THE UNIVERSITY OF BRITISH COLUMBIA

NAME 591: Computer Aided Ship Design Project

Arctic Charter Yacht Concept Design

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EXECUTIVE SUMMARY

This project produced a concept design satisfying the requirements set forth in the *NAME 591 -Computer aided ship design project course.* The goal of the project was to develop a design for an icebreaking charter yacht capable of carrying 21 passengers for an extended period of time through the eastern arctic. This project was undertaken by four Masters of Engineering specializing in Naval Architecture and Marine Engineering from the University of British Columbia as part of the NAME 591 – Computer aided ship design project course. Working together with industry mentors and faculty advisors, a design was produced following the guidelines set forth by our advisors, while keeping the analyses' level of detail consistent with industry standards regarding a concept design stage.

Major emphasis was placed on maximizing the number of passengers on the ship while still having the feeling of being on a spacious and luxurious vessel. Also, the vessel was designed with easy convertibility to a traditional Caribbean touring yacht for the winter months. The final concept is a steel monohull with an overall length of 62 m, a maximum beam of 12 m, a lightship draft of 3.5 m, and a full load weight of 1700 tonnes. The vessel has a crew accommodation deck with 12 crew cabins, a B class passenger deck with 6 cabins, as well as an A class passenger deck that has 4 cabins. The vessel is powered by a diesel electric plant with two main generator sets as the yachts mission profile varies significantly. The propulsion system consists of two engines connected by geared shafts to twin screws, providing a maximum service speed of 25 knots.

Overall, the project determined that a feasible vessel could be designed to meet the requirements set forth by the design project course instructors while providing a desirable passenger vessel.

ACKNOWLEDGEMENTS

The Arctic yacht design team would like to thanks those involved in providing invaluable help and insight throughout the duration of this project.

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Tony Vollmers- Guest Lecturer, STX Marine

Ian Saari- UBC SNAME President

Robert Allan- NAME 591 Mentor, Robert Allan Ltd

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VESSEL OVERVIEW

This section will deal with the perceived client motivation as well as owner requirements. This was the preliminary portion of the project and was done to set out the design requirements and constraints of the vessel. The mission profile, areas of operation, environmental requirements and applicable class and flag state regulations are also detailed in this section.

CLIENT REQUIREMENTS AND MISSION PROFILE

The client that this vessel was designed for was a hypothetical charter company that would be operating an Arctic charter business. The imagined customer base is wealthy outdoor enthusiasts and adventurists looking for a one of a kind Arctic adventure. The main design motivation for this project was to create an environmentally sustainable boat that would be able to navigate the lower to mid Arctic during the winter months. The atmosphere aboard was to be a small intimate atmosphere with ample visibility to the outdoors. This was balanced with the need to have all the comforts of home while aboard the vessel.

In addition to this, the yacht must have the capabilities to provide equipment to allow customers to easily embark and disembark the vessel for day trips, fishing and other outdoor activities. The yacht will also have the capability of providing helicopter tours and heli-skiing services via an on board helicopter.

The mission profile of this boat is to pick up passengers from a predetermined port and transport them to the lower Arctic from where they will tour a pre-designated route that features many of the natural beauties of an Arctic ecosystem. In addition, the boat must be economically viable so as to have a reasonable payback period and money making potential. To increase the operating window for this boat, it was determined that operating in a tropical region during winter months would be economically beneficial to the operating party.

DESIGN REQUIREMENTS

From the customer requirements, the design teamed came up with the design requirements for the vessel so as to fit the customer requirements. The design requirements were determined by researching typical yachts of similar function and passenger boat regulations to determine the amount of passengers, cruising speed and crew requirements. It was determined that an optimal number of passengers is 20-21 placed in a two class system (First and Second Class). Each class would be paying an appropriate sum of money and would be provided with appropriate services, accommodations and amenities. In addition to this the vessel with have the operational requirements documented in Table 1. The passenger number was determined so as to fall within a certain regulation bracket within the IMO SOLAS regulations (International Convention for the Safety of Life at Sea, 2004).

In addition to the Arctic operating requirements, the boat must be designed in such a way that it can be used in tropical areas during the winter months. As such it must contain the required amenities that allow for passenger comfort such as an air conditioning system.

Operational Parameter	Value
Cruise Speed	25 knots
Ice Class	DNV Ice class 1C or equivalent
Passengers	21
Crew	~20
LOA, Beam, Draft (lightship)	62m, 12m , 3.5m
Range	6000 Nautical miles

Table 1: Operational Requirements

AREAS OF OPERATION (ARCTIC)

With the hull class designation of DNV Ice Class 1C, the vessel will be permitted to operate in areas 7-16 of the Arctic Safety Control Zones as regulated by Transport Canada. An approximate layout of these areas is shown in Figure 1.

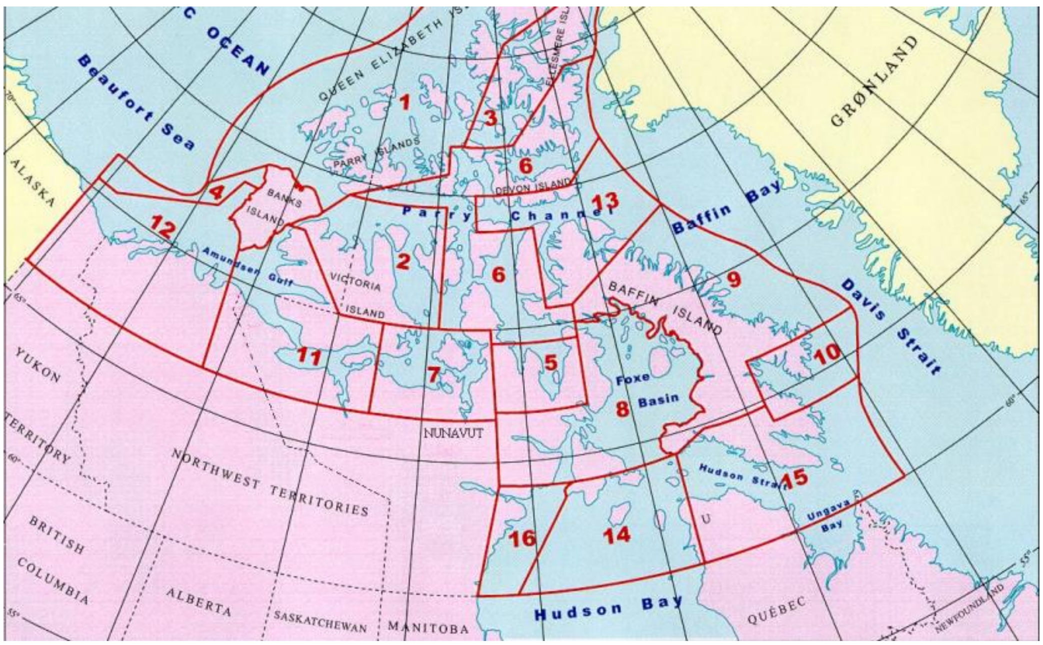


Figure 1: Transport Canada Arctic Safety Control Zones

APPLICABLE RULES AND REGULATIONS

This section will outline the various regulations and regulatory bodies that will be followed and consulted throughout the design process.

CLASS RULES

This vessel will be designed according to Lloyd's Register Rules and Regulations for the Classification of Ships. The ship will be designated as an Ice Class passenger ship.

FLAG STATE

The ship will be registered in Canada as that is where its primary area of operation will be and as such, it must comply with all applicable regulations set out.

ENVIRONMENTAL REGULATIONS

The boat will adhere to all Transport Canada environmental regulation for shipping operations in the Arctic. The propulsion system will be designed such that it meets and exceeds IMO Tier III requirements.

AREAS VOLUMES AND WEIGHTS

This section will document the procedure and results of how the volume, areas and preliminary weight calculations of the ship. The values from here will then be used to determine the hull size and shape.

AREAS AND VOLUMES

The following subsections detail the determination of areas and volumes on the boat. One of the primary design considerations of this boat was to create 2 separate environments within the ship; one for the crew and one for the passengers. This was done so as to keep the two groups separate from each other and as such much of the amenities on the boat had to be duplicated.

CREW ACCOMMODATIONS

To determine the required area for crew accommodations, the required area as dictated by legislation was used. This value is specified is a meagre $2m^2$ per crew, and this value was increased to $7.5\ m^2$ as to increase the comfort of crew. The general layout for was assumed to be 3m by 5m identical cabins with two beds per cabin. For a crew of 21 this resulted in 12 cabins, 3 of which with one bed which were reserved for the captain, first mate and chief engineer. A 25% margin was included to account for walls and doors and other such structures.

In addition, a crew mess measuring 5m by 6m were included and a lounge with the same dimensions as the mess. Table 2 summarizes the crew facilities for the vessel, for the volume calculation it assumed a constant ceiling height of 3m.

Crew	# of Cabins	Beds per Cabin	Area m^2	Height m	Volume m^3
Rooms	12	21	180	3	540
Crew Lounge	21	1.42857143	30	3	90
Crew Mess	21	1.42857143	30	3	90
Main Stairs			20.25	9	182.25
Cabin Corridors, wall lining (25% of cabin area)			45	3	135
Total			**302.25**		**1037.25**

Table 2: Crew Facilities areas and volumes

PASSENGER ACCOMMODATIONS

To determine the passenger accommodation areas and volumes a similar method to the crew facilities was applied. The A class passenger cabins were assumed to approximately $35\ m^2$ and the B class passenger cabins were assumed to be $72\ m^2$ in size. As with the crew accommodation, a 25% margin was applied. The final calculations for passenger rooms are located in Table 3.

Passenger Class	# of Cabins	Outdoor Space	Area m^2	Height m	Volume m^3
A	6		210	3	630
B	4		288	3	864
Cabin Corridors, wall lining (25% of cabin area)			124.5	3	373.5
Total			**622.5**		**1867.5**

Table 3: Passenger accommodations

Passenger common spaces were the next area of consideration when it came to areas and volumes. The details of the assumed values are located in Table 4.

Name / Use of Space	Area m^2	Height m	Volume m^3
Lounge	132	3	396
Office/Meeting Room	15	3	45
Spa	25	3	75
Restaurant	101	3	303
Sauna/ Lower Deck Spa	15	3	45
Lower Deck Outdoor Area	195	3	585
Spa (Upper Deck)	20	3	60
Total	**478**		**1434**

Table 4: Passenger common spaces

A summary of all area and space accommodations is located in Table 5. It should be noted that for all volume calculations a mean ceiling height of 3m was used.

Area	Unit	Volume	Unit
1100.5	m^2	3301.5	m^3

Table 5: Passenger area and volume

SHIP SERVICES

Ship service includes everything that is involved in running the ship this includes hotel and catering as well as navigation and control. Technical areas such as the engine room are covered in a separate section.

