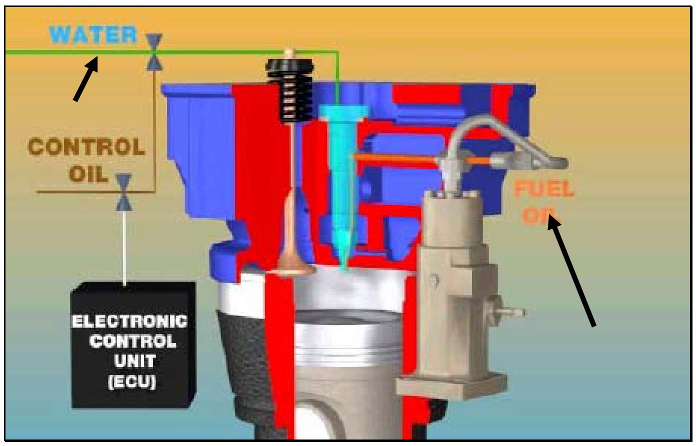


Figure 32: Steam injection operation (Source Wärtsilä)

<u>Gas turbines</u>

Again due to the fact that ULCS are growing a lot there have been thoughts for replacing diesel main engines with gas turbines. Reaching at a power requirement of 116, 6 MW makes the usage of gas turbines a viable solution and maybe will be more appropriate for the case of the Malacca – Max design.

One more reason to use a gas turbine can be the fact that orderbooks of the main engine contractors due to the increased shipbuilding activity of the past years, have been full, hence shipowners have to choose another option from using slow speed, two stroke diesel engines.

Operating a gas turbine however can create a lot of problems, since on site repair cannot be achieved due to its complexity. Furthermore, the training required for the crew is again one factor that has to be taken into consideration since crew operating in commercial vessels are not used to that kind of powering arrangement.

2.5 Propulsion and hydrodynamic aspects of ULCS

In this chapter all the hydrodynamic implications of the ultra large containership design will be demonstrated, from propulsion configurations to cavitation problems by the rudder and the propeller. These hydrodynamic problems are appearing as a result of the increased load on the propeller, thus alternative propulsion concepts have to be found and reviewed for this type of vessels.

The increased size of the ship leads to hydrodynamic problems, which are typical for ULCS:

1. The ULCS with single screw configuration cannot reach the required speed with the available main engines.
2. Based on the fact that in the ULCS design there are extreme conditions of high power density of the propellers, since they are highly loaded, this also affects the flow over the rudders and hence there are cavitation problems to both the propeller and the rudder.
3. Due to the design of the hullform and its extreme dimensions, parametric rolling is an issue of concern.

Propeller cavitation

Hydrodynamically speaking the propeller is one of the most problematic areas for the ultra large containership designs.

The value of the power density over the propeller tip speed of the containership propellers is very high. For example, for an ultra large containership of a capacity of 12.000 TEU is round about 45 m\s and the power density round about 1240 KW\ m^2. These values are extremely high and require a very careful design of the propeller as well as the rudder, which is situated in the slipstream aft of the propeller.

Blade area ratio is in the order of 1.0 and 5 to 7 propeller blades are therefore selected for the propellers, leading to propeller weights in the order of 100 tons and over. Another limit concerning propeller design is the maximum diameter that a propeller of a ULCS can have. This value is dependant upon the ship draught. It is known that a ULCS can have a draught in loaded condition from 15 meters and measuring the maximum one of 21 meters for the Malacca – Max design.

With the value of draft no more than 16 meters, propellers with a bigger diameter than nine meters cannot be achieved, and even if they can be manufactured it will not be efficient in terms of its weight.

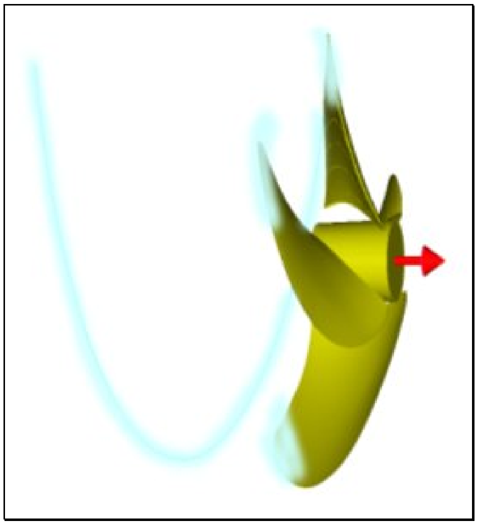


Figure 33: Tip Propeller Cavitation

The demand for high propeller efficiency, acceptable pressure pulses, good propeller hull interaction, and the absence of erosive cavitation lead to a very sophisticated design of propellers with strange and unusual propeller geometries.

For designers to be able to construct the most efficient propeller, special and very sophisticated softwares can be used. More specifically, such computer programs can digitally simulate the propeller operation and hence determine all its hydrodynamic characteristics as well as its cavitation. In addition to the above test, real time trials in scale are conducted in the cavitation tunnels, where scaled models of the propellers are used and their hydrodynamic performance can be observed through their operation.

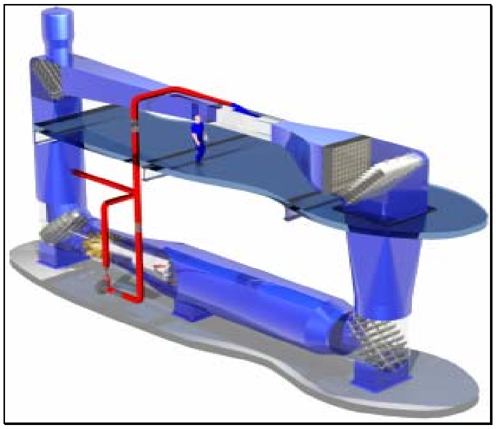


Figure 34; Cavitation tunnel layout

Rudder cavitation

The second most problematic area in terms of hydrodynamics after the propeller is the rudder. This is due to the fact that the rudder is situated in the slipstream of the propeller operation. As a result, any cavitation from the propeller is directly passed through the rudder.

The rudder design for the ULCS cannot be built by simply doing an extrapolation of the sizes from previous containerships design of smaller dimensions. Instead, designers first have to go through the principles of design and ensure that the rudder is operating efficiently in relation to the propeller chosen.

There have been cases in newbuilt containerships where rudder cavitation appeared after a short time of operation due to improper design of the vessel's rudder. Rudder cavitation may lead to material erosion, vibration and noise. The ensuing loss of performance and the necessary repairs can noticeably reduce the economy of ship operation.

Figure 35: Rudder cavitation

For that reason there are various techniques, which can be used to predict the cavitation patterns. One of the most common is the well known Computational Fluid Dynamics (CFD). With this technique, optimization of the rudder design in terms of cavitation can be achieved. This technique is like creating the real operation case in the computer environment. It can be described as running a full-scale model test digitally. All the prediction of this technique in combination with scaled model test can predict the optimum design of the propeller that has to be used.

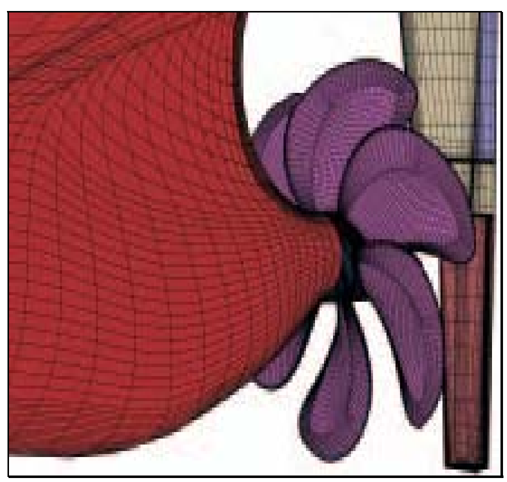


Figure 36: CFD computation

By using CFD computational analysis there have been some design solutions that can be used to avoid the creation of rudder cavitation when the ship is operating at high speed and the rudder is operating at small angles due to the automatic pilot application.

The first solution is the use of a specific rudder design named twisted rudder. Conventional rudders are placed behind the propeller with the rudder cross section arranged symmetrically with the propeller centreline. Despite that, such an arrangement does not take under consideration that the propeller induces a rotational flow, which is strong and intrudes to the rudder blade. As a result, areas of low pressure are created at the rudder resulting in cavitation.

The twisted leading edge rudder design avoids this phenomenon, which leads to better cavitation characteristics.

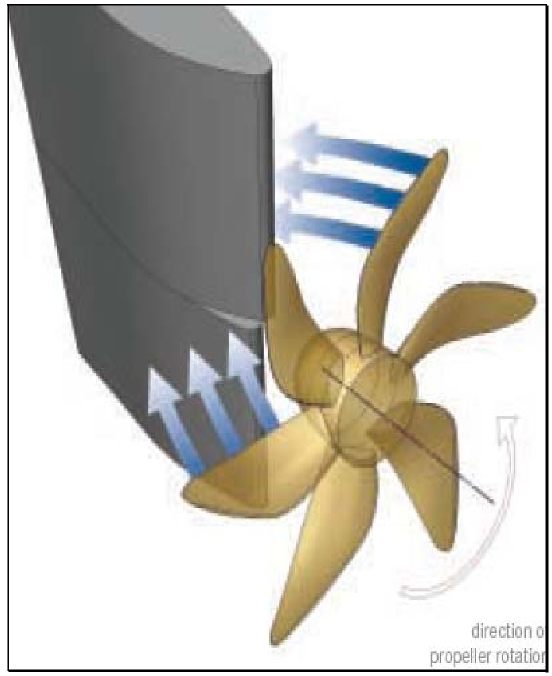


Figure 37: Twisted rudder design.

With this solution there is no rudder horn and, consequently, no gap cavitation, which usually occurs when hub or propeller tip vortices intersect with gaps between the horn and the rudder. This situation can lead to erosion in very critical parts of the rudder, affecting directly its operational efficiency. Furthermore, since the rudder cavitation is reduced, higher propulsion efficiency occurs (power consumption is reduced by 2%), an issue of great importance for Ultra Large Container Ships. In addition, for the construction of the rudder, there is no need to use plates of high thickness to overcome the cavitation problem. Reduced profile thickness is achieved. To conclude with the advantages of using such type of rudder, less vibration is experienced, a major benefit which leads to better propeller / hull interaction as well as better propeller / hull induced vibration characteristics that can create a lot of problems during the voyage of the vessel.

Yet another design that has been invented and might be used in the ULCS is the usage of rubber bulbs at the rudder exactly behind the propeller hub. With such a design better wake can be created, resulting in better hydrodynamic performance.

By using a bulb or a similar structure just behind the propeller, the creation of propeller hub vortices is avoided. Propeller hub cavitation is a major problem in containership design and with regard to ULCS it will be even greater, since the powering needed to propel such a vessel will be of great value, resulting in very high load of the propeller. There are various designs for this idea. One is demonstrated below and is from the well-known company Wärtsilä. Under this design it is obvious that the tip of the propeller is included inside a special structure. As a result, during the rotation of the propeller its hub is not exposed to the open sea, which directly results into eliminating the problem of the hub vortex cavitation. Another design proposed is the one mentioned above where there is a bulb fitted in front of the rudder and just behind the propeller, which again has the exact result as the previous design. Both designs are considered to give an additional power saving of 2%.

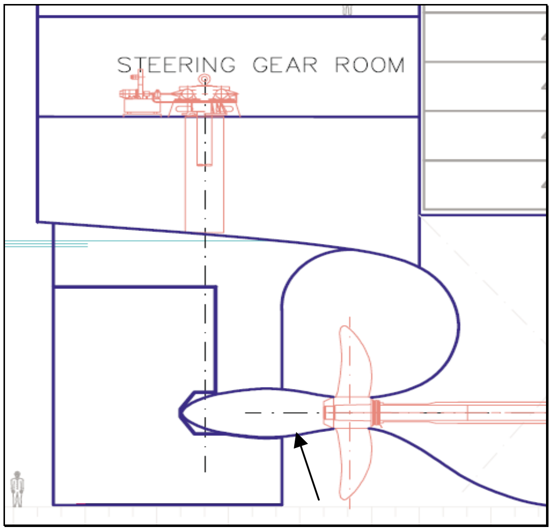


Figure 38: Usage of rubber bulb

One final point for the solution of the rudder cavitation might be the usage of a combined twisted rudder design fitted with a bulb in front of it in order to eliminate the problem of the propeller hub cavitation. It has to be mentioned that twisted rudder has been already applied to post - Panamax containerships having a capacity of 8400 TEU. The results from those have been quite impressive, leading to the fact that this will be a pattern in the future for the Ultra Large Container Ships, based of course on the propulsion configuration that will be used.

Conventional single screw propulsion

The area of the required propulsion configuration is very challenging for the ULCS. There are various propulsion alternatives that can be used and in this chapter all of these alternatives will be discussed, beginning with the simplest one, which is the conventional single screw propulsion.

As far as having conventional single screw propulsion for vessel size beyond 12.000 TEU it is a not very viable solution, since the required power output that has to be transmitted via the propeller shaft is too big and cannot be withstand by one shaftline only.

For the case of the 10.000 TEU design, however, there have been observed various projects running a single skeg configuration. For ULCS, having such a configuration, creates some gains as well as some drawbacks:

1. Firstly and most importantly, the single screw hullform has smaller wetted surface area. This means that from hydrodynamic point of view those ships have lower hull resistance. To compare it with a twin skeg design, the added wetted surface is round about 7%, which is a considerable amount of steel structure resulting in increased total resistance.
2. Furthermore, one engine can be used for this configuration. This fact has the advantage that only one main engine is used. In terms of space optimization this is a good point, but on the other hand there is no redundancy, which is good to have especially for vessels such as ULCS, which have to be on tight schedule during their whole operational life.
3. Even for the 10.000 TEU vessels, using a single screw is quite challenging since the powering requirements have been stretched to the limit. This means that transmitting power of 80.08 MW through a single shaft and having an operational speed of 25 knots requires a propeller that is able to withstand high loads and hence it should have a big blade to area ratio. Those propellers are stretched to the limit, and as a result, hydrodynamically speaking, they might create implications.
4. Cavitation problems in both the propeller tip and the rudder are experienced in such a configuration (please see the sub chapter above – propeller cavitation)

As a concluding remark of this section, it can be seen that single skeg is a very limited solution for the ULCS market and hence other alternatives are more effective.

