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Ice Forces and Ship Response during Ramming and Shoulder Collisions

Phase III - Harmonization of Polar Ship Rules

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Ice Forces and Ship Response during Ramming and Shoulder Collisions

Phase III - Harmonization of Polar Ship Rules

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17. Abstract

The report describes Phase III of a series of projects aimed at determining ice forces on ships, during ramming and oblique collisions. The present report completes the investigation, by numerical and analytical means, of the loads and ship response during head-on ramming. The report presents proposed formulas for maximum ice force, bending moments, shear forces and accelerations. There are also proposed distributions for shear, moment and acceleration along the length of the ship. Extensive reported calculations, and comparisons with 'open water' values support these values. The 'design' equations depend on vessel size, shape, and velocity and on ice strength and thickness. The report also includes a review of ice thickness statistics for the arctic, leading to the conclusion that the 'design' ice feature should not exceed 7m continuous thickness.
The second major part of the report is a preliminary study with a numerical 3D collision model, and comparison to Russian work and literature for oblique collisions. This work shows how sensitive the ice force values are to the assumptions about the ice crushing behavior, and the vessel motions.
For issues of longitudinal strength and head-on ramming, the report recommends, on the basis of the Trondheim Harmonization meetings, to apply the results to a variety of actual vessels for final verification.

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17. Résumé

Le présent rapport décrit la phase III d'une série de projets visant à déterminer les forces exercées par les glaces sur les navires durant l'éperonnage et les collisions obliques. Il complète, par des moyens numériques et analytiques, l'étude des charges et des réactions des navires pendant l'éperonnage par l'avant. Il propose des formules pour le calcul de la force maximale des glaces, des moments de flexion, des forces de cisaillement et des accélérations. Il présente aussi des hypothèses sur la répartition possible du cisaillement, du moment et de l'accélération sur toute la longueur du navire. Ces hypothèses sont supportées par des calculs descriptifs exhaustifs et des comparaisons avec les valeurs recueillies en eaux libres. Les équations dites « de calcul » sont assujetties à divers facteurs tels que la taille du navire, sa forme et sa vitesse, de même que la force et l'épaisseur de la glace. Le rapport comprend aussi une révision des statistiques sur l'épaisseur des glaces dans l'Arctique, ce qui nous permet de conclure qu'en ce qui concerne l'épaisseur continue des glaces, le paramètre de calcul ne devrait pas dépasser 7 m.

La deuxième partie importante du rapport comprend une étude préliminaire des collisions à l'aide d'un modèle numérique en trois dimensions et une comparaison des données recueillies avec des travaux et des documents russes sur les collisions obliques. Ces travaux démontrent à quel point les valeurs des forces des glaces sont critiques pour la formulation des hypothèses sur le comportement du broyage des glaces et les mouvements des navires. Pour ce qui est de la résistance longitudinale et de l'éperonnage par l'avant, le rapport recommande, à la suite des réunions d'harmonisation de Trondheim, d'appliquer les solutions à plusieurs navires actuellement en service pour vérification finale des résultats de l'étude.

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Nomenclature

a	acceleration
a_{max}	maximum acceleration
A	area
AP	aft perpendicular
A_{wp}	waterplane area
C_B	block coefficient
C_{WP}	block coefficient
Fn,max	maximum ice force (normal to stem)
FP	fore perpendicular
h, hice	ice thickness
IPC	International Polar Class
Kx	bow surge stiffness (=0)
Ky	bow heave stiffness
kcr	ice crushing stiffness
kel	ice edge elastic stiffness
L	ship length
LBP	length between perpendiculars
m	meters
M	bending moment
M	ship mass
MN	mega-newtons
Mx	bow surge mass
My	bow heave mass
M_{max}	maximum bending moment
MPa	mega-Pascals
p	ice pressure
p_1	the ice pressure constant ($p=p_1 * A^{-.5}$)
pen	ice edge penetration
Q	shear
Q_{max}	maximum shear
V,*v*	velocity,
t	tonnes
u	ice surge
w	ice heave

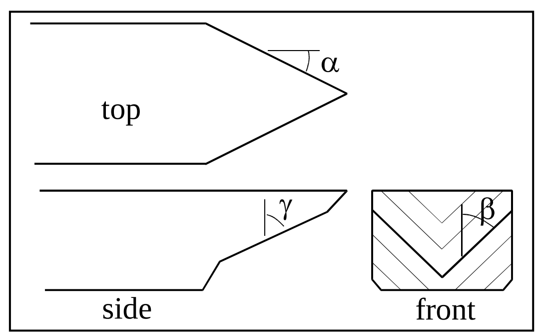
x	position (along ship)
y	position (vertical in 2D model, lateral in 3D model)
z	position (vertical in 3D model)
Δ	vessel displacement
κ	normalized ice strength (with bow fullness and heave stiffness)

$$\kappa = \frac{p_1}{\rho g \cdot A_{wp}} \frac{\sqrt{2}\tan(\alpha)}{\sin(\gamma)\sqrt{\cos(\gamma)\sqrt{\tan^2(\alpha)+\sin^2(\gamma)}}}$$

ρg	weight density of water
σ_f	ice flexural strength
ϕ	ship roll angle
θ	ship pitch angle
ψ	ship yaw angle
Φ	ice pitch angle
Ω	ice yaw angle

bow angles (see sketch):

α	waterline angle (from fwd.)
γ	stem angle (from vert.)
β	frame angle (from vert.)



Résumé

Le processus d'élaboration des règlements de navigation polaire harmonisés se poursuit depuis plusieurs années. Pour que lesdits règlements reposent sur une base solide, il faut en arriver à une entente commune sur la description des charges de glace. Le Règlement sur la prévention de la pollution des eaux arctiques par les navires du Canada s'appuie sur des essais en vraie grandeur et des données expérimentales de même que sur des modèles numériques et analytiques de l'interaction entre les navires et les glaces. Il reste cependant à régler l'importante question de savoir quelle sera la charge de calcul des glaces qui doit être utilisée dans les règlements. Ce problème déjà épineux est compliqué davantage par la nature internationale des travaux, et par le manque d'une méthode communément admise pour calculer les charges de glace. Il a été convenu que tout nouvel ensemble de règles harmonisées devrait se fonder sur des scénarios d'interaction des glaces pertinents, ce qui exige naturellement de pouvoir déterminer la charge des glaces pour chaque scénario, soit par calcul, soit par renvoi à des données en vraie grandeur ou les deux.

Le présent rapport porte sur la phase III d'une série de projets. Au cours de la phase I, on a développé des modèles numérique et analytique de l'éperonnage par l'avant. La phase II a été consacrée au perfectionnement du modèle analytique de l'éperonnage par l'avant et au développement d'un modèle en trois dimensions des collisions obliques. La phase IV à venir tentera de valider le modèle 3D des collisions obliques et d'en accroître la portée à l'aide de données d'essais sur une maquette. Les trois précédents rapports exposent comment l'étude de la mécanique de l'éperonnage a mené à l'utilisation de méthodes numériques et de l'approche analytique pour calculer la charge totale des glaces sur un navire. Deux études ont aussi été entreprises pour examiner ces questions à la lumière d'une analyse probabiliste de la situation de calcul.

Pour chaque scénario décrit dans le rapport, on a tracé des courbes de la force maximale et des moments de flexion de deux familles de navires; la figure S.1 montre les forces par rapport au déplacement pour la famille de navires « Robert Lemeur ». Les valeurs de force illustrent la limite supérieure type qui résulte de la défaillance de flexion.

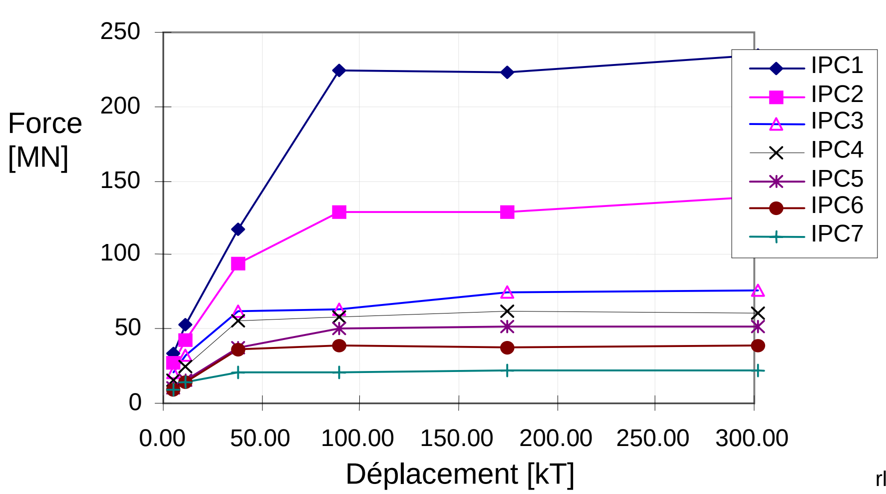


Figure S.1 Force d'éperonnage totale par rapport au déplacement pour les navires de la famille « Robert Lemeur », pour les cas de la CIB.

En combinant les simulations numériques et les résultats des analyses avec la défaillance de flexion, on arrive à décrire une valeur de calcul de la force d'éperonnage à l'aide de l'équation suivante :

$$F_{n.max} = 0{,}54 \cdot K^{15} \cdot \sin^2 y \cdot V \cdot \sqrt{\rho g \,.\, M \,.\, A_{wp}}$$

$$\text{ou } 1{,}35 \cdot \sigma \cdot hice^2 \qquad (3)$$

Pour mettre la formule en application dans un règlement, il suffit d'avoir pour chaque classe de navire les paramètres suivants : vitesse de calcul, épaisseur de la glace et résistance de la glace. On peut choisir des paramètres de manière à obtenir toute la gamme de valeurs voulues. Par exemple, une résistance à la flexion de 0,8 MPa pourrait être utilisée pour toutes les classes.

L'épaisseur de la glace est donc une variable de calcul importante, particulièrement en ce qui concerne les navires d'un déplacement supérieur à 40 000 tonnes. Un graphique de probabilité a été extrapolé à partir des données d'épaisseur des glaces planes du détroit de Fram, du détroit de Davis et de l'Arctique eurasien (figure S.2). Le graphique indique que plus de la moitié de la glace plane est épaisse de 1 à 3 mètres. Il indique aussi une fréquence relativement élevée de glace entre 6 et 7 mètres d'épaisseur. Par conséquent, les navires qui naviguent dans ces régions doivent être conçus pour résister à des glaces de 7 mètres d'épaisseur.

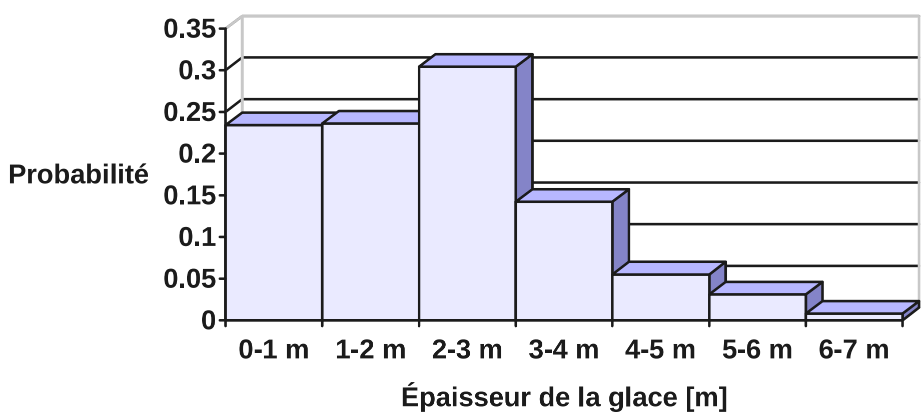


Figure S.2 – Répartition des épaisseurs de glace pour le détroit de Davis, le détroit de Fram et le secteur eurasien.

Les paramètres d'épaisseur de glace utilisés doivent être des valeurs extrêmes. La glace plane de plus de 7 mètres d'épaisseur est extrêmement rare dans l'Arctique. La glace plus épaisse ne se retrouve que dans des configurations spéciales, comme les îles de glace, les icebergs et les crêtes de glace de plusieurs années. On doit considérer les caractéristiques extrêmes comme étant à l'extérieur de l'enveloppe de calcul.

Une fois les forces déterminées, on peut trouver le moment de flexion d'après la formule suivante :

$$M_{max} = 0,1 \cdot L \cdot sin^{-2} y \cdot F_{n.max} \qquad (4)$$

La figure S.3 illustre la répartition des moments de flexion, du cisaillement et des accélérations.

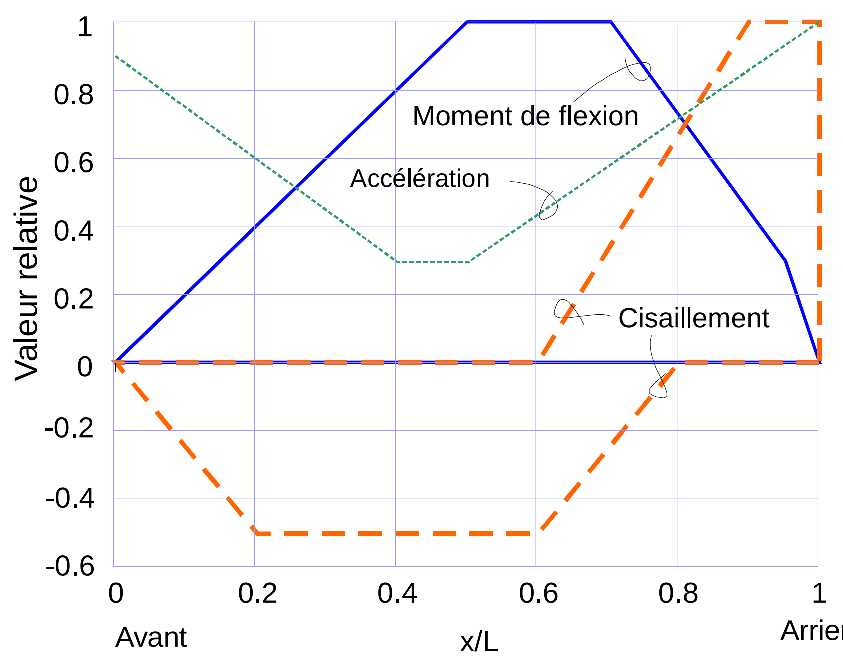
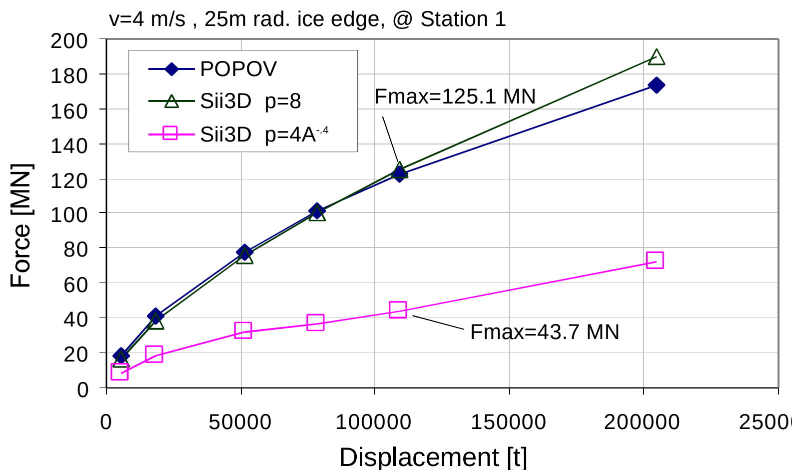


Figure S.3 – Répartition de la flexion, du cisaillement et de l'accélération le long d'un navire.

La modélisation des collisions obliques, où l'influence de la forme de la coque (forme complète) nécessite une attention particulière, doit être développée davantage. Les différences entre le modèle Popov à une dimension et le modèle Sii3D simple ne sont pas assez importantes (voir figure S.4) pour permettre une définition de charge. La modélisation des échancrures dans les glaces (pression/effets de zone) est cruciale.



Force [MN] v Déplacement [t] 25 m de rayon front de glace

Figure S.4 – Comparaison des résultats entre les modèles Popov et Sii3D.

Executive Summary

The process of developing Harmonized Polar Shipping Rules has been underway for several years. The ice load description in the Harmonized Polar Shipping Rules is to be based on a common understanding of the ice loads. The Canadian ASPPR rules have been based on full scale and experimental data along with numerical and analytical models of ship-ice interaction. One issue of continuing importance is the design ice load to be used in the rules. The issue is complex and is compounded by the international nature of the work, and the lack of a commonly agreed method for calculating ice loads. It has been agreed that a new set of harmonized rules should be based on appropriate ice interaction scenarios. This naturally requires that we are able to determine the ice load in each scenario, by either calculation or by reference to full-scale data or both.

This is Phase III, of a series of projects. Phases I was the development of a numerical and an analytical model for head-on ramming. Phase II was the refinement of the analytical model for head-on ramming, as well as the development of a model of 3D oblique collision. The coming Phase IV will be a validation and extension of the 3D-collision model with data from physical model tests. Three earlier reports examined the mechanics of ramming which leads to the total ice load on a ship, using both numerical and analytical approaches. Further, there were two studies which examined the issues using probabilistic analysis of the design situation.

The maximum force and bending moments for the two vessel families are plotted for the scenarios described in the report. Figure S.1 shows the forces vs. displacement for the “Robert Lemeur” family of vessels. The force values show the typical upper limit that results from the flexural failure.

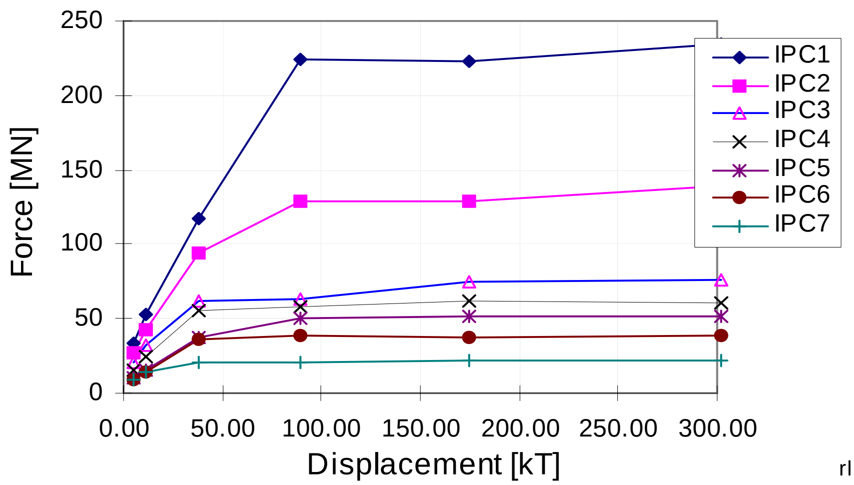


Figure S.1 - Total Ramming Force vs. Displacement for the "Robert Lemeur" vessels, for IPC Cases.

By combining the numerical simulations and analytical results with flexural failure, a design value for ramming force can be described by the equation :

$$F_{n,\max} = 0.54 \cdot \kappa^{.15} \cdot \sin^{.2} \gamma \cdot V \cdot \sqrt{\rho g \cdot M \cdot A_{wp}} \quad or \quad 1.35 \cdot \sigma \cdot hice^{2} \qquad (3)$$

To implement this in a rule, only a design velocity and ice thickness and strength for each class is needed. These can be selected to give the desired range of values. A flexural strength of say 0.8 MPa, could be used for all classes.

Ice thickness is therefor an important design variable, particularly for vessel of displacement above 40,000 tonnes. A probability graph was derived based on level ice thickness data in the Fram Strait, Davis Strait, and the Eurasian Arctic (Figure S.2). The graph indicates that over half of the level ice is between 1-3 meters thick. It also shows a relatively high frequency of ice between 6-7 meters thick. Therefore, the ships traveling this area should be designed to encounter a level ice thickness of 7 meters.

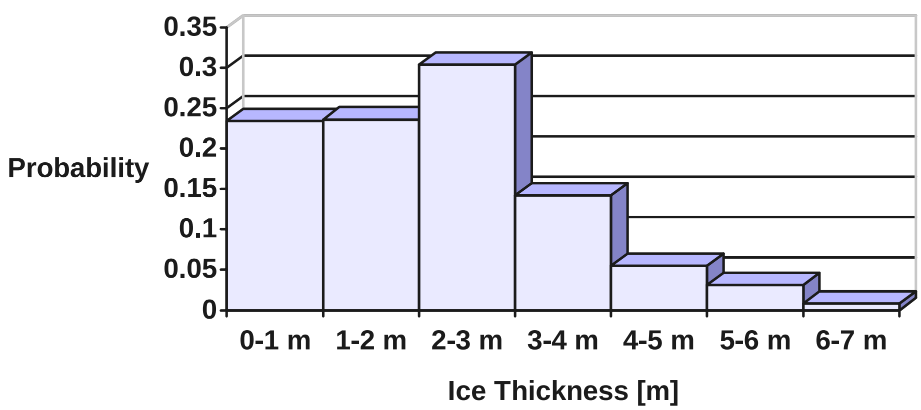


Figure S.2 - Ice Thickness Distribution for the Davis Strait, Fram Strait, and Eurasian Sector.

Limiting ice thickness values should be employed. Level ice above 7m is extremely rare in the Arctic. Thicker ice exist only in features such as ice islands, icebergs and very heavy MY ridges. The extreme features should be viewed as outside the design envelope

Once the force is determined, the bending moment can be found from;

$$M_{\max} = 0.1 \cdot L \cdot \sin^{.2} \gamma \cdot F_{n,\max} \qquad (4)$$

The distribution of bending moments, shear and accelerations are shown in Figure S.3.

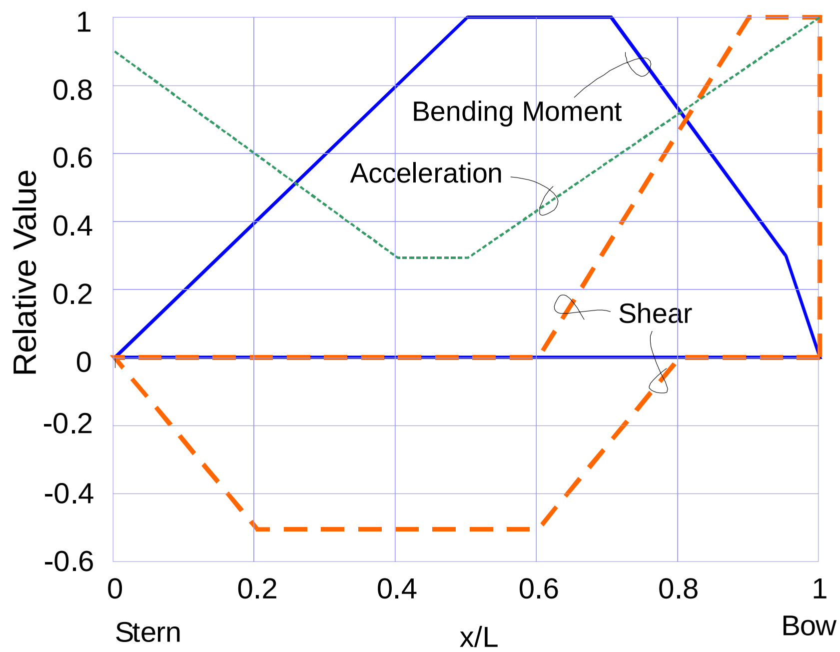


Figure S.3 - Distribution of Bending, Shear and Acceleration along the vessel.

The oblique collision modeling needs further development, with the influence of hull form (full shape) requiring special attention. The differences between the 1D Popov model and the simple Sii3D model are too great (see Figure S.4) to allow a load definition. The ice indentation modeling (pressure/area effects) are crucial.

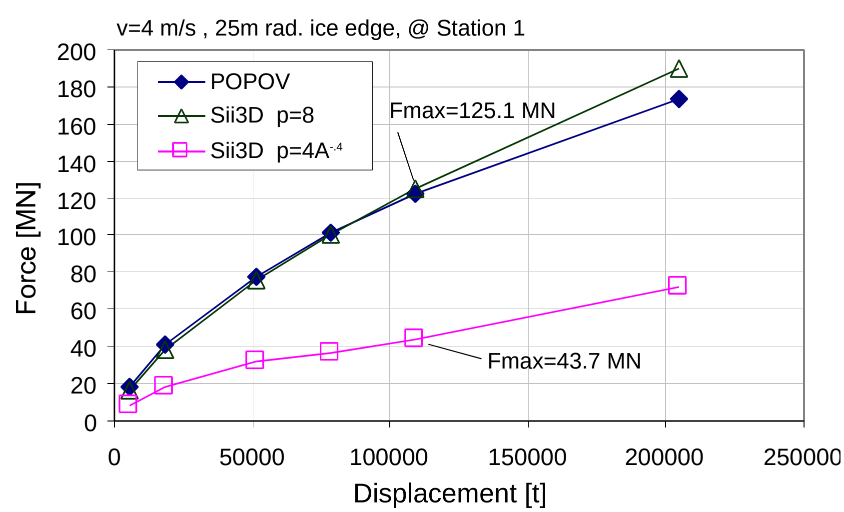


Figure S.4. Sii3D and Popov model results compared.

1. INTRODUCTION

1.1. Background

The process of developing Harmonized Polar Shipping Rules [1] has been underway for several years. The ice load description in the Harmonized Polar Shipping Rules is to be based on a common understanding of the ice loads. The Canadian ASPPR [2] rules have been based on full scale and experimental data along with numerical and analytical models of ship-ice interaction. One issue of continuing importance is the design ice load to be used in the rules. The issue is complex and is compounded by the international nature of the work, and the lack of a commonly agreed method for calculating ice loads. It has been agreed that a new set of harmonized rules should be based on appropriate ice interaction scenarios. This naturally requires that we are able to determine the ice load in each scenario, by either calculation or by reference to full-scale data or both.

This is Phase III, of a series of projects. Phases I was the development of a numerical and an analytical model for head-on ramming. Phase II was the refinement of the analytical model for head-on ramming, as well as the development of a model of 3D oblique collision. The coming Phase IV will be a validation and extension of the 3D-collision model with data from physical model tests. Three earlier reports [3, 4, 5] examined the mechanics of ramming which leads to the total ice load on a ship, using both numerical and analytical approaches. Further, there were two studies [6, 7] which examined the issues using probabilistic analysis of the design situation.

At present we have extensive material covering the case of head-on ramming. This includes full-scale data from several vessels, model scale data from five vessels, [e.g. 8] along with a numerical and an analytical model of the mechanics of head-on impact. The influences of many parameters have been studied and are well understood. The last step left to do for head-on ramming is to pull all the treads together into a rule formulation for checking ramming forces and hull girder bending response.

We have also begun work on the mechanics of oblique collisions, (shoulder collisions) in which the vessel responds in three dimensions instead of just two or one. To date we have succeeded in developing a numerical model, which has been refined once and appears to be running reasonably well and accurately. We need this model to be able to determine the loads on the bow, and the influence of ship and ice parameters. The 3D oblique model is essentially the same as the head-on model, and so it shares the merits and drawbacks of the 2D model. We can therefore have some confidence that the 3D model is reasonably correct. However, questions have arisen regarding the possible importance of the full hull form. At present the contact point is modeled as being a flat plane. We will need to verify the 3D model against full scale and model scale data, and improve it as necessary.

1.2. Scope of the Present Work

The present scope of work builds upon the many prior studies, adding to the development of the harmonized rules. The scope of the present work is as follows:

- for the head-on ramming scenario, to show the parametric influence of parameters by both numerical and analytical models and develop rule formulations to check ramming loads and ship structure response
- for the shoulder collision scenario, to develop scenario ice load models/equations appropriate for the harmonized rules.
- through an examination of Arctic ice thickness values, suggest design ice thickness values for the various proposed classes.

There are two vessel types included in the analysis. Table 1 describes ships which are variants called the “80/20”, which is a form that might be used for a polar cargo vessel. Table 2 describes ships that are variants of the “Robert Lemeur”, which is a spoon-bow icebreaker form. In both cases there are six variants with vessel displacements ranging from five to several hundred thousand tonnes.

Table 1- Parameters for “80/20” Vessels

Parameter \ Variant >	1	2	3	4	5	6
Length (m)	100	150	210	242	270	333
Beam (m)	14.3	21.4	30.0	34.6	38.6	47.6
Draft (m)	5.4	8.1	11.3	13.0	14.5	17.9
Block Coef. C_B			0.72			
Waterplane Coef. C_{WP}			0.8			
Waterline angle α (deg)			30			
Stem angle γ (deg)			30			
Angle α (deg) (@0.05L)			31.3			
Angle β (deg) (@0.05L)			59			
Angle α (deg) (@0.10L)			21.4			
Angle β (deg) (@0.10L)			49			

Table 2 - Parameters for “Robert Lemeur” Vessels

Parameter \ Variant >	1	2	3	4	5	6
Length (m)	79.13	100	150	200	250	300
Beam (m)	19.03	24.05	36.08	48.1	60.13	72.15
Draft (m)	5.50	6.95	10.43	13.91	17.39	20.86
Block Coef. CB			0.7			
Waterplane Coef. CWP			0.9			
waterline angle α (deg)			85			
stem angle γ (deg)			15			
angle α (deg) (@0.05L)			36.2			
angle β (deg) (@0.05L)			70.5			
angle α (deg) (@0.10L)			17			
angle β (deg) (@0.10L)			60.5			

For the study of head-on ramming and longitudinal strength two complimentary methods were employed. One was a numerical model of ramming, called Sii (Ship-ice-interaction). The second approach taken was that of an analytical treatment and solution of the ramming equations.

The combination of the two approaches is very useful. Not only do the two results serve to verify and strengthen the other, but also the combination allows for development of an algebraic design equation, even for non-linear cases.

