AUTHENTICATION

The below signed to the fact that all of the analysis and work were developed by the design team members. Where information was obtained from sources outside of project team, such sources are properly cited and credited.

Jon Mikkelsen — Faculty Advisor

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OWNER'S REQUIREMENTS

Introduction

The primary respondent to marine oil spill emergencies in the west coast, Western Canada Marine Response Corporation (WCMRC), intends to add a larger pollution control vessel to their growing fleet of oil spill response vessels and barges.

Environmental Area of Operation

- Ability to operate in open ocean environment at the edge of BC Territorial Waters.

Crew Accommodation

- 12 Crew and 4 supernumeraries, Office
- Meet *Transport Canada - Towboat Crew Accommodations* and *MLC 2006* Regulations

Limiting Particular

- Length: 50m max

Speed

Minimum Top Speed (no recovered oil): approx. 13-14 knots

Economic Cruise Speed: approx. 10 knots

Endurance

- Range: 700 nautical miles at 13 knots + 3 weeks standby at 25% power + 250 nm at cruise speed
- Fresh water supply and stores for full complement for 3 weeks

Tankage Capacity, Response Equipment

1. 250 m^3 recovered oil capacity
2. 20 m^3 dispersant with deployable boom arms to spray
3. 2x ISO standard 20-ft containers on deck loaded/unloaded by on deck crane
4. Large offshore capable skimmer, approx. 300 m^3/hr nameplate recovery rate
5. Offshore boom, length is no less than largest VLCC visiting BC waters
6. Workboat capable of towing boom, able to be launched at sea
7. 250 bbl mini barge, able to be launch at sea
8. Large, accessible, onboard storage for additional spill response equipment
9. Deck workshop

Additional Capabilities

- Ability to tow 5000 DWT barge at speed of at least 4 knots
- Able to tow offshore boom at slow speeds without large wake
- Ability to maintain station in sea conditions up to sea state 4
- Propulsion system set up for approx. 1000 hours of operation per year
- Ability to transfer cargo (25t container), fresh water and fuel to other vessels operating in the open ocean environment

Classification

The vessel shall be designed in accordance with the latest *ABS rules and regulations for Steel Vessels under 90 meters in Length* and *Vessels with Oil Spill Response Capabilities (OSR-C1).*

Regulations

- The vessel shall be designed to meet the required rules for marine vehicles operating in Canadian waters:
    - *Transport Canada - Hull Construction Regulations*
- The vessel shall meet intact and damage stability requirements
- The arrangement and equipment of the ship are required to meet the following requirements:
    - *International Convention for the Safety of Life at Sea, SOLAS 1974*
    - *MARPOL – International Convention for the Prevention of Pollution from Ships*
    - *International Convention on Tonnage Measurements of Ships, 1969*
- Meet regulations provided by *EPA Tier 4* and *IMO Tier III* standards

2015-2016 Lisnyk Student Ship Design Competition Score Sheet

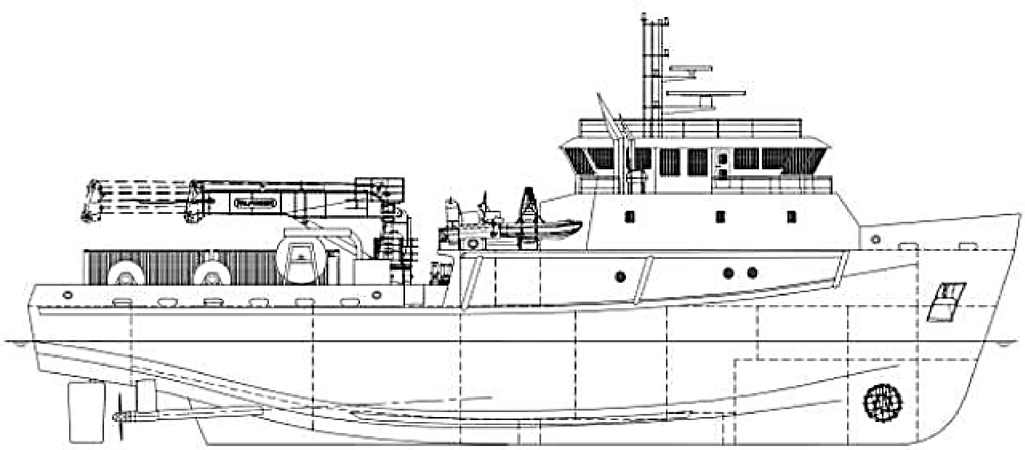
University: UNIVERSITY OF BRITISH COLUMBIA
Design Identification: ______________________
Reviewer: ______________________ **Date:**

Technical Content	Maximum Points	Points Awarded	Sections	Appendix/ Dwg
Report Summary including Table of principal	4		1.0	
Concept selection/initial definition and sizing	8		3.0 – 6.0	
Hull form development	2		6.0	
Lines drawing (Appendix)	2			001 - LINES PLAN
General arrangements (Appendix)	7		4.0 – 5.0, 18.0	003 - GA; 004 - INBOARD PROFILE
Curves of form, floodable length curve	1		20.0, 16.0	
Area/volume summary	2		5.0	APPENDIX L
Capacity plan (cargo holds and tanks) (Appendix)	1		16.0	002 - TANK PLAN
Structural design	3		18.0	APPENDIX G; 006 - STRUCTURAL ARRANGEMENT
Midship section drawing (Appendix)	2			005 - MIDSHIP
Propulsion plant trade-off study	4		8.0, 9.0	
Machinery arrangement including list of principal components (Appendix)	3		11.0	007 - MACHINERY ARRANGEMENT
Electrical Load Analysis/electric plant sizing	2		14.0	APPENDIX F
Major H, M, & E systems and equipment descriptions	4		11.0, 14.0	
Major mission-related systems and equipment	4		12.0, 13.0	
Weight estimate (lt. ship & (2) load conditions)	6		19.0	APPENDIX H
Trim and intact stability analysis	3		20.0	
Damage stability analysis	3		21.0	
Speed/power analysis	3		7.0, 9.0, 10.0	APPENDIX A, B, C
Endurance calculation	2		15.0	APPENDIX D
Seakeeping analysis	2		22.0	APPENDIX I
Manning estimate	2		4.0	
Cost analysis	3		26.0, 27.0	
Risk assessment	2		28.0	
Sub-total	**75**			
Documentation				
Organization	5			
Completeness	3			
Text and graphics (figures and tables)	5			
Sub-total	**13**			
Overall Quality and Originality	**7**			
Compliance with Owner's Requirements	**5**			
Grand Total	**100**			

CONCEPT DESIGN OF A MULTIPURPOSE POLLUTION CONTROL VESSEL

UNIVERSITY OF BRITISH COLUMBIA

DEPARTMENT OF MECHANICAL ENGINEERING



DR. JAMES A. LISNYK

STUDENT SHIP DESIGN COMPETITION

2015-2016

Submitted: June 12th, 2016

EXECUTIVE SUMMARY

This project is a concept design of a Multipurpose Pollution Control Vessel (MPCV) completed by a group of 5 senior Mechanical Engineering students as part of the University of British Columbia's MECH 45X – Capstone design project course. Working alongside Western Canada Marine Response Corporation (WCMRC), faculty and industry advisors, the team attempted to complete one full loop of the ship design spiral in the design of a vessel which meets as many of the owner's requirements as possible while providing analyses, design drawings, and design deliverables to a level of detail consistent with typical industry standard. While one full loop of the design spiral was completed, several iterations were completed for analysis of more critical systems.

The project aimed to assess the feasibility of an MPCV which was able to meet the client's design and operational requirements. This vessel was designed to meet the required rules for marine vehicles operating in Canadian waters under Transport Canada regulations. The vessel was also designed in accordance to the latest ABS rules and regulations for the classification of steel ships under 90 meters in length. The vessel's designation is to be *A1, (E), Towing Vessel, AMS, OSR-C1*; while towing is not the vessel's primary mission, it is included due to the client's intention to use it in certain towing services.

The final design is a 46.5 m long vessel with a forward superstructure and a large working deck area aft. The vessel's top speed is 14 knots, and it is propelled by two diesel engines driving conventional screw propellers. The hull and tank arrangement are designed with intention to provide a large amount of recovered oil storage below deck and no fuel or recovered oil tanks against the vessel's shell, while also meeting endurance requirements. The general arrangement was developed to meet the owner's requirements, *International Convention for the Safety at Sea (SOLAS)* and *Maritime Labour Convention 2006* accommodation rules. Intact stability was evaluated against the *2008 Intact Stability Code* and *ABS Intact Stability Guidelines for towing and crane operation*, while damage stability was evaluated against *ABS OSV Rules* and *SOLAS*. The design team was successful in designing a vessel and meeting the owner's requirements, and can deem the MPCV is a feasible design based on the team's current iteration of the design and the depth of analysis the team was able to complete.

ACKNOWLEDGEMENTS

The design team acknowledges the support that the following industry members have provided throughout the course of the project. A great thanks to the following people for their technical expertise and overall guidance in contributing to the completion of this project.

WESTERN CANADA MARINE RESPONSE CORPARATION
- Darcy Burt
- Scott Wright

UNIVERSITY OF BRITISH COLUMBIA
- Dr. Chris McKesson
- Dr. Peter Ostafichuk
- Dr. Jon Mikkelsen

AQUAGUARD
- Ron Bowden

MARKEY MACHINERY
- Scott Kreis

FINNING CANADA
- Matt McLean
- Allan Novotny

TEEKAY SHIPPING
- Ian Braidwood

ROBERT ALLAN LTD.
- Lawren Best
- Andra Pupac
- Allan Turner
- Oscar Lisagor

VARD MARINE
- Daniel Greig
- Brenden Oke

PALLFINGER MARINE
- Jacob Brian
- Louis LeBourgeois

ROZEMA BOAT WORKS
- Dirk Rozema

HARDING
- Tore Kjell Thorsen

LLOYD'S REGISTER
- Ben Thompson

ABBREVIATIONS

Δ	Displacement
∇	Immersed volume
A_x	Midship area
A_w	Waterplane area
ABS	American Bureau of Shipping
AHU	Air handling unit
C_B	Block coefficient
C_P	Longitudinal prismatic coefficient
C_w	Waterplane coefficient
CER	Cost Estimation relation
D	Depth
DNV	Det Norske Veritas
Fn	Froude Number
g	Acceleration due to gravity ($9.81 m/s^2$)
GA	General arrangement plan
GM	Metacentric height
HPU	Hydraulic power unit
HVAC	Heating, ventilation and air conditioning
ISO	International Standards Organization
I_T	Waterplane transverse moment of inertia
KB	Height of centre of buoyancy
Kg	Kilograms
KG	Vertical centre of gravity
Kts	Knots
LCG	Longitudinal centre of gravity
L_{WL}	Length on the design waterline
MCR	Machinery control room
MDO	Marine diesel oil
MLC	Maritime labour convention
MMR	Main machinery room
MPCV	Multipurpose pollution control vessel
MT	Metric Tonne
Nm	Nautical miles
NURBS	Non-uniform rational basis spline
OSRV	Oil spill recovery vessel
PODAC	Product-Oriented Design and Construction Cost Model
SCR	Selective catalytic reduction
SWL	Safe working load
SOLAS	International Convention for the Safety of Life at Sea
T	Draft
TC	Transport Canada
TCG	Transverse centre of gravity
VCG	Vertical centre of gravity
WCMRC	Western Canada Marine Response Corporation
WDM	Weighted decision matrix

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1.0 SUMMARY OF PRINCIPAL PARTICULARS

Figure 1 - Concept Design of a Multipurpose Pollution Control Vessel

Table 1 - MPCV Principal Particulars

Variable Parameters	Units	Values	Parameters	Units	Actual Values
Length OA	m	46.5	**GM**	m	1.4
Beam OA	m	14.0	**Lightship Weight**	MT	1,300
Length WL	m	45.6	**Design Displacement**	MT	1,870
Beam WL	m	13.5	**Total Power Installed**	kW	3800
Draft	m	5.0	**Cruise Speed**	knots	10.0
Depth	m	6.7	**Max Speed**	knots	14.0
C_b	-	0.59	**Bollard Pull**	MT	36
C_m	-	0.88	**Equipment Number**	-	450
C_p	-	0.67	**Capital Cost**	$mil	40
LCB (Fr.0)	m	22.1	**Life Cycle Cost**	$mil	17

2.0 PROJECT OVERVIEW

2.1 PROJECT STAKEHOLDERS

Because this project addresses a potential environmental concern, the project stakeholders are wide ranging and can impact the design greatly. The primary stakeholders include large oil companies who are the primary clients of WCRMC, and the general BC public.

Table 2 - List of Project Stakeholders

PRIMARY STAKEHOLDERS	
STAKEHOLDER	***PROJECT VALUE***
Western Canada Marine Response Corporation (WCMRC)	The project will provide insight as to whether their vision of adding a larger response vessel to their fleet is feasible or not.
Oil Industry Companies	The project represents diligence by WCMRC and their clients to improve environmental protection along the BC coast in light of potential industry expansion.
WCMRC Crewmen	As the primary users of the project, the crewmen hold a vested interest in the vessel's performance.
UBC Capstone Design Team	The project will provide valuable design experience for each member's future.
SECONDARY STAKEHOLDERS	
STAKEHOLDER	***PROJECT VALUE***
General Public	This project provides potential insurance against an environmental emergency which would result in the public having access to a healthy, clean, and safe coastline.
UBC Mechanical Engineering Program	The completion of this project showcases the skills students have learned through the UBC MECH program.

2.2 CLIENT

The Western Canada Marine Response Corporation, or WCMRC, is a Transport Canada certified Response Organization. WCMRC is the primary respondent for the Western Canadian Coastline and are on standby for emergency response year round. WCMRC's inception came after 1995, when an amendment on the Canada Shipping Act placed regulations on vessels and oil handing facilities in order protect all navigable waters from pollutants.

The WCMRC is funded by their 2000 members across various oil handling facilities, freighters, carriers, and ferries. They are also supported by major oil companies including Imperial Oil, Shell Canada, Chevron, and Suncor. WCMRC's relationship with their clients are driven by regulation and by precaution. These oil companies are mandated to have "an arrangement" with a certified response organization, according the Canada Shipping Act (2001). Further, by the Marine Liability Act of 2001, the owner of ships causing oil pollution damage is completely liable for the cleanup, monitoring and restoration processes; thus, WCMRC provides insurance to their partners in the event of an accident

WCMRC's role in protecting the waters of BC from potential disaster include designing and implementing response plans based on Transport Canada guidelines, maintaining an inventory of effective spill response equipment including skimmers, booms, barges, and response vessels, employing crew members that will facilitate response efforts when needed, and being prepared to deploy all the above resources in the event of a major marine oil spill.

WCMRC was very kind to provide our design team with the list of requirements and share their operations experience with us.

3.0 VESSEL OVERVIEW

This section provides a brief overview of the client's existing fleet of vessels and the design vessel's intended mission profile and area of operation. Along with the owner's requirements, the following information is used to define the overall design requirement in the preliminary stage of the project.

3.1 THE EXISTING FLEET

Below is a sample of WCMRC's current fleet of pollution response vessels. In total, WCRMC's consists of 28 response vessels and more than 50 response trailers, all spread across the lower mainland coast from Vancouver Harbour to Prince Rupert.

Table 3 - WCMRC - Existing Fleet

TYPE	VESSEL NAME	LENGTH (M)	SPEED (KN)	SKIMMING CAPACITY (T/HR)	PRODUCT CAPACITY (T)
RESPONSE VESSEL	Burrard Cleaner No. 4	9.14	40	-	-
	Burrard Cleaner No. 5	7.92	25	-	-
	Burrard Cleaner No. 8	14.32	18	-	2.3
	Burrard Cleaner No. 11	14.32	18	-	2.3
	MJ Green	13.69	25	32.8	10
	GM Penman	19.81	26	32.8	30
RESPONSE BOOM BOAT	Burrard Cleaner No. 6	10.63	30	-	-
	Burrard Cleaner No. 7	11.83	30	-	-
SKIMMER VESSEL	Burrard Cleaner No. 2	14.9	8	16.2	12.3
	Burrard Cleaner No. 3	8.75	17	6	3.7
	Burrard Cleaner No. 9	22.86	11	22	79.5
SKIMMING BARGE	Burrard Cleaner No. 1	12.8	6 (towed)	49.2	15
	Burrard Cleaner No. 12	9.14	6 (towed)	2	15.9
TANK BARGE	Burrard Cleaner No. 10	56.39	-	-	2500.2
	Burrard Cleaner No. 17	51.15	-	8	1023
	Burrard Cleaner No. 18	76.5	-	-	4000

Currently, there are only three vessels (MJ Green, GM Penman, Burrard Cleaner No. 9) that have the capability to respond quickly, contain the spill via skimming, and store the pollutants. In addition, the following items are of note:

- Most vessels in fleet are single purpose (ie. tank barge, fast response vessel)
- Barges are the only vessels with significant (>100t) product capacity
- Skimming barges, and tank barges must be towed
- Majority of vessels are 20m in length or smaller

The result of having few multipurpose vessels is that multiple vessels, such as a fast responder, a skimmer vessel, a barge, and a tugboat for the barge, will have to be deployed for the response to any spill. In the event of a large spill, it will be expected that all vessels will be deployed together and working continuously. Thus, there may be significant benefit for WCMRC to add a multipurpose vessel which can be deployed on its own to handle small or moderate spills as well as act in support with tugging capabilities in the event of a large spill operation.

3.2 MISSION PROFILE

In assessing the vessel's primary modes of operation, the design team and WCMRC developed the following mission profile which describes the typical operations the vessel will be deployed for. Each mission type is separated into a basic function and an approximate time the vessel will spend performing that function.

Table 4 - Mission Profile

<table>
<tr><th>Mission 1a: Oil Recovery</th><th>Hours</th><td rowspan="5">The vessel's primary mission is pollution control in the event of a spill. This involves transiting to the spill site, deploying equipment such as skimmers and containment booms, provide support and storage to the fleet, standby at sea for large recovery operations, and returning to port for offload</td></tr>
<tr><td>Transit (14kts)</td><td>50</td></tr>
<tr><td>Oil Recovery Operation</td><td>160</td></tr>
<tr><td>Standby</td><td>350</td></tr>
<tr><td>Cruise (10kts)</td><td>25</td></tr>
<tr><th>Mission 1b: Oil Recovery & towing</th><th>Hours</th><td rowspan="5">In addition to the typical recovery operations, the vessel is to tow a maximum 5000 DWT barge from the spill site.</td></tr>
<tr><td>Transit (14kts)</td><td>50</td></tr>
<tr><td>Oil Recovery Operation</td><td>160</td></tr>
<tr><td>Standby</td><td>350</td></tr>
<tr><td>Towing (4kts)</td><td>63</td></tr>
<tr><th>Mission 2: Resupply</th><th>Hours</th><td rowspan="5">The vessel's secondary mission is to provide support to vessels offshore by transferring containers with cargo and equipment, fresh water, and fuel oil. This entails transiting to the location with BC waters, offloading equipment or fuel, standing by for additional support, and returning to port.</td></tr>
<tr><td>Transit (14kts)</td><td>110</td></tr>
<tr><td>Offloading</td><td>5</td></tr>
<tr><td>Standby</td><td>10</td></tr>
<tr><td>In port</td><td>10</td></tr>
</table>

3.3 AREA OF OPERATION

As stated by the requirements, the intended area of operation for this vessel is to include any offshore environment from the coastline to the farthest edge of the BC territorial waters, as shown below.

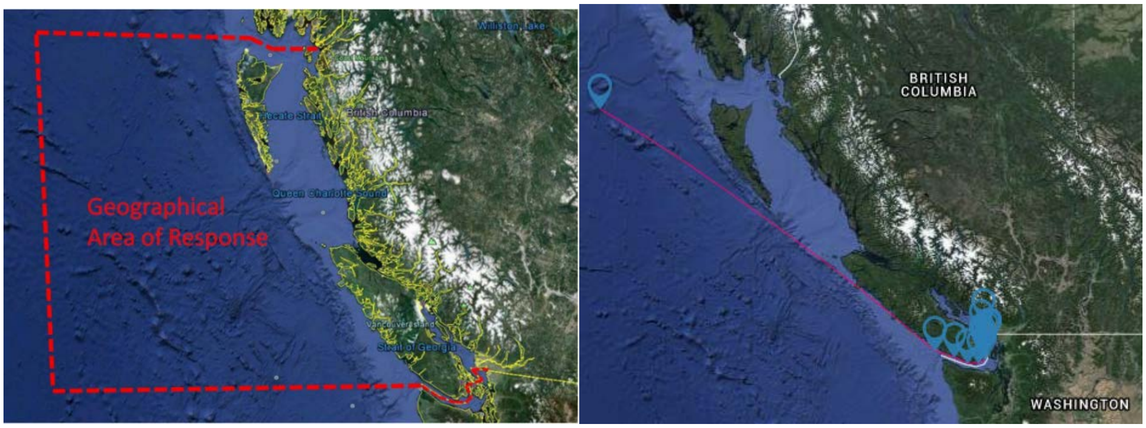

Figure 2 - Area of Response and Longest Distance to Edge

As the vessel is required to travel from any port to the farthest point and return, the longest course of travel is estimated to be 700 nm for the case when the vessel departs from the Vancouver port and has to travel to most northwestern corner of BC waters. This estimate is used in the theoretical vessel fuel consumption calculation.

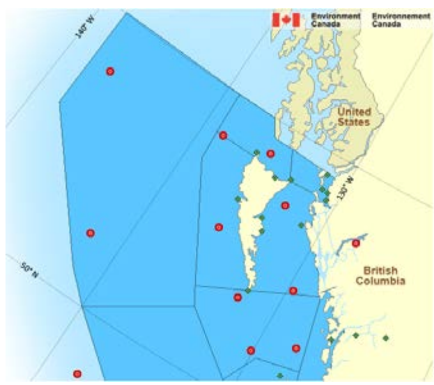

Figure 3 - Sea State Regions of BC Coast

Typical sea conditions for the vessel's operation were also investigated through the Canadian government's historical data of moored marine buoys shown above, these findings were compared to the British Columbia Regional Marine Guide. In total, data was collected from eleven buoys located off the coast of Northern BC. With this data, an average sea state of 4 was estimated.

4.0 VESSEL DEFINITION

The following sections describe the analysis used to come up with the initial area and volume requirements of the vessel.

4.1 PAYLOAD DEFINITION

The design team had to define the payload of the vessel in order to develop the volume and weight balance, which as iterated and used to check the initially selected vessel particulars. Some of the payload requirements were defined by WCMRC in mission statement while others were determined by the design team. The payload items were split into 3 categories: tanks, mission items and complement.

4.1.1 Tanks

The design team used owner's requirements, applicable regulatory rules, reference literature and similar vessel data to determine the required capacities of fuel oil, recovered oil, ballast and fresh water, grey and black water, and minor tanks. For all of the details please refer to *15.0 ENDURANCE AND TANK CAPACITIES*.

4.1.2 Mission Items

As per mission requirements the vessel has to carry following items: a mini-barge, oil recovery equipment and two 20' containers with cargo. The equipment weight information was kindly provided to us by the vendors and could be found in the weight estimate summary.

4.1.3 Complement

According to the owner's requirements the vessel is to carry 12 crew members. This requirement is also defined in the local union rules and meets Transport Canada regulations. After having further discussion with WCMRC, up to 4 government and first nations representatives are to be present during the oil spill operation. Consequently, space for 4 supernumeraries had to be added. The crew and effect weight was estimated to be 170kg per person and the provision weight was taken to be 10kg/person/day.[1]

4.2 AREA AND VOLUME REQUIREMENTS

The design team used reference vessel data and general arrangements to estimate the required floor area and volumes of various spaces on the vessel. The vessel itself was split into three major sections: spaces within the hull and superstructure (which includes wheelhouse), and exterior decks. This breakdown helped with developing the initial General Arrangement and estimating the weight and principal particulars of the vessel, as well as ensuring that all of the spaces needed for the vessel operation were considered. Further, using *International Convention on Tonnage Measurements of Ships, 1969*, the vessel gross tonnage was found to be greater than 500 GT, requiring it to follow *SOLAS* rules.

4.2.1 Hull

Hull areas and volumes concern all the space internal to the vessel from the keel up to the main and forecastle decks. To help simplify the analysis the spaces were divided in the following categories.

4.2.1.1 Technical Spaces

Technical spaces include the following compartments:

- Main Machinery Space and Domestic Machinery Space
- Steering Gear Compartment
- Electrical Space (Switchboard Room)
- Workshop and Stores
- Bow Thruster Compartment
- Pump and Heater Room

[1] Practical Ship Design by D.G.M Watson (1998)

4.2.1.2 Tanks and Voids

The tank capacities were designed to meet the endurance requirements. The voids were used in some places to keep the fuel and recovered oil away from the shell. More details about tank arrangement could be found in *17.0 TANK ARRANGEMENT.*

4.2.2 Superstructure

This section includes all of the spaces from the forecastle deck up to the top of the wheelhouse. The spaces were split into the following categories:

1. Crew Spaces
    a. Cabins and washrooms
    b. Messes and Lounges
2. Service Spaces
    a. Galley
    b. Pilot house
    c. Decontamination Area
    d. Stores and Lockers
    e. Office
3. Technical Spaces
    a. HVAC and Auxiliary Equipment room
    b. Emergency Generator room (as per *SOLAS Chapter II-1 – Part D – Regulation 42*)
    c. Funnels and Air Intakes

4.2.3. Exterior decks

Exterior decks include main deck and forecastle deck. The areas required were determined based on the following:

1. Mission Items
2. Oil Recovery Equipment: Offshore Skimmer and Boom Storage Reels
3. Deck Equipment: Crane and Towing Winch
4. Mooring Equipment
5. Bulwark and Cargo Rails
6. Rescue Craft (as per *SOLAS – Chapter III – Part B – Section III – Regulation 31*)

4.3 AREA AND VOLUME TABLE

The following table provides an initial estimate of required areas and volumes

Table 5 - Initial Estimate of Required Area and Volumes

Hull	**Area (m^2)**	**Volume (m^3)**	**Superstructure**	**Area (m^2)**	**Volume (m^3)**
Technical Spaces	438	1415	Crew Spaces	361	1076
Fuel Oil	-	322	Service Spaces	46	128
Recovered Oil	-	250	Technical Spaces	152	477
Ballast	-	330	**TOTAL**	**558**	**1682**
Fresh Water	-	80			
Grey Water	-	60			
Black Water	-	20			
Void Spaces	-	30			
Minor Tanks	-	40			
TOTAL	**438**	**2547**			

Required main deck area was estimated to be 250 m^2.

5.0 INITIAL SELECTION OF PARTICULARS

One of the main steps in initial stage of ship design is to estimate the overall size of the vessel. The particulars of our vessel are dictated by client's requirements, either in terms of endurance and payload capacity or in terms of dimensional constraints.

The design team's strategy was to develop a parameterization tool that could be used to evaluate the feasibility of the selected vessel particulars, and to use this tool as guidance during the hull modelling stage. The particulars selected in this stage of design were not seen as the exact dimensions of the vessel, but rather were used as a target to aim when the hull was scaled or adjusted.

As a first step, different hull types were evaluated in *6.1 MONOHULL VS CATAMARAN* section, and a monohull was chosen to be the hull type for our vessel. Then the design team compiled a database of existing vessels with similar operational profile and parametric data from reference literature. This information was used to set up design criteria in terms of acceptable ranges for each hull coefficient and non-dimensional ratio. Next step was to convert area and volume requirements into associated weights, leading to our initial weight estimate and the target displacement. By keeping the target displacement constant and changing the vessel particulars, the design team was able to evaluate the effect certain particulars had on hullform coefficients and intact stability.

5.1 REFERENCE VESSELS

After compiling a database of 40 vessels ranging from offshore supply[2] and oil spill response vessels to multipurpose and fishing vessels[3], the design team shortlisted 7 vessels that have the most similar operational profiles and were used in the analysis.

Table 6 - Reference Vessels

Vessel Name	Vessel Type	$\frac{L}{B}$	$\frac{B}{D}$	$\frac{B}{T}$	Loaded Displacement (MT)	C_b	Froude Number	Total Power(kW)
DAMEN OSRV 1050	OSRV	4.6	2.3	2.8	-	-	0.27	3000
Louhi	OSRV	4.7	0.0	2.9	3450	0.68	0.30	7200
RAmpage 4500	OSV	2.9	2.2	2.7	-	0.63	0.35	4080
Trinity	OSRV	4.5	2.6	3.0	2550	0.68	0.25	1909
Bender	OSRV	4.5	2.6	3.1	2610	0.68	0.25	2238
Mariner	OSRV	3.8	2.4	3.3	-	-	0.25	5968
Petrobras	OSRV	3.9	2.6	4.5	-	-	0.21	3400

5.2 VESSEL DIMENSIONAL CONSTRAINTS

The purpose of this project was to evaluate how many requirements could be met while keeping the length of the vessel under 50m in length. The length has a significant effect on the construction cost, resistance and consequently powering requirements of the vessel.

5.3 INITIAL WEIGHT ESTIMATE

The deadweight was determined based on the endurance and client requirements. For the purpose of estimating the particulars, the maximum deadweight was taken which represents the case when the vessel is recovering oil close to the shore, with full recovered oil tanks and fuel oil tanks at 85%. For the lightship weight, vessel spaces were split into categories, so that the weight could be calculated from the area and volume requirements by applying weight coefficients obtained from the industry mentors. The weight coefficients are not revealed in the report since they are proprietary to our mentors.

[2] Young_R_R.A_Review_of_Offshore.Apr.1992.MT

[3] LAMB, T. (2003) Ship Design and Construction (Volumes 2), Chapter 41 – Fishing Vessels

To account for any unforeseen items that may appear later in the design and to make the estimate more conservative, a design margin of 12% was added to the lightship weight as per "Weight Estimating and Margin Manual" written by the Society of Allied Weight Engineers. The end of service life (EOSL) growth margin was used to account for the increase of the vessel displacement due to repairs, refits and equipment addition throughout its service life.

Table 7 - Initial Weight Estimate

Deadweight	Weight (MT)	Lightship	Weight (MT)	Scaled by
Fuel Oil	300	100 - Hull Steel	600	Volume
Fresh Water	80	110 - Superstructure & WH Steel	100	Volume
Recovered Oil	235	200 - Propulsion	100	Power
Minor Tanks	60	300/400 - Electrical & Comm.	35	Power
Crew &Supernum	2	500 - Aux Systems	84	Power/ Volume
Provisions & Stores	2	600 - Outfit	110	Area/Volume
Mission Equipment	50	700 - Deck & Missing Equipment	100	Vendor Info
Total Deadweight (w/o margin)	729	**Total Lightship (w/o margin)**	1129	-
EOSL Margin	5%	**Design Margin**	12%	-
Total Deadweight (w margin)	**765**	**Total Lightship (w margin)**	**1264**	-
TOTAL WEIGHT (w/o margin)			1858	
TOTAL WEIGHT (w margin)			**2030**	

5.4 PARAMETERIZATION TOOL

After calculating the target displacement for the vessel, the design team started a process of selecting vessel particulars. A calculation tool was developed that uses parametric data from the Ship Design and Construction[4] to estimate hull coefficients based on vessel particulars and target displacement. Acceptable ranges for the non-dimensional ratios, hull coefficients and metacentric height were also determined through reference of the same text. If a given set of particulars caused one of the coefficient to fall out of range, the set of particulars was considered infeasible.

The waterline particulars were decided to be the most useful in the early sizing stage since they affect resistance and stability. By varying values for the particulars the design team was able to see the response sensitivity of some of the coefficients to changes in the vessel particular. Using this method, the team was able to determine a set of particulars which satisfied the design evaluation criteria.

Due to a very similar operational profile and available resistance data, the design team decided that vessel parameters should fit within UBC Trawler Series parameters shown below. For more details about the UBC Series refer to 6.5 REFERENCE HULL.

Table 8 - UBC Model Series Parameters

Series	C_b	L/B	B/T	$L/V^{1/3}$
UBC	.53 - .61	2.6 - 4.0	2 - 3	3 - 4.47

5.4.1 Length to Beam Ratio

The length to beam ratio has an effect on the hull resistance, capital cost, directional stability and turning ability. Considering that vessel's length was restricted and a large main deck is required to conduct all of the missions, the vessel was expected to have a relative low L/B. After reviewing the reference vessels and UBC Series the L/B range, the range of this ratio for our vessel was set at **2.8 to 4**.

[4] LAMB, T. (2003) Ship Design and Construction (Volumes 1 & 2), Chapter 11 – Parametric Design

5.4.2 Beam to Depth Ratio

The beam to depth ratio provides an effective early guidance on initial intact stability. Watson and Gilfillan suggest a range of **1.65 to 2.5** for the volume limited vessels[5]. This range was also confirmed with the reference vessels found.

5.4.3 Beam to Draft Ratio

The beam to draft ratio influences wave-making resistance and transverse stability. As indicated in the reference text, the acceptable range was chosen to be between **2.25 and 3.5**. The reference vessels were also found to be in the same range.

5.4.4 Slenderness Ratio, $L/V^{(1/3)}$

The Slenderness ratio range was set to be between **3.0 and 4.47** in order to match the UBC series parameters.

5.4.5 Froude Number

For a full displacement vessel, the Froude number should be low enough to avoid a resistance peak. From the following figure[6], it could be seen that the resistance peak is at a FN of 0.36 for the fishing boats and tugs; therefore, the acceptable range for the design vessel is between **0 and 0.36.**

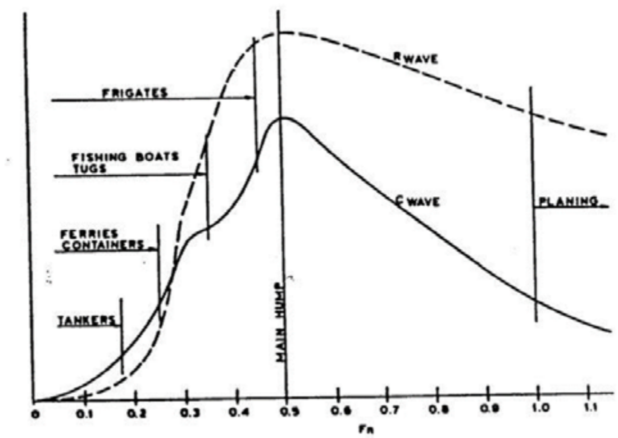

Figure 4 - Resistance Peak Compared to Froude Number

5.4.6 Block Coefficient, C_b

An optimum range of block coefficient was estimated using the Watson and Gilfillan Mean Line[7]. Using the calculated C_B values for Froude numbers at the speed of 13 and 14 knots and UBC Series C_B range, the block coefficient range was set between **0.53 and 0.61.**

$$C_B = 0.70 + 0.125 \tan^{-1}[23 - 100Fn/4]$$

[5] LAMB, T. (2003) Ship Design and Construction (Volumes 1 & 2), Chapter 11 – Parametric Design
[6] WATSON, D. G. M. (1998). Practical Ship Design
[7] LAMB, T. (2003) Ship Design and Construction (Volumes 1 & 2), Chapter 11 – Parametric Design

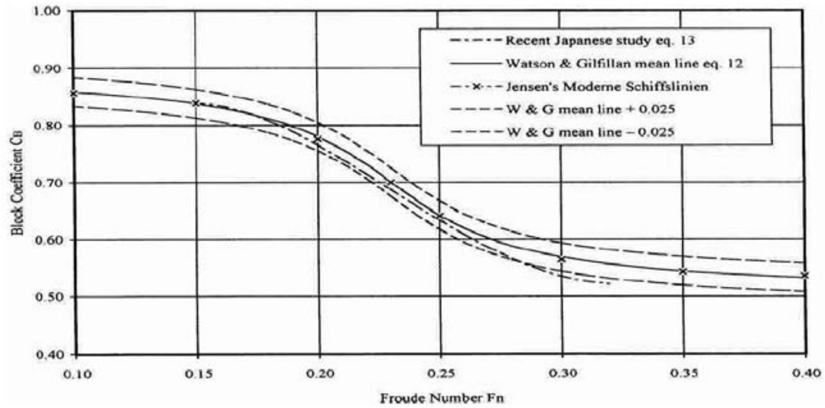

Figure 5 - C_B as a function of Froude Number

5.4.7 Longitudinal Prismatic Coefficient, C_p

At the initial stage, the design team used Sounder's Design Lane[8] to estimate the range of the longitudinal prismatic coefficient, but this resulted in a relative low values for the C_P range because the relationship is based on the vessels with high L/B ratio. Consequently, the UBC series C_P range of **0.6-0.72** was used.

5.4.8 Midship Coefficient, C_m

The design does not place a heavy emphasis on the midship coefficient since it is related to the C_P and C_B. The range of **0.75 to 0.88** was set to match the UBC Series.

5.4.9 Waterplane Coefficient, C_{wp}

The waterplane coefficient was estimated using the following relationship:

$$C_{WP} = 0.262 + 0.810C_p$$

For the purpose of the calculation, the design team assumed the vessel will have a twin screw and a transom stern for the purpose of the calculation. The estimated value of waterplane coefficient was used to calculate the transverse inertia property of the water, and consequently calculate BM_T.

5.4.10 Vertical centre of buoyancy, KB

The value of KB was estimated using Norman's equations[9]:

$$KB = T \times (0.90 - 0.36C_M)$$

5.4.11 Transverse Metacentric Radius, BM_t

BM_T is a function of waterplane transverse moment of inertia, I_T, and immersed volume. In order to estimate I_T without modelling, the following formulas was used:

$$C_I = I_T/LB^3 \, , C_I = \frac{0.096 + 0.89C_{WP}^2}{12}$$

$$\therefore I_T = \frac{LB^3}{12}(0.096 + 0.89C_{WP}^2)$$

5.4.12 Vertical Centre of Gravity

The vertical center of gravity of the lightship was estimated using the data found on US and European offshore supply vessels[10]. The article provided values for VCG/Depth ratio that ranged between **0.76 and 0.89**. The design team used an average value of **0.825** for the VCG estimation

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[8] LAMB, T. (2003) Ship Design and Construction (Volumes 1 & 2), Chapter 11 – Parametric Design
[9] LAMB, T. (2003) Ship Design and Construction (Volumes 1 & 2), Chapter 11 – Parametric Design

5.4.13 Transverse Metacentric Height, GM_t

Based on the estimated values of KB, BM_T and KG, the design team was able to estimate GM_T which provided an initial estimate for the stability of the vessel. It was found that the GM_T in the range from **0.8 to 2** should provide adequate stability while not having too stiff of seakeeping response[11].

5.5 SELECTION OF INITIAL PARTICULARS

After transporting all of the formulas and ranges into the excel spreadsheet, the team was able to study the effect of the particulars on the hull form coefficients as well as the feasibility of the design. The figure below shows the output of the model during the initial stage of the selection process. The coefficients in red identify the coefficients that do not meet the feasibility requirements, while the green represents values that are within the defined acceptable ranges.

Table 9 - Initial Stage of Particulars Selection

Variable Parameters	Units	Values	Estimated	Units	Values	Parameters	Units	Estimated Values	Min	Max
			Immersed Volume	m3	2007	LWL/BWL	-	2.80	2.80	4.00
Length WL	m	40.0	Displacement	t	2057	BWL/T	-	2.23	2.25	3.50
Beam WL	m	14.3	Waterplane Area	m2	459	BWL/D	-	2.23	1.65	2.50
Draft	m	6.40	Midship Area	m2	75	Fr	-	0.34	0	0.36
Depth	m	7.5				Cb	-	0.55	0.53	0.61
Cruise Speed	knots	10.0				Cm	-	0.82	0.75	0.88
Max Speed	knots	13.0	Total Weight	t	2030	Cp	-	0.57	0.60	0.72
						Cwp	-	0.80	-	-
						Cvp	-	0.68	-	-
						KB	m	3.88	-	-
						Iyy (trans)	m4	6519.93	-	-
						BM	m	3.25	-	-
						KG	m	6.78	-	-
						GM	m	0.35	0.8	2
						L/V^(1/3)		3.17	3.00	4.47

Table 10 - Intermediate Stage of Initial Particular Selection

Variable Parameters	Units	Values	Estimated	Units	Values	Parameters	Units	Estimated Values	Min	Max
			Immersed Volume	m3	1971	LWL/BWL	-	3.24	2.80	4.00
Length WL	m	46.0	Displacement	t	2020	BWL/T	-	2.63	2.25	3.50
Beam WL	m	14.2	Waterplane Area	m2	528	BWL/D	-	2.63	1.65	2.50
Draft	m	5.40	Midship Area	m2	62	Fr	-	0.31	0	0.36
Depth	m	6.5				Cb	-	0.56	0.53	0.61
Cruise Speed	knots	10.0				Cm	-	0.82	0.75	0.88
Max Speed	knots	13.0	Total Weight	t	2030	Cp	-	0.61	0.60	0.72
						Cwp	-	0.81	-	-
						Cvp	-	0.69	-	-
						KB	m	3.28	-	-
						Iyy (trans)	m4	7428.83	-	-
						BM	m	3.77	-	-
						KG	m	5.87	-	-
						GM	m	1.17	0.8	2
						L/V^(1/3)		3.67	3.00	4.47

The next figure shows the final iteration of the initial particulars selections. After satisfying all of the evaluation criteria, the design team moved on to the 3D modelling of the hull form. Note that these particulars represented the first guess and that the parameterization tool was used for guidance while modelling the hull form to make sure the vessel meets all of the ranges previously defined and has acceptable resistance and stability, as well as storage capacity. The general arrangement was also developed to evaluate if there is enough storage for all of the equipment carried.

[10] Young_R_R.A_Review_of_Offshore.Apr.1992.MT
[11] WATSON, D. G. M. (1998). Practical Ship Design

6.0 HULL MODELLING

After completing the initial estimate of vessel particulars using a parameterization tool, the design team started developing the hull form of the vessel. The following sections will discuss the rationale behind some of the hull form design decisions, as well as model construction, fairing and modifications made to the hull form. The *001 - LINES PLAN* drawing is attached in the end of the report.

6.1 MONOHULL VS CATAMARAN

The design team faced a challenge when determining a hull type that effectively met numerous conflicting requirements. The vessel is required to have a large working deck and to be a stable platform for various operations at sea, while also having a large storage capacity for the recovered oil. Although displacement catamarans are more stable and have greater deck area, they have relatively small storage capacity inside the demihulls.

In order to assist in the decision between monohull and catamaran – and to introduce a certain amount of objectivity to the process – a weighted decision matrix (WDM) was used. The WDM compared a total of eight parameters, each given a weight based on their perceived importance in accomplishing the various missions intended for the vessel. The weighted factors were also influenced by the conversation the team had with the WCMRC. The monohull and catamaran were then given scores for each parameter based on information found in literature, calculation, or a subjective consensus reached amongst the design team. These scored were then multiplied by the weighting value and totaled to yield the overall performance index for the two concepts. As can be seen in the final scores, the monohull concept comes out ahead of the catamaran for the stated mission and weighting. For this reason, the design team chose to pursue the monohull concept.

Table 11 - WDM: Monohull vs Catamaran Evaluation

		Unweighted		**Weighted**	
Parameter	**Weight**	**Monohull**	**Catamaran**	**Monohull**	**Catamaran**
Storage Capacity	5.0	5.0	3.0	25.0	15.0
Stability	4.5	3.5	5.0	15.8	22.5
Deck Area	4.5	3.0	4.0	13.5	18.0
Speed	4.0	3.0	4.0	12.0	16.0
Towing Capability	4.0	4.5	3.0	18.0	12.0
Seakeeping	3.5	4.0	2.5	14.0	8.8
Cost	3.0	4.0	2.0	12.0	6.0
Maintenance	2.5	3.0	2.5	7.5	6.3
			Total Score:	**117.8**	**104.5**

6.2 SUPERSTRUCTURE LAYOUT

Three typical superstructure locations – aft, midship and forward - were considered for the design vessel and evaluated based on the following criteria as extracted from the client's requirements and comments: available deck space, wheelhouse visibility and crew comfort.

Ultimately, the forward superstructure was selected as it provides the most continuous deck space and good forward visibility. Further, performing the oil recovery operation aft was found more preferred by WCMRC as well as allows for efficient equipment deploying, moving, and towing. Placing the superstructure at the bow will allow for greater versatility in equipment storage and towing at the expense of greater pitching accelerations.

6.3 ROUNDED BILGE VS DOUBLE CHINED HULL

A double chine hull was selected over a rounded bilge based on the reasoning below:

1. Geometric Simplicity
2. Lower construction cost

3. Slightly better seakeeping performance compared to the rounded bilge[12]

Note that the rounded bilge has a slightly lower resistance[13], however, lower construction cost and geometric simplicity were the driving factors in the final selection.

6.4 BULBOUS BOW

The design team has also investigated if the use of a bulbous bow would be beneficial. From charts and data found in reference literature[14], it was found that bulbous bow will not introduce any reduction in wave-making resistance for our vessel hull form and size. Further, the bulbous bow introduces more construction complexity, and as stated above we are trying to avoid this in order to minimize the construction cost of the vessel.

6.5 REFERENCE HULL

At the initial stage of design, a number of Offshore Supply vessels and fishing boats were used as reference for the initial weight estimate and particulars selection. However, for the hullform development, the design team used the UBC Trawler Series parent hull's lines plan as a main reference. The primary reasons why UBC Series were selected are the following:

- Trawler vessels have a very similar operational profile to our vessel.
  - Both require large storage capacity inside the hull and main deck area
  - Both deploy equipment into the water
  - Both recover cargo from the water, and the heaviest loading condition for both vessels is when they are at sea, half way throughout the mission, and not when the vessel is leaving the port
- Resistance data and lines plan were available
- Wide transom provides a larger deck area and additional buoyancy aft

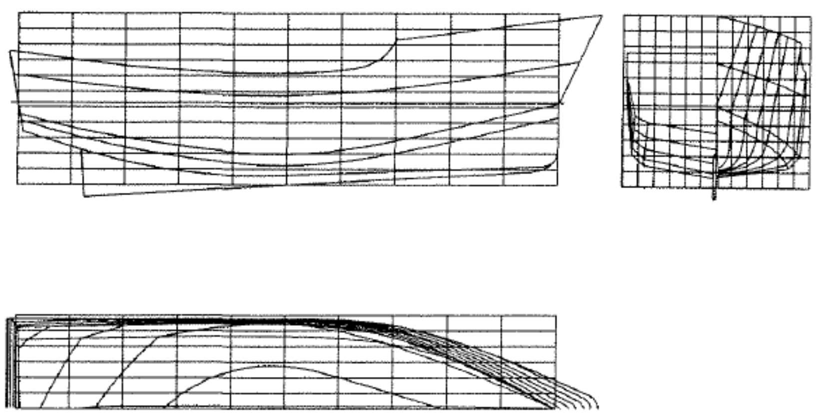


Figure 6 - UBC Trawler Series - Parent Hull Lines PLan

6.6 HULL MODELLING

6.6.1 Setup and Construction

The lines plan of the UBC Trawler Series was used to set up the lines of our vessel. The 2D lines from the profile and plan view were converted into a 3D lines, then the surface was lofted in between. For lofting purposes, it was important to make sure we had the same amount of control points for every curve. After creating the surfaces with 3 vertical and 10 horizontal control points, the next step was to align the surfaces, which could be achieved by matching the locations of the control points of adjacent surfaces. Ideally, we wanted to use as least control points as

[12] ZBOROWSKI, A. & CHU, H. – SNAME Transactions Vol. 100 (1992) Hard Chine Versus Round Bottom
[13] CALISAL, S. & MCGREER, D. – UBC (1993) A Resistance Study on a Systematic Series of Low L/B Vessels
[14] MOLLAND, F. – (2011) Ship Resistance and Propulsion

possible; however, the design team decided to have 4 columns of control points for both entry and run sections, and 3 columns for parallel mid body.

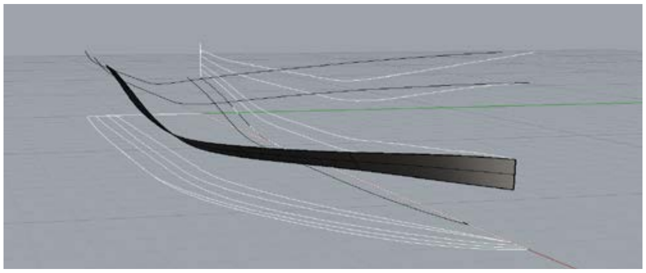


Figure 7 - Hull Construction Set Up

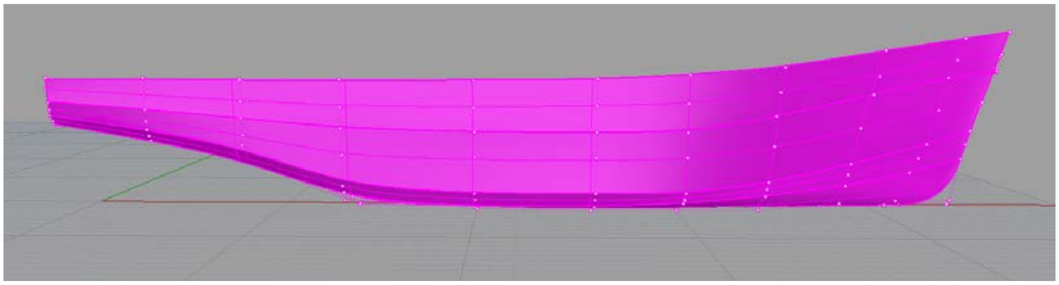


Figure 8 - Hull Model Control Points

6.6.2 Analysis

After scaling the completed model to the initial particulars estimated, it was necessary to measure key geometric properties of the hull in order to obtain the coefficients and to verify with the parameterization tool. The hull model has gone throught a number of iterations in order to make sure that the vessel meets all of the capacity and stability requirements, as well as has relatively low resistance. The parameterization tool was actively used in the intial stage of the design, to make sure the design is within the parameter limits defined by the team.

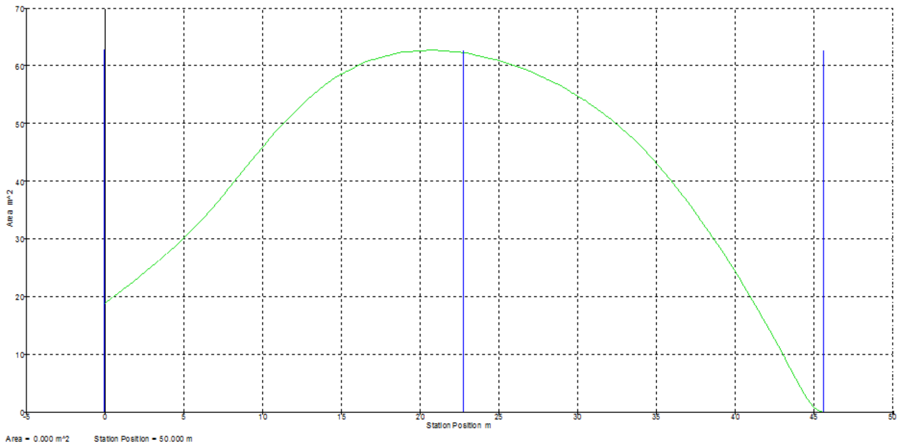


Figure 9 - Sectional Area Curve

The design team also used a sectional area curve to qualitatively measure the performance of the hull. Using a real-time sectional area curve in Orca3D, any sudden changes along the curve could be identified and edited to a more gradual change through that section which should result in an efficient hull form. The centre of buoyancy was also located and the team aimed to have its location between the midship and 2% of the length aft of the midship[15]. Ideally, centre of buoyancy should line up with the centre of gravity of the vessel.

