CONCEPT DESIGN OF LNG BUNKERING SUPPLY VESSEL

UNIVERSITY OF BIRITISH COLUMBIA

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Dr. Christopher B. McKesson

Instructor

The University of British Columbia

Subject: Submission of the Conceptual Design Report of the LNG Bunker Supply Vessel

Dear Dr. McKesson,

We are pleased to present to you the conceptual design of the LNG Bunker Supply Vessel. The project has been completed and the report prepared in accordance to the course requirement for NAME 591 for degree of Master of Engineering in Naval Architecture and Marine Engineering. Furthermore, the project was carried out following standard industrial practices as well as, recommended best practices.

Yours Truly,

UBC- LNG Bunker Vessel Team.

EXECUTIVE SUMMARY

This report details the preliminary concept design of a LNG Bunker Supply Vessel. The project was undertaken by a group of 4 Master of Naval Architecture and Marine Engineering students of the University of British Columbia as part of the NAME 591 Computer Aided Ship Design Course. Whilst working with a mentor Dan McGreer from Vard Marine and members of the industry including Teekay Shipping, and Lloyds Register Marine. The main goal of the project was to address the need for a vessel to be able to bunker LNG to other LNG carrying vessels operating of the coast of B.C. The team in consultation with Teekay, performed extensive research in order to develop a set of mission requirements for the vessel. The project attempted to analyse the current infrastructure of LNG terminal in Kitimat B.C., Vancouver Port, and Nanaimo Port and see the feasibility for having such a vessel in the near future. The design team performed one full loop of the design spiral addressing all major aspects of the design at least once whilst performing many iterations and design matrices for all critical aspects that were key towards meeting the mission requirements.

In the light of ever-tightening emission regulations, LNG as a marine fuel is both a proven and available commercial solution. While different technologies can be used to comply with air emission limits, LNG technology is the only option that can meet existing and upcoming requirements for the main types of emissions (SOx, NOx, PM, CO2). LNG can be competitive pricewise with distillate fuels and, unlike other solutions, in many cases does not require the installation of additional process technology. The growing demand of LNG as marine fuel in near future, has been a huge factor in our decision to design a LNG bunker supply vessel operating on the west coast of Canada.

The concept was created in order to fulfill the mission requirements which was to carry 4500 $m^3$of LNG and 550 m^3 Marine Diesel Fuel from Kitimat to Vancouver port with a design speed of 13 knots. The concept adheres to Lloyds Registers Rules for the Classification of Ships. The final design consisted of a mono hull ship with a Length of 97 meters, Beam of 18 meters and Draft of 5.2 meters. It displaces 6500 tonnes and has a two Rolls Royce Z-Drives and, 1 Bow Thruster, powered by 2 Wartsila 9L20DF, and 1 Wartsila 6L20DF dual fuel Wasilla engines. It accommodates 14 crew members.

As a student in Naval Architecture it was a driving factor for us to learn more and more about ship design. For which we tried to do all the calculations on our own instead of just relying on software, which was a great learning experience. And working on the ship which can be a realistic project in the near future motivated us from time to time.

Future recommendations include more iterations of the design spiral including further optimization including in depth analysis of marine systems, FEA and CFD analysis.

ACKNOWLEDGMENT

The design team would like to acknowledge the following individuals and organizations whose involvement helped make this project possible.

Vard Marine
Dan McGreer

Lloyd’s Register
Ben Thompson

Teekay Shipping
Sergiy Yakovenko

University of British Columbia

Jon Mikkelsen

Dr. Chris McKesson

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1. PROJECT OVERVIEW

The purpose of the project was to come up with a solution to part of Vancouver's lack of infrastructure to supply LNG to LNG carrying vessels and the growing need to address the prospect of using LNG as an alternative fuel solution for ships in the near future. In recent years, there has been a growing concern on air pollution and air quality, the extent and complexity of regulations have increased while regulations have become tougher. Annex VI of the MARPOL Convention applies to all ships trading internationally and has been used as the basis for many regulations. With MARPOL Annex VI, the International Maritime Organization (IMO) has prioritised reduction of NOx and SOx emissions to air. In order to comply with SOx compliance, a low sulphur fuel needs to be used. There are many low sulphur fuels such as Liquefied Natural gas (LNG), Liquefied Petroleum Gas (LPG), and biofuels. Unlike SOx emissions which are a product of fuel sulphur content, NOx emissions are created during the combustion process. How much NOx created depends on the fuel being used. Some fuels such as LNG and methanol, have lower NOx emissions than the marine fuels.

MARPOL Tier III emission limit for NOx will take effect for marine diesel engines installed on ships whose keels are laid on or after January 1st 2016 if they are operating within the North American and US Caribbean Sea. This emission limit is equivalent to 80 % reduction of NOx emissions from marine diesel engines. In order to be compliant to this requirement, there are several possible solutions, a selective catalytic reduction (SCR), exhaust gas recirculation (EGR). These Tier III engine installations can be very different to existing Tier II engines, these differences may take the form of alternative fuels such as natural gas or liquefied natural gas (LNG) change of fuel type to LNG.

LNG is low in sulphur and easily combusted in engines and boilers. Furthermore, Gas engines are widely used in land based industries, and also in LNG carriers for many years. With the new regulations coming into effect within the next few years, the potential for a new fuel that is more environmental friendly can be seen. The LNG would also be compliant to ECA regions, which would make it a viable choice for the ship owners who would be transitioning from the conventional distillates.

A study conducted by Colombia Institute (Institute, 2015) has shown potential promise in B.C. for the shipbuilding sector in the future. This along with a recent federal bid to make B.C. the lead regulator of LNG terminals, would be a great opportunity for the design and construction of LNG vessels.

Hence the core reason for taking up this project was to show that this can be done. By transporting LNG from Kitimat terminals and supplying it to the local vessel running on LNG fuel, we could utilize this and provide a feasible solution by our concept design for a LNG bunkering Vessel which could be taken to other stages by industry professionals.

2. SUMMARY OF PRINCIPLE PARTICULARS

The primary driving factor for the design of this vessel, was the selection and arrangement of the LNG cargo tanks. The group came up with a dozen conceptual designs for a variety of arrangements and tank types. And from our customer's requirement (Teekay shipping), the vessel has to carry 4500 meters cube of LNG, we choose the optimum design and receive approvals from project mentors after consulting with them. This design calls for two Type C IMO approved LNG tanks placed longitudinally. The vessel also carries 550 meters cube of Diesel Oil in order to supply to ships. Table 1 below, overviews the principle particulars of the vessel.

Table 1 Principle Particulars

Particular	Value
L_{WL}	95.87
L_{OA}	97
B_{WL}	17.5
B_{OA}	18
DRAFT	5.2
DEPTH	11.5
BLOCK COEFFICIENT	0.74
PRISMATIC COEFFICIENT	0.75
CLASS	Lloyd's

Particular	Value
LOADED DISPLACEMENT	6500 Tonnes
DEADWEIGHT	3200 Tonnes
LIGHTSHIP WEIGHT	2975 Tonnes
CARGO LNG	4500 m^3
CARGO DEISEL	550 m^3
POWER	4440 KW
DESIGN SPEED	13 Knots
OPERATIONAL AREA	BC Waters
GAS CONSUMPTION	7.2 Tonnes/day

3. VESSEL OVERVIEW

The project became successful due to several reasons, the first was having a well-defined needs statement. Since LNG bunkering vessels are relatively new types of designs, there are very few parent vessels out there and the group lacked adequate information. The only help the group received was a few brochures' with pictures of proposed designs for such vessels. The owner's requirement was well defined and helped us initially have the parameters to which we needed to design. Furthermore, mentor Dan McGreer provided much guidance and feedback on our design, progress, and the further needed iterations for us to be able to complete this project. When necessary, the design team performed calculations based off of available information in order to determine additional requirements.

3.1 ANALYSIS OF NEED

British Columbia is known for its expansive picturesque coastlines, and for its enormous supply of natural gas specifically in the Northeast. An estimated 2933 trillion cubic feet primarily in four areas: the Horn River Basin, the Montney, the Liard Basin and the Cordova Embayment. This is enough natural gas to support energy needs not only in Canada but also around the world for more than 150 years (Columbia, 2015).

Since natural gas is the cleanest, most efficient fossil fuel available, it has world-wide demand. When it is chilled -160 °C, natural gas becomes liquid, shrinking to 1/600th of its original volume. This would make it very efficient and economical to send to the overseas markets.

As of October 2014, it has been proposed that there would be up to 18 industry projects that produce and export LNG from plants along B.C's coast (Columbia, 2015). A key strategy of B.C. government's LNG strategy is to promote the advantages ports in Kitimat and Prince Rupert. Transportation of LNG within British Columbia waters would provide the ideal scenario for a bunkering vessel to be present in order to provide bunkering to LNG carrying vessels.

This gives rise to the purpose of our project. In an initial study, it was determined that there is a lack of such a vessel in the coast of B.C. Furthermore, the infrastructure presented at Kitimat is ideal for a bunkering vessel to bunker LNG and travel down the coast of B.C., once reaching near ports of Vancouver, or Nanaimo, it could bunker LNG to LNG carrying vessels. This is ideal since the provincial government has heavily invested in shipbuilding and LNG. The group saw a golden opportunity to take the initiative and come up with a vessel that will address the needs of LNG vessels that do not have the opportunity to bunker LNG at Vancouver ports as the necessary infrastructures are not present yet.

The team conferred with mentor Dan McGreer, senior Naval Architect at Vard marine, and also with Sergiy Yakovenko from Teekay shipping, to get a better understanding of the customer needs, as well as the project scope and deliverables.

3.1.1 Targeted Customer

In the article *LNG Bunkering Infrastructure Study* (Aagesen, 2010), published by Lloyd's Register, Jesper Aagesen, Senior Surveyor, Ship Design Specialist, said that the year 2015 is an important year for the shipping industry. During that time, Jasper mentioned there will be stricter requirements on fuel oil sulphur content. This will enter into force in emission control areas (ECAs) which are the Baltic Sea, and the North American Coast together with the U.S. Caribbean. Then from 2015, the maximum allowable sulphur content in fuel oils is 0.1 percent in the ECAs. From 2020 onwards, a global requirement of maximum 0.5 percent sulphur (outside of ECAs) will also apply. It is important to understand since Jasper argued that vast majority of the world merchant fleet will enter ECAs during their lifetime and since more ECAs are expected to be introduced in the future, action needs to be taken. Using LNG as an alternative fuel Jasper mentioned would be one of the best alternatives, not only to meet these needs but also eventually leave burning of fossil fuels behind.

The Teekay shipping who are our customer, has shown a lot of interest in our vessel. Teekay Shipping has a lot of stake in the gas sector, especially in LNG carrying vessels. They are experts in the transfer of LNG to other vessels. They could use vessel such as ours for their operation in the Pacific North West region.

3.1.2 Area of Operation

The ship would operate in Pacific North West of the Canadian waters, it would get LNG fuel from Kitimat port and travel down the waters of coastal B.C. and meet LNG fuel ships near Nanaimo or Vancouver and bunker LNG to them. Figure 1 below outlines the locations where the ship would bunker LNG. Furthermore, Figure 2 below shows the nautical mile distance from Kitimat to Vancouver. As can be seen from the figure, it takes about 444 nautical miles from Kitimat to Vancouver. The vessel also needs to go to Nanaimo which is around 33 nautical miles. The ship is carrying two LNG tanks which holds up to 5006 m^3 of LNG fuel. The ship needs to transport 4500 m^3 of LNG. The remaining LNG in the tanks which is 506 m^3 of LNG would be used for consumption by the ship in its journey and some safety margins. Furthermore, the ship is also carrying 550 m^3 of diesel oil which would be bunkered to other vessels.

This area of operation was used as it was part of our customer requirements as they wanted a bunkering vessel which would operate in these waters and be able to bunker LNG fuel to other LNG carrying ships. It also addresses the lack of infrastructure in Vancouver port for providing LNG fuels to ships.

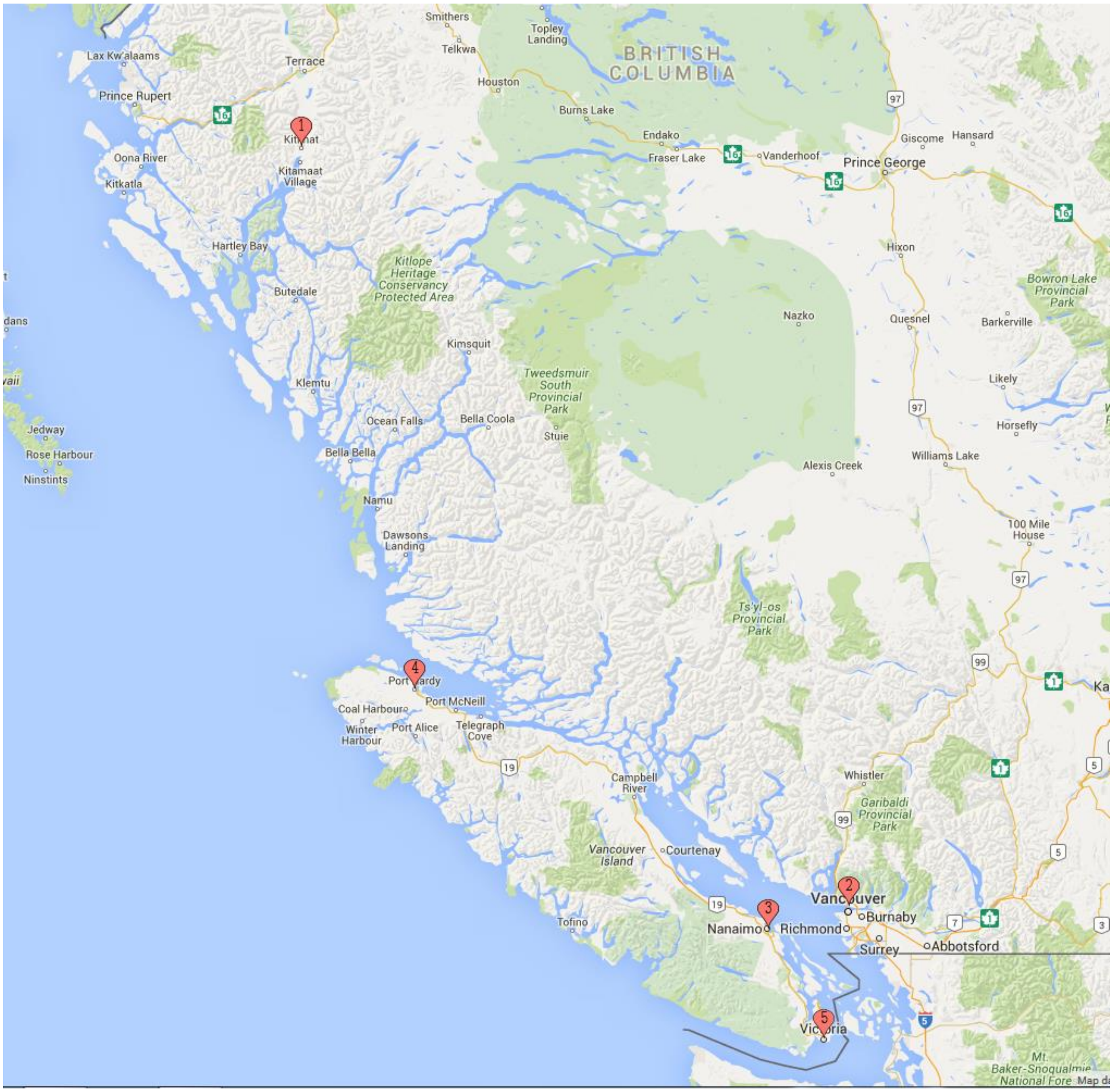


Figure 1 Ship travel path

Location	Distance From Last
1 Kitimat, BC V8C, Canada	N/A
2 Vancouver, BC, Canada	653.38 km

Total: 653.38 km

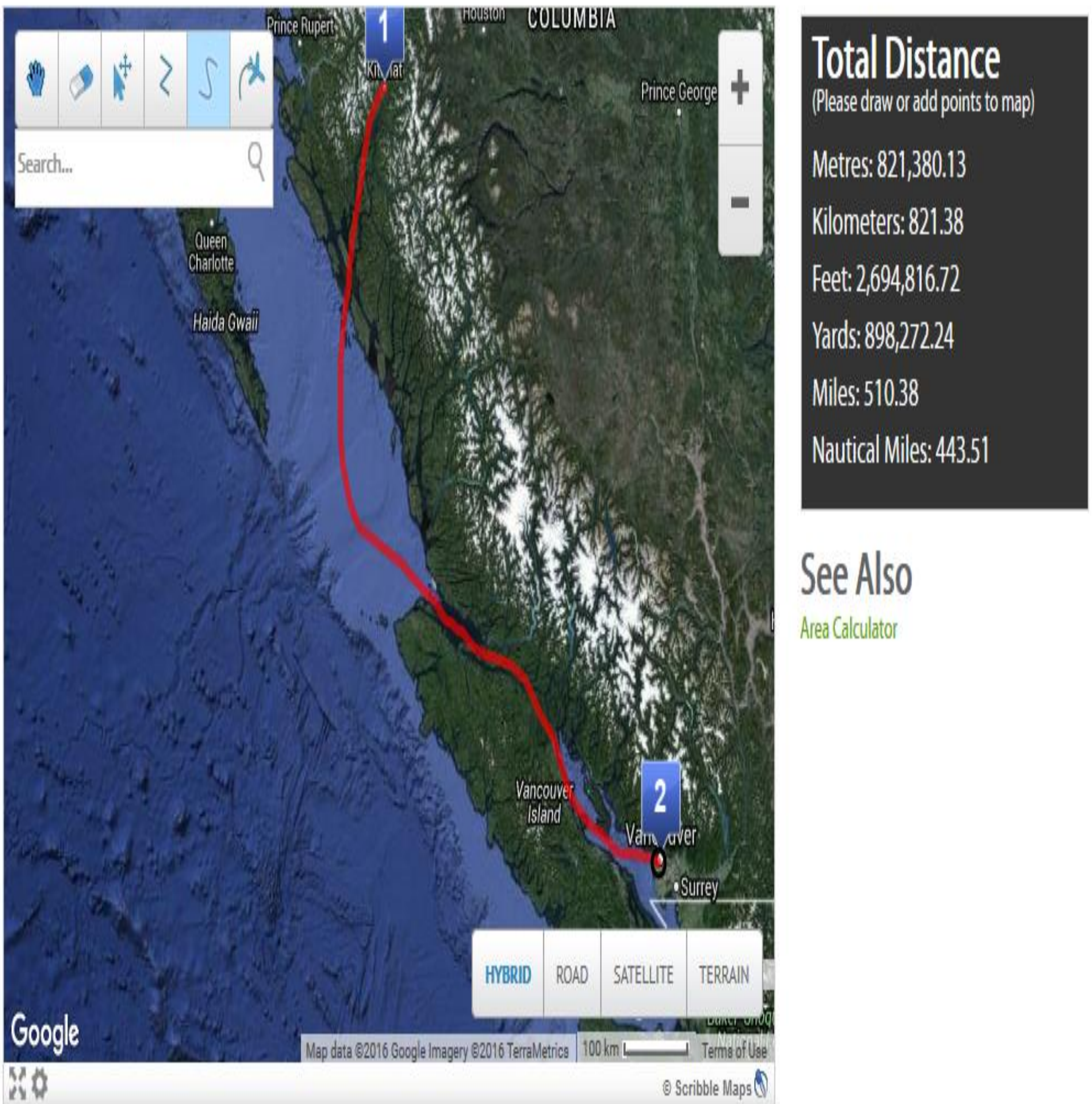


Figure 2 Radial distance from Kitimat to Vancouver

3.1.3 Current and projected shipping in BC coast

The team got in contact with Ben Thompson from Lloyds Register, Ben was very supportive and provided the team with hard data on both the current and projected shipping traffic along the BC coast for LNG vessels as compared to Bulk Carriers. These vessels are only traveling to BC ports and not going to US waters. Table 2 shows this data.

Table 2 Current and projected shipping along the BC coast

TYPE	Size/ Class	DWT(thousand)	Ships per year current	Ships per year projected
LNG	160-170k-CBM	85-90	0	600-1000
Bulk Carriers	Panamax	65	70-80	70-80

As can be seen from the table 2, the current Bulk Carrier ships currently and the projected ones will remain the same value between 70-80 ships, LNG ships however are projected to be a staggering 600-1000 in the near future. This is why addressing the issue and having an LNG bunkering vessel would be very ideal to address it the near future.

3.2 Concept of Operations

The Vessel shall be operated as LNG bunker supply vessel that will serve a varied clientele. The primary mission of the vessel is to provide safe, efficient, reliable, and economic bunkering options to LNG fueled vessels operating in and around Vancouver region.

The vessel has home port Kitimat, and it will load at the Kitimat LNG terminal. The ship will then sail to Vancouver/Nanaimo region following coastal routes, where it meets the client vessel in order to perform the bunkering operations. Once the vessel has bunkered to the client vessel, it will travel back to its home port. All of the ship board operations shall be executed at the home port.

3.3 SMART Requirements

- **Speed:** 13 knots
- **Range**: The vessel will operate over a distance of 1200 nm at service speed.
- **Required Manning:** 14 persons
- **Maneuverability:** The offeror shall carry out maneuverability test during the sea trials along with the owner technical representative.
- **Number of Cabins:** 8 cabins with single occupancy, which includes 6 cabins for all of the officers, 1 for the pilot/owner, and 1 should be kept as spare. 5 double occupancy cabins which will be shared amongst the crew.
- **Medical:** First aid, and emergency response for LNG hazards should be provided on board. There shall one medical room for general treatment of the crew.
- **Sanitary System**: Every cabin shall have its own WC, and there shall be WC in each deck/engine room/bridge.

- **Level of Safety:** The ship shall be built as per Lloyds register Class rules and Transport Canada regulations. The ship should have dedicated muster stations. The vessel shall be equipped with emergency towing arrangements at both ends.
- **Sea Keeping:** The vessel shall be fully operable in sea state 3 as per Beaufort Number.
- **Transfer Rate:** 300 m^3/hr.
- The vessel shall be operated as LNG bunker supply vessel that will serve a varied clientele. The primary mission of the Vessel is to provide safe, efficient, reliable, and economic bunkering options to LNG fueled vessels operating in and around Vancouver region.
- The ship is expected to have an operational life of 20 years. During this period, it shall be taken to a dry dock every 2.5 years for intermediate service, and every 5 years for major service.
- The vessel should operate in 13 knots but be able to operate in different speeds and should be easily maneuvered with maximum reliability.
- The vessel shall be equipped with a dual fuel engine, propelled by diesel and Liquefied Natural Gas (LNG) as per tier 3 restrictions, Annex 6 of MARPOL. The designer shall select the appropriate engine and propulsion option to meet the vessel's speed, propulsion and fuel requirement.
- The vessel shall be equipped with the latest telecom facilities, communications, and navigation systems.
- The vessel will have the following emergency safety feature:
    - Electrical emergency fire pump
    - Emergency air compressor
    - Emergency lighting
    - Emergency generator
    - Emergency battery back up
    - All the doors shall be water tight wherever required, and A60 class standard. Also it shall be fitted with self-closing mechanism.
    - Adequate life boats, and life rafts shall be provided as per Lloyd's Register Rules.
- The vessel shall be equipped with emergency towing arrangements.
- Bunkering of the vessel shall happen on Vancouver/Nanaimo coastal areas.
- 100 tons of domestic fresh water tank shall be provided to serve ships domestic requirements. The water shall be bunkered at Kitimat.
- Underway conditions- At all throttle settings, the accommodation and engine control room will be provided with HVAC. Optimum level of noise vibration as per Lloyd's Register shall be designed.
- The funnel location shall be located at the aft end of the ship in order to prevent the smoke falling onto the open decks. The height of this shall be in accordance as per Lloyd's Register rules
- It shall a hull corrosion prevention system
- The vessel shall carry the necessary drugs and medication for all of the minor health problems
- The operation crew of the vessel shall be certified and competent and will need to have the following ranks:
    - Navigation department
        - 1 Captain
        - 1 Chief officer
        - 1 second officer
        - 3 deck crew

  - Engine department
    - 1 chief engineer
    - 1 second engineer
    - 1 third engineer
    - 3 engine crew
  - Galley department
    - 1 cooks
    - 1 steward

- The vessel shall have Planned Maintenance System (PMS), Garbage Management and Segregation Plan, Emergency Evacuation Plan, Fire Plan, Bunkering Plan, Risk Management Plan, Safety Management System (SMS) as per International Safety Management (ISM), Ship Security Plan (SSP) should comply as per International Ship and Port Security (ISPS)
- All equipment and machinery shall be mounted so that it is accessible for ease of maintenance and inspection so that components are easily replaced with a minimum amount of interference. This includes keeping the overhead in way of main engines free of pipes or cable runs and installation of lifting pad eyes and rails for machinery removal
- The vessel maneuverability characteristics shall allow for rapid, safe and controlled docking in all weather conditions.
- The ships machinery shall be provided with spares as per the necessary planned maintenance system.
- The ship shall receive its provisional stores and spares for engine/deck department at Kitimat port.
- The ship shall be provided with adequate capacity of lubricants.
- The ship shall be provided with adequate capacity of sewage holding tanks as per Lloyds Register rules.
- The vessel shall be provided with a waste oil tank as per MARPOL requirement, the capacity of this tank shall be sufficient for 7 days of operation of vessel which will be discharged at Kitimat Port

3.4 Critical Assumptions

- Assuming the sea draft is sufficient for the ship to operate without grounding
- Assuming the air draft is sufficient for the ship to operate without a major land obstacle i.e. bridges
- Kitimat port has arrangement for reception of following
  - Fuel bunkering facility
  - LNG bunkering facility
  - Sludge and garbage disposal facility
  - Sewage disposal facility
  - Lube oil bunkering facility
  - Catering services
  - Service technicians from the manufactures shall be provided
- There is adequate budget for the construction and design of this vessel
- The vessel and crew are insured by P&I
- 2 Years of Extended Warranty on Main engines, Propulsion System by the Manufacturer.

4.0 Bunker Operations General

Loading LNG into fuel tanks is a different process from loading HFO due to some unique differences in the fuel's characteristics. One difference is that LNG is carried as a boiling liquid, which means temperature and pressure influence the behavior of the liquid. A second difference is that LNG is a cryogenic liquid at temperatures of about -162°C (-259°F), and consequently, it is hazardous to personnel and any conventional steel structures or piping with which it comes into contact. A third difference is that the vapor from typical petroleum bunkering is not considered to create a hazardous zone because the flash point is above 60°C (140°F), and is simply vented through flame screens to the atmosphere. In contrast, LNG vapor can form explosive clouds in confined spaces and is considered hazardous. This requires special handling of the vapor when bunkering.

Methods of filling LNG storage tanks have been developed wherein there is no vapor emitted from the tanks, or the vapor is returned to the bunkering vessel or terminal. Lines used for bunkering must at the completion of bunkering be drained of LNG and the remaining gas vapors removed using nitrogen. Any liquid remaining in the pipes that is trapped between closed valves will boil and expand to fill the space available. If that space is small, the pressure developed by the expanding vapor can increase to dangerous levels and cause the pipes to burst or valves to be damaged. Where there is a risk of natural gas pressure buildup, such as LNG storage tanks and piping systems, relief valves are required to safely allow the excess pressure to be released as a final safety measure. Relief valves should be properly located so the hazardous zone created by the release of vapor is not near any operational areas aboard the vessel. In general, relief valves should tie into a vent mast which directs the gas away from all critical areas.

LNG is bunkered at cryogenic temperatures so special equipment and procedures are required. Any contact of personnel with the fuel will cause severe frostbite. Spillage of even small amounts of LNG can cause structural problems as unprotected normal structural steel can become embrittled by the cold liquid, leading to fracture. Stainless steel drip trays, break-away couplings, and special hose connections that seal before uncoupling are often used to protect from spillage.

Communication between the receiving ship and the bunkering facility is always important, but it is even more critical when handling LNG. Because of the greater potential for hazardous situations with LNG bunkering, proper procedures should be followed and understood between the person- in-charge on the bunkering facility and receiving ship. Security and safety zones around the bunkering operation need to be set up to reduce the risk of damage to property and personnel from the LNG hazards, reduce the risk of outside interference with the LNG bunkering operation, and to limit the potential for expansion of a hazard situation should LNG or natural gas release take place.

4.1 Bunkering Timeline

Assuming all the bunker is taken by a single vessel and cargo pumps are running at full speed of 300 m^3/hr, the time limit for the bunker scenario is for 17 hours for the complete procedure. It would take about 1 hour before bunkering, 15 hours during bunkering, and 1 hour after bunkering.

However it is very unlikely that all the cargo will be taken by a single vessel. Normally 1 ship bunkers around 2000-2500 m^3 of LNG at a time.

4.2 Key Characteristics Affecting Tank Capacity for Bunkering LNG

Typical LNG characteristics, including chemical components and composition, heating value, methane number, liquid density, and methane vapor pressure (boiling pressure) are provided in the Appendix. The following characteristics represent key considerations for handling LNG and highlight its important differences from typical liquid fuel storage and bunkering.

Bunkering (Loading) Temperature: At atmospheric pressure, natural gas will liquefy at a temperature of about -162°C (-260°F). As LNG increases in temperature, its vapor pressure increases and its liquid density, decreases. These physical changes need to be considered because they may increase the required storage tank volume and pressure rating.

Filling Limit: The filling limit of an LNG tank is the maximum allowable liquid volume in the tank, expressed as a percentage of the total tank volume. The filling limit is not the same as the loading limit. The maximum filling limit for LNG cargo tanks is 98 percent at the reference temperature.
This same limit is expected to apply to LNG fuel tanks. A higher filling limit may be allowed on a case-by-case basis based on requirements from classification societies and regulatory bodies.

Reference Temperature: The reference temperature is the temperature corresponding to the saturated vapor pressure of the LNG at the set pressure of the pressure relief valves. For example, if the LNG tank has a pressure relief valve set pressure of 0.7 barg (10.15 psig), then the reference temperature is -154.7°C (-246.4°F), which is the temperature that natural gas will remain a liquid at
0.7 barg (10.15 psig).

Loading Limit: The loading limit is the maximum allowable liquid volume to which the tank may be loaded, expressed as a percentage of the total tank volume. This limit depends on the LNG densities at the loading temperature and reference temperature and is determined by the following formula:

$$LL = FL\left(\frac{\rho_R}{\rho_L}\right)$$

Where: LL = loading limit

FL = filling limit

= LNG density @ reference temperature

ρ_L = LNG density @ loading temperature

Typical loading limits for gas fueled vessels are expected to range from 85 to 95 percent depending on tank type, pressure relief valve settings, and other vessel specific considerations.

Effect of Temperature and Pressure on Loading Limit: To understand the effect of temperature and pressure on the loading limit, it is helpful to consider an example where LNG and vapor are not being consumed from the tank. In this case, the LNG tank is a closed system and remains at a saturated condition, meaning the liquid and vapor are in equilibrium. Even though the tank is insulated, some heat will leak into the tank and cause an increase in the liquid and vapor temperatures while they remain in a saturated condition.

Liquid density decreases as temperature increases. If the tank is nearly full, the space available for vapor is relatively small, so the increase in liquid volume due to a lower density can significantly reduce the available vapor space volume. This decrease in available vapor volume as a result of the temperature changes will result in higher vapor pressure.

If the tank temperature is allowed to increase unchecked, the pressure in the tank will increase to the point where the pressure relief valves open. The temperature of the LNG at this point is the reference temperature. Because the density of the LNG at the reference temperature is lower than the density at the loading temperature, and given the formula for the loading limit, it is clear that the loading limit will always be lower than the filling limit.

As the pressure relief valve setting is increased, the reference temperature of the LNG also increases, which has the advantage of increasing the amount of time it takes for the tank to reach the pressure relief opening pressure. However, because the reference temperature is higher, the LNG density at the reference temperature will be lower, resulting in a greater difference between the LNG density at the loading and reference temperatures than in tanks with a low relief valve setting. This presents a tradeoff between initial loading capacity and the time it takes to reach the set pressure of the relief valve.

Heel: The volume of LNG that is normally left in the tank before bunkering is called the tank heel. This small volume of LNG keeps the LNG tank cold before it is refilled during bunkering. The required tank heel should be calculated with the assistance of the tank designer and fuel gas designer based on several variables such as tank size and shape, ship motions, heat inflow from external sources, gas consumption of the engines, and bunkering and voyage schedule. As a general rule of thumb, for initial design considerations a tank heel of 5 percent can be assumed.

Usable Capacity: In general, the usable capacity of the LNG tank is equal to the loading limit minus the heel, expressed as a percentage of the total tank volume. The usable capacity is the consumable volume of bunkered LNG in the tank.

4.3 Operational Issues aboard the receiving Ship

4.3.1 During the Bunkering Process

When receiving LNG bunkers, the receiving ship needs to implement several operational procedures that are unique to LNG. These procedures include special communications and monitoring, emergency shutdown, cryogenic material precautions, inerting and purging, firefighting and electrical isolation or bonding.

1. Communications and Monitoring: Communications between the receiving ship and bunker supplier is critical for carrying out the bunkering operation safely. Communications should be established before the bunker hoses are connected and can end after the hoses are disconnected. It is important for the supplier and receiver to both speak a common language and fully understand each other.

   Although currently there are no established standards, compatibility of all communication links between the receiving ship and bunker supplier must be confirmed and tested.

   Radio and communication equipment for involved persons should include the following considerations:

   - Radio equipment to be used in the safety zone during the operation should be designed for use in hazardous areas and should be intrinsically safe.
   - Any radio equipment, cell phones, or portable electronic equipment in the safety zone that are not intrinsically safe should be removed from the area.

   In addition to the communication system, a monitoring system with data link may be provided. The monitoring system allows both parties to monitor their own systems as well as critical aspects of the other's system. This data link may be an integral part of the emergency shutdown system or independent. Integrated systems allow for automatic shutdown of the bunkering operation upon receiving an alarm, such as from the gas, fire, or smoke detection systems, or from manual activation. The typical technologies used for data and communication links in the LNG industry include electrical and fiber optic cables, radio frequency and pneumatics. All of the listed technologies, except pneumatics, have the capacity to transfer additional information, such as communications or monitoring of other important, but non-LNG related systems. Pneumatic systems are simple and dependable, but generally only capable of sending one signal. They are typically used as the emergency shutdown.

2. Emergency Shutdown (ESD): Having a means to quickly and safely shut down the bunkering operation by closing the manifold valves, stopping pumps, and closing tank filling valves is essential to ensure safety. The ESD should be capable of activation from both the bunker receiving ship and the bunker supplier, and the signal should simultaneously activate the ESD on both sides of the transfer operation. No release of gas or liquid shall take place as a result of ESD activation. Typical reasons for activation of the ESD include the following:

   - Gas detection
   - Fire detection
   - Manual activation from either the supplier or receiver
   - Excessive ship movement
   - Power failure
   - High level in receiving tank
   - Abnormal pressure in transfer system
   - High tank pressure
   - Other causes as determined by system designers and regulatory organizations

3. Special Precautions for LNG: The issues associated with cryogenic substances like LNG are extremely important to understand and respect. LNG cannot simply be handled as 'cold diesel'. It is in fact extremely cold and can cause serious burns to human flesh. Even uninsulated LNG pipes and equipment can become cold enough to cause serious injury to personnel. In addition, the cryogenic temperatures are cold enough to cause steel to become brittle and crack. Because of these issues, the piping system, material requirements, and safety issues are much different than for an oil fuel system. The hull or deck structures in areas where LNG spills, leaks or drips may occur must be either suitable for the cold temperatures or protected from the cold temperatures.

   Drip trays are commonly used to contain LNG leakage and prevent damage to the ship's structure. This includes the location below any flanged connection, which are typically fitted with spray shields, in the LNG piping system or where leakage may occur. Drip trays should be sized to contain the maximum amount of leakage expected and made from suitable material, such as stainless steel. Cryogenic pipes and equipment are typically thermally insulated from the ship's structure to prevent the extreme cold from being transferred via conduction. These requirements are especially important at the bunker station because this is where LNG leaks or spills are most likely to occur.