For oblique rams, a numerical model, Sii_3D was used. This model is in many respects similar to Sii_2D, in that it models the collision as a set of coupled differential equations, and treats the interaction geometry with simple planar calculations.

The scenarios investigated are based on those described in [9] for a set of 4 cases nominally representative of the Canadian Arctic Classes (CAC1 to CAC4) (Table 3) as well as 7 potential International Polar Classes (IPC1 to IPC7) (Table 4). The collision scenarios are described in terms of ship speed and ice parameters. Each of these scenarios is applied to the 12 vessels described above (Table 1 and Table 2).

Table 3- Grid of Scenario Values: Ramming Impacts for ASPPR Vessels

Parameter/Class	CAC1	CAC2	CAC3	CAC4
Ice Thickness, m	∞	∞	∞	∞
Floe Diameter, m	∞	∞	∞	∞
Bending strength, MPa	0.8	0.8	0.8	0.8
Crushing Strengths: Canadian model*	$3.5A^{-0.4}$	$3.5A^{-0.4}$	$3.5A^{-0.4}$	$3.5A^{-0.4}$
Ship speed, m/s	8.2	6.6	4.9	3.3

Table 4 - Grid of Scenario Values: Ramming Impacts for IPC Vessels

Parameter/Class	IPC 1	IPC 2	IPC 3	IPC 4	IPC 5	IPC 6	IPC 7
Ice Thickness, m	15	12	10	10	10	10	8
Floe Diameter, m	∞	∞	∞	∞	∞	∞	∞
Bending strength, MPa	0.8	0.65	0.5	0.45	0.4	0.3	0.25
Crushing Strengths: Canadian model*	$5A^{-0.4}$	$4A^{-0.4}$	$3.5A^{-0.4}$	$3A^{-0.4}$	$2.5A^{-0.4}$	$2A^{-0.4}$	$1.5A^{-0.4}$
Ship speed, m/s	6	5	4	3	2	2	2

Notes * - the Canadian model assumes a pressure/area relationship, of the form $P=CA^{-e}$

2. Head-On Ramming

2.1. Description of the Sii 2D Numerical Model

The Sii_2D model [3,4, Appendix A] is a simulation of the head-on ship-ice collision implemented in Mathcad. Figure 1 illustrates the collision scenario. The ship strikes the ice on the stem and crushes the ice edge. The ship is free to move in the vertical plane, in heave, surge, pitch and hull flexure. The ice may break in flexure, depending on its thickness.

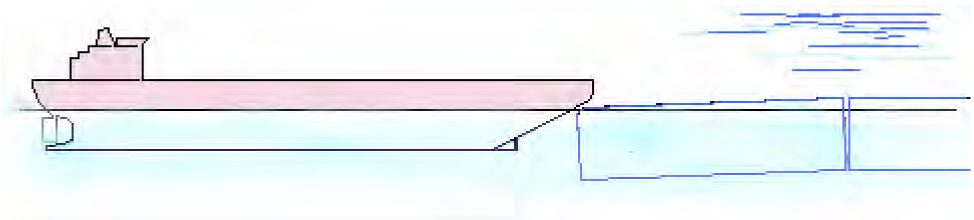


Figure 1 Head-on Ramming scenario.

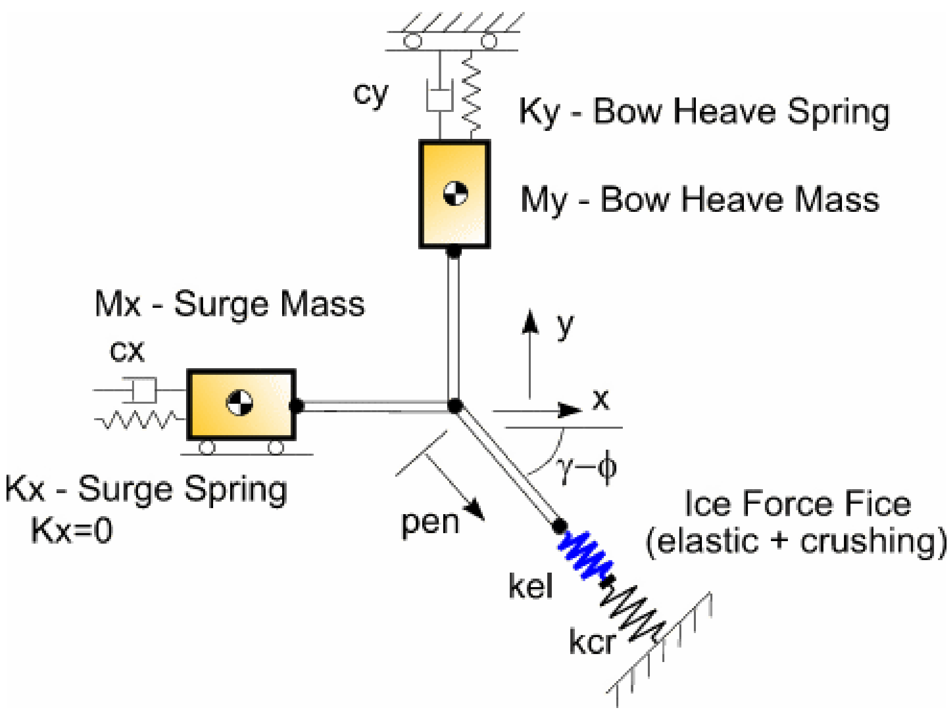


Figure 2 Idealization of ramming mechanics in Sii_2D.

The Sii_2D model uses a time-step numerical integration technique to simulate the ramming. Responses in surge, heave, pitch and first mode bending are simulated, for both the ship and ice floe (floe breaks but does not flex in bending). The modes are modeled as discrete masses, resulting in a set of coupled differential equations. The Sii model can employ any mathematical statement for ice indentation force, including non-linear ones. The model has been exercised for a range of 'design' scenarios. Earlier work [3] has shown that Sii is capable of reproducing full-scale collision data.

2.2. Results for IPC Rams

The maximum force and bending moments for the two vessel families are plotted below, for the scenarios described in Table 4. Figure 3 shows the forces vs. displacement for the "Robert Lemeur" family of vessels. Figure 4 shows the bending moments for the same set of runs. (All data is shown in Appendix B).

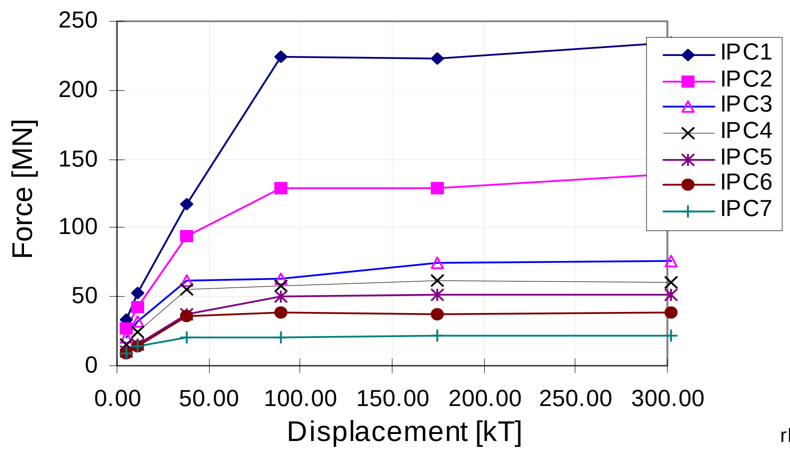


Figure 3. Total Ramming Force vs. Displacement for the "Robert Lemeur" vessels, for IPC Cases.

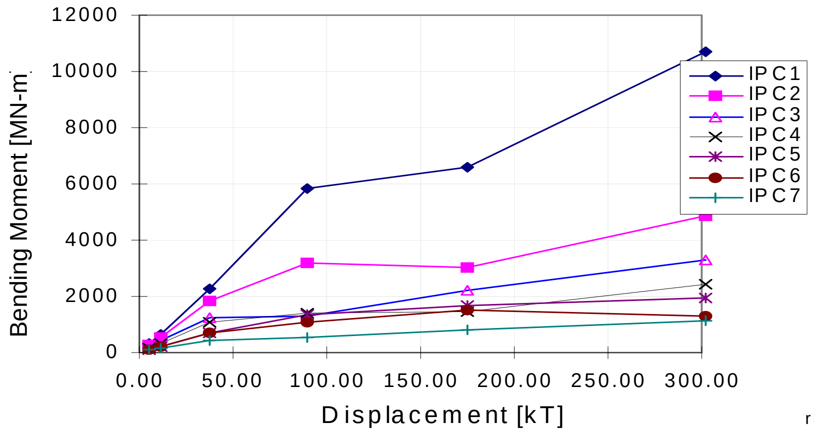


Figure 4. Total Bending Moment vs. Displacement for The "Robert Lemeur" vessels, for IPC Cases

Figure 5 shows the forces vs. displacement for the "80/20" family of vessels, for each of the class conditions indicated in Table 4. Figure 6 shows the bending moments for the same set.

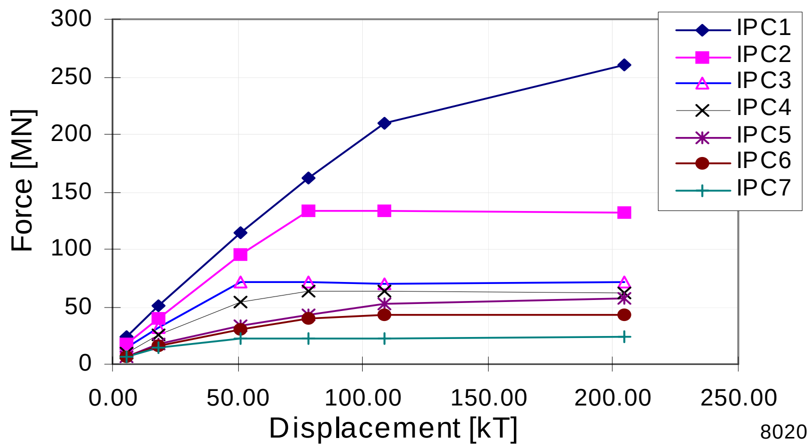


Figure 5. Total Ramming Force vs. Displacement for The "80/20" vessels, for IPC Cases.

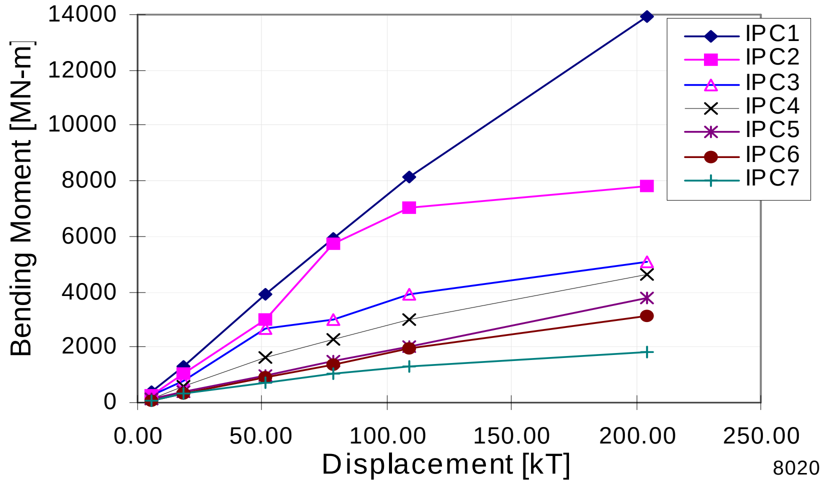


Figure 6. Total Bending Moment vs. Displacement for The "80/20" vessels, for IPC Cases

2.3. Analytical Model

The analytical model of head-on collision [3, 4] has been further developed. The solution is found by the use of Laplace transforms. The resulting solution is quite long to state in closed form. The model was applied to the cases mentioned above, with the exception that $p \sim A^{-.5}$ (rather than $p \sim A^{-.4}$ as was given in Table 3). For the 8020 vessels, with the CAC scenarios, the analytical results are given in Figure 7, and compared with numerical results for runs of Sii with $p \sim A^{-.5}$ (as in the analytical model). The comparison is excellent, but should not be surprising. The two approaches solves very similar differential equations, one numerically and one analytically.

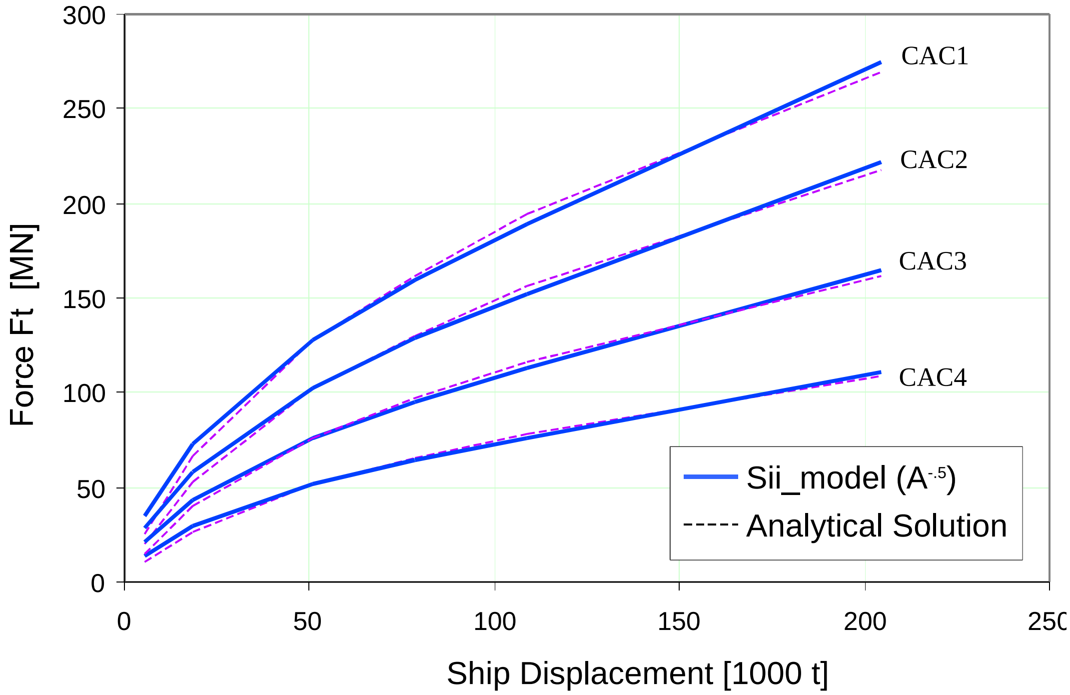


Figure 7. Comparison of Analytical and Numerical results for the 8020 vessels ($p \sim A^{-.5}$ for both).

The advantage of the analytical solution is that it gives the solution in terms of the ship and ice parameters. In addition, it directly models the distribution of bending and shear. This allows for the development of a design equation, in which the constants can be selected even for the case of non-linear collisions. The analytical force equation has the form;

$$F_{n,\max} = C \cdot \kappa^{a} \cdot \sin^{b} \gamma \cdot V \cdot \sqrt{\rho g \cdot M \cdot A_{wp}} \qquad \textbf{(1)}$$

where;

γ is the stem angle

α is the waterline angle

κ is a normalized ice strength (with bow fullness and heave stiffness)

$$\kappa = \frac{p_1}{\rho g \cdot A_{wp}} \frac{\sqrt{2}\tan(\alpha)}{\sin(\gamma)\sqrt{\cos(\gamma)\sqrt{\tan^2(\alpha)+\sin^2(\gamma)}}}$$

p_1 is the ice pressure constant ($p = p_1 * A^{-.5}$)

V is velocity,

M is ship mass,

A_{wp} is waterplane area

ρg is the weight density of water

a, b and C are constants to be determined.

Figure 8 shows a comparison of the numerical results for p~A-.4 with the analytical results (same as above). This shows the sensitivity of the force to the ice pressure. The comparison indicates that for larger vessels, the ice pressures cause a significant effect. The $A^{-.4}$ values are ~30% above the $A^{-.5}$ values.

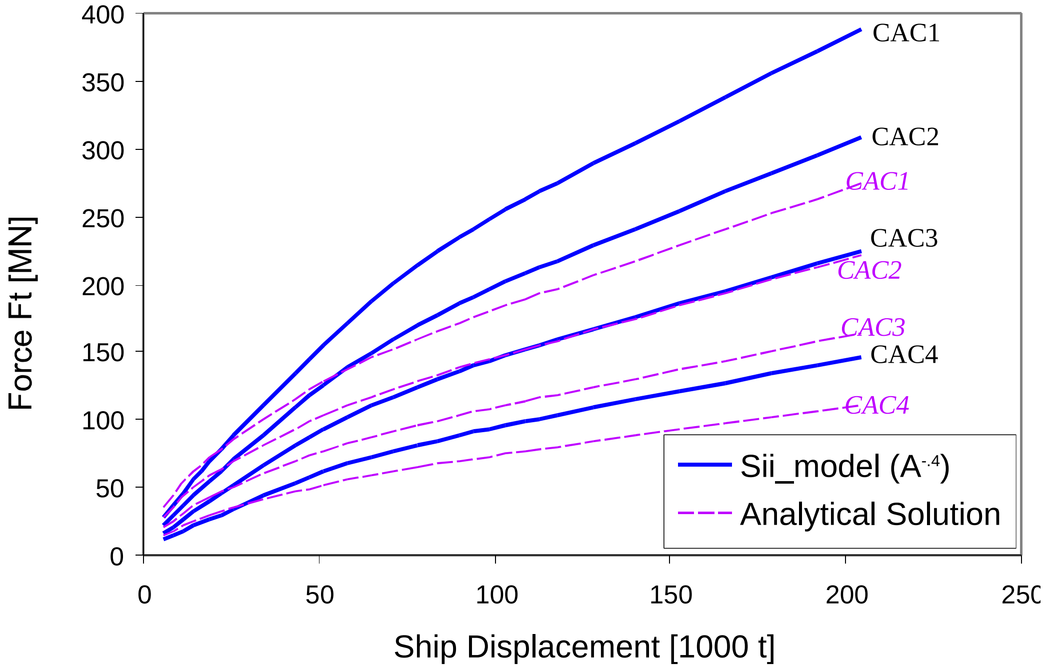


Figure 8. Comparison of Analytical and Numerical results for the 8020 vessels ($p \sim A^{-.5}$ for analytical, $p \sim A^{-.4}$ for numerical)

2.4. Discussion of Ramming Results

The results plotted above show the influences of several parameters. The influence of displacement is strong, with force being approximately proportional to $\Delta^{.7}$. This influence is limited by flexural failure in ice of finite thickness.

The influence of velocity can be seen in Figure 9 and Figure 10. These plots are for the ASPPR cases, in which velocity is varied independently. The plots show that for both the "Robert Lemeur" and "80/20" hull forms, for all displacements, the force is essentially linearly proportional to velocity.

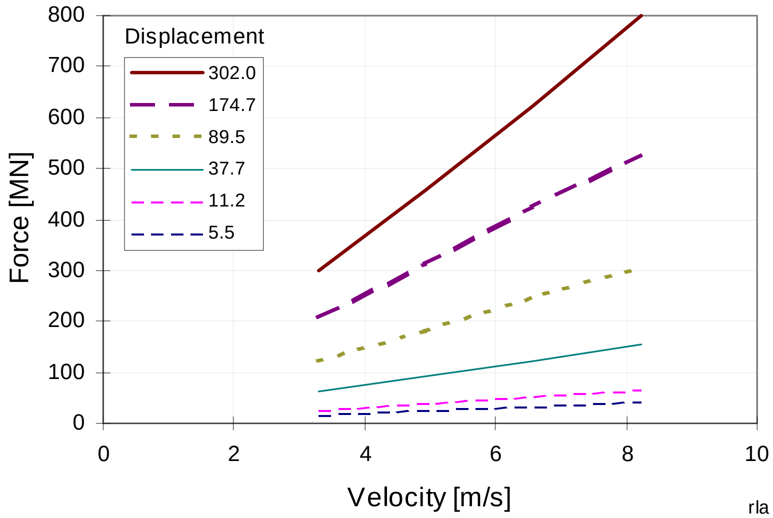


Figure 9. Force vs. velocity for the "Robert Lemeur" vessels, for ASPPR Cases

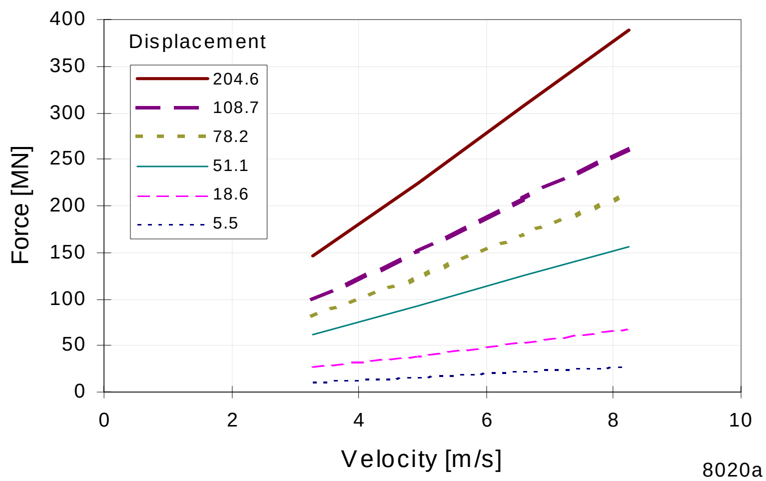


Figure 10. Force vs. velocity for the "8020" vessels, for ASPPR Cases

It is not so easy to plot the sensitivity to velocity for the IPC cases, because there are several parameters varying at once. One way around this is to plot the data versus a standard equation, to see how well the Sii simulation is matched by the equation.

In earlier reports [3,4] an equation for the maximum normal ramming force was proposed (this is a variant of equation (1):

$$F_{n,\max} = 0.766 \cdot \kappa^{0.4} \cdot \sin^{0.2} \gamma \cdot \sqrt{M \rho g A_{wp}} \cdot v \qquad \textbf{(2)}$$

This equation was based on an analytical solution of the ramming mechanics equations of motion. The complete analytical solution (described in [3,4]) was simplified to give the equation. The equation does not account for flexural failure, and so is only valid for head-on rams in very thick ice. To examine the Sii results for the IPC and ASPPR cases, it was decided to compare a modified equation (eqn. 3) which adds a flexural failure limit to eqn.2.

$$F_{n,\max} = \min\left| \begin{array}{c} 0.766 \cdot \kappa^{0.4} \cdot \sin^{0.2}\gamma \cdot \sqrt{M\rho g A_{wp}} \cdot v \\ \\ 1.2 \cdot \sigma_f \cdot h^2 \end{array} \right. \qquad \textbf{(3)}$$

Figure 11 shows equation (3) compared to the Sii results on a linear scale. Perfect agreement would be indicated if all points were on the 1:1 line. The plot indicates that there is a disagreement of as much as ~30% . Figure 12 shows the same comparison a log plot. The values for the 8020 runs are in better agreement than the "Robert Lemeur" runs. This may be because the 8020 is a more typical shape, and closer to the ships used when equation (2) was derived.

The next step has been to modify terms in equation (3), while keeping the form of the equation unchanged. By adjusting terms in the equation to maximize the fit, a modified equation (eqn. 4) was developed. The new equation fits the Sii results much better, and is;

$$F_{n,\max} = \min\left| \begin{array}{c} 0.534 \cdot \kappa^{0.15} \cdot \sin^{0.2}\gamma \cdot \sqrt{M\rho g A_{wp}} \cdot v \\ \\ 1.35 \cdot \sigma_f \cdot h^2 \end{array} \right. \qquad \textbf{(4)}$$

Figure 13 shows equation (4) compared to the Sii results on a linear scale. Perfect agreement would be indicated if all points were on the 1:1 line. Equation (4) vs Sii has a slope of 1.0007, and an R^2 (correlation) value of 0.9954, which indicates excellent agreement. Figure 14 shows the same comparison a log plot.

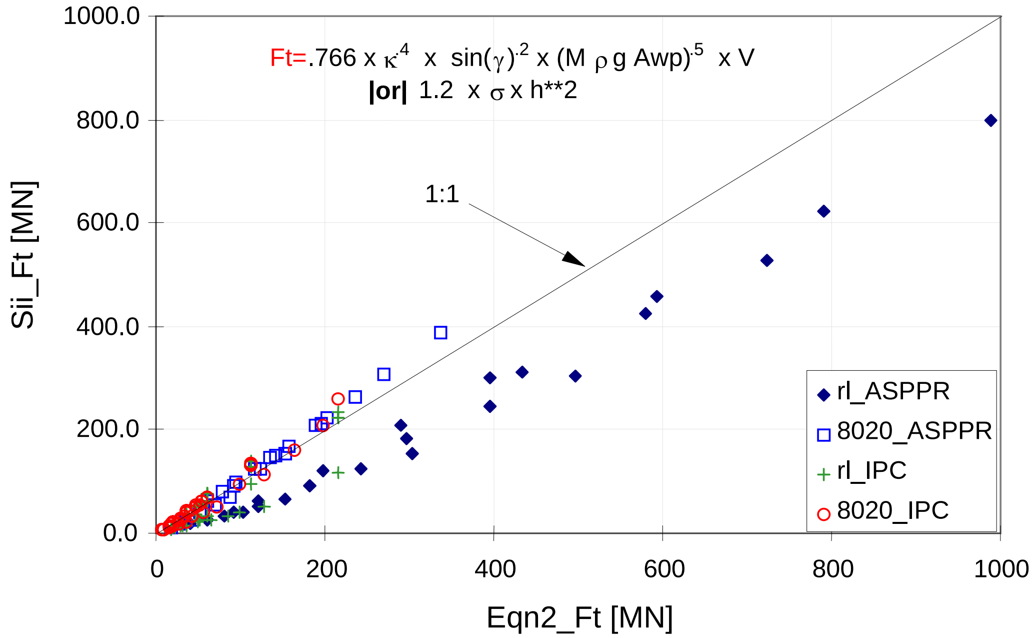


Figure 11. Comparison of Eqn. 3 with the Sii model results for both ships and both sets of conditions (linear scale).

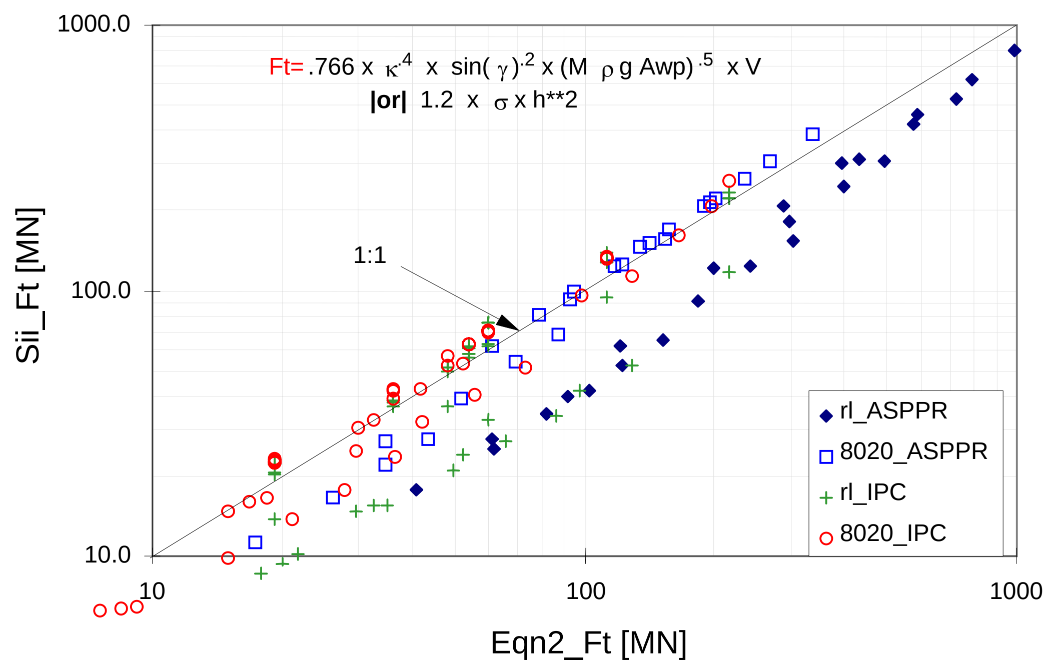


Figure 12. Comparison of Eqn. 3 with the Sii model results for both ships and both sets of conditions (log scale).

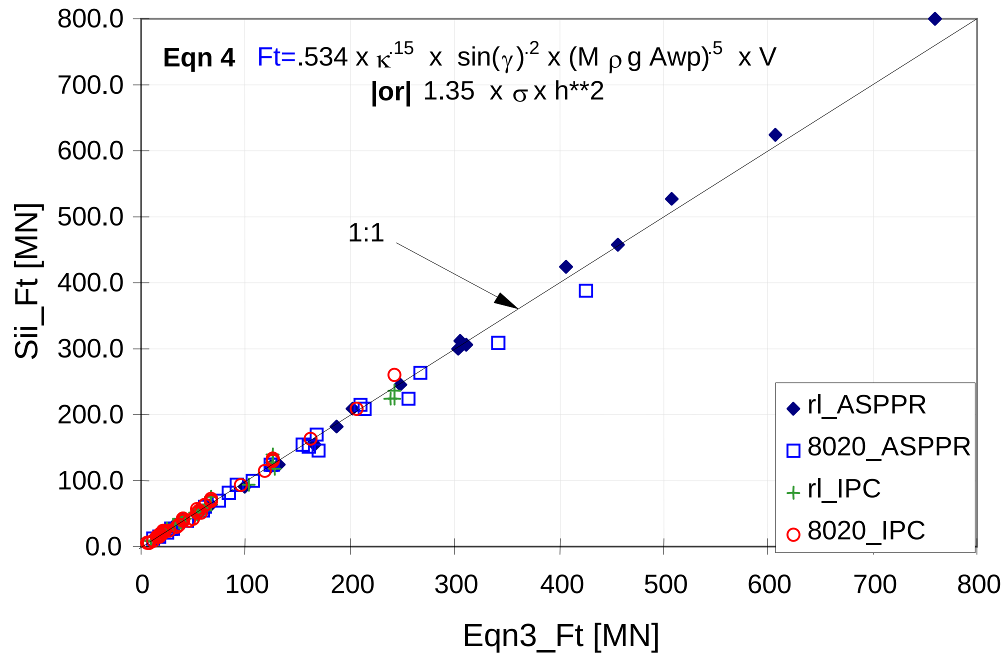


Figure 13. Comparison of Eqn. 4 with the Sii model results for both ships and both sets of conditions (linear scale).

