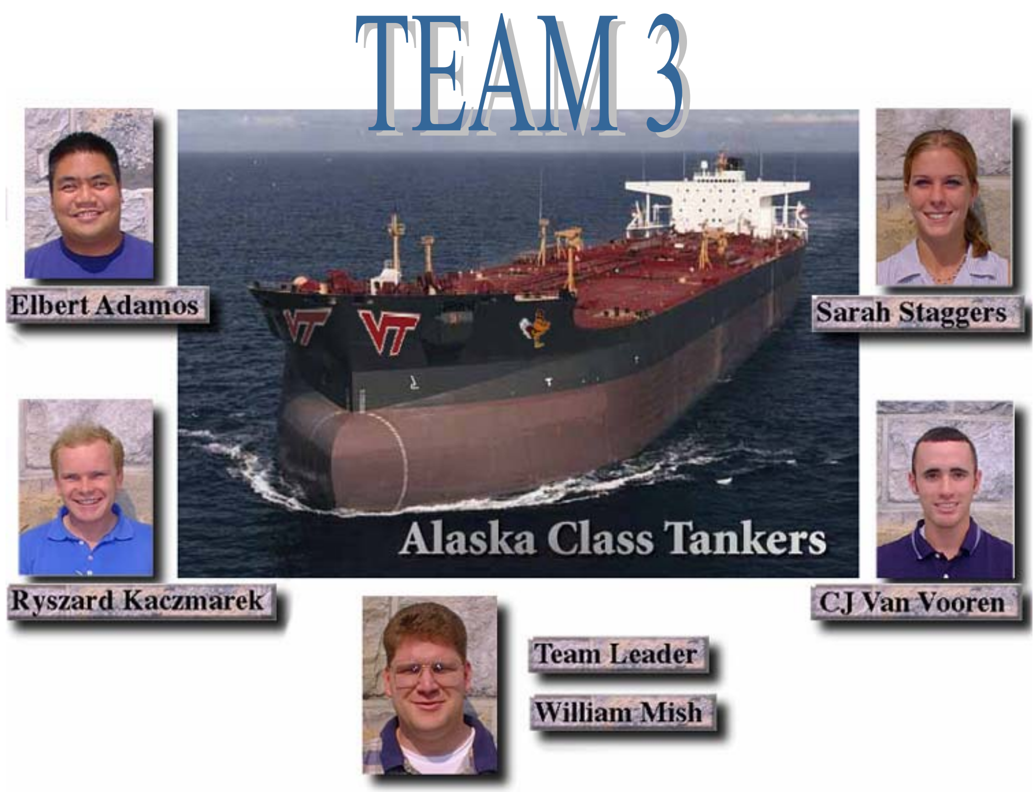
Virginia Tech
Aerospace & Ocean Engineering

Optimum Risk Tanker Design Report

An Analytical Process for a TAPS Tanker Design



ORT LO
Ocean Engineering Design Project
AOE 4065/4066

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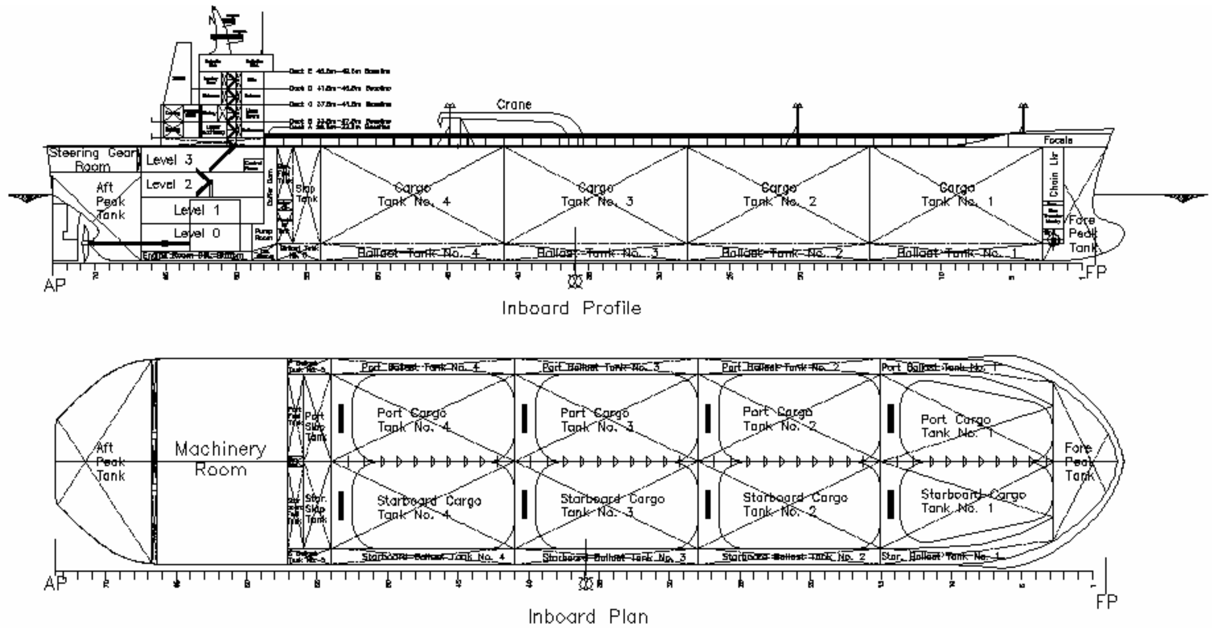
Executive Summary



The goal of the Optimum Risk Tanker (ORT) LO is to transport oil from the Trans Alaskan Pipeline System to the Northern Pacific utilizing a design which is low in cost and low in risk. This design is achieved by analyzing the owners' requirements, defining the mission, optimizing cost and risk, and exploring various ship concepts. A Pareto Genetic Algorithm is used to identify feasible ships on a non-dominated frontier.

The LO ORT assigned to our team is one of four designs selected from the non-dominated frontier for feasibility study. It represents the low cost option. The ORT LO tanker meets all necessary requirements and regulations. The hull form is optimized for good seakeeping and fuel efficiency. The structural configuration is designed to ABS 2000 standards and is highly producible and maintainable. The propulsion system produces ample power to propel the ship efficiently and effectively. Mechanical and electrical components satisfy the requirements necessary for the vessel to perform its mission. Cargo systems ensure safe and proficient cargo storage and transfer. The ballast system allows the vessel to meet stability requirements when needed. The Manning Plan for the ORT LO tanker contains sufficient crew to operate the vessel according to Federal Regulations. The deckhouse satisfies owners' requirements for crew habitability and the navigation deck exceeds regulations for visibility. Tank arrangements are designed to optimize environmental protection and provide easy maintenance. The machinery space optimizes space arrangements of various components of cargo, propulsion, and electrical equipment. Weights for all of the vessel's components are balanced and optimized for trim and stability. Intact stability is satisfactory in all loading conditions and meets the IMO A.167 Righting Energy Criteria with a margin of safety in all cases. Damage stability criteria is satisfied for all damage cases and loading conditions. The maneuvering characteristics are exceptional for its trade and route characteristics.

Principal Characteristics	
Length Overall	258 m
Length Between Perpendiculars	251 m
Beam, Molded	49.78 m
Depth, Molded Upper Deck at side	27.5 m
Draft, Full Load	16 m
Cb	0.83
Cp	0.834
Cx	0.995
DWT	140,000
Displacement	167,983 MT
Lightship Weight	27,983 MT
Draft Design	15.8 m
Sustained Speed at Design Draft and 90% rated horsepower (Approx.)	16 Knots
Endurance Speed	15 Knots
Endurance Range	10,000 nm
100% Cargo Capacity	167,105 m^3
Fuel Oil Tankage	2,935 MT
Diesel Oil Tankage	113 MT
Lube Oil Tankage	23 MT
Fresh Water tankage	236 MT
Machinery	Diesel
Rated Horsepower	30,560 hp
Number of Passengers	3
Number of Crew	20
Propeller (1) Blades	4
BCC	$112.7 mi
TOC	$198.2 mi
Risk	0.098 m^3

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Acknowledgements

The members of Team 3 would like to thank everyone who has aided in the completion of this design report. Without their tremendous contributions, this report would not have been possible. We would specifically like to thank:

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All Ocean Design Team members whose collective research and support facilitated various areas of the design process

About the Authors

The authors of the Optimum Risk Tanker Design Report will utilize the knowledge that they have gained from this report in a variety of ways. William Mish will be moving on to Band Lavis and Associates in Severna Park, MD where he will work in concept design. Ryszard Kaczmarek will join the US Navy's Civil Engineering Corps after attending OCS in Pensacola, FL this summer. Sarah Staggers has accepted a job in the structures department of Newport News Shipbuilding in Newport News, VA. Elbert Adamos will be joining the Combatant Craft Department, Ship Systems, Carderock Division in Suffolk, VA. C.J. Van Vooren will work for the Sealift department at CSC Advanced Marine in Arlington, VA.

1.0 Requirements and Plan

1.1 Owner's Requirements

This report describes the design process for an Optimum Risk Tanker (ORT). The primary mission for this vessel is to transport crude oil from the Trans Alaskan Pipeline System (TAPS) in the Northern Pacific to the West Coast of the United States. Therefore this ship is a Jones Act Ship. Expert opinion was solicited from ARCO Marine, Inc. to define customer requirements. Specific owner's requirements are located in Appendix A.1.

The vessel must have the capabilities to travel to China where repairs and dry-docking will occur. The Projected Operational Environment (POE) factors that must be considered include sea state conditions, sea and air temperatures, and ice hazards. System operational requirements include cargo and ballast pumping capabilities, speed, crude oil washing (COW) system, inert gas system (IGS), emissions, and possibly ballast water exchange in the future. All of these systems must work together in a safe, timely manner, while accommodating the schedule constraints of a round trip of 10.5 days. The vessel must comply with U.S. COFR, port regulations, and ABS Class rules. The POE factors and applicable regulations are detailed in Section 2.2.

1.2 Design Philosophy, Process, and Report Organization

The traditional approach to ship design is largely an 'ad hoc' process. Primarily, experience, design lanes, rules of thumb, preference, and imagination guide selection of design concepts for assessment. Often, objective attributes are not adequately synthesized or presented to support efficient and effective decisions. This project uses a total system approach for the design process, including a structured search of design space based on the multi-objective consideration of cost and risk. Figure 1.2.1 provides a flow chart of the design process used in this project.

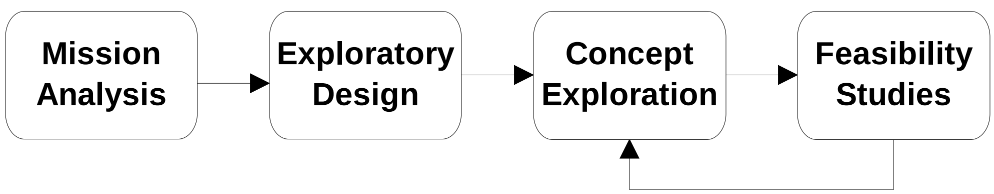


Figure 1.2.1 Design Process

The designer and customer work together during the Mission Analysis to define the ship mission and general requirements. The results of this phase are summarized in the COR. Exploratory Design consists of acquiring and understanding information on current and future ship technologies and their potentials. In Concept Exploration, a closed form analytical method is used for calculating risk. A pareto-genetic algorithm (PGA) is used to search the design parameter space and identify non-dominated design concepts in terms of risk and cost. All important system and design trade-off studies are made simultaneously as part of this ship system optimization. Once the non-dominated concept frontier is identified (see Figure 1.2.2), the baseline concept design is selected based on the customer's preference for cost and risk. The shape of the frontier may have a 'knee' in the curve, a region where there is a sharp discontinuity. The bottom of this knee is a "best buy region." The Concept Exploration process and the baseline concept design are described in detail in Chapter 3. The Feasibility Studies include more detailed analyses for mission, hydrostatics, stability, structure, sea keeping, station keeping, weights, arrangements, cost and manning. The Feasibility Studies follow the more traditional design spiral (Figure 1.2.3). All of these are described in Chapter 4.

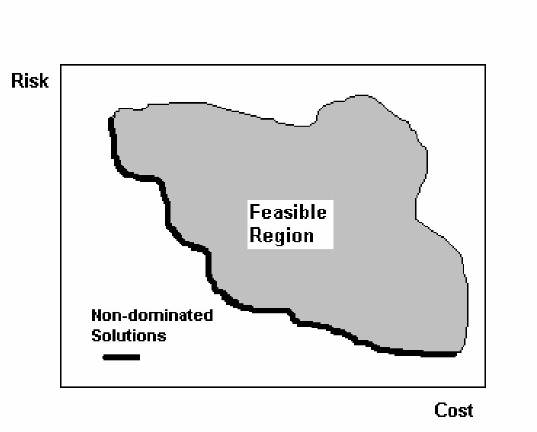


Figure 1.2.2 Risk Non-dominated Frontier

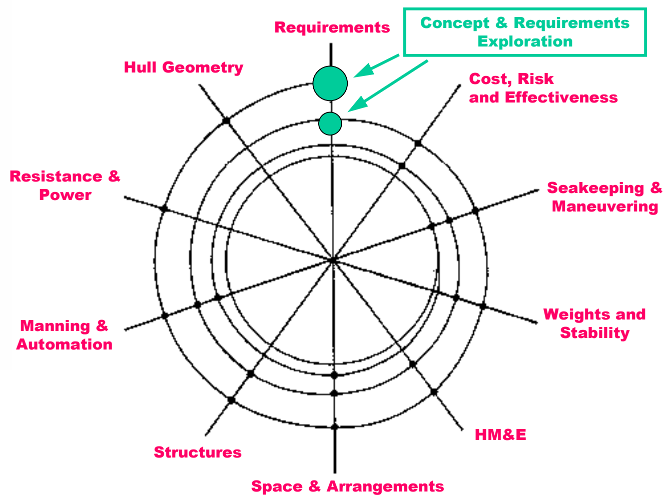


Figure 1.2.3 Design Spiral

1.3 Work Breakdown

A five-person team was established with each member specializing in a particular area of expertise. This approach allows each person to draw on their past experience with the chosen area of expertise providing a solid foundation of knowledge while maintaining an efficient investigation into the design problem. In addition, a team leader was selected to facilitate an efficient and organized project. Individual areas of expertise are listed in Table 1.3.1. In addition to having separate specialties, the entire team worked on several mini projects to bring forth the risk function and the parametric tanker model.

Table 1.3.1 Work Breakdown

Name	Specialization
Bill Mish (Team Leader)	Hull / Hydrostatics / Hydrodynamics
Sarah Staggers	Power / Propulsion / Resistance
CJ Van Vooren	Weights / Synthesis / Editor
Ryszard Kaczmarek	Structures / Producibility
Elbert Adamos	Subdivision / Arrangements

1.4 Resources

Throughout the design process, various software packages were used to facilitate design analysis. In the concept exploration phase, MathCad software was used to develop the ship synthesis model. This code is then input into a Fortran optimization program. As the design process continues, other software is used to facilitate analysis needed in each team member's area of expertise. Table 1.4.1 provides a list of each software package and the analysis in which it has been utilized.

Table 1.4.1 Software

Analysis	Software Package
Arrangement Drawings	AutoCAD
Hullform Development	FastShip
Hydrostatics	HecSalv
Resistance/Power	NavCad
Ship Motions	SMP
Ship Synthesis Model	MathCad/Fortran
Structure Model	SafeHull

2.0 Mission Definition and Risk Optimization

The primary mission of the ORT is to transport crude oil between the Trans-Alaskan Pipeline System (TAPS) in Port Valdez, AK and the West Coast of the United States.

2.1 Concept of Operations

Over 600 voyages will be performed during the lifetime of the ship. Thus, reliable operation in the severe environments in the Northern Pacific and sensitive marine port environments are required. The average round trip is roughly 15 days with two days in port and 13 days at sea (Figure 2.1.1).

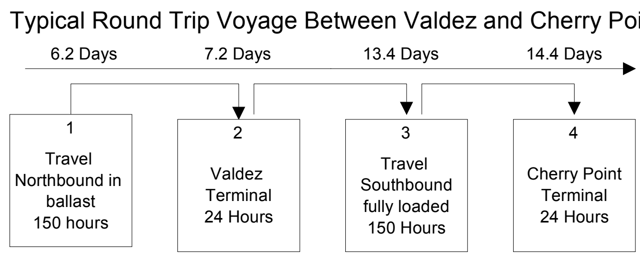


Figure 2.1.1 Typical Voyage Round Trip Between Valdez and Cherry Point

The entrance to Port Valdez begins in the Gulf of Alaska through Prince William Sound. The tanker travels through the Hinchinbrook entrance following dedicated traffic lanes to Valdez Arm and Valdez Narrows. Once entering Hinchinbrook, tug escort to Port Valdez is required. If the winds are 31-40 knots upon entrance, extra tug escorts are required. If the winds are more than 40 knots, Valdez Narrows is closed completely. A number of channel specifications exist:

- Average width of channel – 3180 ft
- Minimum width of channel – 800 ft
- Average depth of channel – 800 ft
- Minimum depth of channel – 350 ft
- Six turns total (three left, three right)

The length of the route from the Valdez Arm to Port Valdez is approximately 22 miles. Throughout Prince William Sound, USCG-supplied VTS is required to navigate the waters surrounded by a diverse wildlife population.

The entrance to Cherry Point begins unescorted from the Pacific Ocean to Port Angeles. Once in Puget Sound, a Washington State licensed pilot must be on board until arrival at the port. Like Prince William Sound, Puget Sound is home to a very diverse wildlife population. Port characteristics such as the ones just described are used in the oil outflow risk model.

2.2 Required Operational Capabilities and Projected Operational Environment

The minimum necessary capabilities for the vessel to perform its mission are its required operational capabilities (ROC). They include:

- <u>Transport</u> crude oil in incident free, year-round operation limited by U.S. Code of Federal Regulations (33 CFR 165.1303b), OPA 90, and U.S. cabotage laws regarding crude oil trade. Systems must load and offload cargo alongside harbor piers, offshore facilities, and lightering within the bounds of port regulations.
- <u>Provide</u> cargo and ballast capabilities to load/offload/deballast/ballast in 24 hours.
- <u>Provide</u> COW capabilities. These systems use electric driven pumps to clean the residual crude oil inside the cargo tanks. The tanks are cleaned while cargo unloading.
- <u>Provide</u> an IGS to prevent explosions in the cargo tanks. These systems utilize the exhaust of the diesel engines to fill the cargo tanks during transport and loading/offloading procedures. These systems ensure a explosive cargo fumes and air in the tanks do not form a volatile mixture.
- <u>Provide</u> precise navigation using an electronic chart display and information system (ECDIS) and the vessel traffic service (VTS). These navigation systems ensure the tanker uses the most current nautical information during transit.

- Provide ballast water exchange to prevent the transportation of dangerous microorganisms from one region to another. This precaution should be installed pending expected future regulatory constraints.
- Provide war-time compliance. Tankers must be able to join in the national emergency effort performing military sealift command standards for underway replenishment.

The projected operational environment for the vessel is the Trans Alaskan Pipeline System (TAPS) trade in the Northern Pacific. The primary route for the tanker is the trade route between Valdez, AK and Cherry Point, WA. Other possible ports for the off-loading of oil in this trade are Long Beach, CA and San Francisco, CA. The most probable sea state in the Northern Pacific corresponds to Sea State 4, which has a mean significant wave height of 1.88 meters and a mean sustained wind speed of 19.0 knots. A complete table of the annual sea state occurrences in the Northern Pacific is shown in Appendix A.1.2. Ice is a significant factor for a TAPS trade tanker. Within the approach route to Valdez, Alaska, there are approximately 10-15 large icebergs.

2.3 Objective Attributes: Risk and Cost

For the exploration of this tanker concept, oil outflow, risk and cost are the objective attributes. Risk is quantified in terms of probability of damage and mean oil outflow. Probabilities of damage are based on grounding and collision while oil outflow is based on the mean oil outflow due to grounding (bottom damage) and collision (side damage). The combination of results from probability of damage and oil outflow produces a quantitative risk value. Cost is comprised of components such as manning, fuel, lead ship construction cost (BCC), and maintenance.

2.4 Constraints and Standards

An oil tanker operating in U.S. waters is required to meet standards specified by the U.S. Coast Guard (USCG) as well as international regulations set by International Maritime Organization (IMO) and MARPOL, the International Convention for the Prevention of Pollution from Ships. The USCG enforces the Oil Pollution Act of 1990 (OPA 90), which requires tankers to have double hull construction. MARPOL 73/78 requires tankers to have segregated ballast tanks, COW abilities, IGS, and slop tanks. US COFR and MARPOL also has subdivision and stability requirements, and necessitates a hypothetical oil outflow calculation. The concept design must consider several physical constraints necessary for feasibility. Constraints include:

- Propulsion power
- Machinery box volume
- Deckhouse volume
- Cargo block volume
- Deadweight tonnage
- Stores capacity

The optimization program uses these constraints to eliminate unfeasible ships from the concept exploration design space. After this process, the owners would select a feasible ship with their preferred combination of physical constraints.

3.0 Concept Exploration

3.1 Ship Synthesis Model and Optimization

3.1.1 Ship Synthesis Model

In the concept exploration phase of the design process, it is necessary to balance each investigated ship. Therefore, with the aid of MathCad software, a ship synthesis model was developed which balances a ship in terms of weight, displacement, volume, area and power based on a given set of design parameters. This method allows variation of design parameters, while maintaining a feasible ship. Risk is calculated using an oil-outflow risk model. A simplified total ownership cost (TOC) is calculated using a weight and producibility-based cost model. TOC is comprised of various components such as lead ship construction costs, crew, fuel, and maintenance. Figure 3.1.1.1 provides a flowchart of this process.

The MathCad ship synthesis model is the tool used to balance each ship in the optimizer. The model is described in the remaining sections of this chapter and in Appendix A.2. Design parameters and system alternatives considered in this optimization are provided in Section 3.1.2.

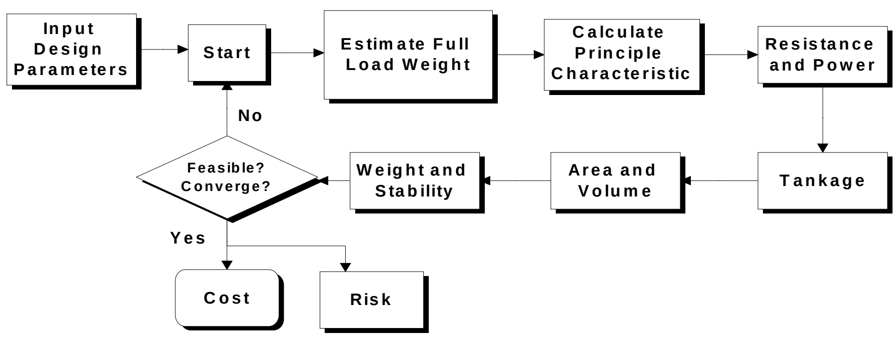


Figure 3.1.1.1 Ship Synthesis Model

3.1.2 Trade-Off Technologies, Concepts and Design Parameters

Each ship design is described using 13 design parameters (Table 3.1.2.1). These design parameters are input into the ship synthesis model described above. The ship is then balanced, checked for feasibility, and ranked based on cost and risk. The design parameters can be broken down into four categories: Hull Form and Structural Concepts, Propulsion and Electrical Concepts, Automation and Manning and Cargo Systems. The hull form and structural concept parameters are: Beam to Draft Ratio, Length to Beam Ratio, Block Coefficient, Depth to Draft Ratio, Deck Height, Stern Type and Structural Margin Factor. The propulsion and electrical parameters are: propulsion system type and electrical redundancy. The manning factor reflects the automation and manning concept. The cargo system parameters are: the double bottom height, double side width, and the number of cargo holds. Each design parameter is limited to a feasible range (Table 3.1.2.1). For example, the structural margin factor has a range of 1.0 to 1.5. This number determines how thick the hull plating is beyond the necessary structural thickness required by ABS standards. When multiplied by the number of increments (Table 3.1.2.1) and added to the minimum plate thickness (based on plate loading), the result is the total thickness of the plating. The trade off is corrosion and strength risk verses cost. With thicker plating, the ship's total cost increases, but has less structural risk. Thinner plating has less total cost, but more structural risk.

Table 3.1.2.1 Design Parameters

DP	Description	Metric	Range	Increments*
1	Beam to Draft Ratio	ND	2-4	40
2	Length to Beam Ratio	ND	5-7	40
3	Block Coefficient	ND	0.7-0.9	40
4	Depth to Draft Ratio	ND	1.2-2.0	40
5	Double Bottom Height	m	2-4	20
6	Double Side Width	m	2-4	20
7	Manning Factor	N/A	0.5-1.0****	10
8	Structural Margin Factor	N/A	1.0-1.5	5
9	Deck Height	m	3-4	10
10	Number of Cargo Holds	N/A	4-8	4
11	Propulsion System Type	N/A	1-6**	6
12	Electrical Redundancy	N/A	1-2***	2
13	Stern Type	N/A	1-2*****	2

* The increments represent the number of steps analyzed between the range values.
** The propulsion system type ranges from 1-6. 1-3 represent different engine types for a singal engine and 4-6 represent different engines for a dual engine system.
*** Electrical redundancy is either 1 or 2 representing no redundancy or redundancy.
**** The manning factor ranges from 0.5-1.0 representing the number of crew on the ship.
***** The stern type is either 1 or 2 where 1 is a producible stern and 2 is an efficient stern.

3.1.2.1 Hull Form and Structural Concepts and Parameters

There are seven parameters that control the hull form and structural concepts. The first four describe the actual hull form with standard ship design coefficients: Beam to Draft Ratio, Length to Beam Ratio, Block Coefficient, and Depth to Draft ratio. These allow the optimizer to choose a variety of ship shapes and sizes while allowing the math model to vary the actual dimensions (to balance the ship) without affecting the general shape of the ship. This also allows the designers to quickly create a hull in FastShip. The stern shape parameter allows the optimizer to explore fuel efficiency versus producibility cost. The deck height parameter is the height of the individual decks in the deckhouse. This allows the optimizer to explore a variety of deck heights for producibility while allowing the math model to balance the deckhouse with its restrictions (number of crew, visibility, and storage). The structural margin factor allows the optimizer to search the design space for the optimum combination of plate thickness versus corrosion failure risk.

3.1.2.2 Propulsion and Electrical Concepts, Alternatives and Redundancy

The two alternative systems of propulsion considered in the exploratory design are the integrated power system (IPS) and the inline mechanical system. IPS can be used with a traditional fixed pitch propeller, and a podded propulsion system. The advantages of IPS are flexibility of arrangements, lower noise/vibration, increased maneuverability with pods, cleaner electrical power, and ease of maintenance. Disadvantages of the system are higher installation cost, weight and grounding risk if a podded propulsor is used.

For the inline mechanical system, a slow speed diesel engine system can be used with a Controllable Reversible Pitch Propeller (CRP), Controllable Pitch (CPP), or a Fixed Pitch Propeller (FPP). In addition, the contra-rotating propeller system may be used in both cases. The benefits of a slow speed diesel include its proven technology, cost efficiency, maintainability, and lower installation cost. Medium speed diesel engines are not considered in this concept exploration due to time and information constraints.

In analyzing the propeller systems, the contra-rotating propeller system is determined to be a high efficiency system. However, the increased risk and underdeveloped technology make this concept too risky. The CPP has positive characteristics such as reduced emissions, increased engine life, increased maneuverability, and elimination of heavy clutches. The disadvantages of this system are its cost, maintenance, and complexity. From the analysis of the FPP system, low weight, low cost, and proven technology are its benefits. The negative characteristics of this system are limited maneuverability and required engine/propeller matching.

Due to its low cost and risk, the chosen system was the fixed pitch propeller powered by a slow speed diesel engine. Preliminary ship displacement and other requirements indicated that propulsion engines should be in the 25,000-35,000 bhp range for non-redundant systems (1 shaft) and 12,500-17,500 bhp for the redundant systems (2 shafts). The summary of the main propulsion engines considered in the concept design is presented in Table

3.1.2.2.1. All of the engines and their characteristics are included in the optimization process for final trade-off analysis.

Table 3.1.2.2.1 Engines Options Considered in the Concept Design

Opt. No.	Engine Select.	Engine Maker	No. Of Cyl.	Power Gen. BHP	kW	Optim. rpm r/min	Optim. Prop. size ~ mm	Prop wieght Ton	Weight ton	Lmin mm	W mm	H mm	Volume m^3	SFOC g/BHPh	g/kWh	Cost $170/BHP
1	S50MC-C	Man B&W	6	12870	9480	127	5450	32.1	207	6439	5000	8950	288.1	126	171	$2,187,900
2			7	15015	11060	127	5650	35.5	238	7289	5000	8950	326.2	126	171	$2,552,550
3			8	17160	12640	127	5850	39.9	273	8139	5000	8950	364.2	126	171	$2,917,200
4	L50MC	Man B&W	8	14480	10640	148	5200	50.6	276	9175	4500	7825	323.1	127	173	$2,461,600
5	S42MC	Man B&W	10	14700	10800	136	4700	26.2	232	9476	4400	8050	335.6	130	177	$2,499,000
6			11	16170	11880	136	4800	29.9	249	10224	4400	8050	362.1	130	177	$2,748,900
7	L58/64	Man B&W	8	15120	11120	420	5500~130 rpm	35.9	198	11600	3550	5140	211.7	130	177	$2,570,400
8	S70MC-C	Man B&W	6	25320	18630				555	8971	7500	12500	841.0	124	169	$4,304,400
9			7	29540	21135	85	N/A	N/A	624	10161	7500	12575	958.3	124	169	$5,021,800
10	S70MC	Man B&W	7	26740	19670				648	10915	7300	12225	974.1	124	169	$4,545,800
11			8	30560	22480	85	N/A	N/A	722	12161	7300	12225	1085.3	124	169	$5,195,200
12	L70MC	Man B&W	8	30760	22640	95	N/A	N/A	667	11992	6800	10850	884.8	128	174	$5,229,200
13	K80 MC-C	Man B&W	7	34300	25270	104			875	12528	6500	11125	905.9	126	177	$5,831,000
14	L 80 MC	Man B&W	7	34580	25480				864	12658	6800	11775	1013.5	128	174	$5,878,600
15	RTA 48T-B	New Sulzer	7	13860	10185	127	N/A	N/A	225	6950	6300	9030	395.4	126	171	$2,356,200
16			8	15840	11640	127	N/A	N/A	250	7800	6300	9030	443.7	126	171	$2,692,800
17	RTA 52U-B	New Sulzer	7	15225	11200	137	N/A	N/A	270	7925	6570	8745	455.3	128	174	$2,588,250
18	RTA 58T-B	New Sulzer	5	14450	10625	105	N/A	N/A	281	6381	7200	10880	499.9	125	170	$2,456,500
19			6	17340	12750	105	N/A	N/A	322	7400	7200	10880	579.7	125	170	$2,947,800
20	RTA 72 U-B	New Sulzer	6	25140	18480				565	9300	7000	11875	773.1			$4,273,800
21			8	33520	24640				715	12000	7000	11875	997.5			$5,698,400
22	RTA 84 C	New Sulzer	5	27550	20250				740	10400	8800	13130	1201.7			$4,683,500
23		New Sulzer	6	33060	24300				850	11500	8800	13130	1328.8			$5,620,200

Note:

- Lmin is the length of the block itself and not the length of the pulleys, turn wheels, and auxiliary systems
- H is the clearance height needed for the vertical lift of the engine
- Two digits numbers indicate the diameter of the piston in cm, MC is the engine program, and the C stands for the compact design. The letters L and S in front indicate super long and long stroke (stroke/bore ratio.)

Based on fuel consumption, size, weight, redundancy, and available information, the following Man B&W engines are chosen for further consideration and trade-off in the optimization:

1. S70MC-C (6 cylinders)
2. S70MC (8 cylinders)
3. L80MC (7 cylinders)
4. S50MC-C (6 cylinders)
5. S50MC-C (7 cylinders)
6. S50MC-C (8 cylinders)

The first three selected engines were considered in the non-redundant systems (1 shaft) and the remaining three in the redundant systems (2 shafts/2 propellers). The redundant systems decrease grounding risk, but increase the costs, space required and weight of the ship. The tradeoffs of single versus twin screw systems are analyzed in the math model. Characteristics such as brake horsepower, specific fuel oil consumption, weight and size are incorporated in the math model. These characteristics determine the speed, size of the machinery box, and the price of the propulsion plant. The analyses are performed in the Machinery section of the math model (Appendix A2).

The electrical system concept is also considered for redundancy by being a DP in the PGA. The maximum required power is based on the maximum functional load for a winter cruise condition. The electric loads considered are the propulsion plant, cargo pumps, steering machinery, lighting, control systems, firemain, auxiliaries, hotel services, and HVAC system. Summation of all these loads and electric power margins results in a Maximum Functional Load (MFL). The elements of trade-off are the cost, weight, reliability and space. A second electric plant increases the reliability of the ship's electric services but increases weight, cost, and space.

The Power Take-Off (PTO) system along with the diesel generators are analyzed and accepted in the concept design. The PTO system required Power Conversion Units (PCU). The redundant options include redundant PTO and PCU. The ship service and emergency generators are examined later in the design process.

3.1.2.3 Automation and Manning

The crew size is based on three different factors: the number of engines, the volumetric size of the tanker, and the manning factor. The manning factor describes the automation level of the vessel with a low manning factor representing high automation, and vice versa. As the ship gains more propellers, the need for more workers to maintain more engines increases. As the ship gains size, the same need for a larger crew is reflected in the aforementioned crew size function. The manning factor is the only one that can be altered in terms of levels of ship automation. A manning factor of 0.5 describes a minimum crew of specialists to monitor the highly automated ship. A manning factor of 1.0 describes the standard number of personnel for a less automated tanker. Efficiency and initial cost increase with more automation. Accident risk decreases with increased manning.

All three factors are used in a function to output a total crew size, N_T. This output is used in the MathCad file (Appendix A.2) to determine the deckhouse volume and crew arrangements. The manning factor of 0.7 and the crew size (N_T) of 20 have been optimized for this vessel. The exact calculations showing the procedure for determining total crew size are located in Appendix A.2, Section "Manning and Deckhouse Volume".

3.1.2.4 Cargo System (Mission) Parameters

The width of the double hull, height of the double bottom, and the number of cargo blocks are the major areas analyzed for the mission concepts. An increased height in the double bottom and an increased width in the double sides make for a safer vessel in collision and grounding. An increased number of subdivisions in the cargo block also reduces oil outflow in an accident. These parameters are adjusted automatically in the optimizer until the optimum risk and oil outflow are achieved.

3.1.3 Concept Design Balance Sub-Models

3.1.3.1 Hull Geometry, Available Volume and Area, and Hydrostatics

The hull geometry is divided into 4 sections (Figure 3.1.3.1.1): the aft section, machinery room, cargo block, and the forepeak. Each of these sections has various parameters that affect their volume and general dimensions. The forepeak and aft section were scaled from a 125,000 Dead Weight Tonnage (DWT) tanker and are scaled up based on the volume of the vessel. These sections are unchanged and only affect the total length and the ballast condition of the ship. The cargo block is defined by calculating the total volume needed to store the cargo, and adding this to the volume of the j-tanks which is calculated based on the double bottom height and side width. Then the cargo block length is adjusted to contain the necessary cargo volume. The machinery room length is set into the remaining length of the ship after subtracting the forepeak, aft section, and the cargo block length from the Length of the Waterline (LWL). This length is checked against the length of the engine, shaft, PTO, and clutch for feasibility. The total LWL is calculated from the ship's displacement and the hull coefficients.

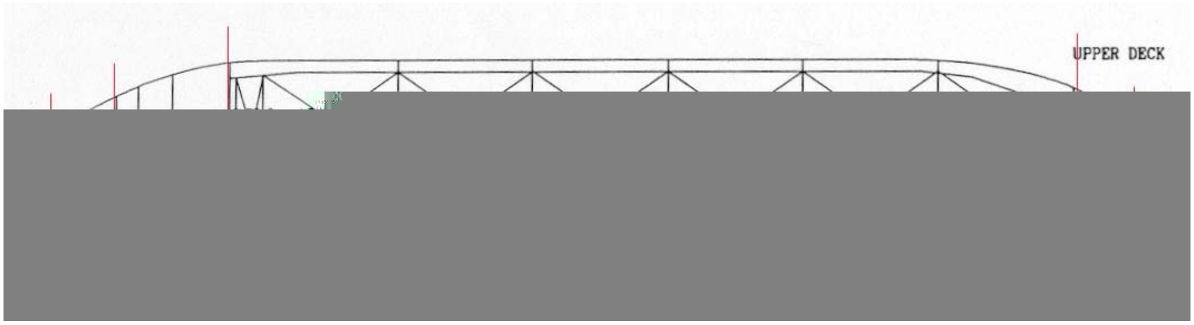


Figure 3.1.3.1.1 Ship Sections

3.1.3.2 Resistance

Total bare hull resistance is a combination of viscous drag and wave making drag effects. The calculations, coded in MathCad, use the HOLTROP method. Frictional resistance (C_f) is calculated based on Reynolds number, using the 1957 ITTC curve:

$$C_f = 0.075/(\log_{10}Re-2.0)^2$$

where Reynolds number is dependent on LWL. The wave making, or residuary, drag calculations account for a bulbous bow. The HOLTROP method also uses a residual drag coefficient module, which finds the residuary drag coefficient (C_r) for different beam-to-draft ratios. This method allows for the exploration of various hull forms, while producing reasonable results. The calculations are illustrated in Appendix A.2 under the Resistance and Power section of the model.

3.1.3.3 Propulsion and Power

Six propulsion plants are considered in the MathCad model shown in Appendix A.2. The selection process of the six plants is described above in Section 3.1.2.2. From these six options, the propulsion plant is determined by the design parameters input to the model. The engine characteristics considered in the model are displayed in Table 3.1.3.3.1 below. These characteristics are used in calculations in the subsequent sections of the MathCad model.

Table 3.1.3.3.1 Engine Characteristics

Characteristics	MathCad Variable
Number of Propulsion Plants	N_P
Brake Horsepower	P_{BPENG}
Specific Fuel Consumption	SFC_{PE}
Length of Engine	L_{ENG}
Width of Engine	w_{ENG}
Height of Engine	H_{ENG}
Weight of Engine	W_{PENG}
Volume of Machinery Box Required	V_{MBreq}

Total effective horsepower includes the ship effective horsepower and the horsepower required to overcome air resistance. Ship effective horsepower is found using the following equation:

$$P_E = R_T V$$

where R_T is the bare hull resistance and V is the velocity of the ship. The air frontal area of the ship incorporates the total height above the water, including the height of the deckhouse, and the beam of the ship. The calculation involves a 5% increase in area to account for masts and equipment. This quantity and the ship effective horsepower are combined and multiplied by a power margin factor, as shown in the following equation.

$$EHP = PMF\ (P_{EBH} + P_{EAA})$$

The power margin factor accounts for 10% fouling and sea state margin. When the total effective horsepower is known, this value is checked against the available horsepower from the propulsion plant selected. Appendix A.2 illustrates the calculations described above.

3.1.3.4 Electric Power

For this design process, the electrical load under winter conditions was found to be the most demanding condition. Therefore, this condition is used to estimate the required electrical power. This configuration is modeled in the Electrical Load section of the math model (Appendix A.2). The electric power redundancy factor, entered into the model as a design parameter, determines the total output of the electric plant. This factor is considered in the calculation of the electric power of the PTO (Power Take Off) units, and the power required from the diesel generators.

The electrical system is divided into the cargo and non-cargo sections. The non-cargo section considers electrical power necessary to operate the propulsion machinery, steering machinery, lighting, firemain, hotel services, auxiliary machinery, and other miscellaneous requirements. These requirement estimates are based on manning, deckhouse and total volumes, rated power of the engine, and the number of propulsion plants. The non-cargo loads are combined with margins to give the ship service maximum functional load (SSMFLM), which provides the required ship service generator power. The cargo section considers the power required to operate ballast pumps, COW pump, cargo pumps, and CSP. The required PTO generator power is calculated by combining the required cargo-related power with ship service power. The required emergency electric power is also provided and used to size the emergency generator. The model also calculates the average 24-hour power required for continuous operation.

3.1.3.5 Arrangements, Required Volume and Area

As mentioned in 3.1.2.3, the arrangements for the crew are based on the number of crewmembers on the ship. In Appendix A.2, Section "Manning and Deckhouse Volume", the living and working areas of the crew are calculated. The volume of the deckhouse and the inlet and exhaust areas contained within the deckhouse are also calculated in that section. Additionally in the "Manning and Deckhouse Volume" section, the ship tankage volume required is calculated using the various tanks which include fuel, lubrication oil, water, sewage, and waste oil.

The "Cargo Volume, Weights, and VCGs" section of Appendix A.2 shows the calculation of the cargo portion of the tanker. The total tank volume of the forepeak and aftpeak ballast tanks are calculated, as well as the space required for the cargo of the vessel. In the same section, the volume required for the machinery box of the tanker is calculated.

For each calculation above, it is necessary to note that the required area and volume must always be less than the available area and volume.

3.1.3.6 Weight

Weight estimates for the concept design optimization are generally adapted from weight parametrics in USN ASSET. ASSET provides classifications for the different weight groups onboard the tanker. The estimates for these groups are developed using coefficients of the weight calculations from the *Millenium* Tanker. The SWBS weight groups for the conceptual design are tabulated below.

Table 3.1.3.6.1 Weight Groups

SWBS Group	Description	Total Weight (MT)
100	Hull and Structure	1.697×10^4
200	Propulsion	1671.75
300	Electric Plant	157.49
400	Navigation, Controls, and Communication	8.012
500	Auxiliary Systems	2347.23
600	Outfit Furnishings	1234.13
	Cargo	1.376×10^4

Full and light ship weight summary calculations, along with each SWBS group weight calculation are located in the MathCad model (Appendix A.2, Section "Weight"). Also included in the weight summary is the calculation for a margin for design and construction.

3.1.3.7 Stability

Stability is handled in the MathCad model by computing the Vertical Centers of Gravity (VCG) for each weight group (SWBS Group). All of the VCG's are combined together to find the KG, then BM, KB and GM are calculated. The GM is divided by the beam to non-dimensionalize it and compared to a range of GM coefficients. This is calculated and compared for both the full load and ballast conditions. (Appendix A.2).

3.1.4 Concept Design Feasibility

In order to determine the feasibility of the design, a series of balance checks are accomplished. Available dimensions from the ship are compared with required values. The available dimensions must be greater than or equal to the required dimensions in for a feasible design. Table 3.1.4.1 compares the required and available values. The areas that are analyzed for the balance checks are:

- Weight
- Load Line
- Propulsion Power
- Machinery Box Dimensions
- Deckhouse Volume
- Cargo Block
- Stability (In Ballast, Full Load)

Table 3.1.4.1 Design Balance

Balance Check	Required	Available
Weight	1.683×10^5 MT	1.684×10^5 MT
Load Line	21.45 m	15.80 m
Propulsion Power	2.606×10^4 hp	3.056×10^4 hp
Sustained Speed	15.74 knots	15.81 knots
Machinery Box Volume	2×10^4 m^3	5.02×10^4 m^3
Deckhouse Length	19.85 m	36.87 m
Cargo Block Length	183.37 m	198.12 m
Ballast Stability (C_{GMB})*	0.08 – 0.25	0.266
Full Load Stability ($C_{GMBFull}$)*	0.08 – 0.25	0.0833

* C_{GMB} = GM / B, $C_{GMBFull}$ = GM_{Full} / B

3.1.5 Cost Model

Only cost components that are dependent on the model's design parameters are included in the TOC (As described in 3.1.1). Other life cycle costs, not included in the TOC, are assumed to be second order or approximately constant for all designs. Annual life cycle costs are discounted to the base year, using an annual discount rate of 7%. Lead ship costs are estimated for each SWBS group using weight-based equations adapted from an early ASSET cost model (Simplified Tanker Cost Model in Appendix A.2). The base year is assumed to be 2000. Equation costs are inflated to the base year from their 1981 values using a 5% average annual inflation rate. The following are included in the basic cost of construction:

- Hull structure
- Propulsion
- Electrical Systems
- Command and Control
- Auxiliary Systems
- Outfit & Furnishings
- Margin Costs
- Integration/Engineering
- Ship Assembly and Support Services

Life cycle costs associated with the vessel include:

- Fuel
- Maintenance

- Penalties
- Manning

Producibility is also considered in TOC. Six producibility factors are calculated and used in conjunction with costs listed above. The factors are based on hull form characteristics, machinery room volume, and deck height. K_N, or complexity factors, which are used to calculate the lead ship cost, are listed in Table 3.9.1. Low K_N factors are selected to reflect commercial versus military construction standards. These factors aide in determining cost by calculating the difficulty of construction. They were adjusted by calibration of results to recent tanker cost data.

Table 3.1.5.1 K_N Values

Ship Component	K_N Value	Choices
K_{N1}, Hull Structures	0.285	Mild/HT steel displacement hull with aluminum deck house
K_{N2}, Propulsion	0.8 1.4 1.3 1.6	Diesel Gas turbine Diesel integrated power system Gas turbine integrated power system
K_{N3}, Electric	0.55	Conventional 60 HZ power, steam or diesel generator drive
K_{N4}, Command, Control & Surveillance	2.0	Modest control systems, sophisticated electronics
K_{N5}, Auxiliary Systems	0.15	Diesel propelled displacement ship
K_{N6}, Outfit & Furnishings	0.36	Conventional displacement ship
K_{N7}, Integration/Engineering	2.0	Lead ship
K_{N8}, Ship Assembly & Support Services	2.0	Moderate tooling, moderate trials

3.1.6 Risk Model

The tanker risk model was developed based on the probability and consequence of an oil outflow event or accident. Grounding and collision result in bottom oil outflow and side oil outflow, respectively. Accident events can be broken down into the following:

- Collision
- Grounding
  - Powered Grounding
  - Drift Grounding

The factors, taken in consideration in the math model, that determine the probability of grounding or collision are:

- Port Characteristics (Per Round Trip)
  - Width of channel
  - Number of turns
  - Length of channel
  - Speed
  - Number of Ships Passed
- Redundancy
  - Steering
  - Propulsion

These are shown in the flowchart, Figure 3.1.6.2. Accident probability is calculated using probabilistic methods such as: Probability Distribution Functions (PDFs) and Poisson processes. Human error, mechanical failure, weather, and assistance failure are probabilistic factors that effect accident probability. In order to estimate risk, the probability of an accident must be combined with the consequence, oil outflow. In collision, side oil outflow is the consequence and in grounding, bottom oil outflow is the consequence. The MARPOL Annex I Regulation [19] method is used to estimate outflow in both side and bottom damage cases. Calculations consider the size of the cargo and slop tanks, the boundaries of the cargo tanks, the pressure in the tanks, the tide, and the oil captured in the ballast tanks. Oil outflow calculations are also probabilistic methods. The total risk is obtained by multiplying the probabilities of collision and grounding by side and bottom oil mean outflow, respectively, and summing the resulting products.

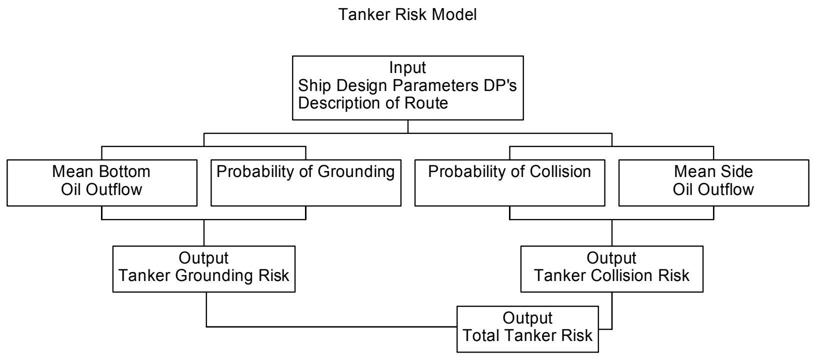


Figure 3.1.6.1 Tanker Risk Model

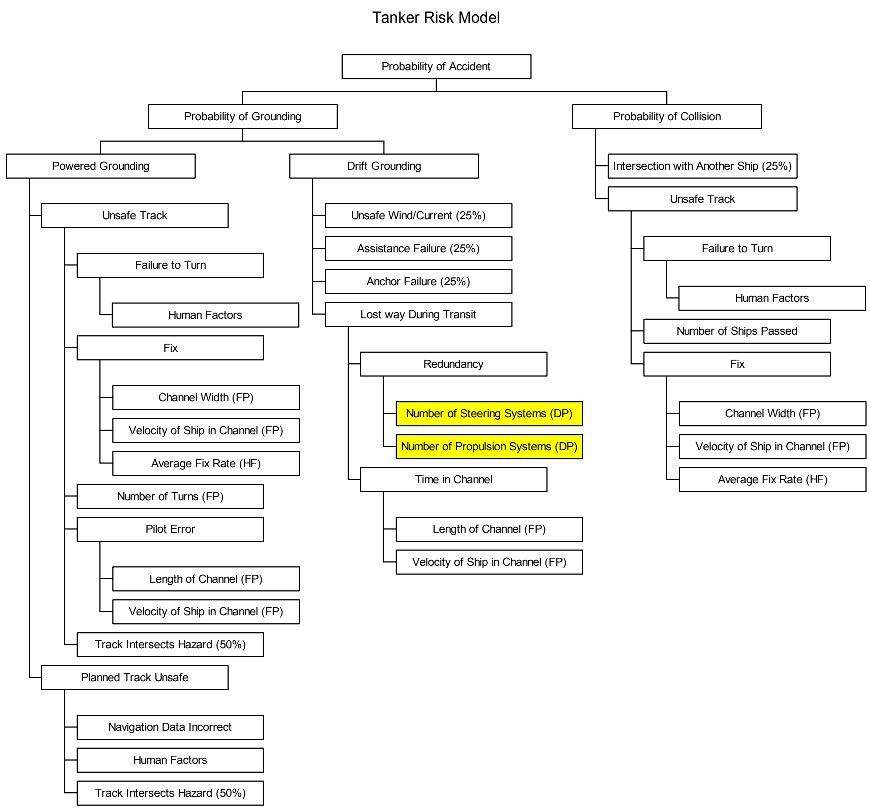


Figure 3.1.6.2 Tanker Risk Model

3.2 Multi-Objective Optimization

3.2.1 Pareto Genetic Algorithm (PGA) Overview and Function

Optimization is accomplished by using a Pareto Genetic Algorithm (PGA). A flow chart for the PGA is shown in Figure 3.1.2.1. In the first design generation, the optimizer randomly creates 200 balanced ships using the MathCad model to balance each ship. Each of these designs is ranked based on their fitness or dominance in risk and cost relative to the other designs in the population. Penalties are applied for infeasibility and niching, in other words, bunching-up in the design space. The second generation of the optimization is randomly selected from the first generation with higher probabilities of selection for designs with higher fitness. Twenty-five percent of these are selected for crossover or swapping of some of their design parameter values. A very small percentage of randomly selected design parameter values are mutated or replaced with a new random value. As each generation of ships is created, the ships spread across the cost-risk design space and frontier. After 200 generations of evolution, a non-dominated frontier of designs is clearly defined on a cost versus risk plot (Shown in Figure 3.12.1). Each ship located on the non-dominated frontier provides the lowest risk for a given cost compared to other designs in the design space.

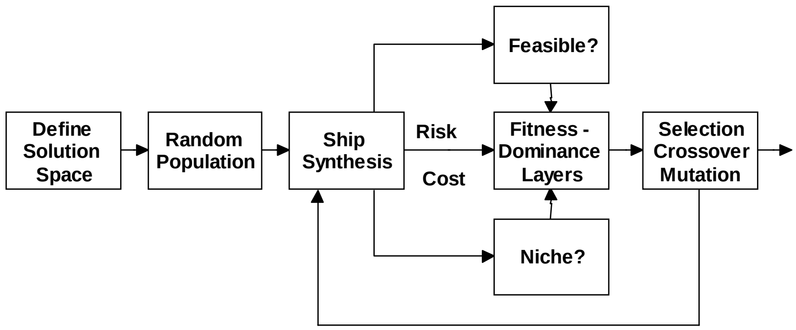


Figure 3.1.2.1 Optimization Process

3.2.2 Optimization Results

Figure 3.2.2.1 shows the final cost-risk frontier with generations 1,30 80, 100, and 200 plotted. The first generation shows an exploration of the design space. As successive generations are formed, the trend is to move toward a lower risk and cost while still exploring the design space. Finally the generations converge on a non-dominated frontier. The frontier shows four distinctive "knees" in the curve, illustrated in the figure as LO, BBL, BBH, and HI (Characteristics shown in Table 3.2.2.1). These "Knees" are distinct irregularities in the curve where substantial risk reduction can occur for a slight increase in cost. LO represents a knee at the lowest cost. These knees each represent a ship design. These designs were assigned for feasibility study by the four teams participating in this project. Our team is assigned the LO design variant.

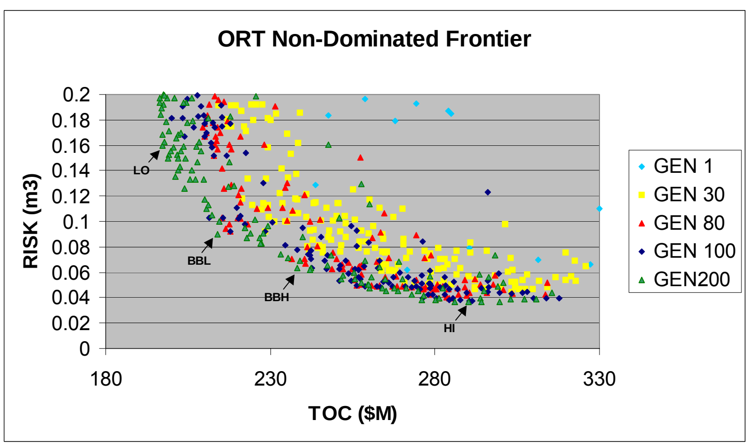


Figure 3.2.2.1 Optimization Results

Table 3.2.2.1 Optimization Ship Results

TEAM	2	1	4	3	
	HI	BBH	BBL	LO	MIL*
DP1 - Cbt	2.35	2.55	2.8	3.15	2.65
DP2 - Clb	6.95	6.45	5.05	5.05	5.6
DP3 - Cb	0.825	0.75	0.83	0.83	0.81
DP4 - CD10	1.245	1.425	1.515	1.74	1.47
DP5 - hdb	4	3.7	2.7	3.9	3
DP6 - wds	4	4	4	4	3
DP7 - manfac	1	1	1	0.7	0.8
DP8 - smf	1.5	1	1	1	1.1
DP9 - HDK	4	4	4	4	3.2
DP10 - Ncargo	8	8	8	4	6
DP11 - Psystype	3	2	2	2	5
DP13 - Nstern	1	1	2	2	2
DP12 - Nkw	2	1	1	1	2
Length on waterline	308.61	294.96	241.71	251.39	258.69
Beam	44.4	45.73	47.86	49.78	46.19
Draft	18.9	17.93	17.09	15.8	17.43
D10	23.52	25.55	25.9	27.5	25.62
Cp	0.829	0.754	0.834	0.834	0.814
Cx	0.995	0.995	0.995	0.995	0.995
Np	1	1	1	1	2
Lightweight	78801.45	45788.79	26747.52	27982.1	32761.74
Full load displacement (LWL)	219122.45	186109.8	167068.52	168303.09	173082.73
Vertical CG at full load	13.076	14.211	14.125	15.415	14.028
W1	68837.05	37840.52	20040.61	21363.13	25979.01
W2	1164.61	1161.76	1161.76	1161.76	1178
W3	215.02	160.15	157.48	157.48	242.07
W4	5.61	5.61	5.61	8.01	7.01
W5	2747.22	2691.79	2548.09	2473.74	2445.24
W6	1371.5	1337.14	1319.97	1234.08	1055.97
W7	137049.72	137485.59	137633.5	137664.72	137610.91
W7	137049.72	137485.59	137633.5	137664.72	137610.91
Sustained speed	15.5	15.53	15.77	15.76	15.8
Lead Ship BCC**	182	139.6	120.1	111.9	153.6
TOC	290.2	238.1	213.8	197.2	252.6
Manning	28	26	25	20	25
Om	0.0042	0.0063	0.0084	0.0139	0.0112

* Represents data based on the ARCO Marine, Inc. Millenium Class Tanker
** BCC represents the Total Lead Ship Construction Cost

Several ships have unique characteristics which would be addressed in their feasibility studies. The low Cp in the BBH ORT created problems for cargo volume and machinery space. The fine hull caused the ship to be unable to accommodate the required cargo capacity of 140K DWT and made it difficult to fit the engine into the machinery space. The HI ORT had a very large W1 cost which exceeds the valid range of the weight parametric. The LO ORT has a low number of cargo divisions which increases the risk associated with mean oil outflow.

3.3 Baseline Concept Design

Our concept design is the lowest cost non-dominated ship. The characteristics of the ship are shown in Table 3.2.2.1 under LO. Its principal characteristics are shown in Table 3.3.1. This design has several unique characteristics. First the manning factor is significantly less then the other ships. The LO ship has 20 crewmembers as opposed 25 to 28 crewmembers on the other ships. This results in a minimum number crew of specialists to monitor the highly automated ship. The next distinctive characteristic is the number of cargo holds. The LO ship has four subdivisions versus eight on the other ships. This causes an increase in risk as compared to the other ships, but a large reduction in weight and cost. Chapter 4 describes the feasibility study performed for this design.

Table 3.3.1 Principal Characteristics

Characteristic	Baseline Value
Length on Waterline	251.39 m
Beam	49.78 m
Draft	15.8 m
Depth	27.5 m
Cp	0.834
Cx	0.995
Number of Engines	1
Light ship weight	27982.1 DWT
Full Load Displacement	168303.09 DWT
Vertical CG	15.415 m
Sustained Speed	15.76 Knots
Number of Men	20
Number of Cargo Divisions	4
Stern Type	Efficient
Height Double Bottom	3.9 m
Thickness of Double Side	4 m
Total Cost	$197.2 M
Risk	0.1597 m^3

4.0 Feasibility Study

4.1 Hull Form, Appendages and Deck House

The hull form was created using FastShip software and the FastShip parametric tanker hull form "FastGen Tanker." The FastGen Tanker begins with the characteristics shown in Table 4.1.1. Working through the FastGen option and selecting "modify gross dimensions" modifies the tanker. FastGen modifies the hull form with parametric parameters to the correct dimensions.

The "FastGen Tanker" hull form was designed to satisfy a ship owner interested in having a full ship with sufficient fineness of the ends to minimize bow slamming and propeller induced vibration. A prismatic coefficient of 0.86 was selected as a target based on expert opinion with tankers in heavy weather. A relatively fine cylindrical bow is chosen having a stem radius of 37% of the half beam, a fine stern with waterline endings less than 20 degrees and generous propeller clearance. This leads to an excellent parent form for the ORT LO.

In FastShip the first change is made by selecting the FastGen option "Modify Cx." Our midship coefficient was 0.995. To reach this number it was necessary to do several iterations. This was accomplished by running the parametric model to a midship coefficient of 0.996 and then coming back down to 0.995. The second change is made by selecting the FastGen option "Modify Sectional Area Curve." This option also requires several iterations. The Cp must be varied in proportion to the percentage of Parallel Mid Body (PMB). By calculating ratios of Cp to PMB, and entering these into FastShip the Cp was lowered to 0.834. At the end of this process FastShip gives a report to compare to desired values.

Table 4.1.1 "FastGen Tanker" Characteristics

Parameter	Value
Cp	0.86
Cx	0.994
Cwp	0.920
FF	0.495
FB	0.462
PMB	0.444
StAx	8.686 Station
Cpa	0.449
LOA	236.887 m
LWL	235.043 m
BWL	32.2 m
Tx	13.1 m
Dx	18.7 m

The "FastGen Tanker" does not have a bulbous bow so the next procedure was to design one. The primary purpose of the bulb at this stage is for speed, fuel economy, displacement and LCB calculations. The overall dimensions and shape are determined using the paper, "Design of Bulbous Bows" by Alfred M. Kracht. In the paper, 3 bulbous bows are described: Δ-type, O-type and ∇-type. (Figure 4.1.1). The ∇-type is chosen for the tanker because of its favorable seakeeping characteristics. The bulbous bow size is determined by calculating A_{BT}, A_{BL}, B_B, and L_{PR} (Figure 4.1.2). The following formulas are used (where C is a coefficient determined from design lane plots based on the C_B (Figure 4.1.3)):

- $A_{BT}=C_{ABT}*A_{MS}$
- $A_{BL}=C_{ABL}*A_{MS}$
- $B_B=C_{BB}*B_{MS}$
- $L_{PR}=C_{LPR}*L_{PP}$

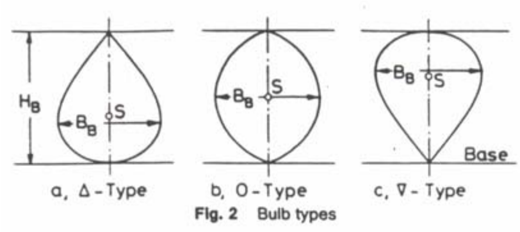


Figure 4.1.1 Bulbous Bow Type[1]

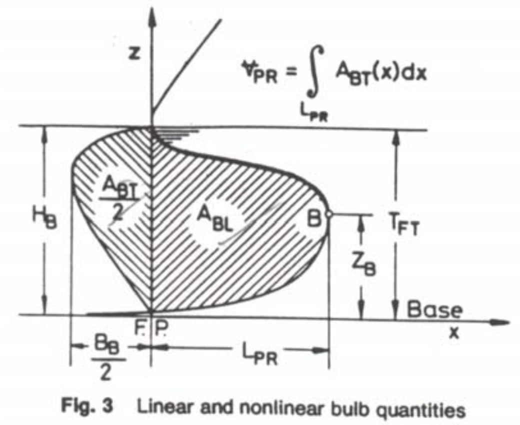


Figure 4.1.2 Linear bulb quantities[1]

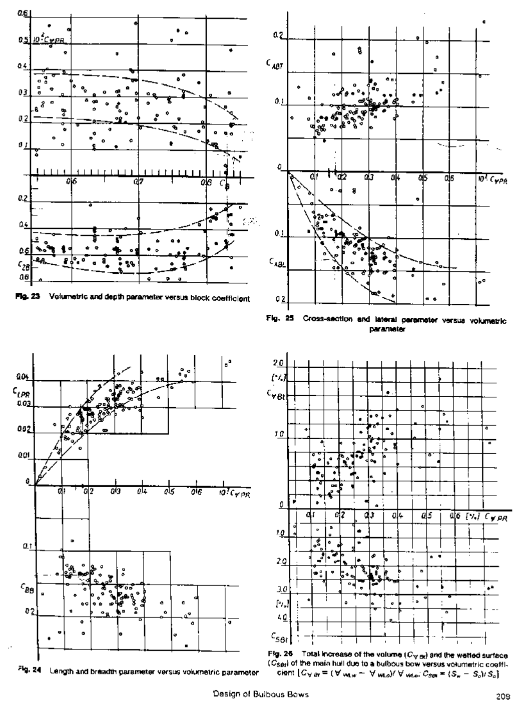


Figure 4.1.3 Design Lane Plots[1]

The paper is not specially designed for ships with low Froude numbers. When the actual parameters (Figure 4.1.2) are calculated, the bulb would have to be cubic to achieve the required volume. It is decided that 3 parameters are more important than the rest: the Profile Area (A_{BL}), the Body Area (A_{BT}), and the height of the center of the bulb (Z_B). The actual dimensions are shown in Figure 4.1.4[1]. The forming of the bow is accomplished in FastShip by pulling the net out and measuring the areas. This is a visual iterative process until the desired shape and required area are accomplished.

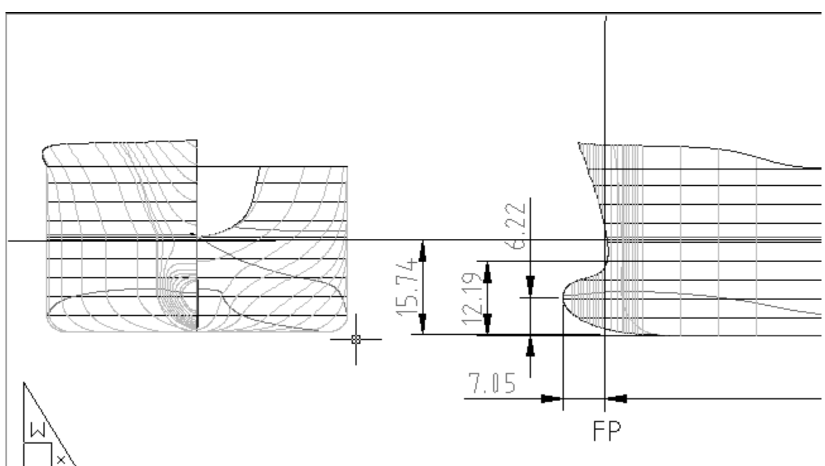


Figure 4.1.4 Bulb Dimensions

The bulwark is formed in the same way as the bulbous bow. Extra net was added to the shear line, and the forecastle was pulled up to the desired shape and height (4m) in the profile view. In the body view the forecastle was pulled out to give some flare (Figure 4.1.5).