The space requirements covered under this section are everything that have to do with ensuring passenger comfort. This includes laundry, cleaning and food services and it is assumed that the crew equivalent services will be met with the same areas. The areas and volume for components of the service facilities are located in tables 5 and 6 with a summary of volume and area in Table 7.

Name / Use of Space	Area m^2	Height m	Volume m^3
Galleys	22	3	66
Provision Store	33	3	99
Garbage	11	3	33
Total	**44.5**		**198**

Table 6: Catering Service

Name / Use of Space	Area m^2	Height m	Volume m^3
Navagation and Radio	220	3	660
Offices	22	3	66
Sick Bay	22	3	66
Total	**264**		**792**

Table 7: Navigation, administration and medical areas

Name / Use of stairs	Area m^2	Height m	Volume m^3
Laundry and Linen Store	22	3	66
Hotel Store	22	3	66
Total	**20**		**132**

Table 8: Hotel Services

Area	Unit	Volume	Unit
374	m2	1122	m3

Table 9: Service facilities area and volume

TECHNICAL FACILITIES AND MISCELLANEOUS STORAGE

This section will cover the volume and area calculations for the technical areas (engine room,etc.) and the miscellaneous storage for such things as boats and sporting equipment.

The technical areas consist of all the mechanical and working components of the boat. Included in the engine and pump room is the exhaust and air intake systems as well as thrusters and stabilizers. The area estimation was done on an average of m^3/kW. As the engine could not be specified at this point in the design, a value of similar yachts of the same role was chosen. This includes the generator specifications as well. The area of the engine room was derived from using an average of a 6m ceiling height (approximately 2 decks high). These calculations are summarized in Table 10.

Name / Use of Space	kW	m^3/kW	Area m^2	Height m	Volume m^3
Engine and Pump Rooms	3500	0.17	96	6	576
Engine Control Room			20	3	60
Generator	1500	0.325	40	3	120
Workshop?			20	3	60
Total			**176**		**816**

Table 10: Technical areas and volumes

The next set of areas and volumes to be estimated was the tanks for the various liquids on board to sustain operation of the ship. This includes fuel and lube oil as well as fresh water, sewage, ballast, fire retardant foam and jet fuel for the helicopter. The data was calculated using average values for similar yachts in the case of operating fluids and then per capita consumption for the estimation of fresh water and the production of sewage. This data is summarized in Table 11.

Name / Use of Space	Consump. Ton/day	Range nm	Endurance days	Margin Factor	Volume m^3
Fuel Oil (g/kWh)	210	6000	13	1.2	245.7
Lube Oil (g/kWh)	1.5	6000	13	5	7.3125
Fresh Water (m3/day)	10.25		8	1.2	98.4
Sewage Holding (m3/day)	3.4		13	0.6	26.52
Ballast					8
Jet Fuel					1.725
Fire Retardant Foam					0.25
Voids				3	24.57
Total					**412.4775**

Table 11: Liquid hold volume estimates

Table 12 and Table 13 cover the volume and estimation of activity related storage as well as equipment storage respectively. All the activity related storage values were estimates derived through a first order guess as to how much space one set of equipment would take up than specifying a number of units that would be available on board. The equipment storage was derived from specifying a typical model of each type of equipment than creating a volume of each item by using its length width and height.

Name / Use of Space	# Avail. On Board	Area / unit	Area m^2	Height m	Volume m^3
Scuba Equipment Storage	10	1	10	3	30
Kayak Storage	4	3	12	3	36
Fishing Equipment Storage	5	0.5	2.5	3	7.5
Hiking/Skiing Storage	20	0.5	10	3	30
Total			**34.5**		**103.5**

Table 12: Activity related storage

Name / Use of Space	# Avail. On Board	Area/unit	Area m^2	Height m	Volume m^3
Helicopter	1		191.5	3.5	670.25
Fishing Skiff	1	8.91	8.91	3	26.73
RIBS	2	7	14	2	28
Total		**15.91**	**214.41**		**724.98**

Table 13: Equipment storage

WEIGHTS

The following section documents the first order approximation of lightweight condition as well as the deadweight condition of the ship. The lightweight condition is comprised of the ship without any fluids or pieces of equipment on board. The deadweight condition consists of the operating condition of the ship with all cargo aboard with all fluid tanks full. The method used in this section was to assume an average weight of volume per component than multiplying the estimated volume by that average (Dan McGreer, 2014). The lightweight ship condition is estimated and documented in Table 14.

Weight Group	Unit	Value	Coeff ton/unit	Weight (ton)
Hull Structure	Hull Vol	4084.208	0.11	449.262825
Superstructure	Dh Vol	3436.5	0.06	206.19
Interior Outfitting	Area	1779.75	0.15	266.9625
Machinery	Pp + Pa (kW)	5000	0.06	300
Ship Outfitting	Volume	7520.708	0.005	37.6035375
Total Hull Volume	Volume	7520.708	0.121	910.005608
Reserve	%	5.00%		45.5002804
Lightweight				**1305.51914**

Table 14: Lightweight ship estimate

Item	Unit	Value	Coeff ton/unit	Weight ton
Equipment Storage	Capacity	5.233	1	5.233
Activity Related Storage	Capacity	1.818	1	1.818
Crew	Persons	22	0.1	2.2
Passengers	Persons	20	0.1	2
Provision and Stores	Persons	42	0.0135	0.567
Fuel Oil	Consumption	245.7	1	245.7
Lube Oil	Consumption	7.3125	1	7.3125
Fresh Water	Consumption	98.40	1	98.4
Sewage in Holding Tanks	Produced	26.52	1	26.52
Deadweight				**389.7505**

Table 15: Additional weight for deadweight condition

HULL DESCRIPTION

The hull form chosen was directly related to the NPL series. This series was chosen for a variety of factors. Firstly, the large swept bow and smooth hull lines provide for an attractive hull design. Secondly, the raked how and shallow entrance angle provide for improved icebreaking performance in brash ice conditions as the hull simply deflects ice chunks off to the side as it moves through the ice. In addition to this, the hull design in a semi planning and thus is efficient at higher transit speeds which may need to be undertaken for short periods of time. The absence of sharp chines and lines also provides for improved performance at slower speeds.

The decision to choose this hull form was also based on the fact that many of the target hull form parameters were met by this hull series. For initial shape generation, a set of offsets was used to create splines within Siemens NX, from here; these were turned into successive sheets which were then joined to create the initial hull design. A screen shot of the initial hull shape is located in Figure 2.

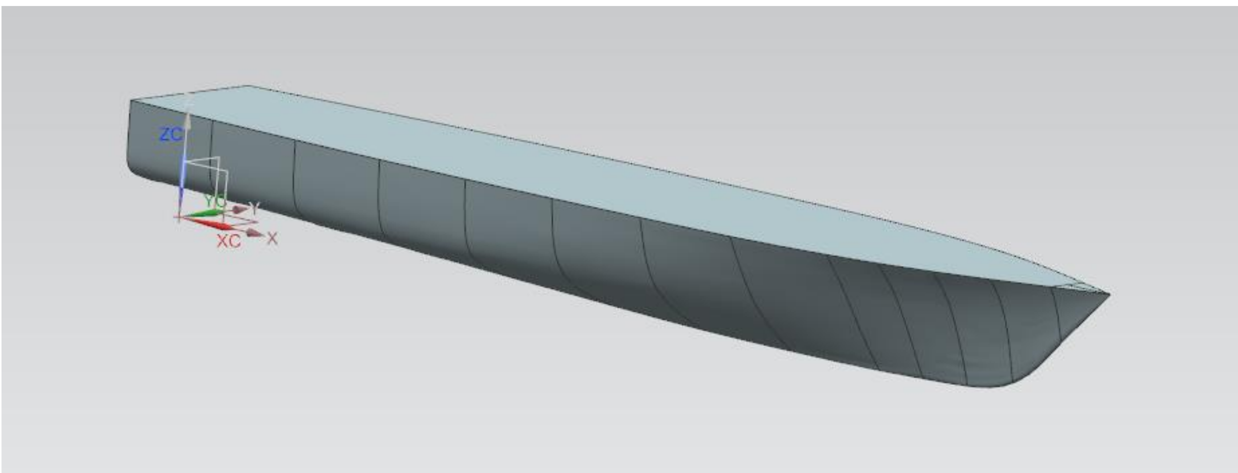


Figure 2: Initial hull design

Table 16 shows a list of target hull parameters. These were determined from the initial volume area and weight calculations and the chosen hull form and design speed.

Length PP	**61.57**	Froude No.	**0.314**
Breadth WL	11.2	**$L/\Delta^{1/3}$**	5.534
Draught	3.7	**L/B**	5.5
L/D	16.5	**B/T**	3
Displacement	1377.505	**C_b**	0.535
		C_p	0.58

Table 16: Vessel particulars

RUDDER SIZING

PRELIMINARY RUDDER DESIGN

Using the Det Norkse Veritas equation, a preliminary estimate of the area of the rudder may be calculated:

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

Where

T = Draft

L_{pp}= Length Between Perpendiculars

B = Breadth

$$S \approx \frac{3.9m \cdot 65m}{100}[1.0 + 25.0 \cdot \left(\frac{11.8m}{65m}\right)^2]$$

$$S \approx 4.624\, m^2$$

Using this preliminary estimate, an aspect ratio can be estimated using a varying range of spans and chords of the rudder. Due to the fact that this is an icebreaking vessel and pieces of ice will be travelling under the keel of the vessel, we would like to minimize the size of the span of the rudder in order to reduce potential vibrations and damage to the rudder and or rudder stock while still maintaining enough depth to minimize the drag force.

Dimensions of Rudders			
Span (m)	Chord (m)	AR	2AR
2.6	1.78	1.46	2.92

Table 17: Span, chord, and aspect ratio of the rudders

Because the rudder is flush against the hull, the control surface will behave as if the span was doubled, therefore for all further calculations, the aspect ratio we will be using is the 2AR value above.

