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TECHNOLOGY FOR THE ASSISTANCE OF LARGE TANKERS IN HEAVY ICE

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FOREWORD

The Winter Navigation Research Board presents in this report No. 56, the outcome of a study on the technology to assist large tankers in ice. The study was initiated to review the feasibility of an icebreaker design capable to assist large tankers of the maximum size in the Baltic Sea. This Baltic maximum tanker was assumed to be 65 metres wide with a draught of 15 metres, which corresponds to a deadweight of about 190000 tonnes. The icebreaker should be able to assist this tanker in the most severe ice conditions and a close tow with the tanker in a notch should be possible. The development of icebreaker technology is also addressed to provide an understanding of the used technology in this new and innovative design.

The study has been conducted with the assistance of Mr. Göran Liljeström, Swedish Maritime Safety Inspectorate.

The Winter Navigation Research Board warmly thanks Mr. Bengt M. Johansson for this report and the novel icebreaker design, which has added a new dimension to the winter navigation.

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Jan-Olof Selén

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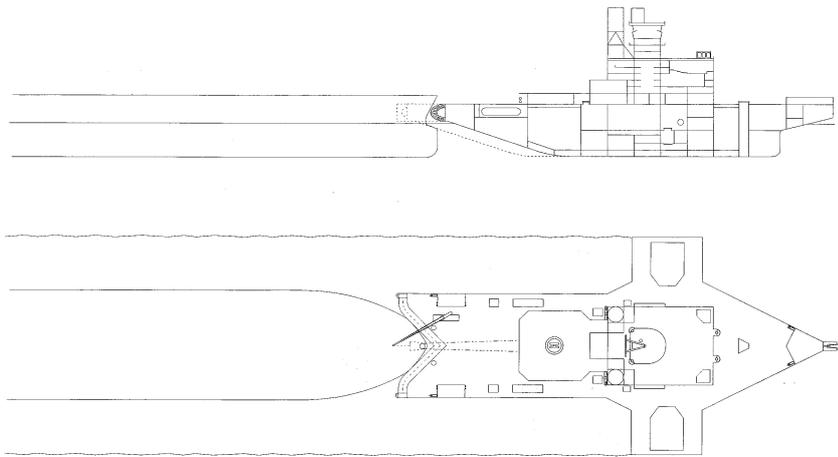
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EXECUTIVE SUMMARY

In order to efficiently assist 50 m wide tankers in heavy ice conditions in the Gulf of Finland an icebreaker capable of breaking a 100 m wide channel is required. In difficult ice conditions, as when the ice is under pressure, the tanker will be towed by the icebreaker while the two vessels are in physical contact with each other.

In the last quarter century ice breaking technology has developed, mainly through full scale tests, to a point where considerably less power is needed to perform a certain ice breaking task. In spite of the proposed icebreakers very large size - water line length 174 m, maximum beam 100 m and 15 m draft - a propulsion power of about 60,000 shp should be enough in order to enable the icebreaker to move continuously in unbroken ice with an average thickness of about 6.5 m.



The following features are installed to achieve this performance - efficient downward breaking portions at the water line of the bow, a large vertical wedge to push the ice to the side of the ship, reamers that widen the broken channel from 48 to 60 m as well as outriggers with ice cutting blades that create a 100 m wide channel behind the icebreaker. In addition the icebreaker will be fitted with auxiliary ice breaking systems - air bubbling, water deluge, heeling, solvent free epoxy paint, stainless steel compound plate as well as hull heating. In concert with the efficient hull form these will guarantee that the icebreaker never becomes beset while also making it possible to move continuously in very heavy ice.

Due to the capability of the icebreaker it is inevitable that it will be used in arctic and antarctic waters when it is not needed in the Baltic Sea. To cope with this environment it is proposed that the ship is designed in accordance with the Canadian proposed rules for navigation in the arctic. The hull plating should be dimensioned to CAC1 standards - the highest class - while the support structure may be dimensioned to CAC2 standards as the ship is designed to move continuously even in heavy ice and not by backing and ramming as existing icebreakers do. The icebreaker can easily be provided with laboratories and moon pools to facilitate this kind of research.

The estimated capital cost of the icebreaker is 250 million US\$ if tendered internationally while the estimated operating cost is 13 million US\$ in addition to fuel and consumables that cannot be estimated without knowing the operating profile of the ship.

Some further work and model tests are proposed in order to further the icebreaker design.

1. BACKGROUND

The size of vessels used for oil transport in the Gulf of Finland has increased in recent years due to the establishment of deeper shipping lanes with a maximum allowable draft of 15.3 m, the maximum possible in the Danish Straits. Future plans also indicate a large increase in the volumes to be transported, resulting in a large increase in tanker arrivals.

Tanker traffic must operate also in winter months when the Gulf of Finland may be partially or totally covered by ice. Present icebreakers are too narrow to create a high quality channel for large ships. Even with two icebreakers assisting one tanker the present icebreakers are able to break the re-frozen ice layer within the shipping lane but are incapable of pushing the broken ice to the side of the channel. As the amount of broken ice in the channel may be considerable, an average thickness of five meters is common, the tanker must have enough propulsion power to push the broken ice mass to the side of the ship and also to overcome the friction at the sides of the tanker between the ship's hull and the compressed ice mass.

This report describes one possible solution to overcome this problem by the use of one large and efficient icebreaker, in the report named Icebreaker For B-Max Tankers, where B-Max indicates Baltic maximum size. The report also describes alternate use for the icebreaker.

2. TANKER DIMENSIONS

For icebreaker assistance the most important dimension of the ship being assisted is its beam. Figure 1, which has been provided by the Swedish Maritime Administration, shows the relationship between deadweight and beam for tankers that potentially could be used in the Gulf of Finland.

This information indicates that an icebreaker especially designed to assist large ships in the Baltic should be optimized for tanker beams of about 50 m, but that it should also be able to assist ships with a beam up to about 70 m without too much loss in efficiency.

3. ICE BREAKING STATE OF THE ART

Successful year round navigation in any area depends upon the ability of icebreakers to escort tankers through the anticipated ice regime consistently, with a minimum of delays, and with no additional risk to ships or crew caused by the ice conditions.

Developments in icebreaker technology in the last quarter century have been inspired in large measure by the oil industry. Proven technological advances during this period have made it possible to construct reliable icebreakers capable of assisting year round tanker transportation within the limits of safety and pollution prevention regulation. Ships presently in service demonstrate that this can be accomplished by icebreakers of much less power than many others still operating with older technology.

Level ice is broken by using the force of the ship to bend the ice to its breaking point, rather than by crushing it. Early experience and theoretical calculations showed that blunt bow forms with small stem angles could break level ice more efficiently than wedge-shaped bows with larger stem angles.

However, problems occur at sea when icebreakers encounter ridges formed due to the movement of highly mobile sea ice. The first sea-going icebreaker, Murtaja, built in Sweden in 1890, had a blunt spoon-shaped bow form which was designed for breaking level ice efficiently. However, the bow pushed ice ahead of the ship so that the ship became beset in ridges. That experience led to sea-going icebreakers being designed with comparatively inefficient wedge-shaped bows while those built for level ice in lakes and rivers had blunt bows. This remained the case until Canmar designed and built the Kigoriak in 1979, the first sea-going icebreaker since Murtaja to have a blunt spoon-shaped bow, see Reference [1].

The Kigoriak addressed the problems of a blunt bow in sea ice by three major design features. The first was a water wash system which pumps large volumes of seawater onto the ice in front of the ship, greatly reducing the friction between the bow and the ice so that the bow rides more easily up onto the ice. It can also provide a stream of water to the ice surfaces along both sides of the ship in order to reduce friction when there is pressure against the hull.

The second consisted of reamers fitted to the hull of the ship at the widest part of the hull. The reamers reduced the friction along the mid-body of the ship. They operate in an asymmetrical fashion: that is, they break ice by bending it downwards as the ship moves forward, and break it by bending upwards when the ship moves backward. The reamers create a channel of about one meter width on each side of the ship, greatly reducing friction between ice and the hull and allowing for greater manoeuvrability in ice.

The third was the installation of a nozzle surrounding the ship's propeller, which has the effect of increasing thrust and protecting the propeller from larger ice pieces.

The difference in ability between the Kigoriak and a more conventional icebreaker with a wedge-shaped bow can be measured. In Reference [2] a graph is presented that shows the necessary shaft power in kW for breaking level ice of different thicknesses at slow speed in the continuous mode. The graph is a representation of the formula $P_s = 676 * B * h^{1.6}$, where "Ps" is the shaft power in horse power, "B" is the beam of the ship in meters and "h" is the thickness of the level ice in meters.

In full scale trials the Kigoriak broke 1.6 meter thick ice at a continuous speed of 3 knots with the hull wash system operational and with a shaft power of 16,400 hp. A conventional icebreaker with a wedge-shaped bow would require shaft power of 27,600 hp to achieve the same ice breaking capability. The Kigoriak needs approximately 60% of the power of a conventional icebreaker to meet this test. Conversely, the Kigoriak is capable of breaking ice 38% thicker than a conventional icebreaker of the same power.

The bow design was improved upon by Canmar in 1982 when it built the Robert LeMeur, Reference [3]. This ship also benefited from the application of low friction Inerta paint. This is a hard solvent free epoxy which, unlike more conventional marine paints, does not suffer extensive damage from contact with the ice. Conventional paint is removed by the ice and the unprotected portions of the hull corrode. The corrosion results in an uneven surface which causes more friction between the hull and the ice. These improvements in the Robert LeMeur led to a further 20% reduction in the power necessary to accomplish the same tasks as the Kigoriak.

Canmar also took part in the design of the Swedish icebreaker Oden, delivered in 1989 with 24,000 hp, Reference [4]. The Oden further improved the Robert LeMeur concept. In addition to using the efficient spoon shaped bow form, Inerta paint and a hull wash system, the Oden was fitted with

larger reamers than its predecessor and a further improvement, a fast heeling system. The system pumps water very quickly within the vessel from one side to the other (as much as 800 tonnes in 25 seconds) rocking the ship in heavy ice so that the reamers more effectively break the ice at the sides of the ship.

In full scale operation the Oden has moved at a continuous speed of about 3 knots in 2 meter thick ice. On several occasions she has reached the North Pole during research expeditions. It was considered remarkable in 1977 when the Russian nuclear icebreaker Arktika became the first surface ship to reach the North Pole. It did so with shaft power of 75,000 hp. The formula set out above indicates that the Oden would have required, for its beam, a power of 60,000 hp without the innovations in icebreaker design developed since the Arktika was constructed; yet it succeeded in its voyages with a shaft power of 24,000 hp. The Oden is able to break 77% thicker ice than a conventional icebreaker with the same particulars.

In the mid-1980s two Finnish icebreakers, Otso and Kontio, were fitted with a stainless steel compound plate in the waterline portion, which further reduces the friction and minimizes wear on the hull due to contact with ice, Reference [5].

Two further developments in technology were incorporated into two Finnish icebreakers, Fennica and Nordica, built in the early 1990s. They have symmetrical reamers, which break the ice by bending it downwards both when moving forwards and backwards [6]. The icebreakers were also fitted with two stern propellers that are able to turn 360 degrees around an almost vertical axis. The initial purpose of the rotating propellers was to improve manoeuvrability in both ice and open water, in order to make dynamic positioning possible in concert with three transverse thrusters in the bow. This objective was accomplished but it has also been found that the propeller wash is able to move broken ice away from the ship, and that it is even effective in breaking up heavy ridges.

All innovations in icebreaker design discussed above have been proven effective in full scale operation, with the result that it is readily feasible to construct an efficient icebreaker to provide year round escorts to tankers in and out of the Gulf of Finland.

4. CHOSEN SOLUTION

4.1 GENERAL

In order to make it easy for a ship to follow an icebreaker the broken channel should be about twice as wide as the beam of the following ship, i.e. for a tanker beam of 50 m the icebreaker should break a 100 m wide channel. This is not a trivial problem but neither is it impossible based on the information available today.

On Oden's first arctic expeditions I made the observation that with the fast heeling system operational Oden was able to proceed without having to resort to backing and ramming in unbroken ice of up to 5 m thickness as long as there were minor leads in the vicinity that made it possible for the broken ice to clear to the side of the ship. If these conditions did not prevail ramming had to be performed when the average ice thickness exceeded 2 m. The challenge is to create a design that is able to provide the same relief as a lead in the vicinity of the icebreaker.

The new concept is described in Figures 2 and 3 which show a 50 m wide tanker being assisted by an icebreaker that breaks a 100 m wide channel. The figures show the tanker being assisted in short tow where the two ships are in physical contact with each other as is the normal operation during extreme ice conditions such as ice pressure or similar. Figure 2 shows the tanker in full load when the bluntness of its bow causes the contact points with the stern notch of the icebreaker to the side of the bow. Figure 3 shows the tanker in ballast and the relative narrowness of the bulbous bow causes the contact point to be in the centre of the two ships.

Figures 4 and 5 describe the proposed hull form of the new icebreaker. In the ice breaking water line the bow has a pronounced downward breaking portion that efficiently breaks the ice in bending. Below this is a large wedge with vertical sides that efficiently transports the broken ice to the sides of the ship. The ice breaking portion forms a reamer at the widest part of the ship and this reamer breaks the ice in bending downwards when going astern as well as when proceeding forwards. Outside the reamer there is an above water structure that forms outriggers that at the extreme width of the ship are fitted with 2 m wide cutting blades in order to create a crack in the ice at the maximum beam.

The parallel mid body portion of the ship extends all the way to the stern in order to keep the broken ice from filling the channel behind the ship too early. The stern is fitted with pronounced skegs at its maximum beam to ensure that water from below the ship is able to move freely into the space behind the icebreaker. Four propulsion units are fitted on each side of the ship in order to create a strong surface current towards the stern in the channel broken by the outriggers. The propulsion units on the side of the ship are able to rotate 360 degrees around a horizontal axis in order to direct the propeller induced current towards the ice floating at the ocean surface. The two stern propulsion thrusters are able to rotate 360 degrees around an almost vertical axis in order to manoeuvre the ship while also creating a strong surface current when propelling the ship forwards.

One important feature of the new concept is the fact that the icebreaker will never become beset in ice, not even in pressure conditions. Another important feature is the capability to tow the ship being assisted in the towing notch with both units moving at exactly the same speed which removes all possibility for collision.

The icebreaker has the following particulars:

Length, over all	197 m
design wl	174 m
Beam, amidships	48 m
over reamer	60 m
maximum	100 m
Depth	24 m
Draft	15 m
Displacement	76,000 tonnes
Propulsion power	60,000 shp

If we assume that the chosen icebreaker is as efficient as the Oden then we may calculate the thickness of ice were it can move at a speed of 3 knots, $h^{1.6} = 60,000 / (0.4 * 676 * 48) = 4.6228$ or $h = 2.6$ m. But assuming that the new features will create the same conditions as a small adjacent

lead during the arctic expedition with Oden that I observed then we will be able to move continuously in unbroken ice that on average is about 6.5 m thick.

Figure 6 shows a longitudinal section of the icebreaker through the centre of the ship. Figure 7 shows a top view with the mobile crane positioned to conveniently pass the towing line to the ship being assisted. If this ship is fitted with a single bollard at the forward end then the topline connection and disconnection may be performed entirely by the icebreaker using the crane which is remotely operated from the conning station. Figure 8 shows the arrangement of the main deck and Figure 9 the arrangement of the deck below which is located 18 m above the base line - BL. The main hull contains the main power generators, the auxiliary ice breaking systems - heeling, deluge and air bubbling - the propulsion units as well as heavy fuel oil, ballast and helicopter fuel tanks. The deck house on the main deck contains auxiliary systems - towing winches, a mobile crane, auxiliary power generation, boilers with economizers collecting heat from the exhaust gases, fresh water makers and fresh water tanks, waste treatment, diesel oil tanks, food storage as well as a wet laboratory area for possible use on research expeditions.

Figure 9A shows a cross section through the port side wing tanks indicating the enclosed ballast water air vent system, the diver access route into the water intake and the cooling water mixing chamber as well as into the sea chest. The drawing also shows the access to the deluge pump room.

Figures 10 and 11 show the arrangement of the lower decks and the tank top.

4.2 ICE CLASS

When winter navigation was initiated in the Baltic Sea, late in the 19th Century, the first ships used had scantlings that were normal on open water ships. It soon became evident that in order to avoid excessive damage due to contact with ice it was necessary to increase the plate thickness and provide additional framing in the hull portion close to the operating water line. It also became evident that propellers and rudders had to be strengthened in order to cope with the higher loads caused by contact with ice. A ship thus strengthened could get a notation "Ice" from the classification society.

In the late 1920's when the Finnish Maritime Administration owned and operated five icebreakers with a combined propulsion power in excess of 20,000 hp it became evident that a more stringent ice classification was needed in order to prioritize icebreaker assistance. Three ice classes were introduced for the Southern part of Finland: 1A for heavy ice, 1B for medium ice and 1C for light ice. In 1930 regulations for this type of ice strengthening were published by the Finnish authorities and with time the major classification societies accepted these classes for use in Baltic ice. In 1960 a stronger ice class 1ASuper was added in order to cover heavy ice conditions in the Northern Baltic Sea.

The regulations of 1930 stipulated added plate thicknesses and intermediate frames as a certain percentage above normal open water scantlings. In 1965, when working at the main office of Lloyd's Register of Shipping in London, England I realized that the new version of the regulations then under consideration would result in smaller scantlings for open water ships. As the ice strength at that time was directly related to the open water scantlings it was inevitable that new ships would have less capability to withstand ice loads than older ships.

To find out how serious this problem could be I decided to study the ice damage records of Lloyd's Register of Shipping in my own time. In the end I found records of almost 200 ships damaged in ice, mostly during the hard winters 1962-63 and 1965-66. The records for the later period were found in the archives of the Finnish Maritime Administration.

Somewhat to my surprise the results showed a large scatter in actual hull strengths for ships of the same ice class. Subsequently I wrote a paper named "On the Ice-Strengthening of Ship Hulls" that was published in Holland, Reference [7], which indicated that ships of about the same main dimensions and engine-output and with the same ice class notation could have an actual ice hull strength that varied by a factor of six. It should be obvious that if a master who has been aggressively operating a strong ship in ice will cause a lot of damage if he or she operates a six time weaker ship in the same manner.

I recommended ice strengthening dependent on the displacement and the power of a ship. A ship with more mass can develop a larger ice load than a ship with a smaller mass when being slowed down by an ice obstacle. A ship with larger power will move at a higher speed than a ship with less power and thus has more kinetic energy when being slowed down by an ice obstacle. In 1971 the Swedish and Finnish Maritime Administrations published ice class rules based on the recommendations presented above, see Reference [8], the "Finnish-Swedish Ice Class Rules 1971".

The Russian Register uses ice classes UL, L1, L2 and L3 which are equivalent to the Baltic classes 1ASuper, 1A, 1B and 1C. In addition they have one higher ice class - ULA - intended for cargo ships navigating in the North East Passage while being assisted by icebreakers. The Russian and Baltic ice rules have in common the fact that they are mainly intended to create ships that are strong enough to follow the icebreakers being provided by the authorities.

In 1972 Canada published ice strength standards in the form of "Arctic Shipping Pollution Prevention Regulations", Reference [9]. These recognize the Baltic ice classes which are called Type A, Type B, Type C and Type D for 1ASuper, 1A, 1B and 1C respectively. In addition there are nine Arctic Classes, i.e. 1, 1A, 2, 3, 4, 6, 7, 8 and 10. In theory the class number indicates the level ice thickness in feet - 1A stands for 1.5 feet - that the ship is able to move in at a continuous speed of 3 knots. This is an important requirement as the Canadian authorities do not at all times have icebreakers stationed in the arctic, especially not in the winter.

The strength requirements in the Canadian regulations of 1972 assume that the breaking of level ice is the deciding load factor and thus the required strength is the same for small ships with minimal power as for large ships with enormous propulsion power. In reality the strength requirement for ships navigating independently in the Canadian arctic is all but totally governed by ramming operations in ice that cannot be broken in the continuous mode of operation. In this mode of operation the mass and propulsion power become dominant for creating the ice loads on the ship hull. It is also interesting to note that the highest ice loads as a rule occur when there is large amounts of open water around thick multi-year ice, as the speed of the ship may be high unless the operator decides to slow down.

The Canadian regulations of 1972 had the Canadian arctic divided into zones in which vessels of different ice classes were allowed to operate within fixed time limits. But it soon became evident that ice conditions varied dramatically within a zone and also that ice conditions varied from year to year. Thus the Canadian authorities had no difficulty in the winter of 1979 - 80 to allow the ice breaking tug Kigoriak - which was fitted with a double skin and was built of cold temperature steel, and thus was unable to cause pollution - to operate year round in the Beaufort Sea where an ice class 6 was required even if she only was registered to ice class 3 standards.

When the new Canadian rules were worked out in the late 1980's it was decided to design the strength of a ship to be adequate for a certain type of ice. At the IceTech 1990 conference held in Calgary this is explained by J.S. McCallum in a paper: "Overview & Summary of the Proposed Revisions to the Canadian Arctic Shipping Pollution Prevention Regulations", see Reference [10]. Table 2A in this paper introduces the new arctic classes in the following manner.

Category	Limiting Ice Type	Navigation Limitation	Principal Function	General Mode of Operation Envisaged
CAC1	Multi-Year	None	Ice-breaker	In M/Y ice proceeds continuously or by ramming to owner's requirements
CAC2	Multi-Year	None	Transit	Takes easiest route. Proceeds in M/Y ice continuously or by ramming to owner's requirements. May be an icebreaker of lesser capability than CAC1. Escorts ships of lesser category
CAC3	Second Year	By ice regime	Transit	Takes easiest route permitted under the ice regime system. Unrestricted in second year ice. Avoids M/Y ice. When not possible proceeds by controlled ramming. May be an icebreaker with capability limited by category and structural strength. Escorts ships of lesser category
CAC4	All First Year	By ice regime	Transit	Takes easiest route permitted under the ice regime system. Unrestricted in first year ice including F/Y ridges. Avoids M/Y ice. When not possible proceeds by cautious ramming or by pushing. May be an icebreaker with capability limited by category and structural strength. Escorts ships of lesser category

The above table clearly describes the self-evident fact that a less capable ship is allowed into an ice regime if it is assisted by an icebreaker designed for that ice regime. The ship following in the channel broken by the icebreaker will not encounter any unbroken ice if the icebreaker is wider than the assisted ship. Neither will the assisted ship have to break ice by ramming which by itself will limit excessive loads on the hull of the ship.

The new Canadian regulations have not been presented to parliament for approval as the Canadian Coast Guard is seeking to get all nations interested in arctic navigation to agree upon a set of harmonized standards for ice-breaking ships. But they have been published in 1993 in draft form under the title: "Arctic Shipping Pollution Prevention Regulations. Proposed Equivalent Standards for the Construction of Arctic Class Ships", Reference [11]. Several ships have been given class notation in accordance with these proposed standards, which is not unusual in the shipping business.

The proposed icebreaker has a propulsion power of 60,000 hp and should be able to break 6.5 m thick ice in the continuous mode. This makes it almost inevitable that it will be used in the arctic during periods when open water or light ice conditions prevail in the Gulf of Finland. Thus it should be strengthened for coping with old arctic ice. The proposed Canadian regulations are the

most suitable as they take into account the fact that ice loads are not of hydrostatic nature but rather very peaky which means that a larger area should be designed for a lower average ice pressure than a smaller area. In 1986 the Oden was designed in accordance with CAC 1 standards of the proposed regulations and she has operated successfully in the high arctic on several occasions with only minor deformations in the plating between frames.

As may be seen from the table above ice classes CAC 1 and CAC 2 are both intended for independent operation in multi-year ice. The higher class, CAC 1, may ram any old ice without limitations. As the new concept is designed to travel in the continuous mode in old ice it would be unnecessary to design the hull for extreme ramming loads, so it seems proper to design the framing and other support structure according to CAC 2 standards. However, based on the Oden experience, the plating should be designed to CAC 1 standards in order to reduce the deformation of the plating. Table 1 shows the scantlings of plating and frames for the various parts of the hull for frame spacings (s) of 1.1118 and 1 m using a high tensile steel with a yield strength (fy) of 490 MPA, i.e. the same as used on Oden. Figure 12 shows the ice class area factors (AF) on the proposed icebreaker.

4.3 STEEL STRUCTURE

Figure 13 shows the principal bulkheads of the proposed icebreaker and Figure 14 the principal transverse members. In the wing tanks, which contain the principal ice strengthening, there is a box structure with bulkheads and decks spaced 6 m apart. In the bow portion of the ship this wing tank structure is supported by decks 6m apart and bulkheads not more than 12 m apart. In the remainder of the ship the wing tank structure is supported by decks not more than 12 m apart and bulkheads not more than 24 m apart.

As may be seen in Figure 13 the transverse bulkheads are turned in the bow portion of the ship in the wing tanks and beyond in order to make them perpendicular to the side shell. This improves strength and makes construction easier.

Figure 15 shows the structural design in the lower portion of the aft pump room and Figure 16 the structural arrangement in the main generator room. Figure 17 and 18 show the structural arrangement in the bow portion of the ship.

Tables 2.1 and 2.2 shows the scantlings of decks and bulkheads designed for various hydrostatic loads and assuming an allowable stress in compression and tension of half of the yield strength of the material and in shear of 57 % of this, i.e. 28.5 % of yield.

4.4 SHIP WEIGHT AND BUOYANCY

Tables 3.1 through 3.9 show a detailed calculation of the steel weight which results in a total steel weight of 29,946 tonnes. Due to the detailed nature of this calculation it should be sufficient to add a contingency of only about 3.5 % for a total steel weight estimate of 31,000 tonnes. As may be seen later in this presentation weight or stability are not of critical nature for this design as a considerable amount of ballast water has to be added in order to reach the ice breaking draft, even with a full load of fuel onboard.

Tables 4.1 and 4.2 show an estimate of the lightship weight of the ship from which it can be concluded that the items apart from the steel should weigh 10,052 tonnes. Due to the greater uncertainty in this calculation it is suggested that a contingency of almost 10 % is added to this weight for a total of 11,000 tonnes which results in a total estimated lightship weight of 42,000 tonnes.

Table 5.1 to 5.3 show a hydrostatic calculation at a design draft of 15 m. The total volume is 74,037 m³ which in sea water corresponds to a weight of $1.025 \times 1.006 \times 74,037 = 76,344$ tonnes.

The coefficient 1.025 is the specific weight of sea water while the coefficient 1.006 indicates the extra volume caused by the thickness of the skin plate which is located outside of the dimensions used in the hydrostatic calculation.

Table 6.1 shows the weight balance at ice breaking draft with all fuel tanks full but for the heavy fuel oil overflow tank that is only filled to 50 % of capacity. As may be seen we need almost 12,000 tonnes of ballast to get the ship down to 15 m draft.

The maximum heavy fuel oil storage is 20,445 tonnes. Proceeding at full ice breaking power the propellers need 44.12 MW while the auxiliary ice breaking systems together with the main engine pumps require an additional 8 MW of power for a total of 52.12 MW. Assuming an electrical transmission efficiency of 0.9 we need 57.9 MW of diesel power. With a specific fuel consumption of 0.18 kg/MWh, 10.422 tonnes of fuel will be used every hour or 250 tonnes every day at full power. Thus the icebreaker has the capability to steam 81.8 days at full power.

When steaming in open water in well charted shipping lanes there is no reason not to empty the ballast tanks in order to save fuel or increase speed. Table 6.2 shows that with full fuel a draft of 13.52 m can be achieved on even keel with a small amount of ballast at the stern.

Table 6.3 shows the condition when breaking ice with half of the fuel left. The fuel should be distributed in such a manner that when the ballast is removed the ship will be at even keel at a draft of 11.37 m as shown in Table 6.4.

Table 6.5 shows the icebreaker at 15 m draft with a minimal amounts of fuel and fresh water immediately prior to dry docking and Table 6.6 shows the ship at even keel with a draft of about 9.4 m immediately prior to dry docking. Not all large repair docks and few large building docks are able to deal with a draft of 9.4 m but with two barges it is possible to get the draft to 7.2 m which all large docks can handle, see Figure 30. When the Oden was built one barge at the stern was needed when undocking the vessel during the construction process.

As may be seen from Figures 9 and 10 all ballast tanks at the side of the ship are below the 12 m level and all ballast tanks in the centre part of the ship are below the 18 m level. Thus no ballast tank is in direct contact with outside cold air which eliminates the need to heat the ballast water.

4.5 SAFETY

The proposed icebreaker has wing tanks between 6 and 15.6 m in width and a double bottom with a height of 3 m. Due to the heavy ice strengthening it should be impossible to penetrate the double skin structure during collision or grounding. It should be noted that the Canadian arctic pollution

prevention regulations assume that an ice strengthened double skin of 0.61 m width makes pollution virtually impossible.

But it is naturally possible to penetrate the outer hull even if it is very strong. Table 7.1 shows the condition after the ship has struck a pinnacle less than 15 m from the surface of the ocean in such a manner that the outer skin has been penetrated along the centre line resulting in all bottom tanks between frame 108 and 162 being flooded. If the contact has also caused damage to the pinnacle it is possible that the ship does not stay grounded causing the condition showed in Table 7.1. The trim is shown as - 4m and is the total trim between frame 0 and frame 186, i.e. the forward most point of the ship. The negative sign indicates that the bow is down and thus the draft at frame 186 will be $16.1 + 2 = 18.1$ m. As the depth of the ship at this point is 24 m a minimum freeboard of 5.9 m is still available.

Table 7.2 shows a condition that is not really possible without sabotage, i.e. with the entire engine room flooded. This would require leakage in one of the pipes that are open to the sea water intakes or to the sea through the bottom of the ship and at the same time not using the ballast pumps to drain the engine room from the incoming water. The four ballast pumps can easily pump out the water entering through one damaged pipe and thus the condition in Table 7.2 can only occur if someone disconnects the automatic start-up of the ballast pumps when water is detected in the bilges.

In Table 7.2 the permeability of the engine room is taken as 0.882. It is assumed that 10 % of the total volume is already taken up by machinery and 2 % of the total volume by structure for a coefficient of 0.9×0.98 or 0.882. In the condition presented in the table the maximum draft at the forward end of the ship is shown as $18.23 + 2.61/2 = 19.54$ m, leaving a minimum freeboard of 4.46 m.

Table 7.3 shows a condition that clearly only is possible as a result of sabotage, i.e. there is a full load of fuel, the engine room has been allowed to flood and the valves into all ballast tanks have been forced open. In this extreme condition the draft at the forward end of the ship will be $20.94 + 2.09/2 = 21.99$ m leaving a minimum freeboard of 2.01 m.

It should be noted that using divers it will be possible to cap the points where the sea water enters the ship. Divers can use the moon pool to reach under the bottom of the ship and cap the openings of the four outlet pipes shown in Figure 15. As shown in Figure 9A there is diver access through bolted doors above the platform deck 18 m above the BL into the sea water intake areas of the ship. This makes it possible to close off the intake openings in the sea chests and the return water openings in the sea water intake and mixing chamber respectively, making it feasible to repair any possible pipe or valve damage before the flooding becomes extensive.