[1] Kracht, Alfred M. "Design of Bulbous Bows." SNAME Transactions. 86 (1979): 197-217.

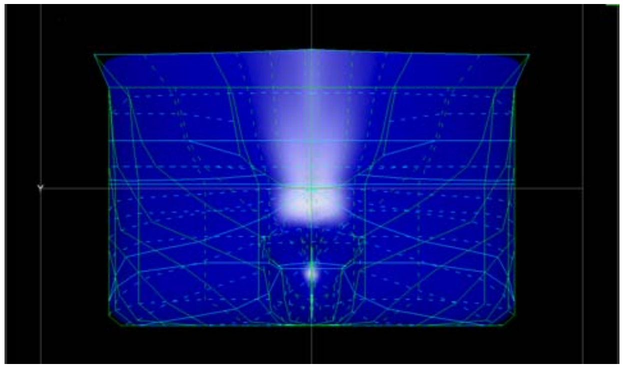


Figure 4.1.5 Bulwark

The deck is formed in FastShip by creating a plate at the deck edge. Net points are then added at the bow and stern to allow for the curvature. The net is then pulled to match the hull form (Figure 4.1.6).

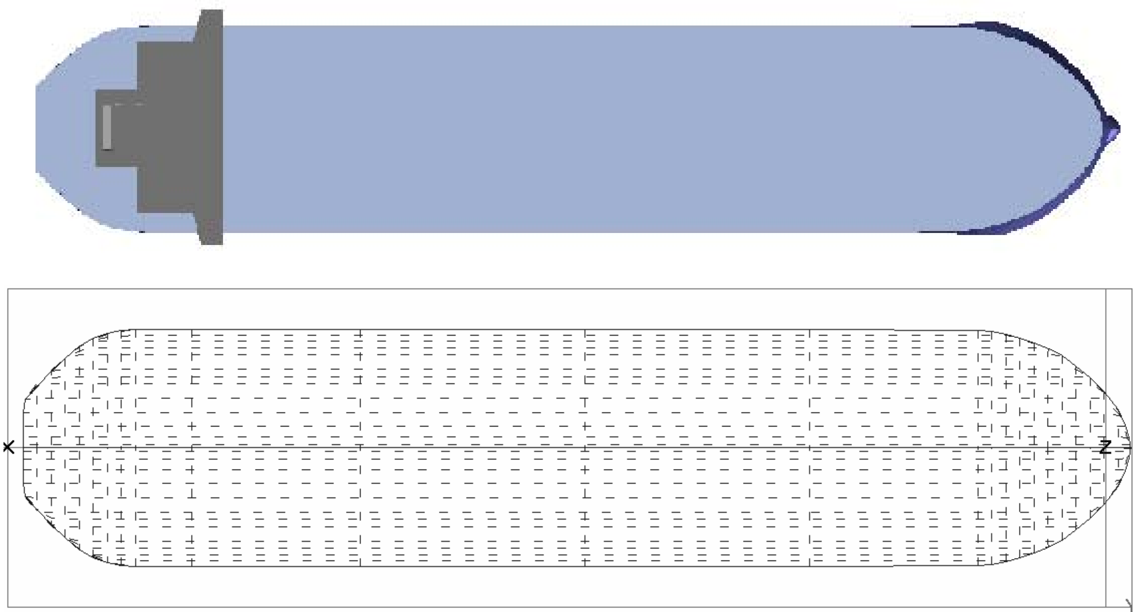


Figure 4.1.6 Deck and Deck Net

The deckhouse is created in AutoCAD R14 by extruding the general features. The dimensions (Figure 4.1.7) were based on the MathCad Model (Appendix 2). These are checked against existing models and it was found that the inert gas room's width needed to be decreased and its length increased to allow for the smokestack. The initial design of the deckhouse is shown in Figure 4.1.8.

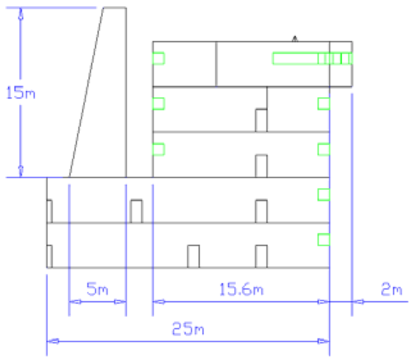


Figure 4.1.7 Dimensions of the Deckhouse

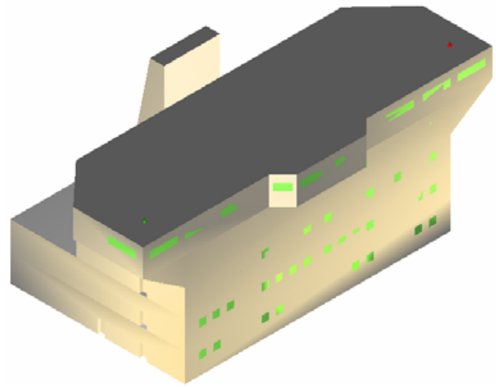


Figure 4.1.8 Deckhouse

The final hull, deck and deckhouse designs are rendered in Figure 4.1.9 and in Drawings D.600-01. The molded offsets are in Appendix A.3.

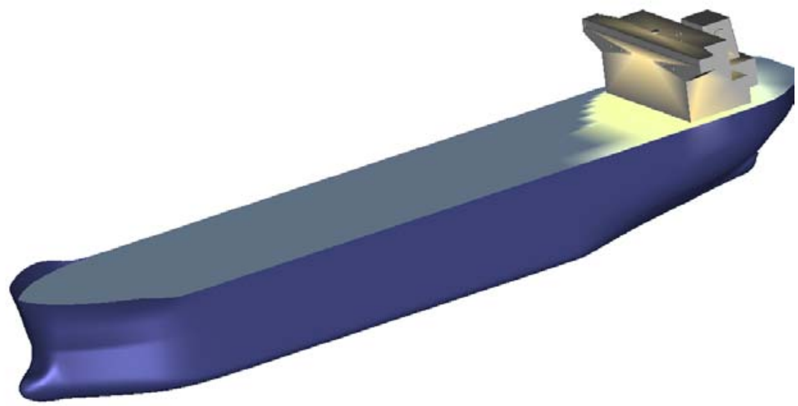


Figure 4.1.9 Final design

Figure 4.1.10 shows the "FastGen Tanker" from which the ORT LO is derived. A comparison of the final details of the tanker with the FastGen Tanker and the MathCad Model specifications is shown in Table 4.1.2. FastShip was used to export the ORT LO hull form into HecSalv and AutoCAD where arrangements, intact and damage stability are done.

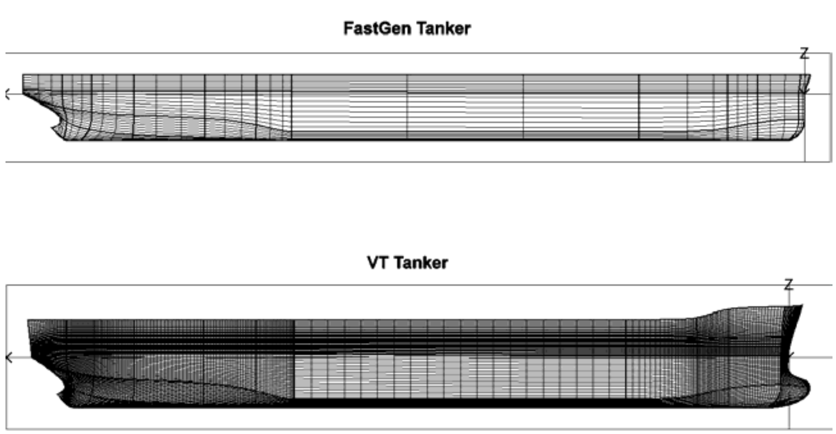


Figure 4.1.10 Comparison of "FastGen Tanker" with ORTLO Tanker

Table 4.1.2 Specification Comparisons

Specification	FastGen Tanker	Math Model Tanker	ORTLO Tanker
Cp	0.841	0.834	0.834
Cx	0.994	0.995	0.995
LBP	236.887 m	251.39 m	251.39 m
BWL	32.2 m	49.78 m	49.78 m
Tx	13.1 m	15.8 m	15.8 m
Dx	18.7 m	27.5 m	27.5 m
L/B	7.36	5.05	5.05
B/Dx	1.72	1.81	1.81
L/D	12.6	9.15	9.15

4.2 Structural Design and Analysis

This structural analysis uses a parent, IMO, CFR and ABA 2000 compliant Double Hull (DH) tanker as a reference. Phase A, one of the two phases of ABS SafeHull, is used for the structural analysis of this design. This phase applies a rule-based assessment to evaluate a proposed structural design. Phase B is a more intensive analysis not necessary for this concept. The result of the assessment undergoes a modification until the weight, producibility, maintenance and the cost requirements are satisfied. The following sections describe the analysis in more detail.

4.2.1 Objectives

The goals of the structural analysis process are to develop a geometric model of the midship cross-section, develop a geometric model of the crude oil bulk cargo tank, develop a geometric model of the J-ballast tank, adjust the materials and scantlings of the structural members, and to document the structural analysis process.

To attain the above stated objectives throughout the structural analysis process, various software packages are used in an iterative manner to facilitate the design analysis. Table 4.2.1.1 provides a list of each software package and the analysis in which it is utilized.

Table 4.2.1.1 Steps and Tools Used

Tasks	Tools	Input	Output
Hull Form	FastShip	Requirements	Basic Geometry
Cargo Block	HecSalv	Requirements	Basic Divisions
Structure	SafeHull	Scantlings	Threshold Values
Adjustment	Eng. Judgement	Limits	Scantlings/Materials
Drawings/Document	AutoCAD/Word	Scantling/Material	Structural Design

4.2.2 Procedures

The longitudinal model of the structure at amidships is analyzed using ABS SafeHull. A sample of the required SafeHull input parameters are presented in Figure 4.2.2.1. Parameters such as beam, draft, depth, speed, length, cargo density, volumes, and block coefficient are obtained from the Baseline Design model (Appendix A.1.1.)

The value of the bilge radius at amidships (2.9 m) is obtained by transferring the lines drawings from the tank form analysis and dimensioning them using AutoCAD.

The length of the cargo block is acquired from the HecSalv analysis (44.2 m).

Phase A of ABS SafeHull is used to modify the longitudinal and transverse geometry of the amidships cross-section, and the material properties of its members.

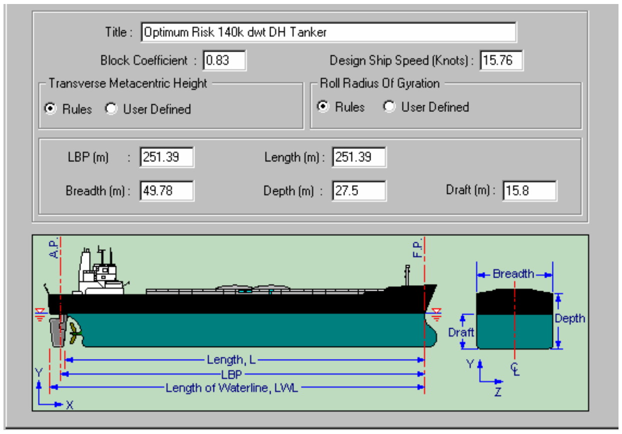


Figure 4.2.2.1 Samples of ABS SafeHull Required Input

The IMO reference DH150 (150K DWT) is used as a parent model. Figure 4.2.2.2 represents the initial geometric concept of that model. It is modified to suit the specifications of the Baseline Design model (Appendix A.1.1). The changes include scantlings, camber (0.5 m level), bilge radius (2.9 m), gunwale radius (1 m), spacing of the transverse bulkheads (44.2 m), web and transverse floor spacing (3.4 m), double bottom height, and the materials of the structural members. The HT32 (3200 kgf/cm^2 yield) and HT36 (3600 kgf/cm^2 yield) steels are used within 10% of the hull depth from the bottom and the upper deck. The MILD (2400 kgf/cm^2 yield) steel is used in the remaining structure. Figure 4.2.2.3 represents the material zones.

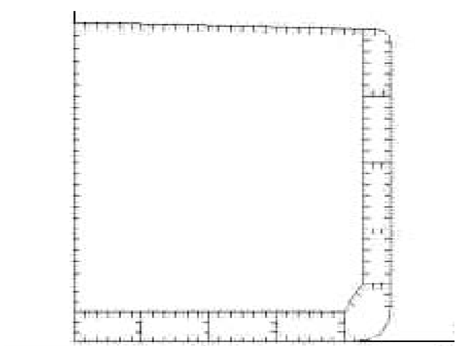


Figure 4.2.2.2 Initial DH150 Longitudinal Members Geometry Concept

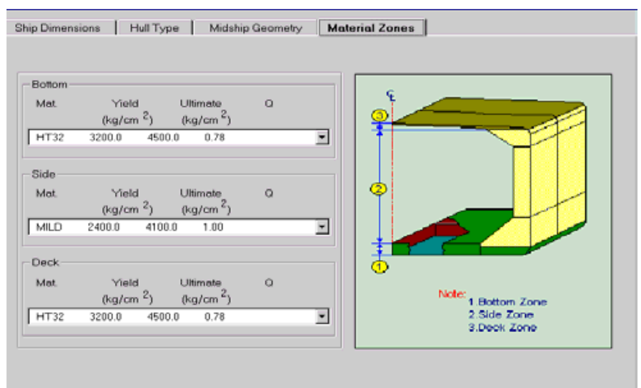


Figure 4.2.2.3 Material zones.

4.2.2.1 Longitudinal Scantlings

Plate properties and the longitudinal stiffener spacing are also modified from the DH150 model. The thickness of the bottom watertight girder is 23 mm. Excessive thickness is avoided by using HT36, higher strength steel. All girders and stringers have three stiffeners, as seen in the Midship Drawing D.2. Center stiffener is discontinuous to allow openings to be over 1 m, with the adjoining stiffeners within 0.15 m from the edges. The proper size of these openings is considered an important factor for easier access and ventilation. The first three non-watertight girders are evenly spaced and numbered from centerline outboard, with Girder I positioned at 4.5 m. The space between two most outboard non-watertight girders is increased to 5.25 m to accommodate an even stiffener spacing and hopper arrangement. The thickness of the girders varies from 12 to 15 mm, depending on the location. Exact characteristics of each girder can be found in Appendix A.4 and Drawing D.2.

The remaining sections are modified to compromise between the acceptable plate thickness and the material. Five segments are provided for the side shells and the centerline bulkhead to allow for the variation in the material and the thickness. The upper deck is divided into three flat segments to allow for the cap plate and the producibility of the deck camber. A detailed report of plate characteristics is provided in the longitudinal section of Appendix A.4.

The spacing of the deck stiffeners is 0.850 m; the remaining stiffener spacing is 0.750 m except as noted on the attached Drawing D.2. There are no longitudinal stiffeners in the gunwale and the bilge, but the transverse stiffeners in the form of brackets are provided. The stiffeners are chosen from the DH150 Stiffener Library, which is comprised of Large Inverted Angle (LIA), standard stiffeners and various other, user defined Level Bars and Built Stiffeners. The largest longitudinal stiffeners with a web depth of 0.400 m are used in the bottom part of the midship section. The detailed stiffener descriptions are provided in the longitudinal report section in Appendix A.4. The distance between adjacent stiffeners of the perpendicular segments, such as the intersection of the centerline bulkhead and the deck, is larger than 0.7 m (flange to flange). This not considered to be an obstacle for a producibility.

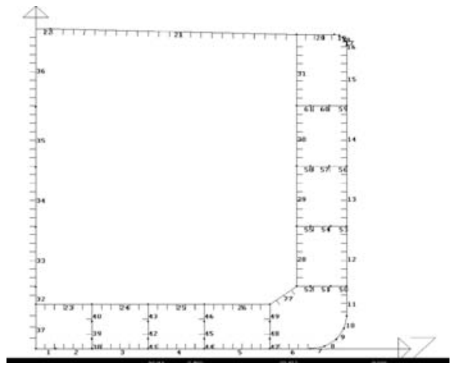


Figure 4.2.2.1.1 Modified ORT Longitudinal Members Geometry Concept

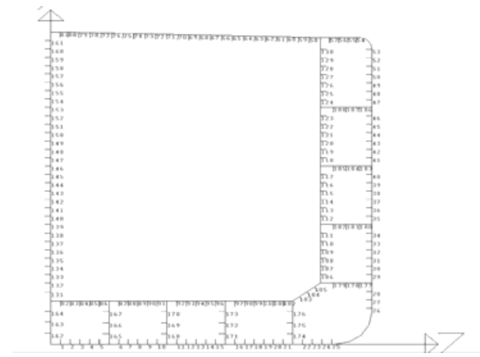


Figure 4.2.2.1.2 Adjusted ORT Longitudinal Members Geometry Concept

The maximum still water bending moments are acquired from the HecSalv intact stability analysis. The ballast hogging (320,000 tf-m) and full load (140K DWT) sagging (-470,000 tf-m) conditions are the extreme still water bending moments applied to the SafeHull analysis. Figures 4.2.2.1.3 through 4.2.2.1.6 show the bending moment plots for the Full Load, Ballast Arrival, Lightship, and TAPS Full Load (125K DWT) conditions. In addition the Lightship weight curve is provided in Figure 4.2.2.1.7. The total bending moment is given in the Longitudinal Section of the Appendix A. 4.

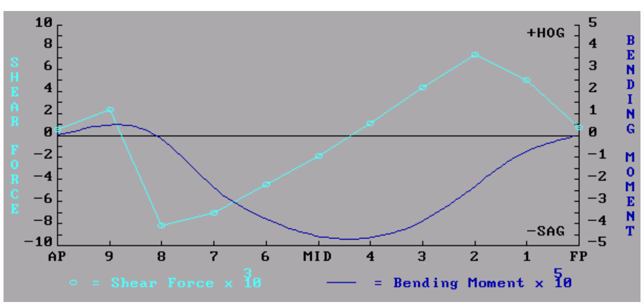


Figure 4.2.2.1.3 HECSALV Full Load (140K DWT) Bending Moment Curve

Figure 4.2.2.1.4 HECSALV Ballast Bending Moment Curve

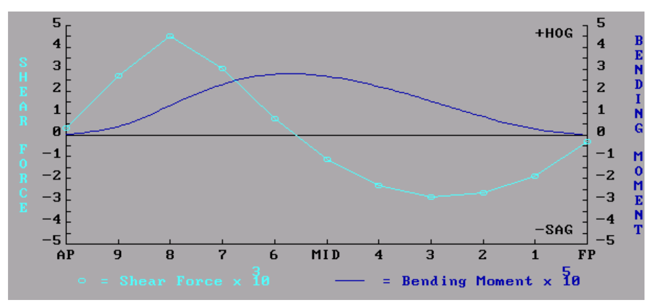


Figure 4.2.2.1.5 HECSALV Lightship Bending Moment Curve

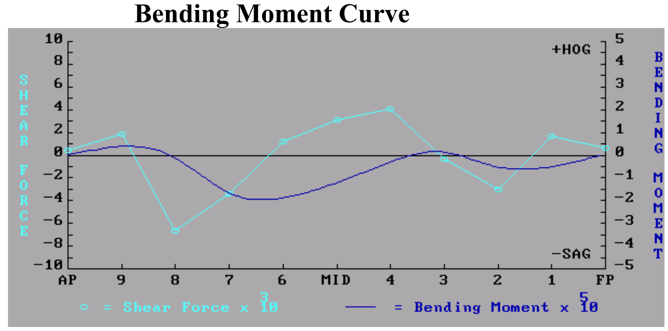


Figure 4.2.2.1.6 HECSALV TAPS (125K DWT) Bending Moment Curve

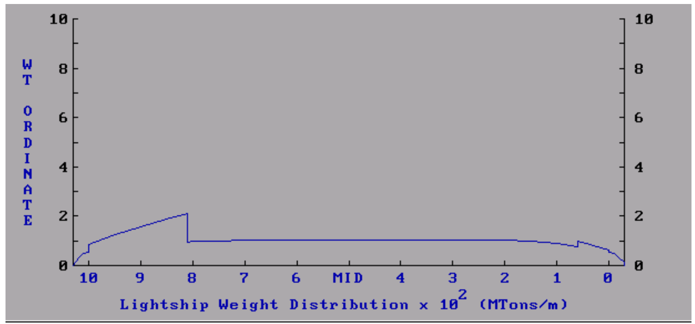


Figure 4.2.2.1.7 HECSALV Lightship Weight Curve

SafeHull estimates the longitudinal members' weights. The transverse members' structural weights and the locations of the centers of gravity are estimated based on the number and location of the transverse bulkheads. The structural weight of the superstructure and foundations is determined in the Baseline Design (Appendix A.1.1.) and the Math Model (Appendix A.2.) The final structural weight estimate exceeds slightly the Baseline Design specification, approximately 400 tonnes. Table 4.2.2.1.1 presents the structural weight breakdown.

Table 4.2.2.1.1 Structural Weight Summary

Structural Elements	Weight [tonnes]	VCG [m]	LCG [m]
Longitudinal Members	14,229	13.2	126
Transverse Members	1,254	12.65	114.65
Deck House, Stacks	474	37.5	215
Foundations	353	12.375	215
Total Group 100	21,842	13.61	129

The cargo tanks and ballast J-tanks are of same length, defined to be 42.2 m. The cargo tanks are 20.89 m wide. The ballast tanks are comprised of the space between the hulls, which is segregated by the watertight bottom girder. Figure 4.2.2.1.8 presents the cargo and ballast tank arrangements. The pressure-vacuum relief valve holds a pressure in the cargo tanks of 2 kgf/cm^2. A cargo density of 0.867 kg/m^3, and a saltwater density of 1.025 tf/m^3 are used in calculating the pressure in the cargo tanks and J-tanks. The exceptions are the J-tanks side transverses, where a density of 0.9 tf/m^3 is used.

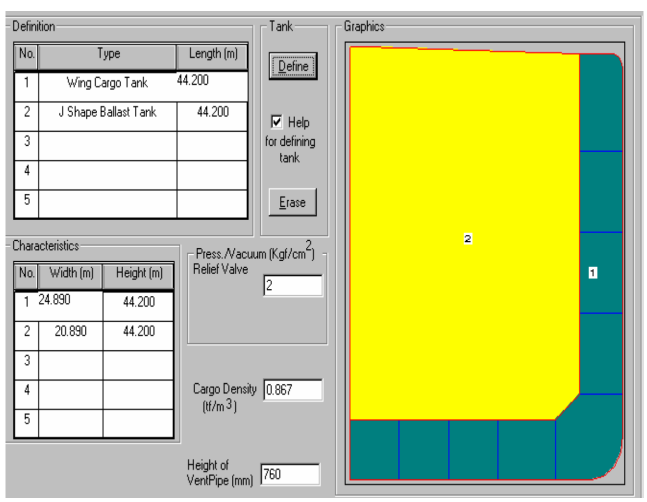


Figure 4.2.2.1.8 Transverse Tanks Arrangement

4.2.2.2 Transverse Scantlings

The cargo block length is divided into an even floor spacing of 3.4 m. This results in a total of 12 inner bottom floors per tank. The same spacing is applied to the transverse webs, deck transverse and vertical bulkhead webs. This arrangement divides each tank into 13 sections. Figure 4.2.2.2.1 shows the selected transverse web configuration with the centerline bulkhead, and without the deck girders.

The main supporting members in the DH150 stiffener library are modified. The resulting dimensions are listed in the Transverse Section of Appendix A.4 and Drawing D.2. The girders are arranged as discussed in the Longitudinal Scantlings section. The floors are 12mm HT32 with a 17mm exception between the most outboard non-watertight girders. They are also provided with a manhole for access and ventilation. Figure 4.2.2.2.4 shows the sample openings used on the DH tanker. The floors are identified by their location with respect to the aft bulkhead of the midship cargo tank. Each floor is also divided into transverse sections between longitudinal girders. The section of the floor closest to the aft bulkhead centerline is labeled (1,1). The first number represents floor number and is followed by the longitudinal non-tight girder number. Girders and floors are numbered starting from the centerline and aft bulkhead respectively.

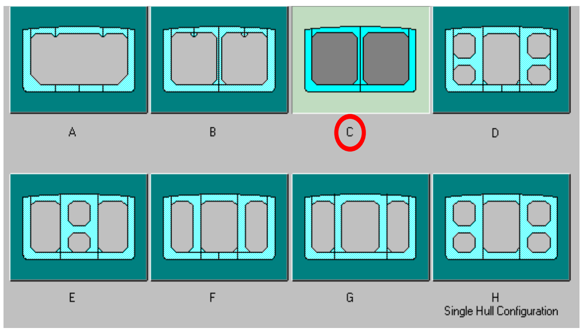


Figure 4.2.2.2.1 Side Transverse Web Configuration

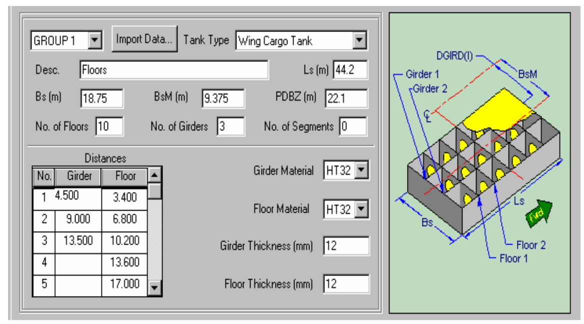
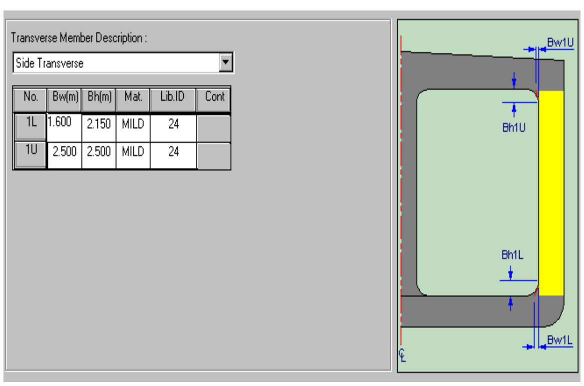


Figure 4.2.2.2.3 Bottom Floor/Girder Configuration

No.	Girder	Floor
1	4.500	3.400
2	9.000	6.800
3	13.500	10.200
4		13.600
5		17.000



No.	Bw(m)	Bh(m)	Mat.	Lib.ID	Cont
1L	1.600	2.150	MILD	24	
1U	2.500	2.500	MILD	24	

Figure 4.2.2.2.2 Transverse Main Supporting Members

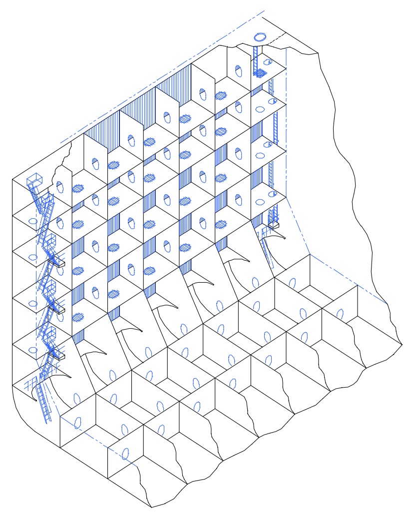


Figure 4.2.2.2.4 Sample Openings Used on the DH Tanker

Due to the length of the cargo tanks and SafeHull limitations, the optimal floor arrangement cannot be input to the model. Only ten floors are allowed to be input into the SafeHull transverse analysis. To overcome that obstacle, the following tactic is used for the purpose of this analysis. It is assumed that the highest stresses occur at the transverse bulkheads. The spacing of the floors applied in the vicinity of the transverse bulkheads are 3.4 m, while the two center floors are spaced 6.8 m from adjacent floors. The stress analysis results are satisfactory in the vicinity of the transverse bulkheads, as indicated in the Transverse Section of the Appendix A.4. The length of the tank dictates investigation of the second scenario where spacing of 3.4 m in the center and 6.8 m in the vicinity of the transverse bulkheads are applied. Following analysis results are satisfactory. Thus, all floor spacing of 3.4 m is accepted. Expert opinion is acquired to resolve this obstacle. The sample of the bottom floor and girder configuration is presented in Figure 4.2.2.2.3.

There are four horizontal girders on the transverse bulkhead at the same height as the side stringers. The modified scantlings of these girders are shown in the stiffener table of the attached Drawing D.2 and the Transverse Section of the Appendix A.4. The scantlings of the deck transverses, vertical webs on the longitudinal bulkheads, and the side transverses are also modified. Figures 4.2.2.2.5 through 4.2.2.2.7 present samples configurations of the main transverse supporting members.

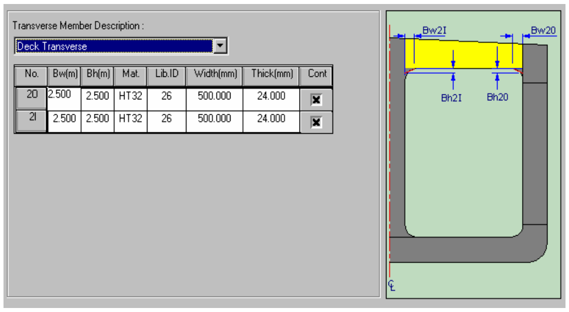


Figure 4.2.2.2.5 Deck Transverse Configuration

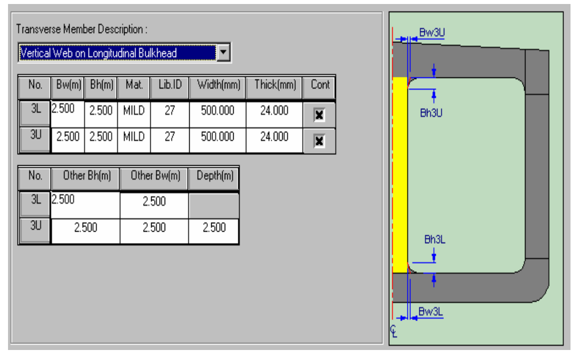


Figure 4.2.2.2.7 Vertical Web on the Longitudinal Bulkhead

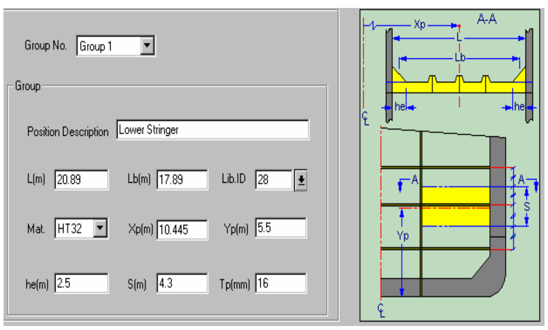


Figure 4.2.2.2.6 Horizontal Girder on the Transverse Bulkhead

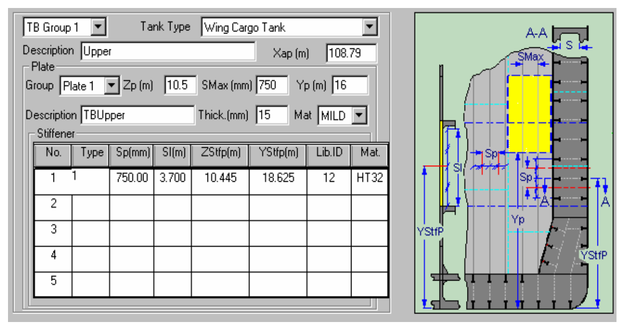


Figure 4.2.2.2.8 Transverse Bulkhead Plate/Stiffener Configuration

The transverse bulkheads are divided into ten segments to allow for thickness and material variations. Those segments include five vertical divisions of the cargo tank bulkheads and five vertical divisions of the J-tank bulkheads. The stiffener spacing on those bulkheads varies from 0.700 m to 0.850 m. A sample of the stiffener and plating configuration is provided in Figure 4.2.2.2.8. The transverse members and their parameters are listed in the transverse member summary report of the Appendix A.4.

4.2.3 Scantling Adjustment

The minimum thickness values and stiffener sizes are achieved through the process of iteration. Each structural member of the SafeHull model is chosen based on a required ABS value, which is considered to be the lowest permissible. Goal values are set equal to those considered to be permissible. Higher values are chosen when influenced by the geometry and producibility requirements. This is estimated based on the combination of expert opinion and engineering principles. Effectively, the stiffeners are spaced accordingly for producibility and easier maintenance. Appendix A.4 lists the corresponding goal and threshold values. These values incorporate structural margin factors required by ABS standards. Figures 4.2.3.1 through 4.2.3.3 illustrate the use of the SafeHull post-processing function for the adjustment of plate and stiffener scantlings.

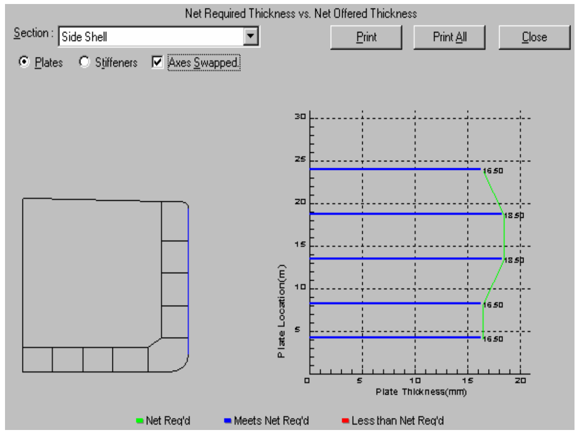


Figure 4.2.3.1 Adjustment of Plates Using SafeHull Post-Processing Function

SafeHull weight estimates of the longitudinal elements are used for the design optimization and the total weight group 100 (structure) calculation. The detailed structural weight report can be found in the Appendix A.4.

The repetitive nature of the structure allows for a more producible module. Low tensile material is utilized wherever possible. The only exception is the watertight bottom girder, where HT36 was used to prevent excessive plate thickness. The scantlings are adjusted according to the final HecSalv analysis, which included the optimized cargo tank length and still water bending moments.

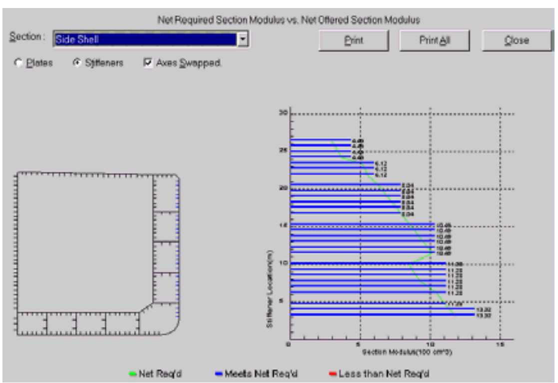


Figure 4.2.3.2 Optimization of Stiffeners Using SafeHull Post-Processing Function

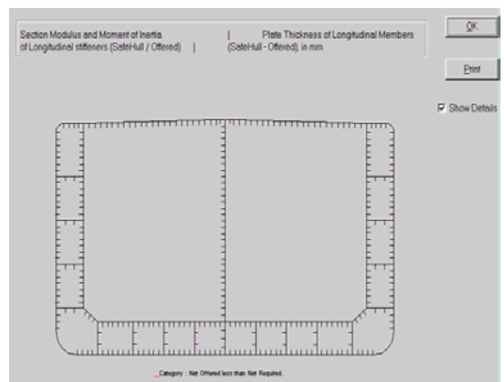


Figure 4.2.3.3 Global SafeHull Post-Processing Function

4.3 Power and Propulsion

4.3.1 NavCad Analysis

To assess the feasibility of the ORT LO, NavCad is used to select the optimum propeller design by analyzing resistance data and engine characteristics. The baseline design specifications for the hull form and engine are given by the math model during the optimization process. The design objective is to find the propeller type with the minimum fuel consumption rate at endurance speed (15 knots). The optimum propeller is then selected to perform a complete system analysis for the single-screw vessel. The system analysis outputs resistance, power, and propeller data for a range of speeds from 8 to 16 knots. Additional ship loading scenarios are entered into NavCad to examine the resistance, power, and fuel consumption rates of the vessel.

Within NavCad, the hull form is defined by a series of ship parameters listed in Table 4.3.1.1. Options for specifying stern and bow shape include U-shape, Normal, or V-shape. The ship stern shape is considered to be normal, and the bow has a U-shape. Saltwater properties and the speed range are detailed in the vessel condition section of NavCad. Metric units are specified for the analysis. The rudder has a total area of 200 m^2, corresponding to 5.03 percent (% of LWL*T). This rudder size is included in the appendage section of NavCad. The oversized rudder allows for increased maneuverability. Environmental data contributing to ship resistance and power are not included in the design case. To develop predictions for the ship resistance, the friction coefficient (C_f) is found using the ITTC equation, and Holtrop method specifies a correlation allowance of 0.00014 and a 3-D form factor of

1.4381. The Holtrop 1984 method is used to calculate the bare-hull resistance of the vessel. The resistance due to the rudder and a design margin, correlating to ten-percent feasibility, are added into the total resistance calculations. Table 4.3.1.2 shows a summary of the resistance calculations for the design case. For comprehensive resistance data, see Appendix A.5.1.1.

Table 4.3.1.1 NavCad Hull Form Parameters

Parameters	Design	Wave	Ballast	TAPS	Full
Length between PP (m)	251.54	251.54	251.54	251.54	251.54
WL bow pt aft FP (m)	0	0	0	0	0
Length on WL (m)	251.54	251.54	251.54	251.54	251.54
Max beam on WL (m)	49.78	49.78	49.78	49.78	49.78
Draft at mid WL (m)	15.80	15.80	10.46	14.45	16.02
Displacement bare (tons)	169055	169055	108260	153912	172227
Max area coefficient	0.995	0.995	0.995	0.995	0.995
Waterplane coefficient	0.913	0.913	0.872	0.905	0.915
Wetted surface area (m^2)	17937.4	17937.4	14717.0	16967.0	17842.0
Trim by stern (m)	0	0	0	0	0
LCB aft of FP (m)	133.57	133.57	114.85	117.23	118.11
Bulb ext fwd FP (m)	7.05	7.05	7.05	7.05	7.05
Bulb area at FP (m^2)	88	88	88	88	88
Bulb ctr above BL (m)	6.22	6.22	6.22	6.22	6.22
Transom area (m^2)	0	0	0	0	0
Half entrance angle (deg)	40	40	40	40	40

Table 4.3.1.2 Resistance Summary for the Design Case

Velocity (kts)	Rbare (kN)	Rapp (kN)	Rother (kN)	Rtotal (kN)	PEtotal (kW)
8.00	371.45	3.54	37.50	412.49	1697.6
10.00	565.58	5.39	57.08	628.07	3231.1
12.00	799.94	7.61	80.75	888.30	5483.8
14.00	1085.58	10.18	109.58	1205.33	8681.1
15.00	1256.85	11.60	126.84	1395.28	10766.9
15.78	1409.31	12.76	142.21	1564.27	12698.7
16.00	1455.95	13.10	146.91	1615.95	13301.1

Rbare = bare hull resistance Rapp = appendage resistance Rother = design margin Rtotal = Total resistance PEtotal = Total effective power

A Man B&W low-speed diesel engine, selected in the concept exploration, powers the ship. The low-speed diesel is a two-stroke, crosshead engine with eight inline cylinders. The stroke-to-bore ratio is 3.82:1. The engine is well suited for operation on low-quality fuels and intended to drive the ship propeller directly without any speed-changing device. Due to the direct drive system, the engine is restricted to an rpm range for which efficient propellers can be designed. The rated power of the engine is 22,480 kW at a rated speed of 91 rpm. The PTO is used to supply electrical power for ship services while the vessel is underway. Therefore, the available rated power of the engine is decreased by 1,000 kW to 21,480 kW to account for this power takeoff from the engine. The modified rated power and the rated rpm are incorporated into the NavCad engine description. Speed-power and speed-fuel consumption curves are generated from the speed-power-efficiency surface for the engine. The curves shown in Figure 4.3.1.1 are maximum efficiency curves. These curves are the simplified input required by NavCad to determine the engine characteristics.

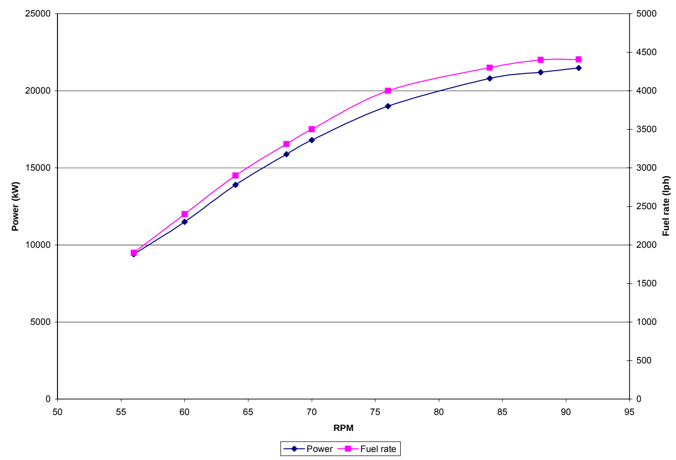


Figure 4.3.1.1 Performance Envelope

Three propeller types are analyzed and compared to find the minimum fuel consumption rate of the engine at endurance speed. The propeller options include a 4-blade fixed pitch propeller (FPP), a 5-blade FPP, and a 4-blade controllable pitch propeller (CPP). In NavCad, the options are defined as separate propeller files varying only in the number of blades and pitch type (FPP or CPP). Table 4.3.1.3 lists the data entered for each propeller type. The expanded area ratio (EAR) is a generic value initially but is optimized with pitch in the analysis. The Kt and Kq multipliers are estimations for commercial vessels. A cavitation breakdown is not applied to any of the propeller options. The maximum propeller diameter is determined by examining the stern section of the ship. The propeller hub is placed where the shafting from the engine protrudes the stern. Ten percent of the distance between the hub and the hull is allotted for clearance between the propeller tip and hull, in the plane of the propeller. The distance between the hub and the hull minus the ten percent clearance is compared to the distance from the hub to the baseline of the ship. The values are 4.74 m and 4.36 m, respectively. The minimum value, 4.36 m, is chosen as the propeller radius, making the propeller diameter 8.72 m. With this propeller diameter, a clearance of 0.91 m, or 17.3 percent, is achieved between the propeller tip and the hull. In Table 4.3.1.3, the maximum propeller diameter is 8.72 m and the minimum is 0.25 m less than the maximum.

Table 4.3.1.3 Propeller Type Options

Parameters	4-blade FPP	5-blade FPP	4-blade CPP
Series	B-series	B-series	B-series
Blades	4	5	4
Exp area ratio	0.65	0.65	0.65
Min diameter	8.47 m	8.47 m	8.47 m
Max diameter	8.72 m	8.72 m	8.72 m
Pitch type	FPP	FPP	CPP
Scale correlation	B-series	B-series	B-series
Kt multiplier	0.97	0.97	0.97
Kq multiplier	1.03	1.03	1.03
Blade t/c	0.0	0.0	0.0
Roughness	0.0 mm	0.0 mm	0.0 mm
Propeller cup	0.0 mm	0.0 mm	0.0 mm

NavCad can analyze the two FPP options together, while a separate analysis is made for the CPP option. The Man B&W engine is selected, and the gear efficiency and gear ratio are specified as one. The design speed of 15 knots is entered. The Keller equation is specified to determine cavitation. Since a reduction gear is not needed and the shaft is relatively short, the shaft efficiency is 0.995. The propeller immersion from waterline to propeller tip is 7.08 m for the design case. During the optimum propeller selection, the options are analyzed for only three speeds, a low speed (8 knots), the endurance speed (15 knots), and a high speed (16 knots). The optimization process is iterative with the first run optimizing EAR and pitch and consecutive runs optimizing only pitch. The EAR value from the first run is gradually increased for subsequent runs to reduce the pressure on the propeller to acceptable limits. Unacceptable output values appear in red in NavCad.

The complete results of each propeller option are shown in Appendix A.5.1.1. Table 4.3.1.4 displays the fuel consumption rates for three ship speeds for each propeller option. The results for each option are very similar, especially between the 4-blade FPP and 4-blade CPP. At the endurance speed, the fuel consumption rates of the 4-blade CPP and 4-blade FPP differ by 0.99 liters per hour (lph). The 4-blade FPP is chosen as the optimal propeller design due to its efficiency, cost, and simplicity advantages over the other options. The optimal EAR and pitch are 0.65 and 8.04 m, respectively.

Table 4.3.1.4 Optimum Propeller Selection

Speed (knts)	Fuel Consumption Rate (lph)		
	4-blade FPP	5-blade FPP	4-blade CPP
8.00	132.99	145.64	71.74
15.00	3414.47	3450.03	3415.47
16.00	4172.42	4213.47	4169.66

Once the optimal propeller is chosen, the complete system analysis is preformed. In NavCad, the 4-blade FPP option is chosen and the optimal EAR and pitch are entered. The engine file is selected, gear efficiency and gear ratio are each one, shaft efficiency is 0.995, and the propeller immersion for the design case is entered (7.08 m). Complete resistance, power and propeller data are generated for the range of speeds shown in Table 4.3.1.2. At the endurance speed, the brake power is 16,182 kW and the fuel rate is 3,414 lph. Total ship resistance, fuel consumption, and brake power are each plotted against ship velocity in Figures 4.3.1.3-5. The system analysis for the design case is included in Appendix A.5.1.1.

Four additional ship loading cases are analyzed. All the loading cases use the optimal propeller selected in the design case, 4-blade FPP. A wave case is analyzed where Sea State 4 wave characteristics are incorporated. This seastate is the most probable in the Northern Pacific with a significant wave height of 1.88 m, sustained wind speed of 19 knots, and most probable modal wave period of 8.8 sec (Appendix A.1.2). These wave characteristics are entered into the environmental section of NavCad. All other parameters are identical to the design case. An arrival ballast case is analyzed to assess the performance of the ship during its typical voyage from Cherry Point, WA to Valdez, AK. Several hull form parameters are altered to represent the in-ballast vessel. These values are obtained from HecSalv during the intact stability analysis (Section 4.9.2). The hull parameters entered into NavCad are shown in Table 4.3.1.1. The propeller immersion changes to 1.74 m due to the change in draft. Engine and propeller characteristics remain the same. A TAPS trade case is analyzed where the tanker is loaded to 125,000 DWT, typical for its voyage from Valdez to Cherry Point (Section 4.9.2). Hull parameters changed in NavCad are presented in Table 4.3.1.1. These hull parameters are also gathered from HecSalv. The propeller immersion for this case is 5.73 m, but all other NavCad inputs are identical to the design case. The final case analyzed is a Full load case, where the ship is loaded to its full capacity, 140,000 DWT. The hull form parameters from HecSalv, inputted into NavCad, are shown in Table 4.3.1.1. Propeller immersion is 7.30 m. Other inputs remain the same.

The available brake power for sustained speed, BHP_{max}, is 90% of the maximum continuous rating (MCR). The MCR of the engine corresponds to the available rated power, 21,480 kW. Therefore, BHP_{max} equals 19,332 kW. For all load cases, the maximum sustained speed corresponding to BHP_{max} must be greater than the endurance speed, 15 knots. All cases satisfy this criterion. Table 4.3.1.5 shows the sustained speeds at BHP_{max} for all load cases as well as fuel rates at these sustained speeds and at the endurance speed. The math model estimated a sustained speed of 15.78 knots for the design case, but the NavCad analysis showed an actual sustained speed of 15.81 knots. Figures 4.3.1.3-5 show the total ship resistance, fuel consumption, and brake power versus ship speed for all cases. Figure 4.3.1.5, the brake power curve, shows the value of BHP_{max}. The wave case has the largest total resistance, fuel consumption, and brake power values compared to the other cases. The resistance and system analyses for the wave case are incorporated into Appendix A.5.1.2. The ballast, TAPS trade, and Full load cases produce acceptable results in all areas of resistance, power, and propeller loads. The results do not exceed the design case, as illustrated in the figures. The system analyses for these cases are shown in Appendices A.5.1.3-5.

Table 4.3.1.5 Summary of Results for Load Cases

Case	Sustained speed at BHP_{max} (knots)	Fuel rate at sustained speed (lph)	Fuel rate at endurance speed (lph)
Design	15.81	4018.34	3414.47
Design Wave	15.08	4024.54	3964.21
Full Load	16.15	4030.74	3279.43
TAPS load	16.44	4046.2	3117.95
Ballast	17.25	4112.8	2697.71

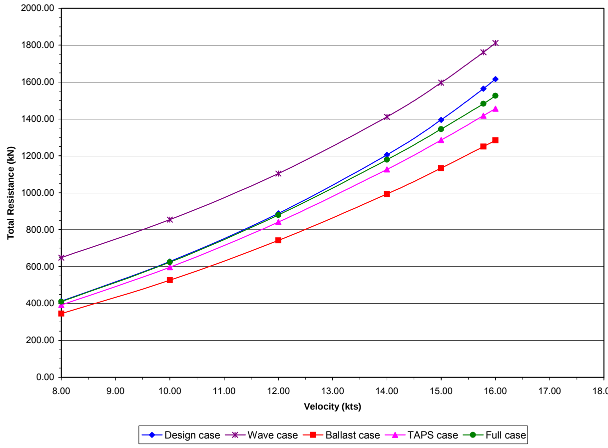


Figure 4.3.1.3 Total Resistance vs. Ship Speed

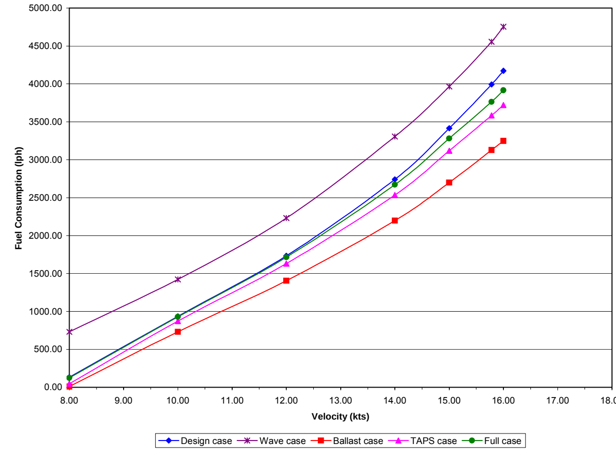


Figure 4.3.1.4 Fuel Consumption vs. Ship Speed

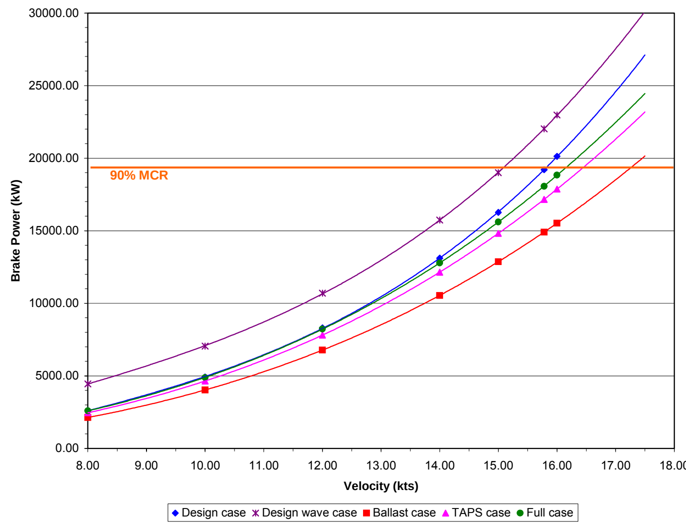


Figure 4.3.1.5 Brake Power vs. Ship Speed

4.3.2 Endurance Electrical Power Analysis

The electrical load required to service the ship over a 24-hour period is needed to determine the electrical endurance fuel weight and volume. The ship service maximum functional load (SSMFL) includes electrical loads for propulsion, steering, lighting, interior communications, firemain, fresh water/fluid systems, general outfit/furnishing, deckhouse heating, and deckhouse ventilation. For the average 24-hour load calculation, 100% of the propulsion and steering loads are incorporated, while 75% of the remaining loads are included. Propulsion and steering are constantly functioning during a 24-hour period, whereas the other loads vary depending on the crew usage. A 24-hour margin factor of 1.2 is included in the calculations. Table 4.3.2.1 shows a summary of the loads that are incorporated into the calculation. The average 24-hour electrical load is 878 kW.

Appendix A.5.2 shows the average 24-hour electrical load calculations performed in MathCad. Section 4.4 contains a complete power analysis summary and a list of electrical equipment.

Table 4.3.2.1 Endurance Electrical Load

Quantity	Input	Output
100% Propulsion Electrical Load (kW)	97.37	
100% Steering Electrical Load (kW)	132.57	
75% Remaining Ship Service Loads (kW)	501.49	
24-hour Margin Factor	1.20	
Average 24-hour Electrical Load (kW)		877.72

4.3.3 Endurance Fuel Calculation

An endurance fuel calculation is performed to find the quantity of fuel oil required completing a 10,000-mile route at endurance speed. The endurance range, 10,000 miles, is specified as the mileage to Hong Kong, China where repairs and dry-docking occur every five years. Assuming no interruptions during the trip, a 10,000 mile voyage at 15 knots takes 27.78 days to complete. The tanker, therefore, is required to travel a maximum of 27.78 days without refueling. Thus, this trip length is used to size the fuel oil tanks. Once the volume of fuel oil for this trip is known, the minimum required volume of the fuel oil tanks is determined. The fuel weight density used in these calculations is 42.3 ft^3/lton.

The endurance fuel calculation is designed to output the required engine fuel weight and volume. The NavCad system analysis for the design case provides the inputs for the calculations such as brake horsepower, shaft horsepower, and the ballast case fuel consumption rate at the endurance speed of the tanker. The total fuel weight and volume are acquired by combining propulsion and electrical fuel requirements. Propulsion endurance specific fuel consumption (SFC) is a measure of fuel rate per brake horsepower per fuel weight density. The propulsion endurance fuel weight is a product of the length of the trip, 27.78 days, the propulsion power at endurance speed, and an average fuel rate allowing for plant deterioration. Electric power SFC is assumed equivalent to the propulsion endurance SFC, since the PTO generator supplies the electric power. The electrical endurance fuel weight is a product of the trip length, average 24-hour electrical load, and average fuel rate allowing for plant deterioration. The average 24-hour electrical load is acquired from the Electrical Load calculations in Section 4.3.2. To find the required volumes of propulsion and electrical fuel weights, allowances for liquid expansion and tank internal structure are included, 1.02 and 1.05, respectively. Table 4.3.3.1 shows a summary of the endurance fuel calculation. The details of the calculations are displayed in Appendix A.5.2.

Table 4.3.3.1 Endurance Fuel Calculation*

Quantity	Input	Output
Rated Power (kW)	22480	
Brake Horsepower (kW)	16182	
Shaft Horsepower** (kW)	16263	
Fuel Rate (lph)	3414.5	
Average 24-hour Electrical Load (kW)	877.72	
Propulsion Fuel Weight (lton)		1709.00
Propulsion Fuel Volume (m^3)		2193.00
Electrical Fuel Weight (lton)		93.61
Electrical Fuel Volume (m^3)		120.09
Total Fuel Weight (lton)		1803.00
Total Fuel Volume (m^3)		2313.00

*at fifteen knots ** shaft efficiency of 0.995

4.4 Mechanical and Electrical Systems

The mechanical and electrical systems within the vessel are determined according to specifications set forth by the optimizer during concept exploration, the MathCad model (Appendix A.2), and expert opinion. A list of the pertinent mechanical and electrical systems for this tanker, containing capacities, dimensions, and weights, is shown in Appendix A.6. The main mechanical and electrical components of the ship and the methods used to size these components are described in the following sections. The arrangement of these systems within the ship is detailed in Section 4.7.4.

4.4.1 Mechanical Systems

Several mechanical systems are categorized under propulsion or auxiliary. Auxiliary contains all the cargo-related systems as well as deck machinery, and other miscellaneous equipment. Under propulsion, the main engine is an eight cylinder Man B&W low-speed diesel as described in Section 4.3.1. The capacity of the engine is 22480 kW at rated rpm of 91. The propulsion system schematic is shown in Figure 4.4.1.1 and in Drawing D.200-01. The ship has a bow thruster, a lateral or tunnel type thruster designed to improve the ship's maneuverability at low or zero ship speed. A bow thruster typically produces 25 lb of thrust per horsepower. The capacity of the bow thruster is 2,237 kW, calculated in the MathCad model. Therefore, the bow thruster is capable of producing approximately 75,000 lbs of thrust. The thrust produced is both variable and reversible, accomplished by using a constant-speed electric motor to drive a controllable pitch propeller. The tunnel is located as far forward as possible to obtain the maximum turning moment from the thrust developed. The tunnel is positioned vertically on the bow section to allow at least one-half the tunnel diameter between the top of the tunnel and waterline and at least one-quarter the tunnel diameter between the bottom of the tunnel and keel.

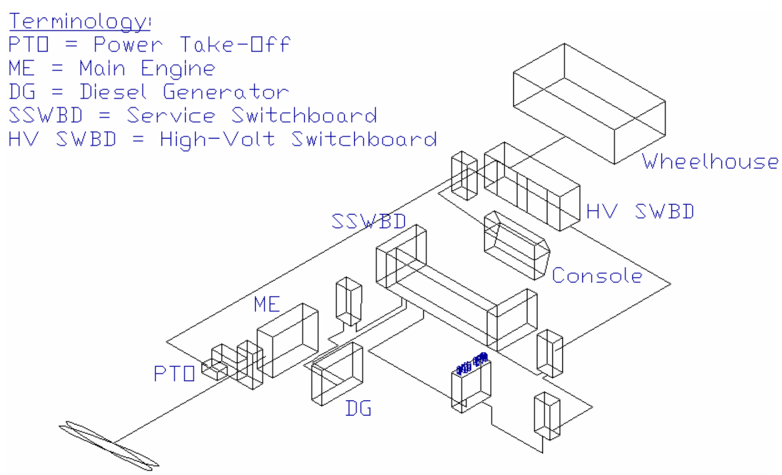


Figure 4.4.1.1 Propulsion System Schematic

Fuel oil, diesel oil, and lubrication oil purifiers are sized based on fuel consumption. The fuel oil and lube oil purifiers service the main engine. Two of each purifier are provided for continuous operation and are connected in parallel. There are two diesel oil purifiers that filter fuel required by the diesel generators. Once started, the purifiers are fully automatic in their operation and are programmed to shut down and alarm when malfunctions occur. Two fuel oil heaters are required to heat the fuel before combustion. The fuel oil heaters contain duplex strainers to filter out contaminants before the fuel is heated. The final outlet temperature of the fuel oil is controlled by a viscometer.

Two auxiliary boilers and two heat-recovery boilers are included in the ship to supply steam for services such as hotel services, cargo or bunker oil heating, and evaporators. The second heat-recovery boiler is installed for redundancy. The exhaust gases from the main engine contain significant available latent heat. The heat-recovery boilers are designed to collect heat from the exhaust gases escaping through the stack. The auxiliary boilers provide the remainder of steam needed on the ship. These auxiliary boilers can provide steam when the main engine is shut down. The ship has three fire pumps that take suction from the sea chests and deliver seawater to the fire mains and hoses. The pumps have capacity and pressure ratings based on the number of hoses and the pressure required at the farthest hose. Two pumps are located on Flat 4 in the machinery room and one pump is installed on Flat 1 to ensure that sufficient backup capacity is available during an emergency.

Desalination plants, known as distillers, are used to produce high-purity fresh water from seawater. The fresh water is needed to supply high-purity makeup water for boilers and potable water for drinking, cooking, dishwashing, hospital, and laundering purposes. A thermal process is used to physically separate fresh water from the dissolved solids in seawater. The fresh water is transformed into a vapor and extracted from the seawater. The vapor is subsequently condensed. The SW/FW heat exchanger is used to cool the main engine. Two distillers and one SW/FW heat exchanger are contained onboard. Port and starboard potable water pumps transfer fresh water to the potable water tank.

Two air conditioning units and two refrigeration units are placed on Flat 1 in the machinery room. The A/C units provide a way to control the environment in the deckhouse and the control room on Flat 1 in the machinery room. The refrigeration units control the environment in specific storage areas in the deckhouse. Low pressure (L/P) air compressors supply compressed air to locations throughout the ship for various uses, such as operating pneumatic tools, cleaning equipment, and starting the engine. Compressors of this type usually have capacities from 100 to 1250 cubic feet/min (cfm) at discharge pressures from 100 to 150 psi. The two compressors operate at a constant speed and need to be cycled on and off to keep the pressure in the air receivers within limits.

Among the auxiliary category, the characteristics of the steering gear are outlined. A rotary-vane steering gear is used to control the position of the ship rudder. The steering gear consists of a housing or stator, containing three vane cavities, and a rotor with vanes attached, which acts as a tiller. The rudder torque is produced by differential pressure that acts across the vanes. At any feasible angle of the rudder, the torque rating remains constant. The rotary-vane steering gear is more advantageous than other designs due to its simplicity, low space requirements, low weight and higher attainable rudder angles. The steering gear is capable of operating from 35 deg to 35 deg at vessel speed above 12 knots and 45 deg to 45 deg at speeds under 12 knots. The steering gear meets or exceeds all IMO standards for tankers.

The two anchor windlasses perform the crudest task on shipboard, hoisting the anchor at average speeds of 30 to 36 ft/min from various depths over 180 feet. The anchor windlasses require rugged construction due to inefficiencies of the system and awkwardness of the chain. The anchor chain is heaved in through the hawsepipe with a roller at the end. The roller reduces friction losses during the process to approximately 20%. The chain is engaged by a wildcat made of five whelps, which is comparable to a 5-tooth sprocket. This arrangement causes the moving chain to jerk which is compounded by its propensity to turn over or “slap” in the hawsepipe. The anchor windlass dimensions and scantlings are dependent upon the anchor weight and chain size. The standard mode of equipment selection for the anchor windlass is governed by ABS rules specific to the ship's classification society. These rules contain tables of required equipment such as anchors, chain cable, towlines, and hawsers. Certain ship dimensional and displacement measurements are substituted into empirical formulas. The results from these formulas correspond to entries in the tables. Mooring winches are used to secure the ship alongside a pier. A mooring winch has a high-capacity brake that can hold a load near the breaking strength of the mooring line. The brake can also be set to slip at a lower tension to avoid line breakage. Automatic mooring winches use an electric drive to automatically render and recover mooring line when the line tension is not within preset limits. There are six mooring winches positioned on the deck. They are sized according to expert opinion.

Cargo systems outlined under auxiliary in Appendix A.6 include cargo pumps, ballast pumps, crude oil washing pump, and cargo stripping pump. The pumps and their related systems are detailed in Section 4.5. Lifeboats, a hose crane, and a store crane are located on the deck of the ship. A sewage treatment plant and incinerator are included on the ship. The sizes of these systems are approximated using expert opinion.

4.4.2 Electrical Systems

To analyze the electrical loads and size the electrical systems on the vessel, the Electrical Load section of the math model in Appendix A.2 is used. The load analysis is designed to determine the power requirements of all electric power-consuming equipment under any given ship operating condition. Within the analysis, the electrical loads are divided into two groups, ship service and cargo (Section 3.1.3.4). The ship service electrical load comprises the electrical requirements of all non-cargo systems. This ship service electrical load is combined with two electrical margin factors producing the ship service maximum functional load (SSMFL). The cargo system electrical requirements are summed with 120% of the ship service electrical load, resulting in the power takeoff maximum functional load (PTOMFL). Figure 4.4.2.1 shows a flowchart of load analysis.

The PTO generator extracts power from the main engine to support ship services while the ship is underway and alongside the pier. The PTO generator also powers the cargo systems during loading and offloading. The PTO generator is placed aft of the main engine to extract its required power before the power is delivered to the shaft. The capacity of the generator is determined in the electrical load analysis. Table 4.4.2.1 shows the required PTO power calculated in the MathCad model and the available PTO power provided by the generator. The PTO generator selected is an eight MW, 1200 rpm machine operating off the PTO gearbox. The PTO is designed to produce power between 50 and 60 Hz at 6600 V. It may be clutched in at main engine speeds up to 80 rpm or de-clutched at any speed.

One of the diesel generators contained onboard is capable of providing the SSMFL and referred to as the ship service diesel generator. It is intended for use while the vessel is in port, while underway when the PTO generator is not available, and during some transitional periods. This generator is coupled directly to the engine that powers it. The ship service generator is capable of producing 1000 kW of power between 50 and 60 Hz at 480 V (Table 4.4.2.1). The other diesel generator is the emergency generator, a 700 kW, 1800 rpm device operating between 50 and 60 Hz at 480 V with a separate diesel engine. The capacity of this generator comprises the essential electrical loads required in an emergency such as propulsion, steering, lighting, interior communications, firemain, fresh water systems, general furnishing, and ventilation. The emergency generator required and available electrical loads are shown in Table 4.4.2.1. Appendix A.6 contains the dimensions and weights of all three generators.

