CONCEPT DESIGN OF AN OFFSHORE PATROL VESSEL FOR THE CANADIAN COAST GUARD

NAVAL ARCHITECTURE AND MARINE ENGINEERING
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NAME 591 – COMPUTER-AIDED SHIP DESIGN PROJECT

EXECUTIVE SUMMARY

This project attempted to produce the concept of designing an offshore patrol vessel to meet the requirements set forth by the Canadian Coast Guard. This project was undertaken by a group of five Master's students from the University of British Columbia as a part of the NAME 591 – Computer-Aided ship design project. The design was produced with the collaboration of industry mentors and faculty advisors concerning the concept design stage. The project was completed by performing the design spiral once and multiple changes were made for more important aspects during the project.

The vessel meets the needs of the offshore patrol vessel for the Coast Guard. The mission profile of the vessel include conducting surveillance on fisheries operations, seizing, recovering and transporting illegal fishing equipment, monitoring and patrolling the oceans, discouraging and smuggling activities and to conduct search and rescue operations. The designed vessel is designated as Ice class B so as to carry out its icebreaking operations. The vessel was designed by powering from by a diesel geared drive set-up. The hullform was created with icebreaking in some regions, open water efficiency and deadweight capacity of the vessel. The general arrangement of the vessel was in accordance with the mission profile of the vessel and based on the current OPV's in operation by the Canadian Coast Guard. 2008 Intact Stability Code was used for the evaluation of intact stability and SOLAS 90 regulations were used for evaluating the damage stability of the vessel.

Overall, the project determined that the vessel designed meets the requirements set forth in the mission profile is stable and feasible.

ACKNOWLEDGEMENTS

The OPV design team would like to acknowledge the following individuals and organizations whose involvement helped us to complete the project.

Organizations:
- SNAME
- SNAME Pacific Northwest

From the University of British Columbia:
- Alan Steeves
- Jon Mikkelson

From STX Canada Marine:
- Dan McGreer
- Tony Vollmers

From Siemens:
- Martin Roy

ABBREVIATIONS AND NOMENCLATURE

AP - Aft Perpendicular
CER - Cost Estimation Relation
CF - Complexity Factor
CNG – Compressed Natural Gas
FP - Forward Perpendicular
GFS – Gas Fueled Ship
IMO – International Maritime Organization
LCB - Longitudinal Centre of Buoyancy
LCF - Longitudinal Centre of Floatation
LCG – Longitudinal Centre of Gravity
MARPOL – International Convention for the Prevention of Pollution from Ships
PACE – Partners for the Advancement of Collaborative Engineering Education
PODAC - Product-Oriented Design and Construction
SOLAS – International Convention for the Safety of Life at Sea
SWBS – Ship Work Breakdown System
TCB - Transverse Centre of Buoyancy
TCF - Transverse Centre of Flotation
TCG – Transverse Centre of Gravity
VCB - Vertical Centre of Buoyancy
VCG – Vertical Centre of Gravity
VOF – Volume of Fluid

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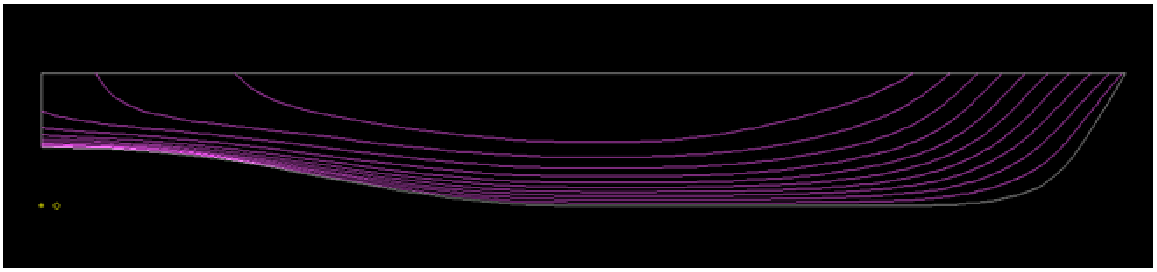
1 SUMMARY OF PRINCIPAL PARTICULARS

The final dimensions of the vessel and hullform were developed to meet the statement of requirements formed based on the current offshore patrol vessels while considering good shipbuilding practice. The principal particulars are summarized in Table 1.



Length (m)	Beam (m)	Draft (m)	Am (m^2)	Aw (m^2)
62.50	11.00	3.50	37.50	37.50
Froude Number	Hull type	Cb	L/B	B/T
0.25	Displacement Hull	0.63	5.68	3.14
Optimum values				
CB	CP	CM	CW	
0.65	0.65	0.98	0.84	
Actual Values				
CB	CP	CM	CW	
0.63	0.65	0.97	0.84	

Figure 1- Principal Particulars

2 PROJECT OVERVIEW

The purpose of the project presented in this report is to design a Fisheries offshore patrol vessel for the Canadian Coast Guard. The project is initiated to develop the vessel as the Canadian government is funding 3.3 billion dollars for building 10 new offshore patrol vessels and the existing OPV's are to be replaced with new ones. The vessel is designed according to the regulations of the CCG and the governing rule sets in accordance to achieve a workable vessel. This report includes the design, development and analysis of the proposed concept vessel designed by Naval Architecture and Marine Engineering (NAME) students from The University of British Columbia, Vancouver.

2.1 PROJECT TEAM

The project was developed by five UBC engineering students of the Naval Architecture and Marine Engineering (NAME) program. The team includes

Zhi Song Liao
Yasasvy Jagarlapudi
Ali Faramarzifar
Kuljeet Kaushal
Yizhou Yang

3 VESSEL OVERVIEW

The initial stage of the project included the defining of the design requirements for the overview of the vessel. This section details the client's motivation, mission profile, area of operation of the vessel, the client's requirements and applicable rules and regulations.

3.1 CLIENT'S BACKGROUND AND MOTIVATION

The following sections present the details of the client, background information on the existing vessels and the design vessel and the motivation of the client for a new design vessel.

3.1.1 Client Profile – Canadian Coast Guard

The mission of the Canadian Coast Guard services is to support government priorities and economic prosperity and contribute to the safety, accessibility and security of Canadian waters. It provides services to ships sailing in the Canadian waters. The Canadian Coast Guard is provided with the responsibility for providing aids to navigation, icebreaking services, marine search and rescue, marine pollution response and channel maintenance among others. The vessel is designed with these services being the primary mission.

3.1.2 Vessel Background

The primary mission for the designed OPV is to conduct surveillance of fisheries operation and to patrol the coastlines and boundaries for the safety of Canadian waters. The vessel is also equipped to carry out search and rescue operations along with ice breaking.

The Offshore Patrol vessels currently used by the CCG are:

- CCGS Cape Roger
- CCGS Cygnus
- CCGS Leonard J. Cowley
- CCGS Sir Wilfred Grenfell

All these vessels CCGS Cape Roger, CCGS Cygnus, CCGS Leonard J. Cowley and CCGS Sir Wilfred Grenfell are home ported at CCG Base St. John's, Newfoundland and Labrador.

3.1.3 Client's Motivation

Since the current Offshore Patrol vessels are in use for a long time and are approaching the end of their design life, they are in need of replacement. Hence, the Canadian government has allotted a funding of $3.3 Billion to build additional 5 offshore patrol vessels among the 10 coast guard ships for the Canadian Coast Guard.

3.2 MISSION PROFILE

The mission profile for the designed offshore patrol vessel was developed based on the mission profiles of the existing Canadian Coast Guard offshore patrol vessels and also for the vessel to be operated during extreme winter, ice breaking capabilities are also added in addition to the existing profile. The vessel is designed as a multi-purpose vessel in order to be able to perform different tasks. The primary mission of the OPV is fisheries patrol, which includes conducting surveillance of the fisheries operation in the sea waters, providing help for fisheries vessels, seizing of equipment used in illegal fishing activities.

3.3 AREAS OF OPERATION

The route in which the vessel is expected to travel is shown in the figure below.

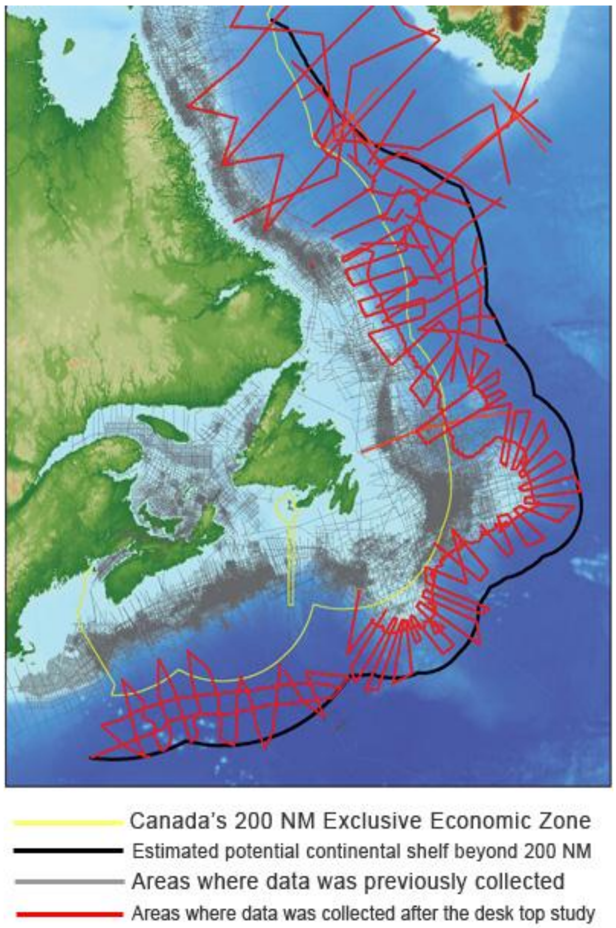


Figure 2 - Areas of operation

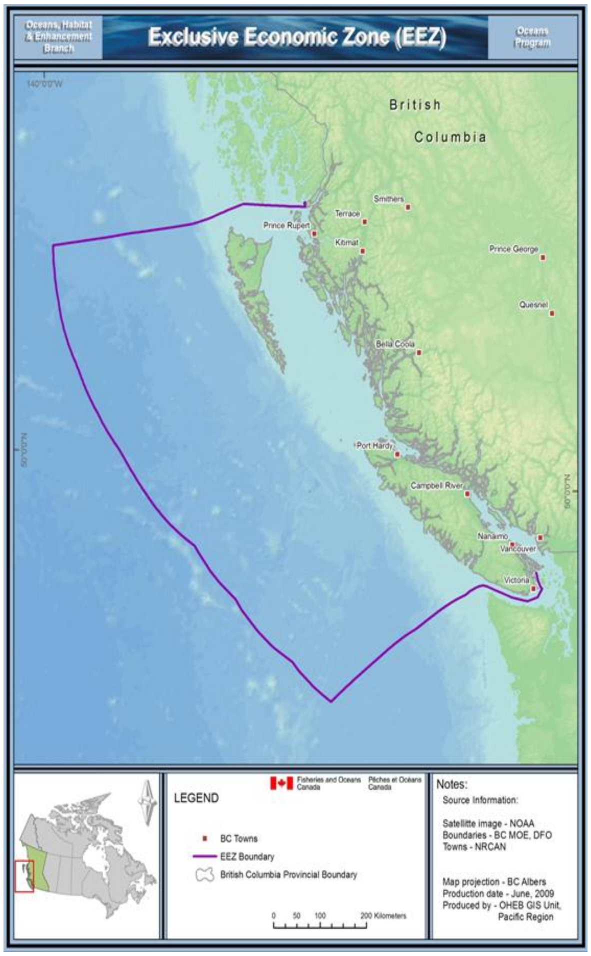


Figure 3 - Areas of operation

3.4 CLIENT'S REQUIREMENTS

The requirements for the vessel were obtained based on the present offshore patrol vessels used by the Canadian Coast Guard. Modifications were made based on the areas of operation. In case of unclear or ambiguous requirements, clarification was sought from our mentors and faculty.

The project attempted to develop a design specified based on the previous offshore patrol vessels operated by the Canadian Coast Guard. As the vessel is designed to travel in both east and west coasts of Canada, it is required that it meets the conditions at both coasts. The requirements of the offshore patrol vessel are explained in detail below:

3.4.1 Dimensional Requirements

The vessel's overall length is 62.50 m, the minimum breadth on the deck must be atleast 11 m and the draft must not exceed 4.25 m at the medium load condition.

3.4.2 Performance Requirements

The following sections outline the vessel's performance requirements.

3.4.2.1 Design Speed
The vessel's maximum speed must be 18 knots and the cruise speed must be 12 knots.

3.4.2.2 Endurance
The endurance of the vessel is for 30 days in both east coast and west coast. It must be able to carry provisions, stores and potable water at sea for minimum of 30 days. The fuel capacity of the vessel must be sufficient for providing a range of 6000 nautical miles at a cruising speed of 12 knots with 20% reserve.

3.4.2.3 Manoeuvring
The vessel must be able to manoeuver close to banks and in areas of minimal water depth below the keel.

The vessel must be able to maintain steerage in WMO Sea State 6 and Beaufort force 10, and maintain steerage by rudder alone at a through-water speed of 2 knots in WMO Sea State 4.

3.4.2.4 Seakeeping and Station-keeping
The vessel must be capable of seakeeping for periods of upto 90 minutes in WMO Sea State 4 with the speeds of wind ranging from 15 knots to 30 knots. The vessel must be able to adjust to the sea conditions with a natural or exclusive roll motion with the comfort levels of the crew.

3.5 APPLICABLE RULES AND REGULATIONS
The following sections outline the rules and regulations that will govern the final design and construction of the vessel.

3.5.1 Class Rules
The design and build of the offshore patrol vessel will be in accordance with the latest Lloyd's Register Rules and Regulations for the classification of Ships. The designations of the offshore patrol vessel are defined as follows:

Vessel Type:	**Offshore Patrol Vessel**
Machinery Type:	**✠LMC**
Fuel Type:	**Diesel**

The class designation for the vessel was determined by reviewing vessels of similar type and purpose. The vessels reviewed were primarily the United States Coast Guard WLB Cutter class vessels and the CCG Type 1050 vessels.

3.5.2 Conventions
The ship's arrangements and equipment are required to comply with the requirements of:

- Load Lines Convention;
- International Convention for the Safety of Life at Sea;
- MARPOL – International Convention for the Prevention of Pollution from Ships;

3.5.3 Flag State

The vessel built will be operated under a Canadian flag and will be designed and built to meet the rules and regulations required for marine vehicles operating under Canadian waters.

4 WEIGHTS, AREAS AND VOLUMES

The preliminary areas and volumes of various spaces on the designed vessel are determined based on studying existing offshore patrol vessels. An existing Offshore Patrol Vessel of the Canadian Coast Guard, “Leonard J. Cowley” was closely examined as the design team has received its general arrangement drawings from the industry mentor. The area and the volume of the spaces are also checked to make sure they meet the Classification Society’s rules and regulations.

This section provides the preliminary estimation of the area and volume of the spaces on the designed vessel at the early stage of the design. Refer to General Arrangement for the finalized spaces on the designed vessel.

4.1 CREW FACILITIES

The designed vessel will have 10 officers and 20 crews. Assuming officers have single rooms and two crews will share one room, there are a total of 20 cabins. According to ABS PUB#102, Crew Habitability on Ships, for a two person cabin, an area of 7 m^2 will meet the HAB requirements; for an officer cabin, an area of 7.5 m^2 will meet the HAB requirements. Minimum headroom of 2030 mm is required in offices, sleeping rooms, dining and recreational rooms, passageways to meet the HAB requirement. The deck height is determined to be 3 m to meet the requirement.

Spaces for Crew Accommodation are listed in the table below:

Crew Accommodation						
Cabin Category	No. of cabins	beds per cabin	Size/ cabin (m^2)	total size (m^2)	height (m)	volume (m^3)
officers	10	1	12	120	3	360
crews	10	2	11	110	3	330
cabin corridors		25% of cabin area		57.5	3	172.5
Total	20	7.23 m^2/crew		287.5		862.5

Table 1 - Crew Accommodation

Crew common places on the designed vessel include a Mess room, Captain Day room, Ship Office, OGD office (for government), Gym, and Hobby/Game room. The officers and the crews will share the same mess room, but have separate tables. According to ABS regulations, a minimum area of 1.5 m^2 per person is required for mess rooms. The size of the spaces is determined by comparing with other offshore patrol vessels and meeting the ABS regulations.

Crew Common Spaces are listed in the table below:

Crew Common Spaces						
Category	Seats	m^2/seat	m^2/crew	Height (m)	Area (m^2)	Volume (m^3)
Mess room	30	1.67	1.67	3	50	150
Captain Day room				3	25	75
Ship Office	8	2.50	0.67	3	20	60
OGD Office				3	20	60
Gym			1.00	3	30	90
Hobby/game room			1.00	3	30	90
Total					175	525

Table 2 - Crew Common Spaces

4.2 SERVICE FACILITIES

Ship service facilities include wheelhouse, sick bay, galley, stores, laundries, etc. The size of these spaces is estimated based on studying existing offshore patrol vessels.

Ship Service			
Use of Space:	Height (m)	Area (m^2)	Volume (m^3)
Wheelhouse	3	60	180
sick bay	3	28	84
Total		88	264

Catering Spaces			
Use of Space:	Height (m)	Area (m^2)	Volume (m^3)
Galley	3	24	72
refrigerated store	3	20	60
dry store	3	20	60
Total		64	192

Hotel Services			
Use of Space:	Height (m)	Area (m^2)	Volume (m^3)
Laundry	3	18	54
Linen Store	3	20	60
Total		38	114

Table 3 - Service Facilities

4.3 TECHNICAL FACILITIES

The size of the technical spaces, like the engine room, engineering store, and control room is determined by studying similar vessels. The fuel and fresh water capacity of similar vessels are plotted verses their range and endurance. Based on the designed vessel's range and endurance, an estimation of the tank spaces is determined from the plots.