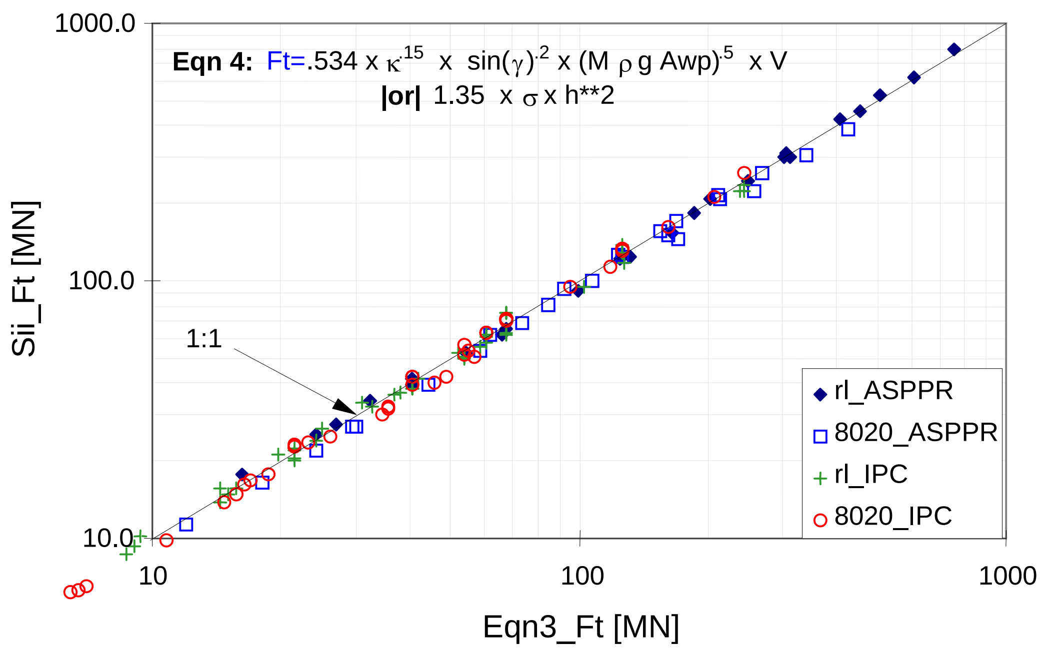


Figure 14. Comparison of Eqn. 4 with the Sii model results for both ships and both sets of conditions (log scale).

These results indicate that equation (4) captures the influence of the parameters of the cases, which included hull form, ice crushing strength, ice flexural strength, ship size, and the length/beam ratio. At this stage the equation looks very promising. It may be warranted to extend the comparison to other ships, and to model and full scale data. The Sii model has shown excellent agreement with model and full scale data in the past, so it is expected that this exercise will only refine the present results.

2.5. Vessel Response

2.5.1. Bending Moments an Shear Forces

The analytical study has shown that bending moments are insensitive to the section modulus of the vessel. The bending moments were also found to be insensitive to the stem angle (even though it affects force). The simple result is that the bending moment in terms of force is;

$$M_{\max} = 0.1 \cdot L \cdot \sin^{-.2} \gamma \cdot F_{n,\max} \qquad (4)$$

Equation (4) can be used in combination with equation (3) to set the longitudinal strength requirements for Polar Class ships. Only ice and speed values for each class are required.

The analytical model produces a distribution of bending moments and shear forces. The distribution along the hull is different than the open water distribution. It is shifted more forward. Figure 2.7 shows the calculated moment distribution in ice ramming, the open water distribution commonly used in rules, and the proposed ice rule. Figure 2.8 shows the same for shear force.

Tables 2.5 an 2.5 give an indication of the relative magnitude of shear and bending in ice compared with open water values for the '8020' vessel. The shear values are note-worthy, partly because they are high, and also because the ice shear is very high in the bow. Special attention should be paid to shear. The issue of combined shear and bending deserves consideration as well.

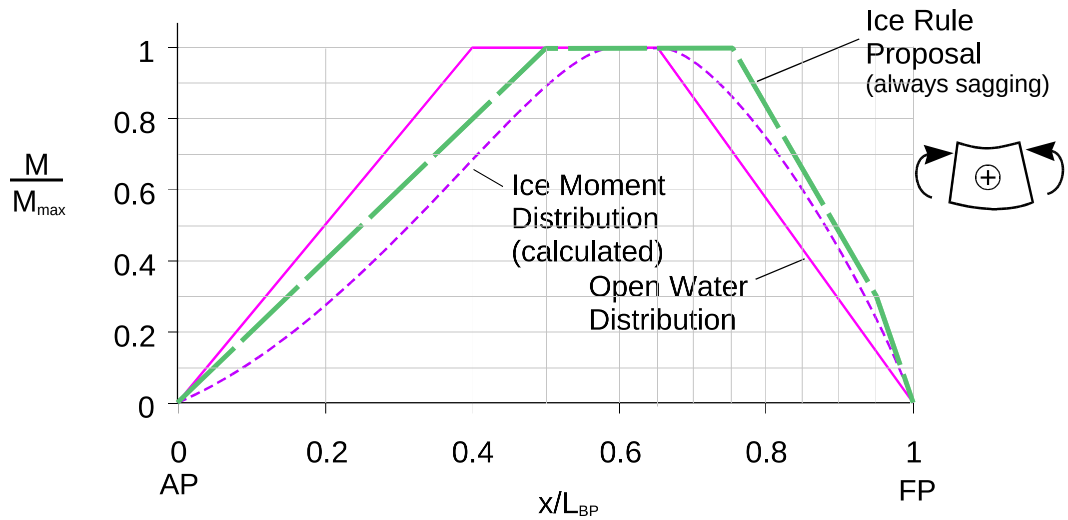


Figure 2.7. Ice Bending Moment Distribution Along Ship.

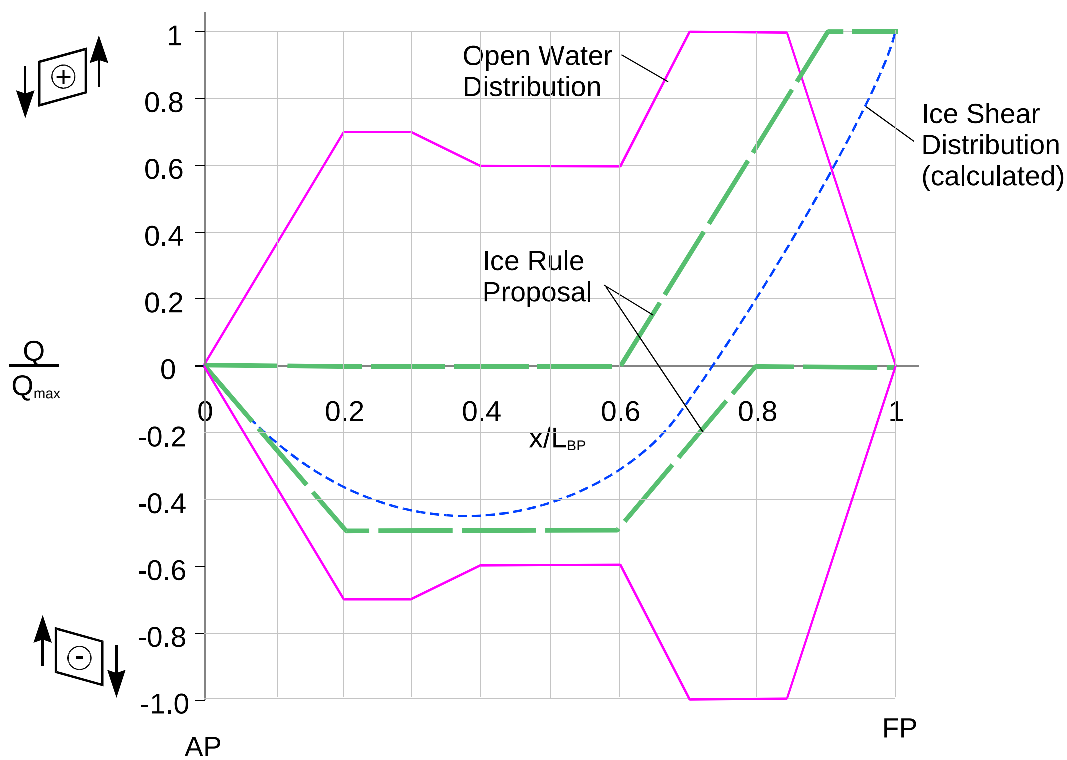


Figure 2.8. Ice Shear Force Distribution Along Ship.

Table 2.5 Maximum Ice Bending Moments as a Function of Impact Speed Compared to Open Water Values.

Ship Length [m]	Mow [MNm]	Mice(v), [v=1,…,8 m/s] [MNm] v =	1	2	3	4	5	6	7	8
40	9.4		5	9	**14**	**19**	**24**	**28**	**33**	**38**
60	34		14	28	**41**	**55**	**69**	**83**	**97**	**111**
80	86		30	59	**89**	**119**	**149**	**178**	**208**	**238**
100	177		54	108	161	**215**	**269**	**323**	**376**	**430**
120	321		87	175	262	**349**	**437**	**524**	**611**	**699**
140	534		132	263	395	526	**658**	**790**	**921**	**1053**
160	831		188	375	563	751	**939**	**1126**	**1314**	**1502**
180	1228		257	514	770	1027	**1284**	**1541**	**1798**	**2055**
200	1740		340	680	1020	1360	1699	**2039**	**2379**	**2719**
220	2384		438	876	1314	1752	2190	**2628**	**3066**	**3504**
240	3172		552	1104	1656	2208	2760	**3312**	**3864**	**4416**
260	4116		683	1366	2049	2732	3415	4098	**4781**	**5464**
280	5221		832	1664	2495	3327	4159	4991	**5823**	**6655**
300	6476		999	1999	2998	3998	4997	5996	**6996**	**7995**

Above Open-Water Values

Table 2.6 Maximum Ice Shear Force as a Function of Impact Speed Compared to Open Water Values.

Ship Length [m]	Qow [MN]	Qice(v), [v=1,…,8 m/s] [MN] v =	1	2	3	4	5	6	7	8
40	0.6		**0.7**	**1.5**	**2.2**	**2.9**	**3.6**	**4.4**	**5.1**	**5.8**
60	1.5		1.5	**2.9**	**4.4**	**5.9**	**7.3**	**8.8**	**10.2**	**11.7**
80	2.9		2.4	**4.8**	**7.2**	**9.6**	**11.9**	**14.3**	**16.7**	**19.1**
100	4.8		3.5	**7.0**	**10.5**	**14.1**	**17.6**	**21.1**	**24.6**	**28.1**
120	7.3		4.8	**9.6**	**14.4**	**19.2**	**24.0**	**28.8**	**33.6**	**38.4**
140	10.4		6.3	**12.5**	**18.8**	**25.1**	**31.3**	**37.6**	**43.8**	**50.1**
160	14.2		7.9	**15.8**	**23.6**	**31.5**	**39.4**	**47.3**	**55.1**	**63**
180	18.6		9.7	**19.3**	**29.0**	**38.6**	**48.3**	**57.9**	**67.6**	**77.2**
200	23.8		11.6	23.1	**34.7**	**46.3**	**57.8**	**69.4**	**80.9**	**92.5**
220	29.6		13.6	27.3	**40.9**	**54.5**	**68.1**	**81.8**	**95.4**	**109**
240	36.1		15.8	31.7	**47.5**	**63.3**	**79.1**	**95.0**	**110.8**	**126.6**
260	43.2		18.2	36.3	**54.5**	**72.7**	**90.8**	**109.0**	**127.1**	**145.3**
280	50.9		20.6	41.3	**61.9**	**82.5**	**103.1**	**123.8**	**144.4**	**165**
300	58.9		23.2	46.5	**69.7**	**92.9**	**116.1**	**139.4**	**162.6**	**185.8**

Above Open-Water Values

2.5.2. Accelerations

The analytical model was used to examine the vertical accelerations that result from ramming. The maximum acceleration (at the bow) can be found to follow the equation:

$$a_{\max} = 1.40 \cdot \kappa^{0.57} \cdot \sin^{0.98} \gamma \cdot \sqrt{\frac{\rho g A_{wp}}{M}} \cdot v \qquad \textbf{(5)}$$

The equation matches the analytical results within 4% over a range of β angles of 15° to 45° and κ values from 0.04 to 8.4. The distribution of values along the vessel varies depending on the vessel properties. The ranges of values are shown in Figure 15, along with a suggested rule curve.

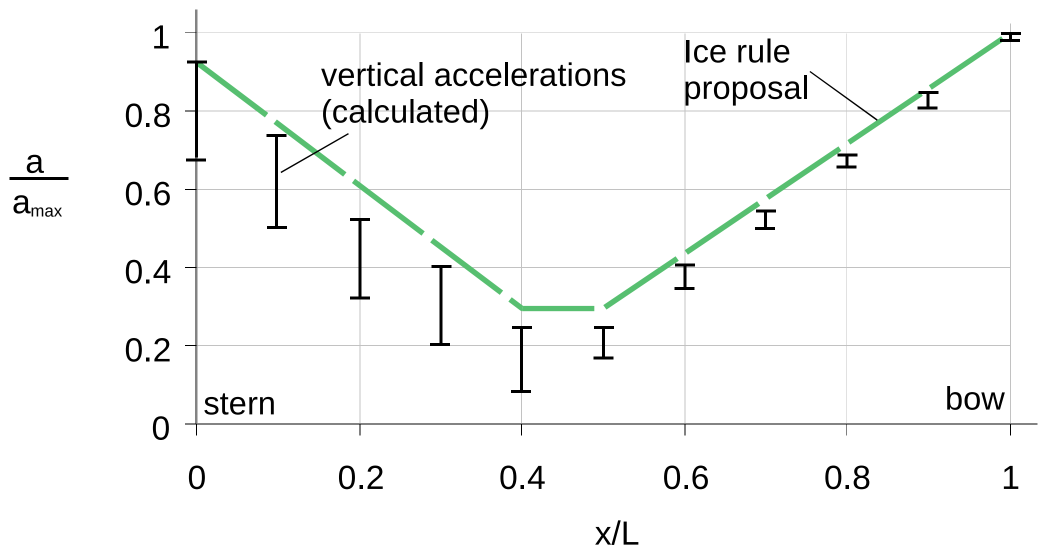


Figure 15. Distribution of vertical accelerations due to ramming.

3. Oblique Collision Studies

3.1. Background

It has been agreed that Polar Classes will be based on design scenarios. The critical scenario for bow design is the oblique collision. While head-on collisions are symmetrical, and thus can be described by 2D models, a shoulder collision results in 6 rigid body ship responses, and required a 3D model. The only existing treatment of the shoulder collision was the Russian model (the Popov model, described below), which considers the collision to occur quickly enough to be modeled by an equivalent 1D collision (a billiard ball collision).

The extensive work on head-on ramming had shown that a 1D model was insufficient, due to the extensive slide-up that occurs. With this in mind a 3D version of Sii was developed. The model is still very preliminary, but does show that under certain circumstances, there is a need to consider 3D effects.

The following sections describe the Sii3D model, the Popov 1D model, and comparisons of their results.

3.2. Numerical Model

The Sii3D model simulates oblique collisions with an ice floe (see Appendix C). The model scenario is sketched in Figure 16. The model consists of 9 mass degrees of freedom (6 for the ship + 3 for the ice) which are modeled with 18 coupled 1st order differential equations, solved step-wise in time. The model considers the ice force from the interaction of the bow (locally a flat plate) with the ice edge (wedge or circular).

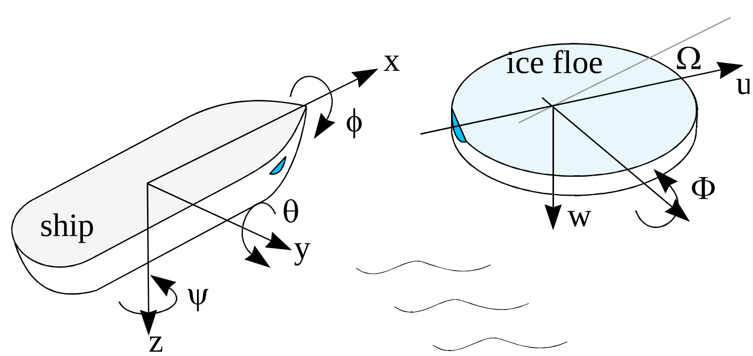


Figure 16 Sii3D model collision scenario.

3.3. Popov Collision Model

The Popov Model [10], as modified and reported in [11], is the Russian approach to modeling oblique collisions. The model assumes that the local pressures are determined by the Russian 'hydrodynamic' model (also described in [11]). This results in relatively high average ice pressures, nominally uniform over the contact zone, and growing with increasing contact area. The ship-ice interaction is modeled as an equivalent 1D collision, with all motion taking place along the normal to the shell at the collision point. As such, no sliding is modeled. This is equivalent to assuming that the impact is very quick.

Reference [11] contains sufficient detail to allow the reproduction of the calculated results. This was done in a spreadsheet model for all the cases reported. Further, a set of sensitivity runs was conducted to allow a comparison of results. Figure 17 shows a set of results from the Popov model, giving the influence of displacement on the total force. (see Appendix E) These runs were performed for ships corresponding to Russian hull forms at a speed of 5.1 m/s (very similar to results shown in [11]).

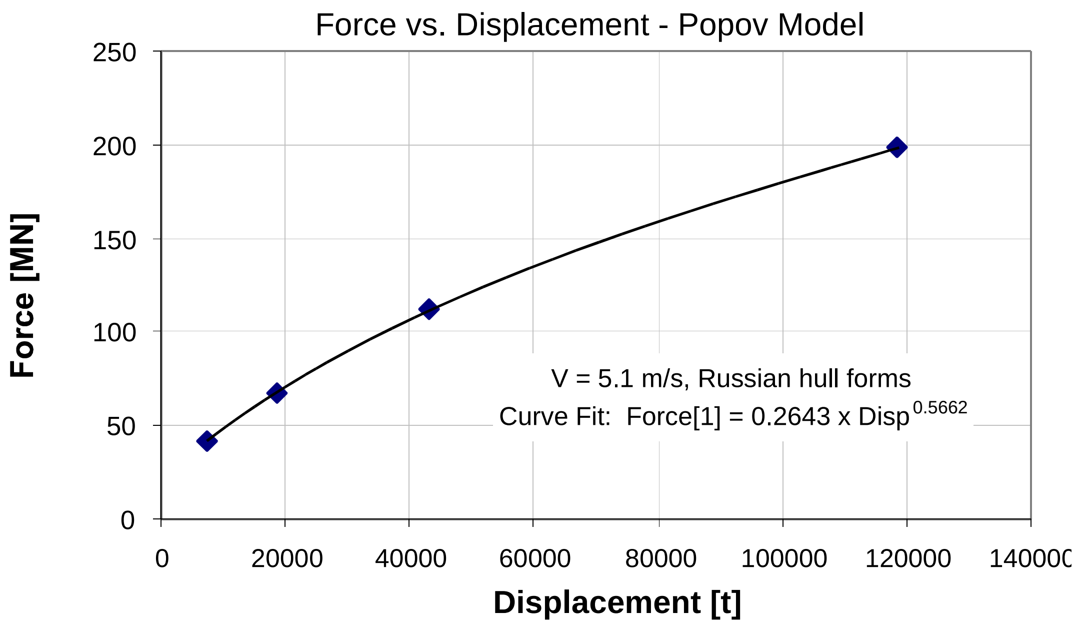


Figure 17. Results of Popov Model (from a spreadsheet developed on the basis of [11])

3.4. Collision Scenarios

The scenarios investigated are based on those described in [9] for a set of 4 cases nominally representative of the Canadian Arctic Classes (CAC1 to CAC4) [2] as well as 7 potential International Polar Classes (IPC1 to IPC7) (Table 4). Each of these scenarios is applied to the 12 vessels described above.

Fore the oblique collisions a 3D version of the Sii collision (see Appendix C) model was used to determine the forces and responses. The results of the full set of runs is given in Appendix D. Plots of force vs. displacement and force vs. velocity are given below. The trends are generally similar to the values for the head-m rams, in the sense that force is proportional to displacement to a power less than one, while force is approximately linearly proportional to displacement.

NOTE : this is the first extensive use of the 3D oblique collision model. These results will require further verification.

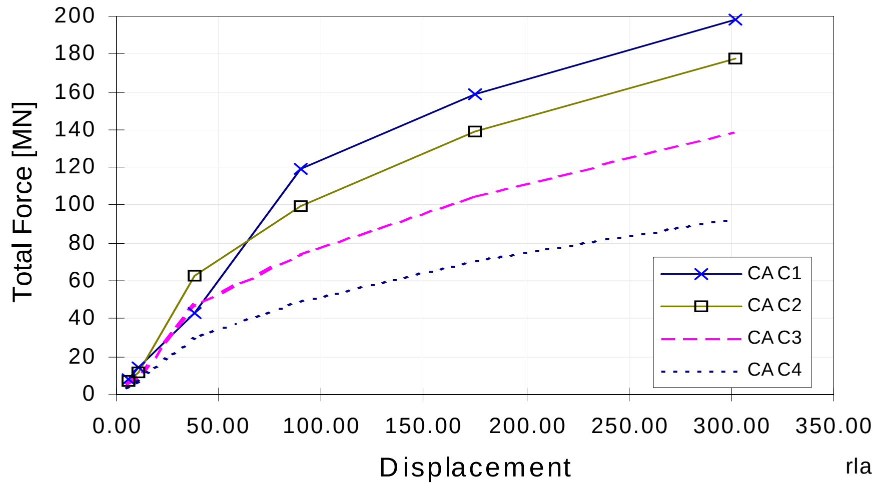


Figure 18. Collision (@0.05) Force vs Displacement for the "Robert Lemeur" vessels, for ASPPR Cases.

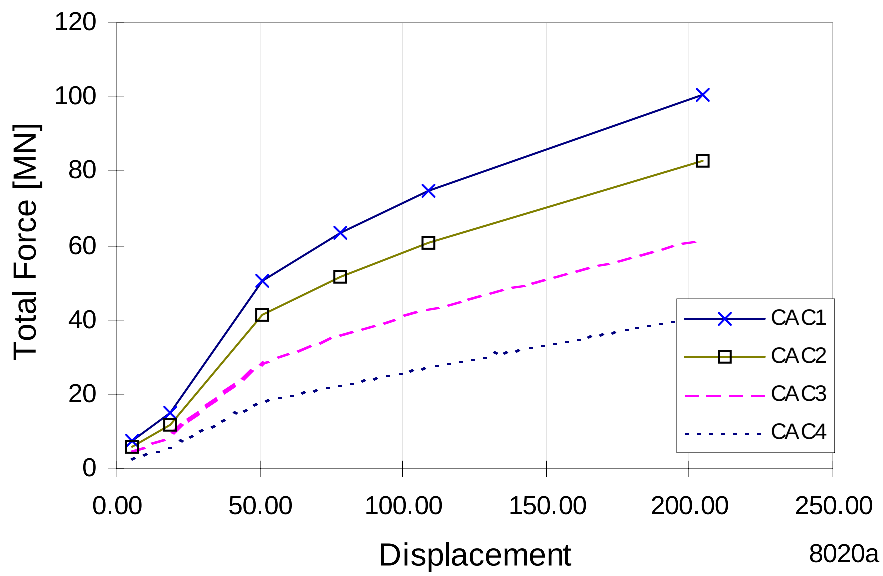


Figure 19. Collision (@0.05) Force vs Displacement for the "8020" vessels, for ASPPR Cases.

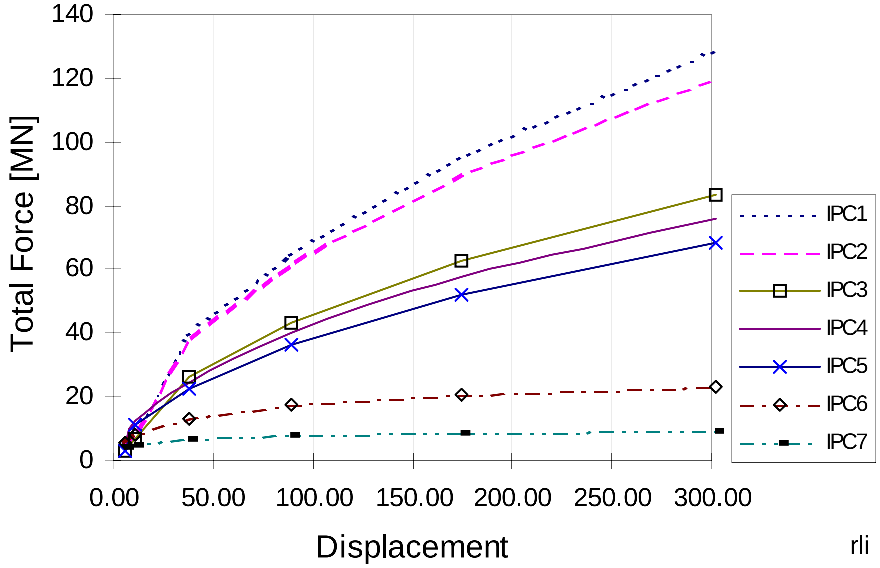


Figure 20. Collision (@0.05) Force vs Displacement for the "Robert Lemeur" vessels, for IPC Cases.

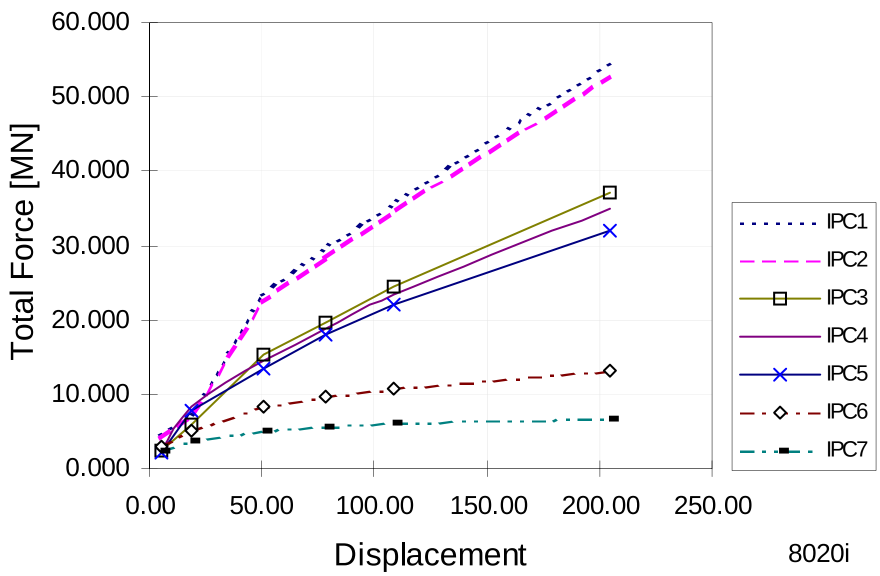


Figure 21. Collision (@0.05) Force vs Displacement for the "8020" vessels, for IPC Cases.

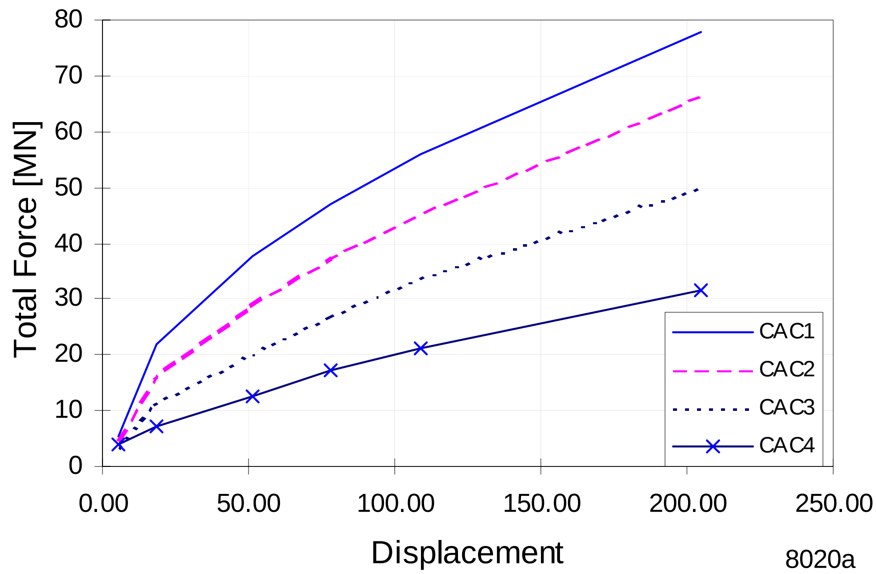


Figure 22. Collision (@0.1) Force vs Displacement for the "Robert Lemeur" vessels, for IPC Cases.

