Environmental
Studies
Revolving
Funds

042 Management of Small Ice Masses

Canada

August 1986

Environmental Studies Revolving Funds
Report No. 042

August, 1986

MANAGEMENT OF SMALL ICE MASSES

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The correct citation for this report is:

Anderson, D.G., D. McDonald, P. Mitten, S. Nicholls and D. Tait. 1986. Management of small ice masses. Environmental Studies Revolving Funds Report No. 042. Ottawa. 183 p.

Published under the auspices
of the Environmental Studies
Revolving Funds.
ISBN 0-920783-41-4

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF TABLES

ACKNOWLEDGEMENTS

A number of people have contributed to this study and without their collective input, much valuable information and discussion would undoubtedly be missing from the final document.

Special thanks are extended to Greg Warbanski of the Husky/Bow Valley East Coast Project, the study scientific advisor. His continued assistance and encouragement were greatly appreciated. He, Peter Wood of ESRF, and Chris Noll of the Newfoundland and Labrador Petroleum Directorate (NLPD) reviewed the manuscript, providing many valuable comments and suggestions.

Operations personnel and industry representatives who gave of their time in the form of interviews or completion of questionnaires, or who otherwise provided information, deserve thanks. Their combined experience made the study relevant in terms of the many theoretical and practical considerations.

However, it must be stressed that despite the contribution of these various people, the responsibility for the contents of the manuscript is the authors' and the responsibility for any errors must be laid at our door.

Finally, thanks must be extended to the staff of the Ocean Engineering Information Centre (OEIC), in St. John's, NF, who assisted in locating most of the appropriate reference material, Debbie Wiseman and Scott Gillis, who patiently drafted the figures which appear throughout the text, and Joan Ghaney who typed the manuscript, in parts many times over. She remained efficient and cheerful in the face of typing, re-typing and re-re-typing.

EXECUTIVE SUMMARY

The primary objective of this study was to improve handling capabilities for small ice masses, thereby allowing offshore operators working in ice infested waters to reduce ice related downtime.

A four phase approach was utilized.

The first task of the study was to gather as much information as possible relating to ice mass management techniques which have been either proposed or actually used. To achieve this, literature searches were conducted at a number of institutions. The primary sources were:

- Ocean Engineering Information Centre (OEIC), Memorial University of Newfoundland, St. John's, NF.
- Queen Elizabeth II Library, Memorial University of Newfoundland Main Library.
- Department of Fisheries and Oceans (DFO) Library, Northwest Atlantic Fisheries Centre, St. John's, NF.
- Bedford Institute of Oceanography (BIO) Library, Dartmouth, N.S.

The findings of this review were then discussed in the context of management of small ice masses (growlers, bergy bits, small icebergs). This yielded a comprehensive summary of work done to date by industry and others, with particular emphasis on those techniques/equipment which may have potential for alleviating or solving the problem at hand.

Several conclusive points become clear from this analysis.

- the present conventionally-used technique of Single Vessel Synthetic Line Towing is inadequate for dealing with small ice masses.
- Prop-washing and bow pushing are best described as stop-gap measures, suited only to near-ideal weather conditions. These techniques can be hard on machinery and have potential for vessel damage.
- The use of a properly designed net holds significant promise for success.
- The use of water cannons warrants further study.

The next step in the process was to develop design criteria for the ice mass to be dealt with, the environmental conditions likely to be encountered and the desired specifications for the proposed system or systems.

To achieve this objective questionnaires were sent to and completed by environmental and operations representatives of various east coast oil and gas exploration companies and experienced captains of supply and fishing vessels working on the Grand Banks. Follow-up interviews were also conducted. Iceberg and environmental factors affecting the system design were extracted from the Marine Statistics (MAST) database supported by Atmospheric Environment Service (AES) and from a brief review of literature and data in the public domain. The major points which became evident are:

- The design ice mass is spherical and ranges from 1000 to 40,000 tonnes.

- Typical extreme environmental conditions are wind speeds of 30-44 Kts, combined seas of 4 to 7 meters, occasional freezing spray and reduced visibility in fog, darkness, and/or precipitation.

- Maximum deployment and recovery times of the proposed system on the order of 1 1/2 hours and 1 hour, respectively, are required.

If the management system for small ice masses is to be a net, the following items are of concern:

- overall weight of the net to be minimized.

- strength/weight ratio of all components to be maximized.

- required storage volume to be kept at a minimum.

- a powered reel for deployment, recovery and storage of the net is recommended. Floatation and ballast materials (or any other attachments) should be selected to facilitate efficient spooling on and off the reel.

The final two phases of the study deal with generation and evaluation of net design alternatives, final design and overall study conclusions and recommendations.

The proposed management system consists of a net measuring 45m x 15m, with an option to expand the size to 45m x 30m. The mesh size is 1.25m square. Construction details are provided in the text. The study concludes that the net be the subject of a testing program. This could range from computer modelling to small-scale prototype testing to full-scale testing in an operational scenario. In addition, the water cannon technique of ice mass deflection is recommended for further development and testing.

Preliminary cost estimates for full-scale, dedicated test programs range from $ 299,000 for the net to $ 453,500 for the water cannon. (Prices in 1986 $ Canadian)

RESUME EXECUTIF

L'objet de cette étude est d'améliorer les moyens de manipuler de petites masses de glaces, et par cela de réduire les dangers aux foreuses flottantes dans les régions enfestées d'icebergs.

Une approche à quatre phases a été utile.

La première phase était de trouver le plus d'information possible des techniques déjà essayées ou proposées de les faire dévier. Les principales sources consultées étaient:

- Ocean Engineering Information Centre (OEIC), Memorial University of Newfoundland, St. John's, NF
- Queen Elizabeth II Library, Memorial University of Newfoundland Main Library.
- Department of Fisheries and Oceans (DFO) Library, Northwest Atlantic Fisheries Centre, St. John's, NF.
- Bedford Institute of Oceanography (BIO) Library, Dartmouth, N.S.

On a discuté les conclusions de cette recherche avec l'idée en vue de faire dévier les petits masses de glaces, particulièrement les bourgingions, fragments d'icebergs, et les petites icebergs. Les résultats nous ont fournis un résumé compréhensif de l'ouvrage déjà fait par l'industrie et quelques autres qu'on pourrait considérer afin d'adoucir ou d'enlever complètement les problèmes.

Plusieurs choses sont claires de cette analyse.

- la méthode employée actuellement de les tirer avec une ligne en arrière d'un bateau de service s'avère inadéquat quant aux petites masses.
- la poussée du silage avec l'hélice ou avec le devant n'est pas très pratique, puisque ces méthodes ne peuvent être utilisées qu'avec des conditions atmosphériques idéales et peuvent entraîner des dégâts aux bâteaux.
- l'utilisation d'un filet est une manière plausible et pourrait être la solution que nous cherchons.
- les jets d'eau à haute pression des canons à l'eau pourraient aussi rendre un grand service.

La prochaine phase était de developper une critère pour manipuler proprement les masses dans tous les temps possibles, quand qu'ils se trouvaient nécessaire. Inclues aussi sont les specifications desirées du système.

On a envoyé des questionnaires aux réprésentatifs de plusieurs compagnies pétrolières qui participent aux forages sur la côte est. On a aussi consulté des capitaines de bâteaux de pêche et de service des Grands Bancs. Des entrevues personnelles ont été faites après cela.

Les facteurs qui affectent la conception du système ont été rélevés de la banque de données MAST du service d l'environnement atmosphérique, et d'autres sources disponibles.

- Le système est concu pour des masses de glaces sphériques qui pèsent entre 1,000 et 40,000 tonnes.

- Les conditions typiques des environs sont des vents de 30-44 noeuds, avec des vagues de 4 à 7 mètres. Souvent ils y a aussi des embrums gelants, de la pluie, de la brume, puis la nuit. Tout ça réduit la visibilité et empêche le travail.

- Le temps maximum de deployer et rêpecher le système proposé est 1.5 heures et 1.0 heure respectivement.

Si le système de manipuler de petites masses de glaces s'avère être un filet, les prochaines considérations sonts très importantes.

- minimiser le poids général.

- porter au maximum la proportion de force contre le poids de toutes les parties constituantes du système.

- minimiser le volume du système.

- une bobine hydraulique pour deployer, repêcher, et entreposer le filet est recommandée.

- le choix des flotteurs et lests devrait être fait avec l'idée de faciliter le deploi et remontage du filet.

Les deux dernières phases de l'étude se concerne avec les propositions alternatives puis leurs évaluations, les conceptions finales, et une étude générale des conclusions et recommandations.

Le système de manipulation proposé se consiste d'un filet de 45 m x 15 m avec une option de la grandir à 45 x 30 m. La maille est 1.25 m carrés. Les détails de construction sont dans le texte. L'étude recommande que le filet soit mis en essai dans un programme d'évaluation. Ceci pourrait commencer avec un modelage d'ordinateur, puis après ça continuer avec un petit prototype à l'échelle, avant d'aboutir au prototype de grandeur nature.

Les coûts préliminaires d'essai à pleine échelle sont de l'ordre de $299,000 pour le grand filet et de $453,000 pour les canons à l'eau (Prix en dollars canadiens 1986).

INTRODUCTION

Hydrocarbon exploration off the East Coast of Canada involves many difficulties and challenges, particularly in the area of coping with environmental conditions. But while experience gained in the North Sea allows design for harsh weather conditions, sea ice and icebergs still pose a serious threat to drilling platforms.

Moving a drilling platform that is threatened by an iceberg is very expensive and time consuming. This necessitates an effective ice management system that will deflect icebergs and smaller ice masses clear of drilling platforms to avoid drilling downtime.

This study looks at existing ice mass management systems plus alternative methods that could be used to increase the success rate of deflecting small ice masses.

The study is carried out in the following phases:

Phase I - Review present and past ice management techniques.

Phase II - Establish design criteria.

Phase III - Undertake conceptual design of new or improved techniques.

Phase IV - Undertake feasibility analysis of conceptual designs and perform detailed design of preferred concept.

During the first phase of the study, all material available on past and present small ice mass management techniques and experiences is compiled and reviewed. Also during this phase, interviews are held with, and questionnaires sent to, all available tow vessel masters.

The second phase of the project is to define the conditions (ice size, seastate, etc.) where small ice masses must be managed. This phase is seen as being necessary because in the review of past and present techniques; one must identify the reasons for failures and/or difficulties and provide the design criteria for new or future systems to enable the feasibility studies and final designs to be carried out. Once design criteria are established, the third phase of the project is to develop several conceptual designs of small ice mass handling systems.

The final phase of the study is the feasibility analyses of the conceptual designs and submission of the final report complete with preliminary and final designs and recommendations for trials and/or future work.

PROBLEM STATEMENT

Significant amounts of drilling downtime are suffered due to encroachment of unmanageable ice masses. A large portion of these are growlers and bergy bits. To date, techniques and/or equipment have not been developed to effectively deal with these small ice masses.

The major component of the problem is that growlers and bergy bits are usually in a state of deterioration, tending to make them unstable. They are often rounded, rendering industry-standard iceberg towing techniques ineffective.

In the period when the majority of icebergs pass through the Hibernia area (March - June), wind speeds in excess of 20 knots are common, with a high occurrence of gale force (or stronger) winds. High sea states are often associated with these winds, making deck work both difficult and dangerous on the conventional anchor-handling/supply tugs used offshore, as well as keeping many low-freeboard pieces of ice completely awash.

Another critical factor associated with high winds and sea states lies in the speculation that the instantaneous velocity of small ice masses in these conditions may approach the orbital velocity of the wave particles, resulting in increased momentum and, hence, potential to damage an offshore structure.

A further weather-induced complication is lower probability of detection. In seas of three metres or greater, typical during a Grand Banks ice season, many growlers and bergy bits can be invisible to marine radar. Many are also rounded, making poor radar targets in any weather.

Deflection attempts using present techniques have, to date, been hindered by all these factors. Conventional single line towing often fails due to rope slip-off or iceberg rolling, while prop-washing requires adept boat handling, which is difficult in rough seas. Rough seas also tend to dissipate the vessel's wake, reducing the effectiveness of prop-washing. In any event, prop-washing, which is hard on machinery, is usually only effective for ice masses in relatively close proximity to the drilling unit, as significant deflection at longer ranges requires continuous application of the technique for long periods of time which is impractical.

The problem, therefore, is to develop a concept which can overcome some, if not all, of these difficulties and so result in a decrease in operational downtime for drilling operations.

PHASE I

REVIEW OF ICE MASS HANDLING METHODS

This phase of the study looks at existing ice mass management systems plus alternative methods that could be used to increase the success rate of deflecting small ice masses.

PAST STUDIES AND/OR EXPERIMENTS

In this section, some ice management methods which have been proposed or attempted in the past are reviewed.

It is recognized that these have been abandoned due to impracticality or ineffectiveness, however, they are included for completeness and also as an indication that, over the years, much thought has been given to this problem.

SUCTION CUP ATTACHMENT

This method would employ a single point towing device developed by Marex Oceanographic Services in Calgary, Alberta. The device, which was simply called DAK, consisted of a 2.1m diameter suction cup, powered by water jets run through ejector nozzles. (Jewett, 1979). The nozzles would serve a dual purpose in that they would be used to move and steer the DAK enroute to the iceberg as well as providing outports for pumped out water during the attachment phase. (Marex, no date). Pumping power was supplied by two 50-hp submersible pumps.

In operation, water would be pumped via standard fire hosing through the ejectors mounted on the hull of the unit's hemispherical body, creating a vacuum inside the body when placed against an iceberg.

The body would be suspended by two buoys vertically in the water and its open end surrounded by a seal constructed of non-intercellular neoprene. The purpose of this was to overcome uneveness on the iceberg's surface and thus provide an air-tight seal between the DAK and the surrounding water.

In the original design, a vacuum sensing line was run from the main body to a gauge on the supply boat to monitor vacuum inside the body and, therefore, allow determination of maximum towing force which could be applied.

To increase lateral stability of the unit while on the iceberg, a series of ten ice picks were situated around the perimeter of the open end. This was done in the hope that it would permit large directional changes to be made while towing.

The main body was constructed of mild steel and the shell was tested to 150 psi.

A 50 ton Safe Working Load (S.W.L.) towing lug was attached to the unit.

While laboratory trials saw suctions of up to 34 tons developed against steel and concrete surfaces, limited field testing which took place in the Labrador Sea in 1976, (Marex, 1976), revealed that problems existed. The unit was unable to generate sufficient holding power against the iceberg and there were apparently problems with deployment and storage of the system. After only preliminary testing, the concept was abandoned as requiring considerable development. The DAK is illustrated in Figures 1 and 2.

DEFLECTION BY ANCHORS

This method was proposed in a paper published by Duncan Mellor in 1980. (Mellor, 1980). The basic idea was to use anchors as pivot points about which icebergs could be swung using their own momentum. This would be done by setting an anchor alongside an iceberg, then connecting the iceberg to the anchor by a wire rope or synthetic mooring line. If the anchor was securely fastened to the ocean floor, the iceberg would swing around the anchor, thus displacing the iceberg to one side.

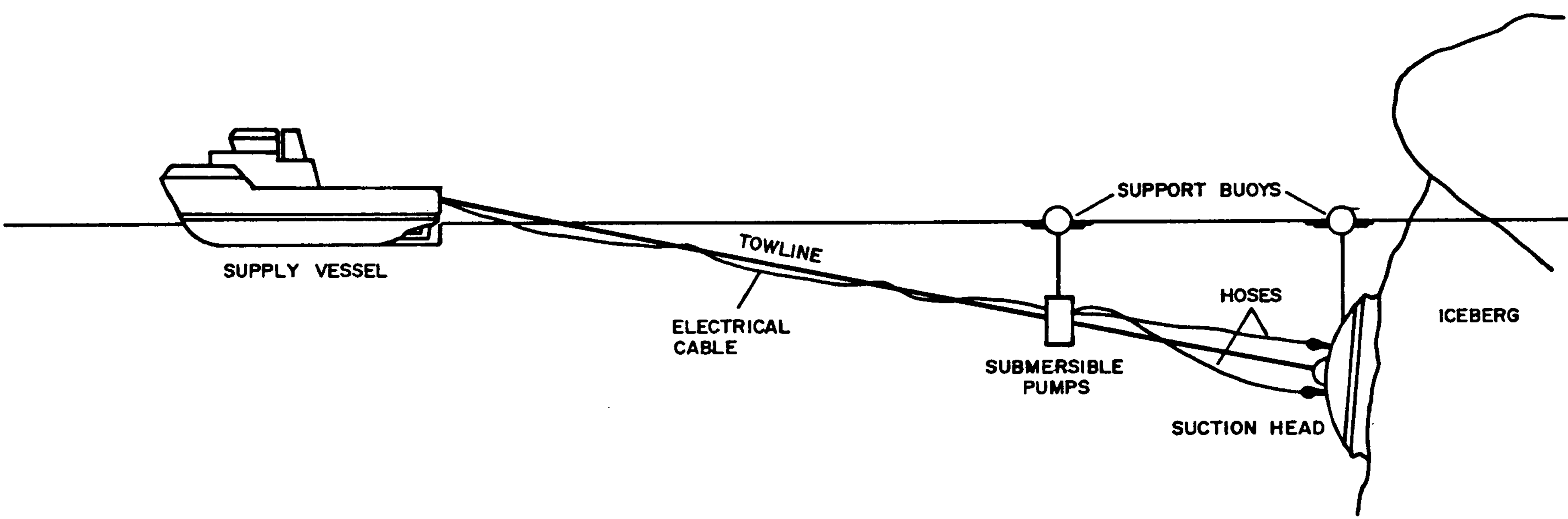
As an extension of this concept, Mr. Mellor feels that to save time and thus reduce the danger zone size, anchors could be set at various points around the rig and left until needed. The tug would then connect the most appropriate anchor to the drifting iceberg. This could swing it out of the danger zone or to another anchor which would swing it out.

The idea seems sound in principle but was never tested. There are several possible reasons for this, the main one potentially being the lack of a method to attach the iceberg to its mooring. If such a method of attachment were devised, it would likely be used directly for towing rather than for use with this technique.

Another impractical aspect of this method would be the amount of work required with heavy marine hardware (i.e. deploying and recovering anchors), making it potentially hazardous to personnel and certainly sea state limited, if conducted from a conventional supply boat. Also, long anchor moorings would be required in deep water. The concept is depicted in Figure 3.

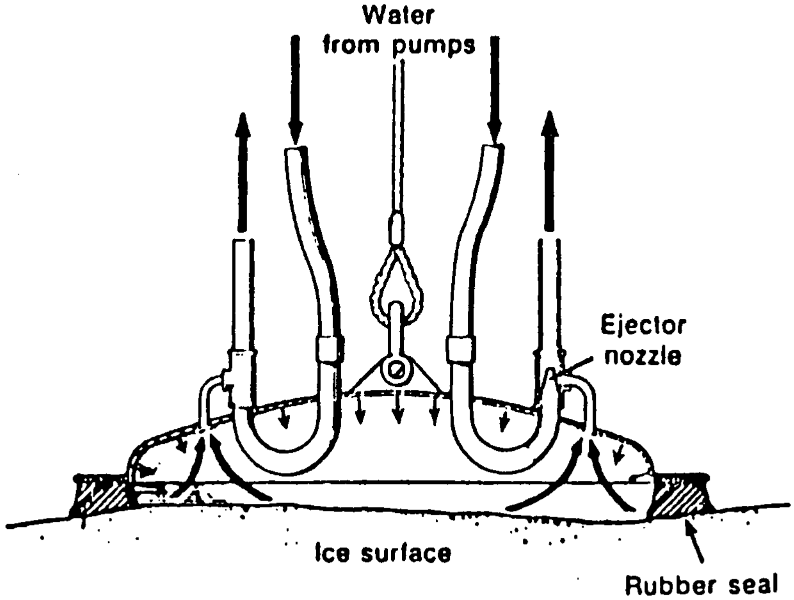
DEFLECTION USING AIR BUBBLES

This idea was described in a U.S. Patent by Anthony C. Mamo in early 1982. (Mamo, 1982). It involves the releasing of a large volume of air bubbles underwater in specific proximity to a portion of the iceberg. Bubbles would be formed by allowing air to escape from openings in a submerged tube structure to form a wall of bubbles. This, according to Mr. Mamo, would raise the water surface at a peripheral portion of the iceberg resulting in an increase in pressure and movement away from the bubble-enveloped side of the iceberg.



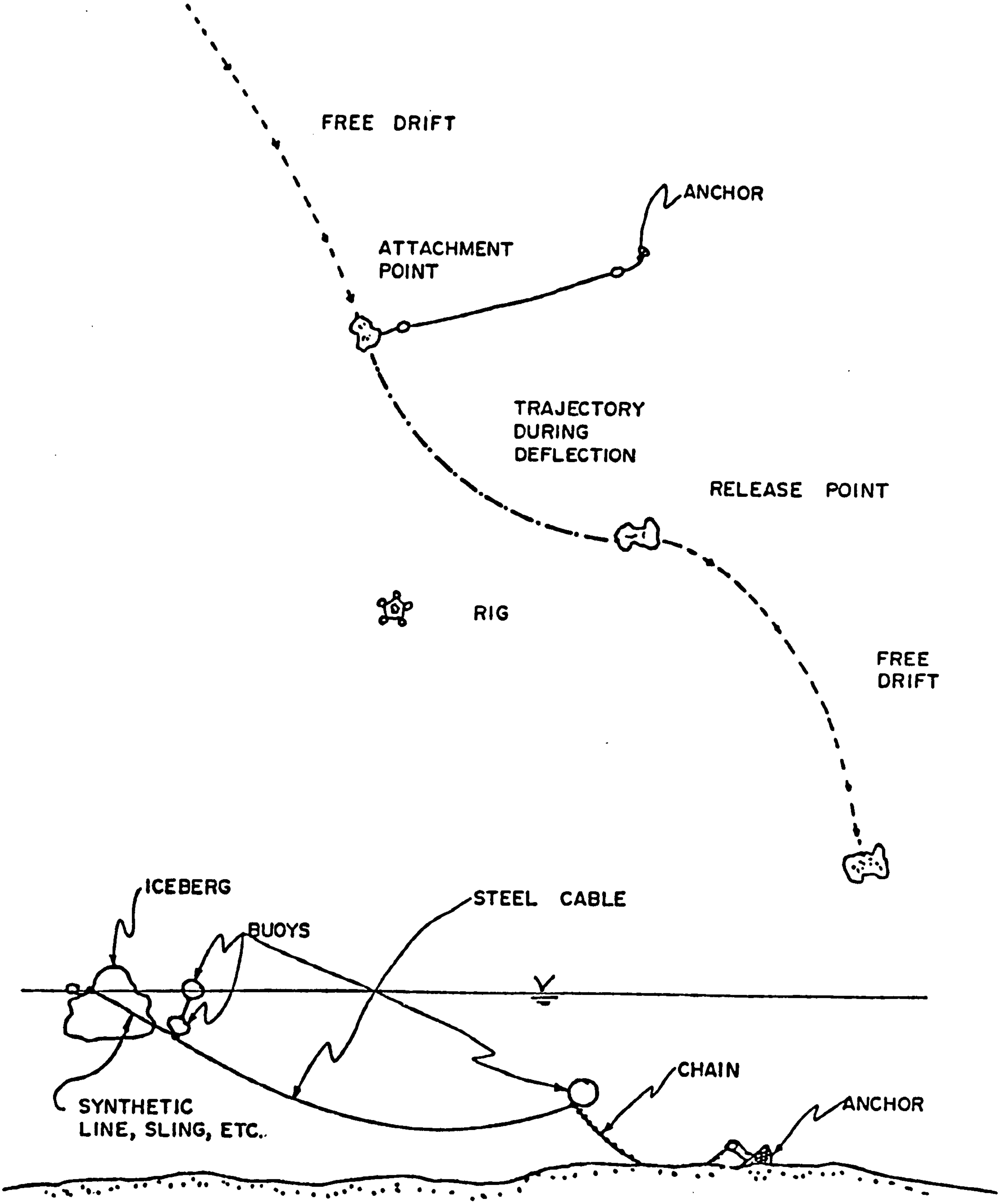
TOWING ARRANGEMENT using 7-ft diameter suction cup (DAK).

Figure 1.



SUCTION HEAD OF DAK

Figure 2.

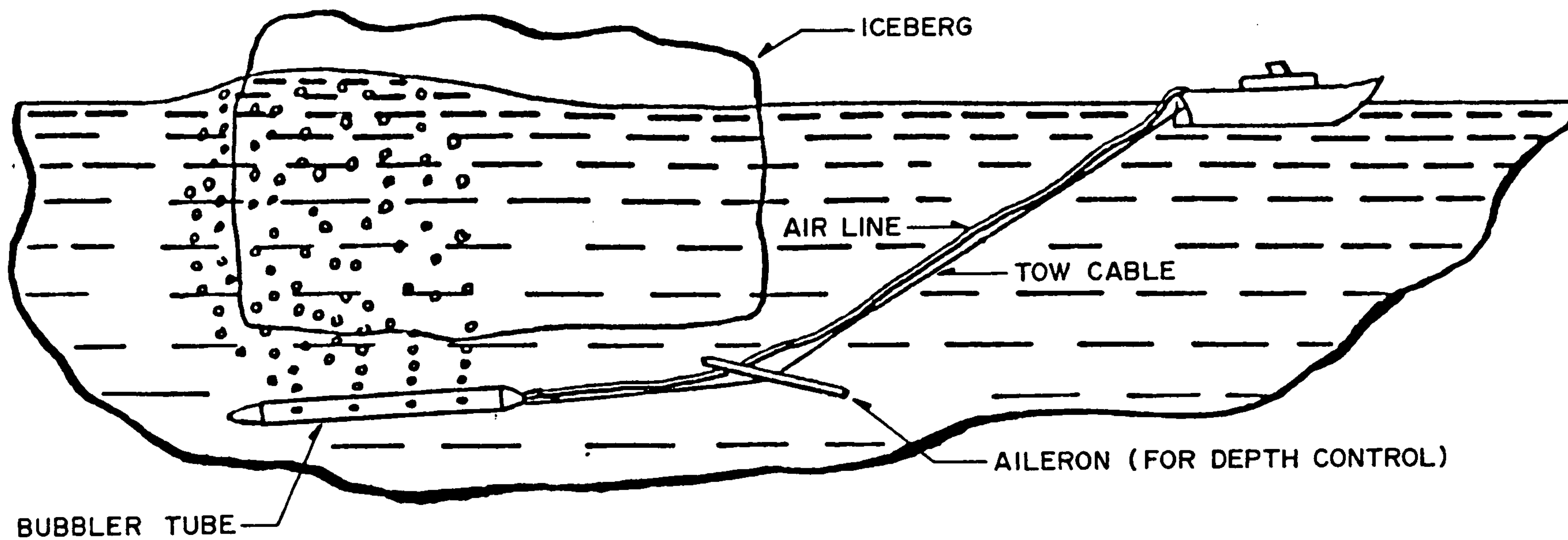


ICEBERG DEFLECTION USING ANCHORS

Figure 3.

In operation, a network of perforated tubes would be positioned beneath the iceberg. The tubing network would be connected by an air supply line to compressors located on the ship. The air released from the tubing would create a wall or curtain of bubbles, which, when acting against the submerged portions of a section of an iceberg would cause it to move away from the tubing. Figure 4 illustrates a typical configuration of this concept as envisaged by Mr. Mamo.

The technique is deemed to be impractical for several reasons. The primary flaw seems to lie in the absence of technical argument to support the fact that the concept could even work. It is also expected that the volume of air required to overcome natural driving forces would be quite large. Finally, there is no thought given to controlling the position of the underwater air bubbler unit. If this method were ever to be developed, substantial design work would be required.



ICEBERG DEFLECTION USING AIR BUBBLES

Figure 4.

PRESENT CONVENTIONALLY USED TECHNIQUES

This section summarizes iceberg deflection methods which are commonly used in operational support of offshore activity. Variations of these methods and other methods which have been used operationally in the past, albeit seldomly, are briefly discussed, as well.

SINGLE VESSEL SYNTHETIC LINE TOWING

This is the industry-standard technique of deflecting icebergs. It involves the use of a 1200m long, 355mm circumference eight-strand plaited polypropylene rope to encircle the iceberg. The rope has a specific gravity of about 0.9 and is usually divided into several sections. The basic procedure as shown in Figure 5, is as follows.

- The rope is payed out over the stern as the vessel approaches the iceberg on the back-bearing of the desired tow heading. The length (number of sections) of rope required is decided based on the size of the iceberg.

- With the rope streaming behind and the inboard end attached to the end of the towing hawser, the vessel circles the iceberg.

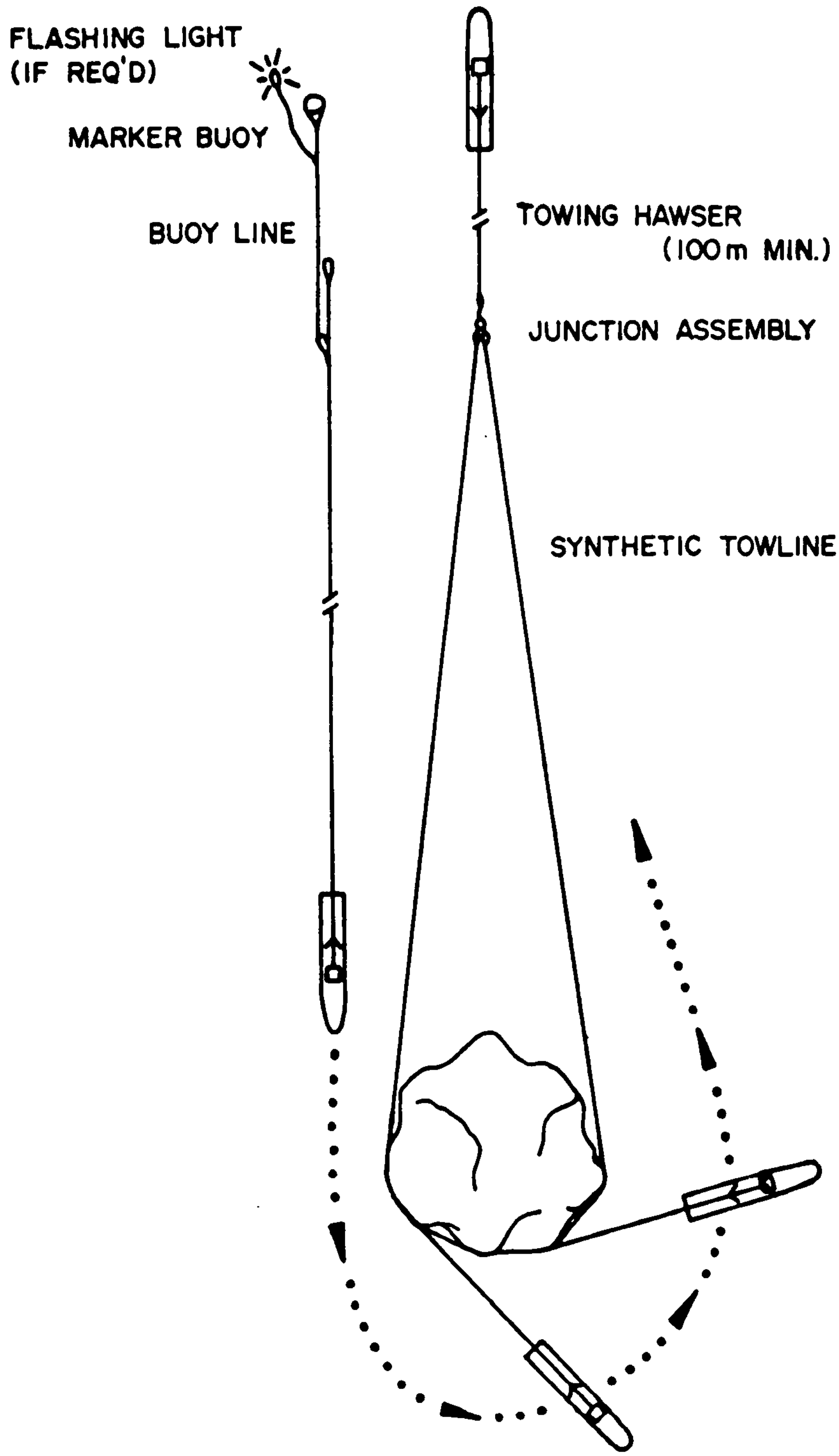
- The trailing end, which normally has a marker buoy and, in darkness or poor visibility, a flashing light attached, is recovered and shackled to the tow hawser. This completes a loop around the iceberg.

- The towing hawser is then payed out in sufficient quantity to create a catenary between the vessel and the iceberg. This serves several purposes. It depresses the line of the tow force to bring it closer to the iceberg's centre of hydrodynamic drag, thereby tending to reduce overturning moment. It also prevents a sudden recoil in the event of towline failure or slippage, as the water would have a damping effect on the submerged towline. Finally, it serves as a shock absorber to compensate for surges in line tension, caused by sea state or iceberg movement.

- Finally, tension is applied and the tow commences.

While this method generally works well for most icebergs, it is largely unsuccessful in dealing with the smaller ice masses which are more prevalent on the Grand Banks. There are several reasons for this.

- Smaller pieces of ice tend to be unstable, seriously limiting the amount of tension which can be applied without causing rollover, since the tow force is applied at the waterline. This is true even with a catenary to reduce overturning moment.



SINGLE VESSEL SYNTHETIC LINE TOWING

Figure 5.

- Smaller pieces are often rounded, with no definite waterline groove. In situations like this, the rope often slips over the ice prior to completion of hawser payout.

- As with any method involving deck work, increased sea states (5 m or greater) imply increased danger when working on the low freeboard decks of conventional anchoring/supply vessels.

- Also associated with high sea states are incidences of rope wash-off. This can happen in relatively calm conditions with smaller, smooth pieces. A swell or wind wave may even wash the towline over the ice mass as soon as it is deployed.

Cases of repeated unsuccessful towing attempts on a single growler or bergy bit are commonplace for the above reasons.

Since as much as 1-2 hours can transpire between tow attempts using this method, valuable time is lost in repeated attempts.

Use of this technique in rough seas also increases the risk of fouling the tow rope in the ship's propellors.

Despite the problems associated with this method for small ice masses, it is by far the most successful method developed to date for larger icebergs.

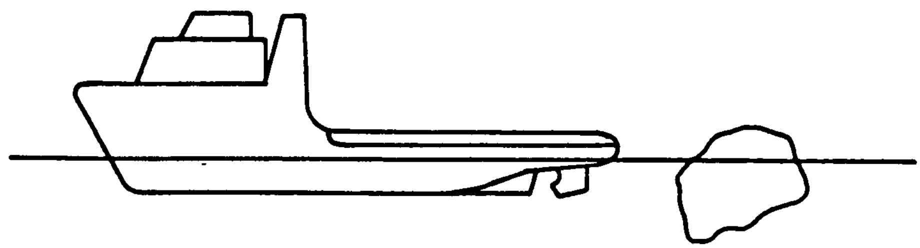
PROP-WASHING

This is, in fact, the only method of dealing with small ice masses to date which has achieved any noticeable degree of success. However, the success rate is still far less than necessary to produce a significant reduction in operational downtime.

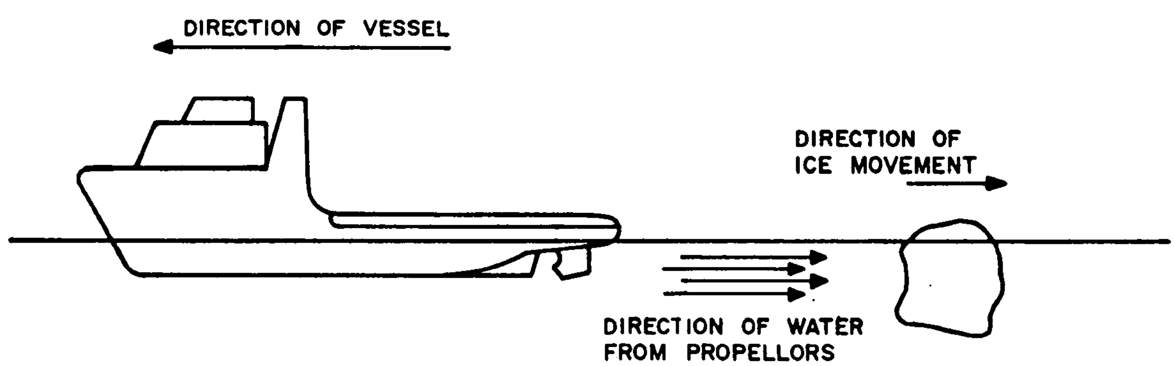
The technique, as shown in Figure 6, involves backing the supply vessel in close to the ice mass and accelerating forward. The wake created by the vessel pushes the growler or bergy bit away from the stern of the vessel. Deflection is achieved by repeated prop-washes.

As mentioned in the Problem Statement, the method is usually only effective for ice in close proximity to the drilling unit since significant deflection at longer ranges requires many hours of prop-washing. This tends to be arduous for the vessel master as well as resulting in high fuel consumption and excessive wear on vessel machinery.

It should be noted that prop-washing was developed for ice management on the Labrador Shelf, which involved dynamically positioned drilling vessels. The much larger alert zone



(1) VESSEL BACKS UP SLOWLY TO GROWLER OR BERGY BIT.



(2) VESSEL ACCELERATES AWAY, CREATING A WAKE TO PUSH ICE MASS IN OPPOSITE DIRECTION.

PROP WASHING

Figure 6.

configurations used around anchored semisubmersibles on the Grand Banks renders the technique valuable mainly as a tool for prevention of an actual collision between a small ice mass and a rig. It rarely results in prevention of operational downtime.

The technique also requires skilled boat handling, which is difficult in rough seas. High sea states also tend to dissipate the vessel's wake quickly, reducing the effectiveness of this method.

BOW PUSHING

This method involves approaching a very small piece of ice and carefully nudging it with the bow of the vessel (see Figure 7). This should only be attempted in calm conditions (less than 1m MCS) as a last resort to prevent an actual rig-ice collision, and in all cases only at the discretion of the vessel master. Also, the vessel should have an ice-strengthened bow as vessel damage has occurred from use of this technique.

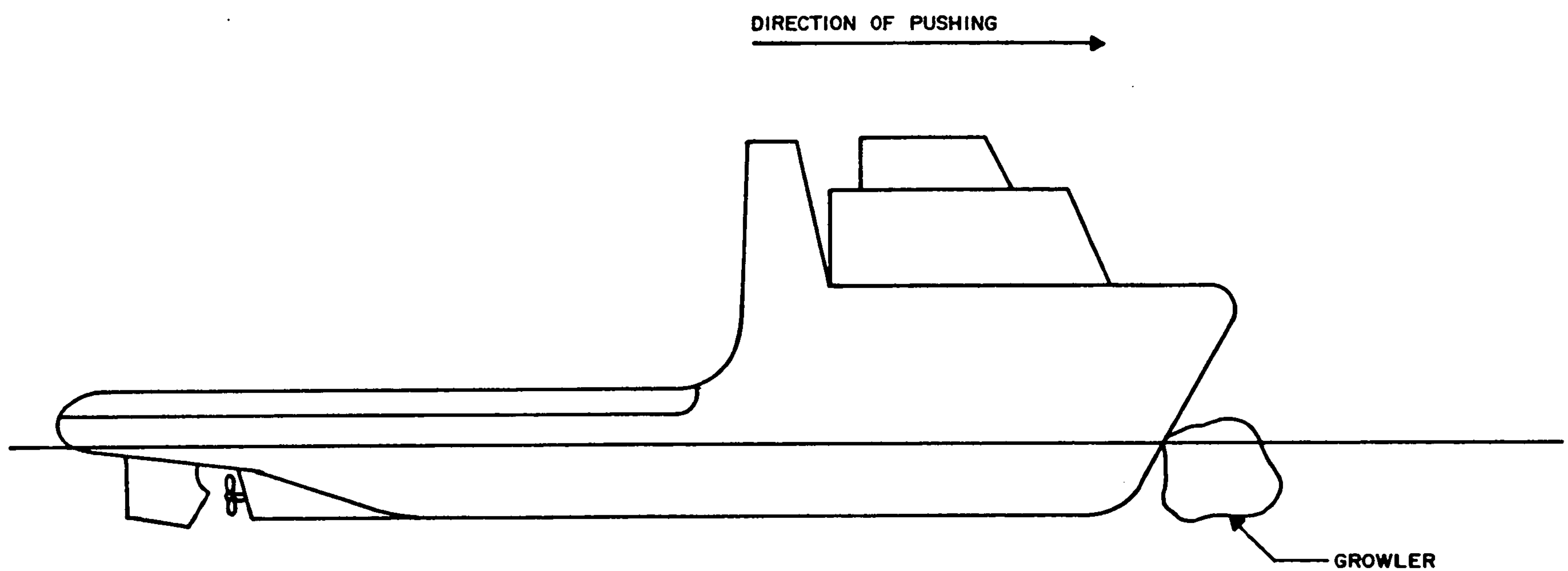
An extension of this is the concept of installing an open-mesh steel frame sometimes referred to colloquially as a "cow catcher" on the bow of an ice management vessel (see Figure 8). The frame would be largely transparent to waves while enhancing the vessel's capability for bow pushing of growlers and bergy bits. The frame would allow good directional control and increased pushing speed. However, this idea has never been implemented for several good reasons, the main one being that the frame would presumably need to be quite sturdy, resulting in substantial additional weight on the bow. A naval architect would likely be required to assess the impact on vessel stability, manoeuvreability, and efficiency, and a costly dry-docking of the vessel would certainly be necessary for both installation and removal of the frame. Also the impact of differential motion between the vessel and the ice mass is unknown. This could be a major shortcoming.

TWO VESSEL TOWING

Two vessel towing has occasionally been used. As with prop-washing, this technique was developed more for ice situations of the kind encountered on the Labrador Shelf. There, it was used sporadically to tow excessively large icebergs or large unstable icebergs. A typical procedure is:

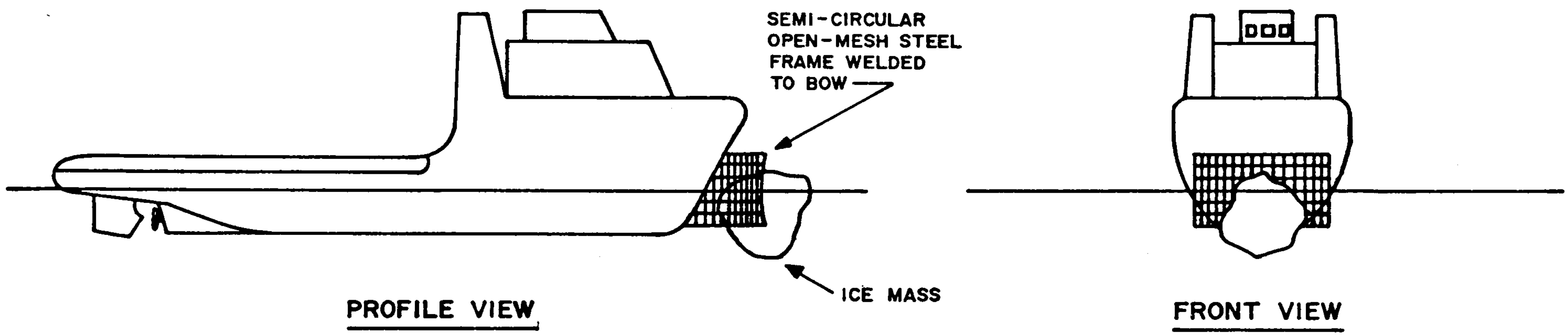
- one vessel positions itself near the iceberg aligned on the desired tow heading;

- the second vessel slowly steams by the stern of the first with one section (400m) of tow rope trailing out behind, attached to its towing hawser;



BOW PUSHING

Figure 7.



PUSHING WITH BOW ATTACHMENT

Figure 8.

- the first vessel recovers the trailing end of the tow rope and shackles it on to their hawser (this section of tow rope acts to aborb shock loading and twist);

- the second boat proceeds around the iceberg;

- both vessels proceed away from the iceberg in the direction of the desired tow heading, while attempting to keep the rope and hawser from sinking below the iceberg by maintaining as much tension as possible given the orientation of the vessels;

- the vessels assume headings 20° to either side of the desired tow direction and apply tension.

This method allows the option of placing either the towing hawser or the rope section in contact with the iceberg. The steel hawser tends to bite into the ice somewhat better than the rope, but is prone to kinking if bent around a relatively sharp ice feature while under tension.

The problems associated with this make it a relatively impractical method. First, two vessels are required. Also, depth control over the tow wire is difficult, which can necessitate repeated attempts.

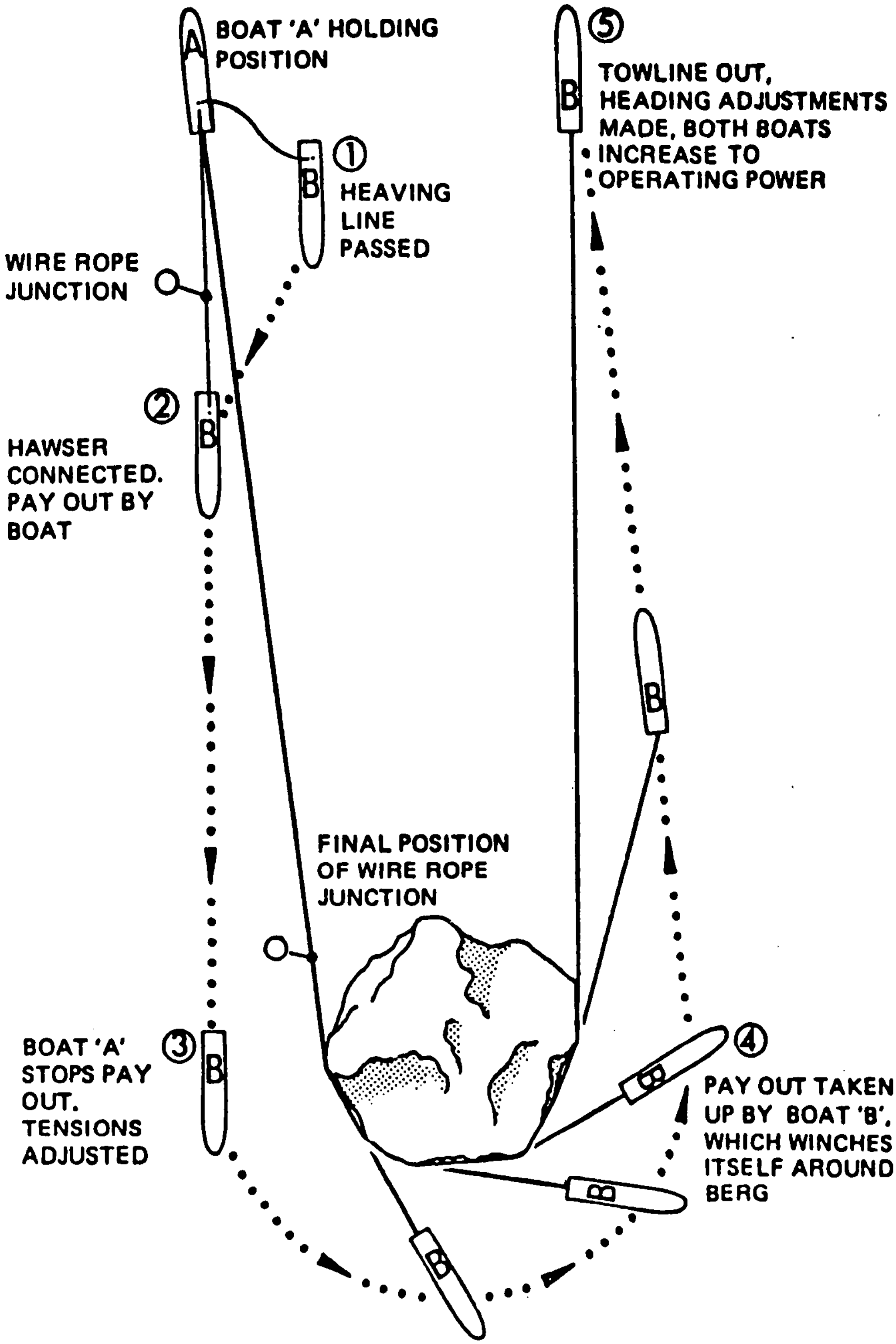
Another difficulty is the tendency to "see-saw" back and forth around the iceberg while towing, due to unbalanced vessel thrust. This requires constant monitoring early in the tow and periodic checks throughout.

The details of the two boat towing procedure vary somewhat from vessel to vessel. A typical deployment using the wire hawsers of both vessels is illustrated in Figure 9.

A variation of this technique using a net or small diameter wire strung between two vessels may be useful for towing of small ice masses, but no documentation of any tests in this area is known to exist at the time of this study.