6.6.3 Main Features and Modifications

A number of modifications were done to the hull form:

1. The run section of the hull was adjusted in order to accommodate the propeller and a rudder and to provide an adequate flow to the propeller. From the reference literature, the propeller and hull clearance were defined as a function of propeller diameter[16]:

Table 12 - Clearance Around Propeller

Clearance	%D
Propeller tip to underside of stern	8
Propeller tip to topside of keel piece	2
Propeller to forward side of rudder	10
Propeller to after side of aperture	15

2. The entrance angle was slightly increased in order to accommodate the bow thruster. Ideally, we would like to keep it similar to the UBC parent model for a better geometric similarity. Thus, a more accurate resistance prediction. The location of the bow thruster tunnel will be discussed in the 22.0 STATIONKEEPING ANALYSIS.
3. The transom stern angle was kept the same, 10 degree aft from vertical axis. In the model tests performed on the UBC Series (low L/B vessels) it was found that the faired stern of 10 degrees recovers some of the lost pressure due to eddy making behind the immersed stern, reducing the overall resistance of the vessel. In addition, another advantages of having a transom stern are larger deck area, increased hydrostatic stability and greater reserve buoyancy aft.
4. The horizontal keel plate was added for better docking performance and to allow attachment of the skeg in order to improve the directional stability. Please refer to the Maneuverability Analysis section for more details regarding effect of the skeg on directional stability of the vessel.
5. In order to decrease the flow separation, the design team created a smoother transition from the parallel mid body to the run section. The transom stern was cut off sharply instead of being rounded into the shell. The rounded transom edge causes water along the hull to break away from the undisturbed streamlines and cause small separation zones.
6. The stem angle was adjusted for better esthetics and seakeeping.
7. Bilge keels were added to provide some additional roll damping at sea.
8. The vessel has a tumblehome superstructure, which eliminates the chance of any damage to superstructure when the designed vessel is performing offloading operation side by side to another vessel at sea.

6.6.4 Fairing, Curvature and Surface Analysis

After the shape of the vessel was constructed and the overall dimensions were determined, the design team used curvature and surface analysis tools to fair the hull. In order for the hull surface to be smooth, the curves used to construct it must be smooth as well. The smoothness is easier to visualize using the curve analysis tool shown below. This tool displays a set of lines that look like needles, which are evenly spaced and perpendicular to the curve or surface. The far ends of the needs are connected with another curve, which represents the second derivative or curvature magnitude along the curve.

[15] WATSON, D. G. M. (1998). Practical Ship Design
[16] LAMB, T. (2003) Ship Design and Construction (Volumes 2) – Chapter 41 – Fishing Vessels

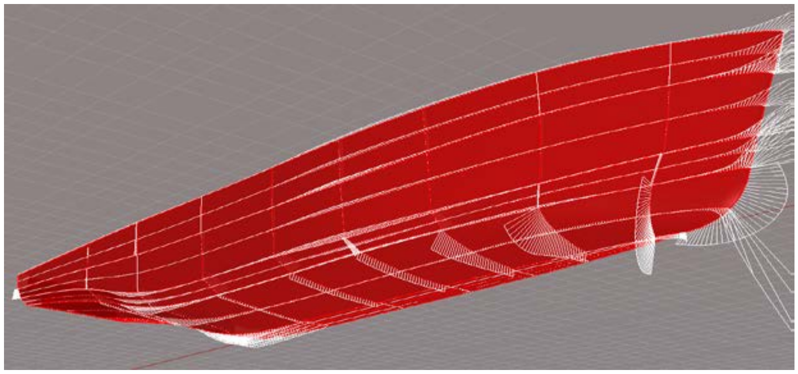


Figure 10 - Fairing Using Curvature Graph

Another powerful tool that was used to evaluate the surface curvature is false-color analysis in Rhino 3D software. This tool was used to gain information about the type and amount of curvature of a surface. Further, it was used to detect any sudden changes like bumps and dents, and to correct them in order to design a fair hull.

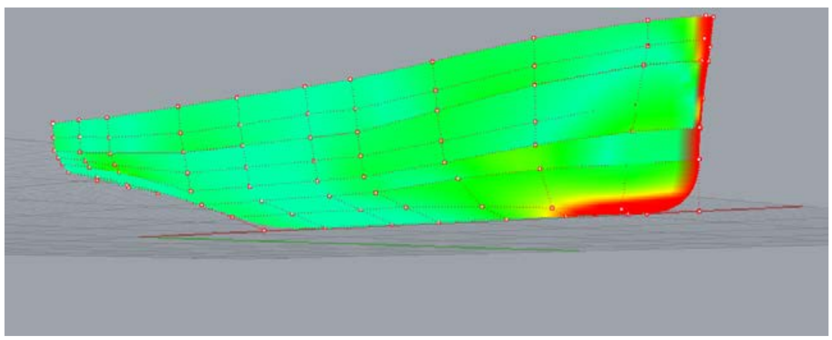


Figure 11 - Curvature False-Color Analysis

6.7 SPONSON STUDY

The design team also evaluated if there is an advantage of adding sponsons to the hull in order to increase the deck area. It was found that sponsons introduce additional resistance, since the stern wave encounters a larger beam, which is depicted in the figures below. The following images were generated via Maxsurf software, which ignores the effects of wave breaking and viscosity.

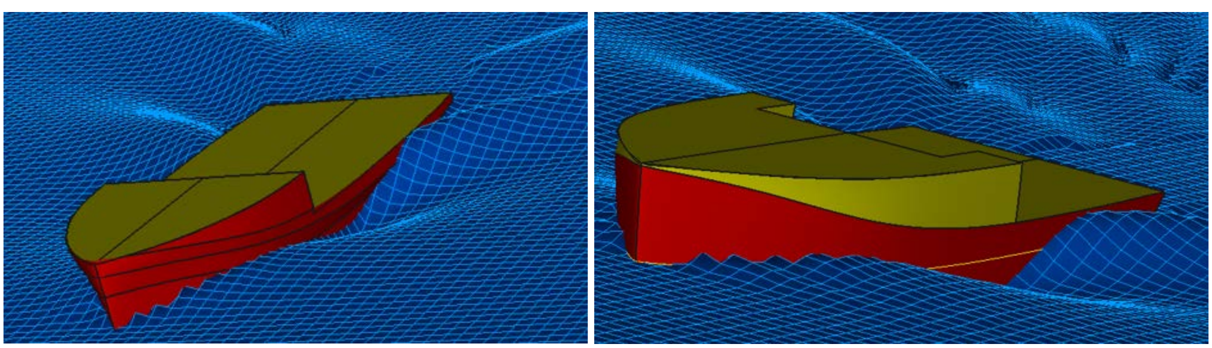


Figure 12 - Sponson Study in Maxsurf Resistance (Hull with Sponsons is on the left)

The team conducted a simple stability check in Maxsurf and found a small increase in GM value. It was decided to stick with original hullform design, and we are recommending to conduct a more detailed study on sponsons in the next stage of the design.

7.0 RESISTANCE ANALYSIS

The design team's vision for the resistance analysis was to develop a parametric tool that could be used to optimize the hull form for lower resistance and to estimate bare hull resistance throughout each iteration or design change.

7.1 BARE HULL RESISTANCE CALCULATION

The following section outlines the bare hull resistance analysis performed.

7.1.1 Scaling from UBC Series Model Test Data

The UBC Trawler Series parent hull was selected as a main reference for modelling due to similar operational profile of trawlers to our vessel and available model test data. The ITTC-57 method and similitude principle were used to estimate the bare hull resistance from the model tests. Further, to have a more accurate estimates and to match the design particulars, an interpolation between 8 models was developed. Refer to *APPENDIX A – RESISTANCE ANALYSIS* for more details about the procedure of the calculations, UBC Series model data, calculation inputs and outputs.

Computations was performed in Excel and programmed to automatically compute the required resistance for different inputs. By varying some of the input parameters, we could observe resistance sensitivity due to changes in hull coefficients and ratios. While trying to optimize the hull in order to achieve smaller resistance, the design team had to keep in mind that the vessel should be stable and have enough capacity for all of the liquids and equipment.

7.1.2 Verification

To verify the results obtained from method above, the design team compared them to the resistance values determined via Holtrop Algorithm, which was developed through a regression analysis of model experiments and full-scale data of cargo and fishing vessels, and via Van Oortmerssen method, which is another popular method used for power estimated of smaller displacement vessels like tugs and trawlers. The Maxsurf Resistance software has a built in module that performs analysis using both methods on the provided hullform and defined design waterline.

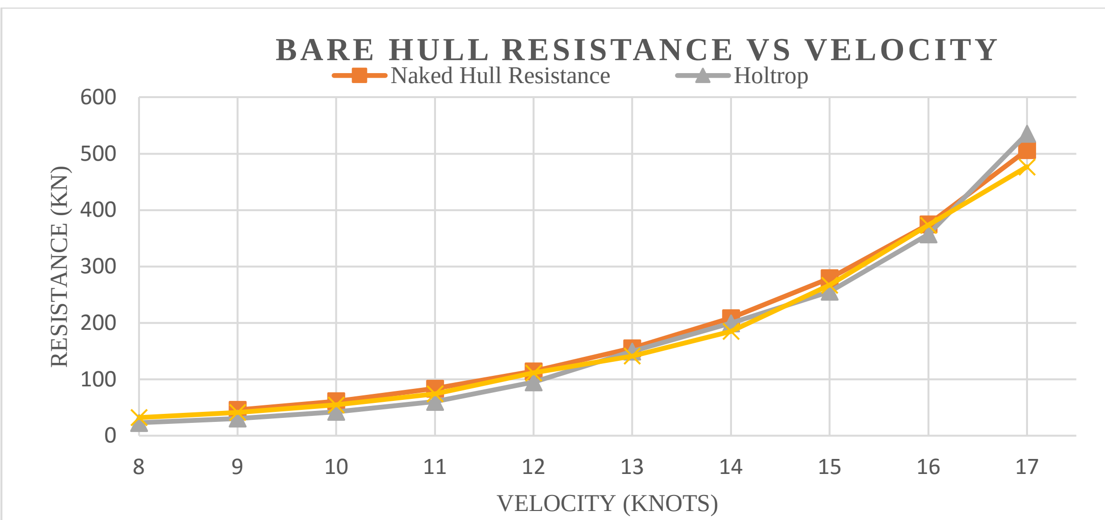


Figure 13 - Bare Hull Resistance vs Velocity

From the figure above it could be seen that the estimated bare hull resistance is within 5% of values obtained from Holtrop and van Oortmerssen. Further, the results were also compared to the powering data obtained for an OSV with similar hull parameters, and it was found that the results had a significant correlation to the actual data (within 10% over the entire curve). Based on results, a correlation allowance of 10% was applied to the output of the calculation.

7.2 RESISTANCE ANALYSIS RESULTS

The graph below displays the total resistance of the designed ship. The appendage drag, resistance due to wind and hull roughness were estimated based on the empirical formulas found in reference literature.

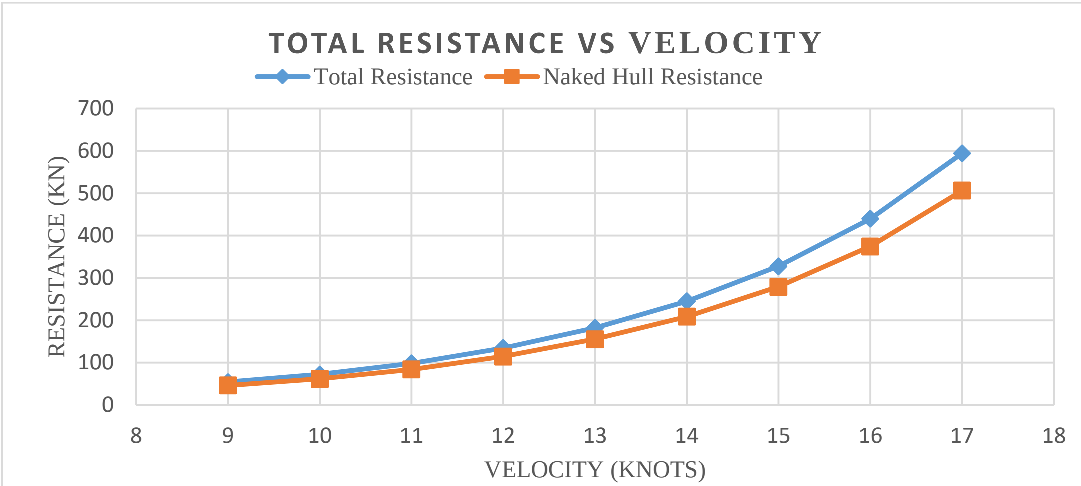


Figure 14 - Total Resistance vs Velocity

7.3 QUALITATIVE ANALYSIS

The design team also wanted to get a better idea about the wave patterns generated by the designed hull and check if there are any significant discrepancies from the Kelvin Wave Pattern. The following were generated via Maxsurf software for a case when the vessel is moving at 14 knots, which is its maximum speed. This model ignores the effects of wave breaking and viscosity, and a more accurate results could be obtained by performing CFD analysis. For this stage of design, the design team was mainly aiming to observe the likely wave pattern behind the vessel at the maximum speed.

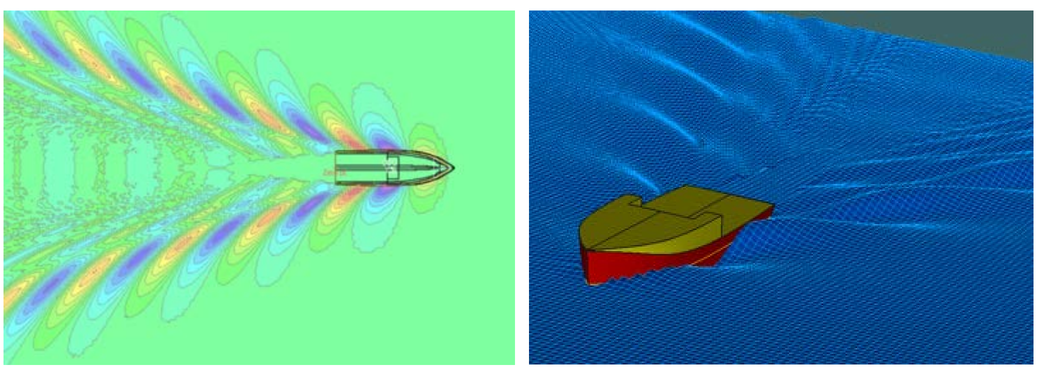


Figure 15 - Wave Pattern at Maximum Speed

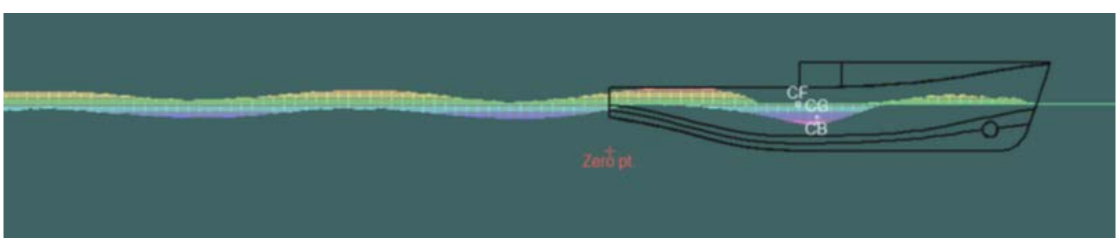


Figure 16 - Wave Pattern Profile View

8.0 POWERING AND PROPULSION CONCEPTS

The following sections outline the evaluation of powering and propulsion concepts from the early stage of the design. Further, the conducted trade-off studies that were used to determine the most viable powering and propulsion system for the design will be discussed as well.

8.1 ENERGY SOURCE ALTERNATIVES

There are multiple options for powering a vessel with various energy or fuel sources; each option has certain drawbacks related to regulations, availability, or readiness. The considered options and reasoning for winnowing are summarized in the table below.

Table 13 - Energy Source Winnowing Table

Energy Source	Selection/Winnowing Reasoning
Diesel	**Needs and Requirements:** does not violate any needs or requirements **Feasibility:** proven operational history in marine industry **Technical Readiness:** proven operational history in marine industry
Renewable Electric (solar, wind, etc.)	**Needs and Requirements:** will need to carry extra fuel to supply support vessels during operations. Also, will have issues with intermittent weather conditions **Feasibility:** has not been implemented at a commercial level yet **Technical Readiness:** small scale tests have been conducted that demonstrate the ability for use in a marine environment
LNG/CNG	**Needs and Requirements:** does not violate any needs or requirements **Feasibility:** Implemented in other areas of the world, but no vessels exist in North America yet. **Technical Readiness:** Fuel distribution networks won't be available on BC coastline until projected 2020-2025, and may not be extensive enough to reach all areas along coast.
Hydrogen Fuel Cell	**Needs and Requirements:** does not violate any needs or requirements **Feasibility:** Has been shown to work on smaller scales **Technical Readiness:** Application has been tested in vessels but hasn't seen any commercial success as of yet. Would still require
Nuclear	**Needs and Requirements:** Does not directly violate needs and requirements; however consequences related to failure are dramatic **Feasibility:** Used in military applications and in some long range arctic vessels but no commercial use as of yet **Technical Readiness:** Is ready for use in marine vessels however there are strict regulations and incredible risks in case of failure

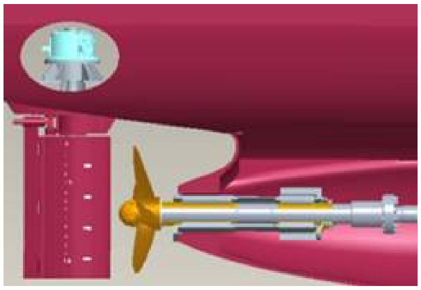
Based on the options above, the design team selected diesel fuel as the vessel's primary energy source. This fuel can be used to power the propulsors directly or to power generators that will power electric motors as shown in Powertrain concepts below.

8.2 PROPULSION CONCEPTS

There is a wide variety of thruster types and configurations to choose from. The more common types and their key advantages and disadvantages are listed below.

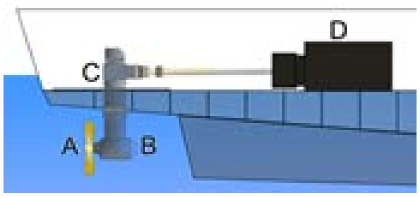
Table 14 - Propulsion Concepts

Conventional Screw



+ Most reliable due to fewer mechanical components and no gearing arrangements (compared to z-drive or azi-pod)
+ Simple to implement
+ Cost efficient
- Not as maneuverable as other drives
- Side thrusters might be required for better station keeping

Z-drive



+ Easier access for maintenance since the motor is mounted inside the vessel
+ Typically more reliable than Azi-pod and Voith
+ Less expensive than Azi-pod and Voith
+ Good maneuverability (similar to Azi-pod)
- Requires some space inside the vessel
- Expensive system

Azimuth Thruster (Azi-pod)

+ Allows greater hydrodynamic and mechanical efficiency when compared to standard z-drive
+ More vessel space in the vessel
+ Low noise and vibration
+ Good maneuverability
+ Lowers vessels VCG
- Inaccessibility of the motor while at sea
- Expensive system

Voith Schneider

+ Highly Maneuverable
+ Allows instantaneous change in direction
+ Low noise and vibration
+ High efficiency
+ Lowers vessels VCG
- Significant increase in navigational draft
- Expensive
- Increase in weight due to the addition of protection guards around the system

The key features of each propulsion system were compared using the Pugh chart. The concepts that were chosen over the others were z-drive and conventional screw. The two concepts were combined with the chosen energy source to create a number of full power train concepts.

8.3 NUMBER OF PROPELLERS

Using the advised limit values for propeller loading and tip speed from the reference literature[17], the design was able to find an optimal amount of propellers and propeller diameter needed to satisfy the power requirements.

Table 15 - Propeller Type Comparison

	Open Propeller			**Ducted Propeller**		
Power/ D^2 (kW/m^2)	225			300		
Number of Propellers	1	**2**	3	1	**2**	3
Power per Propeller (kW)	2908	**1454**	969	2908	**1454**	969
Propeller Diameter (m)	3.6	**2.5**	2.1	3.1	**2.2**	1.8
Rotational Speed (RPS)	3.1	**4.4**	5.4	3.6	**5.1**	6.2

From the table below it could be seen that having two propellers is sufficient, the design team didn't go with three propeller due to increased complexity and volume requirement inside of the hull.

8.4 POWERTRAIN CONCEPTS

The design team narrowed energy source concepts to diesel fuel, and the propulsion methods were narrowed down to a conventional screw propeller and a Z-Drive arrangement. The propulsion method and the fuel sources were combined into three complex concepts for further evaluation:

Table 16 - Powertrain Concepts Evaluation

Concept 1 - Conventional Diesel System & Conventional Screw

Component	Main Engines	GenSets	Gear Box	Shafts	Rudders
Quantity	2	2	2	2	2

Concept 2 - Diesel Electric System & Conventional Screw

Component	GenSets	Switchboard	Variable Drives	Motors	Shafts	Rudders
Quantity	4	4	2	2	2	2

Concept 3 - Diesel Electric System & Z-Drive

Component	GenSets	Switchboard	Variable Drives	Motors	Z-Drive Gearing
Quantity	4	4	2	2	2

Since all concepts require a propeller, propeller size or weight was not included in the evaluation as it would not help differentiate the selections. These concepts were evaluated by the following criteria:

- Weight of all the required components
- Size or Volume of all components
- Fuel Consumption of prime mover multiplied by number of prime movers
- Maintenance - based on number of trades required to service components
- Complexity - based on number of components and interconnections necessary
- Redundancy - number of prime movers that can drive a propeller at a given time
- Maneuverability - qualitative comparison of ability to direct percentage of thrust in another direction
- Cost of all components

[17] LAMB, T. (2003) Ship Design and Construction (Volumes 2) – Chapter 41 – Fishing Vessels

After analyzing the requirements and having a further discussion with WCMRC, the weighting for each criteria was determined. Further, the scores for each parameter were based on information found in literature and data provided by vendors, or a subjective consensus reached amongst the design team.

Table 17 - Powertrain Scoring Matrix

Evaluation Criteria	Weight	Unweighted/ Weighted Scores					
		Concept 1		Concept 2		Concept 3	
Weight	22%	10	2.2	9.7	2.1	7.5	1.7
Size	21%	10	2.1	8.2	1.7	8.4	1.8
Fuel Consumption	20%	9.9	2.0	10	2.0	10	2.0
Maintenance	10%	10	1.0	7.5	0.8	7.5	0.8
Cost	10%	10	1.0	8.5	0.9	7	0.7
Redundancy	9%	6.7	0.6	10	0.9	10	0.9
Complexity	5%	10	0.5	8	0.4	8.7	0.4
Maneuverability	3%	8	0.2	8	0.2	10	0.3
Net Score	100%	8.91		8.4		7.97	
Rank		**1**		**2**		**3**	

Through a Weighted Decision Matrix, the Conventional Diesel System & Conventional Screw ended up being the best choice for the vessel.

8.5 FIXED PITCH VS CONTROLLABLE PITCH PROPELLERS

A Controllable Pitch Propeller was selected instead of a Fixed Pitch Propeller to maximize bollard pull during towing operation, reduce propeller wash when deploying oil containment boom and to eliminate need for a reversing gear to travel astern. The design team believes that these benefits offset the added weight and complexity associated with this kind of system.

8.6 MEDIUM VS HIGH SPEED ENGINES

The next stage of the design process involved an investigation into the benefits of medium or high speed engines, which will lead to a selection of a gearbox and shaft. The comparative benefits of each type of engine are listed below:

Table 18 - Engine Speed Comparison

Medium Speed (GE 6L250MDC Engine)	High Speed (CAT 3512)
• Lower fuel consumption	• Higher power to weight density
• Higher maximum power	• Higher power to volume density
• Can be operated at lower engine speeds	• Lower emission

The lower engine speed of medium speed engines will reduce wear of engine components which will both increase life and decrease maintenance requirements. However, since this vessel will be limited in operation, the high speed engine will be able to operate near full capacity based on manufacturer's specifications.

8.7 SELECTED MAIN ENGINE

Based on the powering analysis discussed in the next section, the selected engine is CAT 3512 - 1903kW, 1800 RPM, D-rating (Intermittent Duty), EPA 4 and IMO Tier III emission compliant.

9.0 POWERING AND PROPULSION ANALYSIS

After estimating the total resistance, the design team had to determine the required power in order to size the main engines. This document will outline the methods used to estimate the power and select propellers throughout the progress of the project.

9.1 EARLY PHASE POWER PREDICTION

At this early stage of the design, to estimate the power requirements, the team determined the Admiralty Coefficient for reference vessels then applied it to our vessel with the formula:

$$AC = \frac{\nabla^{\frac{2}{3}} \cdot V^3}{P}$$

From this, it is estimated that the vessel will require approximately 3,000kW for propulsion.

9.2 INITIAL PROPELLER CALCULATIONS

Reference literature was used to obtain the advised limit values for propeller loading and tip speed for open propeller and propeller with nozzle configurations[18]. The results are summarized in the table below:

Table 19 - Comparison of Propeller Types

2 Propellers, Total Power 3,000 kW		
Parameters	**Open Propeller**	**Propeller w Nozzle**
Propeller Loading, P/D^2 (kW/m^2)	225	300
Tip Speed (m/s)	28 - 30	28 - 30
Bollard Pull Loading, BP/kW (MT/kW)	0.013	0.017
Recommended Diameter (m)	2.54	2.20
Rotational Velocity (rpm)	185 - 200	220 - 235
Bollard pull (MT)	38	49

After completing the bollard pull calculation, the design team found that both open and ducted propeller meet the required power and bollard pull demand. The design tem decided to conduct a more detailed analysis to evaluate if open propellers will satisfy all of the requirements.

9.3 OPEN WATER PROPELLER OPTIMIZATION

In order to evaluate the open water propeller performance and select the optimal propeller, the design team developed a parametric optimization tool based on B-Series propeller data. These propellers are widely used on the ships and have high open water efficiency compared to other propellers.

The K_T and K_Q polynomials, which are the functions of advance ratio, pitch ratio, expanded area ration and number of propeller, were used to set up the propeller optimization tool.

$$K_T = \sum_{n=1}^{39} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_0)^{u_n} (z)^{v_n}. \qquad K_Q = \sum_{n=1}^{47} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_0)^{u_n} (z)^{v_n}.$$

The propeller diameter, expanded area ratio, rotational speed and number of blades were optimized to achieve the highest open water efficiency and thrust, while staying under cavitation limits. The detailed procedure, calculation inputs and outputs are outlined in *APPENDIX B – POWERING AND PROPULSION ANALYSIS*.

[18] LAMB, T. (2003) Ship Design and Construction (Volumes 2) – Chapter 41 – Fishing Vessels

The summary of selected propeller parameters and its performance is outline in the following table.

Table 20 - Selected Propeller Summary

Selected Propeller	Unit	Value	Results	Unit	Value
Number of propellers	-	2	**Max Open Water efficiency**	%	54
Propeller Diameter	m	2.25	**Max Bollard Pull**	MT	35.8
Rotational Speed	RPM	300	**Brake Power per Engine**	kW	1774
Expanded Area Ratio	-	0.95	**Required Engine Torque**	kN m	9.4
Number of blades	-	5	**Engine Speed**	RPM	1800

Based on the selected propeller parameters, the tool was also used to find the maximum attained thrust at every speed of the ship based on the highest torque of the selected engine. The rotational speed was kept constant. Since the vessel has controllable pitch propeller, the optimal pitch for maximum thrust was also found for every speed of the vessel. The results of the optimization are presented in the plot of maximum available thrust vs total resistance, where it could be seen that vessel is capable of attaining the required speed of 14kts.

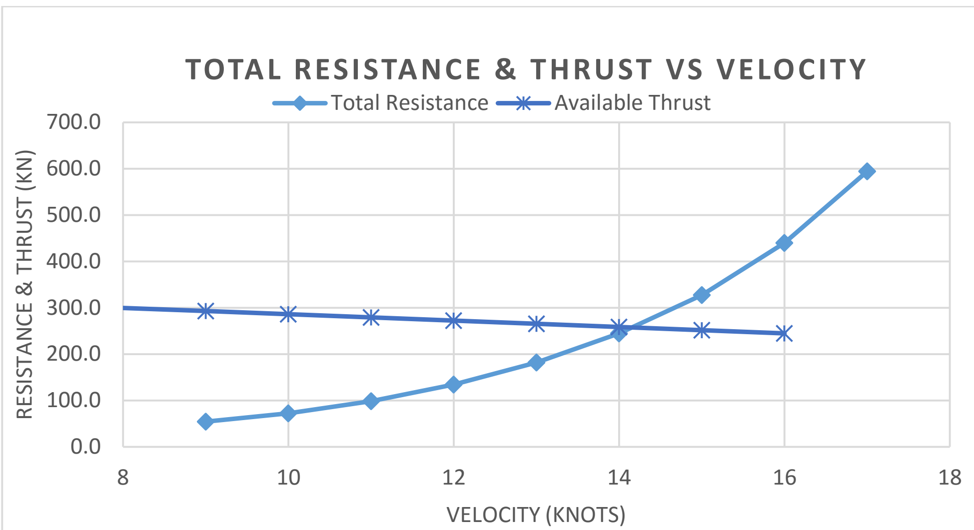


Figure 17 - Total Resistance and Thrust vs Velocity

The bollard pull of the vessel is 36 tonnes, which also meets the client's requirements. Please refer to the 10.0 BOLLARD PULL ANALYSIS section for more details.

9.4 EVALUATION OF PROPELLERS SUSCEPTIBILITY TO CAVITATION

The design team used Burrill Cavitation method to develop an iterative calculation tool that performs cavitation checks for any propeller selected. The following plot is also generated by our calculation tool and it clearly shows that the propellers remain under the cavitation limits for two critical cases. For the first case of vessel traveling at 14 knots, the back cavitation is under 2.5%. For the maximum bollard pull case, the cavitation is around 5%, which is under the upper limit for heavily loaded propeller.

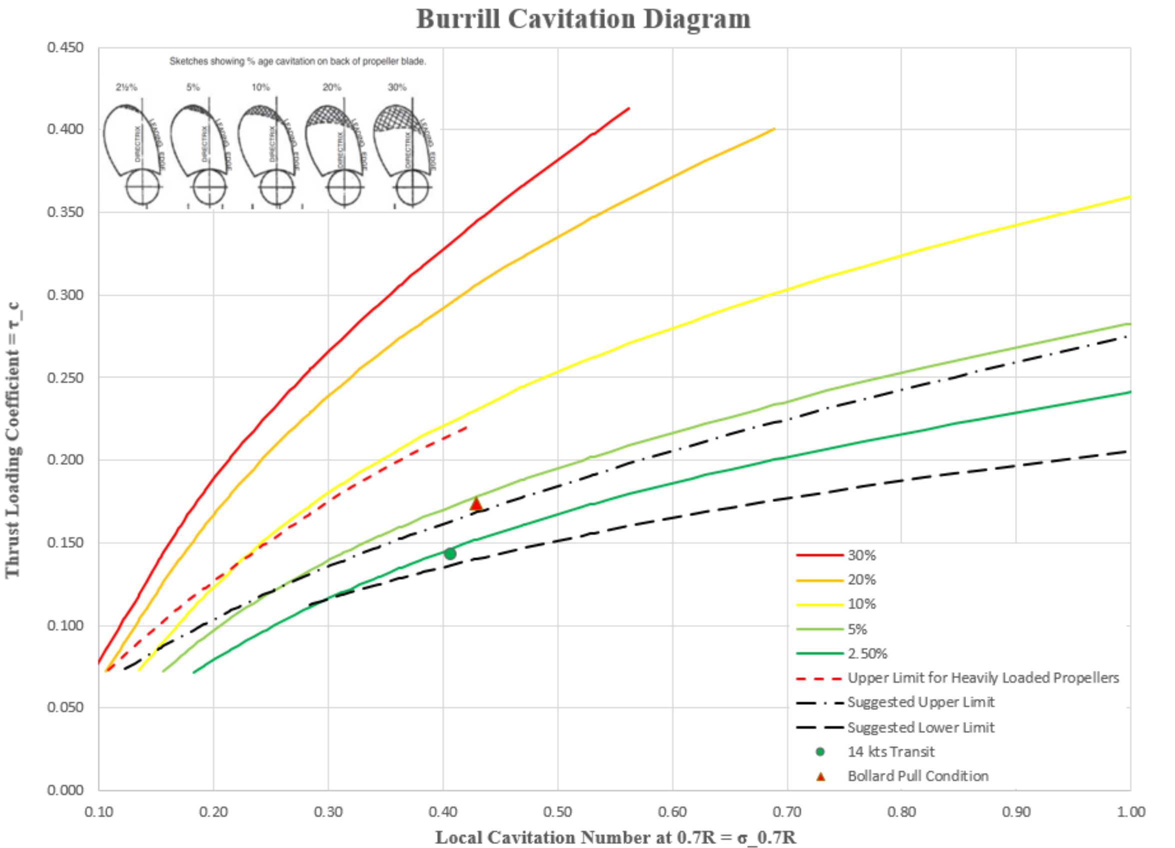


Figure 18 - Burrill Cavitation Diagram

10.0 BOLLARD PULL ANALYSIS

The following sections describe methods used to determine the bollard pull of our vessel and analyze if the vessel can meet the client's requirement in terms of towing. WMCRC wishes the design vessel to be able to tow 5500 DWT barge at a minimum speed of 4 knots.

The following two methods were used to estimate the towing capability of the vessel.

- Method 1: Empirical formula shown in the Appendix G of 'US Navy Towing Manual'
- Method 2: Empirical formula shown in the Appendix A of 'Standards and Guidelines for the Construction, Inspection and Operation of Barges that Carry Oil in Bulk' from Transport Canada

Once the bollard pull at different speeds was determined, it was compared with the thrust capability of the vessel. During a towing operation, it is not possible to maintain 100% power of the main engine for a long period as the engine experiences thermal problem. Therefore, it was considered at 90% only. As could be seen from the figure below, both methods produce similar trends, with a larger discrepancy at lower and higher speeds.

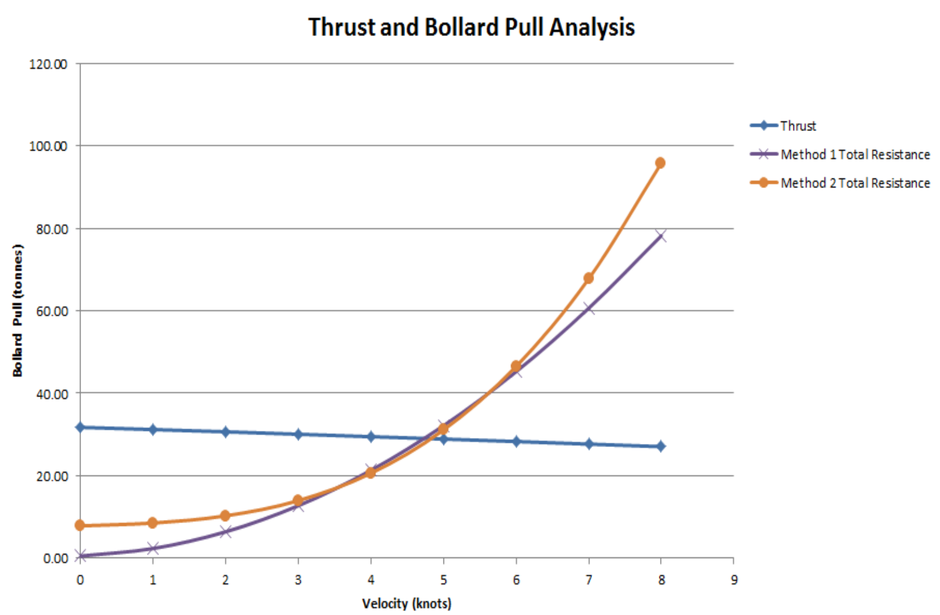


Figure 19 - Thrust and Bollard Pull Analysis

The thrust data from the propeller analysis was combined with the bollard pull analysis in order to find the maximum speed at which the barge could be towed. From the plot below, for both methods, the maximum speed of the design vessel will be approximately 4.7 knots when the design vessel is towing 5500 DWT barge, which satisfies client's requirements. For the details of calculation please refer to the *APPENDIX C – BOLLARD PULL ANALYSIS*.

11.0 VESSEL SYSTEMS & MACHINERY

To ensure that the vessel will be able to function effectively, as well as meet regulation requirements, certain machinery must be installed onboard for safe and consistent operation. This section outlines the machinery requirements according to regulatory bodies as well as client requirements for capacity. For detailed calculations of some of the systems please refer to *APPENDIX E – VESSEL SYSTEMS AND MACHINERY*.

Main engine and generator systems that were considered for design under SWBS include:

- 223 Main Propulsion Batteries
- 241 Propulsion Reduction Gears and Sha
- 243 Propulsion Shafting
- 256 Circulating and Cooling Sea Water System
- 259 Exhaust System
- 261 Fuel Oil Service & Transfer System
- 262 Main Propulsion Lube Oil System
- 324 Switchboards and Transformers

And for other ship systems:

- 511 HVAC Systems
- 520 Seawater Systems
- 521 Firemain and Flushing System
- 524 Auxiliary Sea Water Systems
- 528 Black and Grey Water system
- 529 Bilge and Ballast
- 531 Fresh Water
- 532 Cooling Water
- 545 Tank Heating
- 546 Auxiliary Lubrication Systems
- 551 Compressed Air Systems
- 593 Oily Water and Recovered Oil Systems

The following table summarizes the selected equipment that is outlined in MACHINERY ARRANGEMENT drawing.

Table 21 - Machinery Space Detailed Summary

Machinery	QTY	Make	Model	Required Capacity	Rated Capacity	Selection/ Machinery Arrangement Justification
Bilge/Ballast Pump	2	Azcue	VM-EF-80/16-R	38m3/hr at 6.7 m @1450RPM	38m3/hr at 6.7 m @1450RPM	ABS allows for bilge pump to be used for ballasting Centrifugal self-priming pumps located near sea chest
SCR Catalyst Unit	2	CAT	CEM ECF	-	-	Provided by CAT to meet EPA and IMO emissions
SCR Dosing Cabinet	2	CAT	CEM ECF	-	-	Provided by CAT to meet EPA and IMO emissions
SCR Air Compressor	1	McMaster	41905K1	10CFM @ 70-155PSI	18 CFM @ MIN 135 PSI	Required for SCR operation
Main Engine	2	CAT	3512D Rating	Prop Demand	1902 bkW @1800 RPM	Engines were placed as close as possible to the propeller

Machinery	QTY	Make	Model	Required Capacity	Rated Capacity	Selection/ Machinery Arrangement Justification
GenSet	3	CAT	C18	E-load Demand	550ekW	Placed close to the switchboard room to minimize cables
Starter Batteries	2			8 starts per engine		Stacked on top of each other to save space in engine room
Air Intake Fan	2					Following CAT Installation Guide
Cooling Pump	2					Placed close to the sea chests to decrease piping
Heat Exchangers	2					Placed close to the sea chests
Lube Oil Reservoir	1			Endurance Required		Sized based on gensets, mains, and gearboxes consumption; loose tank
Gearbox	2	ZF	7661	Gear Ratio 6	Gear Ratio 5.92	Gear Ratio was based on the req’d propeller RPM
Propeller Shaft	2					Followed ABS rules on shaft diameters
Fire Pump	2	Azcue	VM-50/20-EF	56m3/hr at 32.18 m at 2900RPM	56m3/hr at 32.18 m at 2900RPM	ABS and SOLAS rules on fire pumps. Centrifugal self-priming vertical pumps located near seachest
Hydraulic PTO Pump	2	HAWE	V30E-270		177kW	PTO to limit the required footprint of a standalone hydraulic power and pump unit
Discharge Pump	4	LAMOR	GTA 70			Locate within tanks to isolate system from other parts of vessel
RO Heater	1	PARAT	MEL-C 600		600kW	Locate close to RO tanks for less losses due to HT
Bow Thruster	1	Schottel	STT 1	500kW	500kW	Sized based on station keeping analysis
Bow Thruster Cooling Pump	1	Schottel				Comes with the bow thruster system
Steering Gear	2	Macgregor	RAM 500			Sized based on the max working torque at 35 degrees
Steering Gear Pumps	2	Macgregor				Part of the steering gear system
FW & FO Transfer Pumps	2					Specified to meet client’s requirements during vessel support operations

The following equipment was considered but not selected. SOLAS and MARPOL are recommended to be used for the sizing this equipment.

Oily Water Separator	Lube Oil Pump	Fuel Transfer Pump	Silencer
Urea Pump	Clean Water Pump	Grey Water Pump	Hot Water Tank
Sanitary Flushing Pump	UV Sterilizer	Sewage Treatment	Make up water Pump

Dispersant Pumps	Switchboards	Transformers	Hydraulic Power Units

The design team used reference vessels to size the equipment and the following compartments based on area/volume requirements developed: HVAC room, Hydraulic System Room, Switchboard room, Domestic Equipment and Workshop. Some of the design considerations are provided below.

Engine Starting Method
The design team selected to use batteries to start main engines and auxiliary generator in order to reduce the need to have compressed air stored below decks.

Emergency Generator Fuel Oil Tank
The tank was sized based on the generator's fuel consumption and SOLAS Deadship Condition requirement on 8 hour minimum operation.

Fire Suppression
FM200 fire suppression system was preferred over the CO2 due to not having any toxic gases and consequently doesn't need to be stored in locker on the exterior deck. To meet SOLAS regulations, the system had to place in the adjacent compartment separated by the bulkhead to the main engine space.

Exhaust Treatment
To meet EPA and IMO requirements, CAT has selected to treat the exhaust gases for NOx with an SCR method. The SCR system injects urea into the exhaust stream to reduce the NOx gases. This means that tanks, pumps, dosing module, and catalyst chambers had to be specified in the ship. Pumps were located close to the tank to reduce priming, and the dosing cabinet located in an easily accessible area. The auxiliary generator engines did not require after treatment since their power rating was below 600 kW. Both SCR unit and silencer were installed in the exhaust stack in order to provide more space for the HVAC ducting in main engine room.

Sea Water Pumps
All pumps that required seawater such as ballast, fire, or cooling pumps are located close to the sea chest in order to reduce the amount of priming required on the centrifugal pumps.

Shafting Arrangement
Due to a relatively long shaft, an oil distribution box that supplies hydraulic fluid to the CPP hub had to be placed closer to the propeller. To access the OD box a shaft tunnel through the tanks had to be designed for servicing of the equipment. The selected shaft had to be hollow so the hydraulic lines could be connected to the CPP hub.

Tank Heater
In order to heat the recovered oil to be discharged effectively, a steam injection system will heat the oil thoroughly. The other alternative would be a heated coil located near the bottom of the tank but that can only heat a small volume of oil at a time. The heater is sized based on the volume of recovered oil and the heating value of steam.

The following formula was used to determine the required energy input of the oil heater.

$$Q = \frac{Volume * 1\left(\frac{kg}{l}\right) * 3440\ \left(\frac{J}{kgK}\right) * 15\ C}{12 * 3600}$$

298kW will be need to heat 250 m^3, which is the maximum volume of recovered oil that could be carried on board. The oil heater could also be used to provide the hot water for domestic purpose and for HVAC.

Sea Chest
The sea chest size was determined based on the required shell area, which has to be three times the area of the shell grating holes. The total area of holes had to be twice the area of the sea valve[19], which was taken as 14" diameter from the reference vessel. [20]

[19] Marine Auxiliary Machinery by H.D. McGeorge (1995)

12.0 DECK EQUIPMENT

The following sections will provide an overview of the rationale behind sizing and selecting the deck equipment. The vendors have been contacted and a few calculations were conducted in order to size the towing winch, anchoring equipment and deck crane.

12.1 TOWING WINCH

The bollard pull value of the vessel was used to determine the required length and breaking load of the cable. The following formulas for the breaking load and the length of cable were obtained from the Guide for the Approvability of Towing Vessels by Noble Denton.

$$BL = 2BP\ ;\quad L_{Cable} = 1200(\frac{BP}{BL})$$

With these quantities calculated the wire rope chart was used to obtain the appropriate size of cable for the application. The calculation yielded an appropriate wire rope length of 1 7/8" at a design factor of 3.5:1. This information as well as a recommended cable length of 600m[21] was specified to Markey Machinery for specification of a winch.

The following equation was used to calculate the cable power, and after taking into account mechanical and motor efficiencies as well as line losses, the required hydraulic power for the winch was calculated.

$$Cable\ HP = \frac{Rated\ Line\ Pull * Line\ Speed}{33000}$$

Table 22-Winch Hydraulic Rated Power

	Symbol	**value**	**unit**
Rated Line Pull	F	88185	lbs
Line speed	V	33	ft/min
Winch Mechanical Efficiency	n_w	0.85	-
Hydraulic Motor Efficiency	n_h	0.9	-
Pump Efficiency & Line Losses	N_p	0.75	-
Cable Power	P_c	88	HP
Winch Input Power	P_w	103	HP
Power at motor ports	P_m	115	HP
Pump Input Power	P_p	**153**	HP

12.2 DECK CRANE

The deck crane with a telescoping boom and appropriate safe working load was selected in order to meet all of the client's requirements. The crane is capable of lifting 25 tons at a hoisting speed of 30 m/min. With this information the following equation was used to calculate the rated power.

$$W_t = \frac{60\,000 H}{\pi d n}$$

W_t = transmitted load, kN
H = power, kW
d = gear diameter, mm
n = speed, rev/min

[20] Gathered from Marine Technology Vol. 32 (July, 1995) – MSRC Responders: Construction and Operation of Sixteen Oil Spill Response Vessels
[21] LAMB, T. (2003) Ship Design and Construction (Volumes 2) – Chapter 49 – Tugs

A motor efficiency of 90% and line efficiency of 75% was applied to the calculation. The rated power of the crane was found to be 181kN.

12.3 EQUIPMENT NUMBER

The equipment number was calculated to be **450** using the following formula taken from ABS rules:

$$EN = k\Delta^{2/3} + mBh + nA$$

k=1; m=0.2; n=0.1; B=molded breadth (m); a=freeboard (m)

Δ= molded displacement, in metric tons to the summer load water line

h= sum of all heights to deckhouses having a breadth greater than B/4 (m)

12.4 ANCHHORING EQUIPMENT

The calculated equipment number was used to size the bower anchors, chain cables and windlass. The chain locker was also sized, assuming the chain will be stored in a conical shape inside of the locker.

12.5 DECK EQUIPMENT SUMMARY

The following table provides a summary of all of the deck equipment selected. For the weight and power demand information please refer to the *APPENDIX H – LIGHTSHIP WEIGHT ESTIMATE* and *APPENDIX B – POWERING AND PROPULSION*, respectively.

Table 23 - Deck Equipment Summary

Deck Equipment	QTY	Selected Equipment	Brief Specifications/ Selection Justification
Deck Crane	1	Palfinger DKT220-25T	Telescoping boom for a longer reach, SWL: 25t at 2.4-6m; 5t at 6 - 15m, max sea-state 4
Rescue Boat	1	Harding RRB-425	4.2m length, 6 person, 6 kts, SOLAS Certified
Rescue Boat Davit	1	Harding NPDS 1300H	Single Point Davit, 1.3t SWL, SOLAS Certified
Workboat	1	Palfinger FRSQ 670 A	6.8m length, oil boom towing capability
Towing Winch	1	Markey TYS 32	Hydraulic, Single drum, 40,000 lbs line pull at 40ft/min. built-in staple
Windlass	1	Markey WES-23	Sized for selected anchors & vendor recommendation
Hydraulic Towing Pins	2	Smith Berger 12T2X12	Retractable, sized using specified wire diameter
Bower Anchors	2	-	Sized using calculated Equipment Number
Chain Cables	413m	-	Sized using calculated Equipment Number, Mild Steel

13.0 POLLUTION RESPONSE EQUIPMENT

Prior to selecting the equipment, the design team had to spend some time understanding the operational requirements during the oil spill response. The following sections will outline the analysis performed and considerations taken to select an appropriate equipment.

13.1 OIL CONTAINMENT

The first step after arriving to the spill site is to deploy floating mechanical barrier, known as boom, in order to enclose the oil and prevent it from spreading. Since the concept vessel will be mainly involved in the offshore oil recovery operations, the following high strength booms capable of containing oil in up to sea state 4 were selected:

Figure 20 - Aquaguard Airflex 107 Boom

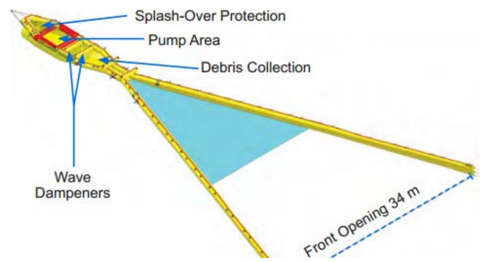


Figure 21 - NOFI Current Buster 6 Boom

13.2 OIL RECOVERY

Skimmers are typically used for separating and recovering oil from the water. The following two offshore skimmer systems were selected to be installed and used on the concept vessel. URO 300 system contains a crane system that is capable of launching and recovering the skimmer on and from the water. Due a relatively small size, Weir skimmer is placed inside of the NOFI Current Buster Boom and could be launched without need of a crane.

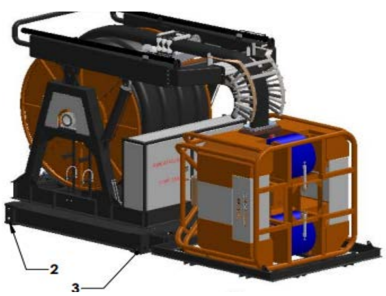


Figure 22 - URO 300 Offshore Skimmer

Figure 23 - Weir Skimmer inside of the NOFI Current Buster Boom

13.3 OIL STORAGE

Aside from storing the recovered oil inside of the vessel tanks, it could be also stored in the mini barge or inflatable floating tank. WCMRC has explicitely expressed that they are only interested in using a mini barge shown in a figure below.

Figure 24 - Oil Storage Mini Barge

Figure 25 - Inflatable Floating Storage Tank

13.4 RESPONSE PLANS

The following is a summary of the procedure in handling a moderate sized spill. Note that intricate details of the operation is left out for convenience; operations are instead described via broad terms to emphasize the work phases involved.

1. Arrival at spill location
2. Deploy workboat via crane
3. Deploy containment boom aft of vessel via workboat tow
4. Boom is deployed until spill is adequately contained
5. URO 300 Skimmer deployed into water for oil recovery
6. Oily water transfers from skimmer head into recovered oil tanks aboard vessel
7. Skimming operation continues until area is cleaned or vessel reaches capacity
8. Skimmer head retrieved onboard and cleaned for future use
9. Boom is wound back onto reels, workboat collected onboard via crane

In the case of larger oil spills, the onboard mini barge may be deployed or a separate storage barge will be towed to the spill to provide extra oily water storage. After the operations are completed or the mini barge or storage barge is filled sufficiently, the vessel will tow it back to the base for offloading.

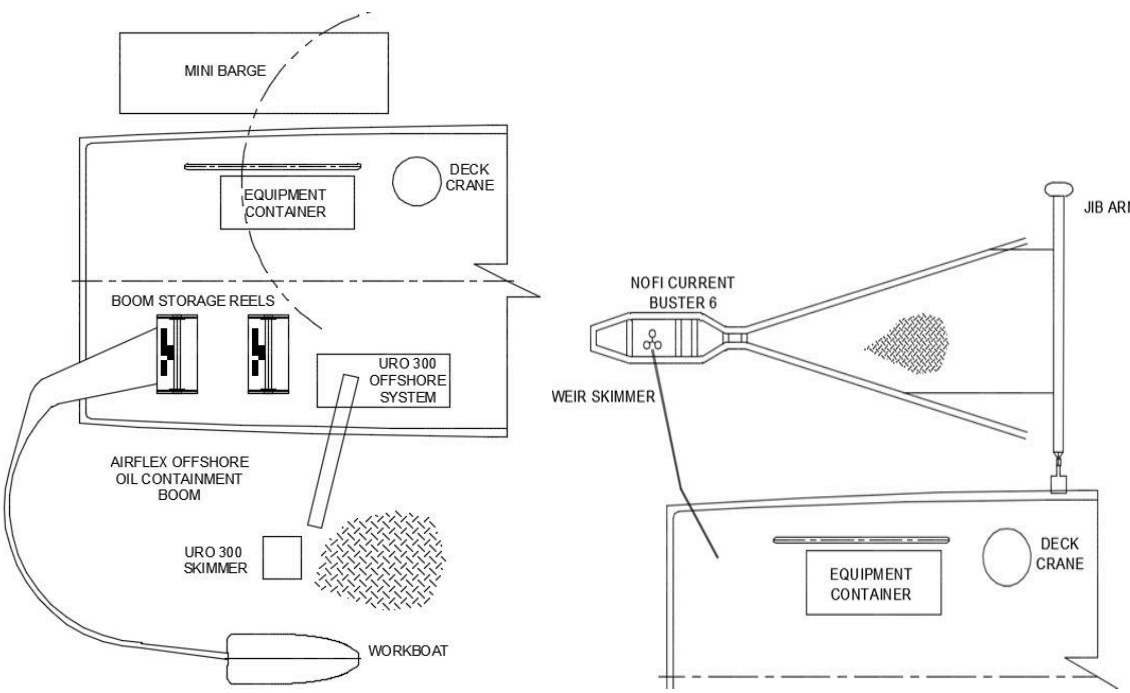


Figure 26 - Offshore Spill Response Plans

13.5 EQUIPMENT SUMMARY

The following table provides a summary of all of the mission equipment selected. For the weight and power demand information please refer to the APPENDIX H – LIGHTSHIP WEIGHT ESTIMATE and APPENDIX B – POWERING AND PROPULSION ANALYSIS.