Technical Spaces			
Use of Space:	Height (m)	Area (m^2)	Volume (m^3)
Machinery Control Room	4	33	132
Steering Room	4	62	248
Engineer store	4	30	120
Workshop 1	3	30	90
Workshop2	4	30	120
Engine Room	4	64	256
Bow Thruster	4	27	108
Emergency Generator	3	66	198
Funnel	16	6	96
Incinerator Room	3	22	66
Total		370	1434

Tanks and Void Spaces			
Use of Space:			Volume (m^3)
Fuel Oil			350
Lub oil			3
Dirty Oil			2
Fresh Water			50
Sewage			0.12
Water Ballast			312.5
void			106.875
Total			824.50

Table 4 - Technical spaces

4.4 EQUIPMENT

Based on the mission profile, the designed vessel will perform Search and Rescue operations and provide oil spill recovery. The area that these pieces of equipment occupy on board is also considered.

SAR		
Use of Space:		Area (m^2)
RHIBs		39
crane		5
Helicopter Hoist		13
Total		56.57

Oil Spill				
Use of Space:	Quantity	Length(m)	Width(m)	Area (m^2)
BoomReel	3	3.15	1.83	17.29
Skimmer	2	0.87	1.02	1.77
Power pack	2	0.99	0.89	1.76
Bladder	2	9.2	1.3	23.92
Total				44.75

Table 5 - SAR Equipment

4.5 GROSS TONNAGE

The Gross Tonnage of the designed vessel is calculated by the following formula:

GT = K x V

K = 0.2

0.02 x $\log_{10}$ (V)

V= Ship's total volume in cubic meters

Total Area (m^2)	1143.82
Total Volume (m^3)	4248.48
Gross Tonnage	1157.98

Table 6 - Gross Tonnage

4.6 LIGHTSHIP WEIGHT

The lightship weight is calculated by multiplying the specific areas and volumes by certain coefficients. The coefficients are determined from the “System Based Design” book by Kai Levander and by discussing with industry mentor.

Lightweight				
Weight Group	Unit	Value	Coeff ton/unit	Weight (ton)
Deckhouse	volume	363.00	0.06	21.78
Hull Structure	volume	3885.48	0.13	505.11
Interior Outfitting	Area	958.50	0.15	143.78
Ship Outfitting	volume	4248.48	0.005	21.24
Machinery				264.00
Total				955.91
Reserve	%	5.00		47.80
Lightweight				1003.70

Table 7 - Lightship Weight

4.7 DEADWEIGHT

Deadweight is determined by considering the crew, equipment, provision, fuel and water on board.

Deadweight				
Item	Unit	Value	Coeff ton/unit	Weight (ton)
Provision & Store	person	30	0.3	9.00
Crew	person	30	0.1	3.00
Fuel oil	volume	350	0.99	346.50
Lube oil	volume	3	0.88	2.64
Dirty oil	volume	2	0.9	1.8
Fresh Water	volume	50	1	50
Sewage	volume	0.12	1.5	0.18
SAR				2.95
Oil Spill				1.11
Deadweight				413.12

Table 8 - Deadweight

4.8 SUMMARY

The total weight is the combined weight of lightship and deadweight. This is only an estimation of the displacement of the vessel at the early stage of design. These weight calculations are needed to determine the optimum parameters of the hull form.

Gross Tonnage	1158
Displacement (ton)	1417

Table 9 - Gross Tonnage

5 HULLFORM DEVELOPMENT AND PARTICULARS

The following sections outline the design and development of the hullform using Rhinoceros 4.0.

5.1 REFERENCE HULL SELECTION

Ships have been designed and built for thousands of years, so it is very rare for a modern hull to be developed from first principles. The typical method for developing a hullform is to select a reference vessel (i.e. parent vessel) with similar desired attributes as a starting point, and make adaptations as necessary.

5.1.1 Available Options

To develop a 3D model of a hull, detailed lines plans are needed to reconstruct the vessel. Lines plans of the example OPV's are proprietary documents so the team had limited access to that information. Hence, the design team decided to use series 64 and NPL series as a starting point.

5.1.2 Operational Profiles

The offshore patrol vessel has a maximum speed of 18 knots, a range of 6,000 nm, and endurance of 30 days. It was designed to meet the ice class, and was commissioned in 1969.

5.1.3 Superstructure

The mission profile includes search and rescue, firefighting, oil spill recovery. In order to meet these requirements, some specific equipment is outfitted on board: Two cranes for launching crafts, two crafts, water guns, inflatable bladders. Besides, other superstructure like engine room and bridge are placed on board due to general arrangement.

5.1.4 Chosen Reference Vessels

The primary reference vessel chosen was the CCGS Leonard J. Cowley, primarily because it has similar mission profile and all hydrodynamic data are same with our proposal design.

Figure 4 - CCGS Leonard J. Cowley

5.2 MODELING THE HULL

5.2.1 Initial Setup

The first step was to determine which key dimensions would be used to manipulate the ship, as well as how these dimensions would scale.

Our proposal is to use a displacement hull, our goal of ship dimensions and parameters are as follows:

Length (m)	Beam (m)	Draft (m)	Am (m^2)	Aw (m^2)
62.50	11.00	3.50	37.50	37.50
Froude Number	Hull type	Cb	L/B	B/T
0.25	Displacement Hull	0.63	5.68	3.14
Optimum values				
CB	CP	CM	CW	
0.65	0.65	0.98	0.84	
Actual Values				
CB	CP	CM	CW	
0.63	0.65	0.97	0.84	

Figure 5 - Dimensions and Parameters

5.2.2 Reference Hull Model

We used the NPL 'Round Bilge Full Scale' model as a starting point. Its shape and parameters are as follows:

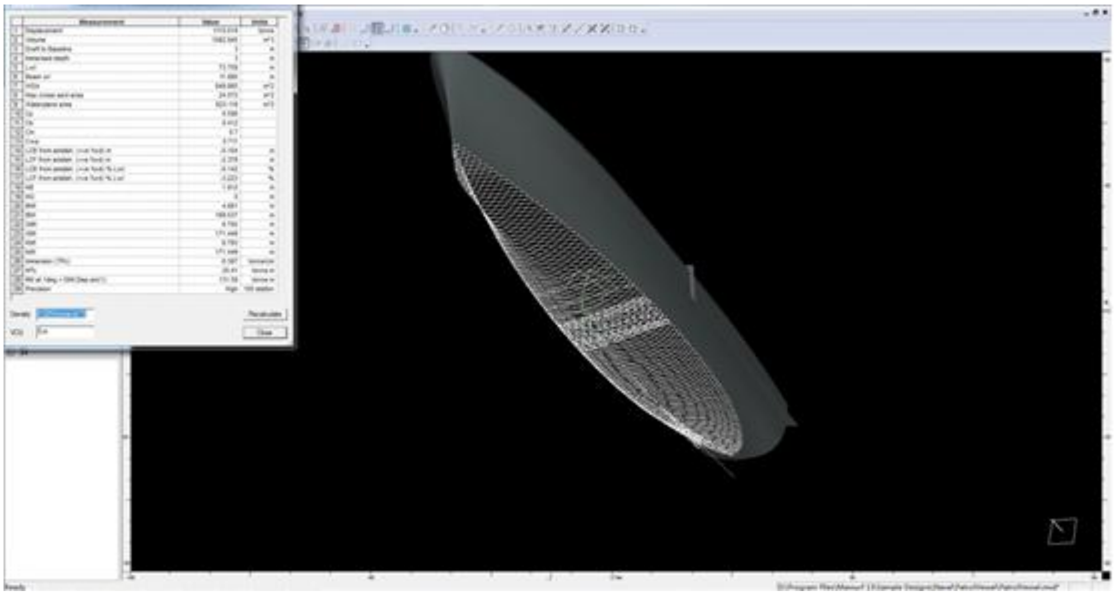


Figure 6 - NPL model

	Measurement	Value	Units
1	Displacement	159.603	tonne
2	Volume	155.711	m^3
3	Draft to Baseline	2.226	m
4	Immersed depth	2.224	m
5	Lwl	39.927	m
6	Beam wl	4.45	m
7	WSA	210.636	m^2
8	Max cross sect area	5.699	m^2
9	Waterplane area	135.031	m^2
10	Cp	0.684	
11	Cb	0.394	
12	Cm	0.656	
13	Cwp	0.76	
14	LCB from amidsh. (+ve fwd) m	-2.518	m
15	LCF from amidsh. (+ve fwd) m	-3.299	m
16	LCB from amidsh. (+ve fwd) % Lwl	-6.307	%
17	LCF from amidsh. (+ve fwd) % Lwl	-8.264	%
18	KB	1.539	m
19	KG	0	m
20	BMt	1.109	m
21	BMl	82.64	m
22	GMt	2.648	m
23	GMl	84.179	m
24	KMt	2.648	m
25	KMl	84.179	m
26	Immersion (TPc)	1.384	tonne/cm
27	MTc	3.365	tonne.m
28	RM at 1deg = GMt.Disp.sin(1)	7.376	tonne.m
29	Precision	High	100 station

Figure 7 - Initial parameters

5.2.3 Modification

The reference hull parameters varied by a large margin to that of the required parameters. So, few modifications were made for this prototype.

First, we scale this model's length (LWL) to 62.5m, then scale the model's beam to 11m, finally scale the depth to 8m.

Then divide the ship to 10 sections longitudinally, and then manipulate control points on each section to make them become the same with NPL series (forward 5 sections) and series 64 (backward 5 sections).

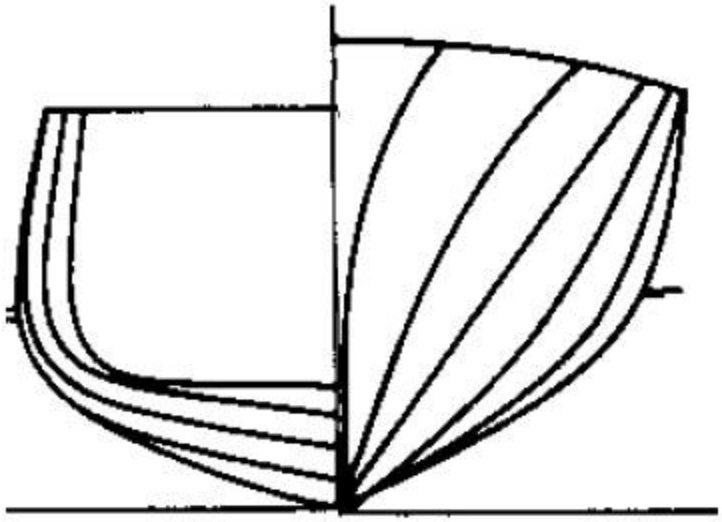


Figure 8 - Lines plan

Finally, we make the body lines of first, second, third sections more smooth than concave to provide more displacement. We elevate the stern part higher from keel to provide space for rudder and propeller. We make the gunwales of last five sections more vertical to provide more space for general arrangement.

After this modification, we get our final model.

5.2.4 Final Model

After adding a forecastle deck (3m high), the final model is designed.

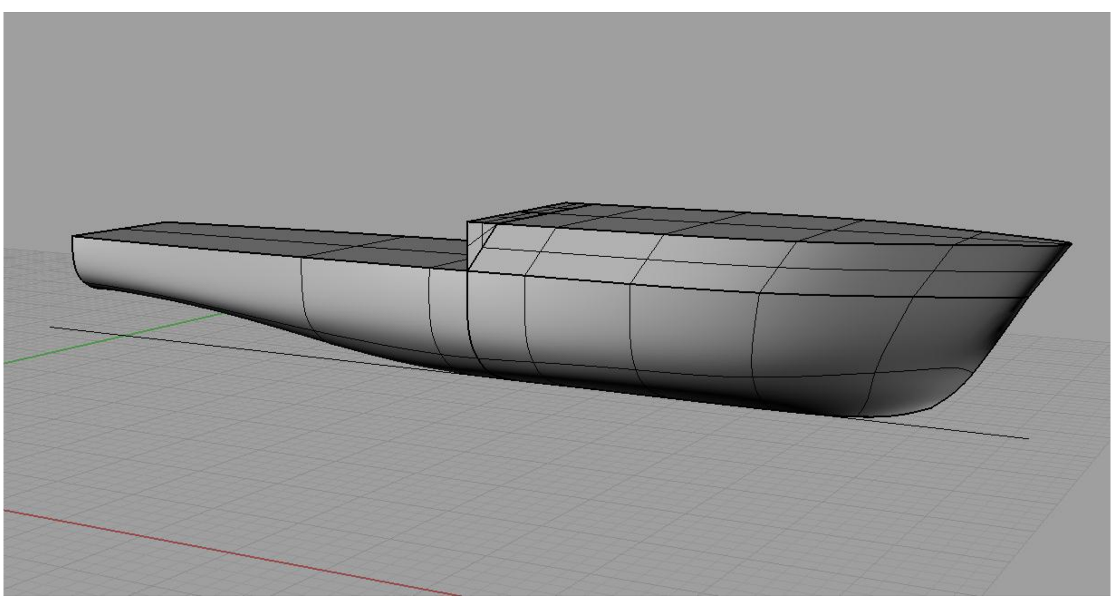


Figure 9 - Final model

	Measurement	Value	Units
1	Displacement	1433.939	tonne
2	Volume	1398.964	m^3
3	Draft to Baseline	4.2	m
4	Immersed depth	4.196	m
5	Lwl	63.28	m
6	Beam wl	12.699	m
7	WSA	793.928	m^2
8	Max cross sect area	37.422	m^2
9	Waterplane area	634.569	m^2
10	Cp	0.591	
11	Cb	0.415	
12	Cm	0.707	
13	Cwp	0.79	
14	LCB from amidsh. (+ve fwd) m	2.754	m
15	LCF from amidsh. (+ve fwd) m	-1.594	m
16	LCB from amidsh. (+ve fwd) % Lwl	4.352	%
17	LCF from amidsh. (+ve fwd) % Lwl	-2.519	%