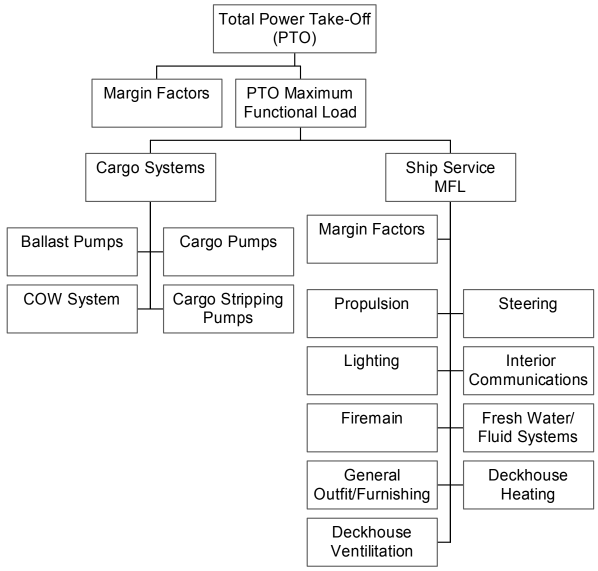


Figure 4.4.2.1 Electrical Load Analysis

The power converter unit (PCU) is required to convert DC power to AC output needed for ship services. The PCU consists of an AC/DC inverter, which receives 690 V input from the step down transformer at frequency between 50 and 60 Hz and provides a 660 V DC output. The 660 V DC from the inverter powers the DC motor, which subsequently drives a 1000 kW, 480 V AC generator. The AC generator is very similar to the diesel generators on the ship. The PCU delivers constant 60 Hz ship service power.

One high voltage (HV) switchboard is fitted in the machinery control room. The HV switchboard is designed to operate at 6.6 kV from 50 to 60 Hz. This switchboard supplies power to two segregated ballast pumps, four cargo pumps, the crude oil washing pump, a cargo stripping pump, and the bow thruster. The HV switchboard also powers the AC/DC inverter within the PCU. A low voltage (LV) switchboard is also contained in the machinery control room. It is designed to operate at 480 V, 60 Hz constant frequency. The LV switchboard can be powered from a 6.6 kV/480 V transformer, the 1000 kW PCU, or the 1000 kW ship service diesel generator. The LV switchboard provides power to a 120 V, 60 Hz service switchboard. A shore power connection of 1000 kW is provided from the LV switchboard. An emergency switchboard is connected to the LV switchboard and operates at 480 V, 60 Hz constant frequency. The emergency switchboard services a fire pump, steering gear, and the emergency generator. This switchboard also powers a 120 V 60 Hz switchboard for ship services via an emergency transformer. All switchboards are sized by expert opinion. Their dimensions are listed in Appendix A.6. A schematic of the electrical system is shown in Drawing D.300-02.

Table 4.4.2.1 Electrical Loads

Electrical Load (kW)	Ship Service	PTO	Emergency	Other
Propulsion	97.37	121.71	98.71	
Steering	132.57	165.71	132.57	
Lighting	84.87	106.09	84.87	
Interior Communications	25.00	31.25	25.00	
Firemain	210.23	262.79	210.23	
Fresh Water and Fluid Systems	13.00	16.25	13.00	
General Outfit/Furnishing	7.90	9.88	7.90	
Deckhouse Heating	297.06	371.33		
Deckhouse Ventilation	30.60	38.25	30.60	
Ballast Pumps		600.00		
Cargo Pumps		5224.00		
COW Pumps		520.00		
Cargo Stripping Pumps		411.00		
Bow Thruster				2237.00
Deckhouse Air Conditioning				191.84
Totals:	**898.60**	**7878.26**		
Electrical Margin Factor	1.00	1.00		
Electrical Margin Factor	1.01	1.01		
Required Generator Power:	**907.58**	**7957.00**	**602.88**	
Available Generator Power:	**1000.00**	**8000.00**	**700.00**	

4.5 Cargo Systems

4.5.1 Cargo-Oil System

At the loading terminal, the cargo-oil system receives the cargo and distributes it to the cargo tanks. When unloading cargo, this system discharges oil from the tanks to the terminal. Our concept design specifies that the vessel contains four cargo subdivisions. Therefore, the cargo system consists of a total of eight cargo tanks and two slop tanks, arranged symmetrically about the centerline bulkhead.

The vessel is capable of transporting two different grades of cargo simultaneously. The system piping is designed to keep different grades of cargo segregated as they flow through the system. A schematic for the cargo-oil system within the tanks and the pump room is shown in Drawing D.700-01. The cargo is loaded through a four-header deck manifold, which merge into two risers and drop into two cargo mains, one port and one starboard. The cargo mains connect to the tanks through stop valves to facilitate in filling specific tanks at a time. Each main is sized according to the maximum loading rate delivered by the pier, 110,000 bbls/hr.

During the offloading procedure, two segregated bottom suction mains, port and starboard, remove the cargo from the tanks. Each suction main is sized for the full capacity of the pumps to which it is normally connected. These bottom mains are connected to tailpipes and serve alternate pairs of cargo tanks. Every tailpipe has a stop valve to allow for the selection of the tanks to be unloaded. These valves also guard against the discharge of cargo into the sea if the shell or piping is damaged. Drawing D.700-01 illustrates the suction mains serving each tank.

The cargo pumps receive the cargo from the two bottom suction mains. Cross-connections with shut valves are provided between the mains in the pump room to permit any pump to take suction from any tank in case of a pump failure. Cargo pumps discharge into two discharge headers. To decrease the risk of deck spills, the discharge headers run through the cargo tanks with risers at the cargo manifold. The discharge piping size is based on the total pump head and required minimum pressure at the deck manifold. The required minimum pressure at the deck manifold for this vessel is 150 psi. A schematic of the cargo system is shown in Drawing D.700-01.

Four electric motor-driven cargo pumps deliver an average pumping rate of 50,000 bbls/hr with a delivery pressure at the ship rail of 150 psi. The unloading time of 14 hours is required to achieve a round trip voyage of 10.5 days from Cherry Point, WA to Valdez, AK and back. This unloading time is used to determine the required pump capacity. The cargo pump specifications are shown in Appendix A.6.

4.5.2 Crude Oil Washing (COW) System

The vessel is required to have a COW system by US COFR, USCG and IMO regulations (Appendix A.1). These regulations set forth the standards for the design and installation of the systems.

Cargo tanks must be washed periodically when the cargo is discharged from the tank and during inspection. This is done in an effort to keep the tank capacity to its full potential and to keep the cargo unloading process efficient. The tanks are also washed to ensure that newly loaded cargo grades are not contaminated by previously carried cargo. The washing process uses high pressure nozzles to spray cargo oil onto the inner surfaces in the tank to dislodge any accumulated residue. Steam is also periodically used to reduce wax build-up in the tanks. If this washing did not take place regularly, the residue would be very difficult to remove and dispose of. Regular washing ensures a higher percentage of cargo is delivered.

A fixed COW system is used on this vessel. It consists of rotating nozzles, which are located throughout the cargo tanks, piping, and a dedicated COW pump (Appendix A.6). There must be enough nozzles so that 90 percent of the tank inner structure can be reached by their programmed spray pattern. The COW pump allows cleaning to be independent of the cargo and ballast systems. The bottom of the cargo tank is cleaned after the cargo is pumped out of the tank and during the discharge of the remaining cargo tanks. For an effective wash of the cargo tank bottoms, the oil must be removed simultaneously as it enters the COW system using eductors. They are supplied with actuating oil by the COW pump and apply suction on the cargo tanks by way of the stripping tailpipes. The eductors discharge into the slop tanks, where the oil is then removed by a cargo pump.

The COW system suction main begins at the COW pump and branches out through the cargo block to service each tank. At the cargo tanks, the piping further divides to connect to each nozzle. This system is shown in Drawing D.700-01.

4.5.3 Cargo Stripping System

The stripping system is engaged to remove the remaining cargo from the tanks when the main cargo piping begins to intake air. Vortices form near the tailpipes which permits air to enter the suction piping. The reduced pressure in the piping can cause lighter components of the crude oil to vaporize. Air and vapor bubbles entering the cargo pumps can produce a loss of suction and speed surges, which may damage the pumps. The stripping system has a separate, relatively small, suction main and tailpipes connecting to each cargo tank. To facilitate unloading, the stripping piping is arranged to remove the residual oil and guide it to a dedicated cargo stripping pump (CSP). The CSP discharges to the cargo pump discharge headers and subsequently to the deck manifold. In addition, the stripping system is designed to pump wash water from cargo tanks to the slop tanks and discharge oily waste from the slop tanks to the deck manifolds. This system can also transport clean water from the slop tanks overboard via an oil-content monitoring system and dewater the pump room in an emergency. The CSP and system are shown in Drawing D.700-01.

Stripping of the cargo tanks involves a dedicated motor-driven positive displacement stripping pump due to its high suction-lift capabilities. The discharge of liquids from the bottom of the cargo tanks to the deck discharge manifold determines the pump head rating. The CSP specifications are shown in Appendix A.6. If the stripping pump fails, the stripping eductors are used. They are powered by the COW pump, which is specified in Appendix A.6.

4.5.4 Ballast System

Ballast tanks and piping are independent of the cargo-oil tanks and piping to eliminate any possibility of discharging oil overboard when deballasting. In addition, this segregated ballast system prevents seawater contamination of the cargo. The ballast system is shown in Drawing D.700-02. The ballast system serves five pairs of port and starboard "J" tanks in the cargo block, a forepeak ballast/trim tank, and an aftpeak ballast/trim tank. There are two ballast pumps located in the pump room, connecting to port and starboard bottom suction mains. The pump specifications are shown in Appendix A.6. The pumps are arranged to apply suction to the two sea chests near the pump room and discharge to the ballast tanks. At each tank, a tailpipe is fitted to its respective ballast main.

The introduction of harmful marine organisms to foreign environments through ballast water exchange is an increasingly important topic in coastal areas. Ballast water exchange in the open ocean is preferred to minimize the environmental risk. This vessel is fitted with a ballast water exchange system that utilizes pressure differences to guide clean water from the ship's bow to the ballast tanks. While the ship is traveling, the pressure differences are produced by the flow along the hull surface. A water inlet is provided at bow and leads the clean water into the ballast tanks via the existing ballast mains. Each ballast tank is fitted with a sea chest at the forward end of the tank. This position of the sea chest achieves the most effective water exchange.

To achieve ballast water exchange, the tank's existing ballast water is discharged by gravity through the sea chest until the pressure differences stabilize at the ship's draft level. Clean water is lead from the bow into the tank and displaces the dirty water through the sea chest. The tank is then filled to its 98 percent intact level with clean water by the ballast pump. This ballast water exchange system eliminates the additional operation and monitoring of auxiliary machinery required by other methods.

4.5.5 Oil-Content Monitoring System

In the process of washing the cargo tanks, the accumulated oil-water mixture is transferred to the slop tanks. The mixture eventually separates due to gravity, and the water with a sufficiently low oil content is discharged overboard. The discharge is monitored to ensure that the oil content limit set by regulatory bodies is not exceeded.

The oil-content monitoring system continually analyzes fluid samples and checks the levels of oil in the fluid. The sampling piping, shown in Drawing D.700-02, connects to the monitor from the overboard discharge above the waterline. The system determines the total quantity of oil discharged overboard per nautical mile from the ship speed and the discharge flow rate. The system automatically shuts the overboard discharge valve if any set limit is exceeded.

4.5.6 Inert Gas System (IGS)

An inert gas system (IGS) is required by regulatory bodies to replace potentially explosive fumes in the cargo tanks with a much safer inert gas. This process prevents any explosions that may occur when there exists a specific concentration of air and fuel. Since static electricity is generated from the washing nozzles, an inert environment is particularly desirable during COW operations. Exhaust fumes from the propulsion system boilers, heat recovery boilers, and inert gas generator supply the inert gas. The gases must pass through a scrubber to cool and remove contaminants from them. The gas is then inert and ready to be supplied to the cargo tanks at this point. The setup of the IGS is shown in Figure 4.5.6.1.

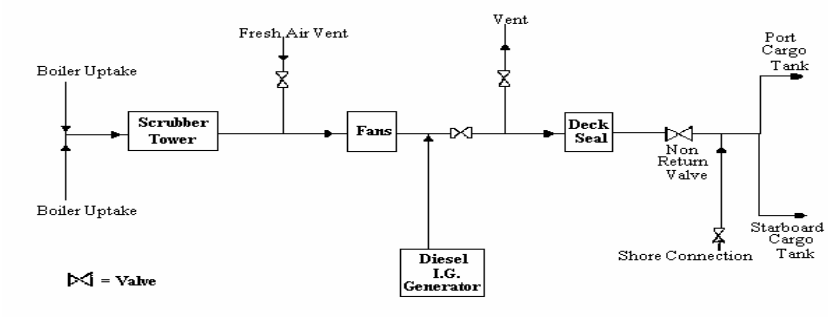


Figure 4.5.6.1 Inert Gas System Schematic

To distribute the gas, a piping and fan system is utilized to deliver the gas to the cargo tanks. Two fans are provided for a combined capacity sufficient to supply a volume of gas equivalent to 125% of the combined capacity of all cargo pumps operating simultaneously. A static pressure of 4 in. of water during the unloading of tanks must be maintained. A valve is located upstream from the fans, capable of closing automatically in case of a fan failure. A branch from the fan suction is capable of discharging into the atmosphere to free the tanks of inert gas during inspection. The distribution system main extends across the top of the cargo tanks with an independently valved branch going to each tank as shown in Drawing D.700-01.

When the IGS is not in operation, both a water seal and a check valve in the inert-gas main downstream from the fans are required to prevent cargo vapors from entering the machinery space. Each tank is vented such that dilution of the inert gas is prevented, and a pressure-vacuum relief is present, isolating the tank from the atmosphere.

4.6 Manning

The Coast Guard Officer-in-Charge, Marine Inspection (OCMI) determines the manning levels for ships by defining the minimum combination of unlicensed and licensed crew for both deck and engineering departments. There is no well-defined method for determining the appropriate manning level of a ship. However, OCMI examines a wide range of factors that can contribute to the safe operation of the ship. OCMI considers factors such as the ship owner's Manning Plan, current regulations, level of shipboard automation, route and trade characteristics, and maintenance facilities. The manning level is listed on the Certificate of Inspection (COI) for the ship. Statues concerning vessel manning are contained in US Code, Part F of subtitle II of title 46 (46 USC Sec. 8101-9308). The Coast Guard has regulations that interpret and implement these vessel manning statutes. These rules for tank vessels are codified in 46 CFR Part 15. The rules define and restrict issues such as watchkeeping, working hours, and licensed officers and crew. OPA 90 also regulates the number of hours worked by tanker officers. Specifically, a licensed individual or seaman is not permitted to work more than 15 hours in any 24-hour period, or more than 36 hours in any 72-hour period, except in an emergency or drill.

The ORT LO has a manning factor of 0.7. The manning factor reflects the level of shipboard automation on the vessel. Within the math model, the value can vary between 0.5 and 1.0, where the former corresponds to a highly automated ship and the latter reflects a less automated ship. A highly automated ship requires a minimal crew, and a less automated ship needs a standard number of personnel. Shipboard automation have taken over many routine monitoring tasks, eliminating the duties of two or three unlicensed individuals on modern diesel engine ships. Some examples of engine room automation include:

- Bridge control of propulsion machinery
- Propulsion machinery safeguard system
- Automatic temperature control of fuel oil, lube oil and cooling water
- Generator safeguard system
- Automatic start of fire pumps to maintain firemain pressure set point

The bridge incorporates controls and monitors for all essential vessel functions. Many navigation, engine control, and communications functions are automated aboard the ORT LO. These functions involve updating charts, plotting position, steering, and creating logs, reports, certificates, and letters. Examples of navigation automation include a Global Positioning System (GPS), MARISAT communications capability, and autopilot systems.

In accordance with regulations and factors considered by OCMI, the Manning Plan for the ORT LO includes 20 crew members. The optimizer selects this crew size. The manning level for this tanker is above the minimum manning level of 17 set forth by current law. Table 4.6.1 shows the distribution and classification of licensed and unlicensed crew allotted for this tanker under the ORT LO column. The table also includes the manning levels of a select few tankers as a means of comparison.

Table 4.6.1 Manning Levels

Dept	Rank	Common Today	ORT LO 140K DWT	USA Chevron 40K DWT	Idemitsu Maru 258K DWT	Danish Moller 300K DWT	Japan Pioneer Plan	Danish Reefer 17K DWT
Deck	Master	1	1	1	1	1	1	1
	Deck Officers	3	3	3	3	3		2
	Crew						7	
	Radio Officer	1	1	1	1		1	1
	Seamen	9	6	6				
	Mechanics				6	4		
Engine	Engineer Officers	4	4	3	3	3	1	2
	Technicians		2					2
	Unlicensed	6	1	1				
Steward	Cooks/Assistants	5	2	2	2	2	1	1
	Total	**29**	**20**	**17**	**16**	**13**	**11**	**9**

The master is considered the ship's commander, chief pilot/navigator, and manager of the ship personnel. The master plans all voyage operations, ensures safe cargo loading and discharge, monitors ballasting operations, and supervises emergency cargo operations. Additional duties include: conducting ship maneuvering while entering and leaving port to ensure safety, monitoring the safety and health of the crew, administering personnel and training policies, and ensuring the maintenance and safe operation of deck equipment and machinery.

Three deck officers are required on the vessel, i.e. chief mate, second mate and third mate. The Chief Mate is primarily the cargo officer for the ship, responsible for safe handling, containment, and transportation of the cargo. This deck officer prepares the cargo transfer plan and plans cargo stowage, including calculation of stability and trim. In the absence of the Master, the Chief Mate is responsible for command of the vessel. Also this officer directs deck crew operations during mooring, maneuvering, and anchoring and supervises Deck Department maintenance.

The Second Mate is the primary watchstander and ship navigation officer. This officer is in charge of voyage management, maintaining and updating the chart inventory. Other duties include: ensuring the readiness and maintenance of all navigational aids and bridge equipment, assisting the Master in the wheelhouse, and assisting the Chief Mate with his duties, particularly cargo handling. The Third Mate is responsible for watchstanding and is the primary safety officer of the ship. This deck officer maintains all the lifesaving and safety equipment aboard the ship and supervises safe docking and anchoring operations. Additional duties include: preparing and conducting safety meetings, assisting the Master in the wheelhouse, assisting the Chief Mate with his duties, and supervising unlicensed deck personnel during wheelhouse and cargo watch.

There are four engineering officers on the vessel, whose titles are Chief Engineer, First Assistant Engineer, Second Assistant Engineer, and Third Assistant Engineer. The Chief Engineer is responsible for the overall management, supervision, operation, and maintenance of the Engine Department. This officer establishes voyage maintenance schedules and is responsible to the Master for the condition of engine spaces and power supplies. Additional duties include: coordinating with the Chief Mate on maintenance for cargo and deck equipment, ensuring compliance with all safety requirements, providing direction for engineering assistance during emergency operations, developing and implementing repair and maintenance of all machinery, and recording all repairs, expenditures, and fuel usage in the Engine Department. The primary role of the First Assistant Engineer is the safe and efficient implementation of Engine Department maintenance. This officer coordinates the waste oil and bilge discharge into environmentally controlled holding tanks, assists the Chief Engineer with fuel consumption and fuel calculations, supervises engine start-ups, and supervises unlicensed personnel.

The Second Assistant Engineer is responsible for the operation of boiler systems and diesel fuel/fuel oil systems. This officer assists the Chief Engineer in taking on bunker fuel while in port and transferring fuel oil while at sea. The officer also administers and supervises watchstanding. The Third Assistant Engineer is specifically responsible for the operation and maintenance of the electrical, lube oil, sanitary, and distillation systems on the vessel. This officer also stands watch in the Engine Department. Two technicians and one unlicensed individual are employed in the Engine Department to assist with machinery operation, maintenance, and repair.

The Radio Officer is responsible for maintaining communications in port and at sea. This officer maintains and repairs the electronics and navigation equipment on the ship. Six seamen are employed on the vessel, where 65 percent must be classified as able seamen. Seamen are responsible for cargo and line handling on deck, operating deck machinery, and performing mooring and anchoring duties. These seamen are also required to stand watch and assist the officers with their duties. Two cooks are required for preparing meals for the crew and maintaining the mess area.

4.7 Space and Arrangements

HecSalv and AutoCAD are used to generate graphical data to assess the space and arrangements feasibility of the ORT LO. HecSalv creates a graphical interface to manipulate the hull form, subdivisions and characteristic sections of the tanker. AutoCAD constructs 2-D and 3-D models of the deckhouse, including inboard and outboard profiles.

4.7.1 Space

Baseline space requirements and availability in the tanker are determined from the MathCad model (Appendix A.2). Parameters output by the MathCad model are as follows: the cargo block length, the machinery box height, length, width, and volume, and the volumes of the waste oil, lube oil, water, sewage and cargo (Table 4.7.1.1). Given the volumes and the hull form, the various tanks are located with HecSalv. Lightship weight, cargo and ballast locations are coordinated with weight and stability analysis to get the proper placement.

Table 4.7.1.1 Hull Required, Available, Actual Parameters from MathCad

Parameter	Required	Available	Actual
Machinery Box Height	18.337 m	27.498 m	25.185 m
Machinery Box Length	24.161 m	36.870 m	30 m
Machinery Box Width	19.3 m	49.781 m	49.78
Machinery Box Volume	$2*10^4$ m^3	$5.02*10^4$ m^3	$3.1443*10^4$ m3
Cargo Block Length	183.367 m	198.116 m	180.9 m
Waste Oil	63.147 m^3	N/A	77 m^3
Lube Oil	20.816 m^3	N/A	24 m^3
Sewage	30 m^3	N/A	98 m^3
Cargo	$1.6193*10^5$ m^3	N/A	1.70519 $*10^5$ m^3

The deckhouse space and arrangements are based on three factors: MathCad model, Millennium model, and expert opinion. The deckhouse is divided into three different sections: machinery area, living quarters, and a navigation deck. The deckhouse is comprised of five decks, accommodating 23 personnel: 20 crew members and 3 additional passengers. The decks are named from the lowest deck (A) to the highest deck (E). Decks A and B are referred to as the machinery of the deckhouse. Decks C and D are the living quarters for crew members. Deck E contains the navigation deck and accommodations for the Master and Engineer of the ship. Details of each deck are discussed in Section 4.7.3.

For the exterior parameters of the deckhouse, the MathCad model outputs requirements for the breadth, length, and height of each deck for all three sections. However, the dimensions of the entire deckhouse differ slightly than the dimensions from the MathCad model. Table 4.7.1.1 illustrates these exterior differences. Table 4.7.1.2 also shows differences between the MathCad model interior deckhouse area requirements and the actual area parameters of the deckhouse model. The differences in parameters in both tables result from a situation of unique equipment space requirements. The details of the exterior dimensions and interior dimensions are discussed in Section 4.7.2 and Section 4.7.3 respectively

Table 4.7.1.2 Deckhouse Required/Actual Parameter Differences

Deckhouse Parameter	MathCad Requirement	Actual Model	Difference
Number of Decks	5	5	0
Height of Each Deck	4m	4m	0
Breadth	41.78m	38.0m	-3.78
Length of Decks A-B	19.84m	25m	+5.86
Length of Decks C-E	14.38m	15.6m	+1.22

Table 4.7.1.3 Deckhouse Area Required/Actual Differences

Deckhouse Area	MathCad Requirement (m^2)	Actual Model (m^2)	Difference
CO_2 Room	94.02	81.88	-12.14
Machinery Shop	274.34	76.00	-198.34
LAN Area	32.51	45.32	+12.61
Bridge	156.73	457.20	+300.47
Total Area	3004.20	3678.40	+674.20
Area of Each Deck	600.84	735.68	+135.84

4.7.2 External

The tanks are all limited by the exterior extents of the hull dimensions as discussed in Section 4.1. Above the machinery space constraints lies the deckhouse. It is situated 200.4 m from the FP and extends 25 m aft in length. Its breadth allows a space of 5.89 m on both the port and starboard sides of the ship. Figures 4.7.2.1 through 4.7.2.4 are the AutoCAD drawings of the deckhouse in four different views, showing various external dimensions. The portholes are modeled in green and the doors for each deck are modeled as black rectangular blocks.

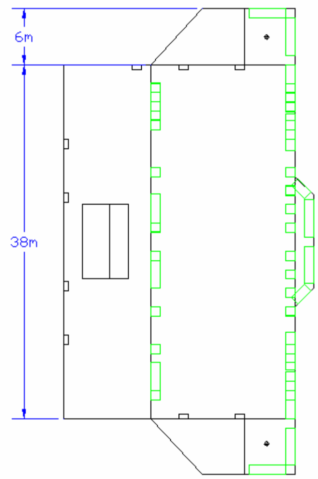


Figure 4.7.2.1 Plan View of Deckhouse

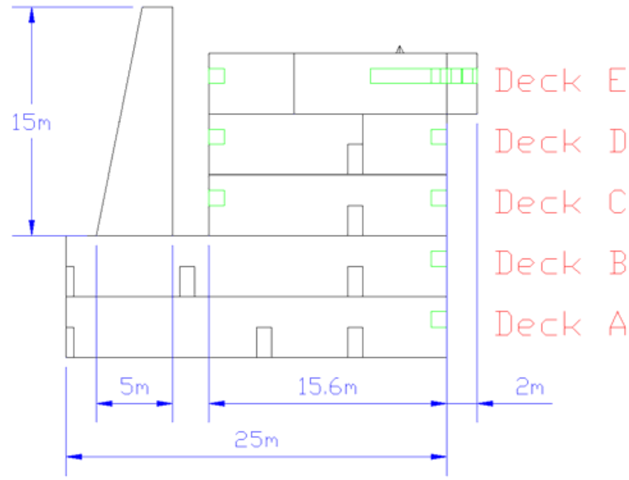


Figure 4.7.2.2 Elevation View of Deckhouse

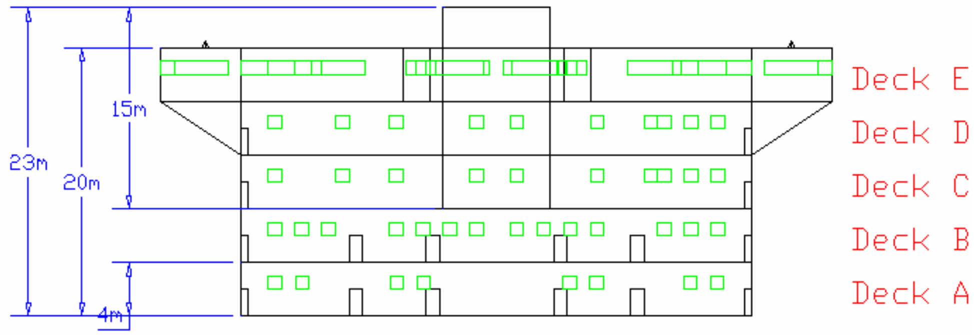


Figure 4.7.2.3 Section View of Deckhouse

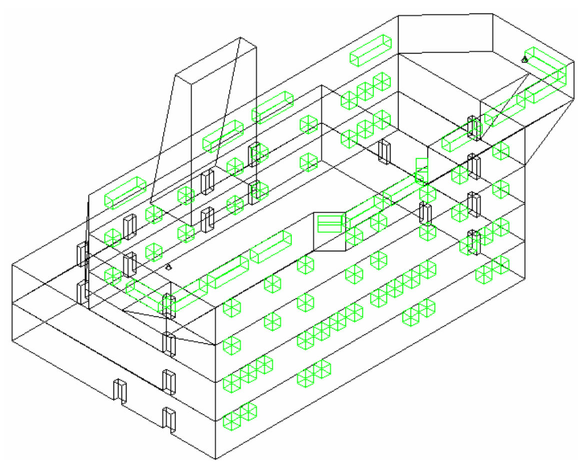


Figure 4.7.2.4 SE Isometric View of Deckhouse

The height of the deckhouse from the floor of Deck A to the top of Deck E is 20 m. This results in deck height separation of 4 m, which includes room for wiring and piping throughout each deck. Therefore, the actual height difference between each deck and overhead is 3 m. The height of the deckhouse results from the USCG visibility requirements for cargo carrying vessels. The mandatory navigation height must allow visibility of a length 500 m forward of the FP of the vessel. This requirement is included in the MathCad model to output the required height of the deckhouse. Due to the USCG requirement, the required height for visibility is 35.93 m. This is the total height of the navigation visibility above the waterline. The available navigation height of the LO ORT Tanker is 53.53 m. This height far exceeds the USCG requirements for navigation visibility 500 m forward of the FP of the ship.

Although, the total height of the decks is 20 m, the extension of the inlet/outlet casing for the machinery room is 3 m above Deck E. This results in an overall deckhouse height of 23 m. For increased outward visibility, the navigation deck is designed with two distinct features. First, it is extended 6 m in both the port and starboard direction from the breadth of the deckhouse. This allows crew members to view the sides of the ship during maneuvering. Additionally, Deck E has wider portholes to offer a panoramic outward view for the crew. On the bridge wings, the locations of the port and starboard portholes allow for viewing in these general directions.

There are exterior doors for all decks except Deck E. All exterior doors will be connected by a series of stairs and walkways. The locations of the portholes and doors correspond to their interior locations (Section 4.7.3). For the aft section of the superstructure, exterior doors allow efficient crew movement in the deckhouse machinery rooms.

The general rectangular shape of the deckhouse is based largely on simplicity for producibility. This block orientation allows an easier modular production of the deckhouse. Figures 4.7.2.5 and 4.7.2.6 show rendered views of the deckhouse from AutoCAD.

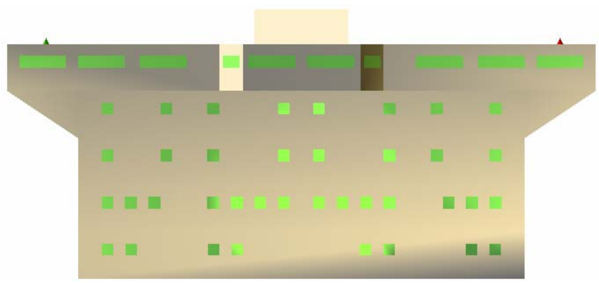


Figure 4.7.2.5 Rendered Section View of the Deckhouse

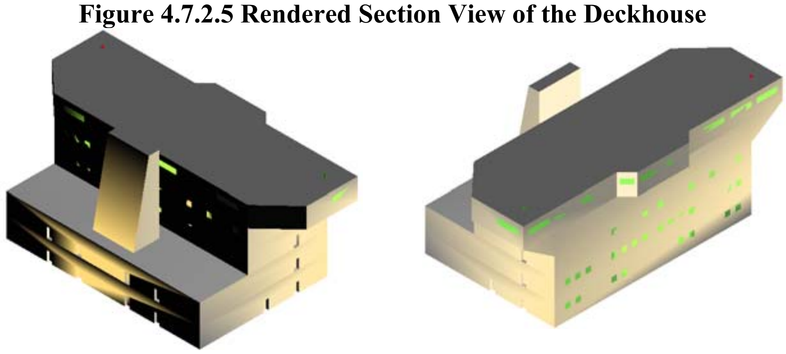


Figure 4.7.2.6 Rendered Isometric Views of the Deckhouse

4.7.3 Internal

4.7.3.1 Tank Space/Arrangements

Arrangements are done in HecSalv using the MathCad model and the parameters discussed in Table 4.7.1.1. For an initial framework, the forepeak tank is placed with its aft extent at the collision bulkhead (5% of LBP - 12.5 m). This allows for the placement of all the other tanks. Expert opinion and stability requirements are used to adjust the tank blocks fore or aft. All tanks locations and volumes are shown on Table 4.7.3.1.1 and in Figure 4.7.3.1.1.

Table 4.7.3.1.1 Tank/Room Locations and Volumes

Tank Space	Location from FP (m)	Volume (m^3)
Forepeak tank	0 - 12.5	7,024
Cargo Tank 1 P&S	12.5 - 54.2	18,211*
Ballast Tank 1 P&S	12.5 – 54.2	8,174*
Cargo Tank 2 P&S	54.2 - 98.4	21,608*
Ballast Tank 2 P&S	54.2 - 98.4	8,539*

Table 4.7.3.1.2 Tank Capacity Plan

Tank	Capacity Volume (98%)	Tank	Capacity Volume (98%)
Forepeak	6,883 m^3	No.5WBTS	1,627 m^3
No.1COTS	17,846 m^3	No.5WBTP	1,627 m^3
No.1COTP	17,846 m^3	Slop P	3,090 m^3
No.1WBTS	8,010 m^3	Slop S	3,090 m^3
No.1WBTP	8,010 m^3	Fuel P	1,717 m^3
No.2COTS	21,176 m^3	Fuel S	1,717 m^3
No.2COTP	21,176 m^3	Waste Oil	75.5 m^3
No.2WBTS	8,368 m^3	Lube Oil	23.5 m^3
No.2WBTP	8,368 m^3	Gen. Fuel	122.5 m^3
No.3COTS	21,176 m^3	Water S	117.6 m^3
No.3COTP	21,176 m^3	Water P	117.6 m^3
No.3WBTS	8,368 m^3	Sewage	96 m^3
No.3WBTP	8,368 m^3	Aft Peak	6,639 m^3
No.4COTS	21,106 m^3		
No.4COTP	21,106 m^3		
No.4WBTS	7,939 m^3		
No.4WBTP	7,939 m^3		

The cargo block starts at the collision bulkhead and extends aft 180.9 m. By subtracting the slop tank length and dividing by four, the cargo block is divided into cargo sections. The cargo block is then divided down the center and the double side and double bottom width of 4 m is subtracted giving the volume of each tank. The slop tanks are added to the design to complete the cargo block. For environmental concerns, the fuel, waste oil, lube oil, and generator fuel tanks are all placed behind the slop tanks with the full double side and bottom width of 4 m. This allows the tanks to be protected from grounding and collision. This configuration also allows a convenient location near these tanks for piping, pumps, and filters. All of these tank auxiliaries can be placed on the second platform of the machinery space, close to the engine. Located behind these tanks is a 6 m pump room that extends vertically up to platform 2 (Figure 4.7.3.1.1).

Due to the fine shape of the aft end of the tanker, the placement of the engine allows extra tank space behind the machinery space. The extra tank size of 30 meters allows for placement of the aft peak tank and the steering gear. A double bottom of height 2.315 m is added to the engine room to allow for grounding protection and a location to mount the engine. The double bottom height is based on the necessary height of the engine foundation to align the shaft with the hull.

The aftpeak tank, potable water, sewage and the steering gear are placed behind the aft engine room bulkhead. Potable water and sewage are placed adjacent to the bulkhead and deck to allow for convenient access to the deckhouse. These are separated by 1.5 m on either side of the sewage tank. This allows access to the steering gear room and separates the tanks. The steering gear is located behind these tanks with the aftpeak tank under the steering gear.

4.7.3.2 Deckhouse Space/Arrangements

The deckhouse space is mainly based on scaling measurements from the Millennium deck plans. The interior dimensions are then detailed for feasibility by comparing dimensions from the requirements of the MathCad model and using expert opinion. This method of comparison is utilized for every aspect of each deck, from the size of the staterooms to the size of the doors.

AutoCAD is used to produce detail interior arrangements of the deckhouse. Each deck has exterior limits of the space from the external measurements described in Section 4.7.2. Each deck is uniquely arranged due to the role it serves for the crew. However, a number of aspects are constant. Elevator and stairs are centrally located in the deckhouse. The elevator services Decks A to D and the stairs connect Decks A-E. There are two exterior doors (port and starboard) on Decks A-D that are joined by a central walkway 1.25 m wide. The living quarters (Decks C-E) have walkways encircling all of the staterooms. In the following figures, all of the walkways are colored by a gray (grid) color. Throughout the deckhouse, various doors allow passage to all the rooms. These doors are all one meter wide. The portholes are located in the external drawings of the deckhouse (Section 4.7.2). Portholes are green and are placed in every stateroom and other various living areas. Additional details include stiffeners (blue) in the walls for deck support. Figures 4.7.3.2.1 through 4.7.3.2.6 are the interior plans for each deck created in AutoCAD.

Deck A is the lowest deck and serves as the machinery deck. This deck is the gateway to the lower machinery space located directly beneath it. The CO_2 room, lower inert gas room, and upper machinery space are on Deck A. The casing houses the inlet/exhaust area from the engine. Fan rooms are also located in section to house the air inlet/exhaust fan equipment. A small hospital is designed on the starboard side of the deck. The change rooms allow crew members to change clothes efficiently before and after work.

Deck B is primarily the mess deck. The galleys and mess rooms dominate this deck. The incinerator and garbage rooms are located next to the galley for efficient removal of waste. On the starboard side, the conference and training rooms allow for crew meetings. Portholes are abundantly placed in the mess room and conference room for crew member hospitality. The inert gas room extends from the Deck B and more importantly, the emergency generator room houses the emergency generator for the ship. More detail of this room is contained in Section 4.7.4.

Deck C contains 14 staterooms and a lounge. In each of the staterooms are one head and one porthole. The crew stateroom is 23.1 m^2 and the area of the head is 4 m^2. Figure 4.7.3.2.4 shows a typical crew berthing. The lounge is 64.71 m^2. For the most part, the heads are designed next to each other for producibility. Pipes for the heads are more easily routed if they are together.

Deck D contains seven staterooms and an exercise room. A training and laundry room also reside on this deck. An office is located on this deck for one of the crew members. As in Deck C, portholes are abundant for crew hospitality.

Deck E is dominated by the navigation deck and staterooms for the Master and Chief Engineer of the ship. The Master and Chief Engineer both have a stateroom and an the Master has a personal office. The navigation deck is 457.20 m^2 and the staterooms are 56.25 m^2. On the sides of the deck, a map room and a bridge wing are used by crew members for navigation. For increased outward visibility, most portholes are two meters in width and are in numerous locations on this deck.

Drawing D.600-03 shows all decks with the placement of various components. Table 4.7.3.2.1 shows the deck locations of equipment in the deckhouse. The numbers beside the equipment names correspond to the numbered equipment as shown in Drawing D.600-03 and Figures 4.7.3.2.1 through 4.7.3.2.6.

Table 4.7.3.2.1. Deck Equipment Locations

Deck Location	Equipment Name	Location Number
Deck B	Emergency Generator	12
Deck B	Emergency Switchboard	16
Deck B	Incinerator	55
Deck E	Bridge Control Console 1	17
Deck E	Bridge Control Console 2	18
Deck E	Bridge Control Console 3	19

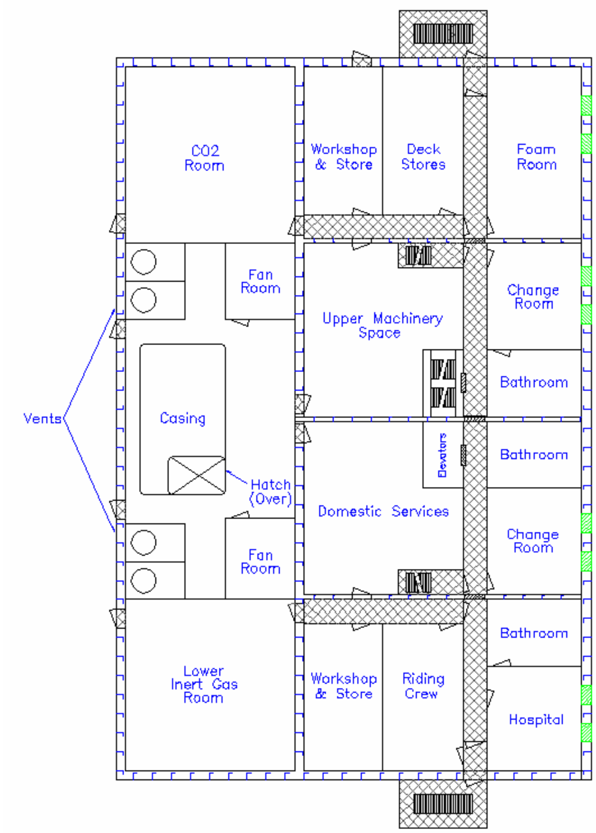


Figure 4.7.3.2.1 Deck A Interior Plan

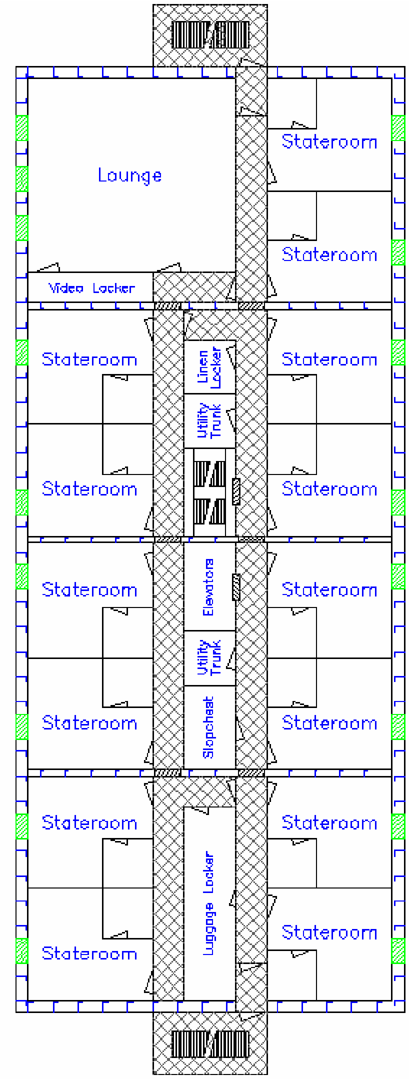
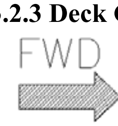


Figure 4.7.3.2.3 Deck C Interior Plan



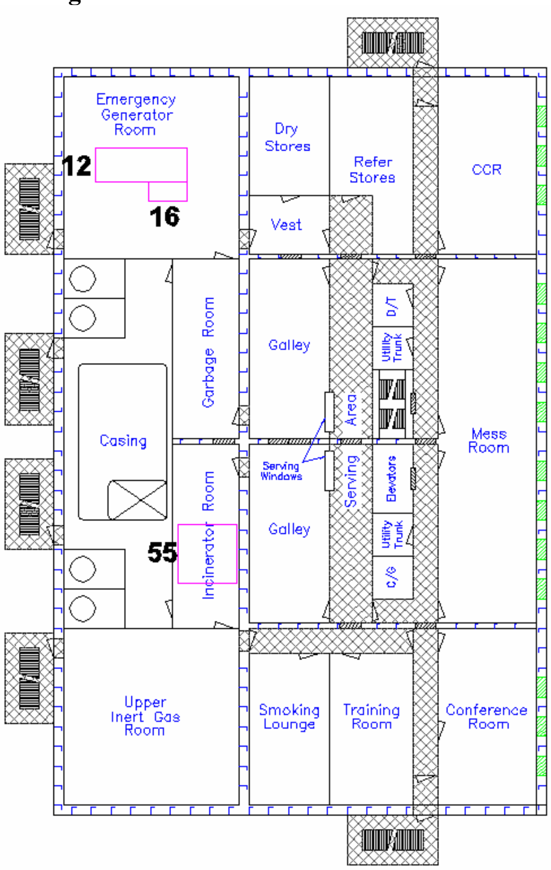


Figure 4.7.3.2.2 Deck B Interior Plan

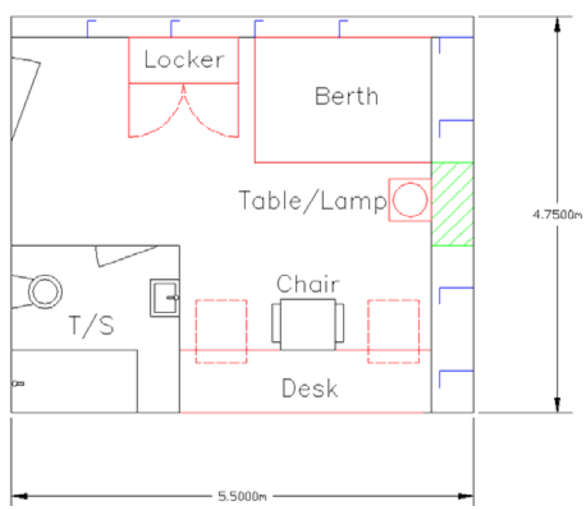


Figure 4.7.3.2.4 Typical Berth Plan

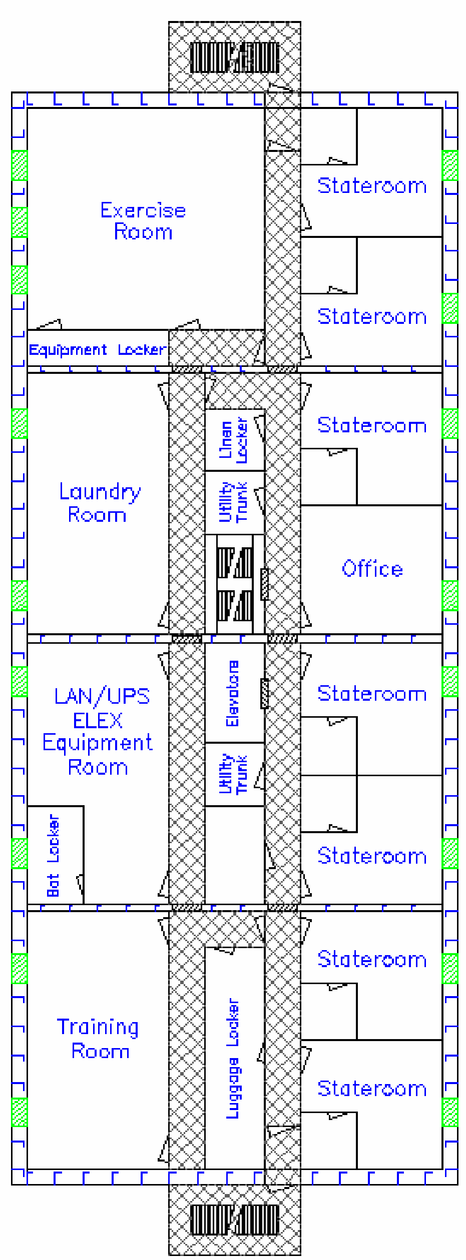


Figure 4.7.3.2.5 Deck D Interior Plan

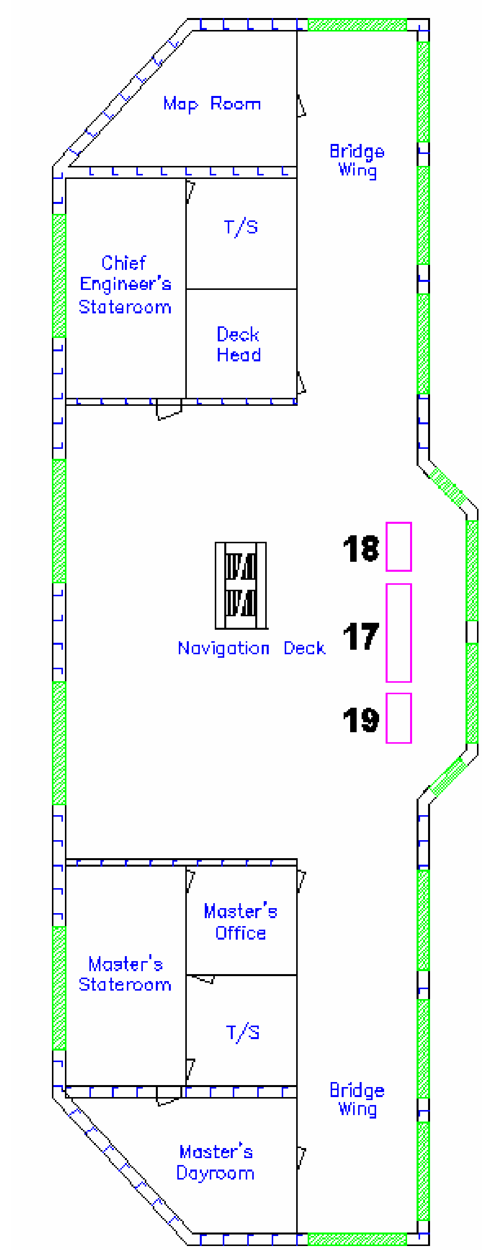


Figure 4.7.3.2.6 Deck E Interior Plan

4.7.4 Machinery

The machinery space begins 200.4 m from the FP and ends 230 m from the FP. Table 4.7.1.1 shows the actual measurements of the machinery space. These constraints are used to arrange the equipment of the machinery space. The machinery space is divided into four Flats: Flat 4 (red), Flat 3 (green), Flat 2 (cyan), and Flat 1 (blue). Figure 4.7.4.1 shows an isometric view of the machinery space flats.

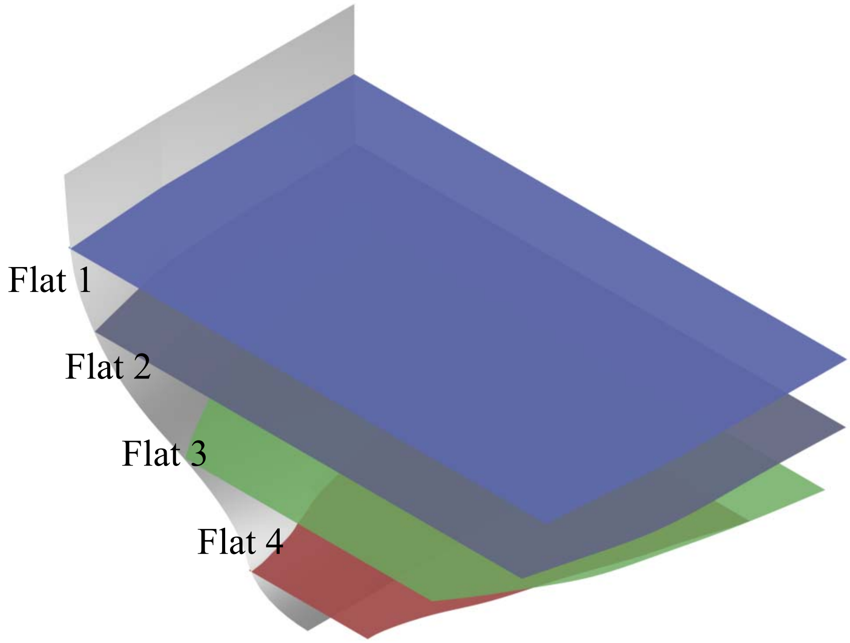


Figure 4.7.4.1 Rendered Isometric View of Machinery Space Flats

Table 4.7.4.1 is an equipment list of the machinery space and the deckhouse. This list includes the flat location, figure number, and dimensions of different components. The flat color in the location column of Table 4.7.4.1 corresponds to the colors of the flats described above. The figure numbers correspond to the equipment numbers of the plan drawings of each deck and flat from Drawing D.600-03.

There are a number of components that are not physically located in the machinery space. However, their function relates directly with equipment located in the machinery space. The bow thruster and steering gear are two such items. Other components are located directly above the machinery space in the deckhouse. Their specific locations for all components are detailed in Table 4.7.4.1.

The components, shown in the Table 4.7.4.1, are located on different flats and decks. The placements of the components are based on stability, functionality, producibility, survivability. Most equipment is arranged about the centerline, having one component situated on the port side of the ship and the second component on the starboard. Most components near bulkheads are located 0.8 m from the actual bulkhead for ease of maintenance. The main engine resides in the center of the machinery space on Flat 4. Therefore, other equipment such as pumps, boilers, distillers, etc. are located near the transverse bulkheads constraining the machinery space. Exact locations and weights of these components are located in Section 4.8. Stairs connect Flat 4 to Flat 1 on the port and starboard side of the engine. All of the flats and decks will be examined in detail to discuss placement of the components. Figures 4.7.4.2 through 4.7.4.8 show isometric views of the machinery space and the deckhouse plans above this space. Drawing D.600-03 shows plan views of each flat and the location of the equipment on the flat. Table 4.7.4.1 is also located on Drawing D.600-03 to identify the equipment with its corresponding number.

Table 4.7.4.1 Equipment Flat Location, Figure Number, and Dimensions

Location	Equipment	Figure No.	Dimensions (m) lxwxh
Flat 4	main engine	1	12.2x8.5x12.2
Flat 4	lube oil purifiers S	8	1.5x1x3
Flat 4	lube oil purifiers P	9	1.5x1x3
Flat 4	pto generator	10	3x1.5x1.5
Flat 4	fire pump 1	28	1x2x1
Flat 4	fire pump 2	29	1x2x1
Flat 4	distiller S	33	3x3x3
Flat 4	distiller P	34	3x3x3
Flat 4	potable water pump S	35	1x1x1
Flat 4	potable water pump P	36	1x1x1
Flat 4	central SW/FW heat exchanger	37	2x2x2
Flat 4	crude oil washing pump	42	1x1x1
Flat 4	cargo stripping pump	43	1.76x1.25x0.975
Flat 4,3	ballast pump S	31	4.87x1.69x1.00
Flat 4,3	ballast pump P	32	4.87x1.69x1.00
Flat 4,3	cargo pump S1	38	6.07x2.28x1.40
Flat 4,3	cargo pump P1	39	6.07x2.28x1.40
Flat 4,3	cargo pump S2	40	6.07x2.28x1.40
Flat 4,3	cargo pump P2	41	6.07x2.28x1.40
Flat 3	aux boiler S	24	3x3x3
Flat 3	aux boiler P	25	3x3x3
Flat 3	heat recovery boiler S	26	3x3x3
Flat 3	heat recovery boiler P	27	3x3x3
Flat 3	L/P air compressor S	46	2x2x2
Flat 3	L/P air compressor P	47	2x2x2
Flat 2	fuel oil purifiers S	4	1.5x1x1
Flat 2	fuel oil purifiers P	5	1.5x1x1
Flat 2	diesel oil purifiers S	6	1.5x1x2
Flat 2	diesel oil purifiers P	7	1.5x1x2
Flat 2	fuel oil heater S	44	1x1x1
Flat 2	fuel oil heater P	45	1x1x1
Flat 2	sewage treatment plant	54	2x2x2
Flat 1	propulsion control console	3	3x1x2
Flat 1	diesel generator(s)	11	4.67x1.7x2.06
Flat 1	pcu (s)	13	3x1x1
Flat 1	high voltage switchboard	14	3x1x2
Flat 1	low voltage switchboard	15	3x1x2
Flat 1	a/c unit 1	20	1x2x1
Flat 1	a/c unit 2	21	1x2x1
Flat 1	refer unit 1	22	1x2x1
Flat 1	refer unit 2	23	1x2x1
Flat 1	fire pump 3	30	1x2x1
Deck B	emergency generator	12	4.67x1.7x2.07
Deck B	emergency switchboard	16	2x1x2
Deck B	incinerator	55	3x3x3
Deck E	bridge control console 1	17	4x1x1
Deck E	bridge control console 2	18	2x1x1
Deck E	bridge control console 3	19	2x1x1
Aftpeak	steering gear	48	2x2x2
Forepeak	bow thruster	2	1x1x2

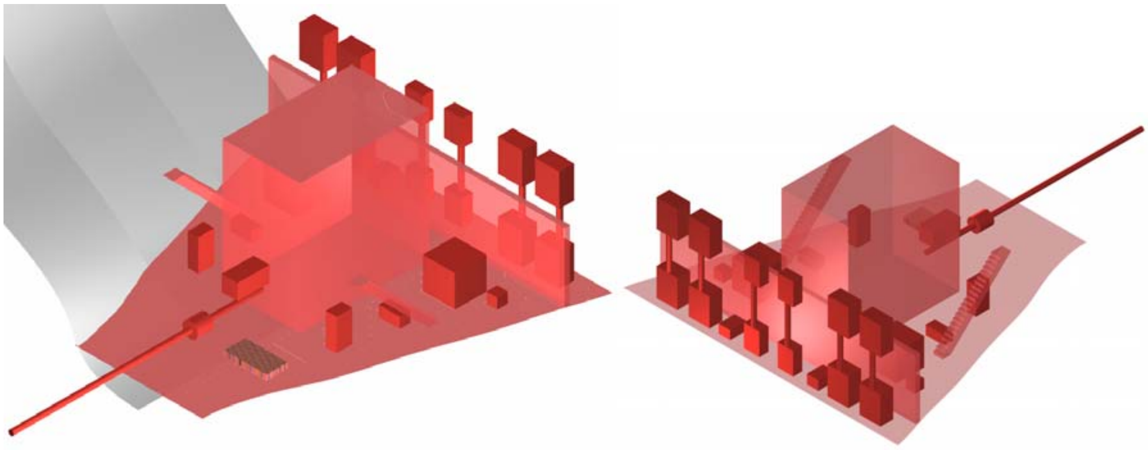


Figure 4.7.4.2 Isometric Views of Flat 4 of the Machinery Space

Flat 4 contains the engine and the pump room. The mounting of the engine is dependent on the shaft height for correct emergence from the hull. The engine resides in the middle of the flat and protrudes into Flat 3. The engine is surrounded by a 2 m maintenance space throughout the machinery space. Drawing D.600-03 shows this spacing for Flats 3 through 1.

The pump room is contained 3 m aft of the 200.4 m bulkhead. It contains the four cargo pumps, two ballast pumps, the COW pump and CSP. These pumps are located next to the 200.4 m transverse bulkhead for placement next to the cargo hold of the ship. This allows piping through the pump room rather than the machinery space. The pipes for the cargo and ballast pumps lead to their corresponding motors in Flat 3. These pipes are surrounded by a watertight seal for protection. Also, the location of these pumps in the pump room allow the isolation of cargo and piping away from all sources of ignition in Flat 4.

Various equipment are located away from pump room. The lube oil purifiers and sumps are located beside the main engine. The distillers and potable water pumps allow maximum suction efficiency from this flat. The SW/FW heat exchanger is located under a hatch in Flat 4. It works in tandem with these components to exchange seawater to freshwater to cool the main engine. Fire pumps 1 and 2 are also located in this flat. Drawing D.600-03 shows a plan view of this flat and the numbered location of the equipment as specified above and in Table 4.7.4.1.

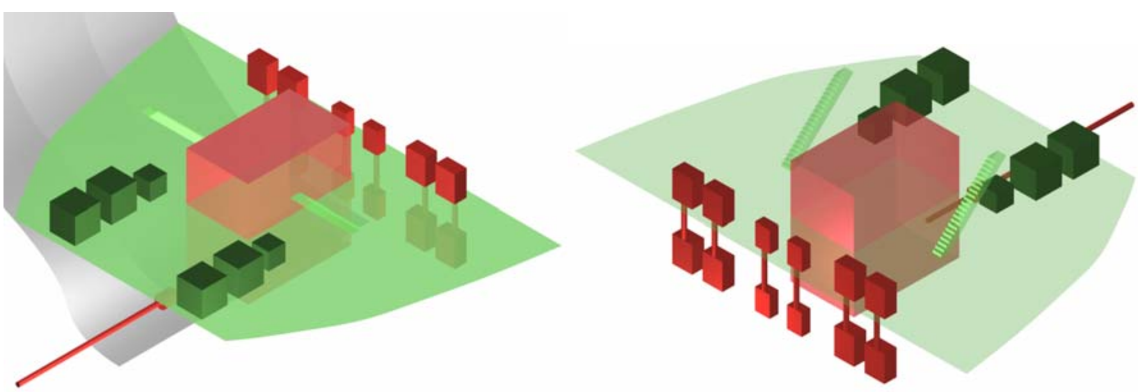


Figure 4.7.4.3 Isometric Views of Flat 3 of the Machinery Space

Flat 3 contains the auxiliary boiler, heat recovery boiler and air compressors. The boilers are located above the shaft to balance their weight with the pump motors located beside the 200.4 m transverse bulkhead. The boilers are near the water tanks, which are located aft of the 230.4 m transverse bulkhead. They are located in the exhaust uptakes of the engine. The additional heat recovery boiler is available for redundancy. The air compressors on this flat allow ease of use for engine starting and other diesel machinery needs. Drawing D.600-03 shows a plan view of this flat and the numbered location of the equipment as specified above and in Table 4.7.4.1.

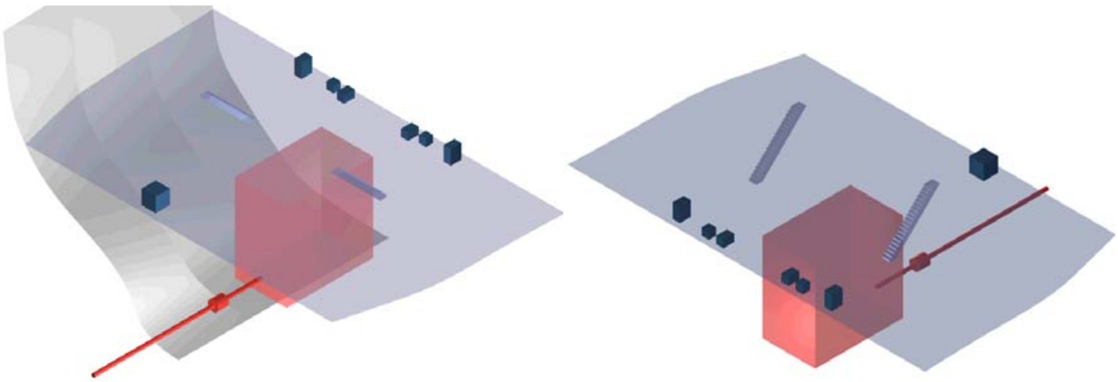


Figure 4.7.4.4 Isometric Views of Flat 2 of the Machinery Space

Flat 2 contains the fuel and diesel oil purifiers, and the fuel oil heaters beside the 200.4 m transverse bulkhead. These components are near the fuel and diesel tanks located opposite the 200.4 m bulkhead. Their placement allows minimum piping through the machinery space. The sewage treatment plant is located beside the 230 m transverse bulkhead. This allows for minimum piping to the sewage tanks beside the same bulkhead. Drawing D.600-03 shows a plan view of this flat and the numbered location of the equipment as specified above and in Table 4.7.4.1.

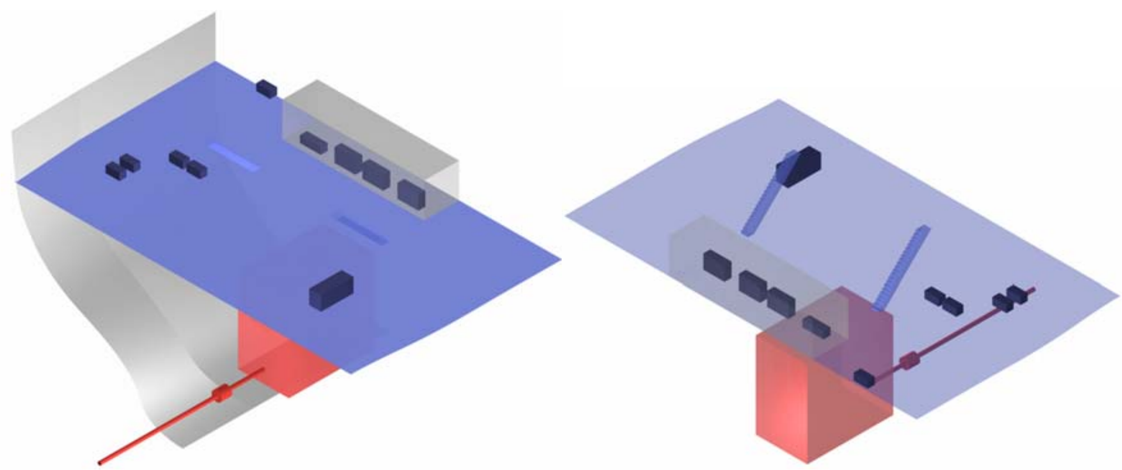


Figure 4.7.4.5 Isometric Views of Flat 1 of the Machinery Space

Flat 1 contains the diesel generator on the starboard side of the flat. The control room contains the LV and HV switchboards, the propulsion control console, and the power conversion unit (PCU). The location of the room allows viewing of the engine during operation of the consoles. The A/C units and refrigeration units are located in this level to provide cooling to the control room and the deckhouse. The refrigeration units circulate freon directly to the chill box and freezer and back. Another fire pump on Flat 1 is for fire fighting duties of the deckhouse and performs in case of failure to fire pumps on Flat 4. Drawing D.600-03 shows a plan view of this flat and the numbered location of the equipment as specified above and in Table 4.7.4.1.

Figures 4.7.4.7 and 4.7.4.8 show plan views of particular sections of Decks B and E. Each figure shows the placement of equipment as specified in Table 4.7.4.1.

