

LABRADOR STRAITS ICE CAPABLE FERRY CONCEPTS

ENGR 7052 – Final Report
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Executive Summary

This project consists of a preliminary design concept for a replacement vessel for the ferry service across the Strait of Belle Isle, between St. Barbe, Newfoundland and Blanc Sablon, Quebec. This service is of great importance, linking the island portion of Newfoundland and Labrador with southern Labrador. The proposed vessel will be capable of year-round service between the island and the mainland. Due to the ice conditions in the Strait during the winter and early spring, the service is currently seasonal, operating from approximately May to mid-January. A vessel with higher ice capability than the current vessel, the MV Apollo, is imperative to ensuring year-round service.

A background study yielded several reasons contributing to the need for a new vessel. First, the MV Apollo is not of an optimum design for her current route and on occasion experiences operational difficulties, including docking in high winds. Furthermore, the MV Apollo is reaching the end of her operational life, and is expected to soon become a financial burden on the province. In addition, increased traffic to southern Labrador is forecasted due to the construction of a highway in Southern Labrador. The region has invested interest in increasing the amount of tourism it attracts, which will require pleasant, reliable, year-round ferry services.

To support this goal of a year round ferry service, the Labrador Straits Development Corporation is currently planning a project to investigate the ice conditions that occur at St. Barbe and Blanc Sablon. This data will support the development of ice class ferries and other passive and active means to prevent the development and buildup of ice in the harbour. This project is still in its developmental stages and is pending government financial backing. Without this information, it is difficult to optimize a single design for this location.

The creation of a mission profile and determination of vessel requirements for the new ferry were completed in consultation with Bruce Moores, the Economic Development Officer of the Labrador Straits Development Corporation. Mr. Moores outlined the basic needs of the vessel, including crossing time, turnaround time, docking facilities, car and passenger capacities, passenger and crew amenities, and a variety of other operational concerns.

In order to fulfill the mission profile with the lack of ice data, three hull form – propulsion options have been considered. Each of these options was developed with an emphasis on the different vessel characteristics. As the time available for this project was limited, the focus is on concept design. As a result, developing suitable hull forms and propulsion options is the primary concern.

The required ice class for the ferry has been determined by studying historical ice data collected from Canadian Ice Services for the East Coast of Canada. The Arctic Ice Regime Shipping System Standards (AIRSS) was developed by Transport Canada to allow captains to evaluate the risk imposed by different ice regimes. The AIRSS has been used to determine the ice class by investigating the ice conditions in the Strait for the

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years 1983-1995, as well as 2007. Using these standards, it was possible to determine the number of days in which various ice classes would have been deemed inoperable. This method revealed that a Canadian Arctic Class Type B vessel is considered unacceptable for this route. This is accurate as the Apollo is approximately equivalent to a Type B ice class. On the other end of the scale, a CAC3 vessel would allow for absolute continuous operations but is considered to be too conservative for this route and is not expected to be the most feasible option. Both Type A and CAC4 vessels were found to be suitable options for this route. Based on the ice regime which normally prevents operations of Type A vessels it is recommended that a Type A vessel with additional structural strengthening (possibly that of CAC4) be selected for the St. Barbe – Blanc Sablon year round ferry.

A parametric study was performed on two types of vessels; ferries and icebreakers. This was done as there are very few ice class ferries, making a parametric study of them difficult. Vessel information was obtained from Transport Canada's Vessel Registration Query System, Ship Design and Construction, and the American Bureau of Shipping Ship Database. Due to the limited information available from these sources, it was supplemented by internet searches of the vessels, which generally provided information such as car and passenger capacity. The ferry study focused on general particulars, vehicle capacities and passenger capacities, while the icebreaker study focused on general particulars and power requirements. The parametric studies and ice study in conjunction with capacity requirements and restrictions led to the choice of general particulars for the vessel.

An initial weight and stability estimate was performed using empirical formulae to ensure that the choice of general particulars was reasonable before further work was performed. These studies considered the steel, machinery, outfit and deadweights. It was determined that the vessel has a significant amount of weight flexibility due to the large amount of ballast required to achieve the vessel's displacement. Based on the stability check, sufficient stability is expected. However, the metacentric height is extremely large and may result in uncomfortable motions. This value has a large amount uncertainty and further stability checks will certainly need to be performed during the design process.

The machinery options and bow forms were selected for each of the vessel options, and a comparison to the MV Apollo was made. Option A focuses on seakeeping characteristics, resembling more traditional ferries. As a result, a conventional propulsion system and a high flare angle bow form was chosen. For Option B, a compromise between good seakeeping and icebreaking capabilities is desired. A similar bow form as Option A is used in combination with a stern incorporating Azipod thrusters. The introduction of Azipod's allows for a drastic improvement in maneuverability coupled with increased overall performance in ice. The focus of Option C was to optimize the icebreaking capability of the vessel. The bow selected was a spoon shape bow. This vessel will be a double-ended vessel, with two azimuth thrusters located at each end. This will give extremely high maneuverability in all ice conditions and allow for hydrodynamic clearing of ice from the ferry channel and away from the wharf, minimizing the need for routine channel maintenance in the harbours with Coast Guard ice breakers.

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Introduction

This report outlines the concept design of an ice class ferry for the Strait of Belle Isle route between St. Barbe, Newfoundland and Labrador to Blanc Sablon, Quebec. The main intent of this project is fulfill the requirements for Engineering 7052 – Ocean Systems Design. However, as this topic has great local interest, especially with respects to the Labrador Straits Development Corporation, this report is intended to serve as a starting point for an optimization study for the replacement of the current ferry service.

Background

One of the important transportation routes linking the island portion of Newfoundland and Labrador to southern Labrador is the ferry service across the Strait of Belle Isle. This route operates between St. Barbe, Newfoundland and Blanc Sablon, Quebec, as shown in Figure 1. Due to the ice conditions in the Strait during the winter and early spring, the service is currently seasonal, operating from approximately May to mid-January.



Figure 1: Map of Ferry Route

The province of Newfoundland and Labrador assumed responsibility for the Blanc-Sablon – St. Barbe route in 1997 from the federal government. The ferry dedicated to the service was the Northern Princess. This 68.6m RO-RO vessel had a capacity of 300 passengers and 55 car units, and a service speed of 13 knots. Customer satisfaction with the ferry service, however, was low. The limited car capacity was insufficient for the needs of the route, and the lack of amenities on the ferry made the voyage unpleasant for passengers.

In 2000, the M/V Apollo replaced the Northern Princess on the route. The Apollo is a much larger vessel, with a length of 100.93 metres, a capacity of 240 passengers, a higher capacity of car units, and a service speed of 17 knots. Due to the increased capacities, higher service speed, and improved passenger amenities, this vessel serves the route much better than its predecessor. However, the Apollo is old, having been built in 1970,

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and is nearing the end of its design life. As the vessel continues to age, it is expected that the vessel will become a financial burden as increased maintenance is required. Also, the increasing age of the vessel has safety implications, as components become unreliable and the hull continues to erode. The size of this vessel is also beyond the needs of this route. The Apollo was actually designed for 1200 passengers, but is certified for only 240. From an operational standpoint, the vessel has some difficulties docking in high winds, and has insufficient ice capability to be able to operate year-round.

Beyond the obvious age of the current vessel, there are several other factors which contribute to the need for a new vessel for the route. First and foremost, a year-round link between the island and mainland portions of the province is needed. This will require a vessel with a higher ice capability than the Apollo. With the completion of the new highway in Southern Labrador, increased traffic is also expected to be experienced for this route. The area also wishes to increase the amount of tourism it experiences. A reliable, enjoyable, year-round ferry service is a necessity in order to achieve this.

Project Goals

The Labrador Straits Development Corporation is currently planning a project to investigate the ice conditions that occur at St. Barbe and Blanc Sablon. This study will investigate ice and weather phenomenon to gain a better understanding of the ice conditions. This data will support the development of ice class ferries and other passive and active means to prevent the development and buildup of ice in the harbour. This project is still in a development stage and financial support is pending. Without this information, it is difficult to optimize a single design for this location.

In order to fulfill the mission profile with this lack of data, three hull form – propulsion options will be considered. Each of these options will be developed with an emphasis on different vessel characteristics.

- A. One hull form will focus more on the seakeeping characteristics and will resemble more traditional ferries. This option will still however require ice class, but will not be optimally designed for the ice environment.
- B. The second option will be a compromise between seakeeping characteristics and ice capabilities, based on the other two concepts.
- C. The third concept will focus on the extreme ice conditions that are expected to occur in the St. Barbe Harbour and in the Strait of Belle Isle. This concept will resemble typical icebreakers in hull form and propulsion options. As a result, it is expected that other factors such as seakeeping may be sacrificed to increase the service capabilities in ice.

These three options will provide the basis for future development and optimization once the ice conditions have been further developed. As the time to complete this project was limited, each design was kept to concept level design only. The focus was on developing suitable hull forms and propulsion options. No effort was placed on developing items such as engine room layouts, detailed general arrangements, life saving plans, etc. Each

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of the tasks was related to the performance of the hull form and other design elements directly related to the requirements of the vessel's ice class.

Mission Profile

To determine the vessel requirements for the new ferry, Bruce Moores, the Economic Development Officer of the Labrador Straits Development Corporation, was consulted. During a teleconference held on May 17th, 2007, Mr. Moores outlined the basic needs of the vessel.