While it is impossible to design a ship out of material with a higher specific weight than water to be unsinkable a risk analysis will show that the chance of getting hurt or killed during life boat tests is considerably higher than the danger of getting hurt or killed during the sinking of the proposed icebreaker. Thus it makes eminent sense to store inflatable life rafts with arctic insulation indoors in a protected location to make sure that they are operational in the minimal possibility that they would ever be needed.

4.6 AUXILIARY ICE BREAKING SYSTEMS

In addition to the ice breaking features described above the icebreaker will be fitted with the following auxiliary systems in order to guarantee its capability to move continuously forward even under extreme ice conditions:

- air bubbling system
- water deluge system
- heeling system
- solvent free epoxy paint
- stainless steel compound plate
- hull heating

Air bubbling systems have been used extensively on icebreakers and ice breaking ships mainly in the bow portion in order to reduce friction between the hull and the ice. Large amounts of compressed air is released below the water line and when rising towards the surface the air drags water with it that penetrates the gap between the hull and the ice. On conventional wedge shaped bows the air bubbling systems have proven beneficial while on more efficient ice breaking bows with more pronounced flare the effect has proven minimal.

On the Robert LeMeur an air bubbling system was installed in the stern in order to improve the clearing of ice ahead of the propellers. The effect of the system proved inconclusive, to a large part due to the insufficient power of the compressor.

On the new icebreaker concept it is proposed to install an air bubbler system across the flat stern portion of the ship with the air pipe located close to frame 46 as shown in Figure 6. The intent is to create a strong current directed aft along the entire 36 m wide flat portion of the stern to stop broken ice from collecting behind the ship. This is especially important when the icebreaker is backing up in order to take a ship in short tow.

The two air compressors are located on the platform deck 18 m above BL as shown in Figure 9. These compressors are also used in case the ship runs aground creating the weight balance shown in Table 7.1 but in such a contact with the bottom of the sea that the ship remains grounded with the bow lifted up and leaving a draft of less than 15 m at the forward end of the wedge. The only way to get off the ground is to blow the tanks between frame 108 and 162 as shown in Table 7.4, where it is assumed that on average 30 cm of water will remain in the tanks. On even keel this would result in a draft of 13.65 m, i.e. 1.35 m less than the draft before grounding. By trimming the ship it is possible to reduce the draft at frame 162 by a further meter as shown in Table 7.5. Tables 7.6 and 7.7 show the weight balances if the ship should run aground with half a load of fuel after the damaged tanks have been blown.

To facilitate the blowing of the tanks the two air compressors have to work in series as indicated in Figure 9. A pipe bend in the starboard compressor exhaust line is unbolted and turned 45 degrees to direct the compressed air through a pipe across the beam of the ship. A pipe bend on the intake side of the port air compressor is turned 90 degrees in order to receive the compressed air from the starboard compressor and a bend in the exhaust pipe is turned 45 degrees to connect the compressor to a longitudinal pipe bringing the compressed air into the port ballast water air vent as shown in Figure 9A. A second pipe across the beam of the ship brings compressed air also to the starboard side ballast water air vent.

In order to blow the ballast tanks between frames 108 and 162 the air pipes from all other ballast tanks should be closed off as should the pipes leading from the ballast water air vents to the sea water intakes. By starting the two compressors air will flow into the flooded tanks until they are almost empty. If the air resistance in the air pipes of the damaged tanks should be too high a valve in the port ballast water vent may be partially opened to allow air to escape through a silencer into the space between the decks at levels 18 and 24 m above the BL. This excess air would escape into the air intake above the starboard air compressor.

Water deluge systems have been used on Kigoriak, Robert LeMeur and Oden. Large amounts of water are pumped on top of the ice to totally flood the ice in order to reduce friction between the bow of the ship and the ice and also to add weight on top of the ice to help cause a breaking failure and also to help submerge the ice below the bow. The water deluge system has proven very beneficial, on average reducing ice resistance by about 20 %.

A side view of the water deluge system for the new icebreaker is shown in Figure 6 while a top view is shown in Figure 9. A propeller pump located in the wing portion in front of the sea water intake sucks large amounts of water from the top portion of the water intake and supplies a large pipe that is brought above the ice breaking water line to distribute the water to ten equally spaced nozzles - Figure 18 - on both sides of the ship. The total water volume pumped should be about 60 m³ per second in order to create a 1 m thick water layer on top of the ice when the icebreaker is proceeding at an average speed of about 2 knots.

Heeling Systems have been used extensively on icebreakers for more than 100 years. Their main task was to reduce the risk of the icebreaker getting stuck and improving the chances of becoming unstuck by changing static friction into a dynamic one, which is considerably smaller. The pumping time was modest as it normally took several minutes to pump the total amount of water from one side to the other.

On Kigoriak and Robert LeMeur no heeling system was installed as the risk of getting stuck was considered small. On the Oden a very fast heeling system was introduced, capable of pumping 800 tonnes of water from one side to the other in 25 seconds. The reason was the planned ability to drastically reduce the turning radius in ice by heeling the ship into the turn, a capability that was subsequently proven in full scale.

But full scale tests also showed that the fast heeling system in concert with the pronounced reamers radically improved the ice breaking capability in heavy ice conditions by concentrating the downward force component on one side of the ship while reducing it on the other.

On the new icebreaker concept it is proposed to keep the amount of water transferred at 800 tonnes while increasing the moment arm from 21.25 m to just over 76 m while reducing the transfer time from 25 second to 15 seconds. The heeling tanks are shown in Figure 9 while the pumping and piping is shown in Figure 10. The length of the large diameter pipe is considerable resulting in a large mass of water traveling at high speed when the ship is upright. The kinetic energy has to be changed into some other form of energy before being able to force the water into the opposite direction. A pump is a very inefficient mean to stop water as it turns into a turbine when its rate of revolution is reduced. The difference in water level between the two tanks is also small and will be insufficient to cause a fast reversal of pumping direction.

A reasonable solution to this problem is to remove the customary air pipe that connects the two heeling tanks and thus create over pressure in the tank being filled while creating under pressure in the tank being emptied. The pump should be disconnected during the reversal process to avoid all chances for it to turn into a turbine that produces useless energy that has to be transferred into heat.

A possible solution to this task is shown in Figure 10. A fixed pitch propeller pump with symmetrical blade sections providing equal efficiency in both directions is attached to a shaft that may be powered from both ends. At each end there is a slip coupling that may be engaged to connect an electric motor to the pump shaft. The motors are of the variable speed variety and are electrically connected to each other, i.e. both are driven by the same control mechanism. The motors rotate in opposite direction, i.e. one drives the propeller to push the water towards the starboard side of the ship while the other drives the water towards the port side when connected to the shaft. Both electric motors are connected to large flywheels in order to store their energy while they are both disconnected from the pump shaft.

Tables 8.1 through 8.3 show a stepwise integration of the pumping process from zero heel to zero heel in about 15 seconds. Most of the equations used in this simulation are straightforward but some have to be confirmed by more involved studies and/or model tests. These assumptions are:

- the mass of water to be decelerated and accelerated is always constant at 267 tonnes
- 80% of the waters kinetic energy is available while the water is being decelerated
- the excess energy in the flywheels is reduced linearly during 6 seconds

Modifications to these assumptions will not change the concept but will influence the power level needed to do the task as well as the minimum and maximum pressures in the tanks. The calculation in Tables 8.1 to 8.3 show that 1.9 MW of pumping power is needed to move about 800 tonnes of water from one side to the other in about 15 seconds.

When starting the heeling system there will be no kinetic energy available in the heeling system and thus the first cycle will only transfer about 450 tonnes of water in about 15 seconds but already after 4 cycles the transferred amount has grown to about 790 tonnes.

A cross section through the heeling tank is shown in Figure 19 while the outrigger structure surrounding the heeling tank is shown in Figure 20. Of the water levels shown in Figure 19 the mean water level is only possible when the heeling tank is not in use as the water level is moving up respectively down at a rate of about 37 cm per second when the tanks are in use causing some major unevenness in the water surface. However, the minimum and maximum water levels will be close to the ones shown in Figure 19 as the water is only moving 1cm in one direction and 1 cm in the other during one second at this stage in the heeling process.

Some of the information at the top of Table 8.1 should be self evident but the following may require some explanation:

- ship/tank 0.5241 means that 52.41 % of the water level in the tank causes pressure in the system as the icebreaker is heeling over at a rate of 47.59 % of the water level in the tank
- air gap 4.6 m indicates the distance from the mean water level to the top of the air pocket under the assumption that the tank and air pocket has a constant horizontal cross section of 220.8 m²

- spec resistance 0.01285 means that the water resistance in the heeling pipe in meters is 0.01285 times the water speed squared

Solvent free epoxy paints have been used on icebreakers and ice going ships since the early 1970's to keep the hull from losing most of its paint during ice operations and thus leading to excessive corrosion and much increased levels of friction between the ice and the hull. Solvent free paints have also been introduced on older ships with great benefit. Today there would be extraordinary circumstances to stop a ship owner from applying solvent free epoxy paint to an icebreaker or ice going ship.

Stainless steel compound plates have been fitted close to the water line on icebreakers since the 1980's to eliminate the excessive wear on the solvent free paints in the areas most influenced by breaking a solid ice cover. On the proposed icebreaker it is suggested to apply stainless steel compound plate in the bow portion from 2 m below the ice breaking water line to 1 m above the ice breaking water line.

Hull heating has not been used on icebreakers, at least not in a conscious manner, but it is proposed that electrical hull heating be provided for the proposed icebreaker in the bow portion from 1m below the ice breaking water line to 0.5 m above the ice breaking water line to make absolutely certain that there will be no pushing of broken ice ahead of the ship at cold temperatures when operating in thin ice.

4.7 CREWING

While owned and operated by Canmar Marine Drilling the Kigoriak was run by a crew of 17 to 18 people who normally spent 6 weeks on board and 3 weeks on leave. For costing purposes it is assumed that the new ice breaker will need a crew of 28 people to run the ship and that these spend the same amount of time on board as on leave.

Figures 21 to 27 show a possible arrangement of accommodation if the ship would be prepared for a large amount of supernumeraries during scientific expeditions. The sleeping quarters include 12 one person cabins and 42 two person cabins for a total of 96 people, i.e. for a total of 68 supernumeraries in addition to the normal crew.

Due to the 100 m total beam of the ship it is not practical or desirable to design a bridge that spans the entire width. Figures 21 and 22 show a proposed alternate bridge arrangement where all command centres are concentrated in a fairly small area on deck 9. During normal operation in open water and ice the deck officer would operate the ship from this level and when sailing in ice the ice pilot would manipulate all available ice data from the conning station on deck 10. When assisting other ships in ice or when operating in very critical ice conditions the deck officer and the ice pilot would switch places in order to achieve maximum efficiency.

Figures 28 and 29 show various mooring arrangements for the proposed icebreaker.

4.8 ALTERNATE USE

In the Baltic Sea the proposed icebreaker would have a limited operating window, leaving considerable amount of time for other employment. Some possibilities are listed below:

- demonstrate that traffic across the Arctic Ocean from the Atlantic to The Pacific is possible at any time of the year
- assistance in all energy related projects in ice infested waters
- research in the Arctic and the Antarctica. As shown e.g. in Figure 9 it is convenient to arrange a moon pool in the forward portion of the icebreaker in order to make research operations possible even in difficult ice conditions. The deckhouse may be extended forward in order to provide more space for laboratories and the moon pool area may be enclosed in order to facilitate research even in very cold temperatures. If the ship would be provided with a dynamic positioning system it would be feasible to perform coring operations in almost any ice condition without the assistance from other icebreakers
- by repositioning the helicopter fuel tanks the entire area between frame 12 and frame 48 on the platform deck 18 m above the BL may be transformed into a 1,296 m² laboratory space, see Figure 9. A 6 m by 6 m moon pool could be added in order to connect this laboratory space with the bottom of the ship

5 COSTS

The only way to get a reasonable price estimate for an icebreaker is to base it on actual icebreakers of similar design that have been built in the past after a competitive bidding process while taking into account inflation and the change in power - which is the dominant factor for the price of an icebreaker.

To account for inflation we may use the Wholesale Price Index in Finland, which appears on the internet with a base of 100 in 1949. In 1978 when the Kigoriak was bid this index was 727 and in 1986 when the Oden was bid the index was 1,264 and in 2004 it will be about 1,710.

When involved in the Oden project I estimated the price to end up at about 50 million US\$ based on the following simple calculation. When Kigoriak was bid its price came to 19 million US\$ after a Canadian subsidy in force at that time which was intended to compensate for the higher building costs when compared to the international market. Inflation influence was $1,264 / 727 = 1.7387$ and Oden's larger propulsion power should increase the price by $24,000 / 16,400 = 1.4634$ for a total price of $1.7387 * 1.4634 * 19 =$ about 48 million US\$. In addition the Oden is fitted with a fast heeling system and proportionally has a larger steel weight which should increase the price to more than 50 million US\$. But only two Canadian shipyards had competed for the Kigoriak while the Oden would be tendered internationally which should lower the price to about 50 million US\$.

The Oden was bid internationally and the Swedish Maritime Administration received offers from Japanese, German, Canadian, Finnish and Swedish shipyards. The prices had a fairly wide range between 50 and almost 100 million US\$. One Finnish and one Swedish shipyard desperately

wanted the building contract and the final price became 41.2 million US\$, which did not provide any reasonable profit for the winning yard.

When estimating a 2004 price for a 60,000 hp icebreaker I assume that a reasonable price for the Oden in 1986 would have been 50 million US\$. The inflation will increase the price by a factor of $1,710 / 1,264 = 1.3528$ and the larger power by a factor of $60,000 / 24,000 = 2.5$ for a total price of $1.3528 * 2.5 * 50 =$ about 169 million US\$.

In addition the larger icebreaker will proportionally have more steel than the Oden and due to the thruster propulsion it has to be equipped with electric transmission. These two major changes will increase the price by about 70 million US\$ for a total estimated price of 239 million US\$. Rounding this to the nearest higher 50 million we get a conservative price estimate of about 250 million US\$.

The annual operating cost for the icebreaker is estimated as follows:

Crew cost	3,360,000	2 crews of 28 man each for US\$ 60,000 / year
Deck & hull	1,500,000	
Engine etc	2,000,000	
General	1,500,000	
Insurance	3,000,000	
Administration	600,000	
Dry dock accrual	1,000,000	

for a total of about 13 million US\$ per year. This does not include costs for fuel and consumables which are entirely dependent of the manner in which the icebreaker is used.

6. PROPOSED FURTHER WORK

As may be seen in Figure 5 it is proposed to use a propeller configuration where the propeller and nozzle is located in front of the support structure. The main reason for this is to reduce the possibility of ice clogging the propeller. For the same reason it is proposed to use a propeller design where the leading edges of the individual blades are located at the forward most edge of the propeller, see Figure 4. The influence on propeller efficiency and cavitation properties must be examined both theoretically and by model tests in open water and in a cavitation tunnel.

Ice model tests should be performed in order to assess the critical items of the new concept, mainly the clearing of the ice around the hull.

As mentioned earlier the critical items of the fast heeling system should be studied in more detail.

A study of the potential uses for such a capable icebreaker should be initiated.

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FIGURES and TABLES

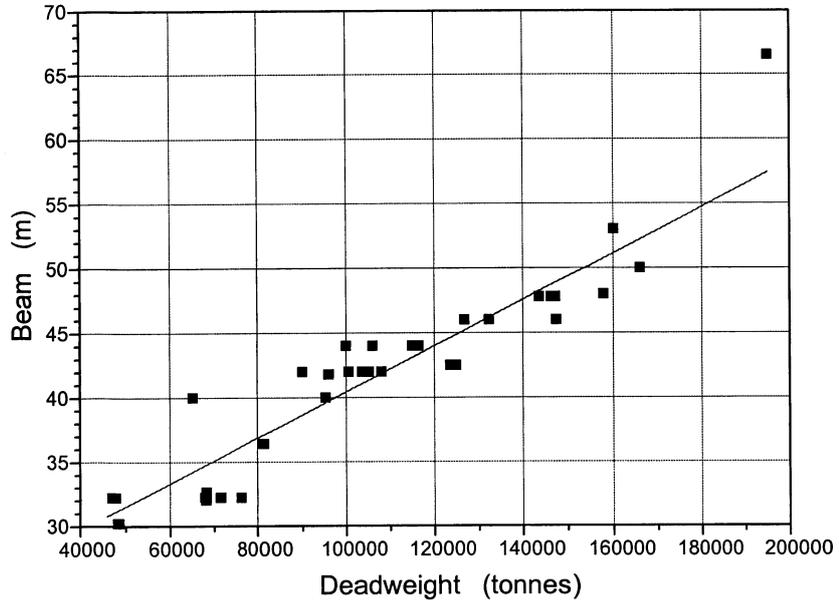
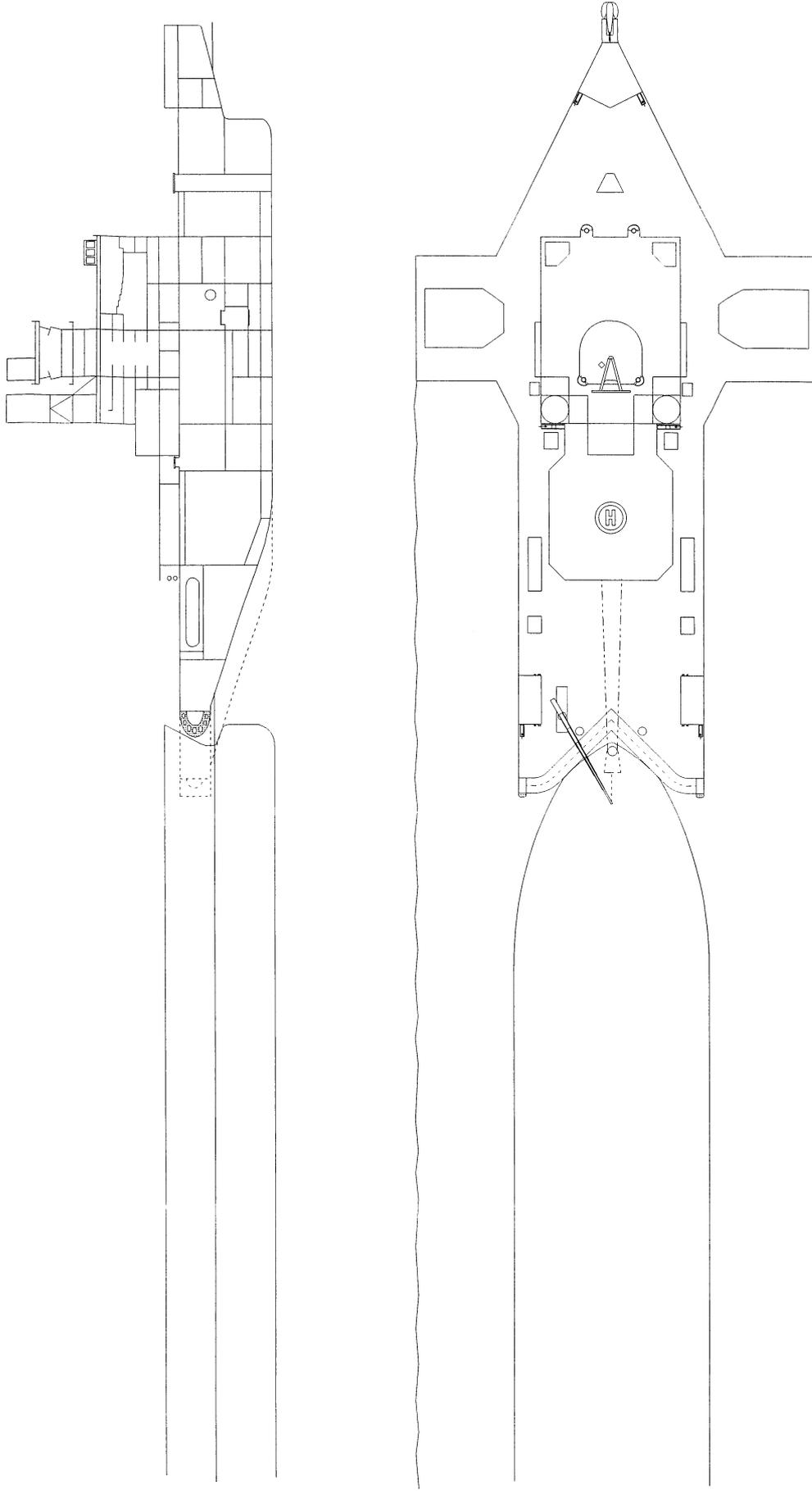


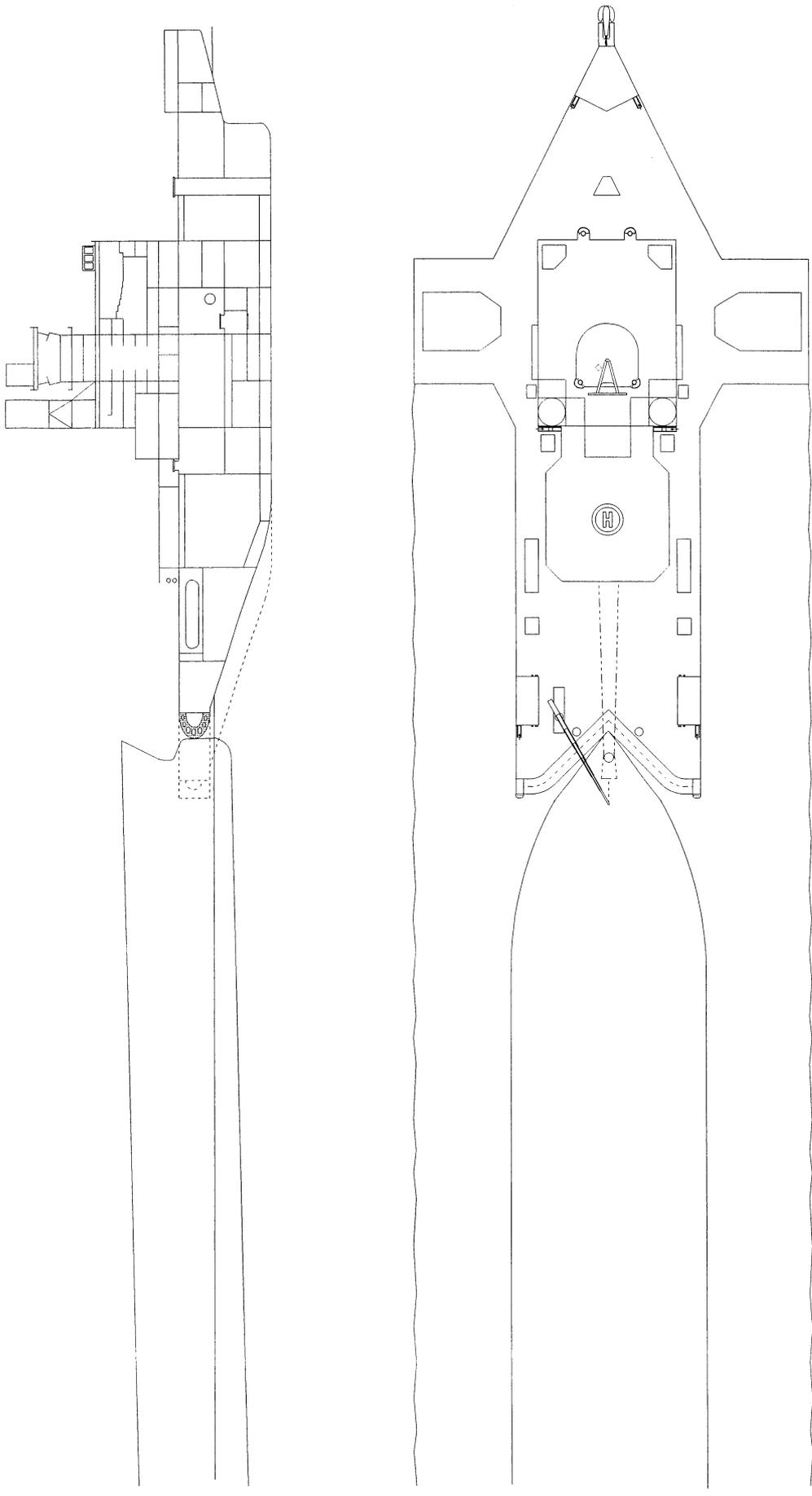
Figure 1 Relationship Between Beam and Deadweight For Existing Tankers



SCALE 1:1,600

ICEBREAKER FOR B-MAX TANKERS
50 M WIDE TANKER IN SHORT TOW
WHILE IN FULL LOAD

FIGURE 2



SCALE 1:1,600

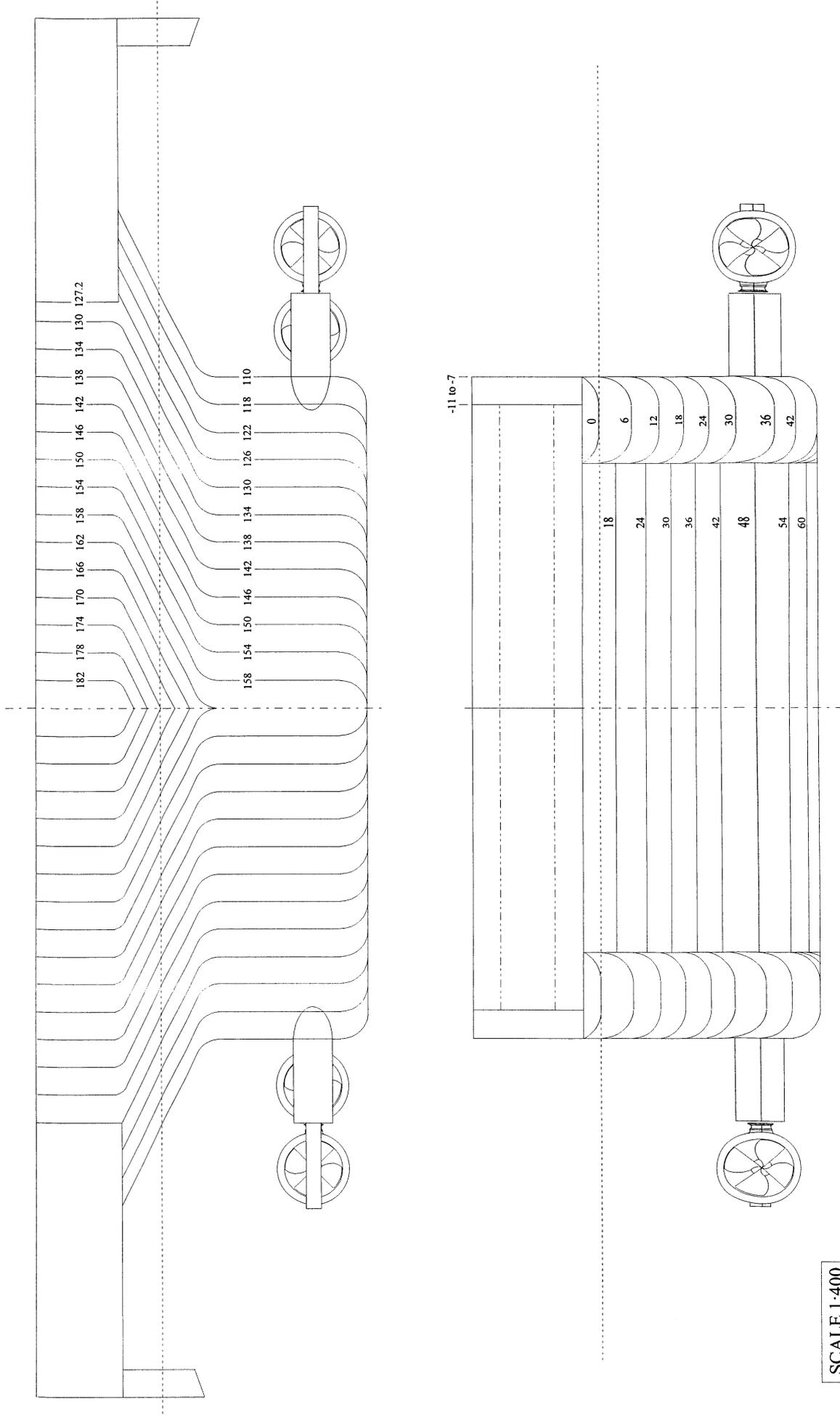
FIGURE 3

**ICEBREAKER FOR B-MAX TANKERS
50 M WIDE TANKER IN SHORT TOW
WHILE IN BALLAST**

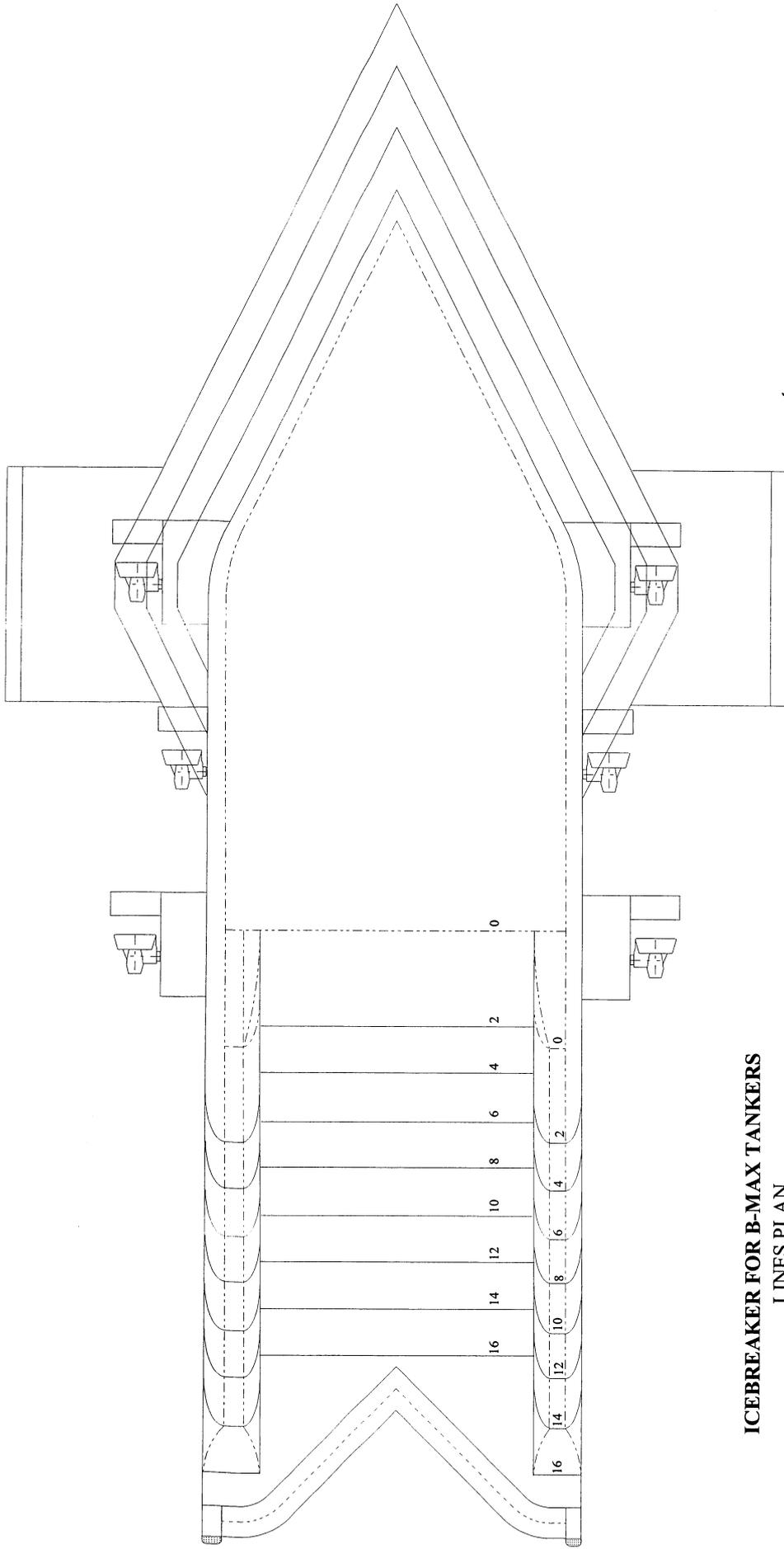
ICEBREAKER FOR B-MAX TANKERS
BODY PLAN

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FIGURE 4



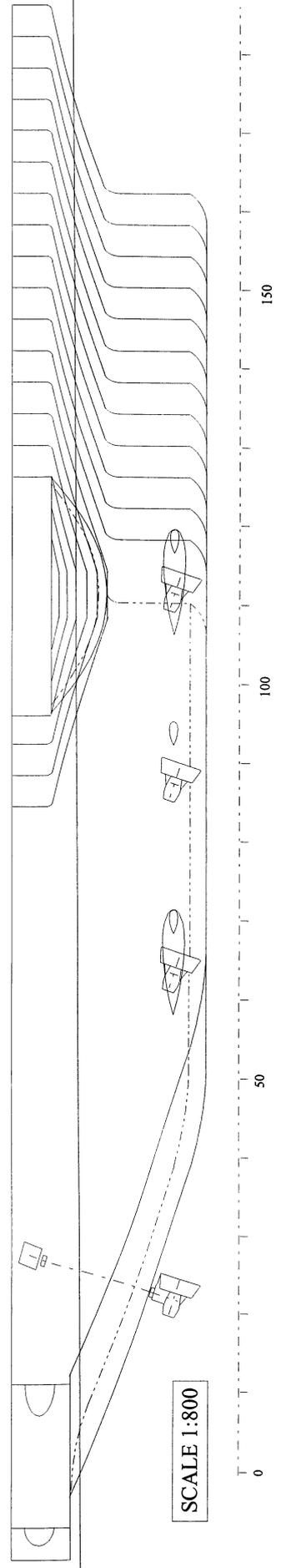
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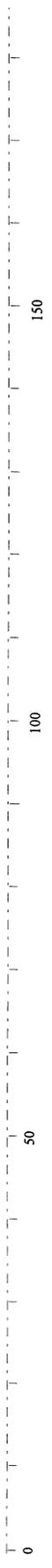
ICEBREAKER FOR B-MAX TANKERS
LINES PLAN