STRAIGHT LINE STABILITY

A vessel possesses straight line stability if the following parameter, C has a positive value:

$$C = Y_v' N_r' - N_v'(Y_r' - m')$$

HULL CALCULATIONS

By using semi-empirical curve fit formulas based on a ship's length, beam and draught, the following hydrodynamic derivatives were obtained for the hull:

Bare Hull Semi-empirical curve fits	
Y'v	-0.01753
N'v	-0.00728
Y'r	0.00387
N'r	-0.00301
m'	0.01168
C	-4.02668E-06*

Table 18: Non-dimensionalized forms of bare hull hydrodynamic derivatives

*It may be noted that the bare hull is not initially straight line stable

RUDDER CALCULATIONS

For the rudder, the following Whicker & Fehlner equation for low AR lift may be used to calculate the coefficient of lift:

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

where,

AR = Aspect Ratio = 2.92

Ω = quarter chord sweep angle, assumed to be 0

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

$$C_{L\alpha} = 3.095$$

By using the following equation, the first non-dimensional hydrodynamic derivative is calculated:

$$Yr'v = \frac{-C_{L\alpha}S}{L^2}$$

Using similar equations, the remainder of the rudder hydrodynamic derivatives are calculated and presented in the following table:

Rudder Derivatives	
Yr'v	-0.00338
Nr'v	0.00123
Yr'r	0.00123
Nr'r	-0.00045

Table 19: Non-dimensionalized forms of rudder hydrodynamic derivatives

Skeg Calculations

By treating the skegs as rudders, similar calculations could be performed for the span, chord, and aspect ratio of the skegs:

Dimensions of Skegs			
Span (avg)	Chord	AR	2AR
1	8	0.125	0.25

Table 20: Span, chord, and aspect ratio of the skegs

Again, by similar calculations, the hydrodynamic derivatives of the skegs may be calculated and are presented in the following table:

Skeg Derivatives	
Ys'v	-0.00070
Ns'v	0.00018
Ys'r	0.00018
Ns'r	-0.00004

Table 21: Non-dimensionalized forms of skeg hydrodynamic derivatives

By summing the hydrodynamic derivatives of the hull, rudders, and skegs, the overall stability parameter may be calculated:

Sum of Derivatives	
Y'v	-0.02162
N'v	-0.00587
Y'r	0.00528
N'r	-0.00350
C	**3.82977E-05**

Table 22: Non-dimensionalized forms of the sums of the hydrodynamic derivatives and stability parameter C

With the addition of the rudders and skegs, the ship is now straight line stable as the stability parameter, C, is now positive.

RESISTANCE

This section covers that calculation of both the bare hull effective horsepower as well as the EHP with the inclusion of appendage drag.

BARE HULL RESISTANCE

As the hull is derived from the NPL hull series, the resistance formulation was relatively straight forward. Initially, it was planned to use Paramarine for all the resistance calculations but due to the design hull speed being slightly outside the parameters of the NPL series regression within the software package would only return error messages and would not compute the resistance. The next method was to simply use C_R values from published values (Molland, 2011). Figure 3 shows EHP curves for both the bare hull and with appendages. The orange curve is the appendage drag curve while the blue curve is the bare hull drag.

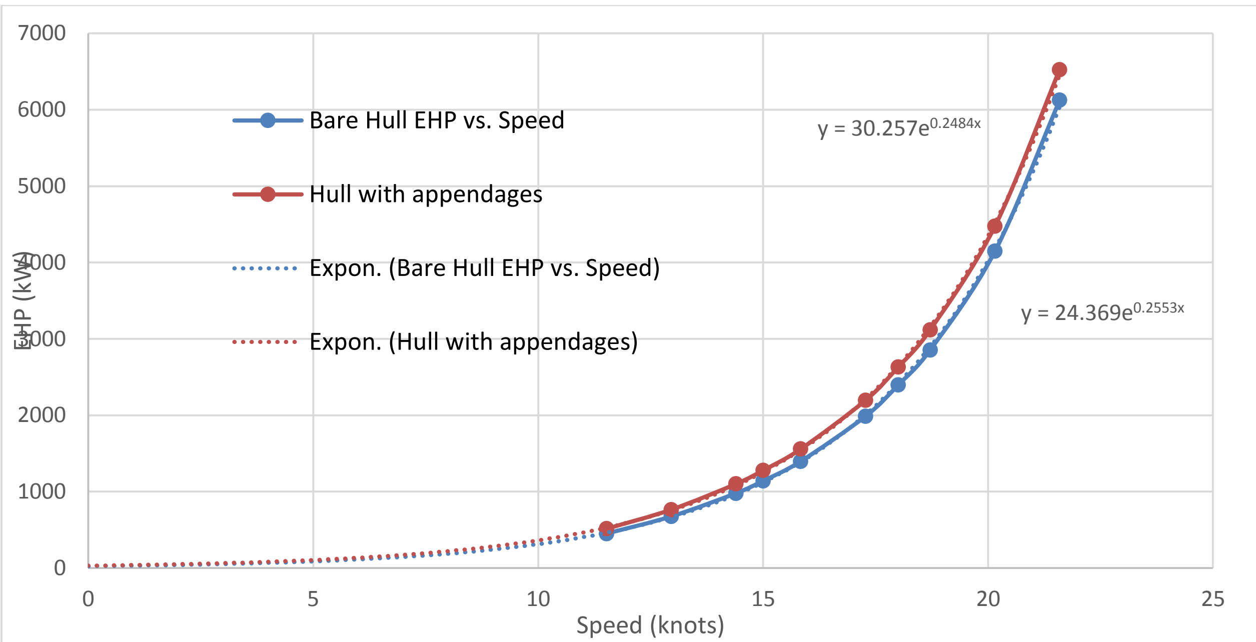


Figure 3: Bare Hull and Appendage drag Resistance

APPENDAGE DRAG

Appendage drag was considered for the following items: rudder, bow thruster and skegs. Drag correlations documented in Ship Resistance and Propulsion were used to find a drag estimate for each item. These were resistances were summed up and added to the bare hull resistance to obtain an overall resistance for the hull (Molland, 2011). Table 23 shows the percentage of appendage of overall drag as a function of speed.

V (knots)	Bare Hull	Appendage Drag	%BH
11.51548801	70.30997183	10.78928832	15.34532
12	88.2453093	12.59850069	14.37658
12.95492401	97.34539065	13.51646389	13.88506
14.39436001	132.1443692	16.53795149	12.51506
15	149.3829345	17.89670882	11.98042
15.83379601	175.4814305	19.85173678	11.31273
17.27323201	231.8151157	23.45603519	10.11842
18	271.0861225	25.38569258	9.364438
18.71266801	313.4898529	27.3492478	8.724125
20.15210401	432.5061344	31.52992856	7.290053
21.59154001	610.9974599	35.99675935	5.891474

Table 23: Appendage Drag

PROPULSION AND POWERING

The section documents the method and rationales used to design and spec the propulsion system used for this boat. This includes the mission profile, primary gensets, propeller selection and propulsion type.

MISSION PROFILE

Mode	Units	Port	Normal Transit (15 knts)	Coastal Transit (12 knts)	Slow Transit	Maneuv.	Ice Breaking
% time		28%	21%	28%	12%	6%	12%
annual hours	h	2435.28	1848.36	2461.56	1086.24	556.26	1086.24
propulsion load	%	0%	0%		0%	0%	0%
propulsion load	ekW	0.00	2087.00	1043.60	181.11	181.11	1940.66
thrusters	ekW	0.00	0.00	0.00	0.00	485.00	0.00
Deck Load	ekW	40.00	0.00	0.00	0.00	0.00	0.00
Ship Service	ekW	625.0	625.00	625.00	625.00	625.00	625.00

Table 24: Operating Profile

The mission profile was derived from considering three different operating modes: Arctic operation, transit and Tropical operation. The percentage of operating time per mode was determined using a weighted average of mode length (i.e months of operation per mode) and a specific breakdown of operating profiles within each mode (i.e. time spent in port, at anchor and steaming). The final operating profile is located in table 18 and is based on 365 days per year of operation.

The deck service load was considered by examining the operation of the crane that we will be used. A preliminary size estimate for the crane yielded a load of 40 kW. The hotel service was estimated by examining yacht of similar size and function and it was determined that 625 kW was an appropriate load.

SYSTEM STRUCTURE

This section will cover the proposed structure of the propulsion system for the arctic yacht. The prime mover type as well as the main propulsor selection will be discussed.

SYSTEM TYPE

It was determined that a diesel-electric generator system will be used in this ship. The rationale for this was based on its applicability to a variable operating profile. IEP are particularly useful because they allow the primary generators to be cycled on and off to allow for the most efficient use of each generator.

For this concept design it was decided that 2 primary diesel generators would be used in conjunction with a smaller high efficiency auxiliary diesel generators. The models chosen were two CAT 3512B gensets for the primary generators and a CAT ACERT C32 generator for the smaller auxiliary generator. The total installed generating capacity for this power plant was 3930 kW.

The main electrical system and electric motors were specified using an ABB booklet supplied by Dan McGreer at STX.

PROPULSION SYSTEM

A fixed pitch, twin screw system was selected as the drive system for this boat. This is due mainly to redundancy which is a favourable characteristic for operation as help is a long way off and getting stranded in ice flows carries quite a substantial risk. The choice to go with a straight shaft system was made for cost reduction purposes and the unavailability of of azipods or z-drives in the required power range.

EMISSIONS AND FUEL COSTS

A vital component of this design process was to make the ship an economical business venture. Thus a fuel cost estimate was a must. In addition to this, an emission estimate must be performed to ensure that the boat will meet emission requirements and if not, what sort of exhaust treatment must be performed. The estimates will be provided yet a detailed design of the exhaust treatment is outside of the scope of the initial design spiral for this vessel.

FUEL COST ESTIMATE

Using the specific fuel consumption at various power loads for the generator sets, a regression was performed so as to interpolate sfc value. These were used to determine a fuel consumption rate as well as the optimal load condition for each generator. The SFC for both generator types are located in Figure 4 and Figure 5.