The first and most important goal of the Labrador Straits Development Corporation is to create a year round link. Therefore, the new vessel must possess icebreaking capabilities sufficient to operate year round in the expected environment. This includes the ability to operate in slob, first year and multi-year ice. The exact ice class of the vessel is to be determined based on investigations into ice conditions in the Strait of Belle Isle.

A second concern was the frequency in which the ferry is to be run. It is desired to maintain the current schedule, with increased scheduling to be fulfilled by a second vessel. The present voyage of approximately 18 nautical miles takes 1.5 hours in fair weather; the new vessel will therefore require a service speed of approximately 14 knots to maintain this crossing time. Also, a turn around time of 2.5 hours in all expected ice free conditions is desirable in order to maintain the current schedule. A service speed of 17 knots in calm water has been selected based on estimated speed reductions in foul weather and to ensure adequate turn around time in the harbours.

The vessel structure and maneuvering capabilities must be able to accommodate the current docking facilities. At present there is a hydraulic lift docking facility at St. Barbe, and regular docking facilities at Blanc-Sablon. The vessel must be of typical roll on roll off (RO-RO) configuration and incorporate loading ramps which can be varied based on the tidal conditions in the harbours in order to facilitate efficient loading and unloading. The maneuvering capabilities of the vessel must be such that it is capable of docking in high winds, a current issue with the Apollo.

The passenger capacity is to be 300 people, with a vehicle capacity of 75 passenger cars and 8 to 10 tractor-trailers. In terms of passenger amenities, the vessel should have a galley and cafeteria services, viewing areas, and lounging areas. The vessel should also be equipped with some passenger cabins, which will mainly be utilized in the winter months, when crossings are longer in duration due to adverse weather conditions. As well as passenger amenities, the vessel must contain full amenities for the crew including accommodations, mess and lounging areas.

Ice Study

The required ice class for the ferry has been determined by studying historical ice data collected for the East Coast of Canada. The Arctic Ice Regime Shipping System Standards (AIRSS) have been developed by Transport Canada to allow captains to evaluate the risk imposed by different ice regimes. The AIRSS works by calculating an ice numeral associated with the ice class. The ice numeral is then used to determine if

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operations are safe. The ice numeral depends on both the ice regime in the area and the ice class of the vessel.

The AIRSS has been used to determine the ice class by investigating the ice conditions in the Strait for the years 1983-1995, as well as 2007. The previous year (2007) has been added to the list to give the reader a sense of the relative ice conditions based on the problems experienced by the fishing fleet and Coast Guard vessels this past winter. To analyze the ice conditions, ice maps for the appropriate years have been collected from Canadian Ice Services. On average, ice maps during this period were collected every 2 to 4 days decreasing to weekly in the later years. From these ice charts, the worst ice regime between St. Barbe and Blanc Sablon was recorded. This included the fractional ice concentrations, ice type and floe size corresponding to each ice component making up the ice regime. From this data, it was possible to calculate the worst case ice numeral for each period corresponding to an ice map. The number of days in which the ice regime was considered “unsafe” according to the AIRSS was then counted to give the total number of days per season considered un-operational by each ice class. The following figure shows the results of this study for four candidate ice classes. See Appendix A for further explanation of the ice numeral calculation.

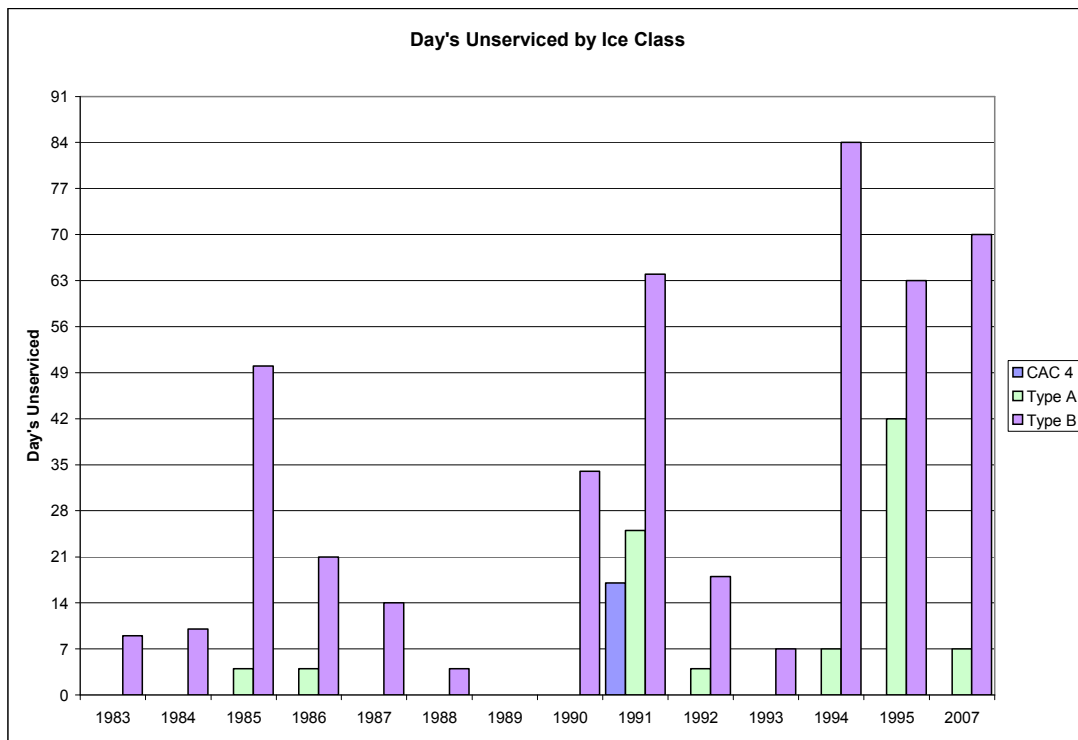


Figure 2: Number of Unserviceable Days by Various Ice Classes

As can be seen above, a Canadian Arctic Class Type B vessel (approximately equivalent to Finnish 1A ice class) is unacceptable as it allows regular periods where the vessel is unable to operate. This situation is even more detrimental as significant freezing of channels in the land fast ice may occur during periods when the vessel is unable to operate. If this happens, the vessel may be stuck at the berth until the land fast ice begins

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to break up or an icebreaker is available to clear the channel. A Type A vessel (approximately equivalent to Finnish 1A Super), allows for more consistent operation. A Type A vessel can safely handle medium first year ice and low concentrations of multiyear ice. A CAC4 vessel has very little down time. These vessels are rated to operate in high concentrations of thick first year and limited amounts of multiyear ice. Only years with very large amounts of multiyear ice stop the operation of a CAC4 vessel. The CAC3 vessel has no downtime in the ice regimes encountered in the Strait of Belle Isle. A CAC3 vessel is rated for large concentrations of second year ice and relatively high quantities of multiyear ice.

As mentioned previously, a Type B vessel is considered unacceptable for this route. Also, a CAC3 vessel would allow for absolute continuous operations, but is considered to be too conservative for this route and is not expected to be the most feasible option. Both Type A and CAC4 vessels would be suitable options for this route. An investigation into the cost differences for Type A and CAC4 vessels would indicate which vessel is optimal from an economic point of view.

The flow regime which normally prevents operations of Type A vessels is relatively high concentrations of thick first year ice accompanied by medium first year in floe sizes of approximately 100 metres. As the floe sizes are generally relatively small, a Type A vessel would be restricted not by propulsive power but by hull strength. It is therefore recommended that a Type A vessel with additional structural strengthening (possibly that of CAC4) be selected for the St. Barbe – Blanc Sablon year round ferry.

It should be noted that the strength and thickness of land fast ice is not recorded on ice maps. For this reason, this study is restricted to the floe ice which occurs outside the harbours of St. Barbe and Blanc Sablon. In general, land fast ice does not play an important role as dedicated shipping channels can be maintained throughout the season. Frequent use of these channels (such as would happen in a ferry operation), would prevent the buildup of significantly thick ice. However, as the ice conditions in the harbours may play a significant role, the ultimate design of a vessel, including the selection of ice class, should depend on the results of the ice study to be performed at St. Barbe.

Another consideration when designing an ice class ferry is to outline the operational procedure in ice. Unlike an icebreaker, the purpose of a ferry is to safely transport passengers and cargo across the Strait. As a result, the worst floe regimes should be avoided by altering course. Also, as ice conditions deteriorate and/or visibility becomes restricted, the service speed of the vessel will have to be reduced to give operators sufficient time to analyze the ice conditions and react accordingly. As a result, it is inappropriate to expect an ice class ferry to maintain a full schedule during the winter season.

Parametric Study

The parametric study was performed on two types of vessels; ferries and icebreakers. This was done as there are very few ice class ferries, making a parametric study of them difficult. The ferry study focused on general particulars, vehicle capacities and passenger

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capacities, while the icebreaker study focused on general particulars and power requirements. Appendix B is a summary of the parametric relationships used.

Ferry Parametric Study

Vessel information for the ferry parametric study was obtained from Transport Canada's Vessel Registration Query System, and the American Bureau of Shipping Ship Database. Data was collected for ferries with lengths between sixty metres and one hundred and twenty metres. Due to the limited information available from these sources, it was supplemented by internet searches of the vessels, which generally provided information such as car and passenger capacity.