Figure 10 - Hydrodynamic data

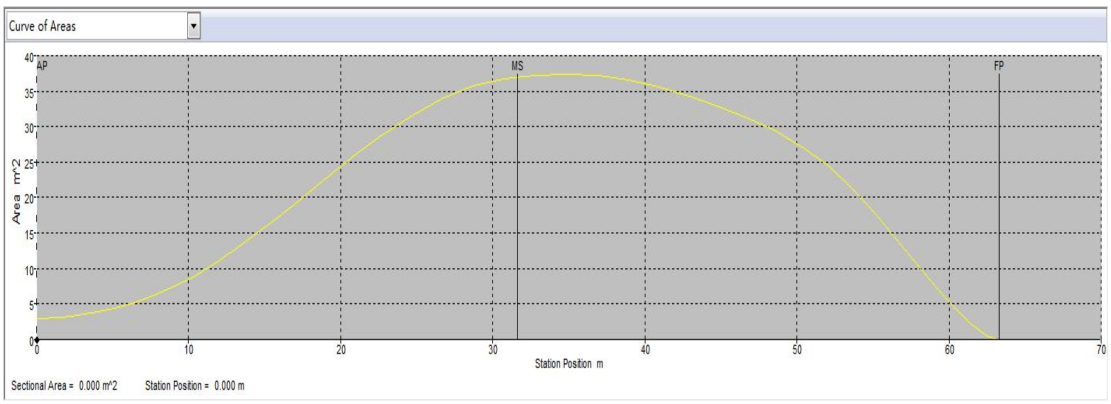


Figure 11 - Curve of area

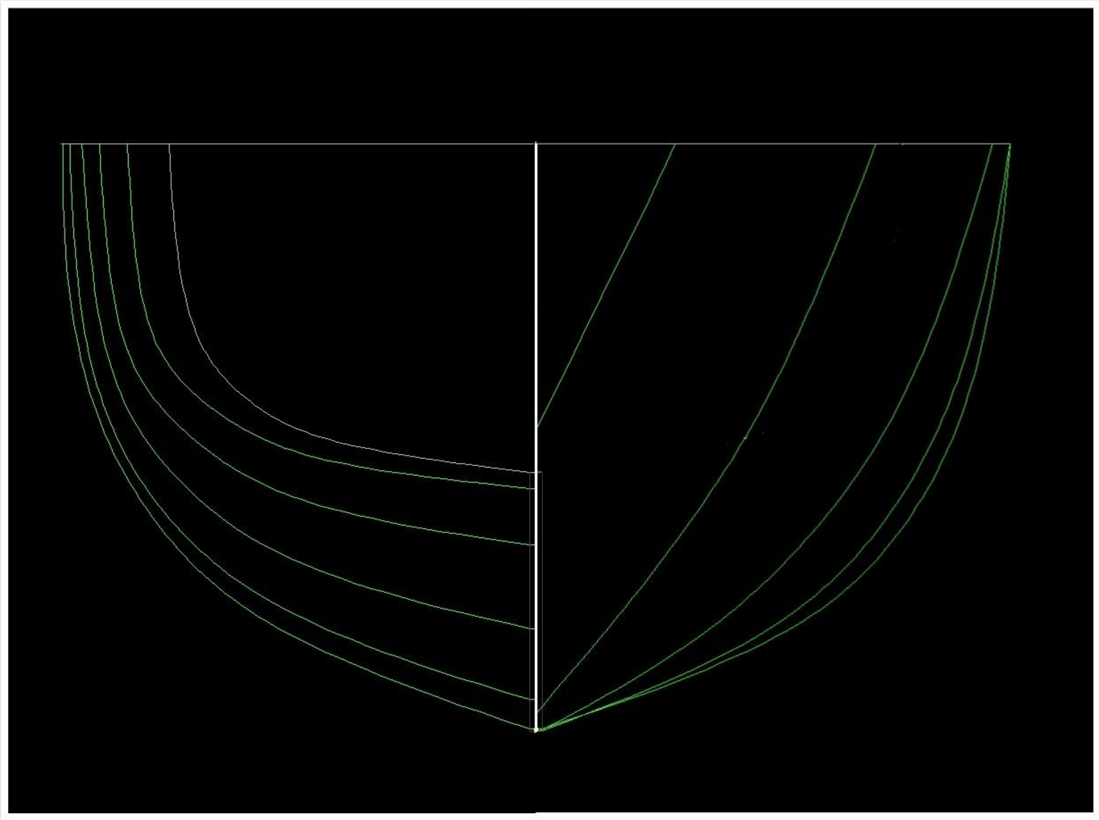


Figure 12 – Final lines plan

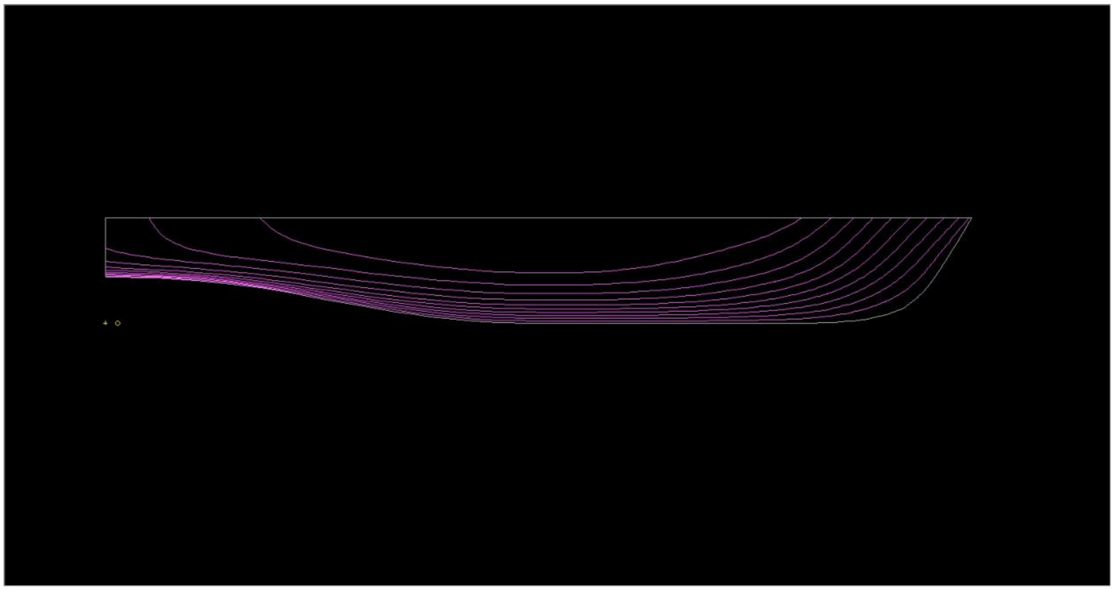


Figure 13 - Final lines plan

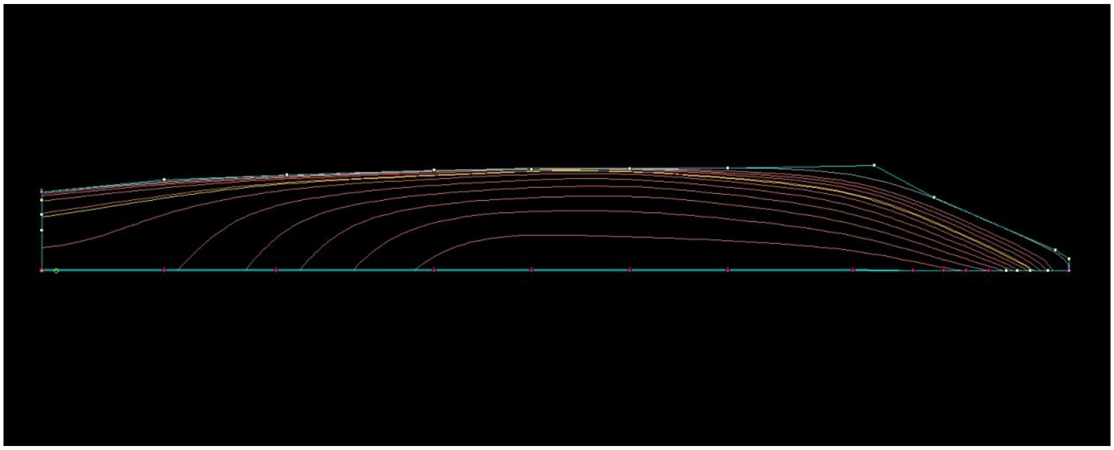


Figure 14 - Final lines plan

5.3 SUPERSTRUCTURE AND OTHER EQUIPMENT

Figure 15 - Mooring system

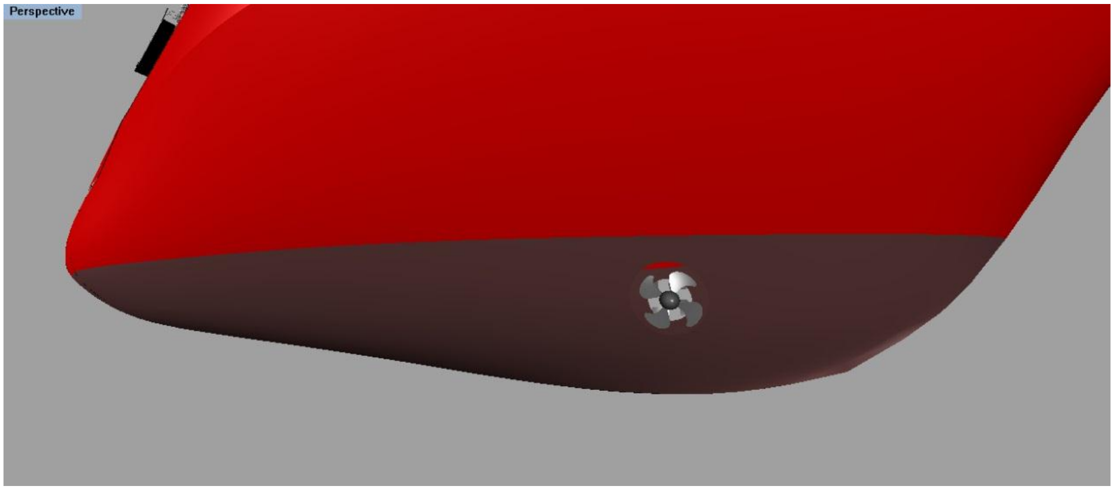


Figure 16 - Bow thruster

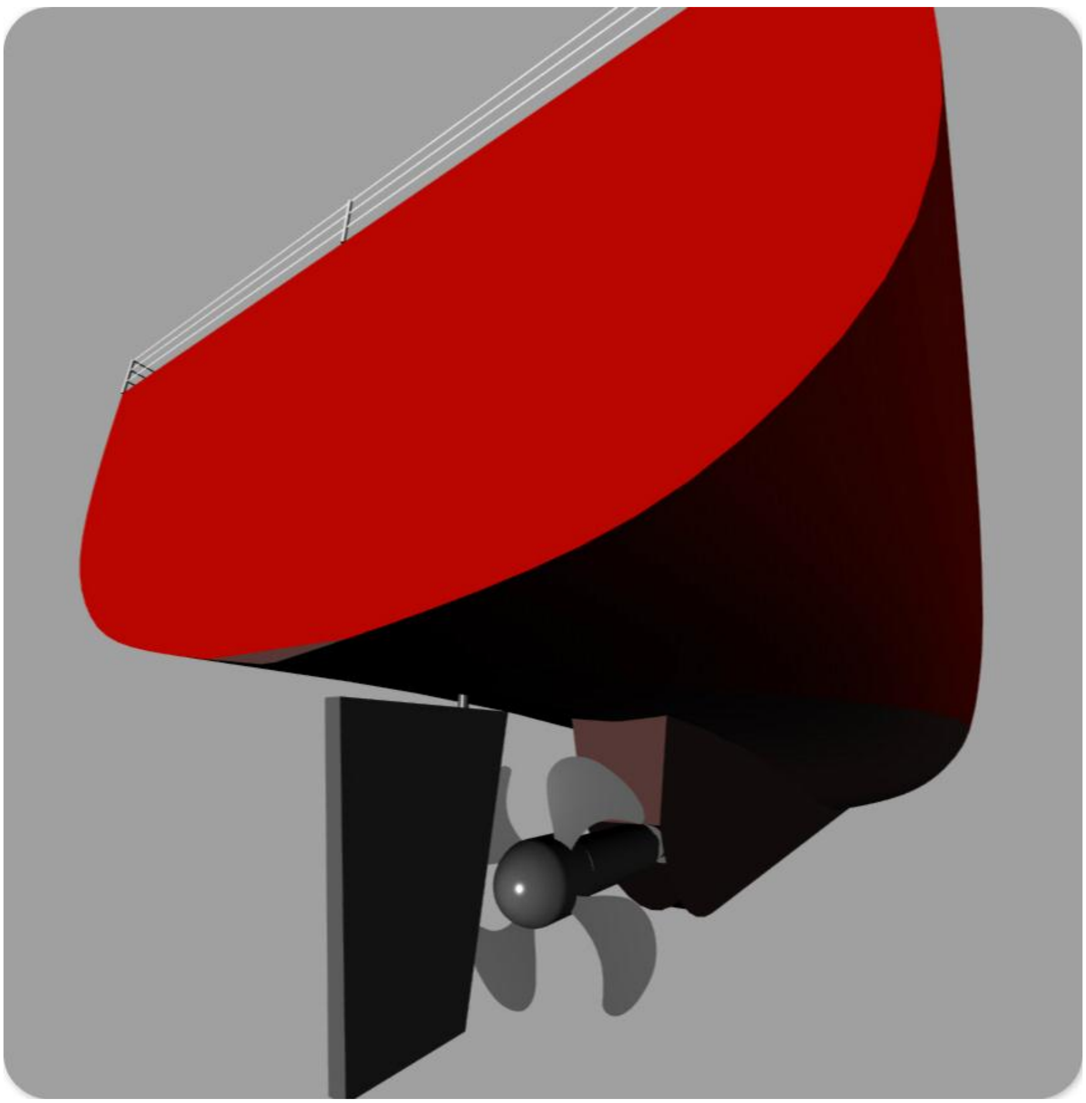


Figure 17 - Propeller and Rudder

Figure 18 - Final design

6 POWERING ANALYSIS

The initial powering analysis and the powering requirement for the vessel with the concept design are explained in this section.

6.1 POWER AND RESISTANCE

The estimation of the power for the vessel is explained in detail in the following sections.

6.1.1 Effective Power Estimation Method

The hull was designed based on the NPL series initially and then changes were made to the hullform. Hence, NPL series could not be used for powering estimation using Paramarine as various factors such as Froude number, Volumetric Froude number etc. were out of range due to modifications in the hull form. Also, since the NPL series is used for planing hulls, the value obtained for the power could not be relied upon.

To improve the powering predictions for the vessel and to find the effective hull resistance, Holtrop powering method in Paramarine was used. The value for the power at the particular speed is obtained from the Speed vs. Power curve obtained in Paramarine.

Holtrop series is generally used for Single-screw and Twin-screw vessels. The OPV vessel designed does not have many similarities with for this series but the ship parameters fall within range and work closely for the Holtrop method in Paramarine. For the results obtained using Paramarine, for the effective power prediction, a correlation factor of 0.001 was applied. Also, using Paramarine, hull roughness and appendage resistance is also taken in account.

6.1.2 Power Estimate Results

Using Paramarine, the effective power prediction was done for the hull using Holtrop method. The figure shows the Speed vs. Power curve based on the propeller efficiencies selected. The effective hull power at that particular shaft speed is calculated from the graph.

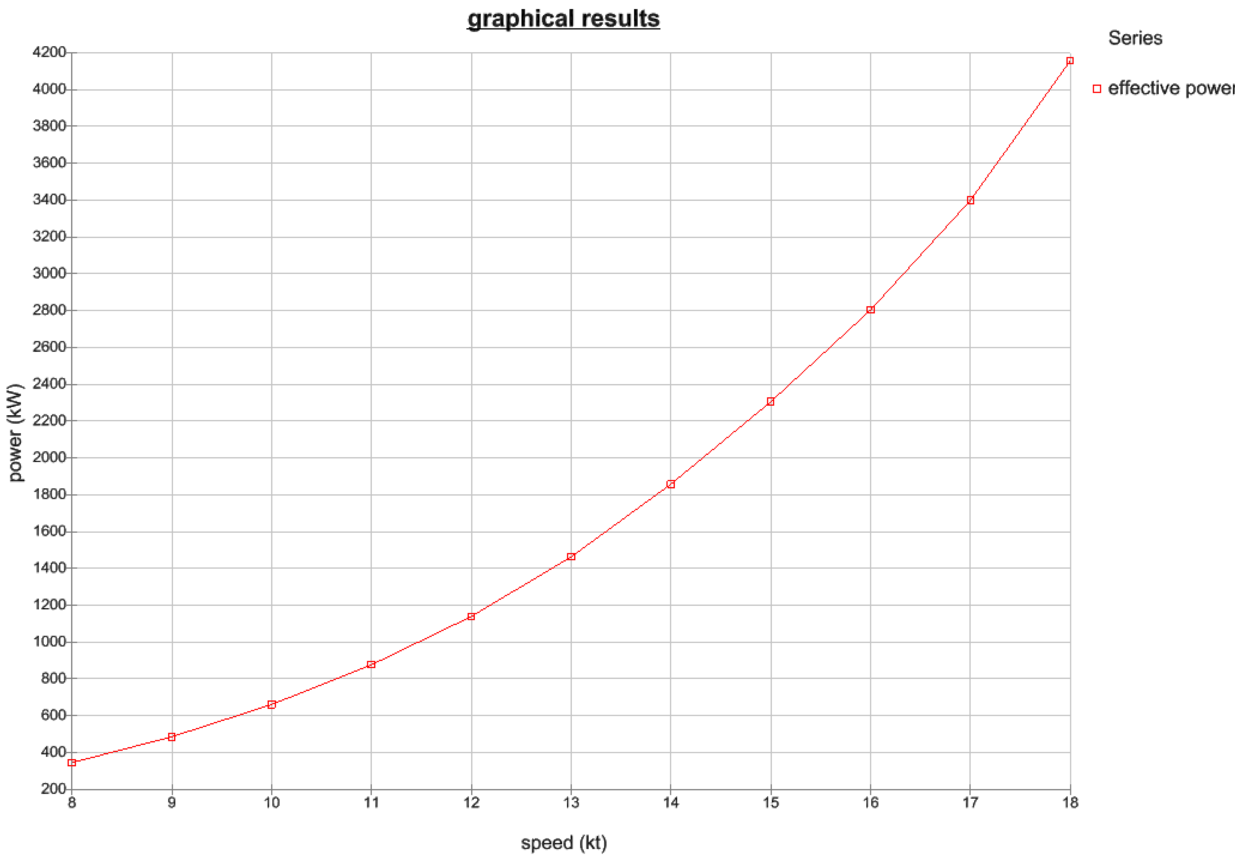


Figure 19 - Speed vs. Power curve using Holtrop Series

6.2 PROPULSION SELECTION

The selection of the propeller is outlined in this section.

6.2.1 Propeller Selection

For the selection of the propeller, Propeller finder feature of paramarine was used. The propeller finder takes the input values and the user defined propeller limits and based on the effective hull power estimated, it selects the propeller suitable.

The values for the propeller limits are selected based on the recommended values by Paramarine. Based on the hull profile, maximum diameter value is selected. Specify diameter search method was used in Paramarine to find the propeller suitable based on the input values. The following propeller was obtained using the propeller finder method.

Design Parameters	Obtained
Propeller series	Wageningen B
Search Method	Specify diameter
Efficiency reduction	Fixed Pitch
Design speed (knots)	18
Number of blades	3
Diameter (m)	3
Blade area ratio	0.350
Pitch ratio	0.724
Design shaft speed (rpm)	362.43
Design advance ratio	0.433
Design open water efficiency (%)	59.218

Table 10 - Powering analysis

7 PROPULSION AND POWERING

7.1 PROPULSION PLANT OF EXISTING VESSEL

The propulsion plants of existing offshore patrol vessels of the Canadian Coast Guard and other countries are carefully studied. Most vessels were found to have diesel mechanical drives as their power plant concept.

The propulsion plant of "Leonard J. Cowley", our reference vessel, was closely studied as we have received more detailed specifications from our mentor. An overview of the propulsion plant is shown below:

	Propulsion Type	**Prime Mover**	**Auxiliary Engines**	**Bow Thruster**	**Max Speed**
L. J. Cowley	Diesel Geared Drive	2 Diesel Engines rated at 1560 kW	3 rated at 400 kW	Yes	15 knots

Table 11 - Propulsion

7.2 MISSION PROFILE

The mission profile of the designed vessel consists of Rescue Mission, Normal Transit (12 knots), High Speed Transit (18 knots), Maneuvering, Oil spill Recovery and Port. The offshore patrol vessel will spend most of its time patrolling under operating speed (12 knots). In case of Search and Rescue Missions (SAR) or pursuing fishing boats, it will operate under the high speed transit mission profile. The Rescue Mission profile is for the rescue operation once the vessel is in place. Transit during SAR is considered as High Speed Transit mission profile. The percentage of time spent in each operation profile is also estimated based on studying existing vessels and discussion with mentor.

The mission profile is shown in the table below:

Mode	Rescue Mission	Normal Transit	High Speed Transit	Manuev.	Oil Spill recovery	port
% of time	5%	65%	10%	5%	5%	10%

Table 12 - Mission Profile

7.3 POWER PLANT CONCEPTS

7.3.1 LNG Engines

Liquefied natural gas (LNG) has been a growing interest as a source of marine fuel in recent years. LNG is very economical and clean with little NOx, SOx and other particulates emissions. It is cheaper compared to HFO or MDO on a price per energy content basis and automatically meets the Tier 3 emission standards. Therefore, LNG can be used to save operating costs and reduce pollution.

However, LNG will require an initial higher engine and equipment costs. More importantly, the mission of the designed vessel is to patrol the Canadian waters which will require a large amount of fuel. The owner's requirements dictate that the vessel will have an endurance of 30 days and a range of 6000 nautical miles. This will require a substantial storage space on the vessel for the LNG tanks which is not ideal for our vessel.