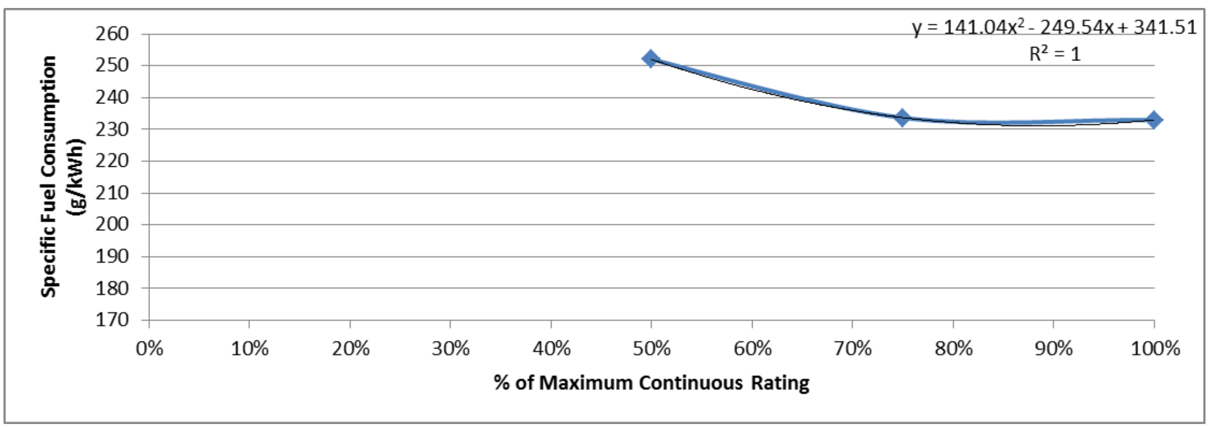


Figure 4: SFC curve for CAT 3512B genset

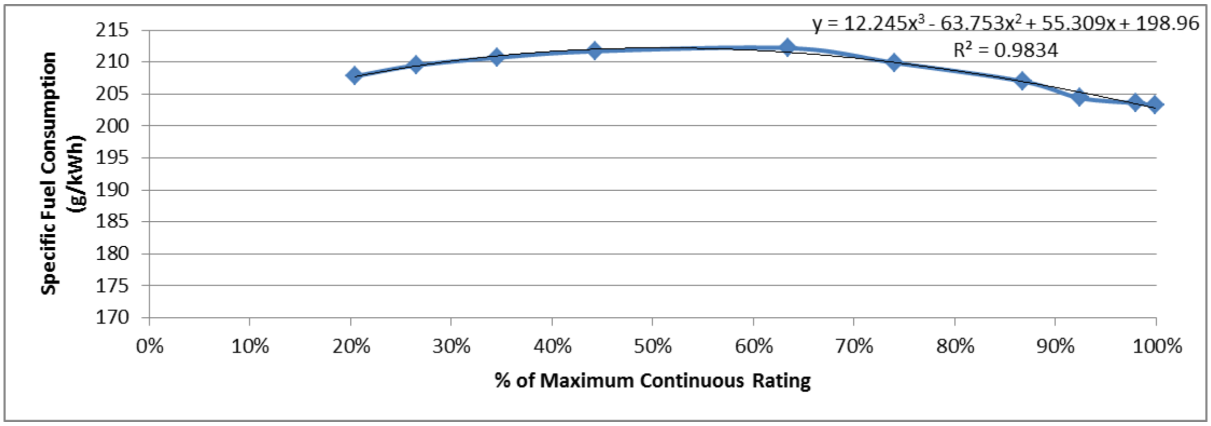


Figure 5: SFC for CAT C32 ACERT genset

The optimal operation point for these generators was determined by observing the lowest point on the regression curve. For the CAT 3512B, this was at approximately 85-90 percent load and the ACERT C32 it occurred at a load of 100%. Using this information and the mission profile the optimal fuel cost was determined. Table 25 summarizes the fuel costs for all operating modes, generators and provides a summary of the overall costs.

total fuel/yr	**t/y**	**337.16**	**1091.04**	**931.96**	**178.02**	**251.69**	**608.01**
annual fuel cost	$	345,593.14	1,118,317.03	955,261.88	182,475.51	257,982.16	623,207.80
total fuel cost	$						3,482,837.51

Table 25: Fuel cost summary

EMISSION ESTIMATE

The emission estimates were performed by using correlations that relate the specific type of emission to the specific fuel consumption. The emissions examined are CO_2 and sulphur and the findings are summarized in Table 27.

CAT 3512C (1)	Units	Port	12 knts	15 knts	Slow Transit	Maneuv.	Ice Breaking
Total Sulphur/yr	Tonne	0.10	0.26	0.28	0.02	0.02	0.08
Total CO2/yr	Tonne	162.49	418.74	452.92	39.14	27.67	137.76

Table 26: Fuel emissions summary

The total CO_2 emission for the year is 1238.71 tonnes and the sulphur emission per year is 0.76 tonnes per year.

From the resistance predictions and the inclusion of a hotel load and deck service load the appropriate generator sets were selected. From the analysis of the emissions, it is evident that for tier III standards to be met, exhaust treatment must be undertaken.

STRUCTURAL

LONGITUDINAL STRENGTH

Vertical Bending Moments – Stillwater conditions

The design stillwater bending moments within 0.4 L amidships are normally not to be taken less than:

$$M_{SO} = 0.0052L^3 \, B \, (C_B + 0.7) \, (kNm)$$

$$M_{SO} = 0.0052 \cdot 61.57^3 \cdot 11.2(.535 + 0.7) \, (kNm)$$

$$M_{SO} = 16787.9 \, kNm$$

Outside 0.4 L amidships MSO may be gradually decreased for zero at F.P. and A.P.

Wave load conditions

$$M_{WO} = 0.11 \, C_W \, L^2 \, B \, (C_B + 0.7)(kNm) \; in \; sagging$$

$$= 0.19 \, C_W \, L^2 \, B \, (C_B)(kNm) \; in \; hogging$$

where,

C_W = wave coefficient = 0.0792L

$$M_{WO} = 0.11 \cdot 0.0792 \cdot 61.57^3 \cdot 11.2 \, (.535 + 0.7) \, (kNm) \; in \; sagging$$

$$M_{WO} = 28126.15 \, kNm \; in \; sagging$$

$$M_{WO} = 0.19 \cdot 0.0792 \cdot 61.57^3 \cdot 11.2 \cdot .535 \, (kNm) \; in \; hogging$$

$$M_{WO} = 21045.4 \, kNm \; in \; hogging$$

BENDING STRENGTH AND STIFFNESS

Section Modulus – Longitudinal Axis

The section modulus requirements within 0.4 L amidships about the transverse neutral axis based on cargo and ballast conditions are given by:

$$Z = \frac{M_S + M_W}{175} 10^3 \, (cm^3)$$

$$Z = \frac{16787.9 + 28126.15}{175} 10^3 \, (cm^3)$$

$$Z = 256651.7 \, cm^3$$

Section Modulus – Transverse Neutral Axis

The midship section modulus about the transverse neutral axis is not to be less than:

$$Z_O = C_{WO} L^2 B (C_B + 0.7) (cm3)$$

where,

C_{WO} = 5.7 + 0.022L

$$Z_O = (5.7 + 0.022L) L^2 B (C_B + 0.7) (cm3)$$

$$Z_O = (5.7 + 0.022 \cdot 61.57) 61.57^2 \cdot 11.2 (.535 + 0.7) (cm3)$$

$$Z_O = 369906.5 cm3$$

TRANSVERSE BULKHEADS

According to DNV Rules for Classification of Ships as well as Lloyd's Registry Rules and Regulations, a ship must have four transverse watertight bulkheads. The collision bulkhead is found near the bow of the ship and its approximate location may be determined by the following equations:

$$x_c\ (minimum) = 0.05L_F - x_r$$

$$x_c\ (maximum) = 0.05L_F + 3 - x_r$$

where,

L_F = Length of waterline

x_r = 0 for ships with ordinary bow shape

$$x_c(minimum) = 0.05 \cdot 62m = 3.1m$$

$$x_c(maximum) = 0.05 \cdot 62m + 3 = 6.1m$$

Two additional transverse bulkheads must be placed on either side of the machinery room, and the afterpeak bulkhead is located aft of the machinery room. In terms of height of the watertight bulkheads, they are in general to extend from the keel of the ship to the freeboard deck.

BOTTOM STRUCTURES

Because our ship is a passenger vessel, a double bottom must be fitted extending from the collision bulkhead to the afterpeak bulkhead. The height of the inner bottom must be sufficient to give good access to all parts of the double bottom.

According to DNV Rules for Classification of Ships, the minimum bottom plating thicknesses of various structural sections of the hull can be determined from the following equations:

Keel Plate and garboard strake:

$$t = 7 + 0.05 \cdot L + t_k\ (mm)$$

Bottom and bilge plating:

$$t = 5 + 0.04 \cdot L + t_k\ (mm)$$

Inner bottom plating:

$$t = 5 + 0.03 \cdot L + t_k\ (mm)$$

Floors and longitudinal girders – center:

$$t = 6 + 0.04 \cdot L + t_k\ (mm)$$

Floors and longitudinal girders – other:

$$t = 6 + 0.02 \cdot L + t_k\ (mm)$$

Transverse Frames:

$$t = 4.5 + 0.015 \cdot L + t_k\ (mm)$$

Bottom longitudinals:

$$t = 4.5 + 0.015 \cdot L + t_k\ (mm)$$

where,

L = length of the ship

t_k = thickness added for corrosion, assumed to be 1.5mm in all areas

A table with the calculated bottom plating thicknesses is on the following page.

Bottom Plating thickness			
	t (mm)	tk (mm)	t total (mm)
Keel Plate and garboard strake	10.08	1.5	11.58
Bottom and bilge plating	7.46	1.5	8.96
Inner bottom plating	6.85	1.5	8.35
Floors and longitudinal girders – center	8.46	1.5	9.96
Floors and longitudinal girders – other	7.23	1.5	8.73
Transverse Frames	5.42	1.5	6.92
Bottom longitudinals	5.42	1.5	6.92

Table 27: Bottom plating thicknesses of various structural members

SIDE STRUCTURES

The side plating thicknesses may be determined using equations similar to the bottom plating thicknesses:

Side Plating, general:

$$t = 5 + 0.04 \cdot L + t_k \ (mm)$$

Side Longitudinals:

$$t = 4.5 + 0.015 \cdot L + t_k \ (mm)$$

Girders:

$$t = 5 + 0.02 \cdot L + t_k \ (mm)$$

A table with the calculated side plating thicknesses is shown below:

Side Plating thickness			
	t (mm)	tk (mm)	t total (mm)
Side Plating, general	7.46	1.5	8.96
Side Longitudinals	4.59	1.5	6.09
Girders	6.23	1.5	7.73

Table 28: Side plating thicknesses of various structural members

HELICOPTER LANDING AREA PLATING

According to Lloyd's Rules and Regulations for the Classification of Ships, the plate thickness for aluminum decks is to be not less than:

$$t = 1.4t_1 + 1.5 \ (mm)$$

where,

t_1= mild steel thickness as determined from the following equation:

$$t_1 = \frac{\alpha s}{1000\sqrt{k}} \ (mm)$$

where,

α = thickness coefficient

s = stiffener spacing = 1000 mm

k = material factor = 1.47 for mild steel

$$t_1 = \log_{10}(\frac{P_1 k^2}{s^2} \ x \ 10^7)$$

The plating is to be designed for the emergency landing case:

$$P_1 = 2.5 f \gamma P_w \ (tonnes)$$

where,

f = 1.15 for landing decks over manned spaces

P_w = the maximum all-up weight of the helicopter, in tonnes = 1.134

γ = location factor = 0.6

$$P_1 = 2.5 \cdot 1.15 \cdot 0.6 \cdot 1.134 \ (tonnes)$$

$$P_1 = 1.956 \ tonnes$$

$$t = \log_{10}\left(\frac{1.956 \cdot 1.47^2}{1000^2} \ x \ 10^7\right) \cdot 1.4 + 1.5$$

$$t = 3.78 \ mm$$

HULL CROSS SECTION

Figure 6 below shows the transverse cross section of our hull at station 5, with labels:

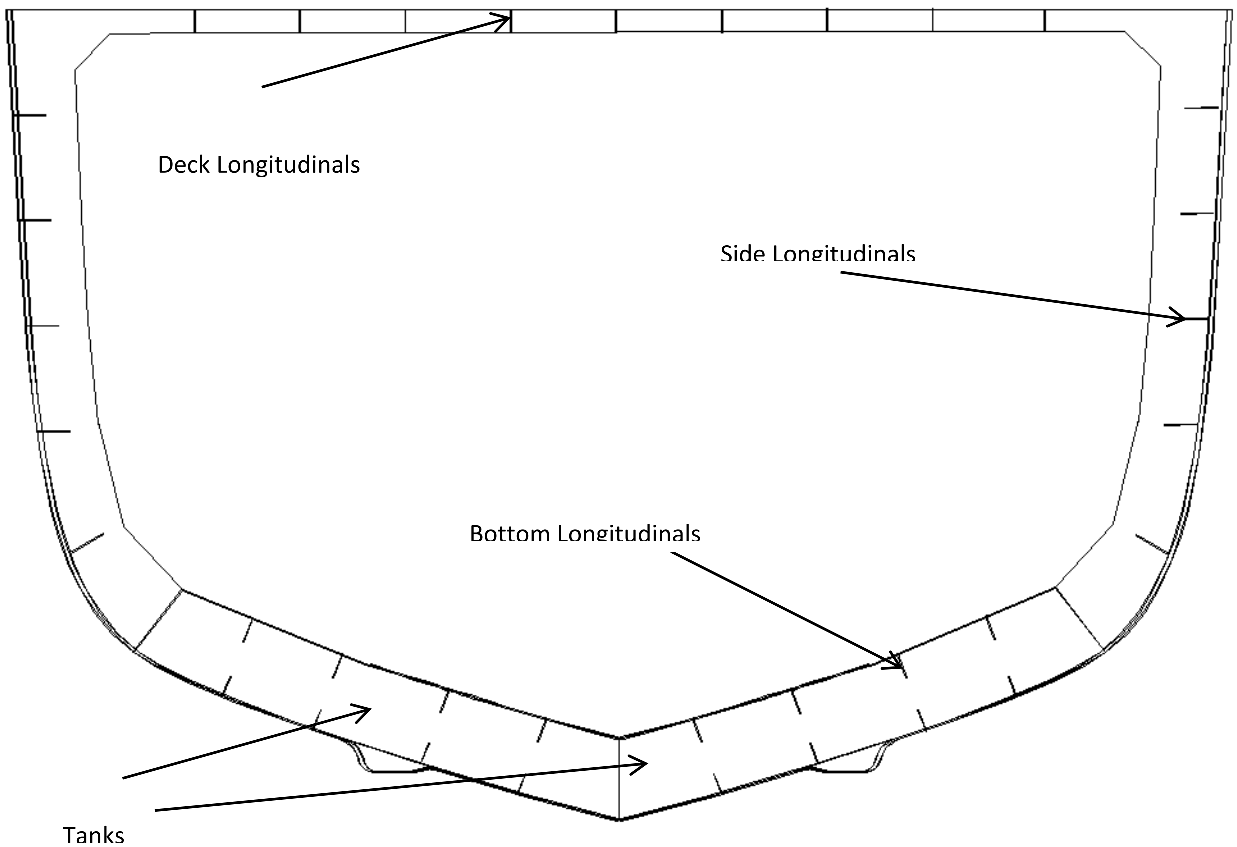


Figure 6: Transverse cross section of the hull

GENERAL ARRANGEMENT

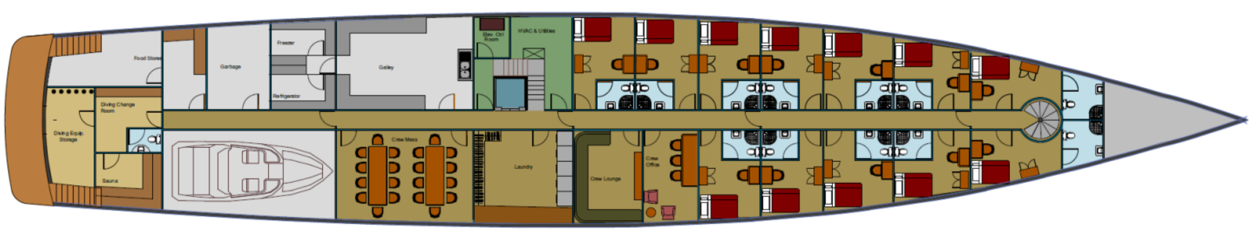
In order to account for the possibility of design changes during the design phase of this vessel potentially after years of service, the *Ice Princess* has been designed in a manner to allow for features to be changed without drastically impacted surrounding areas. A commonality found on all decks of this vessel is the vertical trunk as marked in green on the port side of the below drawings. This space will proceed to house the inlet air, exhaust, and HVAC systems extending through each deck until final ventilation through the overhead support.

An elevator has also been included for on the vessel primarily for crew use, but will serve as handicap access to physically disabled passengers as well. The staircase surrounding the elevator shaft will primarily be used by the crew, however it will also act as an emergency escape for passengers to reach the life rafts located on the A class deck. For aesthetic purposes, the life raft canisters have been incorporated into the seating located on this deck. Through the use of the elevator, food and hotel supplies can be delivered to passengers in a more efficient and safe manner than through the use of the stairs. The additional vertical space for the cradle and pulley system has been accounted for in this design, while the elevator control room can be found on the Crew Deck.

Washrooms for crew and passengers have been located adjacent to surrounding rooms to allow for easy construction and reduced piping cost. Additionally, passenger washrooms have been located in a similar vertical trunk to achieve the same benefits.

Larger images of all decks can be found in the *General Arrangement* section of the Appendix.

CREW DECK



ACCOMMODATION

Due to the demanding and remote operating conditions of the *Ice Princess,* crew comfort was considered to be of great importance when designing this vessel. Crew berths are able to comfortably house one or two crew members with a "hideable" top bunk. Each room also contains an individual head complete with a sink and shower, desk, and wardrobe closet. The Captain and First-Mate rooms can be found on the topmost deck with direct access to the bridge.

LIVING SPACES

The crew mess and lounge can comfortably seat 20 crew members at once, and will be complete with household furnishings such as televisions, lounge seating, and bookshelves, with additional room to appease additional owner requirements. The crew office allows off duty crew to access the internet and remain in contact with family and friends.

SERVICE SPACES

As the demands on the service staff for this vessel will be large due to the 20 passenger capacity, the GA's reflect an ideal flow to allow services to be stocked, prepared, and delivered in the most efficient means possible. As mentioned in the economic analysis, the *Ice Princess* will be in port for a limited 3 day period, requiring an extremely efficient procedure for removing waste and resupplying stocks. To promote this, a passage exists from the stern loading area directly to the waste, food, and hotel storage areas.

The galley has been placed within close proximity to the food stores in addition to direct access to the refrigerator and freezer. Prepared food can then be distributed to the crew in the crew mess located just across the centre hallway, or to the passengers through the use of the elevator.

With a similar consideration to that of food distribution, the close proximity of the laundry room to the elevator allows for the distribution of linens to the passengers to be as efficient as possible. Additionally, the forward spiral staircase allows for service crew to access passenger rooms in a discrete manner to avoid crew-passenger interaction. This staircase also provides access to the machinery room located on the deck below. The machinery space will be further discussed in a later section.

DIVING AREA & SAUNA

As one of the primary objectives for this vessel is to promote eco-tourism, scuba diving capabilities have been established as a requirement for this vessel. While operating in the Arctic Ocean and Hudson's Bay area, the water temperature will make wet suits a requirement for passengers wanting to go on an underwater adventure. A large storage space has been provided to accommodate the increased equipment requirements, in addition to a change room and day head. There is direct access to the loading platform from this space, allowing minimal equipment handling and quick access to the water. The sauna will provide additional comfort and relaxation for guests looking to warm up from a cool swim or dive. The location of the sauna directly adjacent to a bulkhead allows for SOLAS Chapter II-2 Part B compliance, as saunas require A-15 class boundaries for high risk accommodation spaces.

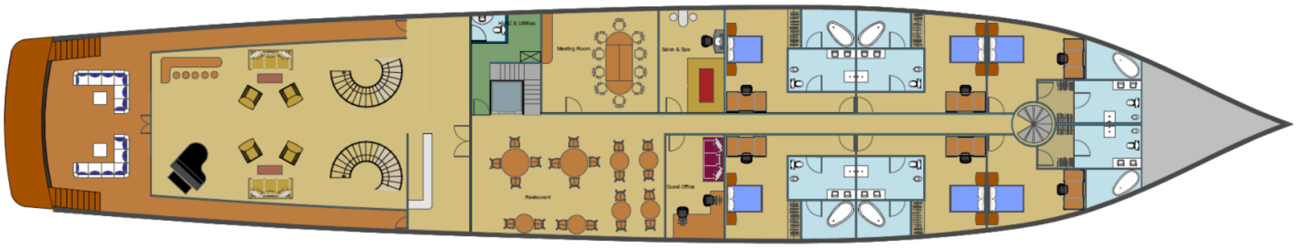
SIDE LAUNCH

A side launch area has been included in the design to provide the passengers a smaller vessel for day trips into small ports or tours of areas inaccessible by the *Ice Princess.* The side launch area has been designed to accommodate a 7m skiff, however space can be used to house a submersible, Jet skis, or any water equipment the owner requires. In order to ensure maximum damage stability and safety, this compartment will have watertight bulkheads located on either side.

GARBAGE STORAGE

Due to the relatively short trips from port, an incinerator was deemed unnecessary aboard the *Ice Princess.* Instead, a large garbage storage room can be found on the crew deck. This room will be kept cool to slow down the decomposition of waste food items and thus minimize the smell. As an air conditioning system will already be in place on this deck, few additional resources are needed for this room besides additional thermal insulation.

B CLASS DECK



Due to the cold climate of the Arctic even in the summer, it was important to ensure maximum indoor living satisfaction for passengers, yet still provide enough exterior living space for the Caribbean charter during winter months. Top of the line acoustic and thermal insulation will be used in all passenger spaces to ensure their privacy and comfort. As seen in the above picture, this deck provides accommodation for B class passengers in addition to the primary interior dining and lounging area for all passengers. The deck of this floor provides a watertight barrier, eliminating the need for watertight bulkheads to proceed through the passenger decks. As SOLAS states a primary fire barriers must be located within 48m, the bulkhead located aft of the HVAC and utilities space will act as the primary fire barrier and extend throughout the height of the passenger and bridge decks.

B CLASS ACCOMMODATION

All B class rooms were designed to allow passengers to connect with the beautiful Arctic landscape while maintaining the comfort of a luxury yacht. Equipped with queen-sized beds, desks, and additional seating, passengers can experience the outside environment through full sized windows extending the length of their room. The bathroom includes twin sinks, a large soaker bathtub, shower, and toilet/butt washing station. As daylight will be present 18+ hours of the day during the summer months in the Arctic, all rooms will be equipped with light-eliminating blinds to ensure maximum passenger comfort.