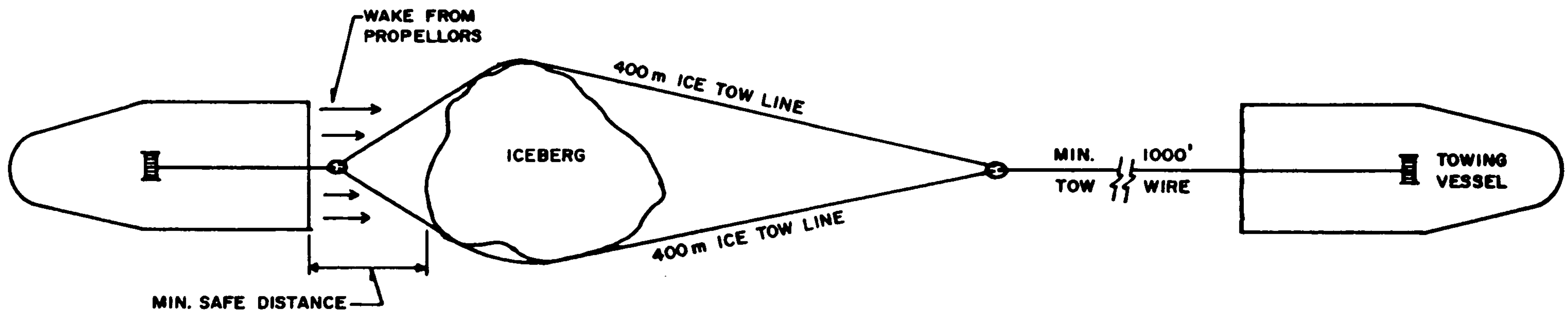
Another interesting towing arrangement involving two vessels has recently been tried with good success at BP Resources, Baie Verte J-57 wellsite in the Gander Block near Newfoundland. (Allsop, 1985). The method is referred to as the SKRAN system (from the names of the two vessels involved in its development, M.V. SKANDI ALFA and M.V. RANDFONN).

In this technique, one ship deploys two 400m lengths of the tow rope in the normal way but with a pennant attached to the tow rope's joining shackle. The second ship recovers the pennant and connects its tow wire to the shackle. Then, either the second vessel can remain close to the iceberg and aid the tow with its propeller wash or it can simply pay out some hawser to aid in keeping the rope down on the back of the iceberg. This configuration is illustrated in Figure 10.



TYPICAL TWO BOAT TOWING PROCEDURE

Figure 9.



SKRAN METHOD OF MOVING UNTOWABLE ICEBERG UP TO 300,000 TONS

Figure 10.

VARIATIONS OF CONVENTIONAL TECHNIQUES

This section discusses ideas which essentially employ conventional techniques, but use slightly modified equipment or procedures. Some have actually been used while others are still in the conceptual stage for reasons of impracticality.

Sinking Towlines

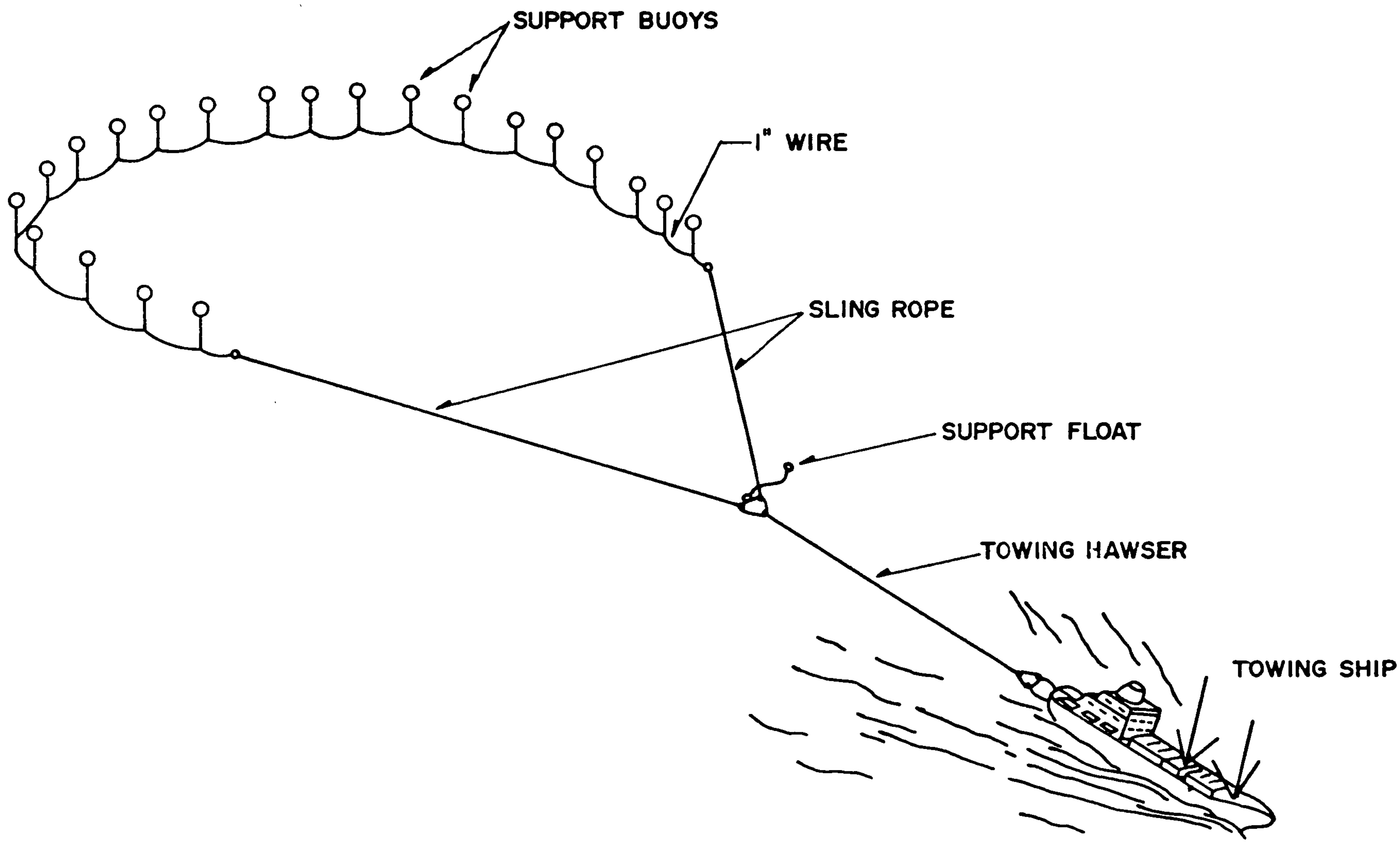
The concept of sinking towlines was first suggested in the early 1970s by researchers at Memorial University (Bruneau and Dempster, 1972) and uses the same basic procedure as single vessel synthetic line towing, except that instead of using a material with a specific gravity less than water, one with a negative buoyancy would be used. This could be a material such as Kevlar, nylon, or even a steel cable (say, 12mm diameter). Buoyancy would be provided through the use of floats attached to the towline by straps (see Figure 11).

The length of the straps would be based on an estimate (or measurement, if possible) of the central elevation of the iceberg. The larger the ice mass, the greater the depth of the towline. This would presumably bring the line of the tow force as close as possible to the most likely centre of rotation of the ice, thus minimizing the overturning moment and hence, the chance of overturning. While the principle is sound enough, the technique is considered impractical for small masses. Since small masses have much less inertia to resist rolling than larger icebergs, and tend to be unstable anyway, even exact placement of the line would not guarantee that the iceberg would not roll. Also, the method generally would be time consuming as the strap lengths likely need adjustment for each tow attempt. In addition, handling and storage with flotation attached could be a problem. The flotation could be removed between tows, but this would further increase deployment and recovery times. However, this method may have potential for the management of large, unstable icebergs.

One alternative to the single sinking towline which has been suggested involves the use of two lines. In one proposed configuration (see Figure 12), both lines would be made of a sinking material and buoyed up with floats, such that both lines would be in contact with the iceberg at predetermined depths below the water line.

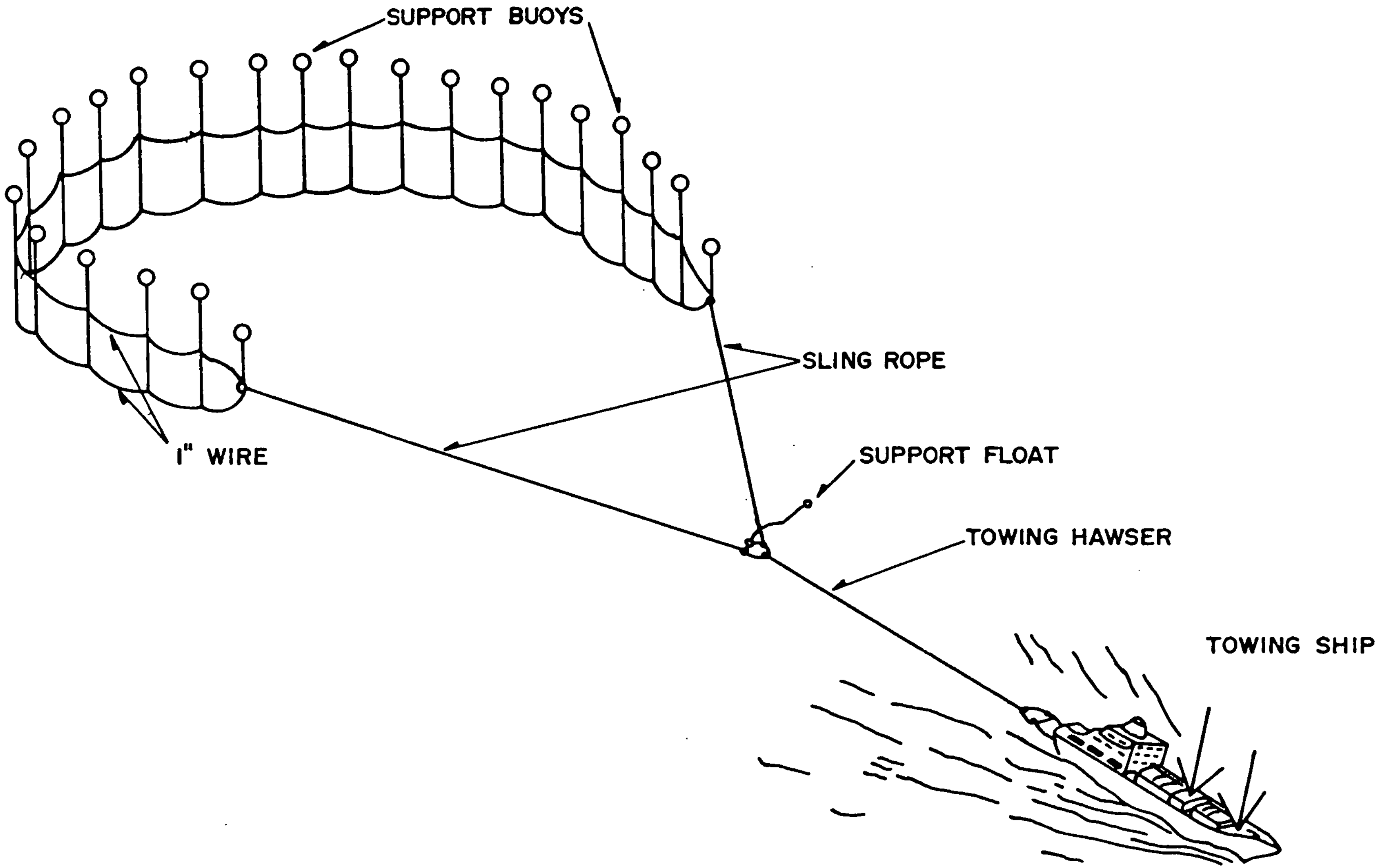
In another possible form (see Figure 13), the towing system would be comprised of a single sinking line and a floating line. The floating line, combined with the Norwegian buoy floats, would support the whole assembly in the water.

These two line variations of this concept probably have a better chance of success than the single sinking line concept,



SINKING TOWLINE

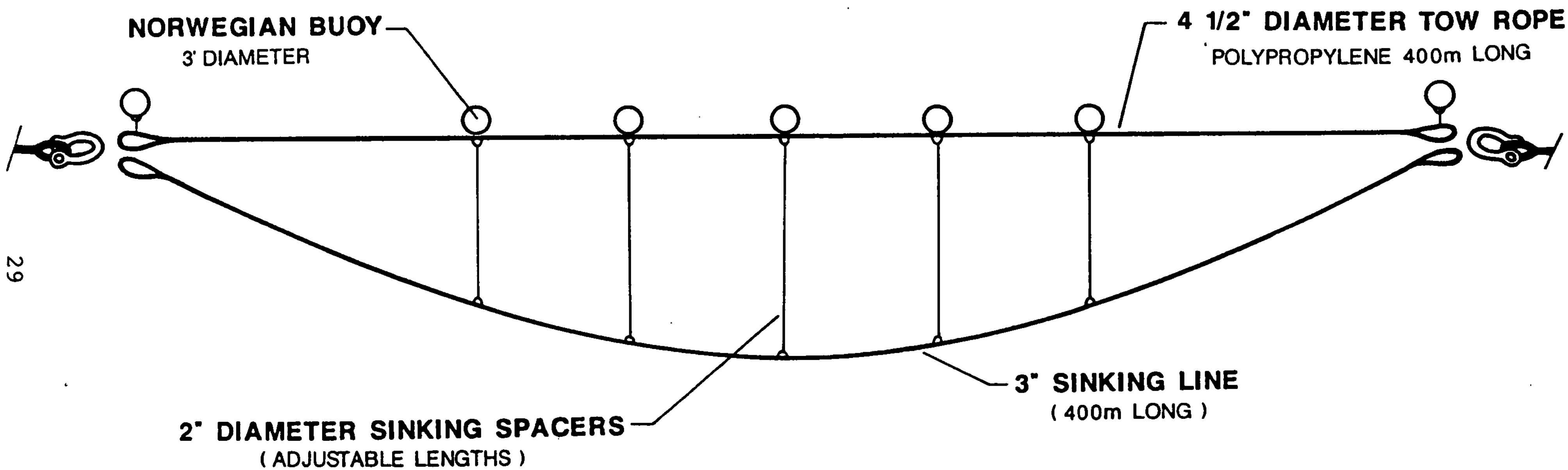
Figure 11.



SINKING DOUBLE-TOWLINE SLING

Figure 12.

SINKING/FLOATING TOWLINE COMBINATION



NOTE

Adjustable length spacer straps allow the vessel master to select the depth that the sinking towline comes to bear against the underwater surface of the iceberg.

HUSKY/BOW VALLEY MAY 85

Figure 13.

at least for small ice masses. However, they would still seem to be somewhat vulnerable to handling problems. As with the single sinking line method, they would be time consuming to deploy if depth adjustment was required for each tow.

In fact, the configurations shown in Figures 11 and 12 were actually tested on seven different icebergs (five with double wire, two with single wire). After testing, it was concluded that the double wire sling worked better but it was noted that this was much more difficult to handle than the single wire arrangement.

Another conclusion was that size limit for towing was dependent on vessel power.

Double Looping

An interesting variation of the single vessel tow has been previously tried during iceberg towing trials offshore Labrador and recently attempted on the Grand Banks. It involves making two circuits of the iceberg prior to recovery of the trailing end of the tow rope, forming a double loop. Once towing is applied, a snug grip on the iceberg may result. Unfortunately, applications of this variation have not been documented or are not in the public domain and its potential and limitations are not well known at this time. The tow configuration is illustrated in Figure 14. It would appear that a primary concern with this method would be the possibility of overrunning the tow line during the second loop.

One potential way of alleviating the likelihood of tow rope overrunning is to form the double line with two separate ropes, as illustrated in Figure 15. In this mode of deployment, both rope segments would be joined at the outboard end and payed out simultaneously. A potential problem with this alternative would be tangling (i.e. rope segments wrapping around each other) during deployment.

A general criticism of the double loop method is that it probably contributes to reducing rope life, as chafing of the rope against itself under tension might introduce excessive abrasion.

Slip-Knot or Choke Method

This technique is again similar to the single vessel tow. Instead of attaching the trailing end of the tow rope to the end of the towing hawser, the shackle is put through the eye of the trailing end and around the standing portion shackled to the hawser. The vessel then steams away from the iceberg. This creates a noose and causes the rope to tighten around the iceberg at its waterline. Recovery can be accomplished either by simply pulling the rope off over the iceberg with excessive tension or by means of a buoy and tag line attached to the trailing end prior to deployment.

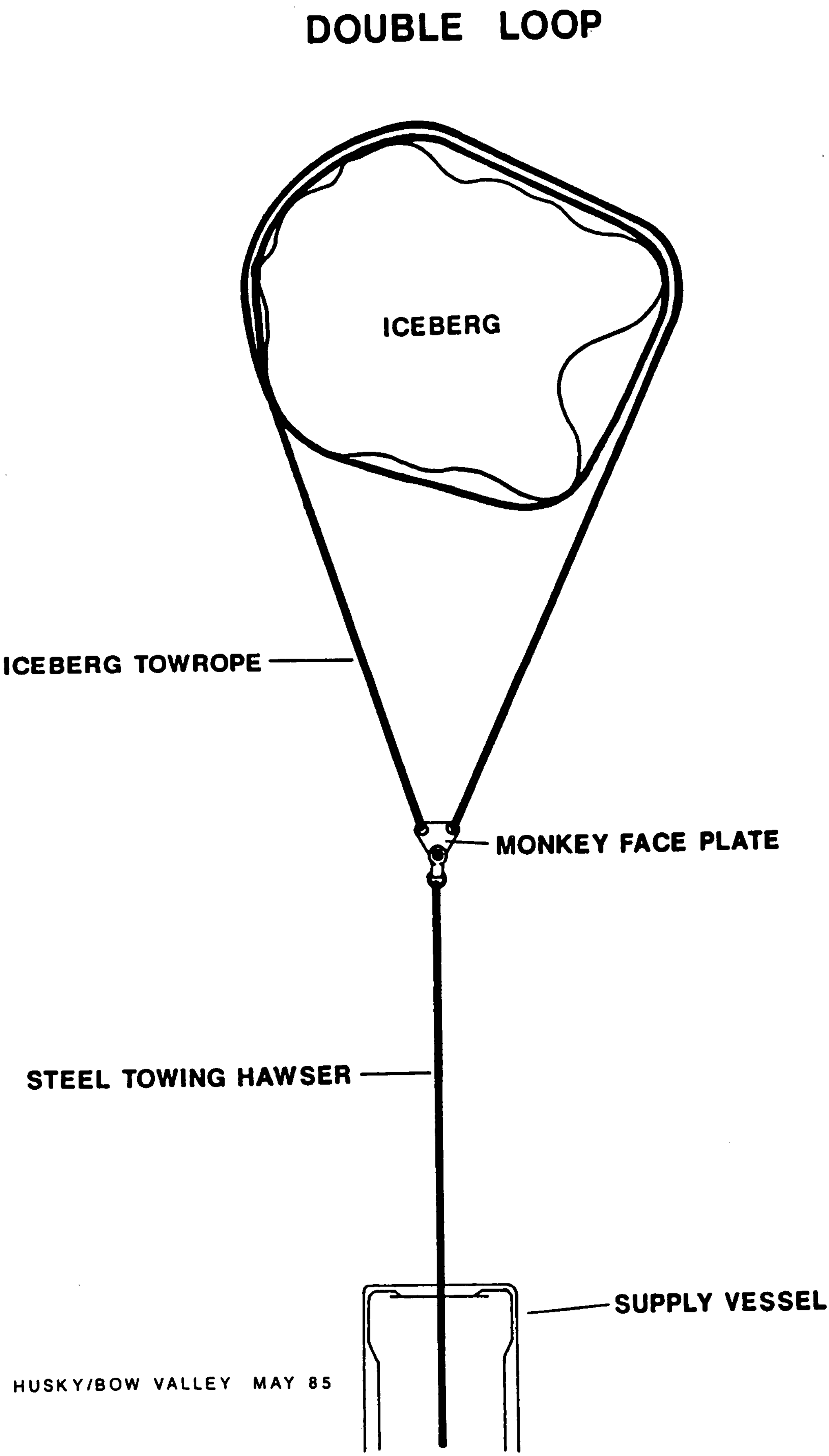
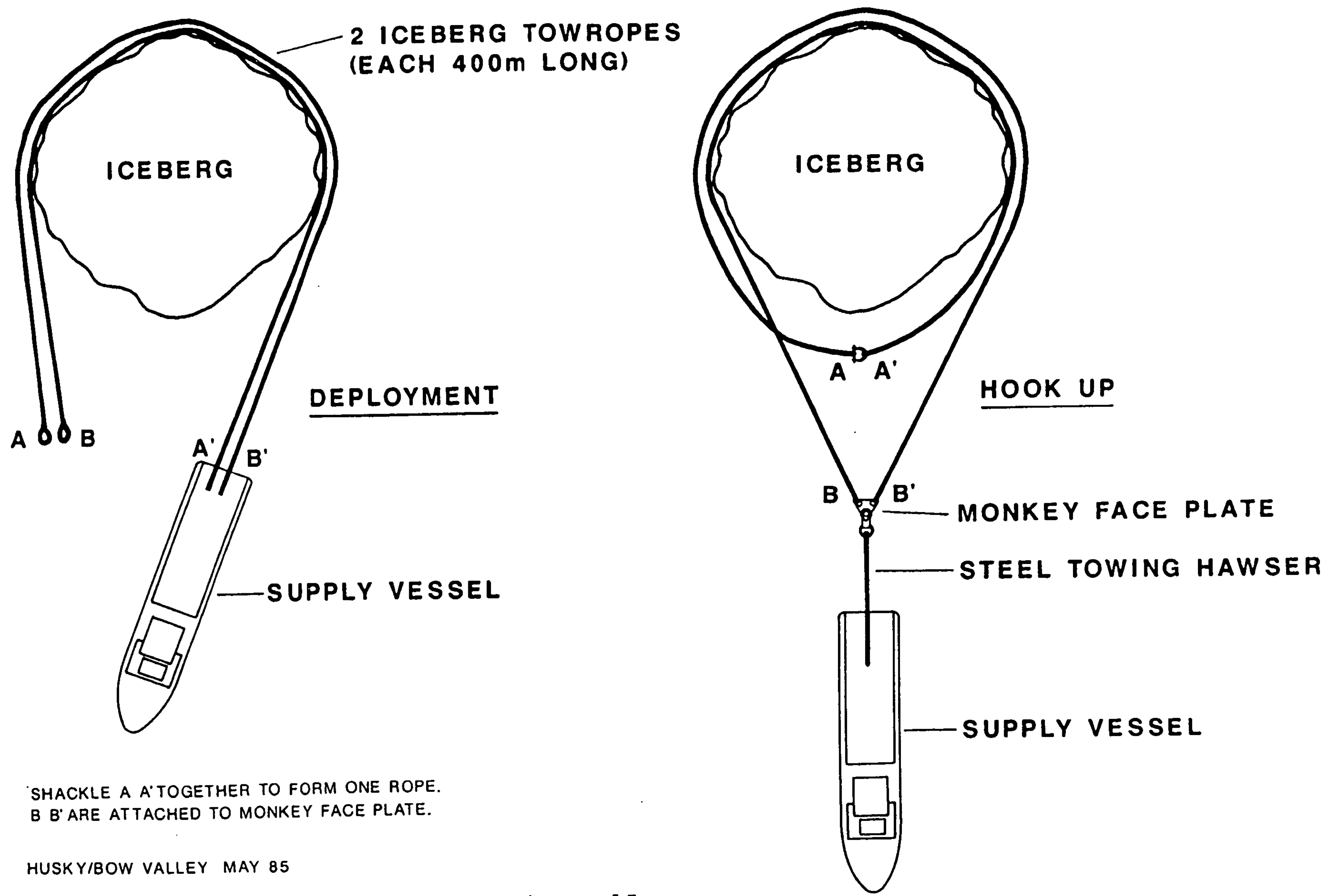

DOUBLE LOOP
ICEBERG
ICEBERG TOWROPE
MONKEY FACE PLATE
STEEL TOWING HAWSER
SUPPLY VESSEL
HUSKY/BOW VALLEY MAY 85

Figure 14.

TWO LINE DOUBLE TOWING LOOP



SHACKLE A A' TOGETHER TO FORM ONE ROPE.
B B' ARE ATTACHED TO MONKEY FACE PLATE.

HUSKY/BOW VALLEY MAY 85

Figure 15.

Potential drawbacks of this method are that recovery may not always be straightforward and with only one end of the tow rope connected to the steel hawser, tow rope tensions would be equal to towing tension, instead of half that value, as for a normal hook-up.

This method was however employed successfully on a small iceberg in May of 1984 by Captain Lorne Messervy of the M.V. SEAWOLF 101 and is shown in Figure 16.

High Sea State Deployment

This is really a special case technique in deploying the single vessel tow, which also may be used with other methods and because of prevailing weather conditions on the Grand Banks during the ice season, it is used frequently there.

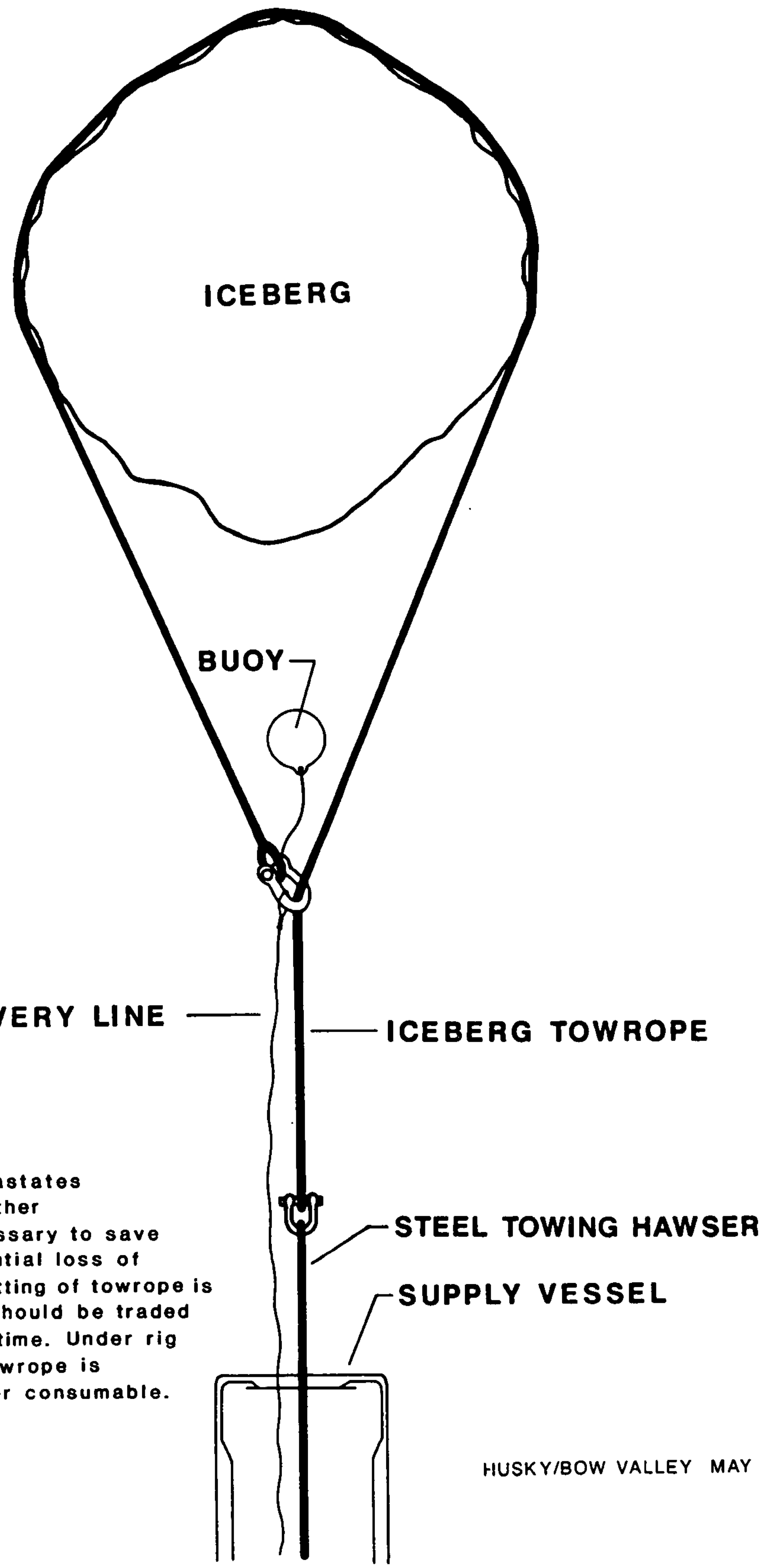
During periods of high wind and sea state, vessels approach the iceberg to be towed from downwind as opposed to the back-bearing of the desired tow heading. This minimizes the time (during deployment) that the vessel must be broadside to the sea. In addition, it ensures that during pickup of the trailing end of the tow rope, it drifts away from and not toward the ice mass. A tow heading as close as possible to the desired one is assumed after successive, gradual course changes.

Catenary Towing Principle

This is a technique worth mentioning which is used specifically for unstable icebergs. It has been used with occasional success on small ice masses.

The technique involves paying out steel towing hawser in sufficient quantity to bring the line of action of the tow force closer in line with the centers of hydrodynamic drag and gravity of the iceberg. This reduces the rolling moment applied to the iceberg by a given tow force as illustrated in Figure 17.

SLIP KNOT

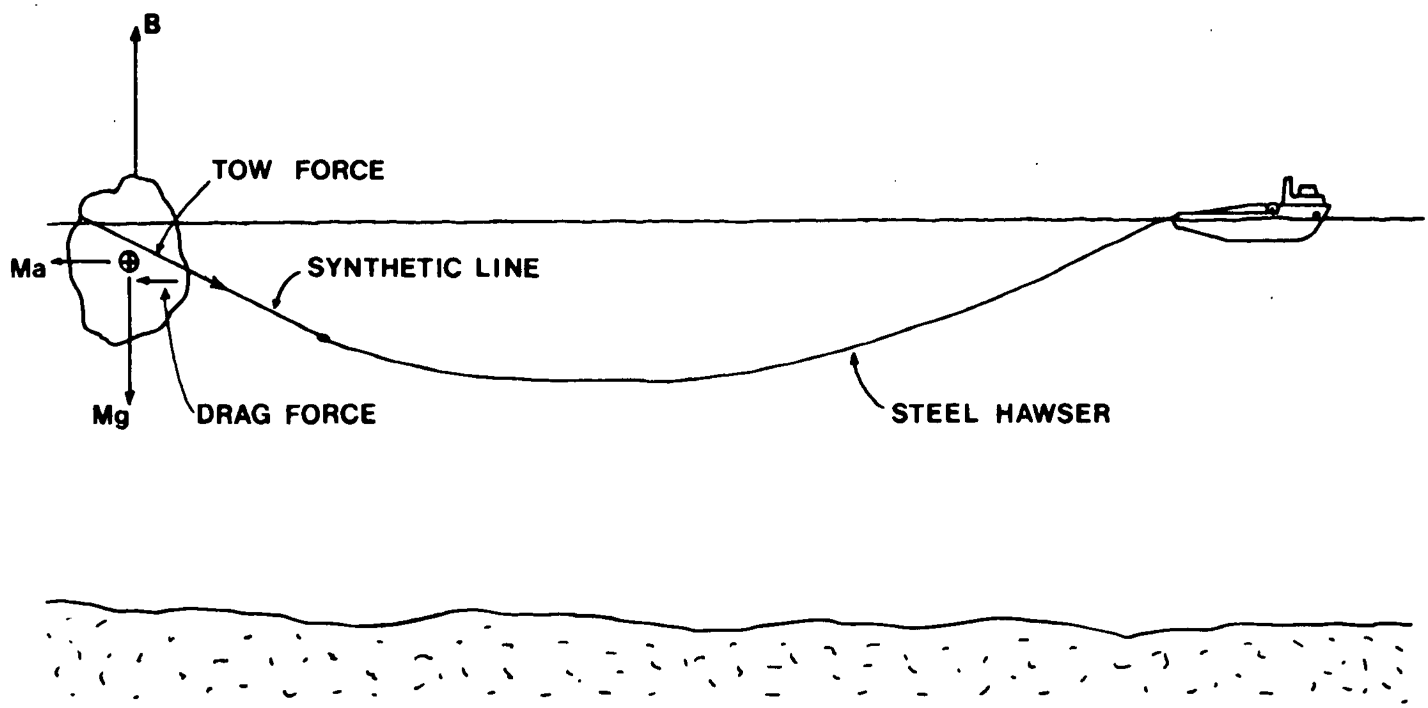


NOTE

Deployable in higher seastates when unable to deploy other methods, and when necessary to save rig shutdown time. Potential loss of portion of towrope if cutting of towrope is required to disconnect should be traded off against lost drilling time. Under rig down time conditions towrope is considered expendable or consumable.

HUSKY/BOW VALLEY MAY 85

Figure 16.



B = BUOYANT FORCE

Ma = RESULTANT DRIFT FORCE

Mg = GRAVITATIONAL FORCE

USING THE STEEL HAWSERS CATENARY TO REDUCE OVERTURNING MOMENT

Figure 17.

ONGOING RESEARCH AND DEVELOPMENT

NETS

An area of intense interest in the last year has been the development of an effective net for towing small ice masses.

Nets of various types have been tried since the early 1970s. Perhaps the earliest attempts were made by Marex, Ltd., in support of Labrador Shelf exploration activities using a net designed by them in 1971. (Marex, 1971). This net is shown in Figure 18.

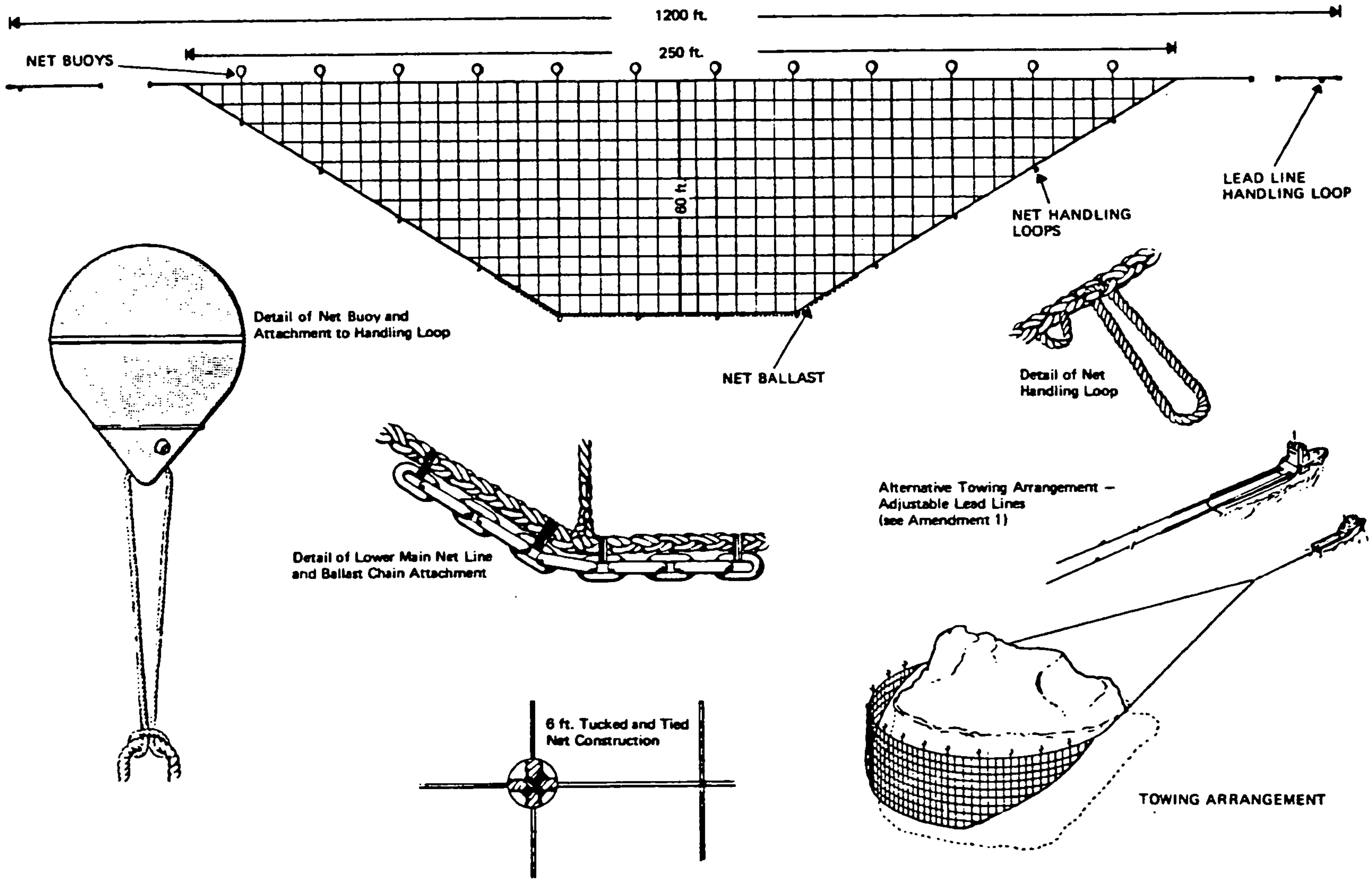
Towing logs from environmental reports prepared by Marex for Eastcan document attempted use of the net offshore Labrador a total of seven times from 1973 to 1978. These early attempts met with failure, mainly as a result of design faults and handling problems. However, one thing became clear after these trials - this particular design was still prone to the same slip-off problems that plagued the use of the conventional towline.

A closer look at the net reveals that it is, in essence, merely a towline with a flap of mesh attached to it and when viewed in light of more recent work, obviously could not perform as desired.

After the last of the attempts to use this particular net in 1978, interest in nets on behalf of industry waned, although it was recommended for development in practically every environmental summary report for wellsites where icebergs were prevalent. This indicated that there were a number of operationally-oriented people who felt that a net had potential as an ice management tool, particularly for smaller pieces which were known to be difficult to handle by conventional means.

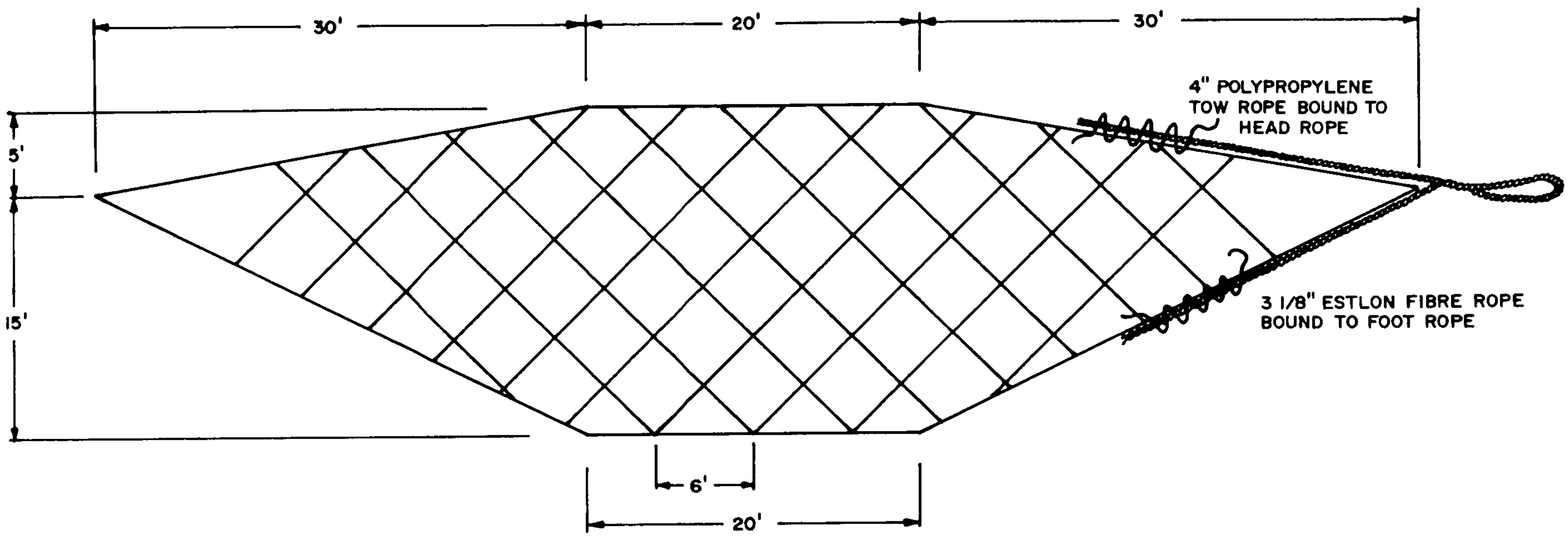
Then, in 1984, Husky/Bow Valley (H/BV) initiated an in-house growler net development program in response to operational concerns created by untowable bergy bits and growlers near drilling units on the Grand Banks. The first prototype (see Figure 19) was fabricated in June of 1984 and tested in early July. From discussions with H/BV personnel involved, test results were encouraging with a number of test targets towed successfully. Criticisms of the net were that it was too small and that mesh size and buoyancy requirements need optimization.

Based on these recommendations and in consultation with marine personnel, a second net was fabricated in November of 1984.



MAREX GROWLER TOWING NET

Figure 18.



HUSKY-BOW VALLEY GROWLER NET
PROTOTYPE #1

Figure 19.

This net was essentially a scaled up version of prototype #1 (see Figure 20). Preliminary trials were attempted in January, 1985, in Witless Bay (near St. John's) but non-availability of appropriately sized ice masses precluded full testing until May of that year when it was used in an operational setting. While the net performed well on several occasions, deficiencies were still obvious. The main criticism was that there seemed to be insufficient tension in the bottom member, resulting in a tendency for the net to creep up over the iceberg during the tow.

Then, in June of 1985, two copies of a prototype #3 (Figure 21) net were built and sent into the field for operational testing. The new design was to result in tension being applied first along the bottom of the net, below the surface of the water and close to the center of rotation of the iceberg. These last nets still await a proper evaluation since due to the lateness in the Grand Banks iceberg season, no appropriate growlers were available. It was, however, tested with little success on several larger pieces.

H/BV, in consultation with Husky Marine, drew the following preliminary conclusions about nets:

- To be effective, the net should completely encircle the ice mass. Therefore, a net should be proportional to the size of the ice mass.

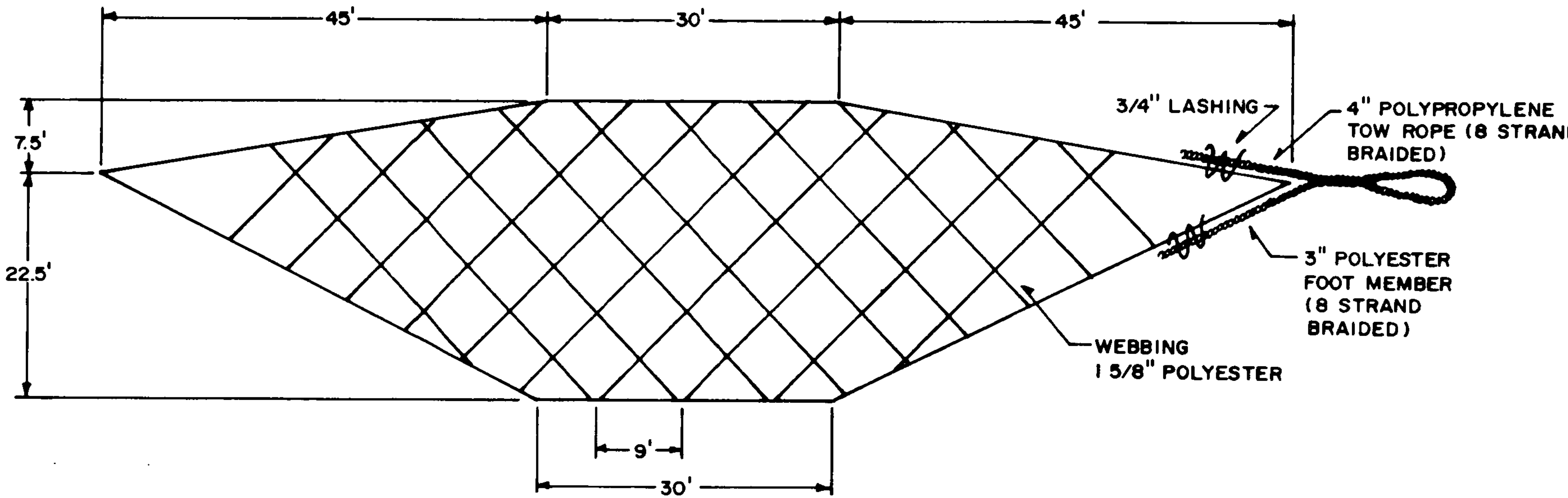
- A dedicated storage spool is required. The spool should be located properly (i.e. on main deck with clear run to stern) and powered to aid in deployment and recovery.

- Conventional supply/anchor handling vessels may not be suited for net handling.

- Tow force must be properly distributed between top and bottom of the net. Ideally, independent control of top and bottom bridle tensions is desired.

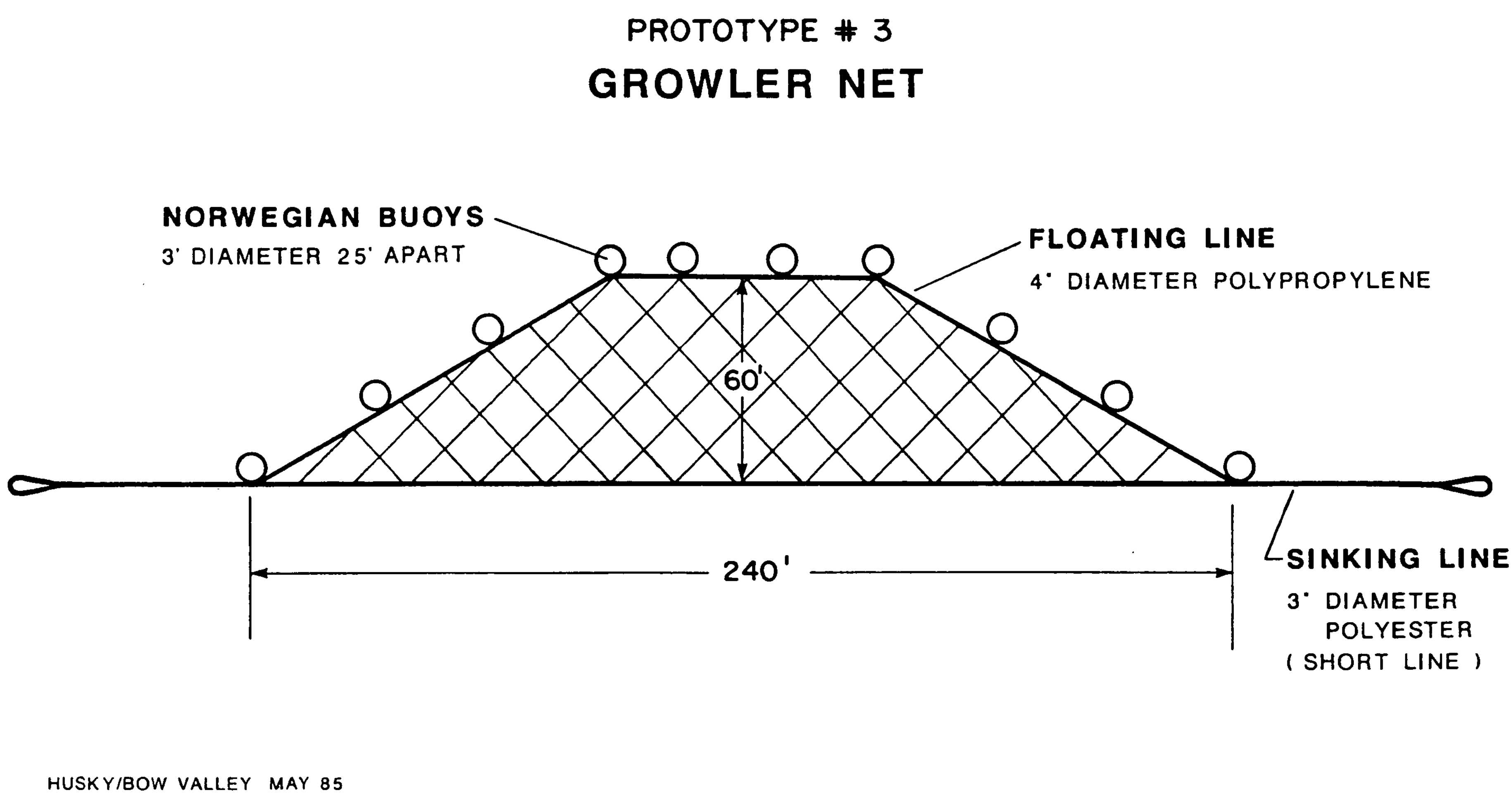
Petro-Canada has also shown a renewed interest in nets over the last year, sparked mainly by a successful use of H/BV's prototype #2 net in early 1985 which saved operational downtime for both operators. As a result of this incident, Petro-Canada proceeded to build their own copy which was then placed on the M.V. ACADIAN GAIL, then on charter to Petro-Canada. Through personal conversation with the vessel's Master (Capt. Clinton Guptill), it is known that several unsuccessful tow attempts took place before a net was made by Acadian Offshore Services. The net was built by the crew of the M.V. ACADIAN GAIL.