7.3.2 Diesel Electric

For a fully Integrated Electric Plant (IEP), the prime mover drives the generator which then supplies power to electric motors. Propulsion, auxiliary motors and ship service power all draw from a common source of electric energy. This allows efficient distribution of loadings on the prime movers which are ideal for vessels with variable operation profiles. If designed appropriately, IEP will have less operating costs than mechanical drives. For this design, diesel engine is the prime mover and will drive the generators. Another major advantage of diesel electric concept is that it allows flexible machinery arrangement. No mechanical linkage is required between the prime movers and the propeller; generator sets can be placed on upper decks if desired.

One of the disadvantages of diesel electric is that there is a higher loss of efficiency during transmission. As a result, diesel electric is not ideal for vessels that operate continuously at sea under the designed speed. The initial installation and machinery costs are also much higher. Moreover, electric power plant requires a larger equipment space comparing to a conventional mechanical drive powering system. For an offshore patrol vessel, where weight and space is important, this propulsion concept is not ideal.

7.3.3 Diesel Mechanical Drive

This propulsion concept is the most common type of propulsion plant for offshore patrol vessels. In this propulsion system, diesel engines transfer the power to the propeller through shaft and other mechanical connections. Gearboxes are used to match the engine rpm and the propeller rpm. Ship service and auxiliary machineries can be powered by small generators or shaft generators.

Diesel mechanical drive is widely used and readily available. The propulsion plant design is also relatively simple with high transmission efficiency. The initial cost of buying the engines is also less compared to diesel electric.

One of the disadvantages of diesel mechanical drive is that the prime movers need to be close to the propeller. This will generally dictate the main engine room location on a vessel. Machinery arrangement for diesel mechanical drive is also less flexible compared to diesel electric.

7.4 PROPULSION SYSTEM

7.4.1 Brake Power Estimation

From Paramarine, the effective horse power (EHP) verses speed curve is generated. One must note that are several losses from the engine brake horse power (BHP) to the effective horse power, for instance, shaft, gearbox, propeller loss. Therefore, EHP needs to be divided by several coefficients to get the BHP. Open water propeller efficiency is 0.7. Assuming the shaft seal efficiency is 0.98 and all other efficiency being 1, the propeller load in each mission profile is estimated.

The estimated propeller load is shown in the table below:

Mode	Rescue Mission	Normal Transit	High Speed Transit	Manuev.	Oil Spill recovery	port
% of time	5%	65%	10%	5%	5%	10%
Propeller load (kW)	1600	1311.95	4679.3	218.66	218.66	0

Table 13 - Estimated Propeller Load

7.4.2 Prime Movers Selection

Based on the mission profile and the loading in each profile, one can see that there are three major loading conditions. Ideally, one wants to achieve high loadings on diesel engines to minimize fuel consumption and reduce maintenance. After careful consideration and discussions with mentors, it was decided that the father-son approach plus a Power Take in (PTI) motor is best suited for this scenario.

One of the selected main engines (father) is CAT 6M32C and has a rated power of 3000 kW with a specific fuel rate (sfr) of 178g/kWh. It is turbocharged with a dry weight of 37.5 tonne.

The smaller engine (son) is CAT 9M20C and has a rated power of 1710 kW with a specific fuel rate of 190g/kWh. It is turbocharged with a dry weight of 15 tonne.

During the low loading profiles, the PTI motor is used to drive the propeller. Auxiliary generators are used to power the PTI motor. During the normal transit profile, the smaller engine CAT 9M20C is used to power the propeller. During high speed transit, both the father and son engines are used to power the propulsion. The two different sized diesel engines are mechanically connected with a combining gear. The PTI motor is on the back of the gear box in line with the input pinion of the son engine. Each input path has a clutch. The general arrangement is shown in the figure below:

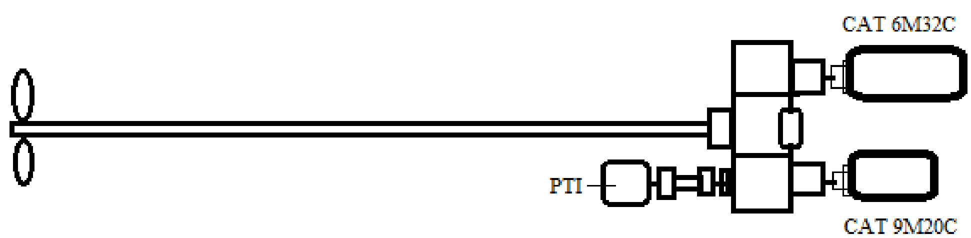


Figure 20 - Gear box

7.4.3 Auxiliary Generators Selection

Ship service power in each operating mode is estimated based on studying existing vessels. The auxiliary generators will provide power for ship service, bow thruster and the PTI motor. To optimize loading conditions, three auxiliary generators have been selected. Two of the generators are CAT C18 ACERT, with a rated power of 525 ekW. The other generator is CAT C18 ACERT, with a rated power of 330 ekW. There is also an emergency generator, CAT C9, with a rated power of 200ekW.

Assuming 350 days of operation per year and mechanical loads will have an additional 10% loss when they are powered by the generators, a more complete mission profile is shown in the table below:

Mode	Units	Rescue Operation	Normal Transit	High Speed Transit	Maneuv.	Oil Spill Recovery	Port
% time		5%	65%	10%	5%	5%	10%
annual hours	h	420	5460	840	420	420	840
Propeller load	kW	1600.00	1311.95	4679.30	218.66	218.66	0
thruster	ekW	450	0	0	450	450	0
ship service	ekW	500	400	400	400	600	300
Total Generator load	ekW	950.00	400.00	400.00	1092.95	1292.95	300.00

Table 14 - Mission Profile

7.4.4 Power Load Arrangements

For all loading conditions, it is desired to have a high percentage loading on the diesel engines to minimize specific fuel consumption and fuel cost. Having loadings close to the rated load will also reduce the maintenance cost for diesel engines.
As a result, the loading condition in each operating mode is optimized such that the percentage loading on each diesel engine is maximized. For detailed loading conditions, see Appendix A– Loading Conditions.

7.4.5 Propulsion Fuel

Marine Diesel Oil (MDO) is selected as the fuel source for the Offshore Fishery Patrol Vessel. MDO is a very common type of fuel for the marine industry and is readily available. All of the engines selected are able to operate on MDO.

8 GENERAL ARRANGEMENT

The general arrangement concerned the overall layout of all ship spaces, with a particular focus on Main Deck and above. The summary of all ship spaces from Main Deck and above is discussed in the following sections. All the figures relating to the general arrangement are attached in the Appendix – B.

8.1 CONCEPT GENERAL ARRANGEMENT

The following sections present the major aspects of the general arrangement of the offshore patrol vessel.

8.1.1 Vertical Access and Trunks

The following sections discuss the areas of the vessel providing vertical accessibility, either for personnel, machinery or services.

8.1.1.1 Main Stair Tower

The main stair tower is located forward within the superstructure between frames 45-50, on centerline. The stair tower runs from lower deck to the navigation bridge with sufficient accesses on each deck and weather deck, forward of exhaust casing, engine room intake air trunk and service trunk. All of these spaces span multiple decks and grouping them together increased the efficiency of the overall arrangement as the exhaust casing and intake air trunk are located directly above the main engine room below main deck.

The stair towers including landings are located in an area 12.3 sq.m on both the main and upper decks.

8.1.2 Hold Deck

Main spaces on this deck are: steering room, engine and auxiliary machinery spaces, bow thruster room and tanks for fuel, fresh water and ballast water.

Tank compartments on this deck are separated by means of two transverse bulkheads from other spaces.

Forward of the tank compartment there are workshops and then bow thruster compartment.

8.1.2.1 Doors and access on hold deck

Engine room is isolated from other compartments by two water tight and fire class bulkheads on fore and aft of engine room space. There are two fire class and water tight sliding doors on each of these bulkheads.

A water tight door divides the compartment between engine room and steering room to provide the required damage stability.

8.1.2.2 Accesses to and from hold deck
There are two stair towers on this deck. One is at about mid-ship for access to machinery compartment and another is at fore for access to workshop and bow thruster compartment.

8.1.2.3 Escape Routes
There are four ladders to deck above (main-deck). One escape hatch is aft of the steering room for the steering compartment. Aft of the engine room there is an escape hatch to deck above, for the case there is no access to main stair tower. There is an escape hatch to main-deck from the forward workshop on hold deck, which can be used as the second means of escape other than stair. Bow compartment has an escape route to main-deck through the escape hatch on fore bulkhead.

8.1.3 Main Deck
Cabins for the crew and their entertaining and service spaces for crew are located on main-deck. Mess-room with an area 18 sq.m is located for all personnel on-board, including crews and officers.

Galley and provision stores (cool room, cold room and dry store) are located on this deck and near the mess-room to give a convenient handling of food services. The hatch above this deck eases supply of provisions for this store.

Cabins:

- Cabins with single bed
  Single bed cabins are with different sizes (from 6sq.m to the biggest 9sq.m) to accommodate crew based on their ranks of seniority.

- Cabins with bunk beds.
  There are 5 cabins each with 9sq.m of area to accommodate total of 10 crews.

8.1.3.1 Accesses to and from main-deck
To smooth and ease movement of the crew on this deck there are 3 stair towers. Aft stair tower to upper-deck, main stair tower on mid-ship, and fore stair tower to access upper-deck and lower-deck (hold deck). The aft stair tower gives easy access to the working deck for the crew from their accommodation compartment.

8.1.3.2 Escape routes
There are two escape hatches aft and two escape hatches fore, as alternate means of escape from main-deck to upper-deck

8.1.4 Upper Deck
Officers are accommodated forward of upper-deck and officers will have their entertainment room on the same upper deck.

Cabins:

- Cabins with single bed
  Four cabins each between 4.5 sq.m and 6 sq.m can accommodate five officers.

- Cabins with bunk bed

Four cabins each 7 sq.m are to accommodate four officers and also four guests or government officers on-broad.

Also a two crew cabin aft of the accommodation on upper-deck is for senior crew who need quick accesses to open deck.

8.1.4.1 Accesses to and from upper-deck

Main stair tower and forward stair tower provide access from upper-deck to deck above (forecastle deck) and deck below (main deck)

8.1.4.2 Escape routes

The forward stair tower to forecastle deck or water tight doors aft of the accommodation on this deck can be used as alternate routes of escape from this deck.

8.1.5 Forecastle Deck

Day room and cabin for each of the captain and chief engineer of the vessel are located on forecastle deck.

8.1.5.1 Accesses to and from forecastle-deck

The stairs at port and starboard to navigation bridge and main stair tower to upper-deck and navigation deck give easy and quick access of captain and chief engineer to working stations.

8.1.6 Navigation bridge

Navigation area has a total are of 90sq.m, which provide enough area for the navigation devices and also a station for the fishery officers to monitor and surveillance the fishing activities at sea.

9 WEIGHTS AND CENTRES ESTIMATE

As initially a rough estimate and lightship weight was development form different coefficients, in order to be more precise and more accurate which would further help in accurate analysis of hydrostatics and stability. The following outline comprehensive work undertaken to estimate vessel weight and centers, considering lightship and deadweight items.

9.1 LIGHTSHIP WEIGHTS AND CENTRES

Lightship weights and centers estimate help to come up with a number of total lightship weight and location of centroid at beginning of vessel service life. For calculation of intact and damaged stability analysis figure of longitudinal center of gravity (LCG), transverse center of gravity (TCG) and vertical center of gravity (VCG) is needed. The respected analysis is discussed in sections of this report. Different theoretical process for the calculation of lightship weights and centers are discussed in following sections.

9.1.1 Considered Approaches

The team considered many different approaches in order to calculate lightship estimate and few approaches are discussed as follows

9.1.1.1 SWBS-Based Itemized Breakdown

The SWBS based method is typically itemized breakdown approach in which weight and centroid location of every object on the vessel and categorizing them with SWBS section. The team concluded this method to be most accurate though it is time consuming and there is a factor of error. Detailed information about all equipment items on vessel is required.

9.1.1.2 Scaled Material Take-Off

This method basically uses structural analysis, which is mainly developing accurate midship section drawing. From the midship section drawing consisting of structural items for both web frames and regular frames, scaled material takeoff is possibility for getting weight estimate. Knowing available references for determining unit weights of structural steel members, so weights of representative frame from the midship can be calculated easily. The weights are then scaled according to number of frames of vessel and changing dimensions due to curvature variation. Seeing the complexity and needed accuracy of mid ship section drawing the design team dropped the scaled material take-off method.

9.1.1.3 Estimation Using Coefficients

As discussed earlier but useful to put in theory, estimation using coefficient was the first initial weight calculation method. Coefficients were taken from major weight group of vessel and multiplied by corresponding scaling factor to determine the overall lightship estimate. This gives a direction and rough estimate of lightship weight which served in initial working in stability and related where the lightship weight was required. As this method has no insight into locations of vessel center so it is pretty rough.

9.1.2 Selected Approach

It is basically the combination of itemized breakdown and coefficient based method. The representative model can be determined for main items, including this method increases the accuracy of the weights. The coefficient based method could make up residual weights of unidentified equipment and distributed weights such as piping and outfitting material. This method helped the team with determining more accurate initial weight distribution. The team came up with a collective approach of scaling and also widely used the reference vessel drawings and information

9.1.3 Estimation of Weights and Centres

The vessel weight group was divided into corresponding SWBS section to present the lightship estimate in a conventional manner. The following elaboration is done as follows

9.1.3.1 SWBS 100 – Structure

The SWBS-100 was sub divided into hull weight and superstructure separately.

Weight Group	Weight	LCG	VCG
100-Structure	639	32.2	5.2
Hull	479	36	3.166
Superstructure	159	21.5	9

Table 15 - SWBS 100

The hull weight of 639 tons was calculated from applying coefficient and multiplying with hull volume. The main deck was considered as a sort of demarcation between the superstructure and hull. The LCG for the hull weight was determined by scaling the known LCG of reference vessel by the overall length. LCG=LCG(LOA/LOA(reference). The hull structure was assumed to be symmetric about the center line and hence TCG was assumed to be 0.0m. The calculation of VCG was in the similar fashion but the depth was scaled such as VCG= VCG(D/D(reference). Similarly the weight of superstructure was determined in a similar fashion as of hull such as corresponding weight coefficients was multiplied with the volume of superstructure volume to obtain 159 tons. The centroid of weight was assumed to be same as the centroid of overall volume. The LCG and VCG were calculated by scaling with the reference vessel.

9.1.3.2 SWBS 200 – Machinery, Mechanical and Propulsion

For this SWBS section combined approach using weight and itemized breakdown was employed. At this time machine drawing was ready and also general drawings. Knowing location and weight of auxiliary generators, box thrusters, emergency generator, main engines and propeller the VCG and LCG was calculated,. For engines the VCG was assumed to be above crank case while for bow thrusters VCG was assumed to be of same size as compartment. The VCG of the emergency generator was assumed 1m above the level deck. The generic machine was calculated using coefficients, which is basically items which were unaccounted such as weights of pumps, piping and smaller machinery items distributed throughout decks which was illustrated from machine drawing. Calculation based on power formula was made and consideration was made to avoid repetition of weight calculation.

The summary of weights and centers for SWBS 200- Machinery, Mechanical and propulsion can be found as below

Weight Group	Weight	LCG	VCG
200-Machinery,Mechanical and propulsion	106.38	25.31	3.49
Auxiliary Generator (total 4)	7.6	31.3	3.5
Box Thruster	2.8	58	3.5
Emergency Generator	1.9	23	8
Main engine 1	15	25.2	3.5
Propeller	.45	4	1.7
Main Engine 2	46.4	25	3.5
Generic Machining	32.2	22	3.25

Table 16 - SWBS 200

9.1.3.3 SWBS 300 – Electrical

From the machinery arrangement we scaled the position of electrical equipment and then an itemized approach was applied. The distribution transformers and main switchboard LCG and VCG was calculated by combination of scaling. The weight was calculated by developing with a coefficient and with the volume of the different equipment.

The following table shows the summary of the weights and centers for SWBS 300, which is basically related to, electrical.

Weight Distribution	Weight	LCG	VCG
300-Electrical	18.87	26.8	3.5
Distribution Transformer	7.87	26	3.5
Main switchboard	11	27.5	3.5

Table 17 - SWBS 300

9.1.3.4 SWBS 400 – Communication, Command and Surveillance

The design team decided to use coefficient based technique in determining weight for SWBS 400 section. This is basically accounted for communication and automation equipment. The coefficients were scaled by volume and were itemized breakdown into hull and superstructure separately. The centroid for the weight of communication items in hull was assumed to be similar to the centroid of hull structure. Similarly centroid of superstructure was assumed such as same as centroid for structural weight.

The summary of SWBS 400- communication, command and surveillance is as follows

Weight Group	Weight	LCG	VCG
400-Communication Command & surveillance	27	13.88	2.695
Electricity & automation-hull	15	36.44	3.166
Electricity & automation-Structure	12	21.56	9.0692

Table 18 - SWBS 400

9.1.3.5 SWBS 500 – Auxiliary Systems

Basically in this design team chose to only include comfort zone and addition of bilge ballast and fire system weight was also assumed in it. Assuming auxiliary system weights are accurately described by machinery and machinery outfitting weight coefficients. The comfort zone (HVAC) was scaled by area of all temperature controlled spaces. The table of temperature-controlled spaces can be found later in the report in weight and center section.

The summary of weights and centers for SWBS 500- auxiliary system can be found as follows

Weight Group	Weight	LCG	VCG
500-Auxillary Systems	15.3	34	11

Table 19 - SWBS 500

9.1.3.6 SWBS 600 – Outfit

Itemized breakdown and coefficient based approach was used for weights and cetres for the vessel outfit. The items such as weight and centre of on board equipment, anchor chain were known. The anchors and anchor chain was sized according to Lloyd's Rules for the Classification of Ships, Part 3, Chapter 13, Section 7. The centroid of anchor chain was assumed to be in middle of chain locker. As furnishing represent large portion of outfitting and it was calculated by getting up with a coefficient in a similar manner as comfort system weight. The furnished weight was scaled by area such as list of all furnished space on ship was created with area, volume and centroids. The machinery outfitting was calculated using coefficient and scaled by power value.