Equipment	QTY	Selected Equipment	Brief Specifications/ Selection Justification
Oil Offshore Skimmer	1	Aquaguard URO 300	300 m3/h recovery rate
Oil Curtain Boom	700m	Aquaguard Airflex 107	High Strength boom, 3kts max towing speed, enough to surround largest bulk carrier in BC, requires portable blower to inflate the boom
Oil Buster Boom System	1	NOFI Current Buster 6 & Weir Skimmer	Oil recovery in max sea state 4, contains multiple filtering systems to remove debris & garbage
Oil Boom Reels	2	Aquaguard Sea Reel 350	Hydraulic, removable from main deck, deployment speed of 10 rpm
Oil Telescoping Boom System	1	Lamor LORS	7m reach, used for C-shape oil recovery and in smaller inshore recovery operations
Oil Recovery Mini Barge	1	40' Rozema Barge	40 m^3 capacity as per clients requirement, has lifting lugs for crane launch, 4.5 kts max tow speed

13.6 OFFSHORE SKIMMER RATED POWER

The following formula and efficiencies were used to calculate the rated power of the URO 300 offshore skimmer based on the pressure and mass flow rate of recovered oil.

$$HP = \frac{GPM \times PSI}{1713 \times \text{Efficiency of Pump}}$$

Table 24 Offshore Skimmer Rated Power

URO 300 Z1-10	Value	Unit
Pressure	3000	psi
Flow in	331	L/min
GPM	87	gal/min
HP	153	HP
HPU	115	kW
Motor Efficiency	0.90	-
Line Efficiency	0.75	-
Estimated HPU	**170**	kW

14.0 ELECTRICAL LOAD ANALYSIS

The following sections will outline electrical load analysis conducted in order to determine the total electrical power that our generators have to supply to operate the ship at each operating condition.

The electrical load analysis was generated using NAVSEA DDS 310-1 and Statistical Analysis for Shipboard Electrical Power Plant Design by James M. Wolfe. The design team used information provided to us from vendors to determine power requirement for the equipment and systems on board of the vessel. When information was not available, the power was estimate using the exist OSV vessel data provided to the team by the industry professionals. The utilization and demand factors were determined based on the required equipment and service needs for each of the missions presented. Both summer day and winter conditions were considered in the analysis; however, the resulting electrical load for both was found to be very similar so only the summer day is displayed on the graph below. For more details refer to *APPENDIX F - ELECTRICAL LOAD ANALYSIS*.

During the analysis, the design team evaluated and found that it would be beneficial to install two power take off (PTO) pumps on the gearbox in order to provide power to the hydraulic powered equipment. This arrangement provides an additional power margin in case additional equipment is installed on board and a couple of operations are conducted at the same time. The following equipment was selected in order to satisfy the electrical load requirement for different operations.

- 3 Main Generator: 550kW C18 ACERT, Prime Rating – EM0128-00
- 1 Emergency Generator: 184kW C9 Generator Set
- 2 x PTO Pump: 177kW HAWE V30E-270

The third main generator and emergency generator had to be provided in order to meet SOLAS requirements. The figure below summarizes the total electrical and hydraulic loads and compares them to the total power installed on board.

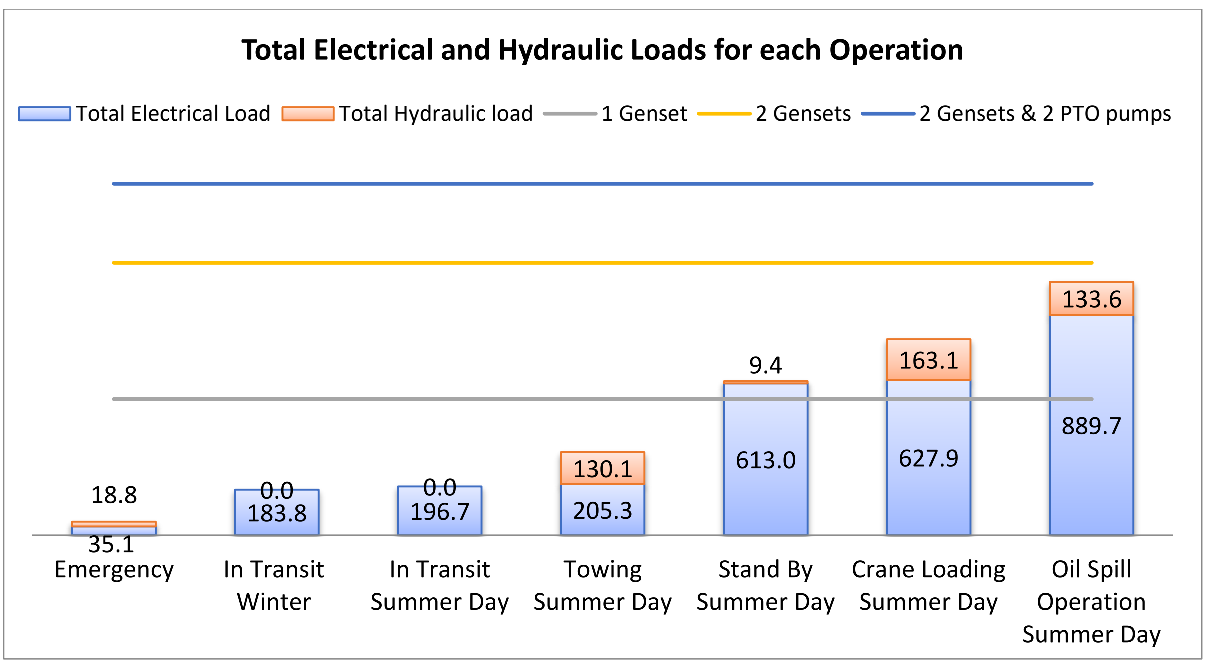


Figure 27 - Total Electrical and Hydraulic Loads for each Operation

15.0 ENDURANCE AND TANK CAPACITIES

To estimate the required tank capacities the design team used owner's requirements, applicable regulatory rules, reference literature and similar vessel data. The following sections outline the analysis performed.

15.1 FUEL OIL

The required fuel oil capacity was determined by analyzing every mission and determining corresponding engine and generator loading and consumption. At the initial stage the design team used fuel consumption rates of a representative engine and generator in the power range required and the loading for every operational condition was estimated. The required fuel oil capacity was taken for the mission with the highest fuel oil demand for the required endurance period of 21 days. After conducting a more detailed power and electrical load analysis the design team obtained a more accurate values for the required capacity. It was found that Oil Recovery & Towing operation will have the highest fuel consumption and the fuel oil tank will have to be sized accordingly to satisfy this mission. For a detailed calculation refer to *APPENDIX D – FUEL CONSUMPTION CALCULATION*.

Table 25 - Required Fuel Oil Capacity Analysis

	Total Fuel Consumption for each Mission (m3)		
Analysis Performed	**Oil Recovery**	**Oil Recovery & Towing**	**Resupply**
Initial Fuel Consumption Estimate with 10% Margin(m3)	264	322	131
Detailed Consumption Analysis with 10 % Margin (m3)	284	**332**	122

15.2 RECOVERED OIL

The recovered oil was considered to be cargo in our case, and the required volume of recovered oil was defined by WCMRC. The density of the recovered oil was taken as 0.92 kg/m^3 (75% oil and 25% sea water).

15.3 BALLAST WATER

Guidelines from Practical Ship Design by D.G.M Watson[22] were used to calculate the capacity of ballast water tanks. The book suggests to use at least 2/3 of the capacity of consumable fluid tanks. The design team went with 70% of consumables as an initial estimate.

15.4 FRESH WATER

The fresh water capacity was determined based on information obtained from reference literature. [23] The fresh water usage in cargo vessels was specified to range from 70 – 250 L/person/day. The design team went with a greater value since during the oil recovery operations a lot of fresh water will be need for the crew to clean up.

15.5 GREY AND BLACK WATER

The reference vessel tank volume data was used to estimate the ratio of grey and black water to fresh water volumes. The grey water volume was taken as 65-70% of FW and black water was taken as 25-30% of FW.

15.6 UREA

The urea tanks were sized as per CAT engine requirement of 8-10% of the total amount of the fuel onboard.

15.7 DISPERSANT

The capacity was determined as per owner's requirement. The density of the dispersant is found to be in a range of 0.95 to 1.02 g/cm^3 assuming a typical dispersant is used.

[22] Practical Ship Design by D.G.M Watson (1998)
[23] Marine Auxiliary Machinery by H.D. McGeorge (1995)

15.8 OILY WATER

The oily water volume was determined using MARPOL 73/78 Revised Guidelines for Systems for Handling Oily Wastes in Machinery Spaces of Ships.

15.9 SLUDGE TANK

The volume was determined using MARPOL 73/78 Regulation 15.1.

15.10 HYDRAULIC OIL

The volume was estimate using the reference vessel data.

15.11 LUBE OIL

The required volume of lube oil was calculated based on the main engine and gen-set lube oil consumption of 0.5-1 g/(kW-hr).

15.12 SUMMARY

The following table provides a summary of the required tank volumes that were used in initial sizing stage of the vessel and while developing tank arrangement.

Table 26 - Required Tank Volumes

Liquid	Total Required Volume (m3)
Fuel Oil	332
Recovered Oil	250
Ballast Water	330
Fresh Water	84
Black Water	22
Grey Water	58
Urea	30
Dispersant	20
Oily Water	5
Hydraulic Oil	3
Lube Oil	1
Sludge	1

16.0 TANK ARRANGEMENT

The following sections outline the justification and process of the design vessel's tank arrangement.

After developing a 2D arrangement, the tanks were defined in Maxsurf software to perform the stability analysis. These tanks were created by manually defining the longitudinal, transverse and vertical coordinates of tank corners. Tank permeability and density of liquids inside the tanks were included as well. Sea chests and bow thruster tunnel were defined as non-buoyant volumes.

During the stability analysis the tank arrangement has gone through quite a few iterations, and in the end the design team was able to find an optimal tank arrangement that meets endurance requirements and related regulations.

16.1 FLOODABLE LENGTH CURVE

At the original stage of the design the floodable length curve shown below was developed which helped us to place the watertight bulkheads and some of the tanks. However, after having discussion with WCRMC and the industry, the likelihood of the bottom damage occurring for this vessel in BC waters is very small, hence the design had only to meet ABS OSV rules, which only considers the side damage.

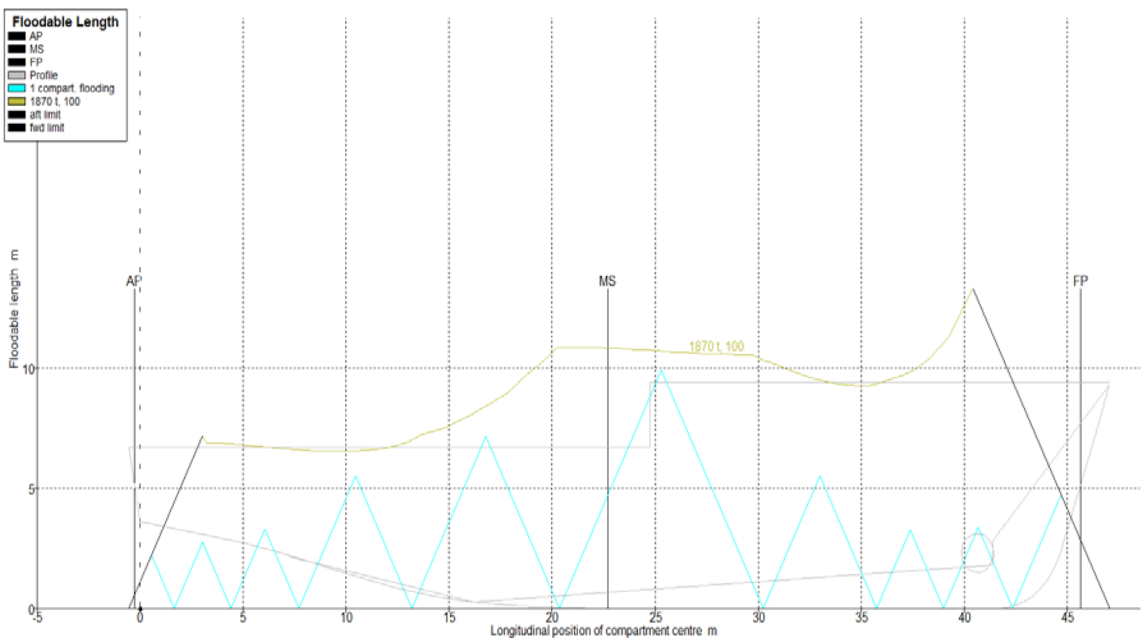


Figure 28 - Floodable Length Curve

16.2 TANK SIZE AND ARRANGEMENT OPTIMIZATION

The following considerations have been made when sizing and arranging the tanks:

1. *Fuel Oil And Recovered Oil Tanks Placed Inside Of Hull*

As a pollution control vessel, it is ideal to minimize the risk of the vessel itself releasing pollutants into the environment. Therefore, fuel oil and recovered oil tanks are placed inside the hull so as to be protected by wing and double bottom tanks in the event of a collision.

2. *Number Of Tanks In Vessel Minimized*

The number of tanks were minimized to decrease the amount of piping and pumps required, and to decrease the overall time of inspections.

3. *Optimize Size Of Tanks*

By minimizing the number of tanks, the tank size increases leading to a larger free surface effect and a negative effect on vessel stability. Throughout the intact and damage stability analysis the team was able to determine the optimal size of the tanks while meeting all of the stability criteria.

4. *Stability Requirements*

The size of the wing tanks and double bottom tanks was dictated by the damage stability requirements. To minimize the number of damaged tanks in every damage case, the length of the wing tanks was designed to be greater than the longitudinal damage extents defined in ABS OSV Rules, resulting in only 2 wing tanks damaged per case.

5. *Bottom Damage Stability*

The design team decided to fit double bottom tanks where practicable so as that a detailed evaluation of bottom damage stability can be avoided. As per SOLAS Chapter II-1 – Regulation 9 – Double Bottoms in Cargo Ships, the double bottom tanks should be continued out to the ships sides in such a manner as to protect the bottom to the turn of bilge. Such protection will be deemed satisfactory if the inner bottom is not lower at any part than a plane parallel with the keel line and which is located not less than 760mm measure up from the keel line, and need not to be taken as more than 2,000mm.

6. *Symmetry About Centerline*

The tank arrangement had to be symmetric about the centerline of the vessel in order to achieve zero heel.

7. *Consumable Tank Location*

In an ideal case, all tanks with consumables would be located near the longitudinal centre of buoyancy. However, due to required size of the engine room and arrangement of the stairs, the design team was unable to achieve that with this design.

8. *Recovered Oil Tank Location*

Recovered Oil tanks were located separated by the fuel tanks, which are considered to be cofferdams, from other machinery compartments, in order to meet ABS requirements for vessels with oil spill response capabilities.

9. *Fresh, Black And Grey Water Tank Location*

Fresh, Black and Grey Water were located as close to crew spaces as possible to minimize the length of piping required. Grey and black water tanks were placed in double bottom in order to lower the centre of gravity of the vessel. The fresh water tank height was reduced and instead made longer in order to decrease the centre of gravity of the vessel.

10. *Fresh Water Tank Separation*

In order to prevent any contamination from adjacent tanks, the fresh water tanks were separated by a cofferdam from the black and grey water tanks.

11. *Sea Chest Locations*

Sea chests were located port and starboard as low as possible so as to collect the coolest temperature of sea water.

12. *Tank Space Inspection and Construction*

All tanks must have enough space for a person to perform an inspection. Where practicable, the design team sized and located the tanks so that there are two manholes located either on the main deck or inside the machinery/technical spaces. Where possible, all of the tanks and structure supporting it should be easily constructed and welded.

16.3 TANK ARRANGEMENT

In addition to the *002 - TANK ARRANGEMENT* drawing, please also refer to the following 3D model.

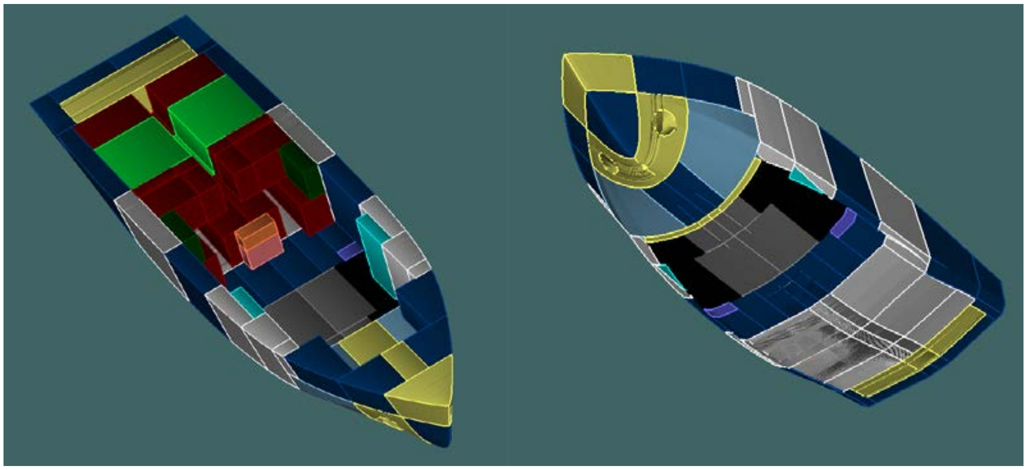


Figure 29 - Tank Arrangement - Top View (Left), Bottom View (Right)

LEGEND							
	Fuel Oil		Dispersant		Grey Water		Hydraulic Oil
	Recovered Oil		Fresh Water		Black Water		Oily Water
	Ballast Water		Compartment		Urea		Sea Chest

16.4 CAPACTIY SUMMARY

From the developed 3D model, a capacity of every tank could be measured, and the tanks were designed to meet all of the endurance requirements, as shown in the table below.

Table 27 - Tank Capacity Volumes

Liquid	Total Required Volume (m3)	Total Design Capacity (m3)
Fuel Oil	332	340
Recovered Oil	250	250
Ballast Water	330	360
Fresh Water	84	90
Black Water	22	24
Grey Water	58	60
Urea	30	30
Dispersant	20	20
Oily Water	5	5
Hydraulic Oil	3	3
Lube Oil	1	1.5
Sludge	1	1.5

Due to a small volume, Lube Oil and Sludge are contained in loose tanks, placed in the engine room, tank top level.

17.0 GENERAL ARRANGEMENT

The following sections provide a brief overview of the reasoning behind the arrangement of all of the compartments and equipment. The applicable rules governing the layout of spaces will be discussed as well. Please refer to the *003 - GENERAL ARRANGEMENT* and *004 - INBOARD PROFILE* drawings for complete layout details. *APPENDIX L – AREA/VOLUME SUMMARY* contains details about major compartments, rationale behind their location and regulations met.

17.1 PASSAGEWAYS, VERTICAL ACCESS AND ENTRIES

The main features and considerations regarding entries and passageways on the vessel are presented below.

- All of the passageways are at least 1.0 m in width with some accommodation passageways having a width of 1.2m to improve the traffic flow.
- Shaft passageway had to be designed in order to provide access to the oil distribution box supporting CPP hub.
- Passage way from the main engine room to the steering gear compartment has to be on the centerline, in order to have symmetric tanks.
- All stairs have 45 degree angle to provide more comfortable environment for the crew and have at least 0.9m in clear width as per *SOLAS* regulations. The stairs are arranged to have 1.9m head clearance.
- To meet *Transport Canada* regulations for towing vessels, all of the watertight doors under main deck have to be sliding doors.
- In order to improve the traffic flow, the entries into compartments throughout the ship are aligned with the passageways.
- Interior doors avoid opening into passageways so they are remained clear
- Exterior doors open in an orientation that prevents the ingress of water due to breaking seas or spray over the deck

17.2 EMERGENCY ESCAPES

Emergency escapes are provided from the main engine space, steering gear and bow thruster compartments, as well as mess/lounge space, in order to meet *SOLAS Regulations*. Further, the emergency escape from the main engine space had to be surrounded by the steel trunk as per *ABS Rules.*

17.3 BRIDGE DECK

After touring existing vessels in WCMRC and having a further discussion with the client, the wheelhouse was required to have a great visibility and control panels had to be arranged on both forward and aft sides. Bridge deck wings were added in order to improve the visibility during the pollution control and offloading operations. The exhaust air pipes were arranged in the way to provide maximum visibility for the crew, by lining it up with the structure of the wheelhouse. The floor area of the bridge deck was sized using general arrangements of the reference vessels. The life raft were placed on both port and starboard sides of the bridge deck to meet *SOLAS*.

17.4 FORECASTLE DECK

In order to keep crew accommodations clean and away from the noise during the oil recovery operation, they were placed on the forecastle deck. The accommodation spaces were designed to meet *Maritime Labor Convention 2006* and *Transport Canada Towboat Crew Accommodations.* Some of the requirements are as follows:

- Maximum number of crew members is 2 per room
- Minimum room space is $5m^2$
- Minimum permitted headroom in accommodation spaces is 2.03m
- For each person a room has a closet, desk, and seating
- The maximum number of people that can share a bathroom or shower is 6
- Main accommodation spaces must be above the main deck
- Every space need to have a port light (source of daylight)

- The chief engineer and the captain are required to have their own accommodation spaces.

Bunks were orientation in the longitudinal direction to decrease crew discomfort in roll. Although the water closets are not required in every room they add to the convenience and ease of use of the space.

The HVAC room was designed for the main ventilation system and was sized based on reference vessels. The room was arranged in order to accommodate the air intake and exhaust ducting. When developing a general arrangement, the design team took into account 50mm joiner liners, 150mm bulkhead insulation and 250mm insulation and stiffening again the shell

17.5 MAIN DECK

The following points outline the major equipment on the main deck and rationale behind its location. At least 0.9m of passageway clearance was provided between every piece of the equipment on the main deck

Deck Crane

- Located on the port side of the vessel to provide more visibility for the operators in the bridge
- Has a telescoping boom to reach all area on the deck
- Enough clearance is provided around the crane for the attached ladder and platform

Towing Winch

- Situated on the centerline of the vessel near the midship for a better weight balance
- If the winch was off the centerline it would introduce additional undesirable heeling moment on the vessel during the operation
- Retractable towing pins were selected to the save space on the main deck
- Stern roller to be installed in order to aid towing operation

20’ ISO Containers

- Securely stowed to the 2.0m in height cargo rail on the port side
- Clearance is maintained between the containers and crane boom support as well as mooring bits

URO 300 Offshore Skimmer System

- Counter balances the crane, so the transverse centre of gravity is closer to the vessel centerline
- Oily water sump was placed beside the system in order to clean up the skimmer after recovering oil
- Recovered oil manifolds were placed beside the system to decrease required length of hoses

Boom Reels

- Oriented facing the stern of the vessel for ease of deployment and towing during operation
- Enough boom is provided to contain a largest bulk carrier operating in BC waters

Emergency Generator Room

The space houses the emergency generator, with a diesel oil tank sized to meet SOLAS requirement along with the emergency switchboard and ship’s battery system. T

Casing

The casing was arranged symmetrically about the centerline and extends up throughout the ship. It houses the exhaust after treatment system, an SCR unit, and silencer.

Decontamination Area and Entry Lobby

The entry lobby and decontamination area are the main entry point from the exterior of the vessel to the interior cabin spaces. The client emphasized a strong desire to shield interior spaces from potential exterior contaminates, and provide crew with space to change and clean up prior to entering the accommodation spaces. Crew can also enter interior spaces through office/conference room from main deck.

Galley and Mess Lounge
The mess/lounge was designed to have 1.5 m^2 floor area per person, as per *MLC 2006*.'

Supernumerary Accommodations
The supernumerary accommodation are deigned to the *MLC 2006* as well.

17.6 MEZZANINE AND TANK TOP

The engine room is split into two levels in order to effectively connect all of the technical spaces and to store all of the required equipment inside of the hull. For more details about the equipment stored refer to *007 – MACHINERY ARRANGEMENT* drawing and *11.0 VESSEL SYSTEM & MACHINERY* section of the report.

18.0 STRUCTURAL DESIGN

The following section summarizes the structural analysis performed that was used to develop the midship section and structural arrangement of the main deck of the vessel. Please refer to the end of the report for the *005 - MIDSHIP STRUCTURE* and *006 - MAIN DECK STRUCTURAL ARRANGEMENT* drawings. The structure was designed to meet the *ABS Rules for Building and Classing - Steel Vessels under 90 Metres in Length – 2015.*

The design team's strategy was to first evaluate what type of framing should be used. After developing an initial main deck and tank top structural arrangements, the design team found that transverse method of framing would be best suited for our vessel. Further, being a relatively short vessel, the bending moments are not that significant for vessel to be longitudinally framed. Then the structural rules and formulas defined by ABS were used to size all of the structural components. Using these components and their locations with, a section modulus of the midship section was calculated and compared to the required section modulus defined by rules. A detailed summary of the structural calculations is presented in the *APPENDIX G - STRUCTURAL ANALYSIS.*

Below is a structural summary for the mid ship section. Note that the main deck plating (aft) and the pillar are not part of the mid ship section in actuality, but are included in the table below for ease of reference.

Table 28 - Midship Structure Summary

Mid Ship Summary					**Frame #: 43**	
			Req t/SM	w/ Margin	Selected	
ABS #	Category	Item	mm/cm^3	mm/cm^3	mm/cm^3	Section
3-2-10/1.3	Shell Plating	Keel Plate	8.10	8.51	12	PL
3-2-2/3.3		Bottom Plating	8.10	8.51	10	PL
3-2-2/5.1		Side Plating	7.81	8.20	8	PL
-		Stiffeners	-	-	180x8	BF
3-2-2/5.1		Forecastle Side Plating	6.14	6.45	8	PL
-		Bilge Plating	-	-	10	PL
3-2-14/1.3		Bulwark Plating	-	-	6	PL
3-2-3/3.1.2	Deck Plating	Main Deck (Superstructure)	5.48	5.75	8	PL
3-2-3/3.1.1		Main Deck (Aft)	5.79	6.08	10	PL
3-2-4/1.3.1	Double Bottom	Center Girder, thickness	7.97	8.37	10	PL
3-2-4/1.3.3		Center Girder, depth	872.85	916.50	10	PL
3-2-4/1.5		Side Girder, thickness	6.29	6.60	8	PL
3-2-4/1.7		Floor, thickness	6.29	6.60	8	PL
-		Floor, Stiffeners	-	-	100x8	FB
3-2-4/1.13		Inner-Bottom Plating, thickness	8.08	8.48	12	PL
3-2-7/5.1	Side Frames	Side Bulkheads	4.60	4.83	10	PL
3-2-7/5.3		Side Bulkhead Stiffeners	-	-	180x8	BF
3-2-5/11.3		Side Stringer	7.82	8.21	10	PL
3-2-6/3.3	Deck Structure	Main Deck CL Girder			500x14	Web
3-2-6/3.3			235.39	247.16	200x16	Flange
3-2-6/1.5		Deck Girders			500x14	Web
-			235.39	247.16	200x16	Flange
3-2-6/5.3		Pillar	-	-	219 OD Sched 80 Pipe	
3-2-7/5.1	Watertight Bulkheads	Plating	4.60	4.83	8	PL
3-2-7/5.3		Stiffeners	38.74	40.68	180x8	BF
3-2-8/5.1	Deep Tank	Plating	6.50	6.83	10	PL
3-2-8/5.3		Stiffeners	83.86	88.06	180x8	BF

18.1 INPUT PARAMETERS

The following vessel particulars are examples of input parameters applied to the ABS sizing formulas:

Table 29-Vessel Particular Inputs

Vessel Particulars			
Summer Load WL Length	D_{LWL}	45.9	m
96% DLWL	-	44.1	m
Rule Length	k	44.1	m
Moulded Breadth	B	14	m
Moulded Depth	D	6.7	m
Scantling Depth	D_s	6.7	m
Moulded SWL Draft	T	5.0	m
Scantling Draft	d	5.0	m
Block Coefficient	C_B	0.59	
Frame Spacing	s	550	mm

18.2 CALCULATED MINIMUM SECTION MODULUS

As defined in ABS 3-2-1/3.1, regarding the longitudinal hull girder strength, the minimum section modulus, at amidships, is determined as shown below, where C_1 and C_2 are constants defined by the regulation.

$$SM_{req} = C_1 C_2 L^2 B (C_b + 0.7) = 0.\mathbf{22}\ \boldsymbol{m^3}$$

18.3 CALCULATED MINIMUM HULL GIRDER MOMENT OF INERTIA

As defined in ABS 3-2-1/3.5, regarding the longitudinal hull girder strength, the minimum hull girder moment of inertia, at amidships, is determined as follows, where L is the length of the vessel and SM is the minimum required section modulus as defined above. Based on this regulation, the minimum hull girder moment of inertia is calculated to be:

$$I_{req} = \frac{L(SM)}{33.3} = 0.\mathbf{3}\ \boldsymbol{m^3}$$

18.4 STILL WATER BENDING MOMENT CALCULATION

Further, to check calculations, the design team also used Maxsurf software to calculate the bending moment and shear force on the vessel by analysing the net load from the buoyancy and weight distribution of the model for the heaviest loading condition - 98% consumables, 98% recovered oil, and 100% mission equipment. The output of the analysis is displayed in the plot below.

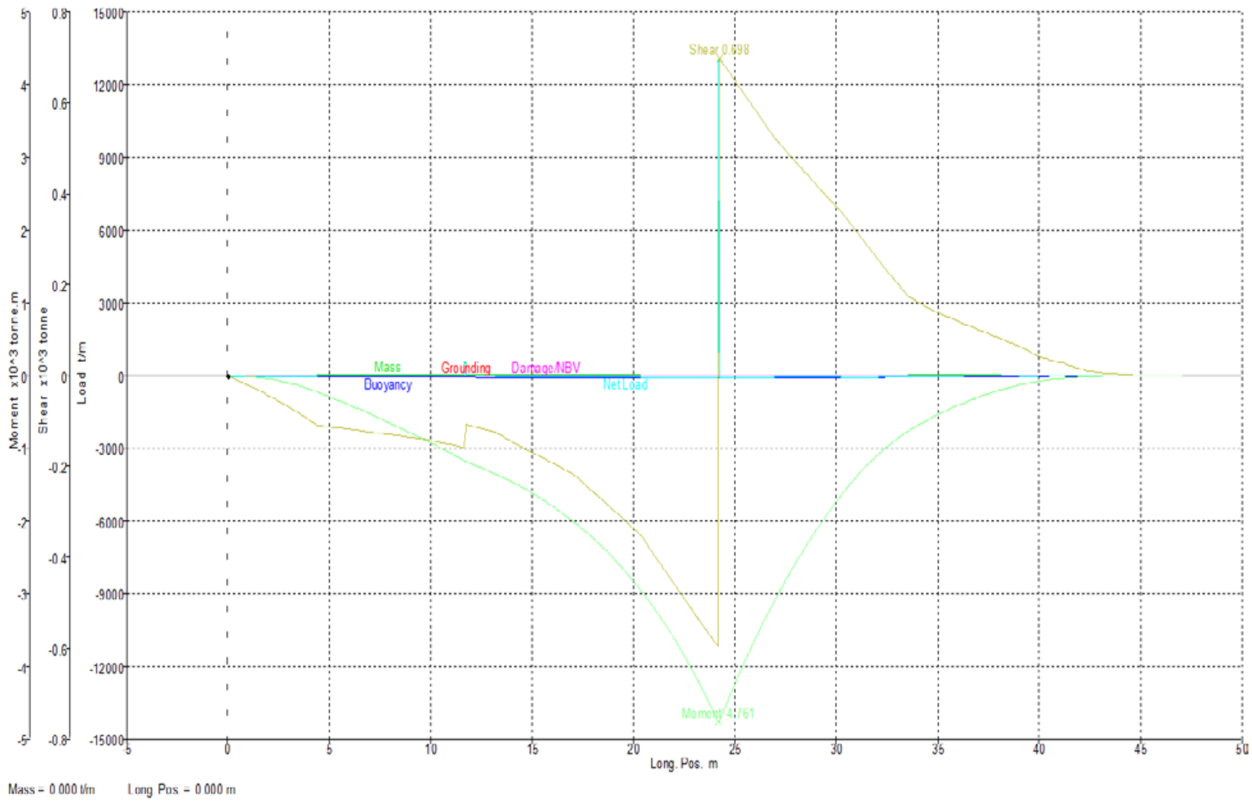


Figure 30 - Bending Moment and Shear Force at the Heaviest Loading Condition

The section modulus was estimated using simple beam bending equations:

$$\sigma = \frac{My}{I} = \frac{M}{S}$$

$$M = 4750\ tonne\ \cdot m = 46{,}597{,}500\ N \cdot m$$

$$S_{req} = \frac{M}{\sigma_{yield}} = \frac{46{,}597{,}500\ N \cdot m}{235{,}000{,}000\ N/m^2} = 0.20\ m^3$$

The following table summarizes the calculated minimum required section modulus from ABS rules and Maxsurf analysis, and compares them to the designed section modulus of the midship section.

Table 30 - Maxsurf Section Modulus Calculation

	ABS Rules	Maxsurf Analysis	Designed Midship
Section Modulus (m^3)	0.23	0.2	1.03

The designed section modulus exceeds the minimum requirements and has a margin to withstand additional loading during the towing operation or extreme weather conditions. By meeting the ABS structural requirements, the vessel also satisfies *Transport Canada Hull Construction* regulations.

19.0 WEIGHT ESTIMATION

In the initial stages of the design process a rough weight estimate was developed to set vessel's target displacement and select initial particulars. A more accurate weight estimate was developed in order to properly analyze the hydrostatics and stability of the vessel in a greater detail. The following sections will outline the estimation of weights and centres of gravity for the lightship and deadweight. The vessel lightship weight groups were broken into their corresponding SWBS sections to present it in conventional manner.

19.1 INITIAL LIGHTSHIP WEIGHT ESTIMATE

For the initial weight estimate area and volume requirements were converted to the weights using coefficients provided to us by the industry mentors. The design team was also provided a weight summary of each SWBS group of one of the OSV vessels. The ratiocination scaling method outlined below was used to determine the lightship weight from the reference vessel to compare it to the lightship weight estimated during initial particular selection stage. The following formulas were used in the analysis, variable G was calculated using parent ship's weight and particulars L, B and D.

100 - Structure Weight

$$W_1 = G \cdot L(B + D)$$

200 - Propulsion equipment weight

$$W_{2d} = W_{2p} \cdot \sqrt{\frac{SHP_d}{SHP_p}}$$

W_{2d} = Propulsion equipment weight of the design ship

W_{2p} = Propulsion equipment weight of the parent ship

SHP_d = Shaft Horsepower, maximum for design ship

SHP_p = Shaft Horsepower, maximum for parent ship

500 - Vessel systems weight

$$W_{4d} = W_{4p} * \frac{(LBD)_d}{(LBD)_p}$$

W_{4d} = Vessel system weight of the design ship

W_{4p} = Vessel system weight of the parent ship

$(LBD)_d$ = Product of length, beam and depth of the design ship

$(LBD)_p$ = Product of length, beam and depth of the parent ship

600 - Outfit Weight

$$W = G \cdot L(B + D)$$

300 & 400 - Electrical equipment weight

$$W_{3d} = W_{3p} * \frac{KW_d}{KW_p}$$

W_{3d} = Electrical equipment weight of the design ship

W_{3p} = Electrical equipment weight of the parent ship

KW_d = Installed power of the design ship

KW_p = Installed power of the parent ship

Group 600 - Deck equipment weight

$$W_{5d} = W_{5p} * \frac{(LBD)_d}{(LBD)_p}$$

W_{5d} = Deck equipment weight of the design ship

W_{5p} = Deck equipment weight of the parent ship

$(LBD)_d$ = Product of length, beam and depth of the design ship

$(LBD)_p$ = Product of length, beam and depth of the parent ship

Figure 31 - Ratiocination Method Overview

The calculated weights were found to be very similar to previously estimated values. The weight of 700 group is greater since the design team obtained weights of some of the mission and deck equipment from vendors and added it to the weight estimate.

Table 31 - Weight Ratiocination Summary

Lightship – SWBS Groups	Weight (MT)	
	Weight Coefficients Applied to Area/Volume Requirements	Ratiocination Scaling from a Reference OSV Vessel
100 & 600 - Hull & Outfit	810	800
200 - Propulsion	100	108
300/400 - Electrical	35	37
500 - Vessel Systems	84	122
700 - Deck & Mission Equipment	100	169
Total (w/o margin)	1129	1247
Margin	12%	10%
Total (w/ margin)	**1264**	**1346**

In the initial stage the lightship center of gravity was estimated using the data found on US and European offshore supply vessels.[24]

19.2 DETAILED LIGHTSHIP WEIGHT ESTIMATE

The following sections provide an overview of the weight estimation process for each SWSB group. For the itemized weight estimate please refer to *APPENDIX H – LIGHTSHIP WEIGHT ESTIMATE*

19.2.1 SWBS 100 – Structure

While earlier iterations of the weight estimate were determined with a use of weight coefficients and overall hull and superstructure volume, this weight estimate involves calculation of the steel weight based on the midship section structure of the vessel. This is done by estimating the overall internal structural volume per one section, then applying a “scaled material-take off” approach, and integrating through the length of the ship. That is to say, the hull structural volume fraction at the midship frame is determined, the vessel’s approximate sectional area curve is then applied to this density fraction to determine the estimated hull structure volume at each frame. The shell plating was split into different groups based on the thickness, and the area was measured from the modelling software to calculate the total shell plate area. Area of each deck and bulkhead was measured from the General Arrangement drawing and 3D model.

The following assumptions and considerations were made for this calculations:

- The girders were assumed to run continuously throughout the length of the ship.
- The floor area per section was multiplied by the plate thickness to get the floor volume per one section.
- 35% stiffener weight percentage was applied to all of the bulkheads and floors. This percentage was determined from the ratio of required stiffeners per plate area while performing structural analysis. Assumed similar throughout the ship.
- 5% bracket weight percentages were applied to total weight.

The weight of the wheelhouse and superstructure above the forecastle deck was estimated using weight coefficients that were previously used.

[24] Young_R_R.A_Review_of_Offshore.Apr.1992.MT

19.2.2 SWBS 200 – Propulsion Equipment

An itemized approach was used to estimate the weight for the propulsion machinery. The weight of the main equipment was provided to us by the vendors and location of centre of gravity was measure from the general arrangement (GA) drawing. For items that didn't have weight information, the values were estimated from conversations with industry and reference literature. A higher 12% allowance margin was applied since some of the components were estimated and design team didn't have a lot of experience with propulsion equipment.

19.2.3 SWBS 300 – Electrical

Electrical System weight was estimated using a combination of the itemized approach and the coefficient based scaling approach. Main and emergency generators weights were specified and their locations measured on the GA. The weights of items such electrical cables, lighting, transformers and switchboards are scaled using coefficients or estimated based on reference vessels.

19.2.4 SWBS 400 – Control & Navigation Equipment

The control and navigation equipment include equipment such as antennae, navigation electronics, alarms, and other communication systems. These items were not intended to be part of the team's project scope, so weights for these items are estimated or scaled based on reference vessels.

19.2.5 SWBS 500 – Auxiliary Systems

Auxiliary equipment includes all pumping systems and HVAC within the vessel. A combination of itemized approach, for all pumps, and coefficient based scaling, for HVAC and piping, is used for the overall estimate. An example of pumps which have been given a specified weight are listed below:

- Ballast/Bilge Pump
- Fire Pump
- Urea Pump (for exhaust system)
- Black Water/Grey Water/Clean Water Pumps

For pumps without a vendor specification, weights were estimated to be a standard weight of 125 kg as a placeholder. HVAC and plumbing layouts are considered outside the current scope of the project; therefore, these weights are estimated by reference vessels or by empirical methods. The machinery arrangement was used to determine the weight centroids of the equipment.

19.2.6 SWBS 600 – Outfit & Furnishing

The category includes a variety of items including ladders, staircases, and hatches in for the outfit aspect. Furnishing is generally made up of weights for each crew accommodation space such as the individual cabins, the galley, and offices. Though each section are broken down into specific items, each specific weight were estimated based on reference vessel data or applying scaling coefficients measurements from the GA.

- Outfitting (eg. floor grating, ladders, staircases, hatches) – estimated via reference vessels
- Crew Spaces (eg. crew lounge, galley, office) – applied scaling coefficient from mentors to measured volume from GA
- Crew Spaces – crew cabins and washrooms – a typical weight of a 2 person cabin and washroom based on reference vessels is used for all similar crew cabins

19.2.7 SWBS 700 – Deck & Mission Equipment

The majority of deck equipment and mission equipment are itemized and specified based on vendor information and the location of each piece of equipment is estimated based on GA.

19.2.8 Lightship Weight Summary

The overall lightship weight of the vessel is presented in the table and figure below. 8% design margin was used to account for uncertainties in the estimations and to account for the potential risk of underestimating the vessel weight, as per "Weight Estimating and Margin Manual" developed by the Society of Allied Weight Engineers.

Table 32 - Overall Weight Breakdown

SWBS -Lightship	Weight (MT)
100 - Hull Structure	757
200 - Propulsion System	55
300 - Electrical System	51
400 - Command and Surveillance	3
500 - Auxiliary Systems	57
600 - Outfitting and Furnishings	181
700 - Deck & Mission Equipment	100
Total Weight (w/o margin)	1204
Margin	8%
Total Weight (w margin)	1300

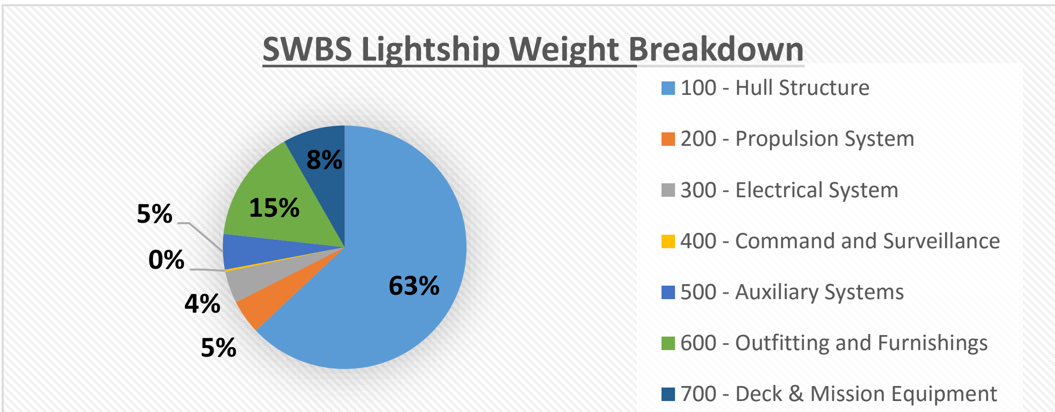


Figure 32 - SWBS Lightship Weight Breakdown

19.3 DEADWEIGHT ESTIMATE

The dead weight of this vessel consists of the crew and provisions, oil spill response equipment, and the liquids within tanks.

19.3.1 Crew and effects

The weights of the crew, effects and provisions were approximated based on the number of crewmen (12) and supernumeraries (4), and the length of operation (21 days) as specified by the original requirements. The crew and effect weight was estimated to be 170kg per person and the provision weight was taken to be 10kg/person/day.

19.3.2 Mission equipment

The mission equipment was selected as per client's requirements. The weight centroids were taken from the general arrangement.

Table 33 - Deadweight Item Summary

Deadweight Items	Weight (MT)
Crew & Effects	2.7
Provisions	3.3
40' Mini Barge	5
2 x Containers	40
Total Weight:	**51**

19.3.3 Tank Liquids

After conducting endurance analysis and defining tanks inside of the Maxsurf software, the tank capacities and weight centroids were determined and varied for different loading conditions. Please refer to the 16.0 TANK ARRANGEMENT for more details.

19.4 LOADING CONDITIONS

In order to evaluate vessel's intact stability the following four conditions were considered, which are in accordance with the *2008 IS Code, Part B, Chapter 3, Section 3.4, Item 3.4.1.2.*

The permeability of the tanks was assumed to be 98%, which corresponds to a full tank. For every loading case, the design team evaluated untrimmed (overall trim is greater than 0.15m and heel angle is over 0.3 degrees) condition first, and went over a number of iterations in order to minimize the amount of ballast water carried and to achieve even trim condition. The lightship weight and location of the centre of gravity was based on our weight estimate, same applies to the mission equipment and/or any cargo carried on board.

19.4.1 Ballasted Departure, 98% Consumables, 100% Mission Items

This condition corresponds to a case when the vessel is leaving the port with all of the mission equipment and provisions on board.

Table 34 - Departure Loading Condition

Item Name	Loadcase	Total Mass	LCG	TCG (Port Negative)	VCG	FSM
		MT	m	m	m	MT m
Lightship	1	1300	24.2	0	5.6	
Provisions & Mission Equipment		51	11.7	-3.6	7.7	
Tanks		519				179
Total Loadcase		**1870**	**22.15**	**0.00**	**5.17**	**179**
Summary of Loading						
Fuel Oil	98%	Black Water	10%			
Recovered Oil	0%	Urea	98%			
Ballast Water	15%	Oily Water	10%			
Fresh Water	98%	Hydraulic Oil	98%			
Grey Water	10%	Dispersant	98%			

19.4.2 Ballasted Departure, 98% Consumables, 100% Mission Items, 98% Recovered Oil

This condition corresponds to a case when there is a large oil spill near the port, and the vessel will be in its heaviest and the worst case operational condition. This condition also represents a case when the vessel is transporting fuel oil instead of recovered oil.

Table 35 - Near Port Recovered Spill Loading Condition

Item Name	Loadcase	Total Mass	LCG	TCG (Port Negative)	VCG	FSM
		MT	m	m	m	MT m
Lightship	1	1300	24.2	0	5.6	
Provisions & Mission Equipment	1	51	11.7	-3.6	7.7	
Tanks		783				285
Total Loadcase		**2134**	**21.87**	**0.00**	**5.04**	**285**
Summary of Loading						
Fuel Oil	98%	Black Water	10%			
Recovered Oil	98%	Urea	98%			
Ballast Water	23%	Oily Water	10%			
Fresh Water	98%	Hydraulic Oil	98%			
Grey Water	10%	Dispersant	98%			

19.4.3 Ballasted Arrival, 10% Consumables, 0% Mission Items (Lightest Condition)

This condition corresponds to case when the vessel is returning to the port with no mission items, 10% provisions and 10% consumables.

Table 36 - Lightest Loading Condition

Item Name	Loadcase	Total Mass	LCG	TCG	VCG	FSM
		MT	m	m	m	MT m
Lightship	1	1300	24.2	0	5.6	
Provisions & Mission Equipment	0	0	0	0	0	
Tanks		264				185
Total Loadcase		**1564**	**22.49**	**0.00**	**5.21**	**185**

Summary of Loading			
Fuel Oil	10%	Black Water	98%
Recovered Oil	0%	Urea	10%
Ballast Water	36%	Oily Water	98%
Fresh Water	10%	Hydraulic Oil	10%
Grey Water	98%	Dispersant	10%

19.4.4 Ballasted Arrival, 10% Consumables, 100% Mission Items, 98% Recovered Oil

Corresponds to the case when the vessel is returning to port after completing a large oil spill operation.

Table 37 - Return to Port Loading Condition

Port Negative

Item Name	Loadcase	Total Mass	LCG	TCG	VCG	FSM
		MT	m	m	m	MT m
Lightship	1	1300	24.2	0	5.6	
Provisions & Mission Equipment	1	51	11.7	-3.6	7.7	
Tanks		359				182
Total Loadcase		**1710**	**21.97**	**-0.11**	**5.20**	**182**

Summary of Loading			
Fuel Oil	10%	Black Water	98%
Recovered Oil	98%	Urea	10%
Ballast Water	0%	Oily Water	98%
Fresh Water	10%	Hydraulic Oil	10%
Grey Water	98%	Dispersant	10%

20.0 INTACT STABILITY

The following sections provide an overview of intact stability analysis performed to evaluate if the vessel is capable of safely performing all of the required missions for four loading conditions defined in the previous section. Aside from evaluating against the International Code on Intact Stability, also known 2008 IS code, the design team also determined the stability of vessel while performing towing and crane operations as per ABS rules. Further, during the analysis, the design team was able to minimize the number of tanks and optimize their locations.

20.1 REGULATIONS

The following rules were used in this analysis:

1. *International Code on Intact Stability, 2008, also known as 2008 IS Code*

This code provides mandatory criteria for the righting lever curves, as well as vessels response to wind and wave effects. These rules also provide information on how to account for a free surface effect in the tanks containing consumable liquids, ballast water and recovered oil.

2. *Transport Canada Stability Requirements*

Transport Canada rules require meeting the 2008 IS Code requirements.

3. *ABS Steel Vessels Under 90m in Length - Part 5 - Chapter 11 Vessels Intended for Towing, Appendix 1 - Intact Stability Guidelines for Towing Vessels*

These rules provide formulas on how to calculate a heeling moment, when towing another vessel, as well as requirements that need to be satisfied.

4. *ABS Steel Vessels Under 90m in Length - Part 5 - Chapter 12: Fishing Vessels - 7.5 Heeling Moment due to Onboard Crane Use*

Using these rules, the design team was able to calculate the heeling moment during the crane operation and evaluate if it is possible to satisfy client's requirement of moving a container from the design vessel to another.

20.2 FREE SURFACE EFFECT

In order to perform an accurate analysis, and to meet *2008 IS Code, Part B, Chapter 3, Section 3.1* requirements, we had to account for the free surface effect in the following tanks:

1. For tanks containing consumable liquids, consider either the transverse pair of tanks or single centerline tank with the greatest free surface effect.
2. For tanks containing ballast water, the most onerous free surface condition to be assumed to account for intermediate stages of filling the tanks during the voyage.
3. For minor tanks, the following formula was used in order to evaluate if the tank's free surface effect could be neglected. $\frac{M_{fs}}{\Delta_{min}} < 0.01$ m, where $\mathbf{M_{fs}}$ is tank free surface moment (tonne-metres) and $\mathbf{\Delta_{min}}$ is displacement at service draft without cargo, minimum ballast and 10% stores.

20.3 DOWNFLOODING POINTS

After setting up the tanks in Maxsurf Software, the potential down flooding points or critical points had to be defined. All of the hatches on the main deck were considered to be watertight, so the only two down flooding points are as follows:

Table 38 - Down flooding Points

Down flooding Points:	LCP (from Fr.0, m)	TCP (off CL, m)	VCP (from BL, m)
Engine Room (ER) Air Intake	24.2	3.1	10.4
Weathertight door to the ER	24.75	0.6	7

At this stage of the design, vent locations on the main deck were not considered.

20.4 ANALYSIS

20.4.1 OPTIMIZATION OF BALLAST WATER TANKS

After defining the tanks and creating four load cases previously described, the intact stability of the vessel was evaluated and it was found that in all four cases the vessels trim was greater than 0.15m and in some cases the vessel's heel angle was over 0.3 degrees. That is why in all of the cases the vessel had to be ballasted. Maxsurf has an Auto Ballasting tool that was used to find an optimal condition with minimum ballast and full ballast tank, so that the vessel has almost 0 trim and 0 heel angle. It was found that in practice it is better to manually adjust as many tanks as possible and then use the automatic ballasting to set just the last few tank to the required level.