4. Inerting and Purging: Before bunkering, it is necessary to inert and purge the bunker hoses and other warm bunker lines. In order to prevent a flammable gas mixture, the inerting process includes displacing air from the bunker lines with inert gas, typically nitrogen, to ensure the oxygen content is less than or equal to 1 percent. Purging, also known as gassing up and gas filling, is the process of displacing the inert gas with warm natural gas. Purging can either be done with vapor purge lines, which force vapor from the tank through the bunker lines; or by slowly pumping small volumes of LNG through the bunker lines, which will quickly vaporize and purges the lines. After the bunker lines have been inerted and purged, the lines are slowly cooled to the temperature of LNG with the use of cold LNG vapor and/or LNG. This process prevents the risk of cold shock and damage that would occur if LNG was allowed to flow through the warm hoses and pipes at the normal flow rate. Once the bunker lines have been cooled, the transfer of LNG can begin.

   After bunkering, it is very important to drain the bunker lines so that LNG does not remain trapped in pipes or hoses. If LNG remains trapped in a sealed section of a pipe or hose, it will warm, vaporize and pressurize the pipe and may cause the pipe or hose to burst. One way to drain the bunker line is to allow the LNG to vaporize in the pipes while the valves leading to the ship's fuel tank are left open. This allows the LNG and natural gas vapor to flow to the tank. Purge connections also can be used after bunkering to force the remaining LNG into the ship's fuel tanks.

   When bunkering is complete and the lines have been drained of LNG, it is necessary to inert the LNG bunker lines to prevent a flammable gas mixture from accumulating in the pipes or hose. Inerting is to be completed prior to disconnecting the bunker lines. Typically, nitrogen is used to displace the warm natural gas from the bunker lines. The bunker facility and receiving ship should agree on the means to properly manage and dispose of the remaining natural gas and nitrogen so that the natural gas is not released into the atmosphere. This may be accomplished by pushing the natural gas and nitrogen mixture back into the bunkering facility tanks or by using gas combustion units or boilers. Furthermore, it should be confirmed with all agencies having jurisdiction over the bunkering operation that the proposed procedure is acceptable. Figure 3 shows a typical sequence for a simplified bunkering process including the inerting and purging of the bunker hose and associated piping.

5. Safety and Firefighting: SOLAS Chapter II-2 can be referenced for fire protection requirements for an LNG fueled vessel. A permanently installed fire extinguishing system will typically be fitted at the bunker station and drip trays. Manual release of the system should be easily possible from

outside, but near, the bunker station.
In addition, portable dry chemical fire extinguishers are typically located near the bunker station and in nearby areas with easy access by the crew. For enclosed or semi-enclosed bunker stations, a fixed fire and gas detecting system should be fitted.

A water curtain is frequently fitted wherever large quantities of cold LNG can leak and damage critical structural components, such as the ship's side shell directly below the LNG bunker station and bunker hoses and above the waterline.

Fighting LNG fires is not a simple task. Completely extinguishing an LNG fire could leave a pool of LNG which will continue to release gas that could reignite in a much more intensive fire. The most important first step is to cool any surrounding tanks or pipes that contain LNG, natural gas or other flammable substances, and to cool spaces that contain critical machinery and accommodations. This will help prevent the spread of the fire and reduce its consequential damage. Intensive heating of LNG tanks by an outside fire impinging on the tank can lead to excessive venting of the tanks. Spraying large quantities of water bya deluge system or from hoses or monitors is generally the recommended method of cooling. Medium or high-expansion foam sprayed on a liquid pool LNG fire also can reduce the intensity of the flames, reducing the potential for damage to surrounding areas, but will not stop the release of gas.

6. Electrical Isolation: Vessels transferring or receiving low flashpoint flammable liquids, such as LNG, need to take additional precautions against ignition resulting from electrical arcing. Two causes of arcing are static electricity buildup in the LNG bunker hose and differences in potential between the ship and bunker supplier's facility, including the quay or pier, trucks, bunker vessels, etc. It used to be common practice to connect a bonding cable between a ship carrying low flashpoint flammable liquids and the loading or offloading facility to physically ground the two objects together to equalize the difference in potential. However, it was noted that the bonding cable was not fully effective at equalizing the potential. Furthermore, if the cable accidentally broke or became detached, the chances of arcing would be greatly increased.

   An effective way of preventing arcing is to isolate the ship and the bunker supplier using an isolating (insulating) flange fitted at one end of the bunker hose only, in addition to an electrically continuous bunker hose. The isolating flange, an example of which is shown in Figure 3, prevents arcs from passing between the ship and facility even if there is a difference in potential. Furthermore, because the hose is electrically continuous and one end is grounded to either the ship or the bunker supplier, static electricity will effectively be dissipated. An alternative method is to use one short section of insulating hose without any isolating flanges, but with the rest of the bunker hose string electrically continuous. To ensure that the ship is completely isolated from the supplier, it may be necessary to isolate mooring lines, gangways, cranes, and any other physical connections. This is typically done by using rope tails on mooring lines, insulating rubber feet on the end of gangways, and prohibiting the use of certain equipment that would otherwise pose an unacceptable risk of arcing.

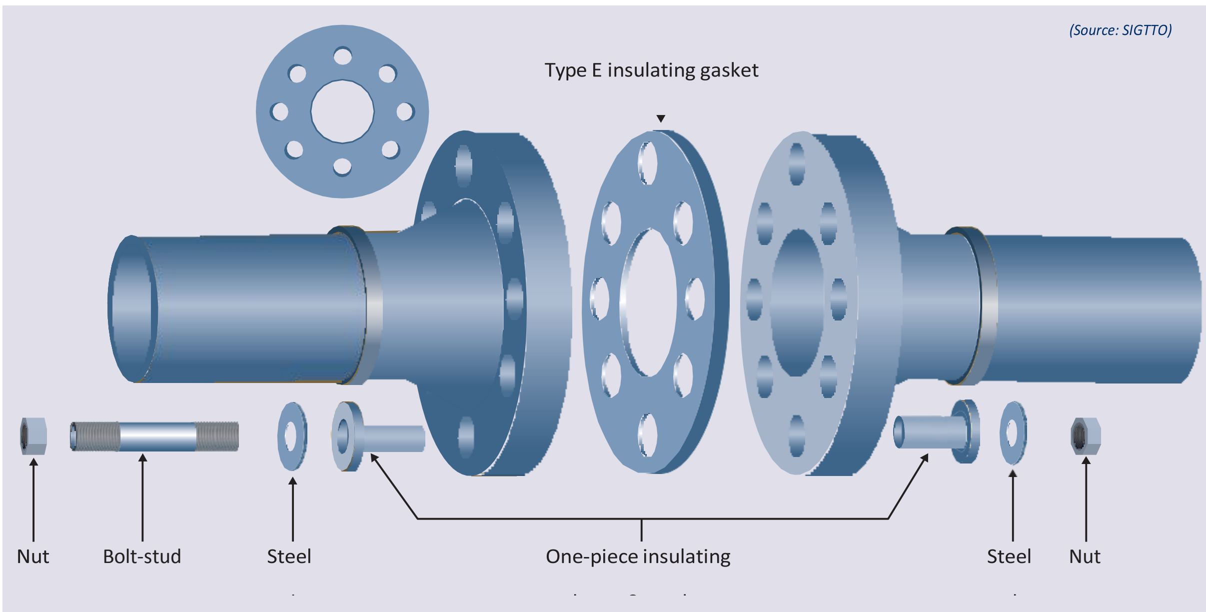


Figure 3: Electrical Isolation

4.3.2 Other Operational Phases Related to LNG Storage

In addition to the actual bunkering process, there are several LNG handling and storage operations on board the receiving ship that are unique to cryogenic fuels. These involve managing the storage tank temperature and the mixing of LNG of different densities.

1. Initial Gassing Up: Before the initial filling of an LNG fuel tank or after it has been completely emptied and gas-freed, it will be full of air. Before LNG can be introduced to the tank, the air needs to be removed by inerting the tank (typically with nitrogen) to ensure an explosive mixture of gas and air is never present in the tank. Some ships might not be fitted with a nitrogen generator or nitrogen storage tank with sufficient capacity to inert the entire fuel tank or tanks. This task might be accomplished by the LNG bunker supplier or another source, such as a nitrogen tank truck or a fixed tank onshore. Even if the ship has a large enough nitrogen capacity, it should have proper connections to accept an outside source of nitrogen in case of system failure or emergencies.

   LNG bunkering can begin only after the LNG fuel tank has been properly inerted, purged and cooled down. The tank is inerted with nitrogen gas. After inerting the tank, the inert gas is typically displaced with warm natural gas. Displacing the inert gas with warm natural gas is known as purging, gassing up or gas filling. The inert gas is either returned to the shore facility or vented. Venting of the inert gas is stopped when the natural gas vapors are detected. It should be confirmed with all agencies having jurisdiction over the bunkering operation whether the inert gas can be released into the atmosphere; some agencies may require that the inert gas be captured and stored or processed since it could contain natural gas. The tank is then gradually cooled in stages to the temperature of the incoming LNG. The cooldown process can be accomplished using cold natural gas and/or LNG.

This initial cooldown is typically done by spraying LNG into the fuel tank to slowly cool the piping, the tank and the gas in the tank. This is a slow process that uses a much lower flow rate than normal bunkering to ensure uniform cooling and minimize induced thermal stresses in the tank. The cooldown process may take several hours, typically 12 to 18 hours, depending on the size of the tank. The cooldown procedure is typically developed by the tank's manufacturer and includes directions for the use of the tanks spray nozzles and bottom filling. Once the tank is cooled to the specified temperature, continuous filling of the tank can continue to the desired level. Although the procedures and sequence of events will differ, the use of cold nitrogen gas and/or liquid nitrogen also is common for the cooldown process.

2. Transit and Storage: During transit, the ship's fuel tanks will normally contain some quantity of LNG. The volume of cold LNG in the tank, as a minimum, should be sufficient to maintain the cold temperature in the tank. Tank pressure during transit can be maintained within acceptable limits by consuming LNG or by using vapor control methods. Draining and Stripping: The requirement to strip the LNG fuel tank prior to entry into a shipyard may vary worldwide depending on shipyard or port authority policies. Tank stripping can be accomplished by building up the tank pressure to force the LNG out of the ship's tank to another tank, or by using stripping pumps. Any liquid left in the tank after stripping can be removed by circulating warm methane vapor from the ship's vaporizer. After stripping, the tank will need to be inerted with nitrogen. If human entry and inspection is required, the tank has to be purged with fresh air to gas-free.

   As specified in the ABS Gas Fueled Ships Guide, all LNG fueled ships also should have some means of emptying the fuel tanks without relying on the ship's own gas machinery system. This capability would allow another vessel or shore side facility to empty and strip the LNG fuel tank for scheduled events or in case of an emergency where the tank could release gas.

3. Rollover: When LNG from different sources with different densities are mixed (such as during a bunkering operation when new LNG is introduced into a tank), the LNG with the higher density

(typically lower temperature) settles at the bottom with the lighter density on top. If the tank remains relatively stationary (no sloshing or mixing takes place) heating of the lower part of the tank will decrease its density and increase its vapor pressure, but the hydrostatic pressure of the LNG on top will keep gas from boiling off. If the density difference becomes too large or the tank is disturbed so rapid mixing occurs, the LNG with higher vapor pressure at the bottom will rise up and encounter the lower pressure at the top of the tank. This is called rollover and can lead to rapid boil-off and generation of large amounts of vapor in extreme cases. This could lead to a large gas release through the pressure relief valves.

LNG density can vary significantly with change in temperature, but it also can vary depending on the physical composition of the LNG. As LNG warms, the lighter components boil off first and the remaining LNG has a different composition, with an increased density. According to the Society of International Gas and Tanker Operators (SIGTTO) publication, *Guidance for the Prevention of Rollover in LNG Ships*, studies have shown that density differences as low as 1 kg/m^3 can lead to stratification if the LNG fill rate is very slow. This hazard has occurred in shore terminals where there is no motion of the tank, and potentially is a hazard for ships which remain stationary in port. A vessel rolling at sea will have less of a tendency for this to occur because the sloshing of the LNG in the tank will cause mixing. It is unlikely for bunkered LNG to have the same temperature and density as the LNG remaining in the fuel tank, so it is important for the LNG to be thoroughly mixed during bunkering.

A typical way to minimize the risk of stratification is to use the top or bottom fill lines to mix the incoming LNG with the retained heel in the tank. If the bunkered LNG is lighter (lower density) than the heel, the bottom filling connection should be used. This will cause the bunkered LNG to rise to the top of the denser heel, mixing in the process. Conversely, if the bunkered LNG is heavier (higher density) then the top filling connection should be used. Mixing jet nozzles fitted to the fill line in the bottom of the tank can be used to increase movement within the tank and help to mix the bunkered LNG with the existing contents of the tank. Once the vessel goes to sea and rolling commences, mixing will tend to happen naturally, reducing the risk of rollover.

4.4 Bunker Operations

The use of standardized procedures and checklists from existing projects may be helpful as guidance. However, vessel-specific procedures for the bunkering operation should be developed to include any characteristics or features that are unique to the particular bunkering facility and receiving vessel or location.

The following is a simplified bunker operation sequence. Actual sequences will vary depending on the suppliers and receiver's equipment and capabilities. More detailed sequences are currently available online from some ports, such as the Port of Rotterdam.

Before Transfer:

1. Notify port authorities of intent to bunker, when required to do so.
2. Compatibility confirmed between the supplier and receiver regarding equipment, procedures and protocols.
3. Receiving ship moors alongside the quay or pier, or bunker vessel moors alongside receiving ship.
4. Security and safety zones are established.
5. Any pre-bunkering checklist, procedures, and communication protocols are completed and agreed between the supplier and receiver. Persons-in-charge are designated.
6. Communications, monitoring and ESD links have been established. ESD is to be tested.
7. Supplier evaluates tank pressure and temperature (depends on tank types and bunker procedure).
8. Firefighting equipment is readied for immediate use.
9. All safety systems, such as gas detection and alarms, are operational and have been tested.
10. Sufficient lighting is established.
11. All involved personnel put on required PPE.
12. Weather and sea conditions are deemed to be within established limits.
13. Electrical isolation or bonding connections, as applicable, are confirmed.
14. Water spray curtains and drip trays, as applicable, are in place.
15. Supplier's bunker hoses or transfer arms are connected between the supplier's and receiving ship's manifolds.
16. Supplier and/or receiver should inert and then gas up and cool down all required bunker lines and equipment that will be utilized.
17. LNG transfer starts.

During Transfer:

1. Monitor tank levels.
2. Monitor tank pressures and temperatures.
3. Monitor pump transfer rates.
4. Adjust pump flow rates as necessary.

5. Adjust top spray and bottom fill rates as necessary to control tank pressure.
6. Adjust mooring lines and bunker hoses and arms as necessary.
7. Monitor that the integrity of security and safety zones is maintained. Monitor that weather and sea conditions remain within limits.

After Transfer:

1. LNG transfer stops.
2. LNG in lines is allowed to vaporize and displace the remaining liquid back to the tanks.
3. Supplier and receiver inert all bunker lines and bunker hoses utilized during the bunker operations.
4. Supplier's bunker hoses, communications, monitoring, ESD and electrical isolation or bonding connections are disconnected from the receiving ship's manifold.
5. Receiving ship unmoors from the quay or pier, or bunker vessel unmoors from the receiving ship and notifies port authority.

4.4.1 Emergency Procedures

Emergency response planning and preparedness are critical to protect personnel, the environment, the public and assets during an incident. In addition to the typically required emergency response plans aboard the ship, specific plans relevant to an emergency involving the LNG system and bunkering operations also should be developed and implemented.

Emergency procedures can be classed as 'higher level' and 'lower level'. Higher level procedures are intended to provide general instruction to all relevant personnel, while lower level procedures are more specific to certain incidents, areas aboard the vessel, or equipment. The emergency procedures are intended to provide guidance and direction on how to carry out an organized and effective response to an incident, which may include LNG spill and/or gas release, fire or other hazardous situation. Some possible incidents that directly affect bunkering are loss of power by the supplier or receiver, non-LNG related fire near the bunkering, unexpected breakaway of one of the vessels, etc. Emergency procedures also should exist for other external incidents not directly related to the bunkering, such as a fire or gas release on a quay, pier or bunker vessel. Other emergency procedures should handle incidents relating to injury sustained by personnel involved in bunkering, such as frostbite induced by contact with extremely cold LNG or equipment.

It is important that personnel from both the supplier and the receiving ship are familiar with and trained in the emergency procedures and have access to them at all times. The training, drills, and exercises should ensure that all involved personnel understand the procedures, their role and responsibilities, and the use of the emergency response equipment available at the supplier and aboard the receiving ship.

The emergency procedures can be updated to reflect lessons learned from previous incidents or exercises or to reflect any modifications made by the supplier or receiving ship. SIGTTO and other agencies have developed numerous publications specifically related to the hazards of LNG which can be referenced when developing emergency response procedures.

4.4.2 Responsibilities

A designated person-in-charge should be present for every LNG bunkering operation from both the receiving ship and the supplier's side. Aboard the receiving ship, this person-in-charge is normally an officer permanently assigned to the ship who has the proper training and experience with all relevant characteristics of the ship for the purposes of LNG bunkering. This includes the LNG bunkering systems and procedures, monitoring and control systems, shipboard emergency equipment and procedures, and pollution reporting procedures. The supplier also should have a person-in-charge who is familiar and experienced with all aspects of the supplier's bunkering equipment and procedures. Both persons-in-charge should coordinate the bunkering operation and have an adequate understanding of the other party's bunkering capabilities and responsibilities before starting the operation. Both persons should have complete responsibility for their side of the bunkering operation and should be present for the entire duration.

4.4.3 Manning

Well-designed bunker facilities and LNG fueled ships may only require one or two people each during a typical bunkering operation, but additional crew will be necessary for normal vessel operations and should be available in case of emergency or other circumstances. The number of bunker supplier personnel depends on the method of supply (e.g., truck, barge, ship or fixed facility). Actual manning requirements will be dependent on the bunker procedure, facilities, and regulatory requirements. All personnel involved in the bunkering operation should have the necessary training and certification.

Safety/ Major Hazards

LNG presents hazards that are different than conventional marine fuels, like heavy fuel oil (HFO) and marine gas oil (MGO). If released at normal ambient temperatures and pressures it will form a flammable vapor, so the release of LNG or natural gas should be prevented at all stages of the bunkering process. Furthermore, in its liquid phase, LNG is cold enough that it can cause ordinary steel to become brittle and crack, so any contact with steel structures and decks should be avoided. Because of these hazards and others that can occur, safety and the prevention of leakage need to be among the primary objectives in the development of LNG bunkering system designs and procedures.

The three primary safety objectives for bunkering operations are as follows:

- Prevent the occurrence of any hazardous release of gas or liquid.
- In the event of a release, prevent or contain any hazardous situations.
- If a hazardous incident does occur, limit the consequences and harmful effects.

Major Hazards

The primary hazards of LNG are:

- Serious injuries to personnel in the immediate area if they come in contact with cryogenic liquids. Skin contact with LNG results in effects similar to thermal burns and with exposure to sensitive areas, including eyes, tissue can be damaged on contact. Prolonged contact with skin can result in frostbite and prolonged breathing of very cold air can damage lung tissue.
- Brittle fracture damage to steel structures exposed to cryogenic temperatures. If LNG comes into contact with normal shipbuilding steels, the extremely cold temperature makes the steel brittle, potentially resulting in the cracking of deck surfaces or affecting other metal equipment.
- Formation of a flammable vapor cloud. As a liquid, LNG will neither burn nor explode; however, if released from bunkering equipment, it will form a vapor cloud as the LNG boils at ambient temperatures. To result in a fire or explosion, the vapor cloud must be in the flammable range, which for methane is between 5 and 15 percent by volume in air, and there must be an ignition source present.
- Asphyxiation. If the concentration of methane is high enough in the air, there is a potential for asphyxiation hazard for personnel in the immediate area, particularly if the release occurs in confined spaces.

Some of the key hazards are discussed in more detail as follow:

Gas or LNG Release: The release of natural gas or LNG is to be prevented because of its flammable and cryogenic nature leading to many of the hazards which can be done by:

1. There are a number of factors affecting the consequence potential of an LNG release, including: the surface it is released on, the amount released, air temperature, surface temperature, wind speed, wind direction, atmospheric stability, proximity to offsite populations and location of ignition sources. Although LNG vapors can explode (i.e., create large overpressures) if ignited within a confined space, such as a building or ship, there is no evidence suggesting that LNG is

explosive when ignited in unconfined open areas.

2. The primary way to avoid gas release is to make sure at no time a route exists for the gas or liquid to escape over the full length of the bunkering system from the supply tank to the receiving tank, including all pipes and hoses which may contain gas or liquid at any time in the process. No release should occur during the hook-up or disconnect of any components during the bunkering process. To ensure no release occurs at system connect or disconnect, purging of the bunker piping systems with inert gas prior to connect or disconnect is necessary.
3. The bunkering system should be designed so that no breakage or overloading of the bunkering system components will occur during the bunkering process, including consideration of relative motions between the LNG supply tank and the receiving vessel under the full range of wind and weather conditions that could occur during the bunkering process, and considering the range of relative drafts and trims that could occur, plus any motions that may occur from ships passing nearby.
4. In the case of overload or breakage of the connecting hoses, the use of special breakaway fittings and dry-disconnect couplings should prevent the release of any gas or liquid.
5. In the event of bunkering shutdown, measures need to be in place to remove any retained gas or liquid in the system, particularly liquid. Retained LNG can boil off and create hazardous high pressure in the bunkering system.

Fire: One of the greatest safety hazards to the bunkering process is fire at or in the vicinity of the bunkering operations and piping systems. The reason fire is so dangerous is that natural gas is highly flammable and will readily fuel and expand a fire if it is released in the vicinity of the fire. In addition, the heat from fire can cause rapid boil-off of LNG in the vicinity of the fire, which can lead to system component rupture and feed gaseous fuel directly into the fire, greatly expanding the hazard from the fire. The best way to avoid fire is to avoid release of gas and exclude any sources of fire or ignition from the vicinity of the bunkering operation and to have in place measures to fight and prevent the spread of fires that could affect the bunkering operation area.

Rollover and Density Variation: As described in the section on operational issues on the receiving ship, rollover and density variation can be a hazard when bunkering LNG fuel because LNG density changes significantly with change in temperature and as a result of gas boil-off. A hazardous rollover incident can occur when LNG with different density from that in the tank is bunkered without properly mixing the LNG in the tank during the bunkering operation. If a rollover incident occurs, rapid gas boil-off and the subsequent generation of large amounts of vapor could lead to gas release through the pressure relief valves or impair the tank containment. This is more of a risk while a vessel is stationary than for a rolling vessel at sea because the vessel motion will cause mixing. Measures as described in the bunker operation sections of this Advisory should be used to properly mix new and old LNG.

Cryogenic Temperatures: The cold temperature (about -162°C) of LNG is a hazard to normal steel, other materials, and personnel. It will cause embrittlement of normal steel leading to fracture and can similarly cause failure of other materials, such as rubber. It is an obvious hazard to any personnel handling LNG system components. Special materials, such as cryogenic stainless steels, should be used for structures like drip trays that could be exposed to LNG. Countermeasures, such as water curtains, can be used to prevent excessive cooling of any regular steel structures that could be exposed to LNG. Insulation is also necessary on any exposed components, particularly in areas where personnel will be working.

5.0 Special Equipment's

5.1 Nitrogen Plants

One nitrogen generator is installed in the engine room, they are used to produce nitrogen in a gaseous manner which is used for the following functions:

- Purging for pipelines and boil off gas system.
- Purging various parts of the cargo pipping and fuel gas lines.

5.2 Re liquefaction plant

The liquefaction system is designed to provide cargo tank pressure control by liquefying all of the boil-off gas from the cargo tanks during normal ship operations so protecting the tanks from over-pressurisation.

The boil-off gas from each of the cargo tanks is collected in a common vapour main then pre-cooled in a heat exchanger, compressed in a two-stage centrifugal (BOG) compressor, cooled and then condensed in a large multi-pass heat exchanger which is part of the cold box.

The BOG loop consists of the following main equipment:
- Two BOG compressors, one duty and one standby
- Two LNG transfer pumps, one duty and one standby
- One BOG pre-cooler
- One plate-fin cryogenic heat exchanger (part of the cold box)
- One liquid BOG phase separator (part of the cold box)
- Auxiliary systems

The plate fin cryogenic heat exchanger and the separator are assembled in one enclosed module located in the compressor room and is called the 'cold box'.

5.2.1 Pre-Cooler

The pre cooler is there to make sure that the boil of gas (BOG) compressor discharge temperature remains constant, therefore protecting the cold box from a large temperature variations and damages caused by the thermal stress. This consists of a heat exchanger that is in a vertical separator and is designed to cool the incoming BOG from -100 degrees Celsius to -120 degrees Celsius.

Another function of the pre-cooler is to separate the liquid droplets from the vapour in order to protect the compressor from any liquid carry-over. A safety feature in pre-cooler shuts down the BOG compressor and closes the LNG supply value when activated.

5.2.2 BOG Compressors

The BOG compressor is a two stage centrifugal compressor that controls the compressor capacity. This is done by DGV (diffuser guide vanes) which is used on each stage. When one BOG compressor is running, the suction pressure controller will modulate the recycle valve and the DGV's to control the pressure in the cargo tanks. In case the pressure for the cargo tank increases above the set point, the recycle valve closes and the DGV's will open, but this doesn't happen until the valve is fully closed. The BOG compressor is running at 100% capacity when the DGV's are fully open. When however, the suction pressure drops below the set point, the DGV will close and then recycle valve will open.

5.2.3 Cold Box

The compressed boil-off gas transferred from the BOG compressor is cooled and condensed in a large multi-pass heat exchanger called a cold box. The temperature in the heat exchanger is lowest at the bottom (-164°C) and highest at the top where it is slightly above the cooling water temperature. The low pressure nitrogen flows through from the bottom of the cryogenic heat exchanger to the top before it is returned to the suction side of the first stage compressor on the nitrogen compander.

The heat exchanger temperature is allowed to change at a maximum rate of 0.7°C per minute and the expander bypass valve protects the cold box temperature from changing quicker than this.

The cold box is shown in Figure 4. It consists of a plate-fin heat exchanger and a liquid separator assembled inside a pearlite insulated steel casing. A nitrogen purging system ensures that there is an over-pressure in the cold box at all times and a cold box gas detector has been placed in the purging stream outlet to detect if there is a leak inside the cold box.

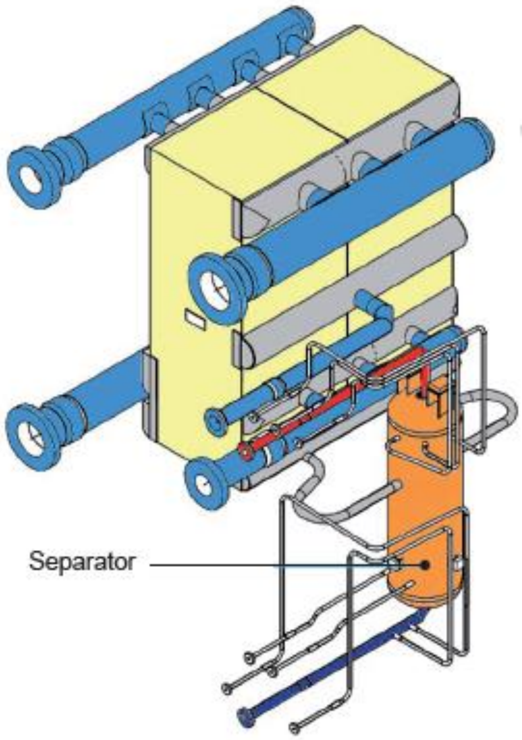


Figure 3 Cold Box with Separator

5.2.4 Cryogenic Heat Exchanger

The liquid BOG and non-condensable gasses would be separated in the separator unit below the cold box, where the liquid phase is returned to the cargo tanks by the differential pressure between the separator and the cargo tank. The gas phase is then vented to the gas combustion unit or it is returned to the cargo tanks. When the system is operating in free-flow mode, the BOG compressors are not operating, in this case liquid BOG is returned to the tanks by the duty LNG transfer pump. A three way valve is used to direct the vented gas to either the Gas Carrying Unit through the vent line or back to the cargo tanks by a separate vapour line. This valve has automatic and manual mode.

5.2.5 LNG Pump

Each Cargo tank is equipped with two independent submersible pumps. The LNG pump skid unit consists of the following:

- Pump
- Pump bearing heater
- Vent gas heater

- Control panel
- Flow element with transmitter

The LNG transfer pumps operate automatically based on the liquid level in the separator. They have a variable frequency drives that would regulate the pump capacity depending on the level controller in the separator, allowing the pump to run on minimum speed until the valve has opened completely. And if the flow is too small, the pump will be turned off. The pumps are also fitted with vent valve to allow purging of the motor cage with nitrogen before first start up, but it is closed under all other operations mode. There is also a vent line with isolated valves for each pump to prevent the pump casing from gassing up.

5.2.6 Vent Gas Heater

The vent gas is heated to the ambient temperature in the unit called the vent gas heater which is upstream of the GCU. The outlet temperature is controlled so that the temperature of the gas stays within the GCU operating limitations.

5.2.7 Nitrogen Re-liquefaction Loop

The main task of the re-liquefaction loop (also known as R loop) is to provide the necessary refrigerant to liquefy the boil-off gas from the cargo tanks. The main components of the R-loop are the following:

- 2 sets of nitrogen commanders (3-stage compressor, an expander, and two stage intercoolers and one aftercooler)
- 1 cold box
- 2 sets of nitrogen booster compressors with 1 on duty and 1 on standby
- 2 sets of nitrogen dryers
- 1 nitrogen reservoir
- Auxiliary systems

There is also a nitrogen booster compressor and associated items to replenish the re-liquefaction loop with nitrogen due to leakages from nitrogen compressor seals. The nitrogen booster compressors will try to maintain a pressure in the nitrogen reservoir based on a set point.

5.2.8 Operations stages

There are the following modes for the Re-liquefaction mode:

- Plant off
- Re-liquefaction plant standstill
- Standby mode
- Re-liquefaction
- Vent gas mode
- Excess boil-off gas mode

Each will be discussed in greater detail in the subsequent sections

5.2.8.1 Re-liquefaction Plant Off

This is the situation where all of the sub-systems associated with the plant are inactive. This case occurs when the plant has started to operate or after gas is freed from the ship in case of an emergency.

5.2.8.2 Re-liquefaction Plant Standstill

This happens when the button for re-liquefaction is pushed, the plant will have access to power, and nitrogen supply. This will make the plant in standstill mode.

5.2.8.3 Standby mode

This mode will be conducted once there is ample liquid present in the cold box separator. The start-up will require that the BOG section of the cold box to have access to BOG from the cargo tank, to be able to build up a liquid level in to separator and avoid sub-atmospheric pressures due to density changes during cooling. Once the liquid in the separator has reached normal liquid level low, and the temperatures in the cold box have stabilized, the standby operation has been reached.

5.3.8.4 Re-liquefaction mode

This occurs when the tank pressure control is performed by one BOG compressor and the BOG compressor capacity is less than or equal to 100% of the max flow. This BOG compressor will provide sufficient head for bringing the Liquid BOG back to the cargo tangs. This operation will commence if anything out of normal operating conditions occur such as a high nitrogen content. Then the vent gas or boil off gas mode will occur.

5.3.8.5 Vent Gas Mode

In case when BOG has a high level of nitrogen content, only a partial re-liquefaction will be applied. In the normal mode, the vent gas which is the non-condensed gas is directed back to the cargo tanks. But in the vent mode, this vent gas will instead be redirected to the GCU.

5.3.8.6 Excessive BOG Mode

In case the BOG compressor is not capable of controlling the cargo tank pressure by itself, a second compressor is started, when this happens the excessive BOG mode has happened. Also when both the compressors are operating, any excess gas which cannot be handled by the re-liquefaction system will be sent to GCU for disposal. This mode can occur when there is a non-equilibrium condition is the tanks i.e. insufficient cooldown of tanks before loading or by rough weather.

6.0 HULL FORM DEVELOPMENT

Based on the cargo capacity of 4500m^3 of LNG and 550m^3 of diesel oil specified in the owner's requirements we tried to fix the length and beam of the vessel. The next step then in figuring out a hull form rested on deciding the tanks as we noted that the choice of tanks played a crucial role in deciding the overall dimensions of the vessels. We analysed three main types of tanks:

1) The Membrane tank
2) The type C Cylindrical tanks
3) The spherical tanks

Apart from the tank type the other factors governing the vessel dimensions were the stability, resistance and the cost of the vessel. We assessed a range of tank arrangement combinations. For each of the hull form developed using different combinations, we formed a model in Rhino and calculated GM and resistance required using Orca. The results of these analysis have been summarised in the table below:

Table 3 Summary of Parametric Study

		LENGTH (m)	BEAM (m)	DRAFT (m)	DEPTH (m)	Cb
1	MEMBRANE TANK	82.45	15	4.5	9.5	0.691
2	CYLINDRICAL - 1 LONGITUDINAL TANK	99.18	12.7	5.15	11.8	0.684
3	CYLINDRICAL - 2 LONGITUDINAL TANK	96.9	15	5	11.5	0.685
4	CYLINDRICAL - 2 TRANSVERSE TANK	88.02	19.5	4.5	9.5	0.617
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	89.02	19.5	4.5	9.5	0.693
6	CYLINTRICAL - 4 VERTICAL (2*2)	79.5	14	5	10.5	0.687
7	SPHERICAL - 2 LONGITUDINAL TANK	53.17	18	9	18	0.687
8	SPHERICAL - 4 TANK (Longitudinal)	91.5	15.4	5.5	11.5	0.687
9	SPHERICAL-1 TANK	34	22	11	22	0.58
10	SPHERICAL-4 TRANSVERSE	26.58	17.28	4.5	9	0.648

		Displacement (tonnes)	DWT (tonnes)	GM (m)	POWER (kW)	POWER REQ (kW)
					(@15 KNOTS)	(RESIS+MARGIN)
1	MEMBRANE TANK	3941.81	1811.72	2.505	4240.7	4876.80
2	CYLINDRICAL - 1 LONGITUDINAL TANK	4547.94	2219.44	1.795	3333.8	3833.87
3	CYLINDRICAL - 2 LONGITUDINAL TANK	5102.69	2537.82	2.319	3946.2	4538.13
4	CYLINDRICAL - 2 TRANSVERSE TANK	4884.69	2172.49	4.714	5015.8	5768.17
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	5548.70	2765.07	3.912	4984.8	5732.52

6	CYLINTRICAL - 4 VERTICAL (2*2)	3918.73	1845.01	2.144	4645.7	5342.55
7	SPHERICAL - 2 LONGITUDINAL TANK	6065.4	2934.35	2.78	18664.5	21464.17
8	SPHERICAL - 4 TANK (Longitudinal)	5457.39	2899.66	2.354	4875.6	5606.94
9	SPHERICAL-1 TANK	4891.54	1343.84	4.171	30306.3	34852.24
10	SPHERICAL-4 TRANSVERSE	1372.8	-448.42	3.548	13046.9	15003.93

Since our vessel was a bunker supply vessel which will have frequent loading and unloading of LNG, enroute in short voyages, we opted to go with independent type C tanks. Another advantage of type C tank was seen in the management of boil off gases as compared to the membrane tank. A detailed tank comparison can be seen in the table below:

Table 4Tank Comparison

Tank Type	Concept	Pressure	Dis-Advantage	Advantage
Membrane Type	Integrated in hull	<0.7bar	• High Boil off • Not gas tight • Very sensitive against pressure holding • Sloshing	• Can be adapted to hull.
Spherical (Moss)	Independent tank	<0.7 bar	• High boil off • Space Requirements	• Very reliable system
Cylindrical Tank	Independent pressure vessel	>2 bar	• Space requirements	• Very solid design • Easy installation • No leakages occurred • No maintenance • Flexible Pressure

Based on estimation of these volumes and taking margins on the cargo volume for equipment, piping, etc. and following safety norms and industry best practices an initial vessel length of approximately 97 meters was estimated. Based on the standard hull form ratios of similar vessel the corresponding beam was found to be 15 meters at a depth of 11.5 meters and a draft of 5 meters.