Twin screw propulsion

One of the other alternatives that it is predicted to be used widely in the ULCS is the twin screw configuration. The conventional twin screw vessel (such as the Malacca – Max design) has as the single crew design a number of benefits and drawbacks as well:

1. A major advantage is the fact that twin skeg arrangement has a round about 3% less propulsion power requirement, from a single screw ship with the equivalent dimensions.
2. Furthermore, two different engine rooms are used, one for each propeller. This offers great redundancy characteristics, making a ULCS more operational efficient and ensuring that tight routeing schedules will be kept without any problems. Redundancy for ULCS is a matter of concern since the value of the cargo that will be transported with these giant ships is very high. The potential economic loss in case of an accident makes redundancy a major issue for ULCS. In that was, economic risk is lowered, something that both ship owners and risk insurance companies want.
3. Moreover, the engines used are having familiar numbers of cylinders. This means that for ULCS, there have been designs of engines having 14 and even 18 cylinders. Those designs are very new and haven't been tested broadly, which means that the reliability of their operation is not known. On the other hand, for the twin skeg design the engines used are the latest additions for the propulsion of the 9.000 TEU era of containerships. Those engines are 12 cylinder ones and well proved to be operating efficiently without any problems.
4. In terms of cost, the lower power requirement for the twin screw gives saving to the fuel consumption and as a result also to the operational costs, but on the other side of the coin, the cost of installation is higher.
5. As already stated, the twin skeg has greater wetted surface, which results is higher resistance. This can be partly compensated for by changing the position of the LCB, locating it more aft wards. With this movement lower wave making resistance is experienced, so the total resistance is a bit reduced.
6. The twin skeg has lower hull efficiency compared with single skeg owing to the less favourable wake field. On the other hand, the propellers used have better

design and performance characteristics and their open water efficiency is much higher from the single skeg design.

7. Finally, it is known that twin skeg is the way to go for the ULCS since the powering requirements are very high. The majority of the designs published until now have this type of propulsion arrangement, clearly notifying that this is probably the most cost effective way to propel vessels of that size at the high speed of 25 knots.

Figure 39: Difference between twin and single screw arrangement (Source: MARIN).

In the next sub chapters some other alternatives will be presented. Those alternatives are based on innovative ideas that generally might be applied in the future in the marine design sector. These ideas will be presented and the feasibility in the container sector will be discussed. They have a greater cost of installation, but savings in the operation of the vessel can be achieved at a considerable amount.

Podded contra rotating propeller

The podded CRP concept feature a contra rotating propeller mounted on an electrical pod located directly behind a single conventional propeller located at the centreline skeg. Both propellers are of the FPP type (fixed pitch propeller). In addition to that, the mechanical type sometimes has the feathering type operation.

This type of configuration has better hydrodynamic performance, since there is no rudder situated; the pod drive is used to navigate the vessel to the direction needed. Compared to a twin skeg configuration again one will find pros and cons to this application.

The main factor though, is that this application has all the advantages of the single skeg hullform mentioned above, plus the fact that the aft propeller takes advantage of the rotative energy left in the slipstream of the forward propeller when It turns to the opposite direction.

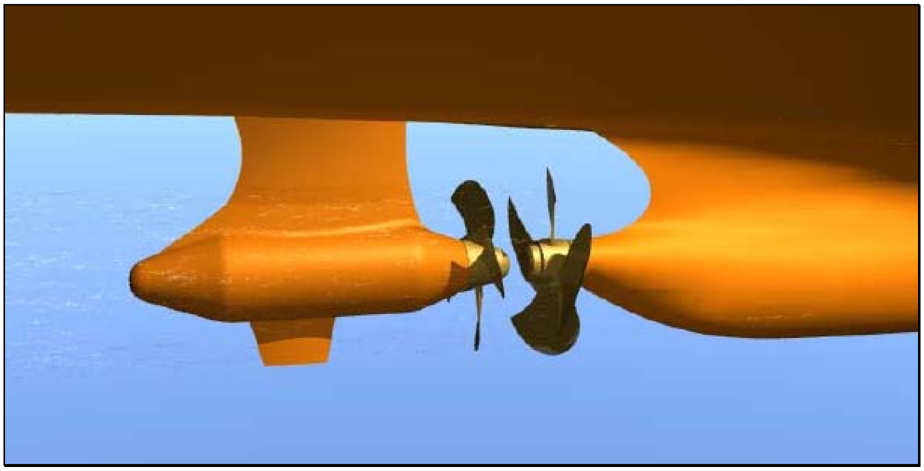


Figure 40: Podded CRP propulsion (Source Wartsila)

In addition to the aspects mentioned above, this configuration has some of the advantages of having twin skeg propulsion. The pod and the mechanical drive are separately driven, which means that each function has its own engine room, resulting again to the issue of redundancy. This application has the hydrodynamic characteristics of the single screw design and the redundancy of the twin skeg one.

Even though the improvement in the resistance characteristics stands as the major gain of using a CRP propulsion, there is yet another very important issue. These podded drives have the possibility to turn around 360 degrees, and as a result there is no need for the use of rudder.

CRP have excellent manoeuvrability performance, which gives the potential to reduce the turnaround time in port owing to faster manoeuvrability. This is especially important for ULCS where for them time is money, and vessels of that size always try to find solutions upon how they will reduce their time when in port.

For this arrangement the power distribution between these two propulsions is usually 70% for the mechanical drive and 30% for the podded drive. In that way, for the mechanical drive the big 12 cylinder engines can be used (like those used to propel the 9.000 TEU ships) and the remainder power output required for the ULCS can be provided by the pod drive (there are pod drives of 22 MW power output)

Consequently, such a design can be used for all the ULCS design no matter what their TEU capacity is. Hence this is a possible scenario for the future.

The only problem that have been experienced during tank and cavitation tunnel testing is that until now there are some cavitation problems with the propeller of the pod drive, when the pod is turning at an angle in order to be able to steer the vessel. In addition to the above, it can be assumed that while such an installation is more costly than having conventional twin skeg propulsion, the gains that are experienced are considerable as well.

In the case of the Malacca – Max, another viable solution would have been to use twin podded CRP propulsion. In that way the power of 116.6 MW would have been split in that way that redundancy is ensured and the diesel engines that will be used will be the ones that have been proven to be reliable and efficient.

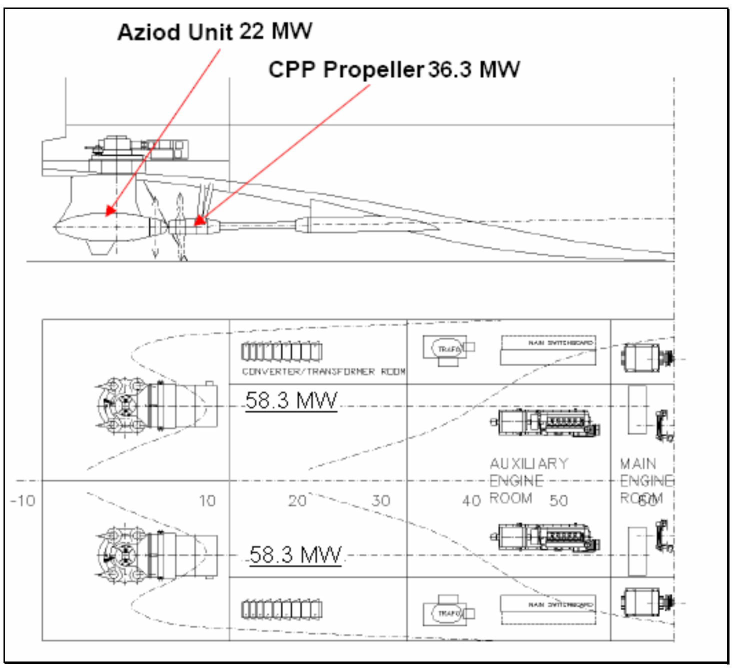


Figure 41: Twin CRP propulsion for Malacca – Max

Other advantages of this system are the following:

- Easy mounting at the shipyard
- No need of stern thrusters
- Flexibility of the general arrangement, resulting in more cargo space.
- Less tug assistance in ports
- Good operation at lower speed
- Better crash stop characteristics

Hybrid propulsion with wing pods

Another potential propulsion set up that can be used for ULCS is the use of single screw propulsion with the addition of two wing pods. Again, with this application, as in the case of the CRP propulsion, the combination of the advantages between single and twin skeg propulsion can be achieved.

In more detail this setup consists of two azimuthing electrical pods, one on each side of a mechanical propeller on the centre line skeg. For the case of the ULCS, which have high power applications, this kind of propulsion can offer high efficiency. The load is split between three propellers instead of two or one; hence better open water efficiency can be yield.

Figure 42: Hybrid propulsion for ULCS (Source Wartsila)

This type of application is most probably better applicable to containership designs of 15.000 TEU and over. Main operation philosophy of this project (by Wärtsilä) is that the centre line mechanically driven propeller is of the feathering type. It is operated at high speed, when the vessel is at high seas, but when approaching ports at low speed is feathering. In that way better resistance characteristics can be achieved. In addition, at low or medium speeds the vessels is operated only by the two wing pods. In that way low engine loads on mechanical diesel engines is not encountered and as a result the negative effects from that case are reduced.

Furthermore, as far as the steering is concerned, at high speed the rudder at the centre line is used and the pods are locked on their position. On the other hand, when the vessel is at low or medium range speed then since the centreline propeller is not operating the wing pods are unlocked and used as rudders. For slow speed range these azipods are giving excellent manoeuvring characteristics despite the size of an ULCS. This flexible manoeuvrability gives to the vessel all the advantages that have been already stated above:

- Reduced port time when entering and leaving the port.
- No need of tug assistance.

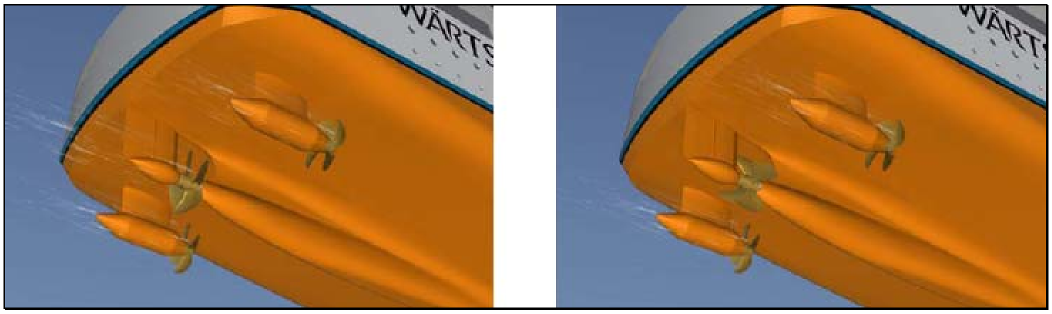


Figure 43: Hybrid propulsion at high (left) and low speed (right) mode (Source Wartsila)

With the description of this last propulsion configuration this chapter comes to an end. All the potential difficulties of the forthcoming ULCS design have been presented and analyzed in deep in order, enabling the reader to understand the root cause of these implications and furthermore to understand the potential solutions to this problem.

Having finished with all the naval architect design problems of the ship itself, the next chapter deals with is another big problem and its potential solution. Ports and their facilities have to change their arrangement; they have to be enlarged in a lot of aspects, in order to be able to accept vessels as the ULCS, and most importantly to be able to operate efficiently the increased cargo capacity.

If the ports adopt all the required changes, then the only factor that plays the key role to the viability of the ULCS is the market itself. From the engineering point of view everything will be fixed and ready to work perfectly, but the market is a sector of great risk that nobody can really predict.

2.6 Safety implications of a ULCS

The issue of safety onboard a ULCS is very important. The extreme dimensions of this vessel create some serious safety implications related to parametric rolling.

In more detail, parametric roll is the unstable roll motion suddenly occurred in the case where heavy head or stern seas are encountered. When designing a ULCS ship this phenomenon should be thoroughly investigated. Parametric role can cause a lot of problems to containerships, it has been first observed from the third generation of containerships.

Major problem is that due to parametric rolling, damages to the containers can happen and in worst case some of them might be lost at sea. The large rolling angles (more than 50º have been observed) in combination with the extreme numbers of stacked tiers might cause this loss.

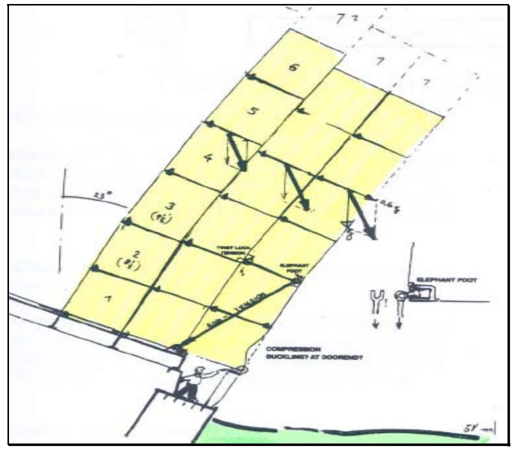


Figure 44: Effect of parametric rolling to containers.

The reason that containerships are vulnerable to such a phenomenon is because they have hull forms with pronounced bows, flat transom stern and wall sided midship section. This type of hullform contributes to the variation of the ship's stability characteristics due to continuously change of the underwater hull geometry as waves are passing through the vessel.

Figure 45: Damages to containerships due to parametric rolling

This problem can be avoided by doing proper tank testing when the ULCS vessel is still at the design stage. Simulation of similar weather conditions that can cause parametric roll can be achieved in large towing tanks

Chapter 3: Design limitations and implications of the ultra large containership port facilities.

3.1 Introduction

This chapter is the second most significant of this dissertation. More specifically, all the implications of the operation of ULCS vessels when they are in port will be discussed and analyzed. The increased size and capacity of the ULCS will bring changes to the port infrastructure. Based on chapter two, although the technical difficulties in building as ULCS can be overcome, there must be equivalent shore side facilities to match its capacity.