Drawings of this net are not available, however, it is known that it was of insufficient strength and used a small (5")



GROWLER TOWING NET
PROTOTYPE # 2

Figure 20.



GROWLER NET

PROTOTYPE # 3

Figure 21.

mesh size and webbing (4mm diameter). The net was basically constructed from fishing twine.

The net was redesigned and the new version was built by two officers of the M.V. ACADIAN GAIL. No drawings of this net are available since it too was modified shortly thereafter to its present configuration. However, there were two features of note. The first was that the net was really comprised of two separate nets overlaid on each other. One net had a 20 ft. square mesh made of 2" polypropylene. These formed the main strength members. The overlay net had a diagonal mesh of 3/4" polypropylene with each individual mesh measuring about 2' to a side.

The second interesting feature of this net was that while the overall dimensions of the net frame (i.e. headrope, footrope, and side lines) measured 100 ft. x 150 ft. (30.5m x 41.7m); the internal portion, when fully spread, measured 140 ft. x 220 ft. (42.7m x 67.1m). This resulted in the formation of a relatively deep pocket.

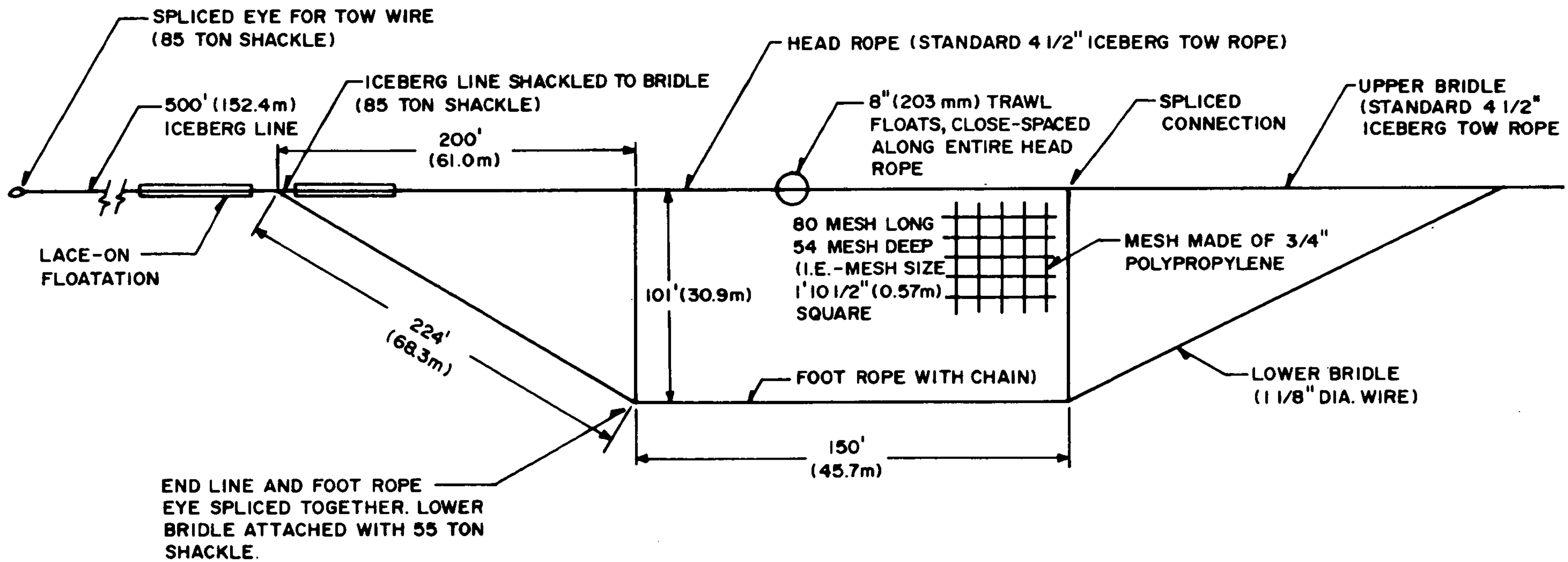
In the present existing version of the Acadian Ice Net (Figure 22), this pocket was removed. According to Mr. G. Tibbo of Acadian Offshore Services, the pocket was not seen to be a real advantage and only increased the complexity of construction. Mr. Tibbo suggests that even with a flat net, the tendency will be to "bag" when wrapped around a growler or bergy bit.

According to the net's designers, the bridle is perceived to be a key element of any net and this particular case is no exception. The bridles are configured to form a right-angled triangle with the lower leg being the hypoteneuse. This, according to Mr. Tibbo, eliminates the tendency of the bridles to close the net.

Capt. Clinton Guptill of the M.V. ACADIAN GAIL reports that the net was used successfully on several occasions, including one incident where the bergy bit rolled several times without loss of tow. The net was tried on a medium-sized iceberg (75m x 60m x 24m or approximately 430,000 tonnes) at the Baie Verte J-57 location (BP Resources Canada Ltd.) (see Figure 23). While tension was achieved, the tow effort was unsuccessful as recounted by an ice observer working on the rig at the time. The net was really not large enough to be much more effective than a single floating line on a piece of this size.

A net was also constructed by ESSO Resources Canada Ltd. in June 1985, with sea trials taking place in July. (Comyn, 1985).

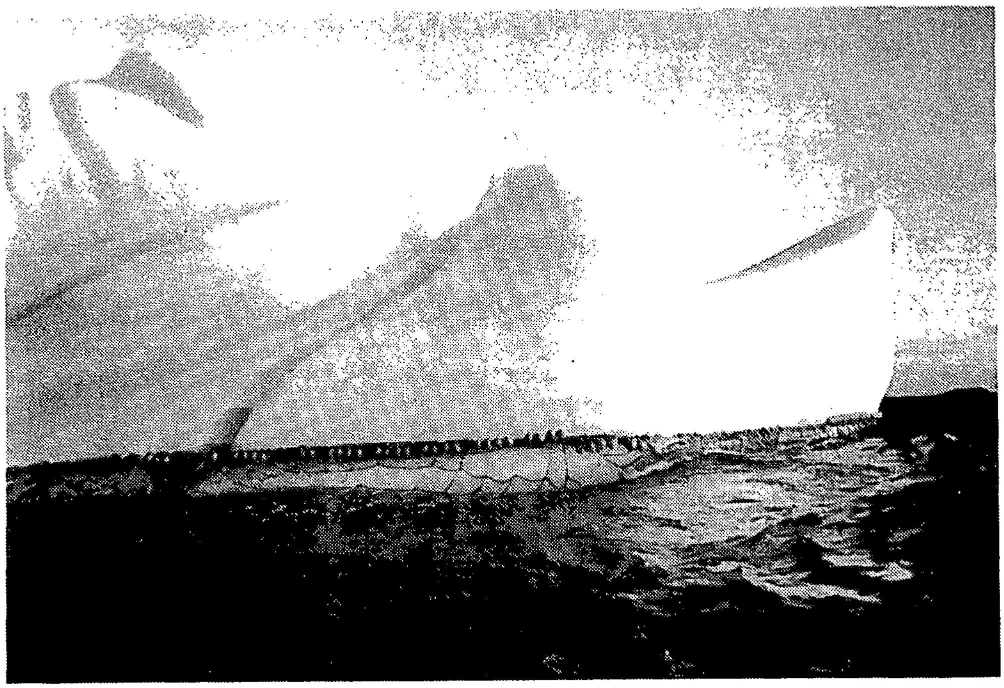
The netting selected was commercial cod trawl made of 6mm diameter double-strand nylon, available in standard sections of



ACADIAN ICE NET (patent pending)

SCHEMATIC DIAGRAM

Figure 22.



Iceberg being netted by M.V. ACADIAN GAIL prior to towing (from "Atlantic Energy News" magazine, November, 1985).

Figure 23.

18.3m x 6.1m (60' x 20'). The net was made by lashing four of these sections to the headrope, made of 19mm (3/4") diameter wire rope wrapped with 16mm (5/8") diameter polypropylene, giving a net with overall dimensions of 61m x 6.1m (200' x 20'). The extra 12.2m (40') was deliberately left in place to encourage the formation of a pocket.

The foot of the net was ballasted with 13mm (1/2") chain while bouyancy was provided by means of 203mm (8") diameter spherical plastic floats, lashed to the headrope at 0.3m (12") intervals.

The ends of the net were reinforced by wrapped wire ropes similar to the headrope. The ends of all ropes were terminated in eye splices to facilitate connection using shackles.

Bridles, each 18.3m (60') long and made of 19mm (3/4") diameter wire rope were shackled to all four corners of the net.

The net's depth could be increased by attaching an extra standard net section to the footrope of the main net. The ends of the foot of this additional section would be attached to the foot of the main net with 8.5m (28') long wire rope pennants, or martingales, also made of 19mm (3/4") wire rope. The design is depicted in Figure 24.

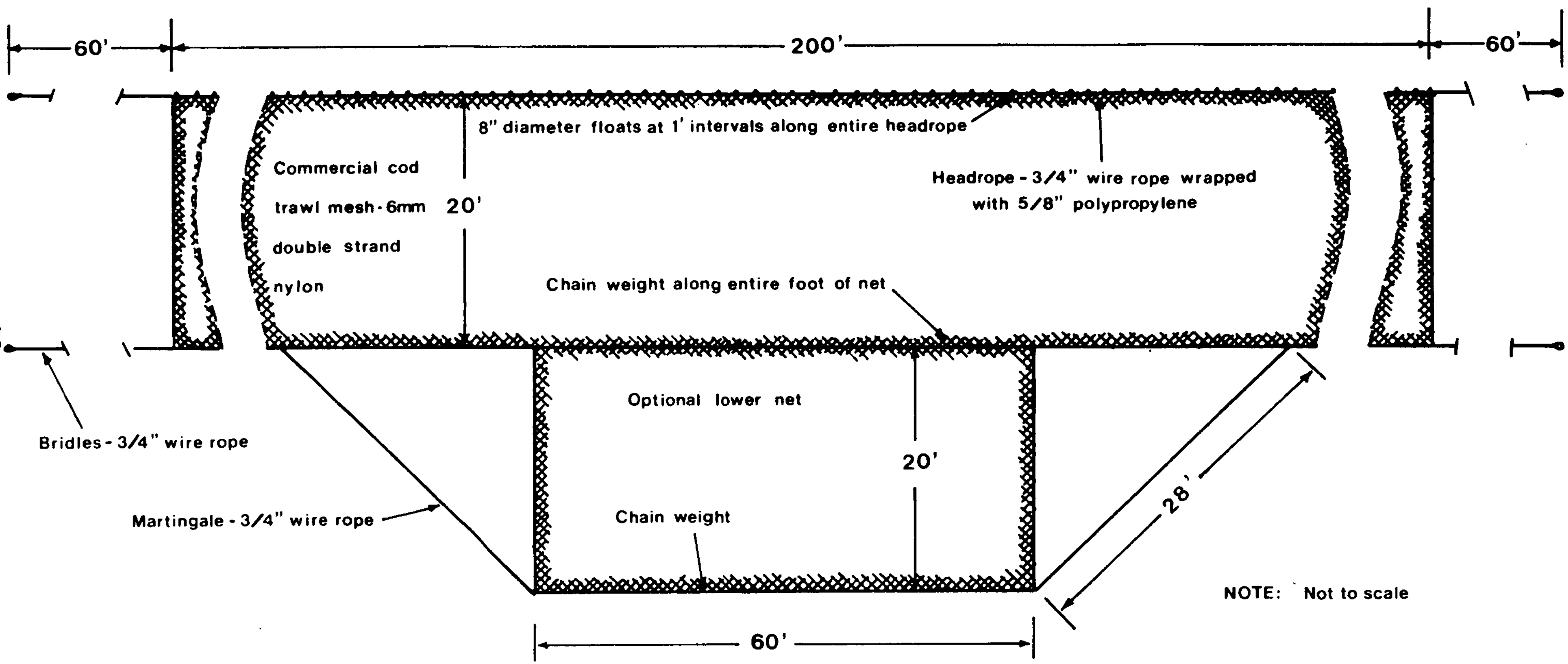
The net was tested on the M.V. SEAFORTH HIGHLANDER from the 6th to the 9th of July 1985 on three different ice masses.

From the tests it was determined that the net performed satisfactorily with regard to local strength, deployment and retrieval, handling on deck and stowage. However, the net was prone to slip off the ice, seriously limiting the allowable tow tension.

The following recommendations were made:

- The usefulness of the net could be improved by integrating it with the regular floating tow rope. A floating tow rope should be used as the head rope, providing similar handling, continuity of strength and additional buoyancy. A longer length, say 700', could readily be provided.

- The towing pennants should also be made from lengths of floating tow rope, in 200' and 700' lengths. As a full length of floating tow rope is still required to be carried for use with large bergs, available storage space will be limited.



ESSO EXPERIMENTAL GROWLER NET

Figure 24.

- The net should be deeper. Sixty feet would be convenient for construction purposes, and might be the practical limit for easy handling.

- Very low power levels should be maintained initially as the tow is started. Only gradual increases should be made.

- The ability of a net to hold on to ice might be improved by the use of a pursing line, which would form a pocket in the net.

It was concluded that, since the net could handle some ice masses which cannot be towed by conventional means, it is indeed a sound concept. However, improvements are still necessary, particularly with regard to net holding power.

In conclusion, it appears that a properly designed net would have obvious advantages for management of small ice masses. Assuming effective design, a net would apply towing force both above and below the central elevation of the ice, thus minimizing the potential for roll. Nets have the potential of being able to be designed in sections allowing increase or decrease in size. This could help reduce handling problems when dealing with smaller pieces. Furthermore, if a small ice mass could be netted well enough, the potential for high tow speeds exists. This would suggest the possibility of being able to clear many pieces out of a given area in minimal time.

It has been suggested by various industry and other personnel that a possible method of towing using a net would be to utilize a vessel which is already designed with net handling in mind such as a trawler.

Alternatives along this line include both the use of a single trawler as well as a modification of the conventional pair-trawl fishing method. A typical arrangement is suggested in Figure 25. This idea is a relatively new one and development would definitely be required but appears to merit further investigation and, therefore, will be discussed more thoroughly in the conceptual design phase of this study.

UNDERWATER DRILLING USING REMOTELY OPERATED VEHICLES (ROVS)

Mobil Oil Canada, Ltd. recently conducted experiments using a remotely operated vehicle (ROV) carrying a high pressure water drill. (Ocean Industry, 1984). The ROV is controlled from the deployment vessel and uses its very high pressure water jet (30,000 psi) to bore a hole in the ice. Expanding bolts are then used to firmly embed the tow anchor into the iceberg near the center of gravity, providing a single point attachment for towing.

TANDEM TRAWLER TOWING OF GROWLER

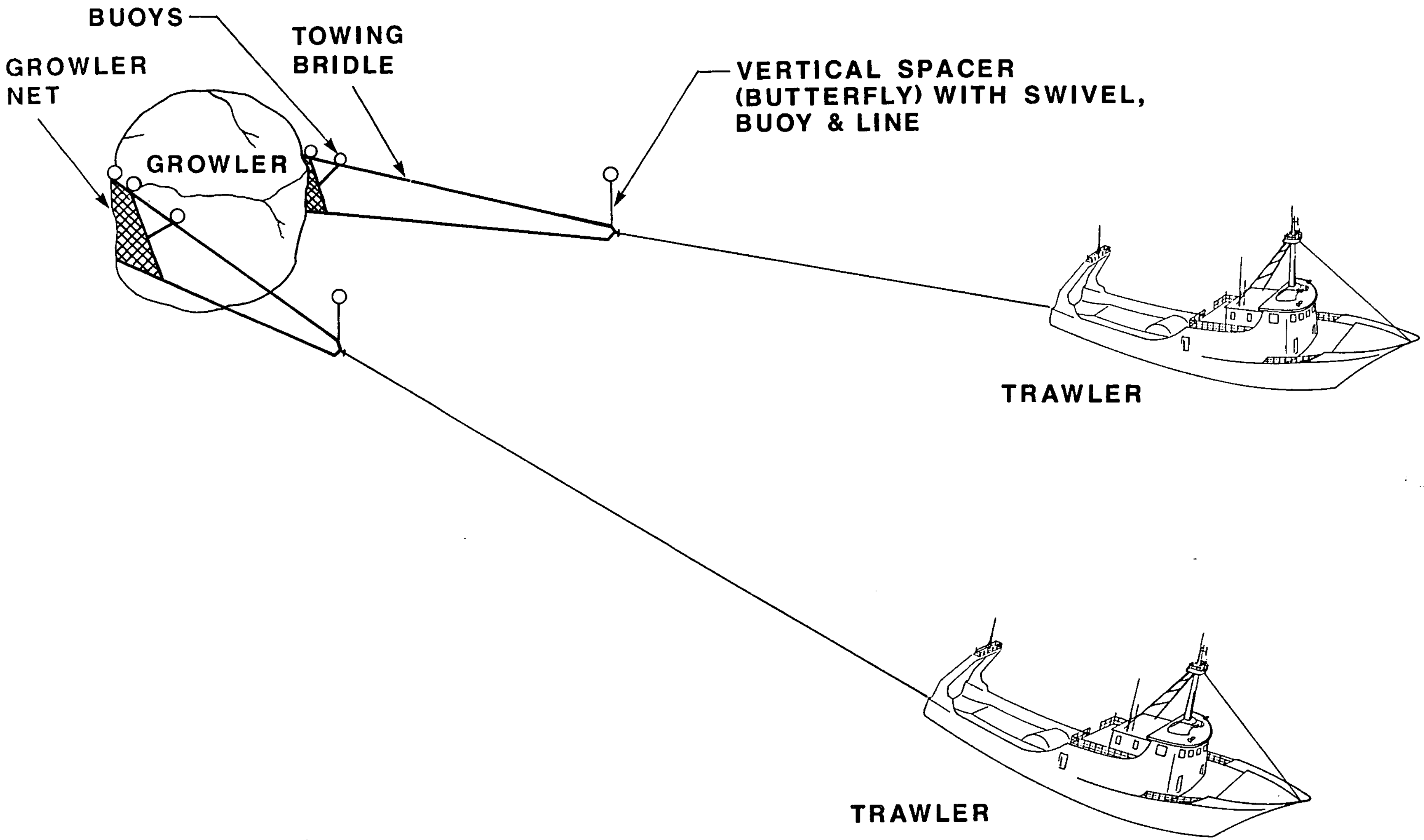


Figure 25.

This would practically negate towing related problems associated with rolling, since the unit should not slip and results in the tow force being more closely in line with the iceberg's preferred axis of rotation than with the single line method. From verbal communications with personnel at Mobil, St. John's, the ROV is heavy and requires a boom to lower it into the water. This raises questions on its deployment and usage during rough sea states. In addition, the system is complex requiring specially trained operations personnel and because of this complex equipment, breakdowns are more likely when compared to a simpler system. It is also likely that this apparatus would monopolize the deck of the supply vessel, preventing that vessel from performing conventional ice management tasks (i.e. towing using main hawser).

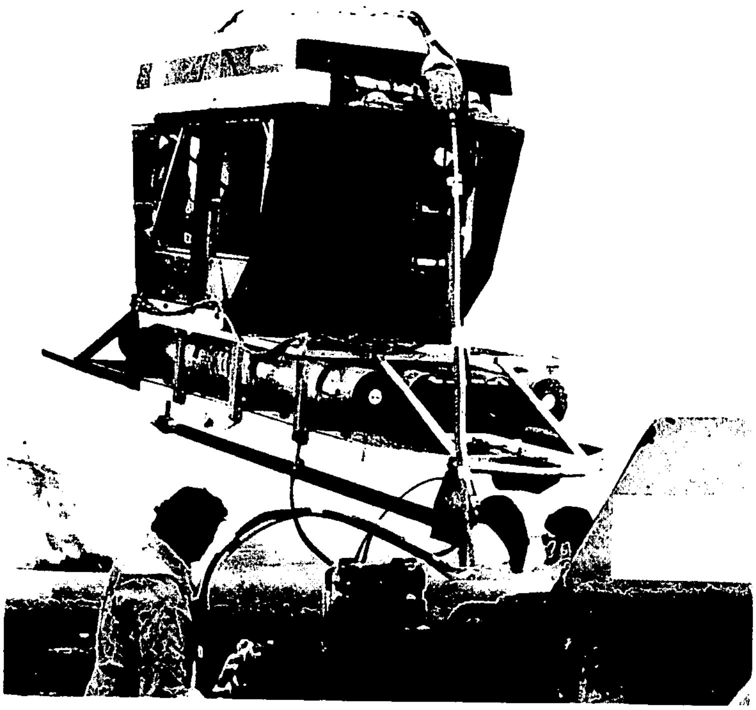
It is also known that the embedded anchors are prone to gradually "creep" out of the iceberg when tension is applied which may be a problem on lengthy tows. On the other hand, a good attachment would allow relatively high tow speeds and, therefore, tows would probably be of a fairly short duration.

This type of a fixed point attachment also raises safety questions about what would happen if the iceberg rolled several times in quick succession. Unless the anchor was pulled free, a situation like this could be hazardous to the vessel. Figure 26 shows the ROV being deployed and in the water with the towline attached.

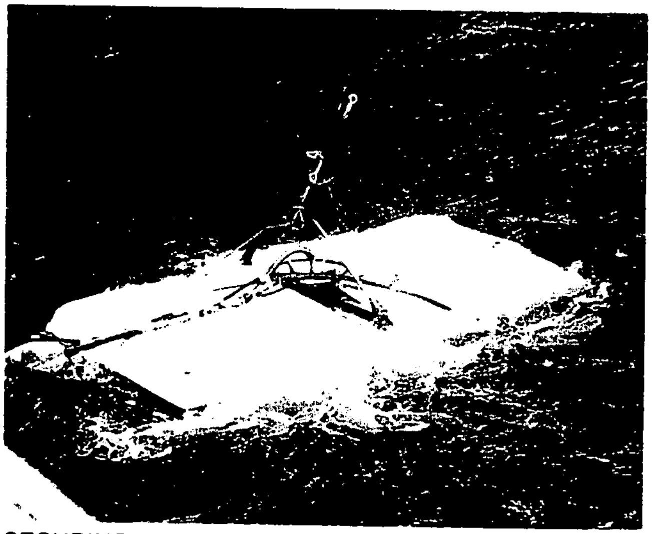
ICEBERG JIGGER

The "iceberg jigger" is a device designed by Ice Engineering, a consulting firm located in St. John's. (Roche, 1984). The iceberg jigger consists of three preheated, spring-loaded rods mounted in a triangular frame which, when the unit is lowered onto an ice mass by a helicopter or by crane from a supply boat, melt into the ice mass. Power is supplied by three lead-acid batteries also mounted in the frame. The orientation of the rods is such that, when fully extended, the unit would resemble a camera tripod. The angle of penetration of the legs provides an anchor point on the iceberg which can then be used as a towing point. The towing line would normally be attached to the jigger prior to its placement on the ice. The unit is shown schematically in Figure 27.

Recovery is accomplished through overstressing of the unit and its surrounding ice by application of excessive tow force. The unit is essentially yanked clear of the ice. The system has positive aspects in that, similar to the ROV, rolling would not necessarily result in loss of tow. However, as with the ROV, it may potentially be dangerous if the iceberg rolled several times consecutively and the jigger did not come free. Also, deployment by helicopter should be possible in half an hour or less plus flying time to the iceberg.



HYSUB ROV, fitted with a water lance, is deployed from a conventional supply vessel.



SECURING THE TOWING LINE. Once deployed, the ROV used expanding bolts to secure the lance deep inside the massive iceberg for towing.

Deployment of ROV for Embedment of Ice Anchor (from "Ocean Industry" magazine, May, 1984).

Figure 26.

The Iceberg Jigger

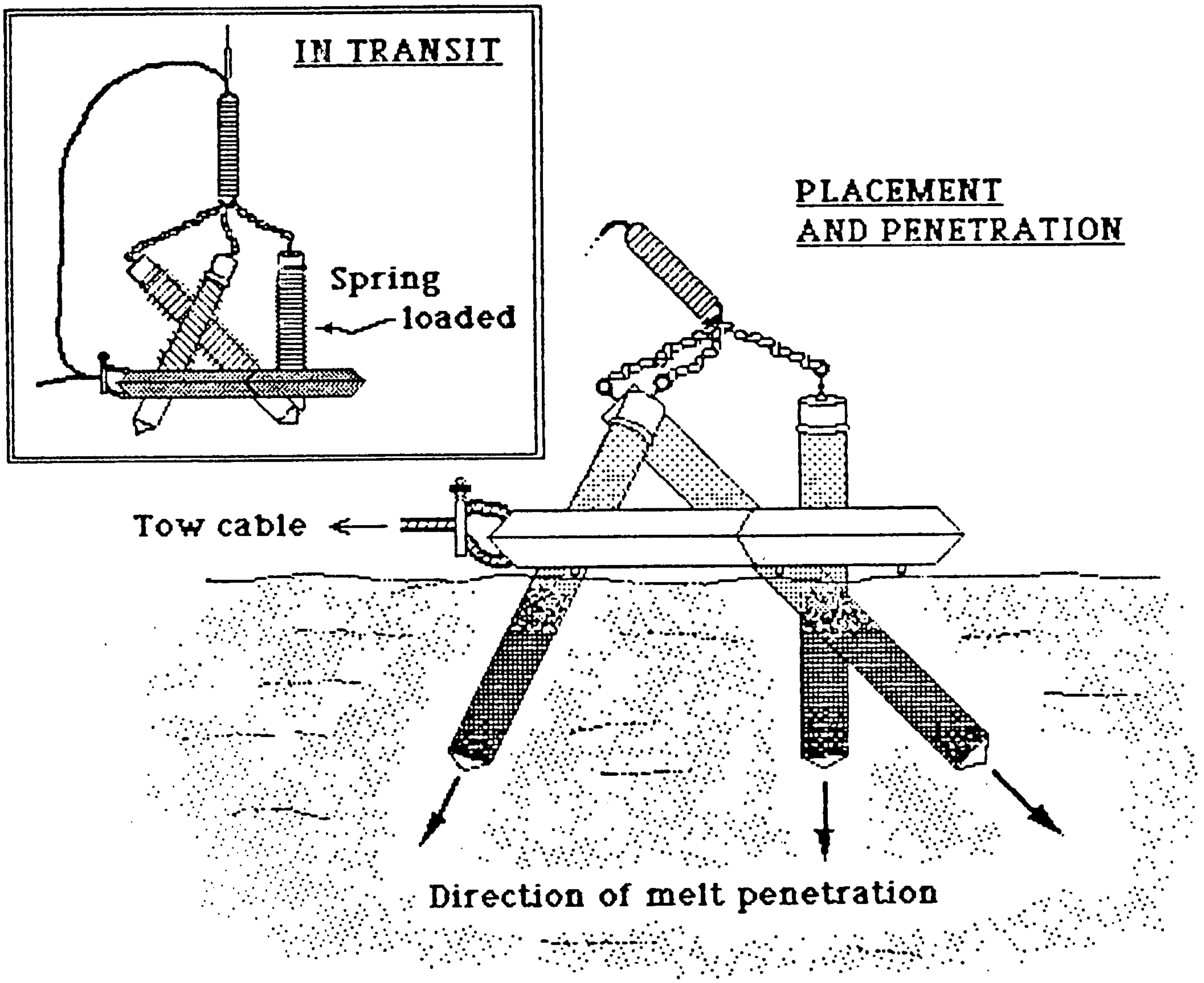


Figure 27.

The iceberg jigger has been recently tested in the Witless Bay area (near St. John's) aboard the M.V. FOGO ISLE. In these tests, deployment was done from helicopters. The main drawback of the system would appear to be that the unit requires repair and possibly replacement after each tow since the recovery procedure normally results in damage. Another disadvantage is that poor flying conditions would prevent deployment by helicopter. This is a serious handicap because fog is quite common during the Grand Banks iceberg season.

Deployment by supply vessel crane is likely to be sea state limited, as well as being restricted by maximum crane reach. It may also pose danger to the vessel since the sides of most ships are not designed to withstand impact forces. The device may have potential but requires further development and modifications.

WATER CANNONS

The term "water cannons" refers to heavy duty firefighting equipment installed on certain vessels capable of pumping large volumes of water up to 60,000 litres/minute (13,200 imperial gallons/per minute). (Canadian Shipping, 1985). Normally, the value is around 36,000 litres/minute (8,000 imperial gallons/minute). Firefighting vessels are usually equipped with two or four of these so called fire monitors, often mounted atop the superstructure.

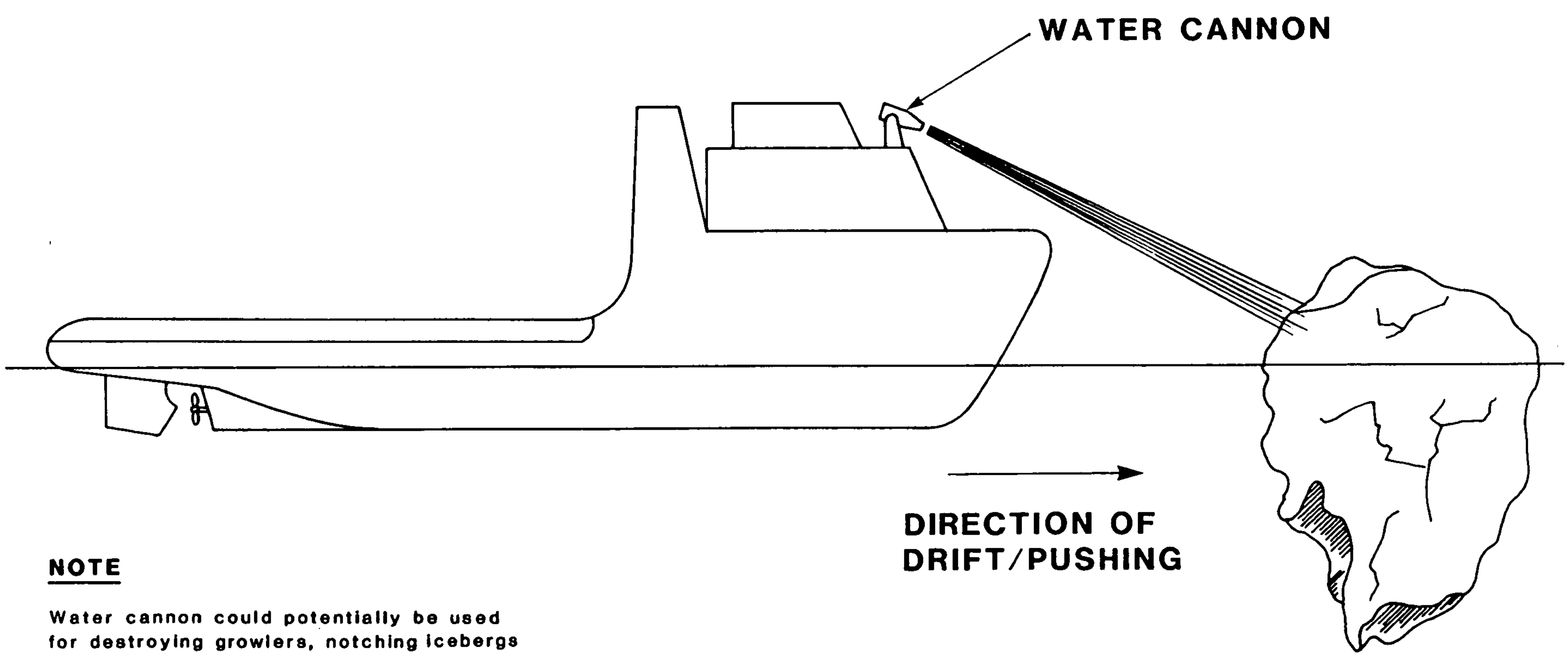
Discussion with vessel captains reveals the magnitude of the force generated by a water jet flow rate of this quantity. Apparently, training all units toward the vessel's stern generates a thrust which can move the vessel at a speed of up to four knots.

For ice management, the jet of water from one or more water cannons is directed at the ice mass (see Figure 28). This serves not only to deflect the mass but to accelerate the decay rate. The simplicity of the method is appealing from an operational point of view.

Negative aspects of this method seem to include the fact that a vessel retrofit would be necessary for installation on vessels not already equipped for firefighting. Also, difficulties associated with keeping the water stream on target in rough seas are not known.

Yet another aspect which could prove to be a detriment is the possibility of freezing spray being blown back from the water jet, causing ice build-up on metal surfaces. In fact, water cannons have actually been used in this manner to create protective ice berms in the Alaska Beaufort Sea for Exxon Corp. (Alaska Construction and Oil, 1985).

WATER CANNON ICEBERG PUSHING



NOTE

Water cannon could potentially be used for destroying growlers, notching icebergs so that a towrope could be properly seated, or to push small pieces of ice.

HUSKY/BOW VALLEY MAY 85

Figure 28.

The concept of using water cannons to manage small ice masses was apparently originated by an ice observer on the drillship, NEDDRILL 2, during the Labrador Sea campaign of 1982. At the time, the first FiFi 1 class vessel (M.V. MAERSK RIDER) to work in east coast waters was on charter to Petro-Canada.

From personal conversation with the ice observer (Pip Rudkin), the vessel requested permission to test its fire monitors as it had just completed sea trials and had not yet had the opportunity to do this. Upon learning that the test went well, Rudkin suggested trying the technique on a piece of ice. It was attempted with the water cannons trained over the stern. The crew of the M.V. MAERSK RIDER reported that the test had gone well but the water jet had somewhat obscured their view of the ice. Unfortunately, this test was undocumented. The idea was suggested as an ice management tool in a number of reports written since that summer.

After a heavy and troublesome iceberg season on the Grand Banks during the spring of 1985, Husky/Bow Valley and Dobrocky Seatech Ltd. staff conducted extensive discussions to explore ice management alternatives to the conventional towrope and propellor washing methods being used at the time. The objective was to reduce rig downtime to a more acceptable level. The water cannon was discussed amongst other ideas, however no vessel equipped with an appropriate water cannon system was available in East Coast Canadian waters at the time. Shortly thereafter BP Resources Canada brought the M.V. SKANDI ALFA to Canadian waters from the North Sea to support drilling operations north of the Grand Banks. The water cannon technique was tested in July, 1985 using the M.V. SKANDI ALFA near the BP Resources Canada Baie Verte J-57 wellsite (Allsop, 1985). A joint engineering evaluation program was set up by Husky/Bow Valley, BP Resources Canada and Offshore Atlantic (Warbanski & Banke, 1985). The objective was to determine the maximum size iceberg that can be managed using this technique and the maximum induced speeds and change of direction that could be achieved.

Driven by the ship's main engines, each of two monitors can produce 2,400 tons of water per hour. The jet reaction from both of these can move the ship at three knots. It takes 18% engine power just to remain stationary.

The vessel moves close to the iceberg, changes to joystick control, and the cannons are started. Various tests were carried out, some with one cannon and others with two. The cannon nozzles were changed to give a better jet with more power, 3,000 tons per hour at 14 bars pressure each or 1 ton per second.

An ice-notching nozzle was tried. It cut into the ice but needed to be gyro-stabilized to be effective. The tests proved, however, that the water cannon technique is a viable one.

Three influences occur. First, movement by direct impact of the water jet. Secondly, the induced current effect of 100 tons per minute of water hitting the sea at a higher velocity. Thirdly, the reduction of iceberg mass due to chipping and accelerated ice melting.

Preliminary results from the seven day intensive test program indicated that the cannons can be used to manage icebergs up to 40,000 tons. Small icebergs such as growlers of about 2,000 tons can be moved in any direction at speeds of up to two knots. Larger icebergs can be induced to change direction by up to 40° from their natural course but with little speed increase.

The conclusion was that water cannons are effective in dealing with smaller untowable ice masses. This method also has the advantage of ensuring that firefighting capabilities are present at any facility requiring ice management. It is, therefore, concluded that this method seems to have great potential and definitely should be further developed.

Another idea utilizing an appropriately equipped FiFi vessel which has been suggested is the use of foam dispersant guns to apply some kind of chemical to the iceberg which would hasten its deterioration. However, care must be taken in the selection of the chemical to be used as it may have undesireable effects on the local environment. Further considerations associated with this idea include:

- required onboard storage capacity (i.e. large tanks may be required);
- effect on vessel's firefighting capability.

On the surface, it would appear to be an unfeasible idea but is mentioned for completeness.

PHASE II

DESIGN CRITERIA FOR THE DEVELOPMENT OF A SMALL ICE MASS HANDLING SYSTEM

This portion of the reports defines the design criteria applicable to the development of a small ice mass management system. Areas addressed include:

- environmental factors
- ice characteristics
- criteria applicable to the design of an ice net.

QUESTIONNAIRE PROGRAM

As the basis of Phase II of the project, Dobrocky Seatech Ltd. distributed questionnaires relating to management of small ice masses to east coast offshore oil and gas exploration companies and to supply/fishing vessel masters operating in the ice infested waters offshore Newfoundland and Labrador. In addition to the questionnaires, follow-up interviews were also conducted with representatives from the above.

DISTRIBUTION OF QUESTIONNAIRES

Two questionnaires, one for offshore oil and gas exploration companies' representatives and one for vessel masters operating on the east coast, were prepared in draft format with the input of our tow vessel master (Capt. S. Nicholls) and our fishing gear handling consultant (Capt. D. Tait), and submitted to the Scientific Authority for approval. Upon making the necessary changes to the draft forms, the questionnaires were sent out in final form.

The questions put to operators' representatives and vessel masters were designed to obtain information on operational requirements for ice handling equipment, problems encountered in the deployment and operation of gear used in the past and design specifications of any equipment to be developed in the future.

Most questions were in the area of the building and handling of iceberg towing equipment. Particular emphasis was paid to the requirements for a towed net capable of handling growlers and other small ice masses.

The first questionnaire was sent to a total of twenty-seven individuals at ten oil and gas exploration companies which are operating, have operated, or were partners in operations on the east coast. Responses were received from six individuals representing four of the oil and gas exploration companies yielding a rate of return of 22% for individuals and 40% for the companies.

The second questionnaire was sent to a total of thirty-three individuals representing ten companies involved in supply vessel or fishing activities on the east coast. Of those questionnaires sent, responses were received from five individuals representing four of the companies questioned, this being a 15% return rate for individuals and a 40% return rate for the companies.

From these figures, it is obvious that response was poor and although much of the information derived from the questionnaires was of real value to this study, the results can not reliably be construed as representative.

The questionnaire methodology initially appeared sound but there were a number of weaknesses which should be avoided if future surveys are to be carried out. A more successful approach would entail the following:

- The questionnaire should be brief and to the point. Where possible, essay questions should be avoided in favour of a "checkpoint" format.

- The questionnaire should be completed in the form of an interview at the respondent's place of work, e.g. on board the vessel where diagrams, equipment, etc., can be readily referred to as part of the question and answer process. If the individual does not mind, a tape recorder could be used to ensure that all information and detailed answers are fully recorded.

- The questionnaire should be completed by a knowledgeable representative of the company conducting the survey, rather than the respondent. This ensures that all questions are answered as completely as possible and any ambiguities can be cleared up on the spot. The workload of completing the questionnaire and any detailed answers is also removed from the respondent, likely generating less gaps and more information.

- All terms should be defined. In some cases, questions were not answered where a respondent did not understand a particular term or its use in the context of a question. Diagrams might help to explain some things.

- Especially in the case of supply vessel masters and contractors, the direct sponsorship of the oil companies helps to generate more favourable response to a questionnaire and to the company conducting the survey. A preliminary or test questionnaire submitted to the proposed respondents for their comments might help to avoid some of the problems encountered in this study and also solicit more direct involvement from them.

The questionnaire responses have not been reproduced in this report due to the limited return rate, gaps, and other deficiencies mentioned above. Instead a summary of the major points raised by the respondents was prepared and is presented in the section titled, "Summary of Questionnaire Responses". Samples of the questionnaires are given in Appendices 1 and 2, while a list of those to whom they were sent is given in Appendix 3.

INTERVIEWS

During the month of February, 1985, Captain David Tait, an independent fishing gear technology consultant, and Captain Shane Nicholls, an offshore supply vessel master with considerable iceberg towing experience in the Davis Strait, offshore Labrador, and on the Grand Banks, conducted a series of interviews in St. John's, Newfoundland. The material collected during these interviews compliments the information presented in the completed questionnaires.

In all, a total of twelve interviews were completed - three with operations personnel from exploration companies currently drilling on the Grand Banks and nine with representatives of offshore supply vessel companies.

A summary of the information collected is presented in the "Summary of Interview Results" section of this report. A list of the personnel interviewed can be found in Appendix 4.

SUMMARY OF QUESTIONNAIRE RESPONSES

The majority of the questionnaire respondents are now, or have been, actively involved in iceberg management.

The general consensus was that the single floating towline method is unsatisfactory for towing small, smooth-sided, and/or unstable ice masses, mainly due to problems with successfully attaching and retaining the towline. Variations on the standard methodology such as weighting the towline, forming a slip knot with a shackle, and employing a double loop about the ice mass (usually with smaller diameter rope, such as vessel mooring lines) have been tried, in most cases with limited success.

Other approaches to small ice mass deflection have primarily included prop washing, which respondents indicated was too taxing on the vessels and machinery, and occasionally bow pushing, which is not favoured and has resulted in hull damage in the past. Both of these methods are effective only in relatively calm sea states and also afford limited directional control.

The questionnaires centred about the use of towing nets as an alternative small ice mass management tool, as was the original intention. This approach elicited a little negative response from some respondents as they felt the questions were overly biased towards nets. However, other phases of the study thoroughly address all actual and proposed ice towing methods and emphasis has also been placed on the use of water cannon as another viable alternative.

Opposition to nets came from those who were familiar with their past use where limited or no success resulted from either improper net design, construction, deployment techniques, or lack of opportunity to conduct meaningful or conclusive testing. Negative points raised in these cases included nets and/or lead lines being too small, vessel crews being untrained in the use of nets (because of the newness of the concept), net entanglement, poor choice of materials, improper flotation or ballast and the methods and effort required to attach these, unsuitable storage and repair facilities onboard the vessels and perhaps vessel capabilities as well in earlier years. Although there have been few trials or operational attempts to tow ice masses with a net, the negative response is based mainly on this small number of historical cases. Recent net trials carried out by Husky/Bow Valley and Acadian Offshore Services, for example, show encouraging success rates.

Most of the responses indicated that a net would be a viable tool for deflecting/towing small ice masses provided a proper engineering design and construction approach were used, supplemented by adequate testing and sea trials. In addition, the net would have to be simple to deploy, recover, and store, with flotation on a powered drum/spool equipped with a brake. No more effort should be involved than for the towline, or as one respondent noted, "it will remain on the reel with excuses given for its ineffectiveness." The potential for net fouling would have to be reduced or eliminated, as this was a major concern. The abilities to increase net dimensions by attaching sections or even a second net, perform other modifications, and effect repairs onboard the vessel were deemed desireable.

Use of the net to clear pack ice or numerous bergy bits or growlers was not seen as a likely application for exploratory drill rig protection, as the rig would likely be moved for any large density of ice within 10 nmi of the wellsite. The use of two vessels towing one or more nets between them received generally unfavourable comments. The extra vessel involved was seen as introducing coordination difficulties and reducing maneuverability while increasing vessel logistics and costs for probably nil or minor improvement.

The vessels in use at present were seen as adequate. Allowances for sufficient work deck and cargo space with a reel installed would be necessary. The more freeboard a vessel has, the more likely net deployment/retrieval can be carried out in adverse seastates. Bow and stern thrusters are necessary for maximum maneuverability during deployment operations and occasionally are necessary during the tow for course changes or maintaining course under severe wind, tide, or current conditions. While it was not specifically addressed in the questionnaire, it is also worth noting that good lighting is required for operations during darkness.

Almost all respondents viewed a tension meter as a useful tool, (to monitor tow tension), but not a necessity. Its uses include detecting loss of tow under poor visibility or weather conditions, detecting rolling of an ice mass by noting sudden increases in tension, preventing application of excessive strain to the towline, and gauging the appropriate tension, rpm, and pitch readings when towing an ice mass similar in size and shape to previously towed masses. It also provides data for subsequent analysis. However, better installation configurations, training, and calibration and maintenance were deemed appropriate for any future use of tension meters. Two respondents noted that towing tension can be roughly monitored via the band brake tension indicator outfitted on most vessels, vessel horsepower output, or propellor pitch (for vessels with variable pitch propellors). One suggested an inexpensive Wheatstone Bridge type of tension meter as an alternative.

Vessel masters viewed a sonar device as a useful tool for underwater surveying of some, but not all, ice masses prior to towing. It was not deemed a necessity, but felt that the more that was known about the ice mass configuration, the better.

SUMMARY OF INTERVIEW RESULTS

Interviews with experienced offshore personnel revealed that the following points are clearly very important in the development of a growler net:

- The net must be easy to handle on deck in a safe manner by a minimum number of deckhands. The design should be light and simple to minimize deployment or recovery effort.

- Handling and storage would be streamlined by the use of an adequately powered drum or spool on the supply deck of the vessel. Although a handling array would take up space on deck, most agreed that design and positioning of the drum could be optimized to eliminate conflicts with the vessel's supply or anchor handling capabilities. Use of a reel would allow fast, steady pay out of a net or line which should also reduce the chances of fouling gear in the ship's propellor.

- Storage of iceberg lines or nets on deck was considered to be both too dangerous and too labour intensive for the deck crew. Deck space/storage might also prove to be a limitation for a sectional net.

- From past experience, abrasion of iceberg handling gear was considered to be a minor problem. Most interviewees considered strength and buoyancy of the materials used to be greater concerns.

- Two interviewees from Acadian Offshore Services who had used the Acadian Ice Net considered it superior in design and success rate to other nets they had used, mainly due to what they claim is an improved bridle design (see Phase I for complete decription of the Acadian Ice Net), although further field testing and and minor design refinements were seen as necessary. Longer lead lines would allow towing of larger icebergs as well. There were both negative and positive attitudes towards using two supply boats towing one net between them.

DESIGN CRITERIA FOR SMALL ICE MASS HANDLING SYSTEM

For any equipment designed for use in the handling of small ice masses, the operating conditions must be well known. Realistic design criteria must be defined so that the gear can be deployed effectively when required. In this section, ice characteristics, environmental operating conditions, and desireable design features in terms of the shortcomings of previous nets are defined for use in conceptual and final ice net designs.

ICE CHARACTERISTICS

Over the past few years, Grand Banks operators have found that shape and stability as well as size have been limiting factors in the successful deflection of ice with the conventional synthetic floating towline method. Smaller icebergs have often been found to be untowable because of their smooth surfaces and/or frequent rolling. Icebergs in the latitude of Grand Banks drilling operations are usually worn smooth by constant wave activity and air and sea temperatures which are generally higher than offshore Labrador. The design of the ice-handling net must also consider towing of pieces of ice larger than those commonly classified as growlers or small bergy bits, as they may present similar problems with respect to shape, stability, and degree of decay and calving occurrence.

From the questionnaires, the design range of ice mass was estimated. An attempt was made to review data and literature in the public domain for common small iceberg dimensions. However, small ice masses are rarely measured. They are usually just classified as growlers or bergy bits with occasional estimates of their length or height.

Vessel captains who completed questionnaires or were interviewed estimated the mean ice size the net should be capable of handling to be approximately 12 meters in length, 8 meters in width and 5 meters in height (above-water dimensions).

The estimate of mean size given by the operators' representatives who were surveyed agreed with this, with average above-water dimensions of 11m x 8m x 5m (L x W x H).

Using the International Ice Patrol (IIP) mass estimation formula of:

$$M = 3 \times L \times W \times H$$

where M = Mass (tonnes)
L = Length (metres)
W = Width (metres)
H = Heigth (metres)

this implies an ice mass of approximately 1,400 tonnes for the average size small ice mass.

While the estimates of mean size made by vessel captains and operators' representatives were similar, those for the largest ice mass which could require management using the net differed.

Captains estimated maximum dimensions of 17m x 14m x 8m (approximately 6,000 tonnes), while operators suggested 25m x 19m x 9m (13,000 tonnes). Further discussion with Grand Banks operators seems to indicate that the system should be able to cope with small icebergs which are simply poor candidates for towrope deflection. This leads to a suggested design mass ranging from 1,000 tonnes to 40,000 tonnes, the upper limit being the estimated maximum manageable mass for the water cannon technique, which at this time, seems to be the main alternative to nets for small ice mass management.