The hull form was developed after gathering data on existing vessels of a similar nature and after a thorough review of the existing rules and regulations for Gas Carriers. The table below shows the details of these parent vessels. After forming the hull form, it was realised that the ship was a little skinny as compared to the parent vessel. Also there was not enough space for inspection of inner hull LNG tank surface. Thus, it was decided to increase the beam to 18 meters. A comparison of the different parent vessels is shown below.

Table 5 Parent Ship Data

	Name of the ship	Length		Breadth	Depth	Draft
		LOA	LBP			
1	Wartsila LNG Bunker WSD59 6.5K	98.8	96.5	19.2	12.7	5.8
2	Concept Naval ENR2		120	18	7	3.5
3	Rolls Royce type NVC 604 GT	89.3	87.1	18.4	8.9	4.9
4	Kawasaki Concept	120	114	18.8	9.5	5.6
5	TG LNG Bunker Vessel	98.6	93	14.2	7.6	4

Name of the ship	Cargo Tank Capacity		Discharge capacity	Design Speed	Gas Consumption	Tank Type
	LNG	MDO			(-/day)	
Wartsila LNG Bunker WSD59 6.5K	6500	550	250	13	9.8	C-type
Concept Naval ENR2	4600	1000	300			C-type
Rolls Royce type NVC 604 GT	4500		250	13		C-type
Kawasaki Concept	6000					C-type
TG LNG Bunker Vessel	3000			12		C-type

These Ships exhibited the following hull form characteristics:

HULL FORM RATIO					
	Name of the ship	**L/B**	**B/T**	**B/D**	**T/D**
1	Wartsila LNG Bunker WSD59 6.5K	5.02604	3.31	1.51181	0.457
2	Concept Naval ENR2	6.66667	5.143	2.57143	0.5
3	Rolls Royce type NVC 604 GT	4.7337	3.755	2.06742	0.551
4	Kawasaki Concept	6.06383	3.357	1.97895	0.589
5	TG LNG Bunker Vessel	6.5493	3.55	1.86842	0.526

The detailed analysis can be found in APPENDIX A

The principal particulars of the finalized hull form are as follows:

PRINCIPAL PARTICULARS	
LENGTH OVERALL (m)	96.99
LENGTH BETWEEN PERPENDICULARS (m)	93
BEAM (m)	18
DEPTH (m)	11.2
DRAFT (m)	5.2
DISPLACEMENT (TONNES)	6500

Following this we developed the lines plan for our vessel using ORCA 3D. The complete lines plan drawing can be found in APPENDIX I. The finalized hull form is shown in the figure below.

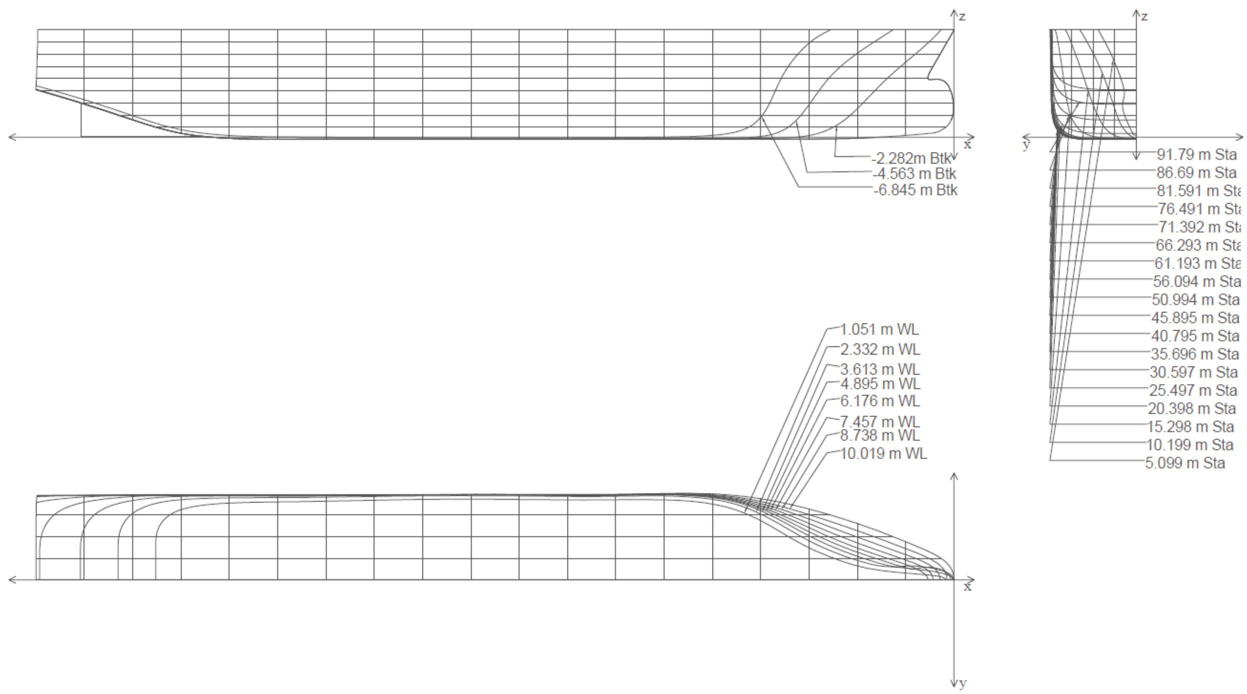


Figure 5 Lines Plan

7.0 Structural design of type C independent tank

Engineering systems for handling liquefied natural gas are designed for an operating temperature of –163°C. Metals for use at such cryogenic temperatures have to comply with exacting demands with respect to their mechanical and physical properties. The tensile strength of metals tends to increase at lower temperature. Metals have to have sufficient strength in service, but also have to be strong enough to be formed and fabricated at ambient temperature. In terms of mechanical properties, the need for adequate toughness is of primary concern. Whether a metal is tough at a given temperature depends upon whether it is able to plastically deform and that depends directly upon the crystal structure of the metal.

The physical properties, such as the thermal conductivity, also have to be considered in the design. The value of the coefficient of expansion will influence the amount of thermal strain induced during cooling to the operating temperature and this influences the detailed design approach for various components.

Before design of the pressure vessels is commenced, the following particulars were taken into consideration:

- Nature of cargoes, together with maximum vapour pressures and minimum liquid temperature for which the pressure vessels.
- Particulars of materials for the construction of the vessels.
- General arrangement plan showing location of pressure vessels in the ship unit.
- Plans of pressure vessels showing attachments, openings, dimensions, details of welded joints.

7.1 METALS FOR APPLICATION AT CRYOGENIC TEMPERATURE

We considered three metals practically established in various applications for handling LNG. There applications, physical and chemical properties are discussed in the tables below.

Different Applications of the chosen materials:

Table 6Materials and Application

Alloy	TYPE	APPLICATION
9Ni	9% Ni steel	Storage tanks
36NiFe	Low expansion, 36%Ni-Fe alloy	Some large storage tank designs. Piping in critical applications.
Al	Aluminum alloy type 5083 (Al-4.5%Mg) Alloy 5154 (Al-3.5%Mg) Alloy 6000 (Al –Si)	Spherical or prismatic storage tanks for ship transportation of LNG. Tubing for the main cryogenic heat exchanger. Forgings such as flanges.

7.2 Physical Properties of Metal used for LNG

Property	T °C	9% Ni Steel	36% Ni Fe Alloy	Al alloy 5083
Density, kg/m^3		7860	8120	2660
Elastic Modulus E, GPa	+20 -196	186 207	148 138	70 81
Thermal Conductivity, W/m°C	+20 -196	28.5 13.0	10.5 5.7	117
Mean Coefficient of thermal expansion, □, 10^{-6}/°C	0 to -196	9.5	1.5	17.5
Theoretical thermal stress in contracting a rigid length from 0 to -163°C, MPa		304	34	228
Theoretical thermal stress in contracting a rigid length from 0 to -163°C, MPa as a percentage of yield strength		51-69%	12.6%	157%

7.3 Mechanical Properties of the material

Property	**T °C**	**9%Ni Steel**	**36% Ni Fe Alloy**	**Al alloy 5083**
Yield stress, MPa	0 -196	441-587 680	270 650	145 165
Ultimate tensile stress, MPa	0 -196	637-834 1100	490 900	290 405
Elongation to break, %	0 -196	17-20 30	40 40	16 36
Impact energy, J	0 -196	125 42	150 100	237 20

7.4 Design of Type C independent tank as per Lloyd's rule:

For this design consideration we fixed the inside radius to 6000mm, and the design pressure to 5 bar. However the values can be changed later if required.

Definition of symbols

Following symbols are used in the given section for design of the C-type LNG tank.

p = design pressure in bar
t = minimum thickness, in mm
Di = inside diameter, in mm
Do = outside diameter, in mm
J = joint factor applicable to welded seams
R_i = inside radius, in mm
R_o = outside radius, in mm
T = design temperature, in °C
σ = allowable stress as per the material properties defined above in material properties.

The design basis for Type C independent tanks is based on pressure vessel criteria modified to include fracture mechanics and crack propagation criteria. The design vapour pressure shall not be less than:

$$Po = 0.2 + AC(\rho_r)^{1.5} \text{ (MPa)}$$

$$A = .00185(\frac{\sigma m}{\Delta\sigma A})$$

With

σm = design primary membrane stress
= 75 N/mm^2 for Aluminum
= 233 N/mm^2 for 9 Ni- Fe
= 233 N/mm^2 for 36 Ni- Fe
ΔσA = allowable dynamic membrane stress
= 55 N/mm2 for ferritic-perlite, martensitic and austenitic steel
= 25 N/mm2 for aluminium alloy (5083-O)
C = a characteristic tank dimension to be taken as the greatest of the following:
h, 0.75b or 0.45l

With
h = height of tank (dimension in ship unit's vertical direction) (m)
b = width of tank (dimension in ship unit's transverse direction) (m)
l = length of tank (dimension in ship unit's longitudinal direction) (m)
ρr = the relative density of the cargo (ρr = 1 for fresh water) at the design temperature

The minimum design pressure is intended to ensure that the dynamic stress is sufficiently low so that an initial surface flaw will not propagate more than half the thickness of the shell during the lifetime of the tank.

Table 6 Summary of Tank Design

Design Pressure should not be less than Design vapour pressure				
P_o = .2+ AC (ρ)^1.5			P_o= Min Design Pressure	
			A= 0.00185*(σm/σa)^2	
			σm < f	
ρ (R.D of LNG)	0.47		C= 0.45 Length of tank	
	A	C	P_o	
Aluminum	0.01665	10.71	0.257458	N/mm2
36 Ni Fe	0.033297	10.71	0.314904	N/mm2
9 Ni	0.034642	10.71	0.319546	N/mm2

7.5 Shell Thickness

The shell thickness shall be as follows:

1. For pressure vessels, the thickness calculated according to given formula shall be considered as a minimum thickness after forming, without any negative tolerance.

$$t = \frac{pR_i}{10\ \sigma_A\ J - .5p} + .75\ \text{mm}$$

2. For pressure vessels, the minimum thickness of shell and heads including corrosion allowance, after forming, shall not be less than 5 mm for carbon-manganese steels and nickel steels, 3 mm for austenitic steels or 7 mm for aluminium alloys.

3. The welded joint efficiency factor to be used in the calculation according to given table below:

Class of Pressure Vessel	Joint Factor
Class 1	1.0
Class 2/1	0.85
Class 2/2	0.75
Class 3	0.60

Since we are designing tanks for carriage of LNG which is stored at – 163 deg C, we decided to go with class 1 pressure vessel keeping an additional FOS. Final Results of the thickness for all the considered materials is given below:

Thickness of Tank		
Al	40.88	mm
9 Ni	13.62	mm
36 Ni- Fe	13.37	mm

Thickness of the spherical ends was determined by the given formula:

$$t = \frac{pR_i}{20\,\sigma_A\,J - .5p} + .75 \text{ mm}$$

Calculated results:

Thickness of Spherical ends		
Al	20.78	mm
9 Ni	7.18	mm
36 Ni- Fe	7.06	mm

Table 7Tank Cost Comparison

	Al	9 Ni- Fe	36 Ni Fe
Outer Radius	6.04	6.01	6.01
Inner Radius	6.00	6.00	6.00
Volume	36.82	12.24	12.01
Weight (tonnes)	97.95	96.20	97.54
Material cost $/ton	1000	600	5000
Approximate total cost	$98,000	$58,000	$485,000

Based on the thickness of the material we calculated the volume of the material required and found the material cost considered for the construction.

Assuming that the main driving factor in selection of the tank material is the cost of the material and the labour charges in construction all together with other costs is approximately going to be same.

Thus, based up on the cost we finalised the material of the tank to be 9Ni-Fe.

7.6 LNG tank Insulation

In order to guarantee the LNG cold temperature of -160°C, high-quality insulation applied in accordance with strict specifications is essential. Insulation systems consisting of Polyisocyanurate (PIR) rigid foam or cellular glass insulation, applied in multiple layers, in combination with high performance vapour barriers are used in order to produce the necessary degree of insulation.

The insulation system is designed to maintain the boil-off losses from the cargo at an acceptable level, and to protect the inner hull steel from the effect of excessively low temperature.

If the insulation efficiency should deteriorate for any reason, the effect may be a lowering of the inner hull steel temperature, i.e. a cold spot and an increase in boil-off from the affected tank. If necessary, increased boil-off gas may be vented to the atmosphere via the vent riser and gas heater, which will result in the loss of LNG. Also the inner hull steel temperature must, however, be maintained within acceptable limits to prevent possible brittle fracture.

We carried out our research further to decide the type of insulation and came across 3 different materials used for the insulation of LNG tanks as approved by Classification societies.

1. PU- Foam Insulation
2. Vacuum Perlite Insulation
3. Aerogel mat Insulation

Their advantages and disadvantages are shown in the table below.

Table 8Insulation Comparison

Type of Insulation	Advantages	Disadvantages	Space Requirement (mm)
PU- Foam Insulation	• Cost Efficient	• Risk of Icing • Expensive Waste Disposal • Needs a secondary barrier	260
Vacuum Perlite Insulation	• Non-Inflammable • Low thermal Conductivity • Has a secondary barrier • Simple Processing • Remaining Insulation after vacuum loss	• Risk of Vacuum loss due to leakages. • High insulation cost with industrial vacuum	35
Aerogel Mats	• Non- Inflammable • Low thermal Conductivity • Each layer has vapour barrier	• High material Costs • Risk of Icing • Needs a secondary barrier	165

We chose to go for Vacuum Perlite Insulation because of its various advantages specified above and choosing any other insulation would have increased the overall height of the cargo hold which was undesired.

8.0 RESISTANCE ESTIMATES

A ship is designed to move through water with minimal force being exerted by it. The force due to the mass of water opposing the movement of the vessel is known as resistance. There are various methods used to predict the resistance faced by the vessel as if moves through the water. Some of these methods include:

1) Empirical methods: Based on data from systematic series, regression analysis and parametric data
2) Numeric Methods: Computational Fluid Dynamics Analysis.
3) Model Testing.

We used the Empirical methods to determine the resistance of the vessel. This being a student project and due to the lack of time a detailed analysis of the resistance and powering was not possible. It would however be worthwhile to undertake a CFD analysis in the future to verify the results obtained from this analysis.

8.1 Overview

The Holtrop method was used to determine the resistance of our vessel. This method of resistance prediction is valid for models of different sizes and thus a very widely used tool for resistance analysis. The resistance components in this analysis are expressed as dimensionless quantities depending on their respective scaling parameter. This dependency varies from model to model owing to differences in hull form.

8.2 Holtrop Method

The Holtrop method is a regression analysis based on historical data of many different ships with varying geometric dimensions. This method is widely used to determine the propulsive power requirement of a vessel in the initial design stages. A number of different resistance prediction are available in the marine industry such as NPL series, Oomertsen method and Holtrop method. Holtrop method of evaluating resistance is typically used for larger vessels .Below is table which clearly shows different categories of ships and based on our vessel prismatic coefficient and L/B ratio falling under tankers and bulk carriers, we chose to predict the bare hull resistance using Holtrop method.

The application is limited to hull forms resembling the average ship described by the main dimensions and form coefficients used in the method.

Parameter ranges for different ship types

Type of ship	F_n	C_P		L/B		Number of ships single screw		twin screw	
	max.	min.	max.	min.	max.	model	full scale	model	full scale
Tankers, bulkcarriers	0.24	0.73	0.85	5.1	7.1	48	13	3	2
General cargo	0.30	0.58	0.72	5.3	8.0	21	17	3	2
Fishing vessels, tugs	0.38	0.55	0.65	3.9	6.3	35	--	3	2
Container ships, frigates	0.45	0.55	0.67	6.0	9.5	6	--	18	1
Various	0.30	0.56	0.75	6.0	7.3	7	6	3	3
Total						117	36	30	10

Figure 7 Parameter Ranges for Different Ship Types

Resistance Prediction:

The total resistance of a ship has been subdivide into:

$R_{Total} = R_F (1+k_1) + R_{APP} + R_w + R_B + R_{TR} + R_A$

where:

R_F friction Resistance according to ITTC- 1957 friction formula

$1+k_1$ form factor describing the viscous resistance of the hull form in relation to R_F

R_{APP} resistance of appendages

R_w wave-making and wave-breaking resistance

R_B additional pressure resistance of bulbous bow

R_{TR} additional pressure resistance of immersed transom stern

R_A model-ship correlation resistance

Based on the total resistance calculated, we found the power estimation of the vessel. The speed Vs Power estimation is shown in the graph below.

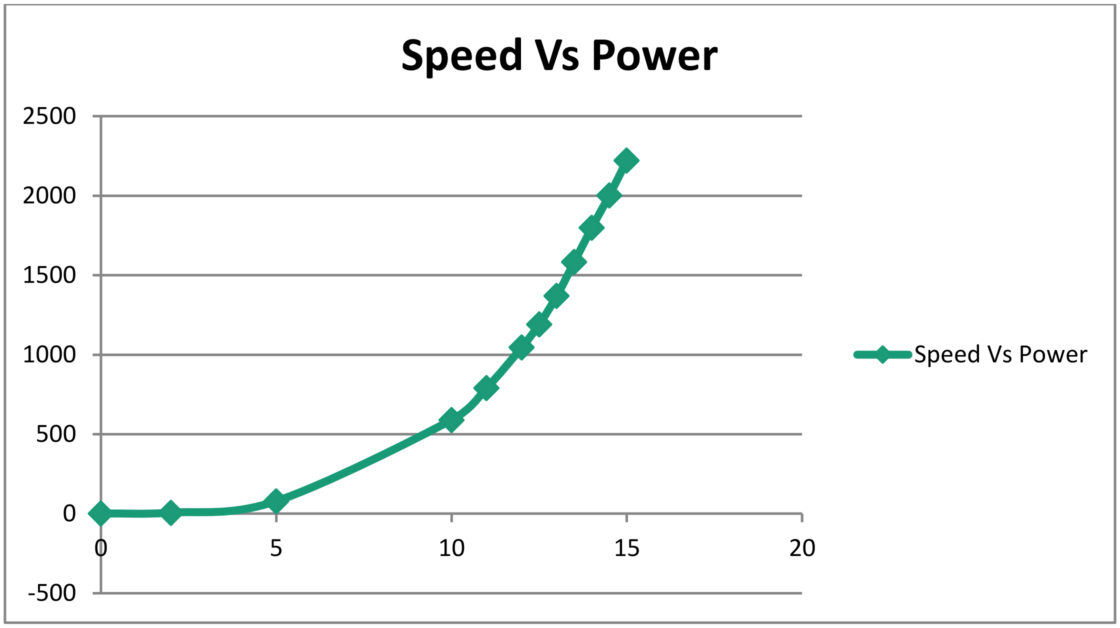


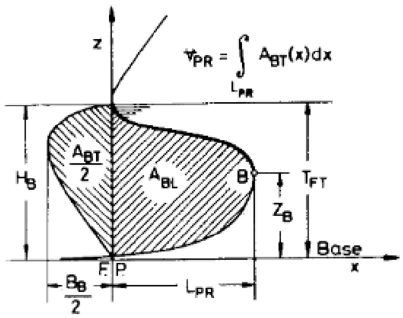
Figure 8 Speed vs Power Graph

8.3 Bulbous Bow considerations:

For reducing wave making resistance, adding a Bulbous Bow to the vessel was considered. In order to calculate the area of the bulb required, we came across typical values of Non-Linear coefficients published by Kracht in 1970 .For calculating the bulb area we considered the nonlinear coefficients and they are mentioned as below:

Bulb Geometry (2)

Non-Linear Form Coefficients



$C_{ABT} = \frac{A_{BT}}{A_{MS}}$ Cross-section Coefficient

$C_{ABL} = \frac{A_{BL}}{A_{MS}}$ Longitudinal Section Coefficient

$C_{VPR} = \frac{V_{PR}}{\nabla}$ Volumetric Coefficient

$t = L_{PP} \cdot |tg(sac)| / [2 \cdot (A_{MS} - A_{BT})]$

Taylor Coefficient (for fast ships)

sac = angle of the standardized SAC with the horizontal, at the FP

Bulbous Bow 12

Figure 8 Bulb Geometry 2

Bulb Geometry (3)

Typical values of the Linear Coefficients (Kracht, 1970)

	MIN	MAX
C_{BB}	0.170	0.200
C_{LPR}	0.018	0.031
C_{ZB}	0.260	0.550

Typical values of the Non-Linear Coefficients (Kracht, 1970)

	MIN	MAX
C_{ABT}	0.064	0.122
C_{ABL}	0.068	0.146
C_{VPR}	0.0011	0.00272

Bulbous Bow 13

Figure 9 Bulb Geometry 3

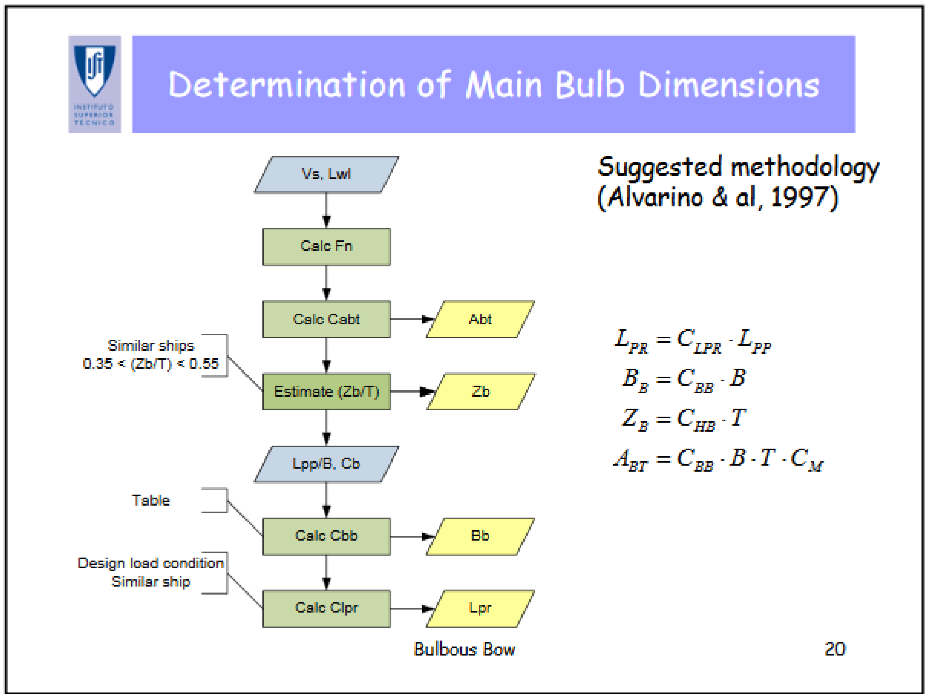


Figure 10 Determination of Main Bulb Geometry

From the table above we found the range of areas for different bulbous bow that can be used for our Vessel. The bulb area was calculated to be in a range from 11.2 m^2 - 22 m^2. In order to choose the right bulb area Holtrop method had a direct empirical relation for the bulb resistance which is mentioned below:

$$R_B = 0.11 \exp(-3 P_B^{-2}) F_{ni}^3 A_{BT}^{1.5} \rho g/(1 + F_{ni}^2)$$

where the coefficient P_B is a measure for the emergence of the bow and F_{ni} is the Froude number based on the immersion:

$$P_B = 0.56 \sqrt{A_{BT}}/(T_F - 1.5\, h_B)$$

and

$$F_{ni} = V/\sqrt{g(T_F - h_B - 0.25\sqrt{A_{BT}}) + 0.15\, V^2}$$

We calculated the total resistance based on different bulb areas, and they are as below:

Bulb area(m^2)	Total Resistance(N)
11.2	163517
21.4	185561
Without bulbous bow	174297

8.4 Propeller Calculation and Prediction of Propulsive Power.

It was clear from the resistance prediction that including a bulbous bow for our vessel had a significant reduction on resistance and power.

For the prediction of the required propulsive power the efficiency of the propeller in open water condition has to be determined. It has appeared that the characteristics of most propellers can be approximated well by using the results of tests with systematic propeller series.

There are statistical prediction equations for calculating K_T , K_Q and J values and by using Wagneigen B-Series propeller charts , an open water efficiency of 65 percent was estimated.

$$K_{T\text{-ship}} = K_{T\text{-}B\text{-series}} + \Delta C_D \, 0.3 \frac{P \, c_{0.75} \, Z}{D^2}$$

$$K_{Q\text{-ship}} = K_{Q\text{-}B\text{-series}} - \Delta C_D \, 0.25 \frac{c_{0.75} \, Z}{D}$$

$$J = \frac{Va}{n * D}$$

$$\Delta C_D = (2 + 4(t/c)_{0.75})\{0.003605 - (1.89 + 1.62 \log(c_{0.75}/k_p))^{-2.5}\}$$

Here ΔC_D is the difference in the drag coefficient of the profile section,P is the pitch of the propeller and

$C_{0.75}$ is the chord length at a radius of 75 percent and Z is the number of blades.In this formula t/c is the thickness –chordlength ratio and K_p is the propeller blade surface roughness.

For this roughness the value of k_p=0.00003m is used as a standard figure for new propellers.

The chord length and the thickness ratio can be estmiated using the following empirical formulae:

$$c_{0.75} = 2.073(A_E/A_O)\,D/Z$$

and

$$(t/c)_{0.75} = (0.0185 - 0.00125\,Z)\,D/c_{0.75}\,.$$

The blade area ratio can be determined from e.g. Keller's formula:

$$A_E/A_O = K + (1.3 + 0.3\,Z)\,T/(D^2(p_o + \rho gh - p_v))$$

In this formula T is the propeller thrust, $p_o + \rho gh$ is the static pressure at the shaft centre line, p_v is the vapour pressure and K is a constant to which the following figures apply:

$K = 0$ to 0.1 for twin-screw ships
$K = 0.2$ for single-screw ships

For sea water of 15 degrees centigrade the value of $p_o - p_v$ is 99047 N/m^2.

The given prediction equations are consistent with a shafting efficiency of

$$\eta_S = P_D/P_S = 0.99$$

and reflect ideal trial conditions, implying:

- no wind, waves and swell,
- deep water with a density of 1025 kg/m^3 and a temperature of 15 degrees centigrade and
- a clean hull and propeller with a surface roughness according to modern standards.

The shaft power can now be determined from:

$$P_S = P_E/(\eta_R\,\eta_o\,\eta_S\,\frac{1-t}{1-w})$$

Where Wake fraction, Thrust Deduction Factor and Relative Rotative efficiency are as given below:

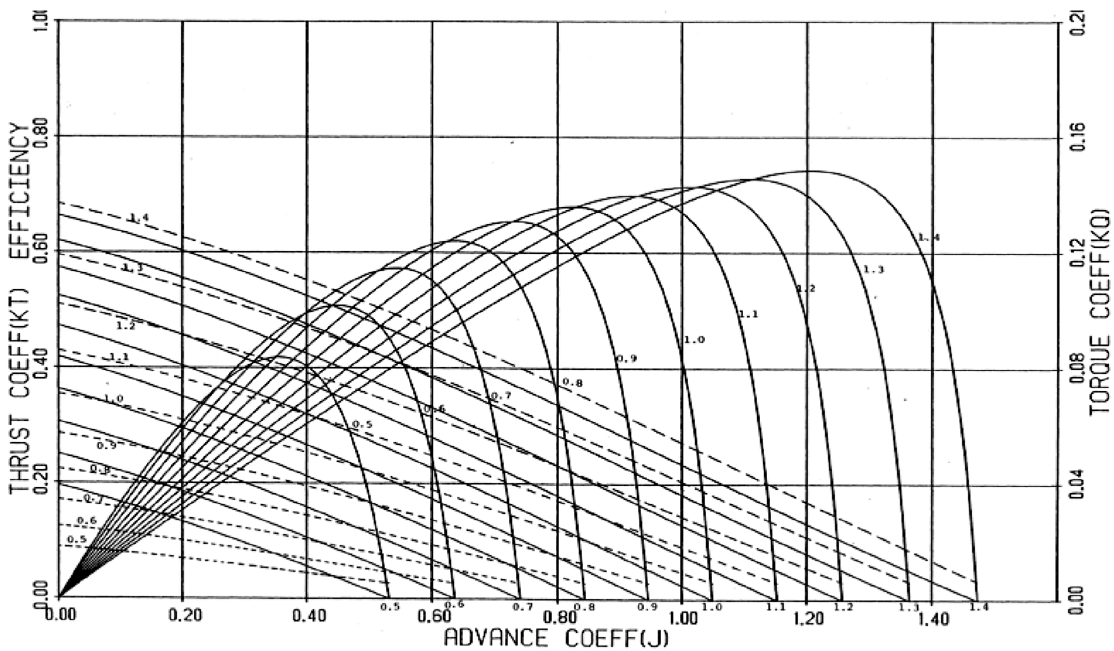
$$w = 0.3095\,C_B + 10\,C_V C_B - 0.23\,D/\sqrt{BT}$$

$$t = 0.325\,C_B - 0.1885\,D/\sqrt{BT}$$

$$\eta_R = 0.9737 + 0.111(C_P - 0.0225\,lcb) + \\ - 0.06325\,P/D$$

Table 9 Propeller Design

Propeller				.@13 knots		
Pitch	2.8	mt		**Kt**	**J**	**desired**
Diameter	2	mt		0.189	1.15	Kt = 0.18
P/D	1.4					J = 1.2
Rpm	140					
Area Prop	2.12	m2		Efficiency	0.65	



The Propulsive power with various bulb area are listed below:

Bulb area(m^2)	Power(KW)
11.2	1733
21.4	1967
Without bulbous bow	1847

It was decided to go with a bulb area of $11.2m^2$

Finally considering efficiencies listed below, the total shaft power, Ps including a service margin of 20 percent was calculated to be around 3500 KW.

$\dot{\eta}_{openwater}=0.65$

$\dot{\eta}_{gen}=0.95$

$\dot{\eta}_{transformer}=0.95$

$\dot{\eta}_{shaft}=0.98$

$\dot{\eta}_{rectifier}=0.94$

9.0 PROPULSION SELECTION

In order to choose the best propulsion selection for our vessel, we had an option of two propulsion systems:

- Conventional Single Screw Propulsion
- Z-Drive Rolls Royce Propulsion

Conventional Single screw propulsion systems are generally fixed or controllable pitch type. Propellers of the FP-type are cast in one block and normally made of a copper alloy. The position of the blades, and thereby the propeller pitch, is once and for all fixed, with a given pitch that cannot be changed in operation. This means that when operating in, for example, heavy weather conditions, the propeller performance curves, i.e. the combination of power and speed (r/min) points, will change according to the physical laws, and the actual propeller curve cannot be changed by the crew. Most ships which do not need a particularly good manoeuvrability are equipped with an FP-propeller.

Propellers of the CP-type have a relatively larger hub compared with the FP-propellers because the hub has to have space for a hydraulically activated mechanism for control of the pitch (an gle) of the blades. The CP-propeller is relatively expensive, maybe up to 2-3 times as expensive as a corresponding FP-propeller. Furthermore, because of the relatively larger hub, the propeller efficiency is slightly lower and also CP propellers do not have the steering capability.

Z-Drives or the Azimuth propulsion are popular for vessels where there is a requirement of high degree of maneuverability. Our vessel being a LNG bunker vessel will require a propulsion system which has good maneuvering capacity and the captain can have full command over the vessel.

An Azimuth thruster is an arrangement of marine propellers placed in pods which can be rotated to any horizontal angle (azimuth). The ships fitted with this system give better maneuverability than a fixed propeller and rudder system. This assembly consists of the podded propeller connected to a motor and an azimuth well to support the propeller. As thrust acts on the assembly, the well is supported by structures like brackets, struts etc.

Azimuth thrusters are mounted on a 360˚ rotating shaft under the ship. The most important advantage of azimuth thruster is an optimal thrust in every direction. There is no rudder required in an azimuth system and hence, the underwater dynamics are improved which not only increase maneuverability, but also azimuth thrusters include the advantages of combined engine systems.

With the invention of azipod propulsion system, steering behavior has been increased. It can be built for pushing or pulling operation, at low or high speeds. Additional maneuverability may be attained by changing the azimuth elevation. Using azimuth thrusters, the crash stop distance can be halved compared to conventional propeller systems.

More advantages are electrical efficiency, better use of ship space, and lower maintenance costs. Ships with azimuth thrusters do not need tugboats to dock, though they still require tugs to maneuver in difficult places.

Finally a matrix was created in order to have better decision, the matrix is shown as below:

Table 10 Propeller Selection Matrix

Selection of Propeller	Importance %		Single Screw	Azimuth Twin Screw
Manoeuverability	40	0.4	1	5
Space	25	0.25	1	3
Efficiency	25	0.25	3	2
Cost	10	0.1	3	1
Total			8	11
Weighted Total			1.7	3.35

Azimuth twin screw was chosen to be the optimal propulsion system for our LNG vessel.

10.0 Main Engine Selection

Choosing a propulsion engine or engines and the most suitable plant configuration for a given newbuilding or retrofit project is not a simple decision. It dictates careful study of the machinery options available and the operating profile of the ship.

There is a wide variety of engines which can be selected and based on the MARPOL Tier III regulations, we decided to go with Dual Fuel engines which complies MARPOL Tier III regulations. Also our vessel was carrying LNG so it was easy for us to manage boil off gases by supplying it to the engines.

Other Advantages of using Dual Fuel Engines/Diesel Electric propulsion:

- Simple shafting arrangements
- Fuel processing machinery and system not required
- Reduced maintenance costs

- Main engines runs at fixed RPM there by reduction of emissions.
- Absolutely no SO_x and NO_x and Particulate matter pollution
- SCR or EGR not required to be fitted in the exhaust system
- DF engines are compact and consumes less space when compared with the conventional two stroke engines
- Easy control of Z-Drive motors
- Higher mechanical and electrical efficiency

Based on the above advantages, we decided to choose the Dual Fuel Diesel Electric Engine system for our vessel.

10.1 Engine Configuration

For carrying out a viable engine configuration, we laid out different conditions and calculated the power requirements for each mode. Below is a table showing power requirements for each mode:

Table 11 Mode of Operation

Power	Load (kW)	Maneuvering	Full Ahead	Bunkering	At Port	Anchoring/Drifting
Propulsion Power	2900					
Bow Thrusters	250					
Service Load	300					
Cargo Pumps	600					
Re-Liquefaction Plant	200					
Nitrogen Generator	150					
Total Load for each mode	-	3350	3200	1500	550	500
Time spent in each mode in %	-	5%	60%	15%	15%	5%
Number of days spent in a year	-	18.25	219	54.75	54.75	18.25

10.2 Engine Selection

Below is the list of Wartsila DF engines which are available and based on our maximum/minimum power requirements , we chose to go with two engines of 9L20DF and one small engine of 6L20DF.