From the data collected in the parametric study, four relationships between vessel particulars were graphed. These included vessel length versus length over breadth; length versus car capacity; length versus passenger capacity; and length versus breadth over depth (as only minimal draft information was available). The length versus passenger capacity chart was checked to ensure that the chosen length generally provided adequate passenger capacity to meet the required value of 300. The ferries of similar length studied generally had much higher passenger capacities than the desired value, so the length is more than adequate for the passenger requirements. The length versus breadth over depth chart was not used due to the extremely large scatter of the data. The remaining two charts were used to help determine the necessary length and breadth of the vessel. However, the length and beam were ultimately chosen to accommodate the required layout and vehicle capacities.

Car capacity is one of the main factors in determining the vessel's dimensions, so this was investigated first. Based on the parametric study charts, an initial length of 100 metres and a breadth of 21 metres were selected. The mission profile states a car capacity of 75 cars and 10 tractor trailers. Ship Design & Construction (Table 38.IV) provided average vehicle space requirements for cars and tractor trailers. Based on the specifications in Ship Design & Construction, and information from various car manufacturers, it was decided that four 3.2 metres lanes would run the centre of vessel with a single 2.6 metres lane on each side. This configuration leaves 1.5 metres per side for structure and access ways to the various levels.

The side lanes will have 'tween decks above running the entire length of the vessel. These may limit the side lanes to 2.4 metres which is still within the guidelines suggested by Ship Design and Construction. The side lanes will be high enough to allow standard pickup trucks while the 'tween decks will be limited to cars. The center lanes have been assumed to be 85 metres long, the next two lanes are assumed to be 75 metres, and the side and 'tween deck lanes are assumed to be 65 metres. This accounts for narrowing of the waterline and room to accommodate the loading ramps as well as the ramps required for 'tween deck access.

The following table shows a summary of the vehicle capacities assuming 5.25 metre long car spaces and 15.75 metre long tractor trailer spaces. Trucks towing sixty foot container units are expected to be longer than this 15.75 metre truck unit. Based on dimensions of

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longer style trucks, the actual capacity may be as low as eight which is still within the mission profile.

Table 1: Expected Average Vehicle Capacities

Number of Lanes	Length of Each Lane	Width of Lane	Type of Vehicle	Total Capacity
2	85 m	3.2 m	Tractor Trailers	10 Trucks
2	75 m	3.2 m	Tractor Trailers	10 Trucks
2	65 m	2.4 m	Pickup Trucks	26 Trucks
2	65 m	2.4 m	Cars	26 Cars

As can be seen in the table, this configuration will allow for 108 cars or 52 cars and 20 trailers or any combination in between. Assuming 10 tractor trailers, this leaves 78 spaces available for passenger vehicles, which is slightly above that stated in mission profile. This leaves flexibility in the design of loading ramps and other machinery that will affect the design of the car lanes.

After determining the vessel length and breadth, the block coefficient was calculated using empirical formulae given in Chapter 11 of Ship Design and Construction. These were calculated using an assumed Froude number of 0.3 (corresponding to a service speed of 17 knots), a reasonable value for ferries of this length. Equations 12 and 13 in Chapter 11 of Ship Design and Construction yielded a range of block coefficients of 0.535 to 0.569. A moderate value of 0.55 was selected as the block coefficient. Ship Design and Construction formulae also yielded a midships coefficient value of 0.95. Each of these values has been assumed for the initial design and may be changed in the future to reflect more accurate estimates and calculations.

The draft of the vessel was chosen to be 4.6 metres due to draft restrictions in the harbours the route services. Also, this draft corresponds to both the current and previous vessels, along with the maximum draft specified when selecting the Northern Princess replacement. This draft value, along with the block coefficient, length, and breadth, gives a volume of displacement of approximately 5313 cubic metres, and thus a displacement of 5446 tonnes. This draft (and therefore displacement) is relatively low for a vessel with this breadth and length. The hull form chosen for such a vessel will therefore have to be carefully evaluated for both stability and seakeeping characteristics.

An initial depth value was assumed to be 6.1m. This value was estimated to meet the freeboard requirements of the US Coast Guard freeboard tables, which, in turn, are based on the International Maritime Organization (IMO) requirements. This value will have to be checked later for a number of factors. First a detailed freeboard requirement calculation will need to be performed to ensure that the selected value is within the regulations. Secondly, the overhead clearance in the machinery room needs to be adequate to fit machinery such as main engines and gear boxes. Finally, the ramp mechanisms will need to be designed such that they can accommodate effective loading and offloading at all tidal conditions. Each of these factors must be given further detail to ensure that the estimated value is practical.

Icebreaker Parametric Study

Vessel information for the icebreaker parametric study was obtained from Ship Design and Construction, Volume II. This contained a list of icebreakers with a variety of reported parameters. The icebreaker lengths ranged from 42.7m to 140.6 m between perpendiculars. This study was used to determine the installed power requirements of the vessel.

From the data collected in the icebreaker parametric study, three relationships between vessel particulars were graphed. These included Froude number versus block coefficient, Froude number versus length to displacement ratio, and Froude number versus Admiralty coefficient. The Froude Number and Admiralty Coefficient are defined below

Froude Number

$$F_n = \frac{V}{\sqrt{g * LBP}} \quad \text{Equation 1}$$

Admiralty Coefficient

$$C = \frac{V^3 * \Delta^{2/3}}{BHP} \quad \text{Equation 2}$$

The Froude number versus block coefficient was used to ensure that a service speed of 17 knots with hull forms typical of ice breaking ships could be realistically achieved. For block coefficients around 0.55, Froude numbers of 0.27 to 0.30 were recorded. A service speed of 17 knots with the selected length of 100 metres yields a Froude number of 0.28 which is well within the range for other typical icebreakers.

The plot for Froude number versus Admiralty coefficient has little correlation. This is not a surprise as icebreakers are often over powered. The power requirement for an icebreaker is also determined based on the ice class of the vessel. As the list of icebreakers likely has a spread in the ice classes, a spread in the Admiralty coefficient is also expected. The range of Admiralty coefficients at the desired Froude numbers yields a power range of 7500 kW to 15000 kW. As this vessel is intended to be an ice going ship and therefore not expected to be breaking large amounts of ice or ridges, the lower power value of 7500 kW has been selected. The actual power requirement will have to be based on the selected ice class rules as well as powering predictions.

Principal Particulars

In summary, the parametric studies and ice study have led to the selection of the particulars for the vessel presented in Table 2. The selected particulars have been compared to the Apollo wherever possible.

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Table 2: Vessel General Particulars

	Design Vessel	Apollo
Length [m]	100	100.93
Breadth [m]	21	17.2
Draft [m]	4.6	4.6
Depth [m]	6.1	11
Displacement [tonnes]	5446	N/A
Block Coefficient	0.55	N/A
Midships Coefficient	0.95	N/A
Service Speed [knots]	17	17
Installed Power [kW]	7500	6660
Car Capacity	108	N/A
Ice Class	Type A with additional hull strengthening	Finnish Class 1A (approx. Type B)

As can be seen in Table 2, the two vessels are roughly the same size. The design vessel is wider and shallower than the Apollo. However, the depth of the Apollo stated in Table 2 is likely to the weather deck, whereas the draft for the designed vessel is to the freeboard deck. This is a significant distinction and renders any comparison of the two values meaningless. It should be noted that displacement and coefficients of form are currently not available for the Apollo, so they cannot be compared at this time. The two vessels have the same open water service speed of 17 knots, indicating the new vessel will be able to maintain the schedule currently in place. The largest differences between the two vessels involve the installed power and ice class. The installed power is higher on the concept vessel, which is reasonable as it is expected to operate in harsher ice conditions than the Apollo. The higher ice class will also ensure much less down time due to ice conditions.

Initial Weight Estimate

An initial weight estimate of the vessel was performed using the method given in the document “Estimating Weights and Centres in Preliminary Ship Design” by Dag A. Friis. Detailed descriptions of the weight estimate calculations are located in

Appendix C. Throughout this process, the expected highest and lowest values of all empirical constants have been used. This results in a range in weight estimates. This method has been used to give an estimate of the error associated with the empirical formulae.

Net Steel Weight Estimate

Watson and Gilfillan’s Method was used to estimate the net steel weight of the vessel. These formulae use empirical constants K which are determined based on data from previous designs. As no data is given, the K values used are based on the literature with expected values for ferries, ranging from 0.024-0.037. For the purpose of weight estimation, initial estimates for the dimensions of superstructures and deckhouses have also been made. The anticipated layout of the vessel includes a vehicle deck (with ‘tween decks), a passenger deck, a crew deck and a bridge deck. The initial estimates for the superstructure are given in Table 3.

Table 3: Superstructure dimensions

	l (m)	b (m)	h (m)
Vehicle Deck	100.0	21.00	5.0
Passenger Deck	75.0	21.00	3.0
Crew Deck	40.0	15.75	3.0
Bridge Deck	10.0	15.75	3.0

Since this is an ice class vessel, the steel weight must be increased to account for the ice strengthening. The table in the document provides a value of 16% increase for an ice class of Finnish 1A Super, which is roughly equivalent to Canadian Type A classification. Due to the additional hull strengthening required for multi-year ice, increase in steel weight for ice class was assumed to range from 18% to 22%.

The centre of gravity of the hull and superstructure was roughly estimated using geometry. The vertical center of gravity, KG , of the hull structure was estimated to be roughly two thirds of the vessel depth. The superstructure KG was estimated by taking the centre of gravity of each deck as being at half that deck’s height. The overall KG for the hull and superstructure steel was then calculated using Equation 3.

$$KG = \frac{\sum KG_i * M_i}{\sum M_i} \quad \text{Equation 3}$$

Using the above methods, a range of net steel was calculated based on the expected range of K values and increases as a result of ice class. The total expected steel weight is on the order of 1700 to 2700 tonnes with an expected center of gravity of 4 metres above the keel.