Weight Groups	Weight	LCG	VCG
600- OUTFITTING	246	31	7.2
Furnished	147	34	7.2
Outfitting- Hull	30	36	3.1
Outfitting-Structure	68	21	9.06

Table 20 - SWBS 600

Categorization of furnished and unfurnished spaces such as calculating LCG, VCG and weight of individual is done from scaling of final general arrangement and machine drawing. The last table shows the calculation of coefficient factor for cabin.

1		Distance (from aft)	volume(m^3)	Vcg
2	sludge tank	19.7	4	
3	Ballast water tank aft	26.4	60	0.6
4	Fuel Oil Tank(DB)	34	60	0.5
5	water ballast DB mid.	42.4	86	0.5
6	Ballast water tank DB fv	51.6	38	0.45
7				
8				Hold Deck
9	Water ballast stern	0.75	70	5.7
10	stearing room	4.5	200	5.4
11	Fuel oil 1P&1S	11	120	4.26
12	FUEL OIL 2P&2S(less)	15.3	92	3.36
13	workshop cold	18.6	67	3.46
14	Tool room	18.6	67	3.46
15	Engine Room	25.2	455	3.5
16	control room	31.3	60	3.5
17	Auxillary machine roon	31.3	60	3.5
18	workshop	35	80	3.5
19	service machinery roon	35	80	3.5
20	Fuel oil central	38.7	53	3.5
21	fuel oil 3p&3S	38.7	86	3.5
22	Fuel oil central	43	70	3.5
22	Fuel oil central	43	70	3.5
23	Water ballast	43	150	3.5
24	water ballast 2	46.6	35	3.5
25	Fresh water tank	46.6	70	3.5
26	Electronic Shop	50	80	3.5
27	store	50	80	3.5
28	water ballast forwd.	55	169	3.5
29	Bow thruster	58	150	3.5
30				
31				Main Deck
32	Deck Store	10.4	80	6.5
33	Dry Store	12.4	55	6.5
34	Cool Room	17.7	36	6.5
35	Cold Room	22	30	6.5
36	Mess Room	21.2	150	6.5
37	Galley	19.8	100	6.5
38	Incinerator	24.6	14.4	6.5
39	Engine Casing	27	36	9.5
40	Washroom Central	30.6	21.6	6.5
41	Crew Cabins(12 crew)	42.6	330	6.5
42	Officer Cabin	50	43	6.5
43	Game Room	48.4	27	6.5

Column1	Distance (from aft)	volume(m^3)	Vcg
sludge tank	19.7	4	
Ballast water tank aft	26.4	60	0.6
Fuel Oil Tank(DB)	34	60	0.5
water ballast DB mid.	42.4	86	0.5
Ballast water tank DB fwd	51.6	38	0.45
Water ballast stern	0.75	70	5.7
Fuel oil 1P&1S	11	120	4.26
FUEL OIL 2P&2S(less)	15.3	92	3.36
Fuel oil central	38.7	53	3.5
fuel oil 3p&3S	38.7	86	3.5
Fuel oil central	43	70	3.5
Water ballast	43	150	3.5
water ballast 2	46.6	35	3.5
Fresh water tank	46.6	70	3.5
water ballast forwd.	55	169	3.5
Bow thruster	58	150	3.5

1	cabin weight estimate	
2	asuuming	
3	Deck Height	3
4	wall Area	30.8
5	Joinery Density	5.3
6		wt/ton
7	Bed frame	0.2
8	Matress	0.55
9	sink and plumbing	0.05
10	Joinery	0.163
11	total	0.963
12	Total cabin coefficient	0.107

9.1.4 Lightship and Deadweight Summary

The following table shows the summary of lightship weights and center for the vessel at beginning of service life. Basically four margins have been applied to lightship weight and VCG which is basically uncertainty in build process, inclining experiment, and final characteristics at acquisition and equipment items. The dead weight items and centers are classified in order to fully specify loading condition used in the intact and damaged stability calculations. The dead weight was divided into basically six parts namely fresh water, fuel oil, lube oil, crew and stores including provision. Keeping into reference of mission and number of personnel working as an average the team came with the numbers as highlighted in the table below.

Weight Group	weight	LCG	TCG	VCG
100-Structure	639	32.2	0	5.2
200-Machinery,Mechanical and propulsion	106.389	25.31312448	0	3.49
300- Electrical	18.87	26.87440382	2.07	3.5
400-Communication Command & survailance	27	13.88	0.12	2.695
500-Auxillary Systems	15.3	34		11
600-outfitting	246.6	31.28343573	0.05	7.21
SUBTOTAL-LIGHTSHIP WEIGHT	1053.159	30.75073493	2.24	5.487484425
DESIGN & BUILD MARGIN	5%			3%
Inclining Error Margin	0%			1%
Contract Margin	1%			1%
Equipment Margin	0.50%			0.50%
SERVICE LIFE LIGHTSHIP WEIGHT	1116.34854	31.28343573	2.24	5.680643877
DEADWEIGHT ITEMS & CENTRES	Max Weight	LCG	VCG	
Fuel Oil	476.67	27.35	3.288	
Lube Oil	2.64	16	3	
Fresh Water	50	42	3.5	
Crew	3	42.6	15	
provisions and store	9	22.1	6.5	

Table 21 - Lightship and Deadweight Summary

10 STRUCTURAL DESIGN

The following section details the concept midship structural arrangement and explains the methodology used for the analysis and validation of the design.

10.1 CLASSIFICATION RULES

The midship section is designed to meet the Bureau Veritas (BV) regulations. Owner's requirements dictate that the designed vessel will have Ice Class B. According to Transport Canada, Ice Class B is equivalent to Ice Class 1A in Bureau Veritas Classification. Structural members within the Ice Belt are designed to meet the Ice Class regulations of BV.

10.2 STRUCTURAL DESIGN

The upper deck is the strength deck. The structure of upper deck, main deck and double bottom deck are all longitudinal framed. To ensure the scantlings meet the BV classification rules, software Mars 2000 was used.

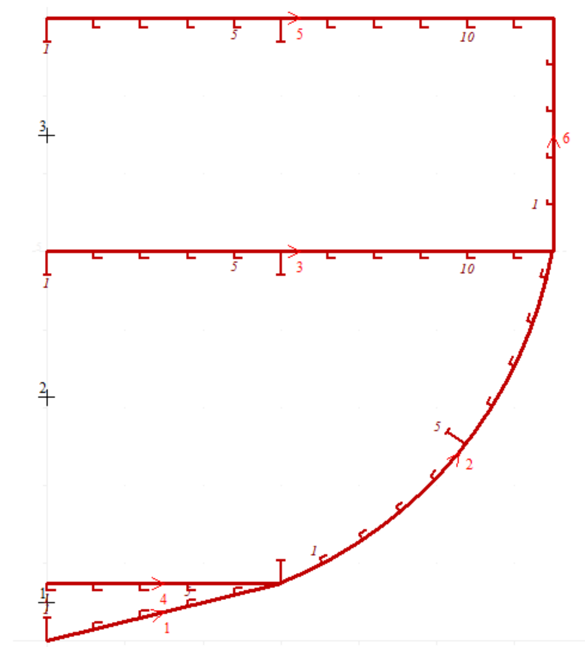


Figure 21- Mars 2000 Midship Section

Angled bars are used as the longitudinal stiffeners. They are cheaper than bulb plates. T-shaped plates are used as the longitudinal girders. The stiffeners are spaced 0.6m apart. The stiffeners located on the top deck have a higher section modulus. The double bottom deck and the side shell below the main deck have larger plate thickness. The designed scantlings are checked to make sure they meet the BV rules and regulations using software Mars 2000. However, the software does not take into account of Ice Class requirements. Therefore, scantling sizes within the ice belt are calculated in Excel to make sure they meet the BV regulations.

10.2.1 Ice Class Requirements

BV Rules for the Classification of Steel Ships – Jan 2014 Part E Chapter 8 discusses about Ice Class regulations. As stated earlier, the designed vessel is to meet the Ice Class 1A requirements of BV.

The upper ice waterline (UIWL) of the designed vessel is 4.2 m and the lower ice waterline (LIWL) is 3.8m. To meet Ice Class 1A requirements, ice belt needs to be at least 0.5 m above UIWL and 0.75 m below LIWL for plating. For stiffeners and primary support members, ice belt needs to be at least 1 m above UIWL and 1.3 m below LIWL.

Within the ice belt region, structural members need to be strengthened to meet the Ice Class requirements.

The minimum plate thickness within the ice belt is determined with the following formula:

$$t = 667s\sqrt{\frac{p}{F_2 R_{eH}}} + t_c$$

Equation 1- Minimum Plate Thickness

The coefficients are calculated in Excel, and the minimum plate thickness is found to be 21.7 mm within the ice strengthened zone.

The section modulus for the stiffeners within the ice belt is determined with the following formula:

$$z = \frac{F_4 p h \ell^2}{m_1 R_{eH}} 10^6$$

Equation 2 - Section Modulus for Stiffeners

The minimum section modulus of the stiffeners is found to be 24.75 cm^3 within the ice belt.

10.2.2 Material Selection

The selected materials for the ship structure are shown in the table below:

Material	Application	Yield Stress (N/mm^2)
Steel Grade A	General	235
Steel grade AH32	Ice Belt	315

Table 22 - Selected Materials

10.2.3 Midship Section

Using Mars 2000, a midship section was created to ensure the scantlings meet the BV regulations.

10.2.3.1 Plating

The plate thickness of the top and the main deck is 10 mm. The plate of the double bottom deck has a thickness of 12 mm. Within the ice belt, side shell plate thickness is 22 mm. This is to meet the Ice Class 1A requirements in BV. The side shell plate above the ice belt has a thickness of 10 mm. The side shell plate thickness below the ice belt is 12mm. Plating is listed in the table below:

Plate	Thickness (mm)
Top Deck	10
Main Deck	10
Tank Top	12
Ice Belt	22
Bilge	12
Sheer strake	10

Table 23 - Side Shell Plate thickness

10.2.3.2 Stiffeners

The longitudinal stiffening in the midship section is listed in the table below:

Stiffening	Profile
Top Deck	L-bar 130x100x12
Main Deck	L-bar 100x100x10
Tank Top	L-bar 100x100x10
Elsewhere	L-bar 100x100x10

Table 24 - Longitudinal stiffeners

Stiffeners are spaced 0.6m apart. The section modulus of the stiffeners located within the ice belt is checked to make sure it meets the Ice Class 1A requirements.

10.2.3.3 Girders

The specification of the longitudinal girders in the midship section is listed in the table below:

Girder	Profile
Longitudinal Girders	T - 300x100x12x12

Table 25 - Girders

10.2.4 Drawing

The midship section drawing including the scantlings can be found in Appendix B – Midship Section

11 INTACT STABILITY ANALYSIS

The following sections discuss the intact stability analysis of the designed offshore patrol vessel. The governing rules and regulations along with the evaluating loaded conditions, righting lever curves and analysis of vessel stability in severe weather conditions are presented.

11.1 GOVERNING RULES AND REGULATIONS

The intact stability analysis for the offshore patrol vessel was evaluated according to the *2008 IS Code i.e. International Code on Intact Stability, 2008.* The properties of the vessel's righting lever curves, and the vessel's response to wind and wave events are the mandatory criteria provided according to the code. It also includes the free surface corrections to be taken into account for the tanks containing consumable liquids and/or ballast water. The vessel's compliance with evaluation criteria according to the code and the free surface corrections made for the tanks for the designed offshore patrol vessel are explained in detail in following sections.

11.2 VESSEL LOADING CONDITIONS

The vessel's intact stability was evaluated for four separate loading conditions according to the *2008 IS Code* for special purpose ships. The loading conditions used are full load departure, full load arrival, ballast departure and ballast arrival. The tanks which are denoted as full capacity are loaded upto 98% capacity as done in common practice.

11.2.1 Full Load Departure

This condition was evaluated according to the *2008 IS Code*. It was assumed that the deadweight items i.e. cargo, stores and mission items are filled upto their capacity. The ballast tanks were evaluated based on the ballasting condition that only sufficient ballast was present on board while departure. All the waste tanks were assumed to be 10% full.

FULL LOAD DEPARTURE

Deadweight items		**Fuel Oil Tanks**	
Provisions	100%	Fuel Oil Tank 1S	98%
Stores	100%	Fuel Oil Tank 1P	98%
Equipment	100%	Fuel Oil Tank 2S	98%
Others	100%	Fuel Oil Tank 2P	98%
TOTAL	152 tonnes	Fuel Oil Tank 3S	98%
		Fuel Oil Tank 3P	98%
Ballast Water Tanks		Fuel Oil Control 1	98%
Ballast Tank Forward P	98%	Fuel Oil Control 2	98%
Ballast Tank Forward S	98%	TOTAL	265 tonnes
Ballast Tank Centre P	0%		
Ballast Tank Centre S	0%	**Fresh Water Tanks**	
Ballast Tank Centre 1	0%	Fresh Water Tank P	98%
Aft Ballast Tank 1	98%	Fresh Water Tank S	98%
Aft Ballast Tank P	0%	TOTAL	50 tonnes
Aft Ballast Tank S	0%		
Ballast Tank 2P	0%	**Minor Tanks**	
Ballast Tank 2S	0%	Lube Oil Tank	98%
TOTAL	183 tonnes	Auxiliary Oil Tank	10%
		Sludge Tank	10%
		Waste Oil Tank	10%
		Black Water Tank	10%
		Grey Water Tank	10%
		TOTAL	55 tonnes

Table 26 - Loading Condition Full Load Departure

11.2.2 Full Load Arrival

This condition was evaluated according to the *2008 IS Code*. It was assumed that the deadweight items i.e. stores and mission items are filled upto 10% capacity except cargo. The ballast tanks were evaluated based on the ballasting condition that only sufficient ballast was present on board which maintains heeling and trimming. All the waste tanks were assumed to be 98% full.

FULL LOAD ARRIVAL

Deadweight items		
Provisions	10%	
Stores	100%	
Equipment	100%	
Others	100%	
TOTAL	140	tonnes
Ballast Water Tanks		
Ballast Tank Forward P	98%	
Ballast Tank Forward S	98%	
Ballast Tank Centre P	0%	
Ballast Tank Centre S	0%	
Ballast Tank Centre 1	0%	
Aft Ballast Tank 1	98%	
Aft Ballast Tank P	0%	
Aft Ballast Tank S	0%	
Ballast Tank 2P	98%	
Ballast Tank 2S	98%	
TOTAL	223	tonnes
Fuel Oil Tanks		
Fuel Oil Tank 1S	10%	
Fuel Oil Tank 1P	10%	
Fuel Oil Tank 2S	10%	
Fuel Oil Tank 2P	10%	
Fuel Oil Tank 3S	10%	
Fuel Oil Tank 3P	10%	
Fuel Oil Control 1	10%	
Fuel Oil Control 2	10%	
TOTAL	27	tonnes
Fresh Water Tanks		
Fresh Water Tank P	10%	
Fresh Water Tank S	10%	
TOTAL	5	tonnes
Minor Tanks		
Lube Oil Tank	10%	
Auxiliary Oil Tank	98%	
Sludge Tank	98%	
Waste Oil Tank	98%	
Black Water Tank	98%	
Grey Water Tank	98%	
TOTAL	50	tonnes

Table 27 - Loading Condition Full Load Arrival

11.2.3 Ballast Departure

This condition was evaluated according to the *2008 IS Code*. Except for the cargo, it was assumed that the deadweight items i.e. stores and mission items are filled upto full capacity. The ballast tanks were evaluated based on the ballasting condition that all the tanks are filled upto full capacity while causing level trim and heel. All the fuel oil tanks were assumed to be 98% full.

BALLAST DEPARTURE

Deadweight items	
Provisions	100%
Stores	100%
Equipment	100%
Others	100%
TOTAL	152 tonnes

Ballast Water Tanks	
Ballast Tank Forward P	98%
Ballast Tank Forward S	98%
Ballast Tank Centre P	0%
Ballast Tank Centre S	0%
Ballast Tank Centre 1	0%
Aft Ballast Tank 1	98%
Aft Ballast Tank P	98%
Aft Ballast Tank S	98%
Ballast Tank 2P	98%
Ballast Tank 2S	98%
TOTAL	272 tonnes

Fuel Oil Tanks	
Fuel Oil Tank 1S	98%
Fuel Oil Tank 1P	98%
Fuel Oil Tank 2S	98%
Fuel Oil Tank 2P	98%
Fuel Oil Tank 3S	98%
Fuel Oil Tank 3P	98%
Fuel Oil Control 1	98%
Fuel Oil Control 2	98%
TOTAL	265 tonnes

Fresh Water Tanks	
Fresh Water Tank P	98%
Fresh Water Tank S	98%
TOTAL	50 tonnes

Minor Tanks	
Lube Oil Tank	98%
Auxiliary Oil Tank	10%
Sludge Tank	10%
Waste Oil Tank	10%
Black Water Tank	10%
Grey Water Tank	10%
TOTAL	55 tonnes

Table 28 - Loading Condition Ballast Departure

11.2.4 Ballast Arrival

This condition was evaluated according to the *2008 IS Code*. It was assumed that the deadweight items i.e. stores and mission items are filled upto 10% capacity except cargo. It is similar to ballast departure condition except all deadweight tanks are filled at 10% capacity. The ballast tanks were evaluated based on the ballasting condition that only sufficient ballast was present on board which maintains heeling and trimming. All the waste tanks were assumed to be 98% full.