DINING AREA

The dining area is equipped with enough seating to comfortably accommodate all 20 passengers at once. This area will operate much like a restaurant; food will be delivered from the galley by the elevator, where it will then proceed to the prep station for any last minute garnish or dish dressing. Crew will then wait on passengers to provide a dining experience equivalent to a gourmet restaurant. The prep station can be utilized in the morning as a breakfast buffet. The tables will be modular to allow for them to be moved and clear a space for additional activities such as dancing or additional lounge areas.

MAIN ATRIUM – BOTTOM FLOOR

The living space in the atrium allows for passengers to relax and mingle with other passengers on board the *Ice Princess*. A bar is located here, in addition to exterior living space for warmer days and evenings.

GUEST OFFICE

While onboard the *Ice Princess,* it is important for passengers to have a means of communication with friends, family, and work even in the most remote areas to ensure their comfort. The guest office will provide passengers with full access to the internet and telephone through the use of advanced communication systems. Additionally, this space can be used as a quiet area outside of the lounge.

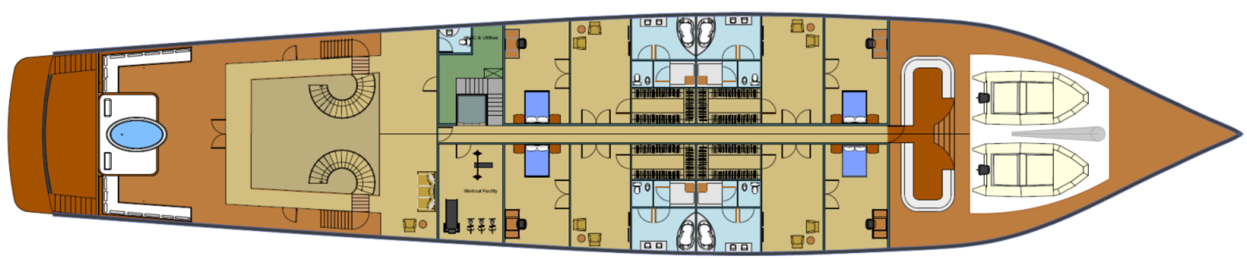
MEETING ROOM

As a means of promoting eco-tourism, the meeting room will act as a space for tour guides to meet with passengers and brief them on the daily tours taking place. Additional lectures on topics such as wildlife and geography will be conducted by experienced guides, providing an educational experience for passengers as well.

SALON & SPA

A salon and spa has also been included aboard the *Ice Princess.* Passengers will be able to relax and enjoy a massage, manicure, or haircut while out at sea in the Arctic or in the Caribbean.

A CLASS DECK



The A Class deck offers a more luxurious, private, and intimate getaway for passengers aboard the *Ice Princess.* In addition to later state rooms, A class passengers will have access to a private bow deck, equipped with exterior seating and large observation deck. The emergency response dinghy's are located under this deck, and can be accessed through two hydraulic doors concealing them and the crane required for launch. In order to accommodate the vertical space required to conceal the dinghy's, the observation deck is 1.1 metres above the A class deck.

A CLASS ACCOMMODATION

Much like the B Class, the primary focus in designing these state rooms was to ensure passengers were able to experience the tranquility and beauty of the Arctic in luxury. Within these four suites are large living rooms with a separate bedroom attached. A walk in closet can be found in the living room. Bathrooms have large Jacuzzi bathtubs and steam showers, in addition to twin sinks and private heads. The additional seating allows for A Class passengers to host guests in a secluded environment.

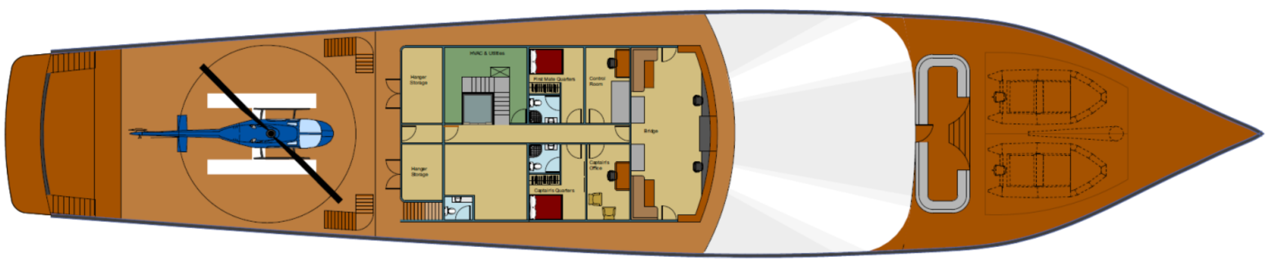
WORKOUT FACILITY

Being a charter yacht, the *Ice Princess* will need to appeal to a variety of passengers with a wide range of lifestyles. The workout facility is available for all guests to use, and allows physically active passengers the opportunity to do so in a beautiful environment.

MAIN ATRIUM – TOP FLOOR

This area provides small lounge areas and access to a day head for passengers. At the stern is exterior lounge accessible to all passengers. This area is equipped with a seating and a large hot pool capable, and allows for guests to socialize and enjoy the surrounding view. The helideck located directly overhead allows for this area to be enjoyed in all weather. Exterior stairs up to the helicopter deck are also accessible from this deck, however passengers will rarely be allowed access to these stairs during Arctic operation as a safety precaution for slipping and helicopter operation.

BRIDGE DECK



As previously mentioned, the Captain and First mate quarters will be located on this deck. This allows for quick access to the bridge in case of emergency. The helicopter pad is also located on this deck. The Civil Aviation Authority, *Standards for Offshore Helicopter Landing Areas* was followed to ensure the helicopter pad was properly accounted for in this area. The emergency generator is also located on this deck, being located a substantial distance from the water level.

CAPTAIN/FIRST MATE QUARTERS

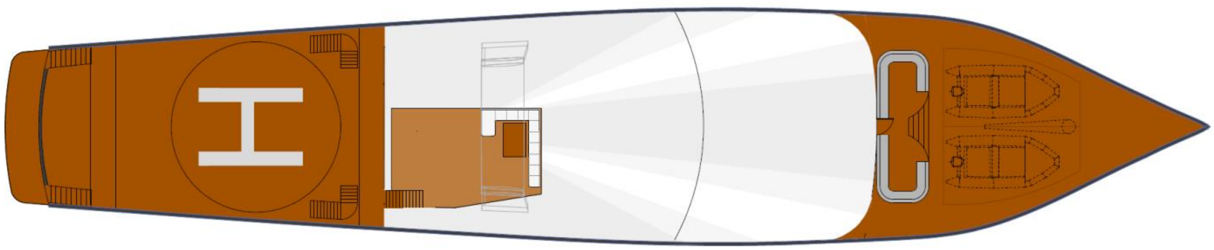
The Captain and first mate quarters are identical, while the Captain has direct access to his/her office. They each contain a queen sized bed, private ensuite washrooms, and a large closet.

HELIPAD AND HANGER

The inclusion of a helicopter aboard the *Ice Princess* was considered to be necessary as defined in the owner's requirements. The helipad as shown in the below diagram has been sized for a Robinson R44 helicopter and meets all regulations as specified by the Civil Aviation Authority, with additional space to allow for safe landing in difficult landing conditions. In order to protect the helicopter from the weather and potential water spray, an inflatable hangar designed by Lindstrand Technologies Ltd. has been deemed most suitable for this application. The durable material, insulative properties, and minimal storage space make this an ideal shelter. As this is a modular structure, storage for the deflated shelter will be in two compartments located just forward of the helipad. A connection to the primary supply of compressed air will also be located on this deck to aid in the inflation of the structure. A specification sheet as provided by the manufacturer of the hangar can be found in the Appendix.

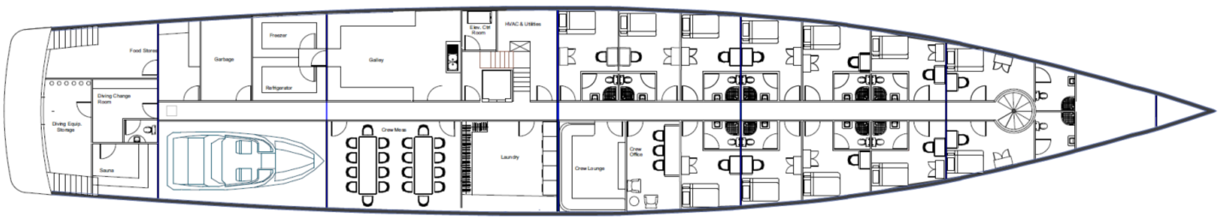
During the Caribbean charters, passengers will have the choice to keep the helicopter onboard the vessel (for an additional fee) or remove the helicopter to open up an additional exterior lounge area.

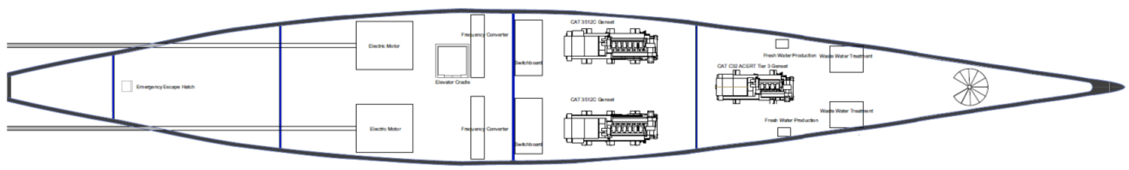
SUN DECK



The sun deck is an exterior living area for guests to relax under warmer weather conditions. The overhead will support the communication systems, while the exhaust will snake through the port side and out the centre. The air intake is located on the exterior of the overheads port side to ensure passengers in this area will not be exposed to potentially loud noises. The intake will be covered by a protective screen to ensure rain and possible spray does not enter the system. It can be noted that both the intake air and exhaust will have extended through the vertical trunk protruding throughout each deck of the vessel.

MACHINERY ROOM & WATERTIGHT BULKHEADS





By incorporating an integrated electric plant into the *Ice Princess*, flexibility regarding the machinery layout was utilized to ensure an optimum layout was used to allow for easy access to all equipment. Additionally, this flexibility proved useful when working with the relatively small floor space found on the machinery deck. Watertight bulkheads are marked in blue lines as shown below, and are equipped with sliding watertight doors in case of flooding. The primary access into the machinery room will be by the spiral staircase located at the bow, however a secondary emergency escape ladder at hatch is also located in the stern. All the equipment seen below has been properly scaled to display their actual space requirements. Preliminary sizing of fresh water and waste water systems has been conducted to further complete the machinery room space.