If the port facilities remain at the same level as today, the trade and the flow of the containers will not be efficient enough, resulting in port delays and cargo conjunction in the storage areas. There is a saying that transportation asset, weather ship, aircraft, train; truck must be in motion to assure its economic survival. As a result port facilities have to be improved in terms of both capacity and performance. Furthermore the harbour waters and approach channels have to be of sufficient size, in terms of depth and breadth, in order to be able to handle the longer, wider and deeper ULCS vessels.

The various implications related with ports are:

- Marine access issues.
- Port operation and equipment used, especially the cargo handling facilities. The terminal should have sufficient area to accommodate the increased number of containers brought by ULCS, and also the crane capacity should be improved.
- Landside access – Intermodal issues.
- Environmental issues.
- IT and logistics.

All the above points will be discussed below, and the exact problems related with the ULCS will be stated. Various solutions and alternatives will be given as well. To begin this analysis, however, a brief overview of what is a container port terminal and how it operates will be given.

3.2 Dedicated container terminals

For the purposes of the container traffic, specialized container terminals are used. This type of ports is not something new, the need for dedicated infrastructure, most of the times due to safety, has often created the need to segment the port areas depending upon the type of cargo transported. As a result, in a port specialized areas for containers, bulk or liquid cargoes can be found (for example Europort in Rotterdam).
In more detail, the container terminals are the most recent trend. The so-called DCT evolved in Asia and North America. In Europe, it was introduced in the early nineties by Maersk, in the transhipment facility of Algeciras.

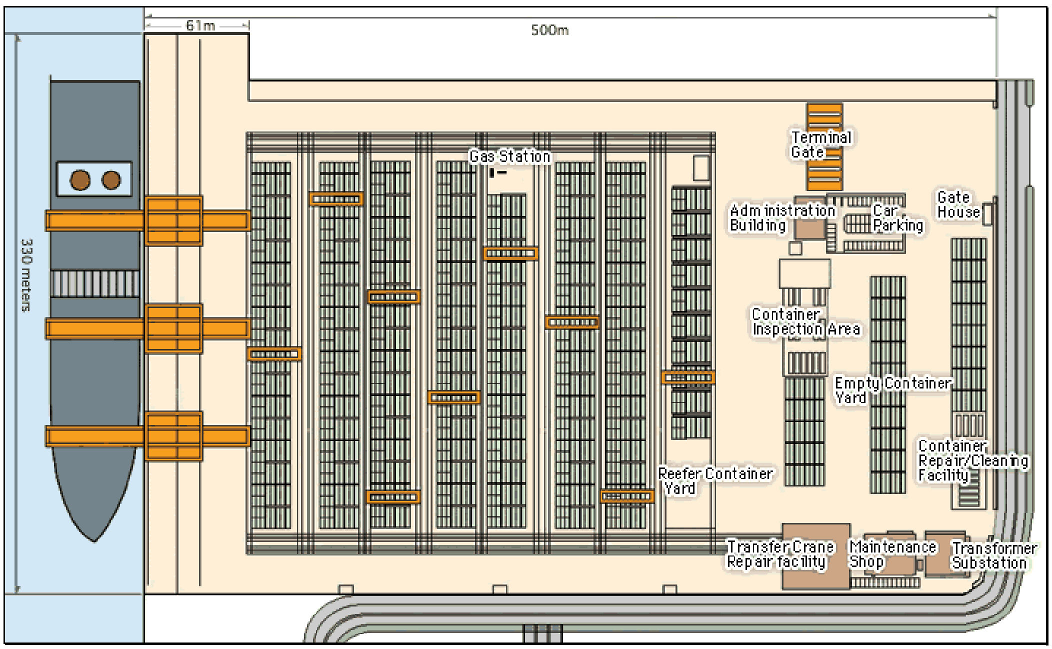


Figure 46: Lay out of a DCT

Based on the schematic representation above and an additional one provided later (Figure 47), a DCT must have the following areas:

1. Quay – Dock: where the vessels are berthing. In the case of ULCS this area has to be more than 500 meters.
2. Gantry cranes: Used for the transportation of the containers from the ship to the shore side.
3. Specialised vehicles, which are used for the transportation of the containers to the specific storage areas.

4. There must be a gas station for the refuelling of the above mentioned vehicles.
5. Storage areas. These areas are used for the storage of the containers. There are various such regions. First of all is the area used for the empty containers, then there is another area for inspection of containers, an additional specialised for the refer containers, and of course there is an area used for repairing and cleaning the already used containers.
6. Crane repair facility and maintenance shop. Used for the maintenance and the repair of any problems related to the cranes and the specialized vehicles used for the cargo movement.
7. Administrative building, used for the coordination and supervision of the port operations.
8. And, of course, a terminal gate and a car parking.

One of the main reasons to have a DCT is that they offer flexibility, reliability, short turn around times and enhanced efficiency in the management of the supply chains to the carriers.

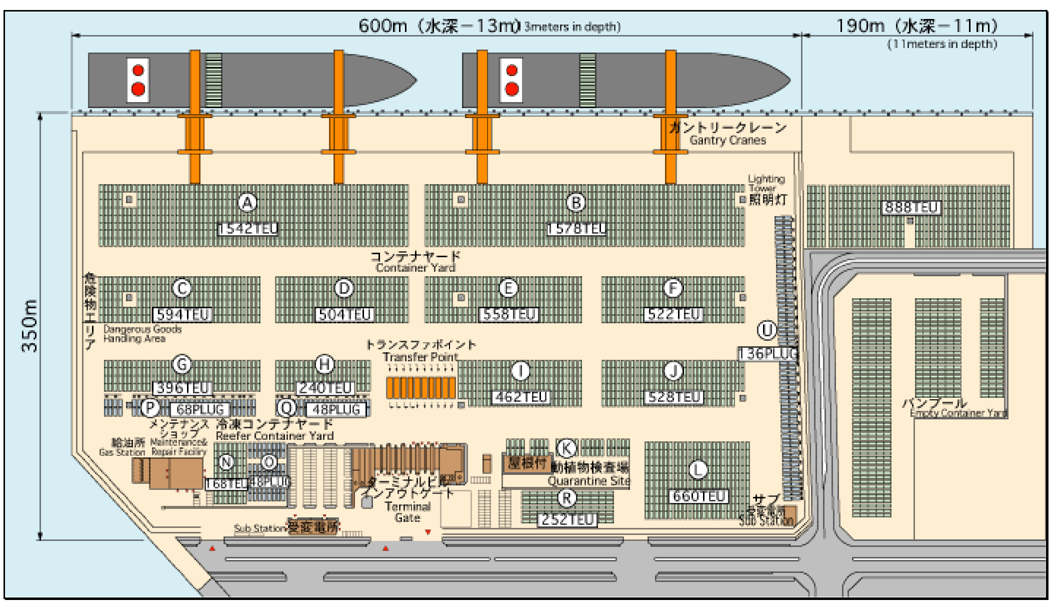


Figure 47: Second lay out of a DCT (Kashi port)

It is obvious that all the areas of a DCT will have to be changed and increase their capacity, if this specialised DCT desires to be a mega hub port and accommodate Ultra Large Container Ships.

3.3 Marine Access implications

This chapter mainly focuses on the implications that can be met up by ULCS when they are trying to enter a port. It includes all the restrictions that can be found from the time the ship is approaching the port till the time it is berthed alongside the quay.

Depth of the harbour

The depth is a major issue for the effective operation of the ULCS. From the designs presented, the values of draft can vary from 16 meters to the maximum, which is 21 meters. As a result all the ports aiming to make use of the ULCS vessels should have a depth of at least 17 meters and above.

This value of depth s quite high, and at the moment there are few ports that can accommodate vessels of that size and that depth. Ports in Asia are ready to be utilized by ULCS, but from the other side of the trade EU ports and those in the USA seem to have difficulties in achieving this draft value. Furthermore, for the case of the depth, the tide should be taken under consideration. When the vessels are alongside the quay they should not be affected by the tidal movement. There must be a clearance between the vessel's keel and the seabed.

The most obvious solution for this implication is dredging. To dredge, however, is a very expensive operation. Besides the cost factor, there might be problems with the natural characteristics of the harbor. For example, the constitution of the seabed might be rocky, making dredging almost impossible. Moreover, there might be some other obstacles that cannot be removed. Some of those can be pipelines, or even some tunnels created for civil transportation. To conclude another very important factor is that even after the end of dredging the depth has to be maintained since there is a great possibility to be covered by the mud of the seabed due to the sea currents.

As it can be seen, achieving a depth of 17 meters or more might be a very difficult and expensive task. The benefits and the drawbacks of such an action have to be considered before taking such a decision.

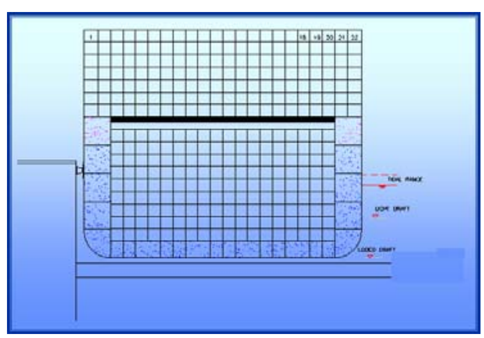


Figure 48: Depth clearence when in berth

Width of the Harbour entrance or the channel used by ULCS

Again as it is already known the width of the ULCS might be a restricting issue for harbours. Breadth values for ULCS have a range of 50 meters to 60. As a result, it might be the case that due to the geographical position of the port, difficulties may be faced in terms of the manoeuvrability and berthing of the vessel.

Furthermore, there is a possibility that the ship should pass through a channel in order to reach a port. In this scenario again there might be difficulties concerning the navigation of the vessel through this route. At this point it should be stated that the width of the vessel might not be the only limiting factor, length is a major problem as well.

Length of the vessel in relation to the port facilities

The length of a ULCS must be taken under serious thought when designing a mega hub port. There are various implications related to this. First of all, the quay at which the vessel will be moored should be of sufficient length as well. In that way maximum number of cranes can be used for the movement of the cargo from the vessel.

Port productivity is directly influenced to the number of cranes and crane lifts per ship work hour. As a result, it is very important to have a quay of round about 500 meters for each ULCS and roughly 5 gantry cranes operating on that. Thus, the length of the ship poses a great challenge to the port facilities, since the vessel has to be unloaded as fast as possible, in order to minimize the time when it is in port.

For existing ports that do not have the sufficient amount of quays length, in order to be able to hostile ULCS should extend their quay and use more gantry cranes per ship. But this again is directly related to the geography of the port. It shall have the required free space to conduct such an extension and furthermore it should ensure that no navigational difficulties will be experienced.

One final issue that has to be addressed is that in the future, big container port terminals will have to be able to host more that one ULCS at the same time. Thus, it might be the scenario that a port can be extended to the limit and host one ULCS, but in the future this might be a drawback if there is no other possibility for further expansion.

3.4 Port operational implications

Having analyzed already the implications that can be found when a ULCS is entering or berthing on a quay of the port, it would have been sensible to continue with the presentation of the implications related to the port operation itself. Thus, this chapter mainly focuses on the implications that can be met up by the time the container is unloaded from the vessel until it moves out of the port premises. In addition to that the reverse process should be taken under consideration as well. This is the process where containers are brought to port from trucks or rail in order to be loaded onboard the vessel.

In port traffic

For the needs of a mega hub port that will be operating with ULCS, the right order of the inport movement of the vehicles and the various other equipment used, will have to be regulated in a very sound manner. In that way maximum transport efficiency can be achieved. Moreover, transport time will be minimized to the possible extent resulting into faster port operations.

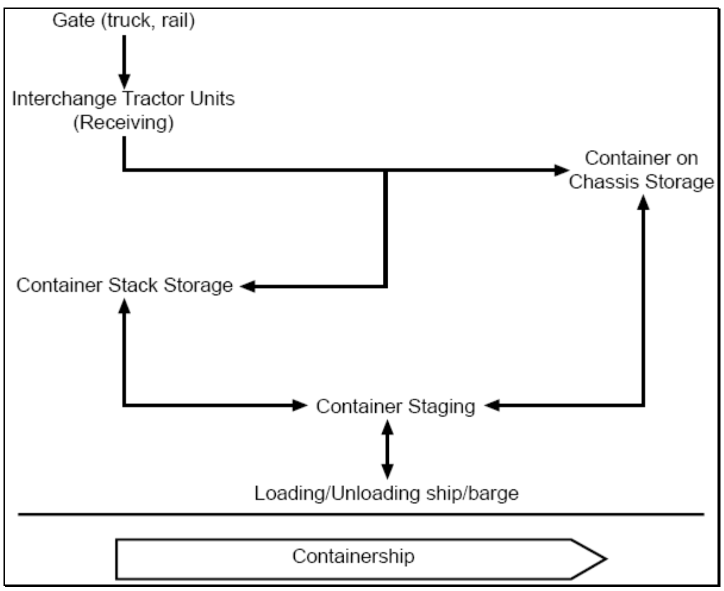


Figure 49: Container transportation through port

As it can be seen from the above figure, a container can have a lot of routeing before being loaded or unloaded to a ULCS. There are various processes concerning this issue:

- Loading / Unloading from the ship
- Movement to the container staging area
- Further movement to the container stack storage, where it can be kept for a long time waiting for the next transportation, which can either be a truck to take it out of the port or it can be a feeder vessel transporting it to another port
- Containers can be transported to the chassis storage as well, if the port is supporting transportation through railway
- Moreover, as already stated, there is the transportation through track outbound to the port.

All the ports have to make clear that all the cargo that has to be loaded or unloaded to a ULCS has to be easily transported, stored and moved out from the port in the fastest possible way. This is a major implication and for that reason a lot of research has been done in order to find a way of how to increase the speed of in port traffic. It has to be done in a way that is efficient, fast enough and of course safe.

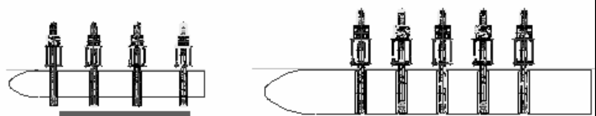
For that reason a lot of experiments have been done in using unmanned transport vehicle (AGV Automated Guided Vehicles), which are directly guided through laser beams. In that way the influence of the human element is minimized and hence the possibility of a human error is reduced. Rotterdam container port terminal is a brilliant example of how such a system can be applied. Despite that, even better and faster solutions have to be found for the future when the ULCS design will be materialised and enter into operation.