BALLAST ARRIVAL

Deadweight items	
Provisions	10%
Stores	100%
Equipment	100%
Others	100%
TOTAL	140 tonnes

Ballast Water Tanks	
Ballast Tank Forward P	98%
Ballast Tank Forward S	98%
Ballast Tank Centre P	0%
Ballast Tank Centre S	0%
Ballast Tank Centre 1	0%
Aft Ballast Tank 1	98%
Aft Ballast Tank P	98%
Aft Ballast Tank S	98%
Ballast Tank 2P	98%
Ballast Tank 2S	98%
TOTAL	376 tonnes

Fuel Oil Tanks	
Fuel Oil Tank 1S	10%
Fuel Oil Tank 1P	10%
Fuel Oil Tank 2S	10%
Fuel Oil Tank 2P	10%
Fuel Oil Tank 3S	10%
Fuel Oil Tank 3P	10%
Fuel Oil Control 1	10%
Fuel Oil Control 2	10%
TOTAL	27 tonnes

Fresh Water Tanks	
Fresh Water Tank P	10%
Fresh Water Tank S	10%
TOTAL	5 tonnes

Minor Tanks	
Lube Oil Tank	10%
Auxiliary Oil Tank	98%
Sludge Tank	98%
Waste Oil Tank	98%
Black Water Tank	98%
Grey Water Tank	98%
TOTAL	50 tonnes

Table 29 - Loading Condition Ballast Arrival

11.3 ACCOUNTING FOR FREE SURFACE EFFECTS

According to *2008 IS Code, Part B. Chapter 3, Section 3.1, Item 3.1.4*, for tanks with consumable liquids either the transverse pair of tanks or single centreline tank with greatest free surface moment should be considered as applying this moment throughout the stability analysis. *Item 3.1.5* for the ballast tanks, stipulated that the most onerous free surface condition be assumed to account for intermediate stages of filling the tanks during a voyage. Hence, for the tanks in which the ratio of tank free surface moment to the displacement at draft with minimum ballast was less than 0.01 m, free surface effects were neglected and for other tanks, free surface effects were considered.

11.3.1 Calculation of Free surface effects in Paramarine

The intact stability analysis was done using Paramarine provided by the UBC Department of Mechanical Engineering. Based on the input given i.e. the location of the tanks, the weight distribution of the tanks and the loading condition, paramarine automatically takes into account the free surface effects and calculates the the angle of heel for each case during the stability analysis. The advantage of using paramarine was it could account for the maximum free surface effect for each tank as specified in the *2008 IS Code.*

11.4 GZ CURVES AND CODE COMPLIANCE

The following sections present the GZ curves for each loading condition as well as the evaluation of the curves for all loading conditions against the criteria set forth in the *2008 IS Code.*

11.4.1 GZ Curves

GZ curves were plotted for each of the given loading conditions. For the curves, the appropriate free surface correction as applied according to the *2008 IS Code*. Based on the GZ curve obtained, the level trim and heel of the vessel and the effect of free surface moment on stability were determined. The GZ curves obtained were evaluated against the *2008 IS Code*. The overall stability of the vessel at each condition was shown.

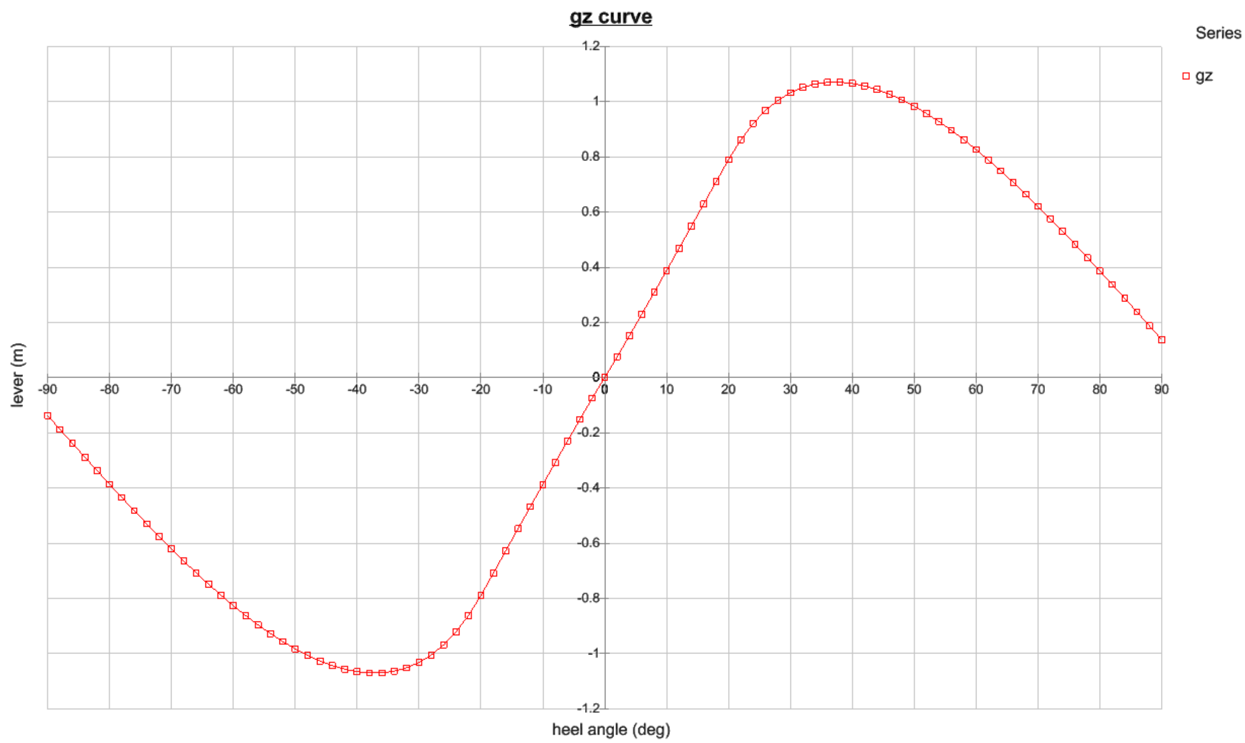


Figure 22 - GZ curve for fully loaded arrival condition

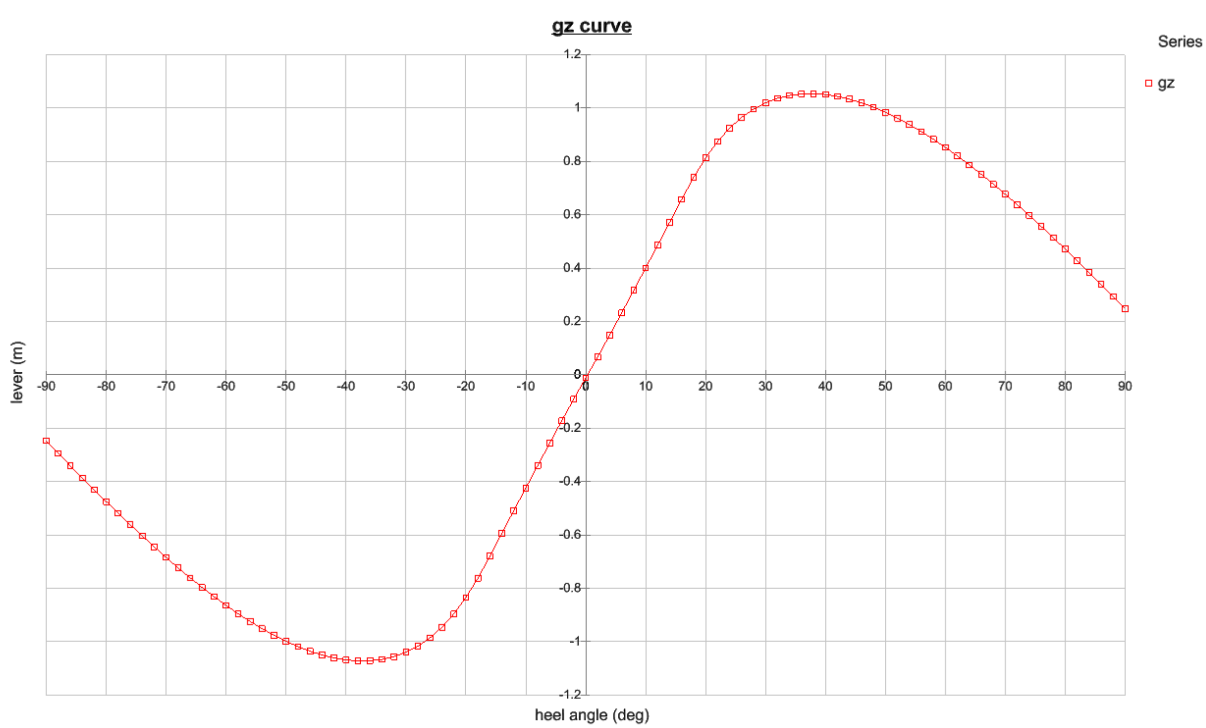


Figure 23 - GZ curve for fully loaded departure condition

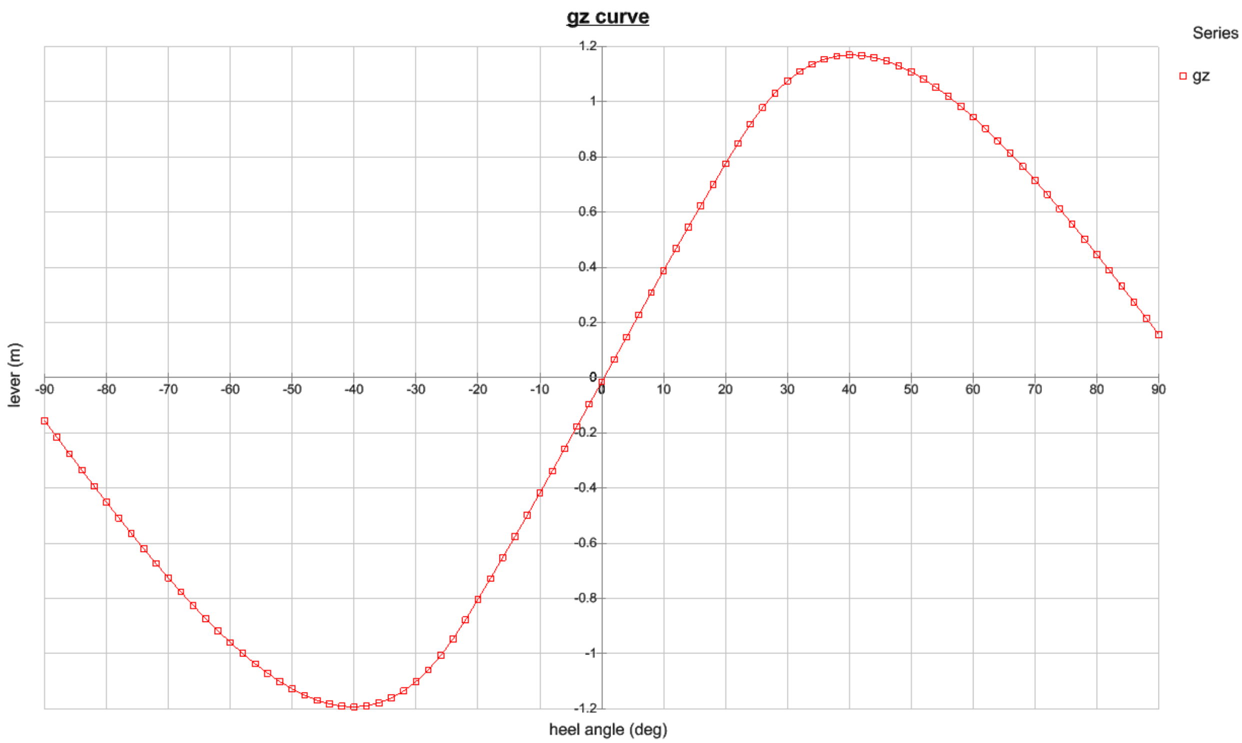


Figure 24 - GZ curve for ballast arrival condition

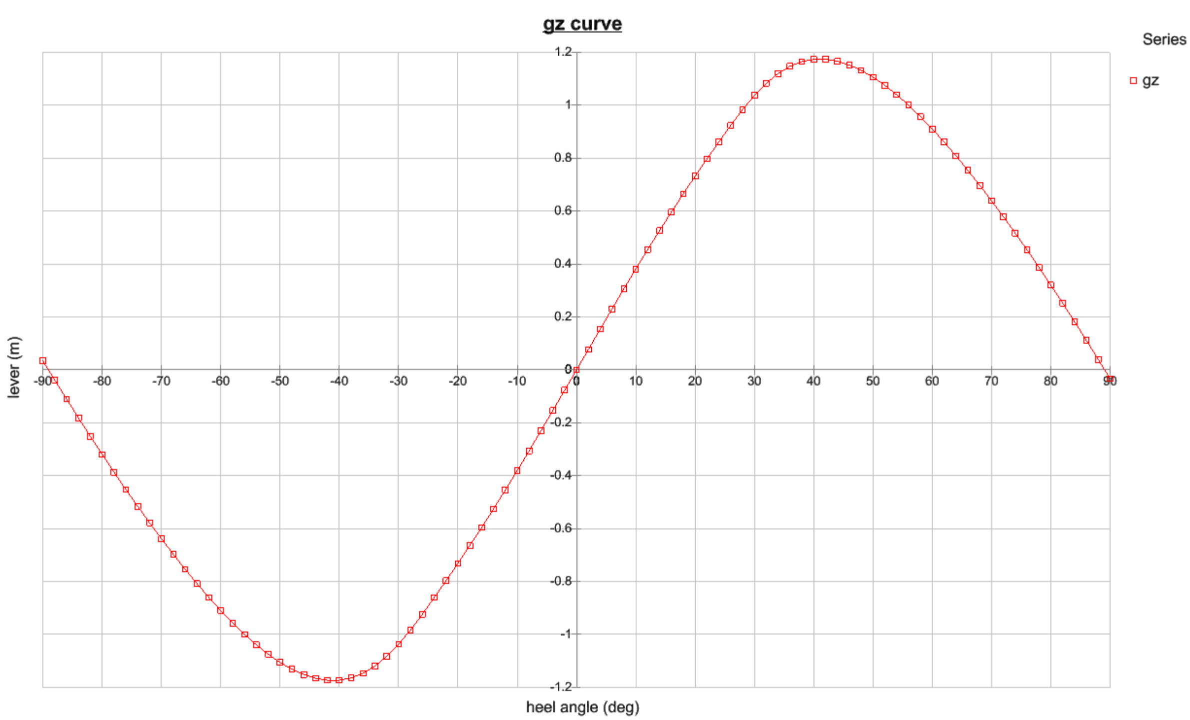


Figure 25 - GZ curve for ballast departure condition

11.5 EVALUATION OF GZ CURVES AGAINST 2008 IS CODE

To determine the stability of the vessel, the GZ curves obtained for each of the four different loading conditions were evaluated against the criteria in *2008 IS Code*. The evaluation criteria and the results of all the loading conditions that were examined are presented below. According to *2008 IS Code*, the following criteria were used to determine if the ship passes the intact stability analysis:

- Initial GM at 0 degrees must be greater than 0.150 m
- Area under GZ curve from 0-30 degrees must be greater than 0.055 metre-radians
- Area under GZ curve from 0-40 degrees must be greater than 0.090 metre-radians
- Area under GZ curve from 30-40 degrees must be greater than 0.030 metre-radians
- Highest GZ in the range of 30 degrees to downflooding must be greater than 0.2 metres
- Maximum angle of GZ must be greater than 25 degrees

The evaluation of the GZ curves was done using the software Paramarine for the *2008 IS Code*. Based on the GZ curves obtained for the loading curves, paramarine software analyses the curve against the *2008 IS Code* and the checks for all the criteria mentioned above.

All the above mentioned criteria are met for the GZ curves obtained for the designed OPV and the GZ curve for all the loading conditions passes by a huge margin.

12 DAMAGE STABILITY ANALYSIS

The damaged stability analysis for the concept vessel in presented in the following sections and discusses the watertight subdivision, analysis method, evaluated damage cases, and results for the designed OPV.

12.1 WATERTIGHT SUBDIVISION

For the damage stability analysis, the designed vessel is divided into 12 separate watertight zones. The table below outlines the vessel spaces contained within each watertight zone.

WATERTIGHT DIVISION COMPARTMENTS				
ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
Aft ballast tank #1	Steering room	Fuel oil tank #3P Fuel oil tank #3S	Fuel oil tank #2P Fuel oil tank #2S Lube oil tank Auxiliary oil tank	Tool room Work shop Sludge oil tanker
ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10
F.O.D P F.O.D S Engine room DB WB P Aft DB WB S Aft	Compressor room Control room Sewage tank Service Mach. room Work shop Service trunk DB Fuel oil P DB Fuel oil S	Fuel oil tank#1P Fuel oil tank#1S Fuel oil tank#1Cntr DB WB Centre P DB WB Centre S	WB #2P WB #2S Fuel oil cntr#2	Fresh water P Fresh water S WB Centre
ZONE 11	ZONE 12	ZONE 13		
Electronic shop Store	Bow thruster room DB WB Fore P DB WB Fore S	WB #1P WB #1S		

Table 30 - Watertight Subdivisions

12.2 ANALYSIS METHOD

The damage stability analysis of the vessel was carried out using Paramarine software available to the design team. Based on the vessel and the criteria selected, the software analyses the damage stability and gives the results for compartments selected. For the analysis of damage stability of the designed vessel, *SOLAS 90* two - compartment criteria was selected. The criteria could be implemented in Paramarine and provided clearer insight into the performance of the vessel when compared with the probabilistic analysis. Probabilistic analysis should be performed if the vessel design is to progress in a full scale.

12.3 DAMAGE ASSESEMENT

The extent of damage required for analysis based on SOLAS 90, the damage cases resulting from those extents and the loading conditions applied to the damage cases are outlined in the following sections. According to SOLAS, for calculation of damage stability, permeability of 95% for tanks and 85% for machinery spaces is allocated.

For the extent of damage, no particular set length was assumed for the longitudinal extent as for each damage case, two compartments were assumed to be flooded. For the transverse extent of the beam, 1/5th of the beam length is considered i.e. 2.2 m from side shell at waterline design length. For the vertical extent of damage, it is assumed to be unlimited.

12.3.1 Evaluated Damage Cases

A total of 12 separate damage cases were evaluated to account for all the combinations of floodable spaces based on the compartment divisions. Since the ship is symmetrical on both sides in terms of compartments, the damage cases were evaluated only for the starboard side and the damage stability performance will be similar on the port side of the ship. The only asymmetries are in the zone 5 but since the divisions are not in the damage area specified, the results on the starboard side are a little adverse. The damage cases and the areas of the vessel deemed flooded after such damage are outlined in the following table.