Different Available Combinations	Wartsila 9L20DF	Wartsila 8L20DF	Wartsila 6L20DF	Wartsila 6L34DF	Wartsila 4L20
Power produced (kw)	1665	1480	1110	3000	800
Fuel Used	Dual Fuel	Dual Fuel	Dual Fuel	Dual Fuel	Diesel
Weight (Tonnes)	11.7	11.1	9.4	13.2	7.2

Combination	2 of 9L20DF + 1 6L20DF
Produces => kw of power	4440

11.0 INTACT STABILITY ANALYSIS

The stability of the vessel is discussed in this section of the report. We have followed IMO A 749 (18) standards to determine the intact stability of the vessel. The intact stability of the vessel was carried out under the following loading conditions:

1. Light ship
2. Fully loaded
3. Partial load condition (50 % cargo)

The intact stability of UBC LNG BUNKERING VESSEL was assessed using Maxsurf. For clarity purposes, the criteria are restated in the table 12 below. For an excerpt of criteria please refer to APPENDIX E. Additionally, the results of the intact stability analysis, are also shown below.

Table 12 Stability Criteria IMO A.749

Criteria	Description(IMO A.749)
1	Area Under GZ curve up to 30 degrees >3.151 mdeg
2	Area Under GZ curve up to 40 degrees >5.157 mdeg
3	Area Under GZ curve from 30-40 degrees >1.719 mdeg
4	Max GZ at an angle of 30 degrees or greater shall not be less than 0.2m
5	Angle of maximum GZ shall not be less than 25 degrees
6	Initial GM transverse should not be less than 0.15 m

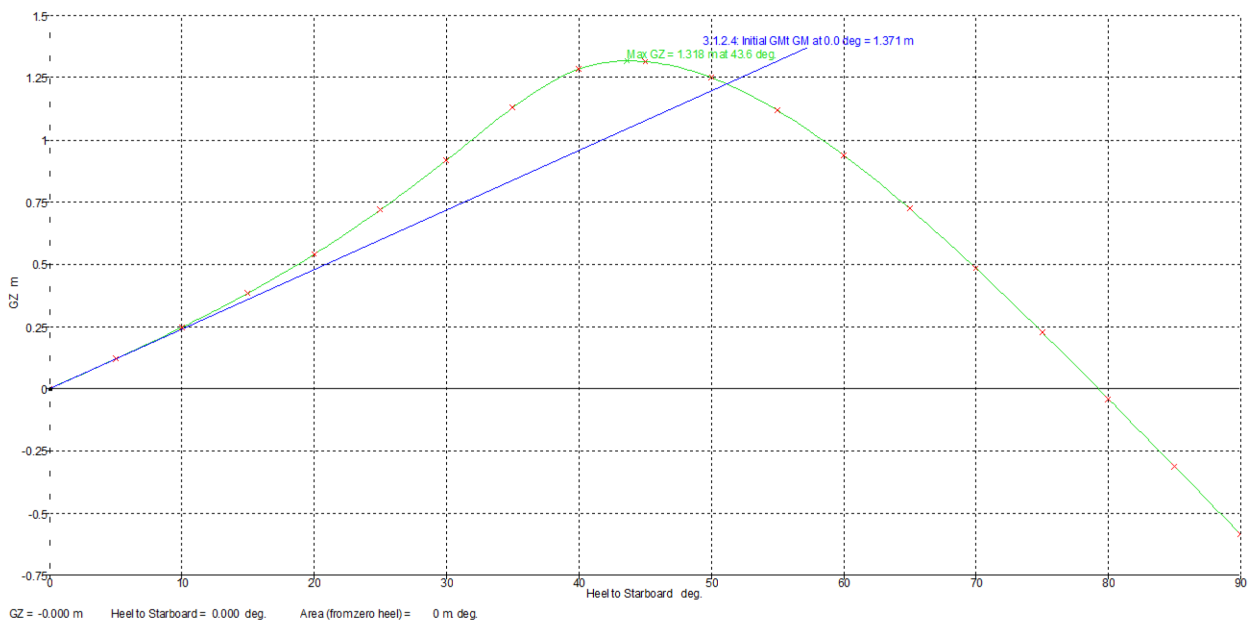
The team used Orca3D, Maxsurf to perform stability analysis for the vessel. The results of these analysis are presented in Figure 3-5 below.

Table 13 Intact Stability Results

Stability Results	Criteria					
Case	1	2	3	4	5	6
Light Ship	PASS	PASS	PASS	PASS	PASS	PASS
Fully Loaded	PASS	PASS	PASS	PASS	PASS	PASS
Partially Loaded	PASS	PASS	PASS	PASS	PASS	PASS

The vessel was expected to be least stable in the fully loaded condition and hence we wanted to make sure we passed this criteria. This was verified using Maxsurf to analyse the stability and plot the GZ Curve. The GZ Curve plot obtained from Maxsurf is shown below.

Figure 11: GZ plot at fully loaded draft.



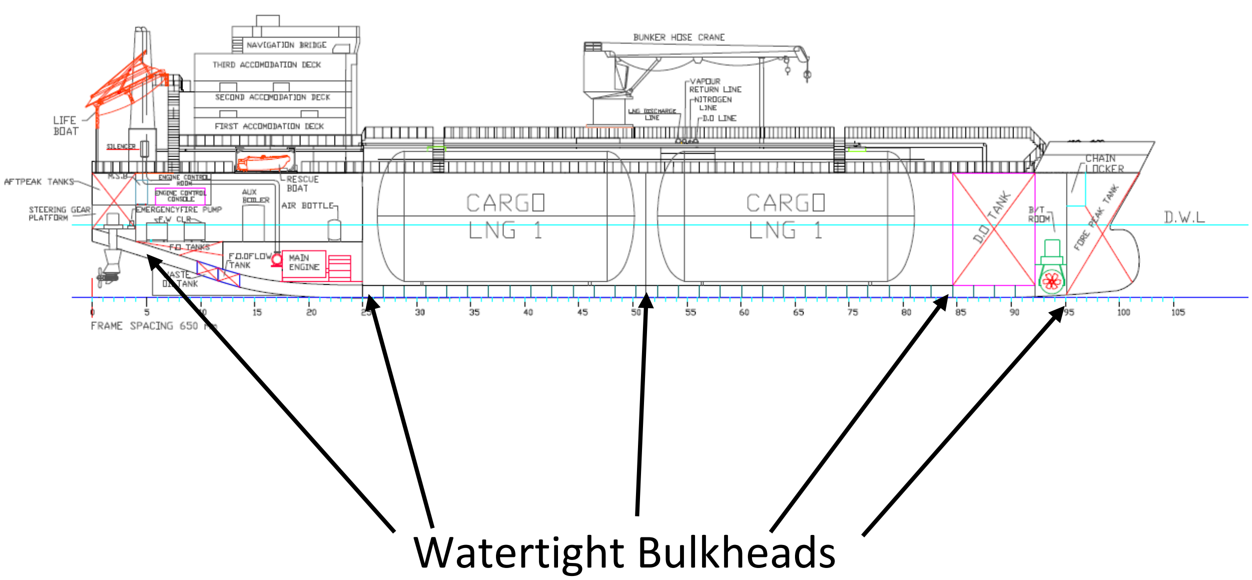
Detailed analysis results are attached as APPENDIX E .

The results of both agree fairly well, with the righting arm peaking at 46.4 degrees heel. The point of vanishing stability was found to be 81.6 degrees for the fully loaded condition. The GM ranges from 1.37 to 5.6 meters for various loading condition. Free surface effect was considered for partial loaded condition

12.0 DAMAGE STABILITY ANALYSIS

The ship is equipped with 5 transverse water tight bulkheads arranged along the length of the vessel. These include, the forward and aft collision bulkheads, engine room bulkheads and bulkheads separating the cargo compartments. In addition to these, two longitudinal bulkheads run along the length of the vessel making it a double hulled vessel in addition to being double bottom. The arrangement of the bulkheads and the water tight compartments are in accordance to Lloyds regulations. The arrangement of these bulkheads are shown in Figure 12 below.

Figure 12: Location of water tight bulkheads.



12.1 Analysis

Maxsurf was used to assess the damage stability. The calculations generated by the program were reasonable overall. As per IGC Codes our vessel was assessed to be of type 2PG. This kind of a vessel with size less than 150 m is expected to be able to sustain one compartment flooding. As per our analysis on Maxsurf it was observed that the vessel is capable of surviving.

12.2 Conclusion

As of today the vessel is equipped with 5 watertight bulkheads in accordance with Lloyd's rules and can with stand up to one compartment flooding in accordance with IGC Codes for Liquefied Gas Carriers of type 2PG.

13.0 General Arrangement

The arrangement of machinery and spaces have been discussed in the following section. This section mainly focuses on the following decks:

1) Main deck
2) First Deck
3) Second Deck
4) Third deck
5) Bottom Platform
6) First Platform
7) ECR Platform

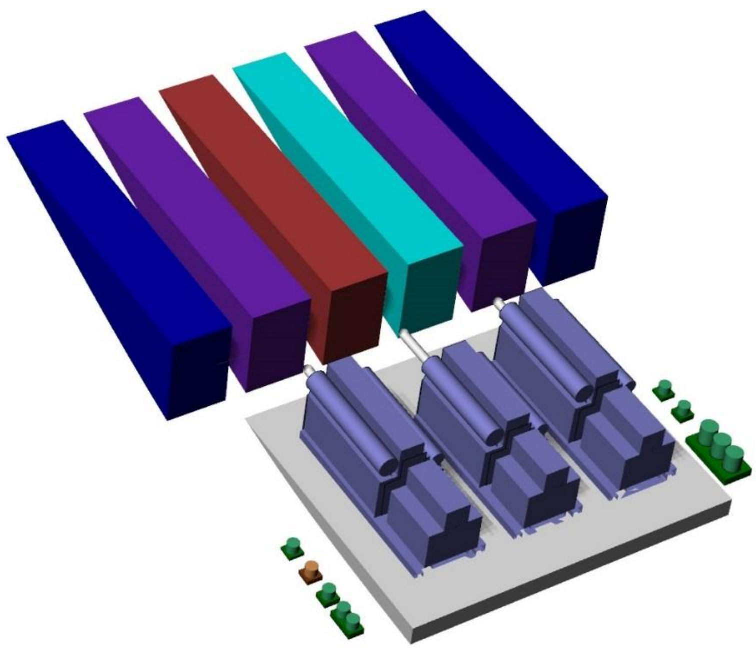


Figure 13: Bottom Platform

E/R Bottom Platform contains 3 main engines (2 Wartsila 9L20DF and 1 Wartsila 6L20DF), auxiliary pumps for Fuel transfer, Ejector Pump, Ballast Pumps, Sea water cooling pumps, and bilge pumps. All the main tanks required for normal operation are placed at this platform which includes 2 tanks for fresh water, 2 diesel oil fuel tanks, 1 lube oil tank, 1 bilge water tank. All tanks are of capacity 33.5 m^3. Also a cofferdam of .76 m is placed between each tank. Sludge tank and waste oil tank are placed in the double bottom.

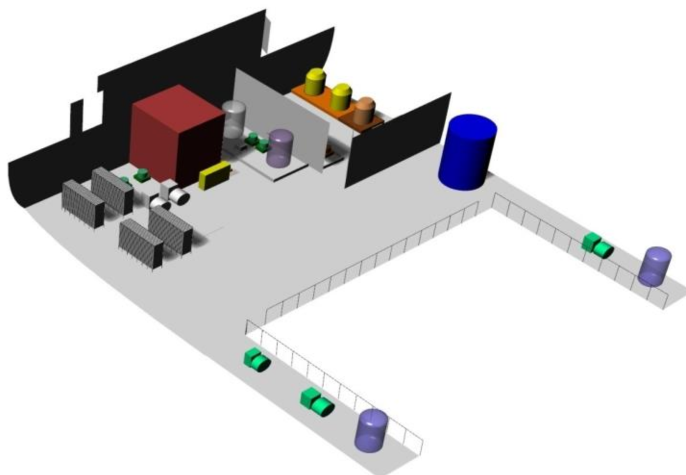


Figure 14: Engine Room 1st Platform

E/R First Platform contains all the major machineries required for normal operation. 2 main air compressors, 1 emergency air compressor, 2 air bottles, fuel preparation room, boiler, fresh water and lube oil coolers, sewage treatment plant, and fresh water preparation plant.

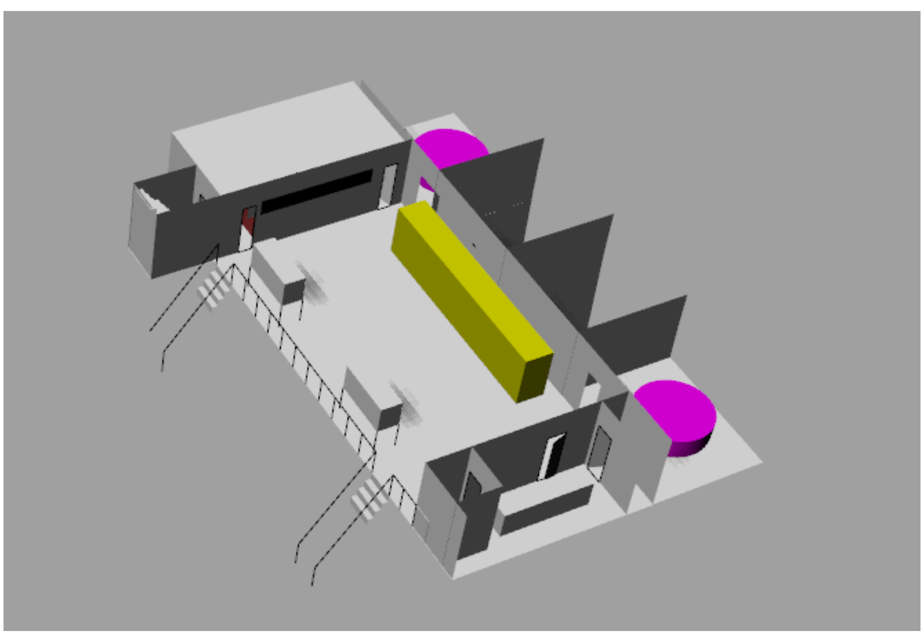


Figure 15: ECR platform

ECR Platform contains a workshop, HT and LT expansion tanks, electric switchboard, and access to steering gear compartment.

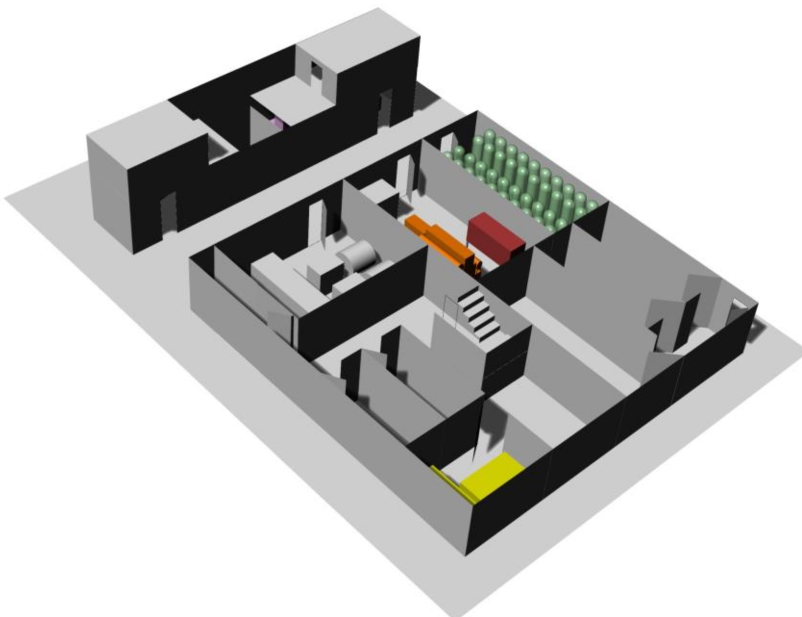


Figure 16: Main Deck

Main Deck: CO_2 fixed fire system is placed on the main deck, along with a fixed foam system. Air conditioning room with air handling unit and compressors is also placed at this deck with access from the back. Emergency generator is placed on the main deck. Main deck also contains the following:

- Galley stores: including general provision stores, meat and fish room, etc.
- Deck/ Engine crew changing room
- Access to ECR from Accommodation
- Cargo handling system: 1 Nitrogen generator plant and 1 Re-liquefaction plant

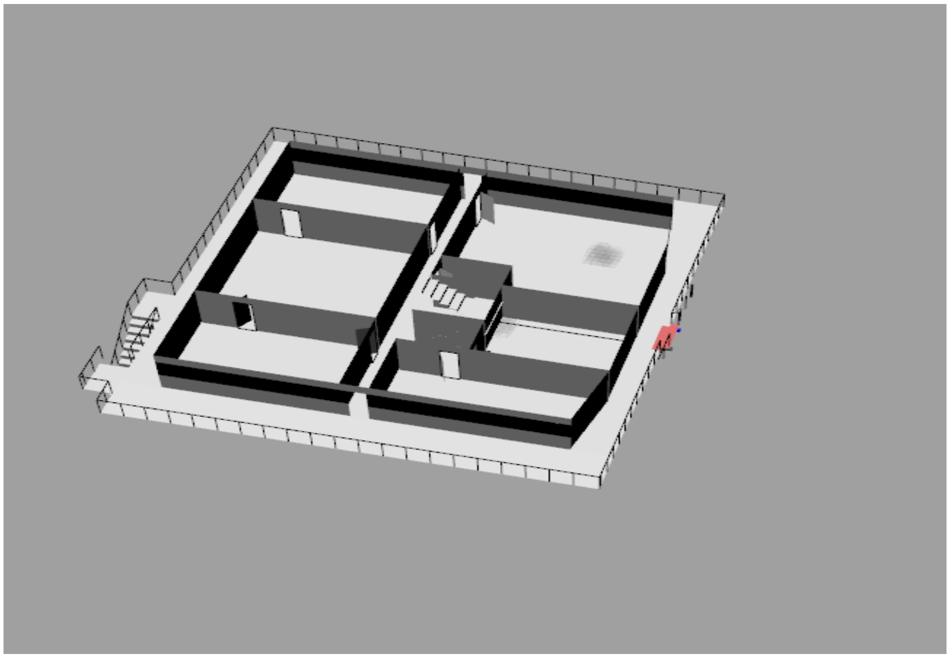


Figure 17: 1st Deck Accommodation

First Deck Accommodation includes galley, 1 officers mess room, 1 crew mess room, 1 cargo control room, 1 ship's office, one recreational room for the crew.

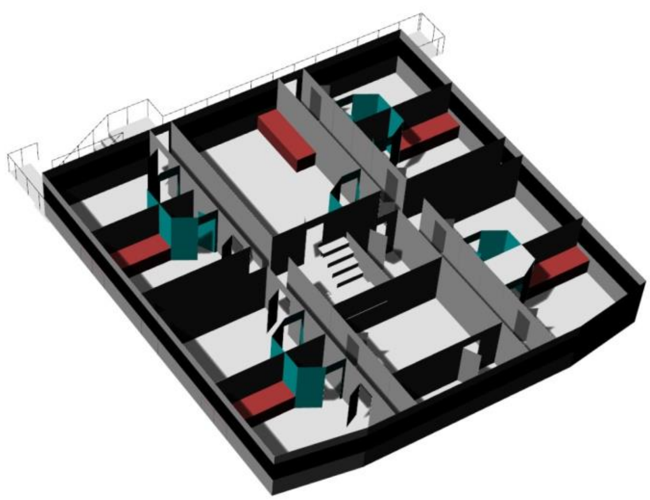


Figure 18: 2nd Deck Accommodation

Second Deck provides Accommodation to 8 crew members (3 for engine, 3 for deck, and 2 for galley staff). Each room has his individual bathroom. Stationary stores, Laundry facilities and a medical inspection room/hospital is placed at this deck.

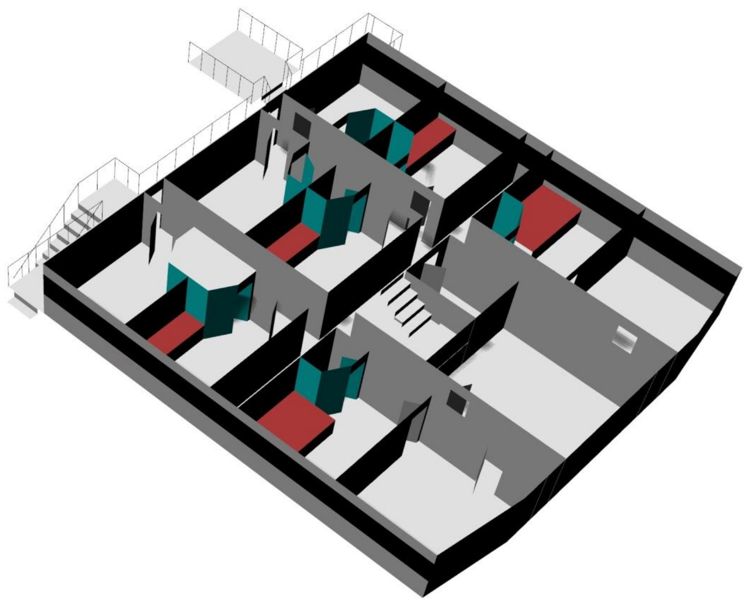


Figure 19: 3rd Deck Accommodation

Third Deck provides accommodation for Chief engineer/ Caption, 2 engineer officers and 2 deck officers. This deck also contains a conference room, owner's cabin and a spare cabin.

The Entire General Arrangement of the vessel can be found in Appendix I

14.0 STRUCTURAL DESIGN

This section describes the structural calculation and the Mid-ship section drawings for our vessel.

14.1 Rule Set

The structural calculations were carried out using Lloyd's Register Rules and Regulations. The rules used for the calculation was for an double bottom oil tanker, the reason for that is because of the close resemblance of the oil tankers structure to our ship in terms of structural members. The rules stipulate the general requirements, local and global loads, scantling requirements including shell envelope plating and framing. An excel sheet was developed for the calculation. In this excel sheet, took the particulars of the vessel and using the Lloyd's formulas the calculation was carried forth. The calculated thickness values for the structural members pass the minimum required thickness as specified in the rules. They were rounded up for a higher value for safety purposes as recommended by general guidelines of Lloyds register.

14.2 Design Methodology

The selection of a structural framing system is a very important design decision. It needs to be made from a consideration of weight, the ability of the vessel to be able to resist global loads, and vibrations. Ships are generally longitudinally or transversely framed.

Historically, early iron and steel vessels were built with transverse framing as this was the tired and used method for wooden ships. (James Roy, 2010). It was not until 1906 when longitudinal framing started being used for the Iron Clad vessels. In this novel design the longitudinal stiffeners and deep transverse web frames were used in the same way that modern arrangements do. The benefit was primarily a lighter structure, which for commercial vessels equated to increased deadweight for a given displacement, and hence a more profitable ship.

Furthermore, from a structural design viewpoint, the most important aspect is the ability of the stiffened plate to carry in-plane loads. Longitudinal bending of the hull girder, due to the buoyancy and weight distribution of the vessel, as well as the action of the waves, will induce stresses in the fore and aft direction. Thin shell plate is susceptible to buckling, and due to the orientation of the stiffeners, a transversely framed panel will have approximately a quarter of the strength of a longitudinally framed panel of the same size and thickness (James Roy, 2010). As a result, transversely framed vessels tend to have to have thicker plating, particularly on the decks, in order to have adequate buckling capacity to resist hull girder loads.

As the size of a vessel increases the significance of hull girder loads increases dramatically; Lloyd's generally require global strength calculations for all vessels over 50m. Currently small vessels are generally transversely framed, and larger vessels, when global loads become significant, are generally longitudinally framed. The transition occurs between 50m and 90m dependent on vessel type and usage.

Since our ship's length is 96 meters, it is considered a long ship and the usage of a transverse framing is not recommended. Therefore, we opted for the longitudinal framing configuration. Longitudinal system has longitudinal frame at the bottom, sides and decks, supported by widely spaced transverse web. This was particularly true for our vessel where we have LNG tanks and also diesel oil tank, where the increased web frame depth did not affect cargo stowage volume. This configuration can be seen in the Figure 20 below.

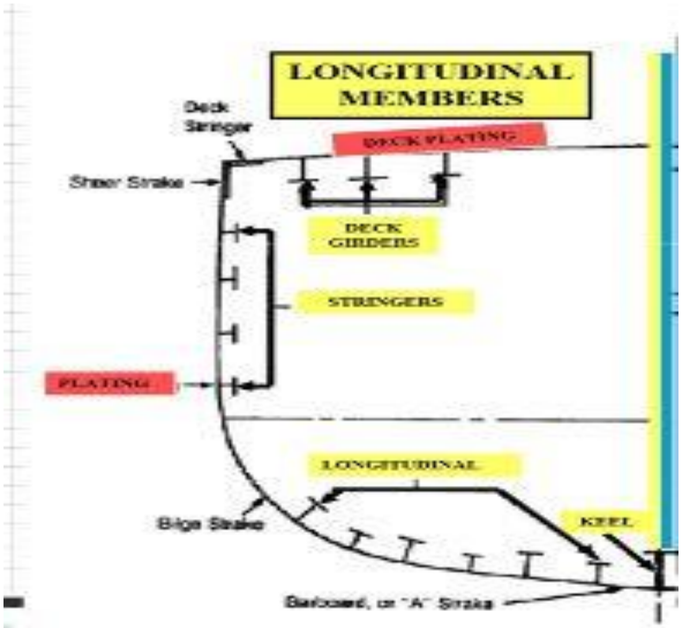


Figure 20: Longitudinal Framing

Following the rules from Lloyd's Register the following thicknesses were calculated:

Table 14 Thickness calculation for members

Members	Calculated Thickness (mm)	Taken Values (mm)
Deck	7.3	10
Bottom Plating Thickness	8.1	10
Bilge Plating	8.1	10
Keel Plate	11.2	12
Side shell above mid depth	6.7	8
Side shell below mid depth	7.3	8
Sheer strake and gunwale	7.3	10
Inner Hull Plate	6.9	9

14.3 Vessel Loading

The still water wave bending moments were calculated using Lloyd's Rules and the corresponding Shear force was evaluated. The following figure shows these results:

Still Water Bending Moment				
LBP		L	93	m
LWL		LWL	93	m
Breadth		B	18	m
Block Coefficient		Cb	0.74	
Navigation coefficient		n	0.8	coastal
Navigation coefficient		n1	0.9	coastal
		96%LWL	89.28	m
		97%LWL	90.21	m
Rule length			90.21	m
Location		x/L	0.5	
Distribution factor		F_M	1	
Wave parameter		C	7.7113745	
	Vertical Wave Bending Moment			
	Hogging	M WV,H	127054	kN.M
	Sagging	M WV,S	-143139	kN.M

	Still Water Bending Moment			
	Hogging	M sWM,H	129133	kN.M
	Sagging	M sWM,S	113048	kN.M

	Vertical Wave Shear Force			
		A	0.8876263	
FQ (positive)	FQ (Negative)	X/L	Positive-kn	Negative-kn
0	0	0	0	0
0.8166	-0.92	0.2	3533.87	-3981.26
0.8166	-0.92	0.3	3533.87	-3981.26
0.7	-0.7	0.4	3029.21	-3029.21
0.7	-0.7	0.6	3029.21	-3029.21
1	-0.887	0.7	4327.45	-3841.16
1	-0.887	0.85	4327.45	-3841.16
0	0	1	0	0

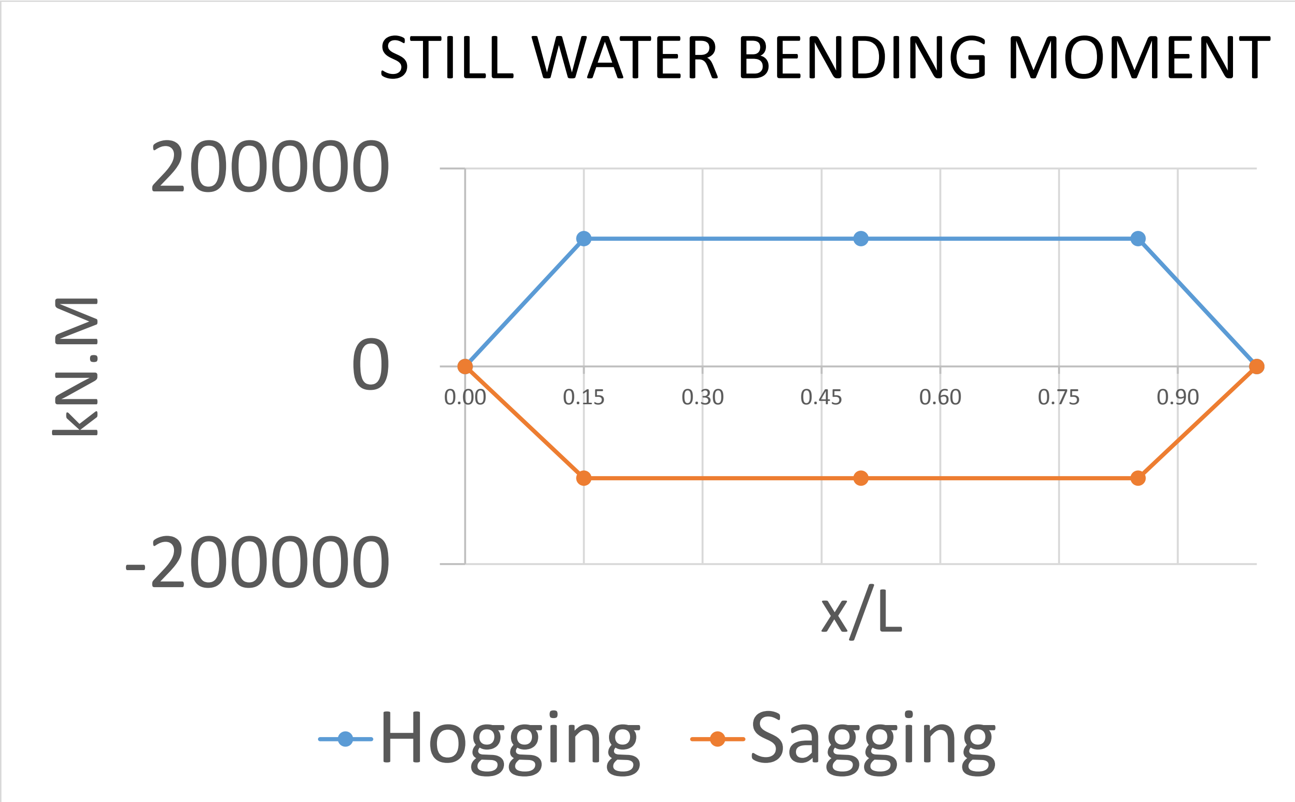


Figure 21: Bending Moment Diagram

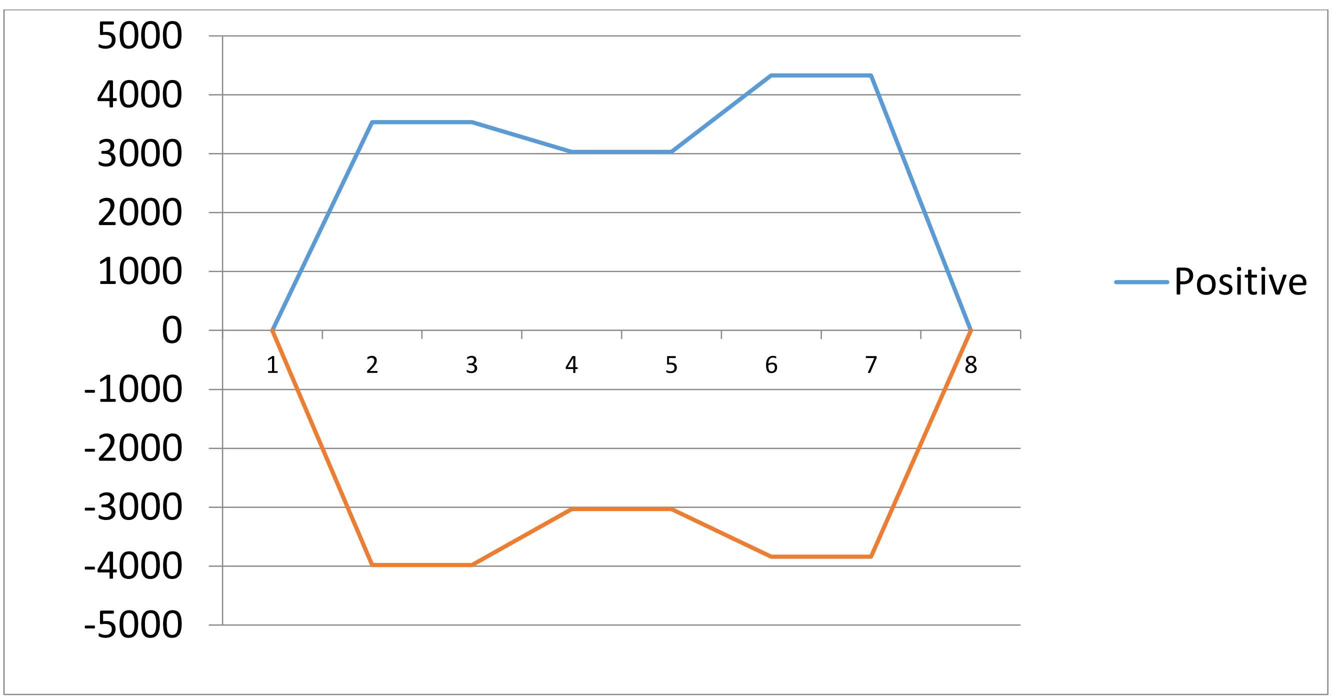


Figure 22: Shear Force Diagram

14.4 Mid-ship Section

A typical mid-ship section of our vessel is shown below. The complete mid-ship section of the vessel can be found in Appendix I.

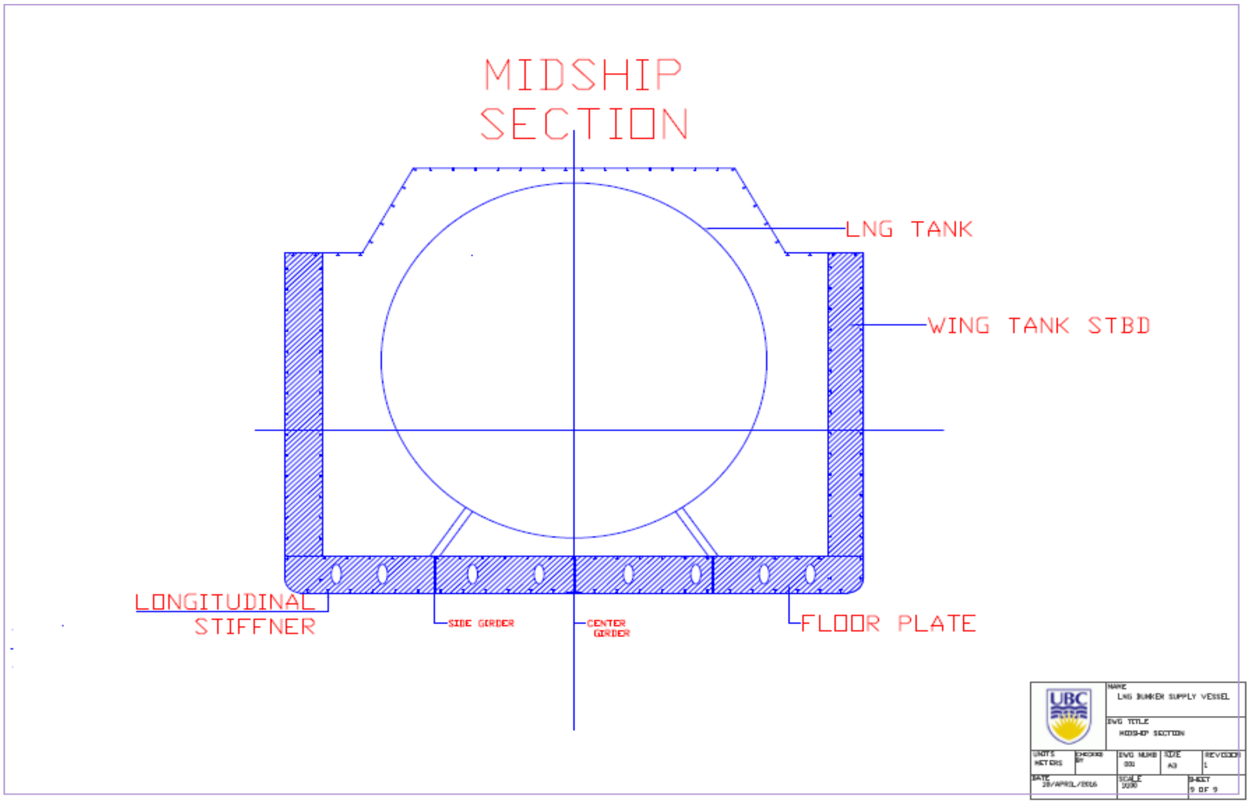


Figure 23Midship Section

15.0 WEIGHT ESSTIMATE

15.1 Parametric Estimate

To carry out the iteration on the ship dimensions and parameters needed to achieve a balance between weight and displacement and/or between required and available hull volume, deck area, and/or deck length, parametric models are needed for the various weight and volume requirements. Some of this information is available from vendor's information as engines and other equipment are selected or from characteristics of discrete cargo and specified payload equipment.