Figure 50: AGV vehicle

Again, however, one of the problems for a port that desires to serve ULCS is that it should have the sufficient space to accommodate the extra storage areas needed as well as the bigger road network required for the quick movement of the cargo. There are limits for each port concerning the effectiveness in port traffic.

These limits are directly related to the space availability and surely the maximum available transport velocity of the equipment used for the container movement. These two factors, space availability and maximum transport velocity, are somehow directly connected. To put it clearly, if the overall space area of the port increases, it means that the truck or any other moving equipment used for cargo transportation has to move faster in order to keep the same transportation time compared with a port that is serving containerships with less TEU capacity.

Some of the latest figures related to transportation speed of ULCS can be found below. For an 8000TEU vessel 25 moves per hour are needed. On the contrary though, for a ULCS 30 moves per hour is the required value. Moreover, the yard size for the same comparison should be increased from 20.000 to 25.000 square meters.



	8000 TEU	ULCS
Quay length (M)	400	500
Yard size (ha)	20	25
Exchange (Boxes)	2000	3300
40' to 20' Ratio	1.6	1.6
Crane (no)	4	5
Single Trolley	√	√
Twin Lift	-	√
Dual Cycle	-	√
Moves / hr	25	33
Berth capacity (teu/year)	640000	1,320,000
teu / m/ year	1,600	2,640
Yard capacity teu / ha	32,000	52,800

Figure 51: Comparison between 8000 TEU and ULCS port (Source: Scott Wilson)

As a result the issue of correct in-port traffic regulation has to be under serious research. Port authorities have to make sure that they can provide continuous and fast enough transportation service to ULCS, because creating delays is not working in favour to anybody.

Cargo handling gantry cranes

The use of the gantry cranes is the final and the first stage (loading / unloading) in the port operation process. It involves the loading and unloading to / from a ship using ship to shore cranes. For the case of the ULCS, since their TEU capacity is increasing enormously, bigger and more efficient cranes should enter in operation.
There are major implications relating to the ULCS gantry crane:

- **Height limitation:** The gantry crane should have the required height in order to be able to operate at the highest possible container tier. That means that the crane should have a clearance height well over the height of a seven to eight container tier that the majority of the ULCS will have. This can create a lot of problems that have to do with the bending moment of the structure during operation, the maximum allowable weight carried by the boom as well as the speed of the container transportation. Furthermore, the height of the crane is directly affected by the weather conditions as well. Strong winds as well stormy weather can have a direct effect to the operation of the gantry crane. The swell of the vessel while in port can create a lot of problems to cranes since the clearances between the containers are really small and hence any movement of the ship in combination with the increased height of the crane can result into serious operational delays.
- **Span outreach of the crane:** The cranes used for the ULCS should have a boom outreach of more than 50 meters. The ULCS designs have breadth from 50 meters to 60 meters, which is the maximum. As a result the crane should have the required span in order to be able to move containers from everywhere onboard the vessel no matter the breadth of the ship. This again will result in structural considerations since the bending moments and shear forces induced will be of great value.
- **Cargo handling speed:** The crane should be able to load or unload containers from the vessel in an increased velocity. Due to the increased capacity of ULCS, minimization of port stays is achieved on that way. But again, this is a major implication for the crane since there are structural, safety and management limits in terms of speeding up the process of cargo handling. This point is directly related to the inport traffic regulation mentioned above. As far as the structural implications are concerned, it is obvious that increased speed means that the crane

should operate at high rates of acceleration as well. This might create problems since the crane should accelerate fast when receiving the container but then brake at the same rate when it reaches the top of the crane and is ready to bring it to the next phase of transportation. All these constant alterations of the container movement transportation in relation to the weather conditions can create a lot of stresses to the crane structure. Those stresses should be reviewed and the designer has to ensure that they can be handled by the crane.

- **Space availability:** Space is an issue again. ULCS gantry cranes have greater dimensions and hence they require bigger area of installation. The foundations for a ULCS crane will be larger from all the cranes that have been built until now. Hence implications in terms of space availability might exist. Additionally, the fact that more cranes in total will be needed (observe figure 49) for the ULCS operation, this might create problems in terms of quay area availability of the port.

There have been ideas of upgrading already gantry cranes operating in a port. This option is probably not a viable solution for the need of the ULCS vessel. There have been upgrades of cranes from Panamax size to Post – Panamax size. Even though such a solution will be very much desired since the port operator is gaining in time consumed to construct it but in money spent as well in terms of the ULCS and with the above implications that have to be faced is most likely that completely new cranes will have to be constructed.

Figure 52: Modification of Gantry crane capacity (Panamax to Post - Panamax)

Purchasing gantry cranes for ULCS operations is a very expensive and risky movement.

As a result port authorities have to make sure that the above implications are satisfied. A general arrangement plan of a possible future ULCS gantry crane is provided below.

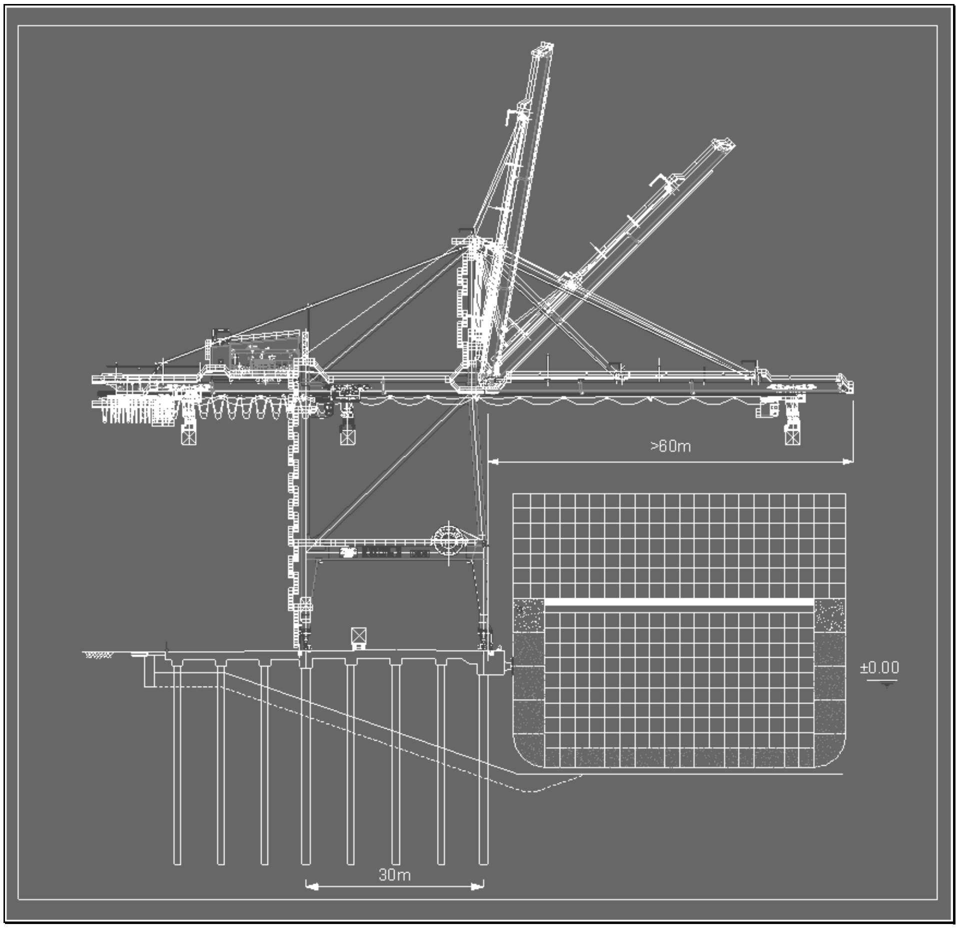


Figure 53 : ULCS Gantry crane (Source: Scott Wilson)

Terminal staffing requirements

A container port terminal is staffed by permanent employees and longshore labour. As it can be understood, moving to the ULCS era the need for staff will be increased. It is highly probable that more labour will be required in order to overcome the increased cargo throughput and faster operation of the port.

This is a major implication for the near future since it means that a high wage bill for the port authority will be created. It might be the case that technology can help (IT) to decrease the number of staff but then, the value of purchasing state of the art technological equipment will be expensive as well. As a result, this issue again is an obstacle standing in front of the ULCS port operation.

3.5 Land side access implications

Having gone through all the possible processes of cargo movement (from ship to port and vice versa) the only section left to be analysed has to do with the surrounding area of the port, and, more specifically, the land side access to the port. The harbour has to be easily and comfortably accessed by both sea and land in order to operate efficiently. As a result, for the case of the ULCS port operators there are some really important issues related to landside operation that have to be taken under consideration. These are:

- Congested truck routes
- Rail and highway crossings
- Not proper development of road network due to land restrictions
- Clearance implications (i.e. double stacked trains passing through tunnels and bridges)

These are extremely significant since ports might be able to expand their area in order to satisfy their operational needs, but on the other hand this expansion might cause restrictions to the land side access.

Truck drivers and train operators should be able to have continuous and fast access to the port in order to transport efficiently the cargo throughput. If they are faced with problems such as congested national roads, a lot of crossings and clearance limitations then delays can occur, which are not desirable since they create implications to the whole process of the container transportation.

In other words, the hinterland, the port itself and the ULCS should be considered as one body. They are completely dependant on each other and they have to be operated perfectly, as designed, in order to achieve the required performance. Any implication happening to any of those three will result in delays, which cost money.

Another important factor concerning the landside access is the comparison between rail and truck transportation. Moving containers by rail is considerably more efficient than moving them by truck (Figure 51).

Furthermore, the average unit rail cost can be 20 – 30 percent less than truck cost, depending of course on the length of the haul and the level of demand. Bearing in mind the above it might be logical for ULCS ports to use as much as possible the option of rail transportation instead of trucks. In other terms the modal split between train and truck can be more than 50 – 50 percent, for example a percentage of 65 to 35 will give an advantage.

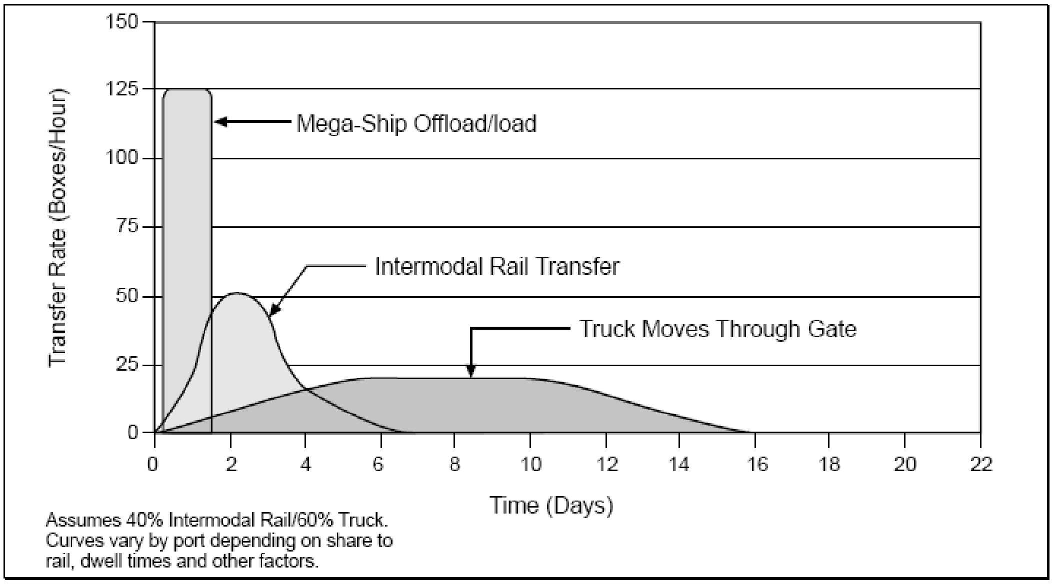


Figure 54: ULCS containership peaking characteristics

Finally, the location of the port is very important in terms of its land side access. It should be avoided to be near highly populated urban areas since it will suffer from and in the same time create traffic congestion that will impede the efficient truck access flow. In addition to that the ports should be located in areas where rail access can be achieved and furthermore is not surrounded by structures like bridges and tunnels, which can pose various restrictions. Moreover, it should be ensured that the highway capacity is sufficient enough and that the gate operation of the port entrance is very fast. There have been cases where the gate was requested to be open 24 hours a day 7 days a week, but this is obviously not achievable due to security reasons.

3.6 Environmental implications

Environmental implications for the ULCS ports exist. The major concerns are the following:

- Modifications to the salinity of the water surrounding the port due to dredging
- Dredging and disposal of the soil
- Loss of land areas

- Increased pollution due to increased truck and rail traffic
- Light and noise pollution
- Pollution from ULCS, engine operation and ballast discharges

Dredging a port in order to increase the depth or the breadth of the channel can cause environmental implications. For an existing port this action will be very common since at the moment there are very little ports that can accept ULCS in terms of draft. Dredging and widening though increases the salinity of the water, which can kill fresh water fish banks that are attached to the surrounding area of the channel. Moreover, the disposal of the dredged soil is a major issue as well. Disposal to the open water usually disrupts the animal life including any possible reefs situated on the seabed.

In addition to the environmental sensitivity, in the case where a port is situated near an inhabited area, there is the problem of light noise and vibration. Expansion of a port will directly result into additional trucks or trains used, increasing the pollutants emitted by their operation. It might be positive that the expansion of a port will create more job positions but the light and noise pollution coming out of the port due to the extended operation hours might create a lot of complications.

The only solution for the environmental implication is cooperation of the port authorities with the environmental organizations and local communities, which are directly affected by its operation. In this way, harmful environmental and residential impacts can be potentially reduced by presenting and discussing alternatives to minimize environmental concerns.

3.7 Information Technology and Logistics

The marine container ports, whether big or small, in our case big, are one link in the container moving global transportation chain. Their operation is directly related to a lot of different operators such as truck drivers, freight forwarders, port authorities; ship owners etc (observe fig. 52). This interrelated network somehow has to be organised in such a way that the efficient operation of the port is ensured and furthermore, globally speaking, that the whole container market is properly stabilised.