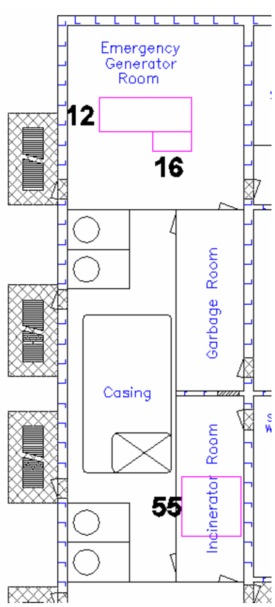


Figure 4.7.4.7 Plan View of Deck B (Emergency Generator and Incinerator Rooms)

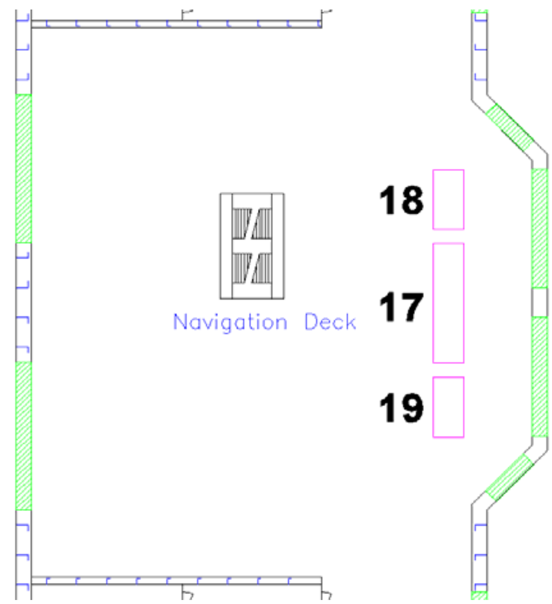


Figure 4.7.4.8 Plan View of Deck E

Deck B contains the emergency generator and the emergency switchboard. These are located in the emergency generator room of Deck B. The incinerator is located in the incinerator room of Deck B. Deck C and Deck D are not shown because they do not contain components from the equipment list of Table 4.7.4.1. Figure 4.7.4.8 is a plan view of Deck E showing three bridge control consoles in the Navigation Deck.

Table 4.7.4.2 shows the vertical locations of these four Flats and the deck heights of the deckhouse. The baseline of these locations is from the full load waterline.

Table 4.7.4.2 Flat/Deck Vertical Locations

Flat/Deck	Vertical Location (from WL)
Deck E	29.7 m
Deck D	25.7 m
Deck C	21.7 m
Deck B	17.7 m
Deck A	13.7 m
Flat 1	5.57 m
Flat 2	-0.43 m
Flat 3	-6.93 m
Flat 4	-13.5 m

Figure 4.7.4.9 shows an elevation view of the machinery space with all four Flats and with the plan layouts of the deck above the machinery space. Figure 4.7.4.10 is a section view of the machinery space and decks. These figures illustrate the vertical locations of the Flats and decks and the equipment therein.

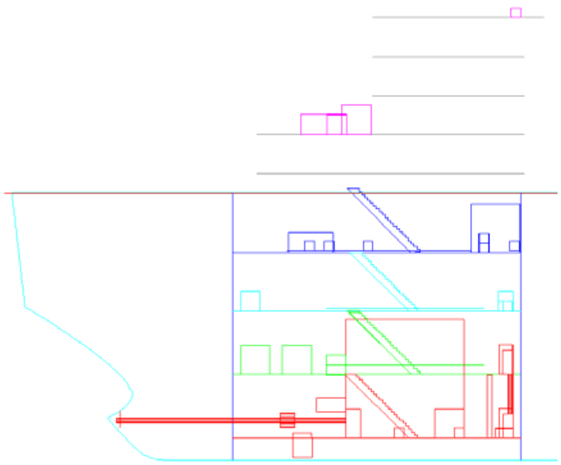


Figure 4.7.4.9 Elevation View of the Machinery Space Flats and Decks

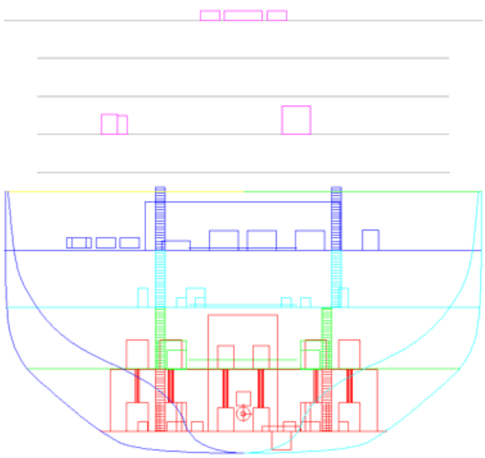


Figure 4.7.4.10 Section View of the Machinery Space Flats and Deck

Figure 4.7.4.11 shows a rendered isometric view of the machinery space as produced in AutoCAD. The layout of the entire machinery space is shown with their corresponding rooms. The equipment in the deckhouse is included in these figures.

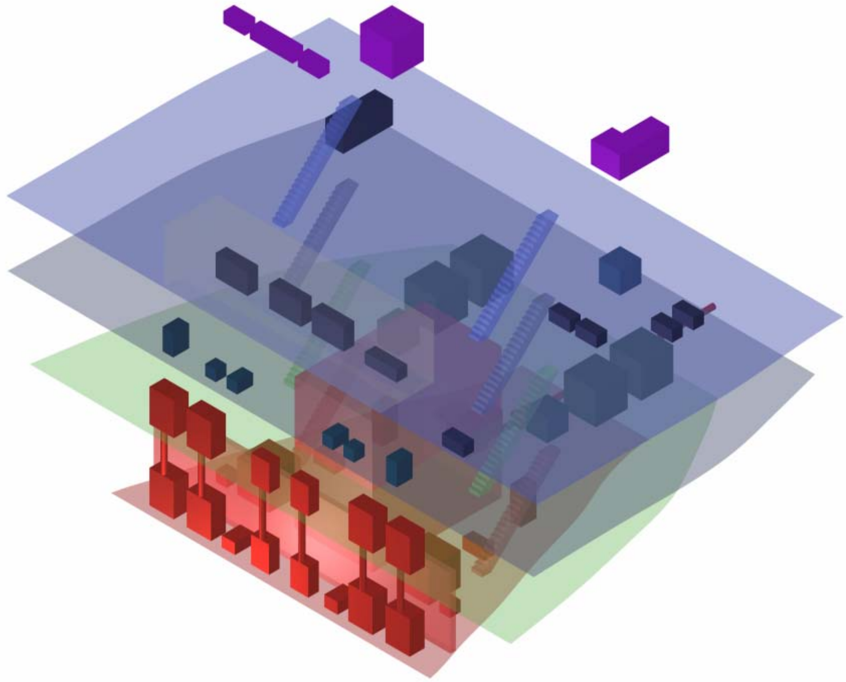


Figure 4.7.4.11 Rendered SW Isometric View of the Machinery Space Flats and Decks

The entire machinery space is controlled by a control system. A preliminary electrical schematic of the control system including the engine, pumps, and steering gear is shown is Figure 4.4.2.2. Also included in the figure are the switchboards shown in Table 4.7.4.1. The electrical schematic shows the interaction of the various components and the electrical loads that will be placed on the generators.

4.8 Weights and Loading

4.8.1 Weights

The weights and centers of gravity for the equipment on the vessel are tabulated and summed in an Excel spreadsheet found in Appendix A.6. This information remains constant and represents the Lightship weight. The sources of data for the weights and centers of this equipment include manufacturer catalogs, program outputs, and expert opinion.

Throughout the vessel, equipment locations are represented by rectangular areas. To find the centers of gravity for these areas (VCG, LCG, and TCG), measurements are taken from the various baselines on the ship to the centers of the rectangular areas. Thes

4.9 Hydrostatics and Stability

4.9.1 General

In order to explore the hydrostatics, intact stability, and damage stability, the tanker is imported into HecSalv. HecSalv allows the user to create the various compartments and tanks described in Section 4.7. The hydrostatics and bonjean curves are calculated using a range of drafts from 1- 27.5 m. From this information, the curves of form, coefficients of form, cross curves, and bonjean curves are calculated and shown in Drawings D.2. With these hydrostatic calculations, HecSalv is able to examine the intact stability in any loading condition. The five conditions examined are the following: Lightship, Ballast Arrival, TAPS Full Load (125K DWT), Full Load (140K DWT) and Summer Load Line Draft (21.4 m). The tanks are filled in HecSalv to reach the correct trim, draft and dead weight tonnage. With the intact conditions created and balanced, damage stability is explored for all the conditions except lightship. Damage is based on the Code of Federal Regulations, Annex I - Regulations for the Prevention of Pollution by Oil (Regulation 25, Section 2, Subdivision and Stability), which is described in detail in Section 4.9.3.

4.9.2 Intact Stability and Loading

In each condition, trim, stability, righting arm information, and strength summaries are calculated. All conditions are compared to the satisfactory intact stability for an oil tanker greater then 5,000 DWT from MARPOL 73/78 Annex 1, Regulation 25A. For satisfactory intact stability, many conditions must be met. In port, GM corrected must be greater than 0.15 m without the use of operational methods in all loading conditions. At sea, the GZ curve area must be greater than 0.055 m-rad up to 30 deg; 0.09 m-rad up to 40 deg and 0.03 m-rad between 30 and 40 deg. The GZ must be at least 0.2 m at an angle greater then 30 deg, max GZ at angle greater then 25 deg, and GM corrected greater then 0.15 m for all loading conditions.

Lightship is the weight of the unloaded ship, which is 27,983 MT for this vessel. Tables 4.9.2.1-2 are the Stability and Trim Summary, and the Strength Summary, respectively. Figure 4.2.2.1.7 shows the lightship weight distribution curve. The stability of the Lightship condition is critical to the performance of the vessel. The bending moments for the structure calculations are also obtained through the analysis of this condition. Figure 4.9.2.1 shows the righting arm summary plot for lightship

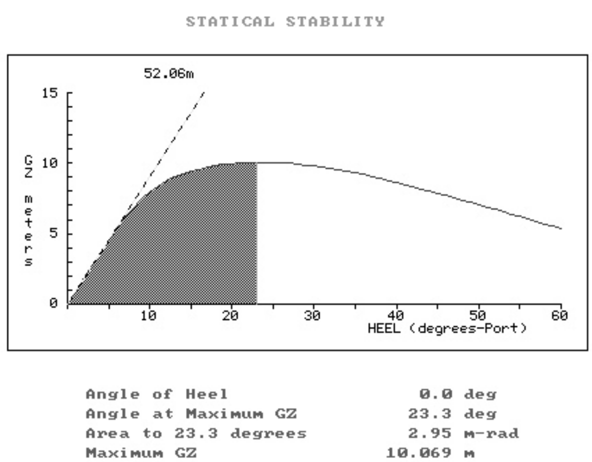


Figure 4.9.2.1 Lightship (GZ) Righting Arm Curve Summary

Table 4.9.2.1 Lightship Trim and Stability Summary

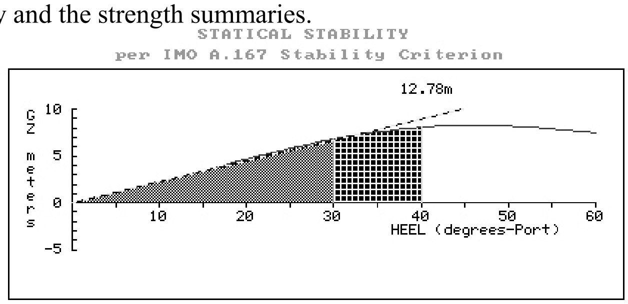
Vessel Displacement and Centers of Gravity					
Item	Weight MT	VCG – m	LCG - m-FP	TCG - m	FSmom m-MT
Light Ship	27,983	13.46	131.640A	0	
Constant	0	0	125.500A	0	0
Misc. Weight	0	0	125.500A	0	0
Cargo Oil	0	0	125.500A	0	0
Fuel Oil	0	0	125.500A	0	0
Lube Oil	0	0	125.500A	0	0
Fresh Water	0	0	125.500A	0	0
SW Ballast	0	0	125.500A	0	0
TOTALS	27,983	13.46	131.640A	0	0
Stability Calculation		**Trim Calculation**			
KMt	65.523	LCF Draft	2.984	M	
VCG	13.46	LCB (even keel)	111.43	m-AFT	
GMt	52.063	LCF	112.52	m-AFT	
F.S. Correction	0	MT1cm	1,419	m-MT/cm	
GMt Corrected	52.063	Trim	3.987	m-AFT	
		Prop. Immersion	109	%	
		List	0	Deg	
Drafts					
A.P.	5.184 m	(17ft- 0.08in)	Aft Marks	5.184 m	(17ft- 0.08in)
M.S.	3.19 m	(10ft- 5.60in)	M.S.Marks	3.182 m	(10ft- 5.29in)
F.P.	1.197 m	(3ft-11.12in)	Fwd Marks	1.197 m	(3ft-11.12in)
Strength Calculation					
Shear Force at 8	4,287 MT				
Bending Moment at 6	258,977 m-MT [HOG]				

Table 4.9.2.2 Lightship Shear Force and Bending Moment Summary

Shear Force & Bending Moment Summary							
	Shear Forces				Bending Moments		
	Location	Buoyancy	Weight	Shear	Buoy. Mom.	Wt.Mom.	Moment
No.	m-FP	MT	MT	MT	m-MT	m-MT	m-MT
10	251.000A	1	262	261	1	739	738H
9	225.900A	658	3,119	2,462	4,071	39,314	35,243H
8	200.800A	3,079	7,365	4,287	47,778	171,087	123,309H
7	175.700A	6,914	9,743	2,828	168,562	385,470	216,908H
6	150.600A	11,542	12,228	686	402,039	661,016	258,977H
MID	125.500A	15,749	14,786	-963	745,636	999,921	254,285H
4	100.400A	19,452	17,400	-2,053	1,188,568	1,403,763	215,195H
3	75.300A	22,645	20,068	-2,577	1,717,965	1,873,833	155,868H
2	50.200A	25,346	22,790	-2,556	2,320,836	2,411,686	90,851H
1	25.100A	27,368	25,410	-1,957	2,985,210	3,017,101	31,891H
0	0	27,982	27,697	-285	3,683,618	3,684,552	934H
Maximum Shear Force at 8: 4,287 MT							
Maximum Bending Moment at 6: 258,977 m-MT [HOG]							

Ballast Arrival is the condition where the ship is arriving to port in a ballast condition. It consists of 0% cargo, 10% fuel, 50% fresh water and ballast as required for 100% prop immersion and zero trim. The ship is ballasted and trimmed to the draft line stated in the MathCad Model (10.4m) by filling the ballast tanks. This allows the tanker to be more stable in severe weather and gives a propeller immersion of 167%. The propeller immersion is at this level to allow for a better flow field into the propeller, making the ship more efficient. The GZ meets the

MARPOL regulations. The maximum shear and bending moment are 7,357 MT at station 9 and 374,225 m-MT in hog at amidships. Figure 4.9.2.2 shows the righting arm summary for the ballast condition. Tables 4.9.2.3-4 show the stability and trim summary and the strength summaries.



	Available	Required
Area to 30.0 degrees	1.80 m-rad	0.06 m-rad
Area to 40.0 degrees	3.12 m-rad	0.09 m-rad
Area 30.0-40.0 degrees	1.31 m-rad	0.03 m-rad
Angle at Maximum GZ	45.9 deg	25.0 deg
Maximum GZ	8.303 m	0.200 m
Initial GM	12.781 m	0.150 m

Figure 4.9.2.2 (GZ) Righting Arm Curve for Ballast Arrival Condition

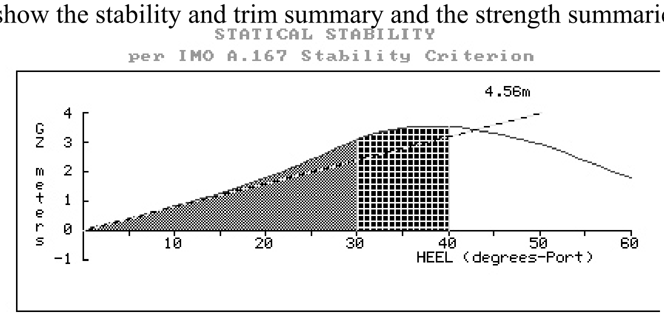
Table 4.9.2.3 Ballast Arrival Trim and Stability Summary

Item		Weight MT	VCG m	LCG m-FP	TCG M	FSmom m-MT
Light Ship		27,983	13.46	131.640A	0	
Constant		0	0	125.500A	0	0
Misc. Weight		0	0	125.500A	0	0
Cargo Oil		0	0	125.500A	0	0
Fuel Oil		300	16.264	195.395A	0	4,689
Lube Oil		93	9.374	195.400A	0	6
Fresh Water		214	24.013	230.499A	0	997
SW Ballast		79,672	9.989	106.916A	0	107,088
TOTALS		108,260	10.931	113.871A	0	112,779
Stability Calculation			**Trim Calculation**			
KMt		24.753 m	LCF Draft			10.467 m
VCG		10.931 m	LCB (even keel)			114.85 m-AFT
GMt		13.823 m	LCF			120.687 m-AFT
F.S. Correction		1.042 m	MT1cm			1,841m-MT/cm
GMt Corrected		12.781 m	Trim			0.575 m-AFT
			Prop. Immersion			167%
			List			0 deg
Drafts						
A.P.	10.169 m	(33ft-4.35in)	Aft Marks	10.169 m	(33ft-4.35in)	
M.S.	10.456 m	(34ft-3.66in)	M.S.Marks	10.457 m	(34ft-3.71in)	
F.P.	10.744 m	(35ft-2.98in)	Fwd Marks	10.744 m	(35ft-2.98in)	
Strength Calculations						
Shear Force at 9						7,357 MT
Bending Moment at MID						374,225 m-MT [HOG]

Table 4.9.2.4 Ballast Arrival Shear Force and Bending Moment Summary

Shear Force & Bending Moment Summary							
		Shear Forces			Bending Moments		
	Location	Buoyancy	Weight	Shear	Buoy.Mom.	Wt.Mom.	Moment
No.	m-FP	Mt	Mt	Mt	m-Mt	m-MT	m-MT
10	251.000A	5	262	257	0	739	738H
9	225.900A	2,112	9,468	7,357	13,426	108,128	94,701H
8	200.800A	9,742	13,714	3,972	152,126	399,264	247,138H
7	175.700A	20,900	23,382	2,482	529,263	853,369	324,106H
6	150.600A	34,033	34,985	952	1,219,733	1,583,575	363,842H
MID	125.500A	47,335	47,167	-168	2,240,812	2,615,037	374,225H
4	100.400A	60,719	59,327	-1,392	3,596,840	3,951,444	354,604H
3	75.300A	74,174	71,543	-2,631	5,289,800	5,593,718	303,918H
2	50.200A	87,759	83,814	-3,945	7,320,066	7,543,410	223,343H
1	25.100A	100,757	95,142	-5,615	9,691,100	9,792,895	101,795H
0	0	107,950	107,497	-453	12,328,597	12,329,355	758H
Maximum Shear Force at 9:			7,357 MT				
Maximum Bending Moment at MID:			374,225 m-MTons [HOG]				

The 125K DWT condition is specific to the TAPS trade because 125K DWT is the maximum limit for tankers allowed to enter Valdez. In this condition, all of the tanks, except the ballast tanks, are loaded to 125K DWT. Cargo tanks 1 and 4 are loaded to 98%, cargo tanks 2 are loaded to 50%, and cargo tanks 3 are loaded to 79%. This gives a total cargo load of 120,082 DWT. The aft peak tank is loaded to 35% to trim out the ship. All other tanks are filled to 98% (Table 4.9.2.5). In this condition, the tanker sits at a draft of 14.5 m, which gives 217% propeller immersion. The GZ criteria are met (Figure 4.9.2.3). The maximum shear and bending moment are 6,152 MT at station 8 and 142,071 m-MT in sag at station 6 (Table 4.9.2.6).Figure 4.9.2.3 shows the righting arm summary. Tables 4.9.2.5-6 show the stability and trim summary and the strength summaries.



	Available	Required
Area to 30.0 degrees	0.71 m-rad	0.06 m-rad
Area to 40.0 degrees	1.31 m-rad	0.09 m-rad
Area 30.0-40.0 degrees	0.60 m-rad	0.03 m-rad
Angle at Maximum GZ	38.2 deg	25.0 deg
Maximum GZ	3.545 m	0.200 m
Initial GM	4.563 m	0.150 m

Figure 4.9.2.3 125K DWT (GZ) Righting Arm Curve Summary

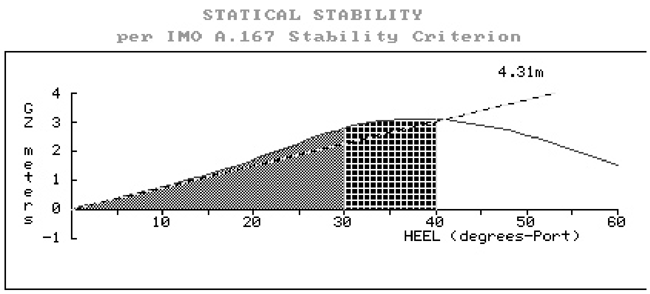
Table 4.9.2.5 125K DWT Trim and Stability Summary

Vessel Displacement and Center's of Gravity					
Item	**Weight MT**	**VCG M**	**LCG m-FP**	**TCG M**	**Fsmom m-MT**
Light Ship	27,983	13.46	131.640A	0	
Constant	0	0	125.500A	0	0
Misc. Weight	0	0	125.500A	0	0
Cargo Oil	120,082	15.835	108.290A	0	209,202
Fuel Oil	2,935	16.264	195.395A	0	0
Lube Oil	205	15.567	195.400A	0	6
Fresh Water	331	24.017	230.499A	0	107
SW Ballast	3,266	14.318	236.956A	0	81,713
TOTALS	154,802	15.399	117.254A	0	291,028
Stability Calculation		**Trim Calculation**			
KMt	21.842 m	LCF Draft	14.535 m		
VCG	15.399 m	LCB (even keel)	117.27 m-AFT		
GMt	6.443 m	LCF	124.943 m-AFT		
F.S. Correction	1.88 m	MT1cm	2,040 m-MT/cm		
GMt Corrected	4.563 m	Trim	0.012 m-AFT		
		Prop. Immersion	217 %		
		List	0 deg		
Drafts					
A.P.	14.528 m	(47ft- 7.98in)	Aft Marks	14.528 m	(47ft- 7.98in)
M.S.	14.534 m	(47ft- 8.22in)	M.S.Marks	14.535 m	(47ft- 8.22in)
F.P.	14.541 m	(47ft- 8.47in)	Fwd Marks	14.541 m	(47ft- 8.47in)
Strength Calculations					
Shear Force at 8	6,152 MT				
Bending Moment at 6	142,071 m-Mt [SAG]				

Table 4.9.2.6 125K DWT Shear Force and Bending Moment Summary

Shear Force and Bending Moment Summary							
		Shear Forces			Bending Moments		
	Location	Buoyancy	Weight	Shear	Buoy.Mom.	Wt.Mom.	Moment
No.	m-FP	MT	MT	MT	m-MT	m-MT	m-MT
10	251.000A	3	262	259	75	739	814H
9	225.900A	4,428	6,716	2,288	31,232	76,945	45,713H
8	200.800A	17,115	10,962	-6,152	288,828	299,010	10,183H
7	175.700A	33,673	30,868	-2,805	920,007	792,243	127,764S
6	150.600A	52,163	53,943	1,780	1,998,349	1,856,278	142,071S
MID	125.500A	70,750	74,423	3,673	3,540,978	3,478,028	62,949S
4	100.400A	89,350	93,685	4,335	5,550,317	5,587,697	37,381H
3	75.300A	107,944	107,378	-566	8,026,675	8,116,518	89,842H
2	50.200A	126,615	122,580	-4,035	10,967,998	10,982,026	14,028H
1	25.100A	144,482	144,626	145	14,375,703	14,347,888	27,815S
0	0	154,489	154,516	28	18,152,152	18,152,114	39S
Maximum Shear Force at 8:	-6,152 MT						
Maximum Bending Moment at 6:	142,071 m-MT [SAG]						

The 140K DWT loading condition is considered the maximum full load condition, and is the designed load line scenario. The draft is given from the MathCad model as 15.8 m. The tanks are loaded in the following manner: Cargo tanks 1 are loaded to 72%, Cargo tanks 2, 3, 4 and all other tanks are loaded to 98% with the ballast tanks used to trim out the ship. In this condition the aft peak tank is filled 58.2 %. The actual draft is 16 m due the additional ballasting necessary to trim the ship (Table 4.9.2.7). The problem of additional ballasting is addressed in Section 5.2.7. The GZ criteria meet MARPOL regulations (Figure 4.9.2.4). The maximum shear and bending moment are 7,591 MT at station 8 and 384,074 m-MT in sag at amidships. Table 4.9.2.8 shows the strength summary.



	Available	Required
Area to 30.0 degrees	0.67 m-rad	0.06 m-rad
Area to 40.0 degrees	1.20 m-rad	0.09 m-rad
Area 30.0-40.0 degrees	0.53 m-rad	0.03 m-rad
Angle at Maximum GZ	38.3 deg	25.0 deg
Maximum GZ	3.124 m	0.200 m
Initial GM	4.314 m	0.150 m

Figure 4.9.2.4 140K DWT (GZ) Righting Arm Curve Summary

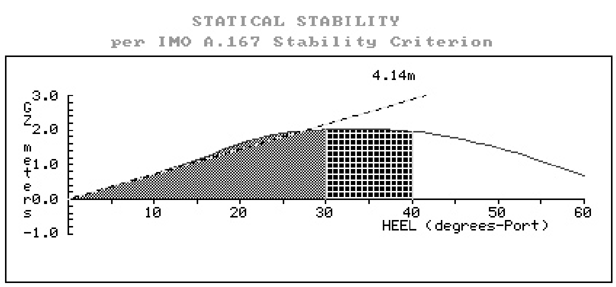
Table 4.9.2.7 140K DWT Trim and Stability Summary

Vessel Displacement and Centers of Gravity					
Item	**Weight Mt**	**VCG M**	**LCG m-FP**	**TCG m**	**Fsmom m-MT**
Light Ship	27,983	13.46	131.640A	0	
Constant	0	0	125.500A	0	0
Misc. Weight	0	0	125.500A	0	0
Cargo Oil	136,814	15.826	109.103A	0	193,477
Fuel Oil	2,935	16.264	195.395A	0	0
Lube Oil	205	15.567	195.400A	0	6
Fresh Water	331	24.017	230.499A	0	107
SW Ballast	5,103	14.318	236.956A	0	81,713
TOTALS	173,372	15.422	118.299A	0	275,302
Stability Calculation		**Trim Calculation**			
KMt	21.324 m	LCF Draft			16.119 m
VCG	15.422 m	LCB (even keel)			118.16 m-AFT
GMt	5.902 m	LCF			126.123 m-AFT
F.S. Correction	1.588 m	MT1cm			2,102 m-MT/cm
GMt Corrected	4.314 m	Trim			0.115 m-AFT
		Prop. Immersion			236 %
		List			0 deg
Drafts					
A.P.	16.176 m	(53ft- 0.87in)	Aft Marks	16.176 m	(53ft- 0.87in)
M.S.	16.119 m	(52ft-10.60in)	M.S.Marks	16.119 m	(52ft-10.59in)
F.P.	16.061 m	(52ft- 8.33in)	Fwd Marks	16.061 m	(52ft- 8.33in)
Strength Calculation					
Shear Force at 8		7,591 MT			
Bending Moment at MID		384,074 m-Mt [SAG]			

Table 4.9.2.8 140K DWT Shear Force and Bending Moment Summary

Shear Force and Bending Moment Summary							
			Shear Force			Bending Moment	
	Location	Buoyancy	Weight	Shear	Buoy.Mom.	Wt.Mom.	Moment
No.	m-FP	Mt	Mt	Mt	m-Mt	m-Mt	m-MT
10	251.000A	-15	262	277	79	739	818H
9	225.900A	5,682	8,553	2,872	43,209	97,256	54,046H
8	200.800A	20,391	12,800	-7,591	357,048	365,432	8,385H
7	175.700A	39,031	32,705	-6,325	1,096,942	904,777	192,165S
6	150.600A	59,582	55,780	-3,802	2,335,626	2,014,924	320,702S
MID	125.500A	80,215	78,988	-1,227	4,090,183	3,706,108	384,074S
4	100.400A	100,846	102,255	1,409	6,362,602	5,980,614	381,988S
3	75.300A	121,453	125,576	4,123	9,152,859	8,839,738	313,121S
2	50.200A	142,130	148,321	6,191	12,458,249	12,283,812	174,437S
1	25.100A	161,931	165,213	3,282	16,279,670	16,227,924	51,746S
0	0	173,059	173,086	27	20,510,600	20,510,558	42S
Shear Force at 8		7,591 MT					
Bending Moment at MID		384,074 m-Mt [SAG]					

The last condition looked at is the Summer Load Line draft, which is given by the MathCad model as 21.4 m. This has to be lowered slightly to 19 m meters because of problems in damage stability. The problem will be discussed further in Section 4.9.3. The condition has similar cargo loading as the 140K DWT. It is achieved in HecSalv by increasing the density of the cargo to 0.990 MT/m3. Cargo tanks 1 are loaded to 84.5%, ballast tanks 4, 5 and the aft peak tank are filled to 98% to trim. The final draft of this loading condition comes out to 19 m. The GZ meets the MARPOL regulations (Figure 4.9.2.5). The maximum shear and bending moment are 11,890 MT at station 8 and 462,617 m-MT at amidships. Tables 4.9.2.9-10 show the stability and trim summary and the strength summaries.



	Available	Required
Area to 30.0 degrees	0.59 m-rad	0.06 m-rad
Area to 40.0 degrees	0.94 m-rad	0.09 m-rad
Area 30.0-40.0 degrees	0.35 m-rad	0.03 m-rad
Angle at Maximum GZ	33.6 deg	25.0 deg
Maximum GZ	2.040 m	0.200 m
Initial GM	4.139 m	0.150 m

Figure 4.9.2.5 Summer Load Line Draft (GZ) Righting Arm Curve Summary

Table 4.9.2.9 Summer Load Line Draft Trim and Stability Summary

Vessel Displacement and Center's of Gravity					
Item	**Weight Mtons**	**VCG m**	**LCG m-FP**	**TCG m**	**FSmom m-MTons**
Light Ship	27,983	13.46	131.640A	0	
Constant	0	0	125.500A	0	0
Misc. Weight	0	0	125.500A	0	0
Cargo Oil	160,614	15.827	107.048A	0	220,823
Fuel Oil	2,935	16.264	195.395A	0	0
Lube Oil	205	15.567	195.400A	0	6
Fresh Water	331	24.017	230.499A	0	107
SW Ballast	16,365	11.484	199.187A	0	125,466
TOTALS	208,434	15.187	119.111A	0	346,402
Stability Calculation		**Trim Calculation**			
KMt	20.987 m	LCF Draft			19.068 m
VCG	15.187 m	LCB (even keel)			119.58 m-AFT
GMt	5.8 m	LCF			126.88 m-AFT
F.S. Correction	1.662 m	MT1cm			2,209 m-MT/cm
GMt Corrected	4.139 m	Trim			0.443 m-AFT
		Prop. Immersion			266 %
		List			0 deg
Drafts					
A.P.	18.849 m	(61ft-10.08in)	Aft Marks	18.849 m	(61ft-10.08in)
M.S.	19.07 m	(62ft- 6.80in)	M.S.Marks	19.071 m	(62ft- 6.83in)
F.P.	19.292 m	(63ft- 3.52in)	Fwd Marks	19.292 m	(63ft- 3.52in)
Strength Calculations					
Shear Force at 8	-11,890 MT				
Bending Moment at MID	462,617 m-MT [SAG]				

Table 4.9.2.10 Summer Load Line Draft Shear Force and Bending Moment Summary

Shear Force and Bending Moment Summary							
		Shear Forces			Bending Moments		
	Location	Buoyancy	Weight	Shear	Buoy. Mom.	Wt. Mom.	Moment
No.	m-FP	MT	MT	MT	m-MT	m-MT	m-MT
10	251.000A	-67	262	329	138	739	877H
9	225.900A	8,062	10,118	2,057	67,471	114,557	47,086H
8	200.800A	26,254	14,365	-11,890	483,918	422,014	61,904S
7	175.700A	48,519	41,006	-7,513	1,416,713	1,079,108	337,605S
6	150.600A	72,759	70,713	-2,046	2,939,660	2,479,958	459,702S
MID	125.500A	97,155	98,113	958	5,072,037	4,609,419	462,617S
4	100.400A	121,619	124,298	2,679	7,817,574	7,400,588	416,986S
3	75.300A	146,129	150,539	4,410	11,178,167	10,849,648	328,519S
2	50.200A	170,795	176,641	5,847	15,152,421	14,957,816	194,605S
1	25.100A	194,555	198,379	3,824	19,742,714	19,676,552	66,163S
0	0	208,115	208,148	34	24,827,702	24,827,668	33S
Shear Force at 8		-11,890 MT					
Bending Moment at MID		462,617 m-MT [SAG]					

All five conditions display excellent intact stability and meet the MARPOL regulations put forth for an oil tanker of greater than 5,000 DWT from MARPOL 73/78 Annex 1, Regulation 25A. These same loading conditions are used to verify that damage stability meets the Code of Federal Regulations.

4.9.3 Damage Stability

The four intact loading conditions are examined for damage stability. Each of these conditions are damaged at critical points along the hull following the Code of Federal Regulations –Annex I - Regulations for the Prevention of Pollution by Oil (Regulation 25, Section 2– Subdivision and Stability). The regulations are stated in Table 4.9.3.1. Essentially, the damage is considered to be a rectangular hole. To examine the maximum damage (filling the maximum tank volume), the opening is placed at bulkheads along the side of the hull. This results in a total of seven major damage cases (Figures 4.9.3.8-14 at the end of Section 4.9.3). Testing each loading case gives a total of 28 damage cases. Each of these cases is compared to the IMO Tanker Criteria (MARPOL Rules) for stability. Damage case summaries for each case are shown in Appendix A.7.

Table 4.9.3.1 CFR Annex I Regulations for the Prevention of Pollution by Oil

	Side Damage	
Longitudinal	$^1/_3\ L^{2/3}$ or 14.5 meters whichever is less	
Transverse	$^B/_5$ or 11.5 meters whichever is less	
Vertical	From molded bottom at centerline upwards with-out limit	
	Bottom Damage	
Extent	**0.3L from FP**	**Any Other Part**
Longitudinal	$^1/_3\ L^{2/3}$ or 14.5 m whichever is less	$^1/_3\ L^{2/3}$ or 5 m whichever is less
Transverse	$^B/_6$ or 11.5 m whichever is less	$^B/_6$ or 5 m whichever is less
Vertical	$^B/_{15}$ or 6 m whichever is less	$^B/_{15}$ or 6 m whichever is less

The Ballast Arrival intact condition is used with each of the damage cases, which are summarized in Table 4.9.3.2. The IMO Tanker Damage Stability criteria are met for each of the seven cases. The "Bow Side Damage" case is the worst case with a heel of 2.1 deg, a maximum GZ of 7.941 m and a maximum GZ angle of 48.8 deg (Figure 4.9.3.1-2). The worst case trim and bending moment is the "Aft Slop Fuel Engine Room Damage" case at 5.846 m trim aft and a bending moment of 585,044 m-MT in hog. This bending moment is far below the total bending moment due to waves (1,000,000 m-MT) used in the structural calculations and therefore is satisfactory. (Figure 4.9.3.2)

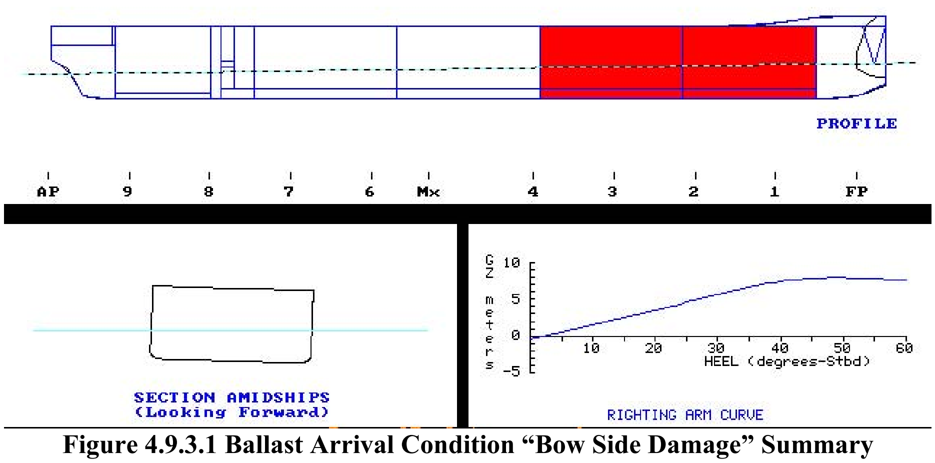
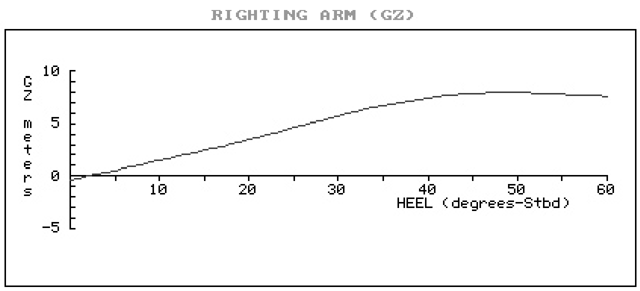


Figure 4.9.3.1 Ballast Arrival Condition "Bow Side Damage" Summary



Evaluated per IMO (MARPOL) Rules for Tankers:	Available	Required
Static Heel Angle	2.1S deg	30.0 deg
Angle at Maximum GZ	48.8S deg	
Maximum GZ	7.941 m	0.100 m
Range of Positive GZ	>57.9 deg	20.0 deg
Gmt (upright damaged)	11.168 m	

Figure 4.9.3.2 (GZ) Righting Arm Curve for Ballast Arrival Condition "Bow Side Damage"

Table 4.9.3.2 Ballast Arrival Damage Conditions

	Ballast Arrival Condition							
Case Name	**Intact**	**Bow Damage**	**Bow Side Damage**	**Side Damage**	**Aft Side Damage**	**Aft Slop Fuel Cargo**	**Aft Slop Fuel Engine Room**	**Aft Damage**
Draft AP (m)	10.473	11.242	9.418	10.655	11.676	11.907	14.587	10.837
Draft FP (m)	10.462	9.268	13.305	11.738	10.739	10.157	8.741	10.461
Trim on LBP (m)	0.012A	1.974A	3.887F	1.083F	0.937A	1.749A	5.846A	0.376A
Total Weight (MT)	108260	105502	119147	116718	116480	114343	121163	110230
Static Heel (deg)	0	0.4P	2.1S	0.7S	0.5S	0.2S	0.2S	0.0P
GMt (upright) (m)	14.133	15.007	11.168	11.752	11.944	12.876	12.958	14.565
Maximum GZ (m)	----	9.271	7.941	8.885	9.146	9.343	8.9	9.746
Max.GZ Angle (deg)	----	47.0P	48.8S	47.4S	46.7S	46.4S	45.8S	46.9P
GZ Pos.Range (deg)	----	>59.6	>57.9	>59.3	>59.5	>59.8	>59.8	>60.0
Outflow (MT)	----	13754	15429	16812	16379	9717	1744	6194
Flooded Water (MT)	----	10996	26316	25269	24599	15800	14646	8164
Shear Force (MT)	----	7197	7768	7347	6947	6870	8224	-5531
B.Moment (m-MT)	----	298466H	435698H	309366H	270881H	370204H	585044H	354138H

The 125K DWT condition is used with all the damage cases to give the damage summary in Table 4.9.3.3. The IMO Tanker Damage Stability criteria are met for each of the seven cases. The worst case is the "Side Damage" with a heel angle of 14.8 deg, a maximum GZ Angle of 42.5 deg and a maximum GZ of 2.519 m (Figure 4.9.3.3-4). The worst case bending moment is also in the "Side Damage" case at 324,227 m-MT in sag. This again is very small compared to the maximum structural bending moment. The worst case trim is in the "Aft Damage" case at 9.602 m aft.

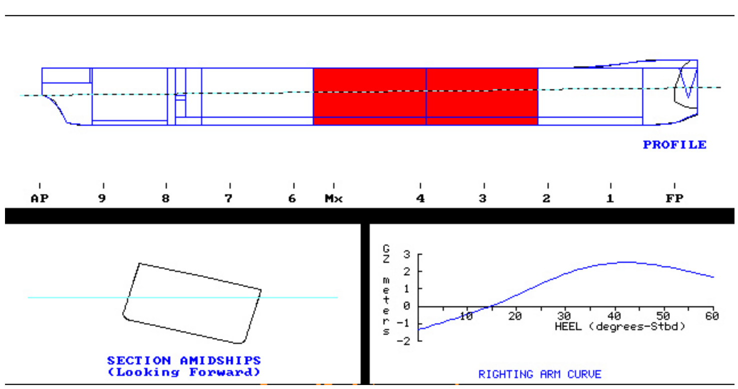


Figure 4.9.3.3 125K DWT condition "Side Damage" Summary

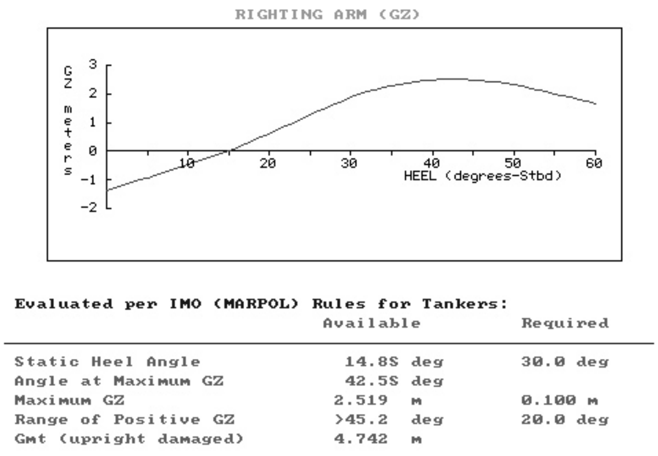


Figure 4.9.3.4 (GZ) Righting Arm Curve for 125 DWT Condition "Side Damage"

Table 4.9.3.3 125K DWT Damage Conditions

125K DWT Condition								
Case Name	**Intact**	**Bow Damage**	**Bow Side Damage**	**Side Damage**	**Aft Side Damage**	**Aft Slop Fuel Cargo**	**Aft Slop Fuel Engine Room**	**Aft Damage**
Draft AP (m)	14.472	13.733	13.131	14.288	14.259	14.059	19.865	21.055
Draft FP (m)	14.444	15.709	18.583	17.847	14.704	14.419	12.156	11.452
Trim on LBP (m)	0.028A	1.977F	5.452F	3.559F	0.444F	0.360F	7.708A	9.602A
Total Weight (MT)	153912	157091	171295	173669	154235	151379	172626	175727
Static Heel (deg)	0	1.4S	13.8S	14.8S	3.5S	1.0P	0.5S	0.1P
GMt (upright) (m)	5.528	5.482	4.32	4.742	4.912	5.187	4.761	5.112
Maximum GZ (m)	----	3.745	2.447	2.519	3.894	3.646	3.386	3.57
Max.GZ Angle (deg)	----	40.5S	42.7S	42.5S	40.8S	40.8P	38.4S	38.5P
GZ Pos.Range (deg)	----	>58.6	>46.2	>45.2	>56.5	>59.0	>59.5	>59.9
Outflow (MT)	----	15326	24604	23937	32784	22246	4121	2493
Flooded Water (MT)	----	18505	41987	43695	33107	19713	22835	24308
Shear Force (MT)	----	-5647	-5978	-7762	-6278	-5841	-6431	-7372
B.Moment (m-MT)	----	204373H	145290S	324227S	180110S	117279S	241866H	314755H

The 140K DWT intact loading condition is used with the damage cases to check for stability requirements. All seven cases meet the IMO Damage Stability Requirements. The worst case is the "Bow Side Damage" case with a heel of 11.6 deg. The worst case trim is the "Aft Damage" case with a trim to the aft of 10.223 m. This is still below the deck level and meets all IMO requirements. The worst case bending moment is the "Side Damage" case with a bending moment of 449,885 m-MT which, is far less than the offered structural design.

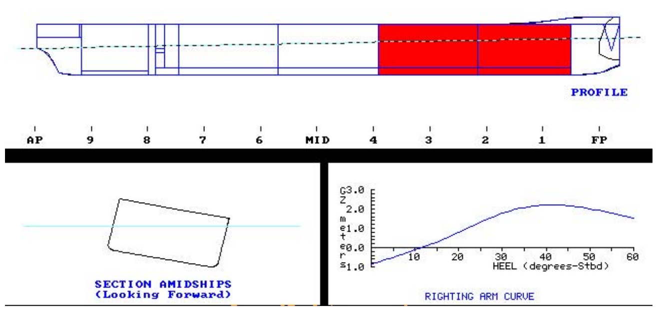


Figure 4.9.3.5 140K DWT Condition "Bow Side Damage" Summary

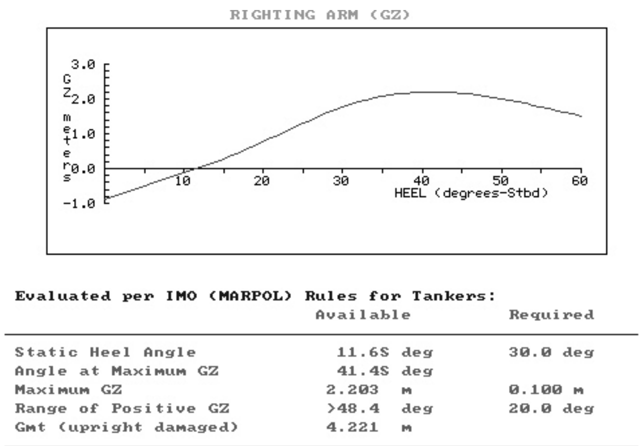


Figure 4.9.3.6 (GZ) Righting Arm Curve for 140K DWT Condition "Bow Side Damage

Table 4.9.3.4 140K DWT Damage Conditions

		140K DWT Condition						
Case Name	**Intact**	**Bow Damage**	**Bow Side Damage**	**Side Damage**	**Aft Side Damage**	**Aft Slop Fuel Cargo**	**Aft Slop Fuel Engine Room**	**Aft Damage**
Draft AP (m)	16.035	13.78	14.418	16.043	16.06	16.421	22.321	23.064
Draft FP (m)	16.009	20.52	19.961	16.303	16.085	15.859	13.374	12.841
Trim on LBP (m)	0.026A	6.741F	5.544F	0.260F	0.024F	0.562A	8.947A	10.223A
Total Weight (MT)	172228	2E+05	186616	174074	172862	173673	194753	196162
Static Heel (deg)	0	7.0S	11.6S	4.9S	4.0S	1.7S	1.0S	0.1P
GMt (upright) (m)	5.171	5.032	4.221	4.81	4.678	4.847	4.559	4.852
Maximum GZ (m)	----	2.575	2.203	3.046	3.21	3.394	2.662	2.893
Max.GZ Angle (deg)	----	39.7S	41.4S	40.7S	40.3S	39.5S	37.7S	37.8P
GZ Pos.Range (deg)	----	>53.0	>48.4	>55.1	>56.0	>58.3	>59.0	>59.9
Outflow (MT)	----	11260	29444	36369	36309	22246	4121	4076
Flooded Water (MT)	----	24889	43832	38215	36944	23691	26647	28010
Shear Force (MT)	----	-5474	-6663	-8232	-8184	-8747	3464	-3190
B.Moment (m-MT)	----	141456S	302207S	449885S	438588S	408175S	173859S	129767S

The Summer Load Line draft is the worst intact and damage stability condition. The initial load line draft of 21.4 m from the MathCad model is satisfactory in intact stability, but fails in damage stability. By adjusting the density of the cargo and the ballast, slightly new Summer Load Line drafts can be tested with the damage cases. The deepest draft with good damage stability is 19 m. This case is summarized below in Table 4.9.3.5. The worst case heel is 10.4 deg. in the "Bow Side Damage" case. This has a maximum GZ of 1.312 m and a maximum GZ angle of 36 deg. (Figure 4.9.3.7-8) Worst case trim is the "Aft Damage" case with a trim of 12.057 m aft. Worst case bending moment is the "Side Damage" case at 539,822 m-MT. This bending moment is much smaller than the offered design bending moment.

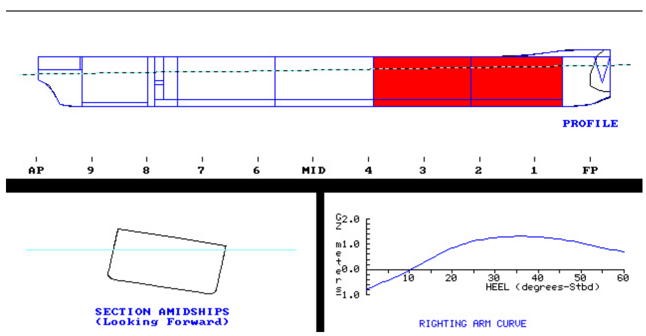


Figure 4.9.3.7 Summer Load Line Condition "Bow Side Damage" Summary

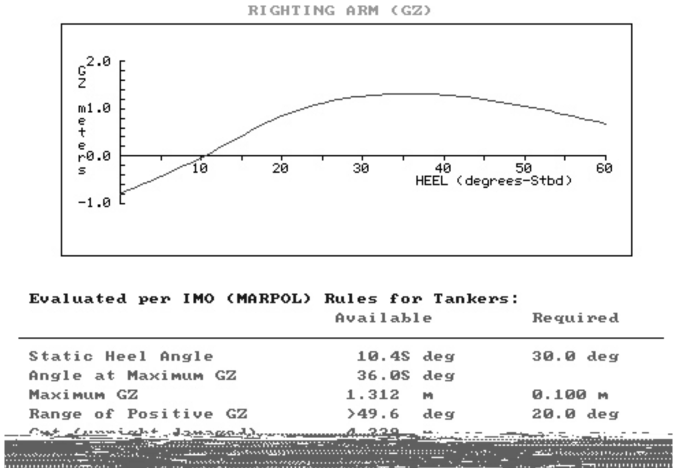


Figure 4.9.3.8 (GZ) Righting Arm Curve for Summer Load Line Condition "Bow Side Damage" Summary

Table 4.9.3.5 Summer Load Line Draft Damage Conditions

	Summer Load Line Draft							
Case Name	Intact	Bow Damage	Bow Side Damage	Side Damage	Aft Side Damage	Aft Slop Fuel Cargo Damage	Aft Slop Fuel Engine Room	Aft Damage
Draft AP (m)	19.091	17.01	17.84	19.153	18.512	18.381	26.484	27.409
Draft FP (m)	19.045	23.358	22.479	19.83	19.107	19.037	15.961	15.353
Trim on LBP (m)	0.046A	6.349F	4.639F	0.677F	0.596F	0.656F	10.523A	12.057A
Total Weight (MT)	208434	221767	221651	213615	205316	204199	235502	237693
Static Heel (deg)	0	6.0S	10.4S	6.9S	1.1S	3.2P	0.3P	0.0P
GMt (upright) (m)	4.841	4.893	4.229	4.56	4.733	4.777	4.409	4.308
Maximum GZ (m)	----	1.623	1.312	1.646	2.238	2.469	1.409	1.316
Max.GZ Angle (deg)	----	33.1S	36.0S	34.7S	35.7S	39.2P	27.9P	26.8P
GZ Pos.Range (deg)	----	>54.0	>49.6	>53.1	>58.9	>56.8	>59.7	>60.0
Outflow (MT)	----	15082	35837	41510	44696	30031	6091	6786
Flooded Water (MT)	----	28415	49053	46691	41578	25796	33158	36044
Shear Force (MT)	----	-9146	-10603	-12332	-10813	-10624	2229	-1984
B.Moment (m-MT)	----	232222S	366992S	539822S	440669S	412284S	136832S	96709S

All four of the intact loading cases pass the seven damage conditions by meeting the IMO Requirements for Damage Stability of Tankers using MARPOL Rules. All of the heel angles, GZ calculations and bending moment calculations are well below their thresholds and will provide a safe ship.

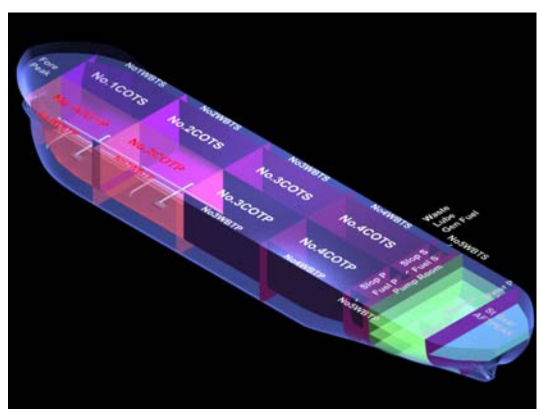


Figure 4.9.3.9 "Bow Damage" Case

Figure 4.9.3.10 "Bow Side Damage" Case

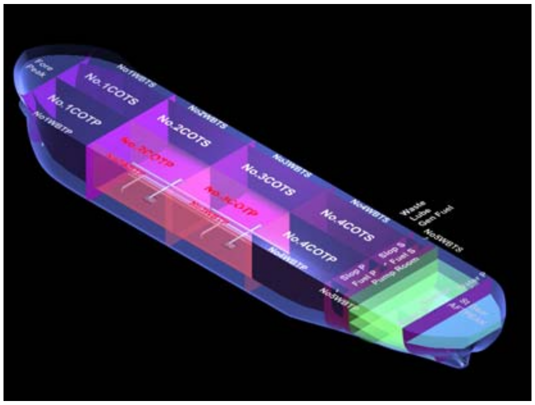


Figure 4.9.3.11 "Side Damage" Case

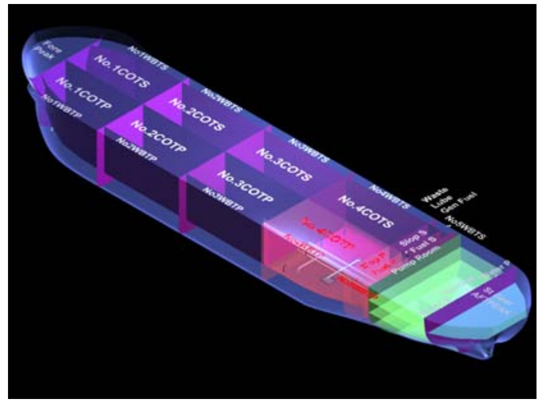


Figure 4.9.3.13 "Aft Slop Fuel Cargo Damage" Case

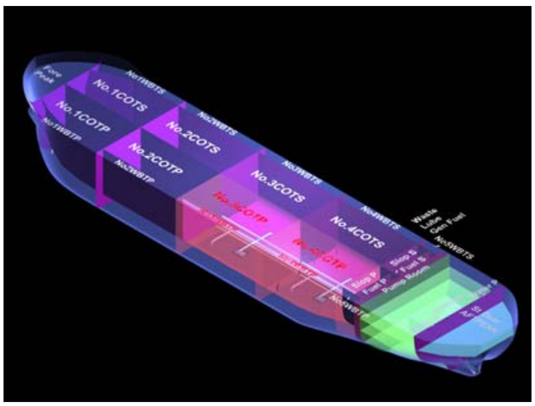


Figure 4.9.3.12 "Aft Side Damage" Case

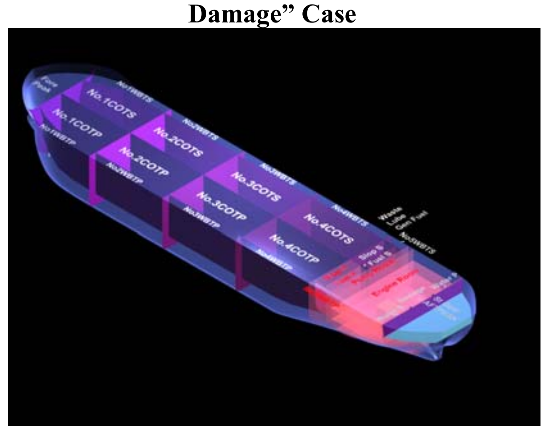


Figure 4.9.3.14 "Aft Slop Fuel Engine Room Damage" Case

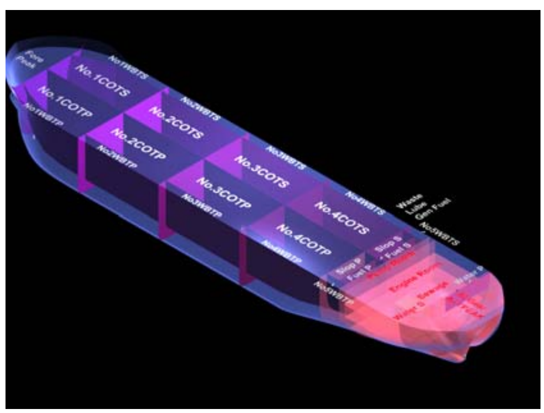


Figure 4.9.3.15 "Aft Damage" Case

4.10 Seakeeping and Maneuvering

4.10.1 Seakeeping

Seakeeping is done by using a 5 degree of freedom FORTRAN program created by MIT. The program builds a Lewis hull form and requires the following information at each station: location, B prime (the transverse distance at the water line of the station), T prime (the vertical distance from the waterline to the bottom of the station), Sigma (the area coefficient), centroid, and the girth. The program is run at two speeds 6.181m/s (12 knots) and 7.727 m/s (15 knots) with two different headings 45 degrees and 135 degrees in two loading conditions 140K DWT and ballast arrival. The location chosen for this is at the bottom of the bulbous bow for the purpose of determining slamming events, bulb immersion events and deck wetness events. Once the information is entered the program is run and the relative motion, velocity, and acceleration RAO's are pull from output. The 140 DWT RAO's are shown plotted in figures 4.10.1.1-4. Once these are acquired a composite Ochi Sea State 6 response spectra is created in Mathcad (Figures 4.10.1.5-6) to multiply the RAO's by to get the motion and velocity response spectra (Figures 4.10.1.7-10). Next a critical velocity for slamming is calculated as well as the probability of slam and the number of slams per hour for each of the eight cases. These are shown in table 4.10.1.1. All Mathcad calculations are shown in Appendix A.9.

Table 4.10.1.1 Probability of Deck Wetnes, Bulb Emersion, and Slamming Events

140K DWT Heading	**Speed**	**Probability of Slam**	**Number of Slams per Hour**	**Probability of Bulb Emersion**	**Number of Bulb Emersion per hour**	**Probability of Deck Wetness**	**Number of Deck Wetness per Hour**
135	6.181	$7.127*10^{-4}$	0.337	$1.667*10^{-3}$	0.788	0.03	14.173
135	7.727	$1.326*10^{-3}$	0.617	$2.7*10^{-3}$	1.256	0.039	18.167
45	6.181	0.141	65.259	0.25	115.777	0.467	216.625
45	7.727	0.047	19.203	0.139	56.975	0.338	139.123
BALLAST ARRIVAL							
135	6.181	$4.589*10^{-5}$	0.023	$1.274*10^{-4}$	0.064	$7.315*10^{-3}$	3.674
135	7.727	$9.76*10^{-5}$	0.048	$2.312*10^{-4}$	0.114	0.01	5.009
45	6.181	$1.647*10^{-5}$	$8.031*10^{-3}$	$6.253*10^{-4}$	0.305	0.018	8.532
45	7.727	$6.272*10^{-6}$	$3.053*10^{-3}$	$6.3*10^{-4}$	0.307	0.018	8.555

The criteria for the TAPS trade are as follows: the prevailing ship headings relative to the direction of the waves are 045 degrees in full load condition and 135 degrees in ballast condition. These correlate to coming and going to Valdez. The table shows that the criteria for seakeeping is met by the tanker. The ship must be able to operate safely 98% of the time at endurance speed on these headings. This means operating safely through a Sea State 7 (Significant Wave Height of 9 m). Safe operation is defined as a maximum of 20 slams per hour assuming full load is the worst case. Looking at Table 4.10.1.1 it can be seen that this criteria is meet.

Limits on accelerations in berthing and working areas are set to account for crew safety and effectiveness. It has been shown that vertical accelerations over 4g's cause discomfort and motion sickness. Therefore a criteria of 0.4g with 0.001 probability of exceedence has been set for the ORTLO. Vertical accelerations are measured at the navigation bridge to get the RAO. This is then multiplied by the Ochi spectrum to get the acceleration response spectra. An acceleration with a 0.001 probability of exceedence is then calculated for the two headings and two speeds. (Table 4.10.1.2) The table shows that the ORTLO is well under the 4g requirement.