Parametric weight estimate was carried out based on ship design and construction by Thomas Lamb. The total light ship weight was given by

$W_{LS} = W_S + W_M + W_O + W_{margin}$

Where:

W_S = the structural weight

W_M = propulsion machinery weight

W_O = outfit and hull engineering weight

W_{margin} = Lightship design (or Acquisition) weight margin that is included as protection against the under- prediction of the required displacement

The estimation of weight at the early parametric stage of design typically involves the use of parametric models that are developed from weight information for similar vessels. A fundamental part of this modeling task is the selection of relevant independent variables that are correlated with the weight or center to be estimated.

15.1.1 Structural Weight

The structural weight includes (1) the weight of the basic hull to its depth amidships; (2) the weight of the super- structures, those full width extensions of the hull above the basic depth amidships such as a raised forecastle or poop; and (3) the weight of the deckhouses, those less than full width erections on the hull and superstructure. Because the superstructures and deckhouses have an important effect on the overall structural VCG and LCG, it is important to capture the designer's intent relative to the existence and location of superstructures and deckhouses as early as possible in the design process.

$$E = E_{hull} + E_{SS} + E_{dh}$$
$$= L(B + T) + 0.85L(D - T) + 0.85 \Sigma\, i h_i + 0.75 \Sigma j h_j$$

This independent variable is an area type independent variable. The first term represents the area of the bottom, the equally heavy main deck, and the two sides below the waterline. (The required factor of two is absorbed into the constant in the eventual equation.) The second term represents the two sides above the waterline, which are somewhat (0.85) lighter since they do not experience hydrostatic loading. These first two terms are the hull contribution E_{hull}. The third term is the sum of the profile areas (length x height) of all of the superstructure elements and captures the superstructure contribution to the structural weight. The fourth term is the sum of the profile area of all of the deckhouse elements, which are relatively lighter (0.75/0.85) because they are further from wave loads and are less than full width.

We calculated the structural weight by using the given formula:

$$W_S = W_S(E) = K\, E^{1.36} [1 + 0.5(C_B' - 0.70)]$$

Where $C_B' = C_B + (1 - C_B)[(0.8D - T)/3T]$

The weight estimate for a single deckhouse can be estimated using the following approach:

$$W_{dh} = W_S(E_{hull} + E_{SS} + E_{dh}) - W_S(E_{hull} + E_{SS})$$

And the structural weight coefficient K was given by the given table:

Ship type	*K mean*	*K range*	*Range of E*
Tankers	0.032	±0.003	1500 < E < 40 000
Chemical tankers	0.036	±0.001	1900 < E < 2500
Bulk carriers	0.031	±0.002	3000 < E < 15 000
Container ships	0.036	±0.003	6000 < E < 13 000
Cargo	0.033	±0.004	2000 < E < 7000
Refrigerator ships	0.034	±0.002	4000 < E < 6000
Coasters	0.030	±0.002	1000 < E < 2000
Offshore supply	0.045	±0.005	800 < E < 1300
Tugs	0.044	±0.002	350 < E < 450
Fishing trawlers	0.041	±0.001	250 < E < 1300
Research vessels	0.045	±0.002	1350 < E < 1500
RO-RO ferries	0.031	±0.006	2000 < E < 5000
Passenger ships	0.038	±0.001	5000 < E < 15 000
Frigates/corvettes	0.023		

15.1.2 Machinery Weight Estimation

The machinery weight in the commercial classification includes only the propulsion machinery primarily the prime mover, reduction gear, shafting, and propeller. We used Watson and Gilfillan method for a useful separation of this weight between the main engine(s) and the remainder of the machinery weight:

$$W_M = W_{ME} + W_{rem}$$

This approach is useful because in commercial design, it is usually possible to select the main engine early in the design process permitting the use of specific vendor's weight and dimension information for the prime mover from very early in the design. If an engine has not been selected, they provided the conservative regression equation for an estimate about 5% above the mean of diesel electric engine data:

$$W_M = 0.72\ (MCR)^{0.78}$$

Where now MCR is the total capacity of all generators in kW. The weight of the remainder of the machinery varies as the total plant MCR as follows:

$$W_{rem} = C_m\ (MCR)^{0.70}$$

$$C_m = .72 \text{ for tankers}$$

15.1.3 Outfitting Weight Estimation

The outfit includes the remainder of the Lightship weight. In earlier years, these weights were classified into two groups as *outfit*, which included electrical plant, other distributive auxiliary systems such as HVAC, joiner work, furniture, electronics, paint, etc., and *hull engineering*, which included the bits, chocks, hatch covers, cranes, windlasses, winches, etc. Total outfitting weight was given by:

$$W_o = C_o LB$$

Where the outfit weight coefficient C_o is a function of ship type and for some ship types also ship length as shown in Figure 24.

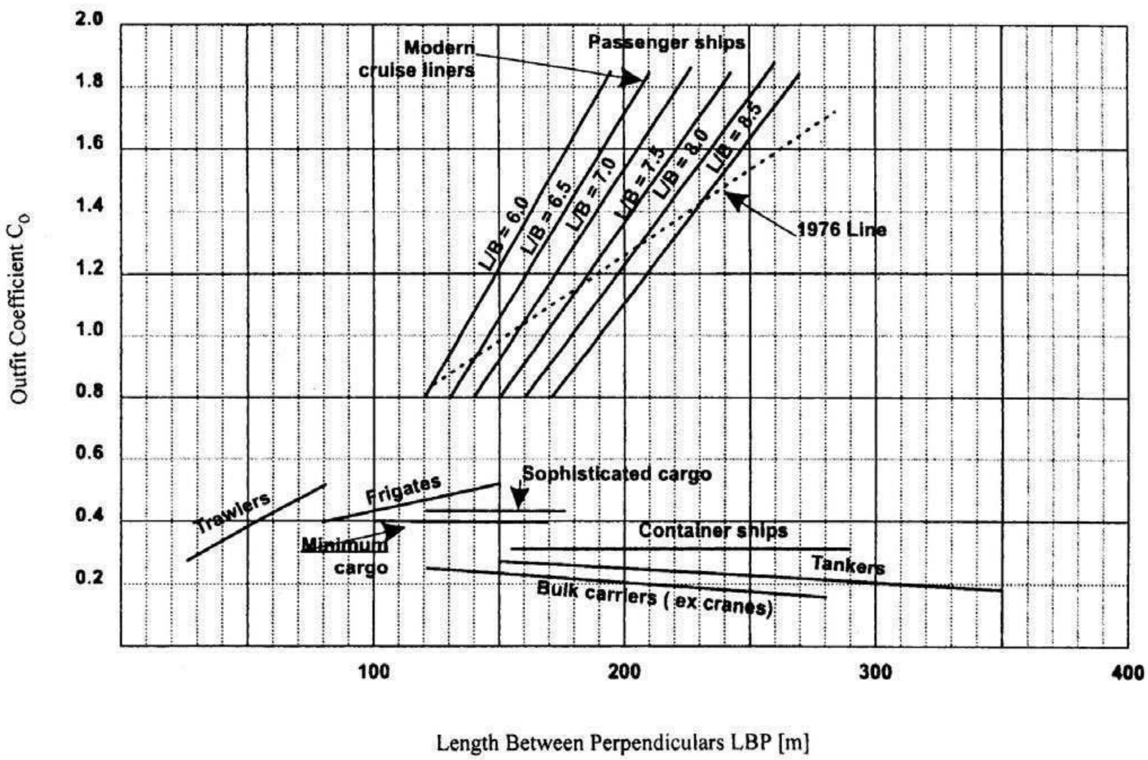


Figure 24: Outfit weight Coefficient

15.1.4 Weight Margins

A typical commercial vessel Lightship design (or acquisition) weight margin might be 3-5%; Watson and Gilfillan recommend using 3% when using their weight estimation models. This is usually placed at the center of the rest of the Lightship weight. This margin is included to protect the design (and the designer) since the estimates are being made very early in the design process using approximate methods based only upon the overall dimensions and parameters of the design.

15.2 Light Ship Weight Estimation

And a detailed weight estimation was calculated manually by using the structural thicknesses from above. The calculated thickness values for the structural members pass the minimum required thickness. They were rounded up for a higher value for safety purposes as recommended by general guidelines of Lloyds register.

Once all the thickness values were calculated, the next step was to develop a second spreadsheet in which all the members for the mid-ship section was counted. Based on the number of members, their thickness, length, and calculated area, their volume was calculated. This volume (mm^3) multiplied by the density of steel (tonnes/mm^3) gave us their weight in tonnes. The total number for each members was obtained by multiplying the weight by total number of members. The total weight was calculated for 3 frame spacing which is 1.95 meters. We divided the total added weight by 1.95 meters and multiplied it by mid-ship length which was 68 meters. This gave us the necessary scaling factor for the mid-ship. Table 15 shows the tabulated weight for the mid-ship.

Midship Section	Number of Members	Thickness (mm	Length (mm	Area (mm^2	Volume (mm^3	Density of steel (tonnes/mm^3	Weight (tonnes)	Total Weight (tonnes)
Longitudinal stiffners	150	9	1950	1188	2316600	7.8E-09	0.018	2.7
Inner hull plating		9	1950	140400	273780000	7.8E-09	2.1	2.1
Web frame	1	9		46320000	416880000	7.8E-09	3.25	3.25
Brackets for double bottom	4	10		720000	7200000	7.8E-09	0.056	0.22
Brackets for main cargo tank	4	10		720000	7200000	7.8E-09	0.056	0.22
Floors	1	10	18000	21600000	216000000	7.8E-09	1.685	1.68
Center girder	1	9	1950	22512	43898400	7.8E-09	0.342	0.34
Side girder	2	8	1950	15072	29390400	7.8E-09	0.229	0.46
Deck plating	-	8	1950	144000	280800000	7.8E-09	2.190	2.19
Bottom + Bilge plating+ side shell	-	10	1950	294800	574860000	7.8E-09	4.484	4.48
Keel Plate	-	12	1950	14400	28080000	7.8E-09	0.219	0.22
Sheerstrake and gunwale	-	10	1950	12500	24375000	7.8E-09	0.190	0.19
thickness of the end bracket plating	12	10	-	1320000	13200000	7.8E-09	0.103	1.24
								19.3
							Scaled	673.5794316

Table 15 Midship weight calculation

This gave us the total weight for a section of the ship. Similar approach was used for other sections of the vessel, i.e. Engine room, superstructure and forward of collision bulkhead which enabled us to get the total structural weight for the vessel which came out to be **1,694 tonnes**.

Due to the lack of data of certain auxiliary systems and detailed pipeline system, the machinery and outfitting weight was directly taken form the empirical formulas given above. The total light ship weight was calculated to be **2937 tonnes**.

Different Group Members	Weight (Tonnes)
Hull Structure Weight	1581
Super Structure Weight	112
Machinery Weight	512
Outfitting Weight	552
Cargo Tanks weight	180
Light Ship Weight	**2,937**

16.0 COST ANALYSIS

This section outlines the cost analysis that was performed for our vessel. The results of these analysis are explained further in this section while the entire cost analysis can be found in Appendix H.

16.1 Construction Cost Analysis

The cost of constructing the vessel was determined based on the weight of the vessel. The weight of the vessel determined from the structural analysis as well as the tank selection were used to determine the material and associated labour cost of the vessel.

The cost of the vessel was estimated to be around 24-25 million dollars as shown below:

Table 16 Cost Analysis

SYSTEM NUMBER	TITLE	WEIGHT [TON]	RATE [MAN HRS/TON]	MAN HOURS	MATERIAL	Material[$/t]
100	HULL	**1696**	**25**	**42,410**	**$1,187,501**	**700**
200	PROPULSION M/C	**64**	**30**	**1,920**	**$896,000**	**14000**
300	ELECTRICAL	**50**	**55**	**2,750**	**$900,000**	**18000**
400	COMMAND & COMM	**25**	**250**	**6,250**	**$875,000**	**35000**
500	AUXILLIARY M/C	**382**	**102**	**39,015**	**$3,442,500**	**9000**
600	OUTFIT	**552**	**55**	**30,381**	**$3,314,304**	**6000**
600	LNG Tanks - 9 NI FE	**177**	**12**	**2,126**	**$106,344**	**600**
800	ENGINEERING			**30,682**	**$10,615,305**	
900	SUPPORT SERVICES			**61,363**		
	SUB-TOTAL LABOR HOURS			**216,899**		
	SUB-TOTAL LABOR DOLLARS					**$ 7,411,838**
	SUB-TOTAL LABOR & MATERIALS					**$ 16,133,487**
	OVERHEAD					**$ 3,517,694**
	TOTAL LABOR, MATERIALS AND OVERHEAD					**$ 19,651,181**
	MARGIN					**$ 1,965,118**
	PROFIT					**$ 982,559**
	Approximate Bid Price					**$ 24,598,859**

16.1.1 Construction Cost Summary

The labour rate was taken to be $30/hr, while the rate for skilled engineering services was taken to be $45/hr. A margin of 15% was taken in to account while a profit of 15% was considered. This falls well within the range of $20 million to $25 million.

17. CONCLUSION

The concept design of a LNG bunker supply vessel revolved around addressing the need to provide an infrastructure to help ships tackle the problem of pollution and comply with the MARPOL tier 3 regulations. These challenges were enhanced and reflected in the owner's requirements. In designing such a vessel we proceeded by identifying the available solutions by taking a look at the existing vessels and performing a parent vessel analysis. Based on the results of these analysis we decided to develop our hull form. From here on we proceeded to analyses the resistance and powering required by our vessel. Based on these results we selected our machinery. The vessel's structure was analysed following Lloyd's Register rules and the weight was estimated thereafter. Apart from these the stability of the vessel was assessed using ORCA 3D as well as MAXSURF. And finally, the drawings were generated using AutoCAD.

Given the limitation of time and resources some issues still need to be resolved. The following should be addressed in subsequent design cycles:

1) Detailed design and analysis of all marine systems including but not restricted to the electrical systems, piping system, HVAC system, etc.
2) Detailed analysis of the life cycle cost as well as the Return on investment for the vessel to be assessed.
3) CFD analysis of the vessel to be carried out to support the resistance and powering estimations made.

In conclusion, we'd like to present to you the conceptual study done for a LNG Bunker Supply Vessel. This vessel will be constructed based on Lloyd's Class rules sail under the Canadian flag. The project was done in accordance to the requirement set up by the University of British Columbia's Naval Architecture and Marine Engineering program.

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APPENDIX A: PARAMETRIC STUDY

		LENGTH (m)	BEAM (m)	DRAFT (m)	DEPTH (m)	Cb
1	MEMBRANE TANK	82.45	15	4.5	9.5	0.691
2	CYLINDRICAL - 1 LONGITUDINAL TANK	99.18	12.7	5.15	11.8	0.684
3	CYLINDRICAL - 2 LONGITUDINAL TANK	96.9	15	5	11.5	0.685
4	CYLINDRICAL - 2 TRANSVERSE TANK	88.02	19.5	4.5	9.5	0.617
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	89.02	19.5	4.5	9.5	0.693
6	CYLINTRICAL - 4 VERTICAL (2*2)	79.5	14	5	10.5	0.687
7	SPHERICAL - 2 LONGITUDINAL TANK	53.17	18	9	18	0.687
8	SPHERICAL - 4 TANK (Longitudinal)	91.5	15.4	5.5	11.5	0.687
9	SPHERICAL-1 TANK	34	22	11	22	0.58
10	SPHERICAL-4 TRANSVERSE	26.58	17.28	4.5	9	0.648
11	Cyl 2L- 88 mt, 15 mt	88	15	4	8	0.698
12	Cyl 2L- 67m,20mt	67	20	4.5	10	0.684

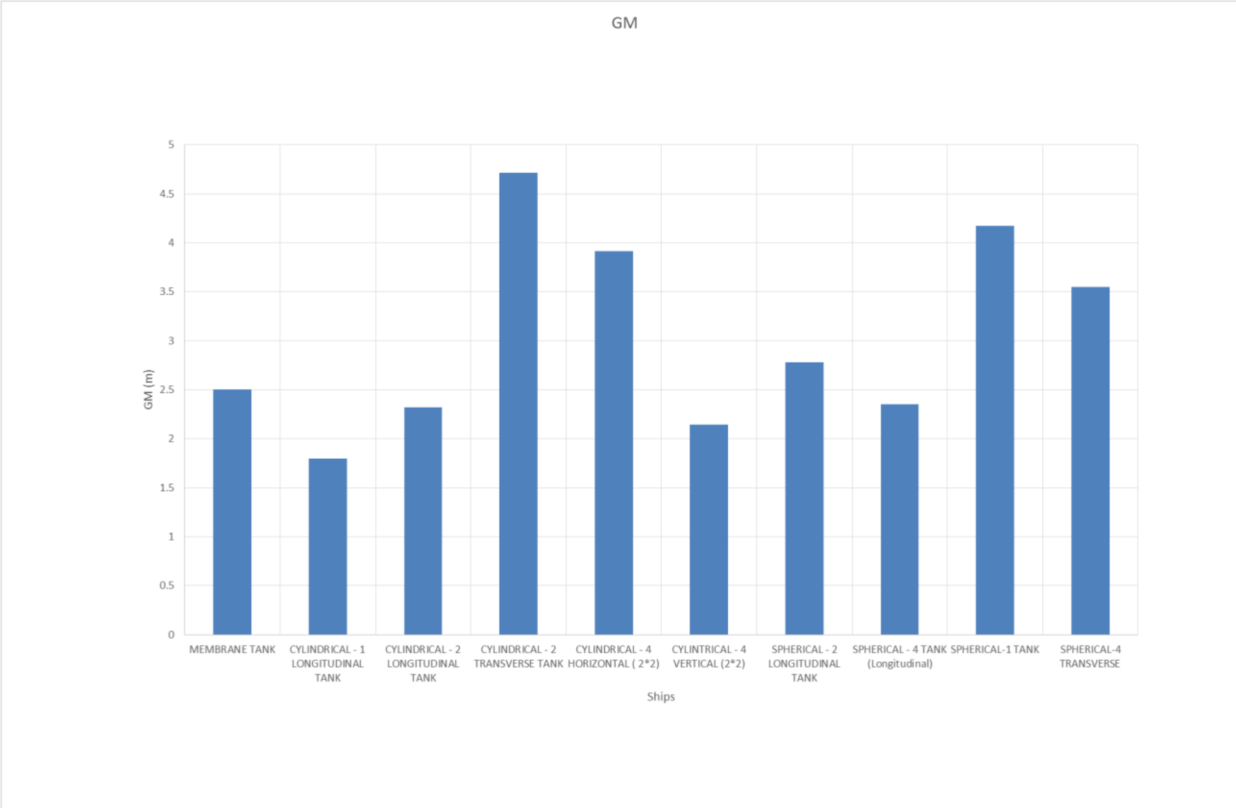
		Displacement (tonnes)	DWT (tonnes)	GM (m)
1	MEMBRANE TANK	3941.815978	1811.711672	2.505
2	CYLINDRICAL - 1 LONGITUDINAL TANK	4547.943085	2219.442769	1.795
3	CYLINDRICAL - 2 LONGITUDINAL TANK	5102.693438	2537.652782	2.319
4	CYLINDRICAL - 2 TRANSVERSE TANK	4884.695756	2172.375549	4.714
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	5548.707289	2765.946107	3.912
6	CYLINTRICAL - 4 VERTICAL (2*2)	3918.733875	1845.011207	2.144
7	SPHERICAL - 2 LONGITUDINAL TANK	6065.43953	2934.279035	2.78
8	SPHERICAL - 4 TANK (Longitudinal)	5457.391459	2899.660784	2.354
9	SPHERICAL-1 TANK	4891.546	1343.87014	4.171
10	SPHERICAL-4 TRANSVERSE	1372.808943	-448.4202642	3.548
11	Cyl 2L- 88 mt, 15 mt	3777.576	1590.376224	2.731
12	Cyl 2L- 67m,20mt	4227.633	1889.813063	4.103

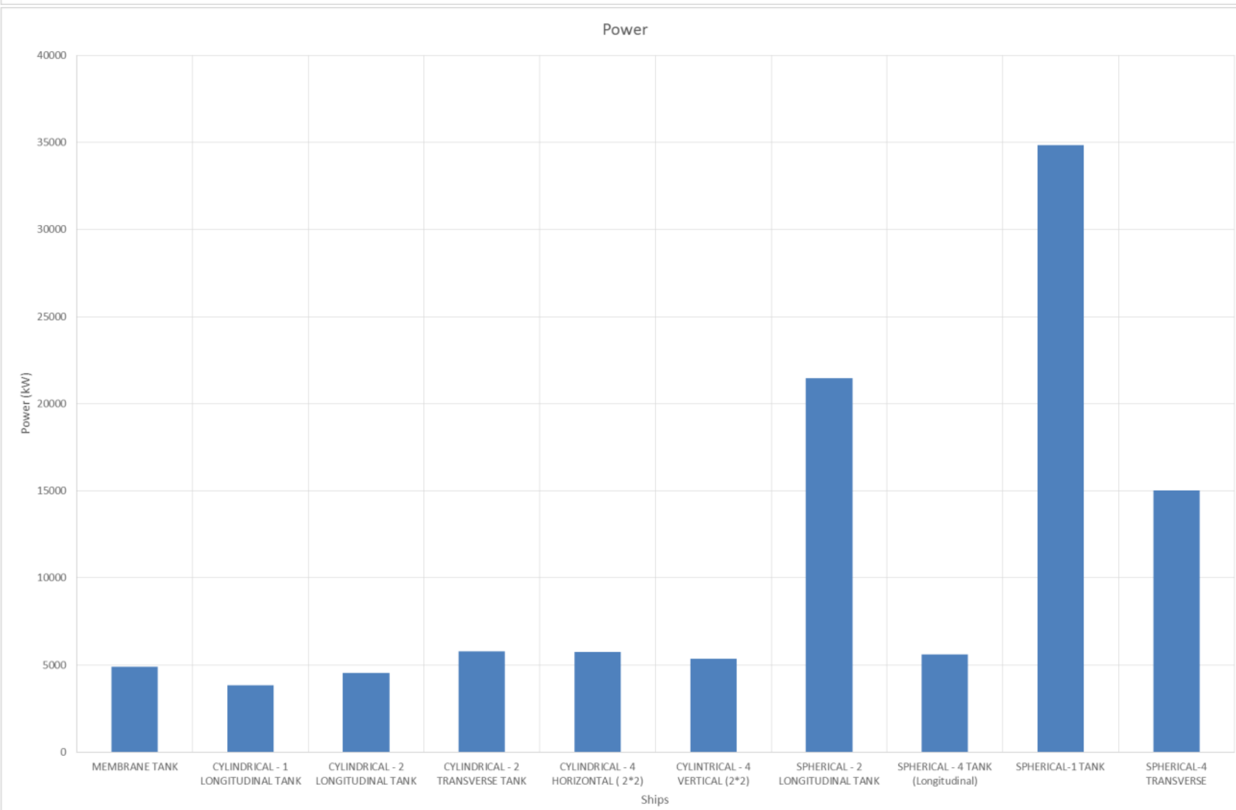
		POWER (kW)	POWER REQ (kW)
		(@15 KNOTS)	(RESIS+MARGIN)
1	MEMBRANE TANK	4240.7	4876.805
2	CYLINDRICAL - 1 LONGITUDINAL TANK	3333.8	3833.87
3	CYLINDRICAL - 2 LONGITUDINAL TANK	3946.2	4538.13
4	CYLINDRICAL - 2 TRANSVERSE TANK	5015.8	5768.17
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	4984.8	5732.52
6	CYLINTRICAL - 4 VERTICAL (2*2)	4645.7	5342.555
7	SPHERICAL - 2 LONGITUDINAL TANK	18664.5	21464.175
8	SPHERICAL - 4 TANK (Longitudinal)	4875.6	5606.94
9	SPHERICAL-1 TANK	30306.3	34852.245
10	SPHERICAL-4 TRANSVERSE	13046.9	15003.935
11	Cyl 2L- 88 mt, 15 mt	4474	5145.1
12	Cyl 2L- 67m,20mt	6069	6979.35

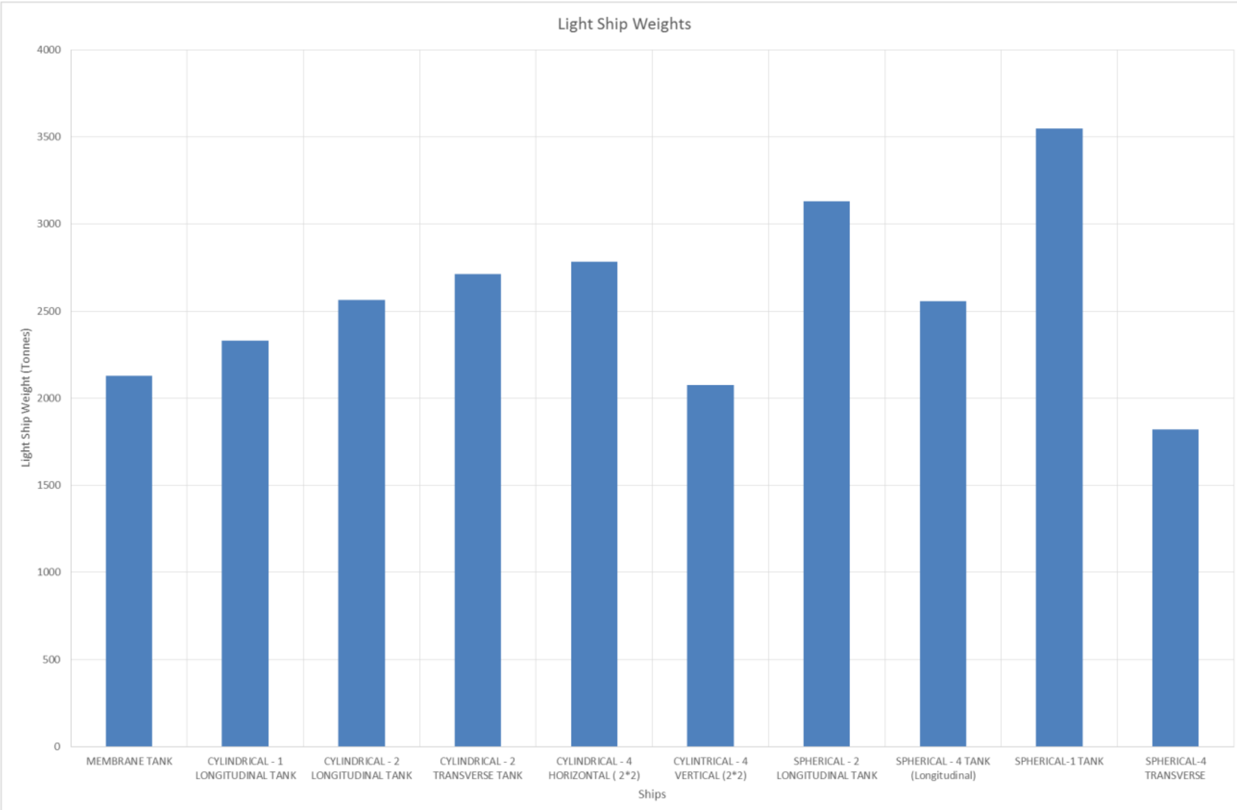
		Lloyd's equipment numeral			
		HULL	SUPER STRUCTURE	DECKHOUSE	Total
1	MEMBRANE TANK	1958.188	153	135	2246.1875
2	CYLINDRICAL - 1 LONGITUDINAL TANK	2330.978	153	135	2618.97795
3	CYLINDRICAL - 2 LONGITUDINAL TANK	2473.373	153	135	2761.3725
4	CYLINDRICAL - 2 TRANSVERSE TANK	2486.565	153	135	2774.565
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	2514.815	153	135	2802.815
6	CYLINTRICAL - 4 VERTICAL (2*2)	1882.163	153	135	2170.1625
7	SPHERICAL - 2 LONGITUDINAL TANK	1842.341	153	135	2130.3405
8	SPHERICAL - 4 TANK (Longitudinal)	2379	153	135	2667
9	SPHERICAL-1 TANK	1439.9	153	135	1727.9
10	SPHERICAL-4 TRANSVERSE	680.5809	153	135	968.5809
11	Cyl 2L- 88 mt, 15 mt	1971.2	153	135	2259.2
12	Cyl 2L- 67m,20mt	1954.725	153	135	2242.725

				Weight coefficent	STRUCTURAL WEIGHT (tonnes)
		K FACTOR	Cb'	Co	
1	MEMBRANE TANK	0.032	0.76196	0.32	1192.245937
2	CYLINDRICAL - 1 LONGITUDINAL TANK	0.032	0.77174	0.32	1476.09841
3	CYLINDRICAL - 2 LONGITUDINAL TANK	0.032	0.7732	0.32	1587.417547
4	CYLINDRICAL - 2 TRANSVERSE TANK	0.032	0.70495	0.32	1545.141286
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	0.032	0.7635	0.32	1612.323208
6	CYLINTRICAL - 4 VERTICAL (2*2)	0.032	0.75795	0.32	1135.490655
7	SPHERICAL - 2 LONGITUDINAL TANK	0.032	0.7496	0.32	1102.756858
8	SPHERICAL - 4 TANK (Longitudinal)	0.032	0.75719	0.32	1502.398844
9	SPHERICAL-1 TANK	0.032	0.664	0.32	794.8529097
10	SPHERICAL-4 TRANSVERSE	0.032	0.7184	0.32	371.7680343
11	Cyl 2L- 88 mt, 15 mt	0.032	0.7584	0.32	1199.576971
12	Cyl 2L- 67m,20mt	0.032	0.76593	0.32	1192.038058

		MACHINERY WEIGHT (tonnes)	OUTFITTING WEIGHT (tonnes)	Light Ship Weight (tonnes)
1	MEMBRANE TANK	542.0983696	395.76	2130.104306
2	CYLINDRICAL - 1 LONGITUDINAL TANK	449.3343859	403.06752	2328.500316
3	CYLINDRICAL - 2 LONGITUDINAL TANK	512.5031085	465.12	2565.040656
4	CYLINDRICAL - 2 TRANSVERSE TANK	617.9341208	549.2448	2712.320206
5	CYLINDRICAL - 4 HORIZONTAL (2*2)	614.9531745	555.4848	2782.761183
6	CYLINTRICAL - 4 VERTICAL (2*2)	582.0720125	356.16	2073.722668
7	SPHERICAL - 2 LONGITUDINAL TANK	1722.144436	306.2592	3131.160494
8	SPHERICAL - 4 TANK (Longitudinal)	604.4198312	450.912	2557.730675
9	SPHERICAL-1 TANK	2513.46295	239.36	3547.67586
10	SPHERICAL-4 TRANSVERSE	1302.484405	146.976768	1821.229208
11	Cyl 2L- 88 mt, 15 mt	565.2228052	422.4	2187.199776
12	Cyl 2L- 67m,20mt	716.9818785	428.8	2337.819937


GM
GM (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
MEMBRANE TANK
CYLINDRICAL - 1 LONGITUDINAL TANK
CYLINDRICAL - 2 LONGITUDINAL TANK
CYLINDRICAL - 2 TRANSVERSE TANK
CYLINDRICAL - 4 HORIZONTAL (2*2)
CYLINTRICAL - 4 VERTICAL (2*2)
SPHERICAL - 2 LONGITUDINAL TANK
SPHERICAL - 4 TANK (Longitudinal)
SPHERICAL-1 TANK
SPHERICAL-4 TRANSVERSE
Ships


Power
Power (kW)
40000
35000
30000
25000
20000
15000
10000
5000
0
MEMBRANE TANK
CYLINDRICAL - 1 LONGITUDINAL TANK
CYLINDRICAL - 2 LONGITUDINAL TANK
CYLINDRICAL - 2 TRANSVERSE TANK
CYLINDRICAL - 4 HORIZONTAL (2*2)
CYLINTRICAL - 4 VERTICAL (2*2)
SPHERICAL - 2 LONGITUDINAL TANK
SPHERICAL - 4 TANK (Longitudinal)
SPHERICAL-1 TANK
SPHERICAL-4 TRANSVERSE
Ships


Light Ship Weights
Light Ship Weight (Tonnes)
4000
3500
3000
2500
2000
1500
1000
500
0
MEMBRANE TANK
CYLINDRICAL - 1 LONGITUDINAL TANK
CYLINDRICAL - 2 LONGITUDINAL TANK
CYLINDRICAL - 2 TRANSVERSE TANK
CYLINDRICAL - 4 HORIZONTAL (2*2)
CYLINTRICAL - 4 VERTICAL (2*2)
SPHERICAL - 2 LONGITUDINAL TANK
SPHERICAL - 4 TANK (Longitudinal)
SPHERICAL-1 TANK
SPHERICAL-4 TRANSVERSE
Ships

APPENDIX B: TANK CALCULATIONS

Design pressure	5	bar	p
Inside Radius	6000	mm	Ri
Design Temperature	-170	deg C	T
Weld Joint Efficency	1		J

Tank Dimensions		
Length	23.8	mt
Radius	6	mt

Weld Joint Efficiency			
Class 1	Class 2 A	Class 2B	Class 3
1	0.85	0.75	0.6

Constants for Allowable stree factor			
	9 Ni	36 Ni- Fe	Al
A	3	3.5	4
B	1.5	1.5	1.5

Thickness of Tank	t= [(P*Ri)/(10*σa*J-0.5*P)] + 0.75			mm
Al	40.88378	mm		
9 Ni	13.62095	mm		
36 Ni- Fe	13.3683	mm		
Torispherical Ends	**t= [(P*Ri)/(20*σa*J-0.5*P)] + 0.75**			**mm**
Al	20.78339	mm		
9Ni	7.182026	mm		
36 Ni- Fe	7.055833	mm		

		Density (Kg/m3)	Allowable stress (σa) (N/mm2)	Tensile strength (Rm) (N/mm2)	Yield Strength (Re) (N/mm2)
Alluminium	5083-0	2660	25	300	145
Nickel	9 Ni Steel	7860	55	700	490
Steel	36 Ni Fe	8120	55	833	612

		Rm/A	Re/B	Lower Value (f)		Membrane Stress *(σm)(N/mm2)*	Min Design Pressure (bar)
Alluminium	5083-0	75	96.666667	75	Mpa	75	2.574579988

Nickel	9 Ni Steel	233.33333	326.66667	233.333	Mpa	233.333	3.149039443
Steel	36 Ni Fe	238	408	238	Mpa	238	3.195464052