Machinery Weight Estimation

Machinery weight was estimated using Schneekluth’s method for diesel engines. It is recommended that the engine weight be increased by 20% for diesel electric installations. As this is an ice class vessel, it is recommended that a diesel electric option be used to

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minimize torque loads which result from propeller ice interactions. The additional 20% has therefore been applied based on the assumption that diesel electric installations will be used. The main engine weight is therefore estimated to range from 90 to 165 tonnes.

The auxiliary and emergency powers have been estimated based on other ferry designs as 500kW and 250kW respectively. With these assumptions, Schneekluth's method yields an additional weight of 20 tonnes for auxiliary and emergency gensets.

Other weights including items such as piping, pumps, noise insulation, spare parts, etc. were estimated to have a range of weight values of 300 to 525 tonnes. Weights for gearing and shafting have been neglected, as an azimuth thruster propulsion system is anticipated. Propeller weight has not been estimated as propulsion design has not yet been completed. However, this is likely to be a significant weight, especially for designs which incorporate azimuth thrusters. The total machinery weight is therefore expected to be in the range of 410-710 tonnes. The centre of gravity of the machinery was roughly estimated to be at half the depth of the vessel.

Outfit Weight Estimation

Outfit weight was estimated using Henschke's formula for passenger vessels, as well as Transport Canada standard TP 13430 to determine gross tonnage. TP 13430 formulae yields a gross tonnage of 6945 tonnes. Converting this value to cubic metres gives 6776 m³. Henschke's formula therefore estimates a range of outfit weight values of 280 to 350 tonnes.

The centre of gravity of the outfitting weights was estimated as being the centre of gravity of the superstructure. It was calculated using Equation 3, where volume has been substituted for mass. Again, the centre of gravity of each deck was taken as half that deck's height. This formula gives a centre of gravity of the outfitting items of 11 metres.

Deadweights

The deadweight of the vessel includes items such as vehicles, passengers and their effects, fuel and lube oil, water tanks including potable water, non-potable water, and grey and black water, and stores. These have been estimated based on values obtained for similar vessels, as well as the passenger and vehicle capacities of the vessel. Fuel weights have been calculated using a time between refueling of one week with an average of three round trips per day with an additional margin of ten percent. Vehicle weights have been estimated using two different vehicle configurations: one with no transport trucks and a second with twelve. The weights of cars and pickups have been determined from various manufacturers while the weight of transport trucks has been determined based on upper limits allowable on roadways.

The centres of gravity for the various deadweights were estimated based on their anticipated locations. For example, the vertical center of gravities, *KG*, of the passenger weights was assumed to be 0.5m above the passenger deck level. The stores were estimated to have a *KG* at half the height of the passenger deck. All tanks were assumed to have a *KG* at half the depth. As some will be double bottom tanks and some will be wing tanks, the *KG* values should average out to be at roughly half the depth. The

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vehicle deck *KG* was calculated assuming that the vehicles are located at 1m above the deck, with 26 cars located on the 'tween decks or 3.5m above the vehicle deck.

Summary of Weights

The initial weight estimate for the vessel is shown in Table 4. The weights have been divided into lightweights, which are weights built into the vessel, and deadweights, which are weights that are regularly loaded and unloaded.

Table 4: Initial Weight Estimates

Initial Weight Estimate			
<i>Lightweight Estimate</i>			
Weight Category	Minimum (Tonnes)	Maximum (Tonnes)	KG (m)
Steel Weight	1700	2700	4
Machinery Weight	410	710	3
Outfit Weight	280	350	11
Total Light Weight	2390	3760	
<i>Deadweight Estimate</i>			
Weight Category	Minimum (Tonnes)	Maximum (Tonnes)	KG (m)
Vehicle Weight	350	460	7.5
Passenger Weight	40	40	12
Stores	10	20	13
Fuel/Lube Oil	40	40	3
Misc. Tanks	40	40	3
Total Deadweight	480	600	
Required Ballast	2600	1100	3

The difference between the total displacement and the sum of the lightweight and deadweight values will have to be made up using ballast, as indicated in the table. The centre of gravity of the ballast, which will be made up of both fixed ballast and temporary ballast using salt water tanks, has been taken as half the depth. The overall centre of gravity of the vessel was calculated using Equation 3. This formula gives an overall centre of gravity of the vessel ranging from 4.0 to 4.5 metres. The large margin between the calculated weights and the displacement (i.e. required ballast) will allow for flexibility in future design decisions. As better estimates are obtained, the deadweight and lightweight values are likely to increase, and the centre of gravity value will be refined.

Stability Check

An initial stability check was performed to determine if the dimensions chosen are satisfactory from a stability point of view. Before a hull form has been developed, the stability can be estimated using the general particulars of the vessels and a number of

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other parameters. The values used to estimate the initial stability have been taken from the parametric study and are outlined in Table 5.

Table 5: Inputs to initial stability check

Property	Value
Density [kg/m ³]	1025
Length [m]	100
Beam [m]	21
Draft [m]	4.6
C _m	0.95
C _b	0.55
Displacement [Tonnes]	5446
C _w	0.65
KG* [m]	4.0 to 4.5

* The *KG* was determined from the weight estimate.

The method used for the initial stability check was obtained from the Engineering 7052 courses notes written by Dag Friis and is outlined in Appendix D. This involved ensuring that the vessel has a positive metacentric height. The metacentric height is primarily a measure of the initial stability of the vessel but also has a major influence on the seakeeping characteristics. Metacentric height is calculated as the difference between the location of the metacentre and the center of gravity. The metacentre has been calculated relative to the keel of the vessel to correspond to the reference point used in the weight estimate.

To determine the location of the metacentre, *KM*, the water plane area (based on the waterplane coefficient) was required. The waterplane coefficient has been estimated using two empirical formulas given in 7052 course notes and summarized below.

$$C_w = C_b + 0.1 \quad \text{Equation 4}$$

$$C_w = C_b - 0.0023T^3 + 0.0521T^2 - 0.349T + 0.8235 \quad \text{Equation 5}$$

Equation 4 gives a value of 0.65, while Equation 5 yields a value of 0.645. Due to the similarity between the results, a waterplane coefficient of 0.65 was chosen.

Based on the initial calculations, the location of the metacentre is about 8.8 metres above the keel. Once the estimated centre of gravity of 4.0 to 4.5 metres is subtracted, a positive metacentric height of about 4.5 metres is obtained which is adequate for a preliminary stability estimate. However, this value is too high from a seakeeping point of view, as the vessel will tend to respond rapidly to induced motions, causing high accelerations. However, this can be corrected by increasing the *KG* with the use of ballast. Raising the location of the permanent ballast will raise the overall centre of gravity resulting in a more comfortable vessel for both crew and passengers.

Despite the high estimate of initial stability, it is re-emphasized that this is not reflective of the stability at large angles of heel, as this is largely determined by the shape of the hull form. The stability at high angles of heel may be drastically reduced by the imposed

draft restriction. This will have to be investigated in further detail once the hull forms have been designed.

Machinery Concept Selection

The three vessel concepts consist of a vessel focused on seakeeping, a compromised seakeeping and icebreaking vessel, and an icebreaking vessel. The focus of each concept largely influenced the machinery options and bow forms chosen for each vessel. The machinery options and bow forms selected are summarized in the list below:

- Option A – Seakeeping
 - Bow: High Frame Flare Angle form
 - Forward Propulsion: Two Bow Thrusters
 - Stern Propulsion: Twin Screw FPP, Conventional Drive
 - Power: Diesel Electric
- Option B – Compromised
 - Bow: High Frame Flare Angle form
 - Forward Propulsion: Two Bow Thrusters
 - Stern Propulsion: Two Azipods
 - Power: Diesel Electric
- Option C – Icebreaking
 - Bow: Flat/Spoon form
 - Forward Propulsion: Two Azipods
 - Stern Propulsion: Two Azipods
 - Power: Diesel Electric
- Current Vessel – Apollo
 - Bow: V-shaped open water bow
 - Forward Propulsion: Bow Thrusters
 - Stern Propulsion: Twin Screw
 - Power: Diesel Mechanical

Option A: Conventional Propulsion, Optimized for Seakeeping

The focus of Option A is a vessel with good seakeeping properties. This is desirable for passenger comfort, but the aspects which provide for good seakeeping limit the vessel's icebreaking capabilities. An icebreaker bow form was selected, the high frame flare angle form (based on Figure 40.11 in Ship Design and Construction, Volume II). Although an icebreaker bow form, the V-shaped bow contributes to good seakeeping properties.

This vessel will also have a more conventional propulsion system, similar to other ferries. A twin screw, conventionally driven system was chosen. The propulsion system will be augmented by two bow thrusters to assist in maneuvering and docking. Power will be supplied by a diesel electric system to eliminate problems associated with high torques associated with ice loading. Also, diesel electric is the most capable of accommodating the different range of speeds the vessel can be expected to operate at, especially when

operating in various ice conditions. As the propeller shaft speed can be easily modified using diesel electric systems, a fixed pitch propeller can be easily incorporated, avoiding the increased complexity of controllable pitch.