20.4.2 HYDROSTATICS & CURVES OF FORM

Maxsurf software is also capable of representing hydrostatic data in curves of form shown below:

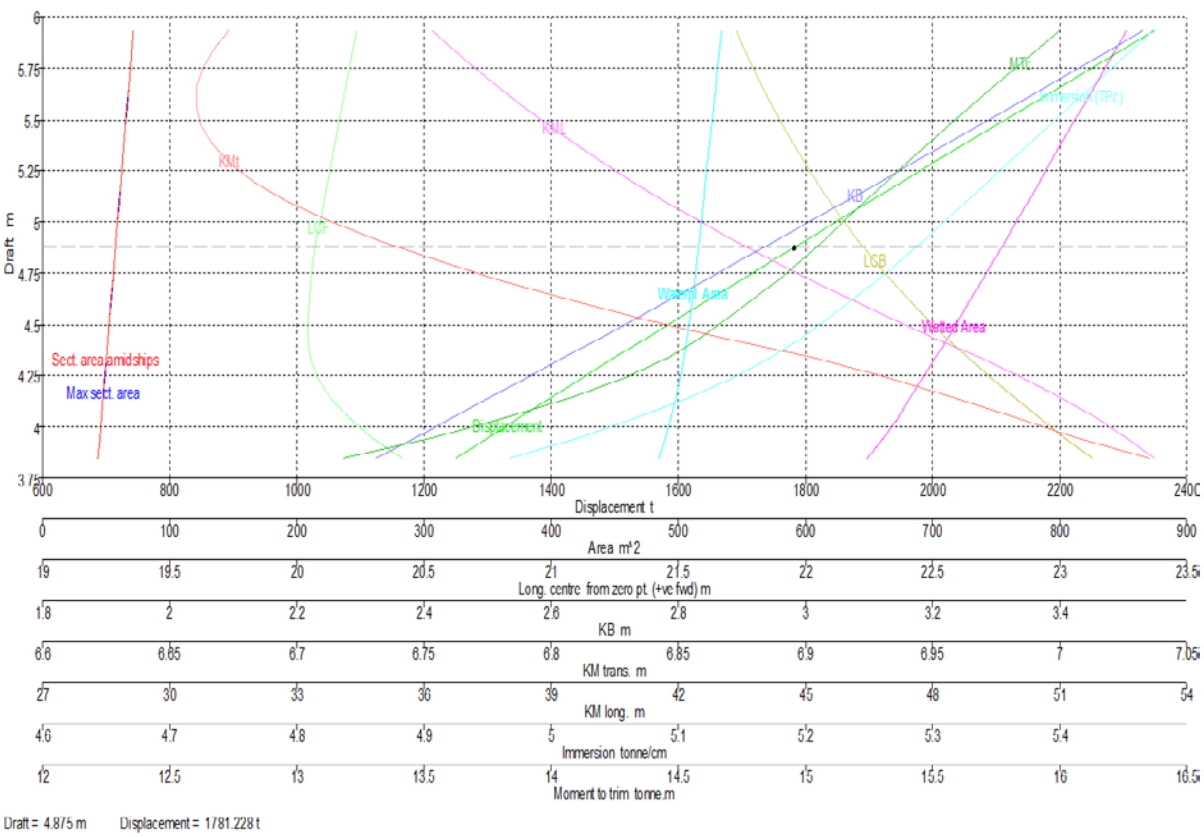


Figure 33 - Hydrostatics

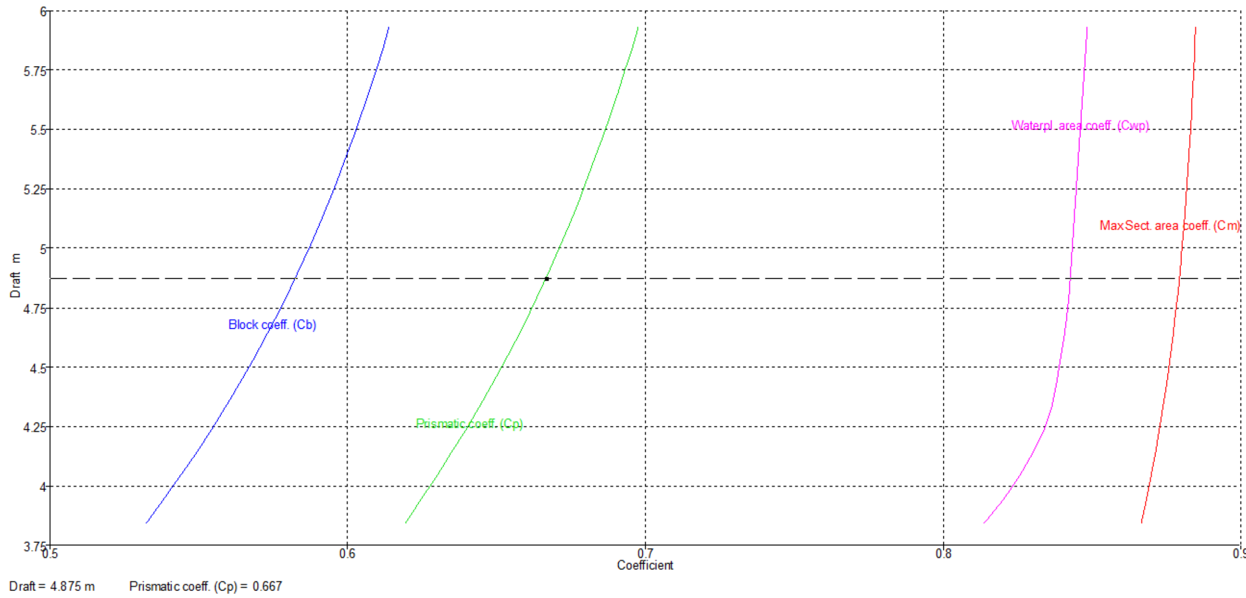


Figure 34 - Curves of Form

20.4.3 IS 2008 CODE COMPLIANCE

The intact stability was evaluated and compared against the Intact Stability Code. The righting lever, GZ, was calculated for a range of heel angles. As a results of this calculation GZ curve was produced for every loading case, and then by integrating the curve the total available restoring or righting energy could be found. The results of the calculation were used to evaluate if the vessel meets the intact stability requirements.

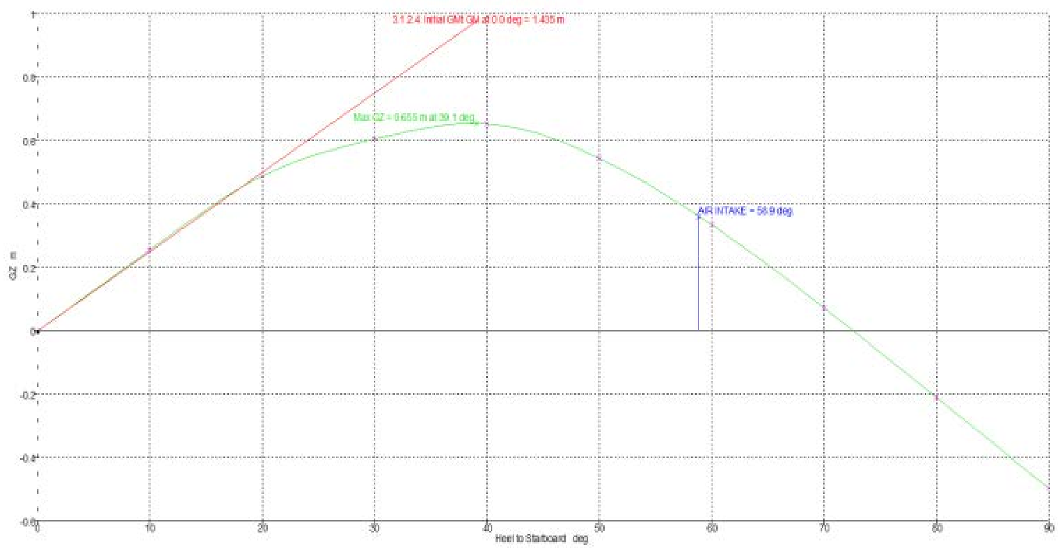


Figure 35 - GZ Curve

20.4.4 WEATHER CRITERION AND CODE APPLIANCE

The ability of a ship to withstand the combined effects of beam wind and rolling is to be demonstrated for each standard condition of loading, meaning that the restoring energy, area b, should be greater than the capsizing energy, area a.

For this analysis, the vessel is assumed to heel to a static heel angle, φ_o, under the action of a steady wind heeling lever, L_{w1}. Resonant rolling of the vessel is assumed with an amplitude φ_1 about the equilibrium position φ_o. A gust wind heeling lever L_{w2} is then applied.

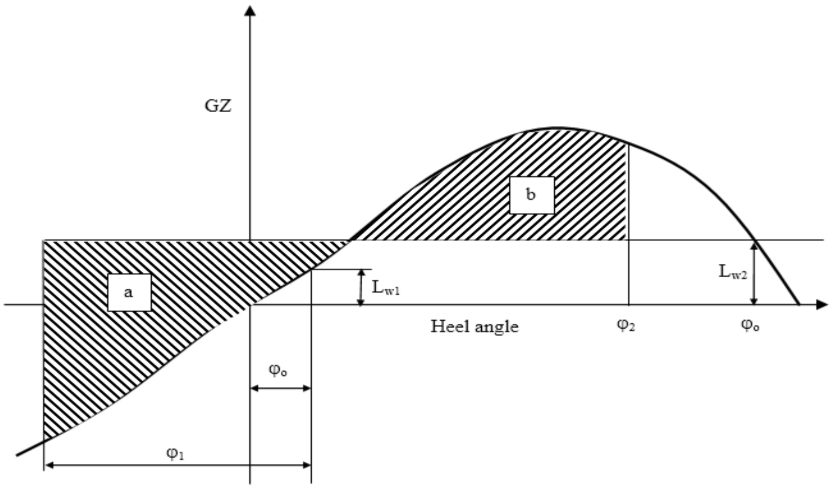


Figure 36 - Weather Criteria and Code Compliance

The following formulae were used to calculate the wind and gust heeling arms:

$$L_{w1} = \frac{PAZ}{\Delta} \qquad (m)$$
$$L_{w2} = 1.5 L_{w1} \qquad (m)$$

Where

P = 0.0514 [MT/m]

A : projected lateral area of portion of ship and cargo above waterline [m^2]

Z : vertical arm from centre of A to centre of underwater lateral area [m]

Δ : displacement [MT]

φ_1 : roll angle

φ_2 : angle of downflooding or 50 deg or φ_c, whichever is less. φ_c is the angle of second intercept between wind heeling lever L_{w2} and the GZ curve.

The criterion also recommends that under the action of the steady wind heeling lever L_{w1}, the angle of heel shall not exceed 16 degrees or 80 percent of the level of deck edge immersion, whichever is less.

20.4.5 TOWING OPERATION AND CODE COMPLIANCE

Same principle applies to towing operation, where instead of wind heeling arm, there is a towline heeling moment, which was calculated usign following formula:

$$Towline\ Heeling\ Moment = C_T \cdot T \cdot h \cdot \cos(\theta)\ [MT \cdot m]$$

Where:

C_T = Coefficient for type of propulsion = 0.5 for twin screw vessels per ABS Rules

T = Maximum bollard pull [MT], obtained from 9.0 BOLLARD PULL ANALYSIS

h = Vertical distance from top of towing bitt to the VCB [m]

The results of towline heeling moment calculation for the ballasted departure case is shown below:

Heeling Arm (m):	**0.043**	**.cos(heel angle)**
Max STBD Heeling Moment (MT.m):	**80**	
Maximum Bollard Pull (MT)	40	
% of BP at 90%	50%	per ABS 90m - Part 5 - Chapter 11 Vessels Intended for Towing
Top of the tow bit (relative to BL)	7.05	
Distance from Tow Bit to VCB	4.0	

Figure 37 - Towline Heeling Moment Calculation

The area of the residual dynamic stability (area between righting and heeling arm curves to the right of the first intercept) up to an angle of heel of 40 degrees should not be less than **0.09** m-rad.

20.4.6 CRANE OPERATION AND CODE COMPLIANCE

To evaluate if the vessel is capable of safely moving a 25 tonne container to adjacent vessel (6m reach), we used *ABS Crane Operation Criteria for Fishing Vessels*. This is a reasonable criteria, since the designed vessel is very similar in operation profile to the fishing vessel's profile.

The Crane Heeling arm consists of two components: one is due to a weight, in our case is a container with oil recovery gear, located some distance from vessel and crane centerline (crane radius in picture below). The second component is due to a crane boom located off the crane centerline during the offloading operation. The following formula was used to calculate the crane heeling arm:

$$Crane\ Heeling\ Arm = \frac{(W_C \cdot R_C)}{\Delta} + \frac{(W_B \cdot R_B)}{\Delta}$$

Where:

Δ = displacement [MT]

W_C = container weight [MT]

R_C = distance from vessel centerline to the centre of mass of the container

W_B = crane boom weight [MT]

R_B = distance from crane centerline to the centre of mass of the boom

The results of calculation for the ballasted departure without recovered oil on board are shown below:

Crane Heeling Arm (m)	**0.171**	
Total Crane Heeling Moment (MT.m)	**320**	Constant for all heel angles as per ABS
1. Heeling Moment due to Crane Boom Off CL (MT.m)	43.5	
2. Heeling Moment due to Container Off CL(MT.m)	276	
Crane Boom Weight (MT)	10.35	From Vendor
Distance from Crane CL to Crane Boom CG (m)	4.2	
Maximum Container Weight (MT)	25.0	
Distance between container and crane CL (m)	7.0	
Distance from Vessel CL (m)	11.05	

Figure 38 - Crane Heeling Arm Calculation

20.5 RESULTS

All of the results of the intact stability analysis are presented in the tables below.

Table 39 - Intact Stability Analysis Results

2008 International Code on Intact Stability (IS)	Ballasted Departure, 98% Consumables	Ballasted Departure, 98% Consumables, 98% RO	Ballasted Arrival, 10% Consumables, no Mission Equip.	Ballasted Arrival, 10% Consumables, 98% RO
Mandatory IS Criteria	**Required/Attained**	**Required/Attained**	**Required/Attained**	**Required/Attained**
Area 0 to 30 (m.deg)	3.2 / 10.6	3.2 / 9.5	3.2 / 12	3.2 / 11.2
Area 0 to 40 (m.deg)	5.2 / 17	5.2 / 14.5	5.2 / 19.9	5.2 / 18.2
Area 30 to 40 (m.deg)	1.7 / 6.4	1.7 / 5.1	1.7 / 7.8	1.7 / 7
Max GZ at 30 or greater (m)	0.2 / 0.7	0.2 / 0.5	0.2 / 0.8	0.2 / 0.7
Angle of Maximum GZ (deg)	25 / 39	25 / 37.3	25 / 39.1	25 / 39.1
Initial GM_transverse (m)	0.2 / 1.4	0.2 / 1.5	0.2 / 1.5	0.2 / 1.5

2008 IS Code - Severe Wind and Rolling Criterion (Weather Criterion)	Ballasted Departure, 98% Consumables	Ballasted Departure, 98% Consumables, 98% RO	Ballasted Arrival, 10% Consumables, no Mission Equip.	Ballasted Arrival, 10% Consumables, 98% RO
	Attained	**Attained**	**Attained**	**Attained**
Ratio of Areas b/a should be greater than **1**	1.5	1.3	1.6	1.6
Equilibrium Heel Angle Should be less than **16 deg**	2.5	1.8	2.8	2.5

ABS - Vessels Intended for Towing	Ballasted Departure, 98% Consumables	Ballasted Departure, 98% Consumables, 98% RO	Ballasted Arrival, 10% Consumables, no Mission Equip.	Ballasted Arrival, 10% Consumables, 98% RO
Towing Operation Criteria	**Required/Attained**	**Required/Attained**	**Required/Attained**	**Required/Attained**
Meet 2008 IS Code Criteria	PASS	PASS	PASS	PASS
Area between Righting and Heeling Arm Curves up to 40 deg (m.deg)	5.2 / 14.9	5.2 / 11.9	5.2 / 17.2	5.2 / 16.2

ABS - Fishing Vessels - Onboard Crane Use	Ballasted Departure, 98% Consumables	Ballasted Departure, 98% Consumables, 98% RO	Ballasted Arrival, 10% Consumables, no Mission Equip.	Ballasted Arrival, 10% Consumables, 98% RO
Crane Operation Criteria	**Required/Attained**	**Required/Attained**	**Required/Attained**	**Required/Attained**
Area between Righting and Heeling Arm Curves up to 40 deg (m.deg)	4.6 / 10.3	4.6 / 13.1	4.6 / 12	4.6 / 12.7
Equilibrium Heel Angle Should be **less than 10 deg**	< 10 / 6.7	< 10 / 5.2	< 10 / 7.7	< 10 / 7
The deck edge immersion angle should be greater than the equilibrium heel angle	6.7 / 14.1	5.2 / 10	7.7 / 18.5	7 / 15.4

After completing the analysis it was found that the vessel meets the intact stability requirements and is capable of safely loading and offloading 25 tonne container at any loading condition, as well as towing a 5000 tonne deadweight barge.

21.0 DAMAGE STABILITY

The damage stability of the concept vessel was evaluated for the same four loading conditions described in 19.0 WEIGHT ESTIMATION. The results of analysis were compared to rules and regulations in order to evaluate if the design is capable of withstanding a damage due to a side collision, while remaining upright. The following document will outline the analysis method, evaluated damage cases and results.

21.1 REGULATIONS

The following rules were used in this analysis:

1. *ABS Steel Vessels Under 90m in Length – Offshore Support Vessels 2015 – Damage Stability Requirements*

This regulations outlines damage extents and criteria that have to be satisfied. The design team decided that using OSV Rules is reasonable, since the vessel with be operating in deep waters majority of the time and there is a very small likelihood of grounding. Hence, the team focused all of the efforts on evaluating the side damage stability.

2. *SOLAS – International Convention for the Safety of Life at Sea – Chapter II-1 – Regulation 9*

As mentioned in the Tank Arrangement document, the double bottom tanks were fitted from the collision bulkhead to the after peak bulkhead, as far as this is practicable and compatible with the design and proper working of the ship. However, any part of the ship that is not fitted with a double bottom shall be capable to withstand bottom damages. The double bottom is not fitted in steering gear and bow thruster compartment, so the design team evaluate bottom damage stability for those two cases in order to meet the double bottom rules.

21.2 DAMAGE EXTENTS

ABS rules defines the following damage extents that were used in our analysis:

Longitudinal Extent = 3.0 + 0.03* L_f [m], where L_f is a freeboard length

Transverse Extent = 0.76 [m]

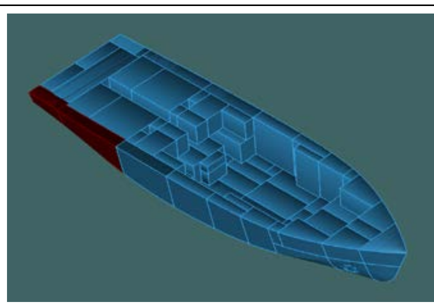
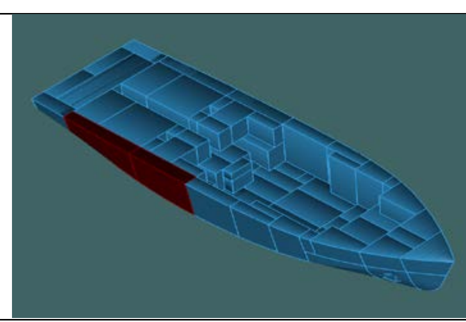
The vertical extent of the damage to be assumed from the keel up to the underside of the main deck. Where double bottom wasn't fitted, the extent of damage defined in SOLAS rules was used:

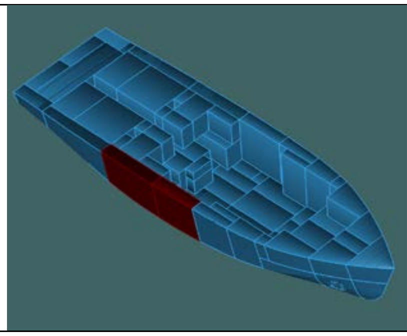
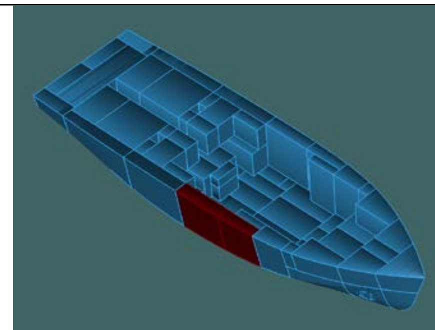
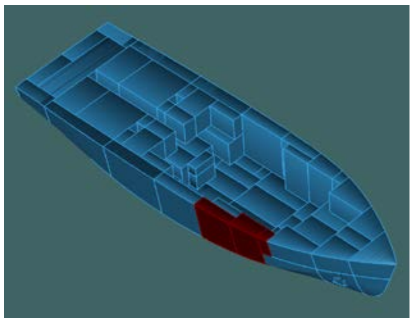
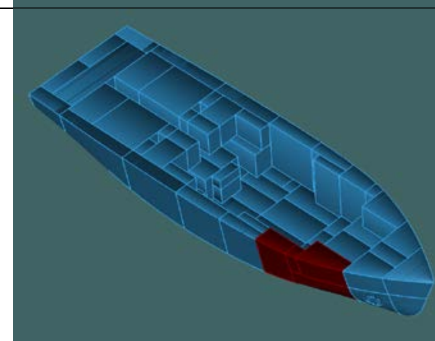
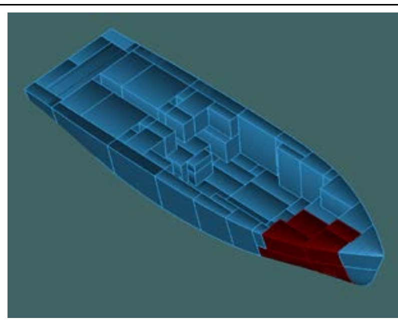
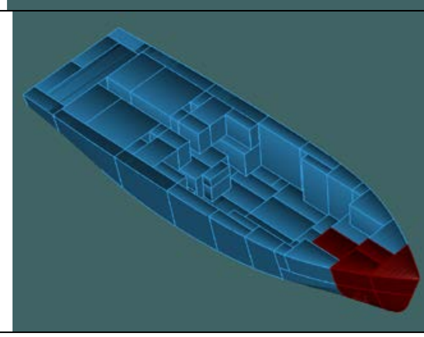
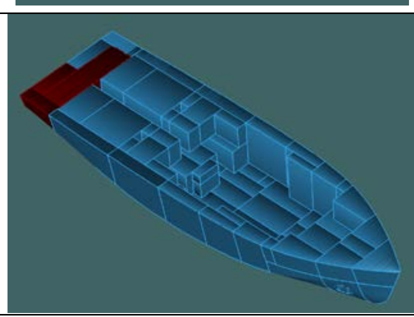
Longitudinal Extent = 1/3*$L^{2/3}$ [m], Transverse Extent = B/6 [m], Vertical Extent = B/20 [m], measured from keel

21.3 DAMAGE CASES

The damaged cases outlined in the table below were based on the damage extents described above. Cases 8 and 9 are the only one where the bottom damage stability was evaluated, since bow thruster and steering gear compartment don't have the double bottom.

Table 40 - Damaged Stability Table

Damage Case	Damaged Tanks & Compartments	Damage Case	Damaged Tanks & Compartments
1		2	

Damage Case	Damaged Tanks & Compartments	Damage Case	Damaged Tanks & Compartments
3		**4**	
5		**6**	
7		**8**	
9			

The damage stability analysis was performed in Maxsurf software, which uses a lost-buoyancy method. It is also worth noting, that for any orientation (heel and trim) of the vessel, the fluid level in tanks is always modelled parallel to the external sea surface in Maxsurf, which represents a real case scenario. During the damage analysis, the vessel was heeled over to the starboard, which represented the worst case scenario due to smaller superstructure volume on the port side providing less buoyancy.

The analysis was performed for all 9 damage cases and every loading condition, and evaluated against the following criteria defined in ABS OSV Rules and outlines in the summary tables below. The OSV rules also state that the immersion of some of the flooding points could be authorized. The design team decided that at this stage of the analysis, the immersion of the edges of the weathertight doors is authorized. In case it is not authorized, the watertight doors could be installed.

The following tables shows that all of the criteria have been satisfied for 4 different loading conditions:

Table 41 - Damaged Stability Results

1. Ballasted Departure, 98% Consumables, 100% Mission Items

Damage Cases	Equilibrium waterline below any opening through which progressive flooding may take place	Equilibrium Heel Angle less that **15deg**	Range of positive stability > **20 deg**
	Pass/Fail	Attained	Attained
1	Pass	6.7	50.3
2	Pass	10.3	46.1
3	Pass	9.8	46.8
4	Pass	7.1	50
5	Pass	6	51.4
6	Pass	8.2	48.1
7	Pass	5.8	48.1
8	Pass	3.0	52.7
9	Pass	4.3	51.2

2. Ballasted Departure, 98% Consumables, 100% Mission Items, 98% Recovered Oil (Worst Case)

Damage Cases	Equilibrium waterline below any opening through which progressive flooding may take place	Equilibrium Heel Angle less that **15deg**	Range of positive stability > **20 deg**
	Pass/Fail	Attained	Attained
1	Pass	6.2	42.3
2	Pass	9.8	37.3
3	Pass	8.9	38.4
4	Pass	6.1	42.5
5	Pass	5.1	43.9
6	Pass	6.9	40
7	Pass	4.8	35
8	Pass	2.4	41.2
9	Pass	4.6	40.3

3. Ballasted Arrival, 10% Consumables, 0% Mission Items (Lightest Condition)

Damage Cases	Equilibrium waterline below any opening through which progressive flooding may take place	Equilibrium Heel Angle less that **15deg**	Range of positive stability > **20 deg**
	Pass/Fail	Attained	Attained
1	Pass	6.3	58.3
2	Pass	10.0	54
3	Pass	10	54.3
4	Pass	7.3	57.5
5	Pass	6.1	59
6	Pass	8.7	55.3
7	Pass	6.7	55
8	Pass	3.3	60.4
9	Pass	4.5	59

4. Ballasted Arrival, 10% Consumables, 100% Mission Items, 98% Recovered Oil

Damage Cases	Equilibrium waterline below any opening through which progressive flooding may take place	Equilibrium Heel Angle less that **15deg**	Range of positive stability > **20 deg**
	Pass/Fail	Attained	Attained
1	Pass	10	49
2	Pass	10	49
3	Pass	10	49.5
4	Pass	7.3	53
5	Pass	6.1	54
6	Pass	8.5	50.5
7	Pass	6.2	50.4
8	Pass	3	55.3
9	Pass	4.4	54

22.0 SEAKEEPING ANALYSIS

The following sections discuss the seakeeping analysis conducted using Maxsurf Motions software on the vessel.

22.1 SETUP

Considering the amount of time the vessel is expected to spend in pollution control and standby modes according to the mission profile, the team believes it is reasonable to analyze motions of the vessel at zero forward speed in different sea states. The analysis will be performed on sea states up to 4, since it is a limiting operational condition for some of the oil recovery equipment. The Bretschneider spectrum will be used as an input for the environmental conditions in the analysis.

Since the concept vessel has a low L/B ratio, the linear strip theory will not provide us with accurate results. On the contrary, the panel method is applicable to a wider range of vessel geometries. It is a first-order radiation hydrodynamic analysis in which a constant panel based boundary element method is used. Panel method generates Response Amplitude Operators (RAOs) for heave, pitch and yaw, but it is only valid for zero forward speed, which represents a condition we are interested in.

The hull surfaces were automatically meshed. Pitch and yaw radii of gyration were taken as 25% of the length of the vessel, roll as 40% of the beam. The analysis was performed at the design draft and zero trim.

22.2 LOCATIONS

Aside from calculation motions at the centre of gravity of the vessel, the following locations were considered in the analysis as well:

Locations	Longitudinal Position from FR. 0 (m)	Distance off centerline (m)	Vertical Position from baseline (m)
Main Deck, outboard, beside skimmer	16.00	6.00	7.50
Main Deck, Aft	4.00	0.00	7.50
Bridge Deck Wing	30.0	4.50	12.80
Master's Cabin	38.50	3.50	10.00

The following formulas are used to find the absolute motion of a point:

$$X_p = X_{CG} - d_y \cdot Yaw + d_z \cdot Pitch$$

$$Y_p = Y_{CG} - d_X \cdot Yaw - d_z \cdot Roll$$

$$Z_p = Z_{CG} - d_x \cdot Pitch + d_y \cdot Roll$$

Where, d_x, d_y, d_z are linear distance from CG to the point.

22.3 RESPONSE AMPLITUDE OPERATORS

The Response Amplitude Operator, also referred to as a transfer function, describes how the response of the vessel varies with frequency. RAO depends on the vessel's geometry, speed and heading. For this analysis, RAOs at different headings were calculated.

The following plot shows RAO calculated for pitch, heave and roll at CG in the following seas. As expected, the roll RAO is zero in the following seas. At low frequencies, heave RAOs tend to unity, this is where the vessel simply moves up and down with the wave and acts like a cork. At high frequencies, the response tends to zero since the effect of many very short waves cancel out over the length of the vessel. For the pitch RAO, the peak will occur close to the vessel's natural period.

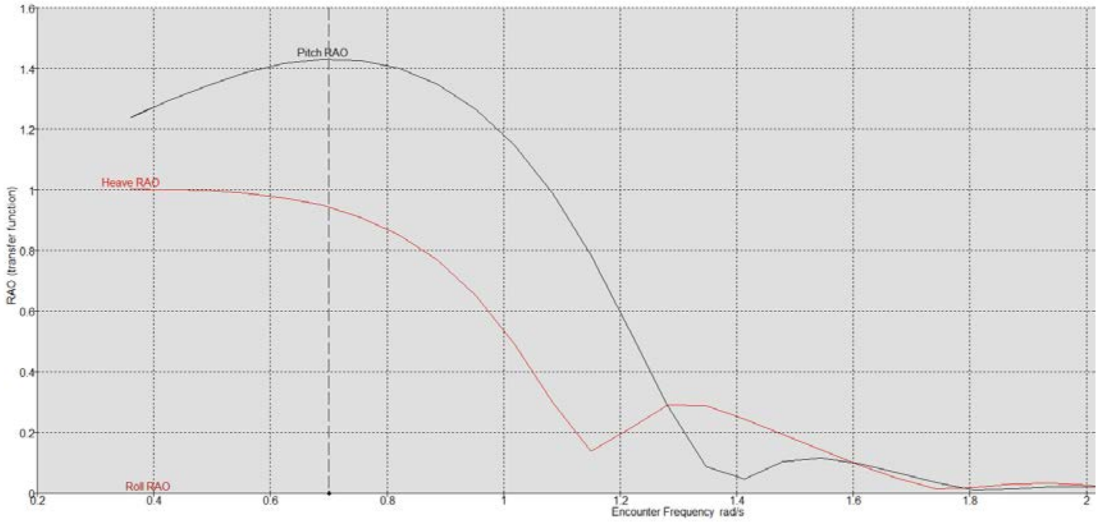


Figure 39 - Centre of Gravity RAO in the following seas

After calculating RAO, the response spectrum could be determined by multiplying the wave spectrum by the square of the RAO.

22.4 MOTION SICKNESS INCIDENCE (MSI)

MSI is the percentage of subjects who start feeling sick in the specified time of exposure to the motions and conditions. The data was derived from the tests on healthy, young, male students who have never been at sea before and were subjected to vertical motions for a period of two hours. Although it is hard to extrapolate these results on the crew men, who have spent a significant amount time at sea, the design team believes that MSI could be still used to evaluate the seakeeping performance and comfort level of the vessel at this stage of the design.

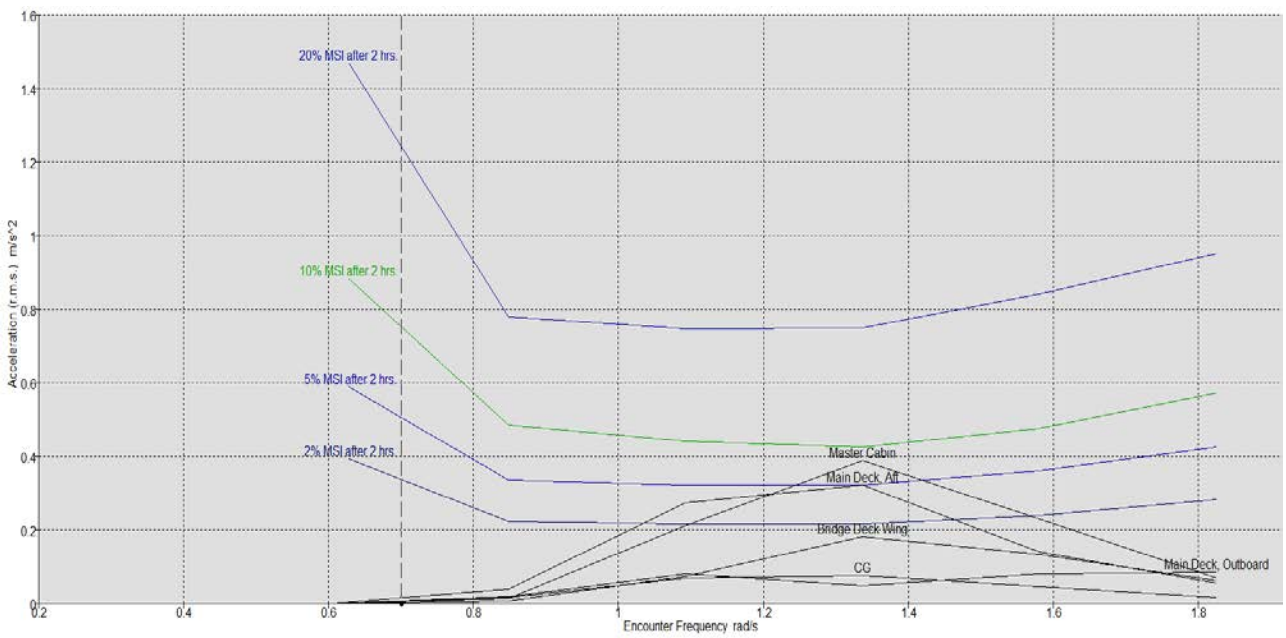


Figure 40 - MSI Accelerations at 60 and 300 degree headings, sea state 3

The MSI acceleration depends on the magnitude of the vertical acceleration at the point of interest on the vessel and is based on the combined effects of pitch, heave and roll. The plots compare vertical MSI accelerations at different points on the ship and the standard curves determined from the tests previously mentioned.

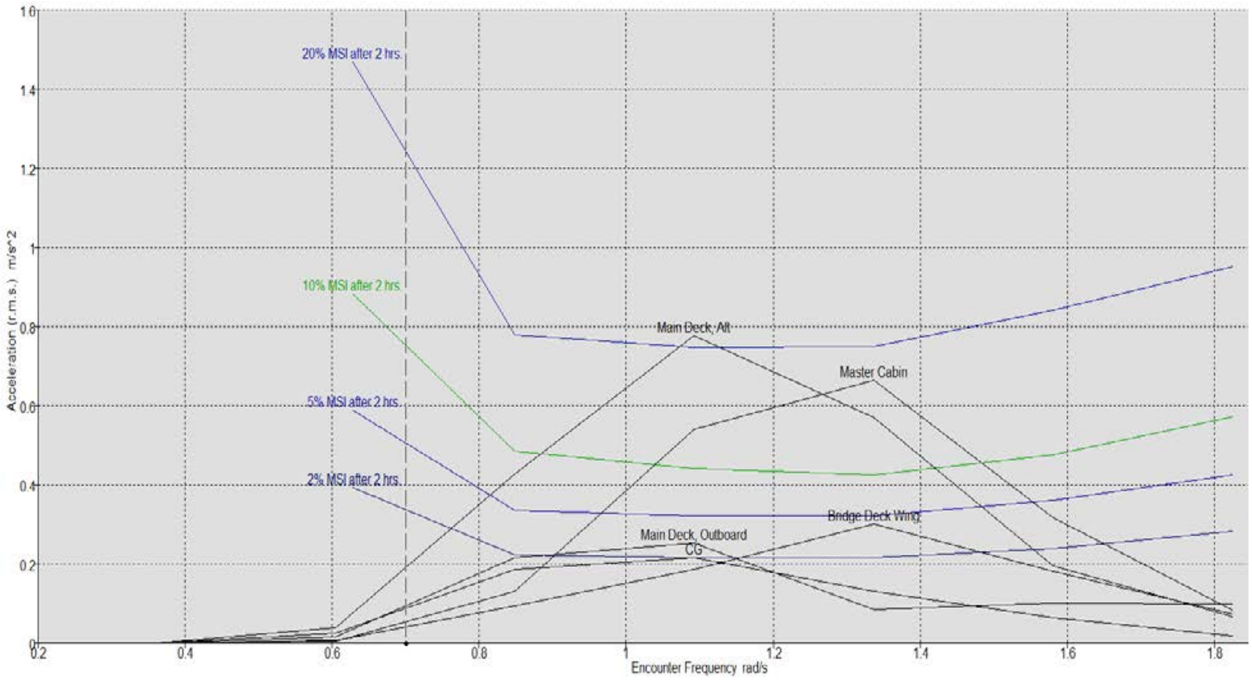


Figure 41 - MSI Accelerations at 60 and 300 degree headings, sea state 3

Both plots represent the worst cases with highest accelerations for sea states 3 and 4. For more plots please refer to *APPENDIX I – SEAKEEPING ANALYSIS*. From the obtained results, the vessel creates safe and comfortable environment for the crew during the oil recovery and offloading operations. However, further computational analysis and model tests should be done to verify the results obtained.

22.5 BILGE KEELS

Maxsurf Motions is not capable of performing the seakeeping analysis when the appendages are added to the 3D model, so the seakeeping improvement due to bilge keels couldn't be quantified. However, after reviewing reference literature the design team decided to add bilge keels to provide additional roll damping for the concept vessel. [25] For the bilge keel arrangement please refer to *001 – LINES PLAN* drawing.

[25] WATSON, D. G. M. (1998). Practical Ship Design

23.0 STATIONKEEPING ANALYSIS

Station keeping is an essential component of a pollution control operation, in order to contain and recover the pollutant the vessel must be able to maintain position given that not doing so could result in damage to the equipment and jeopardy to the crew. This section of report will outline the procedure, assumptions and results that the project saw in order to satisfy the station keeping necessities.

23.1 APPROACH

The design team's strategy was to develop a tool that is capable of the calculating environmental forces acting on the vessel in different sea states, and then use the results of calculation to select an appropriate bow thruster. Since no model test for station keeping were performed on the concept hull, data and formulas from *NAVSEA-DDS-568-1-Thruster-Manoeuvering-Systems* were used. The design team used model test data of T-ARC cable repair vessel hull, which represents a moderate form ship and has the most resemblance to the concept vessel compared to other options.

23.2 CALCULATIONS AND RESULTS

In order to calculate the total environmental forces acting on the vessel at different headings, the wave, current and wind forces had to be determined and combined. The Bretschneider wave spectrum was used in the analysis, and the assumption was made that the worst case is when the wind, waves and current act along the same heading. Please refer to the *APPENDIX J – STATIONKEEPING ANALYSIS* for the calculation details.

A thrust to power conversion factor of 0.15 kN/kW was then used to calculate the available thrust generated by the bow thrusted based on its power. The thrust was compared to the required bow thruster force determined from the environmental loads calculated for every heading angle. The following polar plots were develop to better illustrate the results of the analysis. The blue areas represent orientations relative to the environment at which the vessel will be able to maintain the position, assuming all of the environmental forces act in one direction.

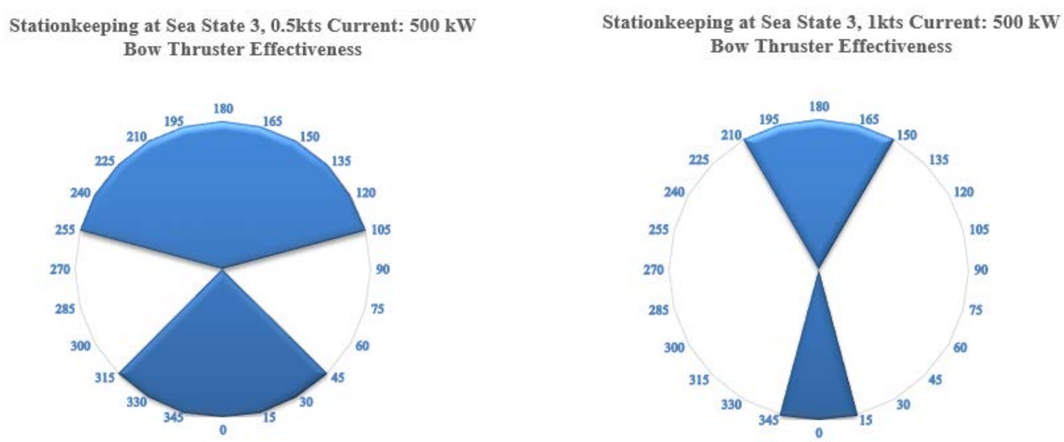


Figure 42 – Station keeping in Sea State 3 with 0.5 and 1kts current

As expected, the largest transverse force will be experienced when the vessel is beam to the sea. The magnitude of longitudinal forces is relatively small when compared to the transverse forces. Having a controllable pitch propellers and enough power, the vessel will be able to maintain position in the longitudinal direction. The largest forces were observed at 75 to 105 degree headings.

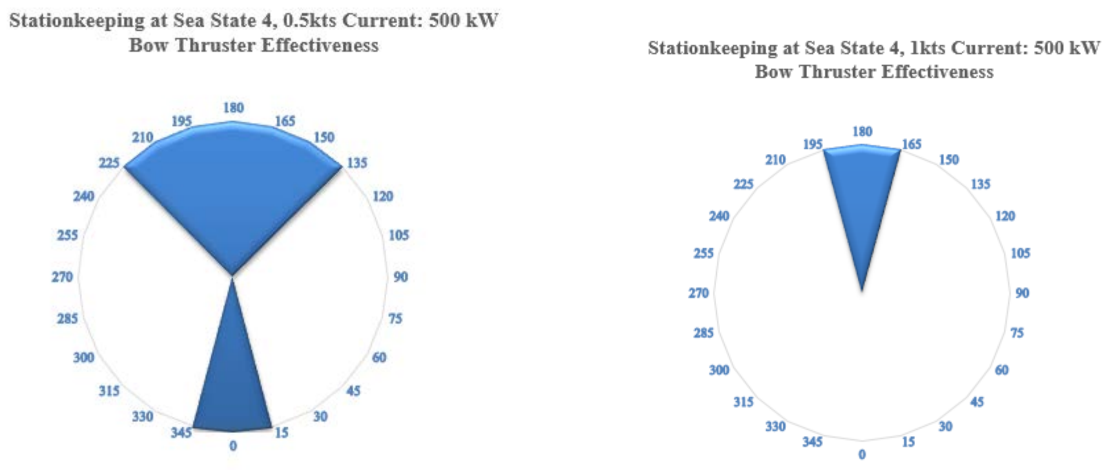


Figure 43 - Station Keeping in Sea State 4 with 0.5 and 1kts currents

The results seemed satisfactory to the design team, especially considering that the analysis and results are for the worst case scenario.

23.3 BOW THRUSTER

A 500kW Schottel STT1 bow thruster was selected for the design vessel. The design team used specifications provided from Rolls Royce and Jastram to determine the optimal location of the bow thruster. The vertical location of the tunnel has to satisfy the minimum water head requirement, while also not being too close to the keel, since the short circuiting of the flow could occur, resulting in a significant loss of thrust. The bow thruster tunnel also has to be long enough to for the flow to be homogeneous, resulting in a higher thrust.

The following table outlines the selected parameters for the bow thruster

Table 42 - Bow Thruster Specification

Thruster Diameter	1.56		**Design**	**Min Recommended**	
Tunnel Diameter	1.6	m	**L/D**	**L/D**	
Min Tunnel Length	3.32	m	2.1	2	3
Max Tunnel Length	5.2	m	3.3	2	3
Keel to Bottom of the tunnel	1.5	m	0.94	1	
Thruster CL to the keel	2.3	m	1.44	1	
Thruster CL to min waterline	2.5	m	1.56	1.5	2

24.0 DIRECTIONAL STABILITY & RUDDER SIZING

The following sections outline the evaluation of ship's ability to resume a straight line path and the design adjustments that were made to make it more directionally stable.

24.1 DIRECTIONAL STABILITY PARAMETER

In the initial design of the ship, the design team evaluated the directional stability of the designed hull. A stability parameter, C, was calculated using the following formula. The vessel is directionally stable when the value of C is greater than zero.

$$C = Y'_v N'_r - N'_v (Y'_r - m')$$

Where: Y'_v = *non dimensional hydrodynamic derivative of the force due to sway* = $\frac{Y_v}{0.5 \cdot \rho \cdot V \cdot L^2}$

Y'_r = *non dimensional hydrodynamic derivative of the force due to yaw* = $\frac{Y_r}{0.5 \cdot \rho \cdot V \cdot L^3}$

N'_v = *non dimensional hydrodynamic derivative of the moment due to sway* = $\frac{N_v}{0.5 \cdot \rho \cdot V \cdot L^3}$

N'_r = *non dimensional hydrodynamic derivative of the moment due to yaw* = $\frac{N_r}{0.5 \cdot \rho \cdot V \cdot L^4}$

m' = *non dimensional weight* = $\frac{\Delta}{0.5 \cdot \rho \cdot L^3}$

V = velocity of the ship , L = length of the ship

The required hydrodynamic derivatives were estimated using the empirical curve fits from the Principles of Naval Architecture Volume 3 (p. 248).

$$Y'_v \simeq -\pi\left(\frac{T}{L}\right)^2\left(1 + 0.40 C_B \frac{B}{T}\right) \qquad N'_v \simeq -\pi\left(\frac{T}{L}\right)^2\left(0.5 + 2.4\frac{T}{L}\right)$$

$$Y'_r \simeq \pi\left(\frac{T}{L}\right)^2\left(0.5 - 2.2\frac{B}{L} + 0.080\frac{B}{T}\right) \qquad N'_r \simeq -\pi\left(\frac{T}{L}\right)^2\left(0.25 + 0.039\frac{B}{T} - 0.56\frac{B}{L}\right)$$

Based on the calculated hydrodynamic derivatives, the stability parameter was found to be -0.05, which means the vessel is not directionally stable. In order to make it directionally stable, a centerline skeg and two large rudders were added to the vessel. The hydrodynamic derivatives of the skeg and rudders were calculated using the following formulae:

$$Y' = \frac{\mathrm{Y}}{0.5 \cdot \rho \cdot V \cdot L^2}$$

$$Y = C_{L\alpha} \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A_R$$

Where:

$$C_{L\alpha} = \frac{1.8\pi\Lambda}{1.8 + \cos\Omega\sqrt{4 + \frac{\Lambda^2}{\cos^4\Omega}}}$$

Ω, sweep angle was taken to be zero; Λ = Rudder/ Skeg Aspect Ratio = $\frac{2b^2}{A_R}$

b = rudder/skeg mean span = mean distance from the hull to the tip of the rudder

A_R = Rudder/ Skeg planform area, the following section discusses the rudder sizing

The skeg was sized in accordance with this calculation. $C_{L\alpha}$ formula is based on a semi-imperical data for low aspect ratio lift (Whicker & Fehlner). The small angle approximation was used. After adding Y'_{skeg} and Y'_{rudder} to the Y'_v, the stability parameter became positive, which indicated that the vessel is directionally stable.

24.2 INITIAL RUDDER SIZING

In the initial stage of the design, for the double screw ships, the single rudder area was estimated to be 5% of the lateral projected area up to the design waterline[26].The rudder area was estimated to be 5 m^2. This values was also confirmed using the following two empirical relations:

From DNV Rules:

$$A_R \approx \frac{T \cdot L_{pp}}{100}\left(1.0 + 25.0 \cdot \left(\frac{B}{L_{pp}}\right)^2\right)$$

From Ship Design for Masters and Mates by C.B. Barrass:

$$A_R \approx K \cdot T \cdot L_{pp}$$

Type of Ship	Typical K
Container ships and passenger liners	0.012-0.017
General cargo ships	0.015
Oil tankers and bulk carriers	0.017
Lake steamers	0.020
Cross-channel ferries, RO-RO ships	0.020-0.030
Coastal vessels	0.020-0.033
Tugs and pilot vessels	0.025-0.040

Figure 44-K Values for Ship Type

Where a K value of 0.02 for tugboats was used.

[26] LAMB, T. (2003) Ship Design and Construction (Volumes 2) – Chapter 41 – Fishing Vessels

25.0 MANEUVERABILITY ANALYSIS

The maneuverability of the vessel was analyzed by determining its tactical diameter (TD), advance (AD), track and head reach using empirical formulas defined in ABS Maneuverability Guidelines (2006) and comparing the values to IMO and ABS standards. The empirical formulas used were developed for vessels of over 55m in length; however, the design team decided that the formulas could be still used in the initial stage of the design to provide us a rough idea of the ship's maneuverability. Further, as a part of result validation, similar calculations were performed on one of reference vessels and it was found that our results fall within same range, meaning that the designed vessel has a satisfactory maneuverability that the similar existing vessel has. Please refer to *APPENDIX K – MANUEVERABILITY ANALYSIS* for the calculation inputs, standards and formulas used.

The following table outlines the results of the calculation and shows that vessel meets IMO standard when travelling at 14 knots design speed.

Table 43 - Maneuverability at 14 Knots

Estimated TD/L	**Maximum Allowed TD/L**	**Status**
2.92	5	Pass
Estimated AD/L	**Maximum Allowed AD/L**	**Status**
3.15	4.5	Pass
Estimated Maximum Track Reach	**Maximum Allowed Track Reach**	**Status**
7.85	15	Pass

The turning ability of the vessel was evaluated by calculating the tactical diameter at different speeds and rating its performance using formulas provided by ABS. The vessel is required to have a minimum rating of 1 at any operating speeds, and as could be seen from the plot below, all of the criteria have been met.

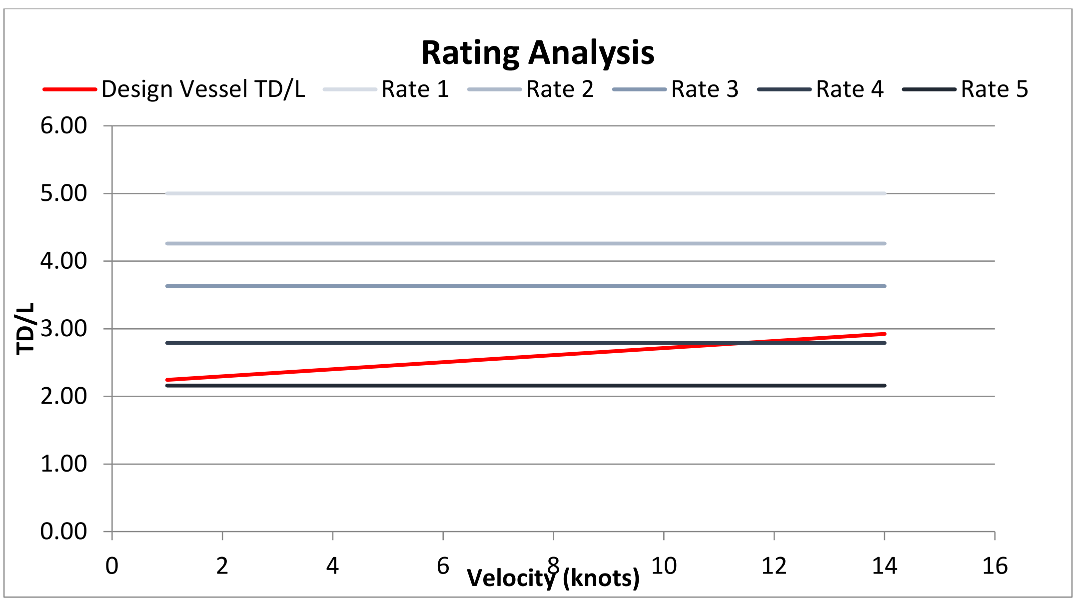


Figure 45 - Rating Analysis

26.0 COST ESTIMATE

The following section outline the approach used to estimate the construction cost of the vessel. The design team also evaluated the optimal location to construct a vessel to have largest cost savings. It was found that building vessel in Turkey and transporting it to Canada will be more cost-effective than building it in Canada. The main reasons for that are lower labor productivity and lack of shipbuilding experience in Canada. Even though a 25% import tariff will have to be paid, the total cost was found to be 14 million lower than cost of the vessel built in Canada. One of the main reasons to that is lower productivity of local shipyards.