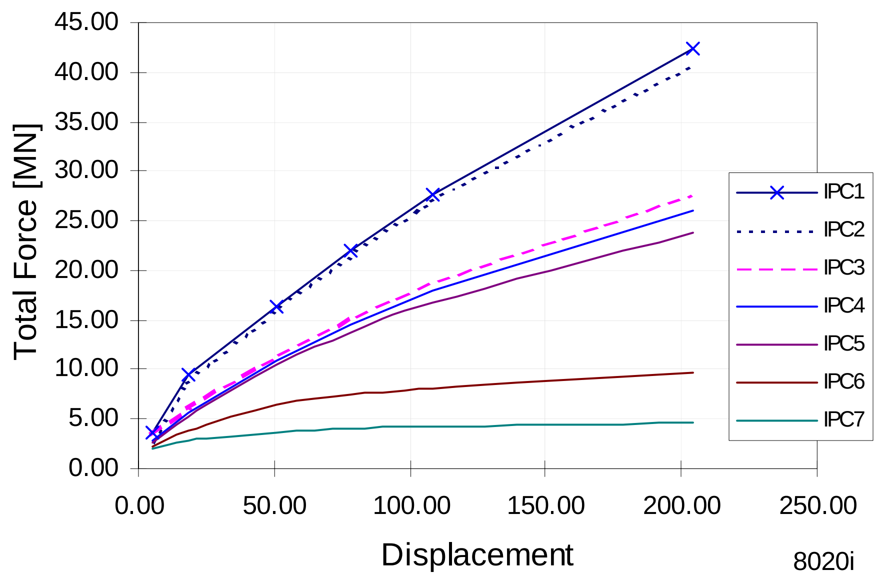


Figure 23. Collision (@0.1) Force vs Displacement for the "8020" vessels, for IPC Cases.

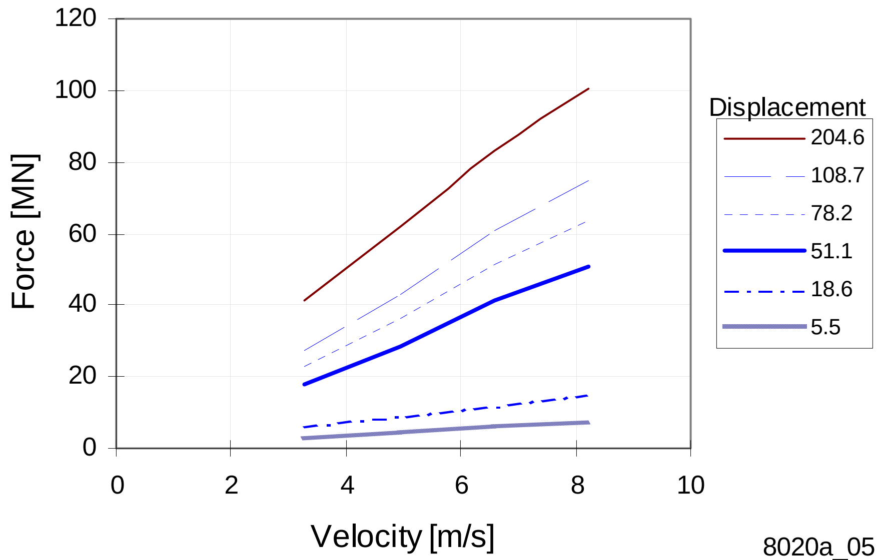


Figure 24. Force vs. velocity for the "8020" vessels, for ASPPR Cases (Oblique Collision @ 05)

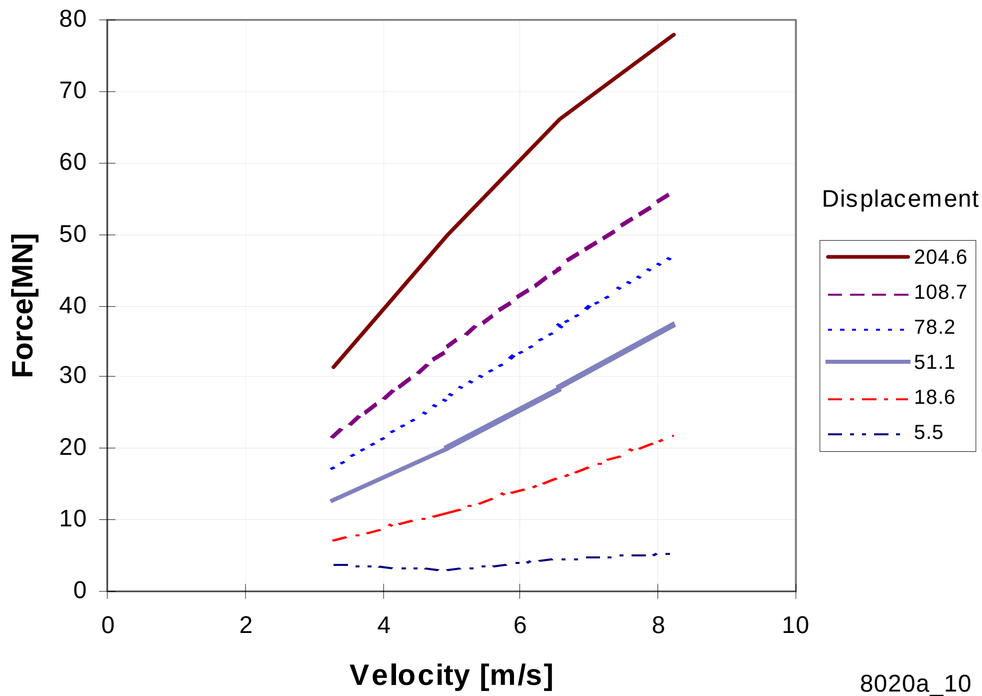


Figure 25. Force vs. velocity for the "8020" vessels, for ASPPR Cases (Oblique Collision @ 10)

3.5. Results and Discussion

The Sii3D model and the Popov model both simulate shoulder collisions. The first set of results had indicated significant differences. To try to close the gap between the models the Sii model was exercised for a set of ship and ice parameters very close to the Popov model. Figure 26 gives three sets of results for Force vs. Displacement. Two sets are Sii3D values and one is the Popov model. The ship sizes and bow angles were the same for all comparable cases. The Popov model uses an ice pressure taken from the Russian hydrodynamic model. To get close to the same effect, the Sii3D model was run (in one set) with an 8 MPa constant indentation pressure, and with the 25m ice edge radius used in [17]. For these conditions the Sii3D and the Popov model give very similar results. The Sii3D model was then run with a different ice pressure model, the one used in the Canadian grid ($p=4A^{-.4}$). The Sii3D results were much lower for these cases.

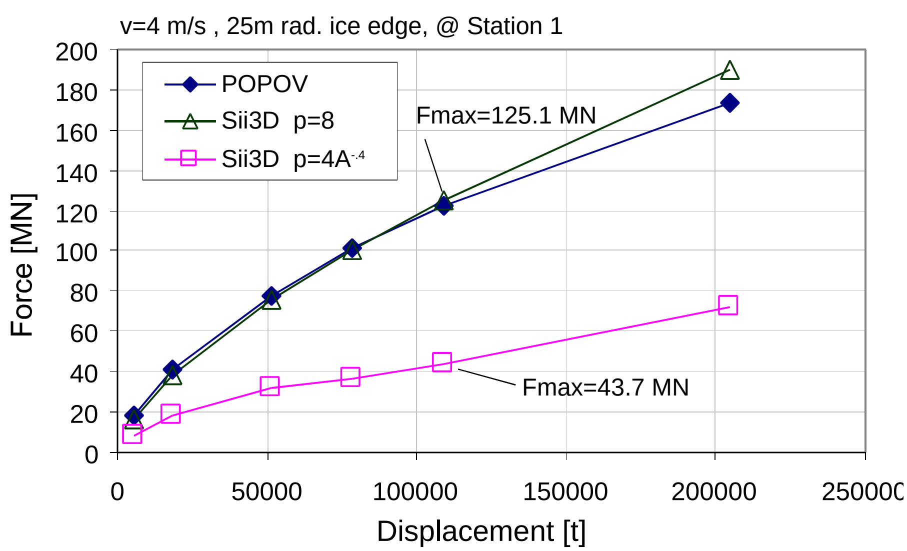


Figure 26. Sii3D and Popov model results compared.

The reason for both the Sii/Popov agreement (in one case) and difference (in the other case) can be seen when two time histories of the Sii3D model are compared. Figure 27 shows two Sii3D runs. The only difference is the ice pressure model. When the ice pressure is high (8 MPa constant) the collision shows a very rapid rise in force. The peak occurs very quickly, before any significant sliding had time to occur. In this circumstance, the 1D assumptions of the Popov model are valid, and the results agree very well. When the ice pressure is lowered ($p=4A^{-.4}$), the collision takes much longer, and the peak force occurs during a second peak (due to vessel rebound). The longer collision uses the energy differently and the peak force is significantly reduced.

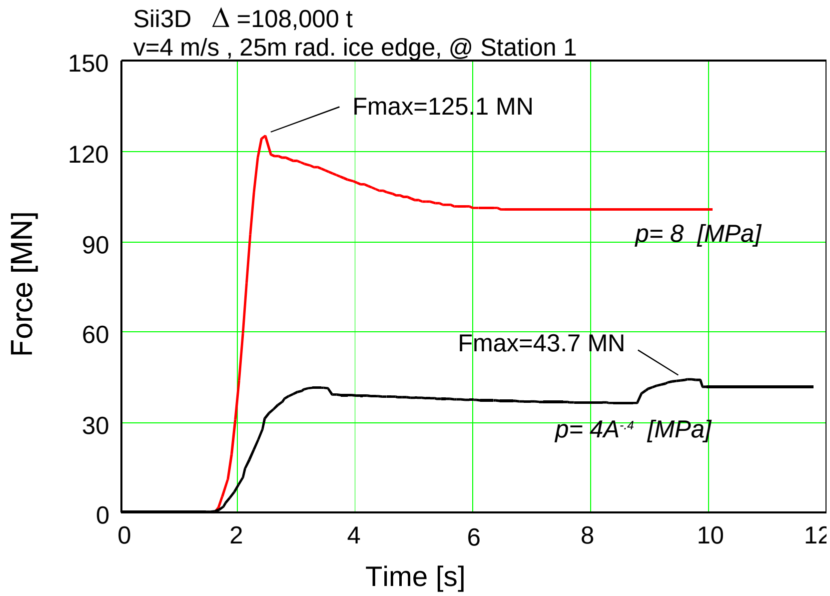


Figure 27. The Sii3D model time histories for two ice pressure models. The high pressure version is comparable to the Popov model.

The ice edge radius assumption is an important aspect in the Russian model. The sensitivity of the results to the edge radius is important. Figure 28 shows a plot of force vs. edge radius for two sets of runs of Sii3D. When the ice pressure is high (comparable to the Russian model), the force is quite sensitive to the radius. However when the lower pressure model ($p{\sim}A^{-4}$) is used the sensitivity is less.

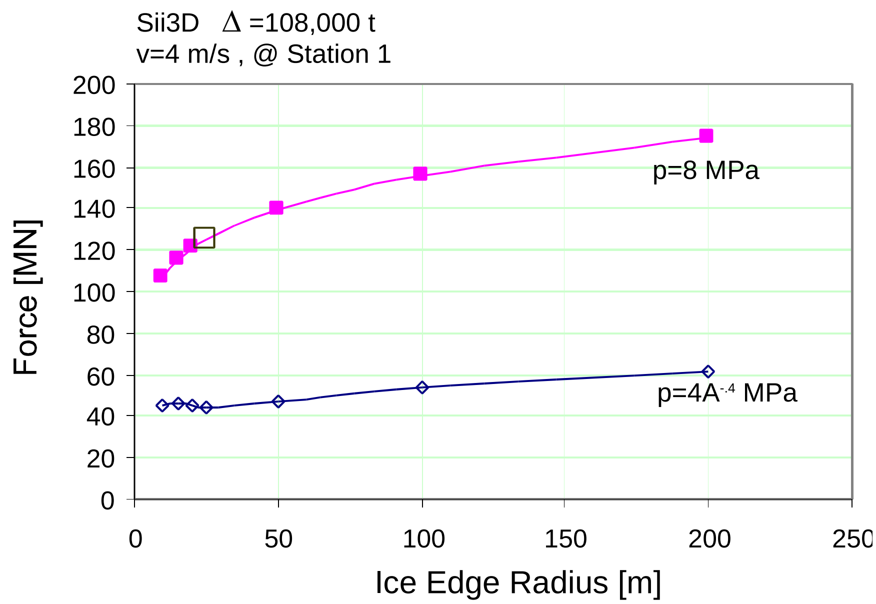


Figure 28. Sensitivity of Sii3D model results to ice floe edge radius.

The oblique collision loads have been shown to be dependent on the ice pressure model. If a lower ice pressure model (i.e. a pressure/area model) is used, the collision takes much longer to reach the peak force, and the total force is much reduced. In the lower pressure case, a further complication arises. If the collision takes a longer time, the idealization of the contact point as a plane (defined by only a, y, z, and α and β angles) may be inadequate. The collision will involve sliding along the hull, and the hull curvature (full form) may be needed to describe the situation. Several Sii3D runs have indicated that the forces continue to rise until the contact comes to the end of the bow plane (the aft knuckle of a simple planar bow). This appears to indicate that actual hull form is needed, if the real force development is to be simulated

4. Ice Thickness Statistics for the Arctic

4.1. Introduction

Ice thickness is arguably the most important ice parameter to ships, and yet it is not easily measurable. Ice thickness can be measured by upward looking sonar from a submarine, or by direct field measurements (drilling). The aim of this section is to provide data that can be used to develop ice thickness values for the collision scenarios.

There are two aspects to be considered when contemplating a design ice thickness. The first is the thickness of ice that coves the sea. This type of data can be gathered from surveys. Secondly, it must be acknowledged that ships make an effort to avoid ice, especially thick ice. Upon encountering ice, the captain of a ship must decide whether to maneuver around the ice, go through the ice, or turn back. This will modify the distribution of ice thickness that a ship will strike, as compared to the distribution of all ice in a given polar region.

This section presents the range of ice thickness values that can be reasonably expected for ice floes in various regions of the Arctic. This was done by extracting ice thickness information from several sources published over the last twenty years. Ice thickness information was investigated for different types of ice, including level (sheet) ice and ridged ice.

4.2. Ice Thickness Data - Level Ice

Ice on the sea surface forms as level sheets. However, compression due to winds and currents can deform the ice, creating ridges and rubble fields. When ice thickness data is gathered manually, the observer can tell if the cover is level ice or deformed ice. When ice thickness data is gathered automatically (as by upward looking sonar), a precise way of separating level from deformed ice is needed. Ice is considered to be level when two thickness values differ by less than 25 centimeters from that of a point 10 meters to either side [12].

Figure 29shows a map of the Arctic with four regions for which high quality ice thickness data can be found in the open literature [12, 13, 14, 15].Level ice thickness values have been obtained from various regions of the Arctic. These regions are indicated on the map (Figure 29). A description of how, where, and when each data set was obtained is given in the following sections. Also included in each section is an ice thickness frequency graph. Please note that these frequencies indicate the probability of a particular ice thickness for entire region considered.

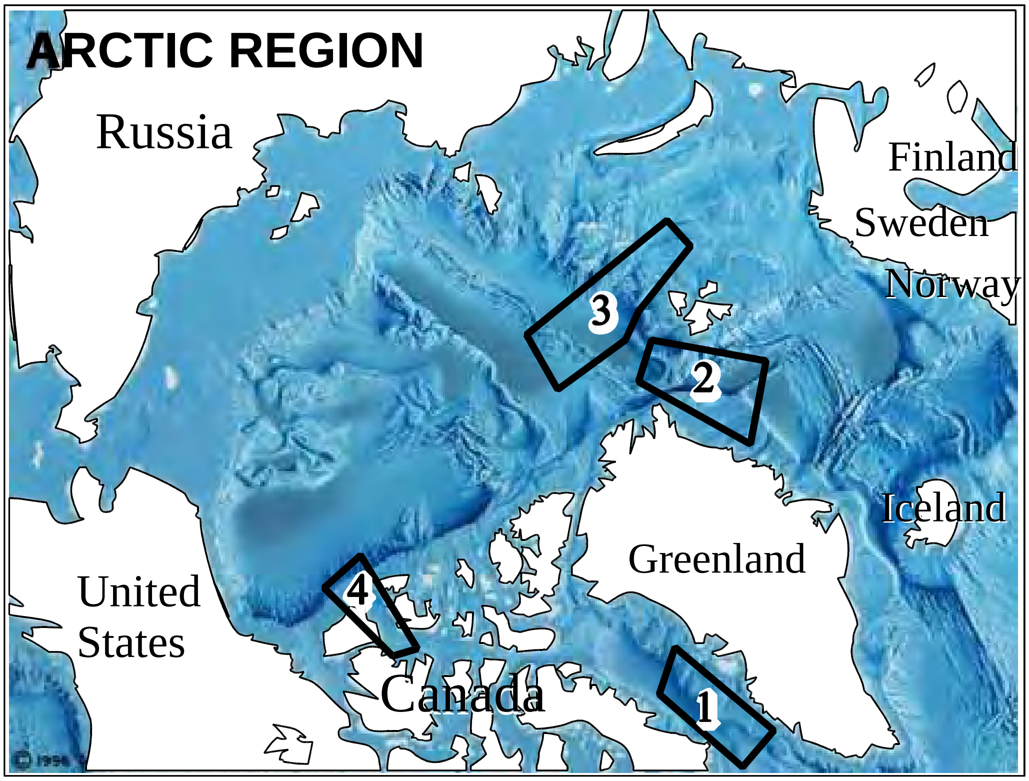


Figure 29 Map of the Arctic, with data regions indicated.

4.2.1. Level Ice Thickness - Davis Strait

Details on data collection:

Where: Davis Strait. Data collected in 13 areas between 58°W, 61°N and 60°W, 65°N (see region 1 in Figure 29).

Collected by: USS Queenfish (nuclear submarine)

Reported by: Wadhams, *from Journal of Geophysical Research* (1985)

Date: Data collected in February, 1967.

Purpose of expedition: To obtain quantitative data on ice thickness distribution in the area.

Method/materials used: Data obtained by submarine sonar.

The ice in Davis Strait is mostly first-year ice and it is carried southward into the Atlantic Ocean. This region does not usually receive as much pack ice from the Central Arctic as the Beaufort Sea or the Fram Strait because Greenland, Ellesmere Island and other islands act as obstacles between Davis Strait and the Central pack. As a result, most of the ice in Davis Strait is level first-year ice that actually forms inside the region. The "marginal ice zone (MIZ)" within 100 kilometers of the ice edge contains 93-100% level ice and the “interior zone” contains 67-91% level ice [12]. These percentages of level ice are greater than any other area of the Arctic.

Figure 26 shows the probability frequency of ice thickness values. These values were digitized from the probability density function provided in Figure 27 [12]. Both graphs consider ice thickness in the interior zone only, not the MIZ. The probability of encountering ice between 0-2 metres thick is over 90%. The thickest level ice in the region is 3-4 metres thick. The MIZ contains mostly first-year ice, over 85% of the ice is less than 1 metre thick, and there is almost no probability that it will be thicker than 3.5 metres.

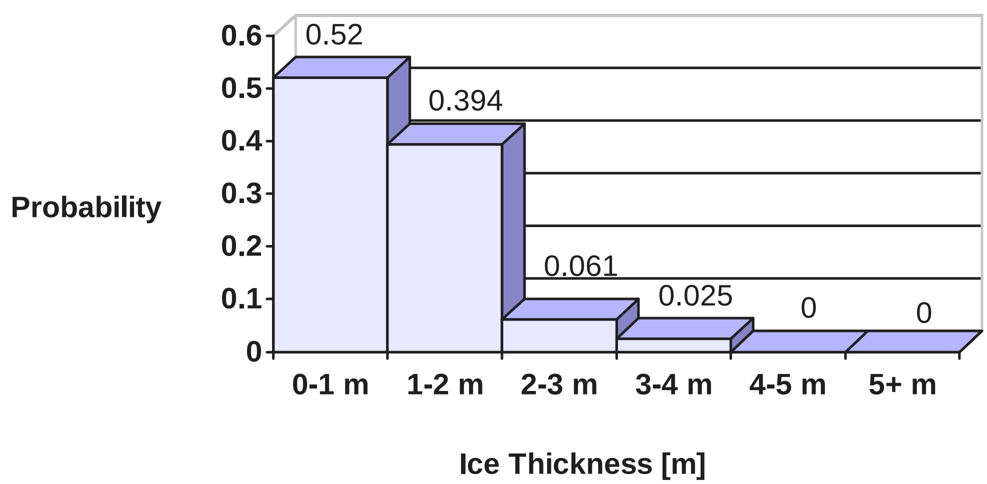


Figure 30 Ice Thickness Probabilities for Level Ice in Davis Strait.

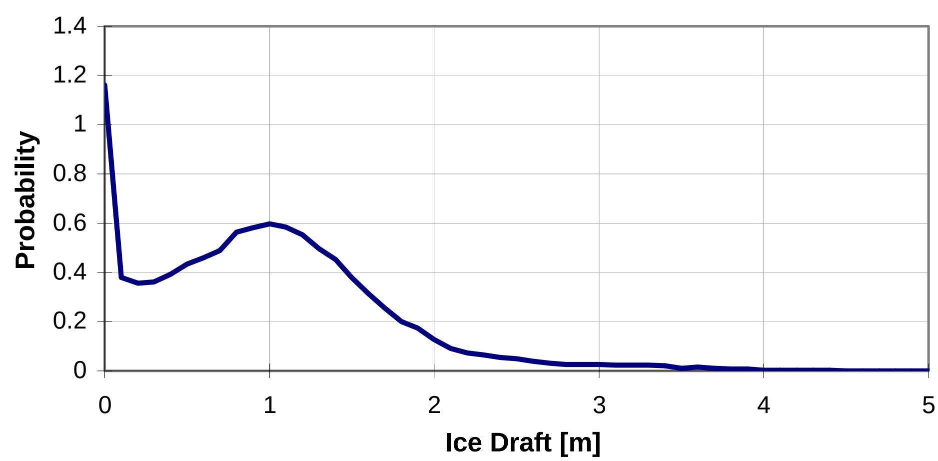


Figure 31. Probability Density Function for Sections 2-11 of Davis Strait Data (extracted from [12]).

4.2.2. Level Ice Thickness - Eurasian Sector

Details on data collection:

Where: European Arctic to the North Pole. Approximately spans the area between 160°W and 90°N to 40°E and 82°N (see region 2, Figure 29)

Collected by: Three icebreakers: the Polar Star, the Polarstern, and the Oden.

Reported by: Eicken et al. from *Journal of Geophysical Research* (November, 1995)

Date: Data collected in August and September, 1991.

Purpose of expedition: To study the thickness, structure and properties of level multiyear ice.

Method/materials used: Cores drilled through entire thickness of the ice.

Figure 28 shows the probability density function for level ice thickness data in the Eurasian sector [13]. This information was digitized to obtain the probability frequency graph in Figure 29. When considering the values presented in these graphs, it is important to consider the large area covered in this study. This area includes the Greenland Sea and a portion of the Central Arctic ice pack, two regions with different ice characteristics. The multiyear ice in the Central Arctic pack is generally thicker than that in the Greenland Sea, meaning that most of the ice between 6 metres and 7 metres is likely to be found between 88°N and 90°N.

Figure 32 indicates that there is a 75% probability that the level ice in the Eurasian sector of the Arctic is between 2 and 4 metres thick and only a 10% probability that the ice in this region is greater than 4 metres thick. However, the probability of encountering ice 6-7 metres thick is higher in this area than it is in most other regions of the Arctic. Thus, ships traveling this region should be prepared to ram through 7 metres of ice.

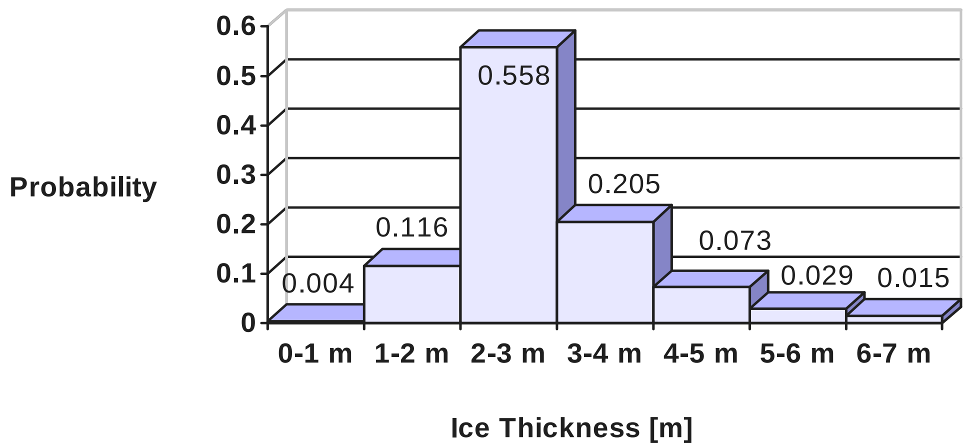


Figure 32. Ice Thickness Probabilities for Level Ice in the Eurasian Sector of the Arctic Ocean.

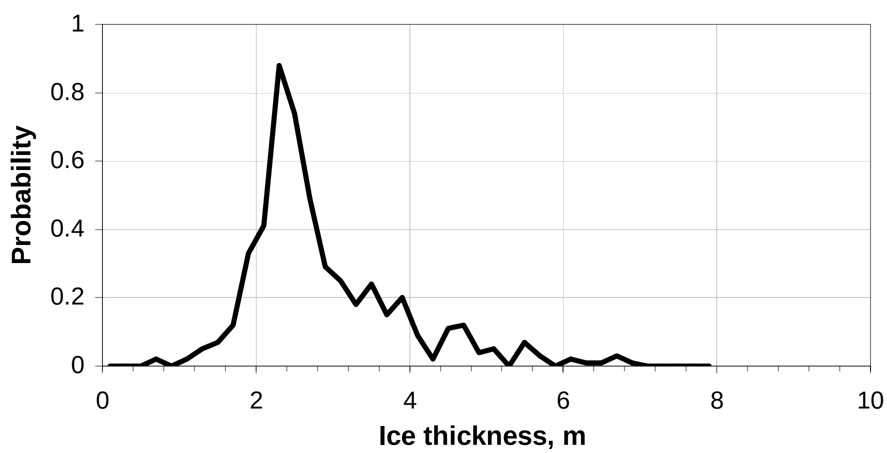


Figure 33. Probability Density Function for Ice Thickness in the Eurasian Sector of the Arctic (extracted from [13]).

4.2.3. Level Ice Thickness - Fram Strait

Details on data collection:

<u>Where:</u> Fram Strait (see region 3 in Figure 29)

<u>Collected by:</u> Lance and Polarstern (icebreakers)

<u>Reported by:</u> Vinje and Finnekasa, Norsk Polarinstitut (1986)

<u>Date:</u> July and August each year from 1981 to 1984.

<u>Purpose of expedition:</u> To investigate the thickness and concentration of ice in the Fram Strait.

Method/materials used: Data obtained by drilling cores through entire thickness of ice.

The Fram Strait is located in the Greenland Sea between the east coast of Greenland and the west coast of Svalbard. The ice thickness distribution in the Fram Strait has considerable variation, from 1-2 metres near Svalbard to 5-6 metres near Greenland [14]. The reason for this variation is that a lot of ice from the Beaufort Sea and the Barents Sea is drawn through the Fram Strait by southward currents. The Eastern portion of the Fram contains a larger concentration of first-year ice from the Barents Sea and the Western portion contains a larger concentration of multiyear ice.

Figure 30 [14] shows the frequency distribution of the thickness of level ice in the Fram Strait. There is a wide range of values, and they are more evenly distributed than in Davis Strait (52% of ice between 0-1 metres thick) or the Eurasian sector (56% between 2-3 metres thick). The even distribution indicates that ships are quite likely to encounter level multiyear ice 6 metres thick in the Fram Strait, and they should be designed accordingly.

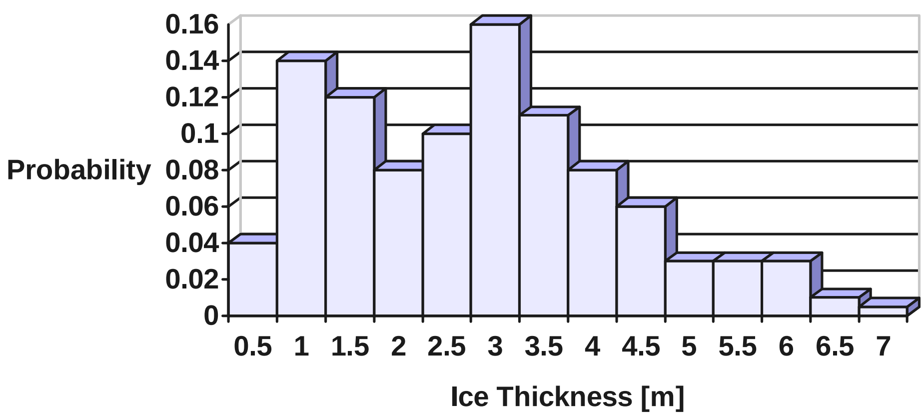


Figure 34. Frequency Distribution of Level Ice Thickness in the Fram Strait (extracted from [14]).

4.2.4. Level Ice Thickness - Queen Elizabeth Islands

Details on data collection:

Where: M’Clure Strait, 25 sites investigated (14 in winter, 11 in summer). (See region 4 in Figure 29)

Collected by: USS *Sargo* (submarine), USS *Seadragon* (submarine)

Reported by: MacLaren, Wadhams, and Weintraub from ARCTIC magazine (June, 1984)

Date: Data collected in February, 1960 (by Sargo) and August 1960 (Seadragon).

Purpose of expedition: To obtain quantitative data on ice thickness distribution in the area.

Method/materials used: Data obtained by submarine sonar.