FRESH WATER PRODUCTION

In order to comfortably provide fresh water for 26 crew members and 20 passengers, an average daily consumption of 225L per person onboard the *Ice Princess* was used, leading to an overall daily consumption of 10,350L. In order to meet this demand, two desalination systems capable of producing 11,340L/day have been chosen. Through conducting preliminary research, a cost analysis has been conducted for the ECHO Tec Desalination systems and can be found in the Appendix. Installing two systems will provide redundancy should one happen to go out of service, a valuable characteristic supported by the remote Arctic travel within this vessels mission profile. The fresh water tank is capable of storing 25,000 L of water, which will provide additional safety precautions.

WASTE WATER TREATMENT

In similar fashion to the fresh water demand, the waste water produced by the passengers and crew was assumed to be 225L each per day with a total of 10,350L. Once again, redundancy was practiced to ensure passenger and crew comfort in the event of a failure. Two ACO Maripur systems have been chosen, and a preliminary specification sheet can be found the Appendix. This system is more essential for operation in the Caribbean, as treatment is required before any water is released into the ocean. However, during Arctic operation treated water cannot be released and must be stored on board the vessel, or pure sewage (black water) may be directly released into the ocean as stated in the Arctic Waters Pollution Prevention Act (AWPPA). The total black and grey water storage capabilities of this vessel are 30,000L and 10,000L, respectively.

TANK ARRANGEMENT

The tank volumes were obtained by balancing, space, COG location and vessel requirements. The relative tank volumes were solved for by using requirements from the passenger, crew and vessel. Preliminary sizing estimates were done on the major machinery systems including sewage, fresh water production, grey water, fuel and fuel oil. NX was then used to balance the COG location of the vessel with the available space.

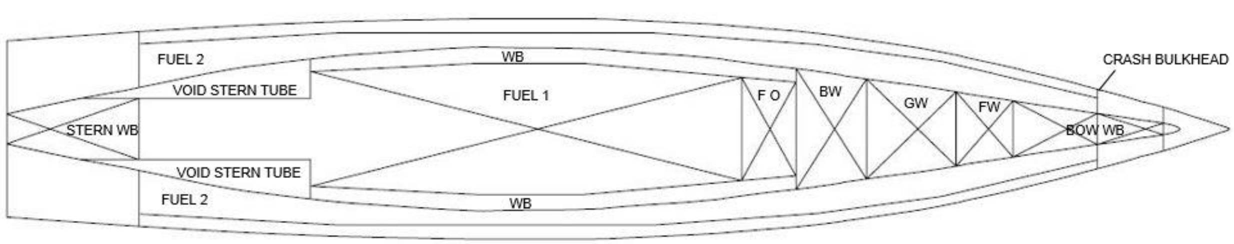
Below is a summary table of the Tank configuration volume results:

Tanks	**Volume m^3**
Bow Ballast	4
Fresh Water	25
Grey Water	30
Black Water	10
Fuel Oil	7.1
Ballast	45
Fuel 1	130
Fuel 2	150
Stern Ballast	4

The arrangement of the tanks was done in accordance with the machinery space and classification rules. Tanks are all placed behind the crash bulkhead and Fuel tanks were all double bottom where necessary, separated from the fresh water tanks. The black, grey and fresh water tanks were all placed near the bow as the main water making machinery is also located there.

There is three water ballast tanks for the vessel. The ballast tanks were as far from the COG as possible to increase their effect on draft and trim control. $4m^3$ tanks were placed at the bow and stern to effectively control trim and another ballast tank was placed in between the double bottom of Fuel Tank 1. This was the lowest point on the vessel which helps lower the CG.

Fuel had the largest tank requirement which resulted in Fuel tanks being arranged below the machinery deck, and also on top of the machinery deck along the side of the hull and beside the machinery space. The tanks are represented as Fuel 1 being below the machinery deck and Fuel 2 being the double bottom tanks on the machinery deck. Below is a picture of the Tank arrangement:



STABILITY

This section will cover intact stability, damage stability and seakeeping analyses performed. The results were used to determine whether the ship met SOLAS requirements.

INTACT STABILITY

The intact stability of this boat was determined under 5 loading scenarios which are summarized in Table 29. Each condition takes into account a full load of passengers and varying levels of fuel in the tanks.

Tank	25% Fuel	75%Fuel	Worst Case	Lightship	Full Tanks
Keel Ballast	50	25	0	0	100
Bow Ballast	50	25	0	0	100
Double Hull Ballast tank	50	25	0	0	100
Heli Fuel	25	75	50	0	100
Lube Oil tank	25	75	50	0	100
Fuel Oil	25	75	50	0	100
Greywater	75	75	50	0	100
Hottub	100	100	50	0	100
Stern Ballast	50	25	0	0	100

Table 29: Intact Stability Results

From the loading conditions, a series of GZ curves were produced using Paramarine. The software inclines the boat and then calculates the water plane and immersed volume for the heel and loading condition. Paramarine was also used to account for the free surface effect of tanks. From the plot of the GZ curves located in Figure 7, it is can be seen that the hull form conforms with SOLAS requirements for general stability of ships.

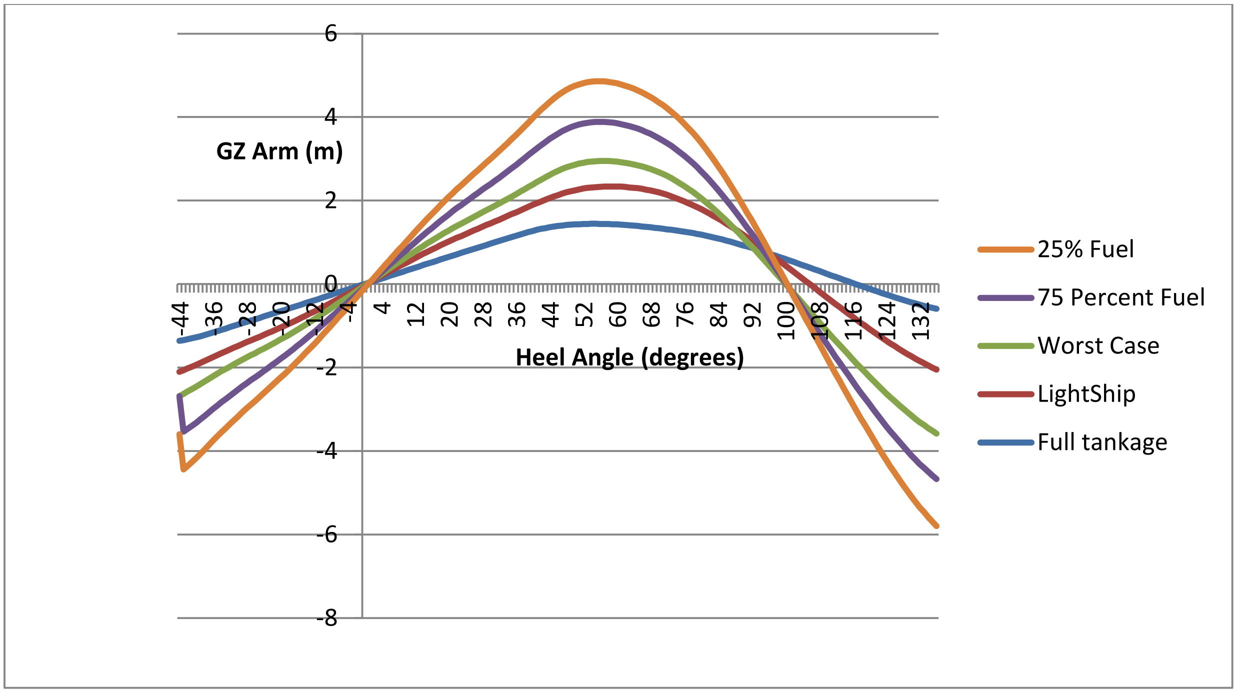


Figure 7: Stability Curves for Various Loading Cases

DAMAGE STABILITY

The damage stability analysis of this ship was used to place the bulkheads such that this vessel would comply with the two compartment regulation of SOLAS. A plot of the floodable lengths is located in Figure 8. The worst case loading condition was used for this study as to produce the most conservative design possible.

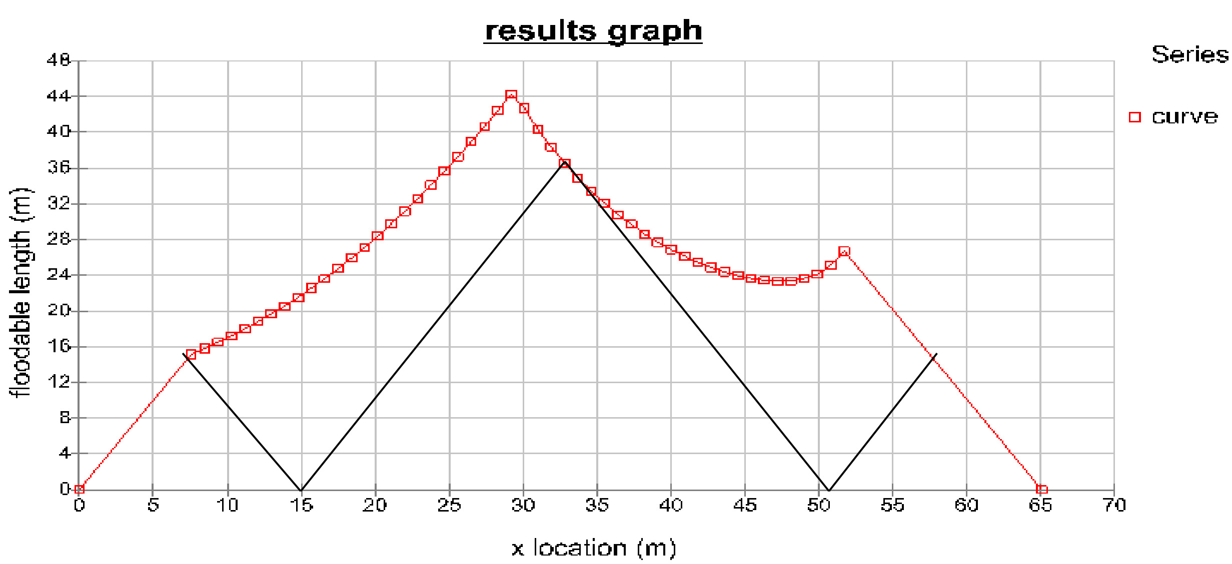


Figure 8: Floodable Lengths

SEAKEEPING

This section will cover the evaluation of the sea keeping performance of the vessel. It should be noted that this performance criteria was not of major concern when developing the hull shape as over loading/ overcrowding was not considered an issue and the fact that the sea state in the arctic archipelago is considered fairly benign relative to open seas.