Design Pressure should not be less than Design vapour pressure

$P_o = .2 + AC(\rho)^{1.5}$ P_o= Min Design Pressure

A= 0.00185*(σm/σa)^2

σm < f

ρ (R.D of LNG) 0.47 C= 0.45 Length of tank

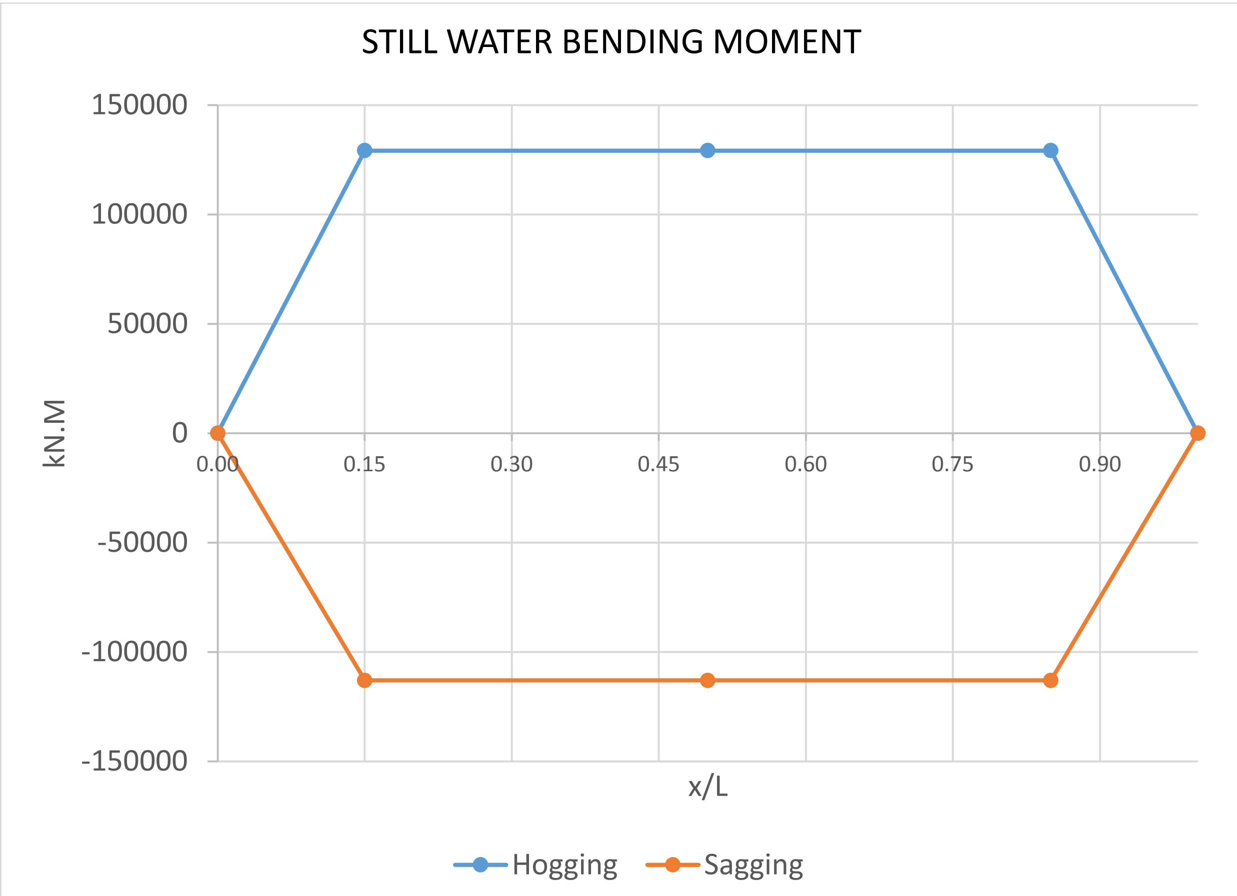
	A	C	P_o	
Alluminium	0.01665	10.71	0.257458	N/mm2
36 Ni Fe	0.033297	10.71	0.314904	N/mm2
9 Ni	0.034642	10.71	0.319546	N/mm2

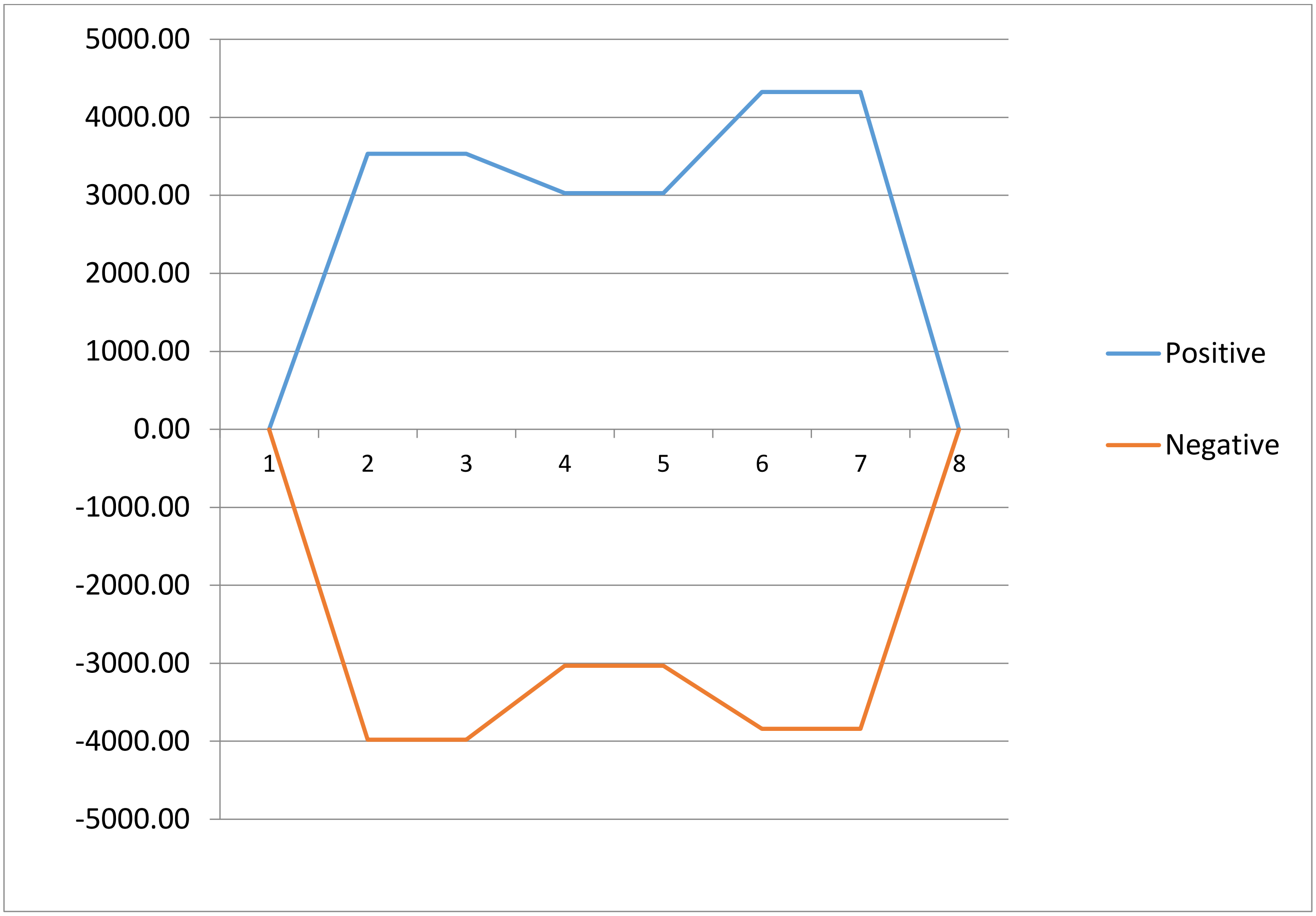
Insulation		
PU- Foam	260	mm
Vacuum perlite	35	mm
Aerogel mats	165	mm

	Al	9 Ni	36 Ni Fe
Outer Radius	6.040883779	6.013621	6.013368297
Inner Radius	6	6	6
Volume	36.82230723	12.24004	12.01275057
Weight	97947.33722	96206.74	97543.53466
Cost $/ton	97947.33722	57724.05	975435.3466

APPENDIX C: STRUCTURAL CALCULATION

Bending Moment Calculations:





3 Wave loads

3.1 Vertical wave bending moments

3.1.1 The vertical wave bending moments at any hull transverse section are obtained, in kN.m, from the following formulae:

- hogging conditions:

$$M_{WV,H} = 190 F_M n C L^2 B C_B 10^{-3}$$

- sagging conditions:

$$M_{WV,S} = -110 F_M n C L^2 B (C_B + 0{,}7) 10^{-3}$$

2.2 Still water bending moments

2.2.1 The design still water bending moments $M_{SW,H}$ and $M_{SW,S}$ at any hull transverse section are the maximum still water bending moments calculated, in hogging and sagging conditions, respectively, at that hull transverse section for the loading conditions specified in [2.1.2].

3.4 Vertical wave shear force

3.4.1 The vertical wave shear force at any hull transverse section is obtained, in kN, from the following formula:

$$Q_{WV} = 30F_Q nCLB(C_B + 0{,}7)10^{-2}$$

where:

F_Q : Distribution factor defined in Tab 3 for positive and negative shear forces (see also Fig 8).

3.1 Rule length

3.1.1 The rule length L is the distance, in m, measured on the summer load waterline, from the forward side of the stem to the after side of the rudder post, or to the centre of the rudder stock where there is no rudder post. L is to be not less than 96% and need not exceed 97% of the extreme length on the summer load waterline.

F_M : Distribution factor defined in Tab 1 (see also Fig 5).

Table 1 : Distribution factor F_M

Hull transverse section location	Distribution factor F_M
$0 \le x < 0{,}4L$	$2{,}5\frac{x}{L}$
$0{,}4L \le x \le 0{,}65L$	1
$0{,}65L < x \le L$	$2{,}86\left(1 - \frac{x}{L}\right)$

In Fig 3 and Fig 4, M_{SW} is the design still water bending moment amidships, in hogging or sagging conditions, whose absolute values are to be taken not less than those obtained, in kN.m, from the following formulae:

- hogging conditions:

$$M_{SWM,H} = 175 n_1 C L^2 B (C_B + 0{,}7) 10^{-3} - M_{WV,H}$$

- sagging conditions:

$$M_{SWM,S} = 175 n_1 C L^2 B (C_B + 0{,}7) 10^{-3} + M_{WV,S}$$

where $M_{WV,H}$, $M_{WV,S}$ are the vertical wave bending moments, in kN.m, defined in [3.1].

Figure 3 : Preliminary still water bending moment distribution for oil tankers, bulk carriers and ore carriers

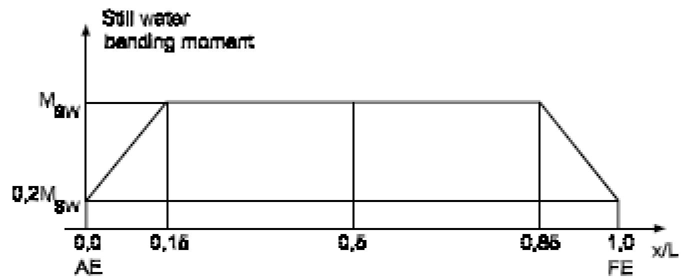
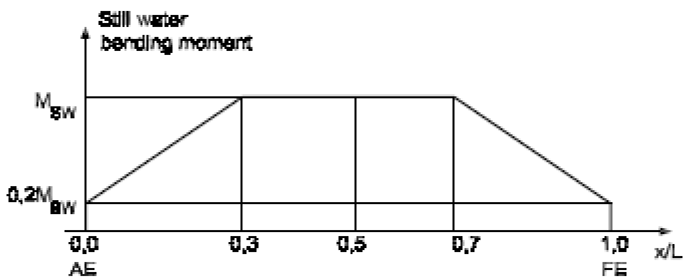


Figure 4 : Preliminary still water bending moment distribution for other ship types



Hull transverse section location	Distribution factor F_Q	
	Positive wave shear force	Negative wave shear force
$0 \le x < 0{,}2L$	$4{,}6A\frac{x}{L}$	$-4{,}6\frac{x}{L}$
$0{,}2L \le x \le 0{,}3L$	0,92A	- 0,92
$0{,}3L < x < 0{,}4L$	$(9{,}2A-7)\left(0{,}4-\frac{x}{L}\right)+0{,}7$	$-2{,}2\left(0{,}4-\frac{x}{L}\right)-0{,}7$
$0{,}4L \le x \le 0{,}6L$	0,7	- 0,7
$0{,}6L < x < 0{,}7L$	$3\left(\frac{x}{L}-0{,}6\right)+0{,}7$	$-(10A-7)\left(\frac{x}{L}-0{,}6\right)-0{,}7$
$0{,}7L \le x \le 0{,}85L$	1	- A
$0{,}85L < x \le L$	$6{,}67\left(1-\frac{x}{L}\right)$	$-6{,}67A\left(1-\frac{x}{L}\right)$
Note 1: $A = \frac{190C_B}{110(C_B+0{,}7)}$		

Table 1 : Navigation coefficients

Navigation notation	Navigation coefficient n	Navigation coefficient n_1
Unrestricted navigation	1,00	1,00
Summer zone	0,90	0,95
Tropical zone	0,80	0,90
Coastal area	0,80	0,90
Sheltered area	0,65	0,80

$$C = 10{,}75 \quad \text{for} \quad 300 \le L \le 350\text{m}$$

$$C = 10{,}75 - \left(\frac{L-350}{150}\right)^{1{,}5} \quad \text{for} \quad L > 350\text{m}$$

4.2 Section modulus within 0,4L amidships

4.2.1 For ships with C_B greater than 0,8, the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the greater value obtained, in m^3, from the following formulae:

- $Z_{R,MIN} = n_1 C L^2 B (C_B + 0{,}7) k 10^{-6}$
- $Z_R = \dfrac{M_{SW} + M_{WV}}{175/k} 10^{-3}$

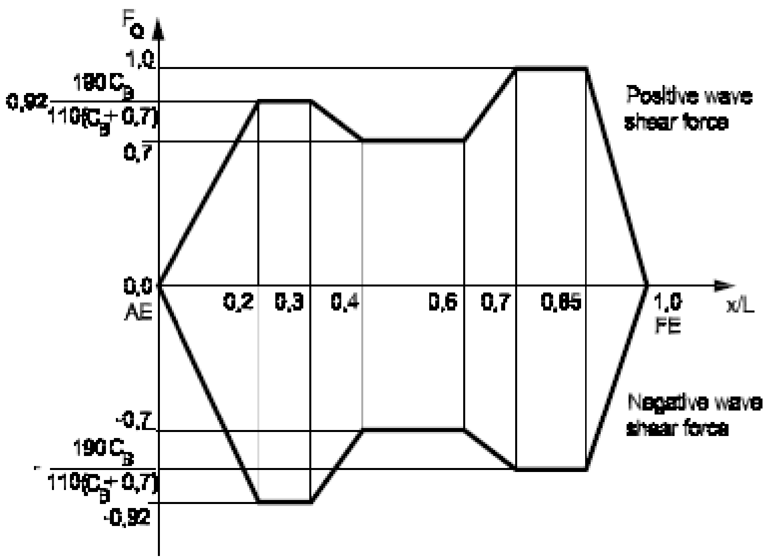
4.2.2 For ships with C_B less than or equal to 0,8, the gross section moduli Z_{AB} and Z_{AD} at the midship section are to be not less than the value obtained, in m^3, from the following formula:

$$Z_{R,MIN} = n_1 C L^2 B (C_B + 0{,}7) k 10^{-6}$$

In addition, the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the value obtained, in m^3, from the following formula:

$$Z_R = \frac{M_{SW} + M_{WV}}{175/k} 10^{-3}$$

Figure 8 : Distribution factor F_Q



2 Hull girder stresses

2.1 Normal stresses induced by vertical bending moments

2.1.1 The normal stresses induced by vertical bending moments are obtained, in N/mm², from the following formulae:

- at any point of the hull transverse section:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_A} 10^{-3}$$

- at bottom:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AB}} 10^{-3}$$

- at deck:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AD}} 10^{-3}$$

STRENGTH CALCULAITONS

Project: LNG BUNKER SUPPLY VESSEL

LLOYD'S			
LBP	L	93.00	m
LWL	LWL	93.00	m
Breadth	B	18.00	m
Block Coefficient	Cb	0.74	
Navigation coefficient	n	0.80	coastal
Navigation coefficient	n1	0.90	coastal
	96%LWL	89.28	m
	97%LWL	90.21	m
Rule length		90.21	m
Location	x/L	0.50	
Distributioin factor	F_M	1.00	
Wave parameter	C	7.71	
Vertical Wave Bending Moment			
Hogging	$M_{WV,H}$	127054	kN.M
Sagging	$M_{WV,S}$	-143139	kN.M

Still Water Bending Moment			
Hogging	$M_{SWM,H}$	129133	kN.M
Sagging	$M_{SWM,S}$	113048	kN.M

x/L	Hogging	Sagging
0	0	0
0.15	129132.60	-113047.50
0.5	129132.60	-113047.50
0.85	129132.60	-113047.50
1	0	0

Vertical Wave Shear Force				
		A	0.89	
FQ (positive)	FQ (Negative)	X/L	Positive-kn	Negative-kn
0	0	0	0.00	0
0.8166	-0.92	0.2	3533.87	-3981.26
0.8166	-0.92	0.3	3533.87	-3981.26
0.7	-0.7	0.4	3029.22	-3029.22
0.7	-0.7	0.6	3029.22	-3029.22
1	-0.887626263	0.7	4327.46	-3841.16
1	-0.887626263	0.85	4327.46	-3841.16
0	0	1	0.00	0

Thickness Calculations:

Ship Parameters	
L	97
B	18
D	11.5
T	5.2
Cb	0.685

Min wing tank width	0.82	m
Min Double bottom hieght	0.76	m

Hull Envelope Plating

Thicknesses as per Table 9.4.1									
Deck	7.30	mm	Also		8.125	mm	(min)	10	
Bottom Plating Thicknes	8.08		Or	9.20	mm			10	
Bilge Plating	8.08			9.20	mm			10	
Keel Plate	11.20							12	
Side shell above mid depth	6.66	mm						8	
Side shell below mid depth	7.25	mm						8	
Sheerstrake and gunwale	7.30	mm						10	should not be less then side shell plating
Inner Hull Plate	6.90	mm						9	

Hull Framing

Bottom stiffners (Z)	221.523	cm3	222
Bulkead Thickness (to)			
Deck, side and bottom longitudinals			
Z Modulus of longitudinals within the cargo tank (cm^3)	196.218		196

Stability of longitudinals		
Ch 4, 7 Hull buckling strength.		
t w= as built thickness of plating, stiffener flange and web used in Table 4.7.1 Standard deduction for corrosion, d t in calculating standard deduction d t, in mm	8.4	
t p = as built thickness of plating less standard deduction d t, in mm, (i.e. t p =t — d t)	6.4	
S = spacing of primary members, in metres	0.65	
τE = elastic critical buckling stress in shear, in N/mm2 (kgf/mm2)	108.8146011	
σ E = elastic critical buckling stress in compression, in N/mm2(kgf/mm2)	71.89570651	
Section 6: Inner hull, inner bottom and longitudinal watertight bulkheads		
Thickness of the inner bottom plating in the holds	8.443139668	mm
(to) scantling thickness for transverse bulkhead	9.672527894	
Side longitudinal in way of double skin tanks, including double skin construction (Z) in cm3	170.352	
Bottom and bilge longitudinal in cm3	155.142	

Transverse Watertight bulkhead		
Thickness	6.596664024	8

Primary members supporting longitudenal framing				
d-DB = Rule depth of centre girder mm	971.4719243			
Thckness of the center girder in mm	8.771775394	12	choose 1100x12 mm	
Thickness of Floors and the side girders in mm	7.80030347	8		
For the primary member:				
d w = depth of member web, in mm	1200			
t w = thickness of member web, in mm	8.48144754	9		
S w = spacing of web frame members, in metres	1950			
For the primary member web stiffener:				
	67.88550611			
For the primary member end bracket, see Figure 9.10.2 Primary member end brackets				
d b = arm length, in metres	1.44			
lb = effective length of the free edge, in metres	2.03646753			
t b = thickness of the end bracket plating, in mm	10	10		

FLOORS		
Thickness	9.743247319	10
Water tight floor thickness	10.77177539	11
Weather Deck Structure		
Thickness	6.667446847	8

Background			
Kl (higher tensile steel factor)	1		

e (base of natural logarithms)			
l (overall length of stiffening member, or pillar, in metres)			
le (effective length of stiffening member, or pillar, in metres)	2.5	min should be 2.5	
t (thickness of plating, in mm)			
s (spacing of secondary stiffeners, in mm)	650	631.6666667	mm
A (cross-sectional area of stiffening member, in cm2)			
C (stowage rate, in m3/tonne)			
Cw (a wave head in metres) 7,71 x 10−2 L e−0,0044 L where L is not to be taken greater than 227	4.874225		
I (inertia of stiffening member, in cm4)			
S (spacing or mean spacing of primary members, in metres)			
Z (section modulus of stiffening member, in cm3)			
Ro (relative density (specific gravity) of liquid carried in a tank but is not to be taken less than 1,025)	1.025		
dc (the height between the ship's base line and the bottom of the cargo pump-room, in metres)			
DWT (deadweight, in tonnes, at the summer load waterline)			
b (the width of plating supported by the primary or secondary member, in metres or mm respectively)			
be (the effective width, in metres, of end brackets as determined from Pt 3, Ch 3, 3 Structural idealisation)			
bi = minimum distance from side shell to inner hull/outer longitudinal bulkhead of the tank in question measured inboard at right angles to the centreline at the summer load waterline, in metres			
db = the distance, in metres, between the bottom of the cargo tanks and the moulded line of the bottom shell plating measured at right angles to the bottom shell plating as shown in Table 9.1.1	0.76		
ds = the distance, in metres, between the cargo tank boundary and the moulded line of the side shell plating measured at any cross-section at right angles to the side she	0.82		
h = the load height applied to the item under consideration, in metres			
L1 = length of ship, in metres, = L	97		
Tm = minimum operating moulded draught of the ship at amidships under any expected cargo loading condition, in metres			

Hull Envelope Plating				
F B = local scantling reduction factor for hull members below the neutral axis	0.77			
F D = local scantling reduction factor for hull members above the neutral axis	0.65			
F M = the greater of F D or F B				
α	46.792781			
σo = specified minimum yield stress, in N/mm2 (kgf/mm2)	235			
σC = maximum compressive hull vertical bending stress, in N/mm2	5.0221422			
f1	0.5			
C1	1			
Z min = minimum hull midship section modulus about the transverse neutral axis, in m3 f 1 k L C 1 L 2 B (C b + 0,7) x 10-6 m3	0.1172832			
z D, z B = vertical distances from the hull transverse neutral axis to the deck and keel respectively, in metres	4	Initial design stage		
Zb	7.5			
σ	150	sigma 150/k initial		
At Deck σD	5.0221422	equal to σC		
At Keel σB	2.6784758			
J	122.62308			
H4 = Load head required for general deep tanks	11.5			
Ht2 = in meters for bottom longitudinals	6.24	6.24	or	7.637113
Ht1 = for bottom longitudinals above waterline	7.072	7.072	or	10.07423
Gamma	0.051			
Effective length of longitudinal, l	2.5	1.5 - 3		

Hull Framing					
b f = the width of the face plate, in mm, of the side longitudinal under consideration					
b f1 = the minimum distance, in mm, from the edge of the face plate of the side longitudinal under consideration to the centre of the web plate					
Alpha	25	shoul d be less than	27.65		
b1 = greater horizontal distance in metres from a point 1/3rd of the height of the strake above its lower edge	15.6				
c1 at deck	0.509554 1				
c1 at D/2	1				
C1 at base	0.588235 3				
C2 at deck	0.723684 2				
C2 at D/2	1				
C2 at base	0.799418 6				
dw depth of web, in mm					
h = distance of longitudinal below deck at side, in metres. For deck longitudinal, h = 0	0				
h o = the distance, in metres, from the mid-point of span of the stiffener to the highest point of tank	5.75				
h1	7.1875	Max of	7.187 5	1.73214 3	1.6 7
h2	5.75				
h3	12.90214 3				
D1	11.5	To be between 10 and 16			
R= sin theta	0.458470 7				
s = spacing, in mm, of bulkhead stiffeners for plane bulkheads.	650				
F1 Fatigue factor determined from Table 9.6.2 Values of F 1	0.12	min value			

		table 9.5.2			
F2 Fatigue factor	0.73	min value table 9.5.2			
Fs (fatigue Factor)	1	min value			

Deck, side and bottom longitudinal				
Z Modulus of longitudinal within the cargo tank (cm^3)	196.21875	196.21875	or	195.1409
5.3.4 Referring Pt 3, Ch 3, 3.2 Geometric properties of section 3.2.3. The webs and flanges are to comply with the minimum thickness requirements of Pt 4, Ch 9, 10 Construction details and minimum thickness.				
5.3.5 The side and bottom longitudinal scantlings derived from Pt 4, Ch 9, 5.3 Deck, side and bottom longitudinal 5.3.1 and Pt 4, Ch 9, 5.3 Deck, side and bottom longitudinal 5.3.2, using the midship thickness of plating, are to extend throughout the cargo tanks. Where the shell plating is inclined at an angle to the horizontal longitudinal axis of greater than 10°, the span of the longitudinal is to be measured along the member. Where the shell plating is inclined at an angle to the vertical axis of greater than 10°, the spacing of longitudinal is to be measured along the chord between members. Where the angle of attachment of side longitudinal clear of amidships varies by 20° or more from a line normal to the plane of the shell, the properties of the section are to be determined about an axis parallel to the attached plating. Angles of slope greater than 40° are to be avoided.				

Stability of longitudinals		

5.6.1 The lateral and torsional stability of longitudinals together with web and flange buckling criteria are to be verified in accordance with Pt 3, Ch 4, 7 Hull buckling strength.		
Ch 4, 7 Hull buckling strength.		
d t = standard deduction for corrosion, see Table 4.7.1 Standard deduction for corrosion, d t	2	Two side exposure to water ballast and/or liquid cargo
s = spacing of secondary stiffeners, in mm. In the case of symmetrical corrugations, s is to be taken as b or c in Figure 3.3.1 Corrugation dimensions in Ch 3, whichever is the greater	650	
t w= as built thickness of plating, stiffener flange and web used in Table 4.7.1 Standard deduction for corrosion, d t in calculating standard deduction d t, in mm	8.4	Assumed thickness initially, only 8.3 and 8.4 are meeting all the criterias specified in green
t p = as built thickness of plating less standard deduction d t, in mm, (i.e. t p =t — d t)	6.4	
E = modulus of elasticity, in N/mm2 (kgf/mm2) = 206000 N/mm2(21000 kgf/mm2) for steel	206000	
S = spacing of primary members, in metres	0.65	
σo = specified minimum yield stress, in N/mm2 (kgf/mm2)	235	
σA = design longitudinal compressive stress in N/mm2 (kgf/mm2)	30	
σ E = elastic critical buckling stress in compression, in N/mm2(kgf/mm2) for us, Compression of plating with longitudinal stiffeners (parallel to compressive stress),	71.895707	
τE = elastic critical buckling stress in shear, in N/mm2 (kgf/mm2)	108.8146	Since exceeds 50 per cent of specified minimum yield stress of the material, the corrected critical buckling stresses in compression (σCRB) and shear (τCRB) are given by:
τ0=σo/sqrt(3)	135.67731	
τA = design shear stress in N/mm2 (kgf/mm2)	110	
τCRB = critical buckling stress in shear, N/mm2 (kgf/mm2) corrected for yielding effects	108.8146	

σ CRB = critical buckling stress in compression, in N/mm2 (kgf/mm2) corrected for yielding effects	71.895707	
7.5 Scantling criteria		
σ CRB >= BσA where beta=1.1 for buckling	33	Satisfied
τCRB>=τA	Satisfied	
dw/tw=<15*sqrt Kl		
dw= less than	126	mm
dw	100	mm

Section 6: Inner hull, inner bottom and longitudinal watertight bulkheads

Thickness of the inner bottom plating in the holds	8.44	mm	more than required for satisfying hull buckling strength		
h = load height, in metres measured vertically as follows: (a) For bulkhead plating, the distance from a point one third of the height of the plate panel above its lower edge to the highest point of the tank, excluding hatchway (b) for bulkhead stiffeners or corrugations, the distance from the mid-point of span of the stiffener or corrugation to the highest point of the tank, excluding hatchway	5.15	midway D/2			
h1	8.85	Max of	6.65	8.857543	
h2	6.65	Max of	6.65	1.732143	1.67
h3 distance of longitudinal below deck at side, in metres, but is not to be less than 0	0.002				
h4	12.30				
h5	6.76		6.65	or	6.766179
D1	12	between 10 to 16			
R= sin theta	0.458				
F1 Fatigue factor determined from Table 9.6.2 Values of F 1	0.12	min(.12)			
s = spacing, in mm, of bulkhead stiffeners for plane bulkheads.	650				
(to) scantling thickness for transverse bulkhead	9.6725279				

tm minimum value of t 0 within 0,4D each side of mid-depth of bulkhead	6.5	Minimum value should not be less than 65. mm			
F2 Fatique factor	0.73		0.72	or min	0.73
tf					
Fs (fatique Factor)	1	min			
Side longitudinal in way of double skin tanks, including double skin construction (Z) in cm3	170.352				
Bottom and bilge longitudinal in cm3	155.142				
Transverse Watertight bulkhead					
s = spacing, in mm, of bulkhead stiffeners for plane bulkheads.	650	As defined above			
Thickness	5.958				
f (constant for thickness)	0.7	1	0.7		
Stiffener modulus (z) in cm3	12.235917				

Primary members supporting longitudinal framing				
b-e1, b-e2 = effective end bracket leg length, in metres, at each end of the member,				
d-DB = Rule depth of centre girder mm	971.47192	971.4719243	should not be less than	650
hc = vertical distance from the centre of the cross-ties to deck at side amidships				
hs = distance between the lower span point of the vertical web and the moulded deck line at centreline				
lb = the distance, in metres, between the transverse bulkheads				
lc = one-half the vertical distance, in metres, between the centres of the adjacent cross-ties or between the centre of the adjacent cross-tie and the centre of the				

adjacent bottom or deck transverse, or double bottom.				
s = spacing of transverses, in metres				
Thickness of the center girder in mm	8.7717754			
Thickness of Floors and the side girders in mm	7.8003035			

Section 10 Construction details and minimum thickness				
For the primary member:				
d w = depth of member web, in mm	1200			
t w = thickness of member web, in mm	8.4814475	8.48144754	or	
S w = spacing of web frame members, in metres	1950			7.5
For the primary member web stiffener:				
A s = cross-sectional area of the web stiffener and associated web plating, in cm2	67.885506			
Is = moment of inertia of the web stiffener and associated web plating, in cm4				
For the primary member end bracket, see Figure 9.10.2 Primary member end brackets				
d b = arm length, in metres	1.44			
lb = effective length of the free edge, in metres	2.0364675			
t b = thickness of the end bracket plating, in mm	10	8.48144754	or	10

Floors		
Floors are defined in section 8.5.1, page 4.1.8.26. Spacing between them is 2.25 m (3·0.75 m), and it shouldn't be less than 3,8 m. Floors thickness is defined as: t = (0.009·dDB + 1)·k1/2 = 9.332 mm, and it should be between 6 mm and 15 mm		
Thickness	9.7432473	
Water tight floor thickness	10.771775	
Water tight floor stiffeners		
Weather Deck Structure		
Thickness	6.6674468	

APPENDIX D: WEIGHT ESTIMATION

1. HULL STRUCTURES		
Midship Section	Weight for each member	Total Weight (tonnes)
Longitudinal stiffeners	0.01806948	2.710422
Inner hull plating	2.135484	2.1
Web frame	3.251664	3.251664
Brackets for double bottom	0.05616	0.22464
Brackets for main cargo tank	0.05616	0.22464
Floors	1.6848	1.6848
Center girder	0.34240752	0.34240752
Side girder	0.22924512	0.45849024
Deck plating	2.19024	2.19024
Bottom + Bilge plating+ side shell	4.483908	4.483908
Keel Plate	0.219024	0.219024
Sheer strake and gunwale	0.190125	0.190125
thickness of the end bracket plating	0.10296	1.23552
		19.31588076
	Net Weight	673.5794316

Engine Room	Weight for each member	Total Weight (tonnes)
Longitudinal stiffeners	0.01806948	2.710422
Inner hull plating	2.135484	2.1
Web frame	3.251664	3.251664
Brackets for double bottom	0.05616	0.22464
Brackets for main cargo tank	0.05616	0.22464
Water Tight Floor + Non Water Tight	1.6848	5.0544
Center girder	0.34240752	0.34240752
Side girder	0.22924512	0.45849024
Deck plating	2.19024	2.19024
Bottom + Bilge plating+ side shell	4.483908	4.483908
Keel Plate	0.219024	0.219024
Sheer strake and gunwale	0.190125	0.190125
thickness of the end bracket plating	0.10296	1.23552

		42.15428076
	Net Weight	324.2636982

Forward of Collision Bulkhead	Weight for each member	Total Weight (tonnes)
Longitudinal stiffeners	0.01806948	0.903474
Inner hull plating	2.135484	2.1
Brackets for double bottom	0.05616	0.22464
Brackets for main cargo tank	0.05616	0.22464
Water Tight Floor + Non Water Tight	1.6848	5.0544
Deck plating	2.19024	2.19024
Bottom + Bilge plating+ side shell	4.483908	4.483908
Keel Plate	0.219024	0.219024
Sheer strake and gunwale	0.190125	0.190125
thickness of the end bracket plating	0.10296	1.23552
Watertight bulkhead	14.6016	14.6016
Panting beams	0.0383292	1.533168
Stringer	0.01533168	1.8398016
Breast hooks	0.702	0.702
		35.5025406
	Net Weight	271.0964662

Structural Bulkhead	Weight for each member	
Watertight bulkhead	19.4688	38.9376
Watertight bulkheads siffeners	0.0741312	2.07567
	Net Weight	41.01327

Decks		
1st Deck (Accomodation)	22.464	22.464
2nd Deck (Accomodation)	22.464	22.464
3rd Deck (Accomodation)	22.464	22.464
01 Level Deck (Engine Room)	22.464	22.464
02 Level Deck (Engine Room)	22.464	22.464

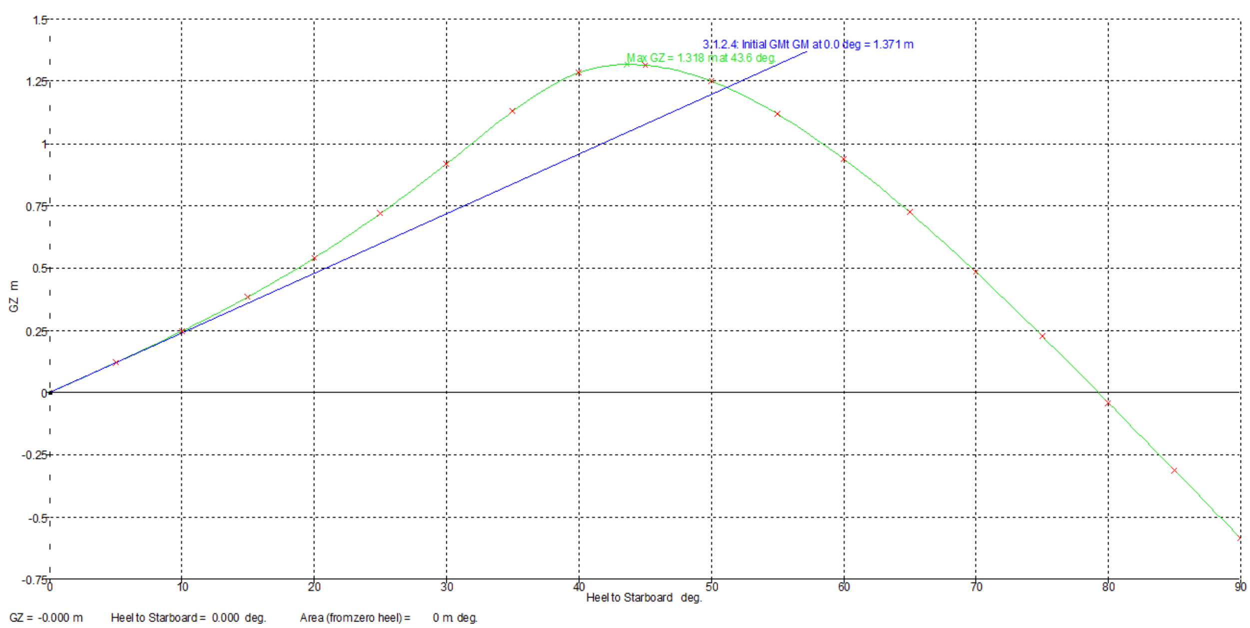
	Net Weight	112.32
Total Hull Structure Weight		1696.431343