M'Clure Strait is an important shipping route. It is also located in an area that features some of the thickest ice floes in the Arctic. Expeditions by the Sargo and Seadragon have shown that in various regions of M'Clure Strait, anywhere from 40% to 70% of the ice is level (see Table 7, [15]).

Due to a lack of appropriate data, an ice thickness frequency distribution could not be prepared for M'Clure Strait, however Table 7 presents some important statistics. Note that one of the headings states "Two depths <1 m with highest frequencies of level ice," and another column gives the depths ">1 m." The depths less than 1 metre are representative of first-year level ice, while the depths greater than 1 metre are representative of multiyear level ice. Thus, the table actually presents the most frequent thickness values for first-year and multiyear level ice.

The values for first-year level ice in the winter (taken by *Sargo*) appear to be greater than the values for those in the summer (*Seadragon*). This is to be expected because of the summer melt. It can also be seen that there is a relatively high frequency of multiyear level ice with a thickness of 6 metres. Therefore, ships entering the M'Clure Strait should be designed for a level ice thickness of at least 6 metres.

Table 7. Distribution of Level Ice in M'Clure Strait (extracted from [15]).

Section	Percentage level ice	Two depths with frequencies ^ level ice		Two depths with frequencies ^ level ice	
Sargo (winter)					
1	56.1	0.9	0.0	3.5	4.0
2	51.1	0.9	0.4	1.7	1.6
3	49.2	0.2	0.7	1.6	1.5
4	53.5	0.9	0.7	2.1	2.0
5	66.5	0.9	0.8	1.5	1.6
6	61.0	0.3	0.9	1.4	1.6
7	65.6	0.9	0.2	1.5	1.4
8	54.0	0.8	0.9	1.2	1.1
9	51.2	0.8	0.7	6.0	2.0
10	47.5	0.7	0.9	4.2	3.7
11	52.1	0.5	0.4	3.1	3.4
12	45.3	0.4	0.6	3.2	3.3
13	65.4	0.9	0.8	1.0	1.3
14	55.0	0.7	0.8	2.4	2.3
Seadragon (summer)					
1	48.6	0.5	0.4	1.1	1.0
2	56.4	0.6	0.7	1.0	1.1
3	64.2	0.4	0.7	1.6	1.7
4	62.6	0.5	0.8	2.0	1.9
5	39.1	0.9	0.8	1.2	1.0
6	53.1	0.4	0.3	3.5	3.6
7	57.2	0.8	0.7	1.0	3.8
8	60.0	0.7	0.8	1.0	2.8
9	64.7	0.5	0.6	2.2	2.3
10	57.4	0.5	0.3	2.2	2.3
11	69.4	0.9	0.7	1.0	1.1

4.2.5. Final Comments on Level Ice

Clearly, there are regional variations in level ice thickness in the Arctic. For example, a ship designed to ram ice 2 metres thick would have little difficulty in navigating Davis Strait, but it would have great difficulty navigating the Queen Elizabeth Islands.

The combined data is plotted in a histogram in Figure 35. One can conclude that nominally level ice can readily be found in thicknesses of up to 7 m. Nominally level means having a thickness gradient of less than 5 deg. Only deformed ice (i.e. MY Ridges and glacial ice is thicker).

Please note that the area this figure represents a very limited portion of the Arctic, and it does not include the Beaufort Sea or the Queen Elizabeth Islands due to a lack of data.

The transit ice conditions survey reported by Tunik in [17] show that ship operations tend to significantly reduce the thickness of ice that ships actually interact with. This is further argument that design ice thickness can be much less than 'nominally infinite'.

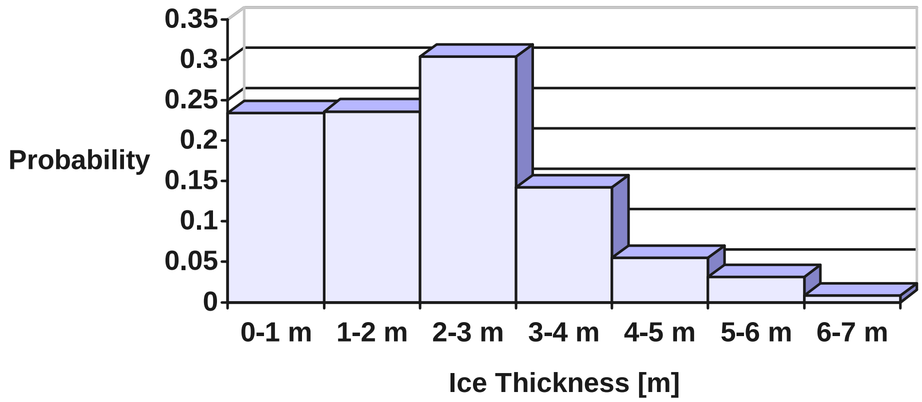


Figure 35. Combined Ice Thickness Distribution for the Davis Strait, Fram Strait, and Eurasian Sector.

4.3. Deformed Ice

4.3.1. First-Year (Consolidated) Ice Ridges

There was not enough first-year ice ridge information collected to produce a reliable thickness frequency distribution. Data is available on only 90 first-year ridges, and is limited to the Beaufort Sea. Most of the consolidation layers are between 0 metres and 2 metres, but there are some ridges with consolidation layers more than 4 metres thick.

A typical first year ridge is illustrated in Figure 36. The keel can be quite deep, and a consolidated layer can form to a thickness much greater than the surrounding level ice. Burden and Timco [16] have completed a database of ice ridges based on research by several investigators. Appendix F gives some ridge data extracted from {16] The ridges are both first-year ridges (which contain a consolidation layer) and multiyear ridges (which are solid ice). Figure 37 is a plot of consolidated thickness vs. keel depth for all the first year ridges in the database. The one clear result is that consolidated thicknesses do not exceed 7 m, a value which just happens to be the same as the approximate maximum level ice values.

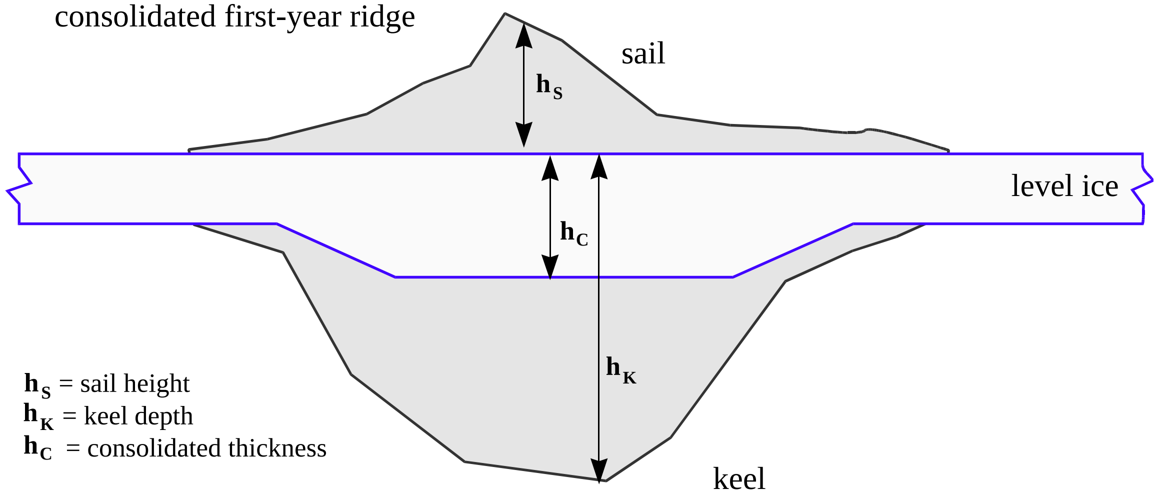


Figure 36. Cross section of typical first year ridge.

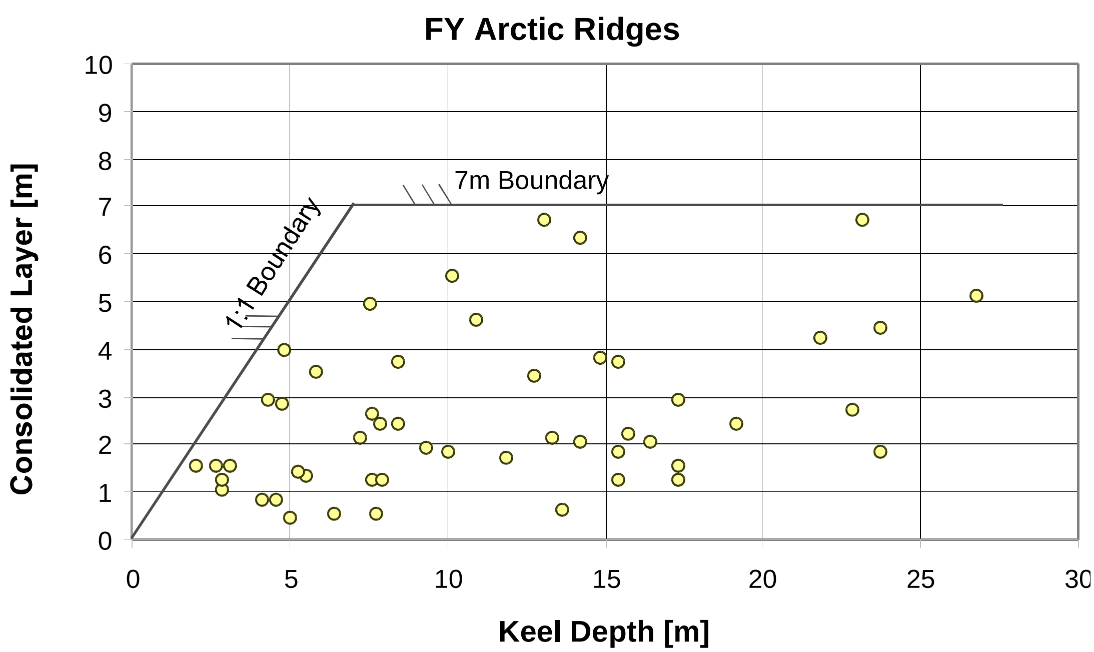


Figure 37. First-year Ridge consolidated thickness vs. Keel Depth [extracted from 16]

4.3.2. Multiyear Ice Ridges

The data for multiyear ice ridges [16]ridges to obtain reliable ice thickness probabilities. It is interesting to note, however, that there were maximum keel depths of over 30 metres identified in the Beaufort Sea and the Queen Elizabeth Islands. Some of the sails above these keels were over 5 metres high. Such a large obstruction is easily sighted by the captain of a ship, who will opt to maneuver around the floe instead of ramming it.

Figure 38 is a plot of sail height vs. keel depth for all the multiyear ridges in the database. Multi-year ridges can have thicknesses of 40 m. However, such ridges also have sails of at least 1/6 of the depth. One would expect that the large MY ridges would be easily detectable, and could be categorized, along with icebergs and ice islands, (and all land) as avoidable hazards, rather than being viewed as possible candidates for an ice collision scenario.

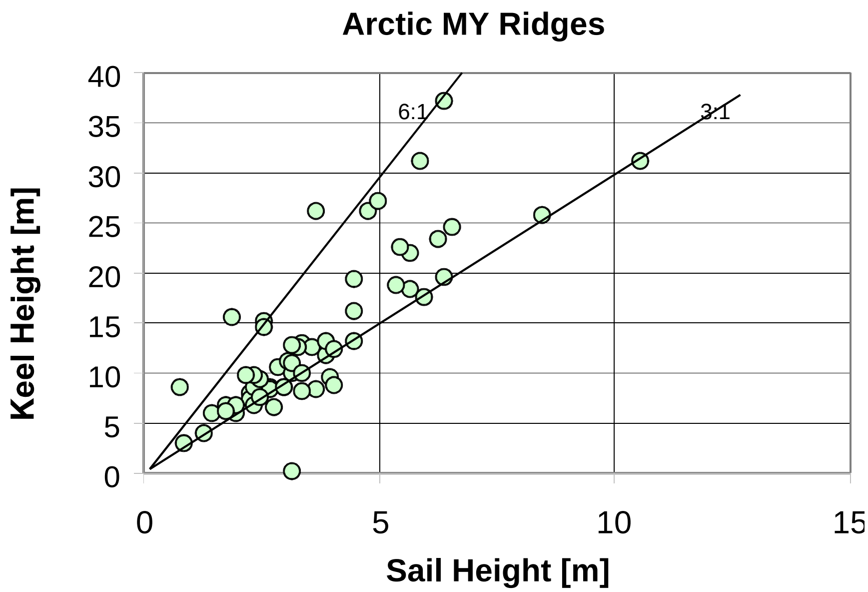


Figure 38. Multi-year Ridge parameters [extracted from 16]

4.4. Route Specific Ice Thickness

The values collected in Sections 4.2 and 4.3 were obtained from either cores drilled into the ice or from submarine sonar. The values were therefore collected over an entire region, which can be called “region specific” ice data [17]. When a ship navigates the Arctic Ocean, the captain will want to avoid very thick ice and sail around it. Thus, the ice characteristics encountered by the ship depend on the route. Data which depends on the path taken by the ship is called “route specific” ice data.

Consider the values in Figure 39 which are based ice encountered by the *Rossia*, a Russian icebreaker. The thickness values were obtained by examining videotapes and photographs of ice fragments that were broken out of the ice cover by the icebreaker [17]. The region specific data (in white) indicates that ice of 8 metres thickness is relatively common. However, the ice thickness encountered by the *Rossia* is “cut off” at 6 metres. This is because the captain of the *Rossia* anticipated very thick ice and opted to sail around it.

One set of data on a particular ship does not provide a very good indication of how much ice a ship is capable of cutting because the captain may have been conservative or the ship may have needed repairs. However, route-specific ice thickness values are very useful in determining a design ice thickness for ships because they provide insight into how much ice the captain believes his ship can conquer. For example, if it was known that a captain was never going to try to ram through 8 metres of ice, then the ship would not need to be designed to cut through 8 metres of ice.

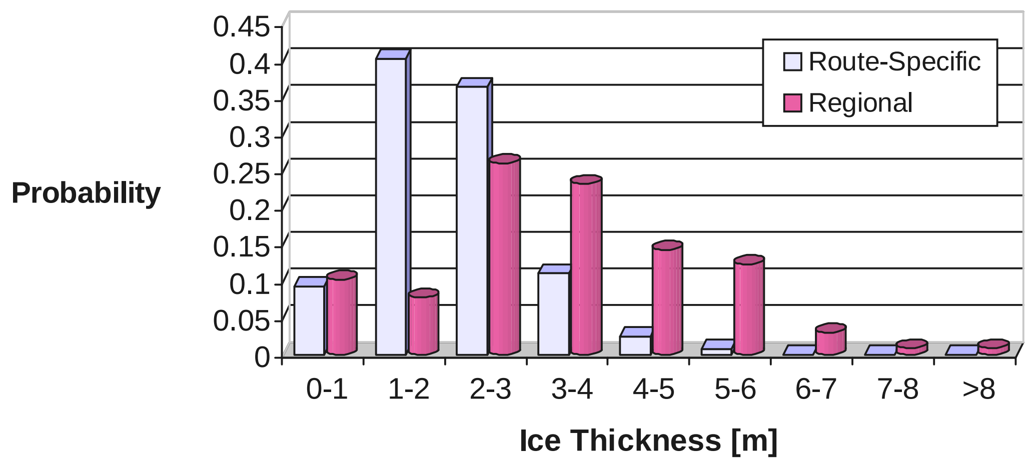


Figure 39. Comparison of Route-Specific and Region-Specific Ice Thickness (extracted from [17]).

4.5. Conclusions

4.5.1. Summary

Ice is considered to be level when the draft of the floe differs from that of a point 10 metres to either side by less than 25 centimetres [12]. In the Arctic, there are regional variations in level ice thickness. Davis Strait is composed of mostly first-year ice and is almost completely level. The thickness of more than half of the ice in Davis Strait is between 0-1 metres, and over 90% of the ice is between 1-2 metres. By contrast, the Queen Elizabeth Islands contain regions where level ice is 6 metres thick. A probability graph was derived based on level ice thickness data in the Fram Strait, Davis Strait, and the Eurasian Arctic (Figure 5.1). The graph indicates that over half of the level ice is between 1-3 metres thick. It also shows a relatively high frequency of ice between 6-7 metres thick. Therefore, the ships traveling this area should be designed to encounter a level ice thickness of 7 metres.

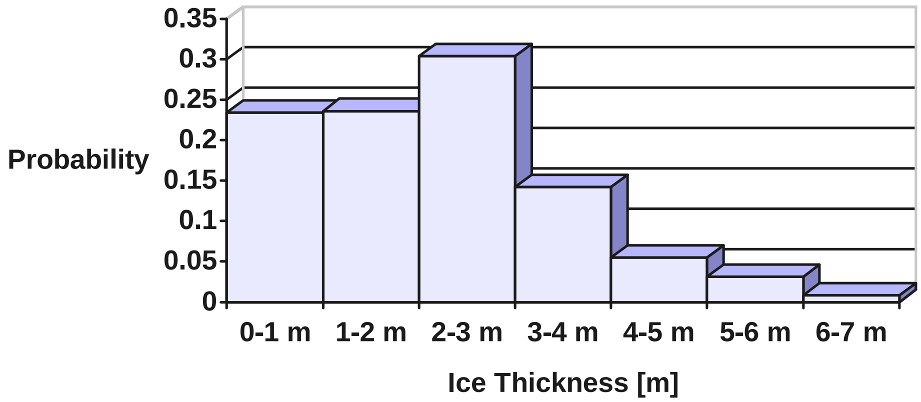


Figure 40. Ice Thickness Distribution for the Davis Strait, Fram Strait, and Eurasian Sector.

Ice ridges are broken ice blocks that thrust above and below converging ice sheets that can be formed either by shear pressure or compressive pressure. They are very common in the Beaufort Sea, Queen Elizabeth Islands, and the Central Arctic ice pack. Due to a lack of data, reasonable ice thickness probabilities could not be obtained.

"Route-specific" ice thickness values are those that depend upon the path taken by the ship. They are useful in determining the design ice thickness for a ship because they provide insight into how much ice the captain believes his ship can conquer. An article by Tunik [17] studied the route-specific ice thickness for the *Rossia*, a Russian icebreaker, and determined that the *Rossia* never cut through ice more than 6 metres thick.

4.5.2. Recommendations

One of the main disadvantages of this report was the lack of raw data. The reference materials used in this report were data analyses in their own right, and it was difficult to perform the desired analysis without the actual. It is recommended that raw data should be obtained for ice ridges and level ice to obtain a better estimation of design ice thickness.

It is recommended that more investigation should be carried out on route-specific ice thickness. Route-specific data should be taken from a number of vessels of different sizes. This data would be useful because if it was known that a captain was never going to try to ram through 8 metres of ice, then the ship would not need to be designed to cut through 8 metres of ice.

It is recommended that further data be obtained for ice ridges in the Arctic. Ridges are features that are very common to ice floes, especially in the shipping routes of the Queen Elizabeth Islands, and must be considered in deriving a design ice thickness.

5. Conclusion

This summary of recent work has given a variety of results, covering head-on ramming, oblique ramming, ice thickness statistics and local pressure patterns. The following suggestions are made.

1) Ramming force can be determined by the equation

$$F_{n,\max} = 0.54 \cdot \kappa^{.15} \cdot \sin^{.2}\gamma \cdot V \cdot \sqrt{\rho g \cdot M \cdot A_{wp}}$$
$$or \quad 1.35 \cdot \sigma \cdot hice^{2} \qquad (3)$$

To implement this in a rule, only a design velocity and ice thickness and strength for each class is needed. These can be selected to give the desired range of values. A flexural strength of say 0.8 MPa, could be used for all classes.

2) The bending moment can be found from;

$$M_{\max} = 0.1 \cdot L \cdot \sin^{.2}\gamma \cdot F_{n,\max} \qquad (4)$$

The distribution of bending moments, shear and accelerations are specified.

3) The oblique collision modeling needs further development, with the influence of hull form (full shape) requiring special attention. The differences between the 1D Popov model and the simple Sii3D model are too great to allow a load definition. The ice indentation modeling (pressure/area effects) are crucial.

4) Limiting ice thickness values should be employed. Level ice above 7m is extremely rare in the Arctic. Thicker ice exist only in features such as ice islands, icebergs and very heavy MY ridges. The extreme features should be viewed as outside the design envelope.

6. References

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4. Daley, C., Hayward, R., and Riska, K., "Ship Ice Interaction : Determination of Bow Forces and Hull Response Due to Head-on and Glancing Impact With an Ice Floe". Transport Canada Report TP-12734E. Memorial University of Newfoundland, St. John's , Newfoundland, Canada and Helsinki University of Technology, Espoo, Finland. March 1996.
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Appendix A

Sii_2D Listing.

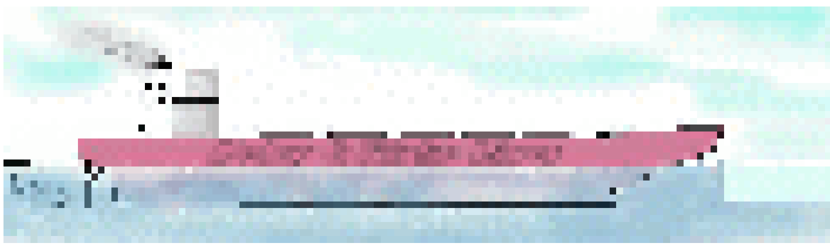
Sii : Simulation of a Ship Ramming Ice

Claude Daley,
Nov. '93

a Mathcad®**6.0+** File

Modified: July, 95, Jan., Mar. 97

File : Sii_2D_H1 - Ship_ice_interaction model for 2D (head-on) ramming. The model is udated to calculate the cases for the Harmonized Rules.



This file calculates the forces on a ship, when ramming a floe of finte thickness and extent. The surge, heave, pitch and bennding of the ship are modelled. The crushing, tipping, and bending of the floe are included.

Disclaimer: The model contains idealizations and assumptions. The author believes that the model fairly represents the mechanics that occurs when a ship strikes an ice edge, based on comparison with available data. However, the model contains numerous parameters, many of which have a significant effect on the particular results. Caution should always be used when applying the results.

INPUT: Ship Parameters

The INP vector is copied from the excel sheet or can be supplied by the user

Main Particulars:

length (m)	$LBP := INP_0$	$LBP = 300$
beam (m)	$B := INP_1$	$B = 72.15$
draft (m)	$T := INP_2$	$T = 20.86$
waterline entrance angle	$alf := INP_7 \cdot deg$	$alf = 1.484$
stem angle (from vert)	$gam := (90 - INP_8) \cdot deg$	$gam = 1.309$
Block coefficient	$CB := INP_3$	$CB = 0.7$
Waterplane coefficient	$CWP := INP_4$	$CWP = 0.9$
ship speed (m/s)	$vship := INP_6$	$vship = 3.3$

INPUT: Ice Parameters

initial penetration	$initpen \equiv 0.1$		
Po (Pa)	$Po := INP_{11} \cdot 1000000$	$Po = 3.5 \times 10^6$	for p_ice = Po A^ex
exponent	$ex := INP_{12}$	$ex = -0.5$	
water density (kg/m^3)	$ro \equiv 1025$		
gravity (m/s^2)	$g \equiv 9.8$		
	$d := ro \cdot g$		
ice density	$roice := ro \cdot .88$		
ice thickness (m)	$hice := INP_9$	$hice = 100$	
floe length (m)	$Lfloe := INP_{10}$	$Lfloe = 1 \times 10^4$	
floe width (m)	$Wfloe := INP_{10}$	$Wfloe = 1 \times 10^4$	
ice flex strength (Pa)	$sigf := INP_{13} \cdot 10^6$	$sigf = 8 \times 10^5$	

Calculated Quantities

displacement (m^3) $Disp := LBP \cdot B \cdot T \cdot CB$ $Disp = 3 \times 10^{5}$

mass of ship (kg) $M := Disp \cdot ro$ $M = 3.24 \times 10^{8}$

area of waterplane (m^2) $AWP := B \cdot LBP \cdot CWP$ $AWP = 1.948 \times 10^{4}$

surge stiffness: $kx := 0$

$n := 1.29 \cdot CWP - .49$

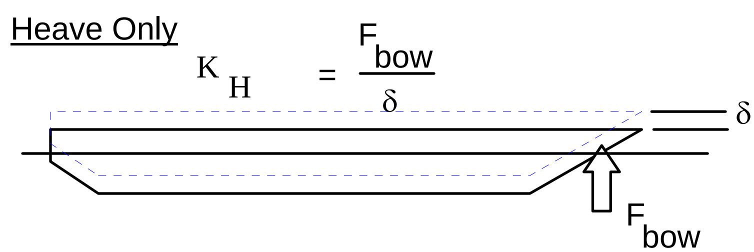
$n = 0.671$

Longitudinal Moment of Inertia of Waterplane

$$I_L := n \cdot \frac{B \cdot (LBP)^3}{12} \qquad I_L = 1.089 \times 10^{8}$$

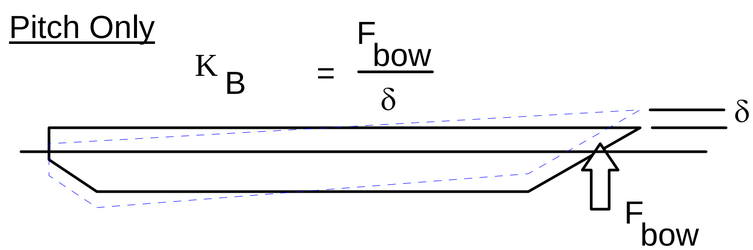
Heave Stiffness MN/m

$K_H := AWP \cdot d$



Pitch Stiffness MN-m/rad

$K_P := I_L \cdot d$



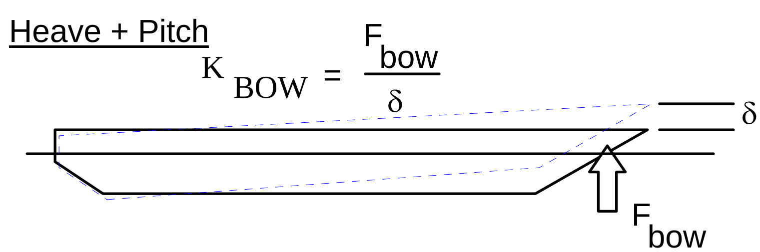
Pitch Stiffness for Bow Force MN/m

$$K_B := \frac{K_P}{\left[\left(\frac{LBP}{2}\right)^2\right]}$$

Vertical Stiffness at Bow

$$ky := \frac{1}{\left(\frac{1}{K_B} + \frac{1}{K_H}\right)}$$

$ky = 3.895 \times 10^{7}$



Vertical Rigid Body Mass at Bow

$My := .2 \cdot AM \cdot Disp \cdot ro$

$My = 1.397 \times 10^{8}$

*<= 37% of ship's mass****
(includes added mass)*

$AM := \frac{.2 + B}{3 \cdot T} + 1$

$AM = 2.156$

Horizontal Rigid Body Mass at Bow

$Mx := Disp \cdot ro \cdot 1.045$

$Mx = 3.385 \times 10^{8}$

*<= 105% of ship's mass****
(includes added mass)*

Generalized bending stress of Pitch/Heave Mode

$\sigma h := \frac{4500000000}{LBP}$

$\sigma h = 15000000$ Pa/m

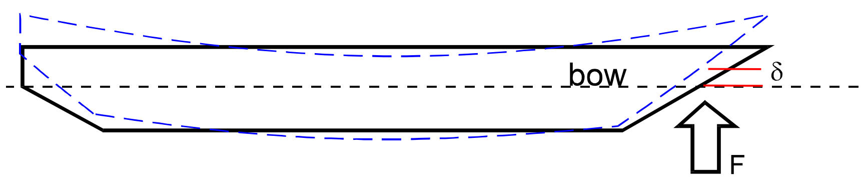
Generalized Mass of 1st Mode

$Mf := 1.045 \cdot LBP^{3}$

$Mf = 28215000$ (kg)

1st Mode Flexure Only

$K_f = \frac{Fbow}{\delta}$



Generalized Stiffness of 1st Mode

$kf := 983600. \cdot LBP$

$kf = 2.951 \times 10^{8}$ (N/m)

Natural frequency of 1st mode

$om1 := \sqrt{\frac{kf}{Mf}} \cdot \frac{1}{2 \cdot \pi}$

$om1 = 0.515$ hz

Generalized bending stress of 1st Mode

$\sigma f := \frac{97000000000}{LBP}$

$\sigma f = 3.2 \times 10^{8}$ Pa/m

Midbody moment of Inertia:

$Im := .000000054 \cdot LBP^{4}$

Midbody total Height:

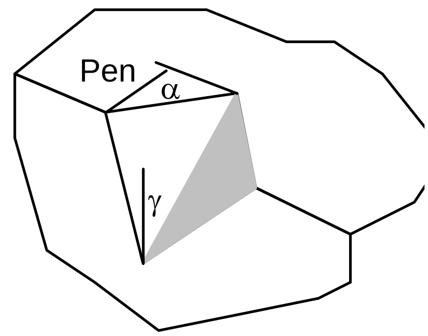
$Hm := 1.15 \cdot T$

Midbody section modulus:

$Sm := \frac{Im}{\left(\frac{Hm}{2}\right)}$

Ice Force Parameters

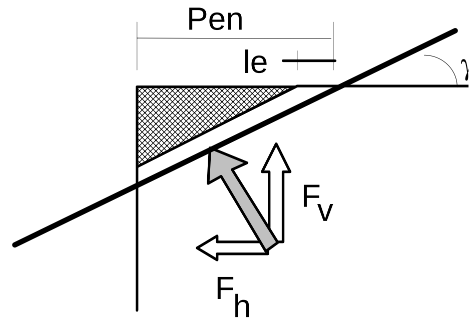
The following functions determine the ship-ice interaction geometry and forces, based on the ship's bow moving horizontally and vertically, and the ice edge moving vertically (it is assumed that the floe is laterally restrained by other ice). Small pitch angles are assumed.