Option B: Compromised Function Vessel

The focus of Option B is to compromise good seakeeping and icebreaking capabilities. The same bow form was selected as Option A for its seakeeping characteristics. Also, this options shares the use of a diesel electric system and bow thrusters. However, the stern propulsion is provided by two azimuthing thrusters. Azimuth thrusters were first introduced on icebreakers in 1993 and have since proven to be both extremely effective and reliable. The ability to direct the wake removes the requirement for rudders and provides superior maneuverability. Vessels equipped with azimuth thrusters are capable of sideways motion in calm weather without the use of any forward propulsion. Also, it has been demonstrated in full scale trials of multiple icebreakers that while directing the wake away from the centerline of the vessel, it is possible to clear and even break a large amount of ice around the hull. This feature of azimuth thrusters allows vessels to widen channels, a feature that will be extremely helpful in keeping an ice-clear channel through the harbor at Saint Barbe as well as keeping ice from forming around the docking facilities.

Option C: Azimuth Propulsion, Optimized for Icebreaking

The focus of Option C was to optimize the icebreaking capability of the vessel. The bow selected was a spoon shape bow (Figure 40.11, SD&C Vol II). This bow has a significant advantage in icebreaking capability over the V-shaped bow of the previous two options, and has the advantage of being easy to construct due to the large percentage of single curvature panels. This vessel will be a double-ended vessel, with two azimuth thrusters located at each end. The double ended vessel will eliminate the need for turning around in the harbours, hopefully eliminating the concern of ice conditions in St. Barbe. The presence of four azimuth thrusters will allow for superb vessel maneuvering, and will allow the vessel to clear ice away from the docking facilities while in stationary position. With four thrusters, two thrusters can be used primarily to move the vessel forward, and the other two can be directed so their wake clears away ice from the vessel's path. A diesel electric system will provide power to the azimuth thrusters.

Current Vessel: The Apollo

The Apollo is fitted with a V-shaped open water bow. The design vessel, no matter which option is chosen, will be fitted with an icebreaking bow form, thus making it much more effective in ice conditions. It was also noted above that the Apollo's bow thrusters are ineffective at maneuvering in high winds. The proposed designs will avoid these issues by using various combinations of bow thrusters and azimuth thrusters to achieve the maneuverability required for the route. The stern propulsion system in the design vessel will also be an improvement over the Apollo. Stern azipods will provide the vessel with superb maneuvering abilities, and good ice clearing characteristics. They will be much more effective in ice than a convention twin screw propulsion system. Option A's

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propulsion system will also be more desirable than the current system, as it will be diesel electric. This will allow the vessel speed to be varied via the propeller rotation, and leads to a very efficient operation. A diesel electric system allows one to shut down unneeded portions of the power supply without effecting performance. This is a significant advantage as the full power of the vessel will seldom be used for open water purposes. This propulsion system will also have more power than the current system, and thus have more capability in ice.

Vessel General Arrangement

Preliminary general arrangements were completed for each of the vessel concepts considered. These general arrangements were mainly to demonstrate that all required spaces on the vessel can be provided. These drawings, numbered as 7052-A-100, 7052-B-100 and 7052-C-100, will require further development during later design stages.

The superstructure decks show a general layout of the passenger and crew spaces of the vessel. The spaces are the same for each of the vessel options, although the layout changes slightly, as Option C is a double-ended vessel. The passenger deck contains spaces such as viewing lounges, cafeteria, galley and stores, quiet lounge, children's play area, craft shop, steward's office, and public washrooms. To ensure accessibility for passengers with disabilities, elevators have been provided for access to all passenger areas, along with two two-person accessible cabins. All public washrooms should also be fully accessible. The crew deck, located above the passenger deck, has some passenger space, such as an outdoor viewing area and passenger cabins. However, this deck contains mainly crew facilities such as a laundry room, cabins, lounge, and mess. The mess is located above the galley, so that food can be supplied via the use of a dumbwaiter. The cabins have been assumed to be two person cabins featuring bunks and a washroom. Space has been provided for a minimum of fifteen crew cabins able to accommodate a total of thirty crew members. The number of crew members for accommodations purposes was based on an estimate of ten to fifteen personnel for ship operations, and approximately fifteen service personnel. The captain and chief engineer have also been provided with private cabins and dayrooms.

The machinery deck in each of the options varies significantly, due to the different propulsion systems to be used. Due to the use of a diesel electric propulsion system for all three options, they all require a machinery room and an electrical room. Options A and B also feature a bow thruster room and an emergency machinery room. The emergency machinery room is required by regulations to ensure redundancy in the event of a fire or a similar event in the main machinery space. Option C does not require an emergency machinery room since redundancy is already provided by dual machinery rooms. The machinery deck also has two azipod compartments, situated at each end of the vessel.

Preliminary Lines Plans

The initial concept design for the hull forms focuses on the general shapes required to achieve the selected general particulars, while focusing on the mission objective for each

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option. At this stage, no attempt has been made to optimize the hull form. This process should, however, be completed in later design stages. The proposed hull forms, or modifications of the proposed hull forms, will form the basis for open water resistance, ice resistance, stability, and seakeeping analysis. Although the hull forms have not been optimized, they should provide a basis for selecting which option will best suit the needs of the Labrador Straits Development Corporation.

Option A has a typical open water bow form and a conventional stern. This hull form is capable of accommodating a twin screw arrangement with propeller diameters up to about 3.5 meters (based on the propeller being located at frame 10). The 'V' shaped bow used on this hull should provide adequate open water resistance and seakeeping properties. As car capacity is a primary concern, the deck area has been made as large as possible. This may become a potential issue in regards to slamming in rough seas. If this is shown to be an issue at later design stages, the length of the vessel may have to be increased to allow for a narrowing of the deck while maintaining car capacity.

Option B has a similar bow form as the previous option and as a result shares the same advantages and concerns. However, the stern configuration has been modified to accommodate azipod units. The stern section rises sharply at the aft end and levels off to give a gradual flat portion of the hull suitable for mounting the azipods. Space has been given to allow for room inside the hull for mounting the mechanical unit. The allowable propeller diameter for this option is about 3.2 meters. However, the hull form has a large amount of flexibility based on the required overhead clearance for the azipod units.

Option C has been designed with a focus on minimizing ice resistance. Therefore, the resulting hull form contains many characteristics commonly found on icebreakers. However, because this option is intended to be a double ended vessel, the bow/stern has been configured to suit azipods. A spoon shaped bow has been chosen resulting in very low flare angles. This type of bow form has been used extensively in the past and has a reputation for providing excellent ice breaking capability. This also gives a suitable platform for mounting the azipod units. This option is also expected to be capable of mounting azipod units with diameters up to 3.2 meters. As an added benefit, this hull form includes a large number of chines, which will make the vessel construction easier and therefore less expensive.

Lines plans for each of these three vessels have been prepared and are presented as drawings numbers 7052-A-110, 7052-B-110 and 7052-C-110.

Conclusion

As a replacement vessel for the Strait of Bell Isle ferry service is required, three preliminary design concepts have been initiated to accommodate year round ferry service. Like most vessel designs, tradeoffs must be made between different design features. The two main issues while designing an ice class ferry are performance in ice, including ice resistance and maneuverability, and seakeeping. Many design decisions affect both of these characteristics in such a way that it is impossible to optimize a hull for both these situations. As a result, the focus has been placed on these decisions and their effect to the overall performance of the vessel.

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To begin the concept design, a parametric study was performed which aided in the establishment of a set of general particulars. Once these were determined, initial weight and stability estimates were completed. The former confirmed that the design vessel has substantial flexibility in terms of weight, and the latter yielded a positive metacentric height, indicating adequate stability. Both of these initial estimates verified that the selection of particulars were reasonable. Further initial design decisions such as selection of propulsion types and hull form characteristics were then decided. General arrangements and lines plans reflecting these changes were then constructed.

In the winter of 2008, the design process will continue and further design considerations will be explored. The focus will be on a comparison of the developed hull forms. This will include the following list of tasks:

- Open Water and Ice Resistance Calculations
- Propeller Selection
- Machinery Selection
- Seakeeping Analysis
- Damage Stability Assessment

An anticipated timeline for the winter semester is given in Appendix E. If time permits, the general arrangements will also be updated to reflect any decision made throughout the term.

There are a myriad of reasons for which the proposed vessels are of superior suitability to the designed service route. Foremost, these vessels are designed specifically for the St. Barbe – Blanc Sablon route. The MV Apollo began servicing this route late in its design life, and has many operational and performance shortcomings. The concept vessels are capable of year-round operation, made viable by their increased power, icebreaker hull form and higher ice class. The proposed vessels will also have the added advantage of increased maneuverability in the harbours.

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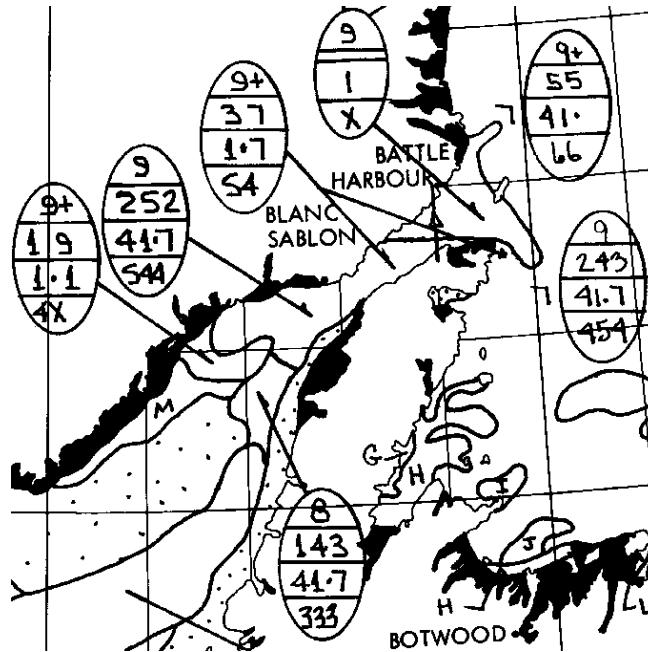
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Appendix A – Ice Study Details

The ice chart shown below is portion of an ice map for the 8th of April, 1991. The ice map shows land fast ice shaded in black around the shoreline of both Blanc Sablon and St. Barbe. Outside the landfast ice in St. Barbe is an area of open water followed by ice covered water closer to Blanc Sablon.