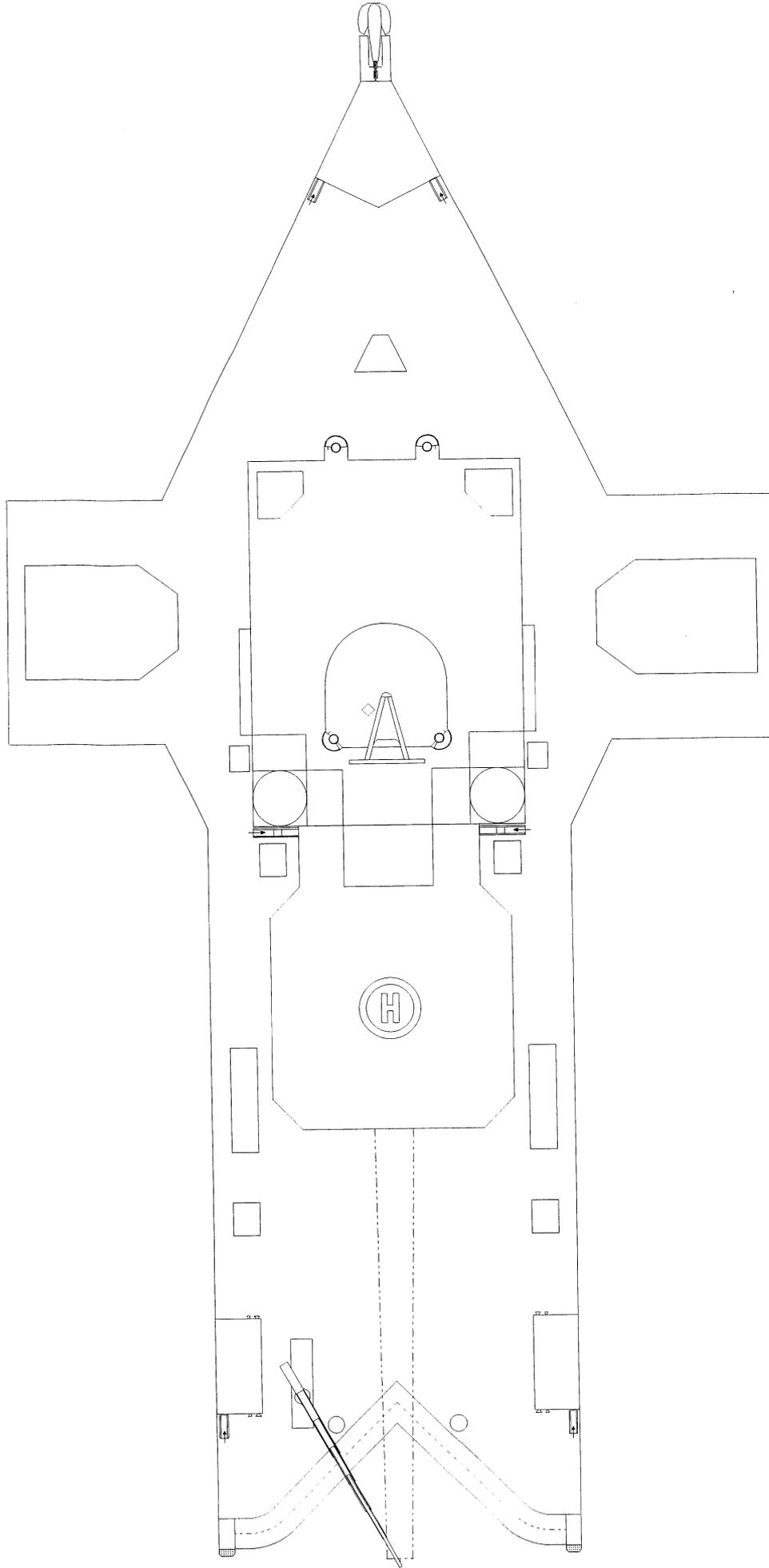
FIGURE 5

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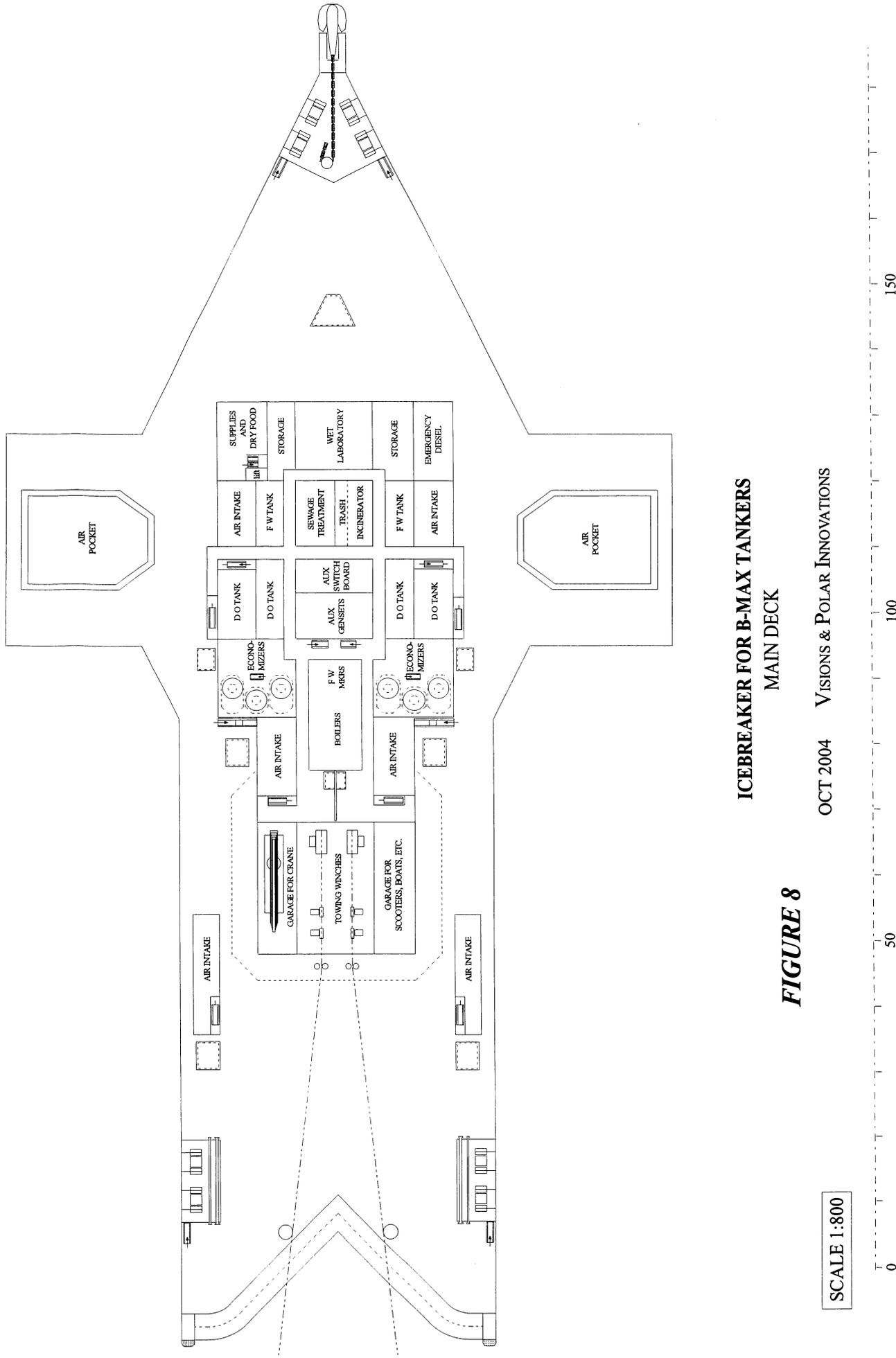


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FIGURE 7

ICEBREAKER FOR B-MAX TANKERS
TOP VIEW WHILE PREPARING FOR SHORT TOW

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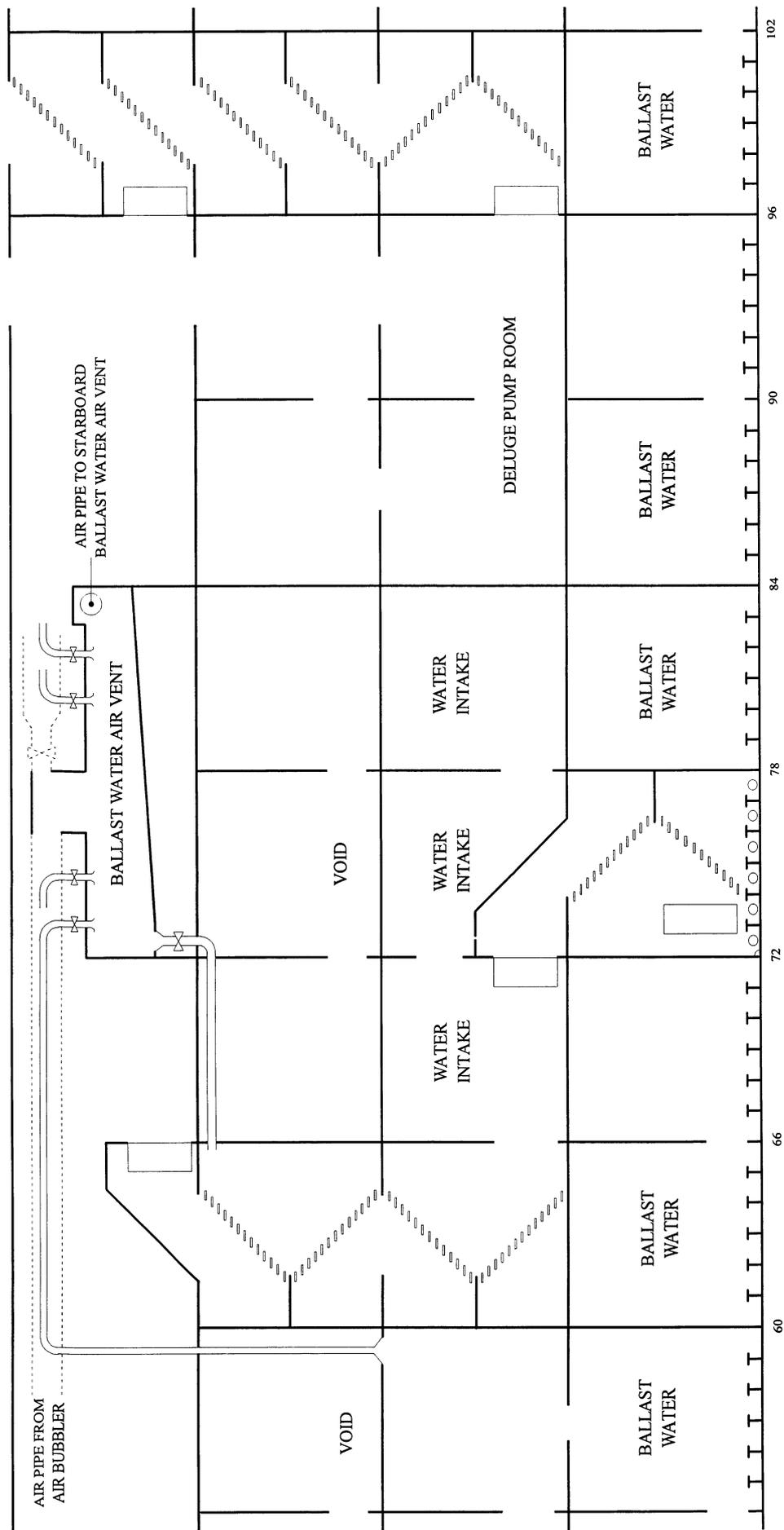
ICEBREAKER FOR B-MAX TANKERS
MAIN DECK

FIGURE 8

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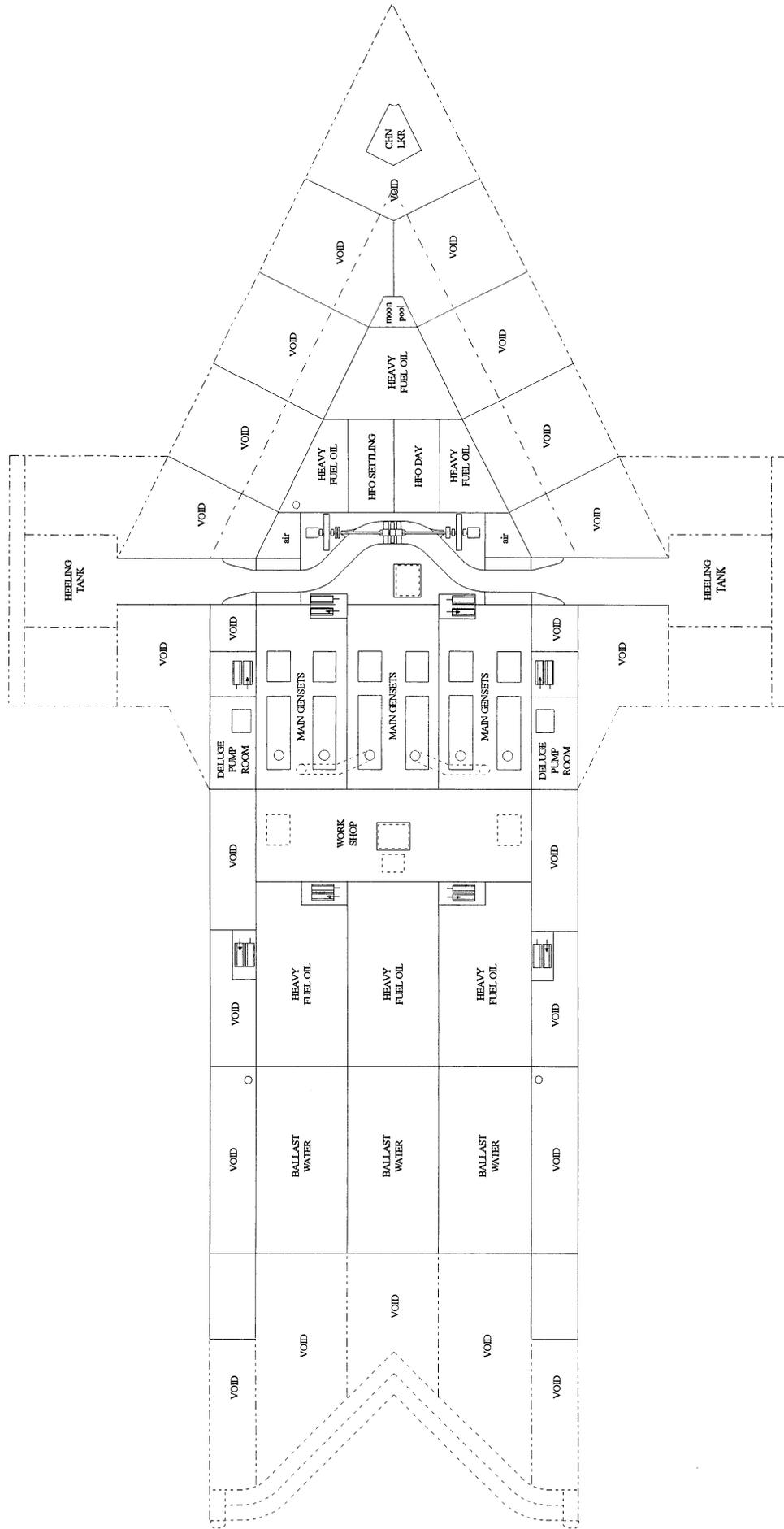


ICEBREAKER FOR B-MAX TANKERS
CROSS SECTION THROUGH PORT WING TANK

FIGURE 9A

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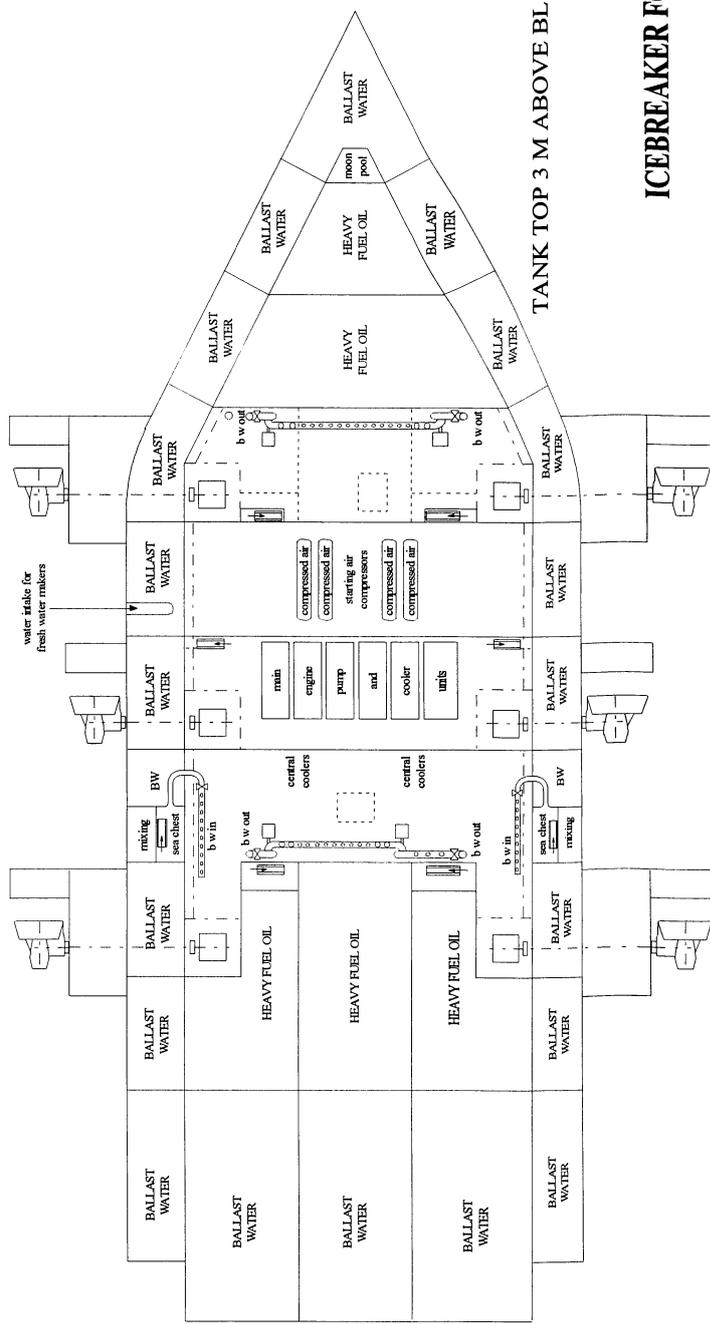
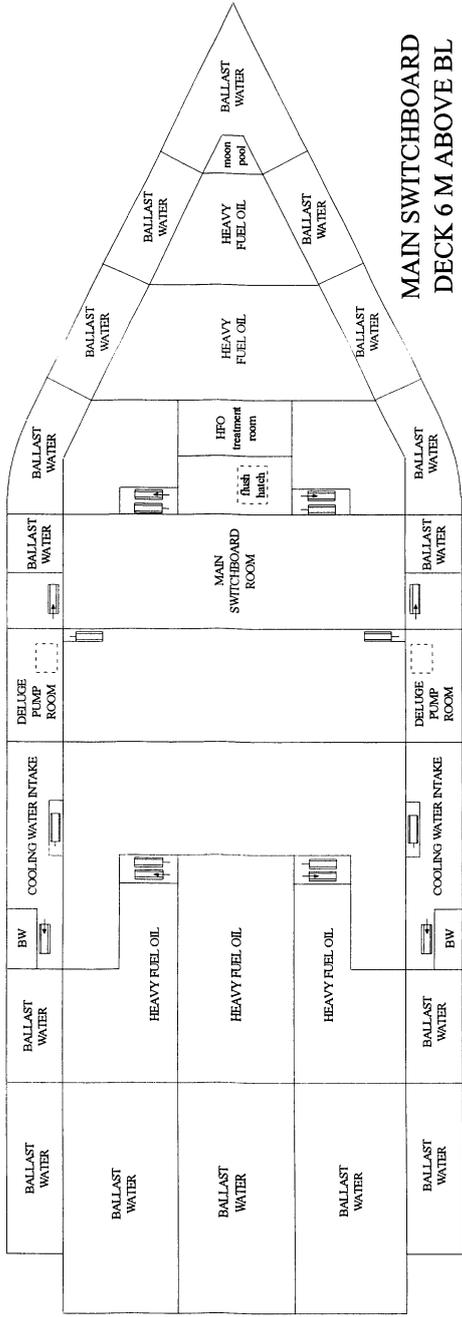
ICEBREAKER FOR B-MAX TANKERS
MAIN GENERATOR DECK 12 M ABOVE BL

FIGURE 10

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SCALE 1:800



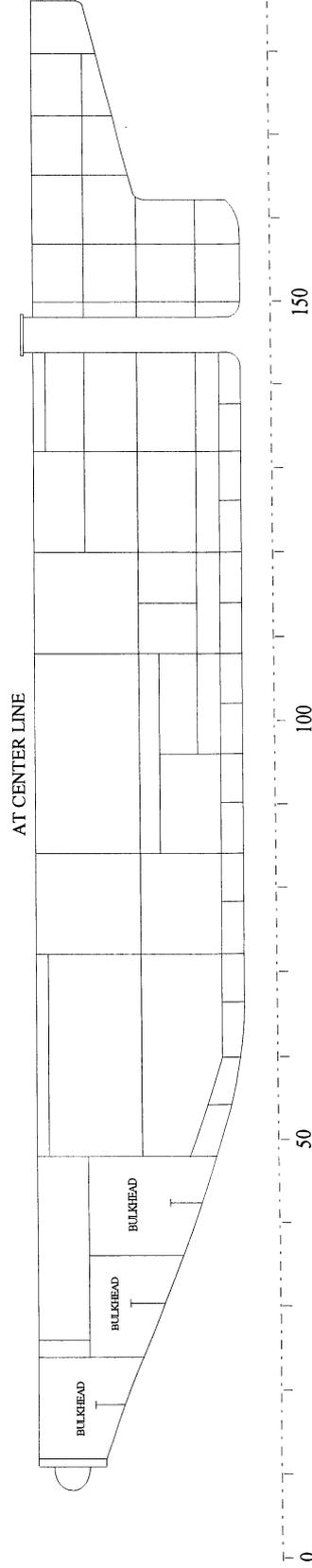
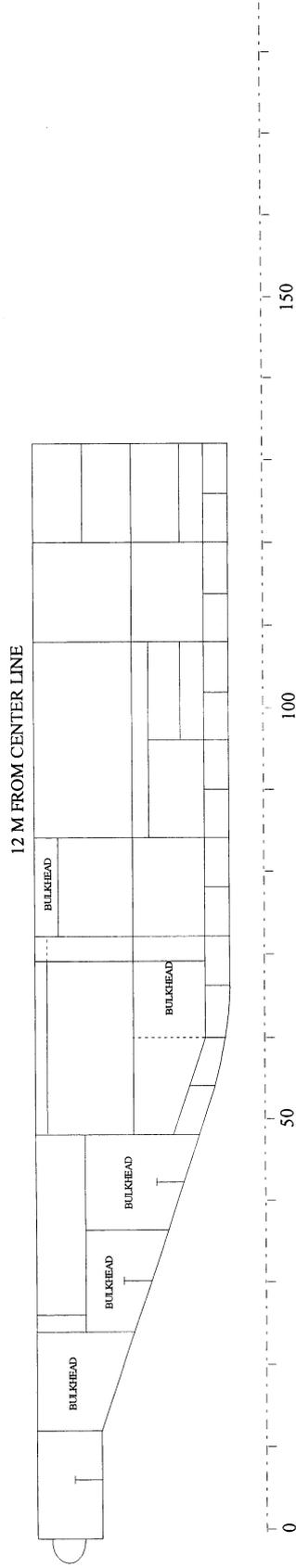
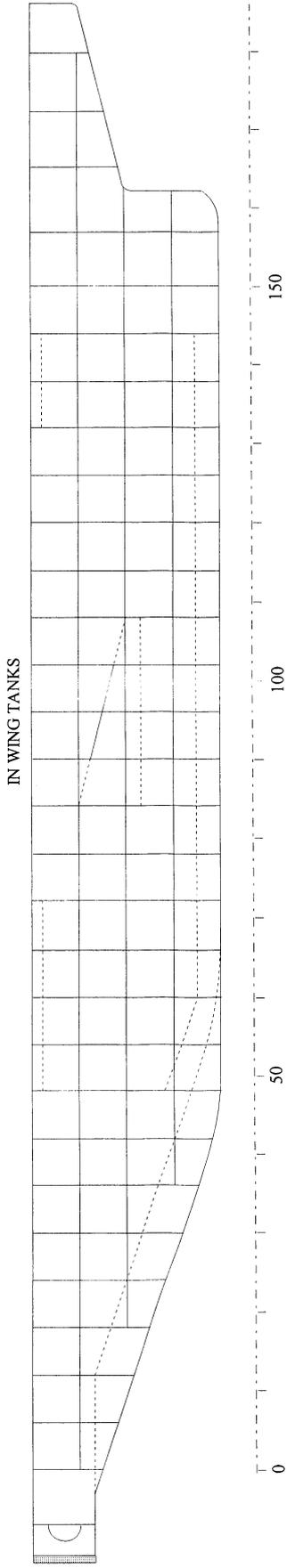