Table 4.10.1.2 Vertical Acceleration at Navigation Bridge

140K DWT Heading	**Speed**	**Acceleration in g's**
135	6.181	0.313
45	6.181	0.289
135	7.727	0.317
45	7.727	0.167

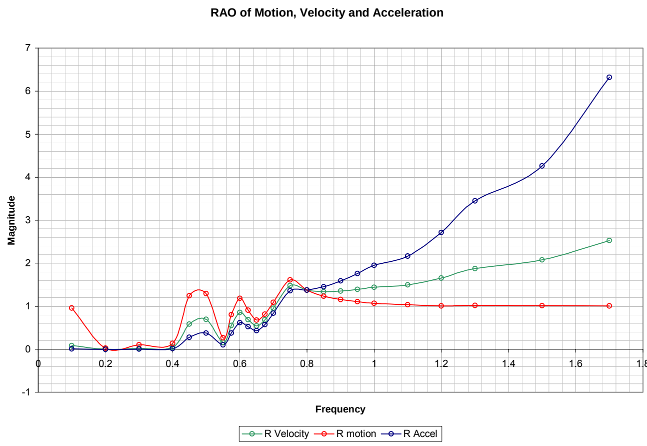


Figure 4.10.1.1 RAO's of 135 deg heading at 6.181m/s

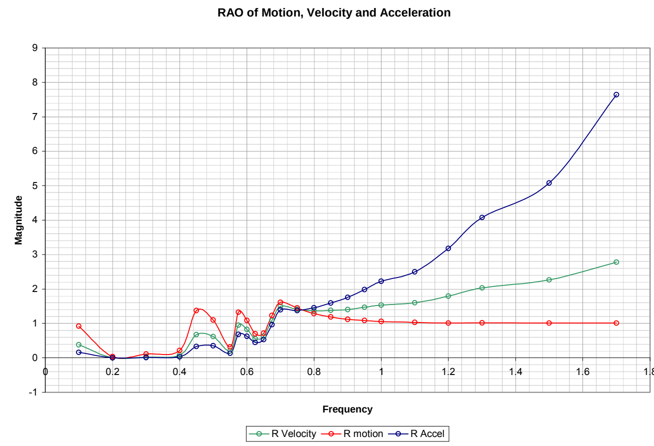


Figure 4.10.1.2 RAO's of 135 deg Heading at 7.727 m/s

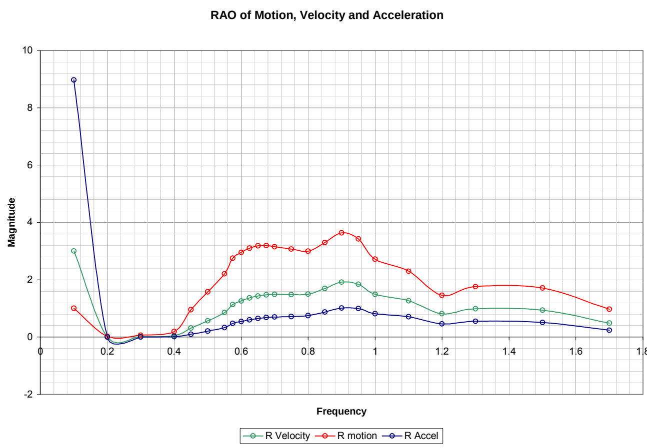


Figure 4.10.1.3 RAO's of 45 deg Heading at 6.181m/s

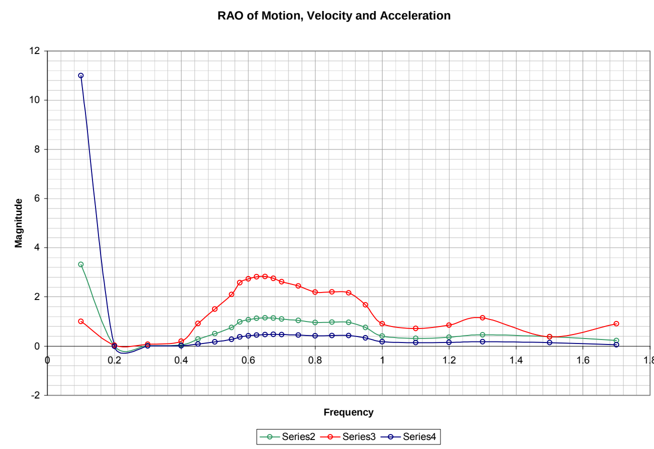
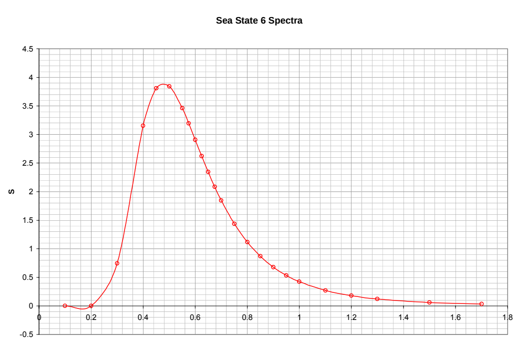


Figure 4.10.1.4 RAO's of 45 deg Heading at 7.727m/s



Response Spectra for 45 deg at 6.181m/s

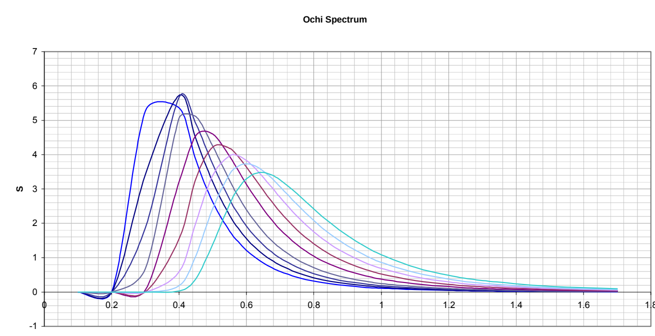


Figure 4.10.1.5 Ochi Spectrum

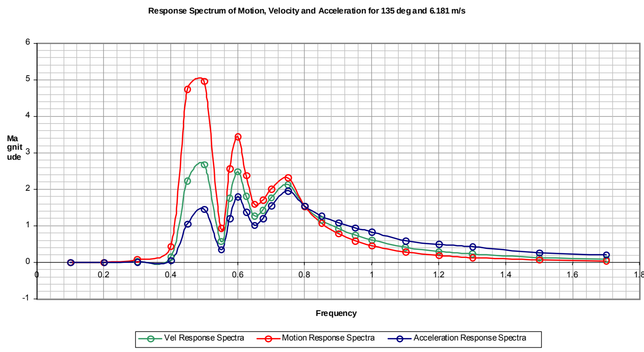


Figure 4.10.1.7 Response Spectra for 135 deg at .181 m/s

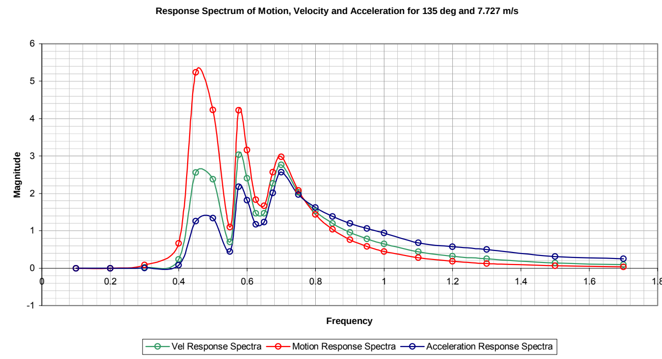


Figure 4.10.1.8 Response Spectra for 135 deg at 7.727m/s

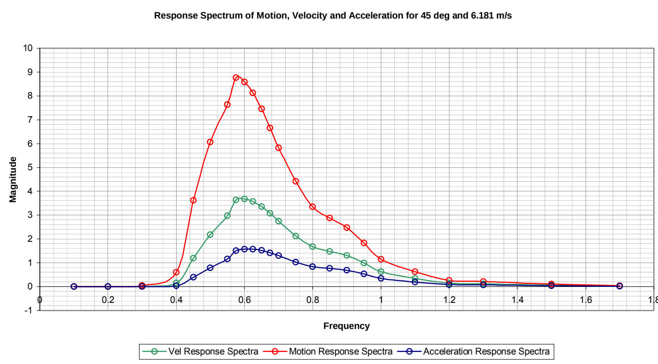


Figure 4.10.1.9 Response Spectra for 45 deg at 6.181m/s

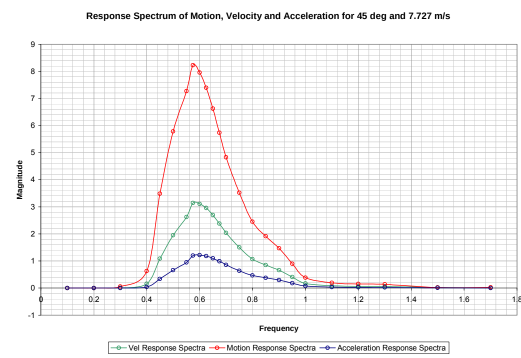


Figure 4.10.1.10 Response Spectra for 45 deg at 7.727m/s

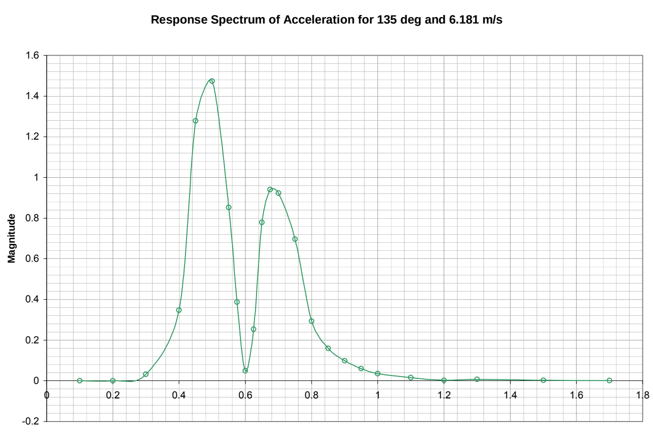


Figure 4.10.1.11 Navigation Deck Acceleration Response Spectra for 135 deg at 6.181m/s

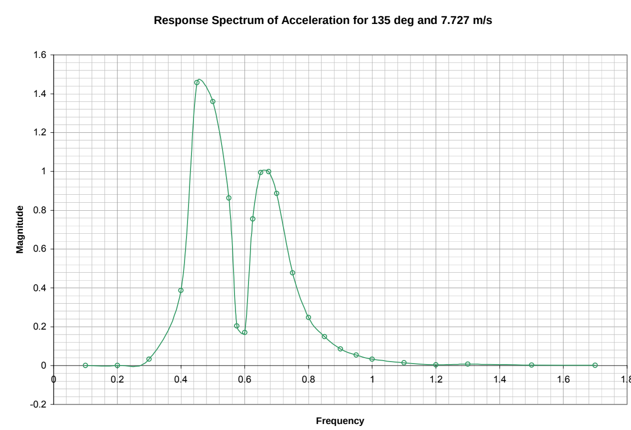


Figure 4.10.1.13 Navigation Deck Acceleration Response Spectra for 135 deg at 7.727m/s

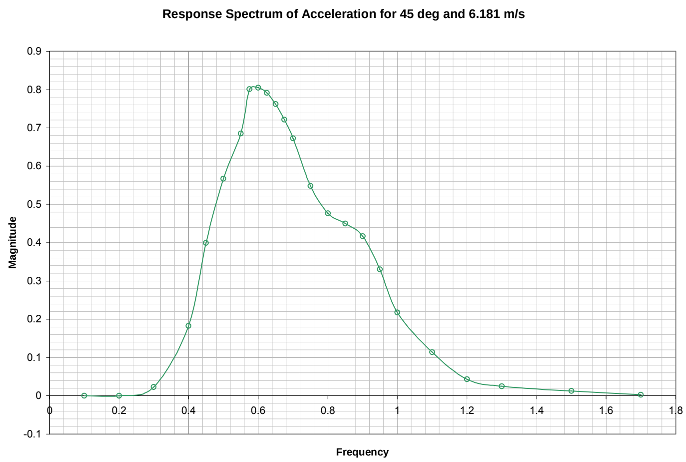


Figure 4.10.1.12 Navigation Deck Acceleration Response Spectra for 45 deg at 6.181 m/s

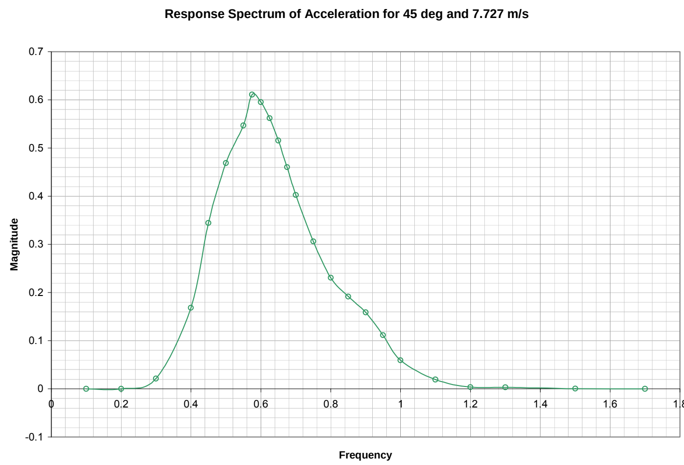


Figure 4.10.1.14 Navigation Deck Acceleration Response Spectra for 45 deg at 7.727 m/s

4.10.2 Maneuvering

Maneuvering predictions for the ORT LO are produced using a University of Michigan, Department of Naval Architecture and Marine Engineering Maneuvering Prediction Program (MPP) developed by M.G. Parsons. The program predicts the turning path characteristics of the vessel such as advance, transfer, tactical diameter, steady turning radius, and steady speed in turn. Figure 4.10.2.1 illustrates the turning path of a vessel. The "execute position of O" in the figure is the point at which the rudder of the ship begins to turn. The advance is the distance from the execute position along the ship's original heading to the point where the ship has turned 90 deg. The transfer is the distance from the original straight-line approach course to the origin of the ship, when it has turned 90 deg. The tactical diameter is the diameter of the initial turning circle of the ship, or the distance between the original approach route and the ship's route when it has turned 180 deg. When the forces affecting the turning vessel reach equilibrium, the ship settles down to a turn of constant radius, denoted the steady turning radius. The steady turning radius is proportional to the ship length and inversely proportional to the rudder deflection angle. The steady speed in turn is the speed of the tanker when equilibrium is reached.

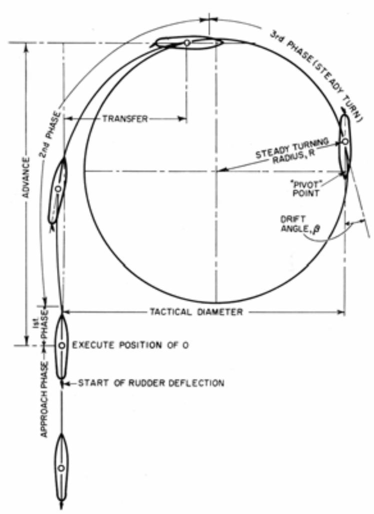


Figure 4.10.2.1 Turning Path Characteristics[2]

[2] Comstock, John P., ed. Principles of Naval Architecture, New Jersey: Society of Naval Architects and Marine Engineers (SNAME), 1967.

The MPP requires inputs such as vessel characteristics, steering characteristics, operating conditions, and water properties. Table 4.10.2.1 displays the input variables and the values entered. The tanker must not exceed a tactical diameter of 1000 m and a transfer of 500 m. With an approach speed of 15 knots and rudder angle at 35.00 deg, the advance is 705.4 m, the transfer is 345.38 m, the tactical diameter is 727.18 m, the steady turning radius is 277.79 m, and the steady speed in turn is 5.51 knots. The steady turning radius is 1.104 ship lengths. The transfer and tactical diameter are far below the requirements.

Table 4.10.2.1 MPP Inputs

Parameter	Input Value
Vessel Characteristics	
Length of waterline, LWL (m)	251.54
Maximum beam on LWL (m)	49.78
Draft forward (m)	15.80
Draft aft (m)	15.80
Block coefficient on LWL, C_B	0.833
Center of gravity, LCG from midships (%LWL, + forward)	-3.10
Yaw radius of gyration as a fraction of LWL	0.225
Submerged bow profile area as a fraction of LWL*T	0.0216
Steering Characteristics	
Total rudder area as fraction of LWL*T	0.0503
Steering gear constant (sec)	2.50
Center of effort of rudder from midships (%LWL, + aft)	49.0
Operating Conditions	
Water depth to ship draft ratio (1000 for deep water)	1000.0
Initial ship speed (knots)	15.00
Water Properties	
Salt water density at 15 deg C (kg/m^3)	1025.87
Salt water kinematic viscosity at 15 deg C (m^2/sec)	0.1188E-05

4.11 Cost and Risk Analysis

4.11.1 Cost Analysis

The Cost Analysis used for this vessel is weight based with adjustments for producibility (Appendix A.8). In order to attain the TOC, the cost section from the conceptual MathCad Model (Appendix A.2) was utilized to construct a Cost Analysis (Appendix A.8). A number of variables dealing with the ship's characteristics had to be re-input into the Cost Analysis in order for it to run correctly. SWBS group weights from the MathCad Model and the Weight Report (Appendix A.6) were input into the Cost Model depending on the completeness of the weight information. The sum of these SWBS groups represents the Lightship weight of the vessel. The Weight Margin Factor (WMF) had to be adjusted to 7.3% so that the actual weight of the vessel agreed with the conceptual weight. The WMF accounts for design error, added equipment, and added weight due to production. Producibility factors associated with different SWBS groups also effect cost. High producibility factors represent complicated structures which will cost more to construct. The cost for the ORT LO is roughly $1 million more than the cost predicted in the conceptual design process (Table 4.11.1.1). The larger cost is due to an increase in SWBS weight groups. All of the Net Present Value (NPV) costs stayed the same for both cases.

Table 4.11.1.1 Cost Comparison

Cost Type	Concept Design ($ mil)	ORT LO ($ mil)
BCC	111.92	112.69
NPV Fuel	34.85	34.85
NPV Manning	24.82	24.82
NPV Maintenance	16.84	16.84
NPV Penalties	0	0
TOC	197.38	198.22

4.11.2 Risk Analysis

Risk Analysis (Appendix A.8) for the ORT LO design is based on the risk section of the conceptual MathCad Model (Appendix A.2). The cargo and slop tank volumes from the 140K DWT loading condition are input into the O_s matrix within the model. This loading condition is used since it represents the worst case risk scenario. Risk is based on the mean oil outflow of the vessel. When the volume of the cargo tanks are reduced, the mean oil outflow is reduced in turn. The tank volumes for the ORT LO are less than those used in the conceptual analysis, so the risk value is reduced (Table 4.11.2.1). The probabilities remain constant for all cases since they have no dependency on tank volumes.

Table 4.11.2.1 Probability, Oil Outflow, and Risk Comparison

Collision Type	Concept Design	ORT LO
$P_{collision}$	2.17×10^{-5}	2.17×10^{-5}
$P_{grounding}$	5.42×10^{-5}	5.42×10^{-5}
P_{OSIDE}	0.890	0.890
P_{OBOT}	0.896	0.896
P_O	0.893	0.893
O_{MS}	2652 m^3	1900 m^3
O_{MB}	1905 m^3	1051 m^3
O_M	0.0139	8.76×10^{-3}
Risk	0.161 m^3	0.115 m^3

5.0 Conclusions and Future Work

5.1 Assessment

The VT Tanker meets or surpasses the requirements set forth by the customer. Table 5.1.1 displays the required and actual specifications for this tanker.

Table 5.1.1 Compliance with Owner's Requirements

Requirement	Specification	ORT LO Tanker
Dead Weight Tonnage	125,000 MT plus 15,000 MT margin for future growth	140080 MT
Endurance Range	10,000 nm at 15 knots	15,612 nm at 15 knots
Minimum Sustained Speed	15 knots at 90% MCR	15 knots at 90% MCR
Maximum Sustained Speed	15.78 knots at 90% MCR	16 knots at 90% MCR
Cargo Segregation	Minimum 4x2 with 2% slop tanks	4x2 with 2% slop tanks
Maximum Full Load Draft	54 ft	51.84 ft (15.8m)
Maximum In-Ballast Height Above Water	50 m	39 m (with mast 49 m)
Maximum TOC	199.44 Million dollars	198.222 Million dollars
Maximum Risk	0.1597 m^3	0.115 m^3
Minimum Double Bottom Height	2.6 m	4 m
Minimum Double Side Width	3.8 m	4 m
Minimum Cargo Block Subdivision	4x2	4x2
Electric Plant Redundancy	1	1
Lightship Weight	27,983.52 MT	27,984.0 MT
Structural Margin Factor	1	1
Minimum Manning	20	20
Minimum Deck Height	4 m	4 m

The ORT LO Tanker incorporates proven technology and equipment throughout its design. The structure is designed using reliable, "off the shelf" materials. Its design is tested and adjusted using ABS SafeHull, a widely used, rule based method. The deckhouse design is based on block orientation which enhances producibility. Another choice of proven technology can be illustrated through the choice of a low-speed diesel engine for efficiency, maintainability, and reliability. The drive train is typical of this type of engine which does not require a reduction gear. The four blade fixed pitch propeller is chosen for its reliable performance in various sea states. The mechanical and electrical systems are sized and selected based on existing tanker technology. The cargo and ballast piping arrangements are derived from previous successful designs. The mechanical approach for a power conversion unit is chosen for proven reliability versus the relatively new solid state electrical approach. The chosen design facilitates production and ensures safe and efficient operation of the ORT LO ship.

5.2 Future Plans

5.2.1 Hull Form, Appendages and Deckhouse

The hull form has several options that should be addressed the next time around the design spiral. From the profile view it can be seen that the stern of the ship is small and has a very steep slope into the propeller area. This results difficulty in placing the rudder post and the rudder in order to have enough surface area and still clear the propeller by the proper distance. The solution to this would be to pull the stern out and flatten the buttocks to the propeller area. This would give a better mounting area, the extra room needed for the rudder and a better flow field to the propeller. A possible problem with this would be a slight increase in drag. Also the stern could be vertical as opposed to an angle to allow for better separation off the hull and better producibility.

The next noticeable option is with the plan view of the hull the stern transitions very fast to the stern. This is due to the attempt to make the hull form very sea worthy in heavy seas. It carries from the parent hull form from the FastGen tanker. The transition from the parallel midbody to the stern lines is abrupt. This will be difficult to fair and build and well as cause separation in the flow field. The next time around the design spiral the stern of the hull could be tapered more to allow for producibility and a better flow field. Also in this area there is a reverse hook of the buttocks which would result in poor producibility and poor flow. The solution to this problem is to make the stern fuller which still providing a nice taper to the shaft.

Looking at the area around the shaft it can be seen that the hull form is much to large to allow good flow to the propeller. This could be tapered down to the hub diameter to allow for a better flow field.

Another change that could be made to the hull form is that the parallel midbody should be moved aft. This would allow for better trim conditions, little or no ballast necessary in the aft peak tank during full loading. This would result in a smaller engine room and the resulting size would have to be studied for feasibility.

5.2.2 Structural Design and Analysis

A complete structural analysis, including SafeHull Phase B, should be pursued with a second time around the design spiral. Particular areas of attention should include the following aspects.

The length of the cargo tanks may expose the transverse members to excessive stresses due to the longitudinal deflection. The vertical stiffeners on floors should be analyzed in detail at the intersection of the plating and innerbottom. This should be analyzed using finite element analysis with a dense mesh, as these prove to be persistent crack problems. The future analysis should include secondary and tertiary stresses on apple-shaped web frame cutouts, butt-welds of plane stiffeners, collars, and transverse bilge brackets. Additionally, requirements for the innerbottom plating should be increased to keep static stress at a safe level, below yield for any combined loading condition. The innerbottom plating thickness should be tapered longitudinally to suit dynamic pressure heads. The implementation of the various types of the stiffeners to improve maintenance and durability should be investigated in greater detail.

5.2.3 Power and Propulsion

Several power and propulsion issues could be improved during a second trip around the design spiral. More diverse propeller options could be considered within NavCad, involving an increased number of blades and/or alternative propeller series. Engine fuel rate is currently the main parameter considered when choosing the optimum propeller. Other factors such as maneuverability, cost, and efficiency could be further investigated and analyzed in the optimization process.

5.2.4 Mechanical and Electrical Systems

More detailed equipment specifications and manufacturer information could be collected and incorporated in the Equipment List and Weight Report. These improvements would produce a more accurate value for Lightship weight and more detail in the machinery arrangement drawings.

5.2.5 Cargo Systems

Different COW systems could be looked at in the future. A combination of deck-mounted and submerged nozzles is worth looking at for time conservation. The benefits of using a dedicated inert gas generator and submersible cargo pumps could be looked at as well.

5.2.6 Manning

Crew size could be reduced if the level of shipboard automation is increased. With increased engine room automation, an unlicensed technician in the Engine Department could be eliminated. The crew size calculation could also reflect trade and route characteristics.

5.2.7 Space and Arrangements

There are two main areas in the space and arrangements of tanks that should be more closely examined. The potable water tanks and the sewage tanks are presently too difficult to build and maintain. Given the opportunity to go around the design spiral again these tanks would be separate tanks located on Flat 1 of the engine room. Separate tanks could be produced to be delivered as "drop-in units" and easily maintained due to easier access to all sides of the tanks. The steering gear room is very large. In the future, it could be utilized as a bosen stores area and a machine shop in addition to its original purpose.

Given another time around the design spiral, ballast tanks 5, port and starboard, should be looked at. These ballast tanks could be eliminated by extending ballast tank 4 under the slop, fuel, waste and generator fuel tanks. This would eliminate extra structure and piping, reducing the lightship weight. This ballast tank extension would have to be studied in the damage stability.

The two meter clearance between the main deck and the deckhouse could be eliminated for maintenance benefits. The catwalk clearance above the deck could be increased to four meters for easier accessibility and safety. These processes would allow for the catwalk over the main deck to match up to the B deck.

The deckhouse central stairs and stairwells should be increased in size. For increased crew mobility within the deckhouse, the stairs could be larger in width and length for each deck. Surrounding the stairs, at least 0.8 m of free space is needed to allow crew members to move freely from one deck to the next. Some exterior aft stairs accessing the Deck B should be traded for interior stairs. Interior stairs would allow crew members access to machinery rooms without moving through extreme weather conditions. The deck heights could be reduced from four meters to three meters and still satisfy the producibility requirements.

The navigation deck (Deck E) could accommodate increased privacy for the Master and Chief Engineer of the vessel. Access to these living quarters should be available without entrance into the bridge area. Future changes should include increased visibility out of the deckhouse. The elevator should also be designed to allow access to the navigation deck.

The following design change to the machinery space of the ship could be addressed in the future. The unusual availability of space in Flats 1 through Flat 3 of the machinery space should be studied for feasibility. An economic study of the reduction of free space in the machinery space could decrease the cost of the construction of the space.

5.2.8 Weights

Many SWBS group weights need to be refined. There are some components that need a more accurate and detailed weight documentation. Some component weights are missing which required estimates to be made. Research could be done to find out weights for the missing components.

5.2.9 Cost and Risk

Since the cost of the vessel is weight-based, refinement of the SWBS weight groups is going to effect cost directly. Ultimately the weight-based cost estimate must be replaced with a more product and process-based calculation.

More research can be done on mean oil outflow and probabilities of grounding and collision to achieve a more accurate risk value. Risk is based on oil outflow and probability, so the quantitative risk value is only as accurate as the data it is computed from.

5.3 Conclusion

The ORT LO tanker meets or exceeds all necessary requirements and regulations. The design of this vessel has been optimized using many different disciplines to ensure a complete analysis.

The ORT LO Tanker hull form has been optimized for the TAPS trade. It is based on a parent hull form design that has good seakeeping abilities while allowing for 140K DWT tank carrying capacity. A bulbous bow has been utilized to reduce wave making and viscous drag as well as increasing fuel efficiency. The bulwark is designed to deflect oncoming waves and reduce deck wetness. This all combines to ensure the ORT LO Tanker will deliver oil in the most demanding of sea conditions.

The structural configuration of the double-bottom hull and cargo tanks results in an effective design that satisfies the owners' requirements. The scantlings of the structural members are within accepted industry producibility limits. The stress distribution of the structure, although it requires further analysis, predicts a successful design. The unusually large innerbottom spacing proves to be a moderate factor in the structural design. The goal of high maintainability is achieved using sufficient openings for access and ventilation. The weight requirement is also met.

The propulsion system within the ORT LO Tanker incorporates a low-speed diesel engine chosen for its cost efficiency, proven technology, and maintainability. The system also includes a four-blade fixed pitch propeller due to its optimal efficiency and minimal fuel rate. The engine, in conjunction with the propeller, produces ample power to propel the ship efficiently and effectively. The propulsion system satisfies the requirements for endurance speed and range. The vessel exceeds the calculations for required endurance electrical power and endurance fuel.

The mechanical and electrical systems on the vessel satisfy the needs of the crew to successfully transport crude oil from the TAPS trade route. The systems facilitate the efficient operation of the tanker. The capacities of the generators on the vessel surpass the required power calculated in the MathCad Model (Appendix A.2). The electrical system is highly effective and safeguarded against failure. Both mechanical and electrical systems include space for future growth.

Cargo systems utilize the most advanced equipment available for safe and efficient cargo handling. The tanker is capable of transporting two grades of crude oil in segregated systems. The cargo piping serves alternative pairs of tanks and is cross-connected for redundancy, allowing any tank to be serviced by any cargo pump. The cargo pumps facilitate the timely loading and unloading of the cargo. To eliminate the possibility of deck spills, the cargo is offloaded through discharge headers that run through the cargo tanks.

The ballast water system is completely segregated from the cargo system to prevent contamination of either system. The ballast water exchange system on the ship requires less operation and maintenance of auxiliary equipment. This system will meet future ballast water exchange requirements. Ballast pumps supply the means for ballasting the ship to ensure stability during the offloading procedures and unloaded voyages .

COW systems ensure the maximum cargo holding capacity and remove crude oil debris from the tanks. IGS is necessary for safe storage of cargo while in route and meets all requirements set forth by the USCG. Oil monitoring systems are utilized to ensure that water-oil mixtures are not discharged into the sea.

The Manning Plan for the ORT LO Tanker contains sufficient crew to operate the vessel according to US COFR and USCG regulations. A conglomerate of licensed and unlicensed individuals perform all the required duties aboard the vessel. There is a high level of shipboard automation that allows a minimal crew of 20 persons.

The deckhouse exceeds the owners' requirements for crew size and additional personnel. The design incorporates the efficient use of five decks: two decks of machinery space, two decks of living quarters, and a navigation deck. Central stairs and elevator, and various exterior entrances allow crew members to move freely through the entire superstructure. Crew accommodations include individual staterooms, galleys, mess areas, and various rooms to provide an excellent crew living environment. The navigation deck provides outstanding visibility of the ship and surroundings, exceeding USCG visibility requirements.

The tank arrangements are designed to optimize environmental protection and provide easy maintenance. The ORT LO Tanker has four meter double side widths and a four meter double bottom height to provide the most protection against collision and grounding. This also provides easy access to the J-tanks for inspection and maintenance which increases overall ship safety and life. All fuel tanks, lube tanks, and waste oil tanks are contained within the four meter double side and four meter double bottom, providing protection against spills and short piping runs.

The machinery space design optimizes the space arrangements of various components of cargo, propulsion, and electrical equipment. The majority of the equipment surrounds the main engine. Components are positioned to work efficiently in performing their duty. Pumps interacting with cargo, ballast, and supply tanks are positioned within close proximity to their respective tanks. Other components are effectively positioned to provide control of propulsion and electrical systems. All equipment in the machinery space performs together in an efficient manner to meet and exceed the owner's requirements.

Weights for the vessel have been balanced and optimized to ensure stability and trim requirements. Weights are summed in all of the loading conditions to ensure for accurate and feasible tonnage.

The tanker has been examined for intact stability in all loading conditions and meets the IMO A.167 Righting Energy Criteria with a margin of safety. Damage stability has been studied for each loading condition in the most critical cases. The damage stability criteria set forth by Annex I - Regulations for the Prevention of Pollution by Oil (Regulation 25, Section 2– Subdivision and Stability) has been satisfied for all possible worst case scenarios and is considered to be successful in all cases and loading conditions.

A seakeeping analysis was performed on the ORT LO tanker with various headings, seas and speeds specific to the TAPS trade route. Deck wetness, slamming and vertical accelerations were checked against a TAPS trade criterion with the ORT LO tanker passing all criteria. Our ship is capable of operating along the TAPS trade route 98% of the time.

The maneuvering characteristics of the ship are sufficient to produce a steady turning diameter of 555.58 meters with a steady in turn speed of 5.51 knots. The ORT LO tanker has turning path characteristics far below the maximum requirements. The tanker maneuvers exceptionally for its trade and route characteristics.

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Appendix A.1 Tanker Requirements and Restrictions

A.1.1 Circular of Requirements

Optimum Risk TAPS - Trade Tanker (ORT)
Circular of Requirements

Requirements:

The customer requires a TAPS (Trans Atlantic Pipeline System) trade tanker to transport crude oil from Alaska to ports on the West Coast of the United States. Some of the specific requirements and specifications are located in Table A.1.1.1

Table A.1.1.1 Tanker Requirements

Requirement	Specification
Dead Weight Tonnage	125,000 MT plus 15,000 MT margin for future growth
Minimum Sustained Speed	15 knots At 90% MCR
Endurance Range	10000 nautical miles At 15 knots
Nominal Cargo Density	0.8674 MT/m^3
Delivery (Base)Year	2000
Service Life	30 years
Discount Rate	7%
Maximum Shipbuilder Profit Margin	8%
Cargo Segregation	Minimum 4x2 with 2% slop tanks
Maximum Full Load Draft	54 ft
Maximum In-Ballast Height Above Water	50 meters

The customer also requires certain specifications for the equipment on the tanker. Four cargo pumps are needed for a total offloading rate of 50,000 bbls/hr at 150 psig. These pumps are also required to sustain a maximum loading rate of 110,000 bbls/hr. Two ballast pumps are required for a total capacity of 110,000 bbls/hr. Piping must be provided for the potential addition of steady-flow ballast water exchange capability. The tanker must be equipped with a bow thruster for increased maneuverability.

A cost/oil pollution risk trade-off frontier must be provided for ship concept selection. The cost factor in the trade-off frontier is defined by the Total Ownership Cost (TOC). TOC includes the acquisition cost for the tanker and costs related to discounted fuel, manning, maintenance, and operational delay. The oil pollution risk factor is defined as an accident consequence. The accident consequence is the product of the mean oil outflow and accident probabilities. The mean oil outflow is determined by the simplified IMO probabilistic method. The accident probabilities include grounding and collision, which allows specific routes, ship design characteristics, and manning to be considered.

Additional goals derived from the concept design cost-risk analysis are located in Table A.1.1.2.

Table A.1.1.2 Tanker Goals from Cost-Risk Analysis

Requirement	Specification
Maximum TOC	199.44 million dollars
Maximum Risk	0.1597
Minimum Sustained Speed at 90% MCR	15.78 knots
Minimum Double Bottom Height	2.6 meters
Minimum Double Side Width	3.8 meters
Minimum Cargo Block Subdivision	4 x 2
Electric Plant Redundancy	1
Minimum Manning	20
Structural Margin Factor	1
Minimum Deck Height	4 meters

Mission Scenarios:

1. Primary Mission Scenario – Port Valdez to Cherry Point, Washington, Puget Sound
   - Port Valdez Approach route
     - Gulf of Alaska to Prince William Sound to Port Valdez, via Hinchinbrook Entrance following dedicated traffic lanes to Valdez Arm and Valdez Narrows.
     - Length of Route from Valdez Arm to Port Valdez – approx. 22 miles
     - Average width of channel – 3180 ft
     - Min. width of channel – 2400 ft
     - Average depth of channel – 800 ft
     - Min. depth of channel – 350 ft
     - Required tug escorts from Hinchinbrook to Port Valdez
     - VTS required and supplied by USCG
     - Six turns total, 3 left, 3 right
     - If winds > 40 knots, Valdez Narrows closed
     - If 31-40 knots, 2-3 extra tug escorts required
     - Environmental concerns due to diverse wildlife population
   - Cherry Point, Washington
     - Tanker unescorted for 70 miles between Pacific Ocean and Port Angeles
     - In Puget Sound must have a Washington State licensed pilot on board

    - 125,000 DWT limit
    - Environmental concerns due to diverse wildlife population
2. Other possible mission scenarios and ports
    - San Francisco
        - Max. Draft – 54 ft
        - Max. Height – 164 ft
        - Number of total turns – 10
        - Distance of transfer – 35 miles
        - Time of transfer – 2.33 hrs
        - Mean channel width – 150 yards
    - Long Beach
        - Accommodates tankers from 50,000 to 260,000 DWT
        - Depth of water – 45 ft
        - VTS oversees a 25 mile range
        - Two, 1 mile wide traffic lanes enter and exit the port
        - 2 mile separation between lanes
        - 12 knot precautionary area
        - Environmental concerns due to diverse wildlife population
        - Air quality issues – reduction in emissions caused by vessels and operations
        - Need for cleaner burning fuel
        - Time to port – 1.808 hrs
    - China (approx. every 5 years for dry docking and repairs)
        - About 10,000 miles from San Francisco to Hong Kong
        - Environment—current issues: endangered marine species include the dugong, sea lion, sea otter, seals, turtles, and whales; oil pollution in Philippine Sea and South China Sea
        - Ports and harbors: Hong Kong, Kao-hsiung, Los Angeles (US), San Francisco (US), Seattle (US), Shanghai (China)
        - Ships are subject to superstructure icing in extreme north from October to May
3. Typical Voyage Timeline - round trip between Valdez and Cherry Point
    - North bound – ship travels in ballast for 150 hours
    - Valdez terminal - loading of crude oil, 24 hours
    - South bound – ship under full load travels for 150 hours
    - Cherry Point – 24 hours required to unload cargo and replenish supplies
    - Entire round trip voyage completed 23 times a year

Times include speed reduction in Gulf of Alaska and Cherry Point ports.

Required Operational Capabilities (ROCs):

1. Cargo and ballast system capacity to load/offload/deballast/ballast in 24 hours.
2. Crude Oil Washing (COW)
   These systems powered by electrical motor driven pumps are used to clean the residual crude oil off the inside of the cargo tanks between ballast and cargo stages of each voyage.
3. Inert Gas Systems (IGS)
   Inert gas systems are used to prevent explosions in the cargo tanks. Without these systems explosive fumes mix with air inside the tanks and become highly volatile. The inert gas systems pump the cargo tanks with inert gas, usually diesel engine exhaust from the diesel engines on board, to prevent these types of explosions.
4. Ballast water exchange
   Ballast water exchange systems are a relatively new precaution in tanker design. These systems prevent the transportation of dangerous microorganisms from one region to another. It may be prudent to install Ballast water exchange systems into current tankers in expectation of future regulatory constraints.
5. Wartime Compliance
   Tankers must be able to take part in the national emergency effort by complying with military sealift command standards for underway replenishment.

Projected Operational Environment:

1. Sea State
   Appendix A.1.2 provides the annual sea state occurrences in the open ocean, North Pacific taken from Principles of Naval Architecture vol. III pg. 28. This definition should be used in ORT seakeeping and structural load calculations.
2. Temperature
   Temperatures of the air and water are also important factors in the operational environment. Appendix A.1.2 is a collection of air temperatures at Valdez, Alaska, and Seattle, Washington. Also there is a collection of water temperatures in Anchorage, Alaska and Seattle, Washington.
3. Ice
   Ice is another factor in the operational environment. There are, on average, 10-15 large icebergs in the tanker lanes at Valdez Alaska. Usually the tankers navigate around the ice so as to not cause any unnecessary risk. Ships can be ice strengthened in order to further protect the bow from ice collision damage. This ice strengthening is divided into classes AA, A, B, and C as defined in ABS Rules for Building and Classing, Section 29. Ice strengthening is not required for the ORT.

ABS Requirements Applicable to Concept Design:

- Construction Requirements specified in SAFEHULL
- Section 5: Rudders and Steering Gears
- Section 17: Superstructures and Deckhouses

- Section 19: Machinery Space and Tunnel
- Section 20: Bulwarks, Ports, Ventilators, and Portlights
- Section 22: Vessels intended to Carry Oil in Bulk
  - General
  - Special Requirements for Deep Loading
  - Arrangement
  - Ventilation
  - Pumping Arrangements
  - Electrical Equipment
  - Testing
  - Machinery Spaces
- Sections 31-42: Construction and Classification of Machinery
  - Conditions of Classification of Machinery
  - Internal-combustion Engines
  - Electrical Equipment
  - Pumps and Piping Systems
  - Propellers and Propulsion Shafting
  - Fire Extinguishing Systems
  - Shipboard Automatic and Remote-control Systems

Applicable CFR's:

- CFR 33 Part 157--Rules For The Protection Of The Marine Environment Relating To Tank Vessels Carrying Oil In Bulk
- CFR 46 Subpart 162.050--Pollution Prevention Equipment
- CFR 46 Part 162--Engineering Equipment
- CFR 33 Part 155--Oil Or Hazardous Material Pollution Prevention Regulations For Vessels
- CFR 33 Subpart D--Crude Oil Washing (Cow) System On Tank Vessels
- CFR 46 Subpart 32.53--Inert Gas System
- CFR 33 Part 151--Vessels Carrying Oil, Noxious Liquid Substances, Garbage, Municipal Or Commercial Waste, And Ballast Water
- CFR 33 Subpart A--Implementation Of Marpol 73/78 And The Protocol On Environmental Protection To The Antarctic Treaty As It Pertains To Pollution From Ships
- CFR 46 Part 111, Electric Systems--General Requirements
- CFR 46 Part 112, Emergency Lighting and Power Systems
- CFR 46 Part 39, Vapor Control Systems
- CFR 46 Part 170, Stability Requirements For All Inspected Vessels
- CFR 46 Part 172, Special Rules Pertaining To Bulk Cargoes
- CFR 46 Part 199, Subpart D: Additional Requirements For Cargo Vessels
- CFR 46 Part 50-64, Subchapter F: Marine Engineering (subsystems are listed, may apply)

Local Regulations:

1. Air pollution
   The Marine Environment Protection Committee (MEPC) of the International Maritime Organization agreed on a program of follow-up action towards implementation of the new Annex VI on the Prevention of Air Pollution from Ships, which was adopted at a conference in September 1997. Annex VI , when it comes into force, will set limits on sulfur oxide and nitrogen oxide emissions from ship exhausts and prohibit deliberate emissions of ozone depleting substances.
2. Anti-fouling paint
   The Marine Environment Protection Committee (MEPC) of the International Maritime Organization has agreed to draft mandatory regulations to phase out and eventually prohibit the use of toxic anti-fouling paints containing toxins such as tributyl tin (TBT).At the recently concluded 21st session of the International Maritime Organization (IMO) Assembly in London in November, a resolution was approved that calls for the elimination of organotin biocides by 2003. The resolution bans the application of tin biocides as anti-fouling agents on ships by January 1, 2003 and prohibits the presence of tin biocides by January 1, 2008.

A.1.2 Annual Sea State Occurrences for the North Pacific

Table A.1.2.1 Annual Sea State Occurrences in the North Pacific

Sea State Number	Significant Wave Height (m)		Significant Wave Height (ft)		Sustained Wind Speed (Knots)*		Percentage Probability of Sea State	Modal Wave Period (Sec)	
	Range	Mean	Range	Mean	Range	Mean		Range**	Most Probable***
0-1	0-0.1	0.05	3-0.3	0.15	0-6	3	1.30	—	—
2	0.1-0.5	0.3	0.3-1.6	1.0	7-10	8.5	6.40	5.1-14.9	6.3
3	0.5-1.25	0.88	1.6-4.1	2.9	11-16	13.5	15.50	5.3-16.1	7.5
4	1.25-2.5	1.88	4.1-8.2	6.2	17-21	19	31.60	6.1-17.2	8.8
5	2.5-4	3.25	8.2-13.1	10.7	22-27	24.5	20.94	7.7-17.8	9.7
6	4-6	5	13.1-19.7	16.4	28-47	37.5	15.03	10.0-18.7	12.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix A.2 Concept Design MathCad Model

TANKER Model - LO ORT

Units

$hp \equiv 33000 \frac{ft \cdot lbf}{min}$ $knt \equiv 1.69 \frac{ft}{sec}$ $mile \equiv knt \cdot hr$ $MT \equiv 1000 \cdot kg \cdot g$ $lton \equiv 2240 \cdot lbf$

Physical

Sea water $\rho_{SW} \equiv 1.9905 \frac{slug}{ft^3}$ $\gamma_{SW} \equiv \rho_{SW} \cdot g$ $\upsilon_{SW} := 1.2817 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$

Air properties: $\rho_A := 0.0023817 \frac{slug}{ft^3}$

Liquids specific $\gamma_F := 42.3 \cdot \frac{ft^3}{lton}$ $\gamma_{LO} := 39 \cdot \frac{ft^3}{lton}$ $\gamma_W := 36 \cdot \frac{ft^3}{lton}$

Input - Owner's Requirements (All

Endurance $V_e := 15 \cdot knt$ $MCR := .9$

Vs is calculated to balance the resistance and installed propulsion e is specified and determines required fuel capacity for specified

Range and stores $E := 10000 \cdot mile$ $T_S := \frac{E}{V_e}$ $T_S = 27.777778 \, day$

Deadweight $DWT := 140321 \cdot MT$ $\gamma_{CARGO} := .8674 \frac{MT}{m^3}$

Cargo Pumps: $N_{COP} := 4$ Ballast $N_{BP} := 2$

Bow $N_{BT} := 1$

Max Section $C_X := .995$

Margins   power: weight:

$KG_{MARG} := 0 \cdot m$ $PMF := 1.0$ $WMF := 0.06$ electrical load $EDMF := 1.0$ $EFMF := 1.01$ $E24MF := 1.2$

Input - Design Parameters (Input from Summary Page at

NCbt := 41	NClb := 41	NCb := 41	NCD := 41	Nhdb := 21
Cbtmin := 2.0	Clbmin := 5.	Cbmin := .7	CDmin := 1.2	hdbmin := 2.0
Cbtmax := 4.0	Clbmax := 7.	Cbmax := .9	CDmax := 3.0	hdbmax := 4.0
Nwds := 21	Nmanfac := 11	Nsmf := 6	NHDK := 11	NNcargo := 5
wdsmin := 2.0	manfacmin := .5	smfmin := 1.0	HDKmin := 3.0	Ncargomin := 4
wdsmax := 4.0	manfacmax := 1.0	smfmax := 1.5	HDKmax := 4.0	Ncargomax := 8

NPsystype := 6   NNkw := 2   NNstern := 2
Psystypemin := 1
Psystypemax := 6

$C_{BT} := Cbtmin + DP_1 \cdot \frac{(Cbtmax - Cbtmin)}{NCbt - 1}$ $C_{LB} := Clbmin + DP_2 \cdot \frac{(Clbmax - Clbmin)}{NClb - 1}$

$C_B := Cbmin + DP_3 \cdot \frac{(Cbmax - Cbmin)}{NCb - 1}$ $C_D := CDmin + DP_4 \cdot \frac{(CDmax - CDmin)}{NCD - 1}$

$h_{DB} := hdbmin \cdot m + DP_5 \cdot \frac{(hdbmax - hdbmin) \cdot m}{Nhdb - 1}$ $w := wdsmin \cdot m + DP_6 \cdot \frac{(wdsmax - wdsmin) \cdot m}{Nwds - 1}$

$ManFac := manfacmin + DP_7 \cdot \frac{(manfacmax - manfacmin)}{Nmanfac - 1}$ $SMF := smfmin + DP_8 \cdot \frac{(smfmax - smfmin)}{Nsmf - 1}$

$H_{DK} := HDKmin \cdot m + DP_9 \cdot \frac{(HDKmax - HDKmin) \cdot m}{NHDK - 1}$ $N_{CARGO} := Ncargomin + DP_{10} \cdot \frac{(Ncargomax - Ncargomin)}{NNcargo - 1}$

$PSYS_{TYP} := Psystypemin + DP_{11} \cdot \frac{(Psystypemax - Psystypemin)}{NPsystype - 1}$ $N_{KW} := DP_{12}$ $N_{stern} := DP_{13}$

$C_{BT} = 3.15$ $C_{LB} = 5.05$ $C_B = 0.83$ $C_D = 1.74$ (Hull coefficients)

$N_{CARGO} = 4$ $h_{DB} = 3.9 \, m$ $w = 4 \, m$ (Double Hull Dimensions and Cargo Block Subdivision)

$ManFac = 0.7$ (Reduction from standard crew size due to automation)

$SMF = 1$ (Structural Margin Factor, 1.0 satisfies ABS corrosion allowance)

$H_{DK} = 4 \, m$ Average deck height (deckhouse)

$PSYS_{TYP} = 2$ $N_{KW} = 1$ (Propulsion System and Power Redundancy Options)

Stern Design: $N_{stern} = 2$ $C_{stern} := if(N_{stern} = 2, -25, -11)$ $PC := if(N_{stern} = 2, .75, .7)$

Principal Characteristics and Coefficients on DWL

$V_{FL} := \frac{W_{FL}}{\gamma_{SW}}$ $C_M := C_X$ $C_P := \frac{C_B}{C_M}$

$LWL := \left(\frac{V_{FL} \cdot C_{BT} \cdot C_{LB}^2}{C_P \cdot C_M} \right)^{\frac{1}{3}}$ $B := \frac{LWL}{C_{LB}}$ $T := \frac{B}{C_{BT}}$

$A_M := C_M \cdot B \cdot T$ $C_W := 0.36 + 0.64 \cdot C_P$ $A_W := C_W \cdot LWL \cdot B$ $D := C_D \cdot T$

$LWL = 251.39474 \, m$ $B = 49.781137 \, m$ $D = 27.498152 \, m$ $T = 15.803535 \, m$ $W_{FL} = 1.684 \cdot 10^5 \, MT$

$C_M = 0.995$ $C_P = 0.834171$ $C_W = 0.893869$ $A_W = 1.118652 \cdot 10^4 \, m^2$ $V_{FL} = 1.641547 \cdot 10^5 \, m^3$

Machinery

$\eta := .98$

$N_P := \begin{cases} 1 & \text{if } PSYS_{TYP}=1 \\ 1 & \text{if } PSYS_{TYP}=2 \\ 1 & \text{if } PSYS_{TYP}=3 \\ 2 & \text{if } PSYS_{TYP}=4 \\ 2 & \text{if } PSYS_{TYP}=5 \\ 2 & \text{if } PSYS_{TYP}=6 \end{cases}$ $P_{BPENG} := \begin{cases} 25320 \cdot hp & \text{if } PSYS_{TYP}=1 \\ 30560 \cdot hp & \text{if } PSYS_{TYP}=2 \\ 34580 \cdot hp & \text{if } PSYS_{TYP}=3 \\ 12870 \cdot hp & \text{if } PSYS_{TYP}=4 \\ 15015 \cdot hp & \text{if } PSYS_{TYP}=5 \\ 17160 \cdot hp & \text{if } PSYS_{TYP}=6 \end{cases}$ $SFC_{PE} := \begin{cases} .124 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=1 \\ .124 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=2 \\ .128 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=3 \\ .126 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=4 \\ .126 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=5 \\ .126 \cdot \frac{kg}{hp \cdot hr} & \text{if } PSYS_{TYP}=6 \end{cases}$

$P_I := N_P \cdot P_{BPENG}$ $P_I = 3.056 \cdot 10^4 \, hp$ $SFC_{ePE} := g \cdot SFC_{PE}$

$L_{ENG} := \begin{cases} 10.161 \cdot m & \text{if } PSYS_{TYP}=1 \\ 12.161 \cdot m & \text{if } PSYS_{TYP}=2 \\ 11.992 \cdot m & \text{if } PSYS_{TYP}=3 \\ 6.439 \cdot m & \text{if } PSYS_{TYP}=4 \\ 7.289 \cdot m & \text{if } PSYS_{TYP}=5 \\ 8.139 \cdot m & \text{if } PSYS_{TYP}=6 \end{cases}$ $w_{ENG} := \begin{cases} 7.5 \cdot m & \text{if } PSYS_{TYP}=1 \\ 7.3 \cdot m & \text{if } PSYS_{TYP}=2 \\ 6.8 \cdot m & \text{if } PSYS_{TYP}=3 \\ 5 \cdot m & \text{if } PSYS_{TYP}=4 \\ 5 \cdot m & \text{if } PSYS_{TYP}=5 \\ 5 \cdot m & \text{if } PSYS_{TYP}=6 \end{cases}$ $H_{ENG} := \begin{cases} 12.575 \cdot m & \text{if } PSYS_{TYP}=1 \\ 12.225 \cdot m & \text{if } PSYS_{TYP}=2 \\ 10.85 \cdot m & \text{if } PSYS_{TYP}=3 \\ 8.95 \cdot m & \text{if } PSYS_{TYP}=4 \\ 8.95 \cdot m & \text{if } PSYS_{TYP}=5 \\ 8.95 \cdot m & \text{if } PSYS_{TYP}=6 \end{cases}$

$W_{PENG} := \begin{cases} 624 \cdot MT & \text{if } PSYS_{TYP}=1 \\ 722 \cdot MT & \text{if } PSYS_{TYP}=2 \\ 667 \cdot MT & \text{if } PSYS_{TYP}=3 \\ 207 \cdot MT & \text{if } PSYS_{TYP}=4 \\ 238 \cdot MT & \text{if } PSYS_{TYP}=5 \\ 273 \cdot MT & \text{if } PSYS_{TYP}=6 \end{cases}$ $V_{MBreq} := \begin{cases} 18000 \cdot m^3 & \text{if } PSYS_{TYP}=1 \\ 20000 \cdot m^3 & \text{if } PSYS_{TYP}=2 \\ 22000 \cdot m^3 & \text{if } PSYS_{TYP}=3 \\ 32000 \cdot m^3 & \text{if } PSYS_{TYP}=4 \\ 35000 \cdot m^3 & \text{if } PSYS_{TYP}=5 \\ 38000 \cdot m^3 & \text{if } PSYS_{TYP}=6 \end{cases}$

$W_{ENG} := N_P \cdot W_{PENG}$ $W_{ENG} = 722 \, MT$ $w_{MBreq} := if(N_P = 2, 2 \cdot w_{ENG} + 24 \cdot m, w_{ENG} + 12 \cdot m)$

$L_{MBreq} := L_{ENG} + 12 \cdot m$ $H_{MBreq} := H_{ENG} \cdot 1.5$

Inlet/exhaust cross section area required for each PE:

$A_{IE} := \frac{40.877 \cdot m^2}{2 \cdot 15015 \cdot hp} \cdot N_P \cdot P_{BPENG}$ $A_{IE} = 41.598439 \, m^2$

Manning and Deckhouse Volume

N_T defines the total crew size, N_A the additional accommodations: $N_A := 3$

$N_T := 10 + ceil\left[ManFac \cdot \left(N_P \cdot 4 + \frac{V_{FL}}{16000 \cdot m^3} \right) \right]$ $N_T = 20$

Provisions: $W_{F31} := N_T \cdot 2.0 \cdot 10^{-3} \cdot \frac{lton}{day} \cdot T_S$ $W_{F31} = 1.128941 \, MT$

General stores: $W_{F32} := 0.0005 \cdot \frac{lton}{day} \cdot T_S \cdot N_T + 0.004 \cdot lton \cdot N_T$ $W_{F32} = 0.363519 \, MT$

Crew: $W_{F10} := 400 \cdot lbf \cdot N_T$ $W_{F10} = 3.628739 \, MT$ $W_{crew} := W_{F31} + W_{F32} + W_{F10}$ $W_{crew} = 5.121199 \, MT$

1) 46 CFR Ch.I 32.20-1 (10-1-98 Edition, conning vision):

$d_m := 2 \cdot m + .02 \cdot LWL$ (minimum draft in ballast) $d_m = 7.027895 \, m$

$L_V := 500 \cdot m + .85 \cdot LWL$ $H_V := \left(\frac{D + H_{DK} - d_m}{500 \cdot m} \right) \cdot L_V + 1 \cdot m$ $H_V = 35.928136 \, m$

2) $A_C := 11200 \cdot ft^2$ Constant areas (lounges, galeys, laundry, elevator, stair tower, LAN, etc.)

$A_{CO2} := 1012 \cdot ft^2$ $A_{MechShop} := 2953 \cdot ft^2$ $A_{LAN} := 350 \cdot ft^2$ $A_{Bridge} := 1687 \cdot ft^2$

$A_{Req} := A_{CO2} + A_{MechShop} + A_C + A_{Bridge} + A_{LAN}$ $A_{Req} = 1.7202 \cdot 10^4 \, ft^2$

3) Living areas: $A_L := (N_T + N_A) \cdot (240 \cdot ft^2 + 18 \cdot ft^2) + 1800 \cdot ft^2$

4) Store areas: $A_S := (N_T + N_A) \cdot 131 \cdot ft^2$ $C_{passage} := 1.157$

5) Total Deck House Area: $A_{DH} := (A_{Req} + A_L + A_S) \cdot C_{passage}$ $A_{DH} = 3.233699 \cdot 10^4 \, ft^2$

6) Number of Deck House Decks: $N_{DK} := ceil\left(\frac{H_V - D + d_m}{H_{DK}} \right)$ $N_{DK} := \begin{cases} 5 & \text{if } N_{DK} < 5 \\ N_{DK} & \text{otherwise} \end{cases}$ $N_{DK} = 5$

7) Area of each Deck House Deck: $A_{DK} := \frac{A_{DH}}{N_{DK}}$

8) Breadth and Length of the Deck House: $B_{DH} := B - 8 \cdot m$ $L_{DHreq} := \frac{A_{DK}}{B_{DH}}$ $L_{DHreq} = 14.380676 \, m$

9) Deck House Volume: $V_D := N_{DK} \cdot H_{DK} \cdot B_{DH} \cdot L_{DHreq}$ $V_D = 4.2437 \cdot 10^5 \, ft^3$

10) Intake / Exhoust Area: $A_{CO2} := 711 \cdot ft^2$ $A_{IG} := 2 \cdot 711 \cdot ft^2$ $A_{Gen} := 711 \cdot ft^2$

$L_{IEreq} := \frac{2 \cdot N_P \cdot A_{IE} + A_{CO2} + A_{IG} + A_{Gen}}{2 \cdot (B_{DH} - 10 \cdot m)}$ $L_{IEreq} = 5.465713 \, m$

11) Required Length for the Superstructure: $L_{SSreq} := L_{DHreq} + L_{IEreq}$ $L_{SSreq} = 19.846389 \, m$

$V_{SS} := L_{IEreq} \cdot 2 \cdot H_{DK} \cdot (B_{DH} - 10 \cdot m) + V_D$ $V_{SS} = 4.734451 \cdot 10^5 \, ft^3$

Resistance and Power

Viscous Drag

$i := 1..9 \quad V_i := i \cdot 2 \cdot knt \quad V_7 := V_e \qquad V_e = 15 \cdot knt \qquad V_8 := V_S \qquad V_S = 15.74 \cdot knt$

Correlation allowance: $C_A := 0.0005$

$A_{BT} := .05 \cdot A_M \qquad A_{BT} = 39.139218\ m^2$

$S := LWL \cdot (2 \cdot T + B) \cdot \sqrt{C_M} \cdot \left(.453 + .4425 \cdot C_B - .2862 \cdot C_M - .003467 \cdot \frac{B}{T} + .3696 \cdot C_W\right) + 2.38 \cdot \frac{A_{BT}}{C_B} \qquad S = 1.756139 \cdot 10^4\ m^2$

$L_R := (1 - C_P) \cdot LWL \qquad L_R = 41.688575\ m$ (Run length)

$c_{14} := 1 + .011 \cdot C_{stern}$

$formfac := .93 + .487118 \cdot c_{14} \cdot \left(\frac{T}{LWL}\right)^{.46106} \cdot \left(\frac{B}{LWL}\right)^{1.06806} \cdot \left(\frac{LWL}{L_R}\right)^{.121563} \cdot \left(\frac{LWL^3}{V_{FL}}\right)^{.36486} \cdot (1 - C_P)^{-.60424} \qquad formfac = 1.27176$

Using the ITTC friction expression: $R_i := \frac{V_i}{\sqrt{LWL}} \qquad R_{N_i} := LWL \cdot \frac{V_i}{\upsilon_{SW}} \qquad C_{F_i} := \frac{0.075}{\left(\log\left(R_{N_i}\right) - 2\right)^2}$

$R_{V_i} := \frac{1}{2} \cdot \rho_{SW} \cdot S \cdot C_{F_i} \cdot (V_i)^2 \cdot formfac$

Wave Making Drag

$C_V := \frac{V_{FL}}{LWL^3} \qquad C_V = 0.01033 \qquad C_X = 0.995 \qquad LWL = 251.39474\ m \qquad B = 49.781137\ m$

$A_{BT} = 39.139218\ m^2$ (bulb section area at FP) $\qquad C_W = 0.893869$

$h_B := \sqrt{\frac{A_{BT}}{\pi}} \qquad h_B = 3.529646\ m$ (height of bulb center)

$A_T := \frac{B \cdot T \cdot C_X}{10} \qquad A_T = 78.278436\ m^2$ (transom area) $\qquad A_M = 782.784364\ m^2$

$Fn_i := \frac{V_i}{\sqrt{g \cdot LWL}}$

Call the residuary drag coefficients module, which calculates C_R for different beam to draft ratios:

$c_3 := \frac{.56 \cdot {A_{BT}}^{1.5}}{B \cdot T \cdot \left(.31 \cdot \sqrt{A_{BT}} + T - h_B\right)} \qquad c_3 = 0.012263 \qquad c_2 := \exp\left(-1.89 \cdot \sqrt{c_3}\right) \qquad c_2 = 0.811156$

$c_5 := 1 - \frac{.8 \cdot A_T}{B \cdot T \cdot C_M} \qquad c_5 = 0.92$

$\lambda_R := \begin{cases} 1.446 \cdot C_P - .03 \cdot \frac{LWL}{B} & \text{if } \frac{LWL}{B} < 12 \\ 1.446 \cdot C_P - .036 & \text{otherwise} \end{cases} \qquad \lambda_R = 1.054711$

$c_{15} := \begin{cases} -1.69385 & \text{if } \frac{LWL^3}{V_{FL}} < 512. \\ 0.0 & \text{if } \frac{LWL^3}{V_{FL}} > 1726.91 \\ -1.69385 + \frac{\frac{LWL}{{V_{FL}}^{\frac{1}{3}}} - 8}{2.36} & \text{otherwise} \end{cases} \qquad c_{15} = -1.69385$

$c_7 := \begin{cases} .229577 \cdot \left(\frac{B}{LWL}\right)^{.33333} & \text{if } \frac{B}{LWL} < .11 \\ .5 - .0625 \cdot \frac{LWL}{B} & \text{if } \frac{B}{LWL} > .25 \\ \frac{B}{LWL} & \text{otherwise} \end{cases} \qquad c_7 = 0.19802$

$c_{16} := \begin{cases} 8.07981 \cdot C_P - 13.8673 \cdot {C_P}^2 + 6.984388 \cdot {C_P}^3 & \text{if } C_P < .8 \\ 1.73014 - .7067 \cdot C_P & \text{otherwise} \end{cases} \qquad c_{16} = 1.140631$

$i_E := 1 + 89 \cdot \exp\left[-\left(\frac{LWL}{B}\right)^{.80856} \cdot (1 - C_W)^{.30484} \cdot (1 - C_P)^{.6367} \cdot \left(\frac{L_R}{B}\right)^{.34574} \cdot \left(\frac{100 \cdot V_{FL}}{LWL^3}\right)^{.16302}\right] \qquad i_E = 51.68439$

$c_1 := 2223105 \cdot {c_7}^{3.78613} \cdot \left(\frac{T}{B}\right)^{1.07961} \cdot (90 - i_E)^{-1.37565} \qquad c_1 = 9.290851$

$m_1 := .0140407 \cdot \frac{LWL}{T} - 1.75254 \cdot \frac{{V_{FL}}^{\frac{1}{3}}}{LWL} - 4.79323 \cdot \frac{B}{LWL} - c_{16} \qquad m_1 = -2.24814$

$m_{4_i} := .4 \cdot c_{15} \cdot \exp\left[-.034 \cdot (Fn_i)^{-3.29}\right]$

$R_{w_i} := V_{FL} \cdot \rho_{SW} \cdot g \cdot c_1 \cdot c_2 \cdot c_5 \cdot \exp\left[m_1 \cdot (Fn_i)^{-.9} + m_{4_i} \cdot \cos\left[\frac{\lambda_R}{(Fn_i)^2}\right]\right]$

$P_B := \frac{.56 \cdot {A_{BT}}^{.5}}{(T - 1.5 \cdot h_B)} \qquad P_B = 0.333373$

$Fni_i := \frac{V_i}{\sqrt{g \cdot \left(T - h_B - .25 \cdot {A_{BT}}^{.5}\right) + .15 \cdot (V_i)^2}}$

$R_{B_i} := \frac{.11 \cdot \exp\left(\frac{-3}{{P_B}^2}\right) \cdot (Fni_i)^3 \cdot {A_{BT}}^{1.5} \cdot \rho_{SW} \cdot g}{1 + (Fni_i)^2}$

$FnT_i := \frac{V_i}{\sqrt{\frac{2 \cdot g \cdot A_T}{B + B \cdot C_W}}}$

$c_{6_i} := \begin{cases} .2 \cdot (1 - .2 \cdot FnT_i) & \text{if } FnT_i < 5 \\ 0. & \text{otherwise} \end{cases}$

$R_{TR_i} := .5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot A_T \cdot c_{6_i}$

$R_{A_i} := .5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S \cdot C_A$

$R_{R_i} := R_{w_i} + R_{B_i} + R_{TR_i} + R_{A_i}$

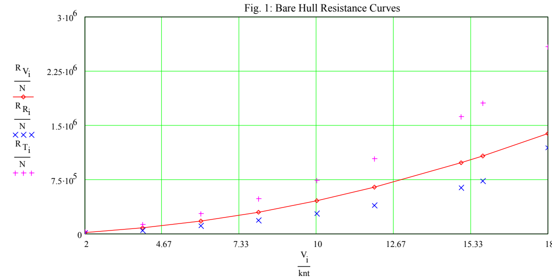
Bare Hull Resistance

$R_{T_i} := R_{V_i} + R_{R_i}$

Ship Effective Horsepower

Bare hull: $P_{EBH_i} := R_{T_i} \cdot V_i$

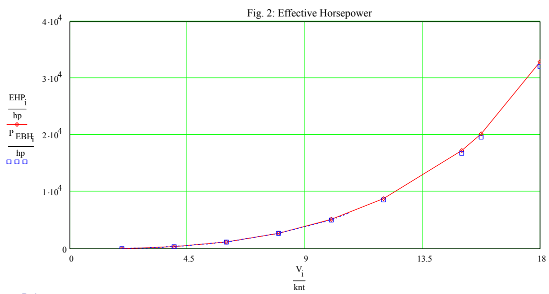
Fig. 1: Bare Hull Resistance Curves



Air frontal area (+5% for masts, equip., etc): $A_F := 1.05 \cdot B \cdot (D - T + N_{DK} \cdot H_{DK})$ $A_F = 1656.683718\ m^2$

$C_{AA} := 0.7$ $P_{EAA_i} := \frac{1}{2} \cdot C_{AA} \cdot A_F \cdot \rho_A \cdot (V_i)^3$

Total effective horsepower: $EHP_i := PMF \cdot (P_{EBH_i} + P_{EAA_i})$



Power Balance

Approximate propulsive coefficient:

$SHP_i := \frac{EHP_i}{PC}$ $SHP_e := SHP_7$ $SHP_e = 2.298913 \cdot 10^4 \cdot hp$ $SHP_S := SHP_8$

Required installed power:

$P_{IREQ} := \frac{SHP_e}{\eta \cdot MCR}$ $P_{IREQ} = 26064.8 \cdot hp$ $P_{IS} := \frac{SHP_S}{\eta \cdot MCR}$ $P_{IS} = 3.050251 \cdot 10^4 \cdot hp$

Space

Total hull volume: $V_{HT} := C_B \cdot LWL \cdot B \cdot D$ $V_{HT} = 2.856292 \cdot 10^5\ m^3$

Total ship volume: $V_T := V_{HT} + V_D$ $V_T = 297646.01\ m^3$

Electrical Load

Based on DDS 310-1. Estimate maximum functional load for winter cruise condition:

$KW_P := 0.00323 \cdot \frac{kW}{hp} \cdot P_I$ (SWBS 200, propulsion). $KW_P = 98.7088 \cdot kW$

$KW_S := 0.0031 \cdot \frac{kW}{ft^2} \cdot LWL \cdot T \cdot N_P$ (SWBS 561, steering). $KW_S = 132.56907 \cdot kW$

$KW_E := 0.0002 \cdot \frac{kW}{ft^3} \cdot V_D$ (SWBS 300, electric plant, lighting). $KW_E = 84.873997 \cdot kW$

$KW_M := 25 \cdot kW$ (SWBS 430+475, miscelaneous). $KW_M = 25 \cdot kW$

$KW_F := 0.00002 \cdot \frac{kW}{ft^3} \cdot (V_T)$ (SWBS 521, firemain). $KW_F = 210.225393 \cdot kW$