The relevant Egg code is shown below. The egg code is organized in four sections. The top section shows the total ice contraction in tenths. The example code indicates that 9/10th of the water surface is ice covered. The second line of the ice code indicates the fractional ice coverage. Each portion of the coverage is then further explained by the last two lines. The third line shows the ice type corresponding to the fractional coverage. The last line shows the floe sizes associated with the ice types.



The example above indicates that 2/10th of the water surface is covered by thick first year ice with floe sizes of 500 to 2000 metres in diameter. Another 5/10th of the water's surface is covered in medium first year ice with floe sizes of 100 to 500 meters. Another 2/10th of the surface is covered by thin first year ice with floe sizes between 100 to 500 meters.

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Once the ice conditions are determined, the ice numeral can be computed. To do so, the partial concentrations are multiplied by the appropriate value taken from the table below. The ice numeral is the sum of each of these products.

$$IN = 2 \times (10 - \sum C_p) + \sum M \times C_p$$

M – Ice multiplier defined in table below

C_p – Partial concentration determined from Egg code

For the example above, the ice numeral would be calculated as follows:

CAC 3

$$IN = 2[10 - (2 + 5 + 2)] + 2(2) + 5(2) + 2(2) = 20$$

CAC 4

$$IN = 2[10 - (2 + 5 + 2)] + 2(1) + 5(2) + 2(2) = 18$$

Type A

$$IN = 2[10 - (2 + 5 + 2)] + 2(-1) + 5(1) + 2(2) = 9$$

Type B

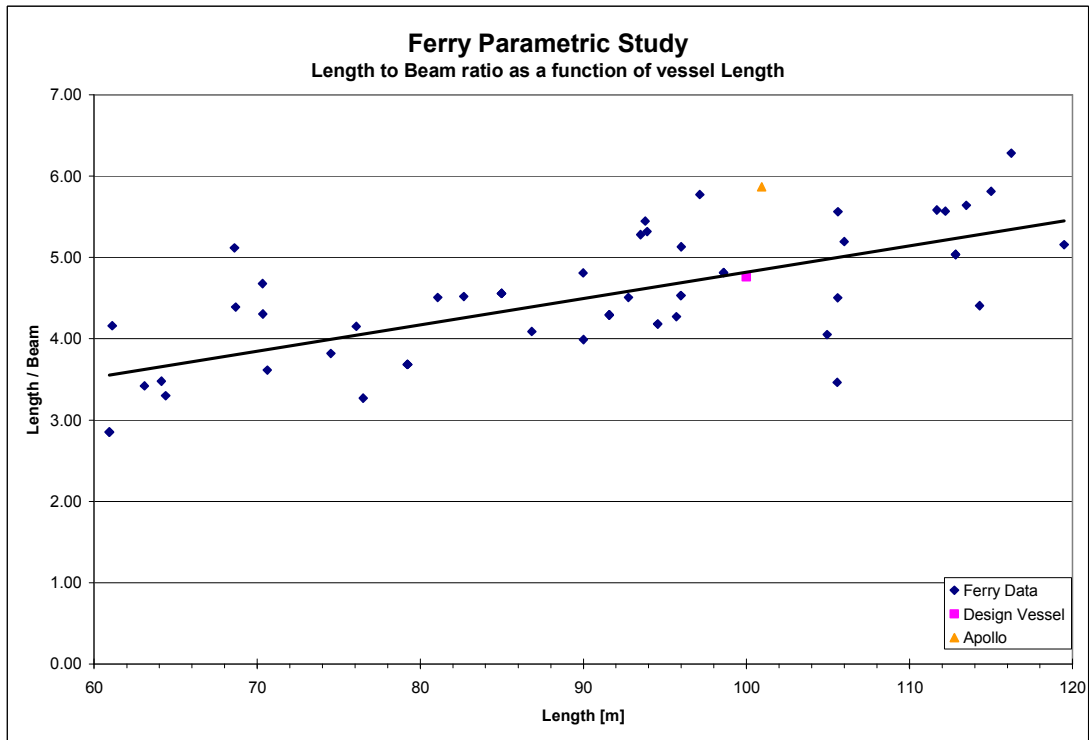
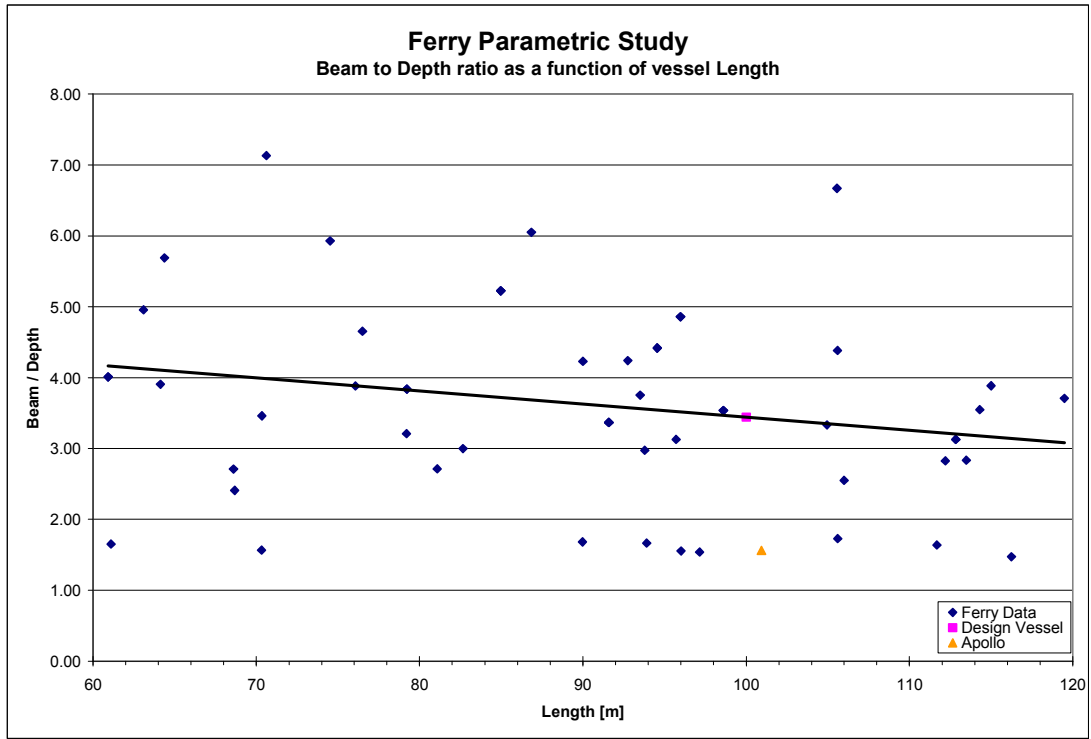
$$IN = 2[10 - (2 + 5 + 2)] + 2(-2) + 5(-1) + 2(1) = -5$$

Ice Classifications	Code Symbol	Typical Ice Thickness	Ship Type			
			CAC 3	CAC 4	Type A	Type B
Open Water			2	2	2	2
New	1	< 10 cm	2	2	2	2
Grey	4	10 – 15 cm	2	2	2	2
Grey-White	5	15 – 30 cm	2	2	2	1
Thin First-Year	7	30 – 70 cm	2	2	2	1
Medium First-Year	1•	70 – 120 cm	2	2	1	-1
Thick First-Year	4•	> 120 cm	2	1	-1	-2
Old	7•		1	-2	-3	-4

Positive ice numerals indicate that the ice regime is safe for travel. Negative ice numerals indicate ice regimes that are to be avoided. Therefore, for the ice regime in question, only classes of Type A and above can safely operate. For this example, the next chart was not published until April 11th. The selected ice chart is therefore counted as being valid for a three day period, rendering the Type B vessel inoperable for those three days. These calculations are performed for the entire season and the total number of inoperable days tallied for each ice class.