APPENDIX E: STABILITY ANALYSIS

Intact Stability:

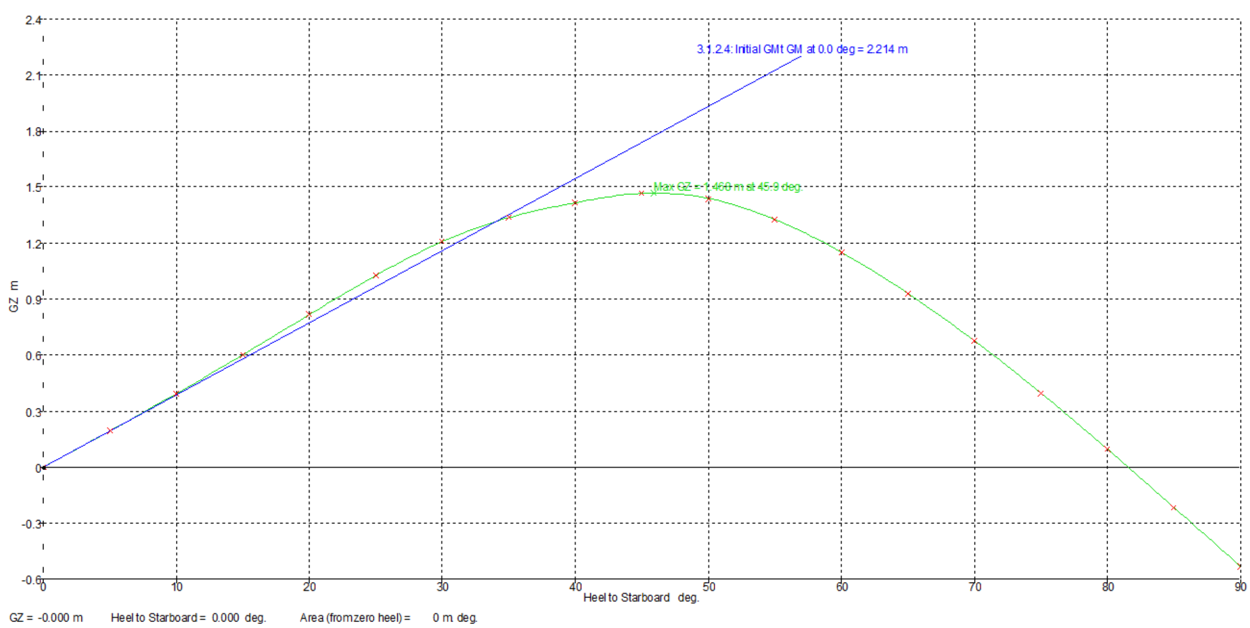
1) Fully loaded

```
Code    Criteria        Value   Units   Actual  Status  Margin                                     %
A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 30                      Pass
        from the greater of
        spec. heel angle        0.0     deg     0.0
        to the lesser of
        spec. heel angle        30.0    deg     30.0
        angle of vanishing stability    79.2    deg
        shall not be less than (>=)     3.1513  m.deg   12.3116 Pass    +290.68

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 40                      Pass
        from the greater of
        spec. heel angle        0.0     deg     0.0
        to the lesser of
        spec. heel angle        40.0    deg     40.0
        first downflooding angle        n/a     deg
        angle of vanishing stability    79.2    deg
        shall not be less than (>=)     5.1566  m.deg   23.5156 Pass    +356.03

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.2: Max GZ at 30 or greater           Pass
        in the range from the greater of
        spec. heel angle        30.0    deg     30.0
        to the lesser of
        spec. heel angle        90.0    deg
        angle of max. GZ        43.6    deg     43.6
        shall not be less than (>=)     0.200   m       1.318   Pass    +559.00
        Intermediate values
        angle at which this GZ occurs           deg     43.6

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.3: Angle of maximum GZ               Pass
        shall not be less than (>=)     25.0    deg     43.6    Pass    +74.54

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.4: Initial GMt                       Pass
        spec. heel angle        0.0     deg
        shall not be less than (>=)     0.150   m       1.371   Pass    +814.00
```



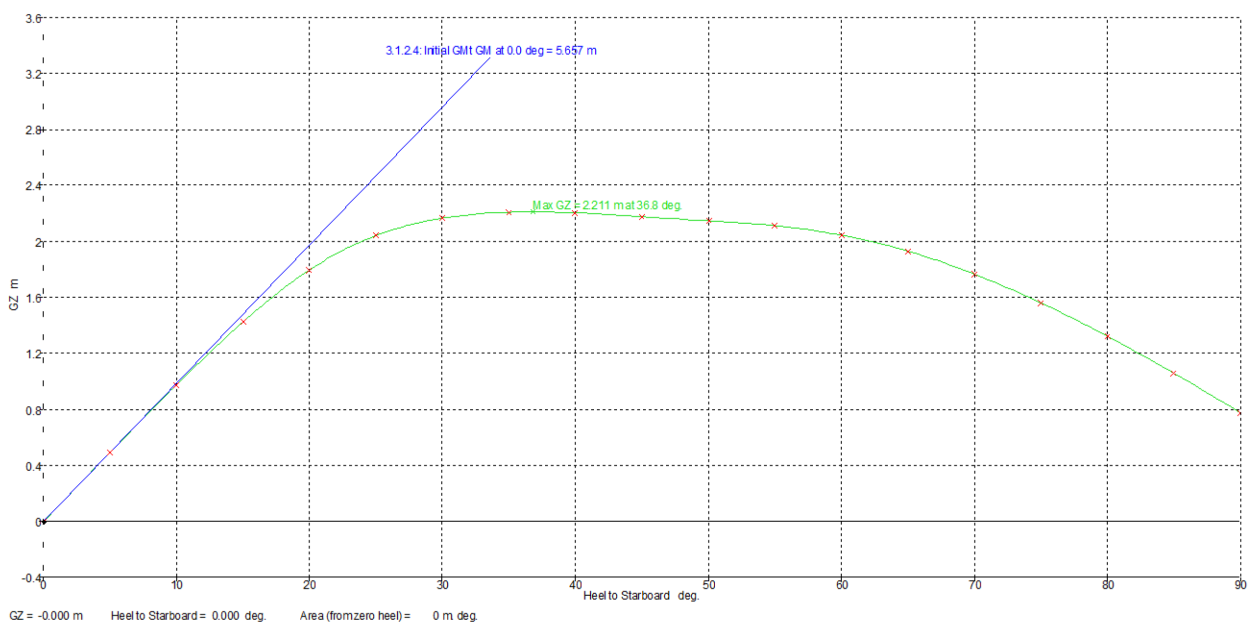
2) Partial Loaded

```
Code     Criteria         Value    Units    Actual   Status  Margin                              %
A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 30                    Pass
         from the greater of
         spec. heel angle         0.0      deg      0.0
         to the lesser of
         spec. heel angle         30.0     deg      30.0
         angle of vanishing stability      81.6     deg
         shall not be less than (>=)       3.1513   m.deg    18.2137 Pass    +477.97

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 40                    Pass
         from the greater of
         spec. heel angle         0.0      deg      0.0
         to the lesser of
         spec. heel angle         40.0     deg      40.0
         first downflooding angle          n/a      deg
         angle of vanishing stability      81.6     deg
         shall not be less than (>=)       5.1566   m.deg    31.4953 Pass    +510.78

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.2: Max GZ at 30 or greater        Pass
         in the range from the greater of
         spec. heel angle         30.0     deg      30.0
         to the lesser of
         spec. heel angle         90.0     deg
         angle of max. GZ         45.9     deg      45.9
         shall not be less than (>=)       0.200    m        1.468   Pass    +634.00
         Intermediate values
         angle at which this GZ occurs              deg      45.9

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.3: Angle of maximum GZ            Pass
         shall not be less than (>=)       25.0     deg      45.9    Pass    +83.64

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.4: Initial GMt                    Pass
         spec. heel angle         0.0      deg
         shall not be less than (>=)       0.150    m        2.214   Pass    +1376.00
```



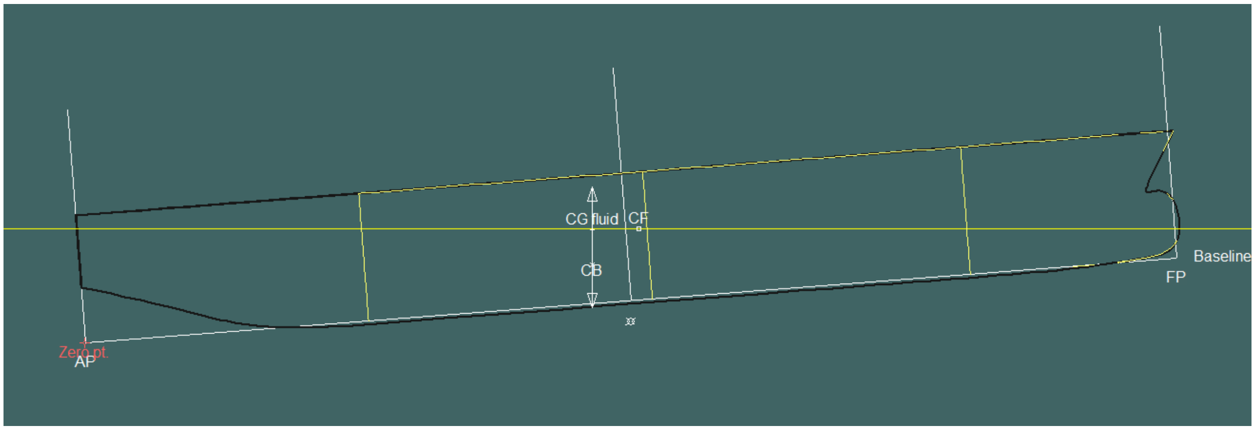
3) Light Ship

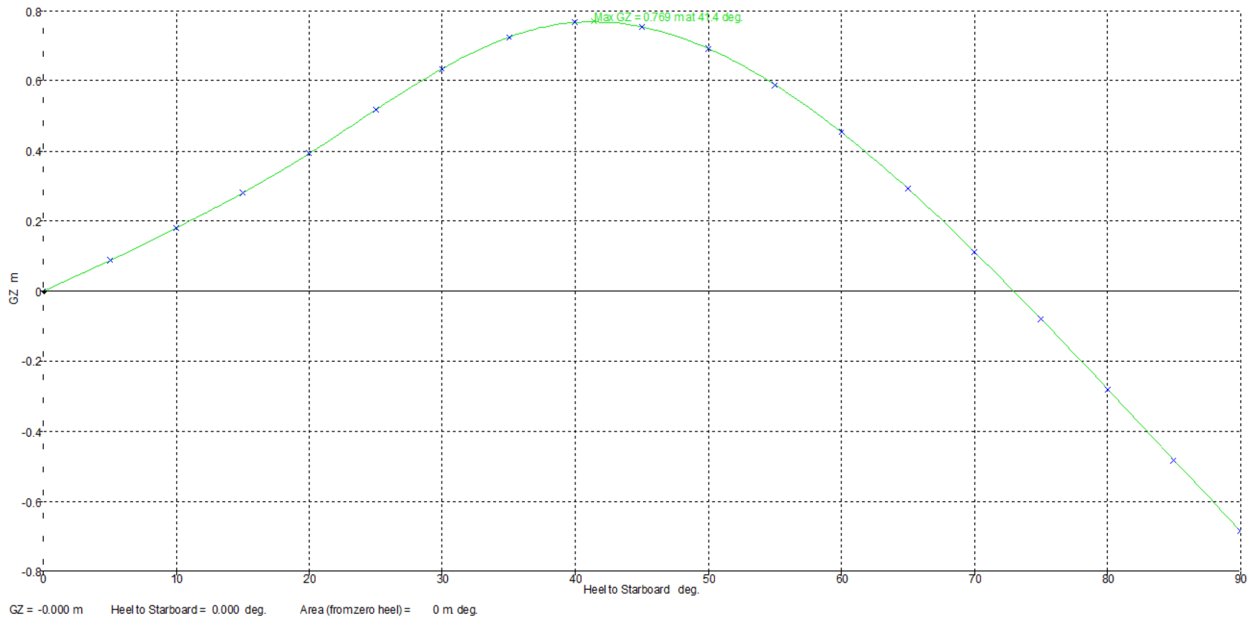
```
Code     Criteria          Value   Units    Actual  Status  Margin                        %
A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 30            Pass
         from the greater of
         spec. heel angle        0.0     deg     0.0
         to the lesser of
         spec. heel angle        30.0    deg     30.0
         angle of vanishing stability    90.0    deg
         shall not be less than (>=)     3.1513  m.deg   39.2330 Pass    +1144.98

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.1: Area 0 to 40            Pass
         from the greater of
         spec. heel angle        0.0     deg     0.0
         to the lesser of
         spec. heel angle        40.0    deg     40.0
         first downflooding angle        n/a     deg
         angle of vanishing stability    90.0    deg
         shall not be less than (>=)     5.1566  m.deg   61.2405 Pass    +1087.61

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.2: Max GZ at 30 or greater  Pass
         in the range from the greater of
         spec. heel angle        30.0    deg     30.0
         to the lesser of
         spec. heel angle        90.0    deg
         angle of max. GZ        36.8    deg     36.8
         shall not be less than (>=)     0.200   m       2.211   Pass    +1005.50
         Intermediate values
         angle at which this GZ occurs           deg     36.8

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.3: Angle of maximum GZ     Pass
         shall not be less than (>=)     25.0    deg     36.8    Pass    +47.27

A.749(18) Ch3 - Design criteria applicable to all ships 3.1.2.4: Initial GMt             Pass
         spec. heel angle        0.0     deg
         shall not be less than (>=)     0.150   m       5.657   Pass    +3671.33
```



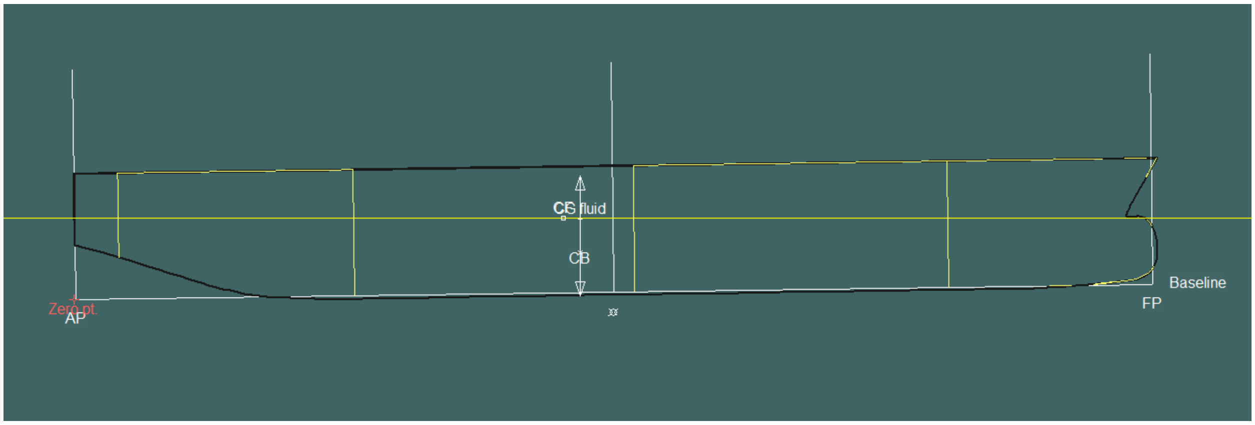
Damage Stability:

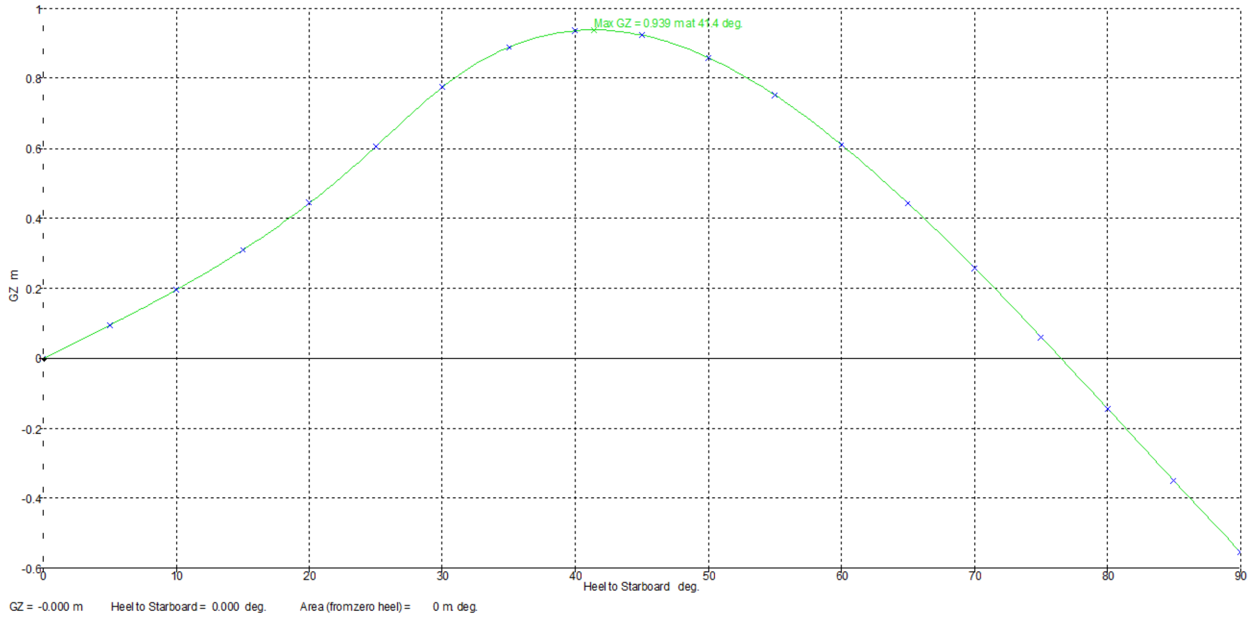
1) Engine room



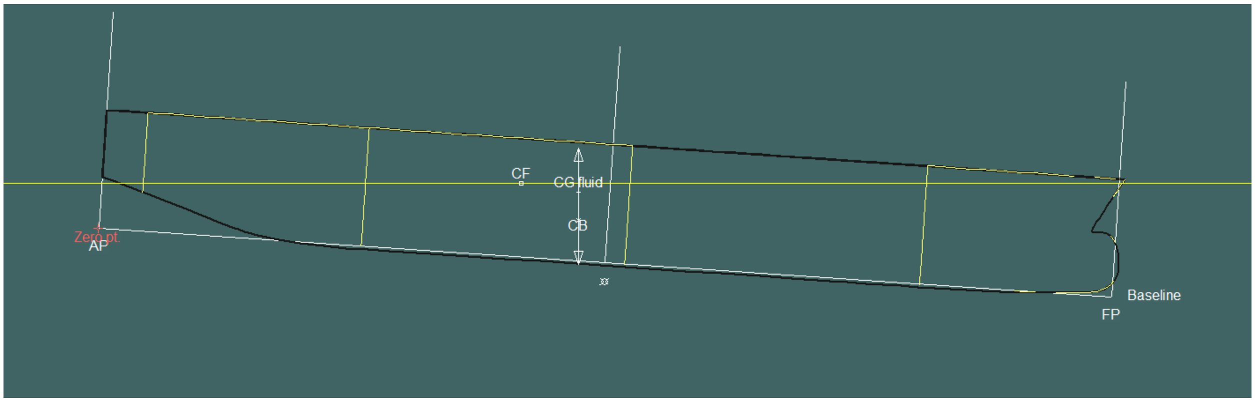


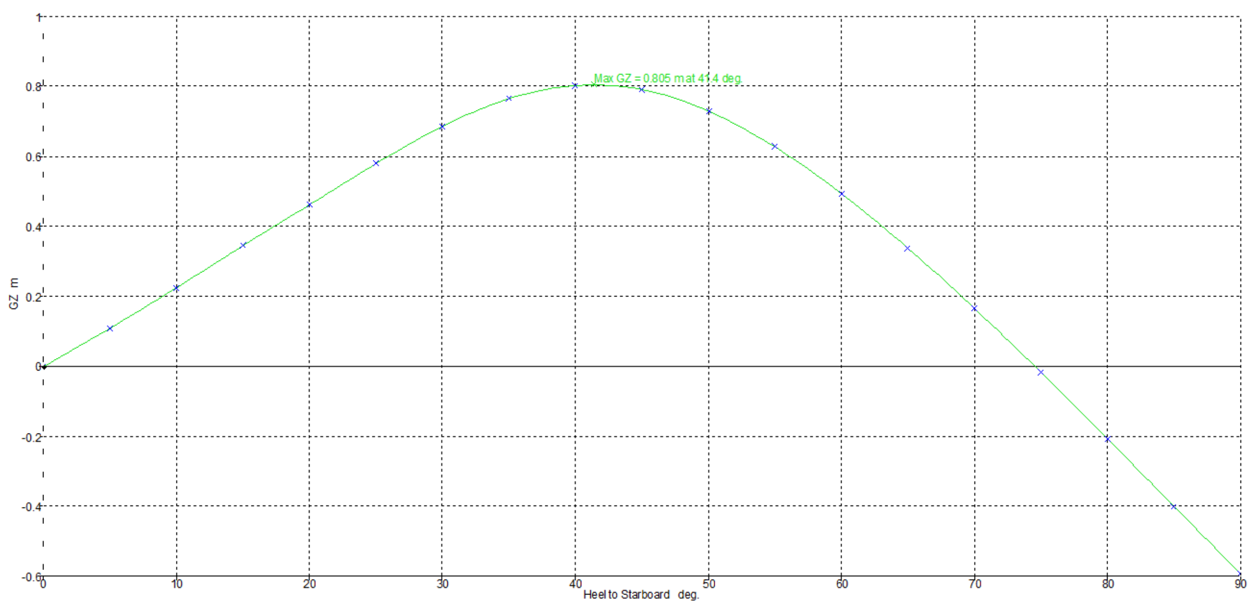
2) Cargo Hold 1



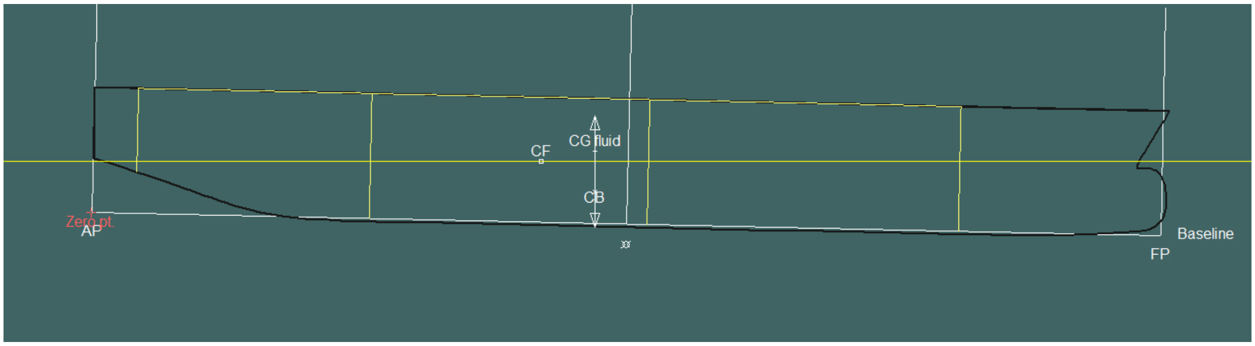


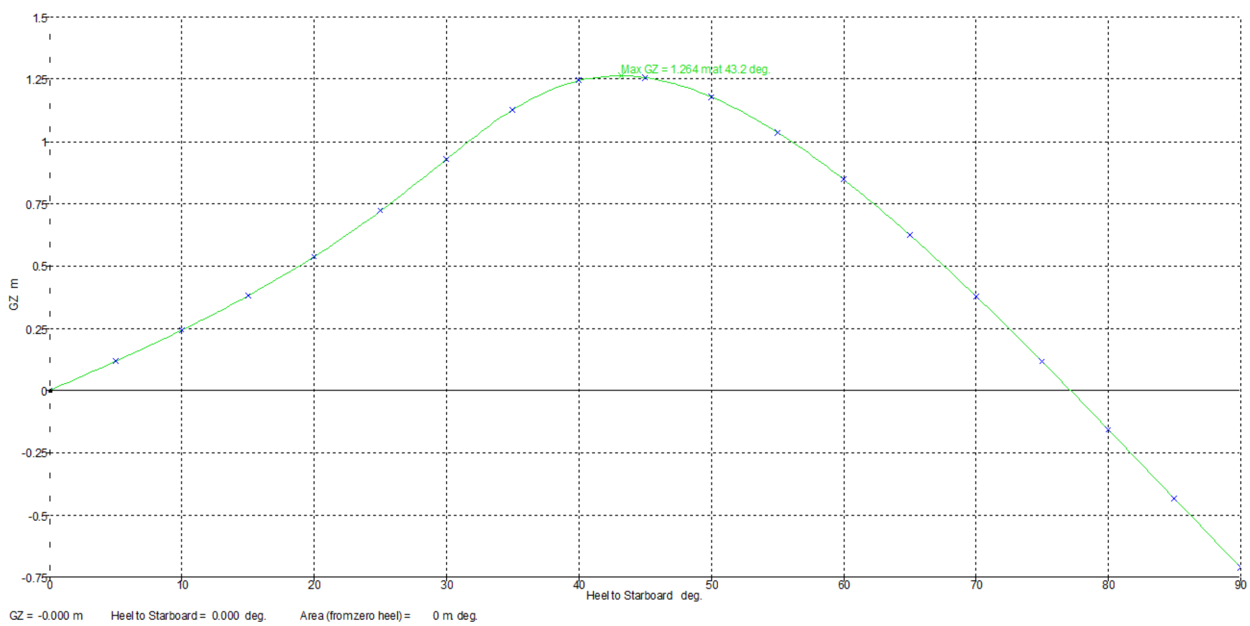
3) Cargo Hold 2





4) Forward of Collision Bulkhead





APPENDIX F: RESISTANCE PREDICTION

SHIP PARTICULARS					
LENGTH	96.99	m			
BEAM	18	m			
DRAFT	5.2	m			
DEPTH	11.5	m		T/L	0.053614
DISPLACEMENT	6717.91536	m3			
Cb	0.74				
Cp	0.75				
Cwp	0.83				
Cx	0.99				
rho	1025.9	kg/m3			
Wetted Surface	2206.330956	m2			
Area midship	146.47	m2			
Area Waterplane	1193.2	m2			
Area Transom Immersed	0	m2			
Viscosity	1.1883E-06	m2/sec			
LCB	45.501	m from aft			
lcb	-0.030869162	relative to percentage of L			
Sapp	50	m2			

Form Factor					
1+K1					
	C13=1+.003 stern	1		Cstern = 0	
	C12 (depends on T/L)	0.52098606			
	LR	24.180135			
1+k1	1.281655298				
Appendage Resistance					
1+K2	bilge keels	1.4			
	Twin Screw Balance Rudder	2.8			
1+K2 equivalent		4.2			

Wave Resistance (Constants)				
C1	3.892268755			
C2	0.420591482			
C5	1			
C7	0.185586143		B/L	
C3	0.209993435			
M1	-2.174657124		C16	1.20604
d	-0.9		C15	-1.69385
LAMDA	0.92285			
HALF ANGLE ENTRANCE				
Ie	33.97372366			

Vk	**V (m/s)**	**Fn (l)**	**Rn**	**Wetted Surface**
knots	m/s	[-]	[-]	m^2
5	2.572	0.083382	2.1E+08	2206.331
10	5.144	0.166764	4.2E+08	2206.331
11	5.6584	0.183441	4.62E+08	2206.331
12	6.1728	0.200117	5.04E+08	2206.331
12.5	6.43	0.208455	5.25E+08	2206.331
13	6.6872	0.216794	5.46E+08	2206.331
13.5	6.9444	0.225132	5.67E+08	2206.331
14	7.2016	0.23347	5.88E+08	2206.331
14.5	7.4588	0.241808	6.09E+08	2206.331
15	7.716	0.250146	6.3E+08	2206.331
16	8.2304	0.266823	6.72E+08	2206.331
17	8.7448	0.283499	7.14E+08	2206.331
18	9.2592	0.300176	7.56E+08	2206.331
19	9.7736	0.316852	7.98E+08	2206.331
20	10.288	0.333529	8.4E+08	2206.331
21	10.8024	0.350205	8.82E+08	2206.331

RESISTANCE											
Friction					Wave Making				BULBOUS BOW		
ITTC Cf	Rf Friction Drag	k1 - Friction form factor	RF(1+k)	R appendage	RW_40	m2	CA	R_A	Fni	Resistance	R-TOT
[-]	[N]	[-]	[N]		[N]						
0.001876	14048.5	1.281655	18005.34	1337.146	0.161813	-5.4E-07	0.000527	3942.168	0.564721	515.8727	**23800.69**
0.00171	51201.89	1.281655	65623.18	4873.429	2049.763	-0.02614	0.000527	15768.67	1.056194	2104.095	**90419.14**
0.001689	61187.09	1.281655	78420.76	5823.827	5160.237	-0.0488	0.000527	19080.09	1.141924	2441.671	**110926.6**
0.00167	71998.9	1.281655	92277.77	6852.901	11036.8	-0.07844	0.000527	22706.89	1.223203	2769.927	**135644.3**
0.001661	77712.13	1.281655	99600.17	7396.691	15890.76	-0.0954	0.000527	24638.55	1.262178	2929.544	**150455.7**
0.001652	83628.95	1.281655	107183.5	7959.858	18639.04	-0.11349	0.000527	26649.05	1.300051	3085.773	**163517.2**

0.001644	89748.44	1.281655	115026.6	8542.314	24212.28	-0.13248	0.000527	28738.4	1.336832	3238.408	**179758**
0.001637	96069.7	1.281655	123128.2	9143.976	37071.99	-0.15214	0.000527	30906.6	1.372535	3387.3	**203638.1**
0.001629	102591.9	1.281655	131487.4	9764.763	53683.73	-0.17229	0.000527	33153.63	1.407172	3532.341	**231621.9**
0.001622	109314.2	1.281655	140103.1	10404.6	63840.39	-0.19273	0.000527	35479.51	1.440762	3673.465	**253501.1**
0.001609	123356.2	1.281655	158100.1	11741.12	70606.26	-0.23388	0.000527	40367.8	1.504873	3943.848	**284759.1**
0.001597	138189.6	1.281655	177111.5	13152.98	112583.8	-0.27456	0.000527	45571.46	1.565029	4198.466	**352618.2**
0.001585	153809.2	1.281655	197130.4	14639.66	222762.1	-0.31406	0.000527	51090.49	1.62141	4437.635	**490060.2**
0.001574	170209.7	1.281655	218150.2	16200.67	343324.4	-0.35189	0.000527	56924.9	1.674206	4661.876	**639262**
0.001564	187386.5	1.281655	240164.9	17835.56	379226	-0.38778	0.000527	63074.68	1.723612	4871.837	**705173**
0.001555	205334.9	1.281655	263168.6	19543.91	360292.5	-0.42159	0.000527	69539.84	1.769824	5068.241	**717613.1**

POWER											
Speed in knots	Power Effective (KW)	wake fraction	thrust reduction factor	Rotative Efficiency	Kt	J	Speed of Advance	Slip	Thrust	Thrust Power	Propulsive Power Assuming efficency for 13 knots
5	61.21536	0.203177	0.20153242	0.968477	0.739547	0.439163	2.049429	0.686312	66091.27	135449.4	**97.04259098**
10	465.116	0.203177	0.20153242	0.968477	0.401527	0.878327	4.098858	0.372624	35883.36	147080.8	**737.3323072**
11	627.667	0.203177	0.20153242	0.968477	0.333923	0.966159	4.508744	0.309886	29841.78	134548.9	**995.0187273**
12	837.305	0.203177	0.20153242	0.968477	0.266319	1.053992	4.91863	0.247148	23800.19	117064.3	**1327.350631**
12.5	967.4302	0.203177	0.20153242	0.968477	0.232517	1.097908	5.123573	0.21578	20779.4	106464.8	**1533.633516**
13	1093.472	0.203177	0.20153242	0.968477	0.198715	1.141825	5.328516	0.184411	17758.61	94627.04	**1733.44371**
13.5	1248.311	0.203177	0.20153242	0.968477	0.164913	1.185741	5.533459	0.153042	14737.82	81551.12	**1978.904411**
14	1466.52	0.203177	0.20153242	0.968477	0.131111	1.229658	5.738402	0.121673	11717.03	67237.02	**2324.823459**
14.5	1727.621	0.203177	0.20153242	0.968477	0.097309	1.273574	5.943345	0.090304	8696.239	51684.74	**2738.738415**
15	1956.015	0.203177	0.20153242	0.968477	0.063507	1.31749	6.148288	0.058936	5675.448	34894.28	**3100.801951**
16	2343.681	0.203177	0.20153242	0.968477	-0.0041	1.405323	6.558173	-0.0038	-366.134	-2401.17	**3715.35658**
17	3083.576	0.203177	0.20153242	0.968477	-0.0717	1.493156	6.968059	-0.06654	-6407.72	-44649.3	**4888.285352**
18	4537.565	0.203177	0.20153242	0.968477	-0.1393	1.580988	7.377945	-0.12928	-12449.3	-91850.2	**7193.24496**

19	6247.891	0.203177	0.20153242	0.968477	-0.20691	1.668821	7.787831	-0.19201	-18490.9	-144004	**9904.565285**
20	7254.819	0.203177	0.20153242	0.968477	-0.27451	1.756654	8.197717	-0.25475	-24532.5	-201110	**11500.81337**
21	7751.944	0.203177	0.20153242	0.968477	-0.34212	1.844486	8.607603	-0.31749	-30574	-263169	**12288.88714**

Resistance @ 13 knots	163517.2131	N
Area of bulbous bow	11.2	m2

APPENDIX G: PROPELLER AND POWERING CALCULATION

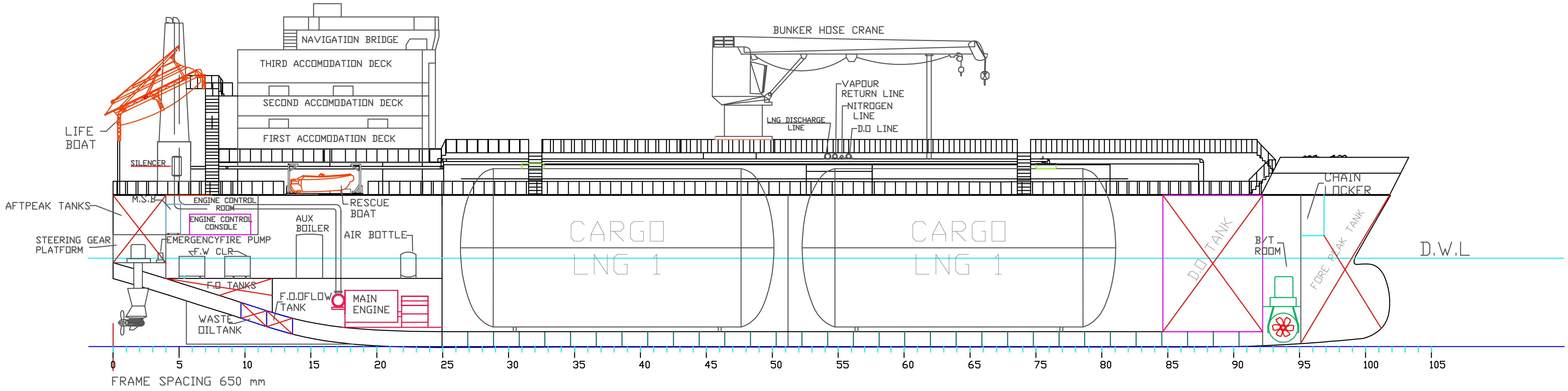
Propeller				.@13 knots		
Pitch	2.8	mt		Kt	J	desired
Diameter	2	mt		0.198715	1.141825	kt= 0.17
P/D	1.4					J= 1.2
Rpm	140					
Area Prop	2.199114858	m2		Efficiency	0.65	