$KW_A := 0.65 \cdot N_T \cdot kW$ (SWBS 530+550, misc aux). $KW_A = 13 \cdot kW$

$KW_{SERV} := 0.395 \cdot N_T \cdot kW$ (SWBS 600, services). $KW_{SERV} = 7.9 \cdot kW$

$KW_H := 0.0007 \cdot \frac{kW}{ft^3} \cdot (V_D)$ $KW_H = 297.058991 \cdot kW$

$KW_V := 0.103 \cdot KW_H$ $KW_V = 30.597076 \cdot kW$

$KW_{AC} := 0.67 \cdot \left(0.1 \cdot kW \cdot N_T + 0.00067 \cdot \frac{kW}{ft^3} \cdot V_D\right)$ $KW_{AC} = 191.839687 \cdot kW$

$KW_{BT} := N_{BT} \cdot 2237 \cdot kW$ $KW_{BT} = 2237 \cdot kW$

$KW_{NC} := KW_P + KW_S + KW_E + KW_M + KW_F + KW_A + KW_{SERV} + KW_H + KW_V$ (non-Cargo)

$KW_{BP} := 300 \cdot kW \cdot N_{BP}$ $KW_{COP} := 1306 \cdot kW \cdot N_{COP}$ $KW_{COW} := 520 \cdot kW$ $KW_{CSP} := 411 \cdot kW$

$KW_{CARGO} := KW_{BP} + KW_{COP} + KW_{COW} + KW_{CSP}$ $KW_{CARGO} = 6755 \cdot kW$

$KW_{SSMFL} := KW_{NC}$ $KW_{SSMFL} = 899.933326 \cdot kW$ Maximum Functional Load

$KW_{PTOMFL} := KW_{CARGO} + \frac{KW_{SSMFL}}{.8}$ $KW_{PTOMFL} = 7879.916658 \cdot kW$ (Assums MG set conversion to SS)

$KW_{SSMFLM} := EDMF \cdot EFMF \cdot KW_{SSMFL}$ $KW_{SSMFLM} = 908.93266 \cdot kW$ (MFL w/margins)

$KW_{PTOMFLM} := EDMF \cdot EFMF \cdot KW_{PTOMFL}$ $KW_{PTOMFLM} = 7958.715825 \cdot kW$ (MFL w/margins)

$KW_{SSGREQ} := KW_{SSMFLM}$ $KW_{SSGREQ} = 908.93266 \cdot kW$ $KW_{EMERG} := 750 \cdot kW$

$KW_{DG} := N_{KW} \cdot ceil\left(\frac{KW_{SSGREQ}}{250 \cdot kW}\right) \cdot 250 \cdot kW + KW_{EMERG}$ $KW_{DG} = 1750 \cdot kW$

$KW_{PTO} := if\left(N_P = 2, N_{KW} \cdot ceil\left(\frac{KW_{PTOMFLM}}{500 \cdot kW}\right) \cdot 500 \cdot kW, N_{KW} \cdot ceil\left(\frac{KW_{PTOMFLM}}{500 \cdot kW}\right) \cdot 500 \cdot kW\right)$ $KW_{PTO} = 8000 \cdot kW$

$KW_{24} := 0.5 \cdot (KW_{SSMFL} - KW_P - KW_S) + 1 \cdot (KW_P + KW_S) + .2 \cdot KW_{CARGO}$ $KW_{24} = 1916.605598 \cdot kW$

Including design margin: $KW_{24AVG} := E24MF \cdot KW_{24}$ $KW_{24AVG} = 2299.926718 \cdot kW$

Space

Tankage

Fuel

Based on [3]. Start with fuel for propulsion systems.
Average endurance brake horsepower required:

$P_{eBAVG} := \frac{SHP_e}{\eta}$ $P_{eBAVG} = 2.34583 \cdot 10^4 \cdot hp$

Correction for instrumentation inaccuracy and machinery design changes:

$$f_I := \begin{cases} 1.04 & \text{if } 1.1 \cdot SHP_e \le \frac{1}{3} \cdot \frac{P_I}{2} \\ 1.03 & \text{if } 1.1 \cdot SHP_e \ge \frac{2}{3} \cdot \frac{P_I}{2} \\ 1.02 & \text{otherwise} \end{cases}$$

$f_I = 1.03$

$SFC_{ePE} = 0.273373 \cdot \frac{lbf}{hp \cdot hr}$

Specified fuel rate: $FR_{SP} := f_I \cdot SFC_{ePE}$

Average fuel rate allowing for plant deterioration: $FR_{AVG} := 1.05 \cdot FR_{SP}$ $FR_{AVG} = 0.295653 \cdot \frac{lbf}{hp \cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e} \cdot P_{eBAVG} \cdot FR_{AVG}$ $W_{BP} = 2064.142357 \cdot lton$

Tailpipe allowance: $TPA := 0.95$

Required propulsion fuel weight: $W_{FP} := \frac{W_{BP}}{TPA}$ $W_{FP} = 2172.781428 \cdot lton$

Required propulsion fuel tank volume (including allowance for expansion and tank internal structure):

$V_{FP} := 1.02 \cdot 1.05 \cdot \gamma_F \cdot W_{FP}$ $V_{FP} = 2787.345259\ m^3$

$SFC_G := 0.4727 \cdot \frac{lbf}{hp \cdot hr}$ $SFC_{eG} := SFC_{ePE}$ (assumes PTO)

Margin for instrumentation inaccuracy and machinery design changes: $f_{1e} := 1.04$

Specified fuel rate: $FR_{GSP} := f_{1e} \cdot SFC_{eG}$

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05 \cdot FR_{GSP}$ $FR_{GAVG} = 0.400327 \cdot \frac{lbf}{kW \cdot hr}$

Burnable electrical endurance fuel weight:

$W_{Be} := \frac{E}{V_e} \cdot KW_{24AVG} \cdot FR_{GAVG}$ $W_{Be} = 278.421645 \cdot MT$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $W_{Fe} = 288.446737 \cdot lton$

Required electrical fuel volume: $V_{Fe} := 1.02 \cdot 1.05 \cdot \gamma_F \cdot W_{Fe}$ $V_{Fe} = 370.032915\ m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $W_{F41} = 2461.228165 \cdot lton$

$V_F := V_{FP} + V_{Fe}$ $V_F = 3157.378174 \cdot m^3$

Other Tanks

Lubrication oil: $W_{F46} := 17.6 \cdot lton$ $V_{LO} := 1.02 \cdot 1.05 \cdot W_{F46} \cdot \gamma_{LO}$ $V_{LO} = 20.816688\ m^3$

Potable water: $W_{F52} := N_T \cdot 7.3 \cdot lton$ $W_{F52} = 146 \cdot lton$ $N_T = 20$

$V_W := 1.02 \cdot W_{F52} \cdot \gamma_W$ $V_W = 151.810013\ m^3$

Sewage: $V_{SEW} := (N_T + N_A) \cdot 2.005 \cdot ft^3$ $V_{SEW} = 1.305831\ m^3$

Waste oil: $V_{WASTE} := 0.02 \cdot V_F$ $V_{WASTE} = 63.147563\ m^3$

Total ship tankage volume required:

$V_{TK} := V_F + V_{LO} + V_W + V_{SEW} + V_{WASTE}$ $V_{TK} = 3394.458269\ m^3$

Cargo Volume, Weights and VCGs

$B_{CB} := B - 2 \cdot w$

$D_{CB} := D - h_{DB}$ $C_{STK} := .6$ $C_{FTK} := .8$

$W_{CARGO} := DWT - W_{F41} - W_{F46} - W_{F52} - W_{crew}$ $W_{CARGO} = 1.376489 \cdot 10^5 \cdot MT$

$C_{CARGO} := \frac{W_{CARGO}}{.98 \cdot \gamma_{CARGO}}$ $C_{CARGO} = 1.6193 \cdot 10^5\ m^3$

$$L_{CTK} := \frac{.98 \cdot N_{CARGO} \cdot C_{CARGO}}{(N_{CARGO} - 1 + C_{FTK} \cdot C_B) \cdot B_{CB} \cdot D_{CB} \cdot (C_B + .164)}$$

$$L_{STK} := \frac{.02 \cdot C_{CARGO}}{C_{STK} \cdot C_B \cdot B_{CB} \cdot D_{CB}}$$

$L_{CB} := L_{CTK} + L_{STK}$ $L_{CB} = 183.367775\ m$

Ballast Tanks

$V_{FPT} := 0.0229 \cdot V_{HT}$ $V_{FPT} = 6540.908448\ m^3$ Forepeak tank volume

$V_{APT} := .00938 \cdot V_{HT}$ $V_{APT} = 2679.201801\ m^3$ Aftpeak tank volume

$V_{BAL} := 2 \cdot [L_{CB} \cdot w \cdot (D - h_{DB})] + (L_{CB} \cdot B \cdot h_{DB}) + V_{FPT} + V_{APT}$ $V_{BAL} = 7.943743 \cdot 10^4\ m^3$

Machinery box

$L_{MB} := LWL - 0.05 \cdot LWL - L_{CB} - 3\ m - 0.062 \cdot LWL$ length of cofferdam = 3m $L_{MB} = 36.870754\ m$ $L_{SS} := L_{MB}$

$H_{MB} := D$ $H_{MB} = 27.498152\ m$ $V_{MB} := (C_X \cdot H_{MB} \cdot L_{MB} \cdot B)$

$V_{MB} = 5.021962 \cdot 10^4\ m^3$ $w_{MB} := B$ $w_{MB} = 49.781137\ m$

Weight

SWBS 100

Hull and Structure:

W1=C100*SMF*(Ncargo+6)/12.*LWL**3*B*(Cb+.7)/(3.*D10-2.*hdb)+Wdh

$W_{DH} := 0.001 \cdot \frac{MT}{ft^3} \cdot V_{SS}$ $W_{DH} = 473.445102 \cdot MT$ $C_{100} := 1.304 \cdot \frac{lbf}{in^3}$

$\sigma y := 3 \cdot 10^8 \cdot \frac{N}{m^2}$ $Mb := 0.009 \cdot LWL^{2.5} \cdot B \cdot \frac{MT}{m^{2.5}}$ $yNA := \frac{B \cdot D + B \cdot h_{DB} + 2 \cdot D^2}{4 \cdot D + 3 \cdot B}$ $C_{100} = 36.094596 \cdot \frac{MT}{m^3}$

$IND := B \cdot D^2 + B \cdot h_{DB}^2 + \frac{4}{3} \cdot D^3 - yNA^2 \cdot (4 \cdot D + 3\ B)$ $tt := \frac{(D - yNA) \cdot Mb}{\sigma y \cdot IND}$ $\sigma y = 3.059149 \cdot 10^4 \cdot \frac{MT}{m^2}$

$Vsteel := LWL \cdot (4 \cdot D + 3 \cdot B) \cdot tt + (N_{CARGO} + 3) \cdot B \cdot D \cdot tt$ $W_{BH} := C_{100} \cdot Vsteel \cdot SMF$ $W_{BH} = 2.089097 \cdot 10^4 \cdot MT$

$W_1 := W_{BH} + W_{DH}$ $W_1 = 2.136442 \cdot 10^4 \cdot MT$ $tt = 0.00774\ m$ $Mb = 4.489498 \cdot 10^5 \cdot MT \cdot m$

SWBS 200

Basic machinery: SWBS 200 Coefficient: $C_{200} := 2.4748$ $W_{ENG} = 722 \cdot MT$

$W_2 := C_{200} \cdot W_{ENG}$ $W_2 = 1786.8056 \cdot MT$

$C_{200} := .01439 \cdot \frac{MT}{hp}$

$W_2 := C_{200} \cdot P_I \cdot N_P^{.7} + W_{ENG}$ $W_2 = 1161.7584 \cdot MT$

SWBS 300 (Modeled on USN ASSET Parametrics) $KW_{DG} = 1750 \cdot kW$

$W_3 := 50 \cdot lton + 0.036 \cdot \frac{lton}{kW} \cdot KW_{DG} + 0.00525 \cdot \frac{lton}{kW} \cdot KW_{PTO}$ $KW_{PTO} = 8000 \cdot kW$

$W_3 = 157.487271 \cdot MT$

SWBS 400

SWBS 400 Coefficient: $C_{400} := 5.52 \cdot lton$ $C_{400} = 5.608579 \cdot MT$

$W_4 := \frac{C_{400}}{ManFac}$ $W_4 = 8.012256 \cdot MT$

SWBS 500

$$W_{AUX} := \left[0.00067 \cdot \left(\frac{V_D}{ft^3}\right)^{1.443} + 5.14 \cdot \frac{V_D}{ft^3} + 6.19 \cdot \left(\frac{V_D}{ft^3}\right)^{0.7224} + 377 \cdot N_T + 2.74 \cdot \frac{P_I}{hp}\right] \cdot 10^{-4} \cdot lton + 200 \cdot lton$$

Aux system operating fluids: $W_{598} := 0.000062 \cdot V_T \cdot \frac{lton}{ft^3}$ $W_{598} = 651.698717 \cdot lton$

$W_{AUXCARGO} := 955 \cdot MT + 1.9 \cdot \frac{MT}{m} \cdot LWL \cdot \frac{(N_{CARGO} + 6)}{12}$

Environmental support: $W_{593} := 8 \cdot lton$

Total: $W_5 := W_{AUX} + W_{AUXCARGO} + W_{593} + W_{598}$ $W_5 = 2473.740418 \cdot MT$

SWBS 600

SWBS 600 Coefficient: $C_{600} := .1027 \cdot \frac{MT}{m^3}$

$W_6 := C_{600} \cdot V_D$ $W_6 = 1234.127395 \cdot MT$

SWBS 700

$W_7 := W_{CARGO}$ $W_7 = 1.376489 \cdot 10^5 \cdot MT$

Weight Summary

Margin for future growth: $W_{margin} := WMF \cdot \sum_{i=1}^{6} W_i$ $W_{margin} = 1583.972743 \cdot MT$

Lightship weight: $W_{LS} := \sum_{i=1}^{6} W_i + W_{margin}$ $W_{LS} = 2.798352 \cdot 10^4 \cdot MT$

Total weight:

$W_T := W_{LS} + DWT$ $W_T = 1.683045 \cdot 10^5 \cdot MT$

Stability

Calculate light ship weight groups center of gravity and moment.

$VCG_{BH} := 0.4863 \cdot \left(D - \frac{2}{5} \cdot m + \frac{h_{DB}}{5}\right)$ $VCG_{BH} = 13.557145\ m$ $P_1 := (W_1 - W_{DH}) \cdot VCG_{BH}$

$VCG_{DH} := D + (0.65 \cdot N_{DK} \cdot H_{DK})$ $VCG_{DH} = 40.498152\ m$ $P_2 := W_{DH} \cdot VCG_{DH}$

$P_{100} := P_1 + P_2$ $VCG_{100} := \frac{P_{100}}{W_1}$ $VCG_{100} = 14.15417\ m$

$VCG_{200} := 0.3265 \cdot D$ $VCG_{200} = 8.978147\ m$ $P_{200} := W_2 \cdot VCG_{200}$

$VCG_{300} := 0.7355 \cdot D$ $VCG_{300} = 20.224891\ m$ $P_{300} := W_3 \cdot VCG_{300}$

$VCG_{400} := (0.755) \cdot (N_{DK} \cdot H_{DK}) + D$ $VCG_{400} = 42.598152\ m$ $P_{400} := W_4 \cdot VCG_{400}$

$VCG_{500} := 0.65 \cdot D$ $VCG_{500} = 17.873799\ m$ $P_{500} := W_5 \cdot VCG_{500}$

$VCG_{600} := 0.867 \cdot D$ $VCG_{600} = 23.840897\ m$ $P_{600} := W_6 \cdot VCG_{600}$

Loads:

$VCG_{Fuel} := 0.70 \cdot D$ $VCG_{Fuel} = 19.248706\ m$ $P_{Fuel} := W_{F41} \cdot VCG_{Fuel}$

$VCG_{Water} := 0.95 \cdot D$ $VCG_{Water} = 26.123244\ m$ $P_{Water} := W_{F52} \cdot VCG_{Water}$

$VCG_{crew} := D + 2 \cdot N_{DK} \cdot H_{DK}$ $VCG_{crew} = 67.498152\ m$ $P_{crew} := VCG_{crew} \cdot W_{crew}$

$VCG_{Cargo} := \frac{0.98 \cdot (D - h_{DB})}{2} + h_{DB}$ $VCG_{Cargo} = 15.463094\ m$ $P_{Cargo} := W_7 \cdot VCG_{Cargo}$

$VCG_{FPT} := 10.5 \cdot m$ $VCG_{APT} := 15 \cdot m$

$$VCG_{Bal} := \frac{V_{FPT} \cdot VCG_{FPT} + V_{APT} \cdot VCG_{APT} + B \cdot h_{DB} \cdot L_{CB} \cdot 0.5 \cdot h_{DB} + 2 \cdot (D - h_{DB}) \cdot w \cdot L_{CB} \cdot [0.5 \cdot (D - h_{DB})]}{V_{BAL}}$$

$VCG_{Bal} = 7.386165\ m$

$P_{Bal} := V_{BAL} \cdot \gamma_{SW} \cdot VCG_{Bal}$ $P_{Bal} = 6.01912 \cdot 10^5 \cdot MT \cdot m$

Total Light Ship vertical moment is (note that variable payload is deducted): $D = 27.498152\ m$

$P_{LS} := P_{100} + P_{200} + P_{300} + P_{400} + P_{500} + P_{600}$ $VCG_{LS} := \frac{P_{LS}}{W_{LS} - W_{margin}}$ $VCG_{LS} = 14.772617\ m$

Vertical CG in departure ballast: $VCG_{BAL} := \frac{VCG_{LS} \cdot W_{LS} + P_{Fuel} + P_{Water} + P_{Bal} + P_{crew}}{W_{LS} + V_{BAL} \cdot \gamma_{SW} + W_{F41} + W_{F52} + W_{crew}}$ $VCG_{BAL} = 9.521653\ m$

Here we assume that the 10% weight margin's CG location is at the CG of light ship.

$KG_{BAL} := VCG_{BAL} + KG_{MARG}$ $KG_{BAL} = 9.521653\ m$

$C_{IT} := -0.537 + 1.44 \cdot C_W$ $C_{IT} = 0.750172$ $T_{BAL} := \frac{W_{LS} + V_{BAL} \cdot \gamma_{SW}}{W_{FL}} \cdot T$ $T_{BAL} = 10.273736\ m$

$KB_{BAL} := \frac{T_{BAL}}{3} \cdot \left(2.4 - \frac{C_P \cdot C_X}{C_W}\right)$ $KB_{BAL} = 5.039106 \cdot m$ $BM_{BAL} := \frac{LWL \cdot B^3 \cdot C_{IT} \cdot \gamma_{SW}}{12 \cdot (W_{LS} + V_{BAL} \cdot \gamma_{SW} + W_{F41} + W_{F52})}$

$GM_{BAL} := KB_{BAL} + BM_{BAL} - KG_{BAL}$ $GM_{BAL} = 13.256029 \cdot m$ $C_{GMB} := \frac{GM_{BAL}}{B}$ $C_{GMB} = 0.266286$

Total Full Load ship: $BM_{BAL} = 17.738577\ m$

Vertical CG of Full Ship $VCG_{Full} := \frac{VCG_{LS} \cdot W_{LS} + P_{Fuel} + P_{Water} + P_{Cargo} + P_{crew}}{W_T}$ $VCG_{Full} = 15.413875\ m$

Here we assume that the 10% weight margin's CG location is at the CG of light ship.

$KG_{Full} := VCG_{Full} + KG_{MARG}$ $KG_{Full} = 15.413875\ m$

$KB := \frac{T}{3} \cdot \left(2.4 - \frac{C_P \cdot C_X}{C_W}\right)$ $KB = 25.431052 \cdot ft$ $BM := \frac{LWL \cdot B^3 \cdot C_{IT}}{12 \cdot V_{FL}}$ $BM = 11.810731\ m$

$GM_{Full} := KB + BM - KG_{Full}$ $GM_{Full} = 4.148242 \cdot m$ $C_{GMBFull} := \frac{GM_{Full}}{B}$ $C_{GMBFull} = 0.08333$

Freeboard (Load Line) Requirement:

$Ftable(L) := 4.62 \cdot 10^{-3} \cdot L + 1.87 \cdot m$ $Fmin := Ftable(LWL) \cdot \frac{C_B + .68}{1.36} + \left(D - \frac{LWL}{15}\right) \cdot 3 \cdot \frac{in}{ft}$ $Tmax := D - Fmin$

Design Balance / Summary - Tanker

$W_T = 1.683045 \cdot 10^5 \cdot MT$ $W_{FL} \equiv 168400 \cdot MT$ $ERR := \frac{W_{FL} - W_T}{W_T}$ $ERR = 5.673142 \cdot 10^{-4}$

$LWL = 251.39 \cdot m$ $B = 49.78\ m$ $T = 15.8\ m$ $A_M = 782.78 \cdot m^2$ $C_W = 0.894$ $A_W = 1.12 \cdot 10^4\ m^2$

$C_M = 0.995$ $C_P = 0.834$

$C_{BT} = 3.15$ $C_{LB} = 5.05$ $C_B = 0.83$ $C_D = 1.74$ (Hull coefficients)

$N_{CARGO} = 4$ $h_{DB} = 3.9\ m$ $w = 4\ m$ (Double Hull Dimensions and Cargo Block Subdivision)

$ManFac = 0.7$ (Reduction from standard crew size due to automation)

$SMF = 1$ (Structural Margin Factor, 1.0 satisfies ABS corrosion allowance)

$H_{DK} = 4\ m$ Average deck height (deckhouse)

$PSYS_{TYP} = 2$ $N_{KW} = 1$ (Propulsion System and Power Redundancy Options)

$$DP \equiv \begin{bmatrix} 23 \\ 1 \\ 26 \\ 12 \\ 19 \\ 20 \\ 4 \\ 0 \\ 10 \\ 0 \\ 1 \\ 1 \\ 2 \end{bmatrix}$$

Stern Design: $N_{stern} = 2$ $C_{stern} := if(N_{stern} = 2, -25, -11)$ $PC := if(N_{stern} = 2, .75, .7)$

Balance Check	Required	Available	Error
Weight:	$W_T = 1.683045 \cdot 10^5 \cdot MT$	$W_{FL} = 1.684 \cdot 10^5 \cdot MT$	$ERR = 5.673142 \cdot 10^{-4}$
Load Line:	$Tmax = 21.447732\ m$	$T = 15.803535\ m$	
Propulsion power:	$P_{IREQ} = 2.606477 \cdot 10^4 \cdot hp$	$P_I = 3.056 \cdot 10^4 \cdot hp$	$W_{LS} = 2.798352 \cdot 10^4 \cdot MT$
$V_S \equiv 15.74 \cdot knt$	$P_{IS} = 3.050251 \cdot 10^4 \cdot hp$		
Mach. box height:	$H_{MBreq} = 18.3375\ m$	$H_{MB} = 27.498152\ m$	
	$L_{MBreq} = 24.161\ m$	$L_{MB} = 36.870754\ m$	
	$w_{MBreq} = 19.3\ m$	$w_{MB} = 49.781137\ m$	
	$V_{MBreq} = 2 \cdot 10^4\ m^3$	$V_{MB} = 5.021962 \cdot 10^4\ m^3$	
Deckhouse limits:	$L_{SSreq} = 19.846389\ m$	$L_{SS} = 36.870754\ m$	
Cargo Block Check	$L_{CB} = 183.367775\ m$	$L_{CBguess} := (0.80 \cdot LWL - 3 \cdot m)$	$L_{CBguess} = 198.115792\ m$
Stability: In Ballast:	$C_{GMB} = 0.266286$	(0.08-0.25 allowed).	$KG_{Full} = 15.413875\ m$
Full Load:	$C_{GMBFull} = 0.08333$	(0.08-0.25 allowed).	$KG_{BAL} = 9.521653\ m$
	$.33 \cdot DWT = 4.630593 \cdot 10^4 \cdot MT$	$V_{BAL} \cdot \rho_{SW} \cdot g = 8.149181 \cdot 10^4 \cdot MT$	(Ballast ROT)

$$W = \begin{bmatrix} 2.136442 \cdot 10^4 \\ 1161.7584 \\ 157.487271 \\ 8.012256 \\ 2473.740418 \\ 1234.127395 \\ 1.376489 \cdot 10^5 \end{bmatrix} \cdot MT$$

$N_T = 20$ $V_{SS} = 1.340647 \cdot 10^4\ m^3$ $KW_{DG} = 1750 \cdot kW$ $KW_{PTO} = 8000 \cdot kW$ $V_{TK} = 3394.458269\ m^3$

SIMPLIFIED TANKER COST MODEL

Units definition

$Mdol := coul$ $Bdol := 1000 \cdot Mdol$ $Kdol := \frac{Mdol}{1000}$ $dol := \frac{Kdol}{1000}$

Input

$i1 := 1, 2 .. 7$

1. Inflation:

Base Year: $Y_B := 2000$ $iy := 1 .. Y_B - 1981$

Average Inflation Rate (%): (from 1981-2000) $R_I := 5.$ $F_I := \prod_{iy} \left(1 + \frac{R_I}{100}\right)$ $F_I = 2.52695$

2. Producability:

Producability factor: $CF := \frac{1}{3}$ $k := 1 .. 6$

$PFprime_1 := CF \cdot \frac{C_B}{N_{stern}} + CF \cdot \left[\frac{(w - 2\ m)}{1\ m}\right] + CF \cdot \left[\frac{(h_{DB} - 2\ m)}{1\ m}\right]$

$PFprime_2 := \frac{V_{MB} - V_{MBreq}}{V_{MB}}$ $PFprime_3 := \frac{(H_{DK} - 3. \cdot m)}{1. \cdot m}$ $PFprime_4 := PFprime_3$

$PFprime_5 := PFprime_3$ $PFprime_6 := PFprime_3$ $PF_k := 1 - .25\ PFprime_k$ $PF_5 := PF_2 \cdot PF_3$

$PF_6 := PF_3$

$$PF = \begin{bmatrix} 0.640417 \\ 0.849563 \\ 0.75 \\ 0.75 \\ 0.637172 \\ 0.75 \end{bmatrix}$$

3. Lead Ship Cost:

a. Lead Ship Cost - Shipbuilder Portion: $\frac{.5 \cdot Mdol}{lton^{.784}} = 0.493798 \cdot \frac{Mdol}{MT^{.784}}$

SWBS costs: (See Enclosure 1 for K_N factors); includes escalation estimate

Structure $K_{N1} := \frac{.285 \cdot Mdol}{MT^{.772}}$ $C_{L_1} := .03395 \cdot PF_1 \cdot F_I \cdot K_{N1} \cdot (W_1)^{.772}$ $C_{L_1} = 34.456049 \cdot Mdol$

\+ Propulsion $K_{N2} := \frac{.8 \cdot Mdol}{hp^{.808}}$ $C_{L_2} := .00186 \cdot PF_2 \cdot F_I \cdot K_{N2} \cdot P_I^{.808}$ $C_{L_2} = 13.43999 \cdot Mdol$

\+ Electric $K_{N3} := \frac{.55 \cdot Mdol}{MT^{.91}}$ $C_{L_3} := .07505 \cdot PF_3 \cdot F_I \cdot K_{N3} \cdot (W_3)^{.91}$ $C_{L_3} = 7.813843\ s^0 \cdot Mdol$

\+ Command, Control, Surveillance

$K_{N4} := \frac{2. \cdot Mdol}{MT^{.617}}$ $C_{L_4} := .10857 \cdot PF_4 \cdot F_I \cdot K_{N4} \cdot (W_4)^{.617}$ $C_{L_4} = 1.485985 \cdot Mdol$

\+ Auxiliary $K_{N5} := \frac{.15 \cdot Mdol}{MT^{.782}}$ $C_{L_5} := .09487 \cdot PF_5 \cdot F_I \cdot K_{N5} \cdot (W_5)^{.782}$ $C_{L_5} = 10.319923 \cdot Mdol$

\+ Outfit $K_{N6} := \frac{.36 \cdot Mdol}{MT^{.784}}$ $C_{L_6} := .09859 \cdot PF_6 \cdot F_I \cdot K_{N6} \cdot (W_6)^{.784}$ $C_{L_6} = 17.841015 \cdot Mdol$

(Less payload GFM cost)

\+ Margin Cost:

$C_{LM} := \frac{W_{margin}}{(W_{LS} - W_{margin})} \cdot \left(\sum_k C_{L_k}\right)$ $C_{LM} = 5.121408 \cdot Mdol$

\+ Integration/Engineering: (Lead ship includes detail design engineering and plans for class)

$K_{N8} := \frac{2. \cdot Mdol}{Mdol^{1.099}}$ $C_{L_8} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099}$ $C_{L_8} = 9.610606 \cdot Mdol$

\+ Ship Assembly and Support: (Lead ship includes all tooling, jigs, special facilities for class)

$K_{N9} := \frac{2. \cdot Mdol}{(Mdol)^{.839}}$ $C_{L_9} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839}$ $C_{L_9} = 11.827806 \cdot Mdol$

= Total Lead Ship Construction Cost: (BCC)

$C_{LCC} := \sum_k C_{L_k} + C_{L_8} + C_{L_9} + C_{LM}$ $C_{LCC} = 111.916626 \cdot Mdol$

\+ Profit:

$F_P := .08$ $C_{LP} := F_P \cdot C_{LCC}$ $C_{LP} = 8.95333 \cdot Mdol$

= Lead Ship Price:

$P_L := C_{LCC} + C_{LP}$ $P_L = 120.869956 \cdot Mdol$

$R_{discount} := 7$

$F_{NPV} := \sum_{i=1}^{30} \frac{1}{\left(1 + \frac{R_{discount}}{100}\right)^i}$ $F_{NPV} = 12.409041$

Annual and Lifetime (30 year) Operation Costs

$T_{steam} := 39 \cdot 8 \cdot day$ $FuelRate := \frac{W_{F41}}{\frac{E}{V_e}}$ $FuelRate = 90.026038 \cdot \frac{MT}{day}$ $T_{steam} = 312 \cdot day$

$C_{NPVfuel} := (F_{NPV} \cdot FuelRate\ T_{steam}) \frac{100 \cdot dol}{MT}$ $C_{NPVfuel} = 34.854668 \cdot Mdol$

$C_{NPVMan} := F_{NPV} \cdot N_T \cdot 100 \cdot Kdol$ $C_{NPVMan} = 24.818082 \cdot Mdol$

At Ve late 20 days / year:

$C_{NPVvpen} := F_{NPV} \cdot \left[\left[10 \cdot day - T_{steam} \cdot \left(1 - \frac{V_e}{V_S}\right)\right] \cdot 50\ \frac{Kdol}{day}\right]$

$C_{NPVvpen} := if(C_{NPVvpen} > 0 \cdot Mdol, C_{NPVvpen}, 0 \cdot Mdol)$ $C_{NPVvpen} = 0 \cdot Mdol$

$Cscantlings = 1 - \frac{SMF - 1}{SMF}$ $Cscantlings = 1$

$C_{NPVmaint} := F_{NPV} \cdot \left[\frac{(N_P \cdot 100\ Kdol + N_{KW} \cdot 100\ Kdol + N_{CARGO} \cdot Cscantlings100 \cdot Kdol)}{ManFac} + 500 \cdot Kdol\right]$

$C_{NPVmaint} = 16.840842 \cdot Mdol$

Total Ownership Cost (NPV): $TOC := P_L + C_{NPVfuel} + C_{NPVMan} + C_{NPVmaint} + C_{NPVvpen}$

$$PF = \begin{bmatrix} 0.640417 \\ 0.849563 \\ 0.75 \\ 0.75 \\ 0.637172 \\ 0.75 \end{bmatrix} \quad C_L = \begin{bmatrix} 34.456049 \\ 13.43999 \\ 7.813843 \\ 1.485985 \\ 10.319923 \\ 17.841015 \\ 0 \\ 9.610606 \\ 11.827806 \end{bmatrix} \cdot Mdol$$

$C_{LCC} = 111.916626 \cdot Mdol$

$P_L = 120.869956 \cdot Mdol$

$TOC = 197.383549 \cdot Mdol$

RISK OF TANKER GROUNDING AND COLLISION

1. Waterway channel, ship and ship track characteristics - assume track is along center of right hand lane in channel with two lanes; averaged for TAPS routes:

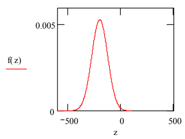
channel width: $ww := 800 \cdot m$ number of turns: $Lturn := 4$ $Rturn := 4$

track distribution: $\mu := -200 \cdot m$ $\sigma := 75 \cdot m$ $DD := 50 \cdot mile$ (per round trip)

Number of ships passed: $N_{ships} := 10$

pdf for location of ship relative to center of channel:

$z := -600 \cdot m, -599 \cdot m .. 100 \cdot m$ $f(z) := \frac{1}{\sqrt{2 \cdot \pi} \cdot \sigma} \cdot e^{\frac{-(z-\mu)^2}{2\sigma^2}}$



Probability and time ship out of channel:

$P_{out} := 1 - \int_{-\frac{ww}{2}}^{\frac{ww}{2}} f(z)\,dz$ $P_{out} = 0.00383$

ship: $v := V_e$ $tout := \frac{DD}{v} \cdot P_{out}$ $tout = 0.766076 \cdot min$

total transit time: $TT := \frac{DD}{v}$ $TT = 3.333333 \cdot hr$

average fix rate: $\lambda fix := \frac{1}{3 \cdot min}$ $TT = 1.2 \cdot 10^4\ s$

1.5 Redundancy (R is number of redundant systems)

$R_{steering} := N_P$ $R_{Prop} := N_P$ $N_P = 1$

2. Management factor matrix

3. Probability shaping factors

4. HEP's - master, mates, crew?

5. Error made in planning track (refer to chart 1)

6. Unsafe planned track $E_{uplan} := 4.581336 \cdot 10^{-6}$

7. Course deviates from direct planned safe track $E_{pilot} := \frac{8.9625 \cdot 10^{-5}}{ManFac}$ (assumes more error w/fewer crew

Average piloting error rate: $\lambda pilot := \lambda fix E_{pilot} P_{out}$ $\lambda pilot = 1.634752 \cdot 10^{-7} \cdot min^{-1}$

8. Course deviates from direct planned safe track (assumes Poisson process for fix errors; failure = at least one piloting error during time out of lane):

Probability of at least one piloting error when out of channel during the whole transit:

$E_{direct} := 1 - e^{-\lambda pilot \cdot TT}$ $E_{direct} = 3.26945 \cdot 10^{-5}$

9. Course deviates in turn from safe planned track (assumes Poisson process for fixes; failure = taking zero fixes before exiting channel on turn)

Time until out of channel, left turn $tL := \frac{ww}{4 \cdot v}$ $tL = 25.884338\ s$ $ww = 800\ m$

Time until out of channel, right turn $tR := \frac{3 \cdot ww}{4 \cdot v}$ $tR = 77.653015\ s$

Probability of no fixes before out of channel during left turn: $pfixL := e^{-\lambda fix tL}$ $pfixL = 0.866059$

Probability of no fixes before out of channel during right turn: $pfixR := e^{-\lambda fix tR}$ $pfixR = 0.649595$

Probability fail to turn: $P_{turn} := .001$

Captain fails to detect failure to turn: $P_{turncapt} := .01$

Course deviates in turn from safe planned track:

$E_{turn} := 1 - (1 - P_{turn} P_{turncapt} pfixL)^{Lturn} \cdot (1 - P_{turn} P_{turncapt} pfixR)^{Rturn}$ $E_{turn} = 6.062 \cdot 10^{-5}$

9.5 Probability of collision during single transit (Based on probability of unsafe track)

$E_{collision} := 1 - (1 - P_{turn} P_{turncapt} pfixL)^{N_{ships}}$ $E_{collision} = 8.660256 \cdot 10^{-5}$ $pfixL = 0.866059$

Probability that the course intersects another ship $P_{shiphaz} := 0.25$

$P_{collision} := E_{collision} P_{shiphaz}$ $P_{collision} = 2.165064 \cdot 10^{-5}$

10. Course deviates from safe planned track and is unsafe $P_{haz} := .5$

$E_{upilot} := (E_{direct} + E_{turn}) \cdot P_{haz}$ $E_{upilot} = 4.665954 \cdot 10^{-5}$

11. Powered course is unsafe

$E_{upower} := E_{upilot} + E_{uplan}$ $E_{upower} = 5.124088 \cdot 10^{-5}$

12. Drift Grounding - Unable to follow safe track

Unsafe wind/current (probability drift intersects hazard):

$P_{drift} := .25$

Assistance failure (unescorted):

$E_{assist} := .25$

Anchor failure:

$E_{anchor} := .25$

Lost way during transit:

$\lambda drift := \frac{0.0011^{R_{Prop}} + 0.00000324^{R_{steering}}}{\frac{340}{mi}} \cdot v$ $\lambda drift = 1.557884 \cdot 10^{-8}\ s^{-1}$

$P_{lostway} := 1 - e^{-TT \cdot \lambda drift}$ $P_{lostway} = 1.869286 \cdot 10^{-4}$ $TT = 1.2 \cdot 10^4\ s$

Unable to follow safe track:

$E_{drift} := P_{drift} E_{assist} E_{anchor} P_{lostway}$ $E_{drift} = 2.92076 \cdot 10^{-6}$

13. Probability of grounding during lifetime

$P_{ground} := E_{upower} + E_{drift}$ $P_{ground} = 5.416164 \cdot 10^{-5}$ $E_{upower} = 5.124088 \cdot 10^{-5}$

16. Probabilities of accidents happening $P_{collision} = 2.165064 \cdot 10^{-5}$ $P_{ground} = 5.416164 \cdot 10^{-5}$

Oil Outflow calculation based on Proposed MARPOL Annex I Regulation [19]

$L := LWL$ $d_s := T$ $D_S := D$ $B_S := B$ $z_l := h_{DB}$ $y := w$ $\rho_s := \rho_{SW}$

$DW := W_{CARGO}$ $C_{100\%} := C_{CARGO}$ $\rho_n := \frac{\gamma_{CARGO}}{g}$ $\rho_n = 867.4\ kg \cdot m^{-3}$

$d_b := 0.3 \cdot D$ $z_u := D$ $\rho_{sw} := \rho_{SW}$ $\rho_{sw} = 1025.861538\ kg \cdot m^{-3}$ $Y_p := B - w$ $B_B := B$

$C := C_{100\%} \cdot 0.98$ $C = 1.586914 \cdot 10^5\ m^3$ $Y_s := w$ $i := 2, 4 .. (2 \cdot N_{CARGO})$

$L_{slop} := L_{STK}$ $L_{cot} := L_{CTK}$

Defining the forward and aft boundaries of the cargo tanks and slop tanks.

$x_{a_i} := .062 \cdot LWL + L_{MB} + 3 \cdot m + L_{STK} + \frac{\left(N_{CARGO} - \frac{i}{2}\right) \cdot L_{CTK}}{N_{CARGO}}$ (Cargo Tanks)

$x_{a_{2 \cdot N_{CARGO}+2}} := .062 \cdot LWL + L_{MB} + 3 \cdot m$ (Slop Tanks)

$x_{a_{i-1}} := x_{a_i}$ $x_{a_{2 \cdot N_{CARGO}+1}} := x_{a_{2 \cdot N_{CARGO}+2}}$

$x_{f_i} := .062 \cdot LWL + L_{MB} + 3 \cdot m + L_{STK} + \frac{\left(N_{CARGO} - \frac{i-2}{2}\right) \cdot L_{CTK}}{N_{CARGO}}$

$x_{f_{2 \cdot N_{CARGO}+2}} := .062 \cdot LWL + L_{MB} + 3 \cdot m + L_{STK}$

$x_{f_{i-1}} := x_{f_i}$ $x_{f_{2 \cdot N_{CARGO}+1}} := x_{f_{2 \cdot N_{CARGO}+2}}$

$i := 1 .. 2 \cdot N_{CARGO} + 2$

$$x_a = \begin{bmatrix} 194.632018 \\ 194.632018 \\ 150.439033 \\ 150.439033 \\ 106.246048 \\ 106.246048 \\ 62.053063 \\ 62.053063 \\ 55.457228 \\ 55.457228 \end{bmatrix} m \qquad x_f = \begin{bmatrix} 238.825003 \\ 238.825003 \\ 194.632018 \\ 194.632018 \\ 150.439033 \\ 150.439033 \\ 106.246048 \\ 106.246048 \\ 62.053063 \\ 62.053063 \end{bmatrix} m$$

Side Damage Probability

Reading in the probability files which are in the same directory as this worksheet

$A := READPRN("psa.prn")$ $B := READPRN("psf.prn")$

$E := READPRN("psl.prn")$ $F := READPRN("psu.prn")$

```
PSA_i := | j <- 0
         | XL_a_i <- x_a_i / L
         | while XL_a_i > A_(j+1,1)
         |   j <- j + 1
         | A_(j,2) + (A_(j+1,2) - A_(j,2)) / 0.05 · (XL_a_i - A_(j,1))

PSF_i := | j <- 0
         | XL_f_i <- x_f_i / L
         | while XL_f_i > B_(j+1,1)
         |   j <- j + 1
         | B_(j,2) + (B_(j+1,2) - B_(j,2)) / 0.05 · (XL_f_i - B_(j,1))

PSL_i := | j <- 0
         | ZD_l_i <- z_l / D_S
         | while ZD_l_i > E_(j+1,1)
         |   j <- j + 1
         | E_(j,2) + (E_(j+1,2) - E_(j,2)) / 0.05 · (ZD_l_i - E_(j,1))

PSU_i := | j <- 0
         | ZD_u_i <- z_u / D_S
         | while ZD_u_i > F_(j+1,1)
         |   j <- j + 1
         | F_(j,2) + (F_(j+1,2) - F_(j,2)) / 0.05 · (ZD_u_i - F_(j,1))
```

The probability that the damage will lie totally outboard of the tank, from MARPOL

This is from the IMO proposal.

$$PSY := \begin{cases} \left(24.96 - 199.6\cdot\frac{y}{B_S}\right)\cdot\frac{y}{B_S} & \text{if } \frac{y}{B_S} \le 0.05 \\ 0.749 + \left[5 - 44.4\cdot\left(\frac{y}{B_S} - 0.05\right)\right]\cdot\left(\frac{y}{B_S} - 0.05\right) & \text{if } 0.05 < \frac{y}{B_S} < 0.1 \\ 0.888 + 0.56\cdot\left[\left(\frac{y}{B_S}\right) - 0.1\right] & \text{if } \frac{y}{B_S} \ge 0.1 \end{cases}$$

$P_{ST} := (1 - PSY)$ $\quad P_{SV} := (1 - PSU - PSL)$ $\quad P_{SL} := (1 - PSF - PSA)$

$P_{S_i} := P_{ST}\cdot P_{SL_i}\cdot P_{SV_i}$

$G := READPRN(\text{"pba.prn"})$ $\quad I := READPRN(\text{"pbp.prn"})$

Probability of breaching compartment from bottom damage

$H := READPRN(\text{"pbf.prn"})$ $\quad J := READPRN(\text{"pbs.prn"})$

$$PBA_i := \left| \begin{array}{l} j \leftarrow 0 \\ XL_{a_i} \leftarrow \frac{x_{a_i}}{L} \\ \text{while } XL_{a_i} > G_{j+1,1} \\ \quad j \leftarrow j+1 \\ G_{j,2} + \frac{G_{j+1,2} - G_{j,2}}{0.05}\cdot\left(XL_{a_i} - G_{j,1}\right) \end{array}\right. \qquad PBF_i := \left| \begin{array}{l} j \leftarrow 0 \\ XL_{f_i} \leftarrow \frac{x_{f_i}}{L} \\ \text{while } XL_{f_i} > H_{j+1,1} \\ \quad j \leftarrow j+1 \\ H_{j,2} + \frac{H_{j+1,2} - H_{j,2}}{0.05}\cdot\left(XL_{f_i} - H_{j,1}\right) \end{array}\right.$$

$$PBP_i := \left| \begin{array}{l} j \leftarrow 0 \\ YB_{p_i} \leftarrow \frac{Y_p}{B_B} \\ \text{while } YB_{p_i} > I_{j+1,1} \\ \quad j \leftarrow j+1 \\ I_{j,2} + \frac{I_{j+1,2} - I_{j,2}}{0.05}\cdot\left(YB_{p_i} - I_{j,1}\right) \end{array}\right. \qquad PBS_i := \left| \begin{array}{l} j \leftarrow 0 \\ YB_{s_i} \leftarrow \frac{Y_s}{B_B} \\ \text{while } YB_{s_i} > J_{j+1,1} \\ \quad j \leftarrow j+1 \\ J_{j,2} + \frac{J_{j+1,2} - J_{j,2}}{0.05}\cdot\left(YB_{s_i} - J_{j,1}\right) \end{array}\right.$$

$$P_{Bz} := \begin{cases} \left(14.5 - 67\cdot\frac{z_1}{D_S}\right)\cdot\left(\frac{z_1}{D_S}\right) & \text{if } \frac{z_1}{D_S} \le 0.1 \\ 0.78 + 1.1\cdot\left[\left(\frac{z_1}{D_S}\right) - .1\right] & \text{otherwise} \end{cases}$$

Also from MARPOL

$i := 2, 4 .. 2\cdot N_{CARGO} + 2$

$$PBP_i := \left| \begin{array}{l} j \leftarrow 0 \\ YB_{p_i} \leftarrow .5 \\ \text{while } YB_{p_i} > I_{j+1,1} \\ \quad j \leftarrow j+1 \\ I_{j,2} + \frac{I_{j+1,2} - I_{j,2}}{0.05}\cdot\left(YB_{p_i} - I_{j,1}\right) \end{array}\right. \qquad i := 1, 3 .. 2\cdot N_{CARGO} + 1 \qquad PBS_i := \left| \begin{array}{l} j \leftarrow 0 \\ YB_{s_i} \leftarrow .5 \\ \text{while } YB_{s_i} > J_{j+1,1} \\ \quad j \leftarrow j+1 \\ J_{j,2} + \frac{J_{j+1,2} - J_{j,2}}{0.05}\cdot\left(YB_{s_i} - J_{j,1}\right) \end{array}\right.$$

$i := 1 .. 2\cdot N_{CARGO} + 2$

$P_{BL} := (1 - PBF - PBA)$ $\quad P_{BT} := (1 - PBP - PBS)$ $\quad P_{BV} := (1 - P_{Bz})$ $\quad P_{B_i} := P_{BL_i}\cdot P_{BT_i}\cdot P_{BV}$

$V_{CTK} := L_{CTK}\cdot B_{CB}\cdot D_{CB}$ $\quad V_{CTK} = 1.742896\cdot10^5\ m^3$ $\quad O_{s_i} := \frac{.98\cdot V_{CTK}}{2\cdot N_{CARGO}}$

$L_{CTK} = 176.77194\ m$

$B_{CB} = 41.781137\ m$

$D_{CB} = 23.598152\ m$

$O_{s_{2\cdot N_{CARGO}+1}} := \frac{.98\cdot .02\cdot C_{CARGO}}{2.}$ $\quad O_{s_{2\cdot N_{CARGO}+2}} := O_{s_{2\cdot N_{CARGO}+1}}$

$O_{s_1} := .98\cdot C_{FTK}\cdot C_B\cdot\frac{V_{CTK}}{2\cdot N_{CARGO}}$ $\quad O_{s_2} := O_{s_1}$

$L_{STK} = 6.595835\ m$

$W_7 = 1.376489\cdot10^5\cdot MT$

$O_{MS} := \frac{\sum_i P_{S_i}\cdot O_{s_i}}{2.}$ $\quad O_{MS} = 2652.288346\ m^3$

$$O_s = \begin{bmatrix} 1.417672\cdot10^4 \\ 1.417672\cdot10^4 \\ 2.135048\cdot10^4 \\ 2.135048\cdot10^4 \\ 2.135048\cdot10^4 \\ 2.135048\cdot10^4 \\ 2.135048\cdot10^4 \\ 2.135048\cdot10^4 \\ 1586.914114 \\ 1586.914114 \end{bmatrix} m^3$$

ENTER p, THE OVER PRESSURE OF IGS, NO LESS THAN 5 kPa: $\quad p := 5\cdot10^3\cdot Pa$

$t_c := \begin{bmatrix} 0 \\ -2.5 \end{bmatrix}\cdot m$ $\quad d_s = 15.803535\ m$ $\quad p = 0.509858\ m\cdot\frac{MT}{m^3}$

Height of the oil still in the cargo tanks after grounding

$h_c := \frac{(d_s + t_c - z_l)\cdot\rho_s - \frac{p}{g}}{\rho_n}$ $\quad h_c = \begin{bmatrix} 13.49034 \\ 10.533626 \end{bmatrix} m$ $\quad z_m := 0\cdot m$

Density of the oil/seawater mixture

$\rho_m := \frac{\rho_s + \rho_n}{2}$ $\quad \rho_m = 946.630769\ kg\cdot m^{-3}$

Height of the oil/seawater mixture captured in the ballast tanks

$h_m := \left[\frac{(d_s + t_c - z_m)\cdot\rho_s}{\rho_m}\right]$ $\quad h_m = \begin{bmatrix} 17.126254 \\ 14.41701 \end{bmatrix}\cdot m$

$B_{tank} := \frac{B_S}{2} - w$ $\quad h_{98\%} := 0.98\cdot(D_S - h_{DB})$ $\quad B_{tank} = 20.890568\ m$ $\quad h_{98\%} = 23.126189\ m$

Calculating the Ouflow of each tank in grounding, with the 0 subscript referring to no tide change and the 2.5 subscript refferring to a 2.5 metre reduction in tide

$O_{B0_i} := \frac{O_{s_i}}{h_{98\%}}\cdot(h_{98\%} - h_{c_1})$ $\quad O_{B2.5_i} := \frac{O_{s_i}}{h_{98\%}}\cdot(h_{98\%} - h_{c_2})$

$b_{cot} := \frac{B_{CB}}{2.}$ $\quad l_{cot} := \frac{L_{CTK}}{N_{CARGO}}$ $\quad l_{slop} := L_{STK}$ $\quad b_{slop} := b_{cot}$ $\quad z := D_S - z_1$ $\quad b_{cot} = 20.890568\ m$

Calculating the oil captured in the ballast tanks with the same subscript system $\quad l_{cot} = 44.192985\ m$

$C_{DB0_i} := .5\cdot(z_l\cdot l_{cot}\cdot b_{cot} + y\cdot l_{cot}\cdot h_{m_1})$

$C_{DB2.5_i} := .5\cdot(z_l\cdot l_{cot}\cdot b_{cot} + y\cdot l_{cot}\cdot h_{m_2})$

$C_{DB0_{2\cdot N_{CARGO}+1}} := .5\cdot(z_l\cdot l_{slop}\cdot b_{slop} + y\cdot l_{slop}\cdot h_{m_1})$ $\quad C_{DB0_{2\cdot N_{CARGO}+2}} := C_{DB0_{2\cdot N_{CARGO}+1}}$

$C_{DB2.5_{2\cdot N_{CARGO}+1}} := \left[.5\cdot\left[\left((z_l\cdot l_{slop}\cdot b_{slop})\right) + y\cdot l_{slop}\cdot h_{m_2}\right]\right]$ $\quad C_{DB2.5_{2\cdot N_{CARGO}+2}} := C_{DB2.5_{2\cdot N_{CARGO}+1}}$

Ensuring the capture does not exceed the outflow

$$C_{DB0_i} := \begin{cases} O_{B0_i} & \text{if } C_{DB0_i} > O_{B0_i} \\ C_{DB0_i} & \text{otherwise} \end{cases} \qquad C_{DB2.5_i} := \begin{cases} O_{B2.5_i} & \text{if } C_{DB2.5_i} > O_{B2.5_i} \\ C_{DB2.5_i} & \text{otherwise} \end{cases}$$

$O_{MB0} := \sum_{i=1}^{2\cdot N_{CARGO}+2} P_{B_i}\cdot(O_{B0_i} - C_{DB0_i})$ $\quad O_{MB0} = 1619.271123\ m^3$

$O_{MB2.5} := \sum_{i=1}^{2\cdot N_{CARGO}+2} P_{B_i}\cdot(O_{B2.5_i} - C_{DB2.5_i})$ $\quad O_{MB2.5} = 2572.630588\ m^3$

$O_{MB} := 0.7 \cdot O_{MB0} + 0.3 \cdot O_{MB2.5}$ $\quad O_{MB} = 1905.278962\ m^3$ $\quad O_{MS} = 2652.288346\ m^3$

$O_M := \dfrac{0.4 \cdot O_{MS} + 0.6 \cdot O_{MB}}{C}$ $\quad O_M = 0.013889$ $\quad 0.6 \cdot O_{MB} + 0.4 \cdot O_{MS} = 2204.082716\ m^3$

COMPARE OM WITH PROPOSED MARPOL ANNEX ONE REGULATION:
OM<= 0.016 FOR C<= 200,000 M^3
OM<= 0.01+(0.006/200,000)*(400,000-C) FOR 200,000 M^3 <= C <= 400,000 M^3
OM<=0.01 FOR C>= 400,000 M^3

$C = 1.586914 \cdot 10^5\ m^3$

$N_{CARGO} = 4$

$1 - PSF_1 - PSA_{2 \cdot N_{CARGO}+2} = 0.789402$ $\quad 1 - PSL_1 - PSU_1 = 0.997327$ $\quad 1 - PSY = 0.140144$

$P_{SIDE} := \left(1 - PSL_1 - PSU_1\right) \cdot \left(1 - PSF_1 - PSA_{2 \cdot N_{CARGO}+2}\right) \cdot (1 - PSY)$ $\quad P_{SIDE} = 0.110334$ $\quad P_{0SIDE} := 1 - P_{SIDE}$ $\quad P_{0SIDE} = 0.889666$

$P_{BOT} := \left(1 - PBF_1 - PBA_{2 \cdot N_{CARGO}+2}\right) \cdot \left(1 - PBS_1 - PBP_1\right) \cdot (1 - P_{BL})$ $\quad P_{BOT} = 0.104272$ $\quad P_{0BOT} := 1 - P_{BOT}$ $\quad P_{0BOT} = 0.895728$

$P_{CB} := .6 \cdot P_{BOT} + .4 \cdot P_{SIDE}$ $\quad P_{CB} = 0.106697$ $\quad P_0 := 1 - P_{CB}$ $\quad P_0 = 0.893303$

RISK

$P_{collision} = 2.165064 \cdot 10^{-5}$

$P_{ground} = 5.416164 \cdot 10^{-5}$

$Risk := P_{collision} \cdot O_{MS} + P_{ground} \cdot O_{MB}$

$Risk = 0.160617\ m^3$

$$O_s = \begin{bmatrix} 1.417672 \cdot 10^4 \\ 1.417672 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 2.135048 \cdot 10^4 \\ 1586.914114 \\ 1586.914114 \end{bmatrix} m^3 \quad P_S = \begin{bmatrix} 0.032956 \\ 0.032956 \\ 0.033795 \\ 0.033795 \\ 0.033795 \\ 0.033795 \\ 0.033795 \\ 0.033795 \\ 0.012892 \\ 0.012892 \end{bmatrix} \quad P_B = \begin{bmatrix} 0.065923 \\ 0.065923 \\ 0.055537 \\ 0.055537 \\ 0.036179 \\ 0.036179 \\ 0.022374 \\ 0.022374 \\ 0.011144 \\ 0.011144 \end{bmatrix}$$

Appendix A.3 Offset Tables

Available upon request

Appendix A.4 SAFEHULL Structural Analysis

Steel Vessels Rules

SafeHull Tanker Requirement

Version: V6.00 (2000 Rules)

Project Name: **LOORT3**

Date: 25-Mar-2000

Time: 23:48:50

Page: 2

2.0 Longitudinal Strength:

2.1 Hull Girder Bending Moments Amidships

Still Water Sagging BM (Msws) =	-470,000.00	(tf-m)
Still Water Hogging BM (Mswh) =	320,000.00	(tf-m)
ABS Vertical Wave Sagging BM (Mws) =	-562,252.31	(tf-m)
ABS Vertical Wave Hogging BM (Mwh) =	526,568.31	(tf-m)
Total Vertical Bending Moment (Mt) =	1,032,252.31	(tf-m)

2.2 Cross Section Information:

LSC Group #	Longitudinal Location. (m) from AP	Description
1	125.70	Mid Ship Section

Steel Vessels Rules

SafeHull Tanker Requirement

Version: V6.00 (2000 Rules)

Project Name:

LOORT3

2.3 Hull-Girder Section Modulus Requirements:

Group Numer:	Location	Material	Gross Reqd SM (SMr, cm2-m)	Gross Design SM (SMa, cm2-m)	SMa/SMr
1	Bottom	HT32	451,321	650,058	
	Deck	HT32	451,321	467,207	

2.4 Material Reference Table:

Mat. No.	Mat. ID	Yield Stress (kgf/cm2)	Ultimate Stress (kgf/cm2)	Q-Factor	Sm
1	MILD	2400.	4100.	1.000	
2	HT32	3200.	4500.	0.780	
3	HT36	3600.	5000.	0.720	
4	HT40	4000.	5200.	0.680	

3.0 Longitudinal Scantlings

LSC Group # 1

X-Coordinate from AP = 125.70 (m)

Description : Mid Ship Section

Steel Vessels Rules

SafeHull Tanker Requirement

Version: V6.00 (2000 Rules)

Project Name: **LOORT3**

2.0 Longitudinal Strength:

2.1 Hull Girder Bending Moments Amidships

Still Water Sagging BM (Msws) =	-470,000.00	(tf-m)
Still Water Hogging BM (Mswh) =	320,000.00	(tf-m)
ABS Vertical Wave Sagging BM (Mws) =	-562,252.31	(tf-m)
ABS Vertical Wave Hogging BM (Mwh) =	526,568.31	(tf-m)
Total Vertical Bending Moment (Mt) =	1,032,252.31	(tf-m)

2.2 Cross Section Information:

LSC Group #	Longitudinal Location. (m) from AP	Description
1	125.70	Mid Ship Section

3.1 Extent of Structure Materials:

Extent
Distance Above Base Line (m)
Required

Range	From	to	Material
1	27.50	24.42	HT32
2	24.42	.00	MILD

3.2 Longitudinal Scantling (Plating) Requirements:

Plate #	Location	Plate ID	Material	Req. Net Offered Net Thick. (mm)	Req. Gross 0.5 mm (mm)	Req. Gross to Thick. (mm)	Offered Gross Thick. (mm)	Thick. (mm)
1	Keel Plate	KPL-01	HT32	18.65	19.00	19.65	19.50	20.00
2	Bottom	BTM-01	HT32	17.15	17.00	18.15	18.00	18.00
3	Bottom	BTM-02	HT32	17.15	17.00	18.15	18.00	18.00
4	Bottom	BTM-03	HT32	17.15	17.00	18.15	18.00	18.00
5	Bottom	BTM-04	HT32	17.15	17.00	18.15	18.00	18.00
6	Bottom	BTM-05	HT32	17.15	17.00	18.15	18.00	18.00
7	Bilge	BLG-01	HT32	17.15	17.00	18.15	18.00	18.00
8	Bilge	BLG-02	HT32	17.15	17.00	18.15	18.00	18.00
9	Bilge	BLG-03	HT32	17.15	17.00	18.15	18.00	18.00
10	Bilge	BLG-04	HT32	17.15	17.00	18.15	18.00	18.00
11	Side Shell	SHL-01	HT32	16.46	16.50	17.96	18.00	18.00
12	Side Shell	SHL-02	HT32	16.46	16.50	17.96	18.00	18.00
13	Side Shell	SHL-03	MILD	18.53	18.50	20.03	20.00	20.00
14	Side Shell	SHL-04	MILD	18.53	18.50	20.03	20.00	20.00
15	Side Shell	SHL-05	HT32	16.46	16.50	17.96	18.00	18.00
16	Gunwale	GWR-01	HT32	16.46	17.00	17.46	17.50	18.00
17	Gunwale	GWR-02	HT32	16.46	17.00	17.46	17.50	18.00
18	Gunwale	GWR-03	HT32	16.46	17.00	17.46	17.50	18.00
19	Gunwale	GWR-04	HT32	16.46	17.00	17.46	17.50	18.00
20	Upper Deck	DEC-01	HT32	13.93	14.00	14.93	15.00	15.00
21	Upper Deck	DEC-02	HT32	16.03	16.00	18.03	18.00	18.00
22	Upper Deck	DEC-03	HT32	13.20	13.00	15.20	15.00	15.00
23	Inner Bottom	INB-01	HT32	15.15	15.50	16.65	16.50	17.00
24	Inner Bottom	INB-02	HT32	15.15	15.50	16.65	16.50	17.00
25	Inner Bottom	INB-03	HT32	15.15	15.50	16.65	16.50	17.00
26	Inner Bottom	INB-04	HT32	15.15	15.50	16.65	16.50	17.00
27	Inner Skin	INS-01	HT32	13.91	14.50	15.41	15.50	16.00
28	Inner Skin	INS-02	HT32	13.19	13.50	14.69	14.50	15.00
29	Inner Skin	INS-03	MILD	13.24	13.50	14.74	14.50	15.00
30	Inner Skin	INS-04	MILD	11.75	12.50	13.25	13.50	14.00
31	Inner Skin	INS-05	HT32	17.98	18.50	19.48	19.50	20.00
32	C.L. Bhd	CTR-01	HT32	13.83	14.00	15.83	16.00	16.00
33	C.L. Bhd	CTR-02	HT32	13.50	14.00	15.50	15.50	16.00
34	C.L. Bhd	CTR-03	MILD	12.97	13.00	14.97	15.00	15.00
35	C.L. Bhd	CTR-04	MILD	11.52	12.00	13.52	13.50	14.00
36	C.L. Bhd	CTR-05	HT32	12.84	13.00	14.84	15.00	15.00
37	WT Bot. Grd.	BGR-01	HT36	21.31	21.50	22.81	23.00	23.00
38	NT Bot. Grd.	NBG-01	HT32	8.71	10.00	10.71	10.50	12.00
39	NT Bot. Grd.	NBG-02	HT32	8.71	10.00	10.71	10.50	12.00
40	NT Bot. Grd.	NBG-03	HT32	8.71	10.00	10.71	10.50	12.00
41	NT Bot. Grd.	NBG-04	HT32	8.71	10.00	10.71	10.50	12.00
42	NT Bot. Grd.	NBG-05	HT32	8.71	10.00	10.71	10.50	12.00
43	NT Bot. Grd.	NBG-06	HT32	8.71	10.00	10.71	10.50	12.00
44	NT Bot. Grd.	NBG-07	HT32	8.71	11.00	10.71	10.50	13.00
45	NT Bot. Grd.	NBG-08	HT32	8.71	11.00	10.71	10.50	13.00
46	NT Bot. Grd.	NBG-09	HT32	8.71	11.00	10.71	10.50	13.00
47	NT Bot. Grd.	NBG-10	HT32	12.48	13.00	14.48	14.50	15.00
48	NT Bot. Grd.	NBG-11	HT32	12.48	13.00	14.48	14.50	15.00
49	NT Bot. Grd.	NBG-12	HT32	12.48	13.00	14.48	14.50	15.00
50	NT Stringer	NTS-01	HT32	11.16	11.00	13.16	13.00	13.00
51	NT Stringer	NTS-02	HT32	11.16	11.00	13.16	13.00	13.00
52	NT Stringer	NTS-03	HT32	11.16	11.00	13.16	13.00	13.00
53	NT Stringer	NTS-04	MILD	11.16	11.00	13.16	13.00	13.00
54	NT Stringer	NTS-05	MILD	11.16	11.00	13.16	13.00	13.00
55	NT Stringer	NTS-06	MILD	11.16	11.00	13.16	13.00	13.00
56	NT Stringer	NTS-07	MILD	11.16	11.00	13.16	13.00	13.00
57	NT Stringer	NTS-08	MILD	11.16	11.00	13.16	13.00	13.00
58	NT Stringer	NTS-09	MILD	11.16	11.00	13.16	13.00	13.00
59	NT Stringer	NTS-10	MILD	11.69	12.00	13.69	13.50	14.00
60	NT Stringer	NTS-11	MILD	11.69	12.00	13.69	13.50	14.00
61	NT Stringer	NTS-12	MILD	11.69	12.00	13.69	13.50	14.00