The seakeeping analysis was performed in Paramarine with assuming a JONSWAP wave spectrum with 6 different significant wave heights: 1.25m, 2.5m, 3.5m, 4.5m, 6m and 9m wave heights each with a wave period of 12.5 seconds.

The main goal was to ensure passenger comfort in transit during heavy weather scenarios as to assess the potential need for stabilization. It was determined that with vertical accelerations exceeding 0.2 m/s^2 cause discomfort that would be out of place on a cruise ship. The operational plots below show the worst case of all sea states at a variety of speeds and headings. The vertical acceleration was determined at amidships at full beam was examined because it was assumed that the worst motions will occur there as it is the point most affected by roll motions.

Figure 9 shows an operability plot for fast transit (15 knts)

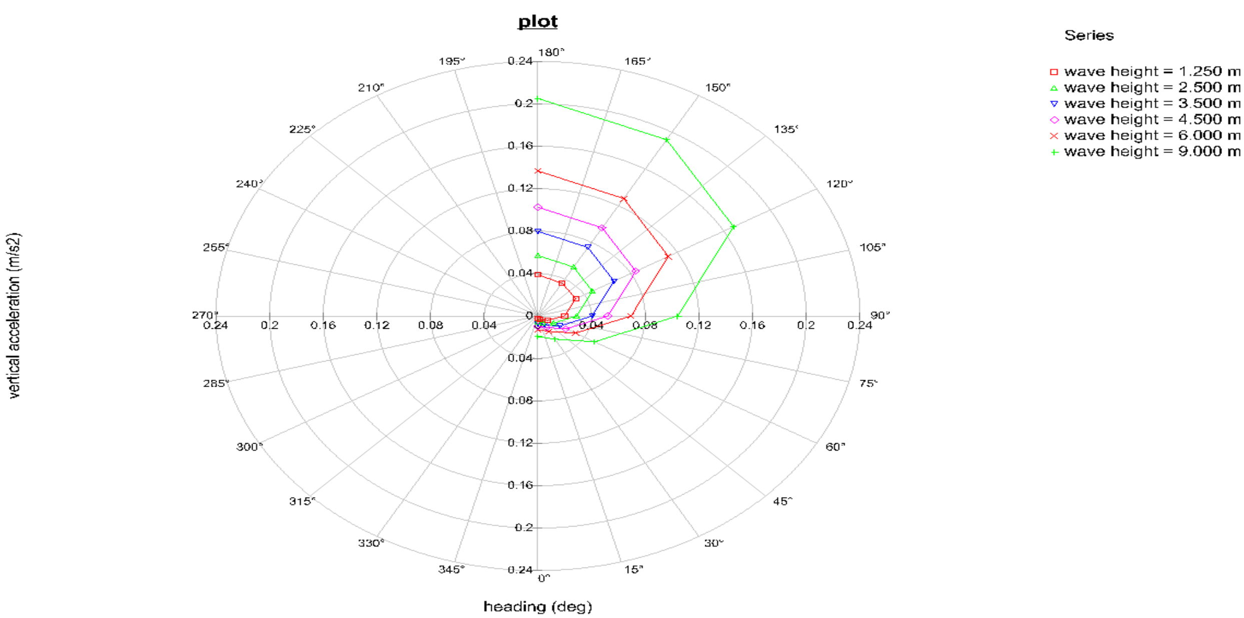


Figure 9: Operability plot at 15 knts

From this plot, it is obvious that the favourable stability characteristics of this hull form lead to a comfortable ride for all passengers in the vast majority of sea state conditions. It is easy to see that vertical acceleration only exceeds the 0.2 m/s^2 threshold in following seas at a wave height of 9m.

A plot for the RAO at max wave height was used to determine the natural frequency for roll. The natural frequency can be observed at 0.16 Hz since this is where the maximum value of the RAO occurs.

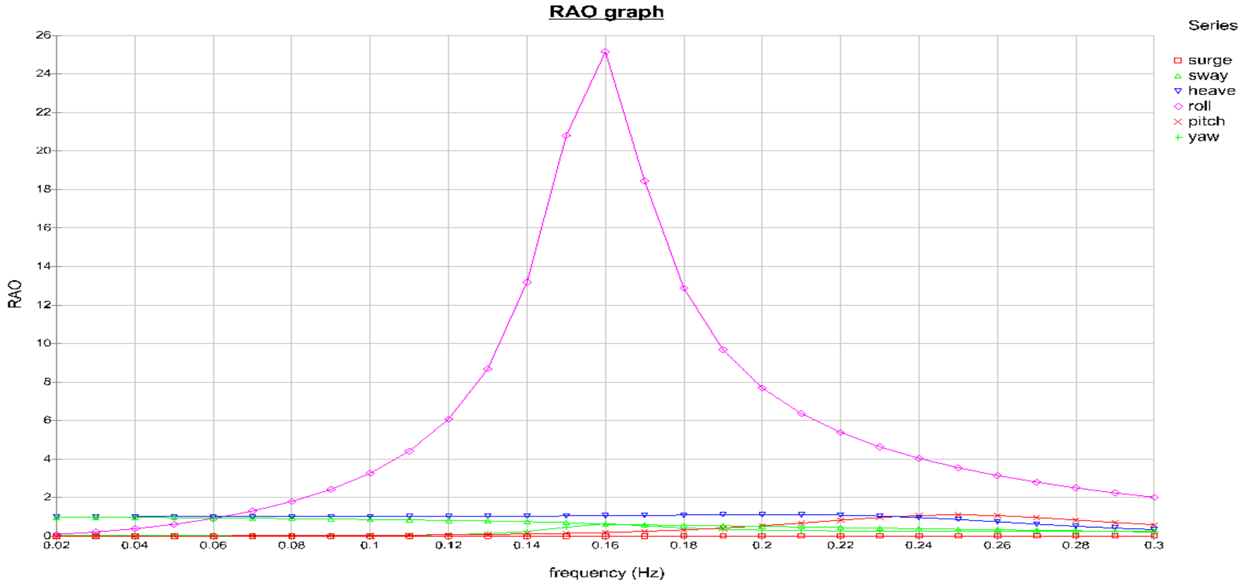


Figure 10: RAO Simulation Results

ECONOMIC ANALYSIS

This section will cover the economic analysis of the boat. A revenue estimation, operating cost estimation, a build cost estimation and a payback period estimation are provided.

REVENUE ESTIMATION

To estimate the revenue for the vessel, two prices were assumed for each class and that determined the passenger revenue for a typical operating year. Table xx summarizes the revenue estimation of the vessel.

	Per Passenger Per trip	# of Passengers	Trips	Total Revenue
A Class	25000	8	15	3,000,000.00
B Class	35000	12	15	6,300,000.00
			Total Revenue	9,300,000.00

Table 30: Revenue Estimation summary

OPERATING COST ESTIMATION

The components of the operation cost were estimated based on per capita usage or rule of thumb for cost estimation for the various components. The crew cost was done by assuming a certain crew make up then using an average salary to determine pay. Those cost estimations are summarized in the table below. A detailed crew cost is located in the appendix.

	Cost Per Year	Method of determination
Approx. Cost Crew	$1,247,400.00	Salary breakdown
Average Fuel	$3,482,837.51	Fuel consumption estimation
Food Stores	$131,785.71	Per capita food consumption
Maintence	$830,926.89	Rule of thumb
Helicopter and Boats	$184,782.00	Cost estimation based on available information
Total Operating Expenses	$5,877,732.12	

Table 31: Operating cost estimation

CONSTRUCTION COST ESTIMATES

This section will cover the estimation of the construction cost estimate for the vessel. This was done by breaking down the components of the ship by system category (i.e. hull, propulsion, electrical etc.) and then using a dollar per tonne estimate to arrive a a material cost. There are also man hours per tonne correlation for each category as well to help estimate the labour required to build the ship. All the correlation data was provided by Tom Lamb. The estimate is summarized in tables xx and xx.

Labour Rate ($/Hour)	**100**	**Margin Rate**	**10%**		
Overhead Rate	100%	**Profit Rate**	5%		
System Number	**Weight**	**Rate (Man hrs/ton)**	**Man Hours**	**Material Rate ($/Man hour)**	**Material**
100	462.600	120	55512	875	$404775
200	63.303	130	8229.39	16000	$1012848
300	27.240	250	6810	25000	$681000
400	35.200	650	22880	40000	$1408000
500	82.350	210	17293.5	11000	$905850
600	271.485	250	67871.33	6000	$1628911.9
800	N/A	N/A	44649.055		
900	N/A	N/A	89298.11		

Table 32: Group weight breakdown

Sub Total Materials Cost	**$6,041,384.92**
Sub Total Labour Hours	312,543.39
Sub Total Labour Dollars	$31,254,338.50
Overhead	$31,254,338.50
Total Cost	$68,550,061.92
Margin	$6,855,006.19
Profit	$3,427,503.10
BID PRICE	$78,832,571.21

Table 33: Bid price summary

PAYBACK PERIOD ESTIMATION

The last section of the economic analysis consists of a payback period estimation on the capital expenditure cost of the vessel. To arrive at this number, the yearly profit (revenue less operating costs) was divided into the construction cost. Using this method, a payback period of 23.04 years was determined.

CONCLUSION AND RECOMMENDATIONS

In the conceptual design of this vessel, creative solutions to unique owner requirements were produced. Beginning with preliminary weight estimates, academic literature was used to determine ideal hull characteristics for vessels with similar operating regimes. Meeting these criteria, the NPL hull series was then determined to be an ideal starting point from which resistance for the hull was determined. Propulsion and prime mover selection was then completed to obtain primary machinery requirements and sizes. Meanwhile, general arrangements were produced to outline the liveable space aboard the *Ice Princess.* Rudder and structural design used best estimates and class rules and regulations to provide detailed approximations of the vessels controllability and structural integrity. Models were then produced to be used in advanced stability software to provide intact and damage stability results for the designed vessel. Auxiliary systems and cost estimates were then determined based on existing vessels.

As only one iteration of the design spiral was completed for this conceptual design, the following is a summary of recommendations for further detailed design:

- Due to the large degree of curvature associated with the NPL hull form, it should be adjusted to better reflect constructability demands.
- The bow should possess a fuller form to increase usable floor space on the below decks.
- Auxiliary systems such as electrical, HVAC, compressed air, and water piping will need to be developed.
- A continuous reiteration of the weight estimates should be carried out as design changes occur to ensure accurate approximation of stability characteristics is maintained.
- A detailed structural design and model is to be completed to ensure adequate structural strength is achieved for this unique vessel.

As the competition for charter vessels in tropical areas becomes greater each year, charter companies are looking to provide passengers with a unique experience to distinguish their vessel from the rest. The *Ice Princess* looks to open up the beauty and remoteness of the Arctic, appealing to clients in search of adventure while maintaining the sense of luxury and security found aboard large charter yachts.

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