The lower end of the range agrees well with existing size definitions (IIP, Grand Banks Joint Operators, Mountain) for growlers while the maximum suggested size falls within the classification limits of small icebergs. This suggests that the design ice mass range is in keeping with the study objectives.

The shape of the ice mass is assumed to be spherical, since this type has a neutral stability (i.e. no preferred orientation) and almost always presents great difficulty to those attempting deflection by means of conventional towrope. It is felt that if a system can cope with this shape, it should be effective on others as well.

ENVIRONMENTAL PARAMETERS

Typical and limiting environmental conditions for ice management operations are very important design considerations.

The questionnaire and interview results suggest typical (Grand Banks ice season) conditions as follows:

wind speed:	20-40 knots
sea state:	3-6 meters
tidal current:	0.5 - 1.0 knots
freezing spray:	occasional

As these are general estimates, it was felt that a review of long term environmental data for the offshore was necessary to yield more reliable and accurate design values. To accomplish this, data were extracted from the MAST (Marine Statistics) data base supported by Atmospheric Environment Service (AES) for the region of 46° to 50°N, 46° to 52°W. This area encompasses most wellsites drilled offshore Newfoundland since 1979 and should, therefore, be appropriate for evaluating conditions which may be experienced in future ice towing/deflection operations. Analysis of winds, waves, visibility, and occurence of fog and freezing spray potential are presented here. Figures indicating the region of interest and various environmental statistics are presented in Appendix 5.

Any ice management system must be adequately designed for successful application in most environmental conditions encountered on the Grand Banks. Deployment and recovery operations are usually particularly sensitive to adverse weather and sea state conditions, especially when considering safety and time factors as well as the potential for equipment fouling or entanglement.

The wind exceedence plots presented in Appendix 5 for each month of the year and for all months combined indicate that 95% of all observed wind speeds do not exceed from 30 to 44 knots in the areas of drilling activity. From November to March, the incidence of strong gale force winds is higher than for other months but the frequency of iceberg operations to date is generally less frequent than for later months of the ice season. However, any deflection system should be capable of operating in extreme conditions of winds up to 44 knots and corresponding average sea states of up to 7m, since the frequency and need for ice deflection operations does vary with season, location, type of drilling/production platform, and operator requirements. The figures in Appendix 5 give monthly mean, median, 95% upper limit and 95% lower limit wind speed values from January to December in the selected area. This allows for easier comparison between months.

The upper limit wind values of 30 to 44 knots specified above correspond to average sea states of 4m to 7m, respectively, from the Beaufort Scale. However, personnel with supply vessel experience feel that maximum combined seas of more than 5m present potential danger to deck crews. This working limit varies with vessel characteristics such as amount of freeboard and positioning/sea-keeping capabilities. Also, in heavy seas, small ice masses may be occasionally submerged, making it difficult to attach any towing gear successfully. Stability of an iceberg may also be reduced under these conditions.

Poor visibility and/or darkness are seen mainly as a hindrance to operations, resulting in increased ship transit and deployment times. There is also the increased risk of entangling ropes in propellors since rope detection in fog or darkness, combined with typical sea conditions, can be extremely difficult.

Other Figures and Tables in Appendix 5 show monthly and annual variability in visibility conditions offshore and typical frequency of fog occurrence in the Hibernia region. September to January show the minimum occurrence of fog ranging from 39% to 43%. As might be expected, these same months show a higher occurrence of good visibility conditions (≥ 5.4 nmi). The months having calmer wind conditions are also those with the poorest visibility and highest occurrence of fog. For example, in June and July, fog is reported at least once on 8 out of 10 days, with visibilities of less than 1/2 nmi occurring with a frequency of 33% to 43%. Overall, visibility conditions will be under 1/2 nmi about 18.5% of the time. Most supply vessel captains prefer to have a minimum visibility of 1/8 nmi or greater in which to operate.

The amount of daylight hours in which to work vary by month and latitude. The months of better visibility also have the shortest duration of daylight. Most captains agree that working in darkness is the same as in fog. The combination of the two impedes towing/deflection operations even more. Obviously, the equipment design should incorporate lights and/or materials which assist deployment, positioning, and recovery of the gear. In these conditions, small ice masses or portions they may calve are more difficult to see and present additional risk to the vessel and crew.

Freezing spray may hamper the deployment and storage of the net as well as the movement of deckhands on the work deck. From information in Appendix 5, the greatest potential for freezing spray is from February to March, again months of historically few ice deflection operations. The potential for at least light freezing spray is highest in January and February at about 20%. Heavy or severe icing is fairly infrequent. When it does occur, primary concern would be for the removal of the ice or retreating out of the area, if possible, not the capability for conducting ice management operations.

NET CRITERIA

This section discusses topics related to the actual detailed design and fabrication of the net(s).

Construction Considerations

Of primary concern are the overall dimensions of the net. Survey results indicate the length should be between 30m and 76m and depth between 10m and 24m. However, most responses suggested a size of approximately 45m x 15m. This recommendation considers both the working area available on conventional offshore vessels and the size of the ice mass to be deflected. However, based on discussion as presented 3 pages previous with regard to ice mass size, this seems to be of insufficient depth. This argument is made in light of the fact that previous net designs (as presented in Phase I) were too shallow and applied the towing force high up on the iceberg near the waterline, providing no real improvement on the floating towline method. This usually results in either the ice rolling free of the net or the net slipping over the top of the iceberg.

Most of the more recent net designs, which have met with more promising results than their earlier counterparts, range from 20-30 metres deep. Based on this, a net 45m long by 30 metres deep is suggested. It is further suggested that this net be comprised of two 15m deep sections attached to one another. This has several advantages, including

- only upper 45m x 15m panel need be used for smaller pieces, reducing handling problems.
- full 30m depth can be used on some small icebergs.
- reduced wear on bottom portion of net (less use).
- each 45m x 15m panel is only slightly larger than the available work space on most supply/anchor handling tugs, facilitating on-site repairs or modifications.

It is proposed that the net be designed to withstand a maximum tow force of 60 tonnes. This will allow down-sizing of the major load-bearing components (i.e. - headrope, footrope, bridles) and hence reduce weight and required storage volume. These two parameters have obvious implications on handling and storage capability. Also, a 60-tonne tow tension should be more than sufficient to successfully deflect the ice masses in question in this study, as described in an earlier section.

A 1.8 meter (6 foot) mesh size was suggesed by some questionnaire respondents, however, it is important to consider that maximizing this parameter can result in significant reductions in both required storage volume and weight. These two parameters should be minimized as much as possible. A smaller mesh, although would allow greater spreading of the applied tow force and decrease tangling potential. The mesh size will be finalized during the actual design.

The main construction material should have as high a strength/weight ratio as possible, considering factors such as resistance to abrasion and cuts, absolute strength and weight, strength loss due to soaking, resistance to salt water, and resistance to sunlight (ultraviolet radiation). Regular examination of the equipment should be carried out to prevent equipment failure offshore. The capability to repair or modify the gear onboard the vessel is a necessity.

The specific gravities of the various construction materials must be carefully analyzed for buoyancy considerations. Previous work suggests that submerged components should be heavier than water, while waterline components should be made of floating material. This ensures that the amount of extra flotation and ballast which must be added is minimized. Flotation collars and ballast material must be selected to allow efficient spooling onto the storage reel, or easy attachment during deployment and recovery. However, any extra effort necessary to attach or remove flotation is not desireable, as this would increase deployment and recovery times.

The stretch factor of the various components should be minimized to reduce net distortion. Also, to assist in reducing net distortion, torque-free components should be used whenever possible. This will be largely determined by the construction of the various components. Finally, consideration of minimum bending radii of the materials used is necessary, as they may be subjected to stress while bent around sharp edges on ice masses and on the storage spool. Easily attached sections which would increase the length and/or depth of the net should be considered for towing small icebergs. Variable lead line lengths may also be required.

Table 1 summarizes some of the more common materials which could be used, and how each rates in various performance categories.

Operational Considerations

Design criteria which apply to actual use of the net are discussed in this section.

A major problem with the previous net designs (as discussed in Phase I) has been maintaining proper orientation during deployment. It is felt that this is largely attributable to poor design in the areas of buoyancy and bridle configuration. For example, the Marex net utilized strapped on buoys which tended to wrap about the net in the water; the lack of a proper bridle did not allow proper distribution of tow force. The reason for this is not fully understood, but seems to be related to the fact that the "bridles" actually contain net webbing. It is thought that this introduces additional forces into the bridles, which affects their behaviour and complicates achievement of proper tow force distribution. This type of an arrangement can also lead to excessive tensions in mesh members.

Maintaining vertical net orientation while in free floating mode is simply a matter of proper use of ballast on the footrope and buoyancy at the headrope. The amount of footrope ballast should be minimized to keep total weight as low as possible. Selection of ballast and buoyancy materials must also take into account their effects on handling and potential for tangling and spool stowage. For example, floats attached to the headrope by lengths of rope (whether they be permanently attached or clipped on during deployment and removed during recovery) are not recommended because they increase the likelihood of tangling and handling problems in general. Flotation collars, on the other hand can be left permanently attached to the headrope and should

Table 1 - Materials Comparison Table

Properties

Material	Construction	Specific Gravity	Average Strength for 1" Diameter (tonnes)	Strength to Weight Ratio' (per 100')	Strength Loss When Wet (%)	Elongation at 20% of Break Strength (%)	Abrasion and Cut Resistance (Wet)	Abrasion and Cut Resistance (Dry)	Flexibility	UV (Sunlight) Resistance	Salt Water Resistance	Other
Nylon	2-in-1 Braid	1.14	15.3	1.3	10	8.0	G	E	E	G	G	Good shock absorption.
Nylon	12-Strand Plait	1.14	14.6	1.2	10	6.5	G	E	E	G	G	Excellent energy absorption; non-kinking.
Polypropylene	Plaited	0.90	9.0	0.9	0	5.5	G	G	G	G	E	
Polypropylene	12-Strand Braid	0.90	8.0	1.0	0	5.0	G	G	G	G		Non-kinking; non-rotating
Polytron	12-Strand Plait	0.91	9.4	1.1	0	4.5	G	G	G	E		Non-rotating.
Polyester	2-in-1 Braid	1.38	16.9	1.1	0	2.5	G	G	E	E	E	Flexible; torque-free.
Polyester	12-Strand Plait	1.38	19.4	1.2	0	2.0	E	E	E	E	E	Non-kinking; non-rotating
Kevlar®	Single Braid	1.44	31.8	2.3	0	1.0	F	F	G	-	-	
Estalon (KARAT®)	8-Strand Plait	0.99	14.1	1.4	0	4.0	G	G	-	G	-	
Kevlar/Duron® Composite**	2-in-1 Braid	1.42	23.6	1.6	0	1.0	G	G	G	-	-	
Nylon/Polyester Composite	2-in-1 Braid	1.24	18.4	1.3	10	6.0	E	E	-	E	-	
Nylon/Polypropylene Composite	2-in-1 Braid	1.01	12.4	1.2	-	6.0	G	G	-	E	-	
Steel Wire	Multi-Strand	7.85	51.6*	0.6*	0	>1.0	G	G	P	E	F	

* Based on minimum break strength.
' Strength/Weight per 100 feet.
** Duron is a registered name for Polyester.

E - Excellent F - Fair
G - Good P - Poor

not adversely affect handling or storage by a significant amount.

Ballast (if necessary) may be comprised of lead weights, chain, or specially constructed leaded rope attached to the footrope. The use of chain increases the concern of fouling metal components, but this risk may be unavoidable if the net is to be properly ballasted. Handling loops on the footrope and or headrope may be useful during deployment and recovery or for spreading the net on deck (or elsewhere) for repairs.

Keeping the net open properly while under tension is a function of bridle design. The bridle must be such that the component of tension tending to close the net is minimized. This topic is addressed fully in Phase III of the report.

A single hookup point or connection on the vessel is preferred over two separate towing points by most captains, as the former affords more vessel maneouverability and requires less deck work during deployment/recovery. Bridle design also has a significant effect on another factor which has plagued previous net designs, namely proper distribution of towing force. The configuration must permit equal force application above and below the likely axis of rotation of the iceberg. This should minimize the likelihood of slip-off over the top or iceberg rolling.

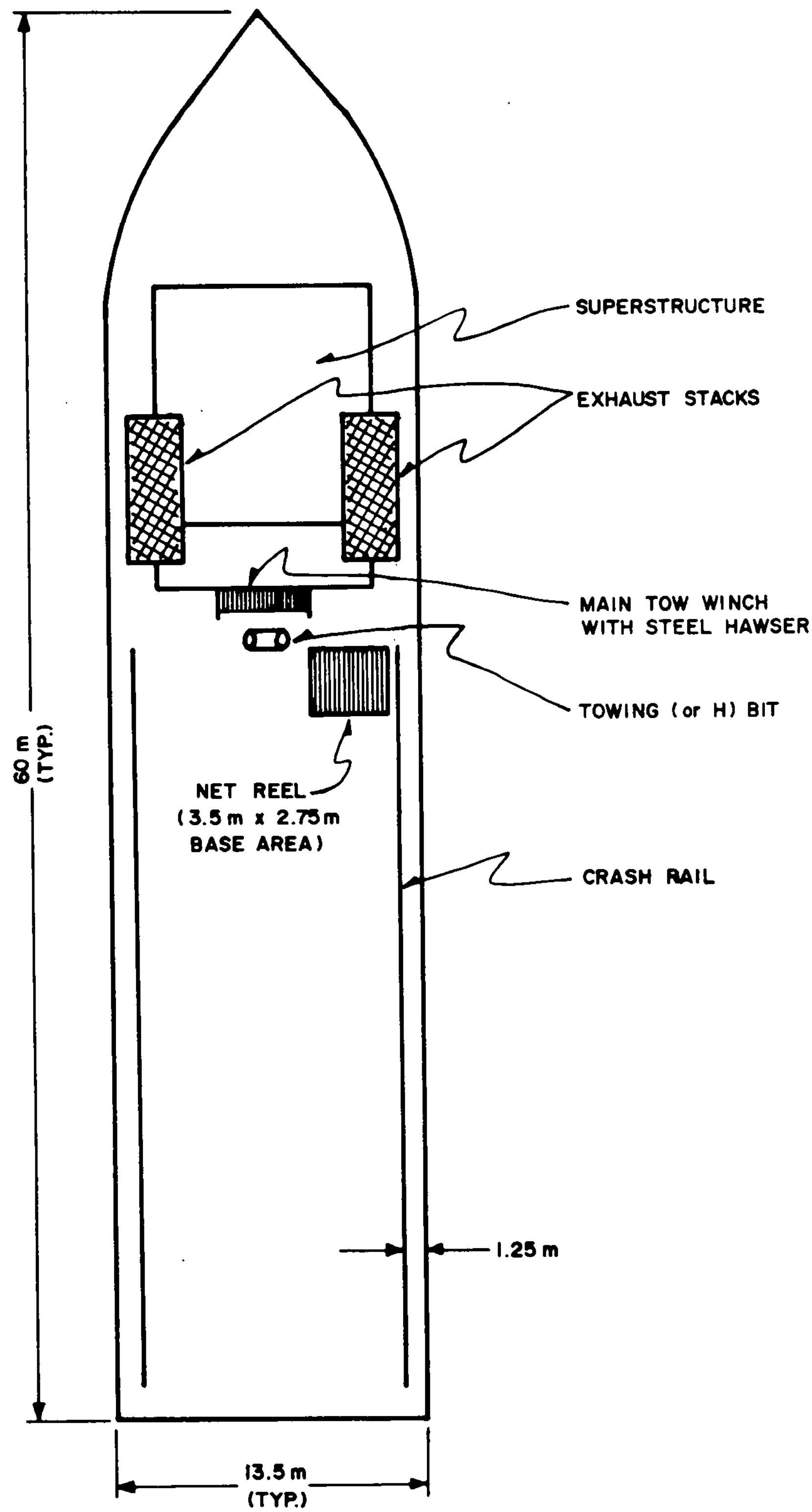
The system should be deployed and recoverable in a reasonable time frame. Times suggested by operations and marine personnel were as follows:

For deployment: avg. = 45 min; max. = 1 1/2 h
For recovery: avg. = 1/2 h; max. = 1 h

These are about the same as for the floating synthetic line method and thus should be realistic values.

The key to achieving these times for deployment and recovery is the use of an appropriately designed winch. The winch, in addition to being used for deployment and recovery, would serve as a storage drum for the net when not in use. The importance of this winch cannot be overstated. This is supported by comments of vessel masters who responded to the questionnaires.

For example, one captain comments, "I feel this is very necessary", while another states, "Definitely. The reel ... turned deployment and recovery into a professional operation", (referring to tow rope reel used by Canterra on Labrador Shelf, 1983). The loss of deck space resulting from installation of a winch, in the opinion of the captains interviewed has no serious implications on the vessel's other functions. From Figure 29,



ICEBERG TOW NET SPOOL MOUNTED ON WORK BOAT

Figure 29.

we can see that when properly installed, the reel takes up a small portion of the available deck space. Thus, the vessel's deck cargo capacity is essentially unaffected. Personnel transfer from rigs and anchor handling duties are also relatively unaffected.

Regardless of these comments, any winch design should be analyzed from the point of view of its potential effect on the vessel's ability to carry out its other duties (anchor handling, cargo carrying, etc.). The winch may need to be removable so that extra space is available outside the ice season.

Considering the prevailing environmental conditions stated in the section on environmental parameters, maintaining visual contact with the net will potentially be a problem. Therefore, the design should allow for attachment of high visibility marker buoys to permit estimation of the net's location and alignment relative to the iceberg. High visibility can be achieved through the use of reflective tape on the buoy or the attachment of flashing lights. Radar reflectors may also be useful.

Vessel Considerations

The vessel to be used for ice management and the crews onboard them are vital to successful operations. In general, most of the vessels in use today are suitable in terms of size, type, and power. However, a few points are worth noting:

- There should be bow and stern thrusters for best manoeuverability during deployment and for enhancing the ability to make course changes and maintain course against strong currents or seas.

- The higher the freeboard on a vessel, the higher the sea states in which the crew can safely work on deck. As stated before, the crew should be able to work relatively safely in up to 5m seas.

- Tension meters and sonar devices installed on a vessel are not a necessity but give the vessel captain that much more information concerning the tow and the iceberg. However, proper maintenance, installation, and calibration of this equipment is essential for it to remain useful.

- The net design itself should include consideration of vessel limitations while manoeuvering. Lead lines must be of adequate length to allow safe circumnavigation of the iceberg, positioning of the net, and hookup for tow. The vessel must also be able to tow at a safe distance (i.e. $\geq$ 300m) in the event that the iceberg rolls or breaks up or if equipment breaks.

- Training of the crew is important. If a net is to be implemented, there should be sufficient trials or preliminary training so that the equipment can be used safely, and efficiently. In addition, feedback from the crew may provide further refinements in the design or operations.

PHASE III

CONCEPTUAL DESIGN OF SMALL ICE MASS MANAGEMENT SYSTEMS

With the design criteria having been established, conceptual design of new or improved small ice management system(s) can now commence. As stated in the proposal, emphasis has been placed on the development of an effective net; and in this phase of the study, three possible net design concepts are presented, along with a discussion of net deployment alternatives. This discussion includes a preliminary evaluation of the possible use of stern trawlers with nets.

In addition to the net concepts, the potential for the use of water cannons is included as a separate concept.

NET CONSTRUCTION OPTIONS

The selection of materials and dimensions to be used in the net systems proposed must consider the design criteria. Fabrication options regarding items such as buoyancy, net orientation and tension distribution between headrope and footrope also need to be evaluated in light of the discussion presented in Phase II.

In this section, design conclusions for a number of key elements in the design of a net are arrived at through logical discussion based upon the given design criteria and considerations.

OVERALL DIMENSIONS

Overall dimensions of the net will be as per the discussion in Phase II - 45m long x 30m deep, comprised of a 45m x 15m upper net panel, which may be used alone for smaller pieces and a bottom panel of the same dimensions which may be attached to handle larger pieces.

This modular feature has several advantages over a unitized configuration:

- handling problems minimized (i.e. - no need to handle full 45m x 30m for all tows).
- reduced wear and resultant longer life of lower panel.
- 45m x 15m is considered by many captains to be a good compromise between ice management capability and manageability on deck.
- lower test program costs. For the purposes of full-scale prototype development, only the upper panel need be constructed. Once this has been optimized, the lower panel design can be modified as necessary prior to construction.

The methodology will be to design a single panel and then suggest a suitable means of attaching two panels together.

MESH SIZE

Mesh size affects several important factors in the design of any net. These include:

- weight: Assuming that the mesh material and size remains unchanged, overall weight will increase as mesh size is reduced and vice-versa.
- required storage volume (affected similarly to weight)

- strength (affected similarly to weight and required storage volume).

- damage threshold: A net with a small mesh size should be able to sustain minor damage without seriously reducing its structural integrity, whereas a net with fewer mesh members (i.e. larger mesh size) may be unuseable if several members are damaged.

- tangle potential: A large mesh size has more potential to tangle than a small one. Fishing gear design information suggests a minimium member diameter to mesh size ratio of 0.02 for entrapment type nets (i.e. seines, dragnets, etc.) (Andreev, 1962). Whether this applies to an ice arrestor net is uncertain; however, it is presented as a design specification guideline.

- cost: Smaller mesh will require more materials (i.e. to reduce mesh size by one half, twice as much material is required). However, although cost is definitely a factor which should be minimized, the other considerations mentioned must take precedence as they have direct implications on the usefulness and performance of the final product.

Based on this discussion, the final mesh size will be determined in the detailed design phase by the strength and size of the mesh material, with the other factors kept in mind.

MATERIALS

The overall goal in choosing and combining the different net materials is to achieve compatability between components within the constraints imposed by design guidelines.

There are two main decisions to be made in the selection process. These are:

- choice of material (i.e. nylon, polyester, polyproylene, composites, etc.)

- construction (i.e. single braid rope, 2-in-1 braided rope, plaited rope, strapping, etc.)

Some properties are a function only of the material. These include:

- specific gravity
- UV resistance
- salt water resistance

while most others are influenced to varying degrees by both factors.

Table 1 (on page 69) gives a good intercomparison of a selection of commercially available materials.

It is important that the component materials are selected such that the amounts of flotation and ballast which must be added to meet stability and buoyancy requirements are minimized. This will reduce construction costs and the resulting weight and required storage volume of the net. These last two reductions will have a positive effect on handling considerations.

This implies that components which will be submerged should be made of sinking materials while the headrope and other waterline components should naturally float.

Headrope/Footrope

Results of previous net testing efforts and discussion with people knowledgeable in this area suggest that the conventional 4 1/2" (114mm) diameter 8-strand plaited polypropylene iceberg tow rope makes an excellent choice as the headrope. It provides the maximum buoyancy of any commercial material and has a track record of proven capability in an almost identical application. However, if polypropylene is chosen a smaller diameter than 4 1/2" could be used (say 3 3/4"). This size has a breaking strength of 102 tonnes and is 18% lighter (and therefore cheaper) than the 4 1/2" size.

Some newer ropes are available which may also be appropriate. A good example is Round Plait™ Polytron™ from Sampson Ropes. It has a 12-strand plait/braid construction that utilizes a high tenacity, abrasion resistant co-polymer called olefin. The construction allows smaller sizes while maintaining higher strength and longer wear life than polypropylene. It is produced with UV inhibitor. The manufacturer quotes the following characteristics:

- 30-40% stronger than 3 and 8-strand polypropylene
- 3-4 times the wear life of polypropylene
- splices as a plait or single braid
- available in orange or grey
- non-rotating and flexible
- excellent UV resistance
- specific gravity 0.91 (floats)

The footrope should be of a material which closely matches the headrope in elongation characteristics. Since it will be submerged, it must necessarily have excellent salt water resistance and abrasion resistance when wet.

Elongation is an important consideration, as excessive differential stretch between the headrope and footrope will result in undesired dimensional distortion of the net. Absolute elongation of headrope and footrope materials is also important, as excessive amounts will result in deformation of the net even if differential elongation is low.

Based on the above discussion, it is obvious that the selection of the footrope will be influenced by the choice of headrope.

If polypropylene is used as the headrope, then a good choice of footrope material, based largely on elongation properties, would be Samson Nystron® Braid. This is a composite nylon/polyester 2-in-1® braided rope. The design of this rope provides high strength retention, good energy absorption and shock mitigation and excellent abrasion resistance, especially in wet environments. It is fully spliceable and has been used for marine applications such as headlines, ship mooring lines, stringing lines and winch lines. The manufacturer also indicates that the rope has excellent UV resistance, is available with protective coatings and has a specific gravity of 1.24 (heavier than water).

With the Polytron™ as the headrope, a compatible material which would be a likely candidate for use as the footrope is 12-strand plaited (Round Plait™) polyester. The rope uses strands of Duron® high-tenacity polyester and is easily spliced. It provides low stretch and high strength with relatively high bearing surface area for excellent abrasion resistance. Protective coatings are available to enhance the latter characteristic.

As with the other three ropes (polypropylene, Nystron® Braid, Polytron™) this rope has been used in various marine applications. The material has a specific gravity of 1.38.

From a performance stand point, both headrope/footrope systems are nearly equivalent. The Polytron™/polyester system is, however, considered marginally better for the following reasons:

- lower absolute stretch than the polypropylene/Nystron® Braid System.
- polyester is heavier than Nystron® Braid, decreasing footrope ballast requirements.
- Polytron™ available in orange, increasing visibility.
- Nystron® Braid loses 10% of its strength when wet.
- Nystron® Braid is significantly more expensive than the other materials mentioned.

A third option is to use polypropylene as the headrope with a polyester rope as the footrope. This alternative is suggested in light of the fact that the Nystron® Braid and Polytron™, while having the proper performance characteristics are specialty ropes and therefore expensive in comparison to polypropylene and polyester. For example, the material used in Polytron™ costs over 2 1/2 times more than polypropylene (per unit weight).

However, the Polytron™/polyester combination is still considered superior due to the fact that, based on information supplied by manufacturers, Polytron™ has a life expectancy 3 to 4 times that of polypropylene. So, while use of this material will result in increased fabrication cost, maintenance and/or replacement costs should be substantially less than with polypropylene.

Comparative prices for the three systems are given below:

		Cost (1986 $ Canadian)
1.	Headrope - 3 3/4" polypropylene	$14.70/meter
	Footrope - 2 1/4" Nystron® Braid	$43.89/meter
		$58.59/meter
2.	Headrope - 3 5/8" Polytron™	$32.40/meter
	Footrope - 2 5/8" polyester	$12.90/meter
		$45.30/meter
3.	Headrope - 3 3/4" polypropylene	$14.70/meter
	Footrope - 2 5/8" polyester	$12.90/meter
		$27.60/meter

Mesh

Material to be used for mesh should have the following properties:

- high strength/weight ratio
- low stretch
- relatively low absolute weight
- specific gravity greater than 1.024 (i.e. heavier than seawater)
- good saltwater resistance
- torque-free (i.e. balanced construction)

Again, referring to Table 1 on page 69, polypropylene and Estalon® (KARAT) can be eliminated based on their specific gravities. Being lighter than seawater gives these materials a tendency to float rather than stay submerged. This is obviously an undesirable characteristic in net mesh. Polypropylene also has one of the lowest strength/weight ratios of commercially available ropes.

Nylon, while having a relatively high strength/weight ratio and a specific gravity of 1.14, is high in elongation. To prevent excessive stretch of net members, large load capacity sizes would still be required resulting in increased weight, cost, and volume.

Kevlar® has many of the necessary attributes (lowest stretch, highest strength/weight ratio, specific gravity - 1.44) and might make an ideal mesh except that it has only fair abrasion resistance. Protective covers and coatings are available and may be suitable, but at a proportionately increased purchase cost. Construction cost and time may also be detrimentally affected by use of these protective measures.

Polyester appears to have the best all-around characteristics to address the concerns listed at the beginning of this section. It has a specific gravity of 1.38 and combines a strength/weight ratio only slightly less than that of nylon with a comparitively low elongation.

Polyester also rates very high in abrasion, cut, UV and salt water resistance and has good flexibility.

The material is also reasonably priced, in comparison to others. However, this is not expected to result in dramatic savings in cost over other materials. This is attributable to the fact that rope materials are often sold by weight and it seems logical that the larger components (i.e. headrope, footrope, bridles) will comprise a greater portion of the net's overall mass than the mesh.

Assuming, therefore, that polyester will be the mesh material, the question remains as to type of construction. The options for small diameter rope are:

- twisted strands
- braided
- plaited

A further option is to use the material in the form of woven strapping, as is available made of polyester. This strapping would be similar to conventional cargo straps or car seat belts and is presently commercially available for use mainly in cargo nets.

The idea of using strapping was suggested by a development of the British Royal Navy during the Falkland Islands crisis.

Runways on the islands were too short to accomodate British fighter jets, so nets were designed and built to absorb excess momentum during landings.

These nets are made by overlaying panels until the desired strength is achieved. Panels measure 58m (190') x 9m (30') and consist of a headstrap and footstrap of polyester connected by a number of vertical polyester straps. Subsequent panels are staggered until the vertical straps are close-spaced (i.e. edge-to-edge) (see figure 30). The resulting nets, as one might expect, are quite strong and are in fact rated to provide a 500 ton stopping force.

Its use in this application attests that the polyester strapping is strong, low in stretch and high in resistance to abrasion and cuts.

It is suggested that if this type of net could be modified for iceberg handling, it may have potential for increasing small ice mass management capabilities.

However, despite the attractiveness and convenience of simply choosing the strapping without further ado, an examination of the various construction options must be carried out. Discussion may reveal that strapping is not the most logical choice.

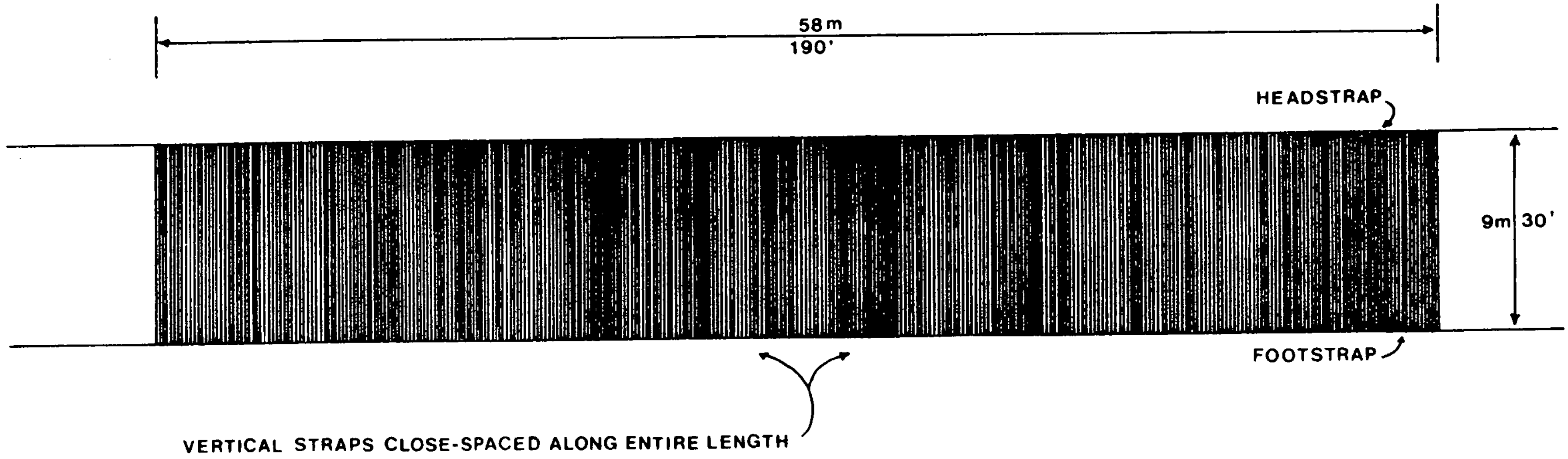
Since the net's resistance to sliding while against an ice surface is a key design consideration, this aspect will be discussed first. Published literature (Bowden and Hughes, 1939) states that the very low friction between ice and different materials is due to a water layer which is formed by frictional heating.

Assuming that the frictional force, F_f, is caused by viscous shear in a water layer between two materials, it can be calculated from the following equation (Oksanen, 1980).

$$F_f = \frac{N_o \, vA}{d}$$

where N_o= viscosity of water (constant)
v = sliding velocity
A = contact area
d = thickness of water layer

Based on this, it can be readily seen that increasing the sliding velocity and/or contact area, or decreasing the water layer thickness will result in increased frictional force. Since the only one of these parameters which can really be controlled at the design stage is contact area, the net mesh



BRITISH ROYAL NAVY JET ARRESTOR NET
(AS AVAILABLE)

Figure 30.

should be so as to maximize this value. A flat construction, as in strapping, offers more contact area than rope, and according to theory should therefore have greater sliding resistance. Also, for equivalent breaking strength, strapping is significantly lighter than rope.

The hydrodynamics of a flat shape also vary significantly from that of circular shapes. Drag forces on flat strapping oriented perpendicular to the relative water movement would be much higher than for rope. This is a useful attribute which will help the net remain open if towed behind the vessel as shown in figure 31. Oriented parallel to the direction of movement, as when the net is streamed out and towed from one end, the straps present a more streamlined form than would a circular rope, reducing drag-induced bridle tension and associated net closing tendancy (as discussed in the following section on Bridle Design.)

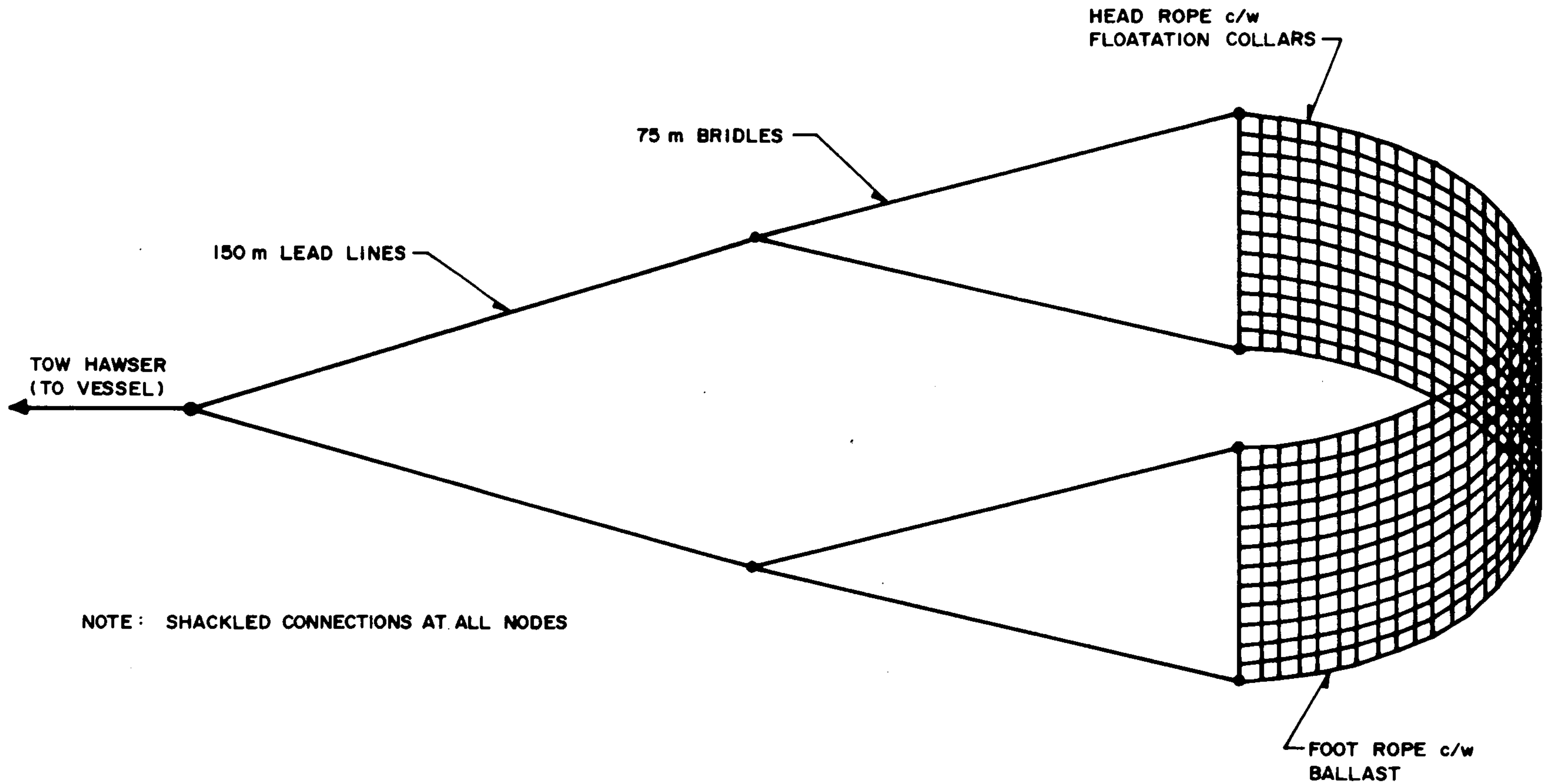
It is also suggested that flat members will have a lower bulking factor (for storage) than circular ones. A useful analogy to further clarify this idea is to imagine flat stones versus spherical stones stored in separate containers. The flat shapes will pack more efficiently than the round ones, with less space wasted.

Also, initial fabrication and/or field repairs could be done efficiently with stitched connections (commonly used with strapping). Ropes would require splicing. While splicing is, of course, a long-accepted standard for rope repair, it can be relatively slow in situations where time is limited. This could be the case if an ice mass was rapidly encroaching on an offshore structure and the net had sustained damage in a previous tow attempt. Straps may be temporarily repaired with commercially-available repair plates and/or special glue. These items can be obtained from the suppliers of the strapping and are quite inexpensive. This aspect of the design will be detailed in Phase IV of the report.

BRIDLE DESIGN

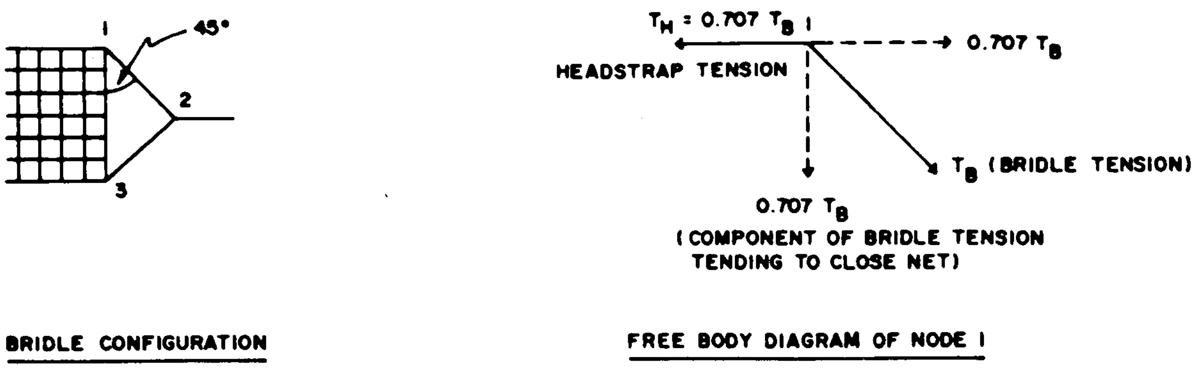
Effective bridle design is thought to be a main component in creating a successful net. Past bridle designs have not allowed appropriate top and bottom tensions, tending in some cases to close the net, or to creep up or down on the ice mass.

The problem of keeping the net open can be minimized by using bridles long enough to minimize the tension component tending to pull the top and bottom together. Longer bridles tend to reduce the angle of tension relative to the top and bottom of the net. Referring to Figure 32, if the bridle tension is equal in both cases, the component tending to close the net in case B is reduced by about 75% from that of case A. In addition for similar towing tensions, the bridle tension

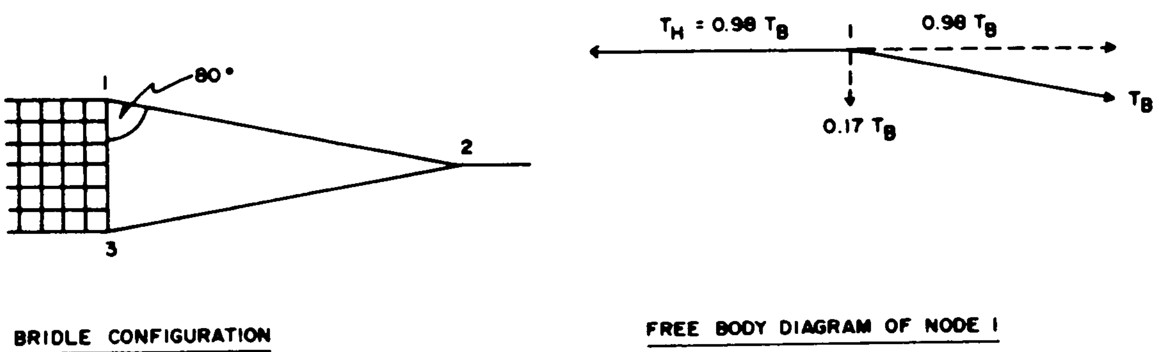


TOWED NET CONFIGURATION

Figure 31.



A. SHORT BRIDLE



B. LONG BRIDLE

EFFECT OF INCREASING BRIDLE LENGTH

Figure 32.

required to balance the tow force would be greater for a shorter bridle (because of the wider interior angle), thereby further increasing the component of force tending to close the net.

Based on this discussion, an arbitrary bridle length equal to five times the net depth is suggested. This keeps the force tending to close the net at a value equal to about 1/10 of the bridle tension. This figure would be finalized in the detailed design phase of the project.

However, while increasing the bridle length alleviates the problem of net closure, it amplifies the potential for tangling of the bridle lines. Therefore, a means is required to maintain vertical separation between top and bottom bridle lines. This is proposed to be achieved through making top and bottom bridles of materials with different specific gravities. Polypropylene is an obvious choice for the top bridle, as it floats and has proven capability for use in similar applications. Another possibility, as discussed earlier, is Polytron™. The bottom bridle should be made of sinking material but selection must consider elongation properties, as the stretch should be roughly equal in both top and bottom bridles to maintain equal distribution of tow force and prevent excessive dimensional distortion.

For conceptual purposes, bridle materials and sizes can be determined based upon similar arguement as presented for selection of the headrope and footrope and are as follows:

- top bridle: 3 5/8" (92mm) diameter Round Plait™ Polytron™ (wet strength of 95 tonnes)

- bottom bridle: 2 5/8" (67mm) diameter Round Plait™ polyester (wet strength of 89 tonnes)

The bridle design would be carried out in detail in Phase IV of the project.

Another key net feature thought to be largely a function of bridle design is tension distribution between headrope and footrope. This will obviously be dependent to some extent on the shape of the ice mass. Consider, however, a spherical piece, as suggested in the design criteria. Depending on how large this piece is, it may be desirable to increase the tension in the headrope or footrope. Experience gained by the Husky/Bow Valley net trials indicates that a common problem with some nets is their tendency to slowly slip (or creep) up over the ice mass. In fact, referring to Phase I, we can see that their latest prototype is designed to overcome this simply by making the footrope shorter than the headrope. While in theory this will increase footrope tensions (in proportion to headrope tension) it still does not allow adjustment in the field.

One possible way to achieve this control is to make the bottom bridle in such a way that it can be shortened with relative ease. This could be done by making the line in two sections. For example, with 75m bridles, the bottom could be comprised of a 70m section shackled to a 5m section. Thus, when both lower bridles are shortened the total length of bridles and footrope would be 185m as compared to 195m for the headrope and upper bridles. The same could be done with the upper bridles if deemed necessary. However, since the major problem previously encountered has been slipping over top of larger pieces, only the lower bridles need be modified this way for design purposes.

HEADROPE AND FOOTROPE SEPARATION

Since the polyester used in the net is heavier than water (specific gravity 1.38), flotation will be required. To diminish potential for handling problems, flotation collars will be used. These will be of the tubular lace-on type.

To ensure that the net will remain open in the water, ballast and flotation are needed in sufficient (equal) quantity to offset forces tending to close it. However, care must be taken to maintain sufficient excess buoyancy to keep the net afloat. Flotation collars along the entire headrope should give enough bouyancy but this will be verified in the final design.

LEAD LINES

Between the ends of the bridles and the tow hawser, lead lines will be used. The force in the lead lines will then be approximately half the towing tension and twice the bridle tension.

Assuming a 60 tonne tow tension, lead line tensions will, therefore, be about 30 tonnes. It is suggested that a floating line (polypropylene) be used for the lead lines. The minimum diameter required to resist this force is about 52mm (2 1/16"). However, to account for shock (dynamic) loads, a safety factor of four is applied, making the force to be resisted equal to 120 tonnes. This dictates a rope size of 104mm (4") diameter. Nominally, the standard 4 1/2" diameter iceberg towline would seem appropriate. Again, to alleviate problems of twist, a rope of braided or plaited construction should be used.

NET DEPLOYMENT ALTERNATIVES

A key to the successful use of a net to tow small ice masses is appropriate deployment.

This section discusses the pros and cons of several suggested broad choices, including the use of two vessels as opposed to one and the use of trawlers for net deployment.

TWO VESSEL VERSUS SINGLE VESSEL

Assuming the net will be used with some sort of powered recovery/deployment spool, a major question arises as to whether the system may be more effectively used by a single vessel or two vessels. Naturally, both options have positive and negative aspects.

Using a single vessel for deployment, as opposed to two, has the advantages of:

- Second vessel available for other duties, in particular, other ice management activities.
- Less fuel consumption than two vessels.
- Much quicker rendezvous time with iceberg. One vessel may be in vicinity while next nearest vessel may be several hours away. This is particularly true of typical Grand Banks situations where watch area is relatively large and a vessel may typically be close to the iceberg relaying hourly positions to the rig.
- Generally simpler deployment with single vessel.
- Not subject to downtime of the second vessel.

Using a two vessel technique has the advantages of:

- More power availability.
- Net is automatically kept spread open.
- Possibly easier to align net properly around iceberg.
- May be possible to use larger net.

The availability of more power is not viewed as a strong advantage, since one vessel of the type now used in support of exploration on the Grand Banks has plenty of power to successfully tow a small ice mass at speeds up to and in excess of 2 knots, providing the vessel can obtain a good hold on the growler or bergy bit. Also, any two vessel tow technique would be prone to the problems described in the description of two vessel towing in Phase I.

Based on the above, it would seem reasonable to suggest that the advantages of using a single vessel outweigh the gains of two vessels in this particular application.

TRAWLER OPTIONS

The idea of using conventional stern trawlers has been suggested as an alternative to using the standard anchor handling/supply vessels, as least for management of small ice masses. The options fall into two categories, namely, single trawler methods and pair trawler methods.

The use of trawlers generally has the following positive aspects:

- Relatively low day rate and fuel consumption (when compared to supply vessels).
- Trawlers are perfectly suitable for reconnaissance or standby duties.
- Higher freeboard deck than supply boats, therefore, able to work in worse sea states.
- Designed originally to handle nets, therefore, little or no modification should be required for installation and proper use of ice net.

The use of a two trawler method has the further advantages of more power availability as compared to a single trawler. In contrast to a two vessel method involving supply boats, this is considered a bonus as trawlers are not designed to function as tugs and, therefore, do not typically have the power required to effectively manage ice masses. The extra power supplied by the second trawler would probably be essential. There is also a question of winch brake power since the tensions used for towing ice would likely be higher than with conventional fishing operations.

However, several disadvantages are associated with the pair trawler method as well. In addition to the same drawbacks as mentioned for two vessel towing techniques in general (see Phase I), the main one is seen to be that if the method is dependent on having both vessels functioning, then loss of one means the other is rendered somewhat helpless. Furthermore, having two extra vessels might cause logistic complications. Also, two trawlers would probably not be significantly less expensive, if not more expensive to operate than a single supply vessel.

In response to this, however, a backup method using a single trawler might be instituted.

An obvious objection to using trawlers is their general unsuitability to other duties often required offshore (i.e. anchor handling, cargo, and bulk capacity). For this reason, it seems safe to assume that these vessels would only be taken on short term charter, mainly for the duration of the iceberg season.

An interesting economic ramification of the use of trawlers is that if a suitable method of ice management were developed for these vessels, it would provide trawler owners with an alternative market to fishing. An arrangement such as this would then be beneficial to both industries.

Based on the previous discussion, the use of trawlers would seem to be attractive enough to be considered a viable alternative to the use of supply vessels, at least for the effective use of a small ice mass net.