Moving to the ULCS era this need will be even more essential. That is the reason why logistics and generally information technology will have a very important and increasing role in the future port expansion.

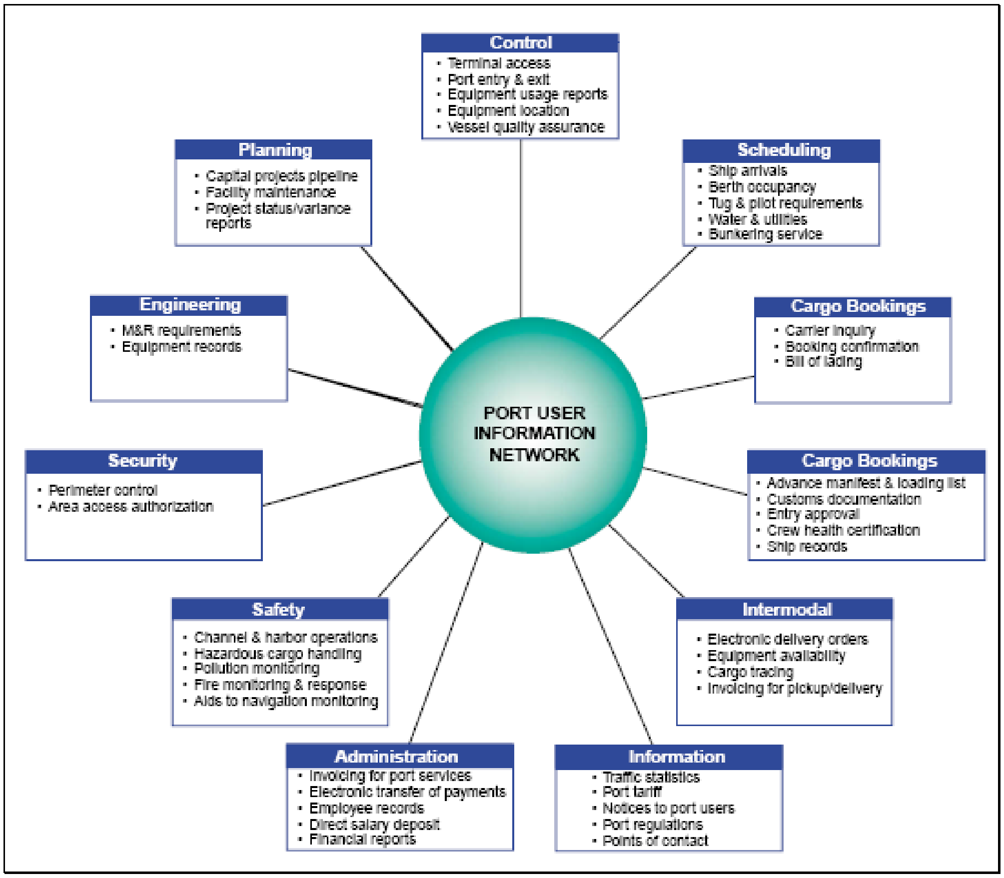


Figure 55 : ULCS Port network (Source: World bank port reform tool kit)

IT has been already increasingly employed throughout the container sector and has revolutionized the way Intermodal traffic is handled. IT is the system used that electronically links port administration, terminal operators, truckers, customs, freight forwarders, ship agents and other port users as it can be seen from the above figure.

The technology offers to the port users real time data upon the status of the cargo, the exact global position of the container that is onboard a vessel, information about the paperwork and the availability of the port facilities, and most importantly enables vessels and ports to be a part of an integrated office infrastructure.

In more detail, having IT and a proper logistics application, the following can be accomplished:

- Cargo delivery is sufficiently reduced.

- More accurate transfer and information recording.
- Manpower reduction can be accomplished since the paperwork required is substantially reduced.
- Provision of advance information on the ship, barge, truck and wagon operator.
- Better understanding of container and cargo movement.
- Improvement of planning and coordination of berths, storage facilities and cargo handling equipment.

Bearing in mind all the above stated aspects, it can be noticed that for ULCS ports, Information Technology and logistics have to be applied to the maximum limit in order to achieve fast and efficient cargo handling and, more importantly, to create a global optimized and interrelated container transportation that can be run smoothly without implications that might result in delays and insufficient operation of the container market.

Chapter 4: Innovative ideas and solutions for the ULCS

Until now the issue of Ultra Large Container Ship has been analyzed in-depth. All the possible implications and problems relating to the ship design itself and the port operations have been discussed. Thus, this chapter will focus on the possible solutions that can be used to overcome the difficulties that the container industry might face in future.

Based on the information presented in the previous chapters, the solutions that will be provided here are mainly focused on:

- Container handling operations
- Port infrastructure
- The changes the container industry has to undergo in order to handle the increased transport capacity of the containers through the ULCS vessels.

Finally, some ideas relating to the engine room installation to the ULCS will be demonstrated. These suggestions, however, are primarily pure thoughts of the author and have not undergone thorough investigation due to the time and word limitation of this dissertation.

4.1 Cargo handling

It is already known that the cargo handling of gantry cranes is one of the major problems that ports are facing. The increased capacity of the ULCS means that more gantry cranes have to be used. This can create a lot of problems since there might be a shortage of available port space. One of the best solutions to that problem comes from the Netherlands and has been especially used in the port of Amsterdam in the Ceres Paragon Terminal.

Having gone through research of this system, the author believes that it can be the future answer to the problem of cargo handling. In more detail, a water basin is created, the ship enters inside this basin and cranes from both sides of the ship can operate simultaneously. Thus, a faster cargo handling rate can be achieved.Furthermore, it is estimated that in this container port eleven gantry cranes can operate at the same time on top of a ULCS, making it the faster container port in terms of cargo handling around the globe.

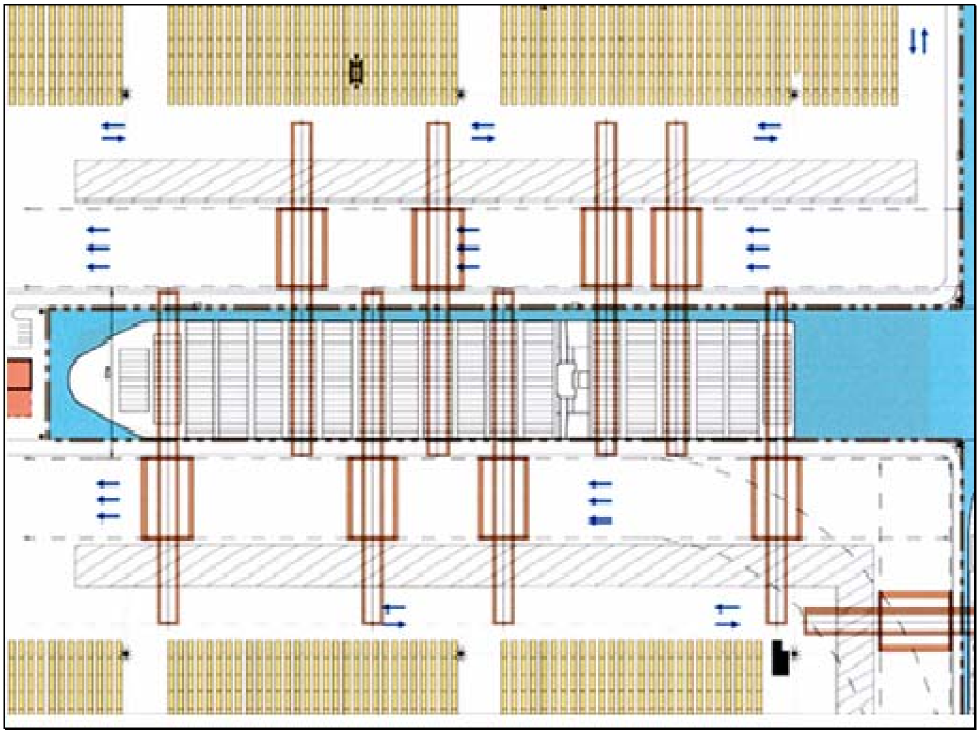


Figure 56 : Ceres Paragon container terminal

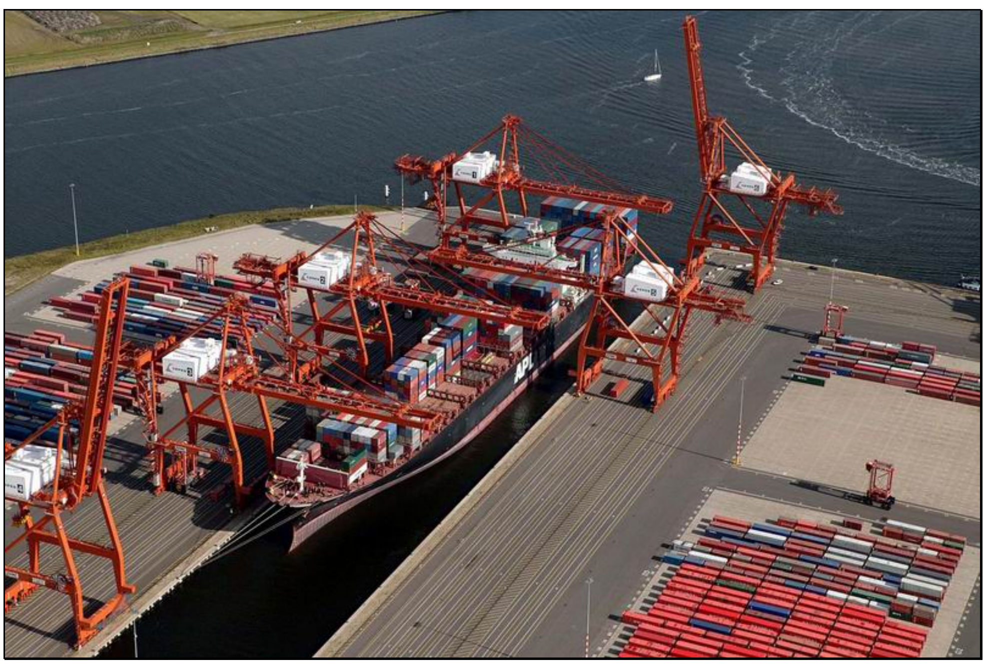


Figure 57 : Water basin in operation

This type of cargo treatment procedure is a very viable solution to the problem of cargo handling. From the figures above it can be seen that those cranes have the ability to move on rail, making them flexible in terms of their operation. If not all cranes are needed in the water basin area, they may move to the quay existing next to the basin. In that way other container vessels can use the gantry cranes. For example, nine cranes can be used for the unloading and loading of a ULCS carriers, while two cranes can be used for the transportation of containers to a transhipment container vessel, which has a considerably smaller capacity demand.

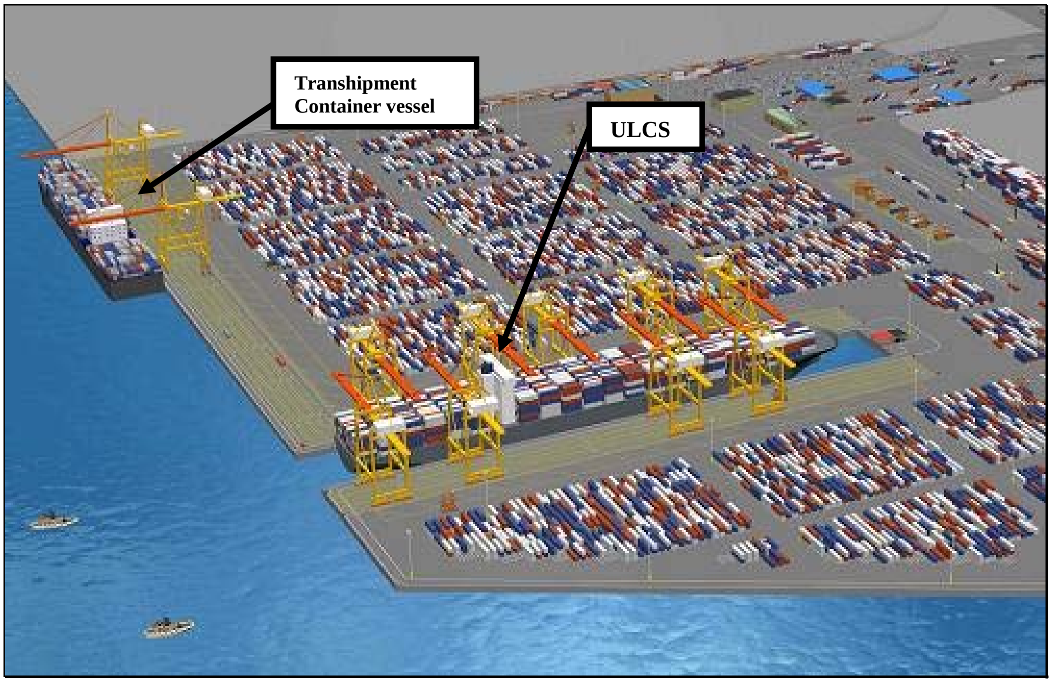


Figure 58: operation of two containerships at the same time.

Yet another advantage of this system is that once the ULCS enters the water basin it is protected from weather conditions and, more importantly, by water currents and waves swell. As a result, the ship structure is stable, which makes the cargo handling operation easier.

In addition, the dredging of the port might be minimized. Instead of dredging the whole area around the port, the authorities can dredge only the area affected by the ships entering and leaving the water basin.

Figure 59: Ceres Paragon terminal by night

Another solution is the use of overhead bridge cranes. In that way, a faster handling of the containers may be achieved. The storage area is controlled by a number of overhead cranes. The flow of the container follows somehow a straight line from the gantry crane to the AGV to the overhead bridge crane and finally to the truck or the rail.