For the analysis, the labor rates were obtained information from the Turkish and Canadian Bureau of Labor Statistics. The overhead rate was estimated to be 85%, which is reasonable values for a small size shipyard. The design team used Product Oriented Design and Construction Model[27] that contains empirical cost estimation relations (CER's) for labor man-hours and material dollar for every SWBS group.

The following table outlines all of the assumptions and results of the calculations for vessel built in Turkey. The design team also had a chance to confirm some of the values with one the Turkish shipyard managers.

Cost Estimate Done by: OS

Multipurpose Pollution Control Vessel

Length	47	m	**Total Power Installed**	3,800	kW	2 x CAT 3512D
Beam	14.2	m	**Total Aux Power**	1,500	ekW	3 x CAT C18
Depth	6.7	m				C9 Emer. Genset
Total Lightship (w 8% margin)	1,300	MT				
Diminution Margin	10%	%				
100 to 700 Groups Labor Rate	17	Euro/hr	**Exchange Rate**	0.91	Euro/US	0.68 Euro/CAD
Engineering & Support Services	27	Euro/hr	**Import Tariff**	25%	into Canada	
Overhead Rate	85%	% Labor Rate				
Yard's Profit	10%	%				
Estimate Allowance	10%	%				

Lightship	Weight	Manhours	Source	Material	Source	Material	Manhours	Material	Total cost
SWBS Groups	**MT**	**per MT**		**$/ MT**		**Euro/ MT**	**Per Group**	**Euro**	**Euro**
100 - Hull Structure	756	125	Plot 1	700	Online	637	94,500	481,572	2,088,072
200 - Propulsion System	55	100	Plot 1	15500	Plot 2	14,105	5,500	775,775	869,275
300 - Electrical System	51	250	Plot 1	25000	Plot 2	22,750	12,750	1,160,250	1,377,000
400 - Com. and Surv.	3	650	Plot 1	40000	Plot 2	36,400	1,950	109,200	142,350
500 - Auxiliary Systems	57	210	Plot 1	10500	Plot 2	9,555	11,970	544,635	748,125
600 - Outfitting and Furnishings	181	250	Guess	5500	Plot 2	5,005	45,250	905,905	1,675,155
700 - Mission Equipment	100	200	Guess		Vendors		20,000	197,470	537,470
800 - Engineering	25%	of total manhours for 100 to 700 groups					47,980		1,295,460
900 - Support Services	50%	of total manhours for 100 to 700 groups					95,960		2,590,920

Total Manhours	335,860	hrs	
Total Labor Cost	7,149,020	Euro	
Overhead Cost	6,076,667	Euro	Total Labor Cost * Overhead Rate
Total Materials Cost	4,174,807	Euro	
Total (w/o allowance)	17,736,354	Euro	
Yard's Profit	1,773,635	Euro	
Allowance	1,773,635	Euro	
Total (w/ allowance & profit)	21,283,625	Euro	
	31,299,448	CAD	

Delivery/ Transportation	650,000	CAD	Industry
Canadian Import Tariff	7,824,862	CAD	
TOTAL	**39,774,310**	CAD	

Figure 46 - Cost Estimation - Turkish

[27] K.J. Ennis (SNAME, 1998) - Product Oriented Design and Construction Cost Model

The table below outlines the cost estimate for the vessel built in Canada.

Cost Estimate Done by: OS

Multipurpose Pollution Control Vessel

Length	47	m	**Total Power Installed**	3,800	kW	2 x CAT 3512D
Beam	14	m	**Total Aux Power**	1,100	ekW	3 x CAT C18
Depth	6.7	m				C9 Emer. Genset
Total Lightship (w 8% margin)	1,300	MT				
Diminution Margin	10%	%				

100 to 700 Groups Labor Rate	30	CAD/hr	**Exchange Rate**	0.75	US/CAD	0.75 US/CAD
Engineering & Support Services	40	CAD/hr	**Import Tariff**	0%	into Canada	
Overhead Rate	85%	% Labor Rate				
Yard's Profit	10%	%				
Estimate Allowance	10%	%				

Lightship SWBS Groups	**Weight MT**	**Manhours per MT**	**Source**	**Material $/ MT**	**Source**	**Material CAD/ MT**	**Manhours Per Group**	**Material CAD**	**Total cost CAD**
100 - Hull Structure	756	125	Plot 1	700	Online	933	94,500	705,600	3,540,600
200 - Propulsion System	55	100	Plot 1	15500	Plot 2	20,667	5,500	1,136,667	1,301,667
300 - Electrical System	51	250	Plot 1	25000	Plot 2	33,333	12,750	1,700,000	2,082,500
400 - Com. and Surv.	3	650	Plot 1	40000	Plot 2	53,333	1,950	160,000	218,500
500 - Auxiliary Systems	57	210	Plot 1	10500	Plot 2	14,000	11,970	798,000	1,157,100
600 - Outfitting and Furnishings	181	250	Guess	5500	Plot 2	7,333	45,250	1,327,333	2,684,833
700 - Mission Equipment	100	200	Guess		Vendors		20,000	197,470	797,470
800 - Engineering	25%	of total manhours for 100 to 700 groups					47,980		1,919,200
900 - Support Services	50%	of total manhours for 100 to 700 groups					95,960		3,838,400

Total Manhours	335,860	hrs
Total Labor Cost	20,727,360	CAD
Overhead Cost	17,618,256	CAD
Total Materials Cost	6,025,070	CAD
Total (w/o allowance)	44,706,546	CAD
Yard's Profit	4,470,655	CAD
Allowance	4,470,655	CAD
Total (w/ allowance & profit)	53,647,855	CAD

Increase in Labor Cost due to lower productivity 80%

Total Labor Cost * Overhead Rate

Delivery/ Transportation	0	CAD	Guess
Canadian Import Tariff	0	CAD	
TOTAL	**53,647,855**	CAD	

Figure 47 - Cost Estimation - Canadian

27.0 LIFE-CYCLE COST

Calculating the life cycle cost of the vessel required a number of assumptions to be made. From discussions with WCMRC, the vessel is expected to conduct only a couple of missions per year. The design team's analysis only considers operational costs related to fuel, crew salary and provisions. The design team wasn't able to find any reference information to estimate salvage value, refit and maintenance costs of the vessel.

27.1 FUEL COST

Determining the fuel costs required research of the average monthly wholesale diesel prices for the previous five years:

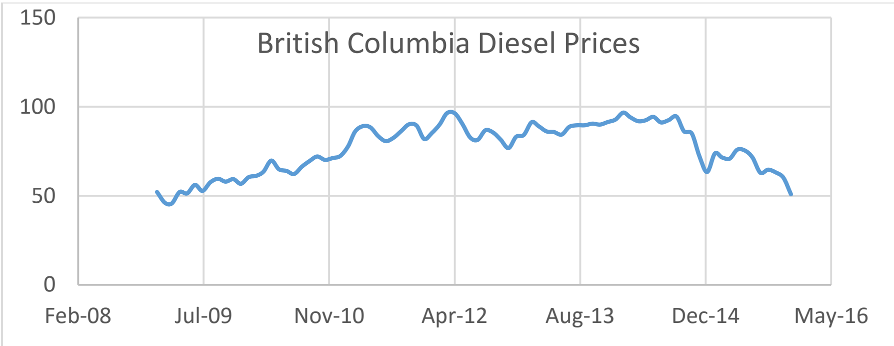


Figure 48 - Diesel Prices in British Columbia (Natural Resources Canada, 2016)

After performing Monte-Carlo simulation with 500 iterations of the mean monthly fuel price and standard deviation, the average unit fuel cost was found to be 766 $/m^3.

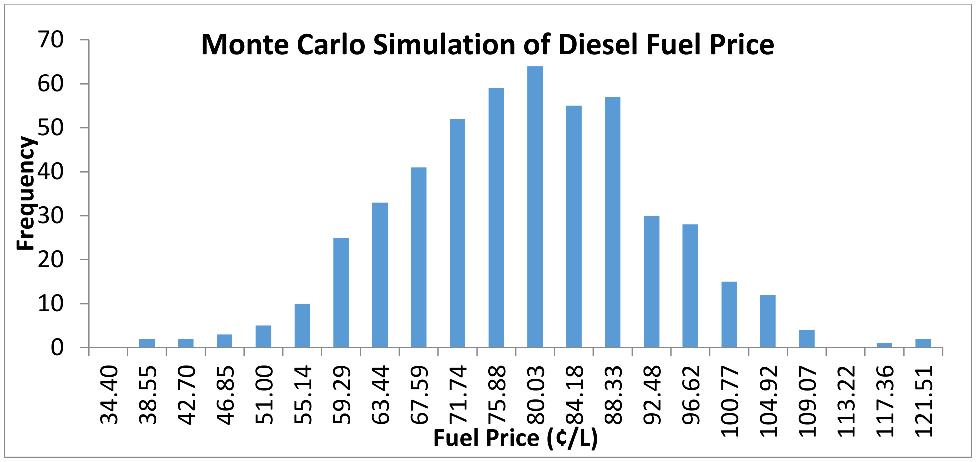


Figure 49 - Histogram of Diesel Fuel Price Simulation

Since we have sized the vessel to fit the mission profile of 3 weeks' operation at sea, we calculated that the fuel would be replenished completely twice per year. The calculation resulted in the fuel cost being $520,823.44, and would not rise directly with inflation due to market volatility that can be seen in the graph above.

27.2 SALARY COST

The salary cost of the vessel was found by researching the average hourly wage of a deckhand which was determined to be roughly $21. The yearly salary cost was found to be $252,000 initially, and will increase each year due to inflation.

27.3 PROVISIONS COST

To supply the vessel with enough food to last an operation it was estimated that it would require $150 per week to feed one deckhand. The cost of food was found to be $10,800.00, and will rise with inflation each year.

27.4 RESULTS

Calculating for the Net Present Value and assuming the only applicable rate being that of inflation at 2% yields:

Table 44 - Net Present Value for Vessel

Fuel	$10,489,867.82
Salary	$6,423,529.41
Provisions	$275,294.12
Sum	$17,188,691.35

And the cash flow diagram shows the yearly costs:

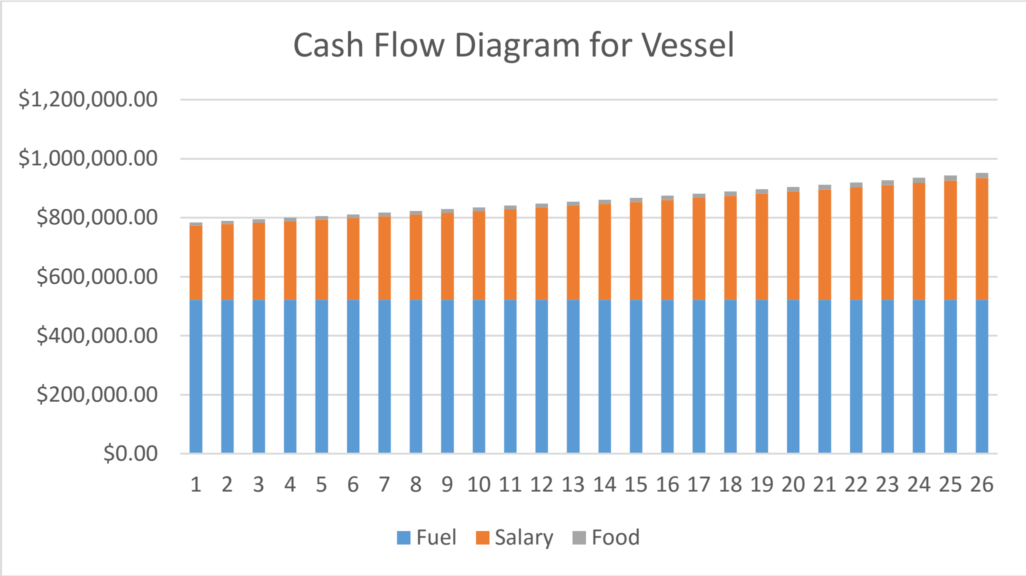


Figure 50 - Yearly Cash Flow for Vessel

This vessel appears to only cost the $17 million with no potential revenue. However, as mentioned above the salvage value wasn't a consideration which could potentially be a substantial positive cash flow. Also, since the Client's stakeholder may require this vessel to gain approval for a pipeline expansion with potential profits that will more than offset the vessel costs.

28.0 DESIGN RISK ANALYSIS

The risk assessment below evaluates the potential risk of the moving forward with the design as is based on the amount of uncertainties and assumptions made in several analysis performed by the team. The risk levels are defined by the team as described in the 5 levels below, with a score of 5 being the largest amount of risk, corresponding to a complete failure to meet the owner's requirement, and a score of 1 being the least amount of risk, which is analyses that are well justified and are comparable to professional naval architecture standards.

28.1 RISK LEVEL DEFINITIONS

The risk levels as defined by the design team are as shown in the table below:

Table 45 - Design Risk Level Definitions

Risk Level	Description
1	Item has been developed and/or analysed using standard naval architecture practices. Assumptions made have been well justified and rework will likely not be necessary
2	Item has been developed using standard naval architecture practices. Further analysis is required to confirm preliminary results. Some rework is possible, with a small probability of major
3	Item has not yet been fully developed and/or analysed, and assumptions made early on may prove incorrect. Further development will likely lead to some rework
4	Rule/Requirement marginally met or unmet. Some rework and/or client requirement changes may be necessary
5	Requirement or rule is not met

28.2 DESIGN RISK ASSESSMENT

The following table outlines the design team's assessment on the risk levels of the each major analysis performed in the design of the vessel:

Table 46 - Design Risk Assessment

Design Risk Analysis		
Analysis Performed	**Analysis& Risk Description**	**Risk Level**
Hull form	The hull form has been developed using adequate reference hull with model test data available. Modifications from references have been based on recommendations found in professional literature and industry. However, a tow tank test and/or CFD analysis will be required to verify the resistance. The preliminary analysis shows that the hull is fair and stable.	2
Weight Estimate	A combination of an itemized and coefficient based approach was used to estimate the weight of the final weight. Also, where possible, the weight estimate was refined using the vendor supplied equipment specifications as inputs. Still, some parts of the analysis were based on careful estimation which may need to be validated.	2
Structural Design	The vessel's structural system was designed following ABS structure regulations and exceeds the minimum thresholds for midship moment of inertia and section modulus. The majority of selected scantling sizes include safety factors which exceed the sizes recommended by ABS, which suggests an overdesign. However, a complete structural analysis was not completed for the entire vessel and will need further analysis and testing to confirm the true weight and performance of structural components.	2

Design Risk Analysis		
Analysis Performed	**Analysis& Risk Description**	**Risk Level**
Powering	The resistance was estimated using the UBC Series resistance data. The result was then validated using a number of other methods. Also, the power required for propulsion has been estimated through various empirical correlations. A tow tank test and/or CFD will need to be used to confirm the results.	2
Electrical Load Analysis	Given the early stage of this project, only a certain amount of equipment were actually specified. Therefore, many assumptions were made to estimate the electrical load of the equipment that were not yet specified. Some rework is recommended.	3
Auxiliary Systems	The systems were sized using ABS rules and vendor information. Due to lack of experience in this area of design, some additional work will be required	3
Intact Stability	The intact stability was analysed using professional naval architecture software. Four loading conditions were examined and free surface effect was also taken into account. The vessel was found to meet the requirements in every scenario. Assuming there are no major changes to the hullform, tank arrangement and the weight estimate, rework will likely not be necessary	1
Damaged Stability	The damage stability was analysed using professional naval architecture software. Four extreme loading conditions and 9 different damage cases were examined free surface effect was also taken into account. The vessel was found to meet the requirement in every scenario. Assuming there are no major changes to the hullform, tank arrangement and the weight estimate, rework will likely not be necessary	1
Seakeeping Analysis	The seakeeping analysis was conducting using a naval architecture software, and a number of reasonable assumptions were taken along the way. A more detailed computer analysis and model testing will be required to get more accurate values	3
Station Keeping	Station keeping analysis was conducted based on the model test results for a significantly larger vessel with a similar hull shape. To get more accurate results, some model test need to be conducted.	3
Maneuvering	The maneuvering analysis was conducted using the empirical formulas provided by ABS. However, the empirical formula has some boundary limits, and the some parameters of the design ship does not fit in the range. A more detailed analysis will be required	4
Cost Estimate	The analysis was conducted by using a combination of empirical formulas. The results were found reasonable by the industry professionals. However, a more detailed life—cycle cost analysis will be required	3

Subject:	**Bare Hull Resistance Calculation Based on the UBC Series Data**		
References:	**1. M.Calisal (1993) - A Resistance Study on a Systematic Series of Low L/B Vessels**	**Done by:**	JY
	2. F.Molland (2011) - Ship Resistance and Propulsions	**Checked:**	OS
	3. 1978 ITTC Performace Prediction Method		

Calculation Procedure

Steps	Models Interpolated	Result	Description
Step 1	Between 7 and 8	**Model A**	L/B ratio in-between 3.06 and 3.98, B/T=2.49, Cp = 0.653
Step 2	Between 9 and 12	**Model B**	L/B ratio in-between 3.06 and 3.98, B/T = 2.99, Cp = 0.653
Step 3	Between A and B	**Model C**	L/B ratio in-between 3.06 and 3.98, B/T =2.49 and 2.99, CP= 0.653
Step 4	between1 and 3	**Model D**	L/B ratio in-between 3.06 and 3.98,B/T = 2.49, CP = 0.7
Step 5	between 4 and 6	**Model E**	L/B ratio in-between 3.06 and3.98, B/T =2.99, CP = 0.7
Step 6	between D and E	**Model F**	L/B ratio in-between 3.06 and 3.98, B/T =2.49 and 2.99, CP =0.7
Step 7	between F AND C	**Design Vessel Model**	L/B ratio in-between 3.06 and 3.998, B/T =2.49 and 2.99, CP in-between 0.653 and 0.7

Inputs

Parameters	**Units**	**Values**
Displacement	t	1870
Length WL	m	45.6
Beam WL	m	13.5
Draft	m	5
Cb	-	0.59
Cm	-	0.88
Cp	-	0.67
LWL/BWL	-	3.4
BWL/T	-	2.7
Wetted Area	m^2	770

Geometric Properties of UBC Series Models

Geometric Properties of UBC Series at Loaded Draft

Model	L (m.)	W_s (m^2)	L/B	B/T	C_b	C_p	C_m	L/V
1	1.552	1.125	3.06	2.49	0.615	0.700	0.878	3.36
2	1.319	0.956	2.60	2.49	0.615	0.700	0.878	3.01
3	2.017	1.462	3.98	2.49	0.615	0.700	0.878	4.00
4	1.552	0.948	3.06	2.99	0.615	0.700	0.878	3.57
5	1.552	1.124	3.06	1.99	0.615	0.700	0.878	3.12
6	2.017	1.232	3.98	2.99	0.615	0.700	0.878	4.25
7	1.552	1.016	3.06	2.49	0.531	0.653	0.813	3.53
8	2.017	1.321	3.98	2.49	0.531	0.653	0.813	4.20
9	1.552	0.929	3.06	2.99	0.531	0.653	0.813	3.75
10	1.552	1.150	3.06	1.99	0.531	0.653	0.813	3.27
11	2.017	1.461	3.98	1.99	0.615	0.700	0.878	3.71
12	2.017	1.208	3.98	2.99	0.531	0.653	0.813	4.46
13	2.017	1.496	3.98	1.99	0.531	0.653	0.813	3.90

Output Summary

Drag due to	**% of Bare Hull Resistance**	
Wind (Air Resistance)	5%	Emperical Formula from Reference 2
Bow Thruster Tunnel	3%	From Rolls Royce Manual
Shafting, bossing	5%	Emperical Formula from Reference 2
Rudders	5%	Emperical Formula from Reference 2
Bilge Keels	2%	Emperical Formula from Reference 2
Hull Rougness	5%	Reference 2

Velocity (kts)	**Bare Hull Resistance (kN)**			**Resistance (kN)**			**Total (w 10% margin)**
	UBC Series	**Holtrop**	**Van Oortmerssen**	**Air**	**Total Appendage**	**Hull Rougness**	
9	40	31	42	2	6	2	**54**
10	53	43	55	3	8	3	**72**
11	73	61	75	4	11	4	**98**
12	100	95	112	5	15	5	**135**
13	135	150	142	7	20	7	**182**
14	181	200	185	9	27	9	**245**
15	243	256	267	12	36	12	**328**
16	326	357	373	16	49	16	**440**
17	440	535	477	22	66	22	**594**

Subject: Propeller Optimization Tool **Done by:** OS

Procedure:

1. In order to have enough thrust to overcome the resistance, the open water thrust has to be calculated using formula on right which accounts for thrust losses due to interference with the hull (thrust deduction factor, t); where t=0.2 for workboats per *Ship Propulsion and Resistance*

$$T_{prop} = \frac{R_{tot}}{(1-t)\#props}$$

2. The actual delivered thrust per propeller, Tactual, is lower than Tprop defined above

$$T_{actual} = T_{prop}(1-t) = \frac{R_{tot}}{\#props}$$

3. The thrust coefficient is calculated using the following formula:

$$K_T = \frac{T_{prop}}{\rho N_{prop}^2 D_{prop}^4}$$

4. Then the advance ratio is calculated the following formula:

$$J = \frac{V_S(1-w)}{N_{prop} D_{prop}}$$

where: V_S= velocity of ship

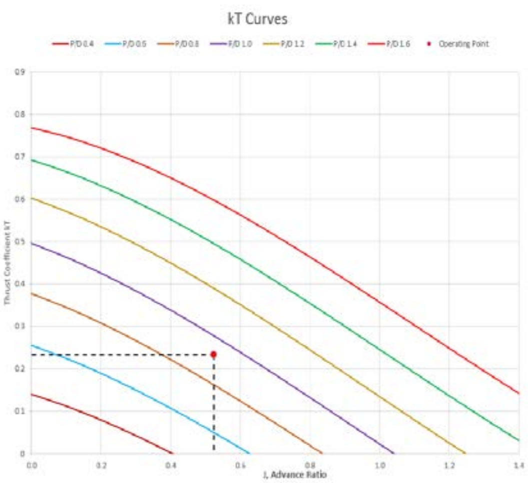
w= wake fraction = 0.18 (taken from literature)

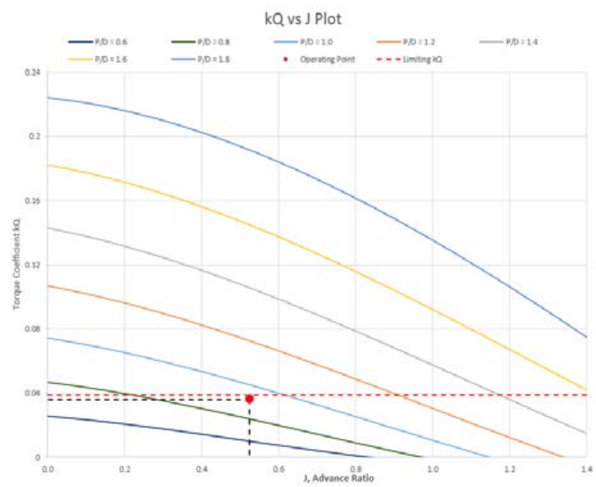
N_{prop}= revolution/second of the propeller

D_{prop}= diameter of propeller

ρ= density of sea water

5. The calculation is performed through several interpolations through KT data, using the advance ratio to find the corresponding pitch ratio, P/D. The following kT vs. J plot (below left) shows the P/D is between 0.8 and 1.





6. Using the found P/D and J, the torque coefficient, KQ, is found through several interpolations. The kQ vs. J plot (above right), shows the selected kQ and confirms that it is under the limiting kQ based on limiting engine torque

$$K_Q = \frac{Q}{\rho N_{prop}^2 D_{prop}^5}$$

7. After finding KQ and KT, the open water efficiency can be calculated with the following:

$$\eta_{open} = \frac{K_T}{K_Q}\frac{J}{2\pi}$$

8. Before calculating the total break power, the following efficiencies are calculated or estimated:

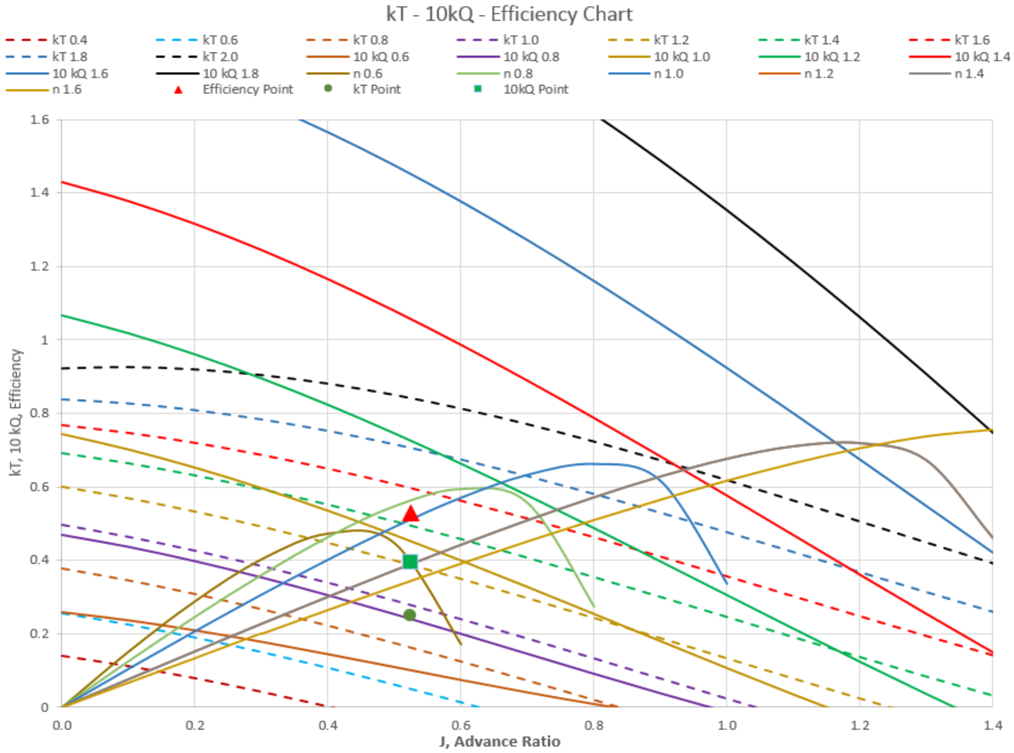
Hull Efficiency	$\eta_H = \frac{1-t}{1-w}$
Relative rotation efficiency to account for multiple propellers rotating in close proximity:	$\eta_R = 1$
Shaft Efficiency:	$\eta_S = 0.975$
Gearbox Efficiency:	$\eta_G = 0.975$

9. The total required brake output power from the engines is given by:

$$P_B = \frac{RV_S}{\eta_H \eta_R \eta_G \eta_S \eta_{open}}$$

When all three plots are combined, familiar propeller curves are generated.

Subject: Propeller Optimization Tool



In addition to calculating the required power and generating the plots shown previously, the calculation tool can also determine bollard pull. The result of this calculation is presented in the table below.

Inputs

Vessel			
Max Speed	Vs	14	kts
		7.196	m/s
Resistance	R	245	kN
Seawater Density	rho	1.0259	MT/m3
Kinematic Viscosity	mu	1.18831E-06	m^2/s
thrust deduction	t	0.2	-
wake fraction	w	0.18	-
Propeller			
Number of Propellers	#_prop	2	Props
Propeller Diameter	D	2.25	m
Rotational Speed	n	300	RPM
		5	rev/s
Expanded Area Ration	EAR	0.95	
Number of Blades	Z	5	blades
Efficiencies			
Relative Rotative Efficiency	n_r	1.00	-
Shaft Efficiency	n_s	0.98	-
Gearbox Efficiency	n_gb	0.98	-
Service Factor	x	0.10	-
Derating	dr	0.85	-
Gearbox			
Gearbox Reduction Ratio		6	

Outputs

Advancee Velocity	V_a	5.90	m/s
		11.48	kts
Advance Coefficient	J	0.52	-
Thrust per propeller (open water)	T	153	kN
Delivered Thrust per propeller	T	122.5	kN
Torque per propeller	Q	53.7	kN*m
Pitch	P	2.08	m
Pitch Ratio	P/D	0.9227	-
Thrust Coefficient	k_T	0.2330	-
Torque Coefficient	k_Q	0.0363	-
Bollard Pull (BP)			
Thrust Coefficient at Va=0	k_T	0.3343	-
Bollard Pull per propeller	T=BP	22.40	MT
Total BP	BP_tot	**35.8**	MT
P/D for max BP	P/D	0.73	
Efficiencies			
Hull Efficiency	n_h	0.98	-
Open Water Efficiency	n_o	0.5359	-

Power

Effective Power	P_e	1763	kW
Thrust Power	P_t	1807	kW
Open Water Propeller Power	P_o	3372	kW
Propeller Power	P_p	3372	kW
Shaft Power	P_s	3459	kW
Total Brake Power	P_b	3547	kW

Power per Engine		**1774**	kW
Required Engine Torque		9.41	kN*m
Engine Speed	n_e	1800	RPM

Subject: Propeller Optimization Tool

Based on the parameters of the selected propellor and the maximum torque of the selected engine, the maximum attained thrust is calcuated at every speed of the ship. The rotational speed is kept constant for this calculation. Since the vesel has controllable pitch propellers, the pitch for maximum thrust is also found for every speed of the vessel. The results of this optimization is presented below:

Maximum Thrust at Different Vessel Speeds

kT	V	J	P/D	Delivered Thrust by Propeller (kN)
0.334	0.0	0.000	0.73	176
0.279	9	0.337	0.85	147
0.272	10	0.375	0.87	143
0.265	11	0.412	0.88	140
0.259	12	0.450	0.90	136
0.252	13	0.487	0.92	133
0.246	14	0.525	0.95	129
0.239	15	0.562	0.97	126
0.233	16	0.600	0.99	123

Evaluation of Susceptibility to Cavitation
Using Burrill Cavitation Method

Inputs:

Atmospheric Pressure	Patm	101353	Pa
Vapor Pressure	Pv	1706	Pa
Seawater Density	rho	1025.9	kg/m3
Advancee Velocity	V_a	5.90	m/s
Propeller Rotational Speed	n	5	RPS
Propeller Diamter	D	2.25	m
Expanded Area Ratio	EAR	0.95	
Number of Propeller Blades	Z	5	Blades
Propeller Immersion	h_im	3.5	m

Outputs:

Resulatan Velocity	V_r	25.4	
Disk Area	A_tot	3.98	m2
Developed Area Ratio	DAR	0.95	
Developed Area	A_dev	3.78	m2
Projected Area Ratio	PAR	0.81	
Projected Area	A_proj	3.23	m2
Thrust Loading Coefficient	τ_c	0.14	
Local Cavitation Number at 0.7R	σ_0.7R	0.41	
% Back Cavitatation		0%	

Bollard Pull

Atmospheric Pressure	Patm	101353	Pa
Vapor Pressure	Pv	1706	Pa
Seawater Density	rho	1025.9	kg/m3
Advancee Velocity	V_a	0.00	m/s
Propeller Rotational Speed	n	5	RPS
Propeller Diamter	D	2.25	m
Expanded Area Ratio	EAR	0.95	
Number of Propeller Blades	Z	5	Blades
Propeller Immersion	h_im	3.5	m

Resulatan Velocity	V_r	24.7	
Disk Area	A_tot	3.98	m2
Developed Area Ratio	DAR	0.95	
Developed Area	A_dev	3.78	m2
Projected Area Ratio	PAR	1.01	
Projected Area	A_proj	4.03	m2
Thrust Loading Coefficient	τ_c	0.17	
Local Cavitation Number at 0.7R	σ_0.7R	0.43	
% Back Cavitatation		5%	

Subject: Bollard Pull Analysis using two methods **Done by:** JY **Checked:** OS

Input

For this analysis, a representative 5500 DWT barge was found on the website of barge fleet operating in BC Waters. The geometric property shown in Table 9 of the barge was used as inputs for the calculations.

Barge Particulars

L	260	ft
B	60	ft
D	22	ft
T	14.7	ft

Method 1: US Navy Towing Manual

Total barge resistance $R_{TOT} = R + G + W$

R, Frictional Resistance

$$R = f_1 \times S \times (V/6)^2$$

where:

R = Resistance in pounds

f_1 = A coefficient depending on the shape of the ship's hull (from Table G-4)

S = Area of the vessel's wetted surface below the waterline, in square feet (from Table G-4)

V = Speed of tow in knots relative to still water.

G, Wave-Forming Resistance

$$G = 2.85 \times B \times f_2 \times V^2 \times K$$

where:

G = Resistance in pounds

B = Cross-sectional area of vessel below waterline in square feet (from Table G-4)

f_2 = A coefficient depending upon the configuration of the vessel's bow and stern (from Table G-4)

V = Speed of tow in knots relative to still water

K = 1.2 (multiplying by this number adds 20 percent for additional resistance from rough water and eddies)

W, Wind Resistance

$$W = C \times .004\,(V_w + V)^2 \times f_3$$

where:

W = Resistance in pounds

C = Cross-sectional area of vessel above waterline in square feet (from Table G-4)

V_w = Speed of wind in knots

V = Speed of tow in knots, relative to still water

Method 2: Transport Canada Formula

The following equation is widely used to calculate the required bollard pull

$$BP = \left\{ \frac{\Delta^{2/3} V^3 + (0.06 \times B \times D)}{120 \times 60} \right\} \times K$$

BP = required bollard pull (tonnes)

Δ = full displacement of towed vessel (tonnes)

V = tow speed (knots)

B = breadth of towed vessel (metres)

D = depth of the exposed transverse section of the towed vessel including deck cargo, measured above the waterline (metres)

K = a factor that reflects potential weather and sea conditions;

- for exposed coastal tows K = 1.0 to 3.0
- for sheltered coastal tows K = 0.75 to 2.0
- for protected water tows K = 0.5 to 1.5

The K value of 3 was used to represent exposed costal tows.

BP Calculation Results

Velocity (kts)	Bollard Pull (MT)	
	Method 1	Method 2
2	5.3	9.1
3	11	12.2
4	18.9	18.2
5	29.2	28.1
6	41.6	42.9
7	56.4	63.5
8	73.4	91

Resistance and Thrust Summary for Towing

Velocity	Thrust @ 90% Power	Design Ship Resistance	Method 1		Method 2	
			Barge Resistance	Total Resistance	Barge Resistance	Total Resistance
0	35.3	0	0.58	0.58	7.89	7.89
1	34.7	0.6	1.79	2.39	7.97	8.57
2	34.09	1.2	5.25	6.45	9.11	10.31
3	33.44	1.81	10.96	12.77	12.19	14
4	32.78	2.41	18.93	21.34	18.21	20.62
5	32.13	3.01	29.15	32.16	28.12	31.13
6	31.48	3.61	41.64	45.25	42.91	46.52
7	30.78	4.22	56.4	60.62	63.54	67.76
8	30.09	4.82	73.36	78.18	90.99	95.81

Subject: Detailed fuel oil consumption analysis **Done by:** JY **Checked:** OS

Operation Cases	In transit 14kts	Cruising 12kts	Oil Spill	Towing	Stand By	Off Loading
Prop. Demand per engine (kW)	1902	900	250	1902	285.3	190.2
Total (kW)	1902	900	250	1902	285.3	190.2
% Loading	100	47.3	13.1	100	15	10

$$SFC\left[\frac{g}{kw*hr}\right] = \frac{SFC\left[\frac{m^3}{hr}\right]*Power*Oil\ Density*n}{1000}$$

n = number of engine or generator at work

$$\text{Oil Density} = 870\frac{kg}{m^3}$$

Mission	Operation	Equip.	Loading	SFC (m3/hr)	Hours	Fuel
Mission 1a Oil Recovery	Transit (14 kts)	Engine	100	0.9	50	47
		Genset	35.8	0.1	50	3
	Oil Recovery Operation	Engine	13.1	0.1	160	20.6
		Genset	93	0.3	160	43.5
	Standby	Engine	15	0.1	350	51.4
		Genset	56.6	0.2	350	62
	Cruise (10kts)	Engine	47.3	0.4	25	10.7
		Genset	35.8	0.1	25	1.5
Mission 1b Oil Recovery & towing	Transit (14 kts)	Engine	100	0.9	50	47
		Genset	35.8	0.1	50	3
	Oil Recovery Operation	Engine	13.1	0.1	160	20.6
		Genset	93	0.3	160	43.5
	Standby	Engine	15	0.1	350	51.4
		Genset	56.6	0.2	350	62
	Cruise (10kts)	Engine	100	0.9	63	59.2
		Genset	61	0.1	63	5.9
Mission 2 Resupply	Transit (14 kts)	Engine	100	0.9	110	103.4
		Genset	35.8	0.1	110	6.6
	Oil Recovery Operation	Engine	10	0.1	5	0.5
		Genset	93	0.3	5	1.4
	Standby	Engine	15	0.1	10	1.5
		Genset	56.6	0.2	10	1.8
	Cruise (10kts)	Engine	15	0.1	10	1.5
		Genset	71.9	0.2	10	2.1

Summary	Total Hours	Total Fuel (m3)	Total Fuel with 10% margin (m3)
Mission 1a Oil Recovery	585	258	284
Mission 1b Oil Recovery & Towing	623	302	332
Mission 2 Resupply	135	111	122

Subject: Bilge/Ballast Pump Selection **Done by:** JC **Checked by:** OS

References: 1. ABS Steel Vessels Under 90 Meters in Length Part 4 Chapter 4.3

Calculation Procedure

5.9.1 Main Line

For the diameter of main bilge line suctions and direct bilge suctions to the pumps:

$d = 25 + 1.68\sqrt{L(B+D)}$ mm $\quad d = 1 + \sqrt{L(B+D)/2500}$ in.

5.9.2 Branch Lines

For the equivalent diameter of the combined branch suctions to a compartment:

$d = 25 + 2.16\sqrt{c(B+D)}$ mm $\quad d = 1 + \sqrt{c(B+D)/1500}$ in.

Inputs

Parameters	Units	Values
Length WL	m	46.7
Beam WL	m	13.9
Depth	m	6.7
Length MR	m	18.7

Bilge Pump Capacity

The capacity of each pump is to be in accordance with the following:

Vessel Length	*Minimum Capacity per Pump*
Below 20 m (65 ft)	5.5 m^3/hr (25 gpm) (hand pump 5 gpm, 1.13 m^3/hr)
20 m (65 ft) or greater but below 30.5 m (100 ft)	11.36 m^3/hr (50 gpm)
30.5 m (100 ft) or greater but below 45.7 m (150 ft)	14.33 m^3/hr (66.6 gpm)
45.7 m (150 ft) and greater	$Q = 5.66d^2/10^3$ m^3/hr $Q = 16.1d^2$ gpm

Outputs

Parameters	Units	Values
Dia. Main	mm	76.66
Dia. Branch	mm	67.39
Flow Rate	m^3/hr	38.34
Head	m	6.70

Subject: Bilge/Ballast Pump Selection and Pipe Requirements

References: 1. ABS Steel Vessels Under 90 Meters in Length Part 4 Chapter 5.2

Calculation Procedure

Main Fire Pumps

5.1.1 Number of Pumps

For vessels of 1000 gross tons and above, the pumps are to be independently power-driven. For vessels less than 1000 gross tons, only one of the pumps need be independently power-driven and one of the pumps may be attached to the propulsion unit.

5.1.2 Total Pump Capacity

The fire pumps required by 4-5-2/5.1.1 are to be capable of delivering for firefighting purposes a quantity of water, at the appropriate pressure prescribed, not less than four-thirds of the quantity required under 4-4-3/3.3 to be dealt with by each of the independent bilge pumps when employed on bilge pumping, using in all cases L = length of vessel, as defined in 3-1-1/3, except that the total required capacity of the fire pumps need not exceed 180 m^3/hr (792 gpm).

5.1.3 Individual Pump Capacity

Each of the fire pumps required by 4-5-2/5.1.1 is to have a capacity of not less than 40% of the total required capacity, but not less than 25 m^3/hr (110 gpm), and in any event is to be capable of delivering at least the two required jets of water. These pumps are to be capable of supplying the water under the required conditions. Where more pumps than required are installed, their capacity will be subject to special consideration.

5.1.4 Pressure

For vessels 1000 gross tons and over with the two power-driven pumps simultaneously delivering through the nozzles specified in 4-5-1/3.11 the quantity of water specified in 4-5-1/3.5.1 through any adjacent hydrants, a pressure of 2.5 bar (2.6 kgf/cm^2, 37 psi) is to be maintained at all hydrants.

For vessels less than 1000 gross tons, the power-driven fire pumps are to have sufficient pressure to produce 12 m (40 ft) jet throw through any two adjacent hydrants located in accordance with 4-5-1/3.5.1.

Inputs

Parameters	Units	Values
Bilge Capacity	m^3/hr	38.34
Press @ Hydrant	Bar	2.5
Depth	m	6.7

Outputs

Parameters	Units	Values
Pump Capaciy	m^3/hr	51.12
Head	m	32.18

Subject: Main Engine Exhaust Pipe Diameter **Done by:** JC **Checked by:** OS

References: 1. CAT Marine Application and Installation Guide
2. CAT 3512C-HD Specifications
3. Inboard Profile Drawing

Calculation Procedure

Exhaust Pipe Diameter to Meet Back Pressure Limits
(Metric Units System)

P – Back pressure limit (kPa) See section on exhaust back pressure limits for specific engine.

$$D = \sqrt[5]{3600000 \frac{LSQ^2}{P}}$$

D – Inside diameter of pipe (mm)

Q – Exhaust gas flow (m^3/min). See engine performance curve.

L – Length of pipe (m). Includes all of the straight pipe and the straight pipe equivalents of all elbows.

$$S\ (kg/m^3) = \frac{352}{\text{Exhaust Temperature} + 273°F}$$

S – Specific weight of gas (kg/m^3)

Formulae for Straight Pipe Equivalent Length of Various Elbows
To obtain straight pipe equivalent length of elbows:

	English Units	Metric Units
Standard Elbow (radius of elbow equals the pipe diameter)	$L = 33 \frac{D}{12}$	$L = 33 \frac{D}{1000}$
Long Radius Elbow radius greater than 1.5 pipe diameters	$L = 20 \frac{D}{12}$	$L = 20 \frac{D}{1000}$
45° Elbow	$L = 15 \frac{D}{12}$	$L = 15 \frac{D}{1000}$

Where:
L – Straight Pipe Equivalent Length of Elbows
D – Pipe Diameter

Inputs

Parameters	Units	Values	
Exhaust Temp	ºF	1301.36	Reference 2
Exhaust Gas Flow	m^3/min	52.74	Reference 2
Vertical Stack Length	m	8.17	Reference 3
Hoirzontal Stack Length	m	3.05	Reference 3
Backpressure Limit	kPa	6.72	Reference 1

Outputs

Parameters	Units	Values	
Specific Weight of Gas	kg/m^3	0.224	
Equivalent Length	m	11.67	Solved with iteration
Inner Pipe Diameter	mm	82.79	Solved with iteration

Subject: Main Shaft Diameter Requirements

References: 1. ABS Steel Vessels Under 90 Meters in Length Part 4 Chapter 3.1
2. ZF 7661 Technical Specifications
3. CAT 3512C-HD Technical Specifications

Calculation Procedure

Solid Shaft Outer Diameter

$$D = 100K \sqrt[3]{\frac{P}{R} \frac{c_1}{U + c_2}}$$

Hollow Shafts
For hollow shafts where the bore exceeds 40% of the outside diameter, the minimum shaft diameter is not to be less than that given by the following equation:

$$D_o = D \sqrt[3]{1/[1 - (D_i / D_o)^4]}$$

where

D_o = required outside diameter, in mm (in.)
D = solid shaft diameter required by 4-3-1/7, as applicable, in mm (in.)
D_i = actual shaft bore, in mm (in.)