ICEBREAKER FOR B-MAX TANKERS

FIGURE 11

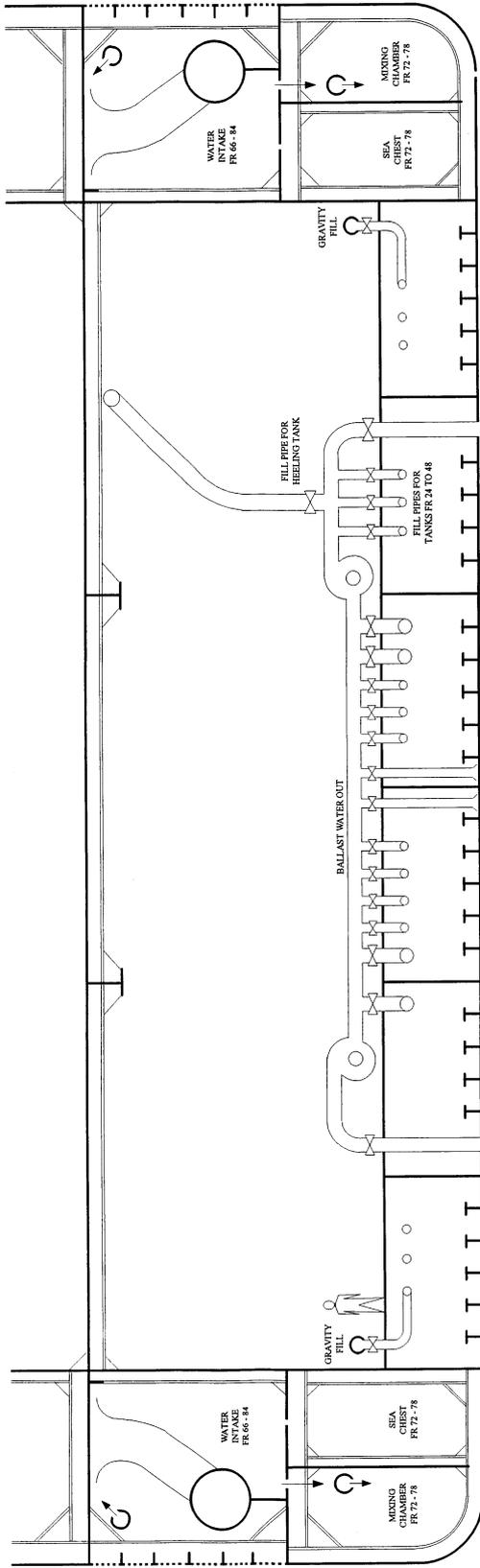
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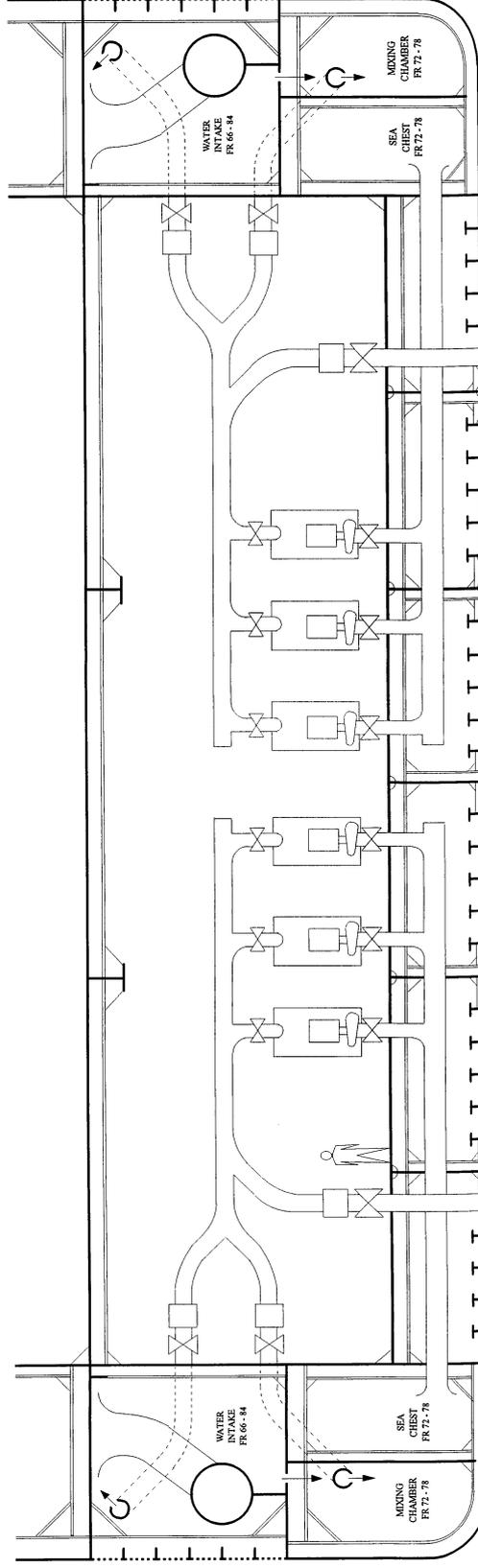


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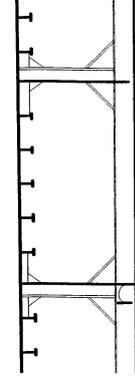
FIGURE 14
ICEBREAKER FOR B-MAX TANKERS
 PRINCIPAL TRANSVERSE MEMBERS
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BALLAST WATER SYSTEM



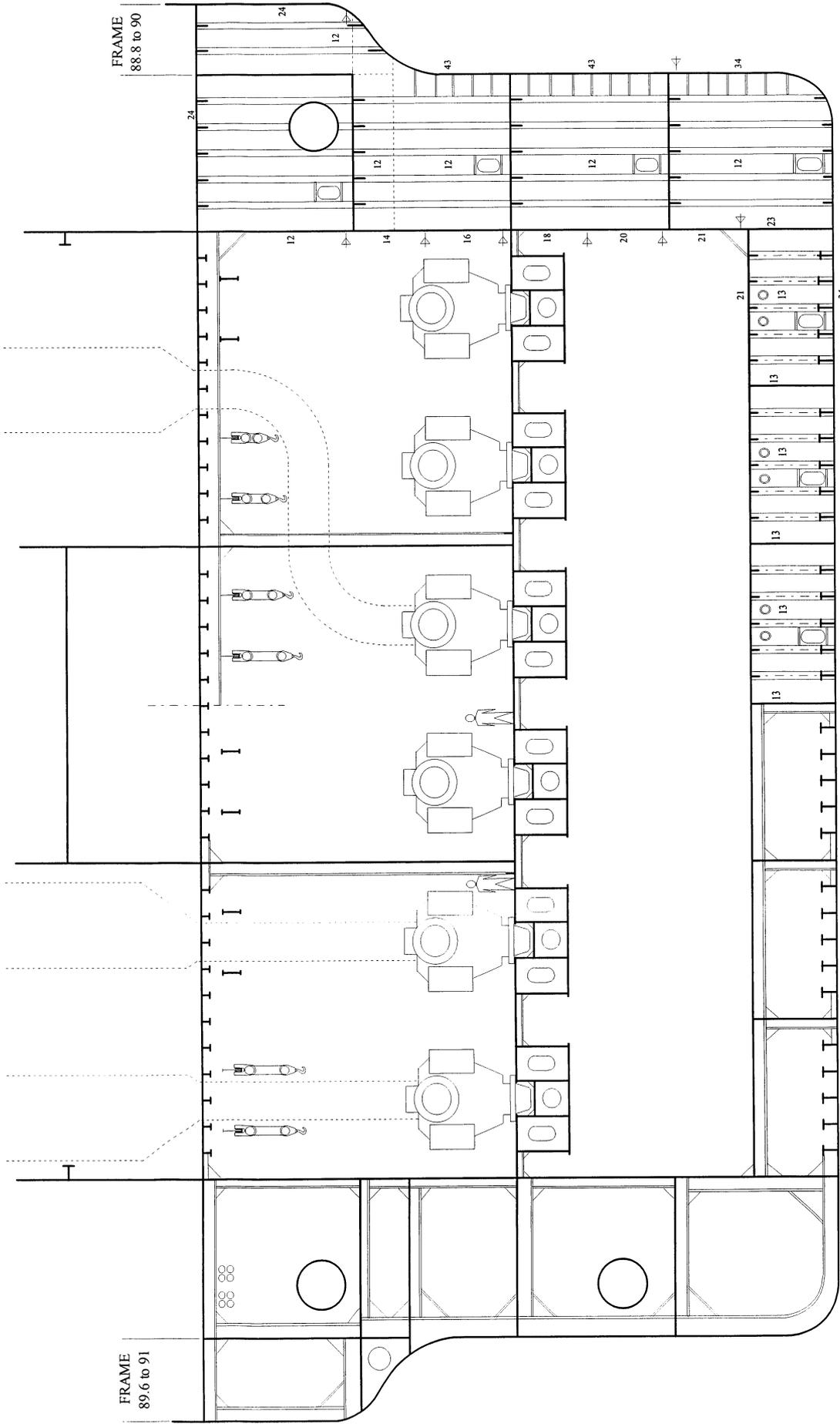
CENTRAL COOLING SYSTEM



ICEBREAKER FOR B-MAX TANKERS

FIGURE 15

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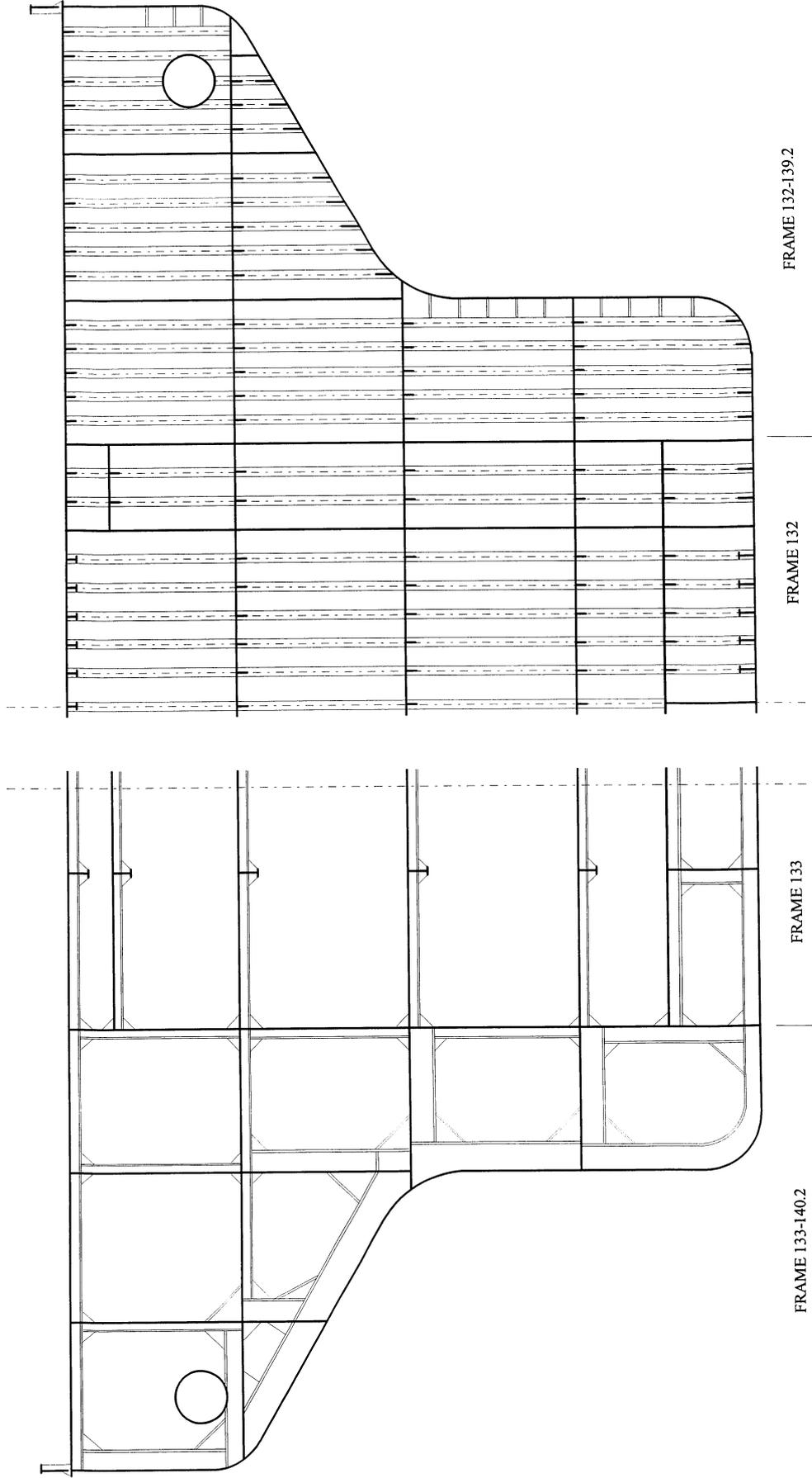


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ICEBREAKER FOR B-MAX TANKERS
TRANSVERSE SECTION

FIGURE 16

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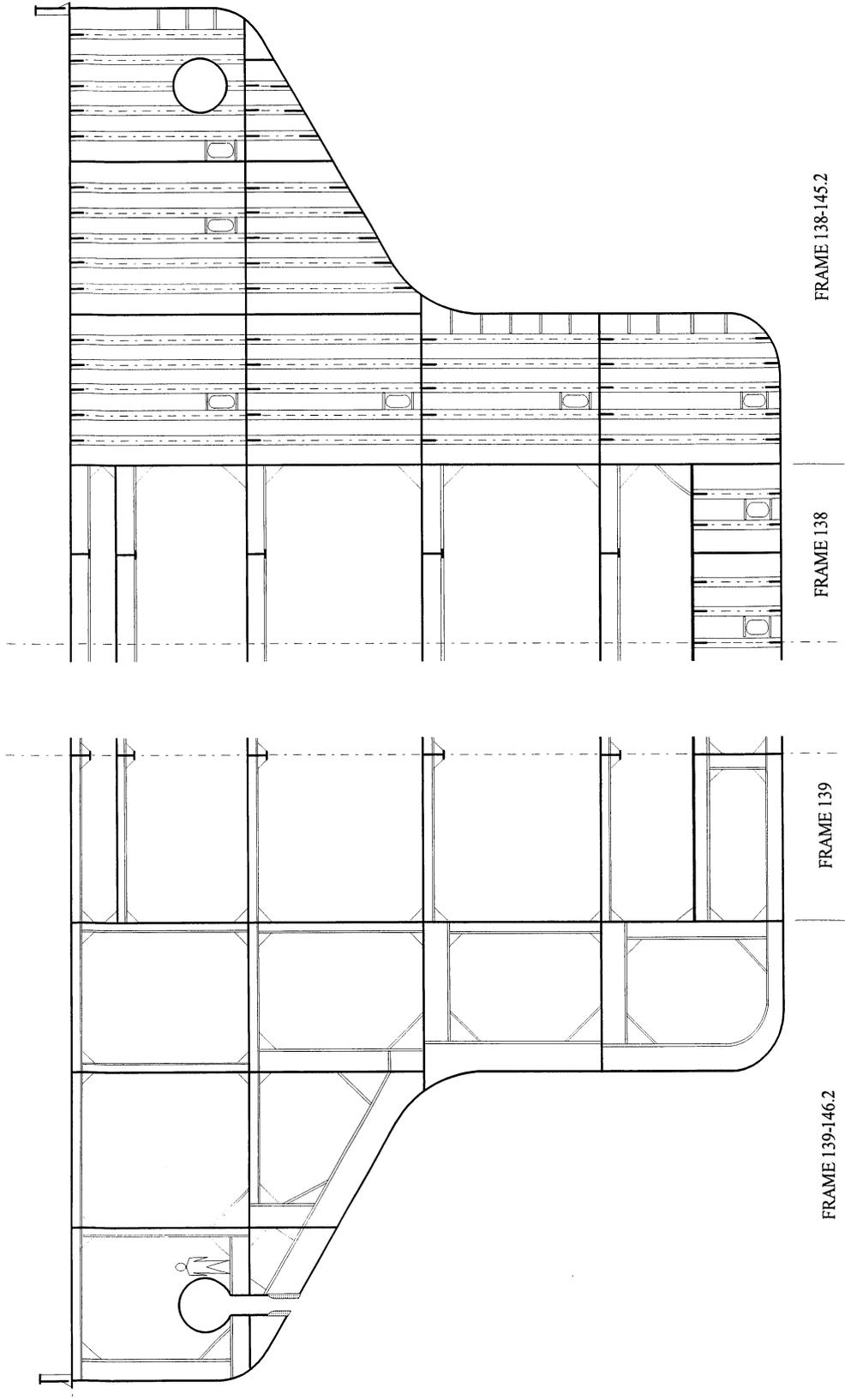


ICEBREAKER FOR B-MAX TANKERS
TRANSVERSE SECTION

FIGURE 17

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ICEBREAKER FOR B-MAX TANKERS
TRANSVERSE SECTION

FIGURE 18

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OCT 2004 VISIONS & POLAR INNOVATIONS

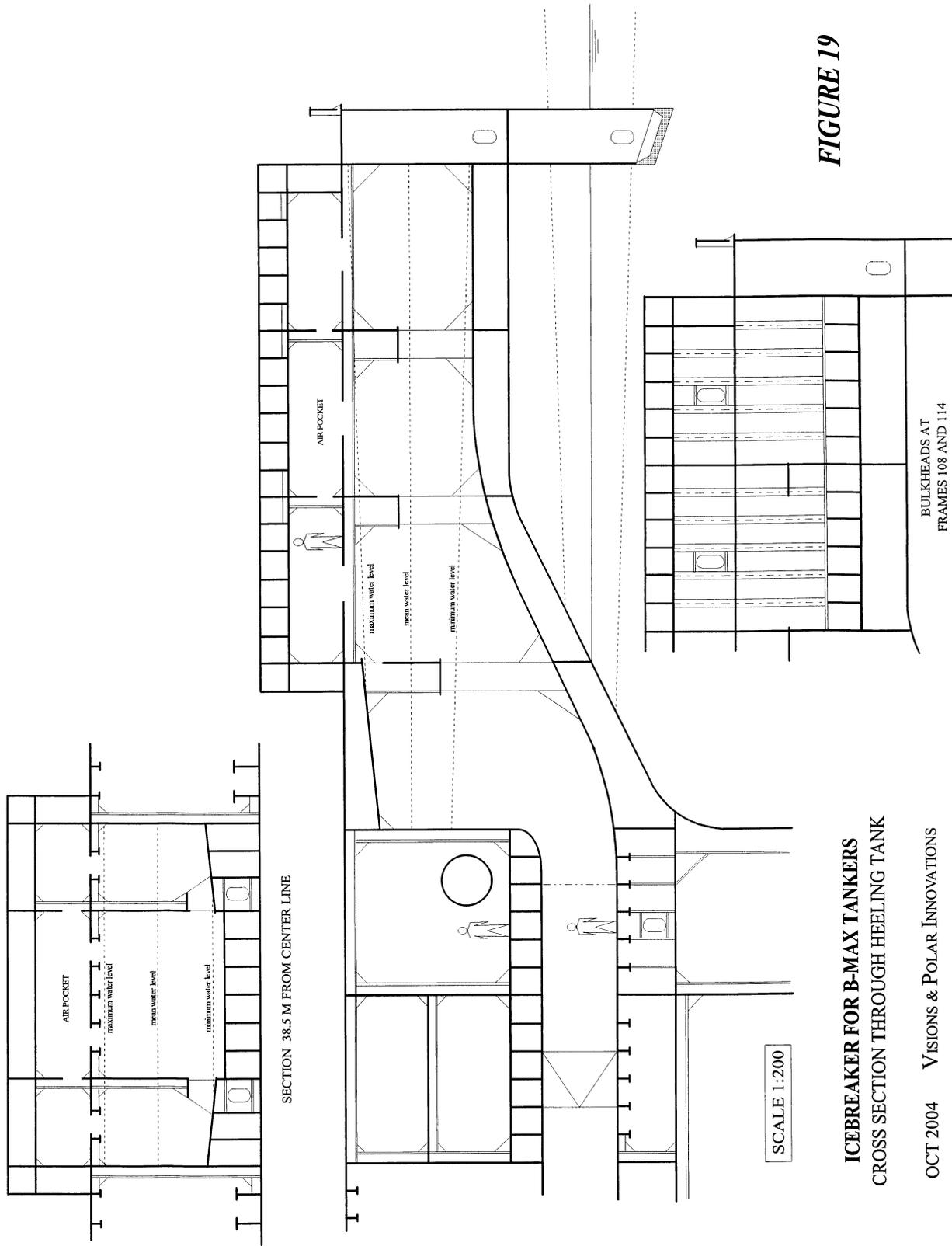


FIGURE 19

**ICEBREAKER FOR B-MAX TANKERS
CROSS SECTION THROUGH HEELING TANK**

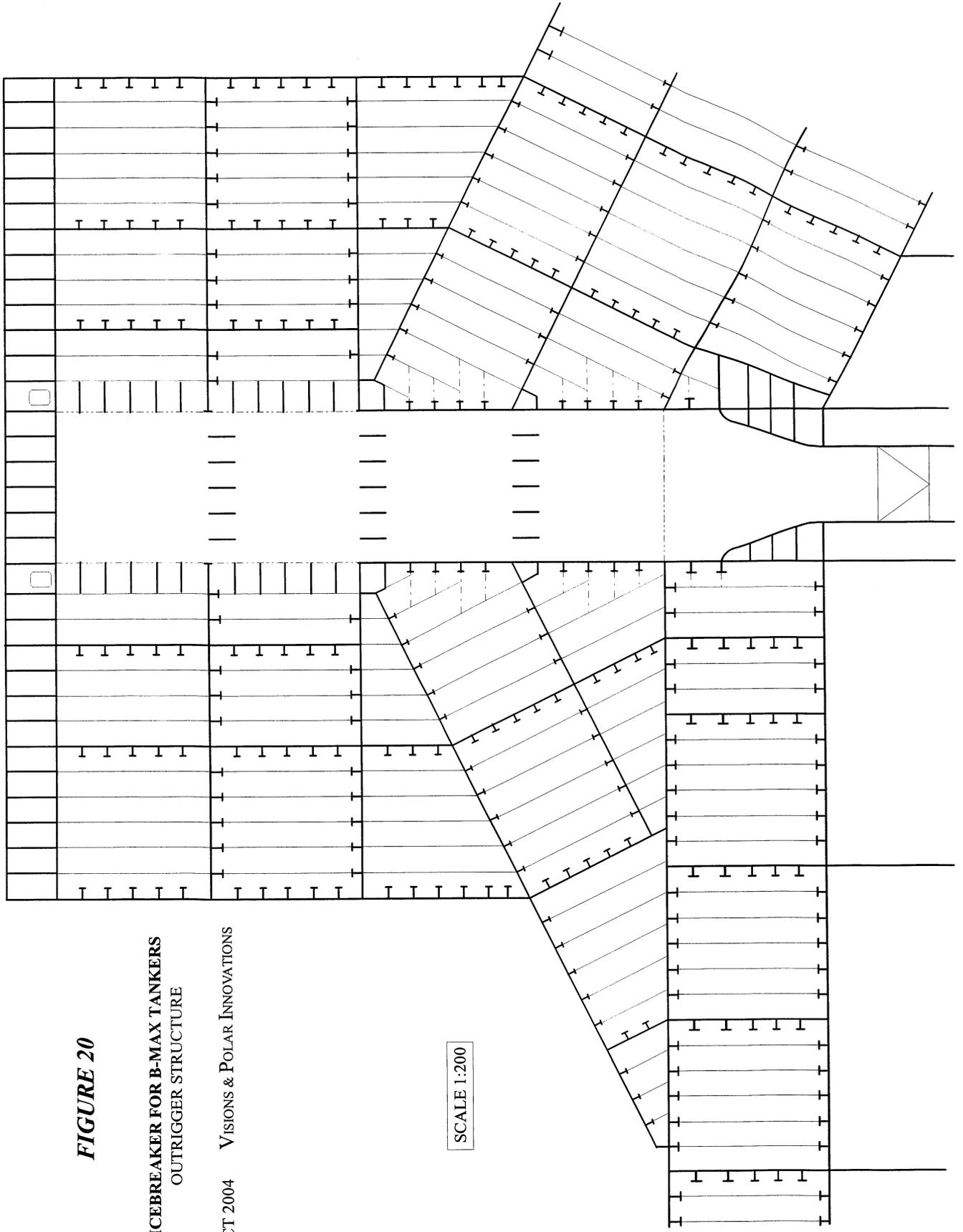
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FIGURE 20

**ICEBREAKER FOR B-MAX TANKERS
OUTRIGGER STRUCTURE**

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SCALE 1:200



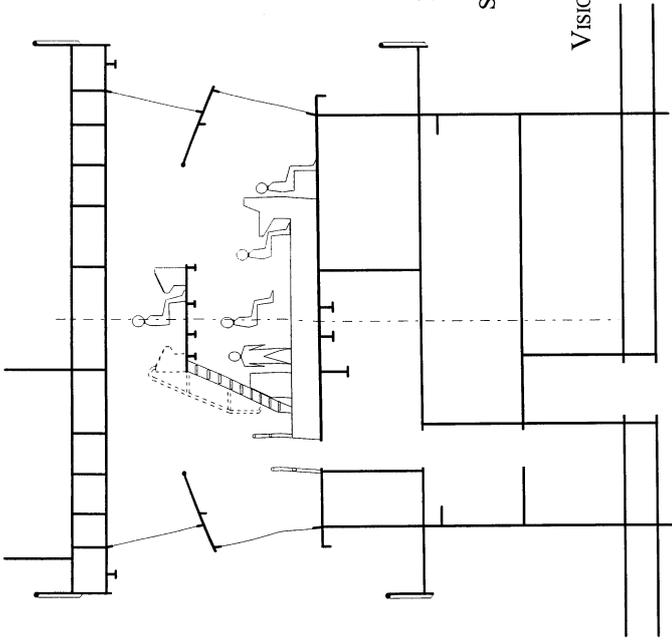
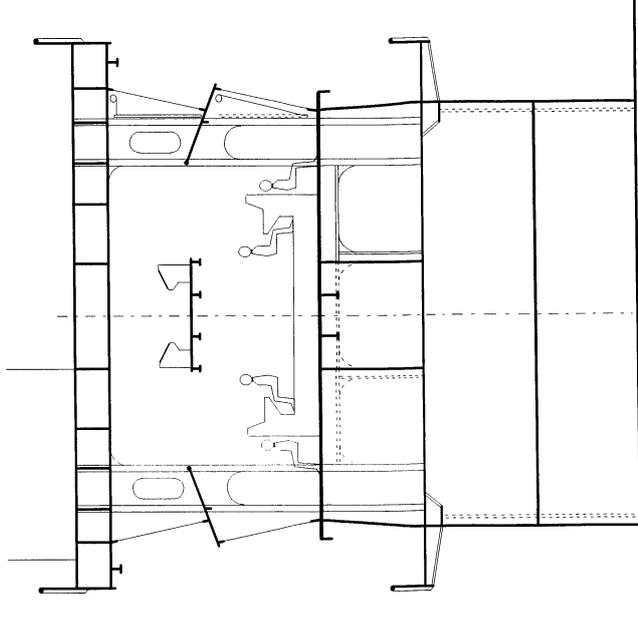
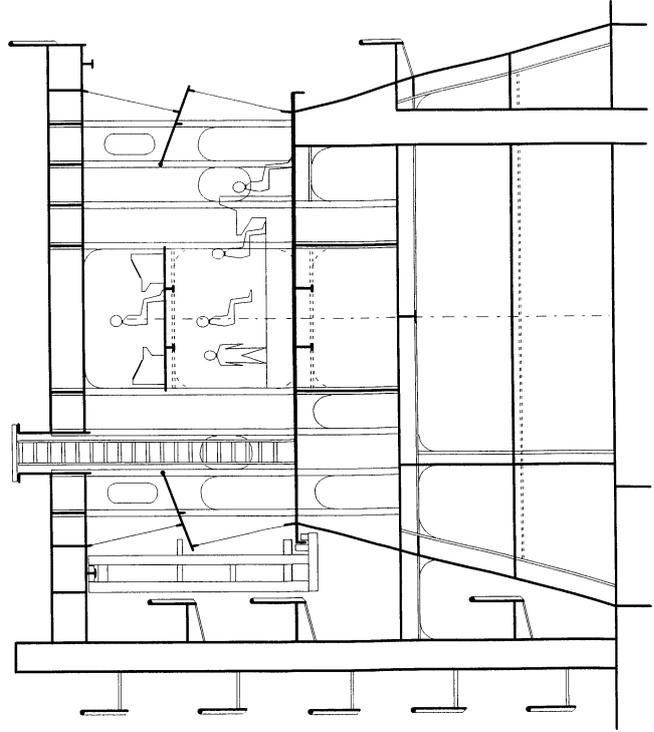


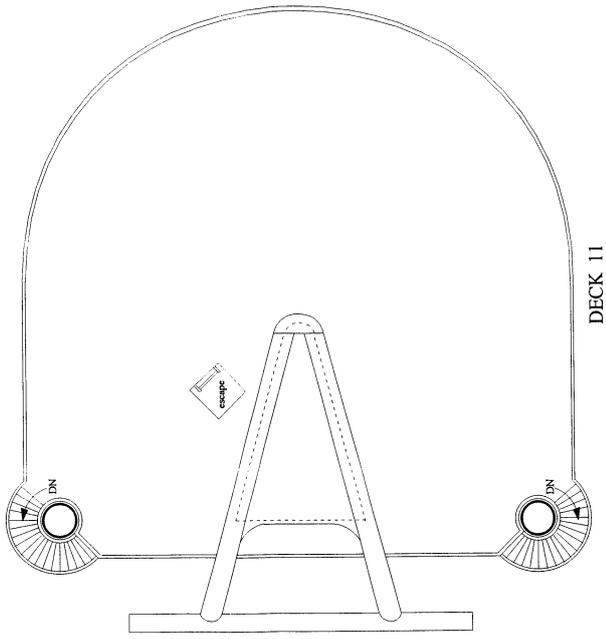
FIGURE 21

**ICEBREAKER FOR
B-MAX TANKERS
SECTIONS THROUGH
BRIDGE TOWER
OCT 2004**
VISIONS & POLAR INNOVATIONS

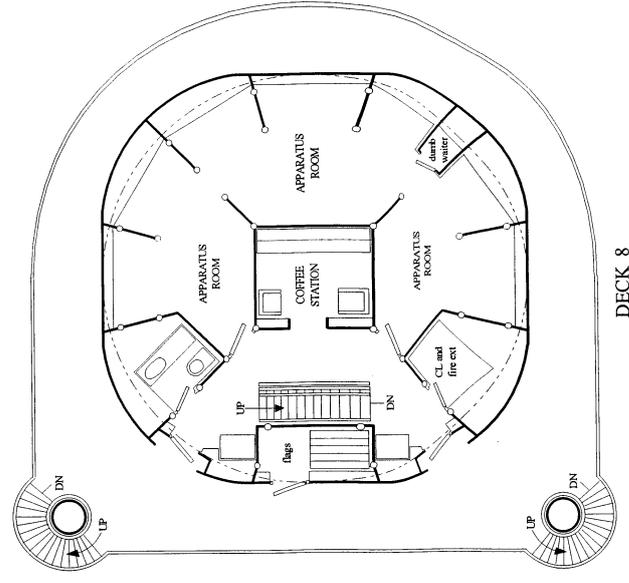


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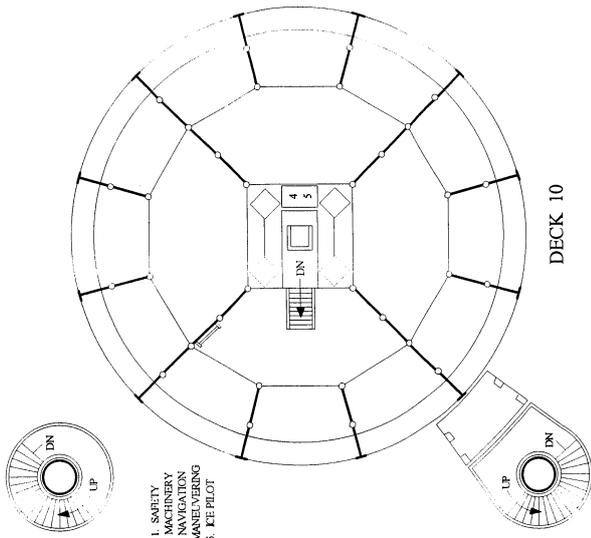