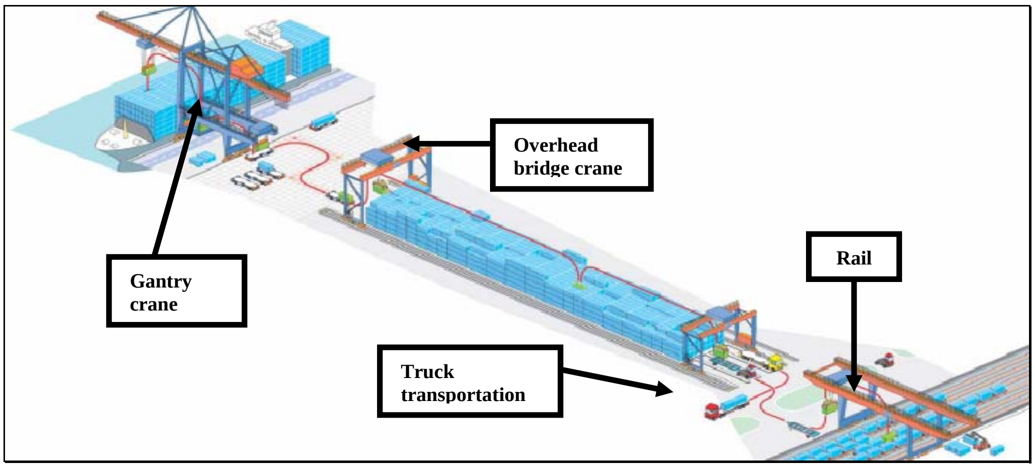


Figure 60: Container flow when using overhead bridge cranes

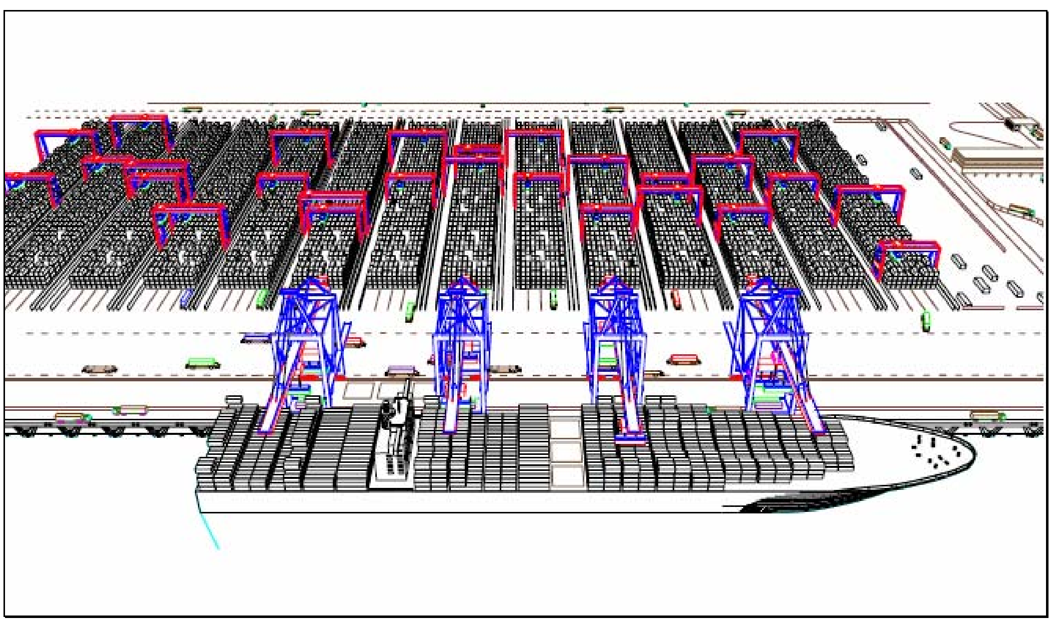


Figure 61: General arrangement of a port using overhead bridge cranes

It is believed that with this kind of container handling the port will be able to accept ULCS vessels with their increased capacity. In addition, space optimization is achieved and in-port traffic is minimized and controlled in the best possible way, since trucks transporting the containers to the inland are only in the very entrance of the port.

4.2 Floating container terminal dedicated to ULCS

The idea of a floating transhipment container terminal is a product of the continuously increasing container transportation. All existing ports will face this problem. The use of a floating container terminal can give a lot of solutions relating to port operation restrictions.

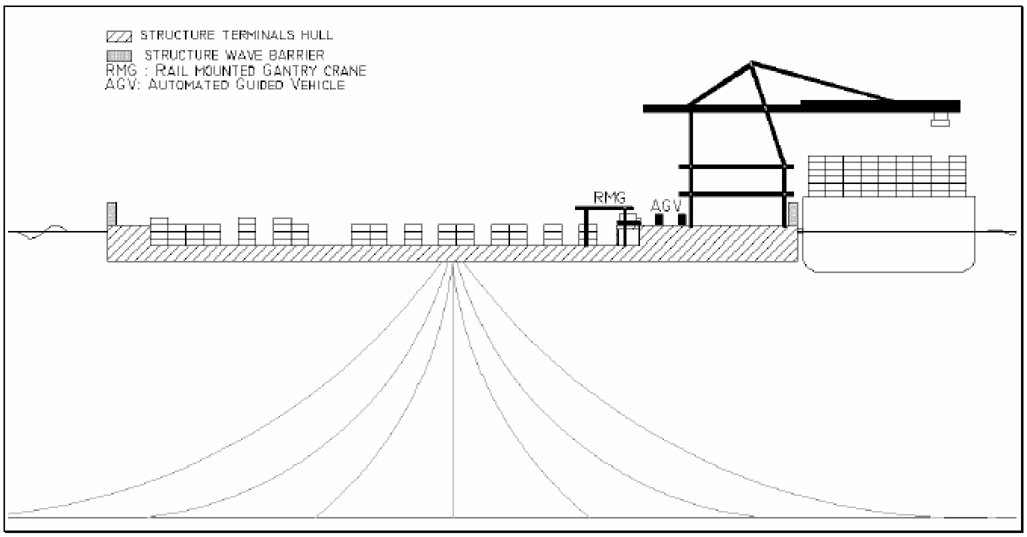


Figure 62: Floating container terminal (Source: [1])

A floating container port can be used when there are the problems of marine access as well as congested traffic in the near by areas of the port. Due to its floating nature it can be transported to the most suitable place, where there are no restrictions.

A major advantage of this innovative idea is the depth restriction that the ULCS are facing. In future, most ports will have to undergo a lot of dredging, which is an expensive solution. Instead of this though, a floating container terminal dedicated only to ULCS can be created a bit outside of the port, and at a place with the required depth. In addition, the port may be used by other containerships with less capacity and draft than ULCS, and perhaps used as a transhipment container terminal.

Despite the above advantages, there are some restrictions that have to be reviewed when designing a floating container terminal. Even though marine access and port operation restrictions might not be present anymore, the following points should be taken under consideration:

- Environmental conditions, such as waves, wind, currents. Loading and unloading operations and effects by passing by vessels through the area. These are very important issues since they can affect the stability of the floating structure.
- The terminal should not interrupt already existing sea infrastructure, such as ship routes. Moreover, the terminal should not affect the marine life and the morphological balances of the surrounding area.
- In addition, the terminal should not be far away from the departure point of the stuff from the land. Hence it should be close to the land access protected by the weather and furthermore environmental friendly.
- The terminal should have enough quay area to serve a ULCS and as well as a feeder vessel. This is due to the fact that only feeder ships can be used for the transportation of the containers from the floating structure to the hinterland.
- The mooring of the floating structure should be as efficient as possible to avoid sea keeping problems while the port is in operation.
- There are also restrictions related to the powering of this structure. It should have enough power and electricity supply in order to operate the gantry cranes and the AGV vehicles.
- The exact location of the port should have the economic potential. More specifically, it should be placed in such a way that the container liner operators are not disturbed by having to undergo extra sea miles to reach the port. It should be located in a strategic position, both in favor of the port operators and the vessels owners.
- High-speed transportation of the personnel has to be provided. This can be easily achieved by using high-speed vessels. It would be sensible to do it by using offshore supply boats since they are high-speed and can provide additional space, which can be further used when a repair has to be conducted. In such a way a spare part of a gantry crane or an AGV can be easily mounted on the open deck area of such a vessel.

One idea with regard to the ULCS is to create a floating terminal in combination with a water basin described above.

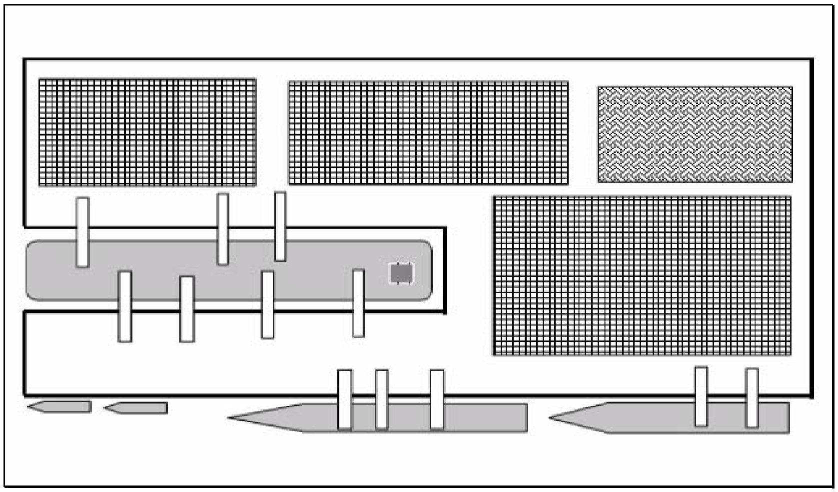


Figure 63: Floating terminal with water basin for ULCS (Source: [1])

In such a way all the advantages stated above can be gained. Furthermore there will be no need of dredging or any other operation related to port facilities restrictions. On the other hand, the problem of floating structure movement in relation to the vessel movement, when in bad weather has to be reviewed. In the case of the water basin, it should have enough breadth and length clearances in relation to the ULCS main particulars so that any contact may be avoided. The mooring of the structure and the vessels berthed to it can be challenging as well, and for that reason the floating terminal should have ballast tanks. In such a way the movement and the draft of the structure can be regulated, depending upon the weather conditions and the loading of the vessels operating to the terminal.

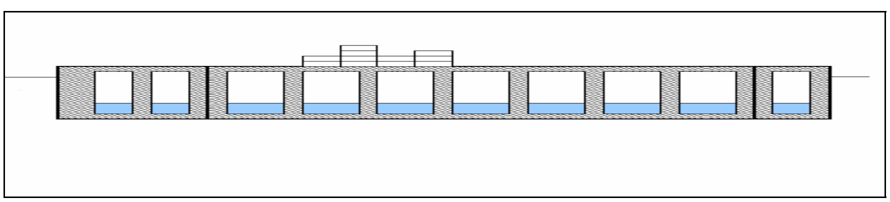


Figure 64: Water ballast tanks of the floating terminal (Source: [1])

The author believes that this can be a viable solution, since all the implications and problems are to a certain extend minimized. The only implication is the factor of cost. On the other hand though, moving to the ULCS era means that ports have to grow, which automatically translates into increased investment cost.

4.3 High speed feeder ships

The entrance of the ULCS vessels in the market will automatically create a need for faster transportation of the containers. Since the mega container vessels entered into operation, another type of containership, known as the feeder ship, has been created. These are the ships used for further transportation of the containers from the mega hub ports to smaller ports with reduced capacity (transhipment ports).

With the entrance of the ULCS the design of the feeder ships has to change as well. They have to be able to withstand the increased cargo capacity of those vessels. One of the solutions is the creation of high-speed feeder ships. In this way, faster container transportation can be achieved, hence reducing the time where a container is situated at the storage area occupying space.

This idea is a very innovative and there have been designs proposed for such types of vessels. There are various alternative hullforms that can be used. Fast monohulls is an option but there have been suggestions of trimarans even pentamarans.

The term high-speed has to be further analyzed with regard to the speed range that classifies a feeder ship as a HSC (Definition in: HSC Code / 1.4.30). In this case, the speed range is from 30 to 35 knots. This is a desirable range since there are some restrictions in terms of powering requirements and cost of construction.

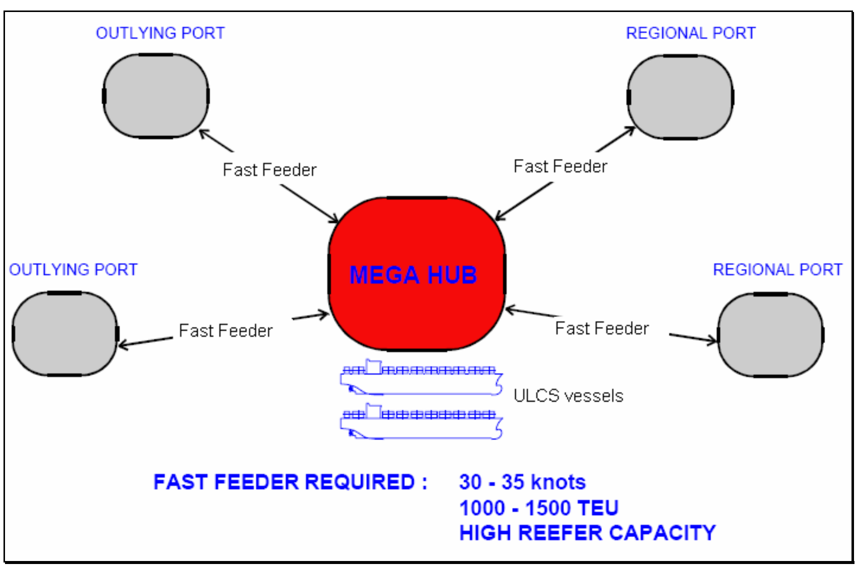


Figure 65: Interaction between ULCS and feeder ships

Going to such speed values there are certain criteria, which make the construction of the vessels quite complicated:

- First of all, the most viable solution for such feeder ships is either a trimaran or a pentamaran. Since the main hullform is then very slender a reduced resistance is experienced, making it possible to achieve high speeds.
- Furthermore, the powering requirement is high as a result a monohulls high-speed design it might not be possible. The trimaran and the pentamaran offer better resistance characteristics, hence high speeds can be achieved with less powering requirement.
- The use of the side hulls of the trimaran and the pentamaran is inevitable, since without those hulls the vessel would have been highly unstable and not sea worthy.
- The capacity of a feeder containership should be round about 1000 to 1500 TEU. This can be translated into a payload area of 13,000 tonnes.
- By result, the optimum feeder ship should be able to transport at high speed a payload of round about 1000 TEU or more at a powering requirement that will not exceed extreme values. That means that the power output should be at the range of 30 to 40 MW.