******Note*******
REQUIRED_GROSS t(mm) = REQUIRED_NET_t(mm) + MINIMUM_CORROSION_MARGIN

3.3 Longitudinal Scantling (Stiffener) Requirements:

Stiffener #	Location Description	Stiffener ID	Stiffener	Material	Req. Net SM (cm3)	Offered Net SM (cm3)	Req. Gross SM (cm3)	Offered Gross SM (cm3)
1	Keel Plate	KPL- 101	400x120x11.5x23 LIA	HT32	1,310.00	1,352.00	1,393.00	1,438.00
2	Keel Plate	KPL- 102	400x120x11.5x23 LIA	HT32	1,310.00	1,352.00	1,393.00	1,438.00
3	Bottom	BTM- 101	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
4	Bottom	BTM- 102	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
5	Bottom	BTM- 103	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
6	Bottom	BTM- 204	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
7	Bottom	BTM- 205	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
8	Bottom	BTM- 206	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
9	Bottom	BTM- 207	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
10	Bottom	BTM- 208	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
11	Bottom	BTM- 309	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
12	Bottom	BTM- 310	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
13	Bottom	BTM- 311	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
14	Bottom	BTM- 312	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
15	Bottom	BTM- 313	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
16	Bottom	BTM- 414	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
17	Bottom	BTM- 415	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
18	Bottom	BTM- 416	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
19	Bottom	BTM- 417	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
20	Bottom	BTM- 418	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
21	Bottom	BTM- 419	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
22	Bottom	BTM- 520	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
23	Bottom	BTM- 521	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
24	Bottom	BTM- 522	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
25	Bottom	BTM- 523	400x120x11.5x23 LIA	HT32	1,310.00	1,320.00	1,406.00	1,417.00
26	Side Shell	SHL- 101	400x120x11.5x23 LIA	HT32	1,182.00	1,332.00	1,258.00	1,417.00
27	Side Shell	SHL- 102	400x120x11.5x23 LIA	HT32	1,144.00	1,332.00	1,218.00	1,417.00
28	Side Shell	SHL- 103	375x120x11.5x20 LIA	HT32	1,110.00	1,128.00	1,187.00	1,208.00
29	Side Shell	SHL- 204	375x120x11.5x20 LIA	HT32	1,047.00	1,128.00	1,121.00	1,208.00
30	Side Shell	SHL- 205	375x120x11.5x20 LIA	HT32	992.00	1,128.00	1,061.00	1,208.00
31	Side Shell	SHL- 206	375x120x11.5x20 LIA	HT32	935.00	1,128.00	1,001.00	1,208.00
32	Side Shell	SHL- 207	375x120x11.5x20 LIA	HT32	902.00	1,128.00	965.00	1,208.00
33	Side Shell	SHL- 208	375x120x11.5x20 LIA	HT32	877.00	1,128.00	939.00	1,208.00
34	Side Shell	SHL- 209	375x120x11.5x20 LIA	HT32	852.00	1,128.00	912.00	1,208.00
35	Side Shell	SHL- 310	375x120x10.5x18 LIA	MILD	1,017.00	1,049.00	1,096.00	1,131.00
36	Side Shell	SHL- 311	375x120x10.5x18 LIA	MILD	986.00	1,049.00	1,062.00	1,131.00
37	Side Shell	SHL- 312	375x120x10.5x18 LIA	MILD	954.00	1,049.00	1,028.00	1,131.00
38	Side Shell	SHL- 313	375x120x10.5x18 LIA	MILD	922.00	1,049.00	994.00	1,131.00
39	Side Shell	SHL- 314	375x120x10.5x18 LIA	MILD	891.00	1,049.00	960.00	1,131.00
40	Side Shell	SHL- 315	375x120x10.5x18 LIA	MILD	859.00	1,049.00	926.00	1,131.00
41	Side Shell	SHL- 416	325x120x11.5x15 LIA	MILD	795.00	804.00	862.00	871.00
42	Side Shell	SHL- 417	325x120x11.5x15 LIA	MILD	763.00	804.00	827.00	871.00
43	Side Shell	SHL- 418	325x120x11.5x15 LIA	MILD	731.00	804.00	792.00	871.00
44	Side Shell	SHL- 419	325x120x11.5x15 LIA	MILD	699.00	804.00	758.00	871.00
45	Side Shell	SHL- 420	325x120x11.5x15 LIA	MILD	667.00	804.00	723.00	871.00
46	Side Shell	SHL- 421	325x120x11.5x15 LIA	MILD	635.00	804.00	688.00	871.00
47	Side Shell	SHL- 522	300x100x10.5x15 LIA	MILD	553.00	612.00	603.00	667.00
48	Side Shell	SHL- 523	300x100x10.5x15 LIA	MILD	540.00	612.00	588.00	667.00
49	Side Shell	SHL- 524	300x100x10.5x15 LIA	MILD	514.00	612.00	560.00	667.00
50	Side Shell	SHL- 525	250x90x10.5x15 LIA	HT32	375.00	449.00	408.00	489.00
51	Side Shell	SHL- 526	250x90x10.5x15 LIA	HT32	349.00	449.00	380.00	489.00
52	Side Shell	SHL- 527	250x90x10.5x15 LIA	HT32	323.00	449.00	352.00	489.00
53	Side Shell	SHL- 528	250x90x10.5x15 LIA	HT32	297.00	449.00	323.00	489.00
54	Upper Deck	DEC- 101	250x100x10.5x14 LIA	HT32	467.00	504.00	519.00	559.00
55	Upper Deck	DEC- 102	250x100x10.5x14 LIA	HT32	467.00	504.00	519.00	559.00
56	Upper Deck	DEC- 103	250x100x10.5x14 LIA	HT32	467.00	504.00	519.00	559.00
57	Upper Deck	DEC- 104	250x100x10.5x14 LIA	HT32	467.00	504.00	519.00	559.00
58	Upper Deck	DEC- 205	200x90x9x12 LIA	HT32	252.00	261.00	298.00	309.00
59	Upper Deck	DEC- 206	200x90x9x12 LIA	HT32	250.00	261.00	297.00	309.00
60	Upper Deck	DEC- 207	200x90x9x12 LIA	HT32	249.00	261.00	296.00	309.00
61	Upper Deck	DEC- 208	200x90x9x12 LIA	HT32	248.00	261.00	294.00	309.00
62	Upper Deck	DEC- 209	200x90x9x12 LIA	HT32	247.00	261.00	293.00	309.00
63	Upper Deck	DEC- 210	200x90x9x12 LIA	HT32	246.00	261.00	292.00	309.00
64	Upper Deck	DEC- 211	200x90x9x12 LIA	HT32	245.00	261.00	290.00	309.00
65	Upper Deck	DEC- 212	200x90x9x12 LIA	HT32	244.00	261.00	289.00	309.00
66	Upper Deck	DEC- 213	200x90x9x12 LIA	HT32	243.00	261.00	288.00	309.00
67	Upper Deck	DEC- 214	200x90x9x12 LIA	HT32	242.00	261.00	286.00	309.00
68	Upper Deck	DEC- 215	200x90x9x12 LIA	HT32	240.00	261.00	285.00	309.00
69	Upper Deck	DEC- 216	200x90x9x12 LIA	HT32	239.00	261.00	284.00	309.00
70	Upper Deck	DEC- 217	200x90x9x12 LIA	HT32	238.00	261.00	282.00	309.00
71	Upper Deck	DEC- 218	200x90x9x12 LIA	HT32	237.00	261.00	281.00	309.00
72	Upper Deck	DEC- 219	200x90x9x12 LIA	HT32	236.00	261.00	280.00	309.00
73	Upper Deck	DEC- 220	200x90x9x12 LIA	HT32	235.00	261.00	279.00	309.00
74	Upper Deck	DEC- 221	200x90x9x12 LIA	HT32	234.00	261.00	277.00	309.00
75	Upper Deck	DEC- 222	200x90x9x12 LIA	HT32	233.00	261.00	276.00	309.00
76	Upper Deck	DEC- 223	200x90x9x12 LIA	HT32	232.00	261.00	275.00	309.00
77	Upper Deck	DEC- 224	200x90x9x12 LIA	HT32	231.00	261.00	273.00	309.00
78	Upper Deck	DEC- 225	200x90x9x12 LIA	HT32	229.00	261.00	272.00	309.00
79	Upper Deck	DEC- 226	200x90x9x12 LIA	HT32	228.00	261.00	271.00	309.00
80	Upper Deck	DEC- 227	200x90x9x12 LIA	HT32	200.00	261.00	237.00	309.00
81	Upper Deck	DEC- 328	200x90x9x12 LIA	HT32	180.00	255.00	213.00	302.00
82	Inner Bottom	INB- 101	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
83	Inner Bottom	INB- 102	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
84	Inner Bottom	INB- 103	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
85	Inner Bottom	INB- 104	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
86	Inner Bottom	INB- 105	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
87	Inner Bottom	INB- 206	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
88	Inner Bottom	INB- 207	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
89	Inner Bottom	INB- 208	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
90	Inner Bottom	INB- 209	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
91	Inner Bottom	INB- 210	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00

92	Inner Bottom	INB- 311	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
93	Inner Bottom	INB- 312	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
94	Inner Bottom	INB- 313	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
95	Inner Bottom	INB- 314	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
96	Inner Bottom	INB- 315	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
97	Inner Bottom	INB- 416	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
98	Inner Bottom	INB- 417	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
99	Inner Bottom	INB- 418	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
100	Inner Bottom	INB- 419	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
101	Inner Bottom	INB- 420	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
102	Inner Bottom	INB- 421	400x120x11.5x23 LIA	HT32	1,220.00	1,317.00	1,303.00	1,406.00
103	Inner Skin	INS- 101	350x120x10.5x16 LIA	HT32	701.00	853.00	774.00	942.00
104	Inner Skin	INS- 102	350x120x10.5x16 LIA	HT32	781.00	853.00	862.00	942.00
105	Inner Skin	INS- 103	350x120x10.5x16 LIA	HT32	690.00	853.00	761.00	942.00
106	Inner Skin	INS- 204	350x120x10.5x16 LIA	HT32	751.00	861.00	814.00	934.00
107	Inner Skin	INS- 205	350x120x10.5x16 LIA	HT32	732.00	861.00	793.00	934.00
108	Inner Skin	INS- 206	350x120x10.5x16 LIA	HT32	712.00	861.00	773.00	934.00
109	Inner Skin	INS- 207	350x120x10.5x16 LIA	HT32	693.00	861.00	752.00	934.00
110	Inner Skin	INS- 208	350x120x10.5x16 LIA	HT32	674.00	861.00	731.00	934.00
111	Inner Skin	INS- 209	350x120x10.5x16 LIA	HT32	655.00	861.00	711.00	934.00
112	Inner Skin	INS- 310	350x120x10.5x16 LIA	MILD	781.00	861.00	847.00	934.00
113	Inner Skin	INS- 311	350x120x10.5x16 LIA	MILD	757.00	861.00	821.00	934.00
114	Inner Skin	INS- 312	350x120x10.5x16 LIA	MILD	733.00	861.00	795.00	934.00
115	Inner Skin	INS- 313	350x120x10.5x16 LIA	MILD	708.00	861.00	768.00	934.00
116	Inner Skin	INS- 314	350x120x10.5x16 LIA	MILD	684.00	861.00	742.00	934.00
117	Inner Skin	INS- 315	350x120x10.5x16 LIA	MILD	659.00	861.00	715.00	934.00
118	Inner Skin	INS- 416	300x100x11.5x16 LIA	MILD	610.00	631.00	662.00	684.00
119	Inner Skin	INS- 417	300x100x11.5x16 LIA	MILD	586.00	631.00	635.00	684.00
120	Inner Skin	INS- 418	300x100x11.5x16 LIA	MILD	561.00	631.00	608.00	684.00
121	Inner Skin	INS- 419	300x100x11.5x16 LIA	MILD	536.00	631.00	582.00	684.00
122	Inner Skin	INS- 420	300x100x11.5x16 LIA	MILD	512.00	631.00	555.00	684.00
123	Inner Skin	INS- 421	300x100x11.5x16 LIA	MILD	487.00	631.00	528.00	684.00
124	Inner Skin	INS- 522	250x90x11.5x16 LIA	MILD	424.00	486.00	459.00	526.00
125	Inner Skin	INS- 523	250x90x11.5x16 LIA	MILD	414.00	486.00	448.00	526.00
126	Inner Skin	INS- 524	250x90x11.5x16 LIA	MILD	406.00	486.00	438.00	526.00
127	Inner Skin	INS- 525	225x90x9x12 LIA	HT32	288.00	331.00	319.00	366.00
128	Inner Skin	INS- 526	200x90x9x12 LIA	HT32	271.00	284.00	299.00	313.00
129	Inner Skin	INS- 527	200x90x9x12 LIA	HT32	253.00	284.00	280.00	313.00
130	Inner Skin	INS- 528	225x90x9x12 LIA	HT32	290.00	331.00	321.00	366.00
131	WT Bot. Grd.	BGR- 101	425x120x11.5x24 LIA	HT36	1,476.00	1,519.00	1,588.00	1,634.00
132	WT Bot. Grd.	BGR- 102	425x120x11.5x24 LIA	HT36	1,441.00	1,519.00	1,551.00	1,634.00
133	WT Bot. Grd.	BGR- 103	400x120x11.5x23 LIA	HT36	1,336.00	1,369.00	1,439.00	1,475.00
134	C.L. Bhd	CTR- 101	350x120x10.5x16 LIA	HT32	804.00	855.00	886.00	942.00
135	C.L. Bhd	CTR- 202	350x120x10.5x16 LIA	HT32	759.00	855.00	837.00	942.00
136	C.L. Bhd	CTR- 203	350x120x10.5x16 LIA	HT32	716.00	855.00	790.00	942.00
137	C.L. Bhd	CTR- 204	350x120x10.5x16 LIA	HT32	698.00	855.00	770.00	942.00
138	C.L. Bhd	CTR- 205	350x120x10.5x16 LIA	HT32	680.00	855.00	750.00	942.00
139	C.L. Bhd	CTR- 206	350x120x10.5x16 LIA	HT32	662.00	855.00	730.00	942.00
140	C.L. Bhd	CTR- 207	350x120x10.5x16 LIA	HT32	644.00	855.00	710.00	942.00
141	C.L. Bhd	CTR- 208	350x120x10.5x16 LIA	HT32	626.00	855.00	690.00	942.00
142	C.L. Bhd	CTR- 309	350x120x10.5x16 LIA	HT32	608.00	847.00	670.00	934.00
143	C.L. Bhd	CTR- 310	325x120x11.5x15 LIA	MILD	747.00	761.00	823.00	839.00
144	C.L. Bhd	CTR- 311	325x120x11.5x15 LIA	MILD	724.00	761.00	798.00	839.00
145	C.L. Bhd	CTR- 312	325x120x11.5x15 LIA	MILD	700.00	761.00	772.00	839.00
146	C.L. Bhd	CTR- 313	325x120x11.5x15 LIA	MILD	677.00	761.00	747.00	839.00
147	C.L. Bhd	CTR- 314	325x120x11.5x15 LIA	MILD	654.00	761.00	721.00	839.00
148	C.L. Bhd	CTR- 315	325x120x11.5x15 LIA	MILD	631.00	761.00	695.00	839.00
149	C.L. Bhd	CTR- 416	325x120x11.5x15 LIA	MILD	607.00	753.00	670.00	831.00
150	C.L. Bhd	CTR- 417	325x120x11.5x15 LIA	MILD	584.00	753.00	644.00	831.00
151	C.L. Bhd	CTR- 418	300x100x10.5x15 LIA	MILD	561.00	581.00	623.00	646.00
152	C.L. Bhd	CTR- 419	300x100x10.5x15 LIA	MILD	537.00	581.00	597.00	646.00
153	C.L. Bhd	CTR- 420	300x100x10.5x15 LIA	MILD	514.00	581.00	571.00	646.00
154	C.L. Bhd	CTR- 421	300x100x10.5x15 LIA	MILD	490.00	581.00	545.00	646.00
155	C.L. Bhd	CTR- 422	300x100x10.5x15 LIA	MILD	467.00	581.00	519.00	646.00
156	C.L. Bhd	CTR- 523	250x90x11.5x16 LIA	MILD	443.00	460.00	487.00	506.00
157	C.L. Bhd	CTR- 524	250x90x11.5x16 LIA	MILD	420.00	460.00	461.00	506.00
158	C.L. Bhd	CTR- 525	250x90x11.5x16 LIA	MILD	396.00	460.00	435.00	506.00
159	C.L. Bhd	CTR- 526	250x90x11.5x16 LIA	MILD	372.00	460.00	409.00	506.00
160	C.L. Bhd	CTR- 527	225x90x9x12 LIA	HT32	275.00	313.00	311.00	354.00
161	C.L. Bhd	CTR- 528	225x90x9x12 LIA	HT32	257.00	313.00	290.00	354.00
162	C.L. Bhd	CTR- 529	200x90x9x12 LIA	HT32	238.00	269.00	267.00	302.00
163	C.L. Bhd	CTR- 530	200x90x9x12 LIA	HT32	219.00	269.00	246.00	302.00
164	C.L. Bhd	CTR- 531	200x90x9x12 LIA	HT32	200.00	269.00	225.00	302.00

******Note*******

GROSS SM (cm3) = REQUIRED_NET_SMr(cm3) x OFERED_GROSS_SM / OFFERED_NET_SMa

3.4 Moment of Inertia (Stiffener within 0.1D from Deck) Requirements:

Stiffener #.	Location	Stiffener ID	Description	Material	Z	Y	Req. Net IX	Offered Net IX
					(m)	(m)	(cm4)	(cm4)
1	SIDE SHELL	SHL- 526	250x90x10.5x15 LIA	HT32	24.89	24.95	2,622.00	10,131.00
2	SIDE SHELL	SHL- 527	250x90x10.5x15 LIA	HT32	24.89	25.70	2,622.00	10,131.00
3	SIDE SHELL	SHL- 528	250x90x10.5x15 LIA	HT32	24.89	26.45	2,622.00	10,131.00
4	UPPER DECK	DEC- 101	250x100x10.5x14 LIA	HT32	23.69	27.50	2,167.00	11,756.00
5	UPPER DECK	DEC- 102	250x100x10.5x14 LIA	HT32	22.99	27.50	2,167.00	11,756.00
6	UPPER DECK	DEC- 103	250x100x10.5x14 LIA	HT32	22.29	27.50	2,167.00	11,756.00
7	UPPER DECK	DEC- 104	250x100x10.5x14 LIA	HT32	21.59	27.50	2,167.00	11,756.00
8	UPPER DECK	DEC- 205	200x90x9x12 LIA	HT32	20.04	27.52	2,414.00	4,918.00
9	UPPER DECK	DEC- 206	200x90x9x12 LIA	HT32	19.19	27.54	2,414.00	4,918.00
10	UPPER DECK	DEC- 207	200x90x9x12 LIA	HT32	18.34	27.57	2,414.00	4,918.00
11	UPPER DECK	DEC- 208	200x90x9x12 LIA	HT32	17.49	27.59	2,414.00	4,918.00
12	UPPER DECK	DEC- 209	200x90x9x12 LIA	HT32	16.64	27.61	2,414.00	4,918.00
13	UPPER DECK	DEC- 210	200x90x9x12 LIA	HT32	15.79	27.63	2,414.00	4,918.00
14	UPPER DECK	DEC- 211	200x90x9x12 LIA	HT32	14.94	27.65	2,414.00	4,918.00

15	UPPER DECK	DEC- 212	200x90x9x12 LIA	HT32	14.09	27.67	2,414.00	4,918.00
16	UPPER DECK	DEC- 213	200x90x9x12 LIA	HT32	13.24	27.69	2,414.00	4,918.00
17	UPPER DECK	DEC- 214	200x90x9x12 LIA	HT32	12.39	27.72	2,414.00	4,918.00
18	UPPER DECK	DEC- 215	200x90x9x12 LIA	HT32	11.54	27.74	2,414.00	4,918.00
19	UPPER DECK	DEC- 216	200x90x9x12 LIA	HT32	10.69	27.76	2,414.00	4,918.00
20	UPPER DECK	DEC- 217	200x90x9x12 LIA	HT32	9.84	27.78	2,414.00	4,918.00
21	UPPER DECK	DEC- 218	200x90x9x12 LIA	HT32	8.99	27.80	2,414.00	4,918.00
22	UPPER DECK	DEC- 219	200x90x9x12 LIA	HT32	8.14	27.82	2,414.00	4,918.00
23	UPPER DECK	DEC- 220	200x90x9x12 LIA	HT32	7.29	27.85	2,414.00	4,918.00
24	UPPER DECK	DEC- 221	200x90x9x12 LIA	HT32	6.45	27.87	2,414.00	4,918.00
25	UPPER DECK	DEC- 222	200x90x9x12 LIA	HT32	5.60	27.89	2,414.00	4,918.00
26	UPPER DECK	DEC- 223	200x90x9x12 LIA	HT32	4.75	27.91	2,414.00	4,918.00
27	UPPER DECK	DEC- 224	200x90x9x12 LIA	HT32	3.90	27.93	2,414.00	4,918.00
28	UPPER DECK	DEC- 225	200x90x9x12 LIA	HT32	3.05	27.95	2,414.00	4,918.00
29	UPPER DECK	DEC- 226	200x90x9x12 LIA	HT32	2.20	27.98	2,414.00	4,918.00
30	UPPER DECK	DEC- 227	200x90x9x12 LIA	HT32	1.35	28.00	2,315.00	4,881.00
31	UPPER DECK	DEC- 328	200x90x9x12 LIA	HT32	.70	28.00	1,725.00	4,496.00
32	INNER SKIN	INS- 526	200x90x9x12 LIA	HT32	20.89	24.95	2,815.00	5,439.00
33	INNER SKIN	INS- 527	200x90x9x12 LIA	HT32	20.89	25.70	2,815.00	5,439.00
34	INNER SKIN	INS- 528	225x90x9x12 LIA	HT32	20.89	26.45	3,062.00	7,156.00
35	CENTER BHD	CTR- 528	225x90x9x12 LIA	HT32	.00	25.00	1,822.00	6,154.00
36	CENTER BHD	CTR- 529	200x90x9x12 LIA	HT32	.00	25.75	1,790.00	4,737.00
37	CENTER BHD	CTR- 530	200x90x9x12 LIA	HT32	.00	26.50	1,790.00	4,737.00
38	CENTER BHD	CTR- 531	200x90x9x12 LIA	HT32	.00	27.25	1,790.00	4,737.00

Part # 2 Transverse Members Summary Report

```
SUMMARY-MAINTRAN                                         25 MARCH 2000   23:23:11
     ABS/SAFEHULL/MAINTRAN  V6.00 (2000 Rules)
     Rules 5-1-4 INITIAL SCANTLING CRITERIA
     SHIP : LOORT3
----------------------------------------------------------------------------------
  Cargo density in WING tank   = 0.8670 (tf/m3) user input
  Cargo density in WING tank   = 0.9000 (tf/m3) used in calculating pressure
----------------------------------------------------------------------------------
 5-1-4/11.7   Web Sectional Area of Side Transverses:
 for Upper Part of Side Transverse
-------------------------------------------------------------------------------
                  | Section Modulus     Web Area    Web Thickness    Web Depth
                  |      (cm3)           (cm2)          (mm)            (cm)
-------------------------------------------------------------------------------
 Required  Net    |       N/A           229.251       10.72            N/A
 Rounded   Net    |                                   10.50
      85%  Net    |       N/A           194.863
 Offered   Net    |     42595.2         440.000       11.00          400.00
 Required Gross*  |       N/A           250.092       11.72            N/A
 Offered  Gross   |     46281.2         480.000       12.00            N/A
-------------------------------------------------------------------------------
 *Note: Required_Gross definition:
                                         Offered Gross
       Section Modulus: = Required Net * --------------
                                          Offered Net

                                         Offered Gross
              Web Area: = Required Net * --------------
                                          Offered Net

         Web Thickness: = Required Net + Corrosion Margin

 for Lower Part of Side Transverse
-------------------------------------------------------------------------------
                  | Section Modulus     Web Area    Web Thickness    Web Depth
                  |      (cm3)           (cm2)          (mm)            (cm)
-------------------------------------------------------------------------------
 Required  Net    |       N/A            31.285       10.72            N/A
 Rounded   Net    |                                   10.50
      85%  Net    |       N/A            26.592
 Offered   Net    |     29086.1         440.000       11.00          400.00
 Required Gross*  |       N/A            34.129       11.72            N/A
 Offered  Gross   |     31714.6         480.000       12.00            N/A
-------------------------------------------------------------------------------

_SUMMARY-MAINTRAN                                         25 MARCH 2000   23:23:11
     ABS/SAFEHULL/MAINTRAN  V6.00 (2000 Rules)
     Rules 5-1-4 INITIAL SCANTLING CRITERIA
     SHIP : LOORT3


5-1-4/15.3.1  Section Modulus of Vertical Web on Longitudinal Bulkhead:

    SM = M/fb

 *** for tankers with one centerline longitudinal bulkhead with
     oiltight centerline bulkhead where both side of bulkhead are equally loaded
     Required NET Section Modulus of Vertical Web on Long. BHD
         SM = M/fb =       4796. (cm3)
              M = k c p s lb**2 10**4
              c = 0.480
  ------------------------------------------------------
 *** for tankers with one centerline longitudinal bulkhead with
     oiltight centerline bulkhead where both side of bulkhead are equally loaded

     Required NET Section Modulus of Vertical Web on Long. BHD
         SM = M/fb =       4796. (cm3)
              M = k c p s lb**2 10**4
              c = 0.480
  ------------------------------------------------------
 5-1-4/15.3.2  Web Sectional Area of the Vertical Web on Longitudinal Bulkhead
```

*** for tanker with NO STRUTS and Longitudinal Bulkhead
Loaded from both sides
Required net Sectional Area for Upper part = 260.25(cm2)
F = k s [Ku l (Pu + Pl) - hU Pu] 10**3 = 281069.2 (kgf)
where Ku = 0.130
*** for tanker with NO STRUTS and Longitudinal Bulkhead
Loaded from both sides
*** UPPER part of Vertical Webs

	Section Modulus (cm3)	Web Area (cm2)	Web Thickness (mm)	Web Depth (cm)
Required Net	6394.2	243.461	10.72	50.40
Rounded Net			10.50	
85% Net	5435.1	206.942		
Offered Net	9214.5	240.000	16.00	150.00
Required Gross*	6789.7	254.677	11.72	N/A
Offered Gross	9784.4	255.000	17.00	N/A

*** LOWER part of Vertical Webs

	Section Modulus (cm3)	Web Area (cm2)	Web Thickness (mm)	Web Depth (cm)
Required Net	7992.7	253.589	10.72	50.40
Rounded Net			10.50	
85% Net	6793.8	45.550		
Offered Net	9214.5	240.000	16.00	150.00
Required Gross*	8487.1	254.938	11.72	N/A
Offered Gross	9784.4	255.000	17.00	N/A

_SUMMARY-MAINTRAN 25 MARCH 2000 23:23:11
ABS/SAFEHULL/MAINTRAN V6.00 (2000 Rules)
Rules 5-1-4 INITIAL SCANTLING CRITERIA
SHIP : LOORT3
5-1-4/11.3.1 Section Modulus of Deck Transverses
SM = M/fb
*** for tankers with one centerline longitudinal bulkhead with only
one of the cargo tank(port or starboard) is loaded (c2 = 0.5)
The required Section Modulus = 82593. (cm3)
85% SM = 70204. (cm3)

5-1-4/11.3.2 Web Sectional Area of Deck Transverse:
*** Wing Tank ***

	Section Modulus (cm3)	Web Area (cm2)	Web Thickness (mm)	Web Depth (cm)
Required Net	82593.2	501.492	10.72	186.68
Rounded Net			10.50	
85% Net	70204.2	426.268		
Offered Net	83844.0	412.500	16.50	250.00
Required Gross*	89188.4	547.082	12.22	N/A
Offered Gross	90539.1	550.000	18.00	N/A

**Warning: The offered value is less than requirement
_SUMMARY-MAINTRAN 25 MARCH 2000 23:23:11
ABS/SAFEHULL/MAINTRAN V6.00 (2000 Rules)
Rules 5-1-4 INITIAL SCANTLING CRITERIA
SHIP : LOORT3
5-1-4/15.5.1 Section Modulus of Horizontal Girder on Transverse Bulkhead
5-1-4/15.5.2 Web Sectional Area of Horizontal Girder on Transverse Bulkhead
*** for WING TANK ***
Girder Description: Lower Stringer

	Section Modulus (cm3)	Web Area (cm2)	Web Thickness (mm)	Web Depth (cm)
Required Net	129810.4	549.333	10.72	357.80
Rounded Net			10.50	
85% Net	110338.9	466.933		
Offered Net	142831.7	581.250	15.50	375.00
Required Gross*	138224.0	602.494	12.22	N/A
Offered Gross	152089.2	637.500	17.00	N/A

_SUMMARY-MAINTRAN 25 MARCH 2000 23:23:11
ABS/SAFEHULL/MAINTRAN V6.00 (2000 Rules)
Rules 5-1-4 INITIAL SCANTLING CRITERIA
SHIP : LOORT3
5-1-4/15.5.1 Section Modulus of Horizontal Girder on Transverse Bulkhead
5-1-4/15.5.2 Web Sectional Area of Horizontal Girder on Transverse Bulkhead
*** for WING TANK ***
Girder Description: Low Stringer

	Section Modulus (cm3)	Web Area (cm2)	Web Thickness (mm)	Web Depth (cm)
Required Net	128106.4	542.121	10.72	357.80
Rounded Net			10.50	
85% Net	108890.4	460.803		
Offered Net	149224.5	581.250	15.50	375.00
Required Gross*	136350.5	594.585	12.22	N/A
Offered Gross	158827.7	637.500	17.00	N/A

_SUMMARY-MAINTRAN 25 MARCH 2000 23:23:11
ABS/SAFEHULL/MAINTRAN V6.00 (2000 Rules)

```
     Rules 5-1-4 INITIAL SCANTLING CRITERIA
     SHIP : LOORT3
 5-1-4/15.5.1  Section Modulus of Horizontal Girder on Transverse Bulkhead
 5-1-4/15.5.2  Web Sectional Area of Horizontal Girder on Transverse Bulkhead
            ***  for WING TANK ***
  Girder Description:  High Stringer
--------------------------------------------------------------------------------
                  |  Section Modulus     Web Area    Web Thickness    Web Depth
                  |       (cm3)           (cm2)         (mm)            (cm)
--------------------------------------------------------------------------------
 Required  Net    |      97657.5         413.268        10.72          357.80
 Rounded   Net    |                                     10.50
      85%  Net    |      83008.9         351.277
 Offered   Net    |     104915.2         437.500        12.50          350.00##
 Required Gross*  |     104827.9         462.860        12.22            N/A
 Offered  Gross   |     112618.6         490.000        14.00            N/A
--------------------------------------------------------------------------------
 Required Inertia for Web Portion =  25815700.00 (cm4)
 Offered  Inertia for Web Portion =  26253640.00 (cm4)
--------------------------------------------------------------------------------
 ##Note: WHERE THE OFFERED DEPTH OF WEB PORTION IS LESS THAN
         THE REQUIRED MINIMUM DEPTH, THE OFFERED DEPTH IS
         ACCEPTABLE WHEN INERTIA REQUIREMENTS SATISFIED.
         (SEE 5-1-4/11.11)

_SUMMARY-MAINTRAN                                      25 MARCH 2000   23:23:11
     ABS/SAFEHULL/MAINTRAN  V6.00 (2000 Rules)
     Rules 5-1-4 INITIAL SCANTLING CRITERIA
     SHIP : LOORT3
 5-1-4/15.5.1  Section Modulus of Horizontal Girder on Transverse Bulkhead
 5-1-4/15.5.2  Web Sectional Area of Horizontal Girder on Transverse Bulkhead
            ***  for WING TANK ***
  Girder Description:  Higher Stringer
--------------------------------------------------------------------------------
                  |  Section Modulus     Web Area    Web Thickness    Web Depth
                  |       (cm3)           (cm2)         (mm)            (cm)
--------------------------------------------------------------------------------
 Required  Net    |      69061.1         292.253        10.72          357.80
 Rounded   Net    |                                     10.50
      85%  Net    |      58702.0         248.415
 Offered   Net    |     104471.1         437.500        12.50          350.00##
 Required Gross*  |      74157.4         327.324        12.22            N/A
 Offered  Gross   |     112180.4         490.000        14.00            N/A
--------------------------------------------------------------------------------
 Required Inertia for Web Portion =  19269896.00 (cm4)
 Offered  Inertia for Web Portion =  25905094.00 (cm4)
--------------------------------------------------------------------------------
 ##Note: WHERE THE OFFERED DEPTH OF WEB PORTION IS LESS THAN
         THE REQUIRED MINIMUM DEPTH, THE OFFERED DEPTH IS
         ACCEPTABLE WHEN INERTIA REQUIREMENTS SATISFIED.
         (SEE 5-1-4/11.11)

_SUMMARY-TRANBH                                      25 MARCH 2000   23:23:13
     ABS/SAFEHULL/TRANBH  V6.00 (2000 Rules)
      Rules 5-1-4/13.1&13.3: TRANSVERSE BHD. PLATE/STIFFENER
     SHIP : Optimum Risk 168 DWT DH Tanker
   ---- Note ----
   Required_Gross_t(mm) = Required_Net_t(mm) + Corrosion_Margin
   Gross_SM(cm3) = Required_Net_SMr(cm3) X Offered_Gross_SM / Offered_Net_SMa
--------------------------------------------------------------------------------
 Cargo density in wing tank = 0.8670 (tf/m3) user input
 Cargo density in wing tank = 1.0250 (tf/m3) used in calculating pressure
--------------------------------------------------------------------------------
    ==============================================================
    * Upper                        * TBUpper                     |
    ==============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
        (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  ---------------------------------------------------------------------------------------
    1  16.000   13.29   13.50        14.00        14.29     14.50           15.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
      (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -------------------------------------------------------------------
  1 18.625   12       852.21       975.63     903.50       1034.34
--------------------------------------------------------------------------------
 Cargo density in wing tank = 0.8670 (tf/m3) user input
 Cargo density in wing tank = 1.0250 (tf/m3) used in calculating pressure
--------------------------------------------------------------------------------
    ==============================================================
    * Middle                       * TBMiddle                    |
    ==============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
        (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  ---------------------------------------------------------------------------------------
    1  10.750   14.95   15.00        15.00        15.95     16.00           16.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
      (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -------------------------------------------------------------------
  1 13.375   20      2247.45      2352.21    2339.78       2448.84
--------------------------------------------------------------------------------
 Cargo density in wing tank = 0.8670 (tf/m3) user input
 Cargo density in wing tank = 1.0250 (tf/m3) used in calculating pressure
--------------------------------------------------------------------------------
```

```
    ===============================================================
    * Lower                         * TBLower                     |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1   5.500   15.34   15.50        16.00        16.34     16.50           17.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1  8.125   21      2398.83      2494.20    2490.72       2589.75
--------------------------------------------------------------------------------
 Cargo density in wing tank = 0.8670 (tf/m3) user input
 Cargo density in wing tank = 1.0250 (tf/m3) used in calculating pressure
--------------------------------------------------------------------------------
    ===============================================================
    * Stool                         * TBStool                     |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1   3.900   16.86   17.00        17.00        17.86     18.00           18.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1  4.700    6       285.01       499.45     305.22        534.86
--------------------------------------------------------------------------------
 Ballast density in ballast tank = 1.0250 (tf/m3)
--------------------------------------------------------------------------------
    ===============================================================
    * Upper                         * Upper-J                     |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1  16.000   11.49   11.50        11.50        12.99     13.00           13.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1 18.790   15      1235.76      1353.68    1307.63       1432.40
--------------------------------------------------------------------------------
 Ballast density in ballast tank = 1.0250 (tf/m3)
--------------------------------------------------------------------------------
    ===============================================================
    * Middle                        * Middle-J                    |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1  10.750   13.30   13.50        13.50        14.80     15.00           15.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1 13.375   18      1745.31      1937.04    1835.16       2036.77
--------------------------------------------------------------------------------
 Ballast density in ballast tank = 1.0250 (tf/m3)
--------------------------------------------------------------------------------
    ===============================================================
    * Lower                         * Lower-J                     |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1   5.500   14.88   15.00        15.50        16.38     16.50           17.00
    ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1  8.125   20      2237.45      2361.36    2337.44       2466.89
--------------------------------------------------------------------------------
 Ballast density in ballast tank = 1.0250 (tf/m3)
--------------------------------------------------------------------------------
    ===============================================================
    * Hopper                        * Hopper-J                    |
    ===============================================================
    ---  PLATE  ---
   No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
         (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
  -------------------------------------------------------------------------------------
    1   0.000   16.37   16.50        17.00        18.37     18.50           19.00
   ---- STIFFENER ----
 No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
 -----------------------------------------------------------------
  1  2.750   11       745.93       832.64     851.74        950.74
--------------------------------------------------------------------------------
 Ballast density in ballast tank = 1.0250 (tf/m3)
--------------------------------------------------------------------------------
```

```
  ===============================================================
  * Inner Bottom                * Inner Bottom-J                |
  ===============================================================
  ---  PLATE  ---
 No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
       (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
 -------------------------------------------------------------------------------------
  1   0.000   16.37   16.50        17.00        18.37     18.50           19.00
  ---- STIFFENER ----
No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
-------------------------------------------------------------------
 1  1.950   17      1546.65      1614.65    1706.77       1781.80
--------------------------------------------------------------------------------
Cargo density in wing tank = 0.8670 (tf/m3) user input
Cargo density in wing tank = 1.0250 (tf/m3) used in calculating pressure
--------------------------------------------------------------------------------
  ===============================================================
  * Deck                        * TBDeck                        |
  ===============================================================
  ---  PLATE  ---
 No.   YP    Required_Thickness     Offered     Required_Thickness         Offered
       (m)  Net(mm) Round_Net(mm)   Net_t(mm)  Gross(mm) Round_Gross(mm)  Gross_t(mm)
 -------------------------------------------------------------------------------------
  1  21.250   11.37   11.50        12.00        12.37     12.50           13.00
  ---- STIFFENER ----
No. YSTFP Stf.ID Required_Net  Offered_Net   Gross    Offered_Gross
     (m)            SMr(cm3)     SMa(cm3)    SM(cm3)     SM(cm3)
-------------------------------------------------------------------
 1 24.150   17      1445.51      1682.56    1520.03       1769.31

_SUMMARY-DBFLGRD                                        25 MARCH 2000   23:23:17
     ABS/SAFEHULL/DBFLGRD  V6.00 (2000 Rules)
     Rules 5-1-4/7.7 BOTTOM GIRDERS/FLOORS
     SHIP : Optimum Risk 168 DWT DH Tanker
 Description:  Floors
 Double bottom side girders(5-1-4/7.7.2)
   ls  =    44.200 (m)      P   =    22.795 (ft/m2)
  Transverse Location From Center Line:     4.500 (m)
  -------------------------------------------
            required     offered
    Location     net  gross    net   gross
   From   To     (mm)   (mm)   (mm)   (mm)
  -------------------------------------------
   0.00   3.40  10.15  12.00  10.00  12.00
   3.40   6.80   9.31  11.50  10.00  12.00
   6.80  10.20   8.71  10.50  10.00  12.00
  10.20  13.60   8.71  10.50  10.00  12.00
  13.60  17.00   8.71  10.50  10.00  12.00
  17.00  23.80   8.71  10.50  10.00  12.00
  23.80  30.60   8.71  10.50  10.00  12.00
  30.60  34.00   8.71  10.50  10.00  12.00
  34.00  37.40   8.71  10.50  10.00  12.00
  37.40  40.80   9.31  11.50  10.00  12.00
  40.80  44.20  10.15  12.00  10.00  12.00
  Transverse Location From Center Line:     9.000 (m)
  -------------------------------------------
            required     offered
    Location     net  gross    net   gross
   From   To     (mm)   (mm)   (mm)   (mm)
  -------------------------------------------
   0.00   3.40  10.15  12.00  10.00  12.00
   3.40   6.80   9.31  11.50  10.00  12.00
   6.80  10.20   8.71  10.50  10.00  12.00
  10.20  13.60   8.71  10.50  10.00  12.00
  13.60  17.00   8.71  10.50  10.00  12.00
  17.00  23.80   8.71  10.50  10.00  12.00
  23.80  30.60   8.71  10.50  10.00  12.00
  30.60  34.00   8.71  10.50  10.00  12.00
  34.00  37.40   8.71  10.50  10.00  12.00
  37.40  40.80   9.31  11.50  10.00  12.00
  40.80  44.20  10.15  12.00  10.00  12.00
  Transverse Location From Center Line:    13.500 (m)
  -------------------------------------------
            required     offered
    Location     net  gross    net   gross
   From   To     (mm)   (mm)   (mm)   (mm)
  -------------------------------------------
   0.00   3.40  10.91  13.00  11.00  13.00
   3.40   6.80  10.00  12.00  11.00  13.00
   6.80  10.20   8.71  10.50  11.00  13.00
  10.20  13.60   8.71  10.50  11.00  13.00
  13.60  17.00   8.71  10.50  11.00  13.00
  17.00  23.80   8.71  10.50  11.00  13.00
  23.80  30.60   8.71  10.50  11.00  13.00
  30.60  34.00   8.71  10.50  11.00  13.00
  34.00  37.40   8.71  10.50  11.00  13.00
  37.40  40.80  10.00  12.00  11.00  13.00
  40.80  44.20  10.91  13.00  11.00  13.00

_SUMMARY-DBFLGRD                                        25 MARCH 2000   23:23:17
          ABS/SAFEHULL/DBFLGRD  V6.00 (2000 Rules)
          Rules 5-1-4/7.7 BOTTOM GIRDERS/FLOORS
          SHIP : Optimum Risk 168 DWT DH Tanker
      Description:  Floors
      Double bottom floors (Rule 5-1-4/7.7.3)
         L   =   251.390 (m)    DB  =     3.900 (m)
```

```
       ls  =    44.200 (m)    P   =    22.795 (tf/m2)
       Bs  =    18.750 (m)    S3  =     3.400 (m)
       s0  =     4.625 (m)    eta =     2.546
     ---------------------------------------------
         Location        required        offered
       From    To      net    gross    net    gross
       (m)    (m)      (mm)    (mm)    (mm)    (mm)
     ---------------------------------------------
    The floor index: 1, with distance from the AFT of the bulkhead:  3.400(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index: 2, with distance from the AFT of the bulkhead:  6.800(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index: 3, with distance from the AFT of the bulkhead: 10.200(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index: 4, with distance from the AFT of the bulkhead: 13.600(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index: 5, with distance from the AFT of the bulkhead: 17.000(m)
       0.00    4.50   14.30   16.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    9.89   12.00   10.00   12.00
      13.50   18.75   22.47   24.50   15.00   17.00
   The floor index: 6, with distance from the AFT of the bulkhead: 23.800(m)
       0.00    4.50   19.07   21.00   10.00   12.00
       4.50    9.00    9.91   12.00   10.00   12.00
       9.00   13.50   13.18   15.00   10.00   12.00
      13.50   18.75   29.96   32.00   15.00   17.00
   The floor index: 7, with distance from the AFT of the bulkhead: 30.600(m)
       0.00    4.50   14.30   16.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    9.89   12.00   10.00   12.00
      13.50   18.75   22.47   24.50   15.00   17.00
   The floor index: 8, with distance from the AFT of the bulkhead: 34.000(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index: 9, with distance from the AFT of the bulkhead: 37.400(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   15.00   17.00
   The floor index:10, with distance from the AFT of the bulkhead: 40.800(m)
       0.00    4.50    9.53   11.50   10.00   12.00
       4.50    9.00    8.71   10.50   10.00   12.00
       9.00   13.50    8.71   10.50   10.00   12.00
      13.50   18.75   14.98   17.00   10.00   17.00
     Note *** The reference of location is the center line of the vessel
```

Exceeding due to SafeHull Limitations (discussed in the design report Sec.4.2)

Part # 3 Longitudinal Members Weight Report

```
   Gross Stiffeners Total    8914.674    1759.235     9.957    14.496
                           Gross Total   36220.469    7147.793    11.500    15.041

                                                25 MARCH 2000   22:43:29      PAGE:  6
        ABS/SAFEHULL/_WEIGHT V6.00 (2000 Rules)
        SECTION WEIGHT CALCULATIONS FOR HULL GIRDER
        SHIP : Optimum Risk 168 DWT DH Tanker                             FILE : LOORT3.OWD
    Gross Summary
    Optimum Risk 168 DWT DH Tanker Scantling group  1  ( x =  125.695 m from AP )
                               (Scantling group length =  251.390 m)
    DEPTH, MOLDED                            =       27.500 m
    BREATM, MOLDED                           =       49.780 m
    SECTIONAL AREA                           =    72441.086 cm2
    STEEL DENSITY                            =        7.850 tonnes/m3
    NEUTRAL AXIS ABOVE BASELINE              =       11.500 m
    WEIGHT OF PLATES           (HALF SHIP)   =     5388.559 tonnes
    WEIGHT OF STIFFENERS       (HALF SHIP)   =     1759.235 tonnes
TOTAL WEIGHT OF SCANTLINGS (FULL SHIP)    =    14295.618
```

Appendix A.5 Power and Propulsion Analysis

A.5.1 NavCad Analysis

A.5.1.1 Design Case

Team 3 7 Mar 2000 11:44 AM Page 1
Displacement hull Resistance Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis parameters ----------

```
[X]Bare-hull: Holtrop-1984 method      [X]Appendage: Holtrop-1988 method
   Technique: Prediction               [ ]Wind     :
   Cf type  : ITTC                     [ ]Seas     :
   Align to : Rbare/W                  [ ]Channel  :
   File     :                          [ ]Barge    :
   Correlation allow(Ca): 0.00014      [ ]Net      :
[ ]Roughness:
[X]3-D corr : form factor(1+k): 1.4381 [ ]Speed dependent correction
```

---------- Prediction Results ----------

Vel kts	Fn	Rn	Cf	[Cform]	[Cw]	Cr	Ct
8.00	0.083	8.71e8	0.001557	0.000682	0.000004	0.000686	0.002384
10.00	0.104	1.09e9	0.001515	0.000664	0.000005	0.000668	0.002323
12.00	0.124	1.31e9	0.001481	0.000649	0.000012	0.000660	0.002281
14.00	0.145	1.52e9	0.001454	0.000637	0.000044	0.000681	0.002275
15.00	0.155	1.63e9	0.001442	0.000632	0.000081	0.000713	0.002294
15.78	0.163	1.72e9	0.001433	0.000628	0.000124	0.000752	0.002324
16.00	0.166	1.74e9	0.001430	0.000627	0.000139	0.000765	0.002336

Vel kts	Rw/W	Rr/W	Rbare/W	Rw N	Rr N	Rbare N	PEbare kW
8.00	0.00000	0.00006	0.00022	659	106970	371450	1528.7
10.00	0.00000	0.00010	0.00034	1132	162699	565578	2909.6
12.00	0.00000	0.00014	0.00048	4037	231544	799938	4938.3
14.00	0.00001	0.00020	0.00065	21133	325050	1085583	7818.6
15.00	0.00003	0.00024	0.00076	44396	390388	1256846	9698.7
15.78	0.00005	0.00027	0.00085	75120	455704	1409306	11440.7
16.00	0.00005	0.00029	0.00088	86434	477054	1455948	11984.1

Vel kts	Rapp N	Rwind N	Rseas N	Rchan N	Rother N	Rtotal N	PEtotal kW
8.00	3539	0	0	0	37499	412487	1697.6
10.00	5390	0	0	0	57097	628065	3231.0
12.00	7605	0	0	0	80754	888297	5483.8
14.00	10176	0	0	0	109576	1205335	8681.1
15.00	11593	0	0	0	126844	1395283	10766.9
15.78	12759	0	0	0	142207	1564271	12698.7
16.00	13097	0	0	0	146905	1615950	13301.1

Team 3 7 Mar 2000 11:44 AM Page 2
Displacement hull Resistance Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data ----------

```
      Water type: Standard Salt
    Mass density: 1025.86  kg/m3
  Kinematic visc: 1.1883e-06  m2/s
```

---------- Hull data ----------

```
Primary:                                  Secondary:
  Length between PP:  251.540 m                Trim by stern:    0.000 m
       Wl aft of FP:    0.000 m               LCB aft of FP:  133.570 m
          Length WL:  251.540 m             Bulb ext fwd FP:    7.050 m
        Max beam WL:   49.780 m             Bulb area at FP:   88.000 m2
    Draft at mid WL:   15.800 m           Bulb ctr above BL:    6.220 m
  Displacement Bare: 169055.0 t                Transom area:    0.000 m2
  Max area coef(Cx):    0.995               Half ent angle:   40.000 deg
    Waterplane coef:    0.913                  Stern shape:   Normal
     Wetted surface:  17937.4 m2                 Bow shape:   U-shape
            Loading:   Load draft

Parameters: Holtrop-1984 method
Fn(Lwl)     0.1...0.8       0.08 Limit
Fn-high     0.1...0.8       0.17
Cp(Lwl)     0.55...0.85     0.84
Lwl/Bwl     3.9...14.9      5.05
Bwl/T       2.1...4         3.15
```

---------- Appendages ----------

```
Total wetted surface (ex. thruster):
           Rudders:    200.000 m2      Drag coefficient: 1.200
   Shaft brackets:      0.000        ------------------ 0.000
              Skeg:      0.000        ------------------ 0.000
     Strut bossing:      0.000        ------------------ 0.000
      Hull bossing:      0.000        ------------------ 0.000
    Exposed shafts:      0.000        ------------------ 0.000
   Stabilizer fins:      0.000        ------------------ 0.000
              Dome:      0.000        ------------------ 0.000
        Bilge keel:      0.000        ------------------ 0.000
Bow thruster diam:      0.000 m      ------------------ 0.000

Parameters: Holtrop-1988 method
None given
```

Team 3 7 Mar 2000 11:44 AM Page 3
Displacement hull Resistance Project: TANKER2.NC3
ORT LO Tanker

---------- Environment data --

Wind:

Wind speed:	0.000 kts
Angle off bow:	0.000 deg
Tran hull area:	0.000 m2
VCE above WL:	0.000 m
Tran superst area:	0.000 m2
VCE above WL:	0.000 m
Total longl area:	0.000 m2
VCE above WL:	0.000 m
Wind speed:	Free stream
Arrangement:	Cargo ship

Seas:

Sig. wave height:	0.000 m
Modal wave period:	0.000 sec

Channel:

Channel width:	0.000 m
Channel depth:	0.000 m
Side slope:	0.000 deg
Wetted hull girth:	0.000 m

---------- Symbols and Values --

Vel = Ship speed
Fn = Froude number
Rn = Reynolds number
Cf = Frictional resistance coefficient
[Cform] = Viscous form resistance coefficient
[Cw] = Wave-making resistance coefficient
Cr = Residuary resistance coefficient
Ct = Bare-hull resistance coefficient

Rw/W = Wave-making resist-displ merit ratio
Rr/W = Residuary resist-displ merit ratio
Rbare/W = Bare-hull resist-displ merit ratio
Rw = Wave-making resistance component
Rr = Residuary resistance component
Rbare = Bare-hull resistance
PEbare = Bare-hull effective power

Rapp = Additional appendage resistance
Rwind = Additional wind resistance
Rseas = Additional sea-state resistance
Rchan = Additional channel resistance
Rother = Other added resistance
Rtotal = Total vessel resistance
PEtotal = Total effective power

* = Exceeds speed parameter

ORT Design Team 3 1 Apr 2000 12:45 PM Page 1
Displacement hull Optimum propeller Project: TANKER2.NC3
ORT LO Tanker

---------- System 1 ---

Description:	B-series FPP - 4 blades
Series:	B-series
Blades:	4
Exp area ratio:	[ ]Opt 0.6500
Diameter:	[ ]Opt 8.7200 m
Pitch:	[X]Opt 8.0402 m

Scale corr:	B-series
Kt mult:	[ ]Std 0.970
Kq mult:	[ ]Std 1.030
Blade t/c:	[X]Std 0.000
Roughness:	[X]Std 0.000 mm
Cav breakdown:	[ ]Apply
Propeller cup:	0.0 mm

Engine file:	A:\ENGINE2.ENG
Rated RPM/kW:	91.0 / 21480.0
Gear ratio:	1.000
Gear efficiency:	1.000

---------- Selection parameters --

Load identity:	Shaft power
Design speed:	15.00 kts
Reference load:	21480.0 kW
Reference RPM:	91.0
Cav criteria:	Keller eqn
Load design point:	100.0 %
RPM design point:	90.0 %

---------- Analysis results ---

Sys	Vel kts	Rtotal N	WakeFr	ThrDed	RelRot	EngRPM RPM	PropRPM RPM
	8.00	412487	0.0000	0.0000	1.0000	41.5	41.5
1	15.00	1395284	0.0000	0.0000	1.0000	77.1	77.1
	16.00	1615951	0.0000	0.0000	1.0000	82.6	82.6

Sys	Vel kts	J	Kt	Kq	PropEff	HullEff	QPC	OPC
	8.00	0.6817	0.1451	0.0240	0.6550	1.0000	0.6550	0.6517
1	15.00	0.6884	0.1424	0.0234	0.6655	1.0000	0.6655	0.6621
	16.00	0.6855	0.1437	0.0236	0.6644	1.0000	0.6644	0.6611

Sys	Vel kts	Thrust N	Delthr N	PD/prop kW	PS/prop kW	PB/prop kW
	8.00	412574	412574	2592	2605	2605
1	15.00	1395542	1395542	16182	16264	16264
	16.00	1616268	1616268	20023	20124	20124

Sys	Vel kts	Fuel lph	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
	8.00	132.897	0.798	19.0	0.0	10.6	0.2794
1	15.00	3414.48	0.801	35.2	0.0	36.0	0.4685
	16.00	4172.42	0.800	37.7	0.0	41.6	0.5110

---------- System 2 ----------

```
      Description: B-series FPP - 5 blades
           Series: B-series               Scale corr: B-series
           Blades: 5                        Kt mult: [ ]Std   0.970
   Exp area ratio: [ ]Opt   0.6500          Kq mult: [ ]Std   1.030
         Diameter: [ ]Opt   8.7200 m      Blade t/c: [X]Std   0.000
            Pitch: [X]Opt   7.8508 m      Roughness: [X]Std   0.000 mm
                                     Cav breakdown: [ ]Apply
                                     Propeller cup:          0.0   mm

      Engine file: A:\ENGINE2.ENG
     Rated RPM/kW: 91.0 / 21480.0
       Gear ratio: 1.000
  Gear efficiency: 1.000
```

---------- Selection parameters ----------

```
    Load identity: Shaft power
     Design speed: 15.00   kts           Cav criteria: Keller eqn
   Reference load: 21480.0   kW     Load design point: 100.0 %
    Reference RPM: 91.0              RPM design point: 90.0 %
```

---------- Analysis results ----------

Sys	Vel kts	Rtotal N	WakeFr	ThrDed	RelRot	EngRPM RPM	PropRPM RPM
	8.00	412487	0.0000	0.0000	1.0000	41.6	41.6
2	15.00	1395284	0.0000	0.0000	1.0000	77.3	77.3
	16.00	1615951	0.0000	0.0000	1.0000	82.8	82.8

Sys	Vel kts	J	Kt	Kq	PropEff	HullEff	QPC	OPC
	8.00	0.6804	0.1445	0.0241	0.6486	1.0000	0.6486	0.6454
2	15.00	0.6868	0.1417	0.0235	0.6583	1.0000	0.6583	0.6550
	16.00	0.6840	0.1431	0.0237	0.6576	1.0000	0.6576	0.6543

Sys	Vel kts	Thrust N	Delthr N	PD/prop kW	PS/prop kW	PB/prop kW
	8.00	412533	412533	2618	2631	2631
2	15.00	1395419	1395419	16358	16440	16440
	16.00	1616118	1616118	20228	20330	20330

Sys	Vel kts	Fuel lph	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
	8.00	145.635	0.796	19.0	0.0	10.6	0.2889
2	15.00	3450.03	0.800	35.3	0.0	35.9	0.5007
	16.00	4213.47	0.798	37.8	0.0	41.6	0.5483

---------- Condition data ----------

```
       Water type: Standard Salt
     Mass density: 1025.86  kg/m3
   Kinematic visc: 1.1883e-06  m2/s
```

---------- Analysis parameters ----------

```
       Pitch type: FPP                        Low speed: 8.00 kts
  Number of props: 1                         High speed: 16.00 kts
 Shaft efficiency: 0.995
   Prop immersion: 7.0800 m
    Analysis type: Run
```

---------- Symbols and Values ----------

```
    Vel = Ship speed
 Rtotal = Total vessel resistance
 WakeFr = Taylor wake fraction coefficient
 ThrDed = Thrust deduction coefficient
 RelRot = Relative rotative efficiency
 EngRPM = Engine RPM
PropRPM = Propeller RPM

      J = Advance coefficinet
     Kt = Thrust coefficinet
     Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
    QPC = Quasi-propulsive coefficient
    OPC = Overall propulsive coefficient

 Thrust = Open water thrust per propeller
 Delthr = Total delivered thrust per propeller
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller

   Fuel = Fuel consumption per engine
 MinP/D = Minimum P/D ratio to avoid face cavitation
 TipSpd = Linear velocity of the propeller tips
   %Cav = Percent back cavitation
  Press = Propeller blade pressure
 MinBAR = Minimum expanded area ratio

      * = Warning of possible cavitation problems
```

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Displacement hull Optimum propeller Project: TANKER2.NC3
ORT LO Tanker

---------- System 3 ----------

Description: B-series CPP - 4 blades
Series: B-series Scale corr: B-series
Blades: 4 Kt mult: [ ]Std 0.970
Exp area ratio: [ ]Opt 0.6500 Kq mult: [ ]Std 1.030
Diameter: [ ]Opt 8.7200 m Blade t/c: [X]Std 0.000
Pitch: [X]Opt 8.0402 m Roughness: [X]Std 0.000 mm
Cav breakdown: [ ]Apply
Propeller cup: 0.0 mm

Engine file: A:\ENGINE2.ENG
Rated RPM/kW: 91.0 / 21480.0
Gear ratio: 1.000
Gear efficiency: 1.000

---------- Selection parameters ----------

Load identity: Shaft power
Design speed: 15.00 kts Cav criteria: Keller eqn
Reference load: 21480.0 kW Load design point: 100.0 %
Reference RPM: 91.0 RPM design point: 90.0 %

---------- Analysis results ----------

Sys	Vel (kts)	Rtotal (N)	WakeFr	ThrDed	RelRot	EngRPM (RPM)	PropRPM (RPM)	Pitch (m)
	8.00	412487	0.0000	0.0000	1.0000	41.2	41.2	8.1405
3	15.00	1395284	0.0000	0.0000	1.0000	77.0	77.0	8.0569
	16.00	1615951	0.0000	0.0000	1.0000	82.9	82.9	8.0014

Sys	Vel (kts)	J	Kt	Kq	PropEff	HullEff	QPC	OPC
	8.00	0.6881	0.1479	0.0247	0.6550	1.0000	0.6550	0.6517
3	15.00	0.6894	0.1428	0.0235	0.6655	1.0000	0.6655	0.6621
	16.00	0.6830	0.1427	0.0233	0.6644	1.0000	0.6644	0.6611

Sys	Vel (kts)	Thrust (N)	Delthr (N)	PD/prop (kW)	PS/prop (kW)	PB/prop (kW)
	8.00	412579	412579	2592	2605	2605
3	15.00	1395545	1395545	16182	16264	16264
	16.00	1616262	1616262	20023	20124	20124

Sys	Vel (kts)	Fuel (lph)	MinP/D	TipSpd (mps)	%Cav	Press (kPa)	MinBAR
	8.00	71.7421	0.805	18.8	0.0	10.6	0.2794
3	15.00	3415.47	0.803	35.2	0.0	36.0	0.4685
	16.00	4169.66	0.797	37.9	0.0	41.6	0.5110

ORT Design Team 3 1 Apr 2000 12:47 PM Page 2
Displacement hull Optimum propeller Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data ----------

Water type: Standard Salt
Mass density: 1025.86 kg/m3
Kinematic visc: 1.1883e-06 m2/s

---------- Analysis parameters ----------

Pitch type: CPP Low speed: 8.00 kts
Number of props: 1 High speed: 16.00 kts
Shaft efficiency: 0.995
Prop immersion: 7.0800 m
Analysis type: Run

---------- Symbols and Values ----------

Vel = Ship speed
Rtotal = Total vessel resistance
WakeFr = Taylor wake fraction coefficient
ThrDed = Thrust deduction coefficient
RelRot = Relative rotative efficiency
EngRPM = Engine RPM
PropRPM = Propeller RPM
Pitch = Propeller pitch

J = Advance coefficinet
Kt = Thrust coefficinet
Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
QPC = Quasi-propulsive coefficient
OPC = Overall propulsive coefficient

Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller

Fuel = Fuel consumption per engine
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

* = Warning of possible cavitation problems

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 1 -------------------------------------

Vel kts	Rtotal N	WakeFr	ThrDed	RelRot	VelAdv kts	EngRPM RPM	PropRPM RPM
8.00	412487	0.0000	0.0000	1.0000	8.00	41.5	41.5
10.00	628065	0.0000	0.0000	1.0000	10.00	51.6	51.6
12.00	888297	0.0000	0.0000	1.0000	12.00	61.6	61.6
14.00	1205335	0.0000	0.0000	1.0000	14.00	71.9	71.9
15.00	1395283	0.0000	0.0000	1.0000	15.00	77.1	77.1
15.78	1564271	0.0000	0.0000	1.0000	15.78	81.4	81.4
16.00	1615950	0.0000	0.0000	1.0000	16.00	82.6	82.6

Vel kts	PropRn	J	Kt	Kq	PropEff	HullEff	QPC	OPC
8.00	3.66e7	0.6817	0.1451	0.0240	0.6550	1.0000	0.6550	0.6517
10.00	4.55e7	0.6861	0.1432	0.0237	0.6599	1.0000	0.6599	0.6566
12.00	5.44e7	0.6891	0.1419	0.0235	0.6636	1.0000	0.6636	0.6603
14.00	6.34e7	0.6897	0.1417	0.0234	0.6655	1.0000	0.6655	0.6622
15.00	6.80e7	0.6883	0.1424	0.0234	0.6655	1.0000	0.6655	0.6621
15.78	7.18e7	0.6862	0.1433	0.0235	0.6647	1.0000	0.6647	0.6614
16.00	7.28e7	0.6854	0.1437	0.0236	0.6644	1.0000	0.6644	0.6611

---------- Symbols and Values ---

Vel = Ship speed
Rtotal = Total vessel resistance
WakeFr = Taylor wake fraction coefficient
ThrDed = Thrust deduction coefficient
RelRot = Relative rotative efficiency
VelAdv = Advance velocity = (1-WakeFr)* Vel
EngRPM = Engine RPM
PropRPM = Propeller RPM

PropRn = Propeller Reynold's number
J = Advance coefficient
Kt = Thrust coefficient
Kq = Torque coefficient
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
QPC = Quasi-propulsive coefficient
OPC = Overall propulsive coefficient

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 2 -------------------------------------

Vel kts	Thrust N	Delthr N	Torque Nm	PD/prop kW	PS/prop kW	PB/prop kW
8.00	412574	412574	595986	2592	2605	2605
10.00	628187	628187	906429	4897	4922	4922
12.00	888460	888460	1280471	8265	8307	8307
14.00	1205552	1205552	1733800	13046	13112	13112
15.00	1395542	1395542	2003342	16182	16264	16264
15.78	1564574	1564574	2241577	19107	19203	19203
16.00	1616268	1616268	2314134	20023	20124	20124

Vel kts	Fuel lph	Sigma	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
8.00	133.02	19.67	0.798	19.0	2.8	10.6	0.2794
10.00	937.06	12.59	0.800	23.6	2.1	16.2	0.3209
12.00	1733.37	8.74	0.802	28.1	1.5	22.9	0.3710
14.00	2741.22	6.42	0.802	32.8	1.1	31.1	0.4320
15.00	3414.47	5.59	0.801	35.2	1.1	36.0	0.4685
15.78	3992.13	5.05	0.800	37.2	1.2	40.3	0.5011
16.00	4172.41	4.92	0.800	37.7	1.2	41.6	0.5110

---------- Symbols and Values ---

Vel = Ship speed
Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
Torque = Propeller open_water torque
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller
Tow = Total tow pull

Fuel = Fuel consumption per engine
Sigma = Cavitation number based on advance velocity
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

```
Team 3                                 7 Mar 2000 11:41 AM        Page 3
Displacement hull System analysis      Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data -----------------------------------------------

       Water type: Standard Salt
     Mass density: 1025.86  kg/m3
   Kinematic visc: 1.1883e-06  m2/s

---------- Analysis parameters ------------------------------------------

      Engine file: A:\ENGINE2.ENG
  Gear efficiency: 1.000                   Analysis type: Run
       Gear ratio: 1                       Cav criteria: Keller eqn
  Number of props: 1
   Prop immersion: 7.0800 m
 Shaft efficiency: 0.995

---------- Propulsor data -----------------------------------------------

      Description: B-series FPP - 4 blades
           Series: B-series               Scale corr: B-series
           Blades: 4                         Kt mult: [ ]Std   0.970
   Exp area ratio: 0.6500                    Kq mult: [ ]Std   1.030
         Diameter: 8.7200                  Blade t/c: [X]Std   0.000
            Pitch: 8.0400                  Roughness: [X]Std   0.000 mm
       Pitch type: FPP                   Cav breakdown: [ ]Apply
                                         Propeller cup:         0.0   mm

---------- Engine data --------------------------------------------------

            Model: ORT Engine #2
        Rated RPM: 91.0
      Rated power: 21480.0  kW

Performance envelope:                  Min fuel/combinator line:
        RPM    Power     Fuel                  RPM    Power     Fuel
                  kW      lph                            kW      lph
   -------- -------- --------             -------- -------- --------
 1.    93.0      0.0      0.0
 2.    91.0  21480.0   4407.0
 3.    88.0  21200.0   4400.0
 4.    84.0  20800.0   4300.0
 5.    76.0  19000.0   4000.0
 6.    70.0  16800.0   3500.0
 7.    68.0  15880.0   3309.0
 8.    64.0  13900.0   2900.0
 9.    60.0  11500.0   2400.0
10.    56.0   9400.0   1900.0
```