CONCEPT NO. 1 - ICE ARRESTOR NET 1

The proposed configuration of this net is depicted in Figure 33. The webbing is made of 1" (25mm) wide woven polyester strapping with a break strength of 10,120 lbs (refer to Appendix 7). Webbing thickness is about 1/8" (32mm).

The headrope is to be made of 3 5/8" (92mm) diameter 12-strand Round Plait™ Polytron™ (manufactured by Samson Ocean Systems, Inc.) while the footrope would be 2 5/8" (67mm) diameter polyester.

It is likely additional flotation will be required at the headrope to ensure proper vertical orientation of the net. This would be in the form of flotation collars. Additional flotation, if more is required, can be added in the form of plastic Norwegian buoys.

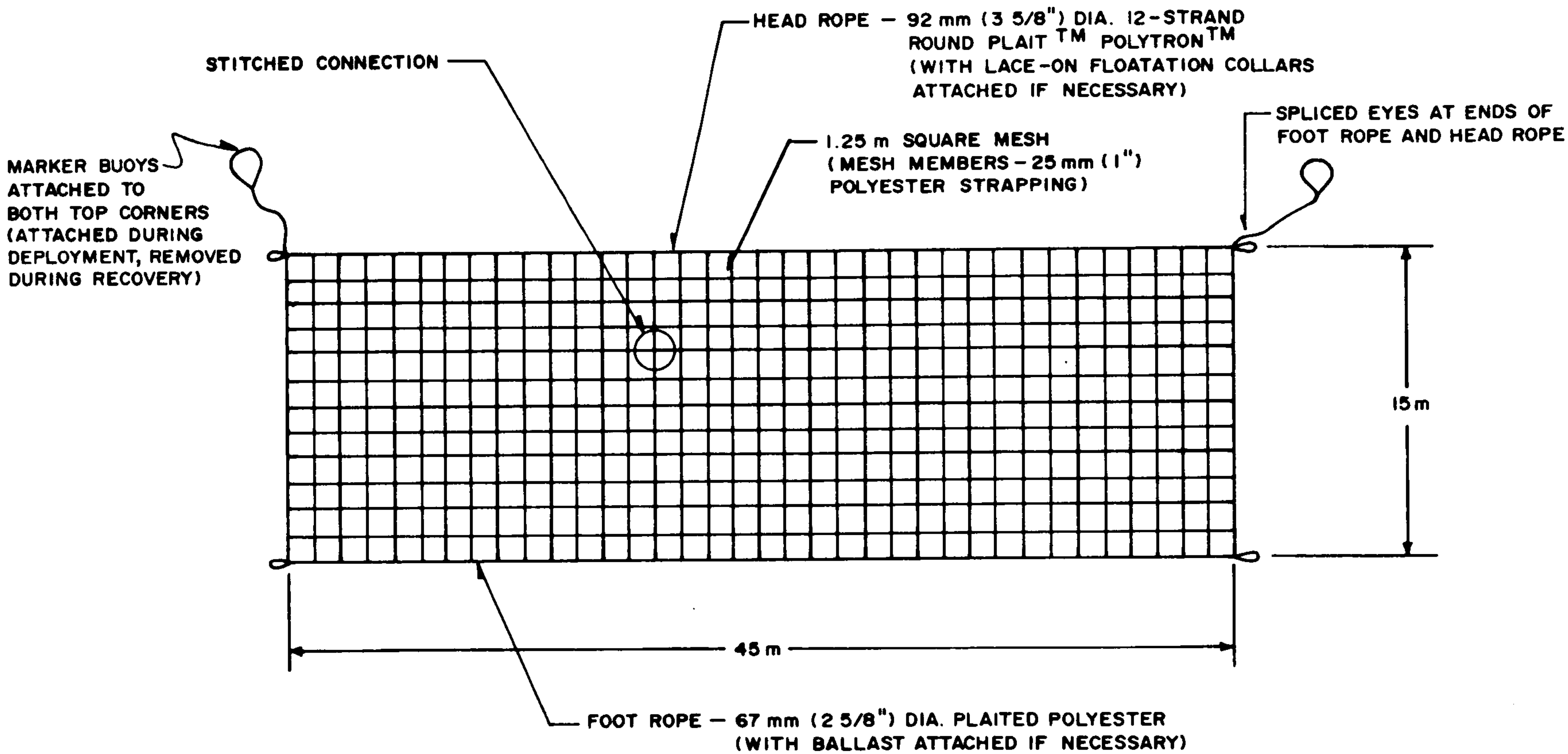
The exact amount of flotation would be determined in the final design of this concept. For conceptual purposes, it is assumed that flotation will be provided along the entire length of the headrope.

The straps are strong, with the mesh members having an estimated breaking strength of 4.5 tonnes. Specifications for the strapping are provided in Appendix 7. Member connections are stitched using nylon twine (approximately 1mm in diameter). A repair kit with instructions is essential and should accompany the net at all times.

The proposed overall dimensions of the single panel rectangular net, which will be used for iceberg handling, are 45m x 15m. This is based on discussion presented earlier.

The mesh size is determined based on the minimum member to mesh size ratio of 0.02, as suggested in the earlier discussion of construction options. With a size of 25mm (0.025m), the ratio implies a maxium mesh size (spacing between members) of 1.25m. Based on the strength of the strapping, it is suggested that this will be a suitable arrangement, giving the net sufficient strength. Eleven horizontal members (as shown in Figure 33) each rated at 4.5 tonnes, gives a total resistance of slightly less than 50 tonnes. Even at the full design tension of 60 tonnes, the maximum tension in the net will not greatly exceed one-half of this value, or 30 tonnes, since the load is split between the two connection points and, as a result, will be taken largely by the main strength members (i.e. headrope, footrope, bridles). The two-point connection design means that the tension in the net is about one-half that in the tow line.

A 1.25m spacing is also convenient for other reasons. It is an even divisor of the length and width dimensions, thereby simplifying construction. Also, a preliminary look at



ICE ARRESTOR NET # 1
CONCEPTUAL DRAWING

Figure 33.

commercially available flotation collars reveals that a common stock length is 44" (1.2m) allowing one to fit nicely along the headrope between adjacent vertical members.

A limited amount of marine hardware is required for use with the net. A list of items and their intended functions is given in Table 2. Typical hardware of this nature is illustrated in Appendix 6.

System Use

This section addresses aspects of actual operations using this particular net system. The three main aspects to be considered are deployment, recovery, and storage.

Deployment manoeuvers will be conducted in the manner currently used for conventional ice line deployment, at least for initial testing. The basic procedure is as follows:

- After a preliminary inspection of the ice mass to determine optimum tow direction, etc., the vessel approaches the ice mass and commences putting the first lead line over the stern. A sea anchor would be attached to increase drag forces and thereby assist in pulling the net out. Also attached to the end of the trailing lead line would be a marker buoy (see Table 2).
- As each end of the net approaches the stern end of the vessel deck, marker buoys are attached before placing the net in the water.
- After all the net is over the stern, the inboard lead line is attached to end of the vessel's tow hawser.
- With the entire net assembly streaming behind, the vessel slowly circles the ice mass.
- The trailing lead line, made visible by the marker buoy attached to its end, is picked up. The sea anchor now serves to inhibit the motion of the trailing end during this phase of the deployment.
- After retrieval of the end, the sea anchor and marker buoy are detached and stowed.
- Before final hook-up of the second lead line to the tow hawser, the alignment of the net is checked and adjusted as required. This is done with the aid of the net-end marker buoys and tugger winches.
- Cable (hawser) is payed out and the tow commences. Excessive cable payout is not required, since the net is already designed to ensure proper tow force alignment.

TABLE 2
Associated Net Hardware

Item	Quantity	Description	Function
1	1	Triangular monkey-face connector plate (optional)	For connecting lead lines to tow hawser.
2	1	85 ton bolt type anchor shackle	Main connecting shackle on end of tow hawser.
3	4	55 ton bolt type anchor shackles	Connecting shackles for ends of lead lines and for 5m bridle spacers (for shortening lower bridles)
4	8	35 ton bolt type anchor shackles	Connecting shackles for ends of bridle lines
5	3	High-visibility marker buoys with capacity for attachment of flashing lights and/or radar reflectors	Marking ends of of net and trailing end of lead line.
6	5	Xenon strobe lights	For attachment to marker buoys
7	2	110" Norwegian buoys	Marking ends of net in good visibility.
8	1	Grappling Hook (Grapnel)	Recovery of trailing end of lead line.
9	1	85 ton marine swivel (optional)	Attachment to end of tow hawser.
10	1	Sea anchor	Attachment to trailing end of lead line during deployment.
11	1	Repair kit with instructions	For on-site repair of failed members or connections.

However, cable payout may allow the net to be used on large or unsuitably shaped icebergs, applying the same catenary principle to reduce overturning moment as often as used in single line tows. Of course, at least 100m of wire should be payed out to submerge the tow line and prevent a sudden recoil in case of failure.

Recovery is straightforward:

- Main tow wire is winched in until its end comes on deck.

- One of the lead lines is detached.

- The vessel then steams away from the detached line and around the iceberg, effectively unwrapping the net from the iceberg. It is important not to steam straight away from the iceberg as in conventional towline recovery as the net may snag or tangle.

- When the net is judged to be clear of the ice mass, the vessel steams ahead slowly until the assembly is streaming in a straight line astern.

- The net is then winched aboard and stowed, with buoys being detached prior to storage.

Storage of the net, as indicated in Phase II (Design Criteria), is accomplished with a powered reel, which is considered to be an integral part of the ice net system, even for preliminary testing.

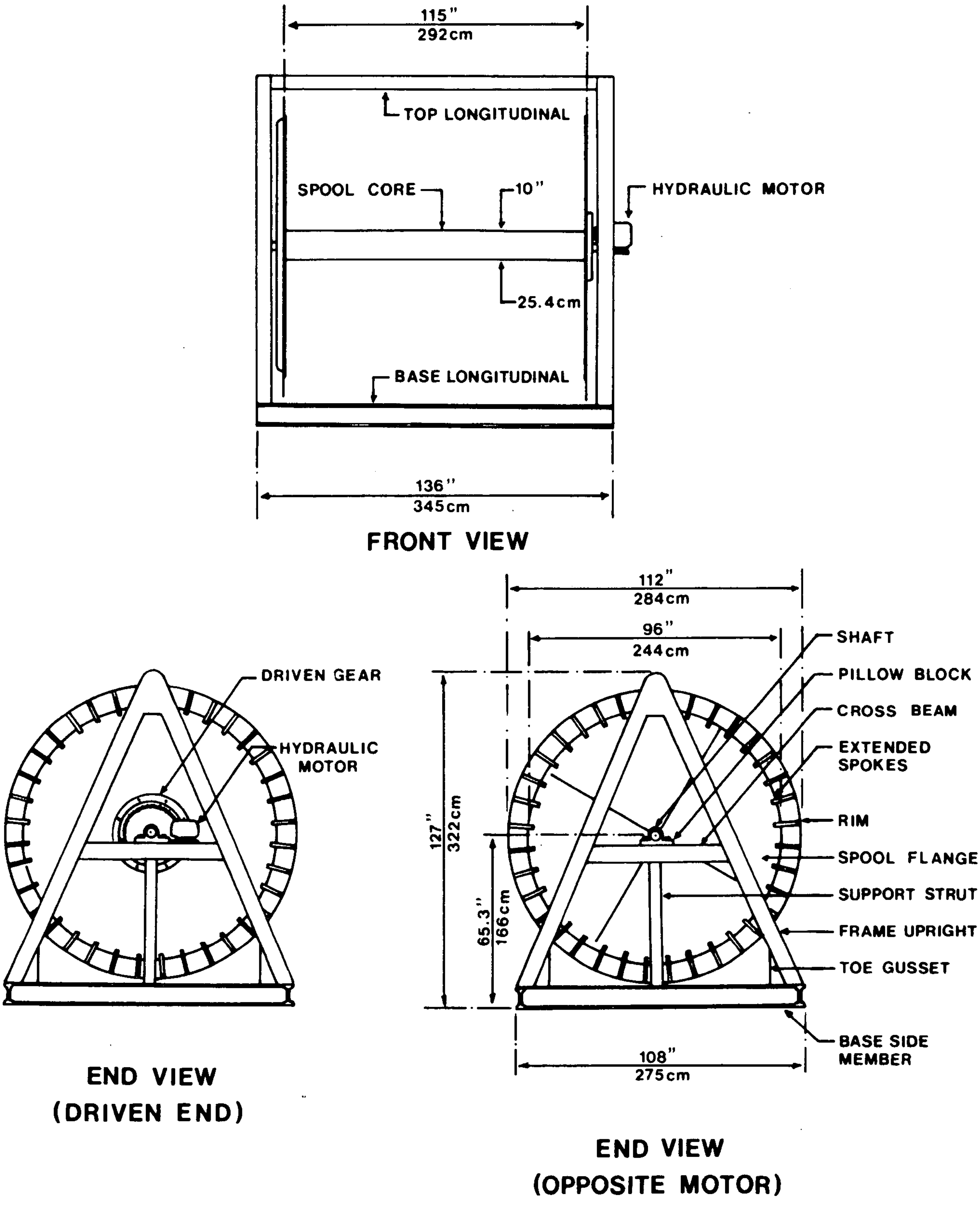
It may be possible to adapt existing pennant line storage reels found aboard a number of tug/supply boats. If a vessel does not have pennant storage reels, consideration should be given to design and construction of a net/ice line reel which could be divided in the center by addition of a third flange, thus having both ice net and conventional ice line systems on one reel.

For the purpose of a test program, several suitable units constructed by a local welding company for an east coast operator based in St. John's may be available for lease. Such a unit is depicted in Figure 34. This unit has an available storage of $18.3m^3$.

General Conformity to Design Criteria

This proposed net appears, at least conceptually, to meet the criteria outlined in Phase II of this study.

The main areas of concern deal with problems encountered with previous nets. Therefore, a discussion of how these issues have been addressed is provided.



TOW NET STOWAGE SPOOL

Figure 34.

The first major criteria was the size of ice mass that a net must be capable of dealing with. This capability is a function of net length and more importantly depth.

Determining the exact mass handling limits, (nominally stated as 1,000 - 40,000 tonnes) is a rather difficult affair. This is due to the fact that no two ice masses are quite alike. However, there are several indicators which may be used to estimate what the actual limites may be.

One way to estimate the upper limit is by comparison with published data. In their 1983 paper, Hotzel and Miller carried out an analysis of data gathered during a number of drilling and scientific compaigns on the Labrador Shelf and Grand Banks. They derived the following statistical relationship between iceberg mass and draft.

$$M = 14.7\ D^{2.5}$$

where D = draft (m)
M = mass (tonnes)

Assuming the net can handle a piece of ice with a draft equivalent to its depth, the above relationship suggests a maximum size capability of about 13,000 tonnes for a 15 metre deep single panel and 72,000 tonnes for the expanded 30 metre deep net.

A second method is somewhat more theoretical but is useful for comparison purposes. Consider a spherical ice mass as suggested in the design criteria. It can easily be shown that for a sphere of iceberg ice (specific gravity approximately 0.89) floating in sea water, the following numerical relationship applies:

$$M = D^3$$

Inserting 15 metres and 30 metres for D yields respective mass values of about 3,400 tonnes and 27,000 tonnes.

Thus it seems reasonable to suggest that the upper limit of manageability for the 15m net will be between 3,500 and 13,000 tonnes, while the corresponding values for the full net would be 27,000 - 72,000 tonnes. This may seem to be a rather broad range, but is probably reaslistic in light of the high shape variability of the ice masses to be contended with.

The lower limit will essentially be determined by the mesh size. If we assume a minimum mesh size of 2m (a conservative number, since a dimension of 1.25m has already been suggested) and a spherical shape, the mass of the largest piece which could get through would be about four tonnes, a virtually insignificant mass in terms of damage potential to an offshore installation or vessel.

Another major problem with previous nets has been inadequate bridle design. Many previous configurations have incorporated the bridle as part of the net itself (i.e. Husky/Bow Valley nets). Earlier discussion explains the disadvantages of this type of arrangement. The bridle of this net was designed to minimize the tendency for the net to close upon itself when in use.

A number of parameters were considered in the selection of the net materials. The polyester strapping which forms the main part of the net is a high strength, low stretch material designed to meet the demands of pulling operations. It has a high abrasion resistance. The 3 5/8" (93mm) diameter Polytron™ rope and the 2 5/8" polyester used for the headrope and footrope (i.e. main tension members) have all the desired characteristics, as discussed earlier.

With regard to environmental conditions, this net should be useable in similar situations where a standard iceberg tow rope could be deployed. The maximum sea state in which the net may be used will vary from vessel to vessel and naturally, there is no rigid cut-off point as the variables of individual vessel stability, crew experience, and confidence cannot be accounted for in this analysis. It does, however, seem reasonable to suggest that the limiting sea state would be higher than for an activity such as anchor handling. This is because, with an appropriate net reel, the only work which should be required aft of mid deck would be the actual recovery of the trailing end. If the man or men performing this task wore safety harnesses, the danger of this task could be greatly reduced in high sea states.

Deployment and recovery times should be possible within 45 minutes and 1/2 hour, respectively, under ideal conditions.

Naturally, these times will increase with worse weather conditions but should not exceed 1 1/2 hours for deployment and 1 hour for recovery. Again, the use of a reel is viewed as essential in minimizing these times as much as possible. Naturally, tugger winches would be used to assist in on deck handling as well.

CONCEPT #2 - ICE ARRESTOR NET 2

As the name implies, this is a modified version of Concept #1. The main difference between the two concepts is that while the former is constructed as a flat net, the latter would be built in a bag shape. The "pocket" of this net would be formed by making internal mesh lines longer than the four main lines (i.e. headrope, footrope, and both sides).

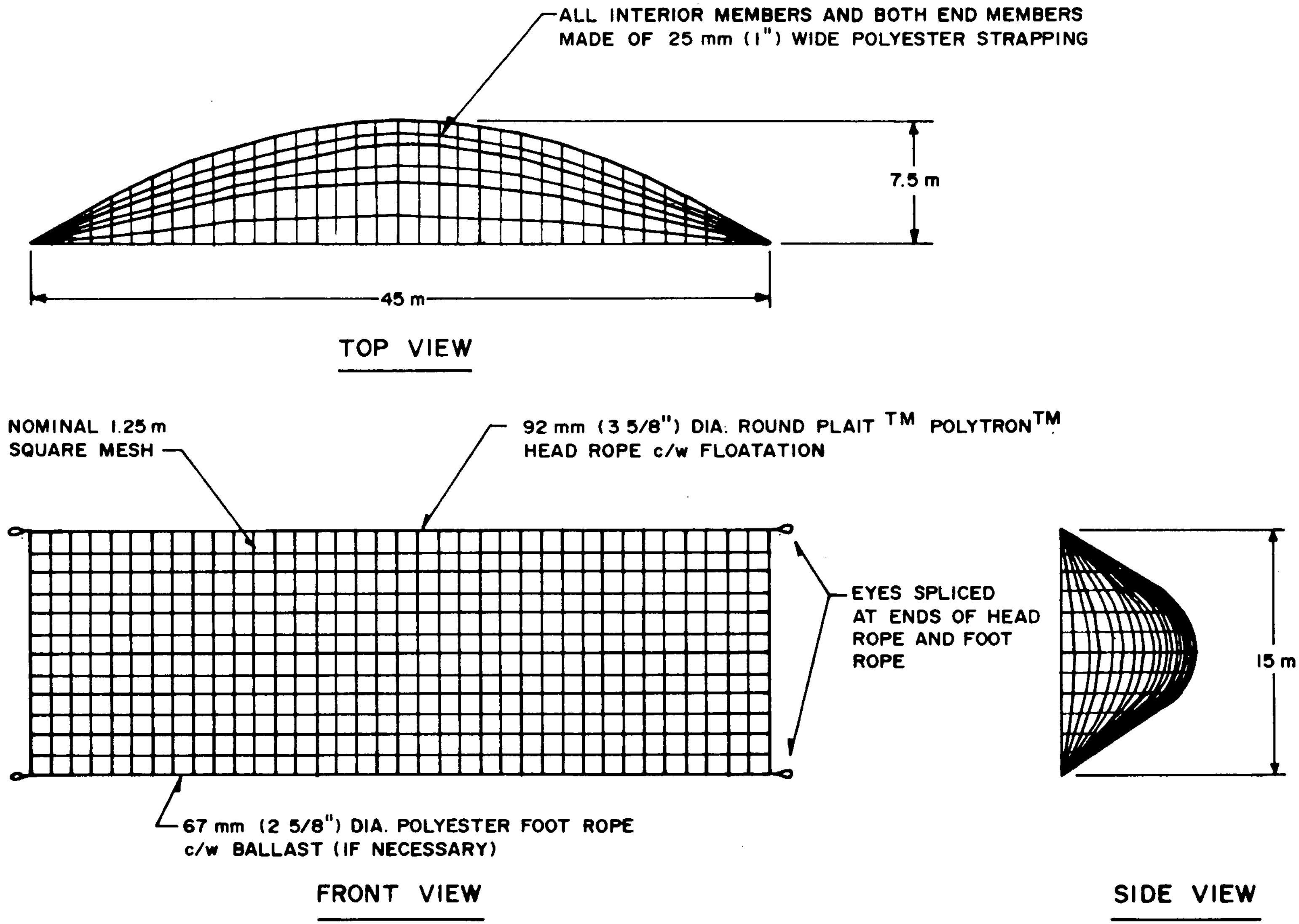
The premise of this idea is that this configuration would lend itself readily to completely surrounding small pieces. It should also be useful on larger pieces, assuming some underwater feature becomes contained by the net. This would make slip-off less likely.

As concluded from Husky/Bow Valley net trials, (see Phase I), if a small troublesome piece could be completely "bagged" by an appropriate net, the piece should not be able to escape, permitting significant tow speed and therefore quick removal of threatening growlers and/or bergy bits from the area of concern. In turn, this should result in significant reductions in operational downtime. The proposed net design is illustrated schematically in Figure 35.

The mesh material would be the same polyester strapping as proposed for Concept #1, with a headrope and footrope also identical to those used in Concept #1. Exact details of buoyancy and ballast are left to the final design phase but would consist of flotation collars and chain (if necessary). Hopefully, bouyancy calculations will confirm that the choice of materials has provided sufficient ballast.

The overall dimensions of that portion of the net forming the frame or four outside borders would be 45m x 15m. However, the lengths of interior members would be longer than this, thus creating the desired "pocket" to entrap smaller pieces. The question of how deep to make the net cannot be answered with a high degree of confidence at this time, so for conceptual illustration purposes an arbitrary figure of 1/2 the net depth or 7.5m is chosen. This figure will be finalized if a detailed design of this concept is performed. To achieve this depth and the correct net shape, member lengths will vary according to position within the net design. For conceptual purposes, exact lengths are not required but can be readily calculated, if necessary.

Mesh size is again chosen to be nominally 1.25m x 1.25m (square) for similar arguments as presented for Concept #1. The word "nominally" is applicable since, due to the shape of the net, some distortion of mesh dimensions will occur during construction. This dimension may be modified in a final design.



ARRESTOR NET # 2

CONCEPTUAL DRAWING

Figure 35.

Since this net is very similar to Concept #1, the bridle configuration would be exactly the same with 75m long bridle lines. The bridle materials have been chosen to minimize the likelihood of tangling and to ensure proper bridle separation. This would mean, as with Concept #1, an upper bridle made of Polytron™ and a lower one made of polyester. To ensure adjustable distribution of tow force, lower bridle spacers (5m removable sections) will be included.

As in Concept #1, lead lines will be made of standard 4 1/2" diameter eight-strand plaited polypropylene rope (iceberg tow rope). This is considered highly appropriate as this rope has a proven track record for iceberg towing and is readily available from a number of suppliers. It also has good shock absorption characteristics, an important consideration for any ocean towing system.

Marine hardware requirements for this net are considered to be identical to those for Concept #1 (see Table 2).

System Use

Again, because of the similarity of design of Concepts #1 and #2, all aspects of deployment, recovery, and storage are considered to be practically identical for the two. Therefore, it is considered redundant to detail these issues again in this section. For specific discussion, refer to the section on system use for Concept #1.

One point should be emphasized, however. Because of the pocket formed by the design of the net, it is even more important that, during recovery, the net should actually be unwrapped from around the ice mass. If the vessel steams straight away after disconnecting the net, it is thought that the likelihood of snagging and resultant damage is greater than for a flat net, such as Concept #1.

General Conformity to Design Criteria

This net would likely meet the design requirements as defined in Phase II, based on similar argument as for Concept #1.

There are, however, some important differences. Because of the bag shape, the net is an unlikely candidate for expansion by means of attaching other identical nets. This, therefore, limits its use to smaller pieces. On the other hand, this shape may be more effective for use in this application than a flat net. Also, the net may be more difficult to repair on a work deck as it will not naturally lie flat and the mesh sizes are not all identical. The shape would also complicate construction, at least when compared to Concept #1, and perhaps cause storage difficulties because of uneven bulk when stored on a reel.

In general, however, these last several issues seem relatively easy to overcome from a design point of view with the only major criticism being the net's size limitation.

CONCEPT #3 - ICE ARRESTOR NET 3

This net is yet another version of our original concept and is depicted schematically in Figure 36.

Similar to Concept #2, it is bag shaped, however, the most interesting feature of this net is that it is comprised of two panels. The first is almost identical to Concept #2, only with a much larger nominal mesh size. The second panel, which is overlayed on the first, consists of a small size mesh made of 3/8" diameter polyester. If the polypropylene mesh becomes torn, conventional splicing techniques can be utilized to mend the damaged area. The relatively small mesh size allows the net to be used on extremely small pieces. This feature would be useful in a situation where a growler or bergy bit is breaking up under tow. Only the smallest of pieces would escape while the main portion of the ice mass would be contained in the net. This would permit relatively high tow speeds, even for badly deteriorated pieces on the verge of disintegration.

The large main mesh is made of the same polyester strapping as in the previous two concepts. The headrope and footrope will also be the same as in the previous two proposed configurations. As with previous concepts, flotation and ballast will be attached as necessary to aid in maintaining the net's proper orientation in the water.

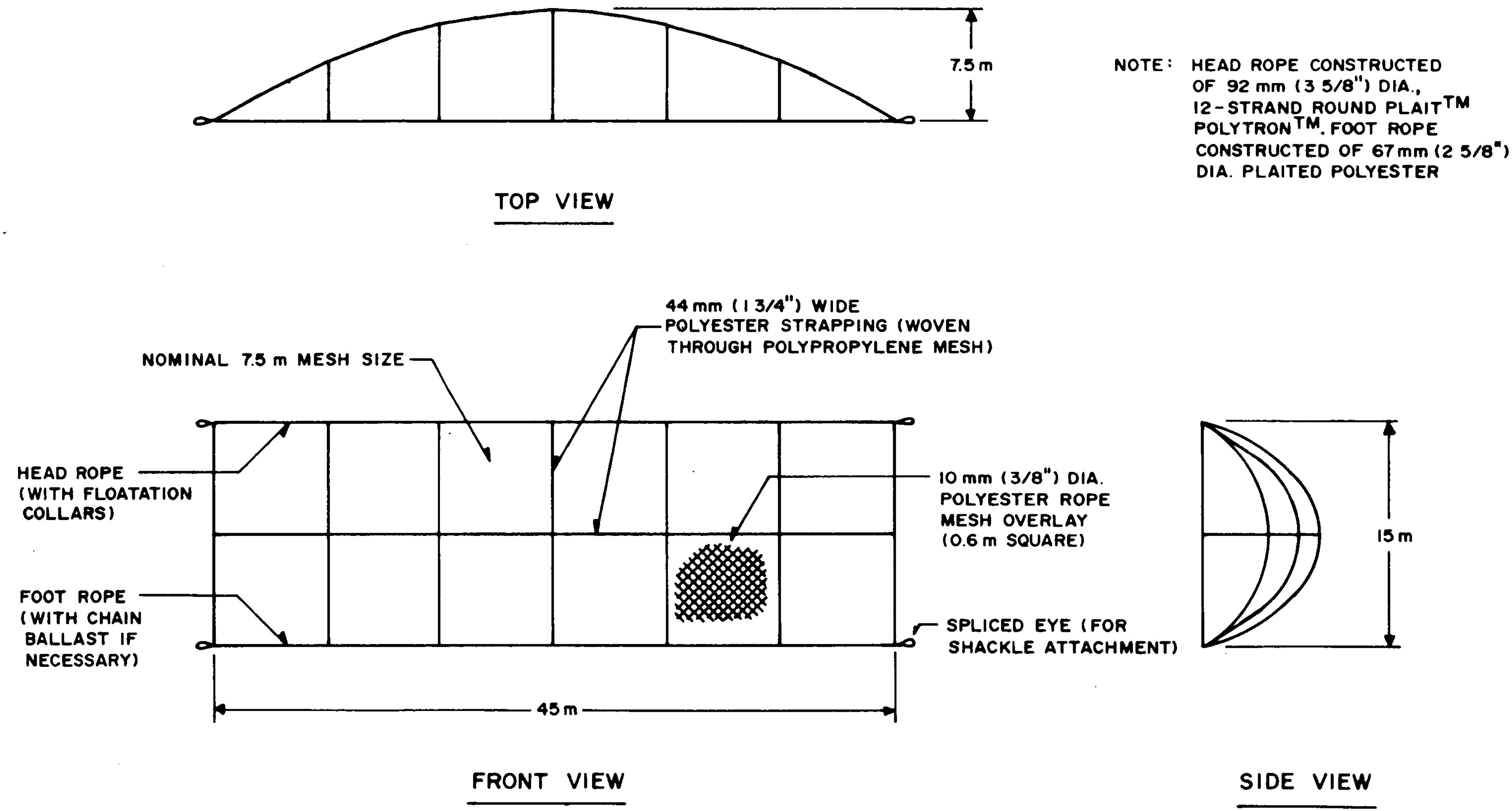
System Use

This net system should be deployable, recoverable, and stored in exactly the same manner as described for Concept #1. Deck personnel should stay well clear of the net during deployment to avoid being caught and possibly pulled over the stern. As with the previous concepts, care should be taken during recovery not to snag the net mesh on some feature of the ice mass as this will likely result in damage to the net. The small mesh size will likely minimize the chance of the net becoming hooked or caught on a major ice feature.

As with the other net systems, the use of a powered deployment/recovery/storage spool is strongly recommended. This is particularly so with this configuration as the additional mesh will increase the weight substantially and make handling more difficult.

General Conformity to Design Criteria

The system should be capable of managing ice masses with a maximum draft of 15-20m and, using catenary as in a single line tow, may be capable of towing small to medium icebergs. This



ICE ARRESTOR NET # 3
CONCEPTUAL DRAWING

Figure 36.

would almost certainly be the case should such an iceberg have a prominent underwater protrusion around which the pocket of the net could wrap.

As with the previous two concepts, the bridle is designed to allow equal distribution of tow force in top and bottom members or higher tow force in the footrope.

All materials used have good performance characteristics in the conditions under which the net will be used (i.e. salt water, ultraviolet, and abrasion resistance).

As with Concept #2, however, a net of this shape does not lend itself readily to attachment of extensions. On the positive side, the small mesh means that even very small pieces could be managed. This design may lend itself to being deployed by two vessels for the clearing of ice debris from a disintegrated growler or bergy bit.

Environmental limitations for use of the net are dictated by the safety of deck work in high seas. However, with proper deployment procedures, this component of the job can be minimized to reduce the risk, thereby permitting effective deployment in sea states up to 6 on the Beaufort Scale.

CONCEPT #4 - WATER CANNON

This idea is proposed as an alternative system in light of its recent successful use by BP Resources Canada in operational support of their Baie Verte J-57 drilling campaign (Allsop, 1985) and the field testing program by Husky/Bow Valley which yielded encouraging results (Warbanski and Banke, 1985).

The water cannon system has several important advantages. If installed properly (i.e. motion-compensated), it should be useable in fairly rough weather since no outside work by vessel crew-members is required. The cannon should, if possible, be bow mounted; however, this may necessitate an expensive retrofit depending on the vessel. With a bow mounting, the water jet will not obscure visibility as much as the conventional over-the-wheelhouse mount now used in FiFi class vessels. This configuration will also maximize the horizontal component of the jet reaction force.

Unlike the net, there is no limitation on the minimum size piece of ice which can be managed using this method. The upper limit of efficient manageability is not known at this time and will naturally be dependent upon the capacity of the system but is thought to be between 10,000 and 20,000 tonnes. The shape of the ice mass and the sea state will also be factors in the effectiveness of this technique.

An added advantage of this system is the fact that it brings with it a dimension of safety because of its capability for use in firefighting, and the elimination of placing men at risk on the back deck during bad weather or sea conditions.

If two or more vessels at a particular location are equipped with effective water cannons, the possibility exists for "herding" several growlers at once. This would be useful if an ice mass broke up in close proximity to an offshore installation. Two cannons would also allow much better directional control and extra power for working on a single piece if the two vessels were able to work in such close proximity. Also, the extra force exerted by a water cannon behind an iceberg could provide significant assistance to conventional towing operations.

The water cannon method is not seen to be the total answer to all ice related problems but could be a key piece of equipment in an integrated system of ice management tools.

PHASE IV

EVALUATION OF ALTERNATIVES, FINAL DESIGN, CONCLUSIONS AND RECOMMENDATIONS

In the previous three segments of this study work done to date in the area of ice management was reviewed. Also, design criteria and concepts were generated.

In this final part of the study, each design concept is subjected to close scrutiny and evaluated based on the design requirements. The concepts with the most promise, as determined by this evaluative process, are then further designed to a level of detail to allow construction.

Finally, the study conclusions and recommendations are given.

EVALUATION OF DESIGN CONCEPTS

SUMMARY OF DESIGN CRITERIA

Prior to evaluation of the concepts presented in Phase III, it is appropriate to quickly review the criteria which will be used in the selection process. These are grouped into two main categories:

- environmental considerations
- system parameters.

The environmental criteria deal with describing typical and limiting meteorological and oceanographic conditions as well as determining the characteristics of the design ice mass. System criteria outline the desired performance capabilities of the small ice mass management equipment and techniques.

The environmental criteria are summarized in point form below:

Maximum Wind Speed - (95th percentile values)
Calmest month - 30 kts (August)
Windiest months - 44 kts (December-February)

Maximum Wave Height - Based on above wind speeds and Beaufort Scale.
August - 4m
Dec. - Feb. - 7m

Freezing Spray - 10% - 20% potential for occurrence during winter months.

Visibility - <1/2 nmi (19% annual occurrence)
<1.1 nmi (22% annual occurrence)
<2.2 nmi (26% annual occurrence)
<5.4 nmi (35% annual occurrence)
$\geq$5.4 nmi (65% annual occurrence)

Fog Days* - Percent occurrence varies from month to month.
Minimum - 39% (December)
Maximum - 84% (July)

Ice Mass Size -

	Minimum	Maximum
Mass	1,000 tonnes	40,000 tonnes
IIP Class.	Growler	Small Iceberg

Ice Mass Shape - spherical (or domed)

*A day on which at least one reported visibility observation was 1km or less.

Ice management system criteria include:

Deployment time	- avg. $\leq$45 min. max. $\leq$1 1/2 hours
Recovery time	- avg. $\leq$1/2 hour max. $\leq$1 hour
Operating Limits	- Should be useable on design ice mass in given environmental conditions.
Construction/ Installation	- Complexity and cost should be minimized.
Material Requirements	- Any materials used must have high abrasion resistance and resistance to salt water and sunlight.

Further criteria specific to a net system are:

Handling	- Potential for tangling to be kept as low as possible.
Tow Force Distribution	- Adjustable distribution of tow force between headrope and footrope is necessary.
Strength	- Should be capable of withstanding a tow tension of up to 60 tonnes.
Storage Reel	- Net should be stored, deployed, and recovered on a suitable powered reel. The reel should not seriously handicap the vessel's other multi-purpose capabilities.
Visibility	- Net should be reasonably visible in darkness or fog.
Flotation/ Ballast	- Should be selected and fitted so as not to adversely affect handling or use with storage reel. - Sub-surface components should have a specific gravity greater than seawater, waterline components should be of floating material.

For further details of design criteria, see Phase II.

RATING OF INDIVIDUAL CONCEPTS

The concepts being evaluated in this section are as described in Phase III of the study:

- Ice Arrestor Net #1
- Ice Arrestor Net #2

- Ice Arrestor Net #3
- Water Cannon

Items such as deployment options (i.e. use of trawlers) are also discussed in the context of the design criteria.

The approach will be to rate, (quantitatively or qualitatively), how well each concept meets key ice management system criteria. After this, overall ratings for each concept relative to the others, will be established. These overall ratings will then form the basis for selection of the preferred concept.

Deployment and Recovery Times

Due to the similarity of design, all three nets, if used under the same circumstances, should be deployable (and recoverable) in comparable time frames with no one exhibiting a clear advantage. Typical times should be within those specified in the criteria (i.e. 3/4 - 1 1/2 hours for deployment; 1/2-1 hour for recovery).

In contrast to this, startup and shutdown times for the use of a water cannon could probably be in the order of 10 to 15 minutes and zero, respectively. The deployment time would be a result of the vessel possibly having to manoeuver to line up properly with the ice mass.

So, in terms of the ability to meet this criteria, the water cannon is easily the favourite.

Limiting Environmental Conditions

The basic limiting parameter for the use of any system deployed over the stern is sea state.

Experience with the use of conventional anchor handling/supply vessels has led to the accepted rule-of-thumb that 5m wave heights are about the limit for safe working conditions on the work deck of this style of vessel. In seas worse than this, the deck is almost sure to be frequently awash, particularly if much manoeuvering is required. Decks awash, especially those with open sterns introduce a significant risk factor to a seaman.

Based on the wave height criteria cited in the previous section (4-7m), this suggests that the use of a net with a conventional supply vessel will be sea state limited, however, it is important to note that those values reflect the range of typical extreme conditions as opposed to average conditions. All three nets would be limited in the same way.

The occurrence of freezing spray would have an adverse effect on the use of a net. While the actual implications for the net itself are not documented, any form of deck work would be extremely dangerous, particularly on metal surfaces covered by accreted ice and/or wet snow.

The environmental limits for water cannon ice management are not known and research is presently being undertaken to provide data on this topic. The most critical performance factor would almost certainly be vessel motion, with heave and pitch being the major components to be compensated for.

Assuming that sufficient motion compensation could be provided to allow use in up to 5m seas and that the system could be remotely controlled from the wheelhouse, a very strong argument in favour of the water cannon over the net is the fact that no outside work would be required. Thus, the level of risk to personnel is practically nil during use of the water cannon.

One possible negative aspect, (although not yet explored), concerns the use of the water cannon in subzero weather. With the ice mass upwind, as could likely be the case, the possibility of freezing spray from the water jet being blown back to the vessel could result in ice accretion.

Without further quantifying the limitations of the water cannon, it is very difficult to assess how it ranks against a net. However, the safety factor is a very strong point making the method appear more desirable.

Ice Mass Limitations

In this section, the upper and lower mass limits of manageable ice masses are estimated for the four concepts. In addition, the potential for enlargement of each of the three nets is addressed.

In their basic single panel configuration, each of the nets should be capable of handling ice masses up to approximately 13,000 tonnes. Depending upon shape, masses much larger (i.e. small iceberg) may be manageable. When increased in size (if possible with all three nets) to the full 45m x 30m, the ice net should be capable, in some cases, of handling pieces up to 70,000 tonnes. The minimum manageable mass will be dependent on mesh size. For Ice Arrestor Nets #1 and #2, this will be about 4 tonnes as estimated in the conceptual design section. Ice Arrestor Net #3 has a much smaller mesh enabling it to cope with proportionately smaller pieces. With a mesh size of about 0.6m, a very small growler (100-200 kg) can be contained.

The approximate upper limit of water cannon potential, as quoted in Phase I, is to move a 40,000 tonne ice mass. However, the reference from which this figure is taken implies that the effectiveness, as one might expect, decreases as the mass limit is approached. Of course, this limit will vary from vessel to vessel. If a water cannon were being specifically designed and installed for ice management, the unit selected may in fact be larger than the one used for the initial test program (described in Phase I). This implies a higher mass limit for effective management.

So, in terms of maximum mass handling capability, both the net and the water cannon seem to be nearly equivalent, with the net possibly offering a slight advantage. However, the water cannon offers a significant advantage over the single panel net.

Ice mass shape will have some effect on this upper limit as well. Unusual shapes of large mass (up to 100,000 tonnes) may be towable with the double net, but unmanageble with the water cannon. The single panel net may occassionally be able to handle masses up to 30,000 tonnes, depending upon ice mass shape.

In terms of minimum manageable ice mass size, the water cannon is definitely the favoured method with essentially no lower limit.

As mentioned earlier, a net could be made to handle larger masses by increasing its size through the addition of extra panels. However, this would only be possible with Ice Arrestor Net #1. The bag shape of the other two configurations does not lend itself readily to expansion while the flat shape of Net #1 does.

If, for instance, the depth were doubled, Net #1 could possibly be used consistently on small icebergs. While there would most likely be an increase in the potential for handling problems, the fact that this net has this capability makes it the favoured one of the three proposed.

Construction/Installation

This is one area where a net has a dramatic advantage over a water cannon. To build and install an ice net would probably be in the order of 5-10% of the cost of retro-fitting a vessel with an appropriate water cannon system. Given a workable net system, the implication of this is that 10 to 20 vessels could be provided with a net and reel for the cost of providing a water cannon system on a single vessel. Also, once a water cannon is installed, it will become a permanent feature of that vessel while net systems can be easily relocated from one ship to another. Through proper design of a portable reel or by outfitting a number of vessels with reels, the system could very probably be exchanged at sea using a rig crane. Of course, this would necessitate some preliminary work on the vessels to which the system could be transferred (i.e. mounting pads, hydraulic adaptations, etc.).

In comparing each of the three nets on the basis of this criteria, Ice Arrestor Net #1 would likely be the least expensive and time comsuming to construct. This is attributable again to the shapes of the latter two and the significant amount of additional material required for #3. While the differences between the three are not expected to be dramatic, they would be sufficient to suggest that Ice Arrestor Net #1 is the most appropriate selection.

Net Criteria

In all criteria specific to nets except handling, the three concepts presented are seen to be equivalent. In the area of handling, it would seem that a flat net would have certain advantages over other shapes. It could be more easily stowed on reels on spread for repair work. In addition, the smaller mesh of #3 would increase the weight and its associated handling problems.

As with some other areas of evaluation, Ice Arrestor Net #1 does not dramatically outperform the others in handling potential. However, there does seem to be a marginal advantage which would give the edge to this net in the selection process.

Trawler Method(s)

The use of a trawler for deployment of nets would likely be prone to many of the same limitations as supply vessels, except in one important area - sea state limitation. Because of the higher freeboard on a trawler's work deck, a net may be safely useable in sea states higher than 5m. This is a critical factor, as one of the main limitations of all existing ice mass management techniques is handling during rough weather. If a net system was deployable using this style of vessel in sea states up to 7 or 8m, this would almost inevitably save a costly rig move at some point and would most certainly reduce drilling downtime.

SELECTION OF PREFERRED CONCEPT

In conclusion, it would seem that methods involving the use of a water cannon offer the most promise for successful ice management. They would be safe, easy and quick to deploy and able to manage a wide range of small ice masses. A drawback is the high cost of installing a properly designed, optimized system.

Nets are prone to some of the same limitations that continue to plague conventional single line techniques and the nets proposed here are somewhat less versatile than the water cannon. However, they offer the advantage of being considerably less expensive as compared to a water cannon technique. Of the three nets proposed, Ice Arrestor Net #1 would appear to be the most suitable.

The limiting effect of sea state may be reduced through the use of trawler(s) to operate a net system.

DETAILED DESIGN OF PREFERRED CONCEPT

This section contains all pertinent information required to construct the design concept selected - namely, Ice Arrestor Net #1. Design calculations are also included.

Since this is now the sole net considered for development, it will be referred to hereafter as simply the Ice Arrestor Net.

The detailed design will begin with the concept as presented in Phase III. As mentioned earlier, the aim here will be to design a single panel and then address features to allow expansion.

Details which need to be finalized are:

- bridle design;
- headrope flotation;
- footrope ballast;
- member connections;
- connections to headrope and footrope;
- features to allow expansion of net size.

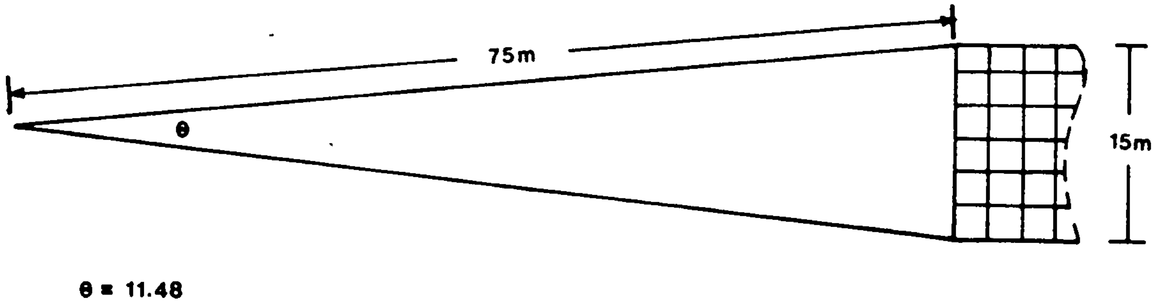
After these are determined, items such as fabrication costs and scheduling, net weight, and storage volume required can be estimated. This information is presented in Appendix 8.

BRIDLE DESIGN

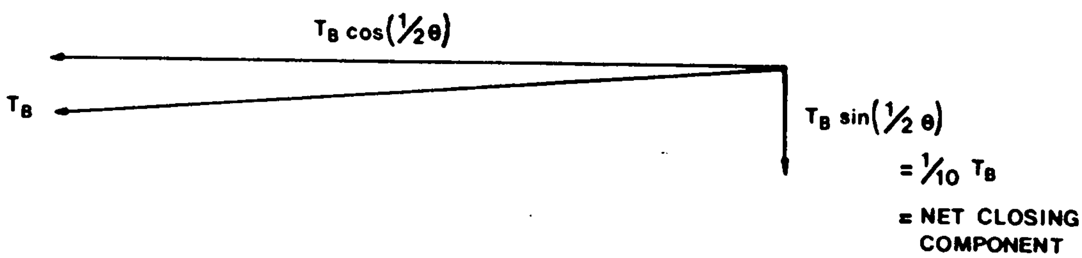
As mentioned in Phase III, a suggested rule-of-thumb for determining bridle lengths is that the length be five times the depth of the net. This, it is argued, reduces the net-closing component of the bridle tension to a level manageable by appropriate selection of headrope flotation and footrope ballast. In the absence of sufficient information to determine the applicability of this rule-of-thumb, it is considered an adequate starting point for the design process. It may, however, require modification after investigation of headrope flotation and footrope ballast requirements, since the net-closing component may still be too high to offset by differential separation.

Based on the rule-of-thumb suggested, for the 15m depth net, 75m long bridles are required. Referring to Figure 37(a), this dictates an interior angle theta, θ, of 11.48° between bridle members under ideal conditions.

If we consider a free body diagram of the top corner of the net as shown in Figure 37(b), the component of bridle tension tending to close the net is readily calculable and is equal to one tenth of the bridle tension. This working figure will be used later in determination of flotation and ballast requirements.



(a) Bridle Configuration



(b) Horizontal and Vertical Components of Bridle Tension

CALCULATION OF NET-CLOSING COMPONENT OF BRIDLE TENSION

Figure 37.

To ensure proper separation of bridles and, therefore, minimize the likelihood of tangling, the bridles will be made of differing materials. The upper bridle will be made of a floating material while the lower one will have a negative buoyancy. An important consideration in the selection of bridle materials is their elongation properties. The elongation of a rope is expressed as a percent of overall length and is given for tensions expressed as a percent of minimum break strength. However, before proceeding with this analysis, attention must first be given to incorporating a bridle design feature to allow adjustment of relative headrope and footrope tensions as this may have to be considered in any analysis of elongation. This could be achieved by the installation of a removeable length of rope at the far end of each of the lower bridles. Thus, by shortening the lower bridles, the proportion of tow force in the footrope would increase.

Shortening the length of each of the lower bridles to 70m and installing a 5m length of rope will ensure that the tension along the footrope will be greater than along the headrope. The rope would be of the same material as the rest of the bridle.

This feature also necessitates the installation of two extra shackles. Instead of one shackle connecting the lower bridle to the leadline, a shackle is required at each end of both adjustment ropes, (see Figure 38).

We must also consider the behaviour of the bridles when configured with a shortened lower bridle as this will result in a somewhat different tension distribution, at least initially.