DECK 11

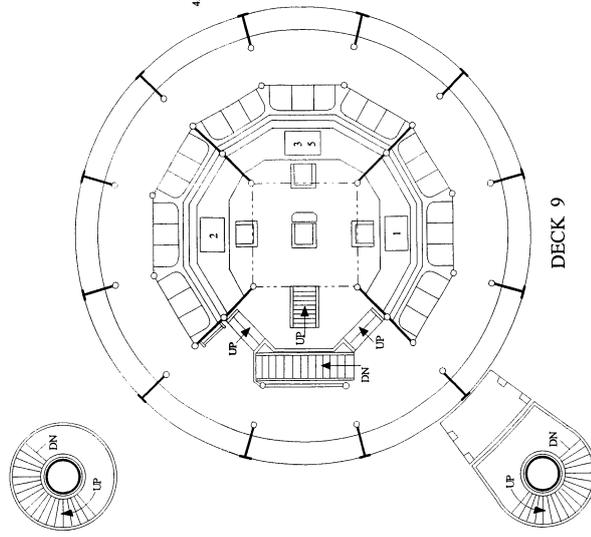


DECK 8

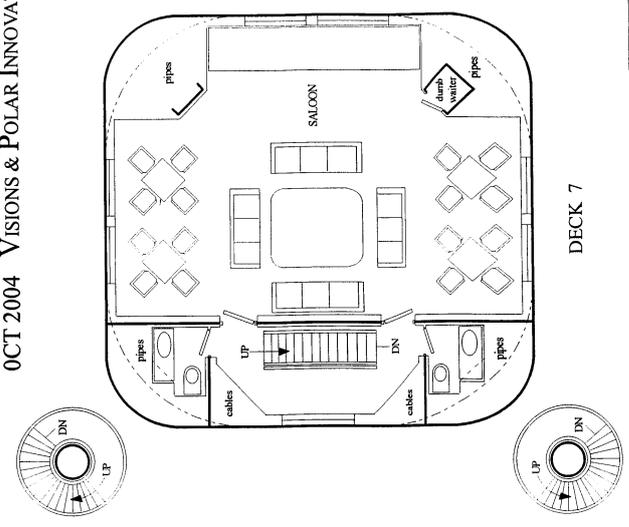


DECK 10

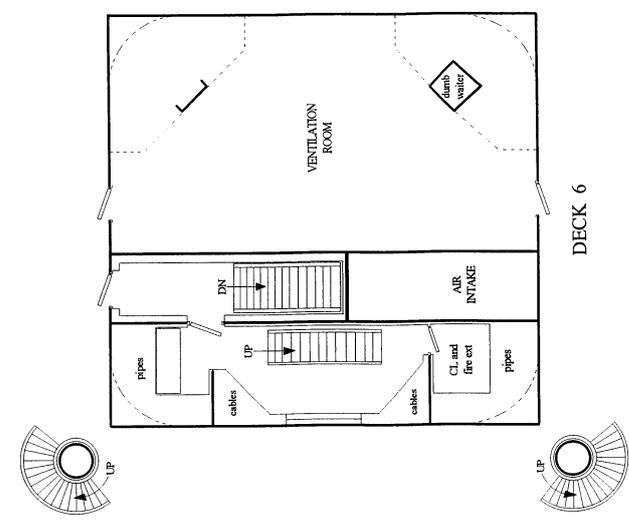
- 1. SAFETY
- 2. MACHINERY
- 3. NAVIGATION
- 4. MANEUVERING
- 5. C/PILOT



DECK 9



DECK 7



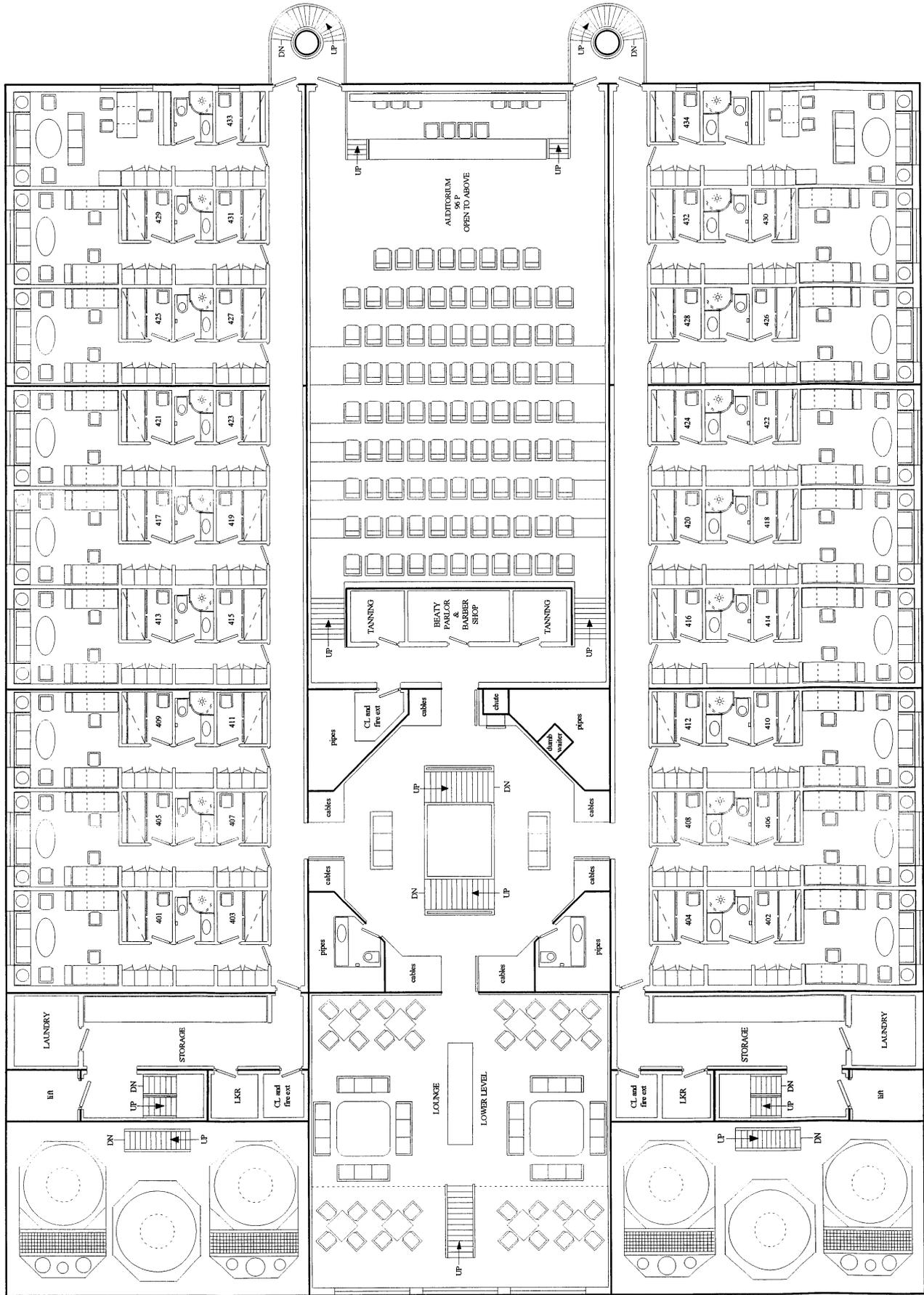
DECK 6

ICEBREAKER FOR B-MAX TANKERS
DECKS IN BRIDGE TOWER

OCT 2004 VISIONS & POLAR INNOVATIONS

FIGURE 22

SCALE 1:200

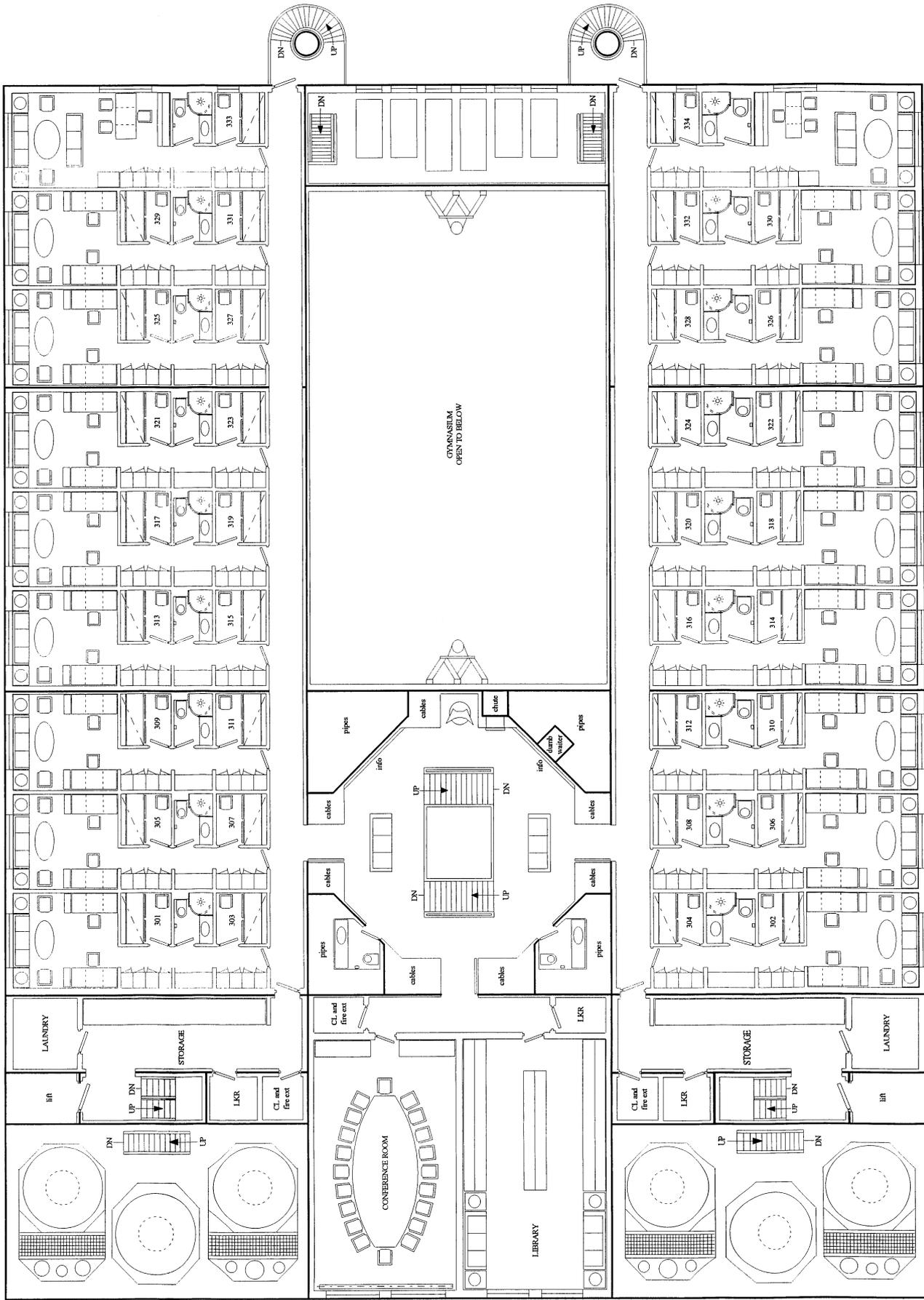


OCT 2004 VISIONS & POLAR INNOVATIONS

ICEBREAKER FOR B-MAX TANKERS
DECK 4

FIGURE 24

SCALE 1:200

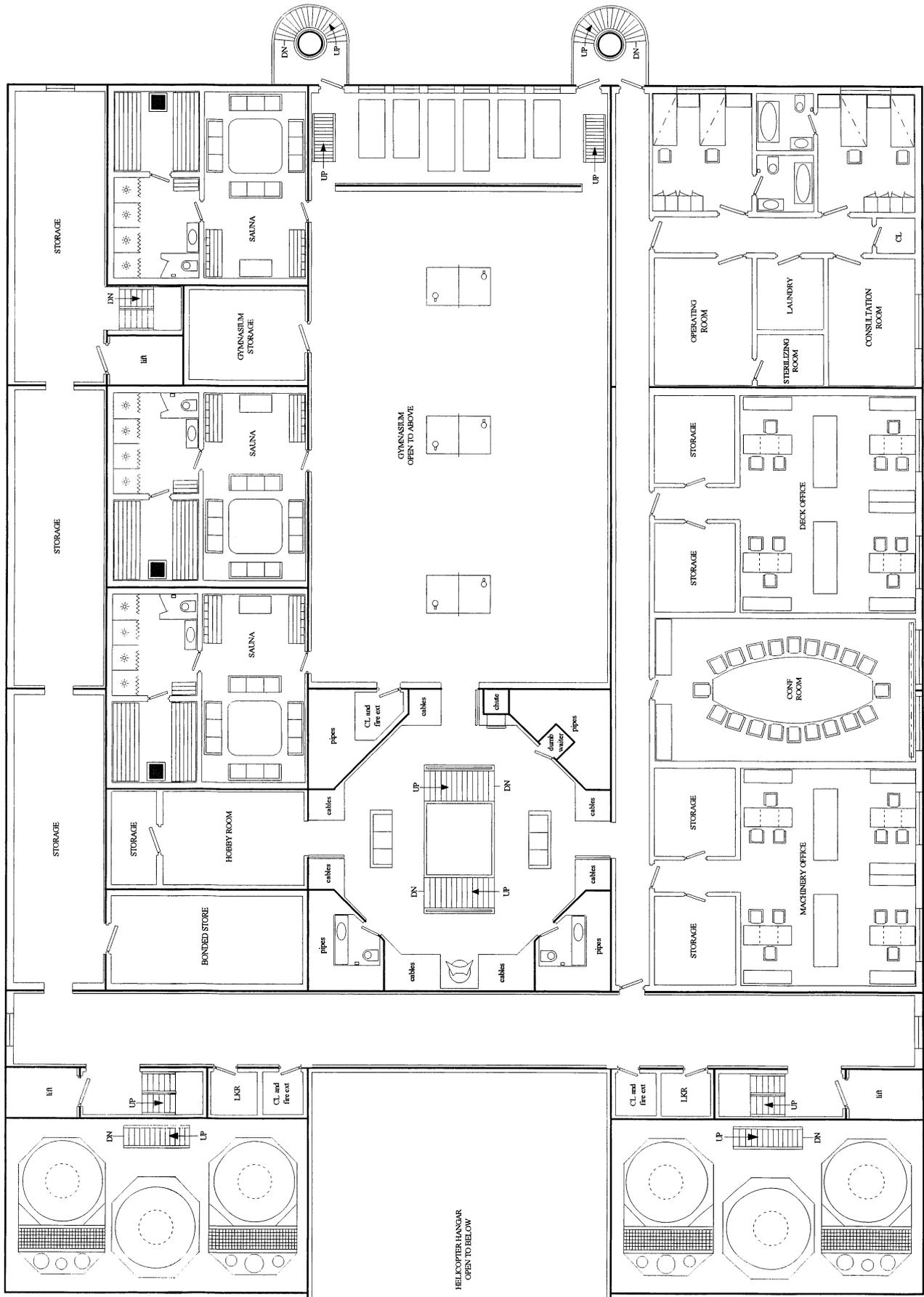


OCT 2004 VISIONS & POLAR INNOVATIONS

ICEBREAKER FOR B-MAX TANKERS
DECK 3

FIGURE 25

SCALE 1:200

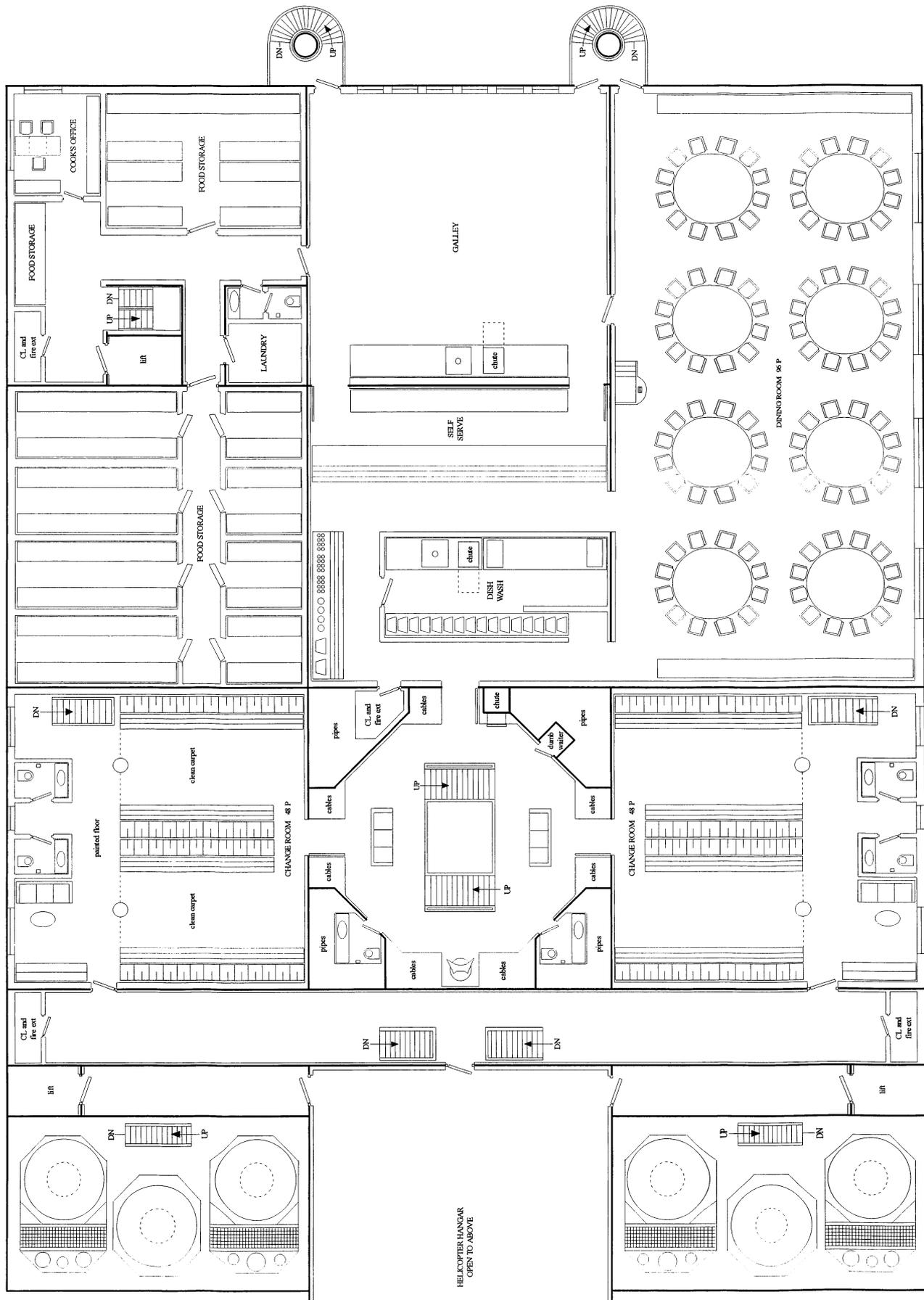


OCT 2004 Visions & Polar Innovations

ICEBREAKER FOR B-MAX TANKERS
DECK 2

FIGURE 26

SCALE 1:200

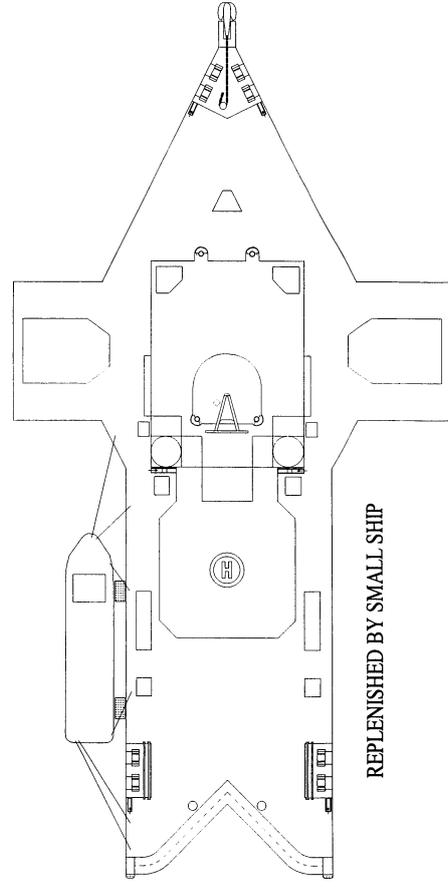
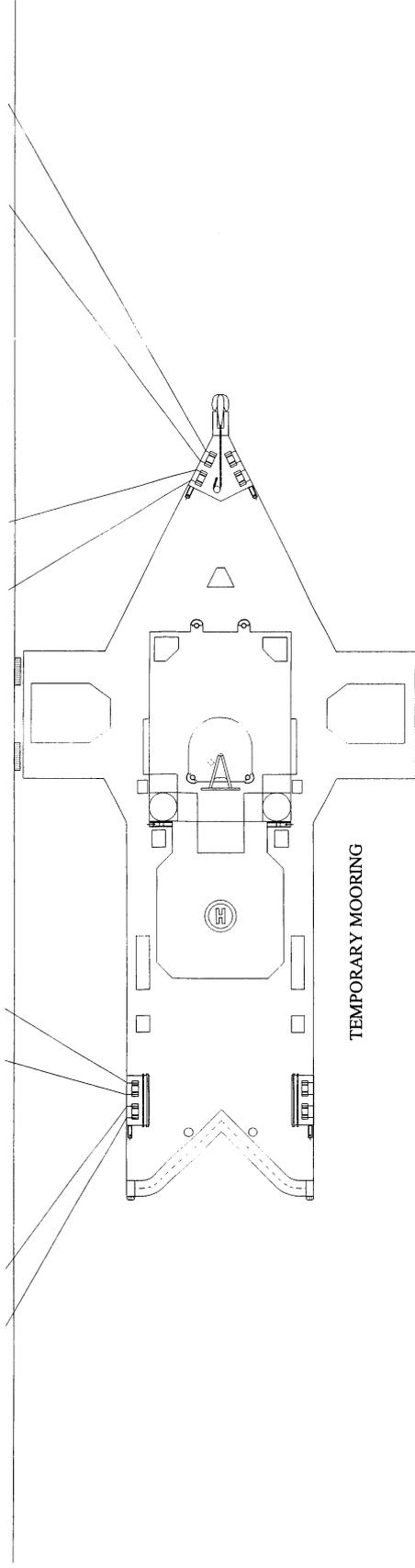


OCT 2004 VISIONS & POLAR INNOVATIONS

ICEBREAKER FOR B-MAX TANKERS DECK 1

FIGURE 27

SCALE 1:200

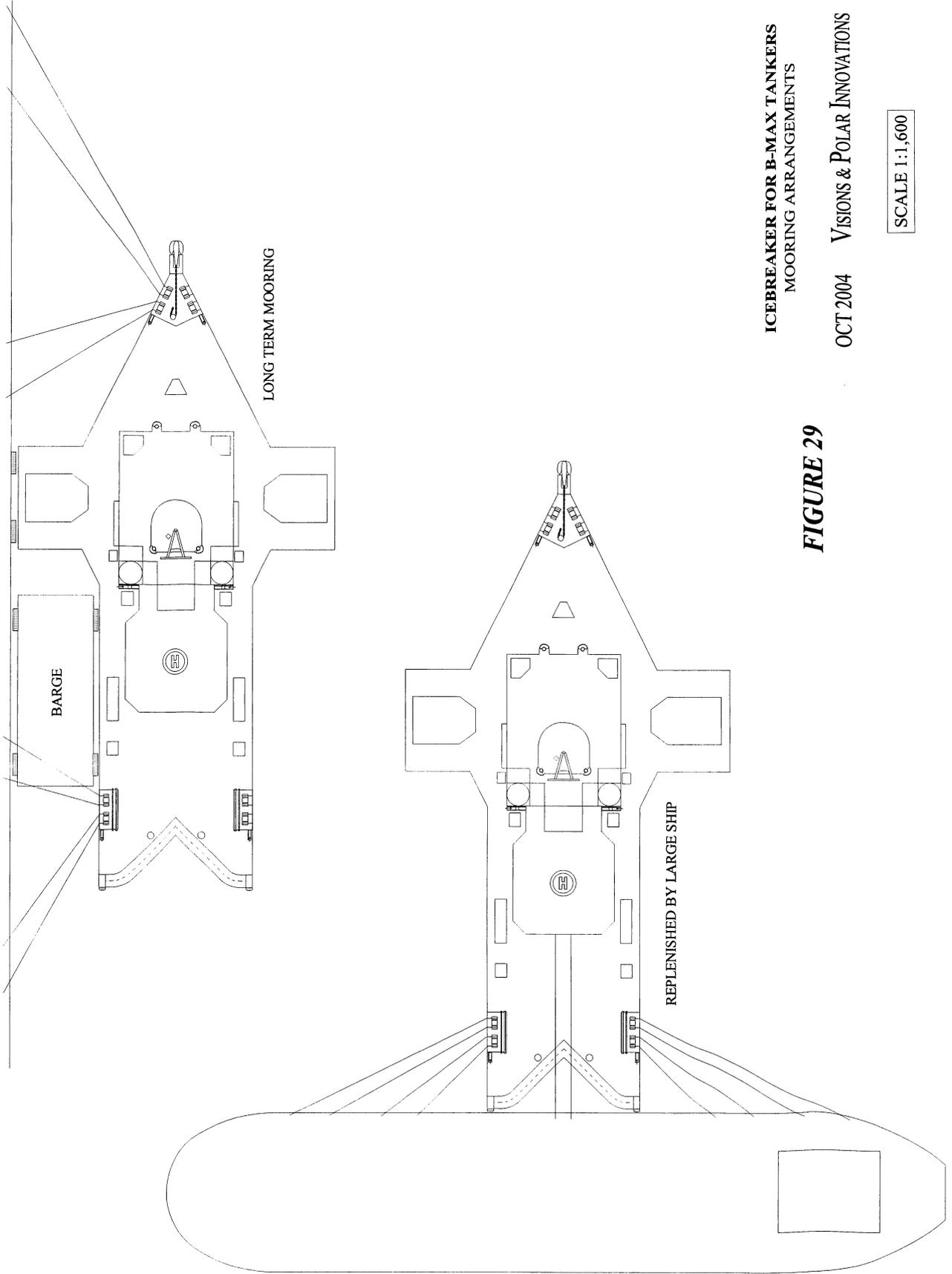


ICEBREAKER FOR B-MAX TANKERS
MOORING ARRANGEMENTS

FIGURE 28

OCT 2004 Visions & Polar Innovations

SCALE 1:1,600

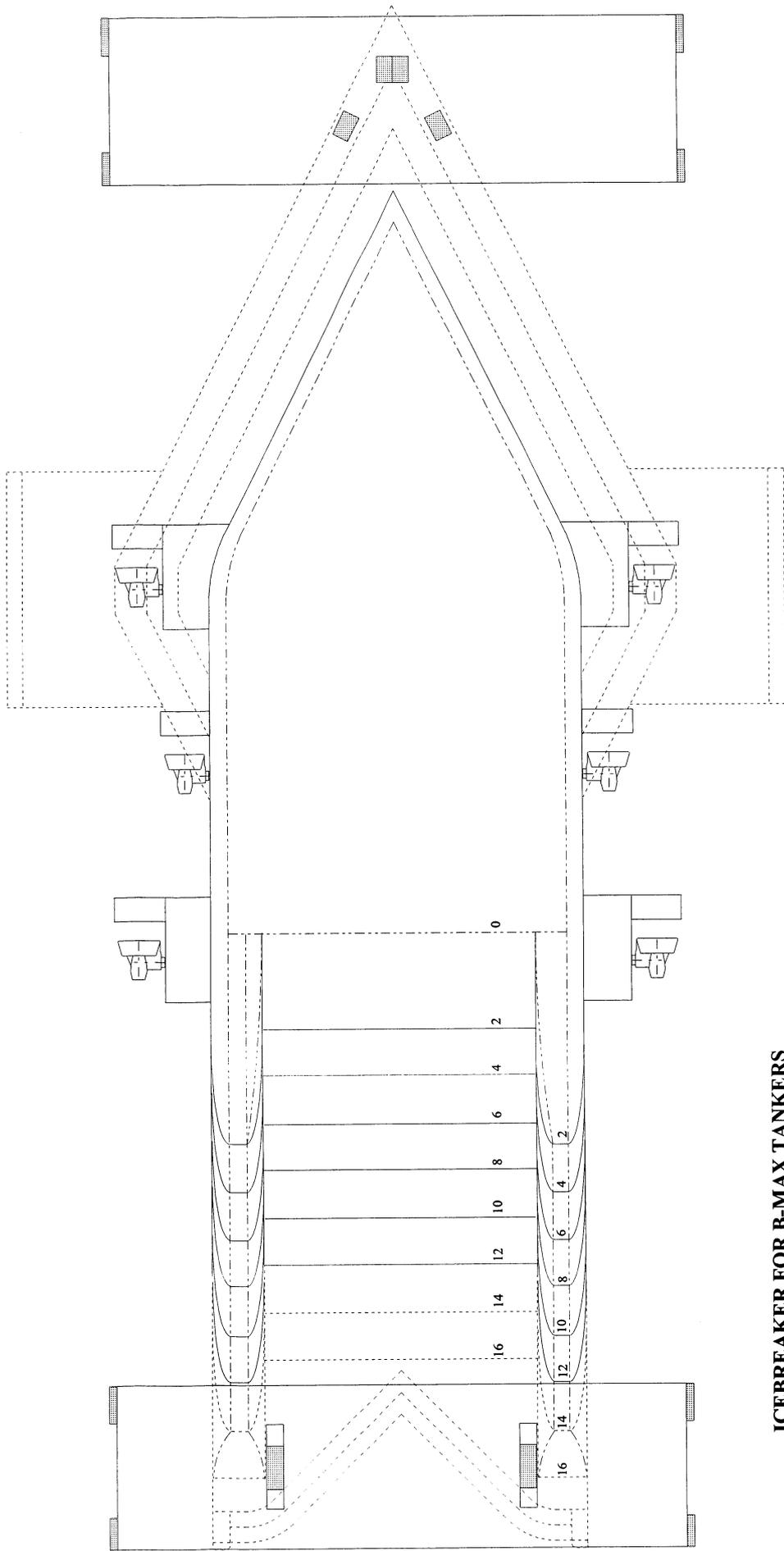


ICEBREAKER FOR B-MAX TANKERS
MOORING ARRANGEMENTS

OCT 2004 VISIONS & POLAR INNOVATIONS

SCALE 1:1,600

FIGURE 29



**ICEBREAKER FOR B-MAX TANKERS
BARGES FOR DOCKING AND UNDOCKING**

FIGURE 30

SCALE 1:800

OCT 2004 VISIONS & POLAR INNOVATIONS

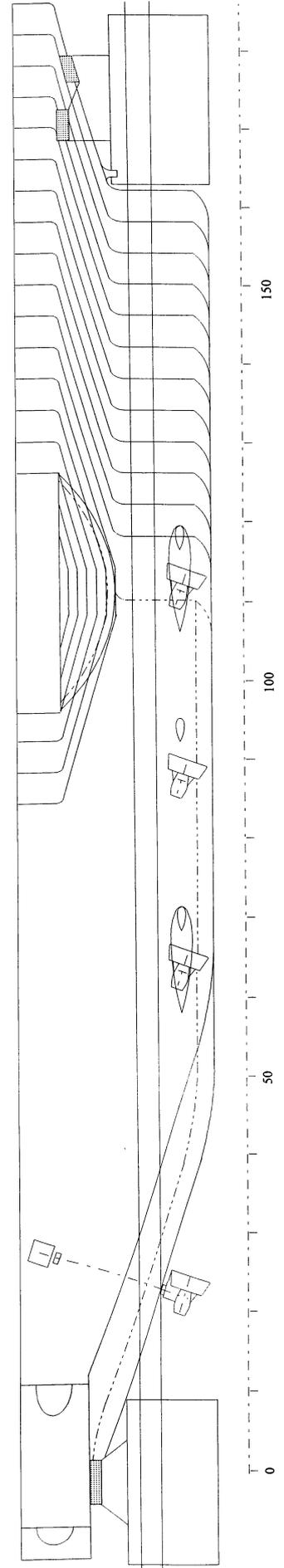


Table 1

Ice Strengthening With Proposed CAC Rules

Class	CF	Displ	Power	CA	Sp of fr	Ldl	VP/span	R1	
2 frames	0.8	75	56	2	4	19.90	0.622	0.73341	
1 plating	1								
	AF	f(y)	s	DPP	plate th				
	1	490	1.118	7.71	63				
	0.7	490	1.118	5.40	53				
	0.5	490	1.118	3.86	45				
	0.3	490	1.118	2.31	36				
	1	490	1	8.62	60				
	0.7	490	1	6.04	51				
	0.5	490	1	4.31	43				
	0.3	490	1	2.59	34				
AF	s	TFSA required	Zp req	Web Height	Web Thickn	Flange Width	Flange Thickn	Zp actual	Weight kg/m ²
1	1.118	371.9	16,748	90	4.3	30	2	24,955	319.85
0.7	1.118	260.3	11,724	80	3.4	30	2	17,194	237.56
0.5	1.118	185.9	8,374	60	3.4	30	2	10,814	188.90
0.3	1.118	111.6	5,024	50	2.3	30	2	6,581	125.22
1	1	339.5	15,289	80	4.3	30	2	20,302	323.20
0.7	1	237.6	10,702	70	3.4	30	2	13,791	238.40
0.5	1	169.7	7,644	50	3.4	30	2	8,151	184.00
0.3	1	101.8	4,587	50	2.1	30	2	6,197	132.00