Inputs

Parameters	Units	Values	
Power	kW	1800	Reference 3
Rated Speed	RPM	300	Reference 3
D_i (Bore)	mm	76.62	Reference 2
U	N/mm^2	600	Reference 1
C_1	-	560	Reference 1
C_2	-	160	Reference 1
K	-	1.15	Reference 1

Outputs

Parameters	Units	Values	
Solid Shaft Diameter	mm	188.7	
Hollow Shaft Diameter	mm	190.4	Solved with iteration

Service	Source	Capacity			U.F	In Transit Summer Day		In Transit Winter Day		Oil Spill Operation Summer Day		Crane Loading Summer Day		Towing Summer Day		Stand By Summer Day		Emergency condition	
		Rated Load	Connected Load																
		KW	Qty.	kW		DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW
HPU equipment																			
Crane HPU	Cal	181.5	1.0	213.5	0.9	0.0	0.0	0.0	0.0	0.2	38.4	0.8	153.7	0.0	0.0	0.0	0.0	0.0	0.0
HPU Winchs	Cal	113.9	1.0	134.1	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	120.7	0.0	0.0	0.0	0.0
HPU for external systems	Est	40.0	1.0	47.1	1.0	0.0	0.0	0.0	0.0	0.2	9.4	0.2	9.4	0.2	9.4	0.2	9.4	0.0	0.0
HPU Rescue Boat Davit	Spec	16.0	1.0	18.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	18.8
Offshore Skimmer HPU	Cal	171.0	1.0	171.0	0.9	0.0	0.0	0.0	0.0	0.5	76.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HPU SeaReel Boom	Spec	7.5	2.0	17.5	1.0	0.0	0.0	0.0	0.0	0.5	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			sum:	**602.0**															
RO Equipment																			
Oily Water Transfer Pumps	Est	10.0	1.0	11.8	0.9	0.0	0.0	0.0	0.0	0.8	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dispersent pumps	Est	7.0	2.0	16.5	0.9	0.0	0.0	0.0	0.0	0.5	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electrical steam boiler	Spec	298.6	1.0	351.3	1.0	0.0	0.0	0.0	0.0	0.7	245.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			sum:	**379.5**															
Steering Gear Compartment																			
Steering Gear	Ref	5.0	1.0	5.9	1.0	0.3	1.8	0.3	1.8	0.3	1.8	0.3	1.8	0.3	1.8	0.3	1.8	0.0	0.0
Steering Pump Port	Ref	30.0	1.0	35.3	0.9	0.2	6.4	0.2	6.4	0.2	6.4	0.2	6.4	0.2	6.4	0.2	6.4	0.0	0.0
steering room supply fan	Ref	1.5	1.0	1.8	1.0	0.9	1.6	0.9	1.6	0.9	1.6	0.9	1.6	0.9	1.6	0.9	1.6	0.0	0.0
			sum:	**37.1**															
HVAC																			
Central AC Unit	Ref	40.0	1.0	47.1	1.0	0.6	28.2	0.0	0.0	0.6	28.2	0.6	28.2	0.6	28.2	0.6	28.2	0.0	0.0
AHU Bridge deck	Ref	2.0	1.0	2.4	1.0	0.7	1.6	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
AHU Forecastle deck	Ref	2.0	1.0	2.4	1.0	0.7	1.6	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
AHU Wheel house	Ref	2.0	1.0	2.4	1.0	0.7	1.6	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
AHU Maindeck	Ref	2.0	1.0	2.4	1.0	0.7	1.6	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
AHU Rest	Ref	2.0	1.0	2.4	1.0	0.7	1.6	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
HVAC Cooling pump	Ref	7.5	1.0	8.8	1.0	1.0	8.8	0.0	0.0	1.0	8.8	1.0	8.8	1.0	8.8	1.0	8.8	1.0	8.8
			sum:	**67.6**															

Service	Source	Capacity			U.F	In Transit Summer Day		In Transit Winter Day		Oil Spill Operation Summer Day		Crane Loading Summer Day		Towing Summer Day		Stand By Summer Day		Emergency condition	
		Rated Load	Connected Load																
		KW	Qty.	kW		DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW
Engine Room Services																			
Ships Service Air Compressor	Est	7.5	1.0	8.8	0.9	0.2	1.6	0.2	1.6	0.2	1.6	0.2	1.6	0.2	1.6	0.2	1.6	0.0	0.0
ER Ventilation Fan	Ref	9.0	4.0	42.4	1.0	0.8	33.9	0.8	33.9	0.8	33.9	0.8	33.9	0.8	33.9	0.8	33.9	0.0	0.0
Generator preheater elements	Ref	12.0	2.0	28.2	1.0	0.1	2.8	0.1	2.8	0.5	14.1	0.5	14.1	0.1	2.8	0.1	2.8	0.0	0.0
Generator preheater pumps	Ref	3.5	2.0	8.2	0.9	0.1	0.7	0.1	0.7	0.5	3.7	0.5	3.7	0.1	0.7	0.1	0.7	0.0	0.0
Fuel Oil Transfer pump	Ref	5.5	1.0	6.5	0.9	0.5	2.9	0.5	2.9	0.5	2.9	0.5	2.9	0.5	2.9	0.5	2.9	0.0	0.0
Fuel Oil Purifier	Ref	2.5	1.0	2.9	1.0	0.2	0.6	0.2	0.6	0.2	0.6	0.2	0.6	0.2	0.6	0.2	0.6	0.0	0.0
Engine Starting Air Compressors	Ref	6.2	2.0	14.6	0.9	0.2	2.6	0.2	2.6	0.2	2.6	0.2	2.6	0.2	2.6	0.2	2.6	0.0	0.0
instrumentation & controls	Ref	0.5	2.0	1.2	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0
Lube oil transfer pump	Ref	0.3	1.0	0.4	0.9	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lube oil purifier	Ref	0.3	1.0	0.4	1.0	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.0	0.0
Bilge and Ballast pump	Ref	6.3	2.0	14.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire & GS Pump	Ref	45.0	1.0	52.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sea water cooling pumps	Ref	12.6	2.0	29.6	0.9	1.0	26.7	1.0	26.7	1.0	26.7	1.0	26.7	1.0	26.7	1.0	26.7	0.0	0.0
Deck Machinery cooling pump	Ref	1.4	1.0	1.6	0.9	1.0	1.5	1.0	1.5	0.0	0.0	0.0	0.0	1.0	1.5	1.0	1.5	0.0	0.0
Cooling W drain Trans. pump	Ref	3.5	1.0	4.1	1.0	0.1	0.4	0.1	0.4	0.1	0.4	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Emergency fire pump	Ref	12.7	1.0	14.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oily Water Separator	Ref	0.4	1.0	0.4	1.0	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.0	0.0
			sum:	**232.1**															
Bow Thruster																			
Bow thruster system HU	Est	2.2	1.0	2.2	1.0	0.0	0.0	0.0	0.0	1.0	2.2	1.0	2.2	0.0	0.0	1.0	2.2	0.0	0.0
Bow thruster SW cooling pump	Est	5.5	1.0	5.5	1.0	0.0	0.0	0.0	0.0	1.0	5.5	1.0	5.5	0.0	0.0	1.0	5.5	0.0	0.0
Bow Thruster	Cal	500.0	1.0	500.0	1.0	0.0	0.0	0.0	0.0	0.8	400.0	0.8	400.0	0.0	0.0	0.8	400.0	0.0	0.0
			sum	**507.7**															
Workshop Services																			
Bench Grinder	Ref	1.0	1.0	1.2	1.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Drill Press	Ref	1.0	1.0	1.2	1.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Lathe	Ref	5.6	1.0	6.6	1.0	0.1	0.7	0.0	0.0	0.1	0.7	0.1	0.7	0.1	0.7	0.1	0.7	0.0	0.0
Arc Welder	Ref	3.0	1.0	3.5	1.0	0.1	0.4	0.0	0.0	0.1	0.4	0.1	0.4	0.1	0.4	0.1	0.4	0.0	0.0
			sum	**12.5**															

Service	Source	Capacity			U.F	In Transit Summer Day		In Transit Winter Day		Oil Spill Operation Summer Day		Crane Loading Summer Day		Towing Summer Day		Stand By Summer Day		Emergency condition	
		Rated Load	Connected Load																
		KW	Qty.	kW		DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW	DF	kW
Lighting																			
Wheelhouse lighting	Est	4.6	1.0	5.4	1.0	0.3	1.6	0.7	3.8	0.3	1.6	0.3	1.6	0.3	1.6	0.3	1.6	0.0	0.0
Interior lighting system	Ref	3.8	1.0	4.4	1.0	0.8	3.5	0.9	4.0	0.8	3.5	0.8	3.5	0.8	3.5	0.8	3.5	0.0	0.0
exterior lighting system	Ref	11.6	1.0	13.6	1.0	0.4	5.5	0.9	12.3	0.4	5.5	0.4	5.5	0.4	5.5	0.4	5.5	0.0	0.0
emergency lighting	Ref	1.0	1.0	1.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.1
			sum	**24.6**															
Fans																			
CO2 locker exhaust fan	Ref	0.5	1.0	1.7	1.0	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.0	0.0
Accomodation space exhaust fan	Ref	1.5	1.0	5.0	1.0	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.0	0.0
supply fans fan	Ref	0.1	1.0	0.4	1.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Emergency Panel fan	Ref	11.0	1.0	12.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	11.6
			sum	**7.1**															
Control and Communication,																			
Entire system	Ref	7.0	1.0	8.1	1.0	0.5	4.1	0.3	2.4	0.7	5.7	0.7	5.7	0.5	4.1	0.5	4.1	0.4	3.3
			sum	**8.1**															
Liquid Transfer Systems																			
Potable Water Pumps	Ref	12.7	2.0	29.9	0.9	0.5	13.4	0.5	13.4	0.5	13.4	0.5	13.4	0.5	13.4	0.5	13.4	0.0	0.0
Potable Water UV sterilizer	Ref	0.1	1.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cargo F.W pump	Ref	42.0	1.0	49.4	0.9	0.2	8.9	0.2	8.9	0.2	8.9	0.2	8.9	0.2	8.9	0.2	8.9	0.0	0.0
Sanitary Flushing Pumps	Ref	12.7	1.0	14.9	0.9	0.0	0.0	0.0	0.0	0.5	6.7	0.5	6.7	0.5	6.7	0.5	6.7	0.0	0.0
Sewage Treatment Plant	Ref	2.0	1.0	2.4	1.0	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.9	2.1	0.0	0.0
Grey Water Transfer Pump	Ref	0.5	1.0	0.6	0.9	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.0	0.0
Black Water Transfer Pump	Ref	2.5	1.0	2.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			sum	**100.3**															
Furnishing																			
Entire Furnishing	Ref	40.0	1.0	47.1	1.0	0.5	23.5	0.5	23.5	0.5	23.5	0.5	23.5	0.5	23.5	0.5	23.5	0.0	0.0
			sum	**47.1**															
Emergency																			
Emergency Fire Pump	Ref	7.5	1.0	8.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.9
E. Genset Preheater Element	Ref	7.5	1.0	8.8	0.9	0.3	2.4	0.3	2.4	0.3	2.4	0.3	2.4	0.3	2.4	0.3	2.4	0.0	0.0
E. Genset Room air supply fan	Ref	2.2	1.0	2.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.3
E. Genset Room electric heater	Ref	18.0	1.0	21.2	0.9	0.0	0.0	0.8	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			sum	**41.4**															

Subject: Structural Analysis Summary **Done by: VC** **Checked by: OS**

Vessel Particulars			
Summer Load WL Length	D_{LWL}	45.9	m
96% DLWL	-	44.1	m
Rule Length	k	44.1	m
Moulded Breadth	B	14.0	m
Moulded Depth	D	6.7	m
Scantling Depth	D_s	6.7	m
Moulded SWL Draft	T	5.0	m
Scantling Draft	d	5.0	m
Block Coefficient	C_B	0.59	
Frame Spacing	s	550	mm

Design Margins	
Structure - Thicknesses	5%
Structure - Section Modulus	5%

Material Constants			
Steel Density	ρ	7800	kg/m^3
Young's Modulus	E	200	GPa
Yield Strength	σ_Y	250	MPa

Section Modulus Summary			**Frame #: 43**		
	Selected Scantling	Quantity	Width/Height	Area	Height Above BL
Item		#	m	m2	m
Bottom Plating					
Keel Plate	12mm PL	1	1.73	0.016	0.00
Bottom Shell Plating	10mm PL	2	4.68	0.042	0.38
Bilge Plating	10mm PL	2	1.15	0.010	1.15
Bottom Structure					
Center Girder	10mm PL	1	1.40	0.014	0.70
Side Girders	10mm PL	2	1.10	0.011	1.24
Inner-Bottom Plating	10mm PL	1	9.30	0.047	0.70
Side Plating					
Side Shell Plating	10mm PL	2	5.20	0.052	4.13
Side Structure					
Side Bulkheads	10mm PL	2	6.09	0.061	3.66
Main Deck Plating					
Deck Plating	8mm PL	1	13.91	0.111	6.70
Main Deck Structure					
Deck Girders - Flange	200x15mm PL	6			
Deck Girders - Web	550x14mm PL	6			
			Total Area	0.382 m2	

Design Moment of Inertia		
Moment of Inertia (ref. axis)	8.82	m4
Neutral Axis	3.64	m

ABS Required		
SM	2244.22	m-cm2
I_{NA}	2969.65	cm2-m2
SM SF	4.6	**PASS**
I_{NA} SF	12.6	**PASS**

Moment of Inertia about NA		
I_{NA}	3.74	m4
	37376.85	cm2-m2

Section Modulus Calculation		
Deck Height (from BL)	6.70	m
Distance from NA to Deck	3.06	m
Section Modulus	1.22	m3
Distance from NA to Keel	3.64	m
Section Modulus	1.03	m3

Design Section Modulus		
SM	1.03	m3
	10273.95	m-cm2

Subject: Structural Analysis Summary **Done by: VC** **Checked by: OS**

Structure Summary					**Frame #: 43**	
			Req. t/SM	w/ Margin	Selected	
ABS #	Category	Item	mm/cm3	mm/cm3	mm/cm3	Section
3-2-10/1.3	Shell Plating	Keel Plate	8.10	8.51	12	PL
3-2-2/3.3		Bottom Plating	8.10	8.51	10	PL
3-2-2/5.1		Side Plating	7.81	8.20	8	PL
-		Stiffeners	-	-	180x8	BF
3-2-2/5.1		Forecastle Side Plating	6.14	6.45	8	PL
-		Bilge Plating	-	-	10	PL
3-2-14/1.3		Bulwark Plating	-	-	6	PL
3-2-3/3.1.2	Deck Plating	Main Deck (Superstructure)	5.48	5.75	8	PL
3-2-3/3.1.1		Main Deck (Aft)	5.79	6.08	10	PL
3-2-4/1.3.1	Double Bottom	Center Girder, thickness	7.97	8.37	10	PL
3-2-4/1.3.3		Center Girder, depth	872.85	916.50	10	PL
3-2-4/1.5		Side Girder, thickness	6.29	6.60	8	PL
3-2-4/1.7		Floor, thickness	6.29	6.60	8	PL
-		Floor, Stiffeners	-	-	100x8	FB
3-2-4/1.13		Inner-Bottom Plating, thickness	8.08	8.48	12	PL
3-2-7/5.1	Side Frames	Side Bulkheads	4.60	4.83	10	PL
3-2-7/5.3		Side Bulkhead Stiffeners	-	-	180x8	BF
3-2-5/11.3		Side Stringer	7.82	8.21	10	PL
3-2-6/3.3	Deck Structure	Main Deck CL Girder		247.16	500x14	Web
3-2-6/3.3			235.39		200x16	Flange
3-2-6/1.5		Deck Girders		247.16	500x14	Web
-			235.39		200x16	Flange
3-2-6/5.3		Pillar	-	-	219 OD Sched 80 Pipe	
3-2-7/5.1	Watertight Bulkheads	Plating	4.60	4.83	8	PL
3-2-7/5.3		Stiffeners	38.74	40.68	180x8	BF
3-2-8/5.1	Deep Tank	Plating	6.50	6.83	10	PL
3-2-8/5.3		Stiffeners	83.86	88.06	180x8	BF

Subject:	Structural Analysis Summary	**Done by: VC**	**Checked by: OS**

ABS Requirements	***ABS 3-2-1/3.1***	**Item: Minimum Section Modulus**

Calculation Parameters			
Constant 1	C_1	6.40	-
Constant 2	C_2	0.01	-
Length of Vessel	L	44.1	m
Breadth of Vessel	B	14.0	m
Block Coefficient	C_B	0.6	-

Constant 1	**L = 44.1 m**	
$30.67 - 0.98L$	$12 \leq L < 18$ m	
$22.40 - 0.52L$	$18 \leq L < 24$ m	
$15.20 - 0.22L$	$24 \leq L < 35$ m	
$11.35 - 0.11L$	**$35 \leq L < 45$ m**	✓
6.4	$45 \leq L < 61$ m	
$0.0451L + 3.65$	$61 \leq L < 90$ m	

Calculation			
		$SM = C_1 C_2 L^2 B(C_B + 0.7)$	
Min. Section Modulus	**SM**	**2244.2**	**m-cm^2**

ABS Requirements	***ABS 3-2-1/3.1***	**Item: Minimum Hull Girder Moment of Inertia**

Calculation Parameters			
Length of Vessel	L	44.064	m
Hull Girder Section Mod.	SMReq	2244.2	m-cm2

Calculation			
		$I = L(SM)/33.3$	
Min. Moment of Inertia	**I**	**2969.6**	**m-cm^4**

ABS Requirements	***ABS 3-2-2/3.3***	**Item: Minimum Bottom Shell Plating Thickness**

Calculation Parameters			
Length of Vessel	L	44.1	m
Frame Spacing	s	550.0	mm
Depth	h	6.7	m
Scantling Draft	d	5.0	m

Calculation			
		$t = \frac{s\sqrt{h}}{254} + 2.5\ mm$	
Bottom Shell Thickness	**t**	**8.1**	**mm**

Depth - Calc.		**D = 6.7 m**	
Largest of the following:			
0.1L	4.41	m	
1.18d	5.90	m	
D	**6.7**	**m**	✓

Scantling Draft - Calc.		**d = 5.0 m**	
Largest of the following:			
0.066L	2.91	m	
d	**5.0**	**m**	✓

ABS Requirements	***ABS 3-2-2/5***	**Item: Minimum Side Shell Plating Thickness**

Calculation Parameters			
Length of Vessel	L	44.1	m
Frame Spacing	s	550.0	mm
Depth	h	6.7	m
Scantling Draft	d	5.0	m

Calculation			
		$t = \frac{s\sqrt{h}}{268} + 2.5\ mm$	
Side Shell Thickness	**t**	**7.8**	**mm**

Depth - Calc.	**D = 6.7 m**		
Largest of the following:			
0.1L	4.41	m	
1.18d	5.90	m	
D	**6.7**	**m**	✓

Scantling Draft - Calc.		**d = 5.0 m**	
Largest of the following:			
0.066L	2.91	m	
d	**5.0**	**m**	✓

Subject:	Structural Analysis Summary	**Done by: VC**	**Checked by: OS**

3-2-2/5.5 - Side Shell Plating @ Ends			
Calculation			
	$t = 0.0455L + 0.009s\ mm$		
Side Shell t @ ends	**t**	**7.0**	**mm**

3-2-2/5.7 - Forecastle Side Plating			
Calculation			
	$t = 0.038(L + 30.8) + 0.006s\ mm$		
Forecastle Plate t	**t**	**6.1**	**mm**

ABS Requirements	***ABS 3-2-3/3.1***	**Item: Minimum Deck Plating Thickness**

Calculation Parameters			
Length of Vessel	L	44.1	m
Frame Spacing	s	550.0	mm
Height	h	See below	

Height - Calc.		
3.1All Decks		
h	**3.66**	**m**
3.1.1Exposed Freeboard Deck-No Deck Below		
h	**2.31**	**m**
3.1.2Exposed Freeboard Deck-Deck Below		
h	**1.89**	**m**
3.1.4All Other Locations		
h	**1.05**	**m**

Calculation			
	$t = \frac{s\sqrt{h}}{254} + 2.5\ mm$		
3.1 - All Decks	**t**	**6.6**	**mm**
3.1.1 - Fb Deck	**t**	**5.8**	**mm**
3.1.2 - Fb Deck - Deck	**t**	**5.5**	**mm**
3.1.4 - All Other Decks	**t**	**4.7**	**mm**

ABS Requirements	***ABS 3-2-4/1.3***	**Item: Double Bottom Structure Sizing**

Calculation Parameters			
Length of Vessel	L	44.1	m
Breadth of Vessel	B	14.0	m
Scantling Draft	d	5.0	m
Frame Spacing	s	550.0	mm
Constant	c	4.7	mm

Calculation			
Centre Girder Thickness	**t**	**7.97**	**mm**
Centre Girder Depth	$\mathbf{h_g}$	**872.85**	**mm**
Side Girder Thickness	**t**	**6.29**	**mm**
Floor Thickness	$\mathbf{t_{floor}}$	**6.29**	**mm**
Inner-Bottom Thickness	$\mathbf{t_{bottom}}$	**8.08**	**mm**

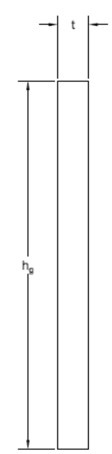
Minimum Girder Thickness - Calc.			
1.3.1 Thickness Amidships			
$t = 0.056L + 5.5$	**t**	**7.97**	**mm**

Minimum Girder Depth - Calc.			
1.3.3 Depth			
$h_g = 32B + 190\sqrt{d}$	$\mathbf{h_g}$	**872.85**	**mm**

Minimum Side Girder Thickness - Calc.			
1.5 Side Girders			
$t = 0.036L + c$	**t**	**6.29**	**mm**

Minimum Floor Thickness			
1.7 Floors			
$t_{floor} = t_{side\ girder}$	**t**	**6.29**	**mm**

Minimum Inner-Bottom Plating Thickness			
1.13 Inner Bottom Plating			
	$t = 0.037L + 0.009s + c$		
Constant c			
In engine space	**1.5**	**mm**	✓
Elsewhere	-0.5	mm	
t	**8.08**	**mm**	



Subject:	Structural Analysis Summary	**Done by: VC**	**Checked by: OS**

ABS Requirements	***ABS 3-2-5/5.1***	**Item: Transverse Side Frames Sizing**

Calculation Parameters			
Length of Vessel	L	44.1	m
Frame Spacing	s	0.550	m
Unsupported Span	l	2.60	m
Height	h	2.58	m
Constant	c	0.915	-

Constant c			
No Tween Decks Above			
	c	**0.915**	✓
Tween Decks Above			
$c = 0.90 + 5.8/l^3$	c	1.231	

Calculation			
		$SM = 7.8chsl^2$	
Min. Section Modulus	**SM**	**68.33**	**cm³**

Straight Line Unsupported Span - Calc.			
Largest of the following:			
Measured from design	**2.60**	**m**	✓
Miniumum	2.10	m	

Height - Calc.			
Largest of the following:			
Measured from design	**2.58**	**m**	✓
0.02L + 0.46	1.34	m	

ABS Requirements	***ABS 3-2-5/11.1***	**Item: Side Stringer Sizing**

Calculation Parameters			
Length of Vessel	L	44.064	m
1/2 Length Supported Fr.	s	2.599	m
Unsupported Span	l	1.98	m
Height	h	2.58	m
Constant	c	0.915	-

Height - Calc.			
Vert. distance from middle of s to freeboard deck			
	h	**2.578 m**	✓
Minimum			
$h = 0.02L + 0.46$	h	1.341 m	

Calculation			
		$SM = 7.8chsl^2$	
Min. Section Modulus	**SM**	**187.44**	**cm³**
Min. Stringer Thickness	**t**	**7.82**	**mm**

Stringer Proportions			
11.3 Thickness			
$h = 0.014L + 7.2$	**t**	**7.82**	**mm**

ABS Requirements	***ABS 3-2-6/5.3***	**Item: Pillar Sizing (Permissable Load)**

Calculation Parameters			
Unsupported Pillar Length	l	3.478	m
Area of Pillar	A	84.13	cm^2
Radius of Gyration of Pillar	r	2.59	cm
Constant	k	12.09	
Constant	n	0.044	-

Calculation			
Permissable Load		$W_a = \left(k - \frac{nl}{r}\right)A$	
	W_a	**337.19**	**kN**

Subject:	Structural Analysis Summary	**Done by: VC**	**Checked by: OS**

ABS Requirements	***ABS 3-2-6/5.5***	**Item: Pillar Sizing (Calculated Load)**

Calculation Parameters			
Mean Length Supported	s	1.65	m
Mean Breadth Supported	b	1.40	m
Height	h	1.614	m
Constant	n	7.040	-

Height - Calc.		
Largest of the following:		
Measured from design	1.61 m	
0.02L + 0.76	**1.64 m**	✓

Calculation		
Calculated Load	$W = nbhs$	
	W	**26.69 kN**

ABS Required		
Permissable Load	337.2 kN	
Calculated Load	26.7 kN	**PASS**

ABS Requirements	***ABS 3-2-6/3.3***	**Item: Deck Girders Sizing**

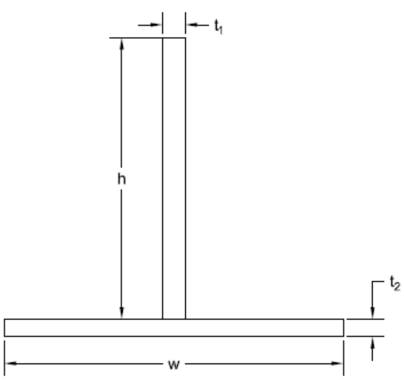
Calculation Parameters			
Length of Vessel	L	0.000	m
Spacing Dk Transverse	b	3.10	m
Unsupported Span	l	3.48	m
Height	h	1.34	m
Constant	c	0.6	-

Beams - Deck Centre Line Girder		
Required SM	189.94	cm^3
Required SM+5% Margi	199.44	cm^3

Calculation			
		$SM = 7.8chsl^2$	
Required Section Modulus	SM_{Req}	**235.39**	cm^3
Design Section Modulus	SM_{Des}	**882.58**	cm^3

Minimum Girder Depth			
3-2-6/3.5 Girder Depth			
$h = 58.3l$	**h**	**202.7674**	**mm**

Selected Section Dimensions			
Girder Web	550x14	PL	
Girder Flange	200x16	PL	
Web Depth	h	50	cm
Web Thickness	t_1	1.4	cm
Flange Width	w	20	cm
Flange Thickness	t_2	1.6	cm



Calculation - Selected Girder Section Modulus

	Area (cm^2)	y (cm)	Ay	Ay^2	I (cm^4)
Web	70.0	25.0	70.0	43750.0	14583.3
Flang	32.0	50.8	32.0	82580.5	6.8
Total	102.0		3375.6	126330.5	14590.2

Total Stiff Area		32.0	cm^2	Web - distance to NA	y	33.1	cm
Location of Neutral Axis		33.1	cm	Flange - distance to NA	y	18.5	cm
Moment of Inertia (CG)	I_{CG}	140920.6	cm^4	**Web - Section Mod.**	SM_{Web}	**882.6**	cm^3
Moment of Inertia (NA)	I_{NA}	29208.1	cm^4	Flange - Section Mod.	SM_{Flange}	1578.3	cm^3

Subject: Structural Analysis Summary **Done by: VC** **Checked by: OS**

ABS Requirements	***ABS 3-2-7/5.1***	**Item: Watertight Bulkhead Minimum Thickness**

Calculation Parameters			
Stiffener Spacing	s	575.0	mm
Plate Distance to WL	h	2.60	mm
Panel Aspect Ratio	α	2.56	-
Constant	q	0.94	N/mm^2
Constant	k	1.0	-
Constant	c	290.0	-
Steel Yield Strength	σ_Y	250	N/mm^2

Aspect Ratio - Calc.		**α = 2.56**	
"Worst Case" Panel Selected			
Panel Width	w	6900	mm
Panel Depth	h	2700	mm
Panel Aspect Ratio	**α**	**2.56**	-

Calculation			
Minimum Plate Thickness	$t = sk\frac{\sqrt{qh}}{c} + 1.5$		
	t	**4.60**	**mm**

Constant k - Calc.	**k = 1.0**		
(1 ≤ α ≤ 2)	$k = \frac{3.075\sqrt{\alpha} - 2.077}{\alpha + 0.272}$		
	k	0.93	
(α > 2)	**k**	**1.00**	✓

Constant q - Calc.		**q = 0.94 N/mm^2**	
Steel Yield Strength	Y	250	Mpa
$q = 235/Y$	**q**	**0.94**	

Constant c - Calc.		**c = 290**	
Collision Bulkhead	c	254	
Other WT Bulkhead	**c**	**290**	✓

ABS Requirements	***ABS 3-2-8/5.1***	**Item: Deep Tanks Minimum Thickness**

Calculation Parameters			
Stiffener Spacing	s	457.1	mm
Height	h	3.87	mm
Panel Aspect Ratio	α	1.45	-
Constant	q	0.94	N/mm^2
Constant	k	0.9	-
Steel Yield Strength	σ_Y	250	N/mm^2

Aspect Ratio - Calc.		**α = 1.45**	
"Worst Case" Panel Selected			
Panel Width	w	4650	mm
Panel Depth	h	3200	mm
Panel Aspect Ratio	**α**	**1.45**	-

Calculation			
Minimum Plate Thickness	$t = sk\frac{\sqrt{qh}}{254} + 2.5$		
	t	**6.50**	**mm**

Constant k - Calc.	**k = 1.0**		
(1 □□/□□2)	$k = \frac{3.075\sqrt{\alpha} - 2.077}{\alpha + 0.272}$		
	k	**0.85**	✓
(□□> 2)	k	1.00	

Constant q - Calc.		**q = 0.94 N/mm^2**	
Steel Yield Strength	Y	250	Mpa
$q = 235/Y$	**q**	**0.94**	

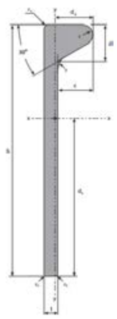
ABS Requirements	***ABS 3-2-10/1.3***	**Item: Plate Keel Thickness**

Calculation Parameters			
Length of Vessel	L	44.1	m
Frame Spacing	s	550.0	mm
Depth	h	6.7	m
Scantling Draft	d	5.0	m

Calculation			
	$t_{Keel} \geq t_{Bottom}$		
Bottom Shell Thickness	**t**	**8.1**	**mm**
Min. Keel Thickness	**t**	**8.1**	**mm**

Subject: Structural Analysis Summary		**Done by: VC**	**Checked by: OS**
ABS Requirements	***ABS 3-2-7/5.3***		**Item: Watertight Bulkhead Stiffeners**

Calculation Parameters			
Stiffener Spacing	s	0.575	m
Constant	c	0.30	
Height	h	3.950	m
Attachment Distance	l	2.70	m



Calculation			
		$SM = 7.8chsl^2$	
Req. Stiffener SM	SM_{Req}	**38.74**	cm^3
Design Section Mod.	SM_{Des}	**157.73**	cm^3

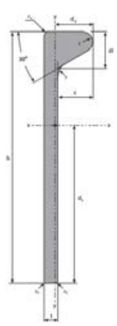
Selected Section Dimensions			
Stiffener	180x8	BF	
Length	b	180	mm
Thickness	t	0.8	cm
Area	A	18.83	cm2
CG Location	dx	10.9	cm
2nd Moment of Area	I_x	606.55	cm4
Plate			
	Width	690	cm
	Thickness	0.8	cm
	Depth	270	cm

Calc. - Selected Stiffener Section Modulus				**Section: 180x8 BF**	
	Area (cm^2)	y (cm)	Ay	Ay^2	I (cm^4)
Plate	552.0	-0.4	-220.8	88.3	29.4
Bulb Flat	18.8	10.9	205.2	2237.2	606.6
Total	570.8	0.0	-15.6	2325.5	636.0

Total Stiff Area		18.8	cm^2	Plate - distance to NA	y	0.8	cm
Location of Neutral Axis		0.0	cm	Flat - distance to NA	y	18.8	cm
Moment of Inertia (CG)	I_{CG}	2961.5	cm^4	Plate - Section Modulus	SM_{Plate}	3831.9	cm^3
Moment of Inertia (NA)	I_{NA}	2961.1	cm^4	Flat - Section Modulus	SM_{Flat}	157.7	cm^3

ABS Requirements	***ABS 3-2-8/5.3***	**Item: Deep Tank Stiffeners Section Modulus**

Calculation Parameters			
Stiffener Spacing	s	0.457	m
Constant	c	0.59	
Height	h	3.867	m
Attachment Distance	l	3.20	m



Calculation			
		$SM = 7.8chsl^2$	
Req. Stiffener SM	SM_{Req}	**83.86**	cm^3
Design Section Mod.	SM_{Des}	**158.22**	cm^3

Selected Section Dimensions			
Stiffener	180x8	BF	
Length	b	180	mm
Thickness	t	0.8	cm
Area	A	18.83	cm2
CG Location	dx	10.9	cm
2nd Moment of Area	I_x	606.55	cm4
Plate			
	Width	465	cm
	Thickness	1	cm
	Depth	320	cm

Calc. - Selected Stiffener Section Modulus				**Section: 180x8 BF**	
	Area (cm^2)	y (cm)	Ay	Ay^2	I (cm^4)
Plate	465.0	-0.5	-232.5	116.3	38.8
Bulb Flat	18.8	10.9	205.2	2237.2	606.6
Total	483.8		-27.3	2353.4	645.3

Total Stiff Area		18.8	cm^2	Plate - distance to NA	y	0.9	cm
Location of Neutral Axis		-0.1	cm	Flat - distance to NA	y	18.9	cm
Moment of Inertia (CG)	I_{CG}	2998.7	cm^4	Plate - Section Modulus	SM_{Plate}	3176.1	cm^3
Moment of Inertia (NA)	I_{NA}	2997.2	cm^4	Flat - Section Modulus	SM_{Flat}	158.2	cm^3

Weight Estimate - Section 100 - Structure

Done by: VC | Checked by: OS | Drawing Used: March 18 | **Items: 13** | **Note:** | **Port negative**

Section 100 - Structure	Source	Volume	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom
	Estimated/ Guessed	m3	MT/m3		t	Fr. 0	m	m	m	MT m	MT m	MT m
Hull	Total of estimated below				630.6	40.5	22.3	4.2	0.0	14047.5	2648.7	0.0
Main Structure	Estimated hull gider volume throughout length of ship using sectional area curve				142.5	-	-	-	-	-	-	-
Floors	Floor volume scaled using sectional area curve, 1 floor per frame				73.6	-	-	-	-	-	-	-
Side Plate Stiff	Added as 35% weight on the approx. weight of side plate				10.4	-	-	-	-	-	-	-
Side BKD Stiff	Added as 35% weight on the approx. weight of side bulkhead				15.2	-	-	-	-	-	-	-
Main Deck Stiff	Added as 35% weight on the approx. weight of main deck plate				12.6	-	-	-	-	-	-	-
Shell Plating	Shell areas measured in software, weight estimated using plate thickness				171.1	-	-	-	-	-	-	-
Tank BKD	Tank areas measured in GA, weight estimated using plate thickness				42.6	-	-	-	-	-	-	-
Tank BKD Stiff	Added as 35% weight on the approx. weight of main tank plates				14.9	-	-	-	-	-	-	-
Superstructure Boundary	Plating length measured in GA, weight esimated using plate thickness				11.7	-	-	-	-	-	-	-
Deckhouse & Wheelhouse	Scaled from Reference Vessel	750	0.11	1	82.5	59.0	32.5	11.5	0.0	2677.1	948.8	0.0
Bulwark	Estimated	-	-	-	7.0	43.0	23.7	7.2	0.0	165.6	50.4	0.0
Mast	Estimated	-	1.1	1	1.1	53.0	29.2	16.3	0.0	32.1	17.9	0.0
		TOTAL WEIGHT			**721.2**		**23.5**	**5.1**	**0.0**	16922.3	3665.7	0.0
		ALLOWANCE MARGIN			**5%**							
		TOTAL WEIGHT (W/ MARGIN)			**757.3**		**23.5**	**5.1**	**0.0**			

Weight Estimate - Section 200 - Propulsion Equipment

Done by: VC | Checked by: OS | Drawing Used: March 18 | Items: 15 | **Note:** | **Port negative**

Section 200 - Propulsion Equipment		Source	Notes	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom
Unit Name	**Unit Model**			MT		MT	Fr. 0	m	m	m	MT m	MT m	MT m
Main Engines	CAT 3512D	Vendor	Dry weight	7.5	2	15.0	43.5	23.9	2.4	0.0	358.9	36.0	0.0
Heat Exchangers	for CAT 3512D	Vendor	-	-	2	-	-	-	-	-	-	-	
Couplings	-	Estimated	-	0.5	2	1.3	40	22.0	2.3	0.0	28.6	3.0	0.0
Gearbox	ZF 7661	Vendor	-	2.5	2	5.0	40	22.0	2.3	0.0	110.0	11.4	0.0
Shaft System	-	ABS Rules	-	4.0	2	8.0	22.5	12.4	2.1	0.0	99.0	16.8	0.0
Stern Tubes	-	ABS Rules	-	0.8	2	1.6	22.5	12.4	2.1	0.0	19.8	3.4	0.0
Propeller	B-series Propeller	Guess	-	0.6	2	1.2	7.5	4.1	1.3	0.0	5.0	1.6	0.0
Steering Gear	Macgregor Poseidon 150-35	Vendor	-	2.2	2	4.4	4.5	2.5	4.3	0.0	10.9	19.0	0.0
Cooling System	-	Estimated	-	0.5	2	1.0	53	29.2	1.7	0.0	29.2	1.7	0.0
Exhaust System													
SCR System (Piping Included)	CAT CEM	Vendor	-	1.7	2	3.4	49.5	27.2	7.2	0.0	92.6	24.5	0.0
SCR Dosing Cabinet and Air Compressor	CAT CEM	Vendor	-	0.2	2	0.4	53	29.2	4.4	0.0	12.1	1.8	0.0
Main Engine Silencer (with Exhaust Piping)	-	Estimated	-	1.0	2	2.0	51	28.1	10.6	0.0	56.1	21.2	0.0
Genset Silencer (w/ Exhaust Piping)	-	Estimated	-	0.3	2	0.6	52.5	28.9	8.0	0.0	17.3	4.8	0.0
Bow Thruster Assembly	-	Estimated	-	5.0	1	5.0	74	40.7	2.0	0.0	203.5	10.0	0.0
			TOTAL WEIGHT			**48.9**		**69.5**	**10.3**	**0.0**	1042.9	155.0	0.0
			ALLOWANCE MARGIN			**12%**							
			TOTAL WEIGHT (W/ MARGIN)			**54.8**		**69.5**	**10.3**	**0.0**			

Weight Estimate - Section 300 - Electrical Equipment

Done by: VC | Checked by: OS | Drawing Used: March 18 | Items: 8 | **Note:** | **Port negative**

Section 300 - Electrical Equipment		Source	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom
Unit Name	**Unit Model**		MT/		t	Fr. 0	m	m	m	MT m	MT m	MT m
Aft Genset	CAT C18	Vendor	4.4	1	4.4	42	23.1	2.2	0.0	101.8	9.7	0.0
Genset	CAT C18	Vendor	4.4	2	8.8	47	25.9	2.2	0.0	227.8	19.4	0.0
Emergency Generator	CAT C9	Vendor	1.5	1	1.5	27	14.9	7.2	-4.5	22.3	10.8	-6.8
Lighting Systems	-	Scaled	10.0	1	10.0	50	27.5	7.0	0.0	275.0	70.0	0.0
Distribution transformers	-	Scaled	3.0	1	3.0	59.5	32.7	5.0	3.4	98.2	15.0	10.2
Main switchboard	-	Scaled	4.4	2	8.8	61	33.6	5.0	2.5	295.2	44.0	22.0
Emergency Generator Switchboard	-	Guess	0.4	1	0.4	50	27.5	9.8	-0.2	11.0	3.9	
Cables	-	Estimated	7.5	1	7.5	50	27.5	6.0	0.0	206.3	45.0	0.0
		TOTAL WEIGHT			**44.4**		**82.9**	**14.6**	**1.7**	1237.5	217.8	25.5
		ALLOWANCE MARGIN			**15%**							
		TOTAL WEIGHT (W/ MARGIN)			**51.1**		**82.9**	**14.6**	**1.7**			

Weight Estimate - Section 400 - Communications, Navigation and Ship Control

Done by: VC | Checked by: OS | Drawing Used: March 18 | Items: 5 | Note: Port negative

Section 400 - Communications, Navigation and Ship Control		Source	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom
Unit Name	Unit Model		MT/		MT	Fr. 0	m	m	m	MT m	MT m	MT m
Antenna Systems	-	Estimated	-	1	0.30	53	29.2	15.0	0.0	8.7	4.5	0.0
Integrated Navigation Electronics & Lighting	-	Estimated	-	1	0.25	55	30.3	13.3	0.0	7.6	3.3	0.0
Interior Communications, Indications and Alarms	-	Estimated	-	1	1.70	55	30.3	13.3	0.0	51.4	22.6	0.0
External Communication Systems	-	Estimated	-	1	0.40	55	30.3	13.3	0.0	12.1	5.3	0.0
Networks and Servers	-	Estimated	-	1	0.40	55	30.3	13.3	0.0	12.1	5.3	0.0
		TOTAL WEIGHT			**3.1**		**30.1**	**13.5**	**0.0**	**91.9**	**41.1**	**0.0**
		ALLOWANCE MARGIN			**10%**							
		TOTAL WEIGHT (W/ MARGIN)			**3.4**		**30**	**13**	**0**			

Weight Estimate - Section 500 - Auxiliary Equipment/ Systems

Done by: VC | Checked by: OS | Drawing Used: March 26 | Items: 42 | Note: Port negative

Section 500 - Auxiliary Equipment (Systems)		Source	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom	COMMENT
Unit Name	Unit Model		MT		MT	Fr.0	m	m	m	MT m	MT m	MT m	
Hold Level													
Engine Room													
Cooling Pump	Included in ME/Genset		0.137	2	0.3	54.0	29.7	1.8	0.0	8.1	0.5	0.0	Included with ME
Ballast/Bilge Pump	Azcure - VM-EF-80/16-R	Vendor	0.137	2	0.3	51.2	28.2	1.8	0.4	7.7	0.5	0.1	
Lube Oil Resevoir	-	Estimated	-	-	0.2	39.5	21.7	2.9	0.0	4.3	0.6	0.0	
PTO Pump (attached to ME)	Hawe - V30E-270	Vendor	0.129	2	0.3	39.5	21.7	2.9	0.0	5.6	0.8	0.0	
Fire Pump	Azcure - VM-50/20-EF	Vendor	0.137	2	0.3	38.0	20.9	1.8	0.0	5.7	0.5	0.0	Estimated VCG based on MA
Urea Pump	Typ. Pump	Estimated	0.125	2	0.3	54.5	30.0	1.8	0.0	7.5	0.5	0.0	Assumed Typ. Pump weight, height
Oily Water Pump	-	Vendor	0.150	1	0.2	54.5	30.0	1.8	0.0	4.5	0.3	0.0	
Ballast Manifold	-	Estimate	0.150	1	1.0	46.0	25.3	1.8	4.4	25.3	1.8	4.4	
Bow Thruster Compartment													
Black Water Pump	Typ. Pump	Estimated	0.125	1	0.1	58.0	31.9	1.8	-1.5	4.0	0.2	-0.2	Assumed Typ. Pump weight, height
Grey Water Pump	Typ. Pump	Estimated	0.125	1	0.1	58.0	31.9	1.8	-1.5	4.0	0.2	-0.2	Assumed Typ. Pump weight, height
Clean Water Pump	Typ. Pump	Estimated	0.125	1	0.1	60.0	33.0	1.8	-1.5	4.1	0.2	-0.2	Assumed Typ. Pump weight, height
UV Sterilizer	-	Guess	0.500	1	0.1	60.0	33.0	1.8	-1.4	4.1	0.2	-0.2	
Emergency Fire Pump	Azcure - VM-EF-80/16-R	Vendor	0.137	1	0.1	62.0	34.1	1.8	-1.5	4.7	0.2	-0.2	Estimated VCG based on MA
Sewage Treatment Plant	-	Guess	0.700	1	0.7	63.0	34.7	1.8	1.4	24.3	1.3	1.0	
FM200 System	-	Guess	1.500	1	1.5	63.5	34.9	1.8	1.2	52.4	2.7	1.8	
Compressor - General Purpose	-	-	0.300	2	0.6	35.0	19.3	4.5	0.0	11.6	2.7	0.0	
Mezzanine Level													
Steering Gear Compartment													
Steering Gear Pump	Typ. Pump	Estimated	0.125	2	0.3	6.2	3.4	4.2	0.0	0.9	1.1	0.0	Assumed Typ. Pump weight, height
Heating System Room													
Tank Heating System	-	Guess	1.500	1	1.5	35.0	19.3	5.1	3.3	28.9	7.7	5.0	
Boiler Make Up Water Pump	Typ. Pump	Estimated	0.125	1	0.1	37.5	20.6	4.2	1.0	2.6	0.5	0.1	Assumed Typ. Pump weight, height
Pump Room													
Dispersant Pump	Typ. Pump	Estimated	0.125	1	0.1	37.5	20.6	4.2	-4.5	2.6	0.5	-0.6	Assumed Typ. Pump weight, height
Sludge Oil Pump	Typ. Pump	Estimated	0.125	1	0.1	37.5	20.6	4.2	-4.5	2.6	0.5	-0.6	Assumed Typ. Pump weight, height
Fuel Oil Manifold	-	Guess	1.000	1	1.0	34.0	18.7	4.2	-4.4	18.7	4.2	-4.4	
Fuel Oil Transfer Pump	Typ. Pump	Estimated	0.125	1	0.1	34.0	18.7	4.2	-3.5	2.3	0.5	-0.4	Assumed Typ. Pump weight, height
Fuel Oil Purifier Module	-	-	1.000	1	1.0	34.0	18.7	4.2	-2.4	18.7	4.2	-2.4	
Domestic Equipment Room													
Sanitary Flushing Pump	Typ. Pump	Estimated	0.125	1	0.1	67.7	37.2	4.2	-1.4	4.7	0.5	-0.2	Assumed Typ. Pump weight, height
Hot Water Tank	-	Guess	0.500	1	0.5	69.5	38.2	4.2	-1.3	19.1	2.1	-0.7	
AC Chiller Unit	-	Guess	1.000	1	1.0	69.5	38.2	4.2	1.4	38.2	4.2	1.4	
AC Chiller Pump	-	Typ Pump	0.125	1	0.1	37.5	67.7	1.8	1.4	8.5	0.2	0.2	Assumed Typ. Pump weight, height
Grease Separator	-	-	0.150	1		37.5	20.6	1.8	0.3	0.0	0.0	0.0	
Miscellaneous													
Heating, Ventilation & Air Cond.	-	Estimated	-	-	5.0	60.0	33.0	2.7	0.0	165.0	13.5	0.0	Estm. locat. near front L/3 at DH h/3
Chilled Water System	-	Estimated	-	-	6.0	60.0	33.0	2.7	0.0	198.0	16.2	0.0	Similar LCG and TCG as HVAC
Refrigeration System	-	Estimated	-	-	1.4	75.0	41.3	7.6	1.6	57.7	10.6	2.2	Estim. based on refrig./freezer in GA
Piping	-	Empirical Estimate	-	-	25.0	43.0	23.7	4.5	0.0	591.3	112.5	0.0	
		TOTAL WEIGHT			**49.5**		**1337.5**	**192.2**	**6.0**	1337.5	192.2	6.0	
		ALLOWANCE MARGIN			**15%**								
		TOTAL WEIGHT (W/ MARGIN)			**56.9**		**1337.5**	**192.2**	**6.0**				

Weight Estimate - Section 600 - Outfit and Furnishing

Done by: VC | Checked by: OS | Drawing Used: March 18 | Items: 28 | Note: Port negative

Section 600 - Outfit and Furnishing	Source	Notes	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom	COMMENT
			MT/		MT	Fr.0	m	m	m	MT m	MT m	MT m	
Floor plates and grating	Estimated	ER, Mezz & Focstle	-	-	15.0	45.0	24.8	4.8	0.0	371.3	72.0	0.0	
Escape Ladders	Estimated	-	-	-	2.0	43.0	23.7	6.0	6.0	47.3	12.0	12.0	
Staircases	Estimated	-	1.5	6	9.0	53.0	29.2	6.0	0.0	262.4	54.0	0.0	
Handrails	Estimated	In ER, Focstle, WH			5.0	53.0	29.2	6.7	0.0	145.8	33.5	0.0	
Weathertight Doors	Vendor		0.6	12	7.2	43.0	23.7	7.6	0.0	170.3	54.7	0.0	
Watertight and Fire Doors	Estimated	-	-	-	8.0	45.0	24.8	5.5	0.0	198.0	44.0	0.0	
Hatches	Estimated	-	-	-	2.0	45.0	24.8	6.7	0.0	49.5	13.4	0.0	
Hull Protection and Coatings													
Paint	Estimated	Interior and Exterior	-	-	8.0	45.0	24.8	6.0	0.0	198.0	48.0	0.0	
Hull Insulation	Estimated	ER, Hull compartments etc	-	-	8.0	45.0	24.8	4.3	0.0	198.0	34.4	0.0	
Crew Spaces - Includes Inside doors, deck coverings, furniture and lining, and insulation													
Cabin and Washrooms	Estimated	-	3.00	5	15.0	57.0	31.4	10.3	5.0	470.3	154.9	75.0	Reference typical weight of 2 person cabin + washroom
Mess and Lounge	Estimated	-	7.40	1	7.4	70.0	38.5	7.5	-1.5	284.7	55.3	-11.1	Measured volume from GA and used RAL scaling factor
Supernumeraries Cabin and Washroom	Estimated	-	3.00	2	6.0	60.0	33.0	7.5	4.4	198.0	44.9	26.6	Reference typical weight of 2 person cabin + washroom
Master/ Chief Engineer Cabin and Washroom	Estimated	-	3.50	2	7.0	68.0	37.4	10.3	0.0	261.8	72.3	0.0	Reference typical weight of masters cabin + washroom
Galley	Estimated	-	6.50	1	6.5	67.0	36.9	7.5	1.0	239.5	48.6	6.5	V from GA, RAL scaling, x2 for heavier equipment (stove, fridge)
Pilot House	Estimated	-	19.30	1	19.3	58.0	31.9	13.4	0.0	615.5	258.9	0.0	V from GA, RAL scaling factor
Entry Lobby	Estimated	-	3.50	1	3.5	48.5	26.7	7.5	0.0	93.4	26.2	0.0	
Decontamination Area	Estimated	-	4.21	1	4.2	56.0	30.8	7.5	-3.7	129.5	31.4	-15.6	V from GA, RAL scaling factor + 2 Washrooms (est 0.7t)
Office	Estimated	-	3.97	1	4.0	50.0	27.5	7.5	5.4	109.2	29.7	21.4	V from GA, RAL scaling factor
Technical Spaces													
Stores/ Lockers	Estimated	Deck Stores/ Locker	2.00	3	6.0	45.0	24.8	7.5	0.0	148.5	44.9	0.0	Deck stores, equip locker, galley stores
HVAC and Auxiliary Equipment Room	Estimated	-	2.55	1	2.6	46.5	25.6	7.5	-5.0	65.2	19.1	-12.8	V from GA, RAL scaling factor, x2 for typically heavier equip.
Emergency Generator Room	Estimated	-	2.70	1	2.7	50.0	27.5	10.3	0.7	74.3	27.9	1.9	Estimated based on scaling reference vessel
Funnels and Air Intakes	Estimated	-	2.5	1.5	3.8	50.0	27.5	10.5	0.0	103.1	39.4	0.0	
Laundry Space	Estimated	-	-	-	1.0	61.0	33.6	7.5	-3.9	33.6	7.5	-3.9	
Trash Disposal Space	Estimated	-	-	-	0.4	39.0	21.5	4.2	6.0	8.6	1.7	2.4	
Workshop	Estimated	-	-	-	8.0	60.0	33.0	7.5	-4.4	264.0	60.0	-35.2	
		TOTAL WEIGHT			**161.5**		**29.4**	**8.0**	**0.4**	**4739.5**	**1288.5**	**67.3**	
		ALLOWANCE MARGIN			**12%**								
		TOTAL WEIGHT (W/ MARGIN)			**180.8**		**29.4**	**8.0**	**0.4**				

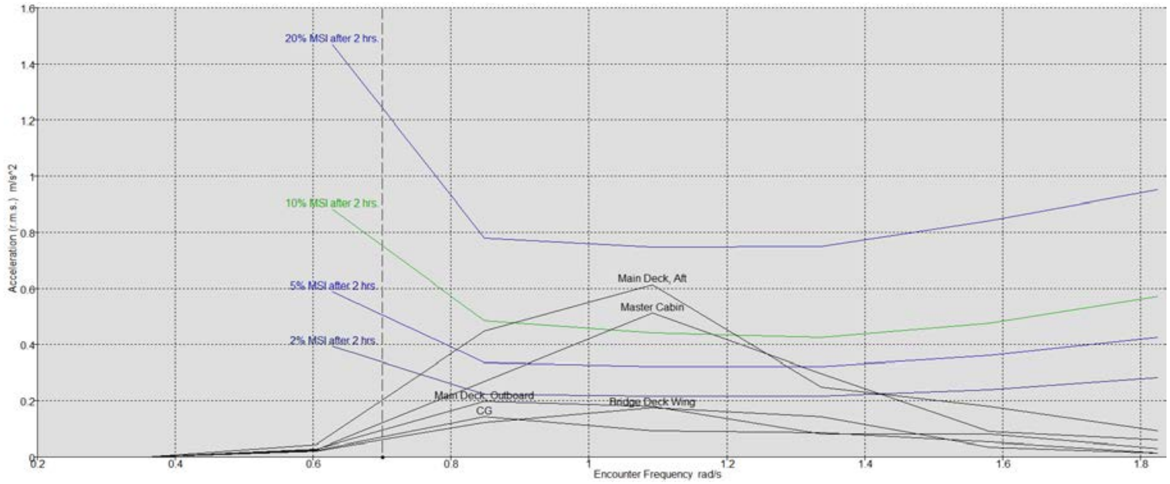
Weight Estimate - Section 700 - Mission & Deck Equipment

Done by: VC | Checked by: OS | Drawing Used: March 18 | Items: 19 | Note: Port negative

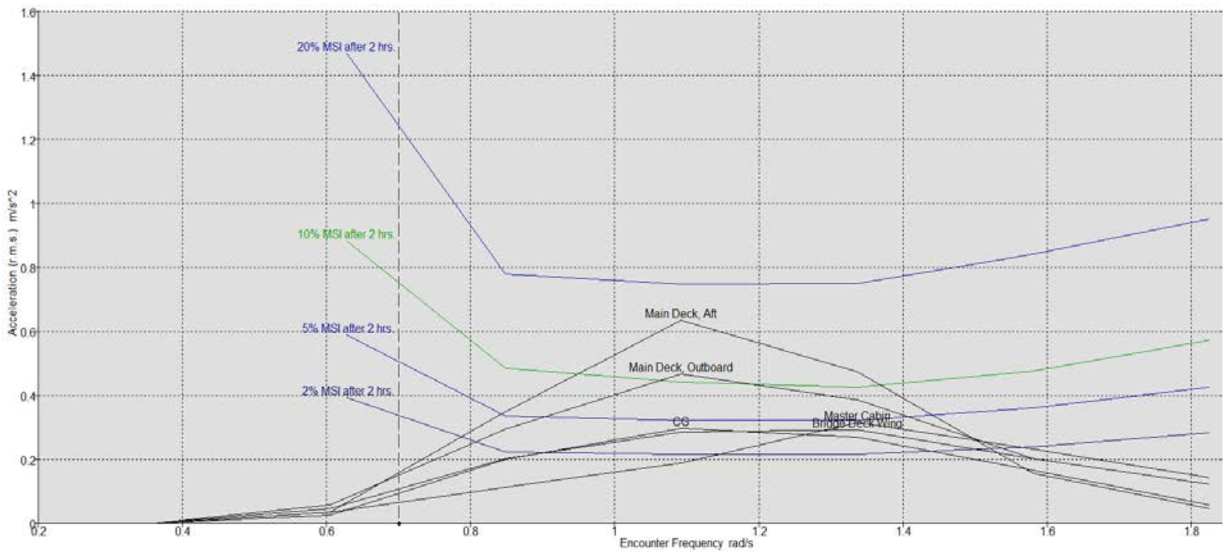
Section 700 - Mission & Deck Equipment	Unit Model	Source	Unit Weight	Quantity	Weight	Frame	LCG	VCG	TCG	L Mom	V Mom	T Mom
			MT/m		MT	Fr. 0	m	m	m	MT m	MT m	MT m
Mission Equipment												
Offshore Skimmer	URO 300	Vendor	15.1	1	15.1	25.2	13.9	8.6	4.54	209.29	129.62	68.60
Offshore Boom	Airflex	Vendor	0.007	700	4.6	11.4	6.3	7.8	4.30	28.92	36.20	19.84
Boom Storage Reel	SeaReel	Vendor	0.6	2	1.1	11.4	6.3	7.8	4.30	7.12	8.92	4.88
Jib Arm	Lamor	Vendor	0.9	2	1.8	20.0	11.0	6.9	0.00	19.25	12.08	0.00
Workboat	Palfinger FRSQ 670 A WB	Vendor	1.8	1	1.8	39.5	21.7	10.2	-5.48	39.11	18.40	-9.87
Deck Equipment												
Crane	Palfinger DKT220-25T-15M	Vendor	27.0	1	27.0	31.0	14.1	10.5	-4.60	380.97	284.31	-124.20
Crane Rest		Estimated	1.5	1	1.5	14.0	7.7	9.0	-6.20	11.55	13.50	-9.30
Towing Winch	Markey TYS-32	Vendor	13.0	1	13.0	38.1	21.0	7.7	0.00	272.42	99.81	0.00
Rescue Boat	Harding RRB 425	Vendor	0.9	1	0.9	43.0	23.7	10.1	5.60	21.38	9.16	5.06
Rescue Boat Davit	Harding NPDS 1300H	Vendor	1.2	1	1.2	43.0	23.7	10.5	4.50	29.09	12.92	5.54
Tugger Winch	Wintech	Vendor	4.0	1	2.0	30.8	16.9	7.3	-2.60	33.88	14.60	-5.19
Hydraulic Tow Pins	Smith Berger 12T2X12	Vendor	2.5	1	2.0	4.0	2.2	6.5	0.00	4.40	13.00	0.00
Anchor Handling and Mooring Systems												
Anchor Windlass	Markey - WES 23	Vendor	6.3	1	6.3	76.0	41.8	9.9	0.00	263.34	62.18	0.00
Anchor	-	ABS Rules	1.4	2	2.9	79.0	43.5	5.5	0.00	125.14	15.96	0.00
Chain	-	ABS Rules	12.7	1	12.7	76.1	41.9	5.5	0.00	531.56	69.85	0.00
Chain Roller	-	Estimated	0.5	2	1.0	76.0	41.8	9.9	0.00	41.80	9.87	0.00
		TOTAL WEIGHT			**95**		**508.7**	**204.1**	**-11.2**	**2019**	**810**	**-45**
		ALLOWANCE MARGIN			**5%**							
		TOTAL WEIGHT (W/ MARGIN)			**99.7**		**508.7**	**204.1**	**-11.2**			

Subject: **Seakeeping Analysis plots generated by Maxsurf - Sea State 4** **Done by:** **OS**