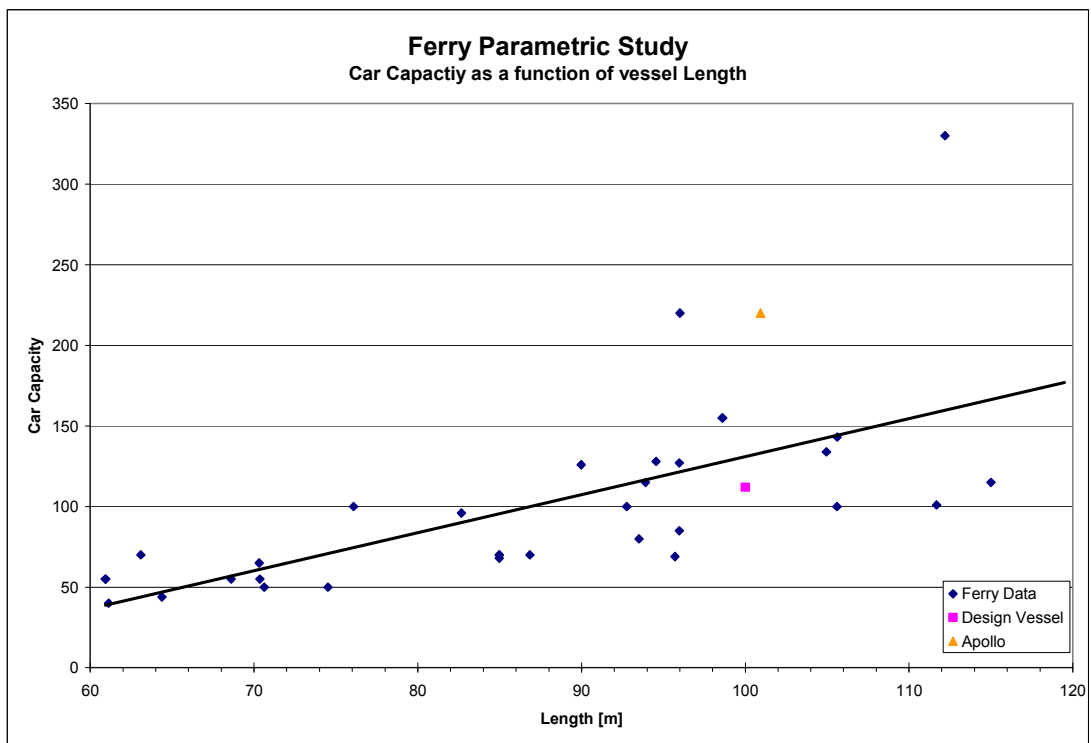
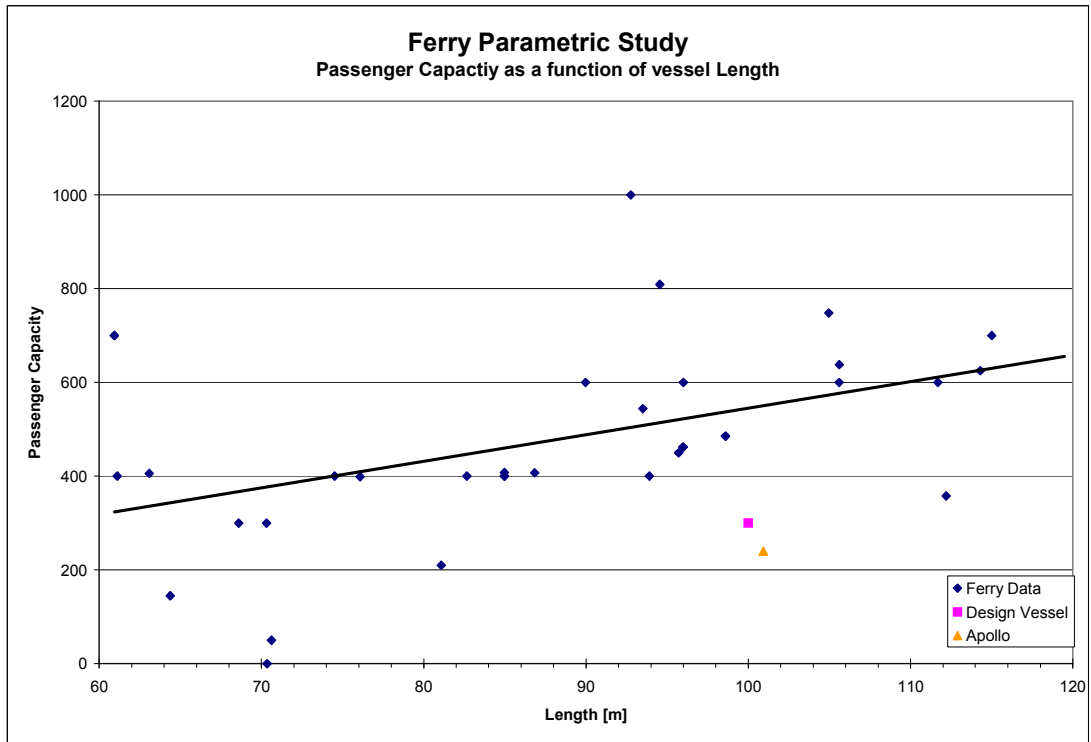
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Appendix B – Parametric Study Charts



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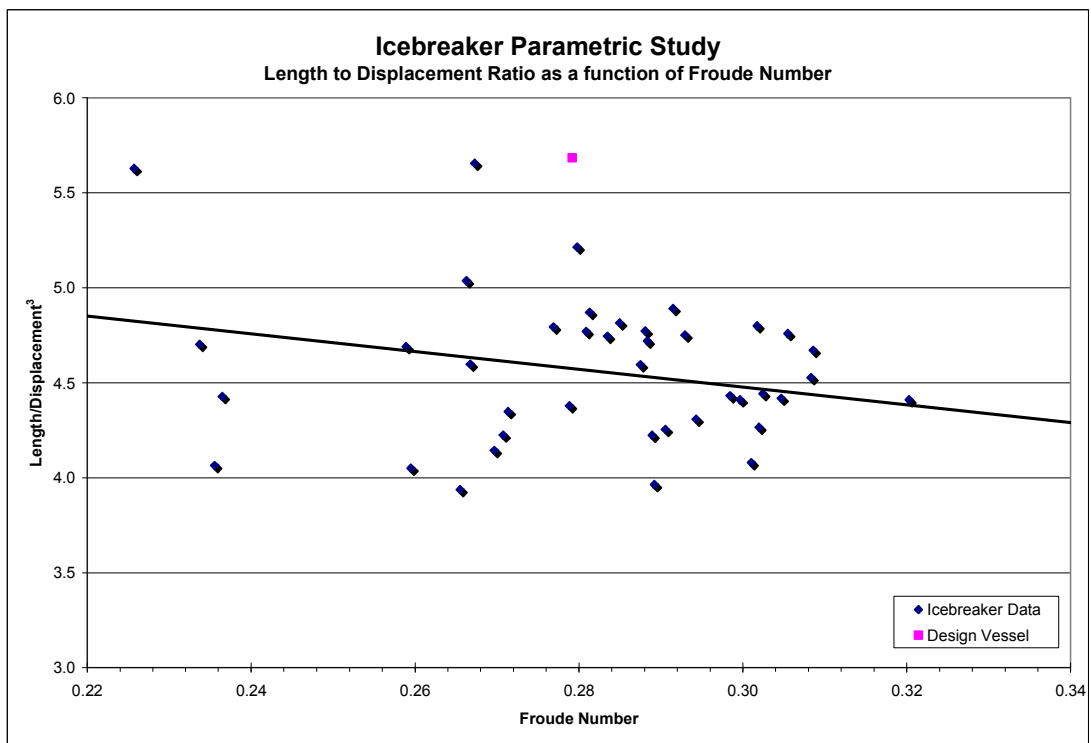
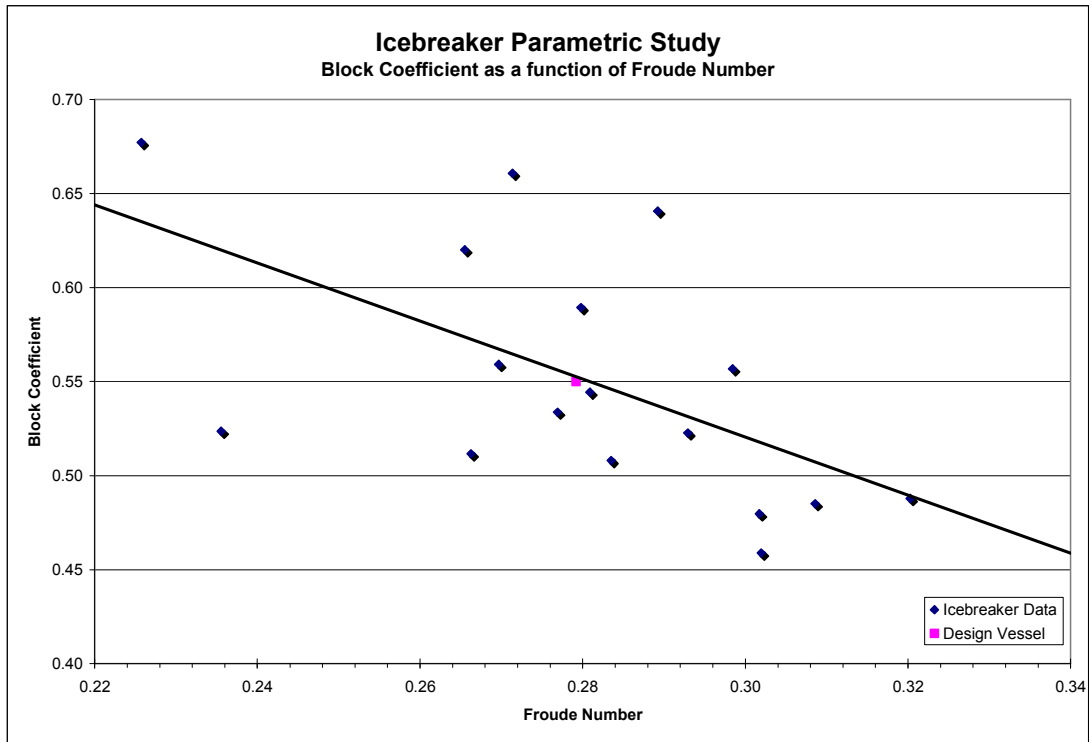