Table 2.1

Scantlings of Structural Members

		Plating					thickness	thickness
spacing	head	sp grav	pressure	yield str	allow str	required	chosen	
1118.034	3	1.025	0.0301658	235	0.5	12.67	13	
1118.034	6	1.025	0.0603315	490	0.5	12.41	13	
1118.034	9	1.025	0.0904973	490	0.5	15.19	16	
1118.034	12	1.025	0.120663	490	0.5	17.54	18	
1118.034	15	1.025	0.1508288	490	0.5	19.62	20	
1118.034	18	1.025	0.1809945	490	0.5	21.49	22	
1118.034	21	1.025	0.2111603	490	0.5	23.21	24	
1118.034	24	1.025	0.241326	490	0.5	24.81	25	
1000	3	1.025	0.0301658	235	0.5	11.33	12	
1000	6	1.025	0.0603315	490	0.5	11.10	12	
1000	9	1.025	0.0904973	490	0.5	13.59	14	
1000	12	1.025	0.120663	490	0.5	15.69	16	
1000	15	1.025	0.1508288	490	0.5	17.54	18	
1000	18	1.025	0.1809945	490	0.5	19.22	20	
1000	21	1.025	0.2111603	490	0.5	20.76	21	
1000	24	1.025	0.241326	490	0.5	22.19	23	
866.0254	3	1.025	0.0301658	235	0.5	9.81	10	
866.0254	6	1.025	0.0603315	490	0.5	9.61	10	
866.0254	9	1.025	0.0904973	490	0.5	11.77	12	
866.0254	12	1.025	0.120663	490	0.5	13.59	14	
866.0254	15	1.025	0.1508288	490	0.5	15.19	16	
866.0254	18	1.025	0.1809945	490	0.5	16.64	17	
866.0254	21	1.025	0.2111603	490	0.5	17.98	18	
866.0254	24	1.025	0.241326	490	0.5	19.22	20	
Deck Framing			sp grav		allow str	shear str		
			1.025		0.5	0.57		
spacing	length	head	pressure	yield str	load	required		sp weight
						area	sect modul	
1118.034	5196.1524	3	0.0301658	235	0.1752472	13.08	646	38.6
1000	6000	3	0.0301658	235	0.1809945	13.51	770	46.4
1000	6000	6	0.0603315	490	0.361989	12.96	739	46.4
1000	6000	12	0.120663	490	0.723978	25.92	1,478	63.6
1000	6000	18	0.1809945	490	1.085967	38.88	2,216	81.6
1000	6000	21	0.2111603	490	1.2669615	45.36	2,586	94.4
1000	12000	6	0.0603315	490	0.723978	25.92	2,955	93.6
1000	12000	12	0.120663	490	1.447956	51.84	5,910	124.8
6000	6000	3	0.0301658	490	1.085967	38.88	2,216	13.0
6000	12000	3	0.0301658	490	2.171934	77.76	8,865	25.6

Table 2.2

Scantlings of Structural Members

Bulkhead Framing				sp grav	allow str	shear str	
				1.025	0.5	0.57	
spacing	length	head		yield str	required		sp weight
		top	bottom		area	sect modul	
1118.034	6000	0	6	235	20.14	1,033	47.2
1118.034	6000	6	12	490	24.15	1,322	54.4
1118.034	6000	12	18	490	38.64	2,147	68.3
1118.034	6000	18	24	490	53.13	2,973	80.5
1000	3000	3	3	235	6.76	193	24.0
1000	5000	3	3	235	11.26	535	36.0
1000	5000	0	5	235	12.51	535	36.0
1000	6000	0	6	235	18.02	924	49.6
1000	6000	6	12	490	21.60	1,182	56.8
1000	6000	12	18	490	34.56	1,921	72.4
1000	6000	18	24	490	47.52	2,660	84.0
1000	10500	1.5	12	490	32.13	2,941	88.8
1000	9000	12	21	490	58.32	4,820	115.2
866.0254	6000	0	6	235	15.60	800	53.6
866.0254	6000	6	12	490	18.71	1,024	61.0
866.0254	6000	12	18	490	29.93	1,663	76.7
866.0254	6000	18	24	490	41.16	2,303	91.5
1000	3000	21	24	490	24.84	702	43.2

Table 3.1

Steel Weight Calculation

		xcg	vcg	nr	length	width	height	spec wt	weight	weight
	Total	94.13	16.84						29,946	29,946
funnels	enclosure 57 to 69 abl	87.5	63	2	21.991	1	12	72	38	
	decks 57 to 69 abl	87.5	63	10	7	7	0.7854	72	28	
	enclosure 51 to 57 abl	87.5	54	2	24.996	1	6	96	29	
	decks 51 to 54 abl	87.5	52.5	4	7	7	0.9463	96	18	
	deck 48 abl aft part	87.5	48	2	7	9.5	1	120	16	
	deck 48 abl fwd part	92.25	48	2	2.5	7	1	120	4	
	bhd fr 84 square part	84	48	2	1	7	6	120	10	
	bhd fr 84 triangle part	84	47	2	0.5	5	6	120	4	
	bhd fr 84 to 91 vertical part	87.5	48	2	7	1	6	120	10	
	bhd fr 84 to 91 sloping part	87.5	48	2	7	1.3017	6	120	13	
	bhd fr 91 triangle part	91	47	2	0.5	5	6	120	4	
	bhds fr 91 to 96 triangle part	92.667	47	4	5	0.5	6	120	7	
	bhd fr 91 to 96 sloping part	93.5	48	2	1.3017	7	6	120	13	193
mast	aft pipe	92	69	1	0.5	10	3.1416	96	2	
	side pipes	99	69	2	9.4	0.5	3.1416	96	3	
	decks	97	66.333	3	5.5	3.8	0.6153	72	3	
	aft bhd	95	65	1	1	3.8	8	72	2	
	side bhds	97.75	65	2	5.7	1	8	72	7	
	fwd bhd	100.5	65	1	1	0.8	8	72	0	16
bridge tower	top railing at fr 94	94	61.6	1	1	16	1.2	108	2	
	top railing fr 94 to 102	98	61.6	2	6	1	1.2	108	2	
	top railing semi circle	106	61.6	1	1.5708	16	1.2	108	3	
	top deck fr 94 to 102	98	60.5	1	6	16	1	288	28	
	top deck fr 102 to 110	105	60.5	1	8	16	0.7854	288	29	
	deck 10 square part	102	57.6	1	3	3	1	120	1	
	deck 10 circular part	102	57.3	1	12	12	0.3436	120	6	
	deck 9	102	54	1	12	12	0.7854	120	14	
	deck 8 railing at fr 94	94	51.6	1	1	16	1.2	108	2	
	deck8 railing fr 94 to 102	98	51.6	2	6	1	1.2	108	2	
	deck 8 railing semi circle	106	51.6	1	1.5708	16	1.2	108	3	
	deck 8 fr 94 to 102	98	51	1	6	16	1	144	14	
	deck 8 fr 102 to 110	105	51	1	8	16	0.7854	144	14	
	deck 7	102	48	1	12	12	0.95	166	23	
	large bhds btw decks 9 and 11	102	57	4	4.4	1	6	120	13	
	small bhds btw decks 9 and 11	102	57	8	2	1	6	120	12	
	sides btw decks 8 and 9	102	52.5	4	12	0.9	3	120	16	
	large bhds btw decks 8 and 9	102	52.5	4	4.2	1	3	120	6	
	small bhds btw decks 8 and 9	102	52.5	8	1.6	1	3	120	5	
	bhd at frame 97.7	97.7	52.5	1	3	1	3	120	1	
	bhds at fr 100.5	100.5	52.5	2	4.7	1	3	120	3	
	bhds in box btw decks 8 and 9	102	52.5	4	3	1	3	120	4	
	sides btw decks 7 and 8	102	49.5	4	12	0.95	3	120	16	
	bhds btw fr 96 and 99	97.5	49.5	2	3	1	3	120	2	
	bhd at fr 99	99	49.5	1	1	12	3	120	4	
	bhds at fr 106	106	49.5	2	2.5	1	3	120	2	
	sides btw decks 6 and 7	102	46.5	4	12	1	3	120	17	
	bhds btw fr 96 and 99	97.5	46.5	2	3	1	3	120	2	
	bhd at fr 99	99	46.5	1	1	12	3	120	4	
	bhd at fr 101	101	46.5	1	1	12	3	120	4	
	bhds at fr 106	106	46.5	2	2.5	1	3	120	2	
	outside stair pipes	95	53.5	2	1	3.1416	17	96	10	
	platforms and stairs	95	53	5	3	3	0.7854	120	4	
railings	95	53.6	5	3	3.1416	1.2	120	7	277	
deck house	shelter tops	128	48	2	6	6	0.875	120	8	
	shelter sides at fr 125	125	46.5	2	1	3	3	120	2	
	shelter sides btw fr 125 and 131	128	46.5	2	6	1	3	120	4	
	shelter sides btw fr 128 and 131	129.5	46.5	2	3	1	3	120	2	
	shelter sides at fr 131	131	46.5	2	1	6	3	120	4	
	deck 6	108	44.5	1	48	36	1	288	498	
	aft side btw decks 5 and 6	84	42.5	1	1	36	3	120	13	
	bhds at fr 91	91	42.5	2	1	12	3	120	9	
	bhds btw fr 91 and 93	92	42.5	4	2	1	3	120	3	
	bhds at fr 93	93	42.5	2	1	12	3	120	9	
	bhd at fr 96	96	42.5	1	1	36	3	120	13	

Table 3.2	Steel Weight Calculation	xcg	vcg	nr	length	width	height	spec wt	weight	weight
deck house	bhds in stair tower	102	42.5	4	6.2426	1	3	120	9	
	bhd at fr 108	108	42.5	1	1	36	3	120	13	
	bhds btw fr 108 and 112	110	42.5	2	4	1	3	120	3	
	bhd at fr 112	112	42.5	1	1	9	3	120	3	
	bhds at fr 120	120	42.5	2	1	12	3	120	9	
	fwd side btw decks 5 and 6	132	42.5	1	1	36	3	120	13	
	longit sides and bulkheads	108	42.5	4	48	1	3	120	69	
	deck 5 aft part	98	41	1	28	36	1	192	194	
	deck 5 forward parts	122	41	2	20	12	1	192	92	
	aft side btw decks 4 and 5	84	39.5	1	1	36	3	120	13	
	bhds at fr 91	91	39.5	2	1	12	3	120	9	
	bhds btw fr 91 and 93	92	39.5	4	2	1	3	120	3	
	bhds at fr 93	93	39.5	2	1	12	3	120	9	
	bhd at fr 96	96	39.5	1	1	36	3	120	13	
	bhds in stair tower	102	39.5	4	6.2426	1	3	120	9	
	bhd at fr 108	108	39.5	1	1	36	3	120	13	
	bhds btw fr 108 and 112	110	39.5	2	4	1	3	120	3	
	bhd at fr 112	112	39.5	1	1	9	3	120	3	
	bhds at fr 120	120	39.5	2	1	12	3	120	9	
	fwd side btw decks 4 and 5	132	39.5	1	1	36	3	120	13	
	longit sides and bulkheads	108	39.5	4	48	1	3	120	69	
	deck 4	108	38	1	48	36	1	192	332	
	aft side btw decks 3 and 4	84	36.5	1	1	36	3	120	13	
	bhds at fr 91	91	36.5	2	1	12	3	120	9	
	bhds btw fr 91 and 93	92	36.5	4	2	1	3	120	3	
	bhds at fr 93	93	36.5	2	1	12	3	120	9	
	bhd at fr 96	96	36.5	1	1	36	3	120	13	
	bhds in stair tower	102	36.5	4	6.2426	1	3	120	9	
	bhd at fr 108	108	36.5	1	1	36	3	120	13	
	bhd at fr 128	128	36.5	1	1	12	3	120	4	
	bhds at fr 120	120	36.5	2	1	12	3	120	9	
	fwd side btw decks 3 and 4	132	36.5	1	1	36	3	120	13	
	longit sides and bulkheads	108	36.5	4	48	1	3	120	69	
	deck 3 above heli hangar	80	35	1	8	12	1	192	18	
	deck 3 aft part	96	35	1	24	36	1	192	166	
	deck 3 mid part	118	35	2	20	12	1	192	92	
	deck 3 forward part	130	35	1	4	36	1	120	17	
	aft side btw decks 2 and 3	76	33.5	1	1	12	3	142.4	5	
	aft sides btw decks 2 and 3	84	33.5	2	1	12	3	120	9	
	bhds at fr 91	91	33.5	2	1	12	3	120	9	
	bhds btw fr 91 and 93	92	33.5	4	2	1	3	120	3	
	bhd at fr 93	93	33.5	1	1	36	3	120	13	
	bhd at fr 96	96	33.5	1	1	36	3	120	13	
	bhd at fr 100	100	33.5	1	1	8	3	120	3	
	bhd at fr 104	104	33.5	1	1	8	3	120	3	
	bhds in stair tower	102	33.5	4	6.2426	1	3	120	9	
	bhd at fr 108	108	33.5	1	1	16	3	120	6	
	bhd at fr 112	112	33.5	1	1	8	3	120	3	
	bhd at fr 128	128	33.5	1	1	12	3	120	4	
	bhds at fr 120	120	33.5	2	1	12	3	120	9	
	bhd at fr 122	122	33.5	1	1	3	3	120	1	
	bhd btw fr 120 and 124	122	33.5	1	4	1	3	120	1	
	bhd at fr 124	124	33.5	1	1	8	3	120	3	
	fwd side btw decks 2 and 3	132	33.5	1	1	36	3	120	13	
	longit sides btw fr 76 and 84	80	33.5	2	8	1	3	142.4	7	
	longit bhds btw fr 84 and 93	88.5	33.5	2	9	1	3	120	6	
	longit sides btw fr 84 and 132	108	33.5	2	48	1	3	120	35	
	longit bhds btw fr 96 and 132	114	33.5	3	36	1	3	120	39	
	deck 2 aft parts	88.5	32	2	9	12	1	192	41	
	deck 2 fwd part	112.5	32	1	39	36	1	192	270	
	aft side btw decks 1 and 2	76	30.5	1	1	12	3	142.4	5	
	aft sides btw decks 1 and 2	84	30.5	2	1	12	3	120	9	
	bhds at fr 91	91	30.5	2	1	12	3	120	9	
	bhds btw fr 91 and 93	92	30.5	2	2	1	3	120	1	
	bhd at fr 93	93	30.5	1	1	36	3	120	13	
	bhd at fr 96	96	30.5	1	1	36	3	120	13	
	bhds in stair tower	102	30.5	4	6.2426	1	3	120	9	
	bhd at fr 108	108	30.5	1	1	16	3	120	6	
	bhd at fr 120	120	30.5	1	1	24	3	120	9	

Table 3.3 Steel Weight Calculation		xcg	vcg	nr	length	width	height	spec wt	weight	weight
deck house	bhd at fr 122	122	30.5	1	1	3	3	120	1	
	bhd btw fr 120 and 124	122	30.5	3	4	1	3	120	4	
	bhd at fr 124	124	30.5	1	1	6.4	3	120	2	
	fwd side btw decks 1 and 2	132	30.5	1	1	36	3	120	13	
	longit sides btw fr 76 and 84	80	30.5	2	8	1	3	142.4	7	
	longit bhds btw fr 84 and 93	88.5	30.5	2	9	1	3	120	6	
	longit sides btw fr 84 and 132	108	30.5	2	48	1	3	120	35	
	longit bhds btw fr 96 and 132	114	30.5	3	36	1	3	120	39	2,607
houses on main deck	air intake tops	50	29	2	12	3.5	1	120	10	
	air intake transv bhds	50	26.5	6	1	3.5	5	134.4	14	
	air intake longit bhds	50	26.5	4	12	1	5	134.4	32	
	mooring houses tops	12	27	2	12	6	1	142.4	21	
	mooring houses transv bhds	12	25.5	4	1	6	3	120	9	
	mooring houses long bhds	12	25.5	4	12	1	3	120	17	
	air pockets roofs	111	28.5	2	8.4	19	1	288	92	
	air pckets transv bhds	111	26.5	4	1	19	5	288	109	
	air pockets long bhds	111	26.5	4	8.4	1	5	288	48	
	mooring house top	170	27	1	16	8	1	142.4	18	
	mooring house aft bhd	164	25.5	1	1	20	3	120	7	
	mooring house fwd bhd	182	25.5	1	1	4	3	120	1	
	mooring house side bhds	170	25.5	2	16	1	3	120	12	
	aft railing	-7	24.6	2	1	6	1.5	120	2	
	railing fr -7 to 11	2	24.6	2	18	1.414	1.5	120	9	
	railing fr -7 to 84	38.5	24.6	2	91	1	1.5	120	33	
	railing fr 84 to 94.8	89.4	24.6	2	10.8	1.118	1.5	120	4	
	railing fr 94.8	94.8	24.6	2	1	21.2	1.5	120	8	
	railing fr 94.8 to 127.2	111	24.6	2	32.4	1	1.5	120	12	
	railing fr 127.2	127.2	24.6	2	1	21.2	1.5	120	8	
	railing fr 127.2 to 186	156.6	24.6	2	58.8	1.118	1.5	120	24	
	deck 1 btw fr 44 and 76	60	29	1	32	32	1	256	262	
	deck 1 btw fr 76 and 84	80	29	1	8	24	1	192	37	
	deck 1 btw fr 84 and 96	90	29	1	12	36	1	192	83	
	deck 1 btw fr 96 and 110	103	29	1	14	39	1	192	105	
	deck 1 btw fr 110 and 132	121	29	1	22	36	1	192	152	
	bhd at fr 48	48	26.5	1	1	18	5	134.4	12	
	bhds at fr 60	60	26.5	2	1	6	5	134.4	8	
	bhd at fr 68	68	26.5	1	1	24	5	134.4	16	
	bhds at fr 72	72	26.5	2	1	6	5	134.4	8	
	bhd at fr 76	76	26.5	1	1	8	5	134.4	5	
	bhds at fr 84	84	26.5	2	1	12	5	134.4	16	
	bhd at fr 93	93	26.5	1	1	11	5	134.4	7	
	bhd on fr 96	96	26.5	1	1	36	5	134.4	24	
	bhd on fr 103	103	26.5	1	1	15	5	134.4	10	
	bhd on fr 108	108	26.5	1	1	33	5	134.4	22	
	bhd on fr 110	110	26.5	1	1	36	5	134.4	24	
	bhd on fr 120	120	26.5	1	1	36	5	134.4	24	
	bhds on fr 122	122	26.5	1	1	10	5	134.4	7	
	bhds on fr 132	132	26.5	2	1	12	5	134.4	16	
	bhd on fr 138	138	26.5	1	1	12	5	134.4	8	
	bhd btw fr 48 and 84	66	26.5	1	36	1	5	134.4	24	
	bhds btw fr 48 and 68	58	26.5	2	20	1	5	134.4	27	
	bhd btw fr 60 and 84	72	26.5	1	24	1	5	134.4	16	
	bhds btw fr 70.5 and 93	81.75	26.5	2	22.5	1	5	134.4	30	
	bhds btw fr 76 and 93	84.5	26.5	2	17	1	5	134.4	23	
	bhds btw fr 84 and 108	96	26.5	2	24	1	5	134.4	32	
	bhds btw fr 93 and 108	100.5	26.5	2	15	1	5	134.4	20	
	bhds btw fr 96 and 108	102	26.5	4	12	1	5	134.4	32	
	bhds btw fr 96 and 110	103	26.5	2	14	1	5	134.4	19	
	bhds btw fr 110 and 120	115	26.5	6	10	1	5	134.4	40	
	bhds btw fr 110 and 132	121	26.5	2	22	1	5	134.4	30	
	bhds btw fr 110 and 138	124	26.5	2	28	1	5	134.4	38	
	air pocket fr 108	108	26	2	1	18	4	132	19	
	air pocket fr 108 to 114	111	26	4	6	1	4	132	13	
	air pocket fr 114	114	26	2	1	18	4	132	19	
air pocket tops	111	28	2	6	18	1	142.4	31	1,751	
main deck	rectangles fr -7 to 114	53.5	24	2	121	6	1	238.4	346	
	triangles fr 0 to 12	8	24	2	12	12	0.5	238.4	34	

Table 3.4		Steel Weight Calculation		xcg	vcg	nr	length	width	height	spec wt	weight	weight
main deck	rectangle fr 12 to 24	18	24	1	12	36	1	238.4	103			
	rectangle fr 24 to fr 114	69	24	1	90	36	1	264	855			
	triangles fr 84 to 98.8	91.2	24	2	10.8	24	0.5	238.4	62			
	rectangles fr 94.8 to 114	104.4	24	2	19.2	26	1	238.4	238			
	rectangles fr 114 to 127.2	120.6	24	2	13.2	14	1	238.4	88			
	triangles fr 114 to 127.2	122.8	24	2	13.2	6.6	0.5	238.4	21			
	triangle fr 114 to 150	126	24	1	36	36	0.5	264	171			
	polygons fr 114 to 150	123	24	2	18	36	2	238.4	618			
	triangle fr 150 to 186	162	24	1	36	36	0.5	238.4	154			2,691
	decks below main deck	cofferdam fr 48 to 72	60	22.5	1	24	36	1	192	166		
cofferdam fr 132 to 144		137	22.5	1	12	18	0.6667	192	28			
fan rooms fr 72 to 84		78	21	2	12	6	1	120	17			
fan rooms fr 108 to 120		114	21	2	12	5	1	120	14			225
transv bhds 18 to 24 m abv BL	fr -11	-11	21	2	1	2	6	279.2	7			
	fr -7	-7	21	2	1	6	6	279.2	20			
	fr -7 to 11 in 45 deg angle	2	21	2	18	1.414	6	279.2	85			
	fr 0	0	21	2	1	6	6	142.4	10			
	fr 6	6	21	2	1	6	6	142.4	10			
	fr 12	12	21	1	1	48	6	142.4	41			
	fr 18	18	21	2	1	6	6	142.4	10			
	fr 24	24	21	1	1	48	6	142.4	41			
	fr 30	30	21	2	1	6	6	142.4	10			
	fr 36	36	21	1	1	48	6	142.4	41			
	fr 38	38	21	1	1	36	6	142.4	31			
	fr 42	42	21	2	1	6	6	142.4	10			
	fr 48	48	21	1	1	48	6	184.8	53			
	fr 54	54	21	2	1	6	6	142.4	10			
	fr 60	60	21	2	1	6	6	142.4	10			
	fr 66	66	21	2	1	6	6	142.4	10			
	fr 69	69	21	2	1	6	6	142.4	10			
	fr 72	72	21	2	1	6	6	142.4	10			
	fr 72	72	21	1	1	36	6	184.8	40			
	fr 78	78	21	2	1	6	6	142.4	10			
	fr 84	84	21	2	1	6	6	142.4	10			
	fr 84	84	21	1	1	36	6	184.8	40			
	fr 88.8 to 90	89.4	21	2	1	2.7	6	142.4	5			
	fr 90	90	21	2	1	6	6	142.4	10			
	fr 94.8	94.8	21	2	1	21.2	6	279.2	71			
	fr 94.8 to 97.5	96.15	21	2	1	6.1	6	142.4	10			
	fr 96	96	21	2	1	6	6	142.4	10			
	fr 100.8	100.8	21	2	1	18.2	6	142.4	31			
	fr 100.8 to 105	102.9	21	2	1	9.6	6	142.4	16			
	fr 102	102	21	2	1	6	6	142.4	10			
	fr 105	105	21	2	1	6	6	142.4	10			
	fr 108	108	21	2	1	38	6	176.8	81			
	fr 108	108	21	1	1	24	6	192	28			
	small bhds on top of outrigger	111	21	27	1	2	6	192	62			
	fr 114	114	21	2	1	38	6	176.8	81			
	fr 114 to 121.2	117.6	21	2	1	16.3	6	142.4	28			
fr 120	120	21	1	1	30	6	142.4	26				
fr 120 to 127.2	123.6	21	2	1	16.3	6	142.4	28				
fr 121.2	121.2	21	2	1	17.8	6	142.4	30				
fr 127.2	127.2	21	2	1	20.8	6	452	113				
fr 126 to 133.2	129.6	21	2	1	16.3	6	142.4	28				
fr 132	132	21	1	1	18	6	142.4	15				
fr 132 to 139.2	135.6	21	2	1	16.3	6	142.4	28				
fr 138 to 145.2	141.6	21	2	1	16.3	6	142.4	28				
fr 144	144	21	1	1	4	6	142.4	3				
fr 144 to 151.2	147.6	21	2	1	16.3	6	142.4	28				
fr 150 to 157.2	153.6	21	2	1	16.3	6	142.4	28				
fr 157.5 to 163.2	160.35	21	2	1	12.9	6	142.4	22				
fr 165 to 169.2	167.1	21	2	1	9.5	6	142.4	16				
fr 172.5 to 175.2	173.85	21	2	1	6.1	6	142.4	10			1,379	
longit bhds 18 to 24 m abv BL	fr -11 to 84	36.5	21	2	95	1	6	279.2	318			
	fr -7 to 114	53.5	21	2	121	1	6	142.4	207			
	fr -11 to -7	-9	21	2	4	1	6	279.2	13			

Table 3.5		Steel Weight Calculation		xcg	vcg	nr	length	width	height	spec wt	weight	weight	
longit bhds 18 to 24 m abv BL	fr -1 to 24	13.5	21	2	25	1	6	142.4	43				
	fr 5 to 36	20.5	21	2	31	1	6	142.4	53				
	fr 11 to 24	17.5	21	1	13	1	6	142.4	11				
	fr 36 to 72	54	21	2	36	1	6	184.8	80				
	fr 48 to 84	66	21	2	36	1	6	142.4	62				
	fr 69 to 72	70.5	21	2	3	1	6	142.4	5				
	fan room fr 72 to 84	78	22.5	4	12	1	3	142.4	21				
	ballast vent fr 72 to 84	78	21	2	12	1	6	142.4	21				
	fr 84 to 94.8	89.4	21	2	10.8	1.118	6	279.2	40				
	fr 84 to 108	96	21	2	24	1	6	184.8	53				
	fr 84 to 114	99	21	2	30	1	6	142.4	51				
	fr 94.8 to 127.2 knife	111	21	2	32.4	1	6	268	104				
	fr 94.8 to 127.2 knife, inside	111	21	2	32.4	1	6	268	104				
	fr 94.8 to 127.2	111	21	4	32.4	1	6	142.4	111				
	fr 94.8 to 108	101.4	21	2	13.2	1.118	6	142.4	25				
	fr 97.2 to 108	100.2	21	2	10.8	1.118	6	142.4	21				
	fr 108 to 114	111	21	2	6	1	6	142.4	10				
	fr 108 to 120	114	21	2	12	1	6	142.4	21				
	fr 114 to 127.2	120.6	21	2	13.2	1.118	6	142.4	25				
	fr 114 to 172.8	143.4	21	2	58.8	1.118	6	142.4	112				
	fr 114 to 162	138	21	2	48	1.118	6	142.4	92				
	fr 114 to 150	132	21	2	36	1.118	6	142.4	69				
	fr 120 to 132	126	21	2	12	1	6	142.4	21				
	fr 127.2 to 186	156.6	21	2	58.8	1.118	6	452	357				
	fr 148 to 186	167	21	2	38	1	6	142.4	65			2,113	
	deck at 18 m above BL	rectangles fr -7 to 114	53.5	18	2	121	6	1	224.8	326			
		rectangle fr 24 to 36	30	18	1	12	36	1	142.4	62			
		rectangle fr 36 to 48	42	18	1	12	12	1	142.4	21			
	deck at 18 m above BL	rectangle fr 48 to 50	49	18	1	2	36	1	142.4	10			
triangles fr 84 to 108		100	18	2	24	12	0.5	142.4	41				
triangles fr 94.8 to 108		99.2	18	2	13.2	6.6	0.5	528	46				
rectangles fr 94.8 to 127.2		111	18	2	32.4	14	1	528	479				
triangles fr 114 to 127.2		122.8	18	2	13.2	6.6	0.5	528	46				
rectangles fr 108 to 120		114	19.5	4	12	6	1	142.4	41				
polygons fr 114 to 180		147	18	2	66	6	1	236.23	187				
polygons fr 114 to 160		137	18	2	46	12	1	142.6	157				
triangle fr 120 to 150		130	18	1	30	30	0.5	189.6	85			1,502	
shell plating 12 to 18 m abl	rectangles fr -7 to -3	-5	16	2	4	6	1	404	19				
	sloping rectangles fr -3 to 9	3	14	2	12	6	1.0541	528	80				
	bottom triangles fr 0 to 12	8	16	2	12	14	0.5	404	68				
	inside vert triangles fr -3 to 9	5	14.667	2	12	0.5	4	404	19				
	inside vert rectangles fr 9 to 12	10.5	14	2	3	1	4	404	10				
	inside vert triangles fr 12 to 24	20	13.333	2	12	0.5	4	404	19				
	sloping bottom fr 12 to 24	18	14	1	12	36	1.0541	404	184				
	outside vert rectangles fr -7 to 9	1	15	2	16	2	1	528	34				
	outside vert triangles fr -3 to 9	5	14.667	2	12	0.5	4	528	25				
	vertical rectangles fr 9 to 84	46.5	15	2	75	1	6	528	475				
	vertical triangles fr 84 to 108	92	14	2	24	0.5	6	528	76				
	sloping triangles fr 84 to 108	100	16	2	24	12	1.118	548.9	353				
	outside rake fr 94.8 to 127.2	111	16	2	32.4	0.65	5.5	480	111				
	inside rake fr 94.8 to 127.2	111	16.4	2	32.4	0.65	4.8333	480	98				
	sloping rectangles fr 108 to 114	111	15	2	6	12	1.118	661.6	107				
sloping polygons fr 114 to 162	138	15	2	48	12	1.118	824	1,061					
sloping triangles fr 162 to 186	170	16	2	24	12	0.559	824	265			3,006		
transv bhds 12 to 18 m abv BL	fr -11	-11	17	2	1	2	2	279.2	2				
	fr -7	-7	17	2	1	6	2	279.2	7				
	fr -7 to 11 in 45 deg angle	2	17	2	18	1.414	2	279.2	28				
	fr 0	0	16.5	2	1	6	3	142.4	5				
	web at fr 0	0	18	2	1	6	4	142.4	7				
	fr 6	6	15.5	2	1	6	5	142.4	9				
	web at fr 6	6	18	2	1	12	4	142.4	14				
	fr 12, wing	12	15	2	1	6	6	142.4	10				
	fr 12, center	12	17	1	1	36	2	142.4	10				
	fr 18	18	16	2	1	6	6	142.4	10				