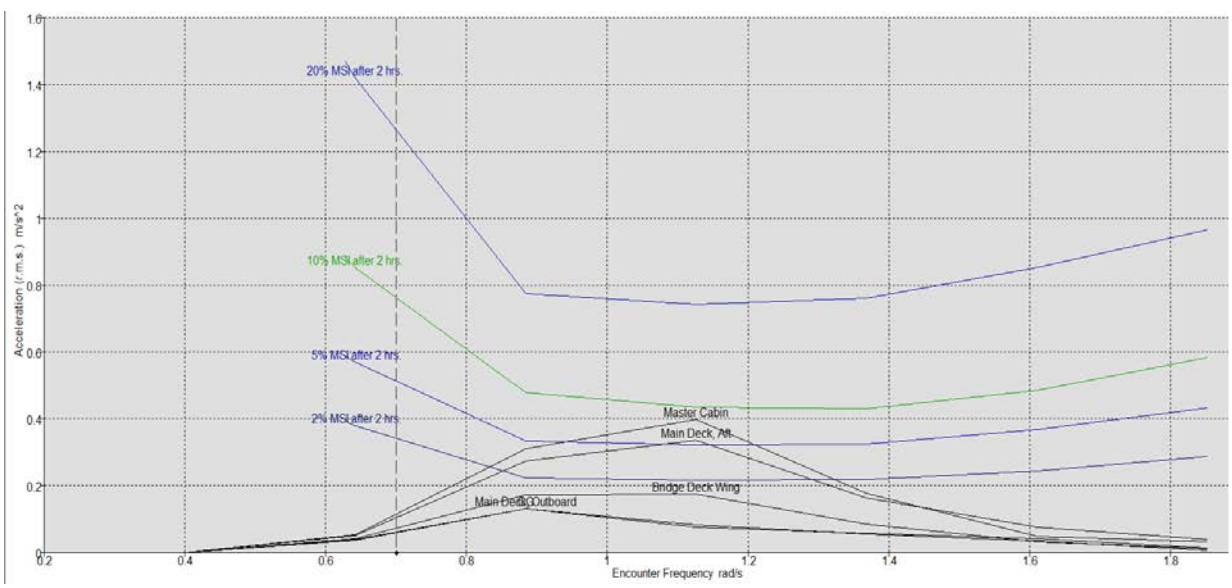
Following Seas
0 deg



Beam Seas
90 deg

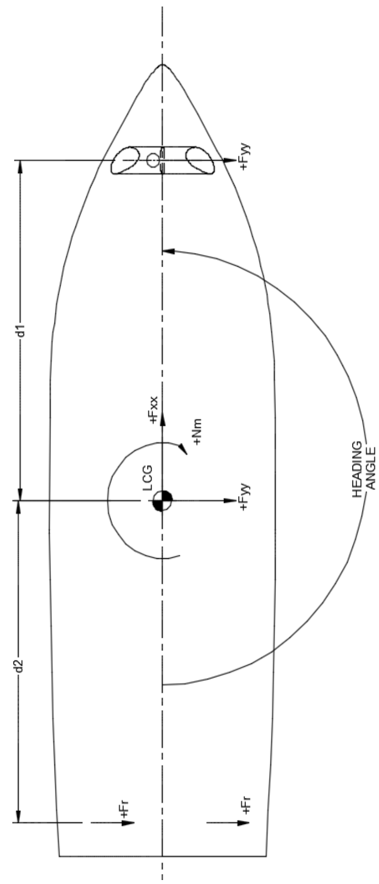


Head Seas
180 deg



Subject: Stationkeeping analysis - Sea State 4, 0.5 kts current	**Done by:**	**OS**	**Checked:**	JY

Reference: NAVSEA-DDS-568-1-Thruster-Manoeuvering-Systems



Inputs

Length	Ls	47	m
Speed	Vs	0	kts
Longitudinal Projected Area	As	271	m2
Transverse Projected Area	Af	132	m2
Sea State		4	
Significant Wave Height	H(1/3)	6.2	ft
Modal Period	To	8.8	s
Current Velocity	Vc	0.5	kts
Bow Thruster			
Distance from CG to Bow Thruster	d1	16	m
Distance from CG to Rudder	d2	22	m

Calculations & Results

Wave Force and Moment

$$F^2_{xx,yy} = \frac{1}{2}\rho g L_s \sum_n \frac{2S_e(\omega_n)\Delta\omega_e R_{xx,yy}(\omega_e,\psi)}{1-\left(\frac{2\omega_n}{g}\right)V_s\cos\psi} \qquad N^2_{mx,yy} = \frac{1}{2}\rho g L_s{}^2 \sum_n \frac{2S_e(\omega_n)\Delta\omega_e R_m(\omega_e,\psi)}{1-\left(\frac{2\omega_n}{g}\right)V_s\cos\psi}$$

Ls = length of the ship

Vs = ship Speed

Ψ = wave Heading Angle

Se = wave spectrum

$H1/3$ = significant Wave Height

To = modal period

ωn = wave absolute frequency

ωe = wave encounter frequency

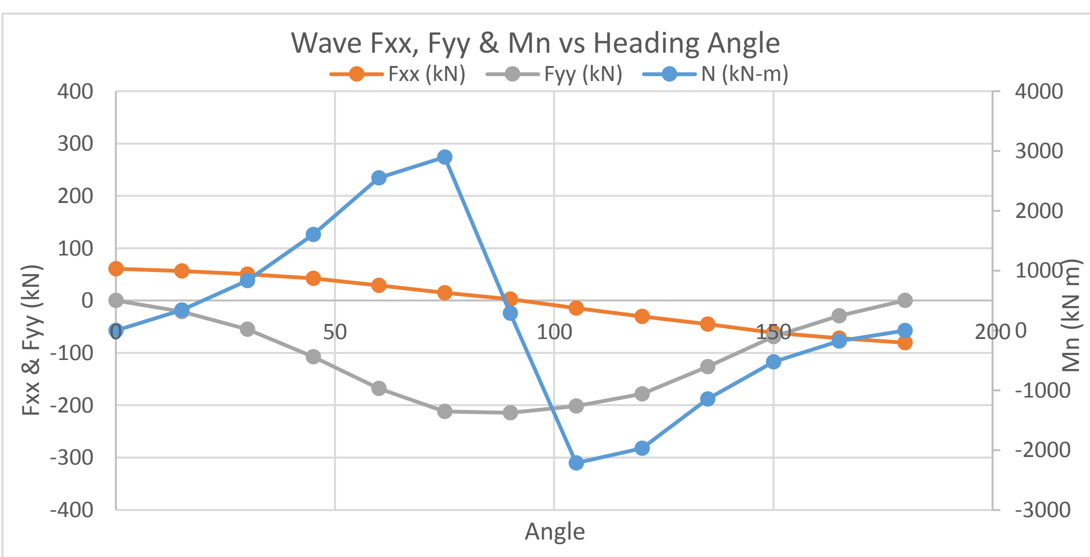
$\Delta\omega e$ = difference frequency

τn = wave period

λn = wave length

Rxx,yy = non − dimensional longitudinal wave force transfer function

Rm = non − dimensional wave moment transfer function taken from Table 3



Subject: Stationkeeping analysis - Sea State 4, 0.5 kts current **Done by:** OS **Checked:** JY

Wind Force and Moment

$$F^{W}_{xx,yy}(\psi) = \frac{1}{2}\rho A_{f,s} V_W{}^2 C_{xx,yy}(\psi) \qquad N^{W}_{m}(\psi) = \frac{1}{2}\rho A_s V_W{}^2 L_s C_m(\psi)$$

$Fxx =$ *longitudinal wind force*

$Fyy =$ *transverse wind force*

$Nm =$ *wind moment*

$Cxx =$ *longitudinal wind force coefficient*

$Cyy =$ *transverse wind force coefficient*

$Cm =$ *wind moment coefficient*

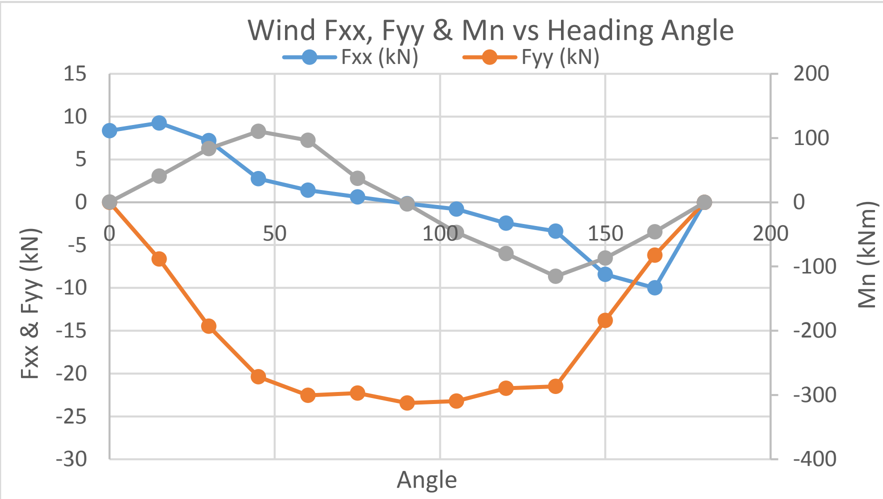
$As =$ *longitudinal projected area of ship hull and superstructure above waterline*

$Af =$ *transverse projected area of ship hull and superstructure above waterline*

$Vw =$ *wind speed*

$\rho =$ *density*

$\psi =$ *Angle from which wind is acting relative to ship heading*



Current Forces & Moment

$$F^{C}_{xx} = 0.5\rho L_s^2(V_{xx}^2 + V_{yy}^2)C^{C}_{xx}$$

$$F^{C}_{yy} = 0.5\rho L_s^2(V_{xx}^2 + V_{yy}^2)C^{C}_{xx}$$

$$N^{C}_{m} = 0.5\rho L_s^2(V_{xx}^2 + V_{yy}^2)L_s C^{C}_{xx}$$

Equation 5- Current Forces

$Fxx =$ *longitudinal current force*

$Fyy =$ *transverse current force*

$Nm =$ *Current moment*

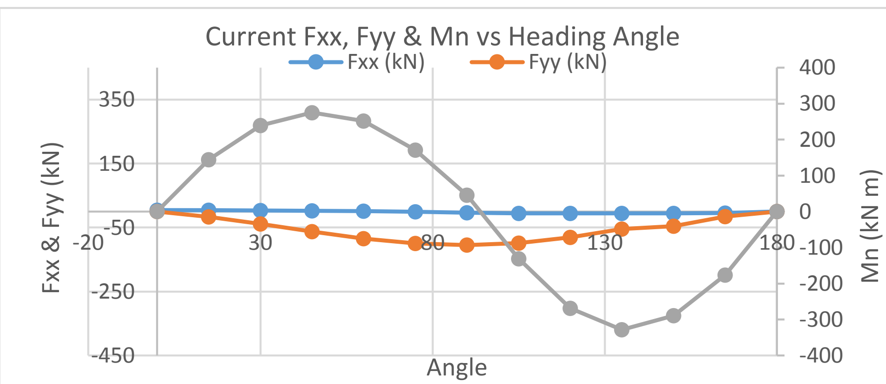
$Cxx =$ *longitudinal current force coefficient*

$Cyy =$ *transverse current force coefficient*

$Cm =$ *Current moment coefficient*

$Ls =$ *Ship Length*

$Vs =$ *Ship Speed*



TOTAL FORCES AND MOMENT

To determine the worst case senario for the environmental loads, the three environmental forces were added (act in same direction)

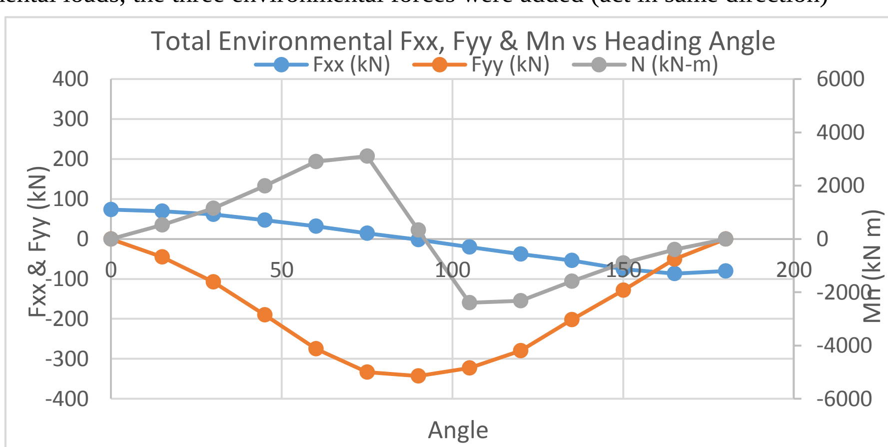
$$F^{e}_{xx,yy} = F_{Total} = F^{2}_{xx,yy} + F^{W}_{xx,yy} + F^{C}_{xx,yy}$$

Equation 10- Total Forces

$$F_{Thruster} = -(F^{e}_{yy} d_3 + N^{e}_{m})/(d_1 + d_3)$$

Equation 11-Bow Thruster Force

From these formulas, the required bow thruster force for maintaining the position was calculated and comparedto the generated thrust by the thruster



Subject: Manueverability Analysis **Done by:** JY **Checked:** OS

Reference: ABS Manueverability Guidelines 2006

Inputs

Variable Parameters	Units	Values
CB	-	0.59
Rudder angle	degree	30
Trim	m	0.15
LWL	m	45.6
BWL	m	13.5
Sp (span of rudder)	m	2.9
Ch (mean chord of rudder)	m	1.7
T	m	5
ST		2
TL	m	5
Ab	m^2	-5.6

ABS and IMO Maneuvering Standards and Criteria

Measure of Maneuverability	Criteria and Standard	Maneuver	IMO Standard	ABS Guide Requirement
Required for Optional Class Notation				
Turning Ability	Tactical Diameter	Turning Circle	$TD < 5L$	Rated $Rtd \geq 1$
	Advance		$Ad < 4.5L$	Not rated $Ad < 4.5L$
Stopping Ability	Track Reach	Crash stop	$TR < 15L$ (1)	Not rated $TR < 15L$ (1)
	Head Reach		None	Rated $Rts \geq 1$

STEADY TURNING DIAMETER

$$\frac{STD}{L} = 4.19 - 203\frac{C_B}{\delta_R} + 47.4\frac{Trim}{L} - \frac{13.0B}{L} + \frac{194}{\delta_R} - 35.8\frac{Sp \cdot Ch}{L \cdot T}(ST - 1) +$$

$$+ 3.82\frac{Sp \cdot Ch}{L \cdot T}(ST - 2) + 7.79\frac{A_B}{L \cdot T} + 0.7\left(\frac{T}{T_L} - 1\right)\left(\frac{\delta_R}{|\delta_R|}\right)(ST - 1)$$

TACTICAL DIAMETER AND ADVANCE

$$\frac{TD}{L} = 0.910\frac{STD}{L} + 0.424\frac{V_S}{\sqrt{L}} + 0.6$$

$$\frac{Ad}{L} = 0.519\frac{TD}{L} + 1.33 \ldots\ldots\ldots\ldots\ldots$$

STOPPING ABILITY

$$S_{low} = A_{low}\log_e(1 + B_{low}) + C....$$

$$S_{high} = A_{high}\log_e(1 + B_{high}) + C.$$

$$C = \begin{cases} C_L & \text{if} \quad V_S < 15\,\text{kn} \quad \text{or} \quad T_{Rv} < 60\,\text{s} \\ C_L\dfrac{V_S}{15} & \text{if} \quad V_S > 0.25T_{Rv} \\ C_L\dfrac{T_{Rv}}{60} & \text{if} \quad V_S \leq 0.25T_{Rv} \end{cases}$$

CL 2.3 if L < 100 m

Vessel Type	Coefficient A	
	Low Boundary, A_{low}	High Boundary, A_{high}
Cargo ship	5	8
Passenger/car ferry	8	9
Gas carrier	10	11
Product tanker	12	13
VLCC	14	16

Type of Machinery	Coefficient B	
	Low Boundary, B_{low}	High Boundary, B_{high}
Diesel	0.6	1.0
Steam turbine	1.0	1.5

Results

Test speed (knots)	Turning Ability		Stopping Ability	
	TD/L	Ad/L	Min Track Reach	Max Track Reach
1	2.24	2.73	4.65	7.85
2	2.3	2.76	4.65	7.85
4	2.4	2.82	4.65	7.85
6	2.51	2.89	4.65	7.85
8	2.61	2.95	4.65	7.85
10	2.71	3.02	4.65	7.85
12	2.82	3.08	4.65	7.85
13	2.87	3.12	4.65	7.85
14	2.92	3.15	4.65	7.85

ABS Rating is based on the following formulas

if $(4.26 - 1.62 \cdot 10^{-6}\Delta) \cdot L < TD \leq 5 \cdot L$ then $Rtd = 1$

if $(3.63 - 1.62 \cdot 10^{-6}\Delta) \cdot L < TD \leq (4.26 - 1.62 \cdot 10^{-6}\Delta) \cdot L$ then $Rtd = 2$

if $(2.79 - 1.62 \cdot 10^{-6}\Delta) \cdot L < TD \leq (3.63 - 1.62 \cdot 10^{-6}\Delta) \cdot L$ then $Rtd = 3$

if $(2.16 - 1.62 \cdot 10^{-6}\Delta) \cdot L < TD \leq (2.79 - 1.62 \cdot 10^{-6}\Delta) \cdot L$ then $Rtd = 4$

if $(2.16 - 1.62 \cdot 10^{-6}\Delta) \cdot L > TD$ then $Rtd = 5$ ..

Results are plotted

Subject: Area/Volume Summary **Done by:** **OS** **Done by:** VC

Deck	Space/ Compartment	Area (m2)	Usable height (m)	Volume (m3)	Location/ Size Rationale/ Related Rule or Requirement
Bridge Deck	Wheelhouse	80	2.2	176	The area was determined based on the equipment from reference vessel
Bridge Deck	Grating	18	-	-	Provides enough space for rescue life rafts
Bridge Deck	Fwd Exterior Deck	29	-	-	
Forecastle Deck	Master Cabin	15.8	2.2	34.76	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	Chief Engineer Cabin	15.7	2.2	34.54	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	2 Crew (P, Fr. 60-65)	11.6	2.2	25.52	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	2 Crew (P, Fr. 53-60)	12.3	2.2	27.06	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	2 Crew (S, Fr. 61-65)	10.8	2.2	23.76	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	2 Crew (P, Fr. 55-61)	11.5	2.2	25.3	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	2 Crew (P, Fr. 48-55)	12	2.2	26.4	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	Passageways	31.2	2.2	68.64	MLC 2006 and Transport Canada Towboat Crew Accommodations
Forecastle Deck	HVAC Room	8.2	2.2	18.04	Sized using a reference vessel data
Forecastle Deck	Stacks	10	-	-	Sized to fit the silencer and SCR Unit
Forecastle Deck	ER Air Intakes	5	-	-	Sized to fit a single air intake fan, as per reference vessel area
Forecastle Deck	Fwd Exterior Deck	40	-	-	Sufficient amount of space for the windlass and mooring bits
Forecastle Deck	Aft Exterior Deck w Grating	81.8	-	-	Space for rescue boat and davit, workboat, mooring bits & muster station
Main Deck	Exterior Deck	285	-	-	Space to accommodate all of mission/deck equipment. Passageway between them for a safe operation
Main Deck	Exterior WC	1.4	2.2	3.08	Provided for convenience of working crew members – will not contaminate indoor spaces in the event of an operation.
Main Deck	Deck Workshop	9.3	2.2	20.46	WCMRC's requirements, Equipment can be easily maintained or stored.

Subject: Area/Volume Summary **Done by:** **OS** **Done by:** VC

Deck	Space/ Compartment	Area (m2)	Usable height (m)	Volume (m3)	Location/ Size Rationale/ Related Rule or Requirement
Main Deck	Hydraulic System Room	6	2.2	13.2	Contains HPU for the additional equipment installed on the vessel
Main Deck	Emergency Genset Room	10	2.2	22	SOLAS requirements, emerg. genset above main deck
Main Deck	Casing/ Exhaust Stack	10	-	-	Sized to fit the silencer and SCR Unit
Main Deck	ER Air Intakes	5	-	-	Sized to fit a single air intake fan, as per reference vessel area
Main Deck	Entry Lobby	12.3	2.2	27.06	Isolated from living spaces to contain pollutants
Main Deck	Decontamination Area	25.3	2.2	55.66	-
Main Deck	Laundry	9.1	2.2	20.02	Operational Requirement, located next to laundry area for contaminated gear clean up.
Main Deck	Mess/ Lounge	22.4	2.2	49.28	MLC 2006 and Transport Canada Towboat Crew Accommodations
Main Deck	Galley	12.9	2.2	28.38	Operational Requirement
Main Deck	Refrigerator/Freezer Space	6.1	2.2	13.42	Operational Requirement
Main Deck	Galley Stores	6.4	2.2	14.08	Operational Requirement
Main Deck	2 Supernumeraries (fwd)	12.7	2.2	27.94	MLC 2006 and Transport Canada Towboat Crew Accommodations
Main Deck	2 Supernumeraries (aft)	14.7	2.2	32.34	MLC 2006 and Transport Canada Towboat Crew Accommodations
Main Deck	Chain Locker	2.4	5.3	12.72	Sized based on the chain cable size
Main Deck	Bosun Stores	11.5	2.2	25.3	-
Main Deck	Passageways	25.4	2.2	55.88	MLC 2006 and Transport Canada Towboat Crew Accommodations
Main Deck	Office/ Conference Room	20.8	2.2	45.76	WCMRC's requirements
Main Deck	Deck Stores	6.1	2.2	13.42	WCMRC's requirements
Main Deck	Garbage Stores	4.5	2.2	9.9	Operational Requirement

Subject: Area/Volume Summary **Done by:** **OS** **Done by:** VC

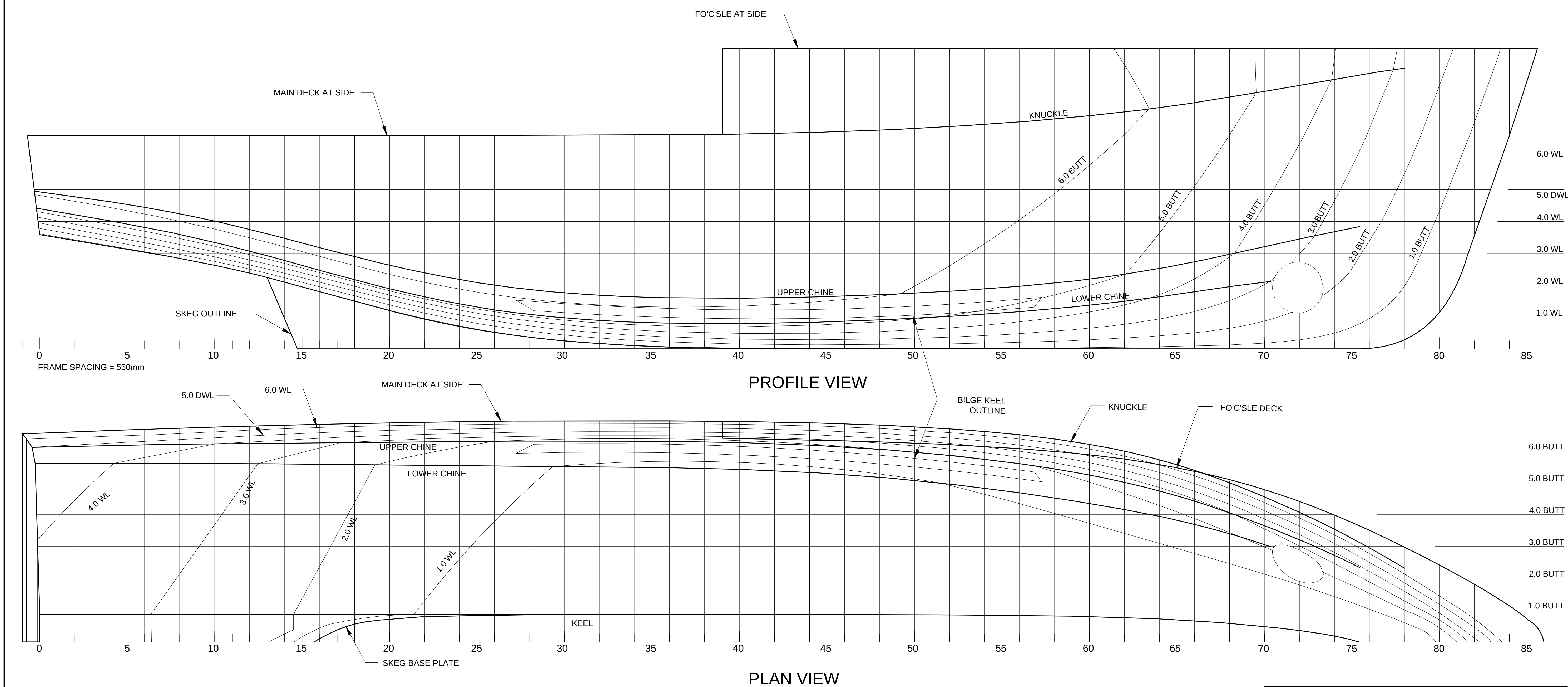
Deck	Space/ Compartment	Area (m2)	Usable height (m)	Volume (m3)	Location/ Size Rationale/ Related Rule or Requirement
Mezzanine	Domestic Equipment Room	19.8	2.2	43.56	-
Mezzanine	Worshop/Stores	19.7	2.2	43.34	Sized based on the workshop equipment
Mezzanine	Switchboard Room	27.4	2.2	60.28	Sized based on the equipment from the reference vessel
Mezzanine	Grating	35.5	2.2	78.1	-
Mezzanine	Pump Room	16.2	2.2	35.64	-
Mezzanine	Boiler/ Heater Room	12.2	2.2	26.84	Sized to provide enough room for the boiler and pumps
Mezzanine	Passageway	15.2	2.2	33.44	-
Mezzanine	Steering Gear Compartment	27	2.2	59.4	The space was minimized to increse the recovered oil storage capacity
Tank Top	Bow Thruster Compartment	19	2.2	41.8	-
Tank Top	Engine Room	133	2.2	292.6	Enough space for propulsion equipment and machinery
Tank Top	Shaft Passageway	19	2.2	41.8	Provides acces to the oil ditribution box and for maintenance of the shaft

PARTICULARS

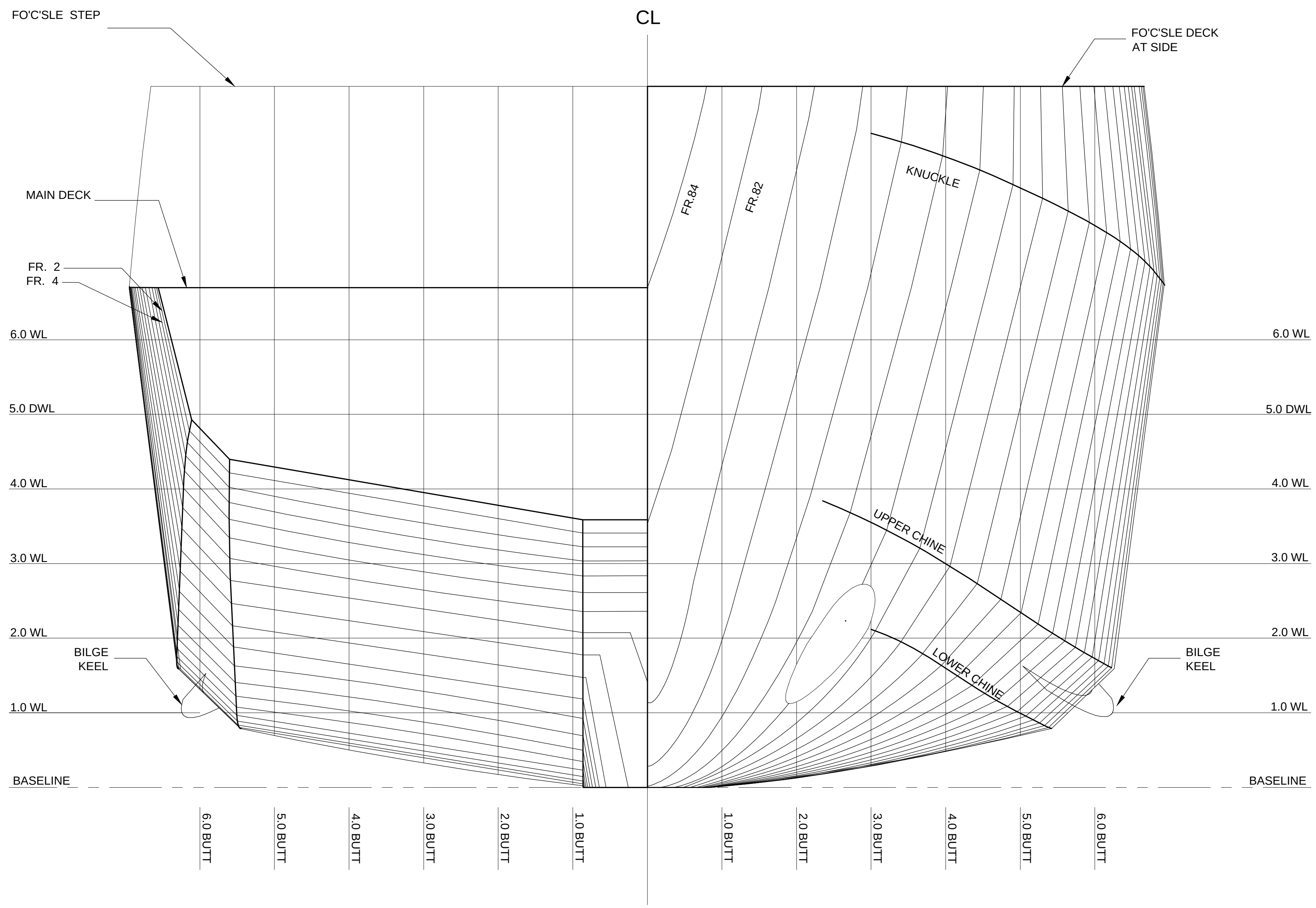
LENGTH, OVERALL	47.3 m
LENGTH, WATERLINE	45.6 m
BEAM, MOULDED	14.0 m
BEAM, WATERLINE	13.5 m
DEPTH	6.7 m
DESIGN DRAFT	5.0 m

ABBREVIATIONS

BUTT	-	BUTTOCK
DWL	-	DESIGN WATERLINE
WL	-	WATERLINE



UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: LINES PLAN			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 001	SIZE: A3	REV: 1
DATE ISSUED: APR 03/16		SCALE: 1:125	SHEET: 1 OF 2	



BODY PLAN

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL				
	DWG TITLE: LINES PLAN				
DRAWN BY: OS	CHECKED BY:	DWG NO.: 001		SIZE: A3	REV: 1
DATE ISSUED: APR. 03/16		SCALE: 1:75		SHEET: 2 OF 2	

TANK	DESCRIPTION	LOCATION (FRAMES)	CAPACITY AT 98% (m3)	LCG (m)	TCG (m)	VCG (m)	FREE SURFACE MOMENT AT 50% LOADING (MT.m)	COMBINED FSM AT 50% LOADING (MT.m)
FUEL OIL TANKS								
FO 1P	Aft Fuel Oil Tank, Port	8 - 14	55.4	6.1	-3.0	5.0	27.6	55
FO 2S	Aft Fuel Oil Tank, Stbd	8 - 14	55.4	6.1	3.0	5.0	27.6	
FO 3P	Fuel Oil Tank, Port	24 - 37	67.3	16.2	-4.2	3.9	7.0	14
FO 4S	Fuel Oil Tank, Stbd	24 - 37	67.3	16.2	4.2	3.9	7.0	
FO 5CL	Fuel Oil Tank, Centerline	24 - 33	80.2	15.5	0.0	3.6	19.2	19
FO 6CL	Fuel Oil Day Tank, Centerline	33 - 35	15.0	18.7	0.0	3.4	5.8	6
RECOVERED OIL TANKS								
RO 1P	Recovered Oil Tank, Port	14 - 24	125	13.2	-2.8	1.8	52.6	105
RO 2S	Recovered Oil Tank, Stbd	14 - 24	125	13.2	2.8	1.8	52.6	
BALLAST WATER TANKS								
BW 1P	Aft Ballast Tank, Port	(-1) - 3	24.0	1.6	-0.4	3.3	14.0	28
BW 2S	Aft Ballast Tank, Starboard	(-1) - 3	24.0	0.8	2.4	5.2	14.0	
BW 3P	Aft Wing Ballast Tank, Port	(-1) - 8	15.0	4.4	-5.0	3.5	0.9	2
BW 4S	Aft Wing Ballast Tank, Stbd	(-1) - 8	15.0	2.3	5.7	5.5	0.9	
BW 5P	Wing Ballast Tank, Port	8 - 24	34.5	13.2	-5.5	1.4	0.8	2
BW 6S	Wing Ballast Tank, Stbd	8 - 24	34.5	13.2	5.5	1.4	0.8	
BW 7P	Wing Ballast Tank, Port	37 - 44	29.9	20.4	-5.7	1.2	0.8	2
BW 8S	Wing Ballast Tank, Stbd	37 - 44	29.9	20.4	5.7	1.2	0.8	
BW 9P	Double Bottom Ballast Tank, Port	37 - 44	10.6	24.2	-2.3	0.2	8.7	17
BW 10S	Double Bottom Ballast Tank, Stbd	37 - 44	10.6	21.6	3.6	0.8	8.7	
BW 11CL	Double Bottom Ballast Tank, Centerline	37 - 44	24.6	24.1	0.0	0.0	34.0	34
BW 12P	Wing Ballast Tank, Port	63 - 71	21.1	34.7	-4.1	4.1	4.5	9
BW 13S	Wing Ballast Tank, Stbd	63 - 71	21.1	34.7	4.1	4.1	4.5	
BW 14CL	Double Bottom Ballast Tank, Centerline	61 - 71	18.2	33.6	0.0	0.0	11.2	11
BW 15P	Wing Ballast Tank, Port	71 - 77	19.6	39.1	-2.2	4.1	6.3	13
BW 16S	Wing Ballast Tank, Stbd	71 - 77	19.6	39.1	2.2	4.1	6.3	
BW 17CL	Forepeak Ballast Tank, Centerline	77 - 83	12.3	42.4	0.0	0.1	2.0	2
FRESH WATER TANKS								
FW 1P	Fresh Water Tank, Port	61 - 71	45.4	35.9	-2.8	2.6	11.2	22
FW 2S	Fresh Water Tank, Stbd	61 - 71	45.4	35.9	2.8	2.6	11.2	
BLACK WATER AND GREY WATER TANKS								
BLW 1P	Black Water Tank, Port	44 - 60	12.2	28.3	-3.1	0.5	5.5	11
BLW 2S	Black Water Tank, Stbd	44 - 60	12.2	28.3	3.1	0.5	5.5	
GW 1P	Grey Water Tank, Port	44 - 60	30	28.4	-0.5	0.1	28.3	57
GW 2S	Grey Water Tank, Stbd	44 - 60	30	28.4	0.5	0.1	28.3	
MISCELLANEOUS TANKS								
UREA 1P	Urea Tank, Port	49 - 55	15.8	28.6	-5.0	4.0	0.2	0.5
UREA 2S	Urea Tank, Stbd	49 - 55	15.8	28.6	5.0	4.0	0.2	
OILY WATER	Oily Water Tank, Centerline	35 - 37	5.0	19.8	0.0	2.1	1.6	2
HYD OIL	Hydraulic Oil, Centerline	35 - 37	3.1	19.8	0.0	3.6	1.4	1
DISP 1P	Dispersant Tank, Port	31 - 37	10.3	18.7	-4.9	5.4	0.5	1
DISP 2S	Dispersant Tank, Stbd	31 - 37	10.3	18.7	4.9	5.4	0.5	

TANK	DESCRIPTION	LOCATION (FRAMES)	CAPACITY AT 98% (m3)	LCG (m)	TCG (m)	VCG (m)	FREE SURFACE MOMENT AT 50% LOADING (MT.m)	COMBINED FSM AT 50% LOADING (MT.m)
VOIDS								
VOID 1P	Double Bottom Void, Port	8 - 14	9.8	7.7	-0.9	2.1	-	-
VOID 2S	Double Bottom Void, Stbd	8 - 14	9.8	7.7	0.9	2.1	-	-
VOID 3P	Double Bottom Void, Port	14 - 24	18.4	13.2	-0.9	0.7	-	-
VOID 4S	Double Bottom Void, Stbd	14 - 24	18.4	13.2	0.9	0.7	-	-
VOID 5P	Double Bottom Void, Port	24 - 37	29.1	19.2	-0.9	0.1	-	-
VOID 6S	Double Bottom Void, Stbd	24 - 37	29.1	19.2	0.9	0.1	-	-
VOID 7P	Wing Void, Port	24 - 37	39.9	20.3	-5.7	1.2	-	-
VOID 8S	Wing Void, Stbd	24 - 37	39.9	20.3	5.7	1.2	-	-
VOID 9P	Wing Void, Port	47 - 55	17.5	26.0	-5.5	1.2	-	-
VOID 10S	Wing Void, Stbd	47 - 55	17.5	26.0	5.5	1.2	-	-
VOID 11P	Wing Void, Port	55 - 63	23.2	31.1	-4.8	1.50	-	-
VOID 12S	Wing Void, Stbd	55 - 63	23.2	32.1	5.2	4.63	-	-
VOID 13P	Void, Port	60 - 61	1.8	33.3	1.7	0.88	-	-
VOID 14S	Void, Stbd	60 - 61	1.8	33.3	1.7	0.88	-	-
VOID 15CL	Forepeak Void, Centerline	77 - 84	23.2	32.1	5.2	4.63	-	-
LOOSE TANKS								
LUBE OIL	Lube Oil Loose Tank, Stbd	59 - 61	1.5	33.0	1.8	3.70	-	-
SLUDGE	Sludge Loose Tank, Port	59 - 61	1.5	33.0	1.8	3.70	-	-

TANK CAPACITY SUMMARY

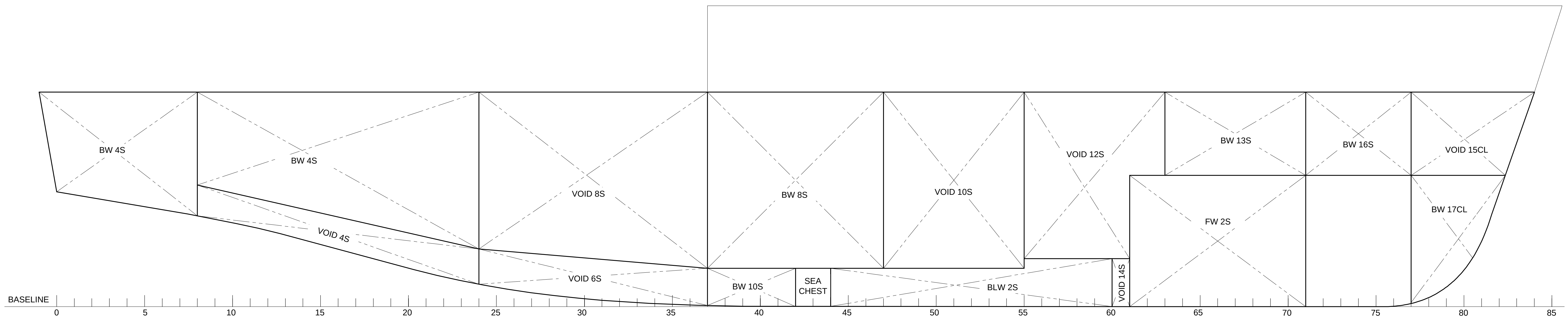
LIQUID	TOTAL CAPACITY (m3)
FUEL OIL	340
RECOVERED OIL	250
BALLAST WATER	360
FRESH WATER	90
BLACK WATER	24
GREY WATER	60
UREA	30
DISPERSANT	20
OILY WATER	5
HYDRAULIC OIL	3
LUBE OIL	1.5
SLUDGE	1.5

ABBREVIATIONS

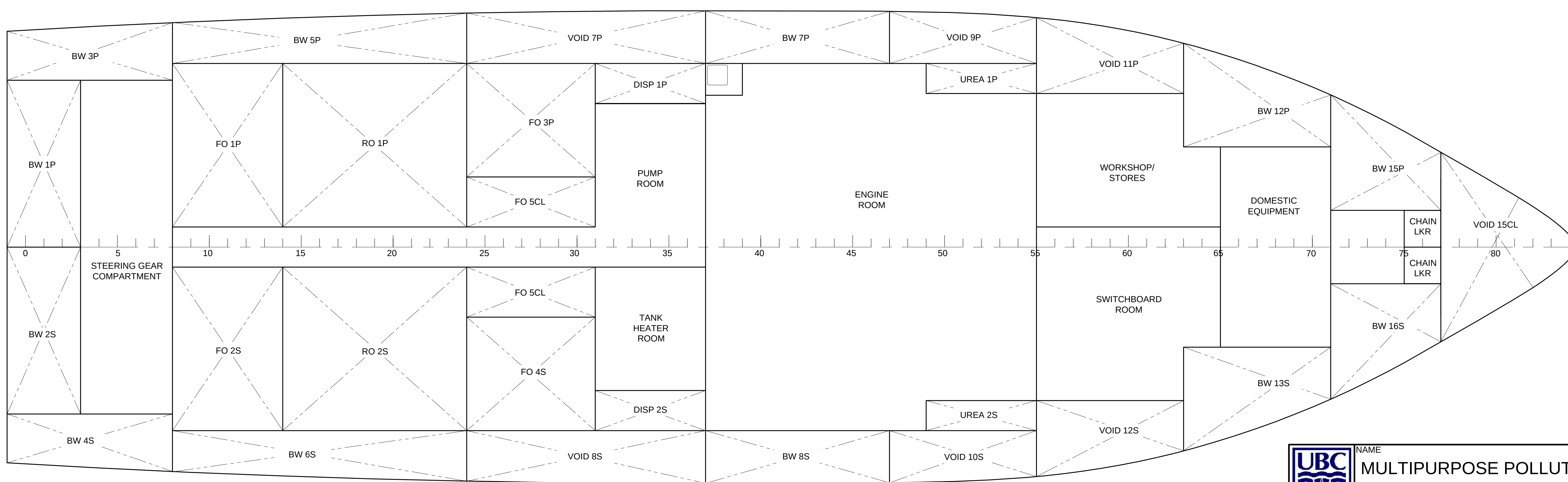
BW - BALLAST WATER
BLW - BLACK WATER
CL - CENTERLINE
DISP - DISPERSANT
FW - FRESH WATER
FWD - FORWARD
FO - FUEL OIL
GW - GREY WATER
LKR - LOCKER
P - PORT
RO - RECOVERED OIL
S - STARBOARD

UBC
MECHANICAL ENGINEERING

NAME				
MULTIPURPOSE POLLUTION CONTROL VESSEL				
DWG TITLE: TANK PLAN				
DRAWN BY: OS	CHECKED BY:	DWG NO.: 002	SIZE: A3	REV: 1
DATE ISSUED: APR 3/16		SCALE: NTS	SHEET: 1 OF 4	



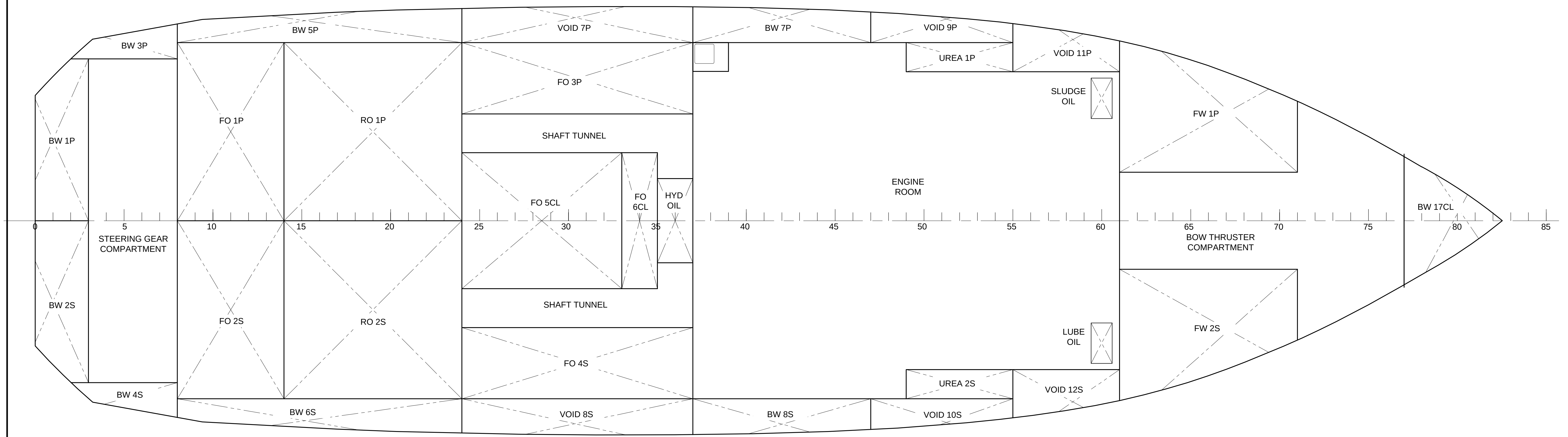
PROFILE VIEW
LOOKING PORT



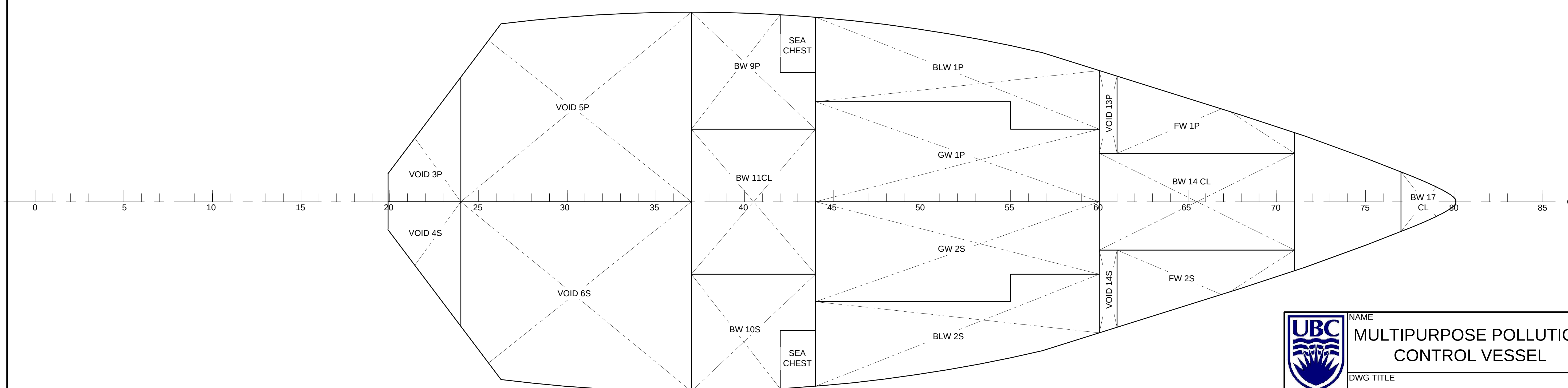
MAIN DECK
6700 ABOVE BL

UBC
MECHANICAL ENGINEERING

NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL				
DWG TITLE: TANK PLAN				
DRAWN BY: OS	CHECKED BY:	DWG NO.: 002	SIZE: A3	REV: 1
DATE ISSUED: APR 3/16		SCALE: 1:125	SHEET: 2 OF 4	



MEZZANINE DECK
4100 ABOVE BL



TANK TOP
1200 ABOVE BL

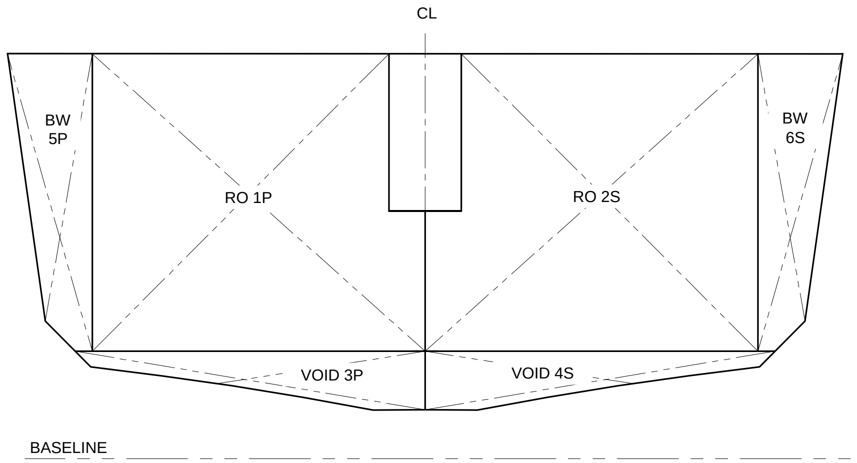
MECHANICAL ENGINEERING

NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL

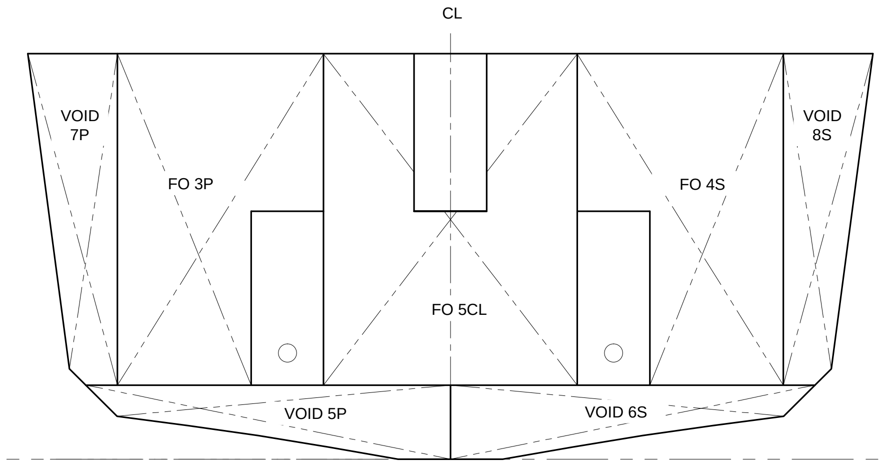
DWG TITLE: TANK PLAN

DRAWN BY	CHECKED BY	DWG NO.	SIZE	REV
OS		002	A3	1

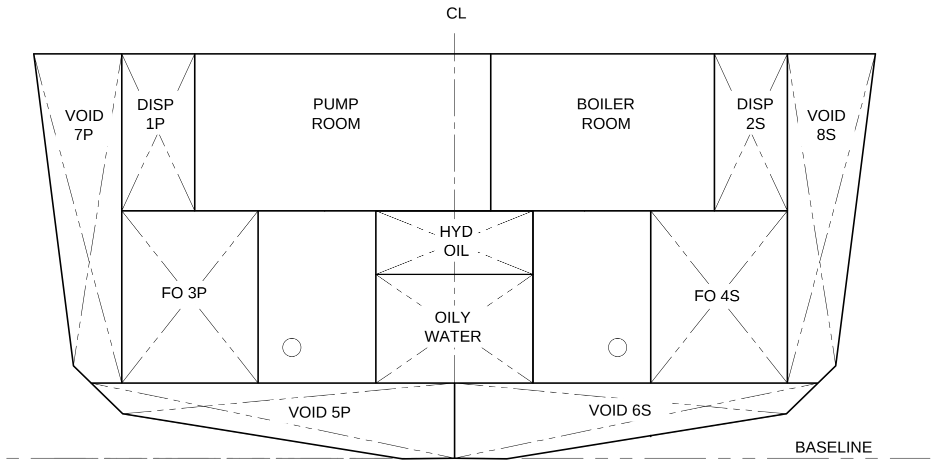
DATE ISSUED	SCALE	SHEET
APR 3/16	1:125	3 OF 4