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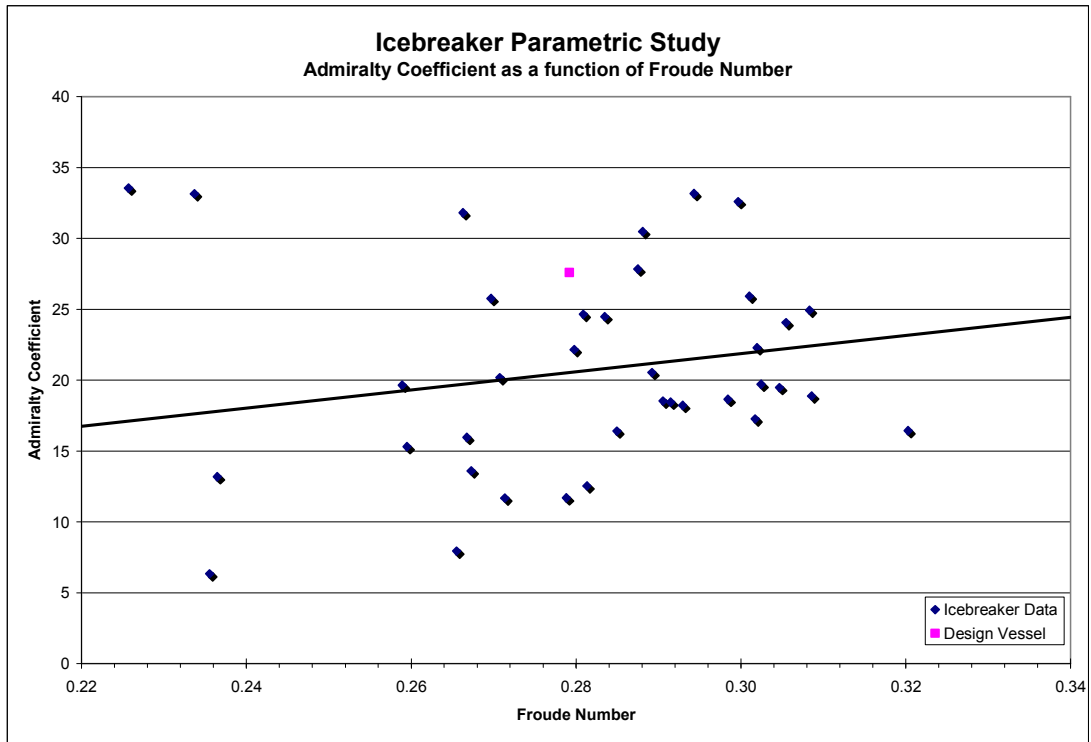


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Appendix C – Weight Estimate Calculations

The reference document used for developing the initial weight estimate of the vessel was “Estimating Weights and Centres in Preliminary Ship Design” by Dag A. Friis.

Net Steel Weight Estimate

Using Watson and Gilfillan’s Method, the net steel weight is given by:

$$W_s = W_{s7} [1 + 0.5(C_{b1} - 0.70)]$$

where:

$$W_{s7} = K * E^{1.26}$$

$$C_{b1} = C_b + (1 - C_b)(0.8D - T)/(3 * T)$$

$$E = E_{hull} + E_{ss}$$

$$E_{hull} = L * (B + T) + 0.85 * L * (D - T)$$

$$E_{ss} = 0.85 * \sum (l_1 * h_1) + 0.75 * \sum (l_2 * h_2)$$

This method yields the following results:

Total Steel Weights		
$C_{b1} =$	0.56	
$E_{hull} =$	2688	
$\Sigma l_1 h_1 =$	725	m^2
$\Sigma l_2 h_2 =$	150	m^2
$E_{ss} =$	729	m^2
$E =$	3416	m
	- Typically 2000 to 5000	
	<u>Low</u>	<u>High</u>
$K =$	0.024	0.037
$f_i =$	18%	22%
$W_{s7} =$	1534	2365
	Tonnes	
$W_s =$	1683	2682
	Tonnes	
KG =	4	4
	m	

Machinery Weight Estimation

Schneekluth's method for diesel engines was used to estimate machinery weight. Using this formulation, the main engine weight in tonnes is given by:

$$W_{me} = w_s * P$$

where

$$w_s = 0.011-0.02 \text{ [Tonnes/kW]}$$

$$P - \text{Engine power [kW]}$$

The diesel generator set weight, assumed to provide the auxiliary and emergency power, is given by:

$$W_{dgs} = P_e * (0.015 + \frac{P_e}{70000})$$

where

$$P_e - \text{Auxiliary and emergency power [kW]}$$

Other weights including items such as piping, pumps, noise insulation, spare parts, etc. are estimated by the formula:

$$W_{mo} = K * P$$

where

$$K = 0.04-0.07$$

$$P - \text{MCR of main engine [kW]}$$

These formulae yield the following weight estimates:

Main Engine Weight			
	<u>Low</u>	<u>High</u>	
$w_s =$	0.011	0.020	t/kW
$W_{me} =$	91	165	Tonnes
Diesel Generator Sets Weight			
	<u>Low</u>	<u>High</u>	
$W_{dgs} =$	19	19	Tonnes
Miscellaneous Machinery Weight			
	<u>Low</u>	<u>High</u>	
$K =$	0.040	0.070	t/kW
$W_{mo} =$	300	525	Tonnes
Total Machinery Weight			
$W_m =$	410	709	Tonnes
$KG =$	3	3	m

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Outfit Weight Estimation

Outfit weight was estimated using Henschke's formula for passenger vessels, given as:

$$W_o = K * V_{conv}$$

where

$$K = 0.04-0.05 \text{ [Tonnes/m}^3\text{]}$$

$$V_{conv} - \text{Gross Tonnage converted to Volume [m}^3\text{]}$$

The gross tonnage was calculated using Transport Canada standard TP13430. TP 13430 Part 2 Section 2.1 gives the gross tonnage as:

$$GT = K_1 V$$

where

$$K_1 = 0.2 + 0.02 \log_{10} V$$

$$V - \text{Total volume of all the enclosed spaces of the ship [m}^3\text{]}$$

These formulae yield the following results:

Total Outfit Weight					
	V (m ³)				
Main Hull	7045.5				
Vehicle Deck	10500				
Passenger Deck	4725				
Crew Deck	1890				
Bridge Deck	472.5				
V = 24633 m ³					
K ₁ =	0.2878				
Gross Tonnage =	7090 Tonnes				
V _{conv} =	6917 m ³				
C =	1.04				
C: 1.00-1.08					
K =	<table border="1" style="display: inline-table; border-collapse: collapse;"> <tr> <td style="text-align: center; padding: 2px;"><u>Low</u></td> <td style="text-align: center; padding: 2px;"><u>High</u></td> </tr> <tr> <td style="text-align: center; padding: 2px;">0.04</td> <td style="text-align: center; padding: 2px;">0.05</td> </tr> </table>	<u>Low</u>	<u>High</u>	0.04	0.05
<u>Low</u>	<u>High</u>				
0.04	0.05				
W _o =	<table border="1" style="display: inline-table; border-collapse: collapse;"> <tr> <td style="text-align: center; padding: 2px;">277</td> <td style="text-align: center; padding: 2px;">346</td> </tr> </table> Tonnes	277	346		
277	346				
KG =	11 m				

Appendix D – Initial Stability Check Calculations

Waterplane Coefficient and Area

The water plane coefficient was estimated from two simple formulas taken from 7052 class notes

$$C_W = C_B + 0.1$$

$$C_W = C_B - 0.0023T^3 + 0.0521T^2 - 0.349T + 0.8235$$

The former gave a value of 0.65, while the latter gave a value of 0.645. Therefore, a C_W of 0.65 was chosen. The water plane area was then determined using the chosen water plane coefficient:

$$A_w = C_W \cdot L \cdot B$$

This formula yields a waterplane area of 1365 m^2

Centre of Buoyancy

The KB was calculated using the water plane and block coefficient as determined above.

$$\overline{KB} = T \left(\frac{5C_W - 2C_B}{6C_W} \right)$$

The result of this formula is a centre of buoyancy located at 2.5 metres above the keel.

Transverse Metacentric Height

The following was used in determining the BM_T :

$$\overline{BM}_T = \frac{K \cdot B^2}{T}$$

where:

$$K = \frac{n^3}{2C_B(6n^3 + 11n^2 + 6n + 1)}$$

$$n = \frac{C_W}{1 - C_W}$$

The above formulas give the location of the metacentre to be 6.3 meters above the centre of buoyancy. Finally, the metacentric height was determined based on the following relation

$$GM = KB + BM - KG$$

When combined with a centre of gravity given in Appendix C, this yields a positive value of 4.5 metres for the metacentric height which is satisfactory for a preliminary stability estimate.

Labrador Straits Ice Capable Ferry Concepts

EN7052 - Final Report

Professor Dag Friis

July 19, 2007

Appendix E – Term 8 Schedule

Term 8

	Week	13	14	15	16	17	18	19	20	21	22	23	24
Resistance Estimates (OW & Ice)		■	■	■	■	■	■	■	■	■	■	■	■
Propeller Selection				■									
Machinery Selection				■	■	■							
Seakeeping Analysis							■	■					
Damaged Stability									■	■			
Updated General Arrangement											■		
Reports & Presentation												■	■

■ - Scheduled Time

■ - Weekends