penetration function : $Pen(x,y,z) := [\,x - (y+z)\cdot\tan(gam)\,]$

vertical projection of area $Area_v(x,y,z) := Pen(x,y,z)^2\cdot\tan(alf)$

pressure in contact $Pres(x,y,z) := Po\cdot Area_v(x,y,z)^{(ex)}$



elastic layer thickless for ice and ship (m)
(- a numerical requirement) : $le \equiv 1$ $frict := .1$

ice elastic force (during elastic contact): $$F_{el}(x,y,z,p) := (Pen(x,y,z) - p)\cdot\left(\frac{Area_v(x,y,z)\cdot Pres(x,y,z)}{le}\right)$$

ice crushing force (during crushing contact) $F_{cr}(x,y,z) := Area_v(x,y,z)\cdot Pres(x,y,z)$

resultant vertical ice force: $F_v(x,y,z,p) := \max\left[\min\left(\left(F_{el}(x,y,z,p)\quad F_{cr}(x,y,z)\right)\right)\quad 0\right]$

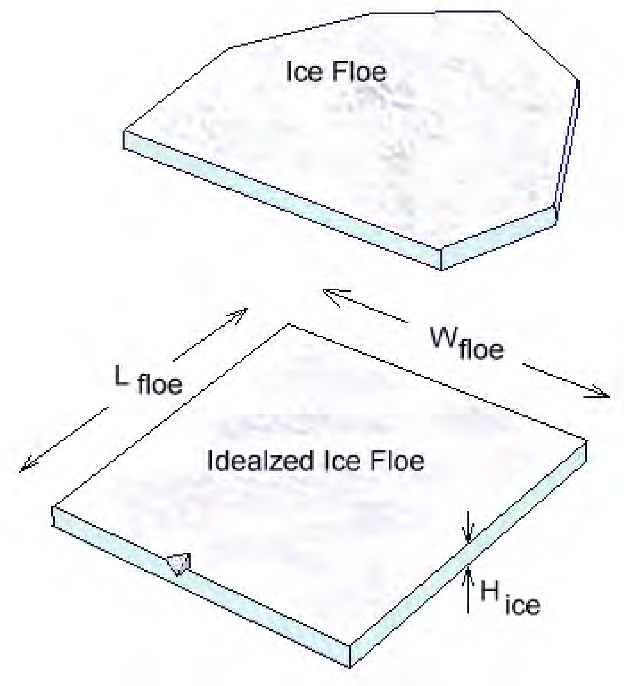
resultant horizontal ice force: $$F_h(x,y,z,p) := \frac{F_v(x,y,z,p)}{\tan(gam)}$$

crushing velocity:
(needed to track crushed depth)

$Crumv(x,y,z,vx,vy,vz,p) := if[p < Pen(x,y,z) - kl\cdot le, \max((0\quad Pen(vx,vy,vz))), 0]$

$kl \equiv .999$

Ice Force Limit Calculations



z-mass of floe (kg)

$$Mz := .451 \cdot ro \cdot hice \cdot Lfloe \cdot Wfloe$$

$$Mz = 4.623 \times 10^{12}$$

floe tipping stiffness (N/m)

$$kz := \frac{roice \cdot g}{3} \cdot Lfloe \cdot Wfloe$$

$$kz = 2.947 \times 10^{11}$$

max tipping force (N)

$$Fzmax := kz \cdot \frac{hice}{9}$$

$$Fzmax = 3.274 \times 10^{12}$$

floe breaking force (N)

$$Fvbend := 1.2 \cdot sigf \cdot hice^2$$

$$Fvbend = 9.6 \times 10^9$$

breaking force limited to long floes

$$F_{vlim} := (Lfloe > 10 \cdot hice) \cdot Fvbend + (Lfloe < 10 \cdot hice) \cdot 10^{10}$$

$$F_{vlim} = 9.6 \times 10^9$$

z-mass of cusp (kg)

$$Mcz := .45 \cdot roice \cdot hice^3 \cdot 5^2$$

$$Mcz = 1.015 \times 10^{10}$$

cusp tipping stiffness

$$kcz := \frac{ro \cdot g}{3} \cdot 5^2 \cdot hice^2$$

max force on broken cusp

$$Fzcmax := kcz \cdot \frac{hice}{9}$$

$$Fzcmax = 9.301 \times 10^9$$

function to determine if the floe is broken in bending

$$Flex(x, y, z, p, e) := (e \le 0) \cdot \left(F_{vlim} < F_V(x, y, z, p)\right) \cdot \frac{1}{.064} + (e > 0)$$

Simulation Parameters

Damping:

surge damping (drag) $cx := 0$

bow heave damping:

critical damping $cy_{cr} := \sqrt{ky \cdot My}$ $cy_{cr} = 7.377 \times 10^{7}$

% of critical $\zeta y := .10$

damping (N/ m/s) $cy := \zeta y \cdot \sqrt{ky \cdot My}$ $cy = 7.377 \times 10^{6}$

ship flexure damping $cf := .0$

ice heave damping $cz := .2 \cdot \sqrt{kz \cdot Mz}$

cusp heave damping $ccz := .25 \cdot \sqrt{kcz \cdot Mcz}$

Initial conditions:

$$y := \begin{pmatrix} initpen \\ vship \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -le \\ 0 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \end{pmatrix}$$

0= surge position - x
1= surge velocity
2= pitch position
3= pitch velocity
4= flexure position -y
5= flexure velocity
6= ice position - z
7= ice velocity
8= crushing penetration
9= crushing velocity
10=breaking condition
11= change in breaking cond

Time step:

$Ty := 2 \cdot \pi \cdot \sqrt{\frac{My}{ky}}$ <= bow heave period $Ty = 11.899$

$Tf := \frac{1}{om1}$ <= 1st mode period $Tf = 1.943$

$dt := \frac{Tf}{10}$ <= time step (sec.)

Time of simulation

$imax := 300$ <= number of time steps

$Tmax := dt \cdot imax$ sec $Tmax = 58.287$ <=total simulation time

$i := 0 .. imax$ $ii := 0 .. imax + 1$

$t_i := i \cdot dt$ <= time vector

Simulation Mechanics

Response functions for Masses Mx and My

These are the accelerations of the masses.

$$Fx(t,y) := \left(-\frac{kx}{Mx}\cdot y_0 - \frac{cx}{Mx}\cdot y_1\right) - \frac{F_h(y_0, y_4, y_6, y_8)}{Mx}$$

$$Fy(t,y) := \left[\left[-\frac{ky}{My}\cdot y_2 + \frac{kf}{My}\cdot(y_4 - y_2)\right] - \frac{cy}{My}\cdot y_3\right]$$

$$Ff(t,y) := \left[-\frac{kf}{Mf}\cdot(y_4 - y_2)\right] + \frac{F_v(y_0, y_4, y_6, y_8)}{Mf}$$

$$Fz(t,y) := (1 - y_{10} > .01)\cdot\left[\left[-\left[\frac{\min((kz\cdot y_6 \ \ Fzcmax))}{Mz}\right] - \frac{cz}{Mz}\cdot y_7\right] + \frac{F_v(y_0, y_4, y_6, y_8)}{Mz}\right] \ldots$$ <-----intact floe +

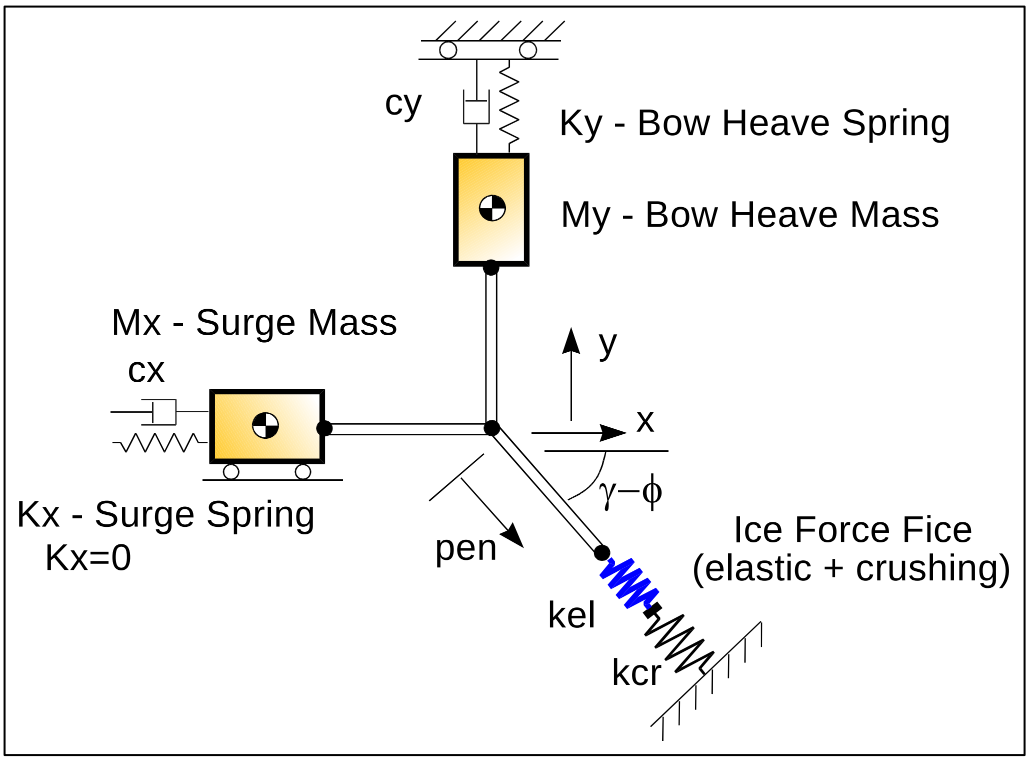
$$+ (y_{10} > .01)\cdot\left[\left[-\left[\frac{\min((kz\cdot y_6 \ \ Fzcmax))}{Mcz}\right] - \frac{cz}{Mz}\cdot y_7\right] + \frac{F_v(y_0, y_4, y_6, y_8)}{Mcz}\right]$$ <---broken cusp

$$Cr(t,y) := Crumv(y_0, y_4, y_6, y_1, y_5, y_7, y_8)$$

$$Brak(t,y) := Flex(y_0, y_4, y_6, y_8, y_{10})$$

$$D(t,y) := \begin{pmatrix} y_1 \\ Fx(t,y) \\ y_3 \\ Fy(t,y) \\ y_5 \\ Ff(t,y) \\ y_7 \\ Fz(t,y) \\ Cr(t,y) \\ 0 \\ y_{11} \\ Brak(t,y) \end{pmatrix}$$

Sketch of system



Coupled R-K Difference Equations:

$Z := \text{rkfixed}(y, 0, Tmax, imax, D)$

<= The simulation takes place by iteratively solving the 12 simultaneous equations in a stepwise manner, using the built-in function **rkfixed**.

<= *SOLVE*

Simulation Results

vship = 3.3 m/s LBP = 300 m

$Po = 3.5 \times 10^{6}$ pa

Fig. 1 - Bow coordinates vs. time

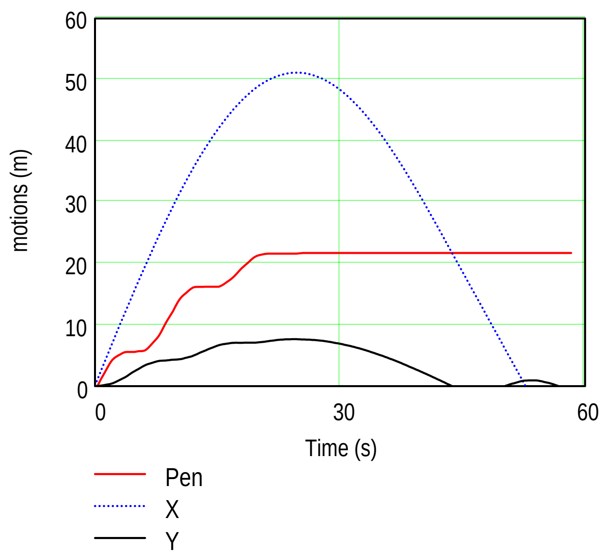
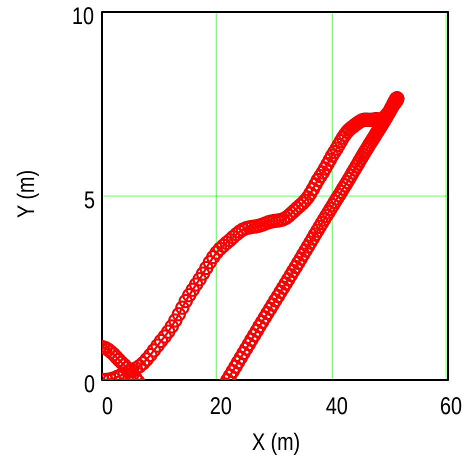


Fig. 2 - Bow coordinates



Vertical Force (MN):

$$Fv_i := \frac{F_V\left[\left(Z^{\langle 1\rangle}\right)_i,\left(Z^{\langle 5\rangle}\right)_i,\left(Z^{\langle 7\rangle}\right)_i,\left(Z^{\langle 9\rangle}\right)_i\right]}{1000000}$$

Horizontal Force (MN):

$$Fh_i := \frac{F_h\left[\left(Z^{\langle 1\rangle}\right)_i,\left(Z^{\langle 5\rangle}\right)_i,\left(Z^{\langle 7\rangle}\right)_i,\left(Z^{\langle 9\rangle}\right)_i\right]}{1000000}$$

Total Force (MN):

$$Ft_i := \left[\left(Fv_i\right)^2 + \left(Fh_i\right)^2\right]^{.5}$$

stress in 1st mode:

$$sig_i := \left[\left(Z^{\langle 5\rangle}\right)_i - \left(Z^{\langle 3\rangle}\right)_i\right]\cdot\frac{\sigma f}{1000000}$$ MPa

Fig. 3 - Vertical and Total Force vs. Time

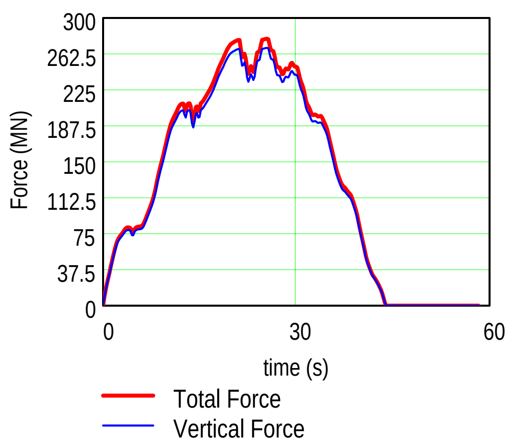
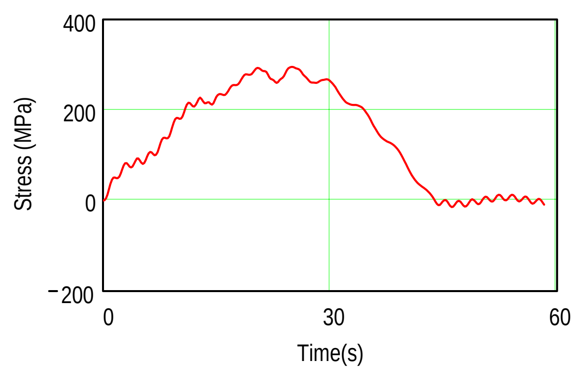


Fig 4. Bending Stress vs Time



Acceleration Functions

$$Ax(x, vx, f, z, cr) := \left[-\left(\frac{kx}{Mx}\cdot x\right) - \frac{cx}{Mx}\cdot vx\right] - \frac{F_h(x, f, z, cr)}{Mx}$$ Bow Surge

$$Ay(y, vy, f) := \left[\left[-\frac{ky}{My}\cdot y + \frac{kf}{My}\cdot(f - y)\right] - \frac{cy}{My}\cdot vy\right]$$ Bow Heave

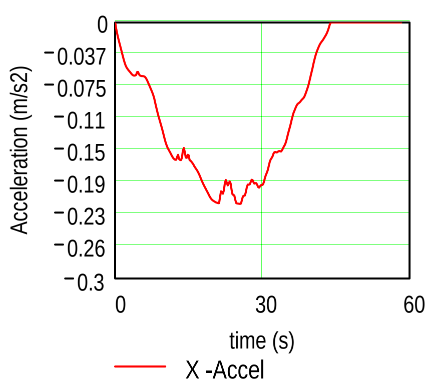
$$Af(x, y, f, z, cr) := \left[-\frac{kf}{Mf}\cdot(f - y)\right] + \frac{F_V(x, f, z, cr)}{Mf}$$ Bending

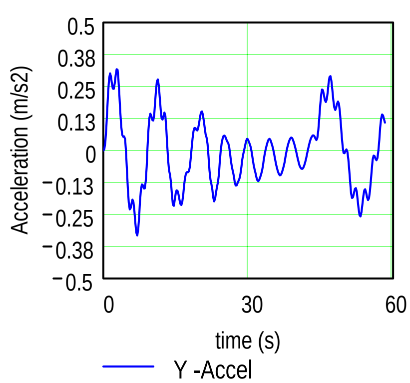
Calculate Accelerations at Bow

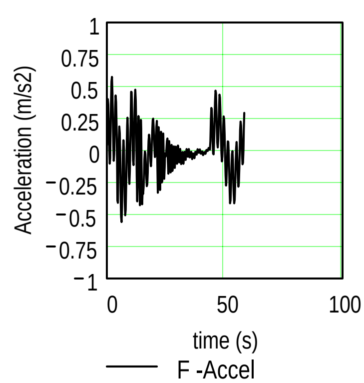
$$AX_i := Ax\left[\left(Z^{\langle 1\rangle}\right)_i, \left(Z^{\langle 2\rangle}\right)_i, \left(Z^{\langle 5\rangle}\right)_i, \left(Z^{\langle 7\rangle}\right)_i, \left(Z^{\langle 9\rangle}\right)_i\right]$$

$$AY_i := Ay\left[\left(Z^{\langle 3\rangle}\right)_i, \left(Z^{\langle 4\rangle}\right)_i, \left(Z^{\langle 5\rangle}\right)_i\right]$$

$$AF_i := Af\left[\left(Z^{\langle 1\rangle}\right)_i, \left(Z^{\langle 3\rangle}\right)_i, \left(Z^{\langle 5\rangle}\right)_i, \left(Z^{\langle 7\rangle}\right)_i, \left(Z^{\langle 9\rangle}\right)_i\right]$$







$BM_i := sig_i \cdot Sm$ $imax = 300$

$FVmax := max(Fv)$ $FTmax := max(Ft)$ $Xmax := max\left(Z^{\langle 1\rangle}\right)$ $Ymax := max\left(Z^{\langle 5\rangle}\right)$ $Zmax := max\left(Z^{\langle 7\rangle}\right)$ $Penmax := max\left(Z^{\langle 9\rangle}\right) + le$

$FVmax = 268.728$ $FTmax = 278.208$ $Xmax = 51.151$ $Ymax = 7.654$ $Zmax = 1.019 \times 10^{-}$ $Penmax = 22.708$

$AXmax := max((max(AX)\ \ -min(AX)))$ $AYmax := max((max(AY)\ \ -min(AY)))$ $AFmax := max((max(AF)\ \ -min(AF)))$

$AXmax = 0.213$ $AYmax = 0.332$ $AFmax = 0.574$

$BMmax := max(BM)$

$BMmax = 1.076 \times 10^{4}$

$$assemble(FV, FT, X, Y, Z, AY, AF, pen, BM, dt, Ft) := \begin{array}{|l} U_0 \leftarrow FV \\ U_1 \leftarrow FT \\ U_2 \leftarrow X \\ U_3 \leftarrow Y \\ U_4 \leftarrow Z \\ U_5 \leftarrow pen \\ U_6 \leftarrow AY \\ U_7 \leftarrow AF \\ U_8 \leftarrow BM \\ U_9 \leftarrow dt \\ \text{for } i \in 10 .. rows(Ft) + 9 \\ \quad U_i \leftarrow Ft_{i-10} \\ U \end{array}$$

Ft =

	0
0	1.225
1	8.967
2	16.238
3	22.838
4	28.833
5	34.491
6	40.122
7	45.892
8	51.723
9	57.311
10	62.264
11	66.286
12	69.32
13	71.57
14	73.399
15	75.154

$res := assemble(FVmax, FTmax, Xmax, Ymax, Zmax, AYmax, AFmax, Penmax, BMmax, dt, Ft)$

$FVmax = 268.728$

res =

	0
0	268.728
1	278.208
2	51.151
3	7.654
4	$1.019 \cdot 10^{-3}$
5	22.708
6	0.332
7	0.574
8	$1.076 \cdot 10^{4}$
9	0.194
10	1.225
11	8.967
12	16.238
13	22.838
14	28.833
15	34.491

$$\begin{pmatrix} Fvmax \\ Ftmax \\ Xmax \\ Ymax \\ Zmax \\ Penmax \\ Aymax \\ Afmax \\ Bmmax \\ dt \\ Ft \end{pmatrix}$$

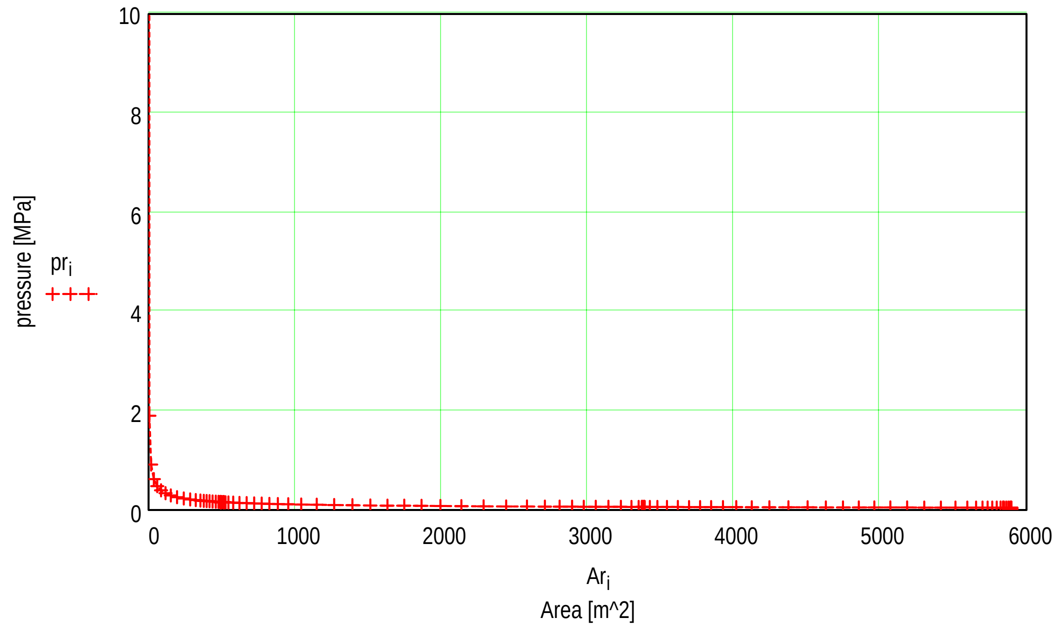
$$INP \equiv \begin{pmatrix} 300 \\ 72.15 \\ 20.86 \\ 0.7 \\ 0.9 \\ 324.00 \\ 3.3 \\ 85 \\ 15 \\ 100.0 \\ 10000 \\ 3.5 \\ -0.5 \\ 0.8 \end{pmatrix} \qquad \begin{pmatrix} LBP \\ B \\ T \\ CB \\ CWP \\ Disp \\ vship \\ alf \\ gam \\ Hice \\ Dice \\ Po \\ ex \\ sigf \end{pmatrix}$$

$$pen_i := \left(Z^{\langle 9 \rangle}\right)_i + le + .00001$$

$$Ar_i := \left(pen_i\right)^2 \cdot \tan(alf)$$

Confirmation that Force/Area follows P/A relationship

$$pr_i := \frac{Fv_i}{Ar_i}$$



Appendix B

Sii_2D Runs.

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run25	run26	run27	run28	run29	run30
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	3.290	3.3	3.3	3.3	3.3	3.3
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	14.05	29.19	51.42	64.34	76.11	110.66
Vert. Force	**Fvmax**	9.824	23.354	53.669	70.35	86.278	126.894
Total Force	**Ftmax**	11.344	26.967	61.971	81.234	99.625	146.525
max surge	**Xmax**	11.267	15.658	21.368	24.756	27.867	35.303
max bow heave	**Ymax**	4.742	5.389	5.638	5.681	5.627	5.365
max ice edge heave	**Zmax**	3.63E-05	1.04E-04	2.20E-04	3.00E-04	3.74E-04	5.57E-04
max penetrat (m)	**Penmax**	3.102	6.392	12.795	16.043	19.025	26.234
max acc. Y	**Aymax**	2.141	1.114	0.779	0.618	0.606	0.478
max acc. Flex(m/s2)	**Afmax**	2.423	1.178	0.922	0.671	0.791	0.581
Max BM (MN-m)	**Bmmax**	182.659	653.325	1.84E+03	2.79E+03	3.85E+03	7.08E+03

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run31	run32	run33	run34	run35	run36
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	20.86	43.35	76.36	95.54	113.02	164.31
Vert. Force	**Fvmax**	14.391	33.976	80.26	107.045	131.497	193.864
Total Force	**Ftmax**	16.617	39.232	92.676	123.604	151.839	223.855
max surge	**Xmax**	16.555	22.895	31.156	35.934	40.393	51.053
max bow heave	**Ymax**	7.17	8.195	8.372	8.626	8.58	8.246
max ice edge heave	**Zmax**	5.42E-05	1.57E-04	3.31E-04	4.51E-04	5.66E-04	8.47E-04
max penetrat (m)	**Penmax**	4.26	8.704	17.904	22.777	27.024	37.339
max acc. Y	**Aymax**	3.342	1.763	1.16	0.999	1.003	0.666
max acc. Flex(m/s2)	**Afmax**	3.326	2.017	1.231	1.2	1.388	0.867
Max BM (MN-m)	**Bmmax**	271.811	993.867	2.81E+03	4.26E+03	5.87E+03	1.08E+04

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run37	run38	run39	run40	run41	run42
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	28.09	58.39	102.85	128.69	152.32	221.32
Vert. Force	**Fvmax**	19.1	46.746	108.33	147.013	180.55	266.676
Total Force	**Ftmax**	22.055	53.977	125.089	169.755	208.481	307.931
max surge	**Xmax**	22.155	30.496	41.411	47.592	53.447	67.433
max bow heave	**Ymax**	9.724	11.117	11.303	11.805	11.779	11.39
max ice edge heave	**Zmax**	7.32E-05	2.12E-04	4.52E-04	6.14E-04	7.73E-04	0.001
max penetrat (m)	**Penmax**	5.409	11.401	22.986	29.652	35.196	48.703
max acc. Y	**Aymax**	4.671	2.384	1.559	1.387	1.189	0.976
max acc. Flex(m/s2)	**Afmax**	5.562	2.947	1.832	1.607	1.529	1.299
Max BM (MN-m)	**Bmmax**	358.748	1.39E+03	3.87E+03	5.85E+03	8.07E+03	1.49E+04

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run43	run44	run45	run46	run47	run48
	Base Ship Name	80/21	80/22	80/23	80/24	80/25	80/26
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	34.9	72.54	127.78	159.89	189.13	274.98
Vert. Force	**Fvmax**	23.682	59.695	134.713	185.102	227.398	336.37
Total Force	**Ftmax**	27.346	68.93	155.553	213.738	262.577	388.407
max surge	**Xmax**	27.404	37.587	50.956	58.419	65.558	82.607
max bow heave	**Ymax**	12.105	13.904	14.103	14.829	14.833	14.405
max ice edge heave	**Zmax**	9.11E-05	2.63E-04	5.68E-04	7.68E-04	9.69E-04	0.001
max penetrat (m)	**Penmax**	6.466	13.97	27.527	35.935	42.669	59.103
max acc. Y	**Aymax**	6.217	3.053	2.122	1.767	1.513	1.173
max acc. Flex(m/s2)	**Afmax**	8.664	4.396	2.67	2.472	2.012	1.516
Max BM (MN-m)	**Bmmax**	458.799	1.79E+03	4.87E+03	7.37E+03	1.02E+04	1.88E+04

Base Cases for IPC classes IPC1-7 for 80/20 vessel and variants

	Run #	run91	run92	run93	run94	run95	run96
	Base Ship Name	80/20	80/21	80/22	80/23	80/24	80/25
	Nominal Class	IPC1	IPC1	IPC1	IPC1	IPC1	IPC1
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	6.0	6.0	6.0	6.0	6.0	6.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	15.0	15.0	15.0	15.0	15.0	15.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	5	5	5	5	5	5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Flex Force limit		**216**	**=1.2*D19*D15^2**				
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	20.357	44.215	98.69	140.845	181.77	225.358
Total Force	**Ftmax**	23.506	51.055	113.957	162.634	209.88	260.221
max surge	**Xmax**	19.422	26.19	34.978	39.86	44.217	75.387
max bow heave	**Ymax**	8.84000	10.59400	11.10600	11.10700	11.65600	11.75400
max ice edge heave	**Zmax**	0.00007005	0.0004527	0.004	0.008	0.01	29.367
max penetrat (m)	**Penmax**	4.241	8.085	15.791	21.218	26.3	31.319
max acc. Y	**Aymax**	5.155	2.697	1.655	1.329	1.256	2.611
max acc. Flex(m/s2)	**Afmax**	9	4	2	2	1	6
Max BM (MN-m)	**Bmmax**	375.383	1329	3937	5939	8145	13910