	Damage Case #1	Damage Case #2	Damage Case #3	Damage Case #4	Damage Case #5
Damaged compartments	WT ZONE #1 WT ZONE #2	WT ZONE #2 WT ZONE #3	WT ZONE #3 WT ZONE #4	WT ZONE #4 WT ZONE #5	WT ZONE #5 WT ZONE #6
Flooded spaces	Water Ballast Steering room	Steering room Fuel oil tank#3S	Fuel oil tank#3S Fuel oil tank#2S Aux oil	Fuel oil tank#2S Workshop Sludge tank	Workshop Sludge tank DB WB S aft Engine room

	Damage Case #6	Damage Case #7	Damage Case #8	Damage Case #9	Damage Case #10
Damaged compartments	WT ZONE #6 WT ZONE #7	WT ZONE #7 WT ZONE #8	WT ZONE #8 WT ZONE #9	WT ZONE #9 WT ZONE #10	WT ZONE #10 WT ZONE #11
Flooded spaces	DB WB S aft Engine room DB fuel oil S Control room Work shop	DB fuel oil S Control room Work shop Fuel oil tank#1S DB WB cntr S	Fuel oil tank#1S DB WB cntr S WB #2S Fuel oil cntr#2	WB #2S Fuel oil cntr#2 Store DB WB Fore S	Store DB WB Fore S Bow thruster room

	Damage Case #11	Damage Case #12
Damaged compartments	WT ZONE #11 WT ZONE #12	WT ZONE #12 WT ZONE #13
Flooded spaces	DB WB Fore S Bow thruster room WB #1S	WB #1S FP void Void S

Table 31 - Damages cases 1 - 12

12.3.2 Evaluated Loading Conditions

For the damage stability analysis, the loading conditions were assumed to be same as for intact stability. The damage cases were applied to both fully loaded and ballast conditions at both arrival and departure loading conditions.

12.4 RESULTS

The results of the analysis for each damage case when applied to each of the loading conditions are explained in the following sections.

The following GZ curves were obtained for the following evaluated loading conditions:

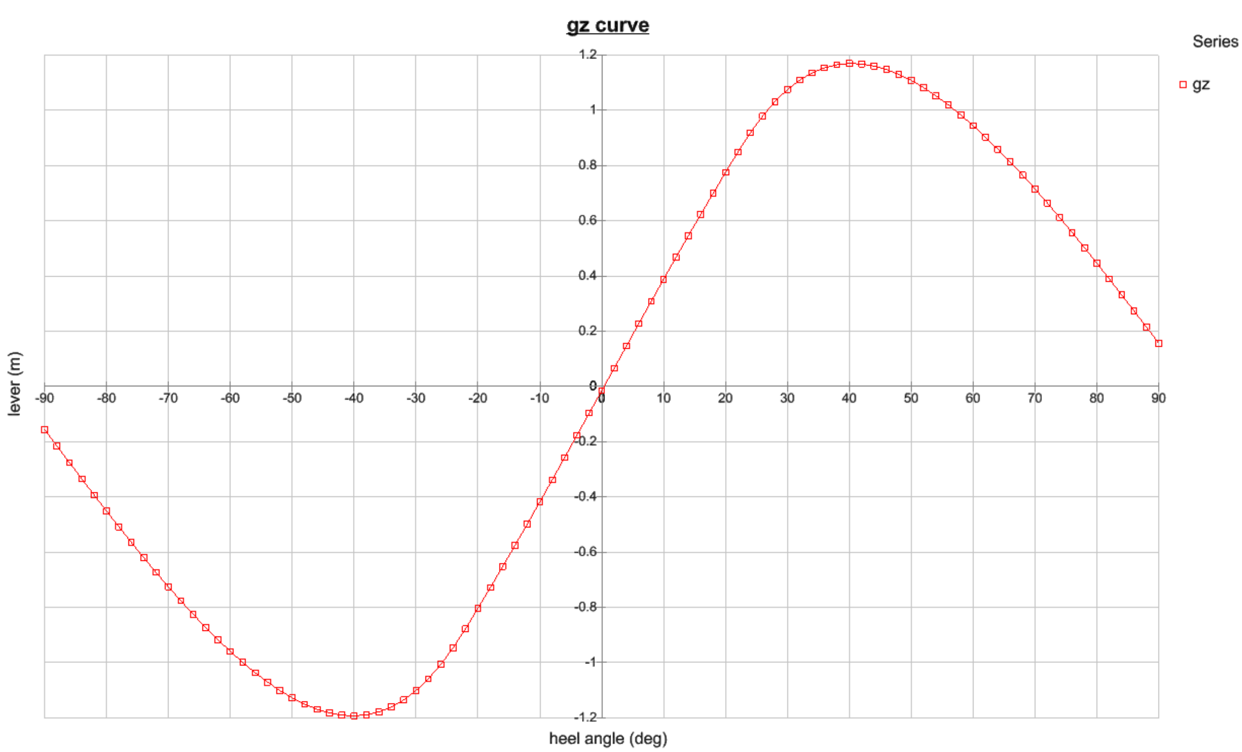


Figure 26 - GZ curve for fully loaded arrival condition

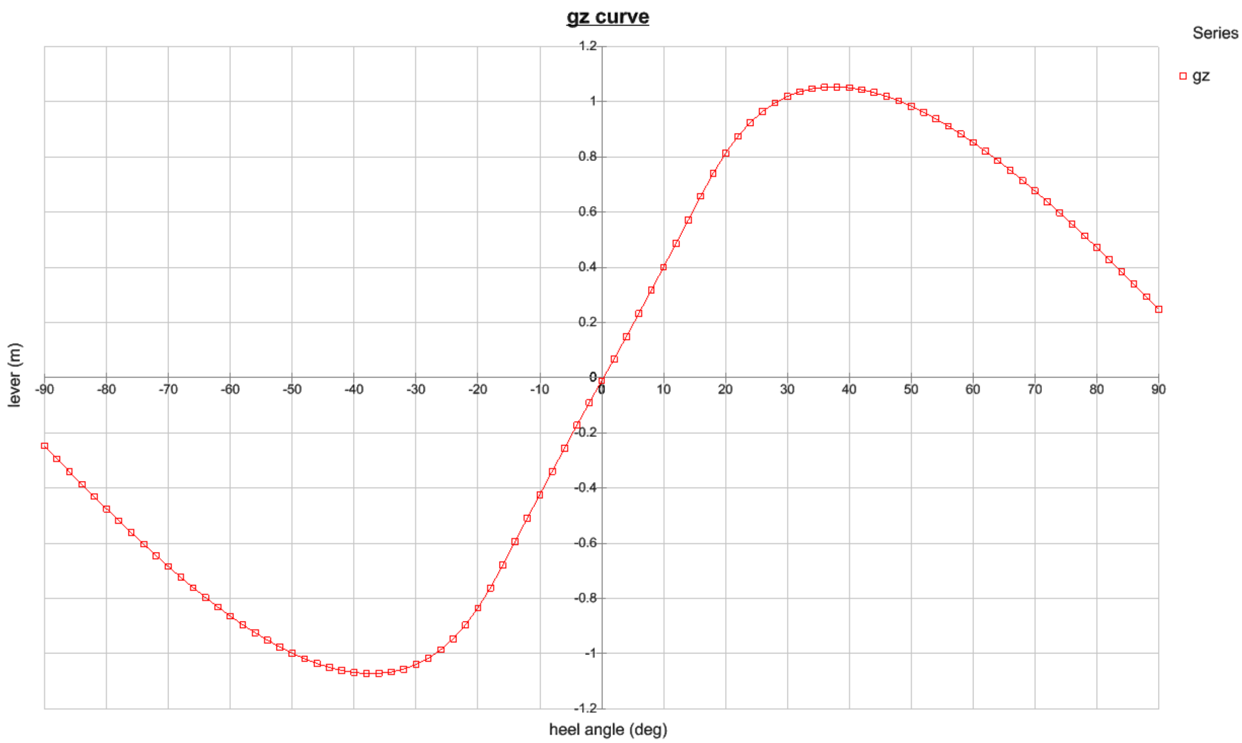


Figure 27 - GZ curve for ballast arrival condition

According to SOLAS 90 – 2, the following criteria were used to determine if the ship passes the intact stability analysis:

- Margin line emergence must be greater than 0 meter
- Righting lever range past equilibrium must be greater than 15 degrees
- Equilibrium angle must be less than 12 degrees
- Area under GZ curve must be greater than 0.015 meter-radians
- Maximum righting lever must be greater than 0.1 meter

The following table presents the results of the obtained GZ curves for the damage cases for the evaluated criteria:

For Damage cases 1 – 3:

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED DEPARTURE CASE #1		CASE #2		CASE #3	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	1.873	PASS	2.372	PASS	2.176	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	48.32	PASS	52.50	PASS	53.29	PASS
Equilibrium angle	less than	12.0	degrees	5.32	PASS	4.99	PASS	6.34	PASS
Area under GZ curve	greater than	0.015	m-rad	0.324	PASS	0.362	PASS	0.481	PASS
Maximum righting lever	greater than	0.100	m	0.423	PASS	0.536	PASS	0.582	PASS
SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED ARRIVAL CASE #1		CASE #2		CASE #3	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.973	PASS	0.992	PASS	1.162	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	49.72	PASS	51.64	PASS	52.32	PASS
Equilibrium angle	less than	12.0	degrees	4.78	PASS	5.82	PASS	6.54	PASS
Area under GZ curve	greater than	0.015	m-rad	0.102	PASS	0.286	PASS	0.352	PASS
Maximum righting lever	greater than	0.100	m	1.025	PASS	1.121	PASS	1.073	PASS
SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST ARRIVAL CASE #1		CASE #2		CASE #3	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.993	PASS	1.032	PASS	1.129	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	51.35	PASS	51.58	PASS	52.92	PASS
Equilibrium angle	less than	12.0	degrees	6.82	PASS	7.22	PASS	7.91	PASS
Area under GZ curve	greater than	0.015	m-rad	0.297	PASS	0.330	PASS	0.423	PASS
Maximum righting lever	greater than	0.100	m	0.532	PASS	0.627	PASS	0.720	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST DEPARTURE CASE #1		CASE #2		CASE #3	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.540	PASS	0.579	PASS	0.677	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	49.72	PASS	48.15	PASS	49.82	PASS
Equilibrium angle	less than	12.0	degrees	7.23	PASS	7.49	PASS	7.80	PASS
Area under GZ curve	greater than	0.015	m-rad	0.132	PASS	0.136	PASS	0.148	PASS
Maximum righting lever	greater than	0.100	m	0.628	PASS	0.739	PASS	0.758	PASS

Table 32 - SOLAS 90 - 2 Compartment flooding - cases 1-3

For damage cases 4 – 6:

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED DEPARTURE CASE #4		CASE #5		CASE #6	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.735	PASS	0.792	PASS	0.867	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	51.76	PASS	51.80	PASS	52.91	PASS
Equilibrium angle	less than	12.0	degrees	4.11	PASS	4.87	PASS	5.72	PASS
Area under GZ curve	greater than	0.015	m-rad	0.324	PASS	0.362	PASS	0.481	PASS
Maximum righting lever	greater than	0.100	m	0.423	PASS	0.536	PASS	0.582	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED ARRIVAL CASE #4		CASE #5		CASE #6	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.973	PASS	0.992	PASS	1.162	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	49.72	PASS	51.64	PASS	52.32	PASS
Equilibrium angle	less than	12.0	degrees	4.78	PASS	5.82	PASS	6.54	PASS
Area under GZ curve	greater than	0.015	m-rad	0.102	PASS	0.286	PASS	0.352	PASS
Maximum righting lever	greater than	0.100	m	1.025	PASS	1.121	PASS	1.073	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST ARRIVAL CASE #4		CASE #5		CASE #6	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.532	PASS	0.619	PASS	0.689	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	35.15	PASS	34.82	PASS	35.69	PASS
Equilibrium angle	less than	12.0	degrees	7.18	PASS	7.52	PASS	7.33	PASS
Area under GZ curve	greater than	0.015	m-rad	0.589	PASS	0.592	PASS	0.513	PASS
Maximum righting lever	greater than	0.100	m	1.342	PASS	1.237	PASS	1.278	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST DEPARTURE CASE #4		CASE #5		CASE #6	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.254	PASS	0.291	PASS	0.374	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	55.75	PASS	54.15	PASS	54.18	PASS
Equilibrium angle	less than	12.0	degrees	4.12	PASS	5.31	PASS	5.88	PASS
Area under GZ curve	greater than	0.015	m-rad	0.392	PASS	0.423	PASS	0.468	PASS
Maximum righting lever	greater than	0.100	m	1.121	PASS	1.180	PASS	1.470	PASS

Table 33 - SOLAS 90 - 2 Compartment flooding - cases 4-6

For damage cases 7 – 9:

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED DEPARTURE CASE #7		CASE #8		CASE #9	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.263	PASS	1.117	PASS	0.982	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	31.64	PASS	42.84	PASS	43.19	PASS
Equilibrium angle	less than	12.0	degrees	7.19	PASS	4.11	PASS	4.78	PASS
Area under GZ curve	greater than	0.015	m-rad	0.297	PASS	0.344	PASS	0.427	PASS
Maximum righting lever	greater than	0.100	m	0.565	PASS	0.640	PASS	0.781	PASS
SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED ARRIVAL CASE #7		CASE #8		CASE #9	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.973	PASS	0.992	PASS	1.162	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	49.72	PASS	51.64	PASS	52.32	PASS
Equilibrium angle	less than	12.0	degrees	4.78	PASS	5.82	PASS	6.54	PASS
Area under GZ curve	greater than	0.015	m-rad	0.102	PASS	0.286	PASS	0.352	PASS
Maximum righting lever	greater than	0.100	m	1.025	PASS	1.121	PASS	1.073	PASS
SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST ARRIVAL CASE #7		CASE #8		CASE #9	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.735	PASS	0.792	PASS	0.867	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	51.76	PASS	51.80	PASS	52.91	PASS
Equilibrium angle	less than	12.0	degrees	4.11	PASS	4.87	PASS	5.72	PASS
Area under GZ curve	greater than	0.015	m-rad	0.324	PASS	0.362	PASS	0.481	PASS
Maximum righting lever	greater than	0.100	m	0.423	PASS	0.536	PASS	0.582	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST DEPARTURE CASE #7		CASE #8		CASE #9	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.257	PASS	0.299	PASS	0.345	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	45.17	PASS	44.12	PASS	44.82	PASS
Equilibrium angle	less than	12.0	degrees	7.93	PASS	7.21	PASS	6.38	PASS
Area under GZ curve	greater than	0.015	m-rad	0.102	PASS	0.236	PASS	0.385	PASS
Maximum righting lever	greater than	0.100	m	0.912	PASS	0.890	PASS	0.863	PASS

Table 34 - SOLAS 90 - 2 Compartment flooding - cases 7-9

For damage cases 10 – 12:

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED DEPARTURE CASE #10		CASE #11		CASE #12	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.487	PASS	0.579	PASS	0.618	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	41.47	PASS	42.94	PASS	42.06	PASS
Equilibrium angle	less than	12.0	degrees	6.92	PASS	5.21	PASS	6.42	PASS
Area under GZ curve	greater than	0.015	m-rad	0.138	PASS	0.318	PASS	0.242	PASS
Maximum righting lever	greater than	0.100	m	1.122	PASS	0.984	PASS	1.378	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				FULLY LOADED ARRIVAL CASE #10		CASE #11		CASE #12	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.658	PASS	0.562	PASS	0.628	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	53.70	PASS	52.43	PASS	51.11	PASS
Equilibrium angle	less than	12.0	degrees	8.92	PASS	7.11	PASS	7.94	PASS
Area under GZ curve	greater than	0.015	m-rad	0.298	PASS	0.391	PASS	0.425	PASS
Maximum righting lever	greater than	0.100	m	0.425	PASS	0.591	PASS	0.527	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST ARRIVAL CASE #10		CASE #11		CASE #12	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.795	PASS	0.688	PASS	1.872	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	59.11	PASS	57.98	PASS	55.42	PASS
Equilibrium angle	less than	12.0	degrees	6.13	PASS	5.66	PASS	5.13	PASS
Area under GZ curve	greater than	0.015	m-rad	0.324	PASS	0.362	PASS	0.481	PASS
Maximum righting lever	greater than	0.100	m	0.565	PASS	1.180	PASS	0.882	PASS

SOLAS 90 – 2 COMPARTMENT FLOODING				BALLAST DEPARTURE CASE #10		CASE #11		CASE #12	
Evaluation criteria	Pass if	Value	Units	Obtained	Result	Obtained	Result	Obtained	Result
Margin line emergence	greater than	0.000	m	0.524	PASS	0.791	PASS	1.842	PASS
Righting lever range past Equilibrium	greater than	15.0	degrees	45.17	PASS	45.28	PASS	46.96	PASS
Equilibrium angle	less than	12.0	degrees	3.61	PASS	4.53	PASS	5.08	PASS
Area under GZ curve	greater than	0.015	m-rad	0.120	PASS	0.502	PASS	0.581	PASS
Maximum righting lever	greater than	0.100	m	0.720	PASS	0.762	PASS	0.917	PASS

Table 35 - SOLAS 90 - 2 Compartment flooding - cases 10-12

The loading conditions were evaluated against the above criteria for all the 12 damage cases. All the criteria were met for all the cases except for the damage case #2 and damage case #11 initially. It was due to the equilibrium angle not being within the stipulated requirements. The design team then made few changes in the compartments so that the ship passes the damage stability analysis. For the damage case #2, a watertight door was fixed so that no flooding occurs beyond the damage point. For the damage case #11, the problem was the excessive ballast at the fore ship and due to the excessive number of tanks in that region. To fix the problem, the ballast was reduced from the particular tank and the ballast in the aft tanks was increased to maintain the stability. After these changes were made and the analysis for the GZ curves was again carried out using paramarine software, all the damage cases passed the evaluation criteria.

12.5 DAMAGE STABILITY CONCLUSIONS

As explained above, the designed vessel is compliant with the evaluation criteria of the SOLAS 90 – 2 compartment flooding analysis. The loading conditions are considered for fully loaded arrival condition and ballast arrival condition and the iterations on the vessel were done until the evaluation criteria was met and the designed vessel passed the damaged stability analysis.