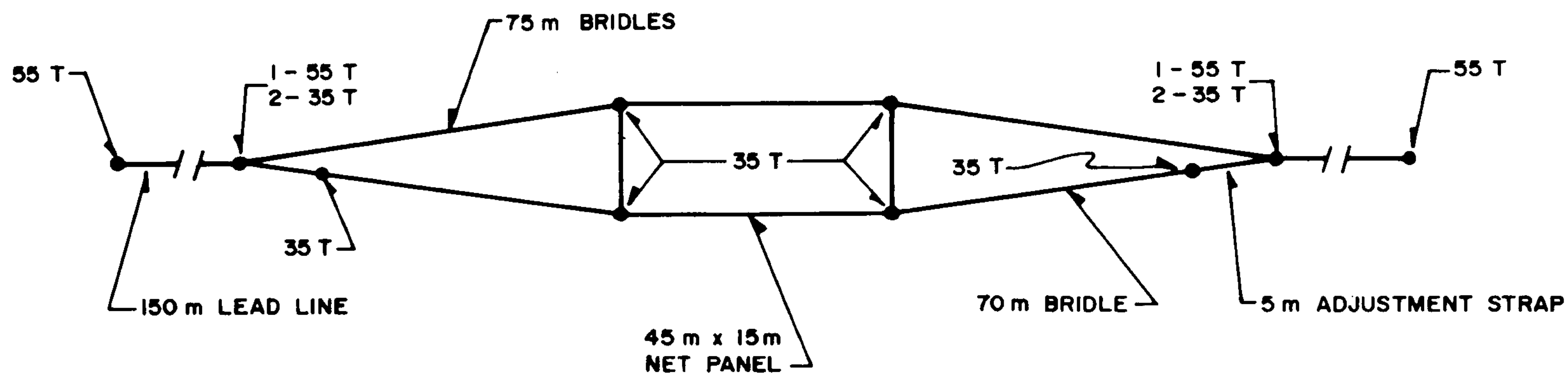
With the adjustment straps removed, the lower bridles now measure 70m each. At this point, all tensions would theoretically be in the lower bridles and footrope. However, as the lower bridle continues to stretch under the increased tension (up to half of the tow tension), the upper bridle will slowly become loaded and some tension will be transferred to the headrope. The exact proportional distribution of tow tension between upper and lower bridles will, therefore, vary as they stretch. However, it can be easily seen that the removal of the adjustment straps will result in more than half of the tension being along the footrope which is the desired effect.

Selection of Bridle Materials

The bridle material selection is based on the following calculations using technical data from Samson Ropes.

Assumptions

- 15 tonne bridle tension (i.e. 1/4 of 60 tonne tow tension)
- Factor of Safety = 6
- Top bridle made of twelve-strand Round Plait™ Polytron™.
- Lower bridle made of Round Plait™ polyester.



NOTE: T = tonne

SHACKLE ARRANGEMENT FOR ICE NET

Figure 38.

The first step is to determine the upper bridle diameter required to safely resist the assumed tension. Applying the factor of safety yields the design tension to be 90 tonnes.

From Figure 39(a), we select the lowest Polytron™ break strength which meets or exceeds this 90 tonne value. The figure selected is 209,000 lbs or 95 tonnes and this corresponds to a diameter of 3 5/8" (92mm) or a circumference of 11" (279mm). A line tension of 15 tonnes, therefore, corresponds to 16% of breaking load.

The elongation induced in the top bridle by a tension of 15 tonnes can be estimated from Figure 39(b).

At 16% of break load, we can see that Polytron™ would have a stretch of about 4%. Therefore, under 15 tonnes of tension, the 75m upper bridle will measure about 78m. We should, therefore, select a lower bridle material and diameter to achieve an elongation of 4% under 15 tonnes of tension.

Also, as recommended earlier, the lower bridle material will have a specific gravity greater than sea water, causing it to sink. From the Phase III discussion of materials it was concluded that a possible appropriate material is plaited polyester.

From Figure 40(b), to achieve a stretch of 4%, a load equal to 17.5% of breaking stength must be applied. Since we are assuming a 15 tonne line tension, this implies a breaking strength of 85.7 tonnes. From Figure 40(a), the size having the nearest breaking strength to this is 2 5/8" (67mm) diameter, with a value of 196,000 lbs. (89 tonnes).

BOUYANCY AND BALLAST REQUIREMENTS

There are three bouyancy conditions to be considered in the selection of flotation and ballast. These are:

- the net must free float in a vertical orientation;

- the net must remain open while being streamed slowly (i.e. 2-3 knots) behind the vessel, as could be the case during deployment or recovery;

- the net must remain open while in place on an ice mass.

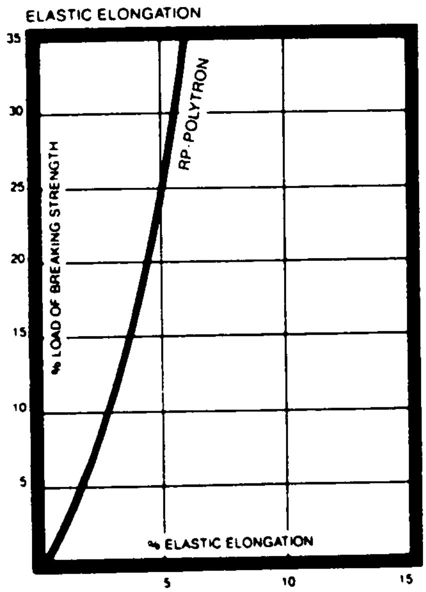
It is obvious that to meet these requirements, the net must have an overall positive buoyancy but sufficient ballast to ensure proper orientation under normal operating conditions. Flotation and ballast will, therefore, not be exactly equal but are dependent on one another. Hence, both requirements are determined simultaneously in the calculations which follow.

ROUND PLAIT™ Polytron Rope

SIZE Dia. (in inches)	Circ.	Approx. Wgt. Per 100 Ft. (in lbs.)	Approx. Breaking Strg. (in lbs.) (1)
1/4"	3/4"	1.1	1,500
5/16"	1"	1.8	2,400
3/8"	1-1/8"	2.8	3,500
7/16"	1-1/4"	3.8	4,550
1/2"	1-1/2"	4.9	6,000
9/16"	1-3/4"	6.3	7,550
5/8"	2"	8.4	9,800
3/4"	2-1/4"	10.5	12,000
7/8"	2-3/4"	14.0	15,600
1"	3"	19.2	20,800
1-1/8"	3-1/2"	24.5	25,800
1-1/4"	3-3/4"	27.0	28,200
1-5/16"	4"	31.9	32,800
1-1/2"	4-1/2"	39.2	39,500
1-5/8"	5"	50.4	49,800
1-3/4"	5-1/2"	58.8	57,500
2"	6"	71.4	68,900
2-1/8"	6-1/2"	84.0	80,100
2-1/4"	7"	96.6	92,000
2-1/2"	7-1/2"	109.0	102,000
2-5/8"	8"	126.0	117,000
2-3/4"	8-1/2"	132.0	128,000
3"	9"	160.0	146,000
3-1/4"	10"	193.0	174,000
3-5/8"	11"	238.0	209,000
4"	12"	280.0	243,000
4-1/4"	13"	328.0	284,000
4-5/8"	14"	378.0	325,000
5"	15"	441.0	375,000

1. Tensile strength based on tests of new and unused rope under laboratory conditions. A Certificate of Compliance is available if requested at time of order.

(a)



(b)

STRENGTH AND ELONGATION DATA FOR ROUND PLAIT POLYTRON™

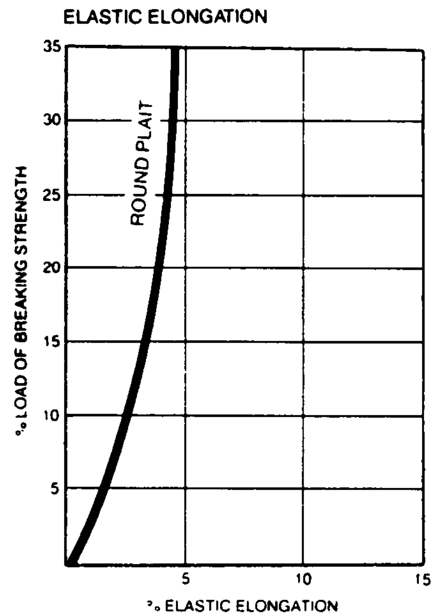
Figure 39.

ROUND PLAIT Polyester Rope

Size Dia. (in inches)	Circ.	Approx. Wgt. Per 100 Ft. (in lbs.)	Approx Av. Breaking Strg. (in lbs.) (1)
1/4"	3/4"	2.3	2,180
5/16"	1"	3.5	3,270
3/8"	1-1/8"	4.6	4,360
7/16"	1-1/4"	5.8	5,450
1/2"	1-1/2"	8.0	7,630
9/16"	1-3/4"	9.2	9,910
5/8"	2"	13.8	13,100
3/4"	2-1/4"	18.4	17,400
7/8"	2-1/2"	27.6	26,200
1"	3"	32.2	30,500
1-1/8"	3-1/2"	41.4	39,200
1-1/4"	3-3/4"	48.3	45,800
1-3/8"	4"	55.2	52,300
1-1/2"	4-1/2"	69.0	65,400
1-5/8"	5"	82.8	78,500
1-3/4"	5-1/2"	96.6	91,600
2"	6"	117	111,000
2-1/8"	6-1/2"	138	131,000
2-1/4"	7"	159	151,000
2-1/2"	7-1/2"	186	177,000
2-5/8"	8"	207	196,000
2-3/4"	8-1/2"	235	222,000
3"	9"	269	255,000
3-1/4"	10"	331	309,000
3-5/8"	11"	403	375,000
4"	12"	484	450,000
4-1/4"	13"	559	517,000
4-5/8"	14"	642	592,000
5"	15"	745	685,000

1. Tensile strength based on tests of new and unused rope under laboratory conditions. Conforms to Samson Rope Specification SOSI-1106. A Certificate of Compliance is available if requested at time of order.

(a)



(b)

STRENGTH AND ELONGATION DATA FOR ROUND PLAIT™ POLYESTER

Figure 40.

The design approach will be to determine flotation and/or ballast requirements to float the net properly and then add additional flotation and ballast in equal quantity as required to offset estimated net-closing forces.

Assuming the net to be free floating, we can now proceed to calculate the required flotation and/or ballast.

The data required for the relevant calculations is given below:

Specific Gravity (S.G.) of sea water, $S.G._w = 1.024$
Specific Gravity (S.G.) of polyester, $S.G._y = 1.38$
Specific Gravity (S.G.) of Polytron™, $S.G._n = 0.91$
Specific Gravity (S.G.) of steel (shackles), $S.G._s = 7.85$
Wt. of 3 5/8" dia. Polytron™ (upper bridles & headrope) = 355 kg/100m
Wt. of 1" polyester strapping (webbing) = 9.2 kg/100m
Wt. of 2 5/8" plaited polyester (lower bridles & footrope) = 309 kg/100m
Wt. of 35 ton forged alloy shackle = 15 kg (approx.)
Wt. of 55 ton forged alloy shackle = 30 kg (approx.)

Sufficient flotation to keep the net afloat, with bridles attached, is the first consideration. The weight which must be supported will be equal to the immersed weight of the heavier than water components minus the buoyant force supplied by the lighter than water components. If this number is a negative quantity, the net has an overall positive buoyancy and will float.

For design purposes, it will be assumed that only 1/2 the bridle length has a direct effect on the bouyancy of the net. The other 1/2 will be assumed to take effect at the shackle connection between the bridle ends and lead line.

The immersed weight of any given component as a percent of its weight in air can be expressed by:

$$\frac{\text{S.G. of component material} - S.G._w}{\text{S.G. of component material}} \times 100\%$$

Consider first the polyester mesh strapping. The total length of the strapping as shown in Figure 1, Phase III, is easily calculable as:

(15m x 37 vertical straps) + (45m x 11 horizontal straps)

or 1050m

The total weight can now be easily calculated:

$$1{,}050m \times 9.2\ kg/100m = 96.6\ kg$$

The immersed weight by percent of total weight is:

$$\frac{1.38 - 1.024}{1.38} \times 100\% = 25.8\%$$

Therefore, the total immersed weight of the polyester strapping is:

$$96.6\ kg \times 0.258 = 24.9\ kg$$

By similar process, the immersed weight of the remaining components can be calculated. The values are summarized below:

4 x 35 tonne shackles	=	52 kg
120m of 3 5/8" Polytron™	=	-53 kg
120m of 2 5/8" polyester	=	96 kg

The negative sign for the Polytron™ reflects the fact that that these are buoyant components.

Summing up all the immersed weights gives a total weight of 120 kg which must be supported.

Commercially available flotation collars can be custom built dependent upon application requirements. However, for design purposes, stock sizes are selected. The standard length of each collar is 44" (1.12m) and from data published by Samson Ocean Systems, the buoyancy provided by each collar (designed for 11" - 13" circumference rope) is 18 lbs. (8.2 kg).

At the stated length, one collar could be fitted along the headrope in the 1.25 meters between each pair of vertical members.

With 36 collars along the headrope, the total buoyant force supplied is 295 kg. Subtracting the immersed weight of the net, we are left with about 175 kg of excess buoyant force. Thus, the net should have no problem whatsoever remaining open while free floating.

The second requirement was that the net remain open while being streamed slowly behind a vessel. Any bridle tension in this mode would be a result of drag forces. It is difficult to tell accurately what these forces will be without carrying out a rather complex analysis but an order of magnitude estimate may be sufficient. It is known that drag forces vary with the square of speed and linearly with surface area. From experiments done by the author while working on an iceberg towing vessel offshore Labrador, 800m of 4 1/2" standard iceberg towline was determined to have a drag of approximately 2 tonnes when towed at 11 kts.

Based on this, it would seem reasonable to suggest that drag forces on the net while towed at a speed of 3-4 kts. would induce bridle tensions of less than one tonne. This implies a net-closing component of less than 1/10 of a tonne. This is less than the balanced ballast and flotation as specified. Therefore, it can be assumed that the net will not experience problems of orientation while being deployed/recovered.

The third requirement was for the net to remain open while in place on the ice mass. There are two main factors in addition to the flotation and ballast which will tend to do this:

- reaction forces of ice mass on net;
- friction forces between ice mass and net.

The first factor will be dependent upon the shape and size of the ice mass. This is easy to understand if one imagines a small spherical piece completely enmeshed by the net. In this case, the ice mass will prevent the net from closing as long as it is in the net.

However, if we take the case of a large cylindrical or blocky piece floating upright which the net can not completely surround, friction is the only tow related force tending to keep the net open. This is illustrated in Figure 41. Smaller ice masses will almost certainly be enmeshed by the net resulting in a situation as depicted in Figure 41(a). Larger pieces (icebergs) may be netted in a similar manner depending upon their underwater features. The design maximum ice mass, again depending on its shape, could possibly have to be towed in the manner shown in Figure 41(b) and this configuration is likely with icebergs.

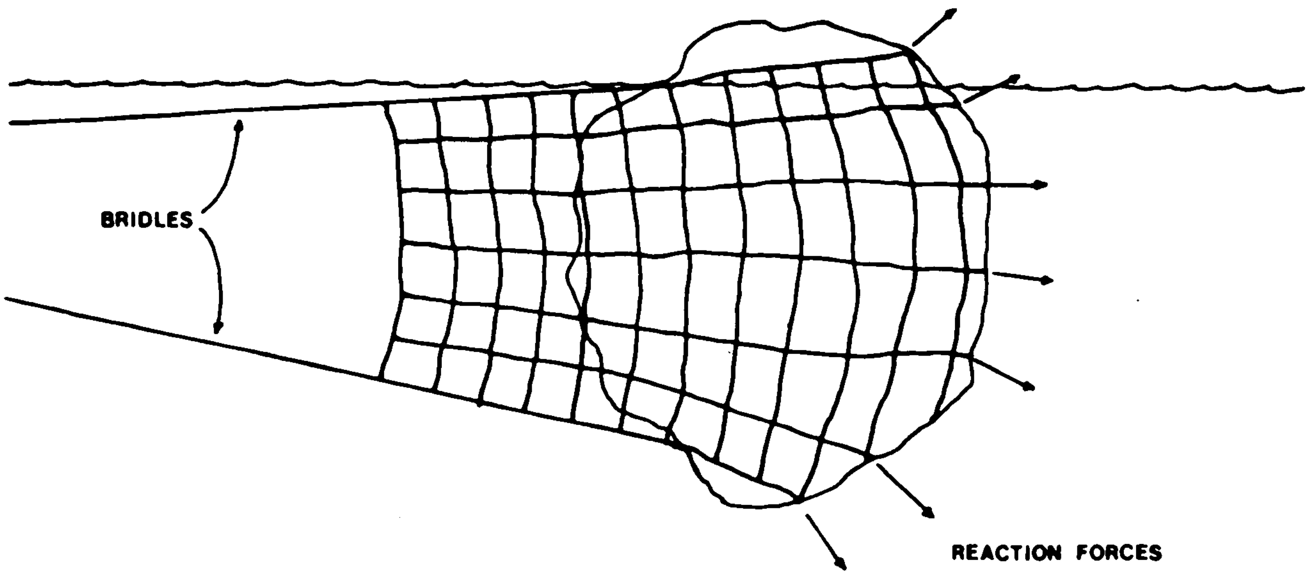
This latter case is the worse circumstance. In this case, the only tow induced force resisting net closure is friction. In designing for this, a value for the coefficient of friction of the polyester against the ice is needed. Documentation of this kind of information is very limited and a value for polyester on iceberg ice is probably non-existent.

In light of this, all that can be really done is to maximize the contact area of the mesh members, as discussed in Phase II.

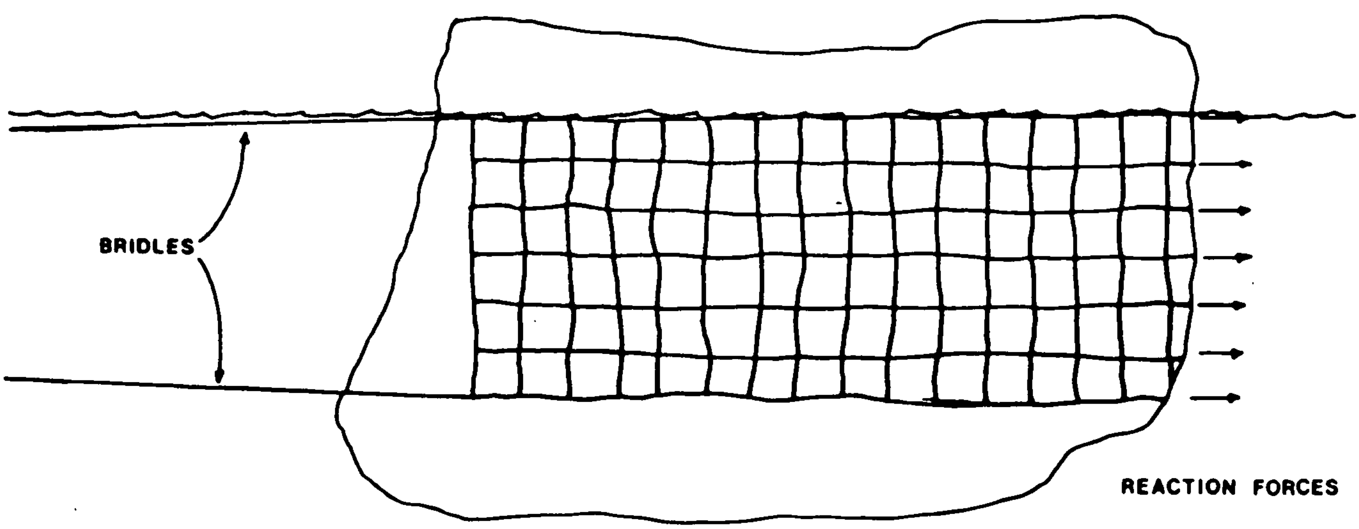
The use of strapping should enhance the holding power of the net, based on this principle.

STRAPPING MEMBER CONNECTIONS

Member connections will be stitched using high strength nylon twine. These details of both interior and end connections



(a) IN THIS CASE, REACTION FORCES HAVE VERTICAL COMPONENTS TENDING TO KEEP THE NET OPEN



(b) IN THIS CASE, REACTION FORCES HAVE LITTLE OR NO VERTICAL COMPONENT

EFFECT OF ICE MASS SIZE/SHAPE ON MAINTENANCE OF PROPER NET ORIENTATION

Figure 41.

are illustrated in Figure 42. The connections are quite strong as these are the same type as used in the British Royal Navy version (to catch jets at the end of short runways). Since the contact area between two intersecting interior members is quite small, a 20cm length of strapping is stitched over each for reinforcement. In any event, a connection repair kit will accompany the net. This kit will also serve to effect repair should a member be torn. Additional strapping would also be included in the repair kit. The kit and associated repair techniques are detailed in a later section.

MEMBER CONNECTIONS TO HEADROPE AND FOOTROPE

These details will be similar to the end member connections shown in Figure 42. The strapping will be wrapped tightly around the rope and stitched back onto itself. A typical connection is shown in Figure 43.

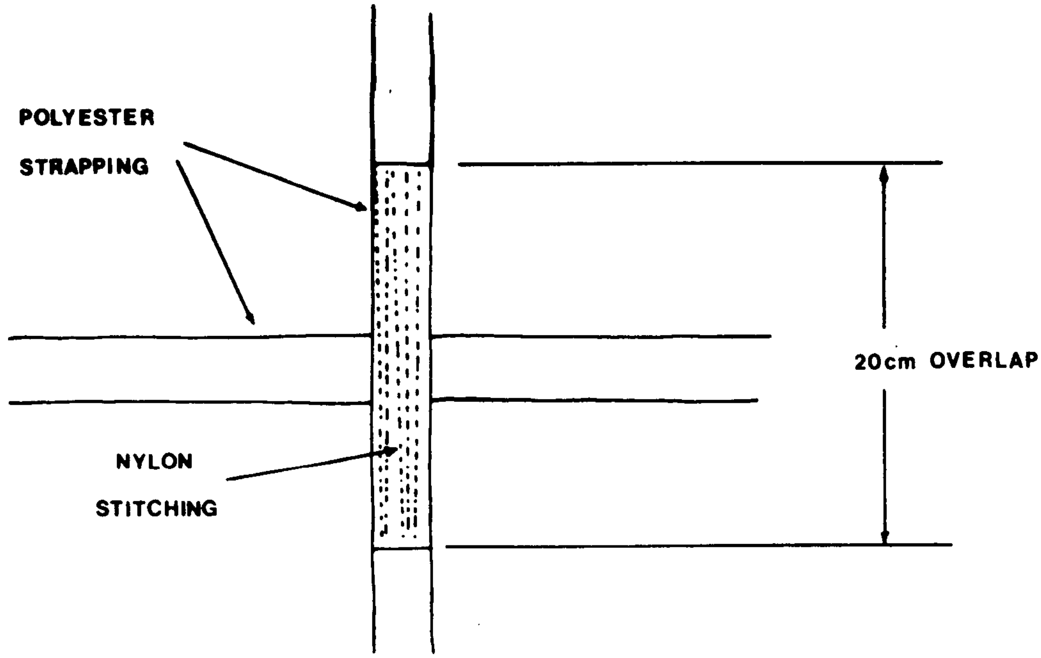
REPAIR KIT

The tow net repair kit will contain materials such that repairs to both breaks in the strapping and breaks in the stitching at cross sections may be quickly and easily mended in the field where more permanent and durable repairs would not be possible.

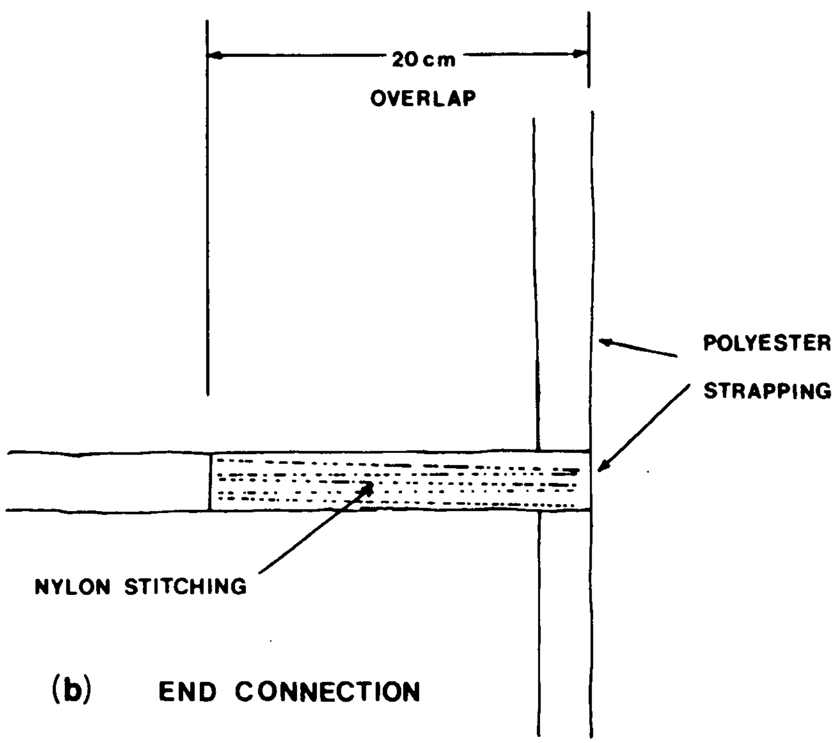
In the event of a break in the webbing, repairs may be affected with the aid of a section of strapping and two thread plates. These very simple devices are available from the strapping supplier and are easy to use. One piece of broken strapping is fed through the two slots in a plate. The repair section is then fed through in the same manner. The two pieces can be tacked together on either side of the plate with hot glue to prevent them from working apart when tension is off the net. The same procedure can then be carried out on the other piece of broken strapping with the other end of the repair section. When tension is applied on the resultant path, increased friction will prevent the two pieces of webbing from slipping out through the slots.

A break in the stitching at the headrope or footrope connections would be repaired by using the thread plate and hot glue. The end of the strapping would be fed through the two slots in the plate and then the plate would be slid down the strapping to a point where the end of the strap could be brought around the rope and also fed through the plate. Hot glue would be used to tack the strap to itself on either side of the plate.

In the event of a break in the stitching of an interior connection, repairs might be affected with the aid of nylon and hot glue. The parted section could be tacked into the proper position with the hot glue and then wrapped with the nylon cord to reinforce the glue tack.



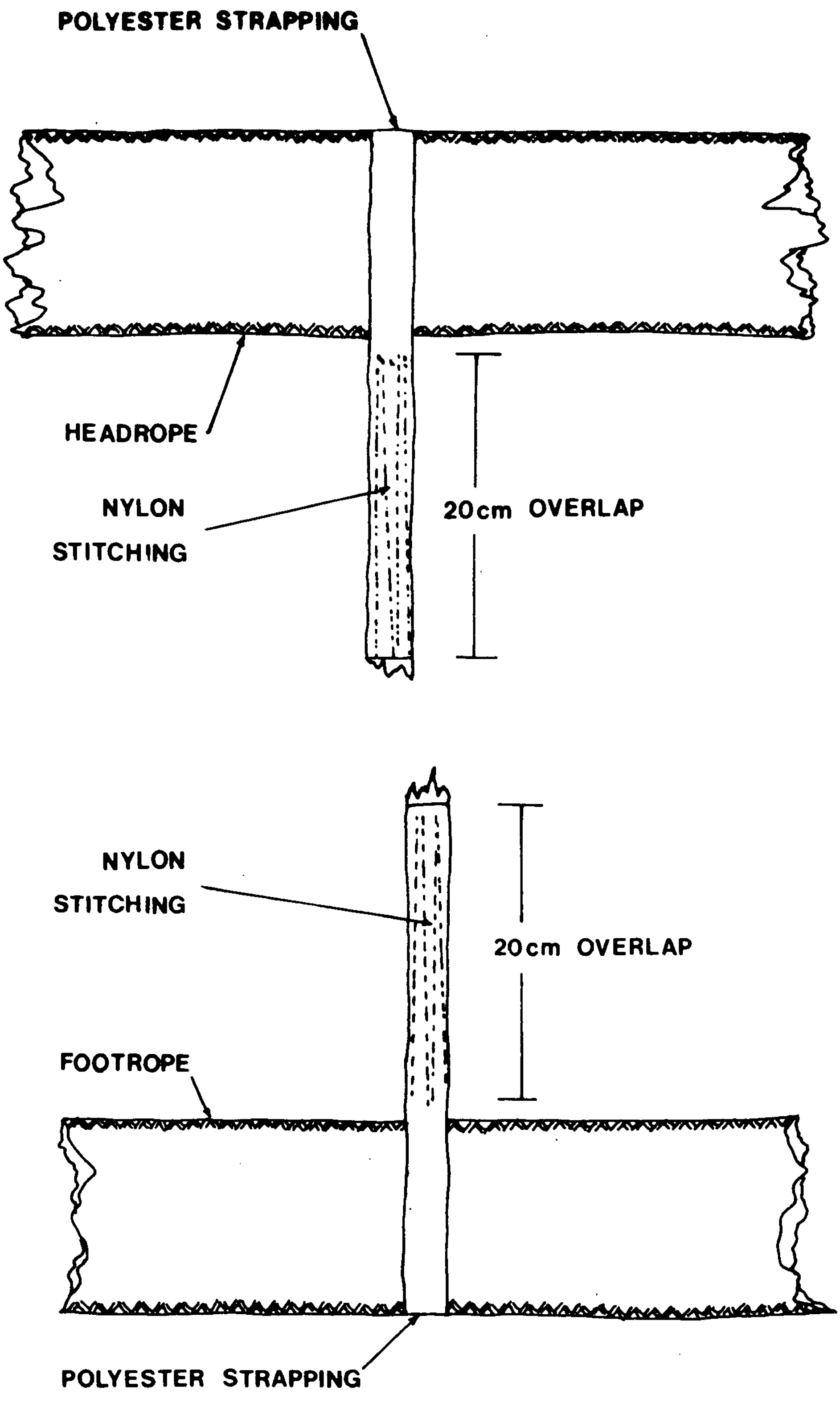
(a) INTERIOR CONNECTION



(b) END CONNECTION

MEMBER CONNECTION DETAIL

Figure 42.



MEMBER ATTACHMENT TO HEADROPE AND FOOTROPE

Figure 43.

Typical repair configurations are illustrated in Figure 44. The cost of the complete kit, including an adequate supply of repair plates, nylon twine, excess strapping, glue, heat gun and container would be in the order of $100 to $150.

FEATURES TO ALLOW EXPANSION OF NET SIZE

The Ice Arrestor Net, if proven workable, will need to incorporate features to allow increase of net depth by the addition of an extra net panel. Depth expansion dictates a need for connection points along the length of the adjacent footrope and head rope.

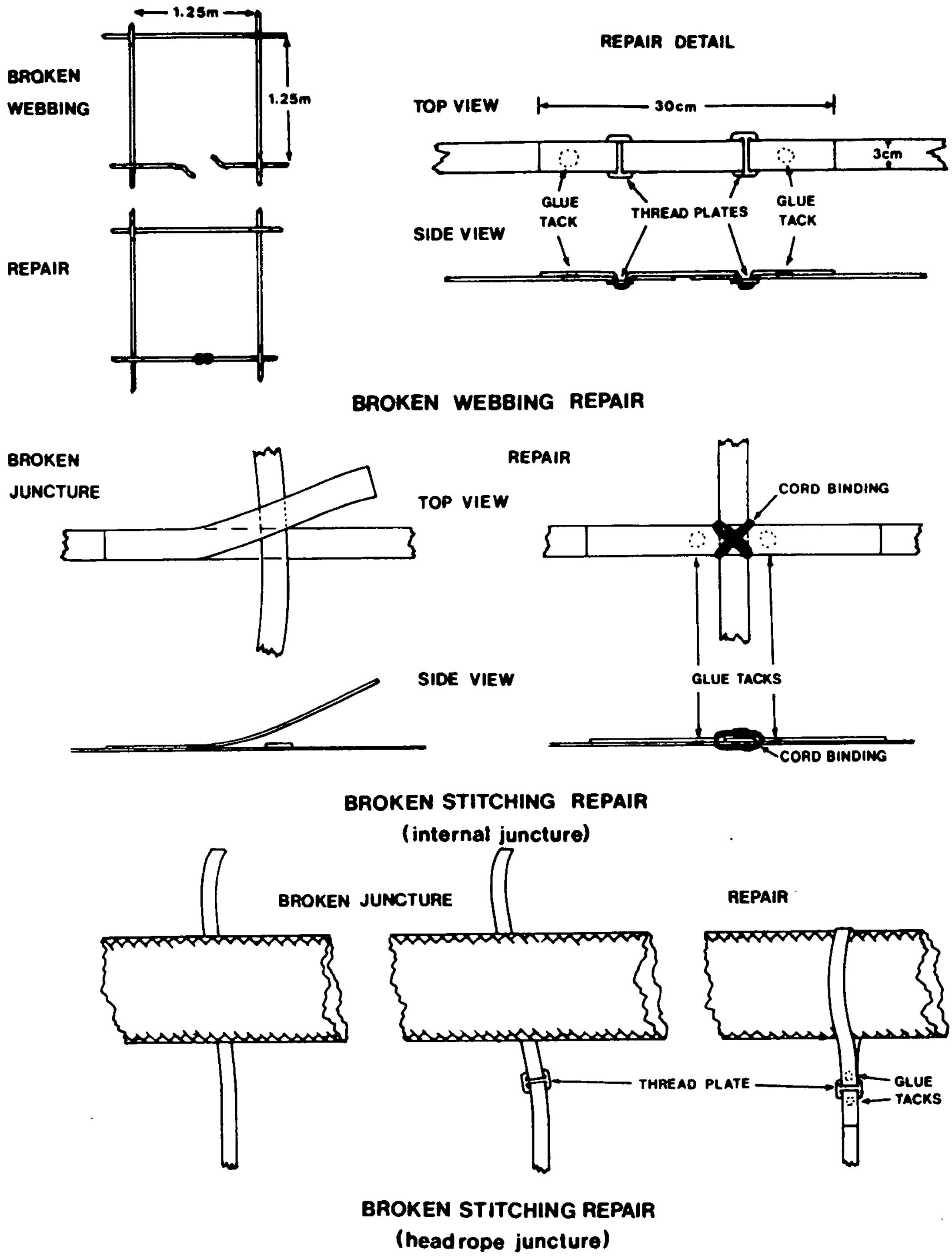
It is felt that, for cost efficiency reasons, the lower net panel be identical to the upper, with the exception of the flotation collars. This permits interchanging of net panels for single panel use and should lead to even wear on both panels, thereby maximizing their useful life expectancy. If extra flotation collars were kept on hand at sea, the lower panel could also then be modified to function as a single panel net, simply by attachment of the collars. The attachment phase would undoubtedly be time consuming, but in the interest of having the panel available for expansion of the ice arrestor net, is seen as necessary. If the nets were to be interchanged, or one was to be transferred to another vessel, the collars could be attached during a period of little or no ice activity.

The two net panels could be joined by means of a series of straps (with buckles) along the footrope of the upper panel and the headrope of the lower panel. The ends of these two ropes could be joined with 25 tonne shackles.

If the net is made deeper, consideration must also be given to the bridle configuration. The most logical suggestion is simply to have each net panel equipped with its own set of bridles. Thus 150m bridles can be made by joining two 75m bridles. This also makes sense from an interchangeability point of view.

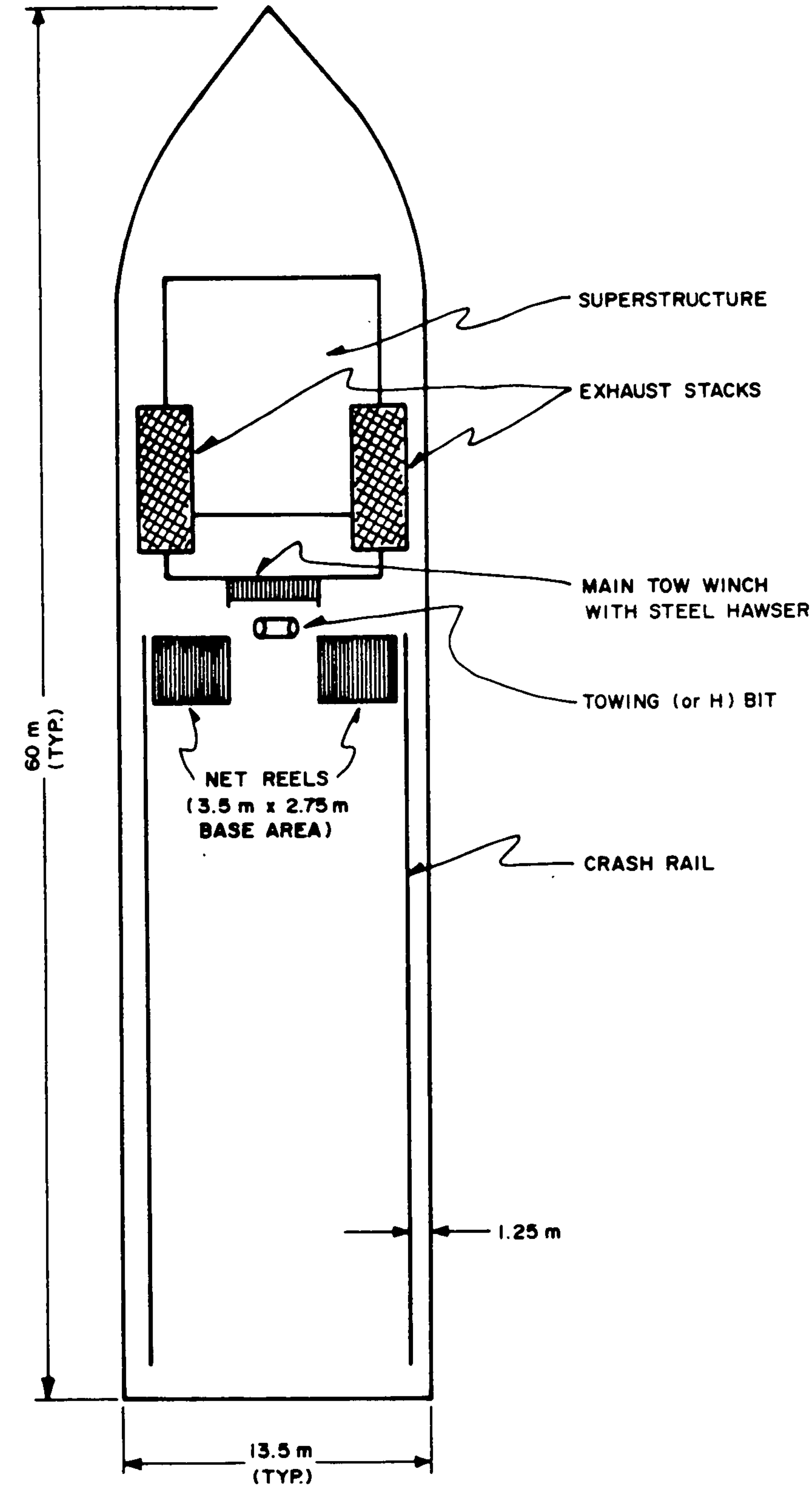
The most obvious method of storing a two net configuration would seem to be with matching port and starboard stowage reels as suggested in Figure 45. This would serve to keep the deck area relatively clear of gear, and minimize deployment/recovery times as much as possible.

By having two separate reels, time in spooling and unspooling would be reduced as compared to having both panels on a single reel through having a smaller volume to deal with. Also joining and separating the nets would be fairly straight forward as they could be simultaneously deployed and buckled or recovered and unbuckled as they went down or came up the deck. With one reel both nets would have to be spooled out entirely on the deck before they could be paired, a time-consuming and complicated process.



NET REPAIR TECHNIQUES

Figure 44.



**NET REEL ARRANGEMENT
FOR DOUBLE PANEL NET**

Figure 45.

With a two reel configuration, a possible deployment procedure could be as follows.

- Using winch with most frequently used net panel, 150m lead line with sea anchor and marker buoy attached is payed out over stern as vessel slowly approaches ice mass.

Note: since 150m lead lines will be used with either the single panel or double panel net, they may be left attached to the most frequently used single panel.

- 75m bridle lines are payed out
- Bridle lines are stopped off and disconnected from first net, while net end marker buoy is attached.
- Second winch is started and bridles of second net are shackled to inboard end of first net's bridles, making 150m bridles.
- Bridle payout continues until second net panel is on deck.
- Bridles are again stopped off and upper bridle is switched over from second (lower) net to first (upper) net.
- Footrope of upper panel and headrope of lower panel are connected using 25 tonne shackle.
- Simultaneous payout of both nets commences, with attachment straps put in place as net is payed out.
- When inside bridles come off winches, net ends are stopped off and interior bridle lines (i.e. lower bridle of upper panel and upper bridle of lower panel) are detached from net.
- Footrope of upper panel is connected to lower panel headrope using 25 tonne shackle.
- Continue payout until extreme bridle ends appear, keeping detached bridle ends on deck.
- The two bridles still attached to the net are stopped off and the detached bridles are shackled in place.
- Payout continues until end of second lead line is on deck.
- Lead line is shackled to tow hawser.
- Deployment is completed as per standard iceberg towing procedure.

It is estimated that this procedure will take approximately 30 to 45 minutes longer than the single panel deployment, making it somewhat time consuming. This should not be a serious problem, however, considering that in cases where the full 45m x 30m net is required, the ice mass will be a small iceberg or large bergy bit. A piece this size could remain undetected until near a rig, but the chance of this is less than for a smaller piece. Thus, sufficient lead time should be available in most cases to conduct net towing operations.

A second obvious criticism of this deployment procedure is that it is somewhat labour-intensive, requiring a fair amount of deck work. It should not, however, be more limited by weather and sea conditions than either the single panel net procedure or standard iceberg towing procedure, since both these methods also require deck work.

Recovery will naturally be very close to the reverse of the deployment procedure.

Should prevalent ice mass size or Captain's preference dictate using the full size net regularly, the whole system could be left assembled. While it will not fit entirely on anything but a very large reel, as much as possible could go on the reel, with the remainder flaked onto the deck. This will speed up deployment and recovery. Undoubtedly, deployment and recovery procedures will be refined through repeated use of the net and details will vary depending upon deck equipment arrangement and Captain's preference.

CONCLUSIONS AND RECOMMENDATIONS

While a large number of devices and techniques for management of small ice masses have been proposed in the past, most have been abandoned for various reasons. It is interesting to note that despite the ideas which have come and gone, several have survived regardless of the results of various testing efforts. The main two which seem to reoccur are:

- net;
- water cannon.

The fact that these ideas continue to be suggested by a number of people knowledgeable in the areas of ice management and/or marine operations is, we would suggest, very strong evidence to support the fact that they are indeed workable concepts. This argument is reinforced by the fact that both these techniques have been used successfully in the past year.

Nets of varying configurations have been tried since the early 1970s. These attempts have been largely unsuccessful and it is our conclusion that the main reason for this is the lack of forethought to several key areas of net design. The most obvious deficiency is the fact that, with the exception of the ESSO Net and Acadian Ice Net, none of the previous designs or prototypes were equipped with what is, in our opinion, a proper bridle arrangement. Another aspect of net use which has been given very little attention is the design or selection of an appropriately powered reel for deployment, recovery, and storage of the net.

Dobrocky Seatech Ltd. feels that these issues have been addressed in this study and it is, therefore, our first recommendation that Ice Arrestor Net #1 (single panel version) be fully evaluated using a conventional supply/anchor handling vessel fitted with a powered reel.

The Ice Arrestor Net incorporates the use of an idea inspired by a net developed by the British Royal Navy to restrain fighter jets at the end of short runways. The mesh members are made of a woven polyester strapping thought to offer certain advantages over rope.

The use of water cannons appears to be very promising for the reasons of simplicity of operation, proven success in an operational scenario, and other reasons as outlined in previous sections of this study. It is, therefore, our second recommendation that, if possible, the vessel selected for net trials be one already equipped with water cannons to allow further testing of this method as well. If this is not possible, a separate test program is recommended.

The concept of using trawler(s) for net deployment is a relatively new one and is largely undocumented. Methods involving the use of this style of vessel may be less prone to sea state limitations. This is attributable to the fact that trawlers have work decks with a comparatively higher freeboard than conventional supply vessels, making deck work safer for personel attempting to deploy equipment. In light of this and the favourable reaction to the idea from members of the marine community, it is deemed worthy of further investigation. Despite the fact that two trawlers would probably cost as much or more to operate than a supply vessel, it is suggested that a test program is worthwhile and could result in significant benefits. This leads to our third recommendation that a pair of trawlers be equipped with the net suggested above and a proper evaluation be conducted.

Implementation of these recommended test programs would require substantial funding. A preliminary cost breakdown for budgetary purposes is provided below:

NET TESTING PROGRAM

Assumptions

- Vessel requires additional equipment to enhance positioning accuracy.
- Vessel day rate of $15,000/day (incl. fuel).

	ITEM	COST ($)**
1.	Construct Ice Arrestor Net*	$ 29,800.00
2.	Develop test plan	1,500.00
3.	Construct net reel	10,200.00
4.	Mobilization/Demobilization of all equipment	6,500.00
5.	Vessel lease for 15 days (includes 3 day mobilization, 10 day test program and 2 day demobilization)	225,000.00
6.	Lease of positioning equipment and operator for 10 day test program	23,000.00
7.	Analysis and reporting	3,000.00
		$299,000.00

*Ice Arrestor Net construction cost includes all hardware required (i.e. bridles, shackles, floatation collars, lead lines, etc.).

WATER CANNON TEST PROGRAM

Assumptions

- Nearest appropriate vessel in United Kingdom.
- Vessel requires additional equipment to enhance positioning accuracy.
- Vessel day rate of $15,000/day (incl. fuel).

** All prices given in 1986 $ Canadian

ITEM		COST ($)
1.	Trip to U.K. for vessel selection	$ 2,000.00
2.	Develop test plan	1,500.00
3.	Mobilization/demobilization of all equipment	4,000.00
4.	Vessel lease for 28 days (includes 14 day round trip to U.K., 3 day mobilization, 10 day test program, and 1 day demobilization)	420,000.00
5.	Lease of positioning equipment and operator for 10 day test program	23,000.00
6.	Analysis and reporting	3,000.00
		$453,500.00

TRAWLER TEST PROGRAM

Assumptions

- Little or no modifications required to trawlers net handling or deck equipment.
- Positioning equipment required on one trawler.
- Trawler day rate of $8,000/day (incl. fuel).

ITEM		COST ($)
1.	Construct Ice Arrestor Net	$ 29,800.00
2.	Develop test plan	1,500.00
3.	Mobilization/demobilization of all equipment	3,500.00
4.	Lease of two trawlers for 13 days (includes 2 day mobilization, 10 day test program, 1 day demobiliztion)	208,000.00
5.	Lease of positioning equipment and operator for 10 day test program	23,000.00
6.	Analysis and reporting	3,000.00
		$268,800.00

Test program costs as outlined above may be reduced significantly depending upon circumstances at the time. If, for example, a suitably equipped FiFi vessel is available in eastern Canadian waters, this would eliminate two weeks of vessel transit time. Also, carrying out the Net Testing Program concurrently with the Water Cannon Test Program is an option which could conserve funds. If this were possible, perhaps a longer field program could be implemented. Furthermore, if testing could be carried out near a fixed reference point which was a good radar target, there may not be a need for expensive positioning equipment.

Still other options include the outfitting of a vessel being used in operational support of a rig with a net and reel or small scale prototype testing at the new Institute for Marine Dynamics facility in St. John's.

These are all options which can be evaluated in the planning stages of any testing program. However, the costs given above are considered to be the minimum necessary to run each program entirely independent of the others.

It is suggested that the test program(s) commence approximately mid to late April, as there should be a plentiful supply of growlers and bergy bits at that time and should take place in the northeastern Grand Banks area. Actual start date should be finalized based on regional ice surveillance results.

APPENDIX 1

Questionnaire
for
Supply Vessel/Fishing Vessel Masters
Operating on the East Coast

MANAGEMENT OF SMALL ICE MASSES

Questionnaire
for
Supply Vessel/Fishing Vessel Masters
Operating on the East Coast

1) Have you been involved in previous techniques and/or experiments to handle small ice masses (i.e. nets, rope towing, water cannon, ice anchors, grappling hooks, propeller washing, bow pushing, suction cups, etc.)? If yes, please elaborate by describing the technique and its success/failure rates and reasons for success/failure, and what are the advantages or limitations over conventional floating rope towing.

2) Please describe your present management techniques for small ice masses and their reliability or success rates.

3) Do you feel an envelope-net system is a viable tool for deflecting/towing bergy bits, growlers, etc.?

4) For the purposes of small ice mass management using a net or tow rope, what do you consider to be a small ice mass?

<u>Mean</u>: length__(m), width__(m), draft__(m), height__(m)
<u>Maximum</u>: length__(m), width__(m), draft__(m), height__(m)

5) What is the most common form of instability while towing small bergs? <u>A</u> Tilting forward, <u>B</u> Tilting backwards, <u>C</u> Revolving on its axis.