	Run #	run97	run98	run99	run100	run101	run102
	Base Ship Name	80/26	80/27	80/28	80/29	80/30	80/31
	Nominal Class	IPC2	IPC2	IPC2	IPC2	IPC2	IPC2
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	5.0	5.0	5.0	5.0	5.0	5.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	12.0	12.0	12.0	12.0	12.0	12.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	4	4	4	4	4	4
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.65	0.65	0.65	0.65	0.65	0.65
Flex Force limit		**112.32**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	15.4	34.896	82.354	114.841	115.794	113.836
Total Force	**Ftmax**	17.782	40.294	95.094	132.607	133.708	131.446
max surge	**Xmax**	16.617	22.76	30.826	35.44	52.208	119.31
max bow heave	**Ymax**	7.34900	8.59800	8.59200	9.11900	9.13700	7.03200
max ice edge heave	**Zmax**	0.00005421	0.001	0.005	46.736	20.507	53.333
max penetrat (m)	**Penmax**	4.045	7.997	16.353	21.477	21.757	21.469
max acc. Y	**Aymax**	3.701	1.926	1.16	3.801	2.81	2.087
max acc. Flex(m/s2)	**Afmax**	4	2	1	8	7	3
Max BM (MN-m)	**Bmmax**	275.194	1031	2996	5744	7014	7801

	Run #	run103	run104	run105	run106	run107	run108
	Base Ship Name	80/32	80/33	80/34	80/35	80/36	80/37
	Nominal Class	IPC3	IPC3	IPC3	IPC3	IPC3	IPC3
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.5	0.5	0.5	0.5	0.5	0.5
Flex Force limit		**60**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	11.84	27.849	61.413	61.73	60.45	61.67
Total Force	**Ftmax**	13.672	32.157	70.914	71.28	69.80	71.211
max surge	**Xmax**	13.585	18.835	26.522	45.648	70.607	119.104
max bow heave	**Ymax**	5.80100	6.63200	6.83500	6.96300	6.002	2.84500
max ice edge heave	**Zmax**	0.00006309	0.001	10.604	20.122	33.90	59.149
max penetrat (m)	**Penmax**	3.632	7.394	14.317	14.523	14.2	14.495
max acc. Y	**Aymax**	2.661	1.41	3.079	2.558	2.213	1.11
max acc. Flex(m/s2)	**Afmax**	3	1	7	4	2.71E+00	1
Max BM (MN-m)	**Bmmax**	237.603	805.257	2682	3000	3895.0	5086

	Run #	run109	run110	run111	run112	run113	run114
	Base Ship Name	80/38	80/39	80/40	80/41	80/42	80/43
	Nominal Class	IPC4	IPC4	IPC4	IPC4	IPC4	IPC4
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3	3	3	3	3	3
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.45	0.45	0.45	0.45	0.45	0.45
Flex Force limit		**54**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	8.538	21.528	46.305	54.568	54.817	54.226
Total Force	**Ftmax**	9.859	24.859	53.469	63.01	63.297	62.615
max surge	**Xmax**	10.488	14.748	20.366	27.3	42.599	80.39
max bow heave	**Ymax**	4.25000	4.64500	4.93000	4.88700	4.79500	3.17700
max ice edge heave	**Zmax**	0.00003003	0.0006509	0.003	9.386	17.875	36.228
max penetrat (m)	**Penmax**	3.146	6.78	12.874	14.832	14.826	14.846
max acc. Y	**Aymax**	1.77	0.959	0.648	1.964	1.691	1.017
max acc. Flex(m/s2)	**Afmax**	2	1	1	3	2	2
Max BM (MN-m)	**Bmmax**	161.994	594.126	1601	2289	2965	4615

	Run #	run115	run116	run117	run118	run119	run120
	Base Ship Name	80/44	80/45	80/46	80/47	80/48	80/49
	Nominal Class	IPC5	IPC5	IPC5	IPC5	IPC5	IPC5
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	2.5	2.5	2.5	2.5	2.5	2.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.4	0.4	0.4	0.4	0.4	0.4
Flex Force limit		**48**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	5.632	14.481	28.344	36.833	44.903	48.849
Total Force	**Ftmax**	6.504	16.721	32.729	42.531	51.85	56.406
max surge	**Xmax**	7.256	10.402	14.675	17.172	19.459	41.994
max bow heave	**Ymax**	2.77400	2.88400	3.02800	2.94800	2.86800	2.60100
max ice edge heave	**Zmax**	0.00001949	0.0001391	0.002	0.003	0.005	15.358
max penetrat (m)	**Penmax**	2.588	5.673	9.958	12.384	14.608	15.722
max acc. Y	**Aymax**	1.028	0.572	0.373	0.288	0.247	0.835
max acc. Flex(m/s2)	**Afmax**	1	1	0	0	0	1
Max BM (MN-m)	**Bmmax**	101.007	363.854	979.683	1479	2023	3796

	Run #	run121	run122	run123	run124	run125	run126
	Base Ship Name	80/50	80/51	80/52	80/53	80/54	80/55
	Nominal Class	IPC6	IPC6	IPC6	IPC6	IPC6	IPC6
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	2	2	2	2	2	2
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.3	0.3	0.3	0.3	0.3	0.3
Flex Force limit		**36**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	5.46	14.002	26.282	33.986	36.556	36.827
Total Force	**Ftmax**	6.304	16.168	30.348	39.244	42.211	42.524
max surge	**Xmax**	7.549	10.967	15.742	18.501	26.136	48.705
max bow heave	**Ymax**	2.68200	2.86700	2.78900	2.70000	2.56000	2.12400
max ice edge heave	**Zmax**	0.00001915	0.0001128	0.001	0.003	6.645	18.905
max penetrat (m)	**Penmax**	3.03	6.661	11.258	13.948	14.828	14.925
max acc. Y	**Aymax**	0.893	0.562	0.337	0.271	0.929	0.649
max acc. Flex(m/s2)	**Afmax**	1	1	0	0	1	1
Max BM (MN-m)	**Bmmax**	96.944	344.299	919.339	1382	1934	3146

	Run #	run127	run128	run129	run130	run131	run132
	Base Ship Name	80/56	80/57	80/58	80/59	80/60	80/61
	Nominal Class	IPC7	IPC7	IPC7	IPC7	IPC7	IPC7
INPUT							
Length (m)	**LBP**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	8.0	8.0	8.0	8.0	8.0	8.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	1.5	1.5	1.5	1.5	1.5	1.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.25	0.25	0.25	0.25	0.25	0.25
Flex Force limit		**19.2**					
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT	**Fvmax**	5.39	12.775	19.523	19.588	19.661	20.054
Total Force	**Ftmax**	6.224	14.751	22.543	22.619	22.703	23.157
max surge	**Xmax**	8.004	11.901	22.845	34.195	43.704	62.354
max bow heave	**Ymax**	2.47700	2.65100	2.45800	2.18000	1.72800	1.09600
max ice edge heave	**Zmax**	0.00001758	0.000534	6.367	14	19.044	28.938
max penetrat (m)	**Penmax**	3.811	7.844	11.188	11.21	11.237	11.426
max acc. Y	**Aymax**	0.75	0.476	1.031	0.867	0.666	0.422
max acc. Flex(m/s2)	**Afmax**	1	0	1	1	1	1
Max BM (MN-m)	**Bmmax**	92.72	315.876	745.184	1064	1321	1839

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run25	run26	run27	run28	run29	run30
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	3.3	3.3	3.3	3.3	3.3	3.3
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	14.05	29.19	51.42	64.34	76.11	110.66
	Man	178	536	1330	1922	2534	4514
Vert. Force	**Fvmax**	8.962	23.255	44.443	56.487	67.571	94.02
Total Force	**Ftmax**	10.348	26.852	51.319	65.225	78.024	108.566
max surge	**Xmax**	11.409	16.539	23.929	28.457	32.697	43.141
max bow heave	**Ymax**	4.686	4.735	4.845	4.586	4.33	4.558
max ice edge heave	**Zmax**	3.60E-05	9.54E-05	1.95E-04	2.53E-04	3.05E-04	4.10E-04
max penetrat (m)	**Penmax**	3.368	8.728	16.712	21.246	25.415	35.354
max acc. Y	**Aymax**	1.981	0.998	0.581	0.47	0.471	0.349
max acc. Flex(m/s2)	**Afmax**	2.066	1.354	0.672	0.578	0.603	0.412
Max BM (MN-m)	**Bmmax**	176.163	617.55	1.54E+03	2.26E+03	3.03E+03	5.48E+03

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run31	run32	run33	run34	run35	run36
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	20.86	43.35	76.36	95.54	113.02	164.31
	Man	264	795	1975	2854	3763	6703
Vert. Force	**Fvmax**	13.024	34.318	65.992	83.874	100.332	139.612
Total Force	**Ftmax**	15.039	39.627	76.201	96.85	115.854	161.21
max surge	**Xmax**	16.93	24.571	35.531	42.256	48.558	64.068
max bow heave	**Ymax**	7.014	7.05	7.194	6.809	6.429	6.739
max ice edge heave	**Zmax**	5.35E-05	1.42E-04	2.89E-04	3.76E-04	4.52E-04	6.09E-04
max penetrat (m)	**Penmax**	4.891	12.895	24.814	31.546	37.737	52.497
max acc. Y	**Aymax**	2.85	1.443	0.88	0.719	0.599	0.511
max acc. Flex(m/s2)	**Afmax**	3.18	1.749	1.045	0.815	0.737	0.601
Max BM (MN-m)	**Bmmax**	263.082	920.365	2.28E+03	3.36E+03	4.50E+03	8.27E+03

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run37	run38	run39	run40	run41	run42
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	28.09	58.39	102.85	128.69	152.32	221.32
	Man	356	1071	2660	3844	5069	9028
Vert. Force	**Fvmax**	17.658	46.06	88.887	112.974	135.141	188.067
Total Force	**Ftmax**	20.389	53.186	102.638	130.451	156.048	217.161
max surge	**Xmax**	22.812	33.103	47.858	56.919	65.412	86.305
max bow heave	**Ymax**	9.423	9.519	9.69	9.172	8.66	9.054
max ice edge heave	**Zmax**	7.19E-05	1.91E-04	3.89E-04	5.07E-04	6.09E-04	8.20E-04
max penetrat (m)	**Penmax**	6.636	17.301	33.424	42.491	50.83	70.717
max acc. Y	**Aymax**	3.838	2.016	1.181	0.966	0.796	0.676
max acc. Flex(m/s2)	**Afmax**	4.58	2.322	1.372	1.152	1.054	0.822
Max BM (MN-m)	**Bmmax**	347.019	1.25E+03	3.07E+03	4.52E+03	6.06E+03	1.12E+04

Base Cases for ASPPR CAC classes for thick ice for 80/20 vessel and variants

	Run #	run43	run44	run45	run46	run47	run48
	Base Ship Name	80/21	80/22	80/23	80/24	80/25	80/26
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
INPUT							
Length (m)	LBP	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**T**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**CB**	0.72	0.72	0.72	0.72	0.72	0.72
waterplane	**CWP**	0.80	0.80	0.80	0.80	0.80	0.80
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angle	**alf**	30	30	30	30	30	30
Stem_angle	**gam**	30	30	30	30	30	30
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	34.9	72.54	127.78	159.89	189.13	274.98
	Man	443	1331	3305	4776	6297	11217
Vert. Force	**Fvmax**	22.01	57.196	110.435	140.361	167.903	233.662
Total Force	**Ftmax**	25.415	66.044	127.519	162.075	193.878	269.809
max surge	**Xmax**	28.348	41.131	59.46	70.719	81.275	107.234
max bow heave	**Ymax**	11.694	11.845	12.038	11.395	10.759	11.232
max ice edge heave	**Zmax**	8.92E-05	2.37E-04	4.83E-04	6.30E-04	7.56E-04	1.02E-03
max penetrat (m)	**Penmax**	8.274	21.505	41.526	52.792	63.152	87.859
max acc. Y	**Aymax**	4.769	2.471	1.497	1.28	1.173	0.858
max acc. Flex(m/s2)	**Afmax**	6.11	2.734	2.036	1.722	1.584	1.11
Max BM (MN-m)	**Bmmax**	431.313	1.55E+03	3.82E+03	5.62E+03	7.53E+03	1.39E+04

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run1	run2	run3	run4	run5	run6
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	3.3	3.3	3.3	3.3	3.3	3.3
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	12.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT					138.24		
	Ftan	**20.74**	**31.22**	**75.42**	**134.03**	**207**	**289.6**
max. Vert. Force [MN]	**Fvmax**	18.5	28.5	63.5	119.5	202.9	306.4
max. Total Force	**Ftmax**	19.184	29.552	65.755	123.746	210.03	317.226
max surge [m]	**Xmax**	18.934	21.764	27.93	33.757	39.54	45.371
max bow heave	**Ymax**	4.859	5.434	6.627	7.561	8.262	8.883
max ice edge heave	**Zmax**	0.00006	0.00011	0.00029	0.00055	0.00088	0.00125
max penetrat (m)	**Penmax**	1.181	1.69	3.307	5.607	8.71	12.284
max acc. Y	**Aymax**	3.317	2.305	1.305	0.847	0.6	0.446
max acc. Flex(m/s2)	**Afmax**	6.289	4.333	2.373	1.878	1.215	0.795
Max BM (MN-m)	**Bmmax**	190	378	1277	3201	6767	12350

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run7	run8	run9	run10	run11	run12
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**30.79**	**46.35**	**111.99**	**199.02**	**307.36**	**430.02**
max. Vert. Force [MN]	**Fvmax**	27.3	41.6	91.9	178.0	302.0	458.3
max. Total Force	**Ftmax**	28.252	43.042	95.169	184.266	312.653	474.472
max surge [m]	**Xmax**	28.14	32.264	41.337	49.838	58.257	66.736
max bow heave	**Ymax**	7.209	8.103	9.886	11.28	12.363	13.314
max ice edge heave	**Zmax**	0.00009	0.00017	0.00044	0.00083	0.00132	0.00188
max penetrat (m)	**Penmax**	1.636	2.326	4.509	7.818	12.126	17.179
max acc. Y	**Aymax**	4.953	3.524	2.019	1.32	0.934	0.698
max acc. Flex(m/s2)	**Afmax**	9.872	6.521	4.286	2.596	2.108	1.361
Max BM (MN-m)	**Bmmax**	276	551	1821	4746	10070	18350

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run13	run14	run15	run16	run17	run18
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**41.47**	**62.43**	**150.84**	**268.06**	**414**	**579.21**
max. Vert. Force [MN]	**Fvmax**	35.8	55.0	121.4	241.8	409.9	621.8
max. Total Force	**Ftmax**	37.081	56.964	125.632	250.292	424.321	643.688
max surge [m]	**Xmax**	37.934	43.435	55.536	66.851	78.038	89.275
max bow heave	**Ymax**	9.682	10.934	13.37	15.236	16.719	18.039
max ice edge heave	**Zmax**	0.00013	0.00023	0.00059	0.00112	0.00179	0.00256
max penetrat (m)	**Penmax**	2.054	2.933	5.677	10.085	15.659	22.186
max acc. Y	**Aymax**	6.665	4.841	2.801	1.84	1.308	0.98
max acc. Flex(m/s2)	**Afmax**	14.881	8.928	7.805	3.282	2.249	1.984
Max BM (MN-m)	**Bmmax**	364	723	2430	6441	13690	24880

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run19	run20	run21	run22	run23	run24
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**51.53**	**77.57**	**187.41**	**333.05**	**514.37**	**719.62**
max. Vert. Force [MN]	**Fvmax**	43.0	67.3	148.7	299.0	511.3	776.5
max. Total Force	**Ftmax**	44.483	69.679	153.924	309.579	529.3	803.852
max surge [m]	**Xmax**	47.142	53.957	68.859	82.812	96.561	110.38
max bow heave	**Ymax**	12.072	13.587	16.654	18.978	20.841	22.469
max ice edge heave	**Zmax**	0.00016	0.00028	0.00074	0.00140	0.00223	0.00320
max penetrat (m)	**Penmax**	2.39	3.474	6.731	12.053	18.821	26.671
max acc. Y	**Aymax**	8.425	6.129	3.551	2.343	1.67	1.254
max acc. Flex(m/s2)	**Afmax**	20.194	12.12	11.337	4.217	2.889	2.187
Max BM (MN-m)	**Bmmax**	452	899	2983	7982	17090	31030

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run1	run2	run3	run4	run5	run6
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	3.3	3.3	3.3	3.3	3.3	3.3
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							11.584
	Ftan	**20.74**	**31.22**	**75.42**	**134.03**	**207**	**289.6**
max. Vert. Force [MN]	**Fvmax**	16.9	25.0	58.3	111.7	182.2	268.5
max. Total Force	**Ftmax**	17.542	25.925	60.32	115.591	188.60	278.016
max surge [m]	**Xmax**	19.1	22.056	28.795	35.734	43.17	51.157
max bow heave	**Ymax**	4.817	5.368	6.41	7.074	7.452	7.659
max ice edge heave	**Zmax**	0.00004	0.00010	0.00028	0.00051	0.00077	0.00102
max penetrat (m)	**Penmax**	1.433	2.113	4.925	9.434	15.39	22.689
max acc. Y	**Aymax**	2.915	2.04	1.043	0.672	0.5	0.321
max acc. Flex(m/s2)	**Afmax**	6.097	4.1	2.016	1.367	0.818	0.579
Max BM (MN-m)	**Bmmax**	178	336	1168	2995	6098	10740

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run7	run8	run9	run10	run11	run12
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**30.79**	**46.35**	**111.99**	**199.02**	**307.36**	**430.02**
max. Vert. Force [MN]	**Fvmax**	24.0	35.6	85.9	166.4	270.2	398.7
max. Total Force	**Ftmax**	24.798	36.862	88.962	172.296	279.715	412.776
max surge [m]	**Xmax**	28.422	32.79	42.769	53.069	64.108	75.969
max bow heave	**Ymax**	7.167	8.006	9.528	10.501	11.11	11.378
max ice edge heave	**Zmax**	0.00006	0.00015	0.00042	0.00076	0.00114	0.00152
max penetrat (m)	**Penmax**	2.014	3.01	7.261	14.063	22.831	33.697
max acc. Y	**Aymax**	4.328	3.029	1.549	0.998	0.673	0.476
max acc. Flex(m/s2)	**Afmax**	9.142	6.088	2.993	2.001	1.215	0.859
Max BM (MN-m)	**Bmmax**	250	478	1729	4478	9071	16190

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run13	run14	run15	run16	run17	run18
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**41.47**	**62.43**	**150.84**	**268.06**	**414**	**579.21**
max. Vert. Force [MN]	**Fvmax**	30.9	46.8	115.4	223.5	362.2	534.5
max. Total Force	**Ftmax**	31.938	48.422	119.432	231.408	374.946	553.333
max surge [m]	**Xmax**	38.363	44.19	57.615	71.488	86.262	102.199
max bow heave	**Ymax**	9.646	10.811	12.839	14.145	14.96	15.312
max ice edge heave	**Zmax**	0.00013	0.00022	0.00057	0.00102	0.00154	0.00205
max penetrat (m)	**Penmax**	2.608	3.951	9.749	18.894	30.603	45.166
max acc. Y	**Aymax**	5.82	4.032	2.09	1.339	0.899	0.636
max acc. Flex(m/s2)	**Afmax**	11.43	8.131	3.981	2.875	1.813	1.156
Max BM (MN-m)	**Bmmax**	323	625	2321	5997	12160	21560

Base Cases for ASPPR CAC classes for thick ice for Robert Lemeur and variants

	Run #	run19	run20	run21	run22	run23	run24
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.95	12.00	40.50	96.00	187.50	324.00
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	100.0	100.0	100.0	100.0	100.0	100.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		straight	straight	straight	straight	straight	straight
OUTPUT							
	Ftan	**51.53**	**77.57**	**187.41**	**333.05**	**514.37**	**719.62**
max. Vert. Force [MN]	**Fvmax**	37.3	56.7	142.4	277.1	450.4	664.1
max. Total Force	**Ftmax**	38.575	58.74	147.379	286.842	466.262	687.574
max surge [m]	**Xmax**	47.705	54.903	71.55	88.752	107.175	126.974
max bow heave	**Ymax**	11.967	13.451	15.969	17.562	18.604	19
max ice edge heave	**Zmax**	0.00016	0.00028	0.00071	0.00127	0.00191	0.00254
max penetrat (m)	**Penmax**	3.144	4.787	12.03	23.41	38.063	56.131
max acc. Y	**Aymax**	7.26	5.028	2.607	1.667	1.117	0.79
max acc. Flex(m/s2)	**Afmax**	13.943	10.105	4.951	2.973	2.379	1.436
Max BM (MN-m)	**Bmmax**	387	758	2858	7388	15170	26790

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run49	run50	run51	run52	run53	run54
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC1	IPC1	IPC1	IPC1	IPC1	IPC1
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	6.0	6.0	6.0	6.0	6.0	6.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	15.0	15.0	15.0	15.0	15.0	15.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	5	5	5	5	5	5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	32.4	50.8	113.4	216.5	215.8	226.9
Total Force	**Ftmax**	33.556	52.544	117.363	224.12	223.41	234.881
max surge	**Xmax**	34.249	39.182	49.729	59.821	151.12	173.235
max bow heave	**Ymax**	8.865	9.959	12.258	14.006	7.136	6.875
max ice edge heave	**Zmax**	0.00009	0.00035	0.00600	23.61000	36.43400	41.57200
max penetrat (m)	**Penmax**	1.404	2.039	3.988	6.838	6.84	7.077
max acc. Y	**Aymax**	6.747	5.072	2.936	3.982	2.4	2.099
max acc. Flex(m/s2)	**Afmax**	24.385	17.087	11.675	6.854	9.453	4.808
Max BM (MN-m)	**Bmmax**	336	675	2276	5821	6579	10720

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run55	run56	run57	run58	run59	run60
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC2	IPC2	IPC2	IPC2	IPC2	IPC2
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	5.0	5.0	5.0	5.0	5.0	5.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	12.0	12.0	12.0	12.0	12.0	12.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	4	4	4	4	4	4
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.65	0.65	0.65	0.65	0.65	0.65
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	26.0	40.5	91.2	124.1	123.9	134.0
Total Force	**Ftmax**	26.919	41.947	94.373	128.433	128.3	138.711
max surge	**Xmax**	28.677	32.894	41.907	82.958	127.619	158.764
max bow heave	**Ymax**	7.312	8.281	10.159	7.678	2.87	1.979
max ice edge heave	**Zmax**	0.00009	0.00051	0.00600	18.58300	31.83900	40.14800
max penetrat (m)	**Penmax**	1.4	2.034	4.001	5.124	5.363	5.518
max acc. Y	**Aymax**	5.225	3.814	2.207	2.927	1.044	0.837
max acc. Flex(m/s2)	**Afmax**	15.825	9.47	8.453	12.594	7.173	5.069
Max BM (MN-m)	**Bmmax**	271	539	1827	3194	3024	4838

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run61	run62	run63	run64	run65	run66
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC3	IPC3	IPC3	IPC3	IPC3	IPC3
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.5	0.5	0.5	0.5	0.5	0.5
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	20.4	31.4	60.1	60.8	72.641	72.9
Total Force	**Ftmax**	21.081	32.534	62.24	62.972	75.20	75.486
max surge	**Xmax**	23.019	26.445	43.418	80.714	105.97	129.989
max bow heave	**Ymax**	5.85	6.619	6.684	2.307	1.364	0.95
max ice edge heave	**Zmax**	0.00012	0.00062	13.08400	21.02600	26.769	33.47800
max penetrat (m)	**Penmax**	1.278	1.843	3.181	3.232	3.66	3.749
max acc. Y	**Aymax**	3.883	2.845	3.077	1.135	0.8	0.556
max acc. Flex(m/s2)	**Afmax**	7.496	5.224	5.398	7.946	5.189	2.852
Max BM (MN-m)	**Bmmax**	209	422	1221	1296	2.19E+03	3299

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run67	run68	run69	run70	run71	run72
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC4	IPC4	IPC4	IPC4	IPC4	IPC4
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	3	3	3	3	3	3
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.45	0.45	0.45	0.45	0.45	0.45
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	15.1	23.2	53.7	55.6	60.2	58.7
Total Force	**Ftmax**	15.586	24.02	55.562	57.609	62.304	60.809
max surge	**Xmax**	17.334	19.971	25.668	56.393	77.802	96.231
max bow heave	**Ymax**	4.39	4.945	6.001	2.89	1.386	0.984
max ice edge heave	**Zmax**	0.00005	0.00035	0.00400	14.79100	19.27400	24.45300
max penetrat (m)	**Penmax**	1.133	1.624	3.272	3.446	3.575	3.58
max acc. Y	**Aymax**	2.685	1.951	1.078	1.275	0.604	0.453
max acc. Flex(m/s2)	**Afmax**	5.269	3.629	2.478	4.659	2.981	1.887
Max BM (MN-m)	**Bmmax**	155	305	1078	1416	1472	2424

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run73	run74	run75	run76	run77	run78
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC5	IPC5	IPC5	IPC5	IPC5	IPC5
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	2.5	2.5	2.5	2.5	2.5	2.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.4	0.4	0.4	0.4	0.4	0.4
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	9.8	15.1	35.6	48.1	49.3	49.4
Total Force	**Ftmax**	10.149	15.619	36.878	49.845	51.066	51.133
max surge	**Xmax**	11.641	13.455	17.409	31.054	47.249	62.076
max bow heave	**Ymax**	2.873	3.264	3.94	3.364	2.235	1.112
max ice edge heave	**Zmax**	0.00003	0.00011	0.00200	7.17500	11.66600	15.14800
max penetrat (m)	**Penmax**	0.919	1.32	2.709	3.49	3.649	3.523
max acc. Y	**Aymax**	1.63	1.13	0.638	1.34	0.8	0.426
max acc. Flex(m/s2)	**Afmax**	3.307	2.005	1.096	4.154	2.285	1.463
Max BM (MN-m)	**Bmmax**	102	200	718	1371	1654	1932

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run79	run80	run81	run82	run83	run84
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC6	IPC6	IPC6	IPC6	IPC6	IPC6
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	10.0	10.0	10.0	10.0	10.0	10.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	2	2	2	2	2	2
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.3	0.3	0.3	0.3	0.3	0.3
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	9.0	14.3	35.1	37.1	36.6	37.0
Total Force	**Ftmax**	9.308	14.754	36.353	38.375	37.887	38.334
max surge	**Xmax**	11.741	13.606	17.72	35.717	48.046	62.757
max bow heave	**Ymax**	2.87	3.245	3.889	2.147	2.095	0.801
max ice edge heave	**Zmax**	0.00003	0.00011	0.00200	8.64900	11.78800	15.45100
max penetrat (m)	**Penmax**	1.032	1.52	3.22	3.407	3.322	3.482
max acc. Y	**Aymax**	1.449	1.039	0.602	1.013	0.753	0.29
max acc. Flex(m/s2)	**Afmax**	2.963	1.737	0.946	2.71	1.876	1.129
Max BM (MN-m)	**Bmmax**	96	192	707	1091	1508	1313

Base Cases for IPC classes IPC1-7 for Robert Lemeur vessel and variants

	Run #	run85	run86	run87	run88	run89	run90
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	IPC7	IPC7	IPC7	IPC7	IPC7	IPC7
INPUT							
Length (m)	**LBP**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**T**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**CB**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**CWP**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Speed (m/s)	**vship**	2.0	2.0	2.0	2.0	2.0	2.0
wl angle	**alf**	85	85	85	85	85	85
Stem_angle	**gam**	15	15	15	15	15	15
Ice thk (m)	**Hice**	8.0	8.0	8.0	8.0	8.0	8.0
Floe Dia (m)	**Dice**	10000	10000	10000	10000	10000	10000
Pressure	**Po**	1.5	1.5	1.5	1.5	1.5	1.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.25	0.25	0.25	0.25	0.25	0.25
Edge shape		**straight**	**straight**	**straight**	**straight**	**straight**	**straight**
OUTPUT							
Vert. Force	**Fvmax**	8.3	13.4	19.5	19.8	21.2	21.4
Total Force	**Ftmax**	8.626	13.864	20.183	20.534	21.916	22.176
max surge	**Xmax**	11.879	13.831	27.384	41.021	53.401	65.338
max bow heave	**Ymax**	2.863	3.223	1.804	0.975	0.594	0.421
max ice edge heave	**Zmax**	0.00005	0.00032	5.61500	10.39500	13.30300	16.67400
max penetrat (m)	**Penmax**	1.233	1.831	2.484	2.546	2.713	2.751
max acc. Y	**Aymax**	1.332	0.971	1.166	0.584	0.293	0.195
max acc. Flex(m/s2)	**Afmax**	2.544	1.477	3.896	1.592	1.061	0.841
Max BM (MN-m)	**Bmmax**	89	178	450	514	814	1150

Appendix C

Sii_3D Listing.

Revision to Oblique Ship-Ice Interaction Model

A Mathcad 6.0 Plus Simulation to Determine Bow Forces on a Ship Due to Glancing Impact with an Ice Floe

written by : Richard Hayward &
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1995

Revision #1 By : Matthew Patey
Oct. 18 - Nov. 30, 1996

Note:
This is not a commercial program
USE WITH CAUTION
For Assistance Contact:
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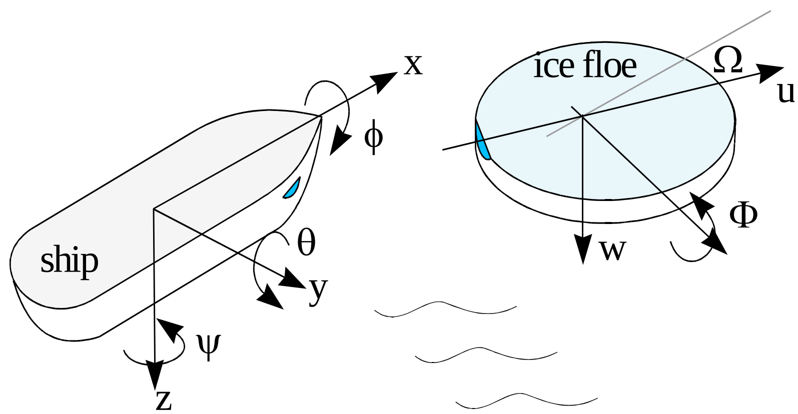
Ship/Ice Dynamic Variables

0	
1	x
2	x'
3	y
4	y'
5	z
6	z'
7	ϕ
8	ϕ'
9	θ
10	θ'
11	ψ
12	ψ'
13	u
14	u'
15	w
16	w'
17	Φ
18	Φ'
19	

The values returned by this worksheet are solved in the order shown. These values are determined by the program which controls the calculation of the solution.