Table 3.6

Steel Weight Calculation

transv bhds 12
to 18 m abv BL

	xcg	vcg	nr	length	width	height	spec wt	weight	weight
web at fr 18	18	16	1	1	36	4	142.4	21	
fr 24	24	15	1	1	48	6	176.8	51	
fr 30	30	15	2	1	6	6	142.4	10	
fr 36	36	15	1	1	48	6	142.4	41	
fr 42	42	15	2	1	6	6	142.4	10	
fr 48	48	15	2	1	6	6	176.8	13	
fr 48	48	15	1	1	36	6	208.8	45	
fr 54	54	15	2	1	6	6	142.4	10	
fr 60	60	15	2	1	6	6	142.4	10	
fr 66	66	15	2	1	6	6	142.4	10	
fr 69	69	15	2	1	6	6	176.8	13	
fr 72	72	15	2	1	6	6	176.8	13	
fr 72	72	15	1	1	36	6	208.8	45	
fr 78	78	15	2	1	6	6	142.4	10	
fr 84	84	15	2	1	6	6	176.8	13	
fr 84	84	15	1	1	36	6	184.8	40	
fr 88.8 to 90	89.6	17.5	2	0.5	2.7	1.5	142.4	1	
fr 90	90	15	2	1	6	6	142.4	10	
sloping mbrs fr 90 to 102	96	15	2	12	6	1.0308	224.8	33	
fr 102	102	15	2	1	6	6	176.8	13	
triangles fr 94.8 to 96.5	95.93	16.933	2	0.5	6.4	3.2	142.4	3	
fr 96	96	15	2	1	6	6	142.4	10	
triangles fr 100.8 to 105	103.6	16.083	2	0.5	9.6	5.75	142.4	8	
fr 105	105	15	2	1	6	6	142.4	10	
triangles fr 108 and 114	111	16	4	0.5	12	6	224.4	32	
rectangles fr 108 and 114	111	15	4	1	12	6	224.4	65	
fr 108	108	15	1	1	24	6	184.8	27	
small bhds in outrigger	111	16	27	1	2	4	192	41	
rectangles fr 114.5 to 116.4	115.45	15	2	0.866	6	6	165	10	
triangles fr 116.4 to 121.2	118	16	2	0.433	12	6	165	10	
fr 120	120	15	1	1	30	6	165	30	
rectangles fr 120 to 122.4	121.2	15	2	0.866	6	6	142.4	9	
triangles fr 122.4 to 127.2	124	16	2	0.433	12	6	142.4	9	
rectangles fr 126 to 128.4	127.2	15	2	0.866	6	6	142.4	9	
triangles fr 128.4 to 133.2	130	16	2	0.433	12	6	142.4	9	
fr 132	132	15	1	1	18	6	165	18	
rectangles fr 132 to 134.4	133.2	15	2	0.866	6	6	165	10	
triangles fr 134.4 to 139.2	136	16	2	0.433	12	6	165	10	
rectangles fr 138 to 140.4	139.2	15	2	0.866	6	6	142.4	9	
triangles fr 140.4 to 145.2	142	16	2	0.433	12	6	142.4	9	
rectangles fr 144 to 146.4	145.2	15	2	0.866	6	6	142.4	9	
triangles fr 146.4 to 151.2	148	16	2	0.433	12	6	142.4	9	
rectangles fr 150 to 152.4	151.2	15	2	0.866	6	6	165	10	
triangles fr 152.4 to 157.2	154	16	2	0.433	12	6	165	10	
rectangles fr 157.5 to 158.4	157.95	15	2	0.866	2.25	6	142.4	3	
triangles fr 158.4 to 163.2	160	16	2	0.433	12	6	142.4	9	
triangles fr 165 to 169.2	166.4	16.25	2	0.433	10.5	5.25	142.4	7	
triangles fr 172.5 to 175.2	173.4	16.867	2	0.433	6.8	3.4	142.4	3	913

longit bhds 12
to 18 m abv BL

rectangles fr -7 to 24	8.5	17	2	31	1	2	176.8	22	
rectangles fr -1 to 24	11.5	17	2	25	1	2	142.4	14	
rectangles fr 5 to 24	14.5	17	2	19	1	2	176.8	13	
rectangle fr 11 to 24	17.5	17	2	13	1	2	142.4	7	
triangles fr 12 to 24	20	14.667	4	12	0.5	4	176.8	17	
triangles fr 12 to 24	20	14.667	4	12	0.5	4	142.4	14	
fr 24 to 114	69	15	2	90	1	6	176.8	191	
fr 24 to 36	30	15	2	12	1	6	176.8	25	
fr 36 to 72	54	15	2	36	1	6	208.8	90	
fr 69 to 72	70.5	15	2	3	1	6	176.8	6	
fr 84 to 108	96	15	2	24	1	6	208.8	60	
fr 108 to 120	114	15	2	12	1	6	142.4	21	
fr 120 to 132	126	15	2	12	1	6	176.8	25	
fr 114 to 150	132	15	2	36	1.118	6	190.4	92	
fr 114 to 158.4	136.2	15	2	44.4	1.118	6	328	195	
fr 114 to 172.8	143.4	16.5	2	58.8	1.118	3	328	129	923

Table 3.7		Steel Weight Calculation		xcg	vcg	nr	length	width	height	spec wt	weight	weight
deck at 12 m above BL	rectangles fr 18 to 114	66	12	2	132	6	1	224.8	356			
	rectangle fr 36 to 84	60	12	1	48	36	1	189.6	328			
	rectangle fr 84 to 108	96	11	1	24	36	1	768	664			
	rectangle fr 108 to 114	111	12	1	6	36	1	189.6	41			
	triangle fr 114 to 150	126	12	1	36	36	0.5	252.8	164			
	polygons fr 114 to 157	133.5	12	2	43	6	1	320	165			1,717
shell plating 6 to 12 m abl	aft part of skeg	18	9	2	18	6	1.0541	528	120			
	inside polygon	25.5	9	2	18	1	6	404	87			
	outside triangle	21	10	2	18	0.5	6	528	57			
	sloping bottom	33	9	1	18	36	1.0541	404	276			
	rectangle fr 27 to 102	64.5	9	2	75	1	6	528	475			
	rectangle fr 102 to 108	105	9	2	6	1	6	647	47			
rectangle fr 108 to 162	135	9	2	54	1.118	6	828	600			1,662	
transv bhds 6 to 12 m abl	fr 12	12	11.5	2	1	6	1	142.4	2			
	fr 18	18	10.5	2	1	6	3	142.4	5			
	fr 24	24	9.5	2	1	6	5	224.4	13			
	fr 30	30	9	2	1	6	6	142.4	10			
	web at fr 30	30	12	1	1	36	4	142.4	21			
	fr 36	36	9	2	1	6	6	142.4	10			
	fr 36	36	10	1	1	36	4	142.4	21			
	fr 42	42	12	2	1	6	6	142.4	10			
	web at fr 42	42	8	1	1	36	4	142.4	21			
	fr 48	48	9	1	1	48	6	224.4	65			
	fr 54	54	9	2	1	6	6	142.4	10			
	fr 60	60	9	2	1	6	6	224.4	16			
	fr 60	60	9	2	1	6	6	267.2	19			
	fr 66	66	9	2	1	6	6	224.4	16			
	fr 69	69	9	2	1	6	6	224.4	16			
	fr 72	72	9	2	1	6	6	142.4	10			
	fr 72	72	9	1	1	24	6	267.2	38			
	fr 78	78	9	2	1	6	6	142.4	10			
	fr 84	84	9	2	1	6	6	224.4	16			
	fr 84	84	9	1	1	36	6	176	38			
	fr 90	90	9	2	1	6	6	142.4	10			
	fr 96	96	9	2	1	6	6	142.4	10			
	fr 102	102	9	2	1	6	6	224.4	16			
	fr 108	108	9	2	1	6	6	224.4	16			
	fr 108	108	9	1	1	36	6	142.4	31			
	fr 114	114	9	2	1	6	6	142.4	10			
	fr 114	114	9	1	1	12	6	142.4	10			
	fr 114.5 to 116.4	115.45	9	2	0.866	6	6	224.4	14			
	fr 120	120	9	1	1	30	6	267.2	48			
	fr 120 to 122.4	121.2	9	2	0.866	6	6	142.4	9			
	fr 126 to 128.4	127.2	9	2	0.866	6	6	142.4	9			
	fr 132	132	9	1	1	18	6	267.2	29			
	fr 132 to 134.4	133.4	9	2	0.866	6	6	142.4	9			
	fr 138 to 140.4	139.2	9	2	0.866	6	6	142.4	9			
fr 144	144	9	1	1	6	6	267.2	10				
fr 144 to 146.4	145.2	9	2	0.866	6	6	142.4	9				
fr 148	148	9	1	1	2	6	267.2	3				
fr 150 to 152.4	151.2	9	2	0.866	6	6	142.4	9				
fr 157.5 to 158.4	157.95	9	2	0.866	2.75	6	142.4	4			634	
longit bhds 6 to 12 m abl	triangles fr 24 to 42	36	10	4	18	0.5	6	224.4	48			
	fr 42 to 48	45	9	4	6	1	6	224.4	32			
	fr 48 to 114	81	9	2	66	1	6	224.4	178			
	fr 48 to 72	60	9	2	24	1	6	267.2	77			
	fr 60 to 69	64.5	9	2	9	1	6	267.2	29			
	fr 69 to 72	70.5	9	2	3	1	6	224.4	8			
	fr 108 to 120	114	9	2	12	1	6	142.4	21			
	fr 114 to 150	132	9	2	36	1.118	6	224.4	108			501
deck at 6 m above BL	fr 36 to 114	75	6	2	78	6	1	224.8	210			
	fr 96 to 108	102	6	1	12	36	1	189.6	82			
	fr 108 to 120	114	6	1	12	12	1	142.4	21			
	triangle fr 114 to 150	126	6	1	36	36	0.5	189.6	123			
	polygons fr 114 to 155	134.5	6	2	41	6	0.866	320	136			572

Table 3.8		Steel Weight Calculation		xcg	vcg	nr	length	width	height	spec wt	weight	weight
shell plating 0 to 6 m abl	btm rectangles fr 27 to 45	36	3	2	18	6	1.0541	404	92			
	inside triangles fr 27 to 42	37	4.3333	2	15	5	0.5	404	30			
	inside btm fr 42 to 60	53	3	1	18	36	1.0541	404	276			
	inside triangles fr 42 to 60	48	2	2	18	6	0.5	404	44			
	outside triangles fr 27 to 45	39	4	2	18	6	0.5	404	44			
	fr 45 to 108	76.5	3	2	63	6	1	404	305			
	fr 108 to 150	129	3	2	42	6	1.118	661.6	373			
	fr 150 to 162	156	3	2	12	6	1.118	824	133			1,296
transv bhds 0 to 6 m abl	fr 30	30	5.5	2	1	6	1	142.4	2			
	fr 36	36	4.5	2	1	6	3	142.4	5			
	fr 42	42	3.5	2	1	6	5	142.4	9			
	fr 48	48	3	2	1	6	6	236	17			
	fr 48	48	5	1	1	36	2	236	17			
	fr 54	54	3	2	1	6	6	142.4	10			
	fr 54	54	3.5	1	1	36	3	188.4	20			
	fr 60	60	3	2	1	6	6	236	17			
	fr 60	60	1.5	1	1	36	3	276.4	30			
	fr 66	66	3	2	1	6	6	142.4	10			
	fr 66	66	1.5	1	1	36	3	188.4	20			
	fr 69	69	4.5	2	2	6	3	276.4	20			
	fr 72	72	3	2	1	6	6	236	17			
	fr 72	72	1.5	1	1	36	6	236	51			
	fr 78	78	3	2	1	6	6	142.4	10			
	fr 78	78	1.5	1	1	36	3	188.4	20			
	fr 84	84	3	2	1	6	6	236	17			
	fr 84	84	1.5	1	1	36	3	276.4	30			
	fr 84	84	4.5	1	1	36	3	176	19			
	fr 90	90	3	2	1	6	6	142.4	10			
	fr 90	90	1.5	1	1	36	3	188.4	20			
	fr 96	96	3	2	1	6	6	236	17			
	fr 96	96	1.5	1	1	36	3	276.4	30			
	fr 96	96	4.5	1	1	36	3	176	19			
	fr 102	102	3	2	1	6	6	142.4	10			
	fr 102	102	1.5	1	1	36	3	188.4	20			
	fr 108	108	3	2	1	6	6	236	17			
	fr 108	108	1.5	1	1	36	3	276.4	30			
	fr 108	108	4.5	1	1	36	3	176	19			
	fr 114	114	3	2	1	6	6	142.4	10			
	fr 114	114	1.5	1	1	36	3	188.4	20			
	fr 114.5 to 116.4	115.45	3	2	0.866	6	6	142.4	9			
	fr 120	120	3	1	1	30	6	263.6	47			
	fr 120 to 122.4	121.2	3	2	0.866	6	6	236	15			
fr 126	126	1.5	1	1	24	3	188.4	14				
fr 126 to 128.4	127.2	3	2	0.866	6	6	142.4	9				
fr 132	132	3	1	1	18	6	236	25				
fr 132 to 134.4	133.2	3	2	0.866	6	6	236	15				
fr 138	138	1.5	1	1	12	3	188.4	7				
fr 138 to 140.4	139.2	3	2	0.866	6	6	142.4	9				
fr 144	144	3	1	1	6	6	236	8				
fr 144 to 146.4	145.2	3	2	0.866	6	6	236	15				
fr 148	148	3	1	1	2	6	267.2	3				
fr 150 to 152.4	151.2	3	2	0.866	6	6	142.4	9				
fr 157.5 to 158.4	157.95	3	2	0.866	2.75	6	142.4	4			754	
longit bhds 0 to 6 m abl	triangles fr 42 to 60	54	4	4	18	0.5	6	236	51			
	polygons fr 48 to 60	54	3	3	12	1	3	150.4	16			
	fr 60 to 114	87	3	2	54	1	6	236	153			
	fr 60 to 72	66	3	4	12	1	6	236	68			
	fr 72 to 78	75	3	2	6	1	6	142.4	10			
	fr 72 to 132	102	1.5	2	60	1	3	142.4	51			
	fr 60 to 144	102	1.5	1	84	1	3	142.4	36			386
tank top	fr 48 to 60	54	4.5	1	12	36	1.054	262.4	119			
	fr 60 to 114	87	3	1	54	36	1	262.4	510			
	fr 114 to 150	126	3	1	36	36	0.5	262.4	170			800

Table 3.9	Steel Weight Calculation	xcg	vcg	nr	length	width	height	spec wt	weight	weight
bottom	fr 45 to 60	52.5	0	2	15	6	1	404	73	
	fr 60 to 114	87	0	1	54	48	1	404	1,047	
	fr 114 to 162	130	0	1	48	48	0.5	404	465	1,585
castings	fr 70	70	4	2					144	
	fr 94	94	4	2					72	
	fr 94.8 to 127.2	111	14.7	2					592	
	fr 118	118	4	2					144	
	fr 161	161	6	1					108	
	fr 161 to 185	173	15	1					225	
	fr 185	185	21	1					54	1,339
thruster supports	top and bottom plates	88.6	4	8	13.2	6	1.1	408	284	
	membranes	88.6	4	40	1	6	2	272	131	
	end plates	88.6	4	4	13.2	1	2	272	29	444
bubbler system	vertical pipe	46	12	2	1	3.1416	12	192	14	
	horizontal pipe	46	5.2	1	1	42	3.1416	192	25	
	ozzles	46	5	12					6	46
deluge system	intake pipe fr 66 to 87	76.5	7.9	2	21	1.8	3.1416	160	38	
	support plate	75	6.5	2	18	1	1	160	6	
	mushrooms	75	9.7	6	1.5	3.1416	3.5	160	16	
	lift pipe fr 87 to 100	93.5	14.4	2	13	1.8	4.4429	160	33	
	pipe frame 100 to 132	116	19.5	2	32	1.8	3.1416	160	58	
	pipe fr 132 to 170	151	19.2	2	38	1.2	3.5123	128	41	
	small pipes nozzles	150	18	20	0.6	3.1416	1.2	96	4	
	nozzles	150	17	20	0.55	3.1416	0.8	800	22	218
heeling system	top plate	111	23	2	6	6	1.0138	192	14	
	outer bottom plate	111	19.3	2	6	12	1	128	18	
	sloping bottom plate	111	16.75	2	6	12	1.0866	160	25	
	top entrance plate	111	17.4	2	6	12	1	208	30	
	bottom entrance plate	111	14.4	2	6	12	1	280	40	
	pipe	114	15.8	1	2.8	24	1.3	192	17	145
tow notch	fr -7.5	-7.5	20	2	1.5708	4	8	312	31	
	fr -7.5 to 10.5	1.5	20	2	2.2211	18	8	312	200	231
wire catchers	tops	-3	27	2	4	4	0.7854	142.4	4	
	sides	-3	25.5	2	4	3.1416	3	238.4	18	22

Table 4.1

Lightship Weight

	Item	Weight		xcg	vcg	length	width	height	fill	spec weight
Lightship		41,052	41,052	90.17	16.89					
Steel		31,000	31,000	94.13	16.84					
Accommodation	bridge	34		102	57	12	12	6	0.785398	0.05
	deck 8	18		102	52.5	12	12	3	0.83	0.05
	deck 7	19		102	49.5	12	12	3	0.89	0.05
	deck 6	21		102	46.5	12	12	3	0.95	0.05
	deck 5,center	86		108	42.5	48	12	3	1	0.05
	deck 5, sides	148		111.5	42.5	41	24	3	1	0.05
	deck 4,center	86		108	39.5	48	12	3	1	0.05
	deck 4, sides	148		111.5	39.5	41	24	3	1	0.05
	deck 3,center	86		108	36.5	48	12	3	1	0.05
	deck 3, sides	148		111.5	36.5	41	24	3	1	0.05
	deck 2	211		112.5	33.5	39	36	3	1	0.05
	deck 1	211	1,215	112.5	30.5	39	36	3	1	0.05
Aux Generators	generator sets	40		100	26					
	exhaust	10		91	44					
	coolers	5		100	26					
	liquids	5		100	26					
	switchboard	20		105	26					
	cables	20	100	100	24					
Towing winches	winches	300		60	26					
	wire	60		62	26					
	small fenders	32		-11.5	20					
	large fender end	151		-9	20					
	large fender inside	960		0	20					
	spare wire	60		62	26					
	rollers	80	1,642	46	25					
Mooring winches and anchor	aft winches	100		12	25					
	aft wire	40		12	25					
	fwd winches	100		172	25					
	fwd wire	40		172	25					
	anchor	30		188	24					
	chain	80		169	20					
	windlass	40	430	165	25					
Cranes etc	cranes	140		60	25.5					
	scooters	10		60	25					
	boats	30		60	25.5					
	life rafts	20	200	60	26					
Boilers etc	boilers	60		80	26					
	liquids	20		80	26					
	sewage treatment	20		115	26					
	liquids	10		115	26					
	incinerator	10		115	25.5					
	liquids	5		115	25.5					
exhaust	10	135	91	43						
Fwd end of deck house	Emergency diesel	30		120	25.5					
	wet lab	37		120	25.5					
	storage	60	127	120	25.5					

Table 4.2

Lightship Weight

	Item	Weight		xcg	vcg
Equipment 18 to 24 m above BL	air bubblers	60		44	19.5
	vertical liquid	16		44	10
	horizontal liquid	32		44	5
	helifuel tanks	80		40	21
	helifuel pumps and pipes	10		48	24
	aft fans	40		78	22
	aft crane	50		78	19.5
	main genset cranes	120		84	22
	fwd fans	40		114	20.5
	fwd crane	40	488	114	22
	Equipment 12 to 18 m above BL	workshop	100		78
main gensets		1200		94	13
liquids		120		94	12
lower exhaust economizers		20		89	28
liquids		90		88	26.5
silencers		60		88	26.5
upper exhaust		90		88	36.5
heeling pump		60		88	56
		200	1,940	117	15.6
Thrusters		aft motors	200		27
	aft shafts	150		25	11.5
	aft props	200		22	4
	two motors	200		63	4
	two shafts	150		63	4
	two props	200		63	4
	two motors	200		87	4
	two shafts	75		87	4
	two props	200		87	4
	two motors	200		111	4
	two shafts	150		111	4
	two props	200	2,125	111	4
	Equipment 3 to 12 m above BL	aft ballast out	100		72
liquids		20		72	3
ballast in		200		85	7
liquids		10		80	3
central coolers		200		81.5	5.5
liquids		30		81	4.5
deluge pumps		100		89	7.9
liquids		70		93	11
main engine modules		180		91	5
liquids		60		91	4.5
main switchboard		300		102	7.5
cables		150		85	6
compressors		20		102	4
containers		40		102	4
HFO treatment		40		118	8
liquids		10		118	8
fwd ballast out		100		120	3.5
liquids		20	1,650	120	3

**Table 5.1
Hydrostatic Calculation**

		I/vol = 21.09 m	draft fr 93			15 m		
		KM = 29.23 m	draft fr 0			15 m		
			trim			0 m, bow up		
frame	local draft	volume	inertia	zcg	xcg	vol*zcg	vol*xcg	
		74,037	1,561,348	8.15	86.74	603,096	6,421,669	
-6.5	15	0	0	0.00	-6.50	0	0	
-5.5	15	0	0	0.00	-5.50	0	0	
-4.5	15	0	0	0.00	-4.50	0	0	
-3.5	15	0	0	0.00	-3.50	0	0	
-2.5	15	0	0	0.00	-2.50	0	0	
-1.5	15	0	0	0.00	-1.50	0	0	
-0.5	15	0	0	0.00	-0.50	0	0	
0.5	15	2	5,328	14.92	0.50	29.83333	1	
1.5	15	6	5,328	14.75	1.50	88.5	9	
2.5	15	10	5,328	14.58	2.50	145.8333	25	
3.5	15	14	5,328	14.42	3.50	201.8333	49	
4.5	15	18	5,328	14.25	4.50	256.5	81	
5.5	15	22	5,328	14.08	5.50	309.8333	121	
6.5	15	26	5,328	13.92	6.50	361.8333	169	
7.5	15	30	5,328	13.75	7.50	412.5	225	
8.5	15	34	5,328	13.58	8.50	461.8333	289	
9.5	15	38	5,328	13.42	9.50	509.8333	361	
10.5	15	42	5,328	13.25	10.50	556.5	441	
11.5	15	46	5,328	13.08	11.50	601.8333	529	
12.5	15	50	5,328	12.92	12.50	645.8333	625	
13.5	15	54	5,328	12.75	13.50	688.5	729	
14.5	15	58	5,328	12.58	14.50	729.8333	841	
15.5	15	68	9,216	12.64	15.50	859.3333	1054	
16.5	15	84	9,216	12.79	16.50	1074	1386	
17.5	15	100	9,216	12.83	17.50	1283.333	1750	
18.5	15	116	9,216	12.82	18.50	1487.333	2146	
19.5	15	132	9,216	12.77	19.50	1686	2574	
20.5	15	148	9,216	12.70	20.50	1879.333	3034	
21.5	15	164	9,216	12.61	21.50	2067.333	3526	
22.5	15	180	9,216	12.50	22.50	2250	4050	
23.5	15	196	9,216	12.38	23.50	2427.333	4606	
24.5	15	212	9,216	12.26	24.50	2599.333	5194	
25.5	15	228	9,216	12.13	25.50	2766	5814	
26.5	15	244	9,216	12.00	26.50	2927.333	6466	
27.5	15	260	9,216	11.86	27.50	3083.333	7150	
28.5	15	276	9,216	11.72	28.50	3234	7866	
29.5	15	292	9,216	11.57	29.50	3379.333	8614	
30.5	15	308	9,216	11.43	30.50	3519.333	9394	
31.5	15	324	9,216	11.28	31.50	3654	10206	
32.5	15	340	9,216	11.13	32.50	3783.333	11050	
33.5	15	356	9,216	10.98	33.50	3907.333	11926	
34.5	15	372	9,216	10.82	34.50	4026	12834	
35.5	15	388	9,216	10.67	35.50	4139.333	13774	
36.5	15	404	9,216	10.51	36.50	4247.333	14746	
37.5	15	420	9,216	10.36	37.50	4350	15750	
38.5	15	436	9,216	10.20	38.50	4447.333	16786	
39.5	15	452	9,216	10.04	39.50	4539.333	17854	
40.5	15	468	9,216	9.88	40.50	4626	18954	
41.5	15	484	9,216	9.73	41.50	4707.333	20086	
42.5	15	500	9,216	9.57	42.50	4783.333	21250	
43.5	15	516	9,216	9.41	43.50	4854	22446	
44.5	15	532	9,216	9.25	44.50	4919.333	23674	
45.5	15	546	9,216	9.12	45.50	4979.5	24843	
46.5	15	558	9,216	9.02	46.50	5035.5	25947	
47.5	15	570	9,216	8.93	47.50	5087.5	27075	
48.5	15	582	9,216	8.82	48.50	5135.5	28227	
49.5	15	594	9,216	8.72	49.50	5179.5	29403	
50.5	15	606	9,216	8.61	50.50	5219.5	30603	
51.5	15	618	9,216	8.50	51.50	5255.5	31827	
52.5	15	630	9,216	8.39	52.50	5287.5	33075	
53.5	15	642	9,216	8.28	53.50	5315.5	34347	
54.5	15	654	9,216	8.16	54.50	5339.5	35643	
55.5	15	666	9,216	8.05	55.50	5359.5	36963	

Table 5.2

frame	local draft	volume	inertia	zcg	xcg	vol*zcg	vol*xcg
56.5	15	678	9,216	7.93	56.50	5375.5	38307
57.5	15	690	9,216	7.81	57.50	5387.5	39675
58.5	15	702	9,216	7.69	58.50	5395.5	41067
59.5	15	714	9,216	7.56	59.50	5399.5	42483
60.5	15	666	6,930	7.26	60.50	4833	40293
61.5	15	666	6,930	7.26	61.50	4833	40959
62.5	15	666	6,930	7.26	62.50	4833	41625
63.5	15	666	6,930	7.26	63.50	4833	42291
64.5	15	666	6,930	7.26	64.50	4833	42957
65.5	15	666	6,930	7.26	65.50	4833	43623
66.5	15	648	9,216	7.33	66.50	4752	43092
67.5	15	648	9,216	7.33	67.50	4752	43740
68.5	15	648	9,216	7.33	68.50	4752	44388
69.5	15	648	9,216	7.33	69.50	4752	45036
70.5	15	648	9,216	7.33	70.50	4752	45684
71.5	15	648	9,216	7.33	71.50	4752	46332
72.5	15	576	9,216	7.87	72.50	4536	41760
73.5	15	576	9,216	7.87	73.50	4536	42336
74.5	15	576	9,216	7.87	74.50	4536	42912
75.5	15	576	9,216	7.87	75.50	4536	43488
76.5	15	576	9,216	7.87	76.50	4536	44064
77.5	15	576	9,216	7.87	77.50	4536	44640
78.5	15	648	9,216	7.33	78.50	4752	50868
79.5	15	648	9,216	7.33	79.50	4752	51516
80.5	15	648	9,216	7.33	80.50	4752	52164
81.5	15	648	9,216	7.33	81.50	4752	52812
82.5	15	648	9,216	7.33	82.50	4752	53460
83.5	15	648	9,216	7.33	83.50	4752	54108
84.5	15	720	9,216	7.50	84.50	5400	60840
85.5	15	720	9,216	7.50	85.50	5400	61560
86.5	15	720	9,216	7.50	86.50	5400	62280
87.5	15	720	9,216	7.50	87.50	5400	63000
88.5	15	720	9,216	7.50	88.50	5400	63720
89.5	15	720	9,216	7.50	89.50	5400	64440
90.5	15	720	9,216	7.50	90.50	5400	65160
91.5	15	720	9,216	7.50	91.50	5400	65880
92.5	15	720	9,216	7.50	92.50	5400	66600
93.5	15	720	9,216	7.50	93.50	5400	67320
94.5	15	720	9,216	7.50	94.50	5400	68040
95.5	15	720	9,216	7.50	95.50	5400	68760
96.5	15	720.0313	9,507	7.50	96.50	5400.467	69483.02
97.5	15	720.2813	10,107	7.50	97.50	5404.184	70227.42
98.5	15	720.7813	10,732	7.51	98.50	5411.556	70996.95
99.5	15	721.5313	11,383	7.52	99.50	5422.522	71792.36
100.5	15	723.1156	21,664	7.53	100.50	5445.742	72673.12
101.5	15	726.1946	22,366	7.56	101.50	5490.458	73708.75
102.5	15	729.3407	23,095	7.59	102.50	5535.19	74757.42
103.5	15	732.5539	23,851	7.62	103.50	5580.101	75819.33
104.5	15	735.8342	24,636	7.64	104.50	5625.331	76894.67
105.5	15	739.1816	25,448	7.67	105.50	5670.991	77983.66
106.5	15	742.5961	26,289	7.70	106.50	5717.17	79086.48
107.5	15	746.0777	27,159	7.73	107.50	5763.931	80203.35
108.5	15	748.0951	27,605	7.74	108.50	5790.688	81168.32
109.5	15	748.4609	27,605	7.74	109.50	5795.235	81956.47
110.5	15	748.6438	27,605	7.74	110.50	5797.496	82725.14
111.5	15	748.6438	27,605	7.74	111.50	5797.496	83473.78
112.5	15	748.4609	27,605	7.74	112.50	5795.235	84201.85
113.5	15	748.0951	27,605	7.74	113.50	5790.688	84908.79
114.5	15	740.0464	27,159	7.74	114.50	5727.554	84735.31
115.5	15	724.3148	26,289	7.74	115.50	5605.76	83658.36
116.5	15	708.4003	25,448	7.74	116.50	5481.453	82528.64
117.5	15	692.3029	24,636	7.73	117.50	5354.509	81345.59
118.5	15	676.0226	23,851	7.73	118.50	5224.777	80108.68
119.5	15	659.5594	23,095	7.72	119.50	5092.082	78817.35
120.5	15	642.9134	22,366	7.71	120.50	4956.222	77471.06
121.5	15	626.0844	21,664	7.69	121.50	4816.973	76069.25
122.5	15	610.5	11,383	7.69	122.50	4695.75	74786.25
123.5	15	595.5	10,732	7.70	123.50	4583.25	73544.25
124.5	15	580.5	10,107	7.70	124.50	4470.75	72272.25