6) Would you be more likely to prop wash a small ice mass or use an ice net?

7) What net dimensions, both length and depth, would be required to accommodate the majority of small ice masses?

8) What net dimensions, both length and depth, would be the most effective and most feasible and easiest to handle by your deck crew?

9) Would a net of 150 ft. x 40 ft. be workable, considering that these dimensions represent the average work area of a supply vessel?

10) Would it be acceptable to fit length and depth extensions on board, assuming they can be snapped on with minimum effort? What would be the maximum sea state in which this could be done?

11) Would it be acceptable for crew members to snap floatation buoys on and off the net from a safe position, during shooting and hauling manoeuvers? What would be the maximum sea state in which this could be done?

12) Is there a high incidence of abrasion damage to towing equipment from the ice mass when towing? From your experience, what type of material has the best abrasion resistant properties?

13) How do you feel the net should be constructed? How large need the mesh size be? What materials should be used in construction to aid handling and reduce bulkiness, i.e. nylon webbing, wire rope, polypropylene rope?

14) Do you feel a deck-mounted storage reel for the ice net for those vessels without spare pennant reels would be a suitable idea?

15) Would it be to the operator's advantage or disadvantage to sacrifice deck space, temporarily or permanently, to accommodate reel storage systems for towing hawsers and net, as opposed to manual stowage on deck?

16) What is the opinion on towing arrangments: a single towing point or double hookup to the tow vessel?

17) At present, vessels tow from the center line on a single line. Would it be beneficial to transfer the towing point to the starboard side under the following conditions?
Vessel towing north, wind and tide from the east.
Would you agree this would alleviate the westerly set and drift?

18) Do you feel that two vessels towing one ice net between them could effectively perform in areas of pack ice, bergy bits, etc.?

19) Would you agree that synthetic rope, left to its own devices, presents a severe hazard to shipping (i.e. propeller fouling) and should be stowed on board at all times when not in use?

20) Are bow or stern thrusters employed during towing?

21) What is your opinion on the use of tension meters to monitor the tow?

22) Would the load cell type tension meter be more prone to impact damage than the hydraulic cylinder type?

23) Please supply a range of monitored towline tensions while towing bergs.

24) Do the tension meters fluctuate considerably while towing with synthetic rope? If so, how much?

25) What would be an approximate distance of towing vessel to berg, in order to dissipate propeller wash, before it impinges on the berg and negates the towing effort?

26) At what distance from the ice mass would the vessel commence net shooting procedures? How dependent is their distance on the environmental conditions at that time? What would be the limiting sea state (assume a net size of 150 ft. x 40 ft.)?

27) What is the most predominant factor in the natural movement of small ice masses: A Sea state, B Wind velocity, C Tidal current, D Wind generated currents.

28) What is the current procedure employed to navigate safely around the ice mass prior to towing (i.e. to look for underwater ledges, etc.)?

29) Do you think a basic sonarscope with range, bearing, and tilt incorporated in a hull-mounted transducer with hoist and lowering facilities would be an asset to determine the underwater characteristics of the ice mass prior to encirclement?

30) On a percentage basis, what environmental conditions are most likely during periods of ice mass presence?

Wind (Beaufort Scale)	0-2	3-5	6-7	8-9	10-11	11+
	___%	___%	___%	___%	___%	___%

Tidal Current (knots)	0	0.5-1.0	1.0-2.0	2.0-3.0	3.0+
	___%	___%	___%	___%	___%

Wave Height (feet)	0-1	1-2	2-4	4-8	8-13	13-20	20-30	30-45
	___%	___%	___%	___%	___%	___%	___%	___%

Visibility	Fog	Rain	Snow	Darkness
	___%	___%	___%	___%

Freezing Spray	None	Occasional	Frequent	Continuous
	___%	___%	___%	___%

31) At what sea state do you consider ice net hookup impossible, assuming the ice net hookup to be extremely similar to conventional ice towing line hookup?

32) Other Comments

Should you have additional comments, please list them in the space provided below.

APPENDIX 2

Questionnaire
for
Offshore Oil and Gas Exploration Companies
Operating on the East Coast

MANAGEMENT OF SMALL ICE MASSES

Questionnaire
for
Offshore Oil and Gas Exploration Companies
Operating on the East Coast

1) What are your views on the concept of deflecting small ice masses by an envelope-net system, as opposed to encirclement by the single rope method?

2) For the purposes of small ice mass management using a net or tow rope, what do you consider to be a small ice mass?

<u>Mean</u>: length__(m), width__(m), draft__(m), height__(m)
<u>Maximum</u>: length__(m), width__(m), draft__(m), height__(m)

3) What net dimensions, both length and depth, would be the most effective and most feasible and easiest to handle by your deck crew?

4) What would be a reasonable average and maximum number of small ice masses per rig in your drilling area for normal and extreme ice years?

5) Is there a high incidence of abrasion damage to towing equipment from the ice mass when towing? From your experience, what type of material has the best abrasion resistant properties?

6) Would it be to the operator's advantage or disadvantage to sacrifice deck space, temporarily or permanently, to accommodate reel storage systems for towing hawsers and net, as opposed to manual stowage on deck?

7) What is your opinion on the use of tension meters to monitor the tow?

8) Do you feel that two vessels towing one ice net between them could effectively perform in areas of pack ice, bergy bits, etc.?

9) What is the most common form of instability while towing small bergs? <u>A</u> Tilting forward, <u>B</u> Tilting backwards, <u>C</u> Revolving on its axis.

10) What is the most predominant factor in the natural movement of small ice masses: <u>A</u> Sea state, <u>B</u> Wind velocity, <u>C</u> Tidal current, <u>D</u> Wind generated currents.

11) On a percentage basis, what environmental conditions are most likely during periods of ice mass presence?

Wind (Beaufort Scale)	0-2	3-5	6-7	8-9	10-11	11+		
	___%	___%	___%	___%	___%	___%		
Tidal Current (knots)	0	0.5-1.0	1.0-2.0	2.0-3.0	3.0+			
	___%	___%	___%	___%	___%			
Wave Height (feet)	0-1	1-2	2-4	4-8	8-13	13-20	20-30	30-45
	___%	___%	___%	___%	___%	___%	___%	___%
Visibility	Fog	Rain	Snow	Darkness				
	___%	___%	___%	___%				
Freezing Spray	None	Occasional	Frequent	Continuous				
	___%	___%	___%	___%				

12) Please define the maximum sea state and visibility conditions in which you would like the system to be deployable safely.

13) At what sea state do you consider ice net hookup impossible, assuming the ice net hookup to be extremely similar to conventional ice towing line hookup?

14) What percentage of the time would the net have to be deployed in areas of pack ice? During exploratory drilling? During early floating production?

15) Please define the maximum acceptable initiation and stand down times for towing small ice masses with nets.

16) Please provide, for the vessels you normally use or charter, the following information:

a) overall dimensions;
b) deck size;
c) power developed;
d) bollard pull;
e) hydraulic system specifications;
f) electrical power;
g) country of manufacture;
h) power of search lights;
i) ice classification;
j) main towing winch specifications.

17) Have you been involved in previous techniques and/or experiments to handle small ice masses (i.e. nets, rope towing, water cannon, ice anchors, grappling hooks, propeller washing, bow pushing, suction cups, etc.)? If yes, please elaborate by describing the technique and its success/failure rates and reasons for success/failure, and what are the advantages or limitations over conventional floating rope towing.

18) Do you have the towing logs from past small ice mass towing operations? Would you be prepared to let our company have access to or copies of these logs for use in this study?

19) Are there other personnel in your company of affiliated companies who could provide input to this study? If so, please provide name, address, and telephone/telex numbers.

20) What would you expect to pay for a reliable and effective net and handling system that would be quickly interchangeable amongst your vessels? A less than $75.000, B $75,000 - $100,000, C $100,000 - $150,000, D greater than $150,000.

21) Other Comments

Should you have additional comments, please list them in the space provided below.

APPENDIX 3

Mailing List for Questionnaires

This section lists all companies which received copies of the questionnaire. The responding companies and individuals are indicated with boldface print. In some cases where one individual responded for another, their name is indicated in parentheses.

MAILING LIST
Offshore Oil and Gas Exploration Companies

MOBIL OIL CANADA, LTD.
Atlantic Place
Box 62, 215 Water Street
St. John's, NF
A1C 6C9

Attention: **J. Ransom (M. Hassell)**
J. Benoit
D. North
R. Fraser

PETRO-CANADA INC.
P.O. Box 5190
St. John's, NF
A1C 6H2

Attention: **D. Betts**
B. Garbett

PETRO-CANADA INC.
P.O. Box 2844
Calgary, AB
T2P 3E3

Attention: **J.D. Miller (D. Nazarenko)**
C.M.D. Perry
S. Melrose
A.P. Fink

ESSO RESOURCES CANADA LIMITED
339 - 50th Avenue S.E.
Calgary, AB
T2G 2B3

Attention: L.G. Spedding

BP CANADA INC.
333 - 5th Avenue S.W.
Calgary, AB
T2P 3B6

Attention: E. Somerville
R.M. Redgate

CANTERRA ENERGY LIMITED
P.O. Box 5640
St. John's, NF
A1C 5W4

Attention: S. Johnston
I. Cawardine
W.P. Nicholls

SHELL CANADA RESOURCES LIMTIED
Suite 1810 - Queen Square
45 Alderney Drive
Dartmouth, NS
B2Y 3X6

Attention: R. Fodchuk
R. Barnes

CHEVRON OIL FIELD RESEARCH COMPANY
P.O. Box 446
La Habra, CA 90631
U.S.A

Attention: L. Brooks

MAILING LIST
Offshore Oil and Gas Exploration Companies (cont'd)

SHELL CANADA RESOURCES LIMITED
400 - 4th Avenue S.W.
Calgary, AB
T2P 2H5

Attention: D. Scott

CHEVRON CANADA RESOURCES LTD.
500 - 5th Avenue
Calgary, AB
T2P 0L7

Attention: E. Gartenbaum

ESSO RESOURCES CANADA LIMITED
ESSO Plaza
237 - 4th Avenue S.W.
Calgary, AB
T2P 0H6

Attention: M.I. Comyn
K. Yurkowski

HUSKY/BOW VALLEY EAST COAST PROJECT
Box 79, 215 Water Street
St. John's, NF
A1C 6C9

Attention: G. Warbanski
R. Sauer

GULF CANADA RESOURCES INC.
401 - 9th Avenue S.W.
Calgary, AB
T2P 2H7

Attention: K. Gaida
B.D. Wright

MAILING LIST
Fishing and Supply Vessel or Related Companies

HUSKY MARINE SERVICES
Box 37, 215 Water Street
Suite 707, Atlantic Place
St. John's, NF
A1C 6C9

Attention: **B. Allingham**

WOLF OFFSHORE TRANSPORT LTD.
Topsail Road
P.O. Box 1447
St. John's, NF
A1C 5N8

Attention: Capt. P. Jarmen
Capt. L. Messervey
Capt. M. Zelman

FISHERIES & OCEANS CANADA
Fisheries Department Branch
1649 Hollis Street
P.O. Box 550
Halifax, NS
B3J 2S7

Attention: **J. Rycroft**

DOBROCKY SEATECH LTD.
Suite 48, 1000 Windmill Road
Dartmouth, NS
B3B 1L7

Attention: **Capt. S. Nicholls**

COLLEGE OF FISHERIES, NAVIGATION, MARINE ENGINEERING, AND ELECTRONICS
P.O. Box 4920
St. John's, NF
A1C 5R3

Attention: Capt. Thornhill
Capt. B. Innes

BALDER OFFSHORE CANADA INC.
1525 Birmingham Street
P.O. Box 3550 South
Halifax, NS
B3J 3J3

Attention: Capt. H. Pitcher

HARVEY OFFSHORE SERVICES LTD.
Old Factory Road
P.O. Box 5128
St. John's, NF
A1C 5V6

Attention: A. Cody

SEAFORTH FEDNAV INC.
Suite 809, Atlantic Place
P.O. Box 5099
St. John's, NF
A1C 5V3

Attention: P.C. Locke

NATIONAL SEA PRODUCTS
P.O. Box 31
Atlantic Place
St. John's, NF
A1C 6C9

Attention: Capt. B. Parsons

CROSBIE OFFSHORE SERVICES INC.
P.O. Box 12092
St. John's, NF
A1B 3T5

Attention: Capt. Spellacy

MAILING LIST

Fishing and Supply Vessel or Related Companies (cont'd)

SECUNDA MARINE SERVICES LIMITED
P.O. Box 377
45 Alderney Drive
Dartmouth, NS
B2Y 3Y5

Attention: F. Smithers

TRANSPORT CANADA
Canadian Coast Guard
P.O. Box 1300
St. John's, NF
A1C 6H8

Attention: Capt. A. Rowsell

WIMPEY SABLE MARINE LIMITED
1459 Hollis Street
Halifax, NS
B3J 1V1

Attention: Captain H.A. Allan

APPENDIX 4

List of Interviewed Personnel

LIST OF INTERVIEWED PERSONNEL

Operations Personnel

1. Mike Hassell, Mobil Oil Canada, Ltd.
2. Greg Warbanski, Husky/Bow Valley East Coast Project
3. Erik Banke, Husky/Bow Valley East Coast Project

Supply Vessel Personnel

1. Captain Baxter Allingham, Husky Marine Services
2. Captain Michael Zelman, Wolf Offshore Transport Ltd.
3. Captain Les McIntyre, Offshore Atlantic
4. Captain Eric O'Brien, OSA Marine
5. Chris Bailey, Husky Marine Services
6. Captain Lorne Messervey, Wolf Offshore Transportation Ltd.
7. Gerald Tibbo, Acadian Offshore Services Inc.
8. Captain Clinton Guptill, Acadian Offshore Services Inc.

APPENDIX 5
Environmental Statistics

APPENDIX 5
Contents

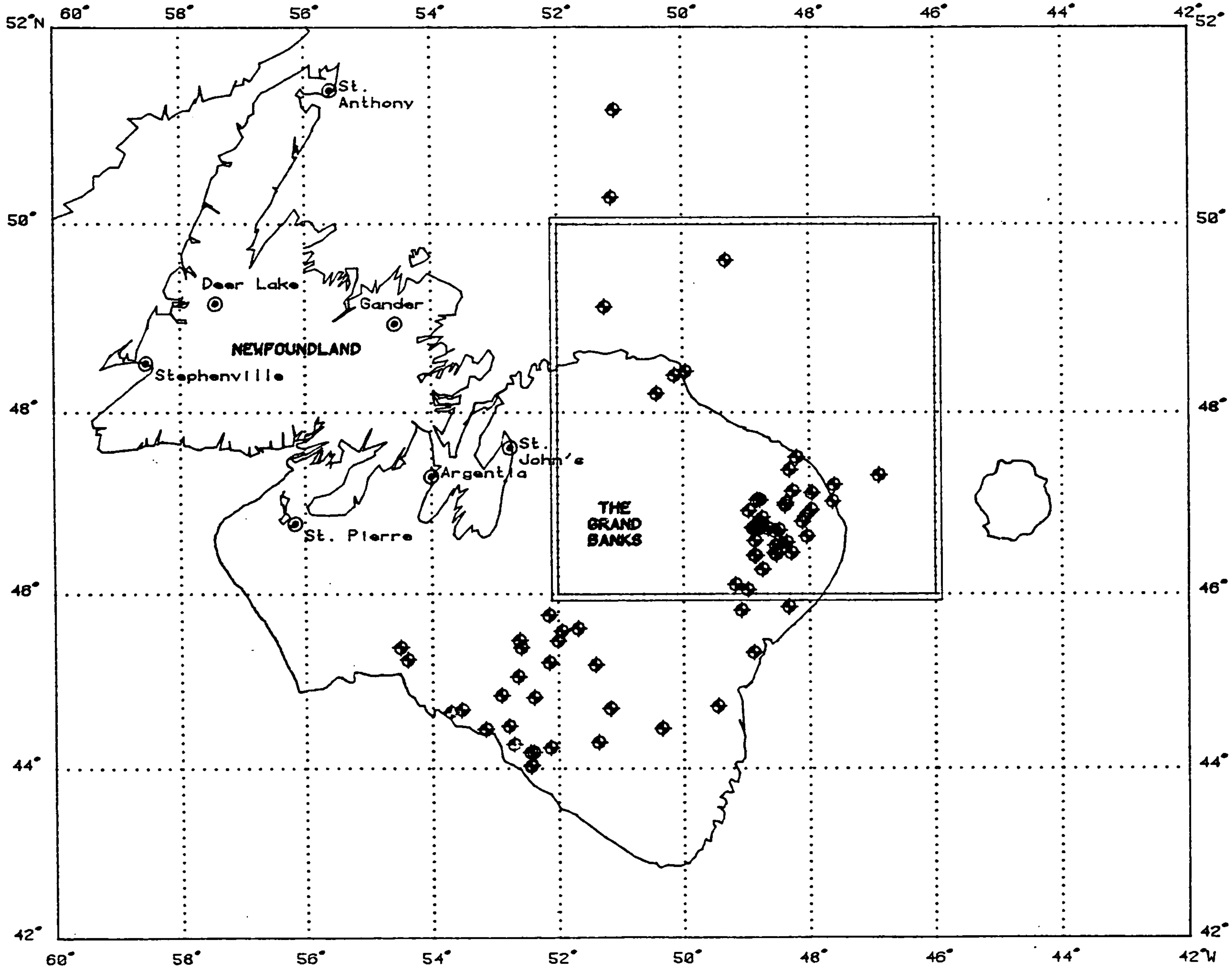


Figure 1. Chart Indicating Study Area Offshore Newfoundland, and 1966-85 Wellsites

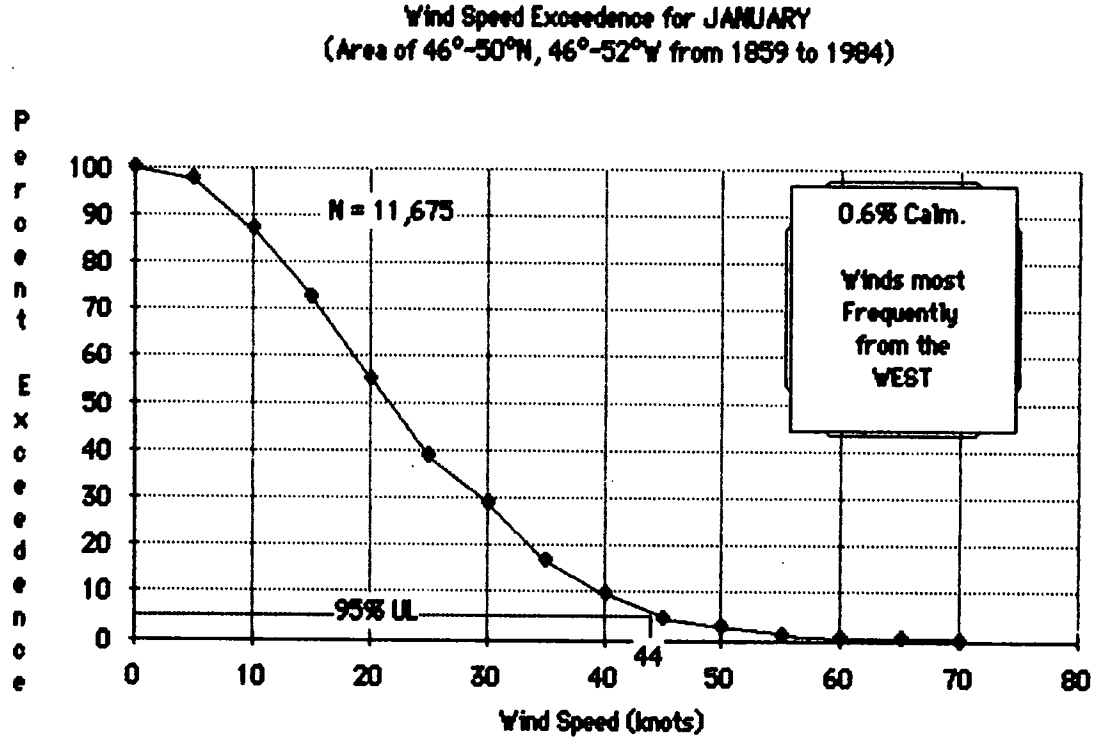


Figure 2.

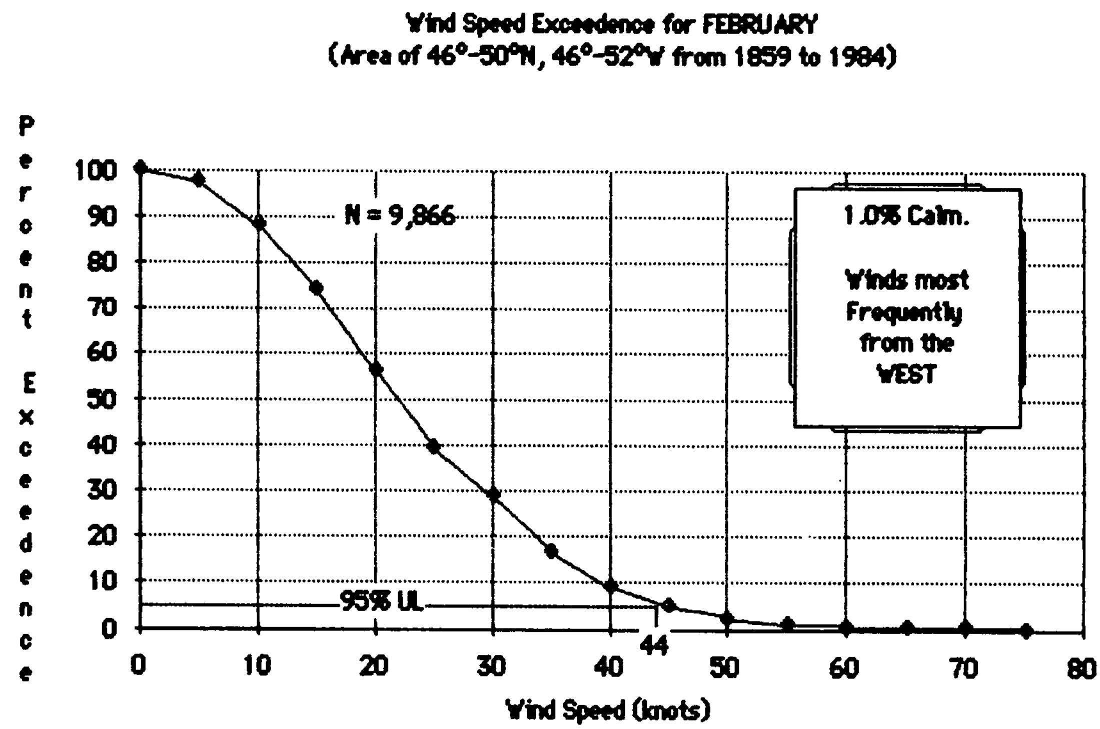
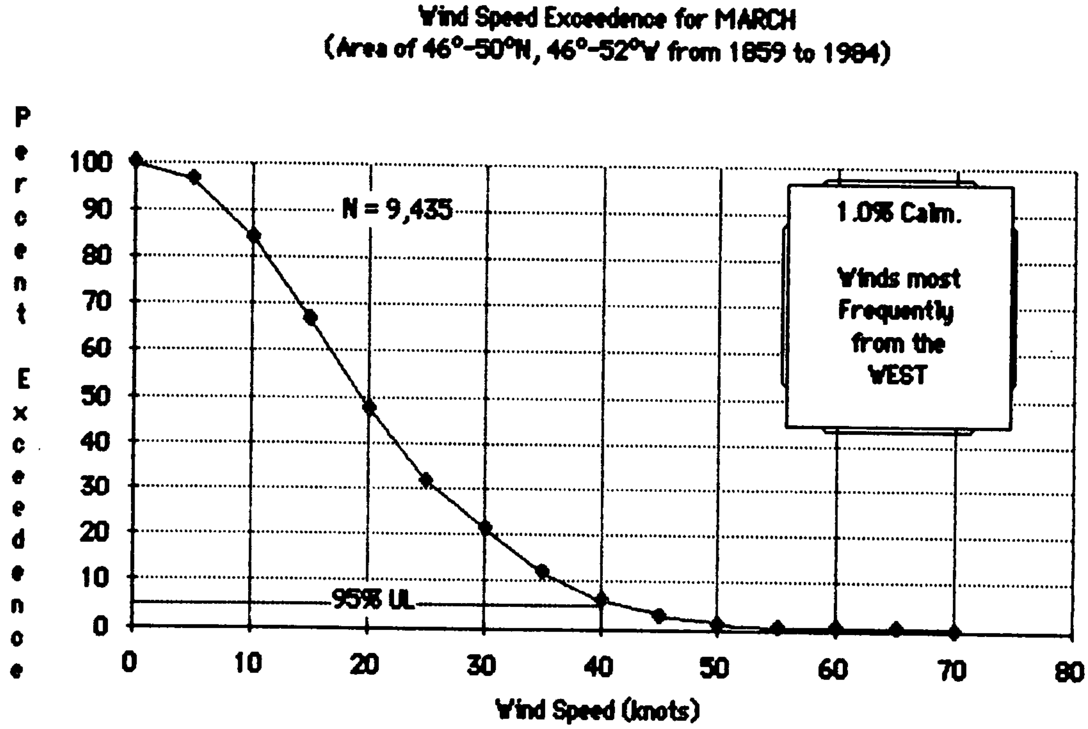


Figure 3.



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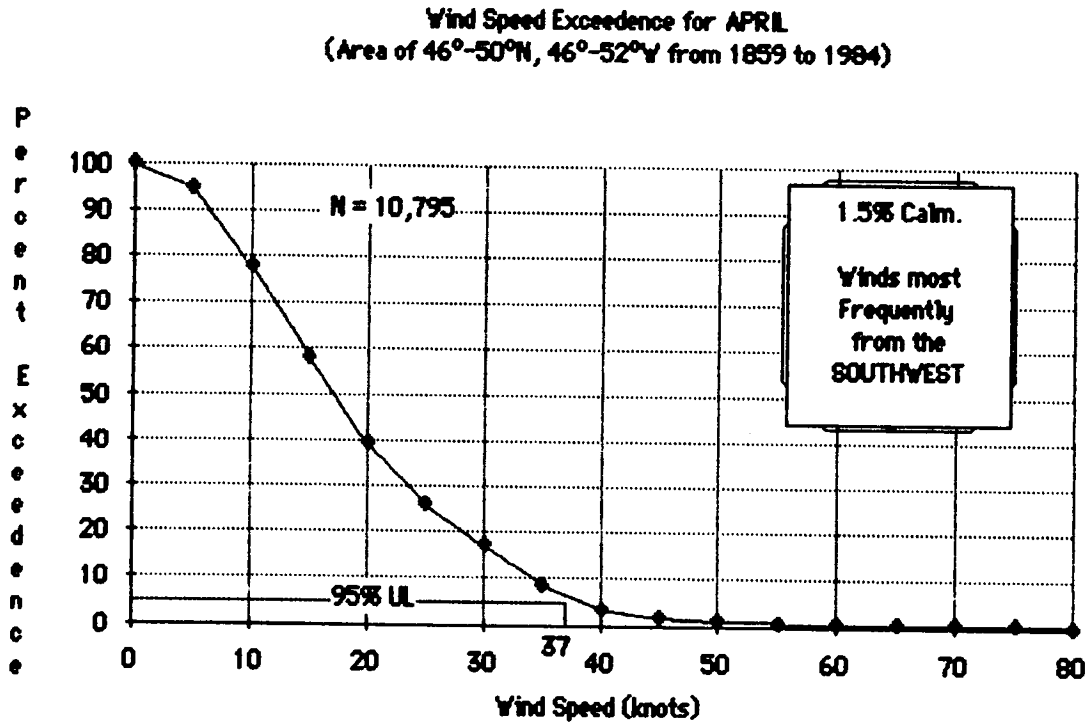
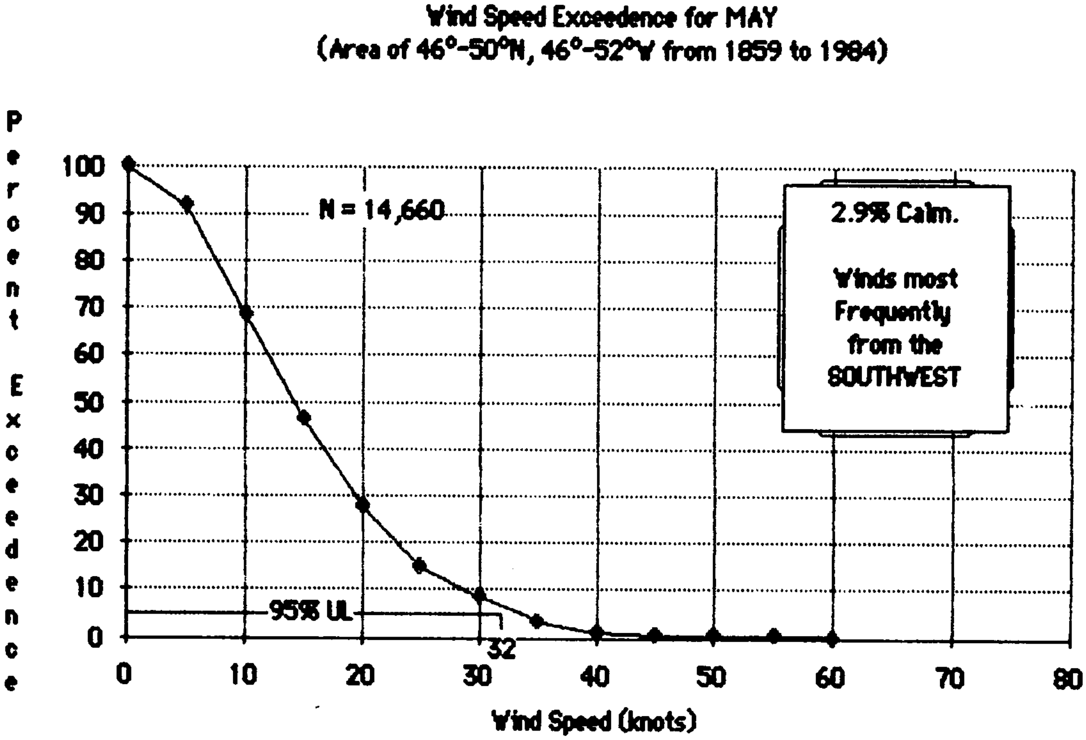


Figure 5.



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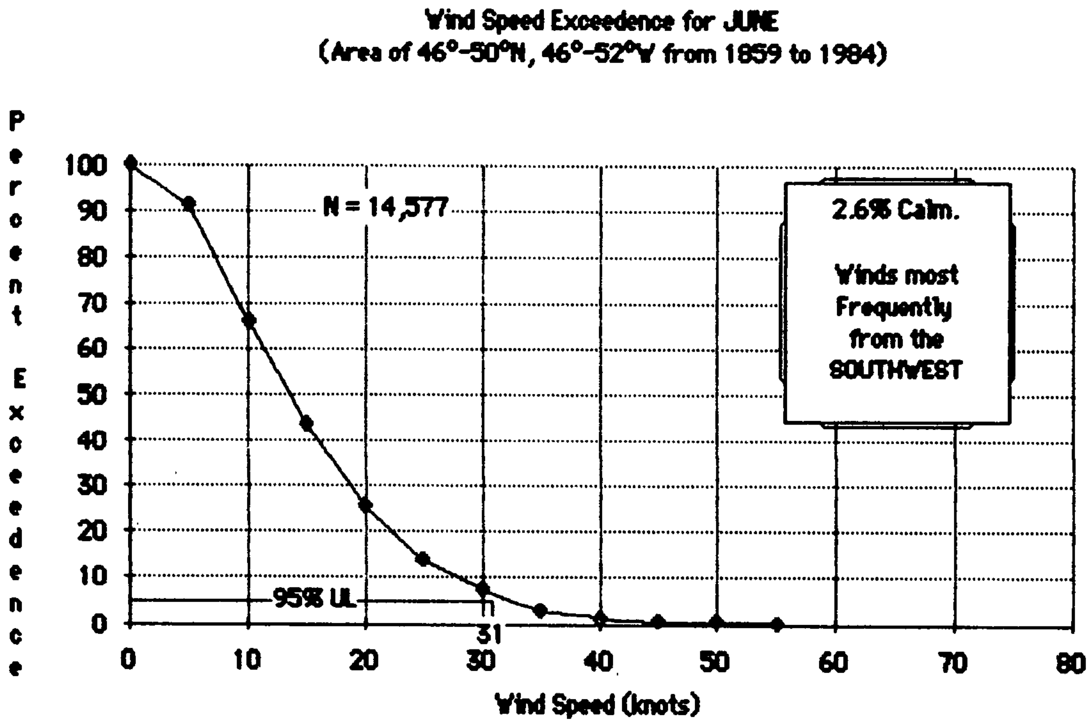

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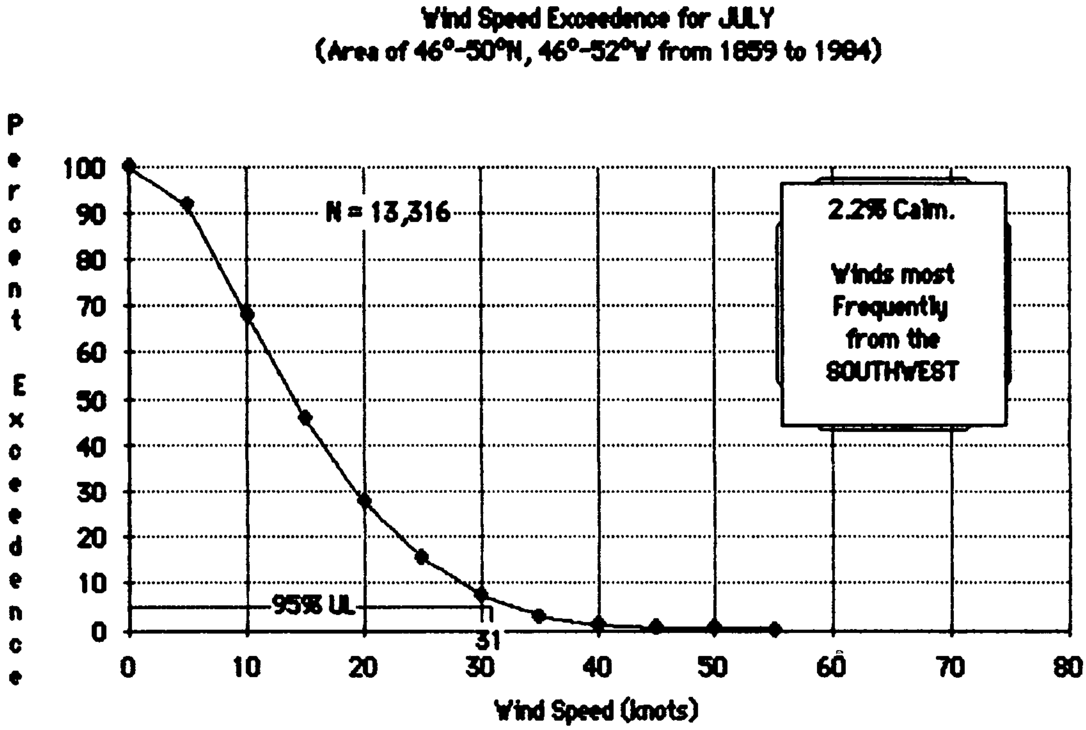

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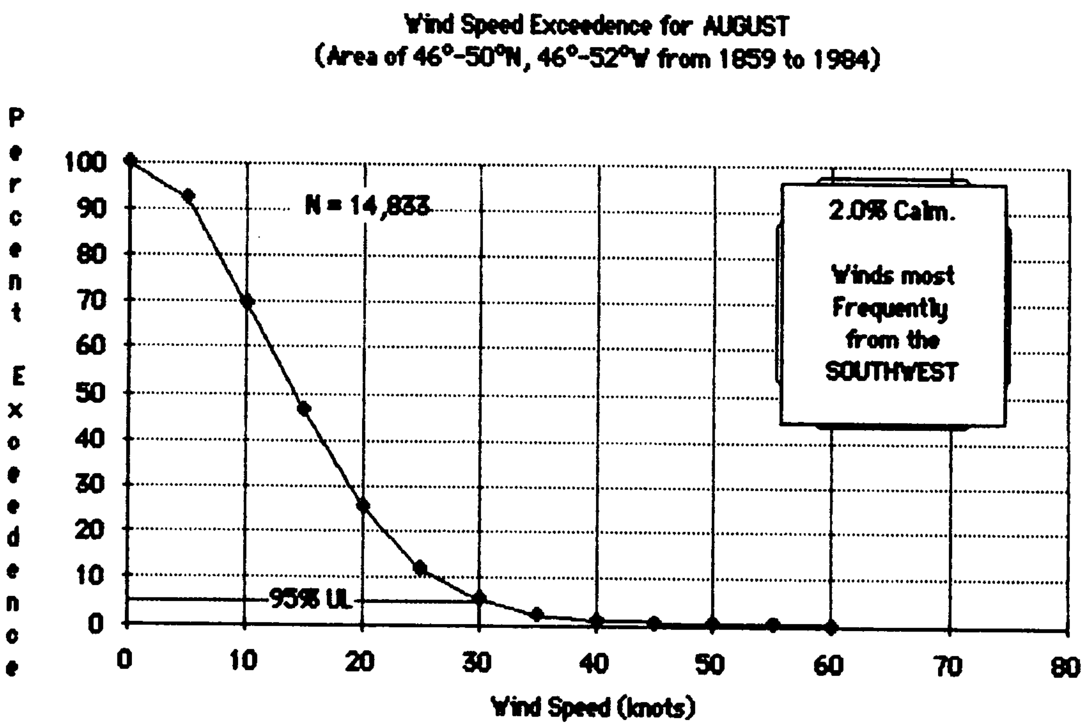

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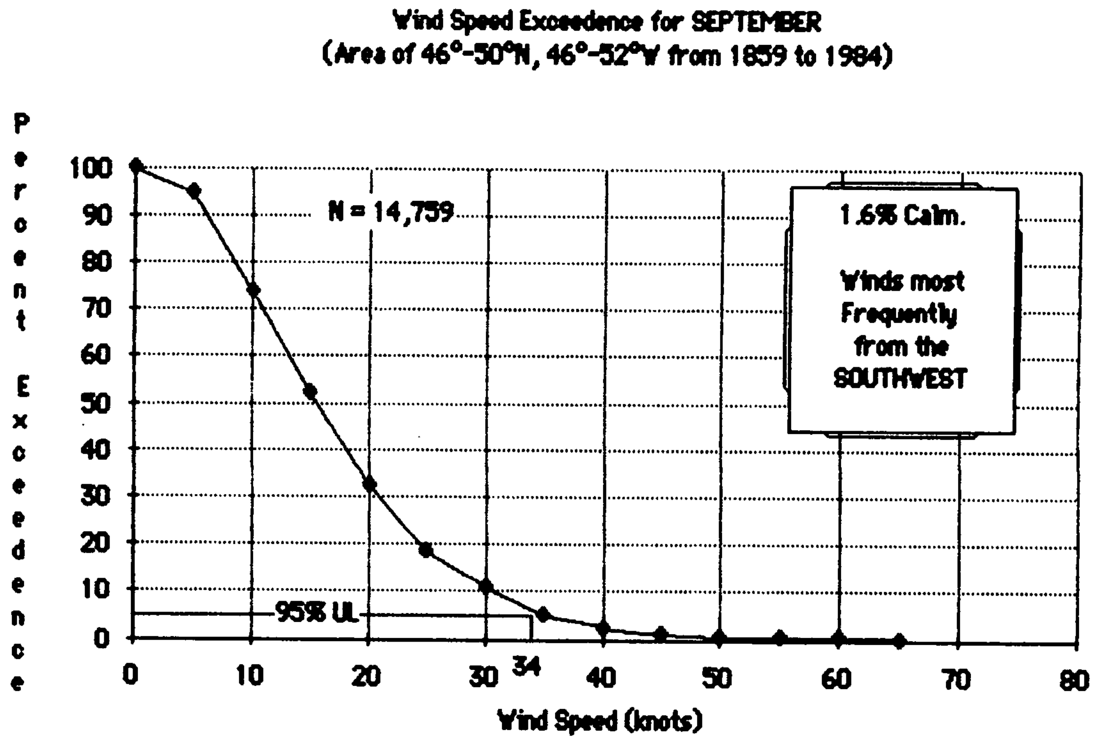
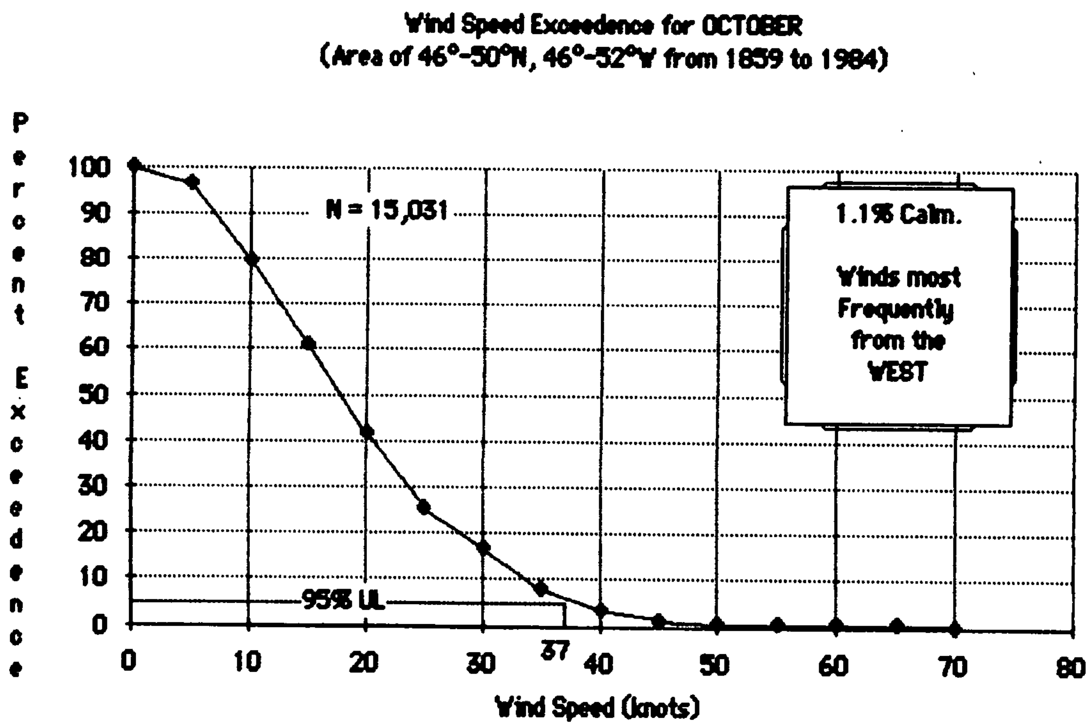


Figure 10.



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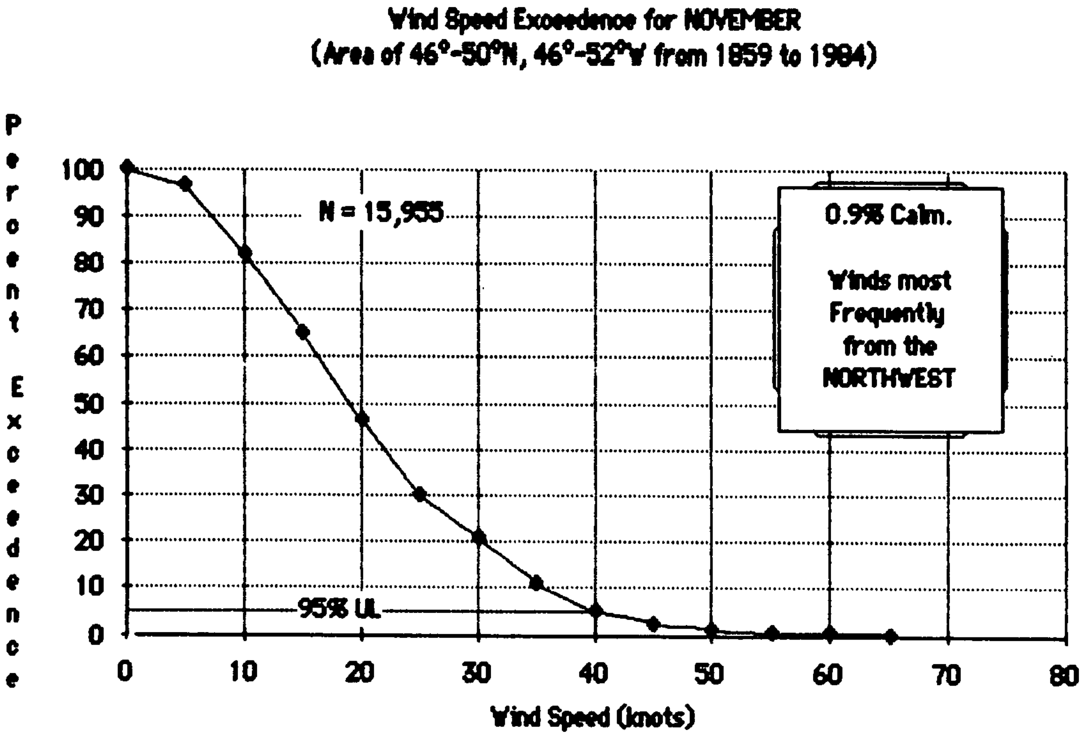

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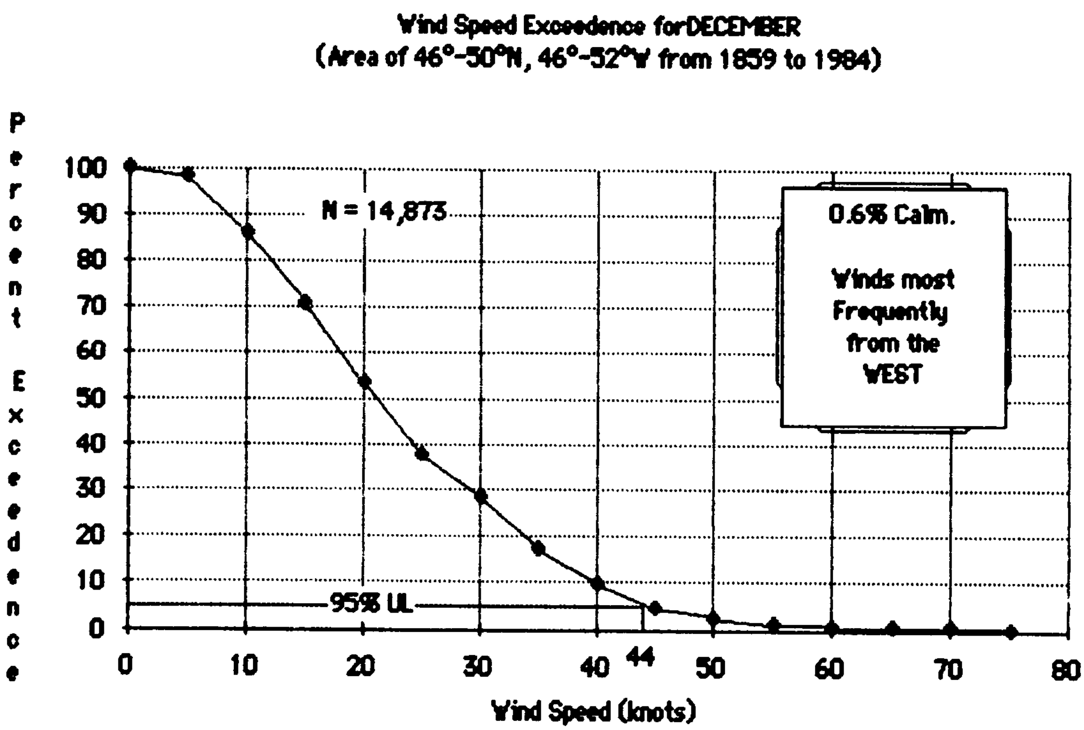


Figure 13.