13 MANEUVERING ANALYSIS

The ability of ship to perform turning cannot be determined in exact numbers, but was assumed. Typically it would be performed either by software such as similitude in MATLAB or by model testing. The team decided to use a simple method for empirical rudder sizing. The following formulas are used:

Det Norske Veritas

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

Equation 3 - Rudder Area

J.M.J. Journée and Jakob Pinkster, Introduction in Ship Hydrodynamics, Delft University.

C.B. Barrass

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

Equation 4 - Rudder Area

C.B. Barrass, Ship Design for Masters and Mates, Elsevier, 2004.

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

Equation 5 - Typical K values

Block Coefficient, Cb	**Balance Ratio**
0.60	0.250 to 0.255
0.70	0.256 to 0.260
0.80	0.265 to 0.270

Equation 6 - Balance ratio

From class notes, the following conventions are used:

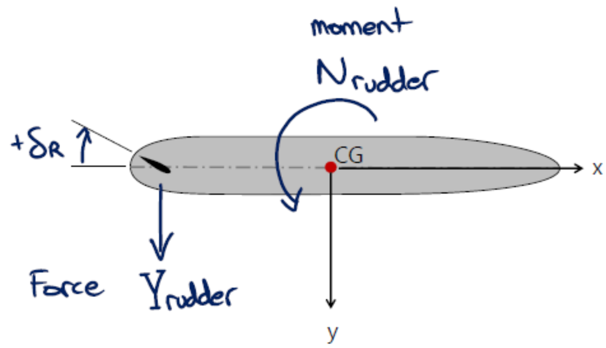


Figure 28 - Forces due to rudder

$$N'_{rudder} = Y'_{rudder} \cdot X'_R$$

X_R is the distance of rudder stock from the center of gravity of the vessel. Apostrophe is a representation of dimensionless. This equation can be broken down as

$$Y'_{rudder} = C_{L\alpha} \cdot S/L^2$$

S is the rudder area and L is length of vessel.

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

Equation 7 - Lift coefficient

Ω is quarter chord sweep angle in radians; AR is the aspect ratio which the design team assumed to be 1.96.

And also Coefficient of lift is defined as:

$$C_L = C_{L\alpha}\alpha + \frac{C_{Dc}}{AR}\alpha|\alpha|$$

Equation 8- Lift coeffecient

$$C_{Dc} = \begin{cases} 0.1 + 0.7\lambda & \text{for a faired tip} \\ 0.1 + 1.6\lambda & \text{for a square tip} \end{cases}$$

For coefficient of drag, Whickler and Fehlner equation was used:

$$C_D = C_{D0} + \frac{{C_L}^2}{0.9\pi AR}$$

Equation 9 - Drag coefficient

C_{Do} is the minimum section drag coefficient defined as:

Section	**Smooth**	**Rough**
NACA0006	0.0050	0.0089
NACA0009	0.0055	0.0091
NACA0012	0.0058	0.0098
NACA0015	0.0065	N/A
NACA0025	0.0081	N/A

Equation 10 - Drag coefficients for different foils

Assuming a rectangular rudder and considering the hull effect A_{Reff} to be 3.9, the design team calculated the rudder area of 9.75m^2. Where b (span) = 3m and c (average chord length) = 3.25m

Taking into consideration of operations the team recommends balanced rudder as minimum control torque is needed for turn as center of pressure on pivot, simply supported with all moveable rudder. Furthermore design teams recommends tapered shaped rudder.

14 SEAKEEPING ANALYSIS

14.1 INTRODUCTION

For the sea keeping analysis of the designed vessel, many assumptions were made. Since the conditions in which the designed vessel is travelling at a particular instant is difficult to calculate, a range of values for different speeds are considered for conducting the sea keeping analysis. For the analysis, the ship is considered to be along beam seas and a sinusoid is considered for the wave pattern.

14.2 ANALYSIS

For the sea keeping analysis, the design team used the Paramarine software available through the Dept. of Mechanical Engineering, UBC. Using paramarine, the roll motion of the ship is determined at various speeds for different sea state conditions. The following wave heights are considered for the different sea state conditions:

Sea state	Wave height
0 - 1	0.06
2	0.30
3	1.12
4	1.88
5	3.24
6	4.97

Table 36 - Wave heights

The vessel's intact stability was evaluated for four separate loading conditions according to the *2008 IS Code* for special purpose ships. The loading conditions used are full load departure, full load arrival, ballast departure and ballast arrival. The tanks which are denoted as full capacity are loaded upto 98% capacity as done in common practice.

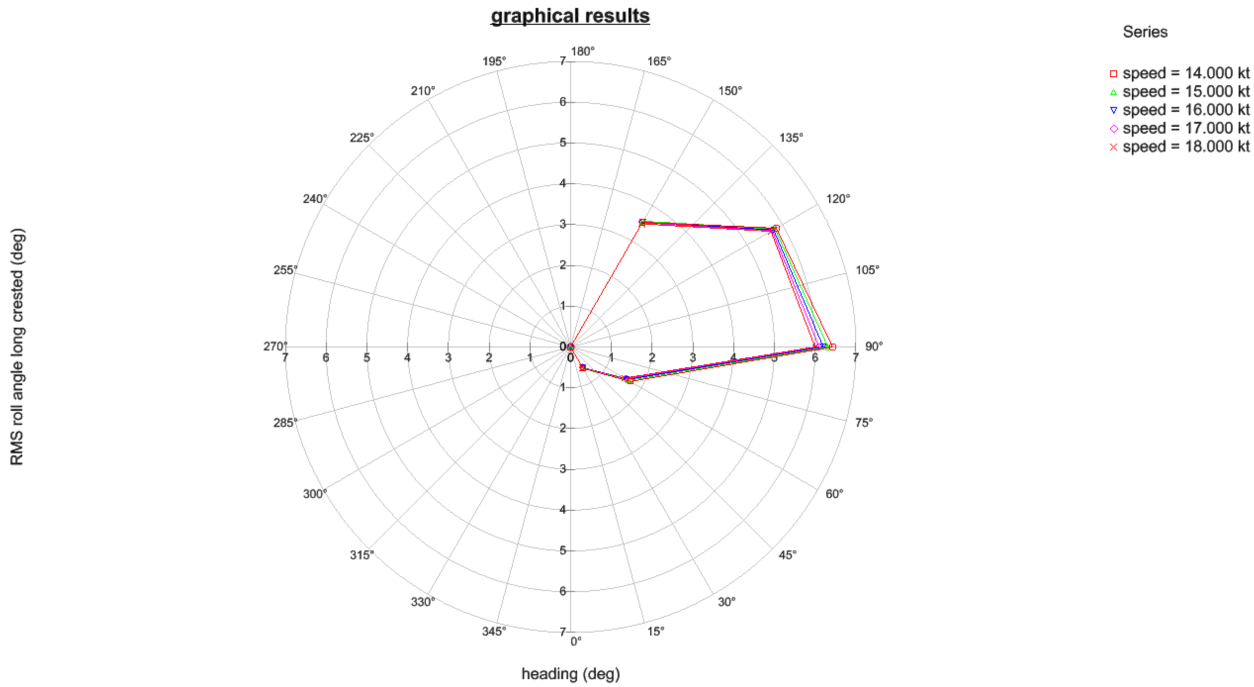


Figure 29 - Roll motion

Based on the results obtained, the maximum roll of the ship at the highest speed of 18 knots is 7.2 at a heading of 90 degrees. The roll varies on the speed of the ship as well as the sea state in which the vessel is travelling.

14.3 CONCLUSION

Since it is difficult to analyze the motion of the ship in waves, basic estimate of the roll motion has been presented. The analysis was done at the highest sea state when the vessel is travelling at highest velocity. This is a critical state of the ship and hence, this case was evaluated. When the vessel is being designed in full-scale, further sea keeping analysis has to be carried out and the motions have to determined based on the wave and wind conditions.

15 COST ANALYSIS

This section of report highlights the cost analysis of the vessel both in terms of initial build cost and overall operating cost through the life of vessel. Cost analysis is done basically to develop an economic plane for our project. The CGC, Government of Canada funded agency will not be getting any benefit from his project. The economic outcomes of these analyses will dictate feasibility and progression to the next stage of the shipbuilding process as well as evaluating alternatives to building new vessels. The initial cost estimate for the CCG will evaluate the feasibility of the proposed design and whether it should be taken forward in the design process. Normally CCG reduces the design requirements with further enhancement and progress of project. The comparison analysis also provides possible alternatives of purchase and operation.

15.1 STAKEHOLDERS

Basically two types of stakeholders can be classified, firstly active or primary stakeholders secondly passive or secondary stakeholders. The table below highlights a few of them.

Primary Stakeholders	**Individual Role**
Government of Canada	Price issues would try to get an affordable vessel.
Canadian Coast Guard	Safety and operation issues
Human Resource Canada (HRD)	Interested in Jobs and economic impact.
Fisheries and Ocean Department Canada	Interested in mission and types of operation
NAME (UBC)Project Team	Evaluation of feasible concept

Secondary Stakeholders	**Business Requirements**
Canadian Public	Tax payers
UBC NAME Program	Academic reasons
Project Sponsor (Dan McGreer)	Technical expertise
NAME director (Jon Mikkelsen)	Grading and learning purposes.

15.1.1 Constraints

The design team chose this design project such as Vancouver Ship yards have been successful in winning contract for this particular type for Canadian coast guard. But the details have been finalized till date 1 Feb 2014; as a result design team had to make assumptions of mission and requirements.

15.2 MARINE COST ESTIMATING

The following theory has been taken form NAME 566 course teachings. The marine cost estimating is very similar to the estimation of weights for marine vessels in that different parametric leading to detailed calculations are used as the design progresses through its various sequential stages. Designers and builders use cost estimates at the Concept Design stage cost estimate as a quick guide to the request for a ROM price from an interested customer. They use the Preliminary Design Cost estimate to check that the price given to the customer is doable with a better understanding of what the craft will look like and the major purchased cost components defined, and the Contract Design Cost estimate as the basis for the negotiated price between the designer/builder and the customer in the Contract. For the Concept Cost Estimate only a few parameters will be used such as weight and speed. For the Preliminary Cost estimate we will have the weight breakdown into the first level of SWBS and this can be used to estimate man hours to build the craft and install equipment. Using the weight a parametric material cost can be estimate for each of the major components, such as structure, machinery outfit, etc. Actual catalog weights can be combined with estimates for the remainder, but this should not give the estimator a false sense of exactness in the estimate. The accuracy of the cost estimates are the same as stated above for weights. The Estimate is a predicted cost of a body of work under anticipated conditions of performance. The estimate requires a greater proportion of the shipyard’s resources to accomplish than all other elements of the bidding process combined. It is the single most important input to the pricing decision. The estimate provides the point of departure and essential tools for the shipyard’s budgeting and cost control and scheduling. Though, estimated cost is not the same as the bid price. As discussed earlier, the pricing is an instrument and expression of the shipyard’s business and marketing policies and a principal means of establishing and maintaining its competitive position. The price is a forecast of market conditions and a pricing decision, which is based, in part, on this forecast and in part on the cost estimate.

15.3 CLASSIFICATION OF COST ESTIMATES:

15.3.1 Detailed Cost Estimate

An extensive cost estimate based on detailed engineering drawings, materials lists and man-hours by the required trades. Estimating detail should be to the maximum extent feasible. Risk and developmental items should be minimal. Class “A” estimates are comparable to fixed price offers. This category should be assigned to the estimate when it can reasonably be expected that the return costs will not vary from the estimate by plus or minus 10%.

15.3.2 Budget Quality Estimate

These are considered to be the highest level of cost estimates attainable in the planning, programming, budgeting and execution process since the more extensive Class “A” estimates are considered post-budget estimates. A Class “C” estimate is the recommended level for estimates of cost to be used in budget submissions and to be used by NAVSEA Program Managers in evaluating Engineering Change Proposals (ECP) for approval or disapproval. The general attributes of a Class C budget quality cost estimate are development by professional cost estimators like SEA 017, provides high confidence that the program can be executed within budget, contains reasonable contingencies commensurate with identified uncertainties and risks, avoids unrealistic management/technical assumptions that may foster subsequent cost overruns of “get well” claims. An approved CDD, a completed Preliminary Design, costs for planned GFE/GFI, and industry capacity analysis are needed. The return costs should not vary from the estimate by plus or minus 15%.

15.3.3 Feasibility Estimates

Conversion/Modernization/Service Life Extension Program (SLEP) Estimates: There are uncertainties related to ship conversions, modernizations, and SLEPs that cannot be resolved until after the contract award; therefore, a Class C classification is never appropriate for these types of estimates. The uncertainties include: (a) scope of the repair package (determined after open and inspect), (b) quality of repair cost estimates, (c) requirements for shipyard industrial and workforce build up and capability for sustaining manning, (d) shipyard workforce limitations to perform needed labor hours of work during scheduled availability, (e) number of ship crews available for production and support work during the conversion, modernization, or SLEP.

15.3.4 Rough Order of Magnitude Estimate (ROM)

ROM estimates are based on design information that does not meet the standards equivalent to ship feasibility. The design study may produce rough order ship weights, but the bases for the weights and other ship design parameters are not founded on sufficient technical information and analysis to support high reliability in the design. Some examples are: (1) a new design of an unconventional ship platform, (2) a ship platform that is initially designed to carry much unconventional or developmental equipment, and (3) a ship designed beyond the current state of the art. Other conditions that call for use of an R classification are as follows: (1) inflating a historical total ship cost 10 years or more, because such a time span is sufficiently long to generate a potential for changes in specifications or an outdating of electronics and combat systems. (2) Projecting out year ship costs beyond the current POM where long range economic and ultimate ship configuration uncertainties are attendant with such projections, (3) using nation- wide or area-wide labor and overhead rates instead of yard specific rates, (4) designing to roughly defined mission requirements.

15.3.5 Directed or Modified Estimate (ROM)

A cost estimate not developed through the normal estimating process, which is either provided by other activities or directed by higher levels. Directed estimates are generally a total cost restriction without a developed design, engineering or a detailed cost estimate. A directed estimate is also a modification of any previous cost estimate, Classes "A" through "R" to conform to budget cuts or restrictions on the cost, which is not based on scope decisions.

15.4 COST ESTIMATING AND PARAMETRIC COST ESTIMATING

The design team basically based on weights of major systems developed a first digit SWBS. A cost estimate not developed through the normal estimating process, which is either provided by other activities or directed by higher levels. Directed estimates are generally a total cost restriction without a developed design, engineering or a detailed cost estimate. A directed estimate is also a modification of any previous cost estimate, Classes "A" through "R" to conform to budget cuts or restrictions on the cost, which is not based on scope decisions. It was divided into labor and material using CERs based on weight. Direct labor cost results from applying labor rate to total man-hours. Overheads were applied as a percentage of direct labor cost. Material, direct labor and overhead, as well as some incidental service costs, were summed and a profit percentage applied to determine bid price. Considerations were made to identify work to be subcontracted, as that becomes part of the material cost. Design and engineering was subcontracted, as it is necessary to add subcontractor liaison hours into the remaining in-house design and engineering estimate. The design team chooses to use Empirical CERs. Basically Empirical CERs are relate cost to system-level parameters like structural weight and propulsion prime mover/power output, or cost relationships for higher level interim products such as blocks or zones. The derivation of the Parametric CERs was done for the three levels of Cost Estimating, namely Concept, Preliminary and Detailed. These correspond with the Concept design, Preliminary Design and Contract Design. We used the following formula for driving equation:

Total Price = 8000 x Cost Compensation Factor x (Cubic Number/4.5) ^ (- 0.15) x (Cubic Number)

Labor man hour CERs was calculated from following formula:

LMH (SWBS) = Item Value x Cost Compensation Coefficient x (Cubic Number/4.5) ^ (- 0.15)

Cubic number is LBT. The spreadsheet was made with input of Weights for SWBS Groups 1 to 7, business values for labor rate, overhead rate, insurance and bonds, and profit. The team used CERs derived from the Cost Estimate Database for each of the Major Groups (1 to 900) to derive the Labor Man Hours. The Material Cost is derived from simple CER x Parameter. The total Price is derived by computing the Totals for LMH and Material and applying all the appropriate extensions. Assuming total crew cost being $ 2,000,000.

SWBS	Labor Man-Hours	Material Dollars
100	CF x 177 x $\text{Weight}_{100}^{0.862}$	800 x Weight_{100}
200	CF x 365 x $\text{Weight}_{200}^{0.704}$	15,000 + 20,000 x Weight_{200}
300	682 x $\text{Weight}_{300}^{1.025}$	25,000 x Weight_{300}
400	1,605 x $\text{Weight}_{400}^{0.795}$	40,000 x Weight_{400}
500	CF x 34.8 x $\text{Weight}_{500}^{1.24}$	Weight_{500} x 10,000+10,000
600	310 x $\text{Weight}_{600}^{0.949}$	5,000 + 10,000 x Weight_{600}

Table 37 - Cost estimating using SWBS

Size Factor	2.29
Ship Type	4
CF	9.14
Labor Rate($/Hr)	150

System Number	Title	Weight [Ton]	Man Hours	Material Cost ($)	Labor Cost ($)
100	Hull	639	418,456	511,200	62,768,458
200	Propulsion M/C	106.4	89,160	2,129,280	13,374,132
300	Electrical	18.9	13,852	471,825	2,077,842
400	Command & Comm	27	22,050	1,080,000	3,307,504
500	Auxilliary M/C	15.3	915	163,000	137,298
600	Outfit	246.6	286,703	2,471,000	43,005,535
800	Engineering		207,784		31,167,693
900	Support Services		415,569		62,335,386
Total		1053	1,454,492	6,826,305	218,173,851

Table 38 - Total Cost Estimation

Overhead Material	136,526,100
Labor Over Head	174,539,081
Sub Total	536,065,337
Profit ($)	64,327,840
Margin ($)	53,606,533
Price ($)	653,999,710

Table 39 - Final Price values

Total Cost

Crew Cost ($/year)	2,000,000
Fuel Cost ($/year)	3,108,380
Total Building Cost ($)	653,999,710

Table 40 - Total Cost