Table 5.3

frame	local draft	volume	inertia	zcg	xcg	vol*zcg	vol*xcg
125.5	15	565.5	9,507	7.71	125.50	4358.25	70970.25
126.5	15	550.5	8,931	7.71	126.50	4245.75	69638.25
127.5	15	535.5	8,379	7.72	127.50	4133.25	68276.25
128.5	15	520.5	7,850	7.72	128.50	4020.75	66884.25
129.5	15	505.5	7,343	7.73	129.50	3908.25	65462.25
130.5	15	490.5	6,859	7.74	130.50	3795.75	64010.25
131.5	15	475.5	6,397	7.75	131.50	3683.25	62528.25
132.5	15	460.5	5,956	7.75	132.50	3570.75	61016.25
133.5	15	445.5	5,536	7.76	133.50	3458.25	59474.25
134.5	15	430.5	5,136	7.77	134.50	3345.75	57902.25
135.5	15	415.5	4,756	7.78	135.50	3233.25	56300.25
136.5	15	400.5	4,395	7.79	136.50	3120.75	54668.25
137.5	15	385.5	4,052	7.80	137.50	3008.25	53006.25
138.5	15	370.5	3,728	7.82	138.50	2895.75	51314.25
139.5	15	355.5	3,422	7.83	139.50	2783.25	49592.25
140.5	15	340.5	3,133	7.84	140.50	2670.75	47840.25
141.5	15	325.5	2,861	7.86	141.50	2558.25	46058.25
142.5	15	310.5	2,605	7.88	142.50	2445.75	44246.25
143.5	15	295.5	2,364	7.90	143.50	2333.25	42404.25
144.5	15	198	2,126	8.09	144.50	1602	28611
145.5	15	198	1,922	8.09	145.50	1602	28809
146.5	15	198	1,730	8.09	146.50	1602	29007
147.5	15	198	1,550	8.09	147.50	1602	29205
148.5	15	220.5	1,382	8.03	148.50	1770.75	32744.25
149.5	15	205.5	1,226	8.07	149.50	1658.25	30722.25
150.5	15	190.5	1,081	8.11	150.50	1545.75	28670.25
151.5	15	175.5	949	8.17	151.50	1433.25	26588.25
152.5	15	160.5	828	8.23	152.50	1320.75	24476.25
153.5	15	145.5	718	8.30	153.50	1208.25	22334.25
154.5	15	130.5	618	8.40	154.50	1095.75	20162.25
155.5	15	115.5	528	8.51	155.50	983.25	17960.25
156.5	15	100.5	447	8.66	156.50	870.75	15728.25
157.5	15	85.5	374	8.87	157.50	758.25	13466.25
158.5	15	70.5	310	9.16	158.50	645.75	11174.25
159.5	15	55.5	254	9.61	159.50	533.25	8852.25
160.5	15	40.5	205	10.39	160.50	420.75	6500.25
161.5	15	25.5	163	12.09	161.50	308.25	4118.25
162.5	15	16.53125	127	14.04	162.50	232.1263	2686.328
163.5	15	13.78125	96	14.12	163.50	194.6602	2253.234
164.5	15	11.28125	71	14.21	164.50	160.2878	1855.766
165.5	15	9.03125	51	14.29	165.50	129.0716	1494.672
166.5	15	7.03125	35	14.37	166.50	101.0742	1170.703
167.5	15	5.28125	23	14.46	167.50	76.35807	884.6094
168.5	15	3.78125	14	14.54	168.50	54.98568	637.1406
169.5	15	2.53125	8	14.62	169.50	37.01953	429.0469
170.5	15	1.53125	4	14.71	170.50	22.52214	261.0781
171.5	15	0.78125	1	14.79	171.50	11.55599	133.9844
172.5	15	0.28125	0	14.87	172.50	4.183594	48.51563
173.5	15	0.03125	0	14.96	173.50	0.467448	5.421875
174.5	15	0	0	0.00	174.50	0	0
175.5	15	0	0	0.00	175.50	0	0
176.5	15	0	0	0.00	176.50	0	0
177.5	15	0	0	0.00	177.50	0	0
178.5	15	0	0	0.00	178.50	0	0
179.5	15	0	0	0.00	179.50	0	0
180.5	15	0	0	0.00	180.50	0	0
181.5	15	0	0	0.00	181.50	0	0
182.5	15	0	0	0.00	182.50	0	0
183.5	15	0	0	0.00	183.50	0	0
184.5	15	0	0	0.00	184.50	0	0
185.5	15	0	0	0.00	185.50	0	0

ICEBREAKER FOR B-MAX TANKERS

Table 6.1

ER perm
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Weight Balance Calculation

Breaking Ice With Maximum Fuel

	spec weight	tank	frames	ullage	tank slack?	tank height	liquid level	weight	inertia	xcg	vcg
ballast 11,986	1.025	center	24 to 48	0.843	1	14	11.802	2,257	3,542	38.05	11.56
	1.025	side	24 to 48	0.8	1	14	11.2	4,166	7,085	38.22	11.23
	1.025	wing	30 to 48	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	48 to 60	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	60 to 72	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	72 to 84	1	0	6	6	1,736	0	79.50	1.87
	1.025	bottom	84 to 96	0	0	6	0	0	0	0.00	0.00
	1.025	bottom	96 to 108	0	0	12	0	0	0	0.00	0.00
	1.025	heeling	108 to 114	0.5	1			1,306	14,170	111	19
	1.025	bottom	108 to 120	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	120 to 132	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	132 to 144	0.2262	1	12	2.7144	785	3,542	137.00	1.36
	1.025	center	144 to 162	1	0	12	12	1,736	0	150.00	6.00
HFO 20,445	0.94	center	48 to 72	1	0	19.5	19.5	4,908	0	60.43	13.20
	0.94	side	48 to 72	1	0	19.5	19.5	7,976	0	58.78	14.10
	0.94		120 to 132	1	0	19.5	19.5	3,781	0	125.32	11.09
	0.94		132 to 144	1	0	19.5	19.5	2,587	0	137.50	12.75
	0.94	settling	120 to 132	1	0	6	6	398	0	136.00	15.00
	0.94	day	120 to 132	1	0	6	6	398	0	136.00	15.00
	0.94	overflow	120 to 132	0.5	1	6	3	398	1,624	136.00	19.50
DO 910	0.86	center	96 to 108	1	0	5	5	405	0	102.00	26.50
	0.86	side	96 to 106	1	0	5	5	506	0	101.00	26.50
FW	1		110 to 120	1	0	5	5	392	0	115.00	26.50
helifuel	0.8		27 to 45	1	0	2.8	2.8	246	0	36.00	20.60
food store			108 to 132					100		120.00	30.30
crew			84 to 132					15		108.00	26.50
spares			72 to 84					200		78.00	15.00
deck store			120 to 132					50		126.00	26.00
light ship								42,000		90.17	16.89
GM	13.88 m						Total Ship Weight	76,344	29,964	86.74	14.94
Draft Trim	15 m 0 m, bow up						Displacement Weight	76,344	1,561,348	86.74	8.15

ICEBREAKER FOR B-MAX TANKERS

Table 7.5

ER perm
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Weight Balance Calculation

**Deballasting After Grounding
By Trimming With Maximum Fuel**

	spec weight	tank	frames	ullage	tank slack?	tank height	liquid level	weight	inertia	xcg	vcg
ballast 9,102	1.025	center	24 to 48	1	0	14	14	2,893	0	37.60	12.73
	1.025	side	24 to 48	1	0	14	14	5,786	0	37.60	12.73
	1.025	wing	30 to 48	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	48 to 60	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	60 to 72	0	0	12	0	0	0	0.00	0.00
	1.025	bottom	72 to 84	0	0	6	0	0	0	0.00	0.00
	1.025	bottom	84 to 96	0	0	6	0	0	0	0.00	0.00
	1.025	bottom	96 to 108	0	0	12	0	0	0	0.00	0.00
	1.025	heeling	108 to 114	0	0			0	0	111	19
	1.025	bottom	108 to 120	0.025	1	12	0.3	163	113,357	114.00	0.15
	1.025	bottom	120 to 132	0.025	1	12	0.3	130	47,822	125.00	0.15
1.025	bottom	132 to 144	0.025	1	12	0.3	87	14,170	137.00	0.15	
1.025	center	144 to 162	0.025	1	12	0.3	43	5,314	150.00	0.15	
HFO 20,445	0.94	center	48 to 72	1	0	19.5	19.5	4,908	0	60.43	13.20
	0.94	side	48 to 72	1	0	19.5	19.5	7,976	0	58.78	14.10
	0.94		120 to 132	1	0	19.5	19.5	3,781	0	125.32	11.09
	0.94		132 to 144	1	0	19.5	19.5	2,587	0	137.50	12.75
	0.94	settling	120 to 132	1	0	6	6	398	0	136.00	15.00
	0.94	day	120 to 132	1	0	6	6	398	0	136.00	15.00
	0.94	overflow	120 to 132	0.5	1	6	3	398	1,624	136.00	19.50
DO 910	0.86	center	96 to 108	1	0	5	5	405	0	102.00	26.50
	0.86	side	96 to 106	1	0	5	5	506	0	101.00	26.50
FW	1		110 to 120	1	0	5	5	392	0	115.00	26.50
helifuel	0.8		27 to 45	1	0	2.8	2.8	246	0	36.00	20.60
food store			108 to 132					100		120.00	30.30
crew			84 to 132					15		108.00	26.50
spares			72 to 84					200		78.00	15.00
deck store			120 to 132					50		126.00	26.00
light ship								42,000		90.17	16.89
GM	9.95 m						Total Ship Weight	73,460	182,287	83.12	15.51
Draft Trim	14.2326 m 4.58 m, bow up						Displacement Weight	73,460	1,430,621	83.12	7.93

Fast Heeling System

Table 8.1

wat eff	0.8	ship/tank =	0.5241	max pump		tank area	220.8 m ²
		Power =	1,900 kW	pressure	10 m	pipe dia	2.8 m
	15	Effic =	0.65			transfer	807 tonnes
Step =	0.1 s	air gap =	4.6 m	end spd	-13.463 m/s	max air p over 6.59 m under 2.84 m	
discon @	6.1 s	spec res =	0.01285	period/2	15 s		
recon @	2.8 s	mass of w =	267,000 kg	max lvl	1.83 m		

time s	tank lvl m	wat speed m/s	volume m ³ /s	pressures and water resistance						F kN	a m/s ²
				tank lvl m	pump m	water res m	air over p m	air und p m	total m		
0	0.000	13.463	82.90	0.00	1.52	2.33	0.00	0.00	-0.81	-50.2	-0.23
0.1	0.038	13.439	82.75	0.04	1.52	2.32	0.08	0.08	-1.00	-62.0	-0.29
0.2	0.075	13.410	82.57	0.08	1.52	2.31	0.17	0.16	-1.19	-73.7	-0.35
0.3	0.112	13.376	82.36	0.12	1.53	2.30	0.25	0.24	-1.38	-85.2	-0.40
0.4	0.150	13.336	82.11	0.16	1.53	2.29	0.34	0.31	-1.56	-96.6	-0.45
0.5	0.187	13.290	81.84	0.20	1.54	2.27	0.42	0.39	-1.74	-107.7	-0.50
0.6	0.224	13.240	81.53	0.23	1.54	2.25	0.51	0.46	-1.92	-118.7	-0.56
0.7	0.261	13.184	81.18	0.27	1.55	2.23	0.60	0.54	-2.09	-129.5	-0.61
0.8	0.297	13.124	80.81	0.31	1.56	2.21	0.69	0.61	-2.26	-140.2	-0.66
0.9	0.334	13.058	80.41	0.35	1.57	2.19	0.78	0.68	-2.43	-150.7	-0.71
1	0.370	12.988	79.97	0.39	1.57	2.17	0.87	0.74	-2.60	-161.0	-0.75
1.1	0.406	12.912	79.51	0.43	1.58	2.14	0.97	0.81	-2.76	-171.2	-0.80
1.2	0.442	12.832	79.01	0.46	1.59	2.12	1.06	0.88	-2.93	-181.1	-0.85
1.3	0.478	12.747	78.49	0.50	1.60	2.09	1.16	0.94	-3.08	-191.0	-0.89
1.4	0.513	12.658	77.94	0.54	1.62	2.06	1.26	1.00	-3.24	-200.6	-0.94
1.5	0.548	12.564	77.36	0.57	1.63	2.03	1.35	1.06	-3.39	-210.1	-0.98
1.6	0.583	12.466	76.76	0.61	1.64	2.00	1.45	1.13	-3.54	-219.5	-1.03
1.7	0.618	12.363	76.12	0.65	1.65	1.96	1.55	1.18	-3.69	-228.7	-1.07
1.8	0.652	12.256	75.47	0.68	1.67	1.93	1.65	1.24	-3.84	-237.7	-1.11
1.9	0.686	12.144	74.78	0.72	1.68	1.90	1.75	1.30	-3.98	-246.6	-1.15
2	0.720	12.029	74.07	0.75	1.70	1.86	1.86	1.35	-4.12	-255.3	-1.20
2.1	0.753	11.910	73.33	0.79	1.72	1.82	1.96	1.41	-4.26	-263.8	-1.24
2.2	0.786	11.786	72.57	0.82	1.73	1.79	2.06	1.46	-4.40	-272.2	-1.27
2.3	0.819	11.659	71.79	0.86	1.75	1.75	2.17	1.51	-4.53	-280.4	-1.31
2.4	0.851	11.527	70.98	0.89	1.77	1.71	2.27	1.56	-4.66	-288.5	-1.35
2.5	0.883	11.392	70.15	0.93	1.79	1.67	2.38	1.61	-4.79	-296.3	-1.39
2.6	0.915	11.254	69.29	0.96	1.82	1.63	2.48	1.66	-4.91	-304.1	-1.42
2.7	0.946	11.111	68.42	0.99	1.84	1.59	2.59	1.71	-5.03	-311.6	-1.46
2.8	0.977	10.965	67.52	1.02	1.86	1.55	2.70	1.75	-5.15	-319.0	-1.49
2.9	1.007	10.816	66.60	1.06	1.89	1.50	2.80	1.80	-5.27	-326.2	-1.53
3	1.037	10.663	65.66	1.09	1.92	1.46	2.91	1.84	-5.38	-333.2	-1.56
3.1	1.067	10.507	64.70	1.12	1.95	1.42	3.02	1.88	-5.49	-340.0	-1.59
3.2	1.096	10.348	63.72	1.15	1.98	1.38	3.13	1.92	-5.60	-346.7	-1.62
3.3	1.124	10.186	62.72	1.18	2.01	1.33	3.23	1.96	-5.70	-353.1	-1.65
3.4	1.153	10.020	61.70	1.21	2.04	1.29	3.34	2.00	-5.80	-359.4	-1.68
3.5	1.180	9.852	60.67	1.24	2.08	1.25	3.45	2.04	-5.90	-365.4	-1.71
3.6	1.207	9.681	59.61	1.27	2.11	1.20	3.56	2.08	-6.00	-371.3	-1.74
3.7	1.234	9.507	58.54	1.29	2.15	1.16	3.67	2.12	-6.09	-376.9	-1.76
3.8	1.261	9.331	57.45	1.32	2.19	1.12	3.77	2.15	-6.17	-382.3	-1.79
3.9	1.286	9.152	56.35	1.35	2.23	1.08	3.88	2.19	-6.26	-387.4	-1.81
4	1.312	8.970	55.24	1.37	2.28	1.03	3.99	2.22	-6.34	-392.3	-1.84
4.1	1.336	8.787	54.10	1.40	2.33	0.99	4.09	2.25	-6.41	-397.0	-1.86
4.2	1.361	8.601	52.96	1.43	2.38	0.95	4.20	2.28	-6.48	-401.3	-1.88
4.3	1.384	8.413	51.80	1.45	2.43	0.91	4.30	2.31	-6.55	-405.4	-1.90
4.4	1.407	8.223	50.63	1.48	2.49	0.87	4.41	2.34	-6.61	-409.2	-1.92
4.5	1.430	8.032	49.46	1.50	2.55	0.83	4.51	2.37	-6.67	-412.7	-1.93
4.6	1.452	7.838	48.27	1.52	2.61	0.79	4.61	2.40	-6.72	-415.9	-1.95
4.7	1.474	7.644	47.07	1.54	2.67	0.75	4.71	2.43	-6.76	-418.7	-1.96
4.8	1.495	7.448	45.86	1.57	2.75	0.71	4.81	2.45	-6.80	-421.1	-1.97
4.9	1.515	7.251	44.65	1.59	2.82	0.68	4.91	2.48	-6.83	-423.2	-1.98
5	1.535	7.052	43.43	1.61	2.90	0.64	5.01	2.50	-6.86	-424.8	-1.99

Table 8.2

time s	tank lvl m	wat speed m/s	volume m ³ /s	pressures and water resistance						F kN	a m/s ²
				tank lvl m	pump m	water res m	air over p m	air und p m	total m		
5.1	1.555	6.854	42.20	1.63	2.98	0.60	5.11	2.53	-6.88	-426.1	-1.99
5.2	1.574	6.654	40.97	1.65	3.07	0.57	5.20	2.55	-6.89	-426.8	-2.00
5.3	1.592	6.454	39.74	1.67	3.17	0.54	5.29	2.57	-6.90	-427.1	-2.00
5.4	1.610	6.254	38.51	1.69	3.27	0.50	5.38	2.59	-6.90	-426.9	-2.00
5.5	1.627	6.054	37.28	1.71	3.38	0.47	5.47	2.61	-6.88	-426.2	-2.00
5.6	1.643	5.855	36.05	1.72	3.49	0.44	5.56	2.63	-6.86	-424.8	-1.99
5.7	1.659	5.656	34.83	1.74	3.61	0.41	5.64	2.65	-6.83	-422.9	-1.98
5.8	1.675	5.458	33.61	1.76	3.75	0.38	5.73	2.67	-6.79	-420.3	-1.97
5.9	1.690	5.261	32.40	1.77	3.89	0.36	5.81	2.69	-6.73	-417.0	-1.95
6	1.704	5.066	31.19	1.79	4.04	0.33	5.89	2.70	-6.67	-412.9	-1.93
6.1	1.718	4.873	30.00	1.80	4.20	0.31	5.96	2.72	-6.59	-408.1	-1.91
6.2	1.731	4.682	28.83	1.81	0.00	0.28	6.04	2.73	-10.87	-672.8	-3.15
6.3	1.744	4.367	26.89	1.83	0.00	0.25	6.11	2.75	-10.93	-676.7	-3.17
6.4	1.756	4.050	24.94	1.84	0.00	0.21	6.17	2.76	-10.99	-680.2	-3.18
6.5	1.767	3.732	22.98	1.85	0.00	0.18	6.23	2.77	-11.04	-683.6	-3.20
6.6	1.777	3.411	21.01	1.86	0.00	0.15	6.29	2.79	-11.09	-686.6	-3.21
6.7	1.786	3.090	19.03	1.87	0.00	0.12	6.34	2.80	-11.14	-689.5	-3.23
6.8	1.794	2.767	17.04	1.88	0.00	0.10	6.39	2.81	-11.18	-692.0	-3.24
6.9	1.801	2.443	15.04	1.89	0.00	0.08	6.43	2.81	-11.21	-694.3	-3.25
7	1.807	2.118	13.04	1.89	0.00	0.06	6.47	2.82	-11.25	-696.3	-3.26
7.1	1.813	1.792	11.04	1.90	0.00	0.04	6.50	2.83	-11.27	-698.0	-3.27
7.2	1.817	1.466	9.02	1.91	0.00	0.03	6.53	2.83	-11.30	-699.4	-3.27
7.3	1.821	1.138	7.01	1.91	0.00	0.02	6.55	2.84	-11.31	-700.5	-3.28
7.4	1.824	0.810	4.99	1.91	0.00	0.01	6.57	2.84	-11.33	-701.4	-3.28
7.5	1.826	0.482	2.97	1.91	0.00	0.00	6.58	2.84	-11.34	-702.0	-3.29
7.6	1.826	0.153	0.94	1.91	0.00	0.00	6.59	2.84	-11.34	-702.3	-3.29
7.7	1.826	-0.176	-1.08	1.91	0.00	-0.00	6.59	2.84	-11.34	-702.2	-2.63
7.8	1.826	-0.439	-2.70	1.91	0.00	-0.00	6.58	2.84	-11.33	-701.6	-2.63
7.9	1.824	-0.701	-4.32	1.91	0.00	-0.01	6.57	2.84	-11.32	-700.6	-2.62
8	1.822	-0.964	-5.93	1.91	0.00	-0.01	6.56	2.84	-11.29	-699.1	-2.62
8.1	1.819	-1.226	-7.55	1.91	0.00	-0.02	6.54	2.83	-11.26	-697.1	-2.61
8.2	1.815	-1.487	-9.15	1.90	0.00	-0.03	6.52	2.83	-11.22	-694.6	-2.60
8.3	1.810	-1.747	-10.76	1.90	0.00	-0.04	6.49	2.82	-11.17	-691.7	-2.59
8.4	1.805	-2.006	-12.35	1.89	0.00	-0.05	6.46	2.82	-11.12	-688.3	-2.58
8.5	1.799	-2.264	-13.94	1.89	0.00	-0.07	6.42	2.81	-11.05	-684.5	-2.56
8.6	1.792	-2.520	-15.52	1.88	0.00	-0.08	6.38	2.80	-10.99	-680.2	-2.55
8.7	1.785	-2.775	-17.09	1.87	0.00	-0.10	6.34	2.80	-10.91	-675.5	-2.53
8.8	1.777	-3.028	-18.64	1.86	0.00	-0.12	6.29	2.79	-10.83	-670.3	-2.51
8.9	1.768	-3.279	-20.19	1.85	-8.56	-0.14	6.24	2.78	-19.30	-1194.9	-4.48
9	1.758	-3.726	-22.95	1.84	-7.50	-0.18	6.19	2.77	-18.12	-1121.9	-4.20
9.1	1.747	-4.147	-25.53	1.83	-6.71	-0.22	6.13	2.75	-17.20	-1064.9	-3.99
9.2	1.735	-4.545	-27.99	1.82	-6.09	-0.27	6.06	2.74	-16.44	-1018.1	-3.81
9.3	1.722	-4.927	-30.34	1.81	-5.60	-0.31	5.98	2.72	-15.80	-978.1	-3.66
9.4	1.708	-5.293	-32.59	1.79	-5.18	-0.36	5.91	2.71	-15.23	-942.8	-3.53
9.5	1.693	-5.646	-34.77	1.77	-4.84	-0.41	5.82	2.69	-14.71	-911.0	-3.41
9.6	1.676	-5.987	-36.87	1.76	-4.54	-0.46	5.73	2.67	-14.24	-881.8	-3.30
9.7	1.659	-6.318	-38.90	1.74	-4.28	-0.51	5.64	2.65	-13.80	-854.6	-3.20
9.8	1.641	-6.638	-40.87	1.72	-4.06	-0.57	5.55	2.63	-13.39	-828.9	-3.10
9.9	1.622	-6.948	-42.78	1.70	-3.86	-0.62	5.45	2.61	-12.99	-804.5	-3.01
10	1.602	-7.249	-44.64	1.68	-3.68	-0.68	5.35	2.58	-12.61	-781.0	-2.93

Table 8.3

time s	tank lvl m	wat speed m/s	volume m ³ /s	pressures and water resistance						F kN	a m/s ²
				tank lvl m	pump m	water res m	air over p m	air und p m	total m		
10.1	1.582	-7.542	-46.44	1.66	-3.52	-0.73	5.24	2.56	-12.25	-758.3	-2.84
10.2	1.560	-7.826	-48.19	1.64	-3.38	-0.79	5.13	2.53	-11.89	-736.3	-2.76
10.3	1.538	-8.102	-49.89	1.61	-3.25	-0.84	5.02	2.51	-11.54	-714.8	-2.68
10.4	1.515	-8.369	-51.53	1.59	-3.13	-0.90	4.91	2.48	-11.20	-693.7	-2.60
10.5	1.491	-8.629	-53.13	1.56	-3.02	-0.96	4.80	2.45	-10.87	-673.1	-2.52
10.6	1.467	-8.881	-54.69	1.54	-2.92	-1.01	4.68	2.42	-10.54	-652.8	-2.44
10.7	1.442	-9.126	-56.19	1.51	-2.83	-1.07	4.57	2.39	-10.22	-632.8	-2.37
10.8	1.416	-9.363	-57.65	1.48	-2.74	-1.13	4.45	2.35	-9.90	-613.0	-2.30
10.9	1.390	-9.592	-59.07	1.46	-2.66	-1.18	4.33	2.32	-9.59	-593.5	-2.22
11	1.363	-9.815	-60.43	1.43	-2.59	-1.24	4.21	2.29	-9.27	-574.2	-2.15
11.1	1.335	-10.030	-61.76	1.40	-2.52	-1.29	4.09	2.25	-8.97	-555.1	-2.08
11.2	1.307	-10.238	-63.04	1.37	-2.46	-1.35	3.97	2.21	-8.66	-536.2	-2.01
11.3	1.278	-10.438	-64.28	1.34	-2.40	-1.40	3.85	2.17	-8.36	-517.5	-1.94
11.4	1.249	-10.632	-65.47	1.31	-2.34	-1.45	3.73	2.13	-8.06	-498.9	-1.87
11.5	1.219	-10.819	-66.62	1.28	-2.29	-1.50	3.60	2.09	-7.76	-480.5	-1.80
11.6	1.188	-10.999	-67.73	1.25	-2.24	-1.55	3.48	2.05	-7.47	-462.3	-1.73
11.7	1.157	-11.172	-68.79	1.21	-2.19	-1.60	3.36	2.01	-7.18	-444.3	-1.66
11.8	1.126	-11.339	-69.82	1.18	-2.15	-1.65	3.24	1.97	-6.89	-426.4	-1.60
11.9	1.094	-11.498	-70.80	1.15	-2.11	-1.70	3.12	1.92	-6.60	-408.6	-1.53
12	1.062	-11.651	-71.74	1.11	-2.07	-1.74	3.00	1.88	-6.32	-391.1	-1.46
12.1	1.029	-11.798	-72.65	1.08	-2.03	-1.79	2.88	1.83	-6.04	-373.7	-1.40
12.2	0.996	-11.938	-73.51	1.04	-2.00	-1.83	2.76	1.78	-5.76	-356.4	-1.33
12.3	0.963	-12.071	-74.33	1.01	-1.97	-1.87	2.65	1.73	-5.48	-339.3	-1.27
12.4	0.929	-12.198	-75.11	0.97	-1.94	-1.91	2.53	1.68	-5.21	-322.4	-1.21
12.5	0.894	-12.319	-75.86	0.94	-1.91	-1.95	2.41	1.63	-4.94	-305.7	-1.14
12.6	0.860	-12.434	-76.56	0.90	-1.88	-1.99	2.30	1.58	-4.67	-289.1	-1.08
12.7	0.825	-12.542	-77.23	0.86	-1.85	-2.02	2.19	1.52	-4.40	-272.7	-1.02
12.8	0.790	-12.644	-77.86	0.83	-1.83	-2.05	2.07	1.47	-4.14	-256.4	-0.96
12.9	0.755	-12.740	-78.45	0.79	-1.80	-2.09	1.96	1.41	-3.88	-240.3	-0.90
13	0.719	-12.830	-79.00	0.75	-1.78	-2.12	1.85	1.35	-3.62	-224.4	-0.84
13.1	0.683	-12.914	-79.52	0.72	-1.76	-2.14	1.74	1.29	-3.37	-208.7	-0.78
13.2	0.647	-12.992	-80.00	0.68	-1.74	-2.17	1.64	1.23	-3.12	-193.1	-0.72
13.3	0.611	-13.065	-80.45	0.64	-1.72	-2.19	1.53	1.17	-2.87	-177.7	-0.67
13.4	0.574	-13.131	-80.86	0.60	-1.70	-2.22	1.43	1.11	-2.62	-162.5	-0.61
13.5	0.537	-13.192	-81.23	0.56	-1.68	-2.24	1.32	1.05	-2.38	-147.4	-0.55
13.6	0.501	-13.247	-81.57	0.52	-1.67	-2.26	1.22	0.98	-2.14	-132.5	-0.50
13.7	0.464	-13.297	-81.88	0.49	-1.65	-2.27	1.12	0.92	-1.90	-117.8	-0.44
13.8	0.426	-13.341	-82.15	0.45	-1.64	-2.29	1.02	0.85	-1.67	-103.2	-0.39
13.9	0.389	-13.380	-82.39	0.41	-1.62	-2.30	0.92	0.78	-1.43	-88.8	-0.33
14	0.352	-13.413	-82.59	0.37	-1.61	-2.31	0.83	0.71	-1.21	-74.6	-0.28
14.1	0.314	-13.441	-82.76	0.33	-1.60	-2.32	0.73	0.64	-0.98	-60.5	-0.23
14.2	0.277	-13.464	-82.90	0.29	-1.58	-2.33	0.64	0.57	-0.75	-46.7	-0.17
14.3	0.239	-13.481	-83.01	0.25	-1.57	-2.34	0.55	0.49	-0.53	-32.9	-0.12
14.4	0.202	-13.493	-83.09	0.21	-1.56	-2.34	0.46	0.42	-0.31	-19.3	-0.07
14.5	0.164	-13.501	-83.13	0.17	-1.55	-2.34	0.37	0.34	-0.10	-5.9	-0.02
14.6	0.126	-13.503	-83.14	0.13	-1.54	-2.34	0.28	0.27	0.12	7.3	0.03
14.7	0.089	-13.500	-83.13	0.09	-1.53	-2.34	0.20	0.19	0.33	20.4	0.08
14.8	0.051	-13.492	-83.08	0.05	-1.52	-2.34	0.11	0.11	0.54	33.4	0.13
14.9	0.013	-13.480	-83.00	0.01	-1.52	-2.33	0.03	0.03	0.75	46.2	0.17
15	-0.024	-13.463	-82.90	-0.03	-1.52	-2.33	-0.05	-0.05	0.94	58.2	0.22