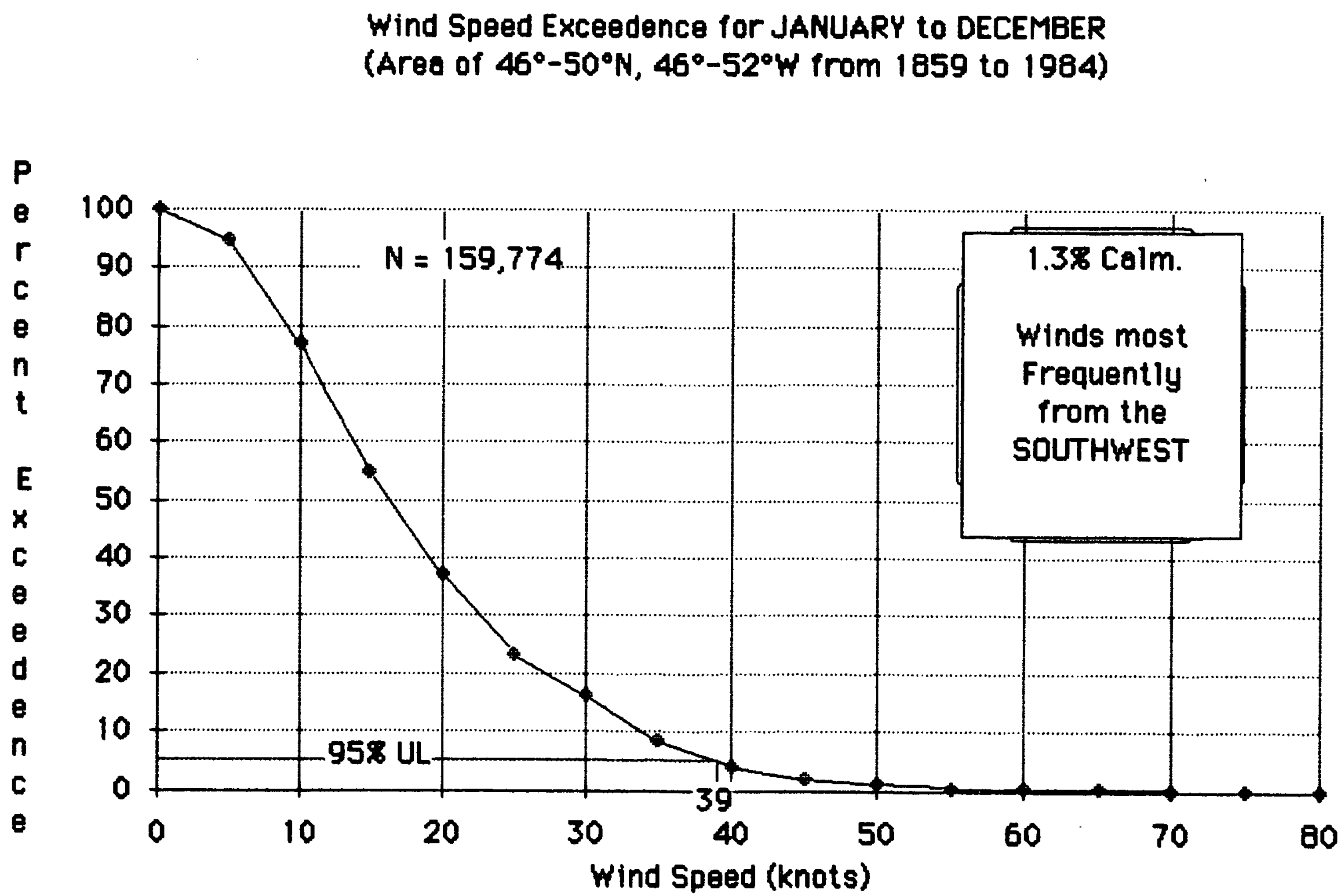
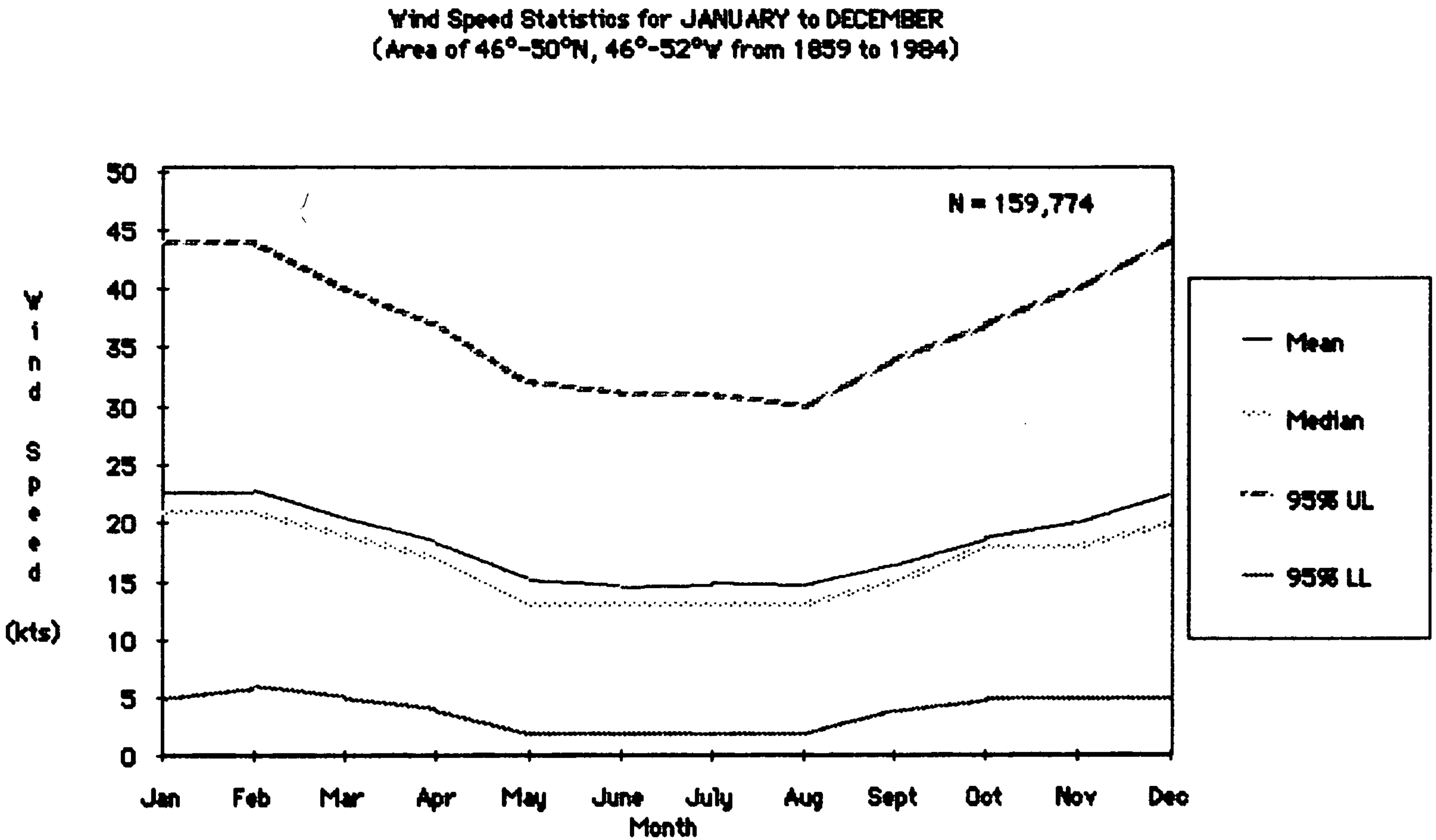

Wind Speed Exceedence for JANUARY to DECEMBER
(Area of 46°-50°N, 46°-52°W from 1859 to 1984)
Percent Exceedence
100
90
80
70
60
50
40
30
20
10
0
N = 159,774
95% UL
39
1.3% Calm.
Winds most Frequently from the SOUTHWEST
0
10
20
30
40
50
60
70
80
Wind Speed (knots)

Figure 14.



Wind Speed Statistics for JANUARY to DECEMBER
(Area of 46°-50°N, 46°-52°W from 1859 to 1984)
N = 159,774
Wind Speed (kts)
50
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
Mean
Median
95% UL
95% LL

Figure 15.

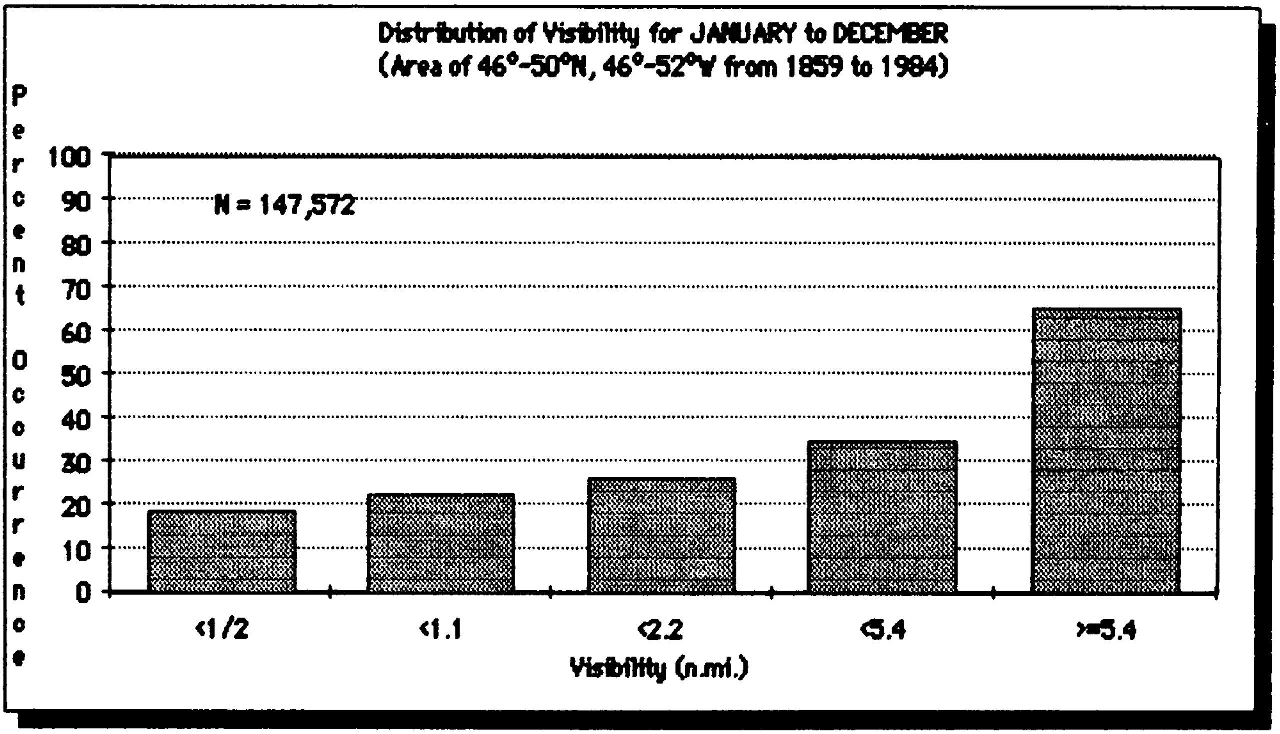


Figure 16.

Table 1. Distribution of visibility by month and overall.

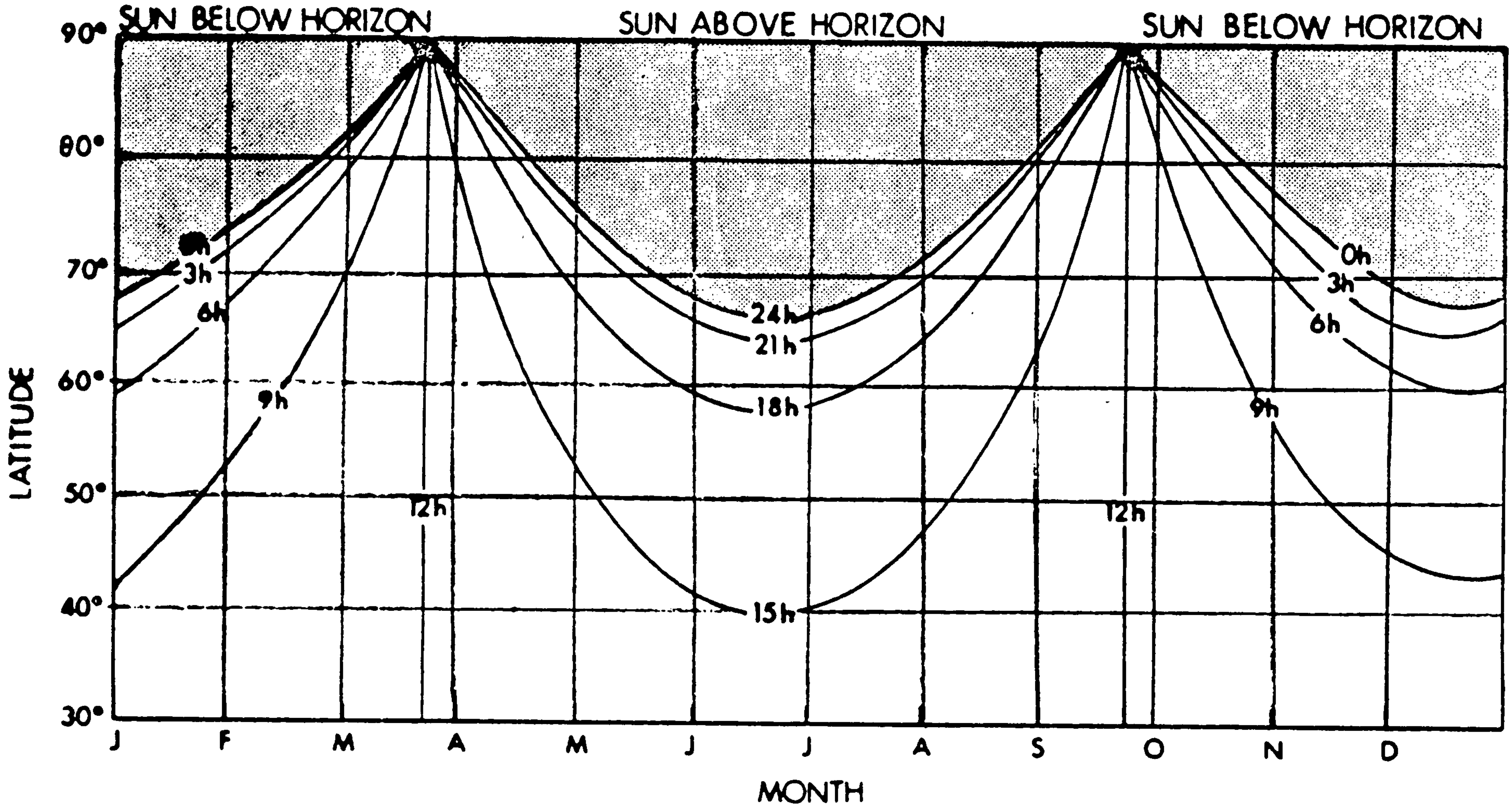
Month	No. of Obs	%<1/2 n.mi	%<1.1 n.mi.	%<2.2 n.mi.	%<5.4 n.mi.	%>=5.4 n.mi.
Jan	10585	8.4	11.5	15.9	26.5	73.5
Feb	9445	11.2	15.1	19.9	31.7	68.3
Mar	9178	13.0	16.7	21.3	31.9	68.1
Apr	10508	20.2	24.8	30.0	40.8	59.2
May	14260	26.2	30.6	34.5	42.9	57.1
June	14099	33.0	37.1	41.0	48.3	51.7
July	12719	43.4	48.2	51.7	58.5	41.5
Aug	13532	22.5	25.8	29.2	37.0	63.0
Sept	12820	11.7	14.4	17.4	24.9	75.1
Oct	13071	9.1	11.4	14.2	21.4	78.6
Nov	14120	9.4	12.3	15.7	23.7	76.3
Dec	13235	7.9	10.7	14.7	24.2	75.8
Jan-Dec	147572	27279	32488	38148	50928	96644
%	100.0	18.5	22.0	25.9	34.5	65.5

Table 2.
Days with Reported Fog at Hibernia

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Fog Days*	99	95	104	151	182	218	205	100	52	60	83	91
Observation Days	250	207	212	256	280	273	244	159	127	139	206	255
Percentage	40	48	49	59	65	80	84	63	41	43	40	39

Note(*): A day on which at least one reported visibility was 1 km or less.

Source: Wellsite Data (1979-1983).

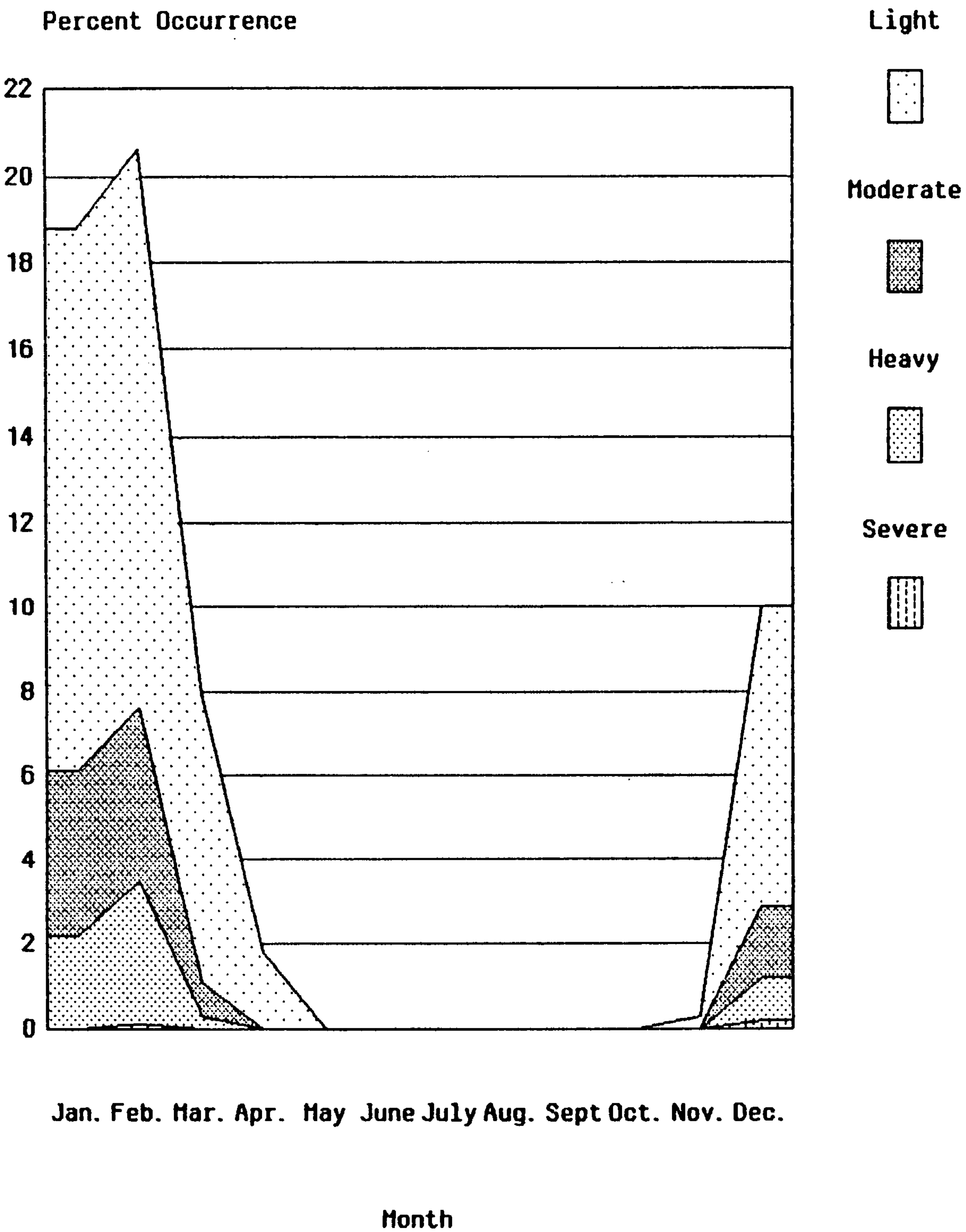


DURATION OF DAYLIGHT (HOURS)

Figure 17. Change in Duration of Daylight by Month and Latitude.

Freezing Spray Potential

(46°-50°N, 46°-52°W)

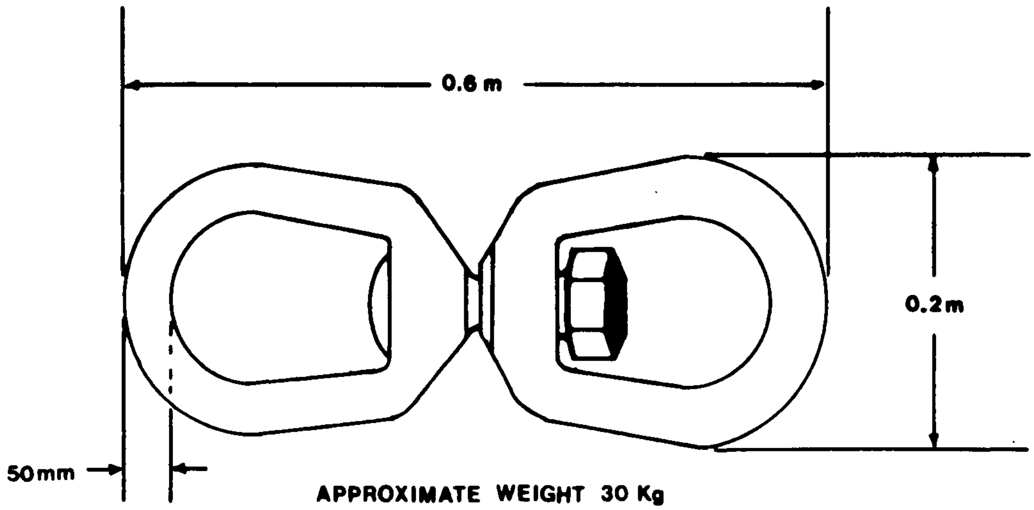


(1859-1984)

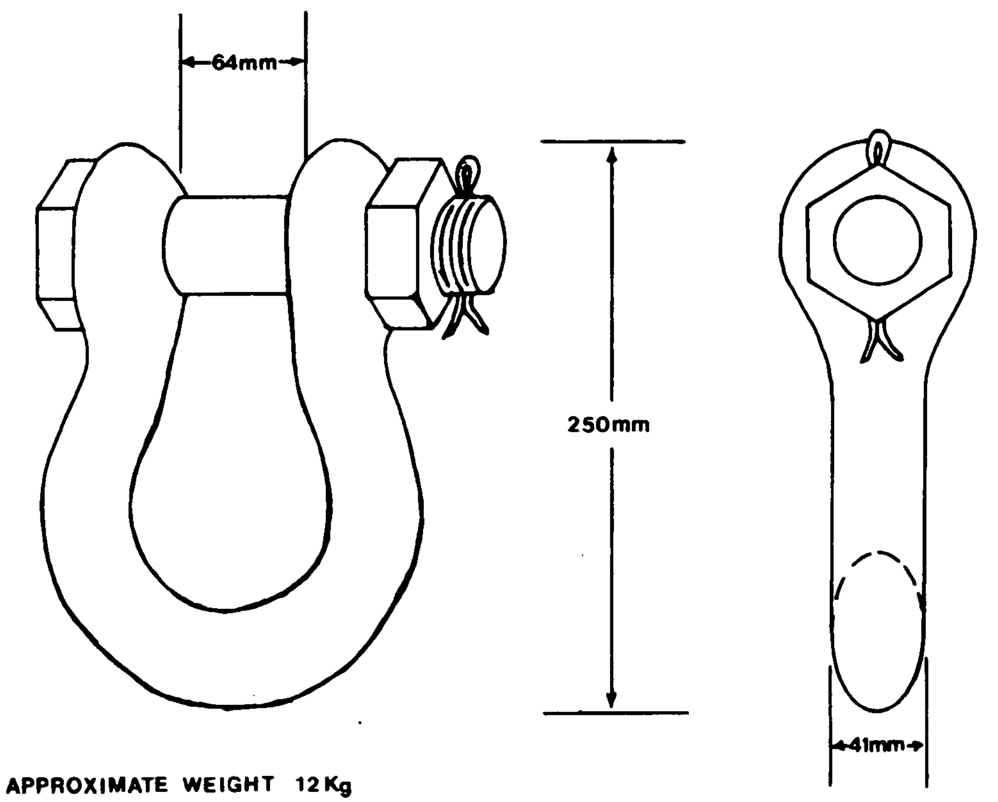
Figure 18.

APPENDIX 6

Typical Marine Hardware

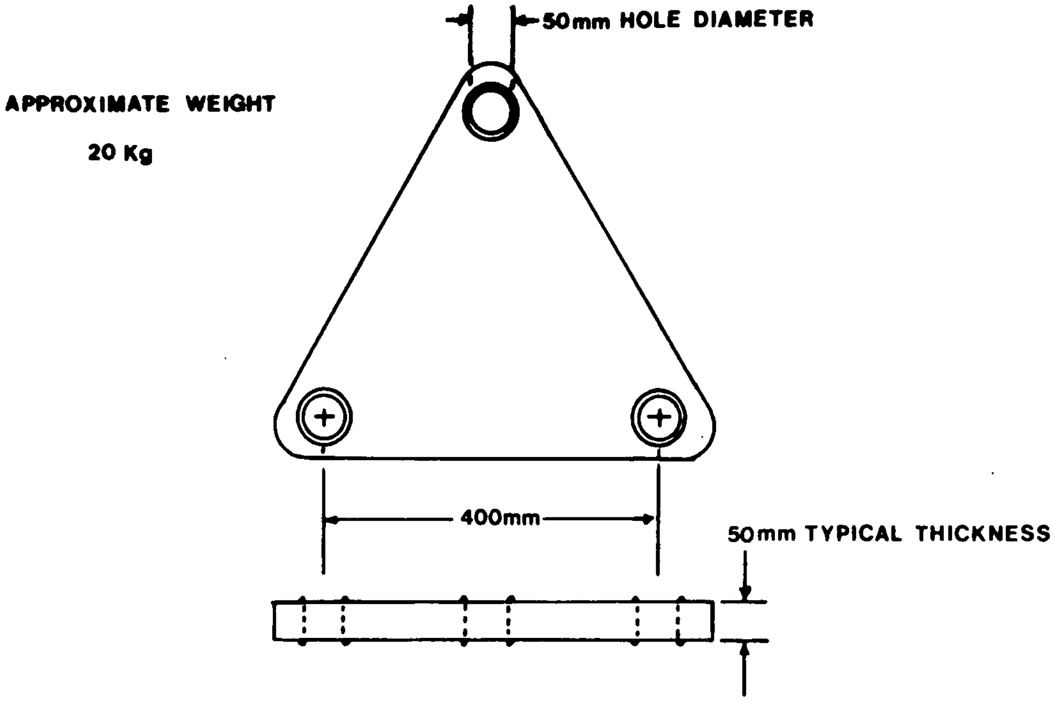


SWIVEL

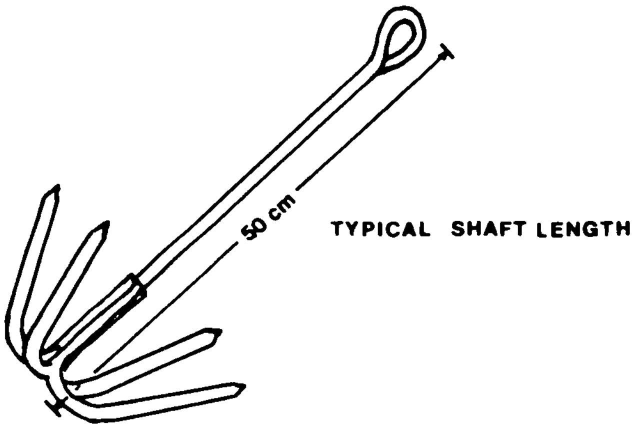


NOTE: S.W.L. (SAFE WORKING LOAD) = 1/6 MINIMUM ULTIMATE STRENGTH

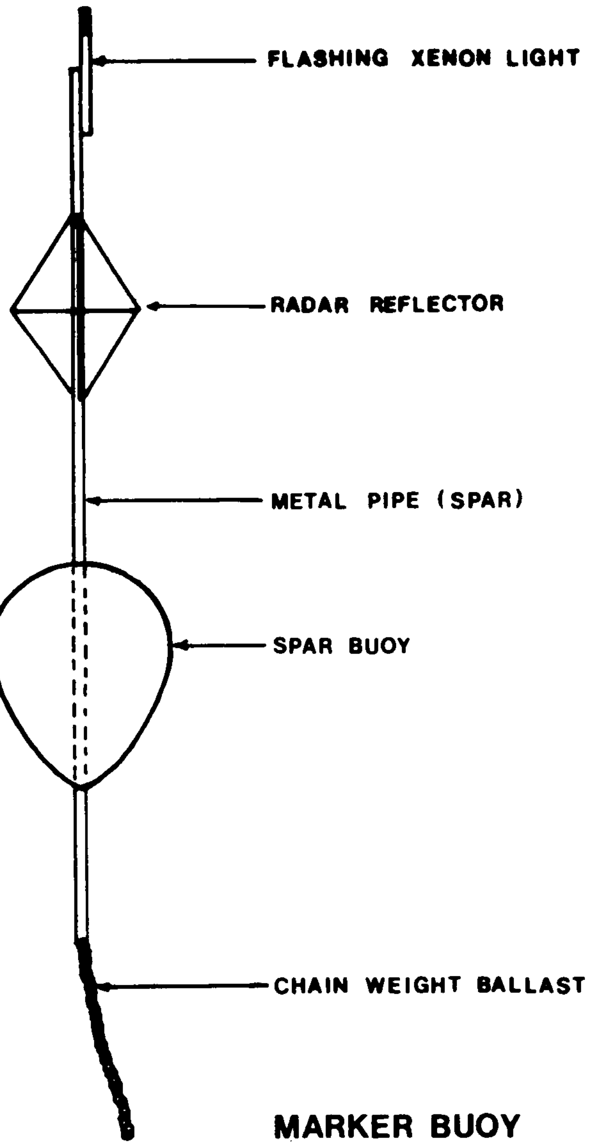
35 TON BOLT TYPE ANCHOR SHACKLE



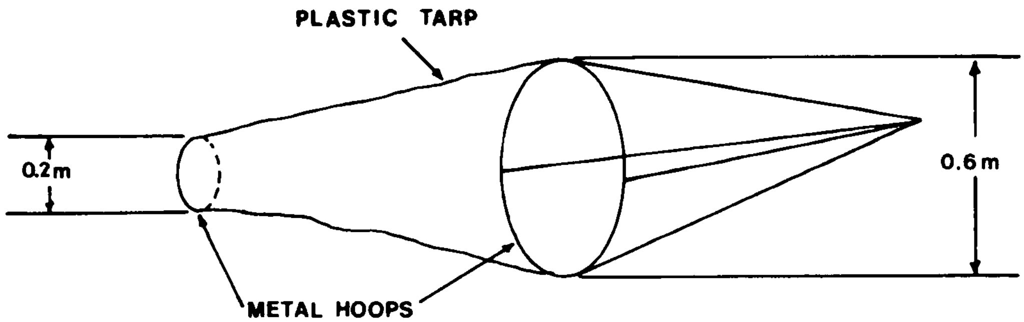
MONKEY-FACE CONNECTOR PLATE



GRAPPLING HOOK



MARKER BUOY



SEA ANCHOR

APPENDIX 7
Strapping and Hardware Specifications

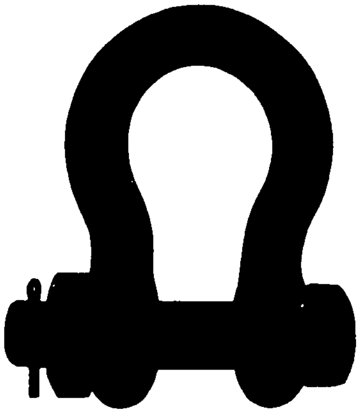
STRAPPING SPECIFICATIONS

S.M.I. NUMBER	COLOR	WEIGHT gr/M	BREAK STRENGTH TENSILE (lbs.)	ELONGATION %
1. 401- 1"	Natural/Nylon	87.2	9860	10.63% @ 2500 lbs.
"	Dyed	92.7	9880	13.13% @ 3600 lbs.
2. 402- 2"	Natural/Nylon	167.0	22,960	6.88% @ 2500 lbs.
"	Dyed	178.0	23,100	5.63% @ 2500 lbs.
3. 403- 3"	Natural/Nylon	242.0	30,940	5.0% @ 2500 lbs.
"	Dyed	256.0	33,220	15.0% @ 10,800 lbs.
4. 404- 4"	Natural/Nylon	322.0	40,400	4.88% @ 2500 lbs.
"	Dyed	340.0	44,200	5.63% @ 2500 lbs.
5. 405- 5"	Natural/Nylon	475.0	62,300	Too Wide for the Machine
"	Dyed	498.0	64,500	"
6. 408- 8"	Natural/Nylon	631.0	78,000	N/A
"	Dyed	N/A	87,000	N/A
7. 442-12"	Natural/Nylon	627.0	80,755	Too Wide for the Machine
"	Dyed	667.0	82,300	"
8. 451- 1"	Natural/PolyESTER	92.15	10,120	5.63% @ 3600 lbs.
"	Dyed	N/A	-----	---------------
9. 452- 2"	Natural/PolyESTER	185.0	18,600	2.5% @ 2000 lbs.
"	Dyed	190.0	21,800	3.5% @ 2000 lbs.
10. 453- 3"	Natural/PolyESTER	269.0	30,900	3.25% @ 2000 lbs.
"	Dyed	N/A	------	----------------
11. 454- 4"	Natural/PolyESTER	365.0	40,040	N/A
"	Dyed	Has Never Been Dyed	------	N/A
12. 1501- 5/8"	Natural/Nylon	18.8	2800	-----------------
"	Finished	18.9	2740	10.63% @ 1000 lbs.
13. 1502- 3/4"	Natural/Nylon	19.591	2100	14.38% @ 1000 lbs.
"	Dyed	19.6	2200	12.50% @ 1000 lbs.
14. 1503- 1"	Natural/Nylon	37.4	3200	15% @ 2500 lbs.
"	Dyed	37.2	3400	18.75% @ 2500 lbs.
15. 1504- 1 3/4"	Natural/Nylon	62.3	8560	15% @ 2500 lbs.
"	Dyed	63.47	8180	12.5% @ 2500 lbs.

S.M.I. NUMBER	COLOR	WEIGHT gr/M	TENSILE (lbs.)	ELONGATION % Pull at
16. 1505- 1 3/4"	Natural/Nylon	102.3	12,120	12.5% @ 2500 lbs.
"	Dyed	105.6	12,300	15.0% @ 2500 lbs.
7. 1505- 1 3/4"	Natural/PolyESTER	117.238	10,260	7.5% @ 2500 lbs.
"	Dyed	120.7	10,360	6.88% @ 2500 lbs.
18. 1506- 3"	Natural/PolyESTER	193.0	16,700	8.13% @ 5000 lbs.
"	Dyed	210.6	17,100	3% @ 2000 lbs.
19. 1507- 4"	Natural/PolyESTER	252.0	23,600	7.5% @ 5000 lbs.
"	Dyed	265.0	24,500	2.13% @ 2500 lbs.
20. 1508- 2"	Natural/Nylon	47.27	5920	6.88% @ 2500 lbs.
"	Dyed	50.616	6120	12.5% @ 2500 lbs.
21. 1509- 2"	Natural/PolyESTER	61.622	6400	8.75% @ 2500 lbs.
	Dyed	61.20	6840	7.50% @ 2500 lbs.
22. 1511- 1½"	Natural/Nylon	25.536	2660	12.5% @ 2000 lbs.
"	Dyed	25.110	2680	10.0% @ 2000 lbs.
23. 1513- 1"	Natural/Nylon	20.654	2940	9.38% @ 1000 lbs.
"	Dyed	20.643	3120	15.63% @ 2500 lbs.
24. 1521- 2"	Natural/Nylon	62.242	5560	9.38% @ 2500 lbs.
"	Dyed	61.809	5620	11.88% @ 2500 lbs.
25. 1521-1+-2"	Natural/Nylon	75.8	8600	16.50% @ 2500 lbs.
"	Dyed	79.7	8800	13.75% @ 2500 lbs.
26. 1530- 1 ½"	Natural/Nylon	63.316	3000	N/A
"	Dyed	57.147	3000	6.88% @ 1500 lbs.
27. 1533- 1"	Natural/Nylon	36.262	3080	N/A
"	Dyed	36.461	3180	16.25% @ 1500 lbs.
"	Dyed	18.1	1600	N/A
28. 1552- 2"	Natural/PolyESTER	158.3	17,640	6.88% @ 10,000 lbs.
"	Dyed	170.364	16,080	13.13% @ 10,000 lbs.
29. 1503-1"	ORANGE/Nylon	31.48	3500	11.25% @ 25~~00~~ lbs.
30. 1518-	Natural/Nylon	69.0	8800	19.84% @ 6,000 lbs.

BOLT TYPE
ANCHOR
SHACKLES

Load Rated



G-2140 S-2140

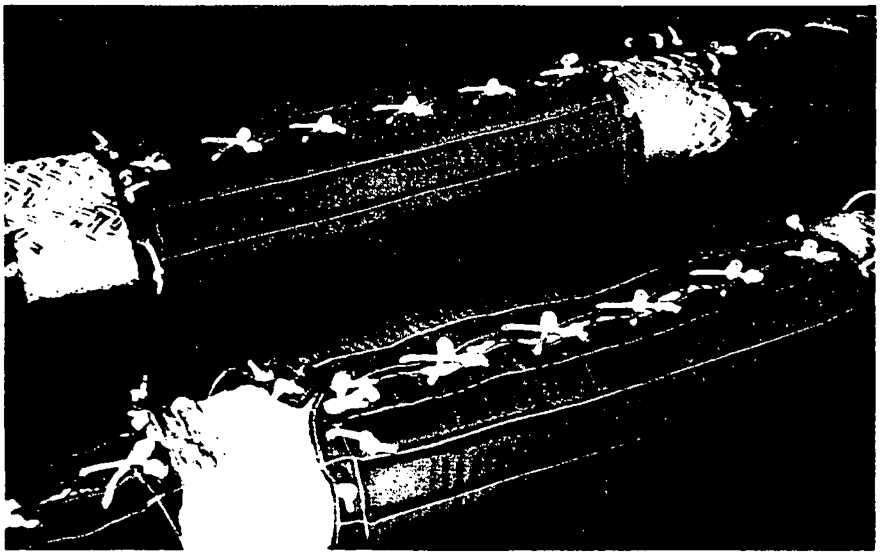
- Safe Working Load is permanently shown on every shackle.
- Alloy bows, Alloy bolts.
- Quenched and Tempered.
- Individually proof tested.

SWL (TONS) WT. (LBS)

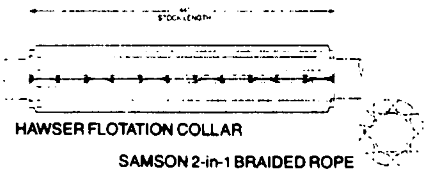
30	1½	5¾	2⅜	1⅝	3⅝	¼	⅛	20.80
40	1¾	7	2⅞	2	4 5/16	¾	⅛	33.91
50	2	7¾	3¼	2¼	5	¾	⅛	51.75
80	2½	10½	4⅛	2¾	6	¾	¼	101.59
110	3	13	5	3¼	6½	¼	¼	178.
140	3½	14⅝	5¼	3¾	8	¼	¼	265.
175	4	14½	5½	4¼	9	¼	¼	338.

*Proof Load is 2.2 times the Safe Working Load.
Minimum Ultimate Strength is 6 times the Safe Working Load.

Flotation and Fenders

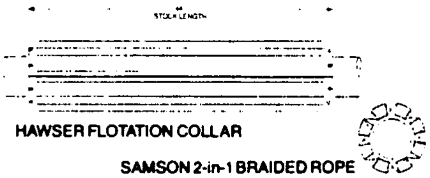


Type A Grommeted Hawser Float



Includes 24 axial positioned grommets, plus 4 radial positioned grommets at each end.

Type B Tubular Hawser Float



Includes 4 radial positioned grommets at each end only. Must be slid over rope.

Samson Rib-Cage Hawser Float

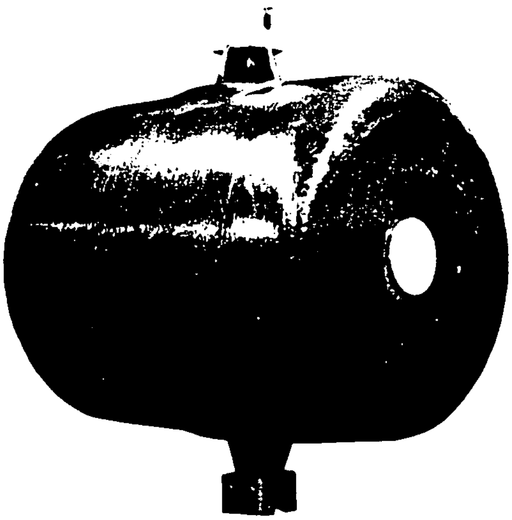
Constructed of double layers of a heavy-duty tear resistant ballistic nylon fabric casing and lightweight flexible closed cell foam ribs.

Size and buoyancy characteristics of ribs are determined by application requirements. When employed over entire length of hawser, floats help extend life of rope by serving as chafe protection as well as flotation. Lace-on design allows easy installation and replacement while in use, and various sizes can be fitted to single or double leg hawser assemblies.

Sleeve type construction available

The Samson Rib-Cage Hawser Float can be left uncoated or it can be sprayed or dipcoated for added abrasion protection and increased anti-fouling properties.

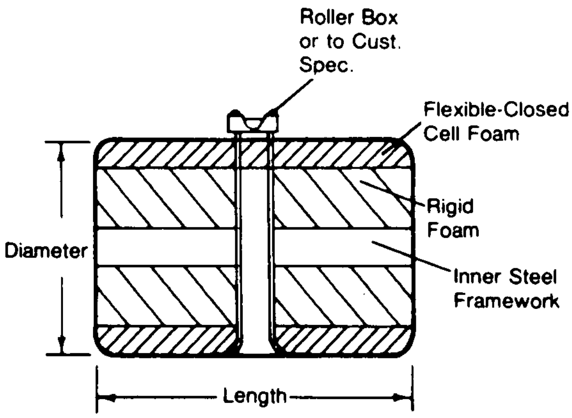
Rope Circ	Buoyancy Per Float
11" - 13" single leg	18 lbs.
14" - 16" single leg	21 lbs.
17" - 19" single leg	26 lbs.
20" - 22" single leg	30 lbs.
10" - 13" strop	30 lbs.
14" - 16" strop	35 lbs.
17" - 19" strop	39 lbs.
20" - 22" strop	44 lbs.
17" - 19" strop splice	48 lbs.
20" - 22" strop splice	52 lbs.



Samson Anchor-Pendant Buoys

Construction consists of a flexible closed cell foam capable of absorbing repeated impacts without loss of shape or elasticity. The foam body is integrated with structural steel elements designed to meet applied loads and enveloped in a protective urethane elastomer outer shell. The outer casing is extremely tough and abrasion resistant and will not corrode, deteriorate or foul even after prolonged use. Rigid foam is used if deep submergence is likely.

These buoys resist cutting and scraping, and they cannot shatter, leak, or burst. Their light weight also greatly reduces handling problems. Optional handling arrangement, including roller boxes, through pipes, chain stoppers, crosses, and under buoy swivels are available for special requirements. Specifications available in Samson Brochure FF-88.



APPENDIX 8

Ice Arrestor Net Cost and Specifications

ICE ARRESTOR NET COST

Bill of Materials
Single Panel Net and Associated Hardware

Item	Description	Quantity Required	Unit Price	Price*
1	4 1/2" dia. 8-strand Polypropylene	305m (3402 lbs)	$ 1.60/lb	5443.00
2	3 5/8" dia. 12-strand Round Plait™ Polytron™	200m (1562 lbs)	$ 4.15/lb	6482.00
3.	2 5/8" dia. 12-strand Round Plait™ polyester	200m (1358 lbs)	$ 1.90/lb	2580.00
4.	1" (9000 lb) polyester strapping	1200m	$ 1.52/m	1824.00
5.	Lace-on flotation collars (for 11" - 13" circ. rope)	36	$100.00/ea	3600.00
6.	35T forged alloy bolt type anchor shackles	10	$145.00/ea	1450.00
7.	55T forged alloy bolt type anchor shackles	4	$320.00/ea	640.00
8.	85T forged alloy bolt type anchor shackles	1	$773.00/ea	773.00
9.	110" Norwegian buoys	2	$ 90.00/ea	180.00
10.	Spar buoys, with radar reflector and light attachment bracket	3	$300.00/ea	900.00
11.	Xenon strobe lights	5	$665.00/ea	3325.00
12.	1/2" Grapnel	2	$200.00/ea	400.00
13.	1/2" dia. polypropylene handling line	30m (4 lbs)	$ 1.60/lb	6.00
14.	1" dia. polypropylene handling line	30m (17 lbs)	$ 1.60/lb	27.00
15.	Net repair kit, with repair plates, nylon twine, glue, heat gun, and storage bin	1	$150.00/ea	150.00
TOTAL COST OF MATERIALS AND HARDWARE			$27,780.00	

*Prices given in 1986 $ Canadian

All the above items are available through most marine hardware dealers and come from Canadian suppliers, with the exceptions of the Polytron™ rope and lace-on floatation collars (Samson Ocean Systems, U.S.A.) and the flashing Xenon lights (Ocean Applied Research, U.S.A.).

Fabrication of the net is estimated to take 10 - 14 days (after receipt of all materials) at a cost of approximately $2000.

The net reel described in the text (see Fig. 34) is available for a construction cost of approximately $10,200. Discussion with the reel's manufacturer, a St. John's based welding and fabricating company, suggests that a typical monthly lease rate would be around $900. There are also several used units available for approximately $7200 each.

Installation and removal costs of the reel would be in the order of $2000 and $1000, respectively.

The incremental cost of fabricating and installing the lower panel net to complete the dual panel system would be significantly less than for the single (upper) panel. There are several reasons for this:

- No lead lines required (4 1/2" dia. polypropylene) since these would be interchangeable
  (est. saving - $5443)

- No floatation collars required for bottom panel headrope
  (est. saving - $3600)

- Little extra hardware required
  (est. saving - $7300)

Materials and hardware for the lower panel should therefore be in the order of $11,000 - $12,000.

Fabrication costs and costs associated with the powered storage reel may decrease somewhat, but will still be in the same range as for the first net.

With respect to maintenance costs, certain items will surely require replacement from time to time as a result of loss or damage. The most expensive of these will likely be the flashing Xenon lights and spar buoys.

ICE ARRESTOR NET

SPECIFICATIONS

Single (upper) panel

DIMENSIONS

1) Net panel

length:	45m
depth:	15m
shape:	rectangular
mesh size:	1.25m square
mesh orientation:	comprised of vertical and horizontal member

2) Bridles

upper: 2 x 75m long, single piece, with splice eyes at both ends

lower: 2 x 75m long, comprised of 70m main bridle and 5m removable adjustment strap. All lines to be terminated with spliced eyes.

3) Lead Lines: 2 x 150m long; with spliced eyes at both ends.

4) Hardware and Accessories

Flotation collars: 44" (1.22m) long grommeted tubular hawser float, suitable for 11" - 13" circumference rope.

MATERIALS

1) Net panel

headrope:	3 5/8" dia. 12-strand Round Plait™ Polytron™
footrope:	2 5/8" dia. 12-strand Round Plait™ polyester
mesh:	9000 lb (1" wide) woven polyester strapping

2) Bridles

upper: 3 5/8" dia. 12-strand Round Plait™ Polytron™

lower: 2 5/8" dia. 12-strand Round Plait™ polyester

3) Lead Lines: 4 1/2" dia. 8-strand plaited spunstaple polypropylene

4) Hardware

shackles: G-2140 forged alloy bolt type anchor

WEIGHT

1) Net panel

headrope: 167 kg

footrope: 145 kg

mesh: 105 kg

2) Bridles

upper: 2 x 272 kg

lower: 2 x 236 kg

3) Lead lines: 2 x 773 kg

4) Hardware

shackles:	10 x 35T:	140 kg
	4 x 55T:	110 kg
	1 x 85T:	50 kg

TOTAL ESTIMATED NET WEIGHT = 3279 kg (7214 lbs)

For comparison purposes, the weight of 1200m of 4 1/2" dia. 8-strand polypropylene (standard iceberg towrope) is 6085 kg (13,386 lbs)

VOLUME

A) Absolute (based on component dimensions)

headrope: 0.31 m^3

footrope: 0.16 m^3

mesh: 0.15 m^3

bridles:

- upper: 2 x 0.51 m^3
- lower: 2 x 0.27 m^3

lead lines: 2 x 1.55 m^3

TOTAL ABSOLUTE VOLUME = 5.28 m^3
(minus flotation collars and other hardware)

B) Actual (incl. bulking factor and allowances for flotation collars, shackles, etc.)

1) Net Panel
$0.62\ m^3 \times 3^* = 1.86\ m^3$

2) Bridles
$1.56\ m^3 \times 2^* = 3.12\ m^3$

3) Lead lines
$3.1\ m^3 \times 2^* = 6.2\ m^3$

4) Hardware
0.5 m^3 (estimated)

TOTAL ESTIMATED VOLUME = 11.7 m^3

* estimated bulking factor

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