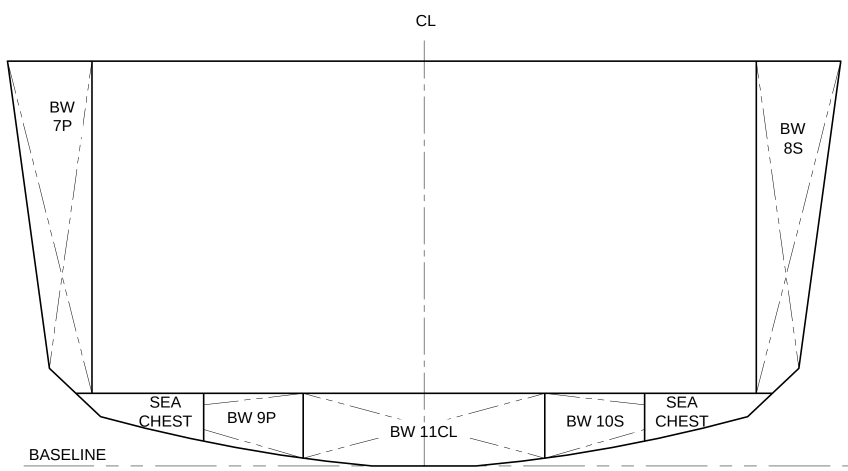
FRAME 23
LOOKING FWD
FRAMES 8 - 24 SIMILAR



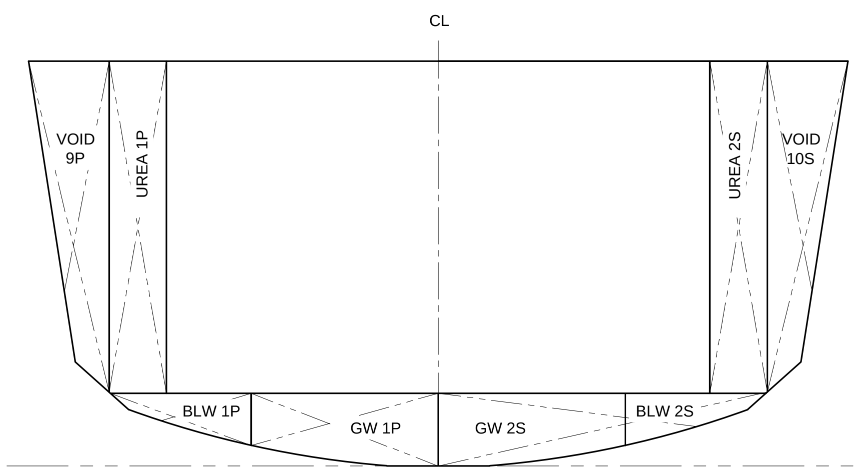
FRAME 25
LOOKING FWD
FRAMES 26 - 34 SIMILAR



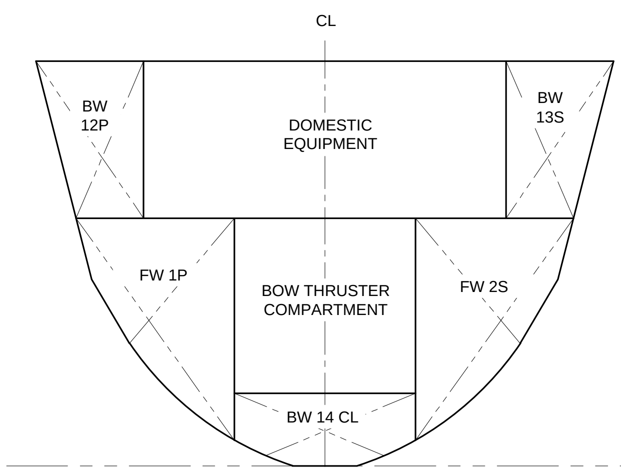
FRAME 35
LOOKING FWD
FRAME 36 SIMILAR



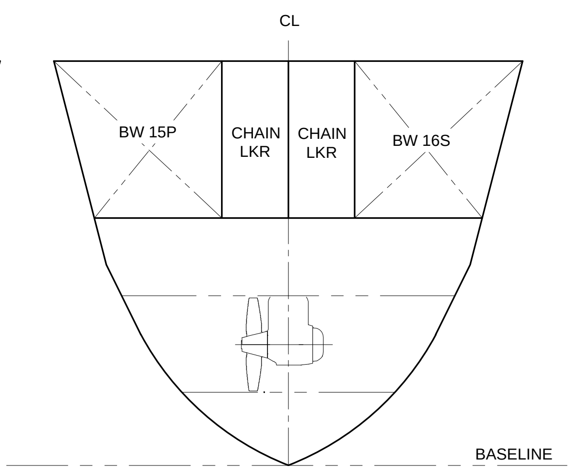
FRAME 43
LOOKING FWD
FRAME 42 SIMILAR



FRAME 49
LOOKING FWD
FRAMES 50 - 55 SIMILAR



FRAME 68
LOOKING FWD
FRAMES 61 - 71 SIMILAR



FRAME 76
LOOKING FWD
FRAMES 75 SIMILAR

MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: TANK PLAN			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 002	SIZE: A3	REV: 1
DATE ISSUED: APR 3/16		SCALE: 1:125	SHEET: 4 OF 4	

PARTICULARS

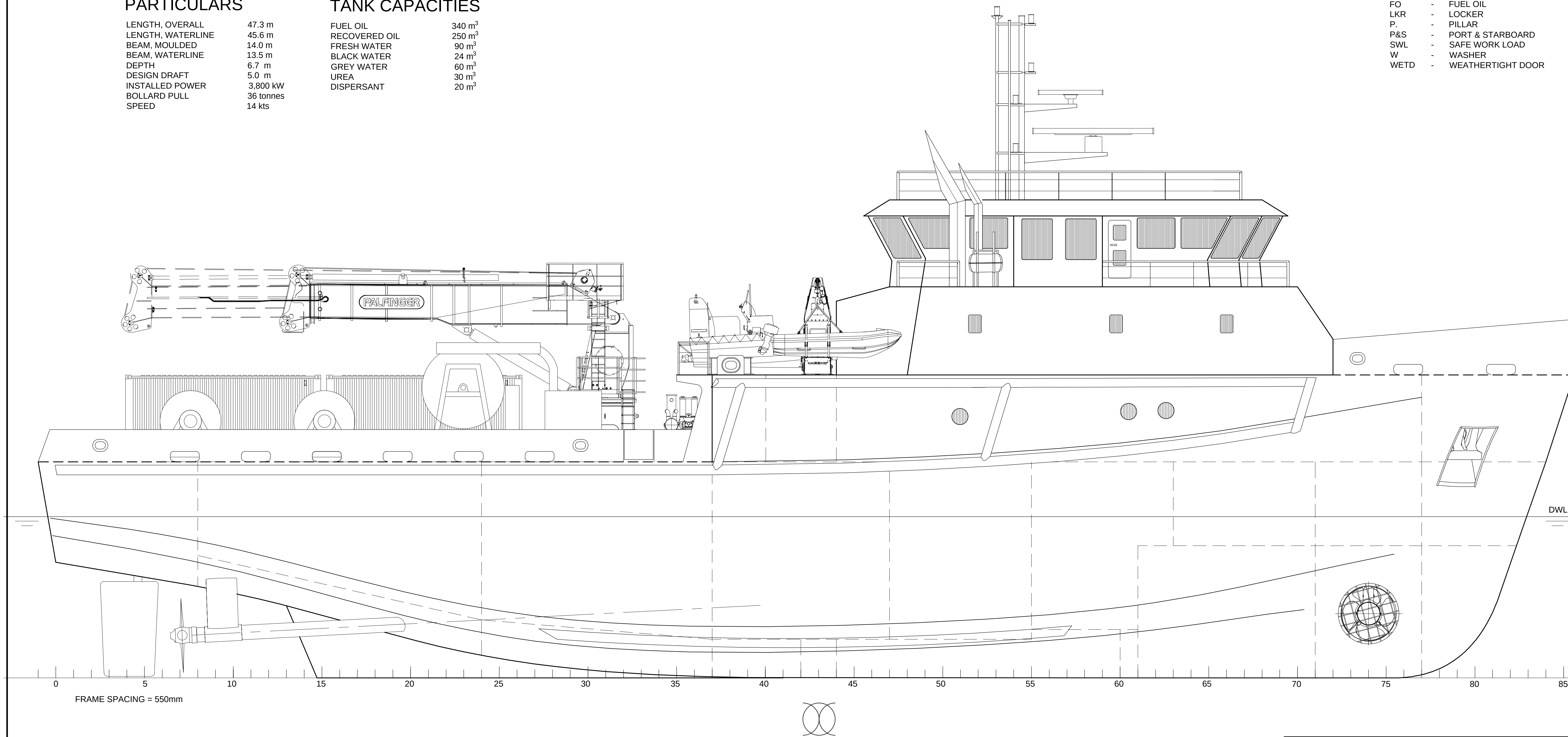
LENGTH, OVERALL	47.3 m
LENGTH, WATERLINE	45.6 m
BEAM, MOULDED	14.0 m
BEAM, WATERLINE	13.5 m
DEPTH	6.7 m
DESIGN DRAFT	5.0 m
INSTALLED POWER	3,800 kW
BOLLARD PULL	36 tonnes
SPEED	14 kts

TANK CAPACITIES

FUEL OIL	340 m^3
RECOVERED OIL	250 m^3
FRESH WATER	90 m^3
BLACK WATER	24 m^3
GREY WATER	60 m^3
UREA	30 m^3
DISPERSANT	20 m^3

ABBREVIATIONS

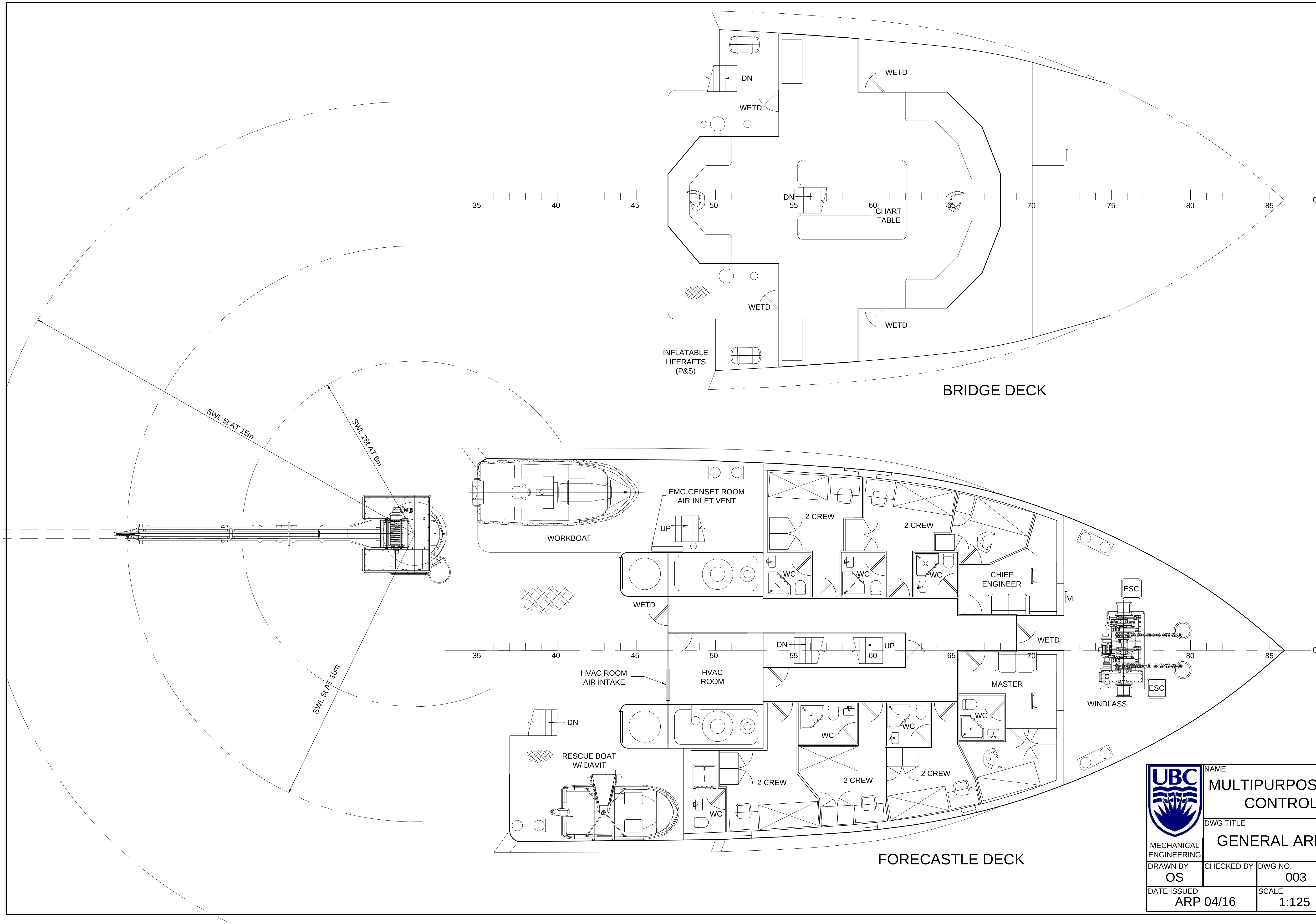
AB	-	ABOVE BASELINE
CL	-	CENTERLINE
D	-	DRYER
DN	-	DOWN
DWL	-	DESIGN WATERLINE
ESC	-	ESCAPE
FL.H.	-	FLUSH HATCH
FO	-	FUEL OIL
LKR	-	LOCKER
P.	-	PILLAR
P&S	-	PORT & STARBOARD
SWL	-	SAFE WORK LOAD
W	-	WASHER
WETD	-	WEATHERTIGHT DOOR



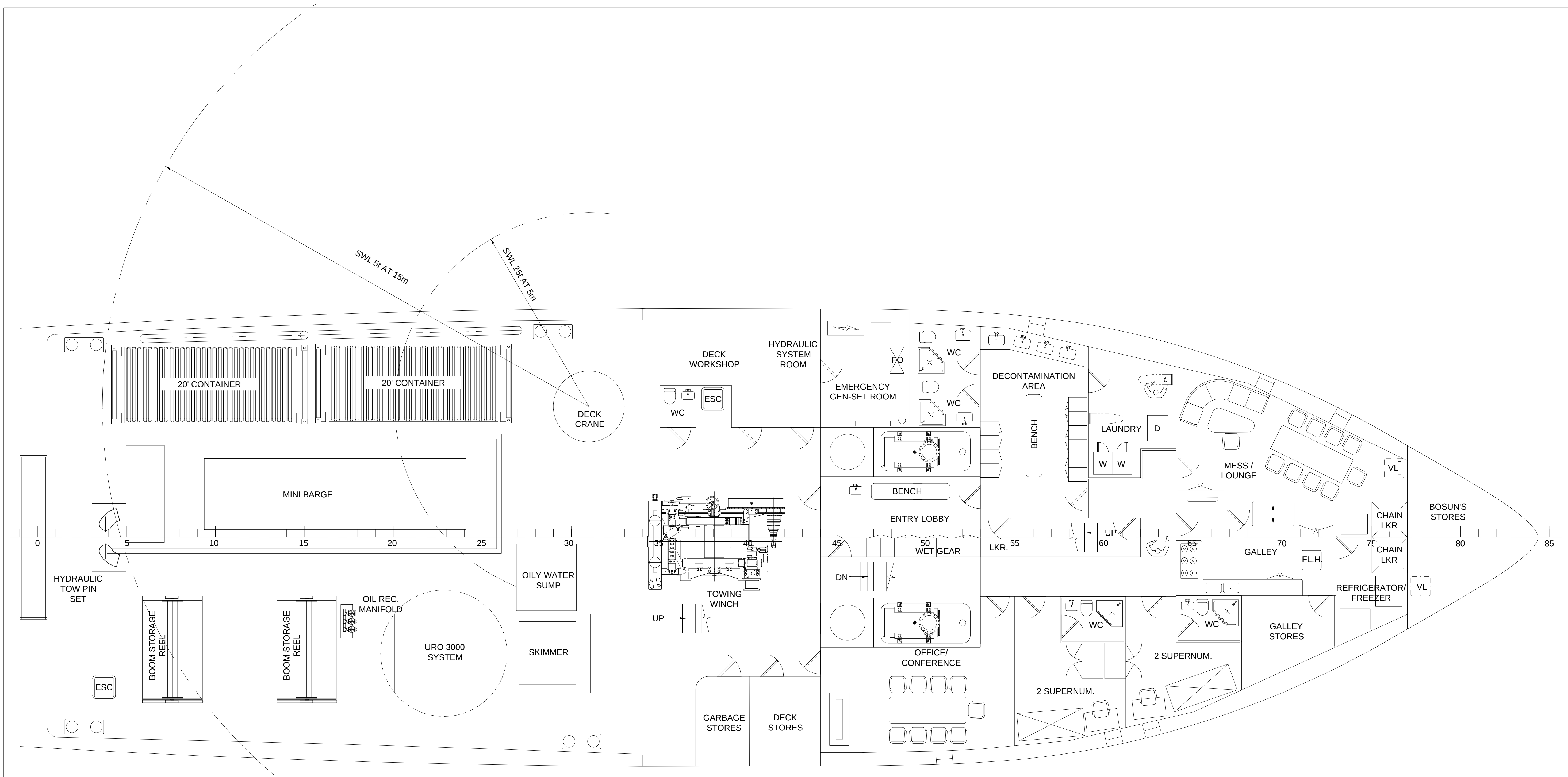
PROFILE VIEW

LOOKING PORT

MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: GENERAL ARRANGEMENT			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 003	SIZE: A3	REV: 3
DATE ISSUED: ARP 04/16		SCALE: 1:125	SHEET: 1 OF 4	

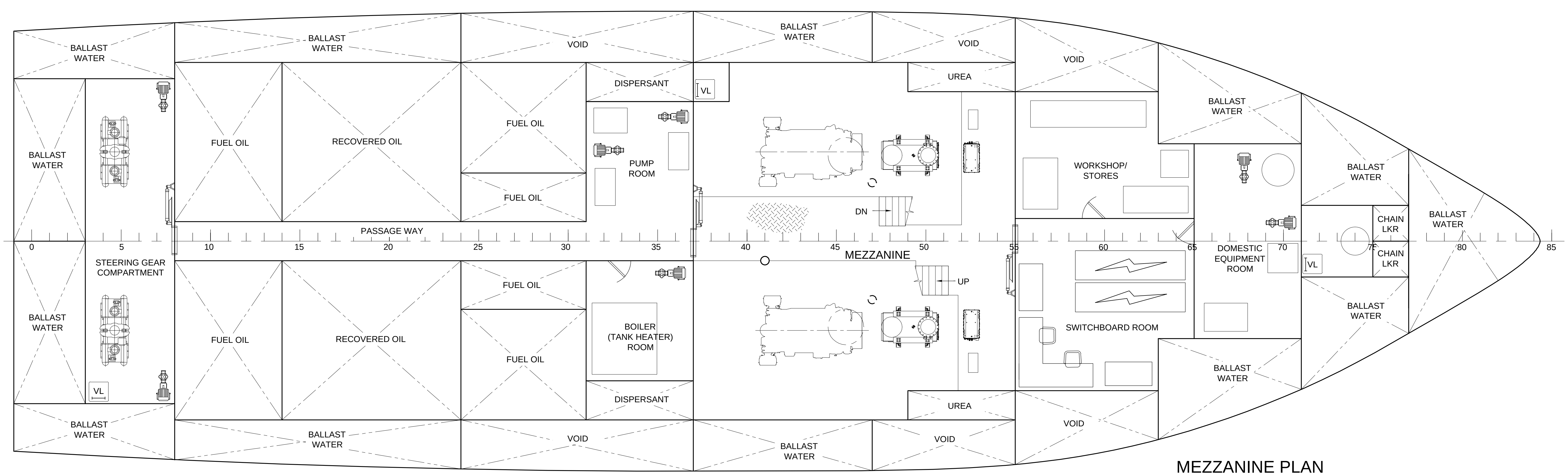


UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: GENERAL ARRANGEMENT			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 003	SIZE: A3	REV: 3
DATE ISSUED: ARP 04/16		SCALE: 1:125	SHEET: 2 OF 4	

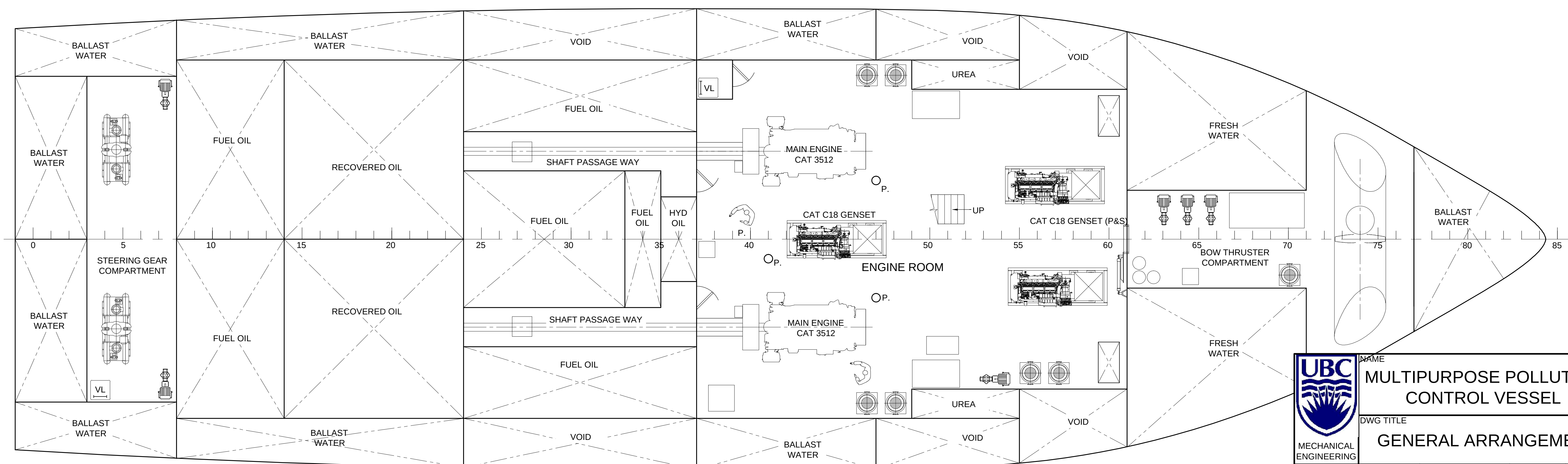


MAIN DECK

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: GENERAL ARRANGEMENT			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 003	SIZE: A3	REV: 3
DATE ISSUED: ARP 04/16		SCALE: 1:125	SHEET: 3 OF 4	



MEZZANINE PLAN



HOLD PLAN

UBC
MECHANICAL ENGINEERING

NAME
MULTIPURPOSE POLLUTION CONTROL VESSEL

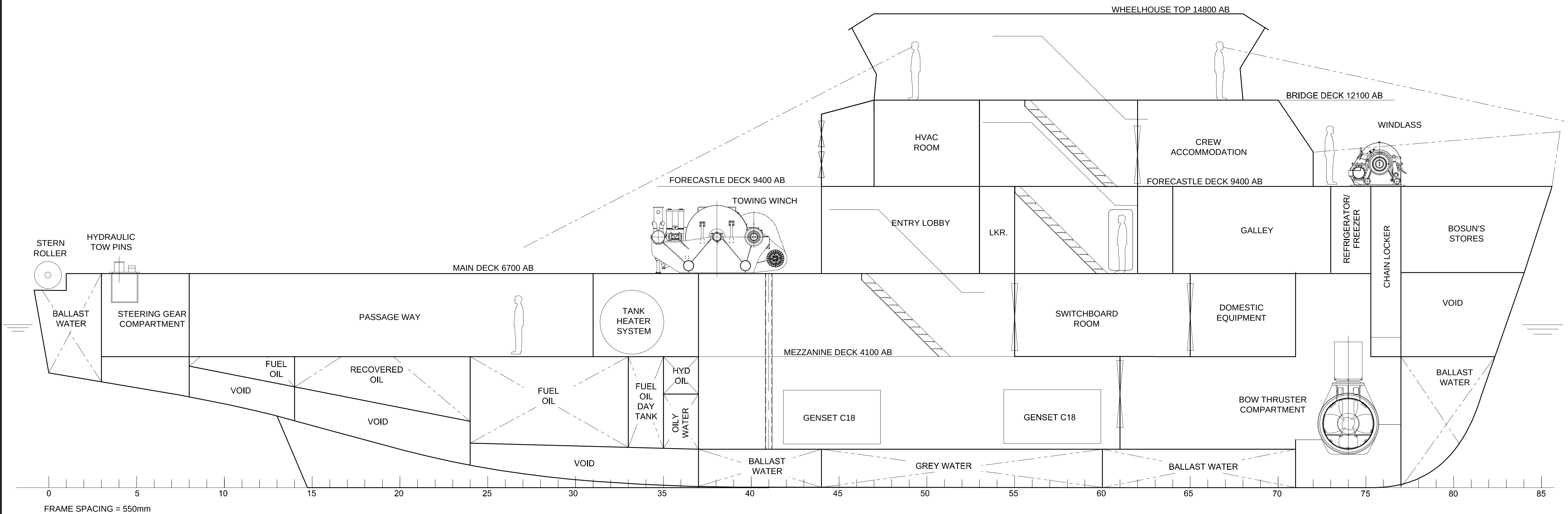
DWG TITLE
GENERAL ARRANGEMENT

DRAWN BY	CHECKED BY	DWG NO.	SIZE	REV
OS		003	A3	3

DATE ISSUED	SCALE	SHEET
ARP 04/16	1:125	4 OF 4

ABBREVIATIONS

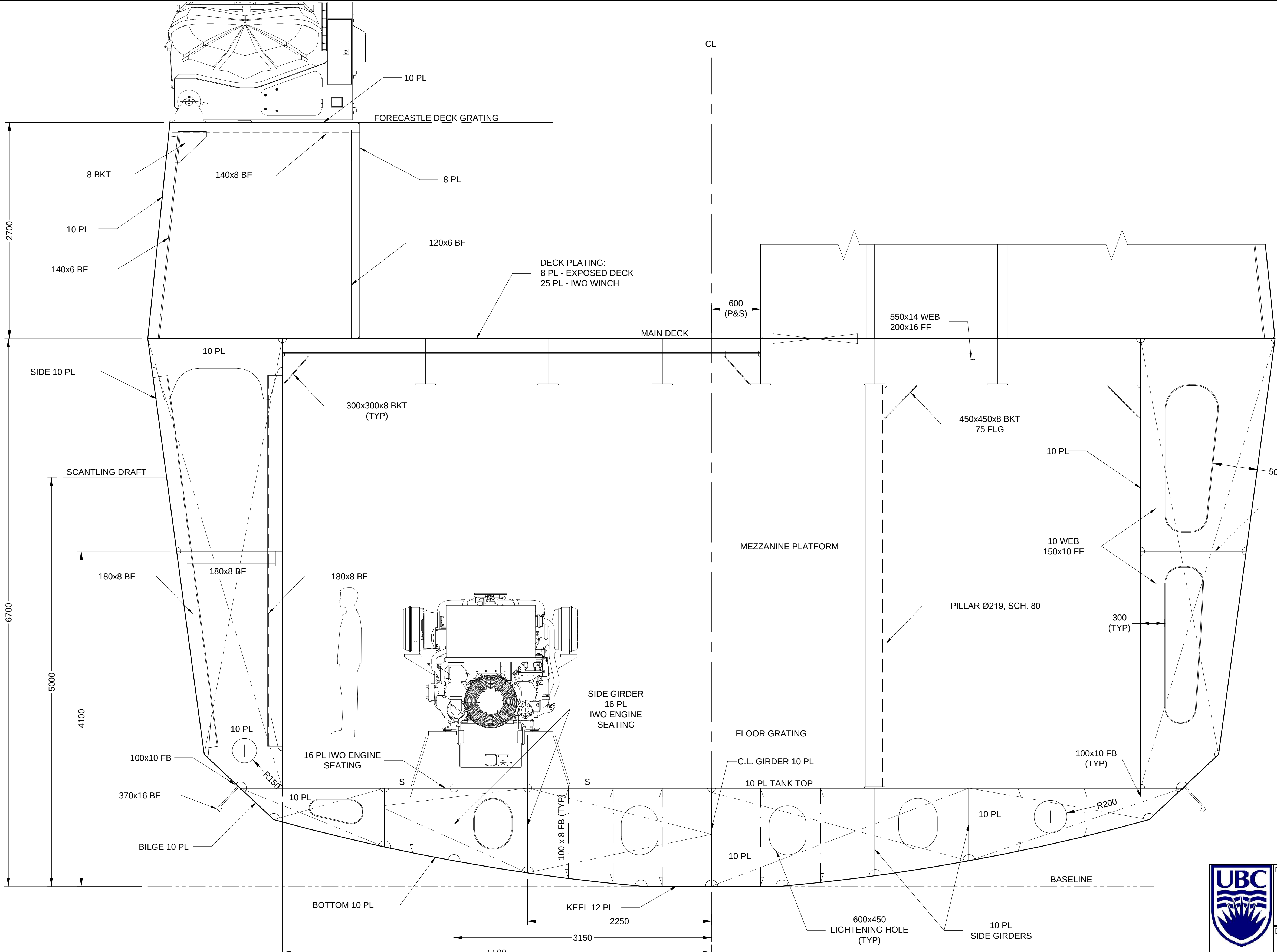
AB	-	ABOVE BASELINE
HYD	-	HYDRAULIC
LKR	-	LOCKER



INBOARD PROFILE

LOOKING STARBOARD

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: INBOARD PROFILE			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 004	SIZE: A3	REV: 1
DATE ISSUED: APR 04/16		SCALE: 1:125	SHEET: 1 OF 1	



MIDSHIP SECTION

FRAME 43 SHOWN
LOOKING AFT
PORT SIMILAR

TYPICAL SECTION

FRAME 47 SHOWN
LOOKING FWD
PORT SIMILAR

ABBREVIATIONS

B., BKT	-	BRACKET
BF	-	BULB FLAT
FB	-	FLAT BAR
FLG	-	FLANGE
FF	-	FACE FLAT
IWO	-	IN THE WAY OF
P&S	-	PORT & STARBOARD
PL	-	PLATE
TYP	-	TYPICAL

END CONNECTION LEGEND

STIFFENER END SNIPED

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: MIDSHIP SECTION			
DRAWN BY: OS/VC	CHECKED BY	DWG NO.: 005	SIZE: A3	REV: 1
DATE ISSUED: APR 04/16		SCALE: 1:50	SHEET: 1 OF 1	

ABBREVIATIONS

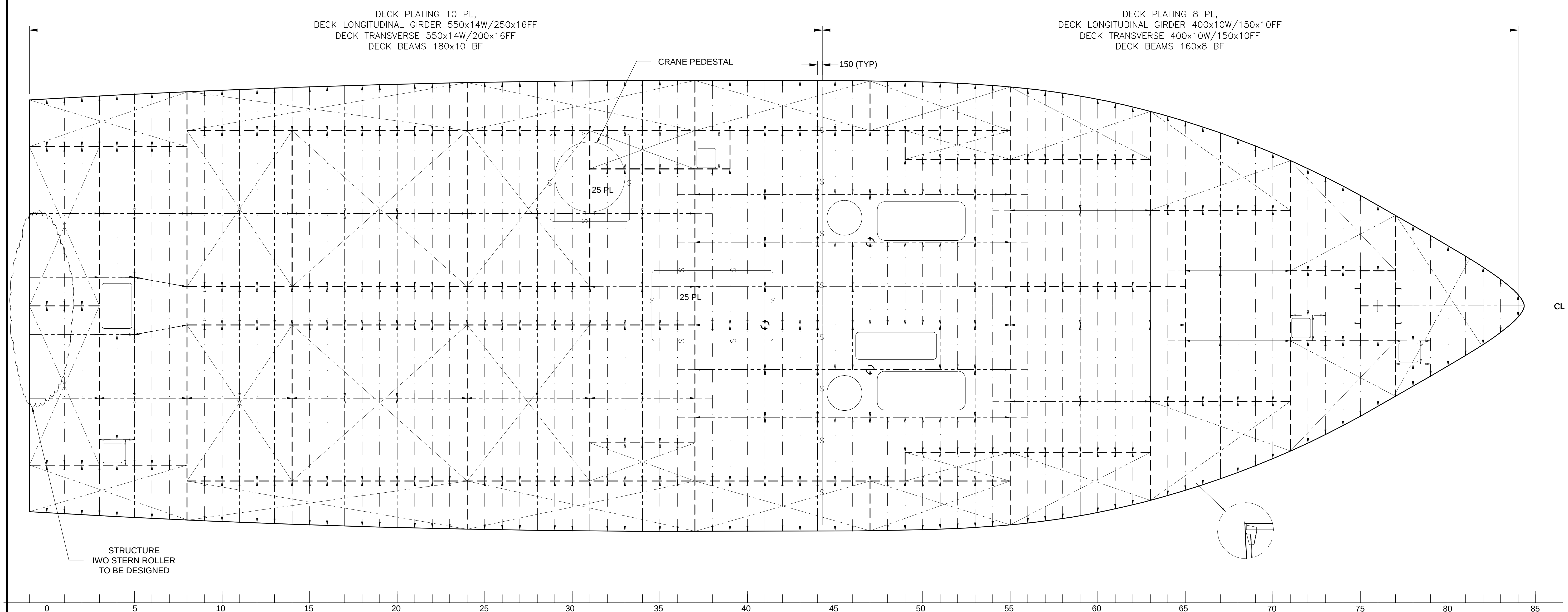
BF	-	BULB FLAT
FF	-	FACE FLAT
P&S	-	PORT & STARBOARD
PL	-	PLATE
TYP	-	TYPICAL

LINE LEGEND

- BULKHEADS
- GIRDERS, TRANSVERSES, WEB FRAMES
- BEAMS, STIFFENERS
- BRACKETS
- PLATE INSERT AREA

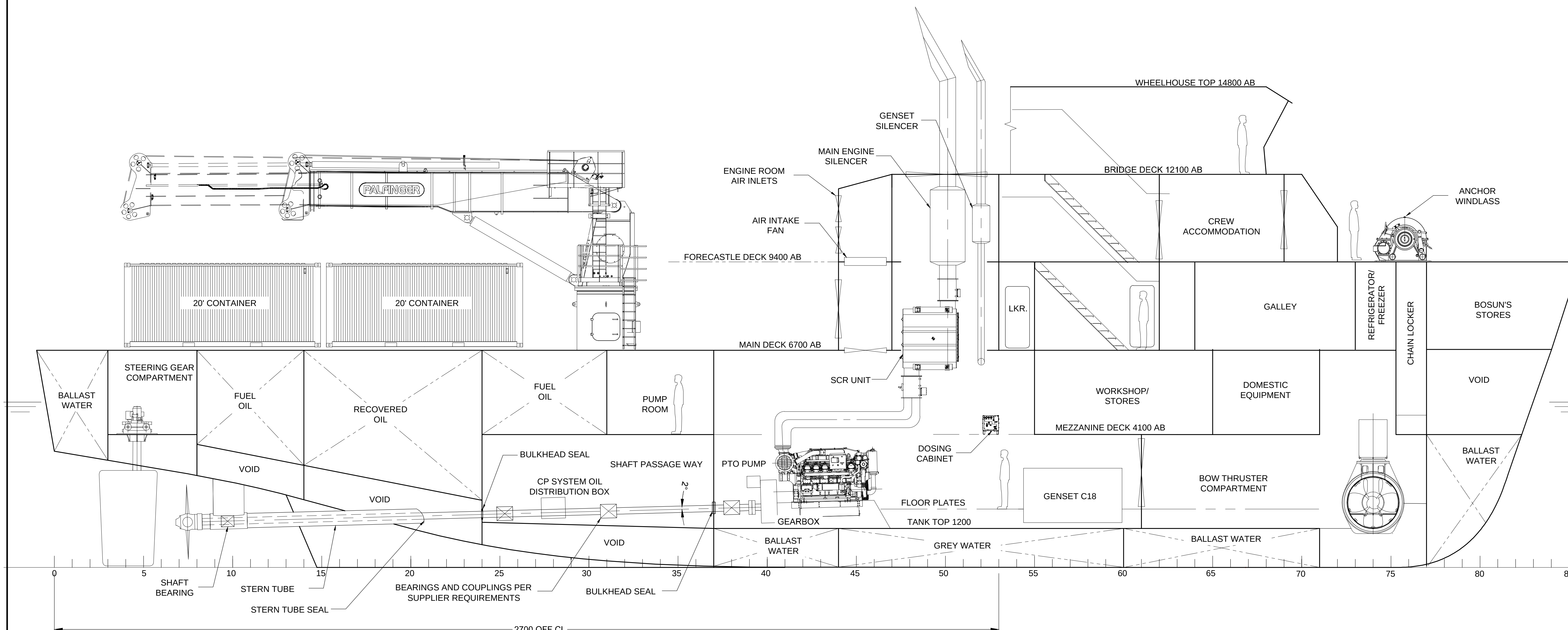
END CONNECTION LEGEND

- STIFFENER WITH BRACKET
- STIFFENER END SNIPED



MAIN DECK

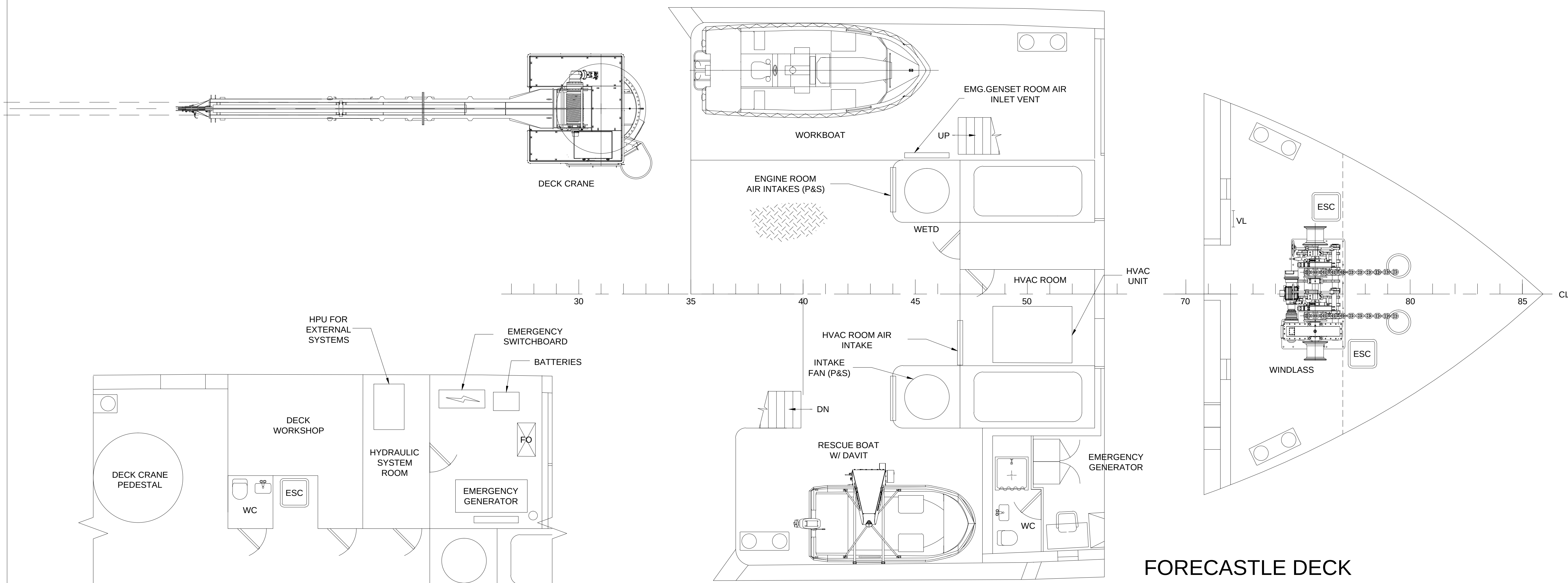
UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: STRUCTURAL ARRANGEMENT			
DRAWN BY: OS	CHECKED BY:	DWG NO.: 006	SIZE: A3	REV: 1
DATE ISSUED: APR 4/16		SCALE: 1:125	SHEET: 1 OF 1	

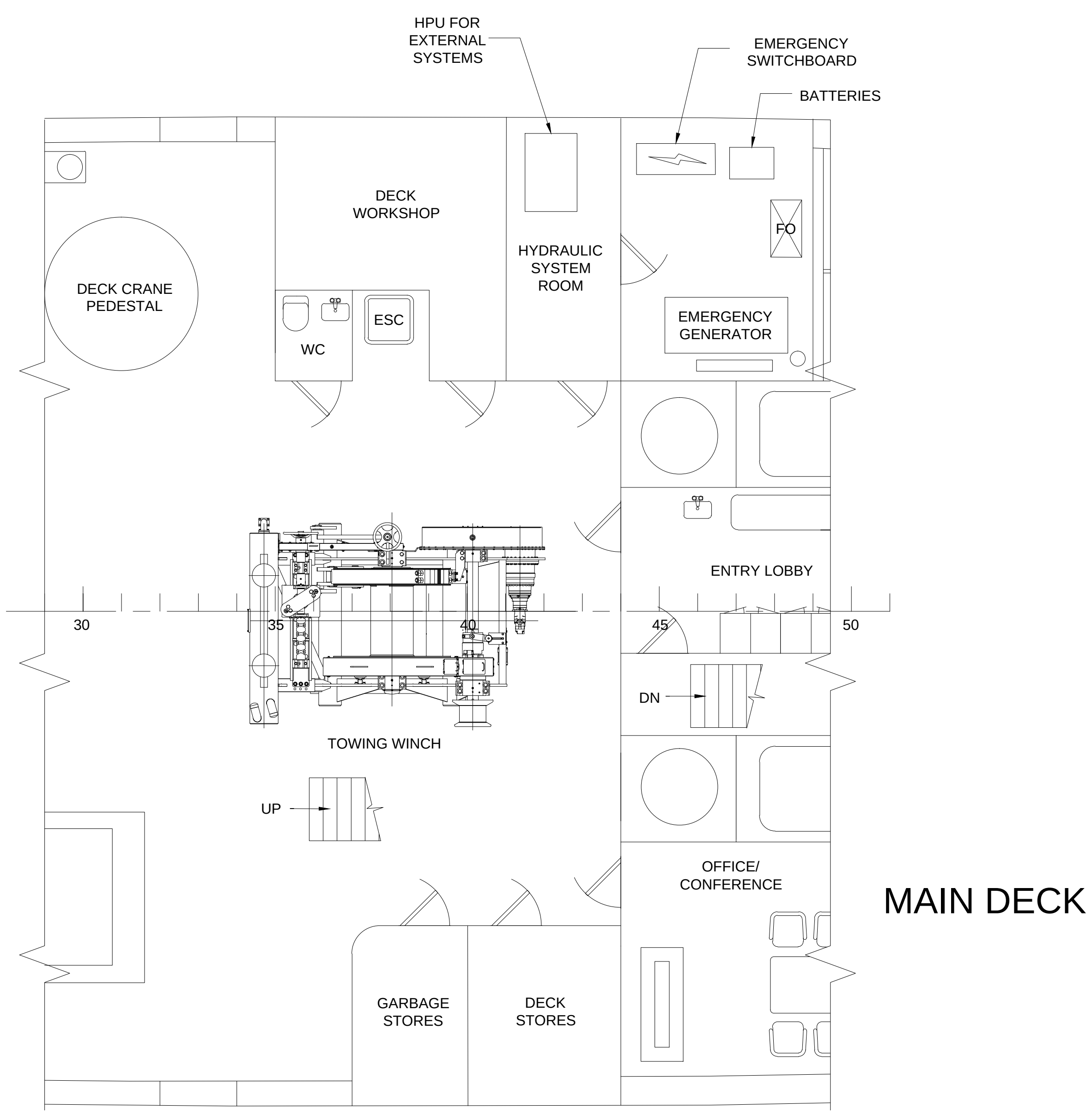


INBOARD PROFILE

LOOKING PORT

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: MACHINERY ARRANGEMENT			
DRAWN BY: OS/JC	CHECKED BY:	DWG NO.: 007	SIZE: A3	REV: 1
DATE ISSUED: APR 04/16		SCALE: 1:100	SHEET: 1 OF 4	





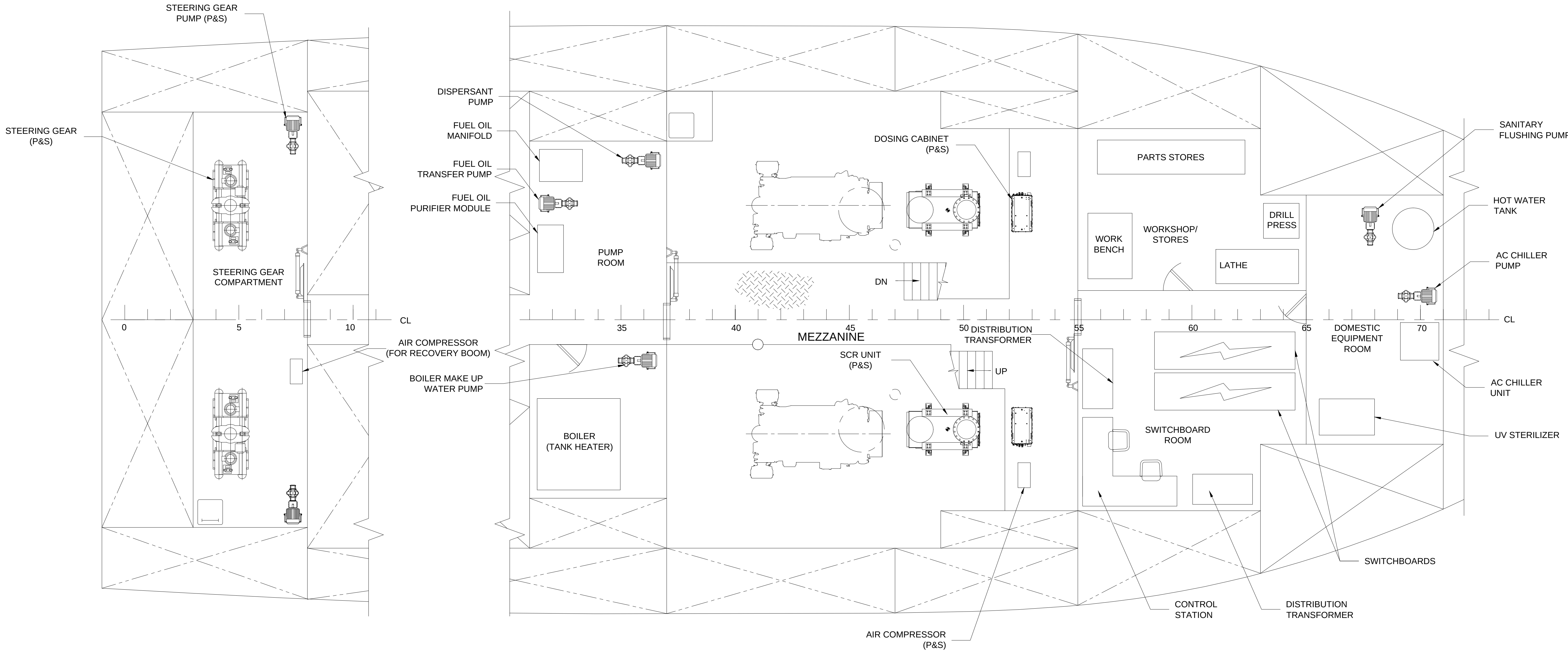
UBC

MECHANICAL ENGINEERING

NAME
MULTIPURPOSE POLLUTION CONTROL VESSEL

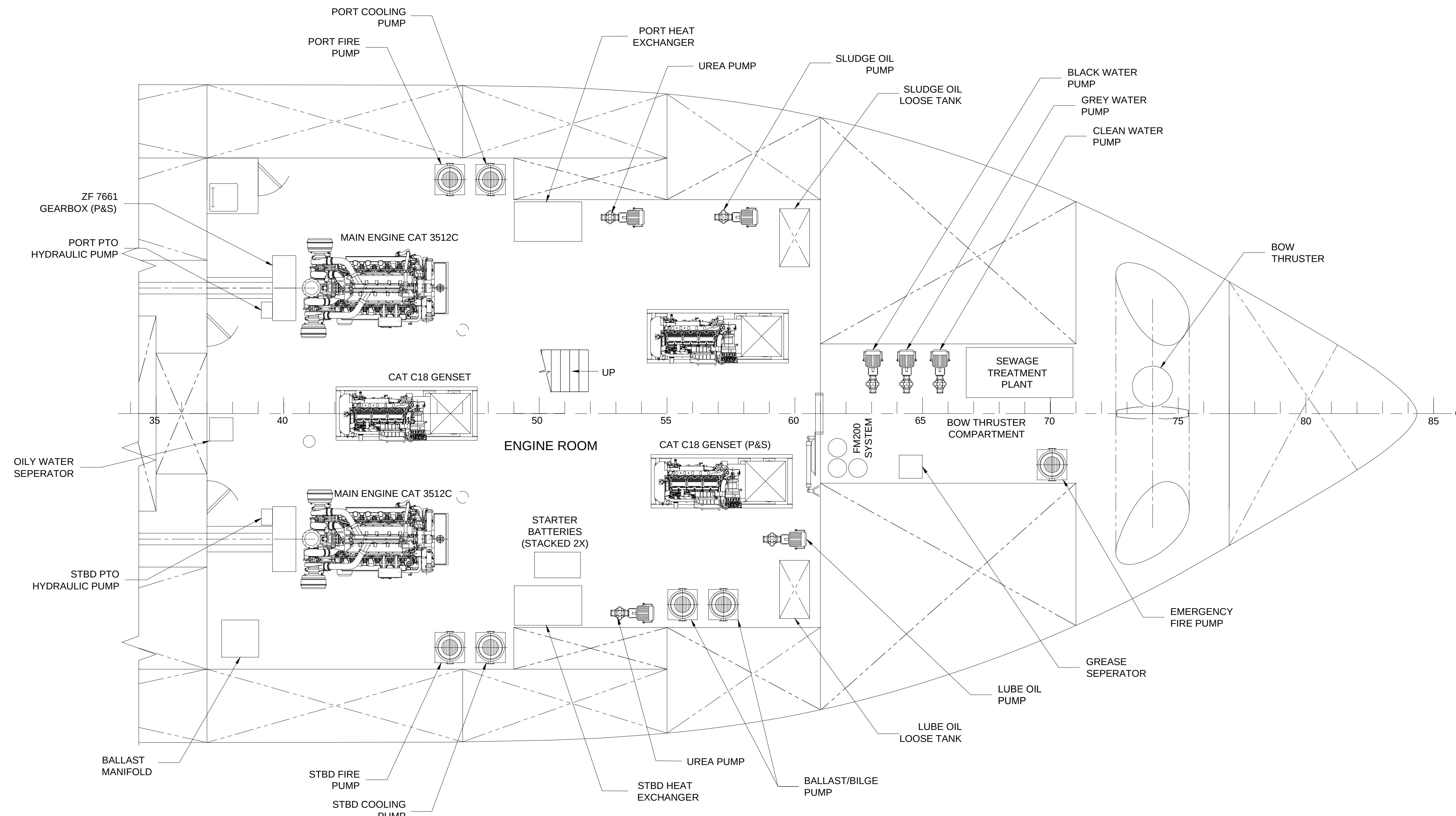
DWG TITLE
MACHINERY ARRANGEMENT

DRAWN BY	CHECKED BY	DWG NO.	SIZE	REV
OS/JC		007	A3	1
DATE ISSUED		SCALE	SHEET	
APR 04/16		1:100	2 OF 4	



MEZZANINE PLAN

UBC MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: MACHINERY ARRANGEMENT			
DRAWN BY: OS/JC	CHECKED BY	DWG NO.: 007	SIZE: A3	REV: 1
DATE ISSUED: APR 04/16		SCALE: 1:100	SHEET: 3 OF 4	



HOLD PLAN

MECHANICAL ENGINEERING	NAME: MULTIPURPOSE POLLUTION CONTROL VESSEL			
	DWG TITLE: MACHINERY ARRANGEMENT			
DRAWN BY: OS/JC	CHECKED BY:	DWG NO.: 007	SIZE: A3	REV: 1
DATE ISSUED: APR 04/16		SCALE: 1:100	SHEET: 4 OF 4	