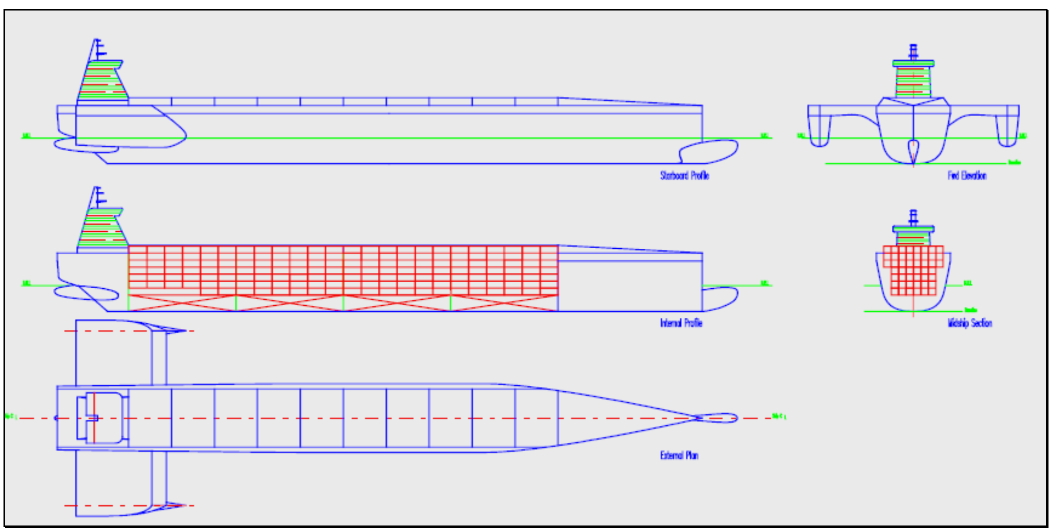


Figure 66: Preliminary trimaran design (Source: Nigel Gee and associates)

These two concept designs can be considered quite futuristic and still at a very immature design stage. Further research has to be done, but tank test results and computer generated trials are showing that this might be a viable solution.

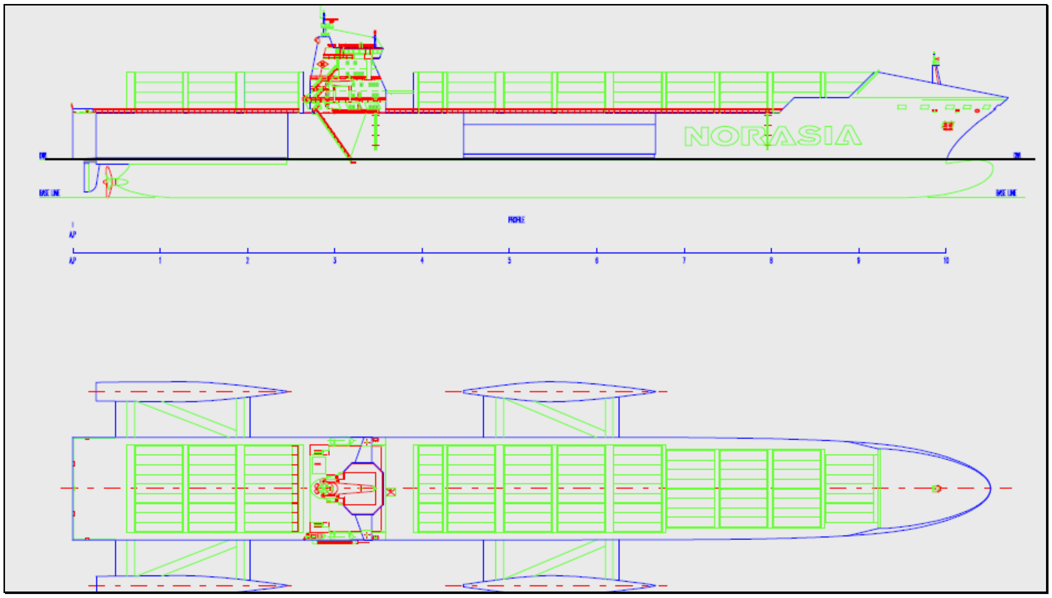


Figure 67: Preliminary pentamaran design (Source: Nigel Gee and associates)

It is a difficult task to achieve such high speeds by using monohulls designs since the powering requirement, due to the increased hull resistance, is not affordable. Coming though, to the near future feeder ships which can reach a maximum speed of 25 knots are on order. This seems to be the limit for the monohull design. With a power requirement of 19 MW this vessel can transport 1400 containers at the speed of 25 knots.

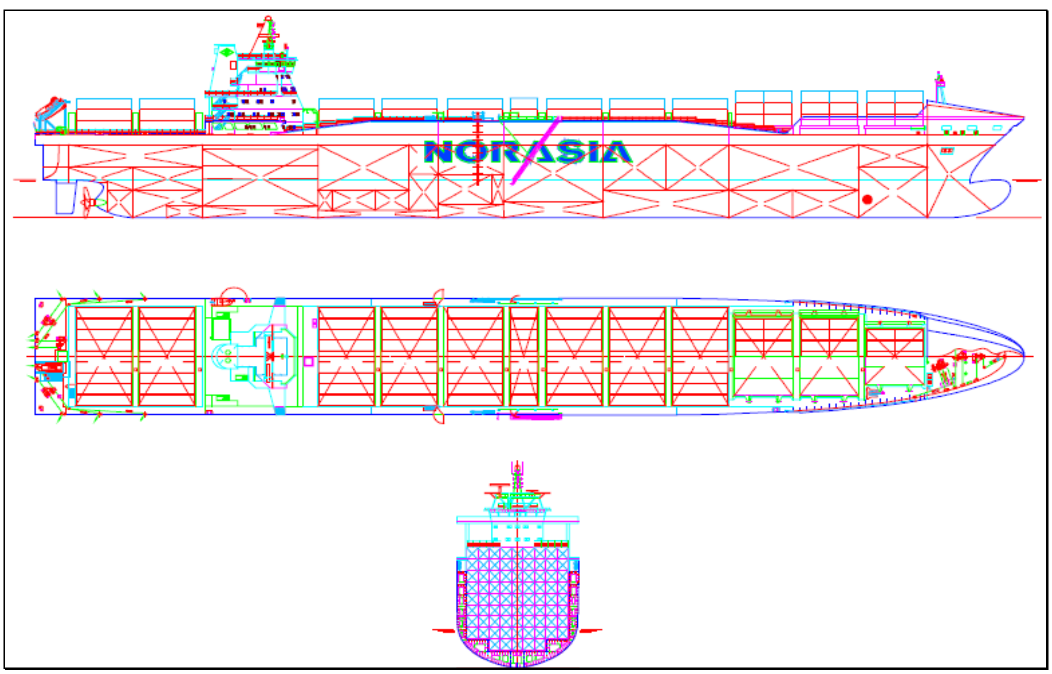


Figure 68: 25 knot 1400 TEU feeder ship (Source: Nigel Gee and associates)

The author believes that this design can be applied to the container market and transport efficiently the increased container cargo of the ULCS vessels. This vessel is the limit of a 25 knot ship with low power requirement. In such a way, high speeds and better fuel consumption can be achieved. Thus, looking to the future, the trimaran and the pentamaran concepts can be applied as well. In addition to the increased speed they have the advantage of increased payload area. Based on the research of Nigel Gee and associates capacities of 2500 TEU or above can be reached with those multihull designs. The future containership market behaviour cannot be predicted. If the Malacca – Max design will ever enter into operation it might be the case that such feeder containerships can be used as well.

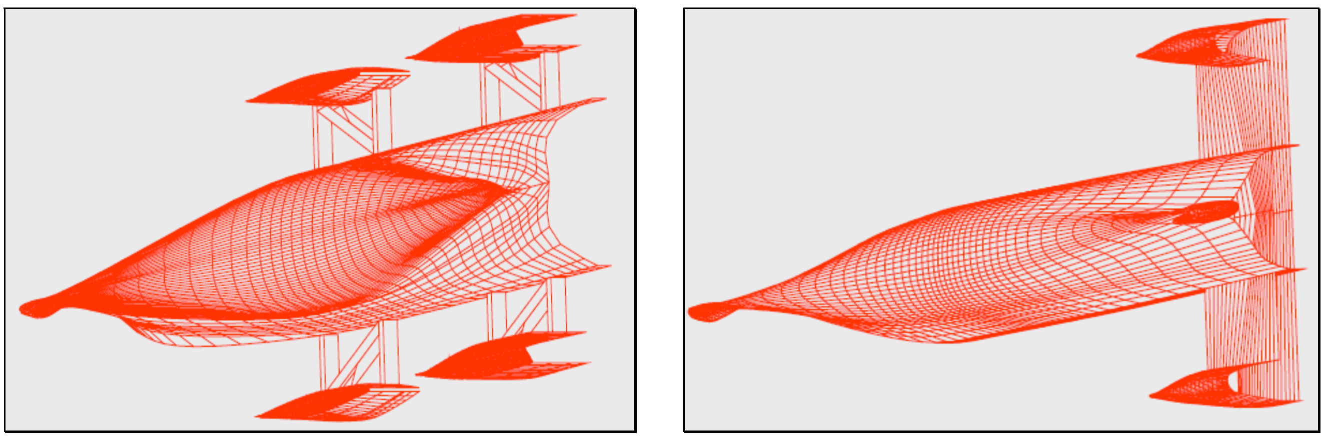


Figure 69: Trimaran and Pentamaran Hull lines (Source: Nigel Gee and associates)

4.4 Engine room location in ULCS

Going through the latest designs revealed by Germanischer Lloyd of ULCS of 12000 and 13000 capacities, the possibility of changing completely the position of the engine room might be able to happen. The author has this idea of positioning the engine room on top of the deck and not inside the hull, maximizing in that way the payload area and probably increasing a lot the TEU capacity of the ULCS.

Scheming through the designs of those two designs by GL, there is an unused area on the deck just above the engine room and in between the two funnels used. This space can be considerably large and it might be the case that it can be used for hosting the main engine or any auxiliary machinery.

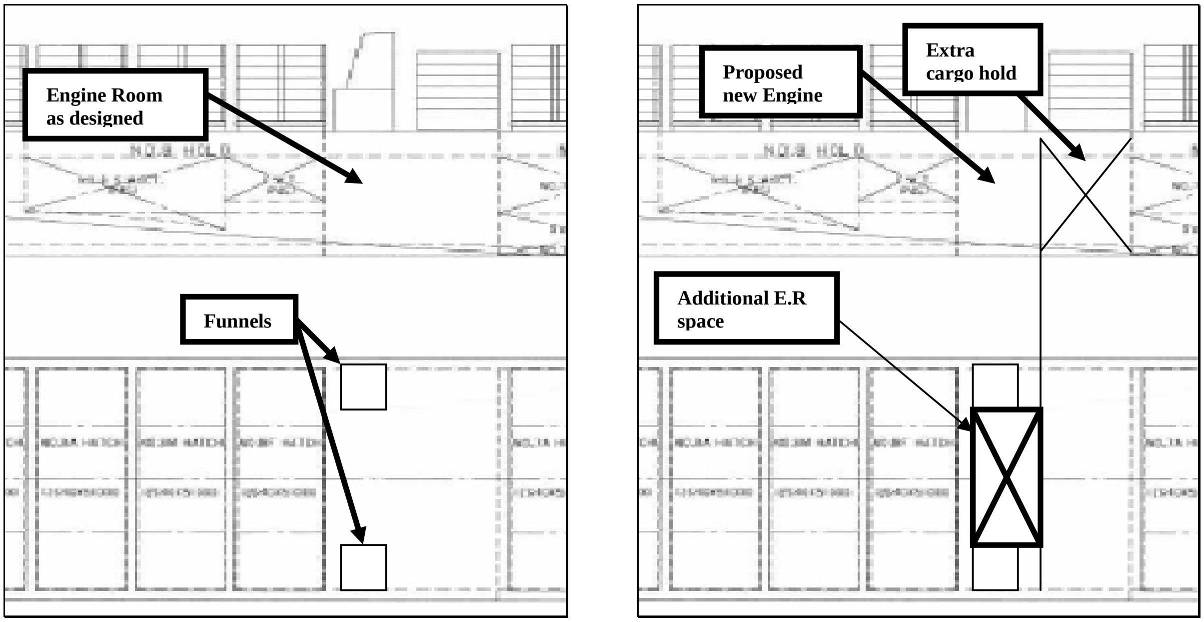


Figure 70: Proposed changes to the design to gain extra cargo space.

As it is described from the above figure, an extra bay can thus be created. It has been calculated that an extra 396 containers can be transported in this way, since in the 12000 TEU design the bay has the length of two TEU, the breadth of twenty containers and the depth of ten. In that way, the total container volume gain would be 400 containers. Subtracting four from the first stack, due to ballast and fuel oil tanks arrangements restrictions, the final number would be 396 TEU.

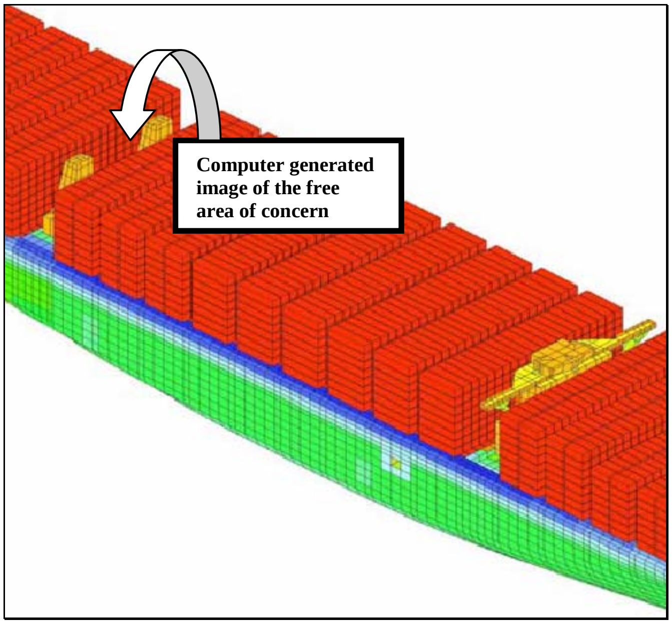


Figure 71: 3-D presentation of the free space available.