APPENDIX H: COST ESTIMATION

SYSTEM NUMBER	**TITLE**	**WEIGHT [TON]**	**RATE [MAN HRS/TON]**	**MAN HOURS**	**MATERIAL**	**Material[$/t]**
100	HULL	**1696**	**25**	**42,410**	**$1,187,501**	**700**
200	PROPULSION M/C	**64**	**30**	**1,920**	**$896,000**	**14000**
300	ELECTRICAL	**50**	**55**	**2,750**	**$900,000**	**18000**
400	COMMAND & COMM	**25**	**250**	**6,250**	**$875,000**	**35000**
500	AUXILLIARY M/C	**382**	**102**	**39,015**	**$3,442,500**	**9000**
600	OUTFIT	**552**	**55**	**30,381**	**$3,314,304**	**6000**

600	LNG Tanks - 9 NI FE	**177**	**12**	**2,126**	**$106,344**	**600**
800	ENGINEERING			**30,682**	**$10,615,305**	
900	SUPPORT SERVICES			**61,363**		
	SUB-TOTAL LABOR HOURS			**216,899**		
	SUB-TOTAL LABOR DOLLARS					**$ 7,411,838**
	SUB-TOTAL LABOR & MATERIALS					**$ 16,133,487**
	OVERHEAD					**$ 3,517,694**
	TOTAL LABOR, MATERIALS AND OVERHEAD					**$ 19,651,181**
	MARGIN					**$ 1,965,118**
	PROFIT					**$ 982,559**
	Approximate Bid Price					**$ 24,598,859**

APPENDIX I: CAD DRAWINGS



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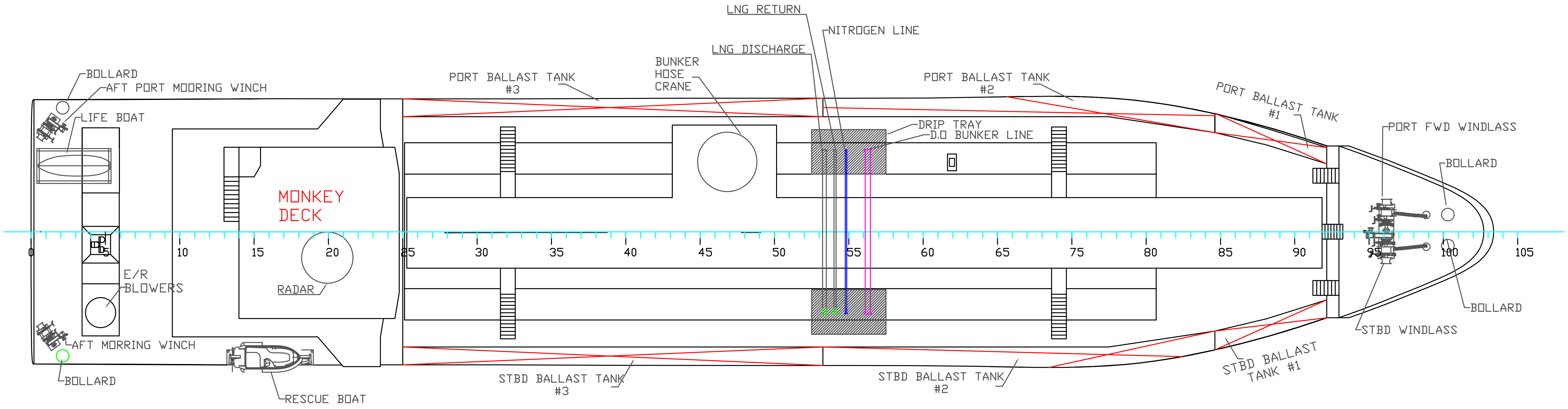

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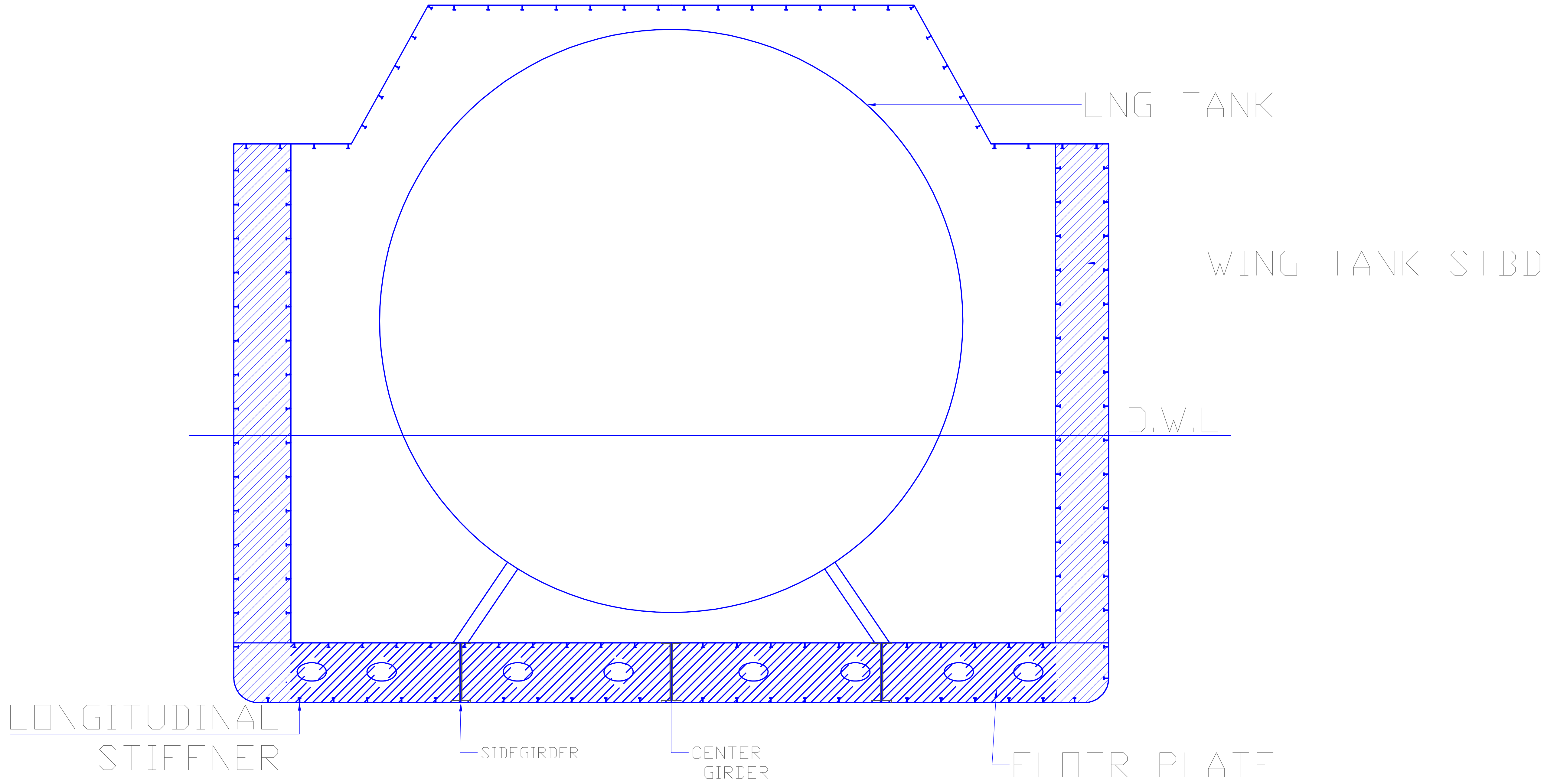
MIDSHIP SECTION



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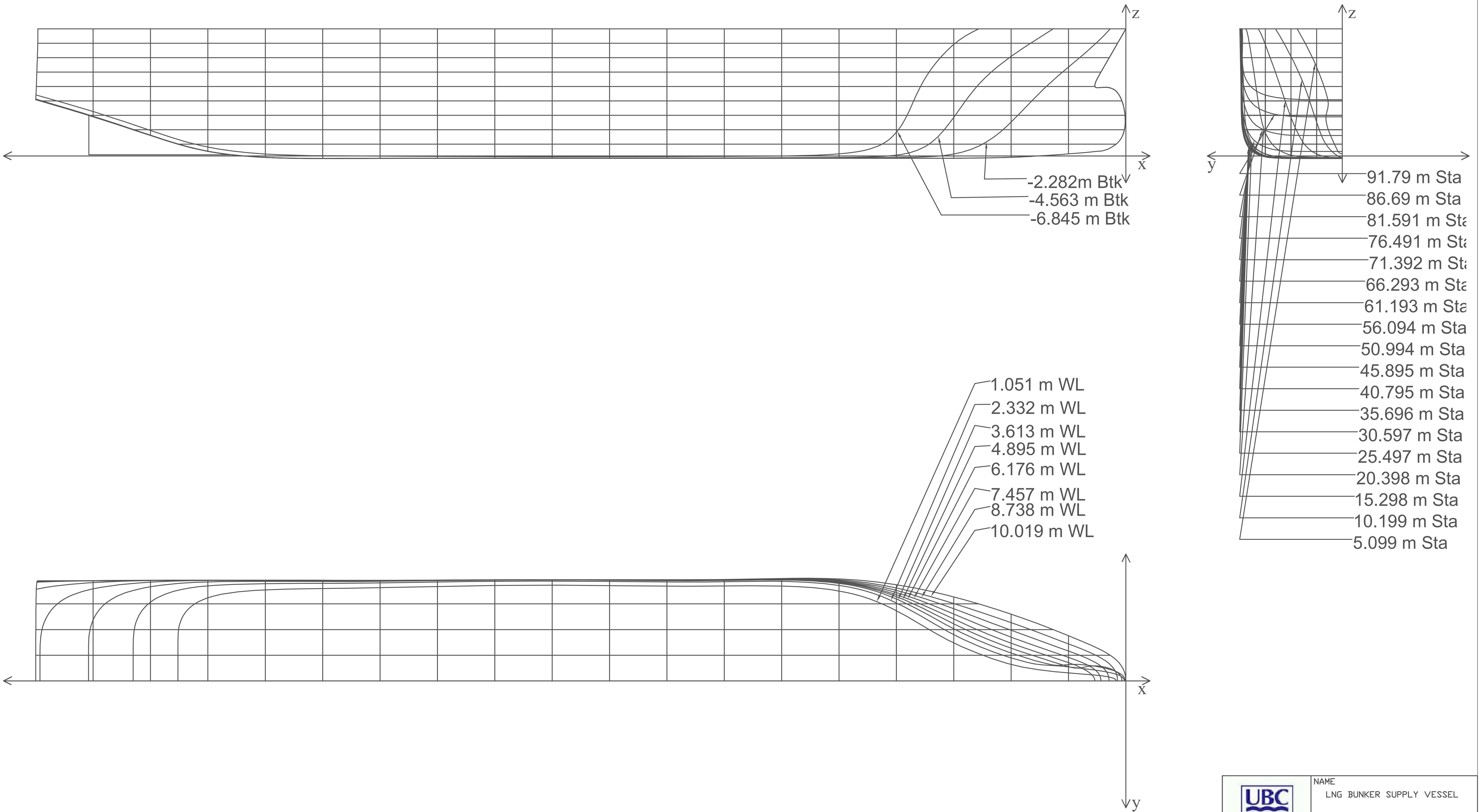

UBC		NAME LNG BUNKER SUPPLY VESSEL		
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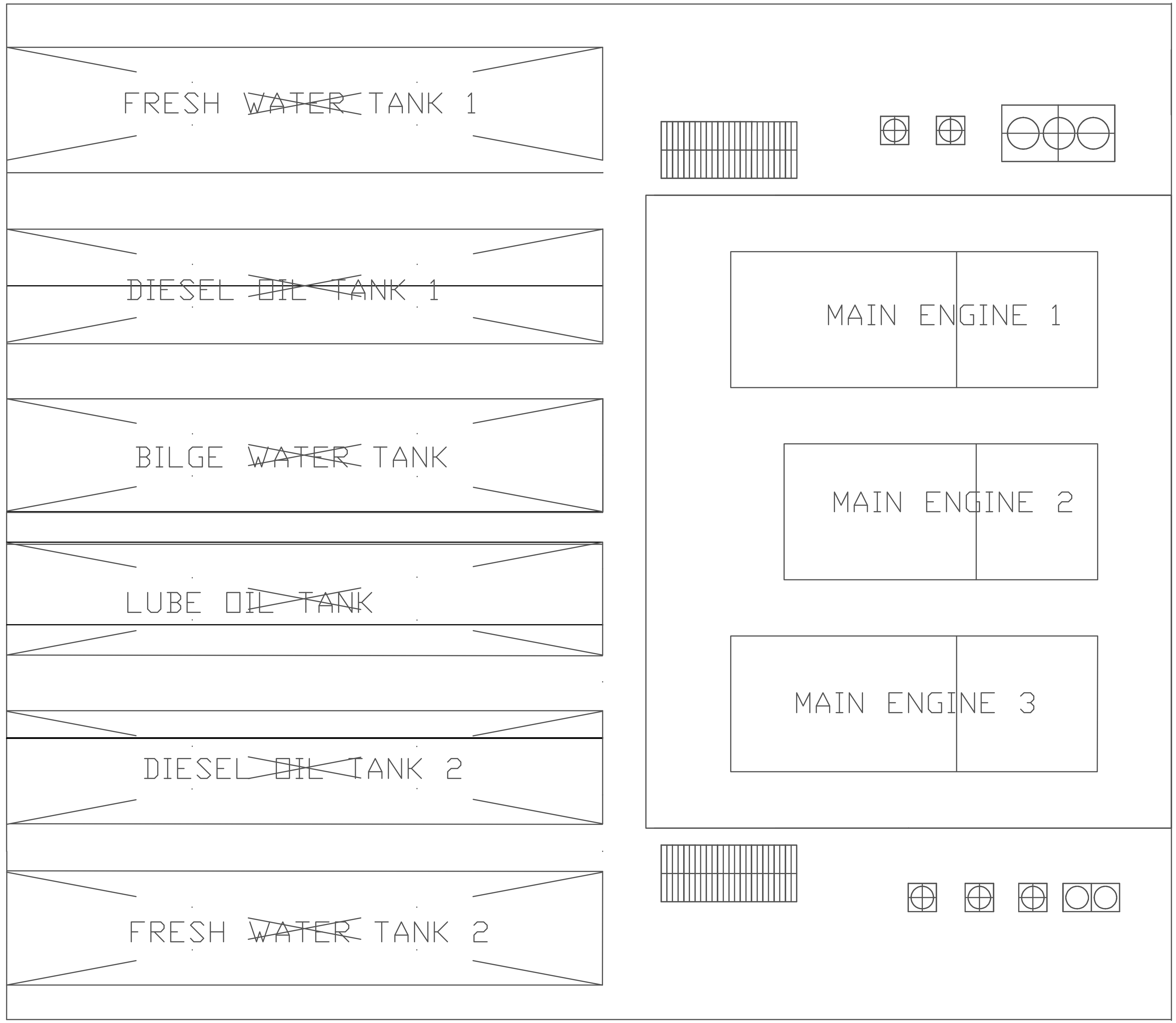
DATE 18/APRIL/2016		SCALE 1:100		SHEET 1 OF 1



BOTTOM PLATFORM

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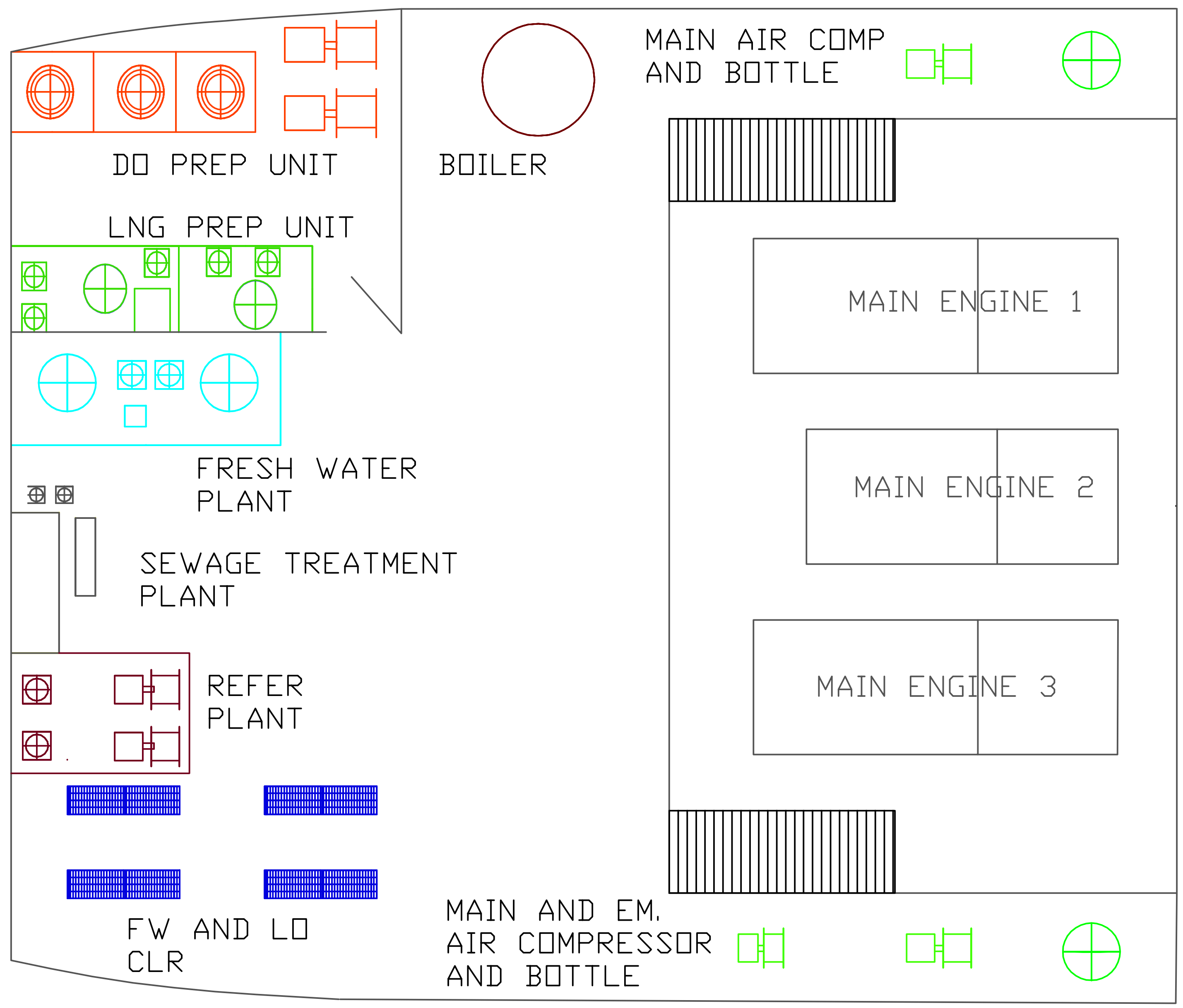
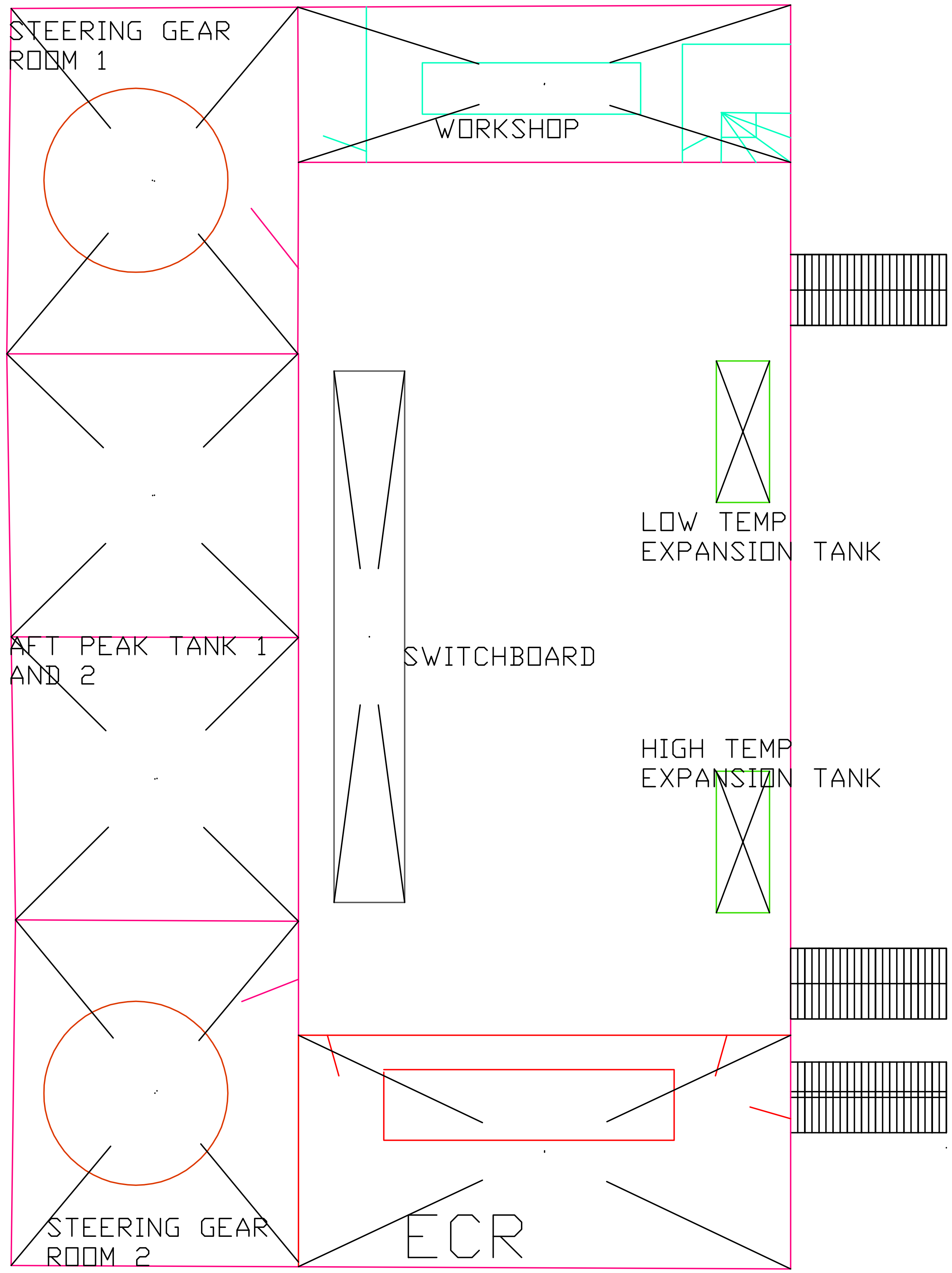
DATE 18/APRIL/2016		SCALE 1:100		SHEET 4 OF 9



ENGINE 1ST ROOM DECK

NAME	LNG BUNKER SUPPLY VESSEL			
DWG TITLE	E/R FIRST DECK			
UNITS METERS	CHECKED BY	DWG NUMB 001	SIZE A3	REVISION 1
DATE 18/APRIL/2016		SCALE 1:100		SHEET 5 OF 9



ECR PLATFORM

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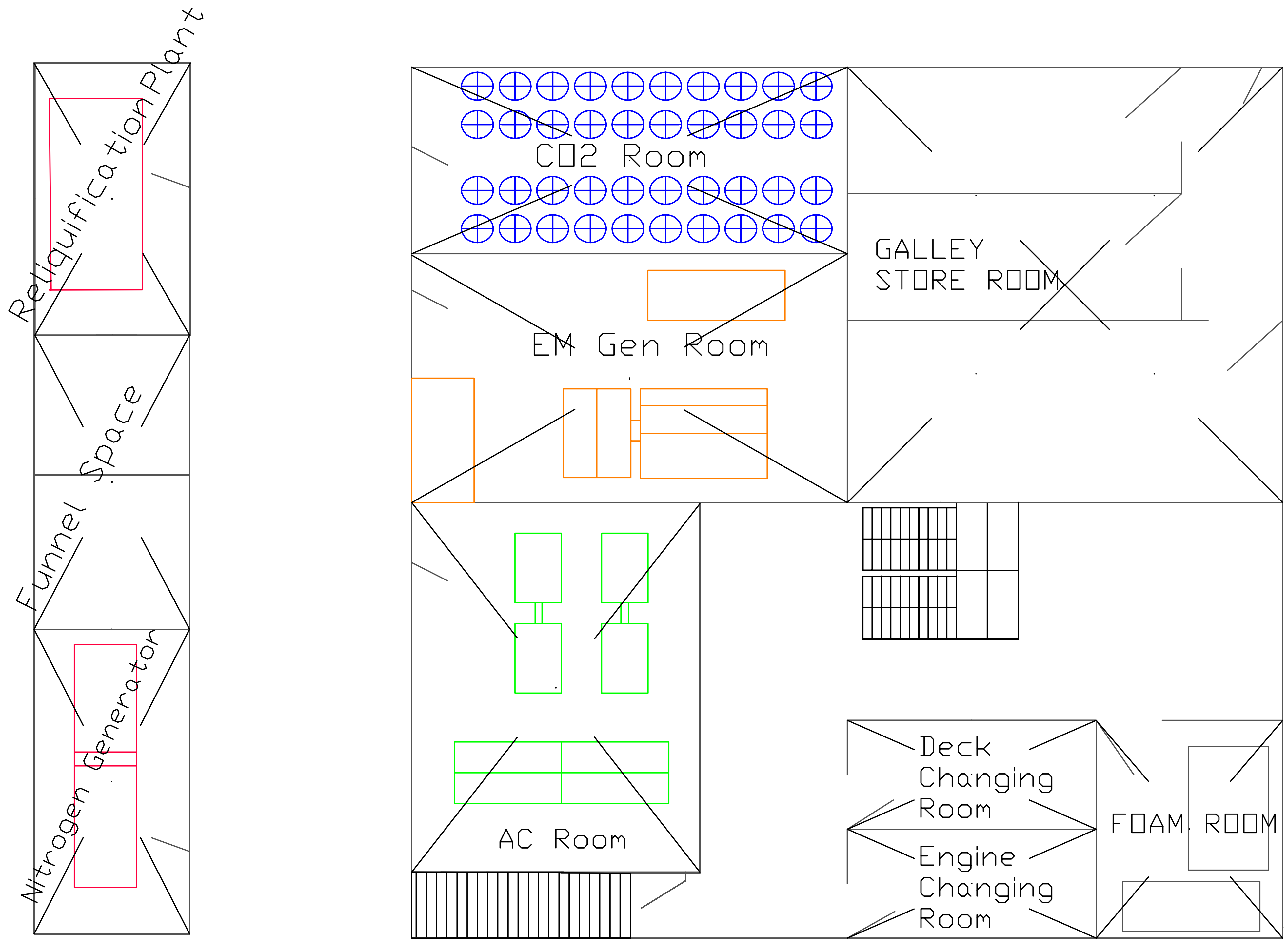

MAIN DECK

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DWG TITLE	MAIN DECK			
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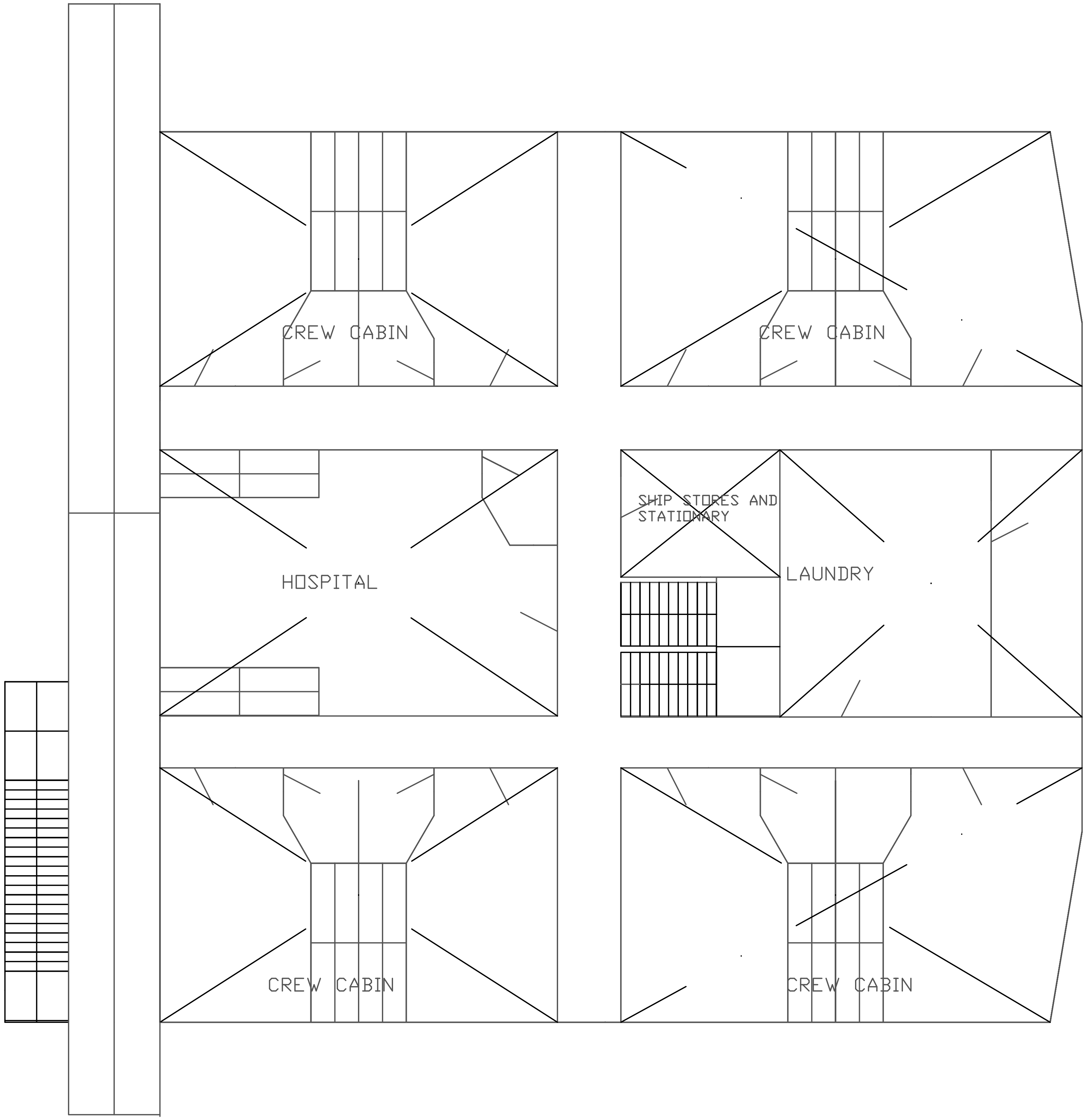
DATE: 18/APRIL/2016		SCALE: 1:100		SHEET: 7 OF 9



SECOND DECK ARRANGEMENT

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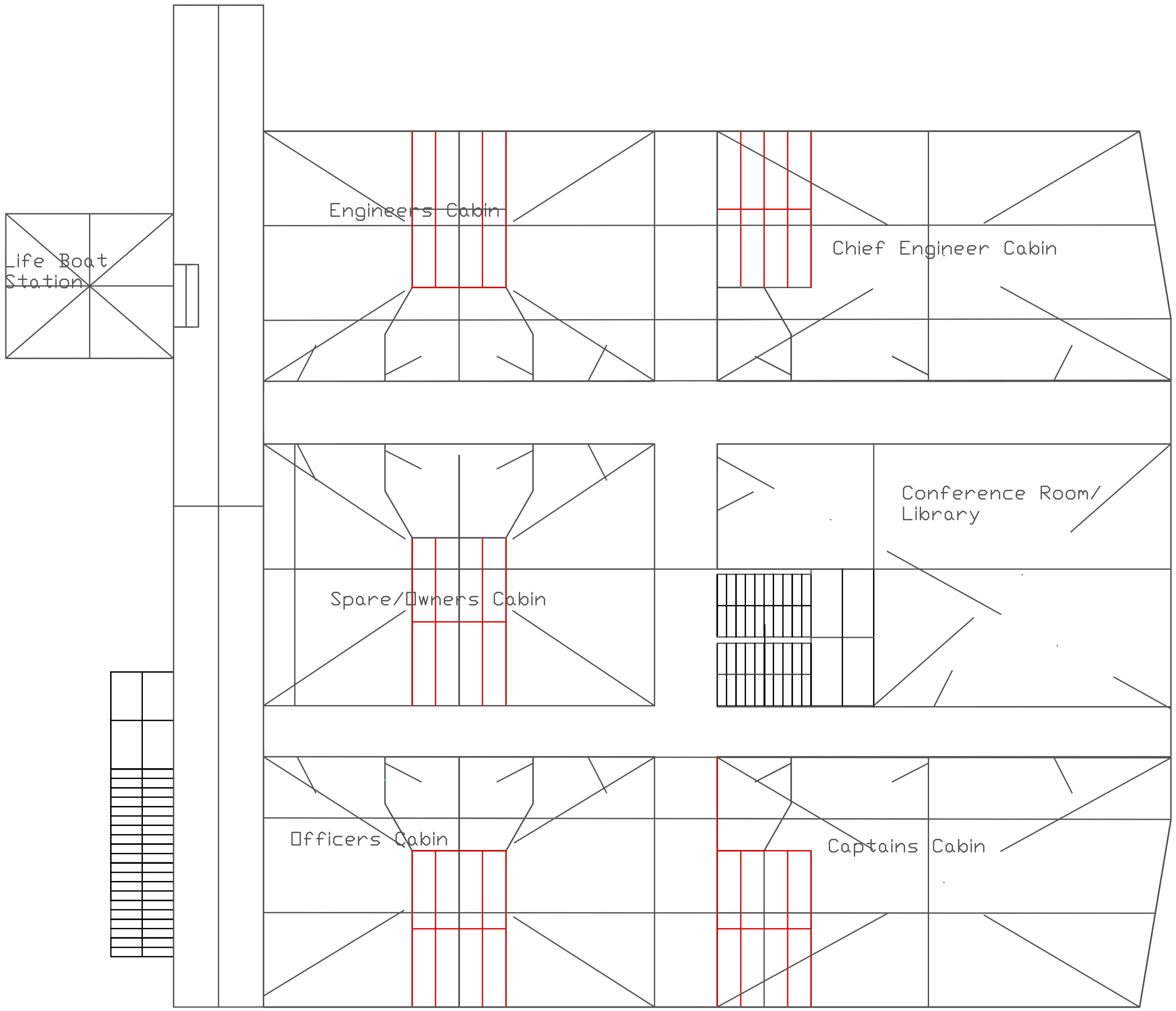
DATE: 18/APRIL/2016		SCALE: 1:100		SHEET: 8 OF 9



THIRD DECK ARRANGEMENTS

NAME: LNG BUNKER SUPPLY VESSEL				
DWG TITLE: ACCOMODATION THIRD DECK				
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DATE: 18/APRIL/2016		SCALE: 1:100		SHEET: 9 OF 9