A.5.1.2 Wave Case

```
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Displacement hull Resistance           Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis parameters --------------------------------------------

[X]Bare-hull: Holtrop-1984 method      [X]Appendage: Holtrop-1988 method
   Technique: Prediction               [ ]Wind     :
   Cf type  : ITTC                     [X]Seas     : NavSea small naval
   Align to : Rbare/W                  [ ]Channel  :
   File     :                          [ ]Barge    :
   Correlation allow(Ca): 0.00014      [ ]Net      :
[ ]Roughness:
[X]3-D corr : form factor(1+k): 1.4381 [ ]Speed dependent correction

---------- Prediction Results ---------------------------------------------
```

Vel kts	Fn	Rn	Cf	[Cform]	[Cw]	Cr	Ct
8.00	0.083	8.71e8	0.001557	0.000682	0.000004	0.000686	0.002384
10.00	0.104	1.09e9	0.001515	0.000664	0.000005	0.000668	0.002323
12.00	0.124	1.31e9	0.001481	0.000649	0.000012	0.000660	0.002281
14.00	0.145	1.52e9	0.001454	0.000637	0.000044	0.000681	0.002275
15.00	0.155	1.63e9	0.001442	0.000632	0.000081	0.000713	0.002294
15.78	0.163	1.72e9	0.001433	0.000628	0.000124	0.000752	0.002324
16.00	0.166	1.74e9	0.001430	0.000627	0.000139	0.000765	0.002336

Vel kts	Rw/W	Rr/W	Rbare/W	Rw N	Rr N	Rbare N	PEbare kW
8.00	0.00000	0.00006	0.00022	659	106970	371450	1528.7
10.00	0.00000	0.00010	0.00034	1132	162699	565578	2909.6
12.00	0.00000	0.00014	0.00048	4037	231545	799938	4938.3
14.00	0.00001	0.00020	0.00065	21133	325050	1085583	7818.6
15.00	0.00003	0.00024	0.00076	44396	390388	1256846	9698.7
15.78	0.00005	0.00027	0.00085	75120	455704	1409306	11440.7
16.00	0.00005	0.00029	0.00088	86434	477055	1455949	11984.1

Vel kts	Rapp N	Rwind N	Rseas N	Rchan N	Rother N	Rtotal N	PEtotal kW
8.00	3539	0	236546	0	37499	649033	2671.1
10.00	5390	0	226414	0	57097	854479	4395.8
12.00	7605	0	216282	0	80754	1104579	6818.9
14.00	10176	0	206150	0	109576	1411485	10165.8
15.00	11593	0	201084	0	126844	1596367	12318.6
15.78	12759	0	197132	0	142207	1761404	14299.0
16.00	13097	0	196018	0	146905	1811969	14914.5

```
ORT Design Team 3                    1 Apr 2000 02:27 PM          Page 2
Displacement hull Resistance         Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data ---------------------------------------------

       Water type: Standard Salt
     Mass density: 1025.86  kg/m3
   Kinematic visc: 1.1883e-06  m2/s

---------- Hull data --------------------------------------------------

Primary:                            Secondary:
  Length between PP:  251.540 m           Trim by stern:    0.000 m
       Wl aft of FP:    0.000 m          LCB aft of FP:  133.570 m
          Length WL:  251.540 m         Bulb ext fwd FP:    7.050 m
        Max beam WL:   49.780 m         Bulb area at FP:   88.000 m2
    Draft at mid WL:   15.800 m       Bulb ctr above BL:    6.220 m
  Displacement Bare: 169055.0 t            Transom area:    0.000 m2
  Max area coef(Cx):    0.995           Half ent angle:   40.000 deg
    Waterplane coef:    0.913              Stern shape:   Normal
     Wetted surface:  17937.4 m2             Bow shape:   U-shape
            Loading:   Load draft

Parameters: Holtrop-1984 method
Fn(Lwl)    0.1...0.8       0.08 Limit
Fn-high    0.1...0.8       0.17
Cp(Lwl)    0.55...0.85     0.84
Lwl/Bwl    3.9...14.9      5.05
Bwl/T      2.1...4         3.15

---------- Appendages -------------------------------------------------

Total wetted surface (ex. thruster):
          Rudders:    200.000 m2      Drag coefficient: 1.200
   Shaft brackets:      0.000        ------------------ 0.000
             Skeg:      0.000        ------------------ 0.000
    Strut bossing:      0.000        ------------------ 0.000
     Hull bossing:      0.000        ------------------ 0.000
   Exposed shafts:      0.000        ------------------ 0.000
  Stabilizer fins:      0.000        ------------------ 0.000
             Dome:      0.000        ------------------ 0.000
       Bilge keel:      0.000        ------------------ 0.000
Bow thruster diam:      0.000 m      ------------------ 0.000

Parameters: Holtrop-1988 method
None given
```

```
ORT Design Team 3                    1 Apr 2000 02:27 PM          Page 3
Displacement hull Resistance         Project: TANKER2.NC3
ORT LO Tanker

---------- Environment data -------------------------------------------

Wind:                                   Seas:
         Wind speed:    19.000 kts     Sig. wave height:     1.880 m
      Angle off bow:     0.000 deg    Modal wave period:     8.800 sec
      Tran hull area:    0.000 m2
        VCE above WL:    0.000 m    Channel:
   Tran superst area:    0.000 m2         Channel width:     0.000 m
        VCE above WL:    0.000 m          Channel depth:     0.000 m
    Total longl area:    0.000 m2            Side slope:     0.000 deg
        VCE above WL:    0.000 m      Wetted hull girth:     0.000 m
          Wind speed:  Free stream
         Arrangement:  Cargo ship

---------- Symbols and Values -----------------------------------------

    Vel = Ship speed
     Fn = Froude number
     Rn = Reynolds number
     Cf = Frictional resistance coefficient
[Cform] = Viscous form resistance coefficient
   [Cw] = Wave-making resistance coefficient
     Cr = Residuary resistance coefficient
     Ct = Bare-hull resistance coefficient

   Rw/W = Wave-making resist-displ merit ratio
   Rr/W = Residuary resist-displ merit ratio
Rbare/W = Bare-hull resist-displ merit ratio
     Rw = Wave-making resistance component
     Rr = Residuary resistance component
  Rbare = Bare-hull resistance
 PEbare = Bare-hull effective power

   Rapp = Additional appendage resistance
  Rwind = Additional wind resistance
  Rseas = Additional sea-state resistance
  Rchan = Additional channel resistance
 Rother = Other added resistance
 Rtotal = Total vessel resistance
PEtotal = Total effective power

      * = Exceeds speed parameter
```

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 1 ----------

Vel kts	Rtotal N	WakeFr	ThrDed	RelRot	VelAdv kts	EngRPM RPM	PropRPM RPM
8.00	649033	0.0000	0.0000	1.0000	8.00	46.8	46.8
10.00	854479	0.0000	0.0000	1.0000	10.00	55.8	55.8
12.00	1104579	0.0000	0.0000	1.0000	12.00	65.1	65.1
14.00	1411485	0.0000	0.0000	1.0000	14.00	74.7	74.7
15.00	1596367	0.0000	0.0000	1.0000	15.00	79.7	79.7
15.78	1761404	0.0000	0.0000	1.0000	15.78	83.8	83.8
16.00	1811969	0.0000	0.0000	1.0000	16.00	85.0	85.0

Vel kts	PropRn	J	Kt	Kq	PropEff	HullEff	QPC	OPC
8.00	4.09e7	0.6046	0.1795	0.0286	0.6034	1.0000	0.6034	0.6003
10.00	4.89e7	0.6343	0.1665	0.0268	0.6266	1.0000	0.6266	0.6235
12.00	5.72e7	0.6527	0.1583	0.0257	0.6409	1.0000	0.6409	0.6377
14.00	6.57e7	0.6635	0.1535	0.0250	0.6494	1.0000	0.6494	0.6461
15.00	7.01e7	0.6660	0.1524	0.0248	0.6517	1.0000	0.6517	0.6484
15.78	7.37e7	0.6665	0.1522	0.0247	0.6525	1.0000	0.6525	0.6492
16.00	7.48e7	0.6664	0.1523	0.0247	0.6525	1.0000	0.6525	0.6493

---------- Symbols and Values ----------

Vel = Ship speed
Rtotal = Total vessel resistance
WakeFr = Taylor wake fraction coefficient
ThrDed = Thrust deduction coefficient
RelRot = Relative rotative efficiency
VelAdv = Advance velocity = (1-WakeFr)* Vel
EngRPM = Engine RPM
PropRPM = Propeller RPM

PropRn = Propeller Reynold's number
J = Advance coefficinet
Kt = Thrust coefficinet
Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
QPC = Quasi-propulsive coefficient
OPC = Overall propulsive coefficient

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 2 ----------

Vel kts	Thrust N	Delthr N	Torque Nm	PD/prop kW	PS/prop kW	PB/prop kW
8.00	648899	648899	902438	4426	4448	4448
10.00	854370	854370	1200146	7014	7049	7049
12.00	1104479	1104479	1561178	10639	10692	10692
14.00	1411382	1411382	2001267	15654	15732	15732
15.00	1596258	1596258	2264078	18902	18997	18997
15.78	1761285	1761285	2496997	21914	22024*	22024
16.00	1811846	1811846	2568041	22855	22969*	22969

Vel kts	Fuel lph	Sigma	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
8.00	731.45	19.67	0.756	21.4	1.9	16.7	0.3249
10.00	1422.14	12.59	0.772	25.5	1.7	22.0	0.3644
12.00	2229.96	8.74	0.782	29.7	1.4	28.5	0.4125
14.00	3305.25	6.42	0.788	34.1	1.3	36.4	0.4716
15.00	3964.21	5.59	0.789	36.4	1.4	41.1	0.5072
15.78	4554.85	5.05	0.789	38.3	1.6	45.4*	0.5389
16.00	4753.18	4.92	0.789	38.8	1.7	46.7*	0.5487

---------- Symbols and Values ----------

Vel = Ship speed
Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
Torque = Propeller open_water torque
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller
Tow = Total tow pull

Fuel = Fuel consumption per engine
Sigma = Cavitation number based on advance velocity
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

```
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Displacement hull System analysis     Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data -------------------------------------------------

       Water type: Standard Salt
     Mass density: 1025.86  kg/m3
   Kinematic visc: 1.1883e-06  m2/s

---------- Analysis parameters --------------------------------------------

      Engine file: A:\ENGINE2.ENG
  Gear efficiency: 1.000                   Analysis type: Run
       Gear ratio: 1                        Cav criteria: Keller eqn
  Number of props: 1
   Prop immersion: 7.0800 m
 Shaft efficiency: 0.995

---------- Propulsor data -------------------------------------------------

      Description: B-series FPP - 4 blades
           Series: B-series                Scale corr: B-series
           Blades: 4                          Kt mult: [ ]Std   0.970
   Exp area ratio: 0.6500                     Kq mult: [ ]Std   1.030
         Diameter: 8.7200                   Blade t/c: [X]Std   0.000
            Pitch: 8.0400                   Roughness: [X]Std   0.000 mm
       Pitch type: FPP                   Cav breakdown: [ ]Apply
                                         Propeller cup:          0.0   mm

---------- Engine data ----------------------------------------------------

            Model: ORT Engine #2
        Rated RPM: 91.0
      Rated power: 21480.0  kW

Performance envelope:                 Min fuel/combinator line:
        RPM    Power     Fuel                 RPM    Power     Fuel
                  kW      lph                           kW      lph
   -------- -------- --------            -------- -------- --------
  1.    93.0      0.0      0.0
  2.    91.0  21480.0   4407.0
  3.    88.0  21200.0   4400.0
  4.    84.0  20800.0   4300.0
  5.    76.0  19000.0   4000.0
  6.    70.0  16800.0   3500.0
  7.    68.0  15880.0   3309.0
  8.    64.0  13900.0   2900.0
  9.    60.0  11500.0   2400.0
 10.    56.0   9400.0   1900.0
```

A.5.1.3 Arrival Ballast Case

```
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Displacement hull System analysis     Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 1 --------------------------------------

  Vel    Rtotal  WakeFr  ThrDed RelRot  VelAdv  EngRPM PropRPM
  kts         N                            kts     RPM     RPM
-----  -------- ------- ------- ------ ------- ------- -------
 8.00    345386  0.0000  0.0000 1.0000    8.00    39.9    39.9
10.00    525795  0.0000  0.0000 1.0000   10.00    49.5    49.5
12.00    741655  0.0000  0.0000 1.0000   12.00    59.1    59.1
14.00    993487  0.0000  0.0000 1.0000   14.00    68.8    68.8
15.00   1133659  0.0000  0.0000 1.0000   15.00    73.6    73.6
15.78   1250116  0.0000  0.0000 1.0000   15.78    77.3    77.3
16.00   1284152  0.0000  0.0000 1.0000   16.00    78.4    78.4

  Vel   PropRn       J      Kt      Kq PropEff HullEff     QPC     OPC
  kts
-----  ------- ------- ------- ------- ------- ------- ------- -------
 8.00   3.52e7  0.7106  0.1320  0.0223  0.6705  1.0000  0.6705  0.6671
10.00   4.38e7  0.7149  0.1302  0.0219  0.6753  1.0000  0.6753  0.6719
12.00   5.23e7  0.7182  0.1287  0.0217  0.6791  1.0000  0.6791  0.6757
14.00   6.09e7  0.7208  0.1276  0.0215  0.6822  1.0000  0.6822  0.6788
15.00   6.51e7  0.7218  0.1272  0.0214  0.6835  1.0000  0.6835  0.6801
15.78   6.85e7  0.7224  0.1269  0.0213  0.6844  1.0000  0.6844  0.6810
16.00   6.94e7  0.7225  0.1268  0.0213  0.6846  1.0000  0.6846  0.6812

---------- Symbols and Values ---------------------------------------------

    Vel = Ship speed
 Rtotal = Total vessel resistance
 WakeFr = Taylor wake fraction coefficient
 ThrDed = Thrust deduction coefficient
 RelRot = Relative rotative efficiency
 VelAdv = Advance velocity = (1-WakeFr)* Vel
 EngRPM = Engine RPM
PropRPM = Propeller RPM

 PropRn = Propeller Reynold's number
      J = Advance coefficinet
     Kt = Thrust coefficinet
     Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
    QPC = Quasi-propulsive coefficient
    OPC = Overall propulsive coefficient
```

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 2 ----------

Vel kts	Thrust N	Delthr N	Torque Nm	PD/prop kW	PS/prop kW	PB/prop kW
8.00	345426	345426	508094	2120	2131	2131
10.00	525850	525850	772582	4006	4026	4026
12.00	741727	741727	1088685	6743	6777	6777
14.00	993578	993578	1456943	10490	10542	10542
15.00	1133760	1133760	1661599	12800	12865	12865
15.78	1250226	1250226	1831406	14830	14904	14904
16.00	1284265	1284265	1880991	15441	15518	15518

Vel kts	Fuel lph	Sigma	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
8.00	***	13.48	0.814	18.2	2.6	8.9	0.2970
10.00	731.64	8.63	0.816	22.6	1.7	13.5	0.3476
12.00	1406.14	5.99	0.818	27.0	1.0	19.1	0.4082
14.00	2196.59	4.40	0.820	31.4	0.7	25.6	0.4789
15.00	2697.71	3.84	0.820	33.6	0.8	29.2	0.5182
15.78	3127.67	3.47	0.821	35.3	1.0	32.2	0.5509
16.00	3248.32	3.37	0.821	35.8	1.1	33.1	0.5605

---------- Symbols and Values ----------

Vel = Ship speed
Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
Torque = Propeller open_water torque
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller
Tow = Total tow pull

Fuel = Fuel consumption per engine
Sigma = Cavitation number based on advance velocity
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data ----------

Water type: Standard Salt
Mass density: 1025.86 kg/m3
Kinematic visc: 1.1883e-06 m2/s

---------- Analysis parameters ----------

Engine file: A:\ENGINE2.ENG
Gear efficiency: 1.000
Gear ratio: 1
Number of props: 1
Prop immersion: 1.7400 m
Shaft efficiency: 0.995
Analysis type: Run
Cav criteria: Keller eqn

---------- Propulsor data ----------

Description: B-series FPP - 4 blades
Series: B-series
Blades: 4
Exp area ratio: 0.6500
Diameter: 8.7200
Pitch: 8.0400
Pitch type: FPP
Scale corr: B-series
Kt mult: [ ]Std 0.970
Kq mult: [ ]Std 1.030
Blade t/c: [X]Std 0.000
Roughness: [X]Std 0.000 mm
Cav breakdown: [ ]Apply
Propeller cup: 0.0 mm

---------- Engine data ----------

Model: ORT Engine #2
Rated RPM: 91.0
Rated power: 21480.0 kW

Performance envelope:

	RPM	Power kW	Fuel lph
1.	93.0	0.0	0.0
2.	91.0	21480.0	4407.0
3.	88.0	21200.0	4400.0
4.	84.0	20800.0	4300.0
5.	76.0	19000.0	4000.0
6.	70.0	16800.0	3500.0
7.	68.0	15880.0	3309.0
8.	64.0	13900.0	2900.0
9.	60.0	11500.0	2400.0
10.	56.0	9400.0	1900.0

Min fuel/combinator line:

RPM	Power kW	Fuel lph

A.5.1.4 TAPS Load Case

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 1 ----------

Vel kts	Rtotal N	WakeFr	ThrDed	RelRot	VelAdv kts	EngRPM RPM	PropRPM RPM
8.00	391916	0.0000	0.0000	1.0000	8.00	41.0	41.0
10.00	596627	0.0000	0.0000	1.0000	10.00	51.0	51.0
12.00	841534	0.0000	0.0000	1.0000	12.00	60.9	60.9
14.00	1127068	0.0000	0.0000	1.0000	14.00	70.7	70.7
15.00	1285813	0.0000	0.0000	1.0000	15.00	75.7	75.7
15.78	1417547	0.0000	0.0000	1.0000	15.78	79.5	79.5
16.00	1456017	0.0000	0.0000	1.0000	16.00	80.6	80.6

Vel kts	PropRn	J	Kt	Kq	PropEff	HullEff	QPC	OPC
8.00	3.62e7	0.6902	0.1413	0.0235	0.6597	1.0000	0.6597	0.6564
10.00	4.50e7	0.6945	0.1394	0.0232	0.6647	1.0000	0.6647	0.6613
12.00	5.37e7	0.6980	0.1379	0.0229	0.6686	1.0000	0.6686	0.6652
14.00	6.25e7	0.7006	0.1368	0.0227	0.6717	1.0000	0.6717	0.6684
15.00	6.68e7	0.7017	0.1363	0.0226	0.6731	1.0000	0.6731	0.6697
15.78	7.03e7	0.7023	0.1360	0.0226	0.6740	1.0000	0.6740	0.6706
16.00	7.12e7	0.7025	0.1360	0.0225	0.6742	1.0000	0.6742	0.6708

---------- Symbols and Values ----------

Vel = Ship speed
Rtotal = Total vessel resistance
WakeFr = Taylor wake fraction coefficient
ThrDed = Thrust deduction coefficient
RelRot = Relative rotative efficiency
VelAdv = Advance velocity = (1-WakeFr)* Vel
EngRPM = Engine RPM
PropRPM = Propeller RPM

PropRn = Propeller Reynold's number
J = Advance coefficinet
Kt = Thrust coefficinet
Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
QPC = Quasi-propulsive coefficient
OPC = Overall propulsive coefficient

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 2 ----------

Vel kts	Thrust N	Delthr N	Torque Nm	PD/prop kW	PS/prop kW	PB/prop kW
8.00	391986	391986	569087	2445	2458	2458
10.00	596725	596725	865354	4619	4642	4642
12.00	841662	841662	1219415	7772	7811	7811
14.00	1127230	1127230	1631688	12086	12146	12146
15.00	1285994	1285994	1860587	14744	14818	14818
15.78	1417744	1417744	2050327	17076	17162	17162
16.00	1456219	1456219	2105695	17778	17868	17868

Vel kts	Fuel lph	Sigma	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
8.00	46.08	18.10	0.802	18.7	2.8	10.1	0.2819
10.00	872.99	11.59	0.805	23.3	2.1	15.4	0.3247
12.00	1629.92	8.05	0.807	27.8	1.4	21.7	0.3759
14.00	2534.12	5.91	0.808	32.3	1.0	29.0	0.4356
15.00	3117.95	5.15	0.809	34.5	0.9	33.1	0.4688
15.78	3582.88	4.65	0.809	36.3	1.0	36.5	0.4964
16.00	3720.90	4.53	0.809	36.8	1.0	37.5	0.5044

---------- Symbols and Values ----------

Vel = Ship speed
Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
Torque = Propeller open_water torque
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller
Tow = Total tow pull

Fuel = Fuel consumption per engine
Sigma = Cavitation number based on advance velocity
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

```
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Displacement hull System analysis    Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data -------------------------------------------------

       Water type: Standard Salt
     Mass density: 1025.86  kg/m3
   Kinematic visc: 1.1883e-06  m2/s

---------- Analysis parameters --------------------------------------------

      Engine file: A:\ENGINE2.ENG
  Gear efficiency: 1.000                  Analysis type: Run
       Gear ratio: 1                       Cav criteria: Keller eqn
  Number of props: 1
   Prop immersion: 5.7300 m
 Shaft efficiency: 0.995

---------- Propulsor data -------------------------------------------------

      Description: B-series FPP - 4 blades
           Series: B-series               Scale corr: B-series
           Blades: 4                         Kt mult: [ ]Std   0.970
   Exp area ratio: 0.6500                    Kq mult: [ ]Std   1.030
         Diameter: 8.7200                 Blade t/c: [X]Std   0.000
            Pitch: 8.0400                 Roughness: [X]Std   0.000 mm
       Pitch type: FPP                 Cav breakdown: [ ]Apply
                                       Propeller cup:          0.0   mm

---------- Engine data ----------------------------------------------------

            Model: ORT Engine #2
        Rated RPM: 91.0
      Rated power: 21480.0  kW

Performance envelope:                Min fuel/combinator line:
        RPM    Power     Fuel                RPM    Power     Fuel
                  kW      lph                          kW      lph
   -------- -------- --------            -------- -------- --------
 1.    93.0      0.0      0.0
 2.    91.0  21480.0   4407.0
 3.    88.0  21200.0   4400.0
 4.    84.0  20800.0   4300.0
 5.    76.0  19000.0   4000.0
 6.    70.0  16800.0   3500.0
 7.    68.0  15880.0   3309.0
 8.    64.0  13900.0   2900.0
 9.    60.0  11500.0   2400.0
10.    56.0   9400.0   1900.0
```

A.5.1.5 Full Load Case

```
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Displacement hull System analysis    Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 1 --------------------------------------

  Vel    Rtotal  WakeFr  ThrDed RelRot  VelAdv  EngRPM PropRPM
  kts         N                            kts     RPM     RPM
-----  -------- ------- ------- ------ ------- ------- -------
 8.00    410011  0.0000  0.0000 1.0000    8.00    41.5    41.5
10.00    624173  0.0000  0.0000 1.0000   10.00    51.5    51.5
12.00    880376  0.0000  0.0000 1.0000   12.00    61.5    61.5
14.00   1179016  0.0000  0.0000 1.0000   14.00    71.5    71.5
15.00   1344984  0.0000  0.0000 1.0000   15.00    76.5    76.5
15.78   1482659  0.0000  0.0000 1.0000   15.78    80.4    80.4
16.00   1525291  0.0000  0.0000 1.0000   16.00    81.5    81.5

  Vel   PropRn       J      Kt      Kq PropEff HullEff     QPC     OPC
  kts
-----  ------- ------- ------- ------- ------- ------- ------- -------
 8.00   3.66e7  0.6827  0.1447  0.0240  0.6555  1.0000  0.6555  0.6523
10.00   4.54e7  0.6871  0.1428  0.0236  0.6605  1.0000  0.6605  0.6572
12.00   5.43e7  0.6906  0.1413  0.0234  0.6644  1.0000  0.6644  0.6611
14.00   6.31e7  0.6933  0.1401  0.0232  0.6676  1.0000  0.6676  0.6643
15.00   6.75e7  0.6944  0.1396  0.0231  0.6690  1.0000  0.6690  0.6656
15.78   7.09e7  0.6950  0.1393  0.0230  0.6699  1.0000  0.6699  0.6665
16.00   7.19e7  0.6949  0.1394  0.0230  0.6700  1.0000  0.6700  0.6666

---------- Symbols and Values ---------------------------------------------

    Vel = Ship speed
 Rtotal = Total vessel resistance
 WakeFr = Taylor wake fraction coefficient
 ThrDed = Thrust deduction coefficient
 RelRot = Relative rotative efficiency
 VelAdv = Advance velocity = (1-WakeFr)* Vel
 EngRPM = Engine RPM
PropRPM = Propeller RPM

 PropRn = Propeller Reynold's number
      J = Advance coefficinet
     Kt = Thrust coefficinet
     Kq = Torque coefficinet
PropEff = Propeller open-water efficiency
HullEff = Hull efficiency = (1 - ThrDed)/(1-WakeFr)
    QPC = Quasi-propulsive coefficient
    OPC = Overall propulsive coefficient
```

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Analysis results - part 2 ----------

Vel kts	Thrust N	Delthr N	Torque Nm	PD/prop kW	PS/prop kW	PB/prop kW
8.00	410096	410096	592751	2575	2588	2588
10.00	624292	624292	901347	4863	4887	4887
12.00	880532	880532	1270135	8181	8222	8222
14.00	1179213	1179213	1699484	12721	12785	12785
15.00	1345205	1345205	1937789	15517	15595	15595
15.78	1482900	1482900	2135262	17971	18061	18061
16.00	1525538	1525538	2196051	18743	18837	18837

Vel kts	Fuel lph	Sigma	MinP/D	TipSpd mps	%Cav	Press kPa	MinBAR
8.00	123.44	19.92	0.798	18.9	2.9	10.6	0.2779
10.00	929.08	12.75	0.801	23.5	2.2	16.1	0.3186
12.00	1715.73	8.85	0.803	28.1	1.6	22.7	0.3673
14.00	2671.10	6.50	0.804	32.6	1.1	30.4	0.4240
15.00	3279.43	5.67	0.805	34.9	1.0	34.7	0.4556
15.78	3763.32	5.12	0.805	36.7	1.0	38.2	0.4817
16.00	3915.10	4.98	0.805	37.2	1.0	39.3	0.4898

---------- Symbols and Values ----------

Vel = Ship speed
Thrust = Open water thrust per propeller
Delthr = Total delivered thrust per propeller
Torque = Propeller open_water torque
PD/prop = Delivered power per propeller
PS/prop = Shaft power per propeller
PB/prop = Brake power per propeller
Tow = Total tow pull

Fuel = Fuel consumption per engine
Sigma = Cavitation number based on advance velocity
MinP/D = Minimum P/D ratio to avoid face cavitation
TipSpd = Linear velocity of the propeller tips
%Cav = Percent back cavitation
Press = Propeller blade pressure
MinBAR = Minimum expanded area ratio

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Displacement hull System analysis Project: TANKER2.NC3
ORT LO Tanker

---------- Condition data ----------

Water type: Standard Salt
Mass density: 1025.86 kg/m3
Kinematic visc: 1.1883e-06 m2/s

---------- Analysis parameters ----------

Engine file: A:\ENGINE2.ENG
Gear efficiency: 1.000 Analysis type: Run
Gear ratio: 1 Cav criteria: Keller eqn
Number of props: 1
Prop immersion: 7.3000 m
Shaft efficiency: 0.995

---------- Propulsor data ----------

Description: B-series FPP - 4 blades
Series: B-series Scale corr: B-series
Blades: 4 Kt mult: [ ]Std 0.970
Exp area ratio: 0.6500 Kq mult: [ ]Std 1.030
Diameter: 8.7200 Blade t/c: [X]Std 0.000
Pitch: 8.0400 Roughness: [X]Std 0.000 mm
Pitch type: FPP Cav breakdown: [ ]Apply
Propeller cup: 0.0 mm

---------- Engine data ----------

Model: ORT Engine #2
Rated RPM: 91.0
Rated power: 21480.0 kW

Performance envelope:

	RPM	Power kW	Fuel lph
1.	93.0	0.0	0.0
2.	91.0	21480.0	4407.0
3.	88.0	21200.0	4400.0
4.	84.0	20800.0	4300.0
5.	76.0	19000.0	4000.0
6.	70.0	16800.0	3500.0
7.	68.0	15880.0	3309.0
8.	64.0	13900.0	2900.0
9.	60.0	11500.0	2400.0
10.	56.0	9400.0	1900.0

Min fuel/combinator line:

RPM	Power kW	Fuel lph

A.5.2 Electrical Load and Endurance Fuel Analyses

Units definition

$hp \equiv 33000 \frac{ft \cdot lbf}{min}$ $\quad knt \equiv 1.69 \cdot \frac{ft}{sec}$ $\quad mile \equiv knt \cdot hr$ $\quad MT \equiv 1000 \cdot kg \cdot g$ $\quad lton \equiv 2240 \cdot lbf$

Physical Parameters

Sea water properties: $\rho_{SW} \equiv 1.9905 \frac{slug}{ft^3}$ $\quad \gamma_{SW} \equiv \rho_{SW} \cdot g$ $\quad \upsilon_{SW} := 1.2817 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$

Air properties: $\rho_A := 0.0023817 \frac{slug}{ft^3}$

Liquids specific volumes: $\gamma_F := 42.3 \cdot \frac{ft^3}{lton}$ $\quad \gamma_{LO} := 39 \cdot \frac{ft^3}{lton}$ $\quad \gamma_W := 36 \cdot \frac{ft^3}{lton}$

Input - Owner's Requirements (All Designs)

$$DP \equiv \begin{bmatrix} 23 \\ 1 \\ 26 \\ 12 \\ 19 \\ 20 \\ 4 \\ 0 \\ 10 \\ 0 \\ 1 \\ 1 \\ 2 \end{bmatrix}$$

Endurance speed: $V_e := 15 \cdot knt$ $\quad MCR := .9$

V_S is calculated to balance the resistance and installed propulsion power. V_e is specified and determines the required fuel capacity for specified range.

Range and stores period: $E := 10000 \cdot mile$ $\quad T_S := \frac{E}{V_e}$ $\quad T_S = 27.778 \cdot day$

Deadweight Tonnage: $DWT := 140321 \cdot MT$ $\quad \gamma_{CARGO} := .8674 \cdot \frac{MT}{m^3}$

Cargo Pumps: $N_{COP} := 4$ $\quad$ Ballast Pumps: $N_{BP} := 2$

Bow Thruster: $N_{BT} := 1$

Max Section Coefficient: $C_X := .995$

Margins power: weight:

$KG_{MARG} := 0 \cdot m$ $\quad PMF := 1.0$ $\quad WMF := 0.06$ $\quad$ electrical load: $EDMF := 1.0$ $\quad EFMF := 1.01$ $\quad E24MF := 1.2$

Input - Design Parameters

NCbt := 41	NClb := 41	NCb := 41	NCD := 41	Nhdb := 21
Cbtmin := 2.0	Clbmin := 5.	Cbmin := .7	CDmin := 1.2	hdbmin := 2.0
Cbtmax := 4.0	Clbmax := 7.	Cbmax := .9	CDmax := 3.0	hdbmax := 4.0
Nwds := 21	Nmanfac := 11	Nsmf := 6	NHDK := 11	NNcargo := 5
wdsmin := 2.0	manfacmin := .5	smfmin := 1.0	HDKmin := 3.0	Ncargomin := 4
wdsmax := 4.0	manfacmax := 1.0	smfmax := 1.5	HDKmax := 4.0	Ncargomax := 8

NPsystype := 6 $\quad$ NNkw := 2 $\quad$ NNstern := 2

Psystypemin := 1 $\quad$ Psystypemax := 6

$C_{BT} := Cbtmin + DP_1 \cdot \frac{(Cbtmax - Cbtmin)}{NCbt - 1}$ $\quad C_{LB} := Clbmin + DP_2 \cdot \frac{(Clbmax - Clbmin)}{NClb - 1}$

$C_B := Cbmin + DP_3 \cdot \frac{(Cbmax - Cbmin)}{NCb - 1}$ $\quad C_D := CDmin + DP_4 \cdot \frac{(CDmax - CDmin)}{NCD - 1}$

$h_{DB} := hdbmin \cdot m + DP_5 \cdot \frac{(hdbmax - hdbmin) \ m}{Nhdb - 1}$ $\quad w := wdsmin \cdot m + DP_6 \cdot \frac{(wdsmax - wdsmin) \cdot m}{Nwds - 1}$

$ManFac := manfacmin + DP_7 \cdot \frac{(manfacmax - manfacmin)}{Nmanfac - 1}$ $\quad SMF := smfmin + DP_8 \cdot \frac{(smfmax - smfmin)}{Nsmf - 1}$

$H_{DK} := HDKmin \cdot m + DP_9 \cdot \frac{(HDKmax - HDKmin) \ m}{NHDK - 1}$ $\quad N_{CARGO} := Ncargomin + DP_{10} \cdot \frac{(Ncargomax - Ncargomin)}{NNcargo - 1}$

$PSYS_{TYP} := Psystypemin + DP_{11} \cdot \frac{(Psystypemax - Psystypemin)}{NPsystype - 1}$ $\quad N_{KW} := DP_{12}$ $\quad N_{stern} := DP_{13}$

$C_{BT} = 3.15$ $\quad C_{LB} = 5.05$ $\quad C_B = 0.83$ $\quad C_D = 1.74$ $\quad$ (Hull coefficients)

$N_{CARGO} = 4$ $\quad h_{DB} = 3.9 \ m$ $\quad w = 4 \ m$ $\quad$ (Double Hull Dimensions and Cargo Block Subdivision)

$ManFac = 0.7$ $\quad$ (Reduction from standard crew size due to automation)

$SMF = 1$ $\quad$ (Structural Margin Factor, 1.0 satisfies ABS corrosion allowance)

$H_{DK} = 4 \ m$ $\quad$ Average deck height (deckhouse)

$PSYS_{TYP} = 2$ $\quad N_{KW} = 1$ $\quad$ (Propulsion System and Power Redundancy Options)

Stern Design: $N_{stern} = 2$ $\quad C_{stern} := if(N_{stern} = 2, -25, -11)$ $\quad PC := if(N_{stern} = 2, .75, .7)$

Principal Characteristics and Coefficients on DWL

$W_{FL} := 168400 MT$

$V_{FL} := \frac{W_{FL}}{\gamma_{SW}}$ $\quad C_M := C_X$ $\quad C_P := \frac{C_B}{C_M}$

$LWL := \left(\frac{V_{FL} \cdot C_{BT} \cdot C_{LB}^2}{C_P \cdot C_M} \right)^{\frac{1}{3}}$ $\quad B := \frac{LWL}{C_{LB}}$ $\quad T := \frac{B}{C_{BT}}$

$A_M := C_M \cdot B \cdot T$ $\quad C_W := 0.36 + 0.64 \cdot C_P$ $\quad A_W := C_W \cdot LWL \cdot B$ $\quad D := C_D \cdot T$

$LWL = 251.395 m$ $\quad B = 49.781 m$ $\quad D = 27.498 m$ $\quad T = 15.804 m$ $\quad W_{FL} = 1.684 \cdot 10^5 \cdot MT$

$C_M = 0.995$ $\quad C_P = 0.834$ $\quad C_W = 0.894$ $\quad A_W = 1.119 \cdot 10^4 \ m^2$ $\quad V_{FL} = 1.642 \cdot 10^5 \ m^3$

$N_P := 1$ $\quad V_D := 4.2437 \cdot 10^5 \cdot ft^3$ $\quad N_T := 20$ $\quad V_T := 297646.01 m^3$ $\quad N_A := 3$

Input from NAVCAD

Values taken at endurance speed $\quad$ lph is fuel rate in ballast condition

$SHP_e := 16263 \cdot kW$ $\quad lph := 2697.71 \cdot \frac{liter}{hr}$ $\quad P_{eB} := 16182 \cdot kW$ $\quad P_I := 22480 \cdot kW$ rated power

Electrical Load

Based on DDS 310-1. Estimate maximum functional load for winter cruise condition:

$KW_P := 0.00323 \frac{kW}{hp} \cdot P_I$ (SWBS 200, propulsion). $\quad KW_P = 97.372 \cdot kW$

$KW_S := 0.0031 \cdot \frac{kW}{ft^2} \cdot LWL \cdot T \cdot N_P$ (SWBS 561, steering). $\quad KW_S = 132.569 \cdot kW$

$KW_E := 0.0002 \cdot \frac{kW}{ft^3} \cdot V_D$ (SWBS 300, electric plant, lighting). $\quad KW_E = 84.874 \cdot kW$

$KW_M := 25 \cdot kW$ (SWBS 430+475, miscelaneous). $\quad KW_M = 25 \cdot kW$

$KW_F := 0.00002 \frac{kW}{ft^3} \cdot (V_T)$ (SWBS 521, firemain). $\quad KW_F = 210.225 \cdot kW$

$KW_A := 0.65 \cdot N_T \cdot kW$ (SWBS 530+550, misc aux). $\quad KW_A = 13 \cdot kW$

$KW_{SERV} := 0.395 \cdot N_T \cdot kW$ (SWBS 600, services). $\quad KW_{SERV} = 7.9 \cdot kW$

$KW_H := 0.0007 \cdot \frac{kW}{ft^3} \cdot (V_D)$ $\quad KW_H = 297.059 \cdot kW$

$KW_V := 0.103 \cdot KW_H$ $\quad KW_V = 30.597 \cdot kW$

$KW_{AC} := 0.67 \cdot \left(0.1 \cdot kW \cdot N_T + 0.00067 \frac{kW}{ft^3} \cdot V_D \right)$ $\quad KW_{AC} = 191.84 \cdot kW$

$KW_{BT} := N_{BT} \cdot 2237 \cdot kW$ $\quad KW_{BT} = 2.237 \cdot 10^3 \cdot kW$

$KW_{NC} := KW_P + KW_S + KW_E + KW_M + KW_F + KW_A + KW_{SERV} + KW_H + KW_V$ (non-Cargo)

$KW_{BP} := 300 \cdot kW \cdot N_{BP}$ $\quad KW_{COP} := 1306 \cdot kW \cdot N_{COP}$ $\quad KW_{COW} := 520 \cdot kW$ $\quad KW_{CSP} := 411 \cdot kW$

$KW_{CARGO} := KW_{BP} + KW_{COP} + KW_{COW} + KW_{CSP}$ $\quad KW_{CARGO} = 6.755 \cdot 10^3 \cdot kW$

$KW_{SSMFL} := KW_{NC}$ $\quad KW_{SSMFL} = 898.597 \cdot kW$ $\quad$ Maximum Functional Load

$KW_{PTOMFL} := KW_{CARGO} + \frac{KW_{SSMFL}}{.8}$ $\quad KW_{PTOMFL} = 7.878 \cdot 10^3 \cdot kW$ (Assumes MG set conversion to SS)

$KW_{SSMFLM} := EDMF \cdot EFMF \cdot KW_{SSMFL}$ $\quad KW_{SSMFLM} = 907.583 \cdot kW$ (MFL w/margins)

$KW_{PTOMFLM} := EDMF \cdot EFMF \cdot KW_{PTOMFL}$ $\quad KW_{PTOMFLM} = 7.957 \cdot 10^3 \cdot kW$ (MFL w/margins)

$KW_{SSGREQ} := KW_{SSMFLM}$ $\quad KW_{SSGREQ} = 907.583 \cdot kW$ $\quad KW_{EMERG} := 750 \cdot kW$

$KW_{DG} := N_{KW} \cdot ceil\left(\frac{KW_{SSGREQ}}{250 \cdot kW} \right) \cdot 250 \cdot kW + KW_{EMERG}$ $\quad KW_{DG} = 1.75 \cdot 10^3 \cdot kW$

$KW_{PTO} := if\left(N_P = 2, N_{KW} \cdot ceil\left(\frac{KW_{PTOMFLM}}{500 \cdot kW} \right) \cdot 500 \cdot kW, N_{KW} \cdot ceil\left(\frac{KW_{PTOMFLM}}{500 \cdot kW} \right) \cdot 500 \cdot kW \right)$

$KW_{PTO} = 8 \cdot 10^3 \cdot kW$

$KW_{24} := \left[0.75 \cdot (KW_{SSMFL} - KW_P - KW_S) + 1 \cdot (KW_P + KW_S) \right]$ $\quad KW_{24} = 731.433 \cdot kW$

Including design margin: $KW_{24AVG} := E24MF \cdot KW_{24}$ $\quad KW_{24AVG} = 877.719 \cdot kW$

Space

Tankage

Fuel

Propulsion power at endurance speed: $P_{eBAVG} := P_{eB}$ $\quad P_{eBAVG} = 1.618 \cdot 10^4 \cdot kW$

Propulsion endurance SFC: $SFC_{ePE} := \frac{lph}{P_{eBAVG} \cdot \gamma_F}$ $\quad SFC_{ePE} = 0.232 \cdot \frac{lbf}{hp \cdot hr}$

Electric power SFC with PTO: $SFC_{eG} := SFC_{ePE}$ $\quad SFC_{eG} = 0.232 \cdot \frac{lbf}{hp \cdot hr}$

Correction for instrumentation inaccuracy and machinery design changes:

$$f_1 := \begin{cases} 1.04 & \text{if } 1.1 \cdot SHP_e \le \frac{1}{3} \cdot \frac{P_I}{2} \\ 1.03 & \text{if } 1.1 \cdot SHP_e \ge \frac{2}{3} \cdot \frac{P_I}{2} \\ 1.02 & \text{otherwise} \end{cases} \qquad f_1 = 1.03$$

$SFC_{ePE} = 0.232 \cdot \frac{lbf}{hp \cdot hr}$

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{ePE}$

Average fuel rate allowing for plant deterioration: $FR_{AVG} := 1.05 \cdot FR_{SP}$ $\quad FR_{AVG} = 0.251 \cdot \frac{lbf}{hp \cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e} \cdot P_{eBAVG} \cdot FR_{AVG}$ $\quad W_{BP} = 1.624 \cdot 10^3 \cdot lton$

Tailpipe allowance: $TPA := 0.95$

Required propulsion fuel weight: $W_{FP} := \frac{W_{BP}}{TPA}$ $\quad W_{FP} = 1.709 \cdot 10^3 \cdot lton$

Required propulsion fuel tank volume (including allowance for expansion and tank internal structure):

$V_{FP} := 1.02 \cdot 1.05 \cdot \gamma_F \cdot W_{FP}$ $\quad V_{FP} = 2.193 \cdot 10^3 \ m^3$

$SFC_G := 0.4727 \cdot \frac{lbf}{hp \cdot hr}$ $\quad SFC_{eG} := SFC_{ePE}$ (assumes PTO)

Margin for instrumentation inaccuracy and machinery design changes: $f_{1e} := 1.04$

Specified fuel rate: $FR_{GSP} := f_{1e} \cdot SFC_{eG}$

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05 \cdot FR_{GSP}$ $\quad FR_{GAVG} = 0.34 \cdot \frac{lbf}{kW \cdot hr}$

Burnable electrical endurance fuel weight:

$W_{Be} := \frac{E}{V_e} \cdot KW_{24AVG} FR_{GAVG}$ $\quad W_{Be} = 90.361 \cdot MT$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $\quad W_{Fe} = 93.614 \cdot lton$

Required electrical fuel volume: $V_{Fe} := 1.02 \cdot 1.05 \cdot \gamma_F \cdot W_{Fe}$ $\quad V_{Fe} = 120.093 m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $\quad W_{F41} = 1.803 \cdot 10^3 \cdot lton$

$V_F := V_{FP} + V_{Fe}$ $\quad V_F = 2.313 \cdot 10^3 \cdot m^3$

Other Tanks

Lubrication oil: $W_{F46} := 17.6 \cdot lton$ $\quad V_{LO} := 1.02 \cdot 1.05 \cdot W_{F46} \cdot \gamma_{LO}$ $\quad V_{LO} = 20.817 m^3$

Potable water: $W_{F52} := N_T \cdot 7.3 \cdot lton$ $\quad W_{F52} = 146 \cdot lton$ $\quad N_T = 20$

$V_W := 1.02 \cdot W_{F52} \cdot \gamma_W$ $\quad V_W = 151.81 m^3$

Sewage: $V_{SEW} := (N_T + N_A) \cdot 2.005 \cdot ft^3$ $\quad V_{SEW} = 1.306 m^3$

Waste oil: $V_{WASTE} := 0.02 \cdot V_F$ $\quad V_{WASTE} = 46.258 m^3$

Total ship tankage volume required:

$V_{TK} := V_F + V_{LO} + V_W + V_{SEW} + V_{WASTE}$ $\quad V_{TK} = 2.533 \cdot 10^3 \ m^3$

Appendix A.6 Weight Report

SWBS	Equipment	Capacity	Gross Dimensions (m) lxwxh	Weight (MT)	VCG (m)	LCG (m)	TCG (m)	VMOM (MT*m)	LMOM (MT*m)	TMOM (MT*m)
100	**Hull Structures:**									
	Longitudinal Structures			13415.0	13.20	126.00	0.00	177,078	1,690,290	0
	Tans. Structural Bulkheads			1254.0	12.65	114.65	0.00	15,863	143,771	0
	Webs and Frames			5532.0	12.93	126.00	0.00	71,529	697,032	0
	Deckhouse, Stacks, Masts			474.0	37.50	215.00	0.00	17,775	101,910	0
	Foundations			353.0	12.38	215.00	0.00	4,370	75,895	0
	TOTAL (SWBS 100)			21028.0						
200	**Propulsion:**									
233	main engine	30560 hp	12.2x8.5x12.2	722.0	8.42	212.30	0.00	6,079	153,281	0
237	bow thruster	2000 kW	1x1x2					0	0	0
252	propulsion control console		3x1x2	6.8	22.37	204.10	6.96	152	1,388	47
261	fuel oil purifiers S		1.5x1x1	3.5	15.87	201.90	4.50	56	713	16
	fuel oil purifiers P		1.5x1x1	3.5	15.87	201.90	-4.50	56	713	-16
	diesel oil purifiers S		1.5x1x2	3.5	16.37	201.90	10.50	57	707	37
	diesel oil purifiers P		1.5x1x2	3.5	16.37	201.90	-10.50	57	707	-37
262	lube oil purifiers S		1.5x1x3	25.0	3.81	217.60	6.50	95	5,440	163
	lube oil purifiers P		1.5x1x3	25.0	3.81	217.60	-6.50	95	5,440	-163
	TOTAL (SWBS 200)			792.9						
								0	0	0
300	**Electrical:**							0	0	0
311	pto generator	8000 kW	3x1.5x1.5		5.72	219.90	0.00	0	0	0
	diesel generator	2000 kW	4.67x1.7x2.06	7.1	22.37	221.90	13.33	159	1,582	95
312	emergency generator	750 kW	4.67x1.7x2.07	7.1	34.50	220.60	-14.00	246	1,573	-100
314	pcu		3x1x1	48.7	21.87	204.10	-7.06	1,065	9,940	-344
324	high voltage switchboard		3x1x2	29.2	22.37	204.10	-1.98	653	5,960	-58
	low voltage switchboard		3x1x2	29.2	22.37	204.10	1.98	653	5,960	58
	emergency switchboard		2x1x2	29.2	34.50	219.10	-12.65	1,007	6,398	-369
	TOTAL (SWBS 300)			150.6						
400	**CC&C**									
438	bridge control consol 1		4x1x1	2.6	46.00	200.90	0.00	120	522	0
	bridge control consol 2		2x1x1	2.6	46.00	200.90	3.50	120	522	9
	bridge control consol 3		2x1x1	2.6	46.00	200.90	-3.50	120	522	-9
	TOTAL (SWBS 400)			7.8						
500	**Auxiliary:**									
514	a/c unit 1		1x2x1	42.4	21.87	216.10	-11.88	927	9,163	-504
	a/c unit 2		1x2x1	42.4	21.87	216.10	-14.38	927	9,163	-610
516	refer unit 1		1x2x1	1.4	21.87	220.10	-17.48	31	308	-24
	refer unit 2		1x2x1	1.4	21.87	222.10	-17.48	31	311	-24
517	aux boiler S		3x3x3	5.3	10.37	227.70	7.54	55	1,207	40
	aux boiler P		3x3x3	5.3	10.37	227.70	-7.54	55	1,207	-40
	heat recovery boiler S		3x3x3	5.4	10.37	223.40	7.54	56	1,206	41
	heat recovery boiler P		3x3x3	5.4	10.37	223.40	-7.54	56	1,206	-41
521	fire pump 1		1x2x1	29.9	2.82	212.90	7.00	84	6,366	209
	fire pump 2		1x2x1	29.9	2.82	212.90	-7.00	84	6,366	-209
	fire pump 3		1x2x1	29.9	21.37	201.00	-16.95	639	6,010	-507
529	ballast pump S		4.87x1.69x1.00	2.6	7.09	201.70	1.84	18	514	5
	ballast pump P		4.87x1.69x1.00	2.6	7.09	201.70	-1.84	18	514	-5
531	distiller S		3x3x3	2.8	3.81	207.70	7.50	11	582	21
	distiller P		3x3x3	2.8	3.81	207.70	-7.50	11	582	-21
533	potable water pump S		1x1x1	13.5	2.82	206.70	10.50	38	2,790	142
	potable water pump P		1x1x1	13.5	2.82	206.70	-10.50	38	2,790	-142
536	central SW/FW heat exchanger		2x2x2	71.2	1.32	222.80	3.95	94	15,863	281

544	cargo pump S1		6.07x2.28x1.40	6.9	7.09	201.70	7.60	49	1,392	52
	cargo pump P1		6.07x2.28x1.40	6.9	7.09	201.70	-7.60	49	1,392	-52
	cargo pump S2		6.07x2.28x1.40	6.9	7.09	201.70	11.09	49	1,392	77
	cargo pump P2		6.07x2.28x1.40	6.9	7.09	201.70	-11.09	49	1,392	-77
	crude oil washing pump		1x1x1	2.5	2.82	202.10	4.82	7	505	12
	cargo stripping pump		1.76x1.25x0.975	2.3	2.82	202.10	-4.82	6	465	-11
545	fuel oil heater S		1x1x1		15.87	201.70	6.45	0	0	0
	fuel oil heater P		1x1x1		15.87	201.70	-6.45	0	0	0
551	L/P air compressor S		2x2x2		9.87	219.30	7.00	0	0	0
	L/P air compressor P		2x2x2		9.87	219.30	-7.00	0	0	0
561	steering gear		2x2x2	30.2				0	0	0
581	anchor windlasses/mooring winch		2x2x2	126.9				0	0	0
582	mooring winches		2x2x2	63.1				0	0	0
583	lifeboats and davits, liferafts			70.7				0	0	0
589	hose crane			30.0				0	0	0
	stores crane			30.0				0	0	0
593	sewage treatment plant		2x2x2	9.2	16.37	228.20	-4.96	151	2,099	-46
	incinerator		3x3x3	9.2	35.00	217.20	5.55	322	1,998	51
	TOTAL (SWBS 500)			709.3						
	weight margin			5294.0	14.50	130.00	0.00	76,763	688,220	0
				Weight (MT)	**VCG (m)**	**LCG (m)**	**TCG (m)**	**VMOM (MT*m)**	**LMOM (MT*m)**	**TMOM (MT*m)**
	TOTALS (Lightship)			27,983	13.51	131.34	-0.07	378,024	3,675,267	-2,052
	Tanks:									
	140K DWT									
	Cargo No.1 S	15,639 MT		11,260	15.87	35.13	9.60	178,696	395,564	108,096
	Cargo No.1 P	15,639 MT		11,260	15.87	35.13	9.60	178,696	395,564	-108,096
	Cargo No.2 S	18,556 MT		18,185	15.80	76.30	10.41	287,323	1,387,516	189,306
	Cargo No.2 P	18,556 MT		18,185	15.80	76.30	10.41	287,323	1,387,516	-189,306
	Cargo No.3 S	18,556 MT		18,185	15.80	120.50	10.41	287,323	2,191,293	189,306
	Cargo No.3 P	18,556 MT		18,185	15.80	120.50	10.41	287,323	2,191,293	-189,306
	Cargo No.4 S	18,495 MT		18,125	15.83	164.68	10.37	286,919	2,984,825	187,956
	Cargo No.4 P	18,495 MT		18,125	15.83	164.68	10.37	286,919	2,984,825	-187,956
	Slop Tank S	2,708 MT		2,654	16.02	190.08	10.21	42,517	504,472	27,097
	Slop Tank P	2,708 MT		2,654	16.02	190.08	10.21	42,517	504,472	-27,097
	Fuel Oil S	1,498 MT		1,468	16.26	195.40	10.36	23,870	286,847	15,208
	Fuel Oil P	1,498 MT		1,468	16.26	195.40	10.36	23,870	286,847	-15,208
	Generator Fuel	115 MT		113	21.00	195.40	0.00	2,373	22,080	0
	Lube Oil	24 MT		23	13.25	195.40	0.00	305	4,494	0
	Waste Oil	71 MT		69	8.00	195.40	0.00	552	13,483	0
	Sewage	98 MT		96	24.00	230.50	0.00	2,304	22,128	0
	Fresh Water S	118 MT		118	24.03	230.50	15.58	2,836	27,199	1,838
	Fresh Water P	118 MT		118	24.03	230.50	15.58	2,836	27,199	-1,838
	Ballast No.1 S	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.1 P	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.2 S	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.2 P	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.3 S	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.3 P	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.4 S	8,136 MT		0	9.08	163.98	17.22	0	0	0
	Ballast No.4 P	8,136 MT		0	9.08	163.98	17.22	0	0	0
	Ballast No.5 S	1,627 MT		0	10.47	192.08	16.35	0	0	0
	Ballast No.5 P	1,627 MT		0	10.47	192.08	16.35	0	0	0
	Aft Peak	6,597 MT		3,958	14.32	236.96	0.00	56,679	937,888	0
	Forepeak	6,597 MT		0	15.15	6.82	0.00	0	0	0
				Weight (MT)	**VCG (m)**	**LCG (m)**	**TCG (m)**	**VMOM (MT*m)**	**LMOM (MT*m)**	**TMOM (MT*m)**
	TOTALS (Full Load)			144,249				2,281,179	16,555,503	0
	TOTALS (Full Load+Lightship)			172,232	15	117	-0.01	2,659,203	20,230,770	-2,052
	Arrival Ballast									
	Cargo No.1 S	15,639 MT		0	15.87	35.13	9.60	0	0	0
	Cargo No.1 P	15,639 MT		0	15.87	35.13	9.60	0	0	0

	Cargo No.1 P	15,639 MT		0	15.87	35.13	9.60	0	0	0
	Cargo No.2 S	18,556 MT		0	15.80	76.30	10.41	0	0	0
	Cargo No.2 P	18,556 MT		0	15.80	76.30	10.41	0	0	0
	Cargo No.3 S	18,556 MT		0	15.80	120.50	10.41	0	0	0
	Cargo No.3 P	18,556 MT		0	15.80	120.50	10.41	0	0	0
	Cargo No.4 S	18,495 MT		0	15.83	164.68	10.37	0	0	0
	Cargo No.4 P	18,495 MT		0	15.83	164.68	10.37	0	0	0
	Slop Tank S	2,708 MT		0	16.02	190.08	10.21	0	0	0
	Slop Tank P	2,708 MT		0	16.02	190.08	10.21	0	0	0
	Fuel Oil S	1,498 MT		150	16.26	195.40	10.36	2,439	29,310	1,554
	Fuel Oil P	1,498 MT		150	16.26	195.40	10.36	2,439	29,310	-1,554
	Generator Fuel	115 MT		12	21.00	195.40	0.00	242	2,247	0
	Lube Oil	24 MT		23	13.25	195.40	0.00	305	4,494	0
	Waste Oil	71 MT		69	8.00	195.40	0.00	552	13,483	0
	Sewage	98 MT		96	24.00	230.50	0.00	2,304	22,128	0
	Fresh Water S	118 MT		59	24.03	230.50	15.58	1,418	13,600	919
	Fresh Water P	118 MT		59	24.03	230.50	15.58	1,418	13,600	-919
	Ballast No.1 S	7,167 MT		7,024	9.58	34.36	15.83	67,290	241,345	111,190
	Ballast No.1 P	7,167 MT		7,024	9.58	34.36	15.83	67,290	241,345	-111,190
	Ballast No.2 S	8,577 MT		8,406	8.72	76.30	17.47	73,300	641,378	146,853
	Ballast No.2 P	8,577 MT		8,406	8.72	76.30	17.47	73,300	641,378	-146,853
	Ballast No.3 S	8,578 MT		8,406	8.72	120.50	17.47	73,300	1,012,923	146,853
	Ballast No.3 P	8,578 MT		8,406	8.72	120.50	17.47	73,300	1,012,923	-146,853
	Ballast No.4 S	8,136 MT		7,973	9.08	163.98	17.22	72,395	1,307,413	137,295
	Ballast No.4 P	8,136 MT		7,973	9.08	163.98	17.22	72,395	1,307,413	-137,295
	Ballast No.5 S	1,627 MT		1,594	10.47	192.08	16.35	16,689	306,176	26,062
	Ballast No.5 P	1,627 MT		1,594	10.47	192.08	16.35	16,689	306,176	-26,062
	Aft Peak	6,597 MT		6,135	14.32	236.96	0.00	87,853	1,453,750	0
	Forepeak	6,597 MT		6,731	15.15	6.82	0.00	101,975	45,905	0
				Weight (MT)	**VCG (m)**	**LCG (m)**	**TCG (m)**	**VMOM (MT*m)**	**LMOM (MT*m)**	**TMOM (MT*m)**
	TOTALS (Ballast)			80,290				806,893	8,646,293	0
	TOTALS (Ballast+Lightship)			108,272	11	114	-0.02	1,184,917	12,321,560	-2,052
	Summer Load Line									
	Cargo No.1 S	15,639 MT		15,279	15.87	35.13	9.60	242,478	536,751	146,678
	Cargo No.1 P	15,639 MT		15,279	15.87	35.13	9.60	242,478	536,751	-146,678
	Cargo No.2 S	18,556 MT		24,675	15.80	76.30	10.41	389,865	1,882,703	256,867
	Cargo No.2 P	18,556 MT		24,675	15.80	76.30	10.41	389,865	1,882,703	-256,867
	Cargo No.3 S	18,556 MT		24,675	15.80	120.50	10.41	389,865	2,973,338	256,867
	Cargo No.3 P	18,556 MT		24,675	15.80	120.50	10.41	389,865	2,973,338	-256,867
	Cargo No.4 S	18,495 MT		24,594	15.83	164.68	10.37	389,323	4,050,140	255,040
	Cargo No.4 P	18,495 MT		24,594	15.83	164.68	10.37	389,323	4,050,140	-255,040
	Slop Tank S	2,708 MT		3,601	16.02	190.08	10.21	57,688	684,478	36,766
	Slop Tank P	2,708 MT		3,601	16.02	190.08	10.21	57,688	684,478	-36,766
	Fuel Oil S	1,498 MT		1,468	16.26	195.40	10.36	23,870	286,847	15,208
	Fuel Oil P	1,498 MT		1,468	16.26	195.40	10.36	23,870	286,847	-15,208
	Generator Fuel	115 MT		113	21.00	195.40	0.00	24,357	292,709	0
	Lube Oil	24 MT		23	13.25	195.40	0.00	1,828	20,126	0
	Waste Oil	71 MT		69	8.00	195.40	0.00	114	3,713	0
	Sewage	98 MT		96	24.00	230.50	0.00	2,304	22,128	0
	Fresh Water S	118 MT		118	24.03	230.50	15.58	2,836	27,199	1,838
	Fresh Water P	118 MT		118	24.03	230.50	15.58	2,836	27,199	-1,838
	Ballast No.1 S	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.1 P	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.2 S	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.2 P	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.3 S	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.3 P	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.4 S	8,136 MT		4,963	9.08	163.98	17.22	45,064	813,833	85,463
	Ballast No.4 P	8,136 MT		4,963	9.08	163.98	17.22	45,064	813,833	-85,463
	Ballast No.5 S	1,627 MT		1,594	10.47	192.08	16.35	16,689	306,176	26,062
	Ballast No.5 P	1,627 MT		1,594	10.47	192.08	16.35	16,689	306,176	-26,062
	Aft Peak	6,597 MT		6,465	14.32	236.96	0.00	92,579	1,531,946	0
	Forepeak	6,597 MT		0	15.15	6.82	0.00	0	0	0
				Weight (MT)	**VCG (m)**	**LCG (m)**	**TCG (m)**	**VMOM (MT*m)**	**LMOM (MT*m)**	**TMOM (MT*m)**
	TOTALS (Summer)			208,700				3,236,537	24,993,550	0
	TOTALS (Summer+Lightship)			236,683	15	121	-0.01	3,614,561	28,668,817	-2,052

	TOTALS (Summer+Lightship)			236,683	15	121	-0.01	3,614,561	28,668,817	-2,052
	125K DWT									
	Cargo No.1 S	15,639 MT		15,326	15.87	35.13	9.60	243,224	538,402	147,130
	Cargo No.1 P	15,639 MT		15,326	15.87	35.13	9.60	243,224	538,402	-147,130
	Cargo No.2 S	18,556 MT		9,278	15.80	76.30	10.41	293,185	1,415,823	96,584
	Cargo No.2 P	18,556 MT		9,278	15.80	76.30	10.41	293,185	1,415,823	-96,584
	Cargo No.3 S	18,556 MT		14,659	15.80	120.50	10.41	293,185	2,235,998	152,600
	Cargo No.3 P	18,556 MT		14,659	15.80	120.50	10.41	293,185	2,235,998	-152,600
	Cargo No.4 S	18,495 MT		18,125	15.83	164.68	10.37	292,776	3,045,757	187,956
	Cargo No.4 P	18,495 MT		18,125	15.83	164.68	10.37	292,776	3,045,757	-187,956
	Slop Tank S	2,708 MT		2,654	16.02	190.08	10.21	43,382	514,737	27,097
	Slop Tank P	2,708 MT		2,654	16.02	190.08	10.21	43,382	514,737	-27,097
	Fuel Oil S	1,498 MT		1,468	16.26	195.40	10.36	24,357	292,709	15,208
	Fuel Oil P	1,498 MT		1,468	16.26	195.40	10.36	24,357	292,709	-15,208
	Generator Fuel	115 MT		113	21.00	195.40	0.00	24,357	292,709	0
	Lube Oil	24 MT		23	13.25	195.40	0.00	1,828	20,126	0
	Waste Oil	71 MT		69	8.00	195.40	0.00	114	3,713	0
	Sewage	98 MT		96	24.00	230.50	0.00	2,304	22,128	0
	Fresh Water S	118 MT		118	24.03	230.50	15.58	2,836	27,199	1,838
	Fresh Water P	118 MT		118	24.03	230.50	15.58	2,836	27,199	-1,838
	Ballast No.1 S	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.1 P	7,167 MT		0	9.58	34.36	15.83	0	0	0
	Ballast No.2 S	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.2 P	8,577 MT		0	8.72	76.30	17.47	0	0	0
	Ballast No.3 S	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.3 P	8,578 MT		0	8.72	120.50	17.47	0	0	0
	Ballast No.4 S	8,136 MT		0	9.08	163.98	17.22	0	0	0
	Ballast No.4 P	8,136 MT		0	9.08	163.98	17.22	0	0	0
	Ballast No.5 S	1,627 MT		0	10.47	192.08	16.35	0	0	0
	Ballast No.5 P	1,627 MT		0	10.47	192.08	16.35	0	0	0
	Aft Peak	6,597 MT		2,375	14.32	236.96	0.00	34,010	562,780	0
	Forepeak	6,597 MT		0	15.15	6.82	0.00	0	0	0
				Weight (MT)	**VCG (m)**	**LCG (m)**	**TCG (m)**	**VMOM (MT*m)**	**LMOM (MT*m)**	**TMOM (MT*m)**
	TOTALS (125K DWT)			125,932				2,448,502	17,042,705	0
	TOTALS (125K DWT+Lightship)			153,915	18	135	-0.01	2,826,527	20,717,972	-2,052