Furthermore, placing the main engine at this free space means that the diesel electric concept with podded propellers should be used. In that way the transmission of power from the main engine to the propeller is achieved by using electric wires and not shaft. By replacing the shaft with wires, even more space becomes available which can be used to store extra containers. Thus, in addition to those recommendations the same design can have additionally more that 396 containers. Unfortunately the author did not have the complete design drawings of the vessel, and could not calculate accurately how many extra containers that can be added with the omission of the shaftline. A rough estimate is that in total about 420 to 450 extra containers can be added. This idea materializes the most desirable goal of a containership designer. The majority of the inner hullform is used as a payload area; hence the maximum container capacity for a vessel can be reached.

Conclusions

The Ultra Large Container Ship concept has been created due to the increased container demand over the past years in this sector of the shipping market. Based on the above research, there are some concluding comments that have to be addressed.

- From a naval architecture point of view, the implications related to the ULCS design can be overcome. The technology needed for the structural, powering and propulsion requirements subsist and can be applied. In terms of extra cost, it can be considered affordable. Shipowners are willing to pay the extra amount of money to build such vessels if they are sure that during her operational life span the vessel will function efficiently.
- This last point has been a major concern in the past months. The container market and the shipping sector in general are highly unpredictable in terms of its future trends. There are a lot of factors affecting it, making it a very risky business. As a result, in terms of the ULCS era, they can only be considered efficient if the container demand continues to rise in the same rates as predicted. (9% a year until 2015).
- China plays one of the major key roles in the container industry. The demand and the exportation rates of its goods make the container industry profitable. If china continues with the same rate of industrial expansion as the past years, then pretty much the trend of the container market can be predicted and be ensured. On the other hand, however, China faces at the moment a lot of problems with its domestic infrastructure improvements as well as with the poverty of its civilians. There have been a lot of speculations that China in a year or two will try to improve the quality of life of its civilians. If something like that happens it is understood that the export potential will decline, having a direct effect on the container industry.
- Since the ULCS is the application of economies of scale to the extreme the risk of having a useless high value investment is ominous if something goes wrong in future. By my personal view, this is the most important limiting factor in terms of building and operating a ULCS vessel. The risk of failure is high, but on the other hand the gain that might happen is very considerable.

- From the port terminal facilities point of view, I believe that things are even more complicated. As it has been already stated, whereas the implications of the ULCS design can be coped with, the port terminals have to undergo huge interface changes in order to operate with ULCS vessels. The depth restriction and the required gantry crane cargo handling are two of the major problems ports are facing at the moment. The port authorities have to invest more money than the shipowners; as a result it might be the case that the required funds do not exist. Some of the solutions proposed, like the high-speed feeder ships, might be viable solutions, but it is my personal opinion that a serious investment has to be done by port authorities if they want to be competitive in the containership market.
- The floating container terminal might be a very good solution if countries want to build a port from scratch, it might be more cost effective compared with a dredging and depth maintenance alternative. A further advantage of the floating terminal is that it is flexible in moving around the globe whenever is needed. By result, the operator has various alternatives if something goes wrong and if a relocation of the structure is needed. In addition, the floating terminal can be situated in countries where the wage allowances are low and where increased man-hours can be achieved. In that way a lot of cost saving can be achieved.

To conclude, I personally believe that the option of the ULCS vessel is possible and can be introduced to the container market and operate efficiently. Recently Maersk has announced that a 13.000 TEU ULCS has been built secretly and has entered the market (M/V Emma Maersk).

Figure 72: M/V Emma Maersk, the biggest container vessel

This range of capacity of ULCS might be the most common design in future. The 15.000 TEU and the Malacca – Max seem to be extreme solutions with extreme risks as well. The problem, though, is the volatility of the market. The risk of loosing the operational efficiency is high and can cause a lot of financial problems and implications in future if shipowners are not careful with their investments. On the other hand, the competition between the liner operators is fierce, leading them to decisions with high risk. The big problem in this case scenario, however, is the adaptation of port terminal facilities. As has been already stated, the investments needed are huge, which create some doubts whether they can be affordable or not. The solutions proposed seem to give a lot of options of how to tackle all the problems relating to ULCS design evolution and port terminal adaptation. From the technical point of view everything is possible, but from the economic point of view the situation seems to be quite complicated. A lot of high-risk investments have to be done and the whole container market has to hope that in future the demand for container transportation will be higher than the supply of container vessels. Similar risky situations have been created in the past, like the boom in oil supply leading to the creation of the ULCC, i.e. the well-known Ultra Large Crude Carriers. Everybody knows though what were the effects after the oil crisis (1973), most of the ULCC vessels were not useful anymore leading the majority of those to the scrap yard or in the best scenario they were used as storage facilities. In the case of the ULCS, however, the problem is even more complicated since the container sector a lot of logistics are involved and the ports terminal facilities have to change as well. The technical implications for the ULCS design and the port facilities can be faced efficiently, the big question is who is willing to make the big step and ignore the high market risks involved, when investing in an Ultra Large Container Ship????.....

References

1	A. Ali (2005), Floating Transshipment Container Terminal, TU Delft Master Thesis.
2	ABS Informational Bulletins, ABS refines rules for Large Containerships, August 2005 http://www.eagle.org/news/pubs/bulletins/info/container_flyer.pdf.
3	ABS Technical Booklet, Giants in the container Industry, Ultra Large Containerships, December 2000.
4	Akira Akiyama, Gary Horn, K.M Wong, Structural Design Challenges of Ultra Large Container Ships, ABS, 2002
5	Alan Haig – Brown, Growing the ships and the fleet, The motor Ship, June 2004
6	Anil Singh, Future Trends in Global Ports, Managing Growth in an era of mergers and acquisitions, IAME Panama 2002 Conference proceedings., November 2002.
7	Backlund A. & Kuuskoski J. – ABB, The contra rotating propeller (CRP) concept with a podded drive motor ship conference, Amsterdam , The Netherlands, March 2000.
8	Becker marine systems, Twisted Rudder TLKSR.
9	Ceres Paragon Terminal, PowerPoint presentation concerning the design of this terminal, 2004.
10	Chang Ho Yang, The impact of bigger vessels on shipping and ports, 2001.
11	Charles Seldon, The competitive features and developing trends of current international Container ports, International Maritime Forum, November 2003.
12	Chaug – Ing HSU& Yu – Ping HSIEH, Shipping Economic Analysis for Ultra Large Containership, Journal of the Eastern Asia Society for Transportation Studies. 2005
13	Chris Wiernicki, More sophisticated analysis needed to determine strength requirements of Ultra Large Container Ships, The motor ship March 2005.
14	Christer Broman, The diesel engine & the environment, Wartsila presentation.
15	Container Ship Focus. Container market outlook remains healthy, August 2005.
16	Cullinane, K. & Khanna, The economics of deploying LargeContainerships, International Conference of Maritime Economics, 1997.
17	David Tozer & Andrew Penfold. A review of prospects for ultra – large comtainer ships and implications for the support fleet, 2003.
18	David Tozer & Andrew Penfold. Ultra – Large Container Ships (ULCS), designing to the limit of current and projected terminal infrastructure capabilities, 2002.
19	DVB, Research and Strategic Planning, The container carrier market and its outlook, October 2002.
20	Edward Dudson, Hans Jorgen Rambech & Ming Kang Wu, Determination of wave bending loads on a 40 knot, long slender open topped containership through model tests and hydrodynamic calculations with particular reference to the effects of hull flexibility on fatigue life, Nigel Gee Associates Ltd, UK, 2002.
21	Eric Heyman, Container Capacity: overcapacity inevitable despite increasing demand, Deutsche Bank Research, April 2006
22	Fairplay, Leap forwards, China Shipping's record capacity ships, 4 December 2003.
23	Friedrich Mewis & Hilmar Klug, The challenge of Very Large Container Ships – a hydrodynamic view, 9th Symposium on practical design of ships and other floating

	structures, 2004.
24	Gerhard Mickeleit & Dirk Groth, Why not upgrading cranes instead of new cranes, Port Technology international,
25	Germanischer Lloyd's, Trends in the developments of the container vessels, Presentation at NTU Athens, May 2005.
26	Ha. Thanopoulou, TcLirn, Mj Beynon & Akc Beresford, An application of AHP on Transhipment port selection: Aglobal perspective, Maritime Economics & Logistics, June 2004.
27	Hans G. Payer, Economic and technical aspects of mega – containerships, IAME annual conference and general meeting in Panama, November 2002.
28	Hans G. Payer. Technological and economic implications of Mega – Container carriers, SNAME 2001 Annual Meeting.
29	Heinrich Schmid & Tomas Aminoff, Sulzer low-speed engines in container liner operation, Wartsila Corporation, April 2003.
30	Heinrich Schmid, Twin - screw propulsion for super container vessels, The ship power supplier, Marine News.
31	Henry Chen, Parametric Roll.
32	Henry S. Marcus & Costas Bardjis, The role of competitive strategies in the international liner industries, 2003.
33	Hercules Charalambides, Pierre Cariou & Marco Benacchio, Costs, Benefits and Pricinf of Dedicated Container Terminals, International Journal of Maritime Economics, April 2002.
34	Institute of Shipping Economics and Logistics- Container Fleet market analysis 2005.
35	Ir. Erik D´hondt, The impact of increasing vessel size on the workload on container terminals, IUMI 2002 New York City, 2002.
36	J.C (Hans) van Ham, The feasibility of Mega Container Carriers, NECTAR – meeting LUGANO.
37	Keith Trace, Globalisation of container shipping: Implications for the North – South liner shipping trades, July 2002.
38	Knut A. Dohilie, Container ship safety – an area for increasing concern? Gard News, November 2004 / January 2005.
39	Lloyd's Register, Container ship focus, August 2005.
40	Lloyd's Register. Head –sea parametric rolling of container ships. Marine Services information sheet, 2006
41	Malacca-max, The Ultimate Container Carrier, Prof. Wijnolst et al., Delft University, Holland, 1999.
42	MAN B&W, Propulsion trends in container ships, 2000
43	Marine propulsion, Box ship power: more cylinders or bigger bores? October / November 2004.
44	Martin Stopford, Is the drive for ever bigger containerships irresistible?, Shipping Forecasting Conference, April 2002.
45	Michael C. Ircha, Serving tommorrow´s Mega size container ships, the Canadian solution, international journal of Maritime Economics, Vol.3 2001.

46	Motor ship propulsion conference 2006, 28th annual event, Powering of giant containerships.
47	Nico Wijnolst, Malacca – Max [2] Container shipping network economy, 2000
48	Nigel Gee & Edward Dudson, Optimisation of the seakeeping and performance of a 40 Knot pentamaran container vessel, 2004
49	Nigel Gee, The pentamaran: a new hull concept for fast freight and carry ferry applications, 2004.
50	Nigel Gee. Some new developments in container vessel design, 2005
51	Oskar Levander, Advanced Machinery Solutions for RoPax Vessels, Wartsila May 2004.
52	Oskar Levander, Machinery solutions for Ultra Large Container Vessels, The ship power supplier, 2002.
53	Petteri Ämmälä, CRÅ Azipod for Ultra Large Container Ships . An advanced cost effective solution.
54	PowerPoint presentation, Stepping up the pace in container terminal efficiencies supported by integrated investment planning in supply chains, 4th intermodal Africa 2006, Namibia.
55	Richard G. Roenbeck, Container losses due to head - sea parametric rolling.
56	Risto Pakaste, CRP Azipod propulsion, the most efficient and versatile propulsion system, January 2004.
57	Rob Harrison, The potential impacts of megaships operations on Gulf port, 2003.
58	Robert Harrison Miguel A. Figliozzi & C. Michael Walton, Mega – Containerships and Mega – Containerports in the gulf of mexico: Aliterature review and annotated bibliography, May 2000.
59	Rod Vulovic, Changing Ship Technology and port infrastructure implications, Trends and future chanllenges for U.S National Ocean and coastal policy.
60	Spyros A. Kinnas, Shreenaath Natarajan, Hanseong Lee, Karan Kakar &Apurva Gupta, Numerical modeling of podded propulsors and rudder cavitation, 2003.
61	T.J Dowd & T.M. Leschine, Container terminal productivity: A perspective. Institute for Marine Studies, University of Washinghton.
62	The Bristol Port Company, Bristol Deep sea container terminal (Ultra Large Container Ships).
63	The Motor ship, AC Drives in marine service, The all electric ship is making progress, June 2004.
64	The motor ship, Designing the Giants, October 2000.
65	The Motor Ship, Power Constraints for the 10.000+TEU Boxship, June 2004.
66	The Motor ship, The other side of the coin, emulsion offered as an alternative to injection, June 2004.
67	The Motor ship, Waiting for the inevitable, Wartsila is ready for steam injection, particularly when energy priced rise, June 2004.
68	The Naval Architect, Container ships provide continuing prosperity – and challenges – for Germanischer Lloyd, January 2005.
69	The Royal Institution of Naval Architects, Design and operation of Container Ships, international Conference, 23 – 24 April 2003.
70	Theo E. Notteboom, Container Shipping and ports: An overview, Institute of transport and maritime management Antwerp, University of Antwerp, June 2004

71	Thomas Kuhmstedt, Containers in the air, Design and operation of container ships. London UK, RINA 2003.
72	Veikonheimo Tomi, The most efficient propulsion system for ULCV, November 2001.
73	Wieke Bockstael – Blok, Igor Mayer, Edwin Valentin, Supporting the design of an inland container terminal through visualization, simulation and Gaming, Proceedings of the 36th Hawaii International Conference on System Sciences, 2003.
74	WMU Report, Transport Efficiency of Container Ship, 2003
75	World Bank Port Reform Tool Kit, Module 2: The evolution of ports in a competitive world
76	Zia Rizvi, The containership: How big? A port authority's Dilemma, PowerPoint presentation.