Constants

Ship Constants

$alf := var_8 \cdot deg$ $bet := var_9 \cdot deg$

length, beam, height, draft:

$alf = 0.546$ $bet = 1.03$

$L := var_0$ $B := var_1$ $H := \frac{B}{\tan(bet)}$ $T := var_2$

(go to end for INPUT vector {var})

$H = 23.175$

block and waterplane coefficient:

$Cb := var_3$ $Cwp := var_4$

added mass coefficients:

$Cmx := 1.1$ $Cmy := 2$ $Cmz := 1.5$

$Cid := 1.2$ $Cip := 1.5$ $Ciu := 2$

density, gravity,

ship speed, bow waterline angle:

$pw := 1025$ $g := 9.807$

$vo := var_7$

$vo = 4$

Ice Constants

ice floe radius, thickness, indentation pressure:

$Rice := var_{11}$ $hice := var_{10}$ $Po := var_{12} \cdot 1000000$ $ex := var_{13}$

$Rice = 300$ $hice = 8$ $Po = 4 \times 10^6$ $ex = -0.5$

added mass coefficients:

$Cmu := 1.5$ $Cmw := 2$ $Ciq := 1.5$

ice density, elastic layer thickness, rebound elastic reduction:

$pi := .9 \cdot 1025$ $elast = 1$ $elred = 0.95$

ice penetration parameters:

$pen\_param := \sqrt{Rice^2 + \frac{1}{4} \cdot hice^2}$ $\kappa := \mathrm{atan}\left(\frac{hice}{2 \cdot Rice}\right)$ Rice

Response Characteristics of Ship

displacement and translational masses:

$displacement_{ship} := L \cdot B \cdot T \cdot Cb \cdot pw$ $\qquad displacement_{ship} = 1.116 \times 10^{8}$

$mass_x := displacement_{ship} \cdot Cmx$

$mass_y := displacement_{ship} \cdot Cmy$

$mass_z := displacement_{ship} \cdot Cmz$

KB, KG:

$$KB := T \cdot \left(\frac{5}{6} - \frac{Cb}{3 \cdot Cwp} \right) \qquad KG := \frac{1}{2} \cdot (KB + T)$$

2nd mom of area of WP- transverse, long'l:

$$I_t := \frac{L \cdot (Cwp \cdot B)^3}{12} \qquad I_l := \frac{B \cdot (L \cdot Cwp)^3}{12}$$

BM - transverse, long'l:

$$BM_t := \frac{I_t}{L \cdot B \cdot T \cdot Cb} \qquad BM_l := \frac{I_l}{L \cdot B \cdot T \cdot Cb}$$

mass moments of Inertia, roll, pitch, yaw:

$$I_\phi := displacement_{ship} \cdot (0.35 \cdot B)^2 \cdot Cid$$

$$I_\theta := displacement_{ship} \cdot (0.25 \cdot L)^2 \cdot Cip$$

$$I_\psi := displacement_{ship} \cdot (0.25 \cdot L)^2 \cdot Ciu$$

GM-transverse, GM-longitudinal:

$$GM_t := KB + BM_t - KG$$

$$GM_l := KB + BM_l - KG$$

stiffness in heave, roll, pitch:

$$K_z := pw \cdot g \cdot Cwp \cdot L \cdot B$$

$$K_\phi := pw \cdot g \cdot Cb \cdot L \cdot B \cdot T \cdot GM_t$$

$$K_\theta := pw \cdot g \cdot Cwp \cdot L \cdot B \cdot T \cdot GM_l$$

Response Characteristics of Ice

ice displacement and translational masses:

$$displacement_{ice} := \pi \cdot Rice^2 \cdot hice \cdot pi \qquad displacement_{ice} = 2.087 \times 10^9$$

$$mass_u := displacement_{ice} \cdot Cmu$$

$$mass_w := displacement_{ice} \cdot Cmw$$

ice mass moment of inertia in pitch:

$$I_\Phi := \frac{1}{4} \cdot displacement_{ice} \cdot Rice^2 \cdot Ciq$$

stiffness of ice in heave, pitch:

$$K_w := pw \cdot g \cdot \pi \cdot Rice^2 \qquad K_\Phi := \frac{pw \cdot g \cdot \pi \cdot Rice^4}{4}$$

Bow Plate Reference Points

3 points define the triangular plane of the bow (stbd. side):

$$ref_{x1} := \frac{1}{2} \cdot L - \frac{B}{\tan(alf)} \qquad ref_{x2} := \frac{1}{2} \cdot L - \frac{B}{\tan(alf)} \qquad ref_{x3} := \frac{1}{2} \cdot L + \frac{(H - T) \cdot B}{1.25 \cdot T \cdot \tan(alf)}$$

$$ref_{y1} := \frac{B}{50} \qquad ref_{y2} := \frac{(H + 0.25 \cdot T) \cdot B}{1.25 \cdot T} \qquad ref_{y3} := 0$$

$$ref_{z1} := 2 \cdot KG \qquad ref_{z2} := KG - H \qquad ref_{z3} := KG - H$$

Determination of Normal Vector to Shell

$$n_{x0raw} := -\left(ref_{y3} - ref_{y2}\right) \cdot \left(ref_{z1} - ref_{z2}\right) \qquad n_{y0raw} := \left(ref_{x3} - ref_{x2}\right) \cdot \left(ref_{z1} - ref_{z2}\right)$$

$$n_{z0raw} := -\left(ref_{x3} - ref_{x2}\right) \cdot \left(ref_{y1} - ref_{y2}\right) \qquad mag_0 := \sqrt{n_{x0raw}^2 + n_{y0raw}^2 + n_{z0raw}^2}$$

$$n_{x0} := \frac{n_{x0raw}}{mag_0} \qquad n_{y0} := \frac{n_{y0raw}}{mag_0} \qquad n_{z0} := \frac{n_{z0raw}}{mag_0}$$

Function Definitions for Iterations

Transformation of bow reference point

$$a\_ref_{1x}(init) := \left[ref_{x1}\cdot\cos(init_8) + (ref_{y1}\cdot\sin(init_6) + ref_{z1}\cdot\cos(init_6))\cdot\sin(init_8)\right]\cdot\cos(init_{10})$$

$$b\_ref_{1x}(init) := (ref_{y1}\cdot\cos(init_6) - ref_{z1}\cdot\sin(init_6))\cdot\sin(init_{10})$$

$$ref_{1x}(init) := (a\_ref_{1x}(init) - b\_ref_{1x}(init)) + init_0$$

$$a\_ref_{1y}(init) := \left[ref_{x1}\cdot\cos(init_8) + (ref_{y1}\cdot\sin(init_6) + ref_{z1}\cdot\cos(init_6))\cdot\sin(init_8)\right]\cdot\sin(init_{10})$$

$$b\_ref_{1y}(init) := (ref_{y1}\cdot\cos(init_6) - ref_{z1}\cdot\sin(init_6))\cdot\cos(init_{10})$$

$$ref_{1y}(init) := (a\_ref_{1y}(init) + b\_ref_{1y}(init)) + init_2$$

$$ref_{1z}(init) := -ref_{x1}\cdot\sin(init_8) + (ref_{y1}\cdot\sin(init_6) + ref_{z1}\cdot\cos(init_6))\cdot\cos(init_8) + init_4$$

Determination of Ice CG

Impact at Station 1 (0.05 L from bow)

$$CGice_x(init) := 0.45\cdot L + (init_{12} + Rice)\cdot\sin(alf)$$

$$CGice_y(init) := 0.05\cdot L\cdot\tan(alf) + (init_{12} + Rice)\cdot\cos(alf)$$

$$CGice_z(init) := \left(\frac{pi}{pw} - \frac{1}{2}\right)\cdot hice - (T - KG) + init_{14}$$

Calculation of Penetration

$$a\_n_x(init) := \left[n_{x0}\cdot\cos(init_8) + (n_{y0}\cdot\sin(init_6) + n_{z0}\cdot\cos(init_6))\cdot\sin(init_8)\right]\cdot\cos(init_{10})$$

$$b\_n_x(init) := (n_{y0}\cdot\cos(init_6) - n_{z0}\cdot\sin(init_6))\cdot\sin(init_{10})$$

$$n_x(init) := a\_n_x(init) - b\_n_x(init)$$

$$a\_n_y(init) := \left[n_{x0}\cdot\cos(init_8) + (n_{y0}\cdot\sin(init_6) + n_{z0}\cdot\cos(init_6))\cdot\sin(init_8)\right]\cdot\sin(init_{10})$$

$$b\_n_y(init) := (n_{y0}\cdot\cos(init_6) - n_{z0}\cdot\sin(init_6))\cdot\cos(init_{10})$$

$$n_y(init) := a\_n_y(init) + b\_n_y(init)$$

$$n_z(init) := -n_{x0}\cdot\sin(init_8) + (n_{y0}\cdot\sin(init_6) + n_{z0}\cdot\cos(init_6))\cdot\cos(init_8)$$

$$v(norm, cgice, ref) := |norm\cdot(cgice - ref)|$$

$$minpen(init, norm) := pen\_param\cdot\cos(\operatorname{asin}(norm_2) + init_{16} - \kappa)$$

$$\zeta(init, ref, cgice, norm) := minpen(init, norm) - v(norm, cgice, ref)$$

Determine Moment Arms

$$h1(init, norm, maxpen) := \frac{maxpen}{\cos\left(\operatorname{asin}\left(norm_2\right) + init_{16}\right)}$$

$$n'_x\left(norm\_new_z, norm\right) := \sqrt{\frac{1 - \left(norm\_new_z\right)^2}{1 + \left(\frac{norm_1}{norm_0}\right)^2}}$$

$$n'_y\left(norm\_new_x, norm\right) := \left(norm\_new_x\right) \cdot \frac{norm_1}{norm_0}$$

$$n'_z(init) := \sin\left(init_{16}\right)$$

$$a\_CGice'_x(init, norm) := \sin\left(init_{16}\right) \cdot \sin\left(\operatorname{atan}\left(\frac{norm_0}{norm_1}\right)\right)$$

$$b\_CGice'_x(init, hor\_pen, norm) := \left(\frac{1}{2} \cdot hice - \frac{2 \cdot hor\_pen}{5 \cdot \tan\left(\operatorname{asin}\left(norm_2\right) + init_{16}\right)}\right)$$

$$CGice'_x(init, norm, cgice, hor\_pen) := cgice_0 - a\_CGice'_x(init, norm) \cdot b\_CGice'_x(init, hor\_pen, norm)$$

$$a\_CGice'_y(init, norm) := \sin\left(init_{16}\right) \cdot \cos\left(\operatorname{atan}\left(\frac{norm_0}{norm_1}\right)\right)$$

$$b\_CGice'_y(init, norm, hor\_pen) := \left(\frac{1}{2} \cdot hice - \frac{2 \cdot hor\_pen}{5 \cdot \tan\left(\operatorname{asin}\left(norm_2\right) + init_{16}\right)}\right)$$

$$CGice'_y(init, norm, cgice, hor\_pen) := cgice_1 - a\_CGice'_y(init, norm) \cdot b\_CGice'_y(init, norm, hor\_pen)$$

$$CGice'_z(init, norm, cgice, hor\_pen) := cgice_2 - \cos\left(init_{16}\right) \cdot b\_CGice'_y(init, norm, hor\_pen)$$

$$common\_arm(norm, norm\_new, cgice\_new, ref) := \left|\frac{norm \cdot (cgice\_new - ref)}{norm \cdot norm\_new}\right|$$

Verify Contact Within Extent of Bow

These constants are used to define the x-y projection of the bow boundaries. The easiest way to make the comparison is to tranform the x and y moment arms into the rotated system of reference.

$$m_1 := \frac{ref_{x2} - ref_{x1}}{ref_{y2} - ref_{y1}} \qquad m_2 := \frac{ref_{x2} - ref_{x3}}{ref_{y2} - ref_{y3}} \qquad m_3 := \frac{ref_{x3} - ref_{x1}}{ref_{y3} - ref_{y1}}$$

$$b_1 := ref_{x1} - m_1 \cdot ref_{y1} \qquad b_2 := ref_{x3} - m_2 \cdot ref_{y3} \qquad b_3 := ref_{x1} - m_3 \cdot ref_{y1}$$

$$a\_arm_{x\_rot}(init, arm) := \left(arm_1 \cdot \cos\left(init_6\right) + arm_2 \cdot \sin\left(init_6\right)\right) \cdot \sin\left(init_{10}\right)$$

$$b\_arm_{x\_rot}(init, arm) := \left[arm_0 \cdot \cos\left(init_8\right) + \left(arm_2 \cdot \cos\left(init_6\right) - arm_1 \cdot \sin\left(init_6\right)\right) \cdot \sin\left(init_8\right)\right] \cdot \cos\left(init_{10}\right)$$

$$a\_arm_{y\_rot}(init, arm) := \left(arm_1 \cdot \cos\left(init_6\right) + arm_2 \cdot \sin\left(init_6\right)\right) \cdot \cos\left(init_{10}\right)$$

$$b\_arm_{y\_rot}(init, arm) := \left[arm_0 \cdot \cos\left(init_8\right) + \left(arm_2 \cdot \cos\left(init_6\right) - arm_1 \cdot \sin\left(init_6\right)\right) \cdot \sin\left(init_8\right)\right] \cdot \sin\left(init_{10}\right)$$

$$arm_{x\_rot}(init, arm) := a\_arm_{x\_rot}(init, arm) + b\_arm_{x\_rot}(init, arm)$$

$$arm_{y\_rot}(init, arm) := a\_arm_{y\_rot}(init, arm) - b\_arm_{y\_rot}(init, arm)$$

$$c1(init, arm) := m_1 \cdot arm_{y\_rot}(init, arm) + b_1$$

$$c2(init, arm) := m_2 \cdot arm_{y\_rot}(init, arm) + b_2$$

$$c3(init, arm) := m_3 \cdot arm_{y\_rot}(init, arm) + b_3$$

contact on bow ? Y/N = 1/0:

$$contact(in, a) := \begin{cases} 1 & \text{if } \left(arm_{x\_rot}(in, a) > c1(in, a)\right) \cdot \left(arm_{x\_rot}(in, a) < c2(in, a)\right) \cdot \left(arm_{x\_rot}(in, a) > c3(in, a)\right) \\ 0 & \text{otherwise} \end{cases}$$

Determine Area of Contact

This function defines the ice edge geometry, round or wedge shaped

$$Area\left(\Phi, hor\_pen, norm_z\right) := \frac{4}{3} \cdot \frac{\sqrt{2 \cdot Redge \cdot hor\_pen^3 - hor\_pen^4}}{\sin\left(asin\left(norm_z\right) + \Phi\right)}$$

FORCE CALCULATIONS

Drag Forces

Coefficients

$$C_{Dy} := -pw \cdot \left[3.245 \cdot (1 - Cb) \cdot T^2 \cdot \frac{L}{B} - 0.03975 \cdot L \cdot T\right]$$

$$C_{D\psi} := \begin{cases} \left[-pw \cdot \left[0.85 \cdot \left(Cb \cdot \frac{B}{L} - 0.157\right)^{1.5} + 10.005\right] \cdot L^4 \cdot T\right] & \text{if } Cb \cdot \frac{B}{L} - 0.157 > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$C_{Du} := -2 \cdot pw \cdot Rice^2$$

Forces

$$D_y(init) := C_{Dy} \cdot \left|init_3\right| \cdot init_3$$

$$D_\psi(init) := C_{D\psi} \cdot \left|init_{11}\right| \cdot init_{11}$$

$$D_u(init) := C_{Du} \cdot \left|init_{13}\right| \cdot init_{13}$$

Factor for Consideration of Elastic Layer
(which accounts for the elastic response of both the ship and the ice)

$$factor(pen, last\_pen) := \begin{cases} \frac{pen}{elast} & \text{if } (pen > last\_pen) \cdot (last\_pen < elast) \\ \frac{pen}{elast} \cdot elred & \text{if } (pen = last\_pen) \cdot (last\_pen < elast) \\ elred & \text{if } (pen = last\_pen) \cdot (last\_pen > elast) \\ \frac{elast + pen - last\_pen}{elast} & \text{if } (pen > last\_pen) \cdot (last\_pen > elast) \\ \frac{elast + pen - last\_pen}{elast} & \text{otherwise} \end{cases}$$

Definition of vector of first derivatives for use in numerical method.

$$F(init, ShipF, ShipM, Ice) := \begin{pmatrix} init_1 \\ \dfrac{ShipF_0}{mass_x} \\ init_3 \\ \dfrac{ShipF_1 + D_y(init)}{mass_y} \\ init_5 \\ \dfrac{ShipF_2 - K_z \cdot init_4}{mass_z} \\ init_7 \\ \dfrac{ShipM_0 - K_\phi \cdot init_6}{I_\phi} \\ init_9 \\ \dfrac{ShipM_1 - K_\theta \cdot init_8}{I_\theta} \\ init_{11} \\ \dfrac{ShipM_2 + D_\psi(init)}{I_\psi} \\ init_{13} \\ \dfrac{Ice_0 + D_u(init)}{mass_u} \\ init_{15} \\ \dfrac{Ice_1 - K_w \cdot init_{14}}{mass_w} \\ init_{17} \\ \dfrac{Ice_2 - K_\Phi \cdot init_{16}}{I_\Phi} \end{pmatrix}$$

Sii_3D_rev Solution Program

This program returns a matrix of 21 columns : the first column is time, the next 18 are the ship/ice dynamic variables as listed in the figure above, and the last 2 are extent of penetration and hull force, respectively.

```
res := | t ← 0
       | Z[0,0] ← t
       | for k ∈ 0..17
       |    initial_values[k] ← 0
       | initial_values[1] ← vo
       | initial_values[0] ← −15
       | for k ∈ 1..18
       |    Z[0,k] ← initial_values[k−1]
       | Z[0,19] ← 0
       | Z[0,20] ← 0
       | dt ← simt / imax
       | for i ∈ 1..imax
       |    | t ← t + dt
       |    | Z[i,0] ← t
       |    | ref[0] ← ref1x(initial_values)
       |    | ref[1] ← ref1y(initial_values)
       |    | ref[2] ← ref1z(initial_values)
       |    | cgice[0] ← CGicex(initial_values)
       |    | cgice[1] ← CGicey(initial_values)
       |    | cgice[2] ← CGicez(initial_values)
       |    | norm[0] ← nx(initial_values)
       |    | norm[1] ← ny(initial_values)
       |    | norm[2] ← nz(initial_values)
       |    | test ← ζ(initial_values, ref, cgice, norm)
       |    | Z[i,19] ← if(test ≥ Z[i−1,19], test, Z[i−1,19])
       |    | check ← 1
       |    | hor_pen ← 0
```

$$F\_common \leftarrow \left| \begin{array}{l} hor\_pen \leftarrow h1\left(initial\_values, norm, Z_{i,19}\right) \\ norm'_2 \leftarrow n'_z(initial\_values) \\ norm'_0 \leftarrow n'_x\left(norm'_2, norm\right) \\ norm'_1 \leftarrow n'_y\left(norm'_0, norm\right) \\ cgice'_0 \leftarrow CGice'_x(initial\_values, norm, cgice, hor\_pen) \\ cgice'_1 \leftarrow CGice'_y(initial\_values, norm, cgice, hor\_pen) \\ cgice'_2 \leftarrow CGice'_z(initial\_values, norm, cgice, hor\_pen) \\ com\_arm \leftarrow common\_arm(norm, norm', cgice', ref) \\ \text{for } n \in 0..2 \\ \quad arm_n \leftarrow cgice'_n - com\_arm \cdot norm'_n - initial\_values_{2 \cdot n} \\ check \leftarrow contact(initial\_values, arm) \\ -Area\left(initial\_values_{16}, hor\_pen, norm_2\right)^{1+ex} \cdot Po \cdot factor\left(Z_{i,19}, Z_{i-1,19}\right) \cdot check \end{array} \right. \quad \text{if}$$

$$\text{break} \quad \text{if} \quad check \neq 1$$

$$Z_{i,20} \leftarrow \frac{-F\_common}{1000000}$$

$$Forces \leftarrow norm \cdot F\_common$$

$$Moments_0 \leftarrow Forces_2 \cdot arm_1 - Forces_1 \cdot arm_2$$

$$Moments_1 \leftarrow Forces_0 \cdot arm_2 - Forces_2 \cdot arm_0$$

$$Moments_2 \leftarrow Forces_1 \cdot arm_0 - Forces_0 \cdot arm_1$$

$$Ice_0 \leftarrow -F\_common \cdot \cos\left(\operatorname{asin}\left(norm_2\right)\right)$$

$$Ice_1 \leftarrow -F\_common \cdot norm_2$$

$$Ice_2 \leftarrow Ice_1 \cdot \left[Rice - \frac{3}{5} \cdot (hor\_pen) \right]$$

$$K_0 \leftarrow dt \cdot F(initial\_values, Forces, Moments, Ice)$$

$$K_1 \leftarrow dt \cdot F\left(initial\_values + \frac{1}{2} \cdot K_0, Forces, Moments, Ice\right)$$

$$K_2 \leftarrow dt \cdot F\left(initial\_values + \frac{1}{2} \cdot K_1, Forces, Moments, Ice\right)$$

$$K_3 \leftarrow dt \cdot F\left(initial\_values + K_2, Forces, Moments, Ice\right)$$

$$step \leftarrow \frac{1}{6} \cdot \left(K_0 + 2 \cdot K_1 + 2 \cdot K_2 + K_3\right)$$

$$initial\_values \leftarrow initial\_values + step$$

$$\text{for } m \in 0..17$$

for $m \in 0..17$

$Z_{i,m+1} \leftarrow initial\_values_m$

Z

Results Matrix:

only partially printed

res =

	0	1	2	3	4	5	6
0	0	-15	4	0	0	0	0
1	0.06667	-14.73333	4	0	0	0	0
2	0.13333	-14.46667	4	0	0	0	0
3	0.2	-14.2	4	0	0	0	0
4	0.26667	-13.93333	4	0	0	0	0
5	0.33333	-13.66667	4	0	0	0	0
6	0.4	-13.4	4	0	0	0	0
7	0.46667	-13.13333	4	0	0	0	0
8	0.53333	-12.86667	4	0	0	0	0
9	0.6	-12.6	4	0	0	0	0
10	0.66667	-12.33333	4	0	0	0	0
11	0.73333	-12.06667	4	0	0	0	0
12	0.8	-11.8	4	0	0	0	0
13	0.86667	-11.53333	4	0	0	0	0
14	0.93333	-11.26667	4	0	0	0	0
15	1	-11	4	0	0	0	0

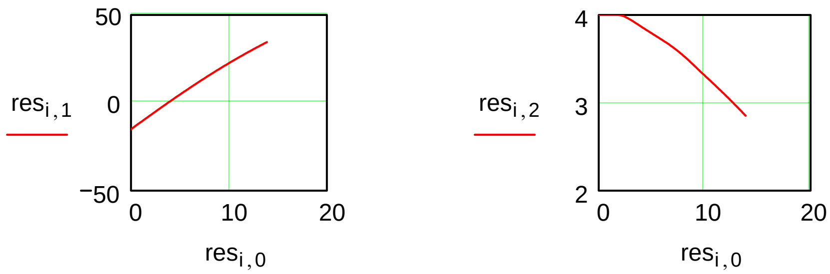
$i := 0..(rows(res) - 2)$

$maxforce_0 := 0$

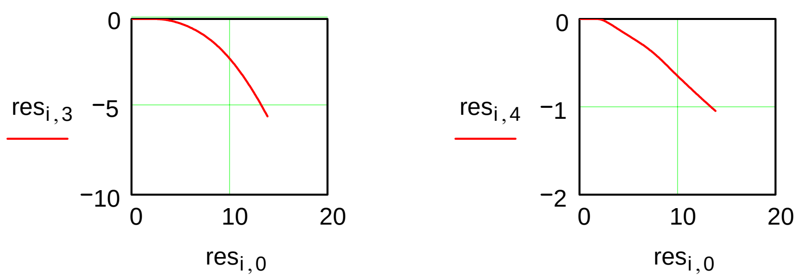
$maxforce_{i+1} := if\left[\left(res_{i,20}\right) > maxforce_i, res_{i,20}, maxforce_i\right]$

$Max\_Force := maxforce_{rows(res)-1}$

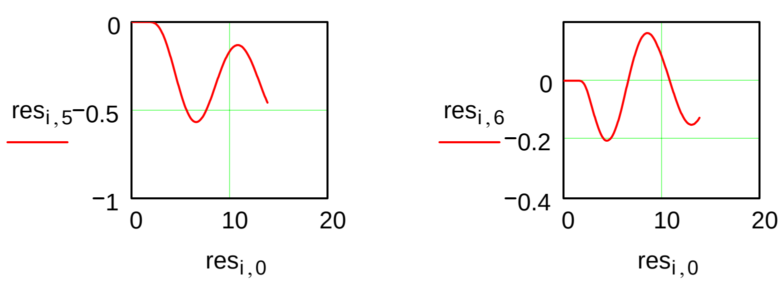
Result Plots



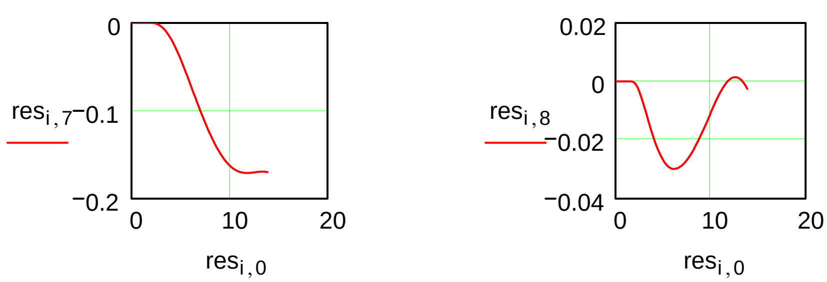
x, x'



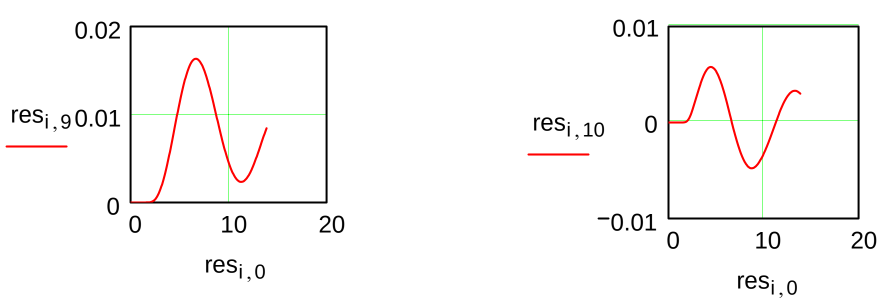
y, y'



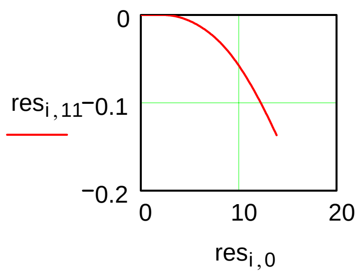
z, z'

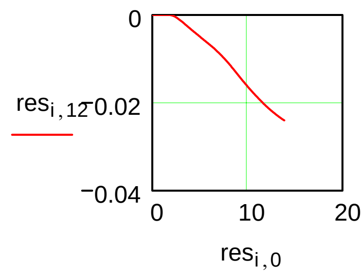


r, r'



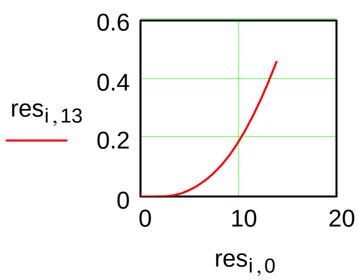
, p'

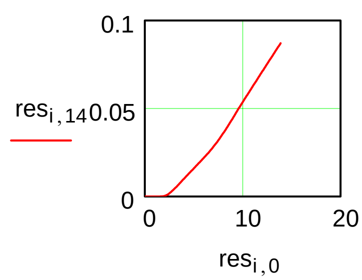




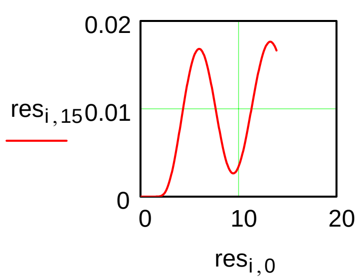
yaw, yaw'

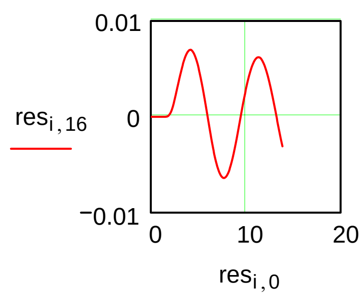
ICE FLOE MOTIONS



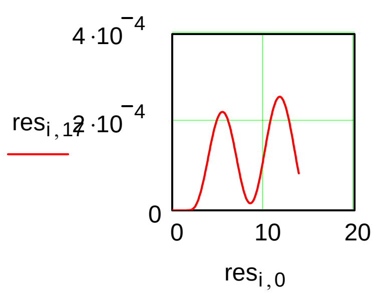


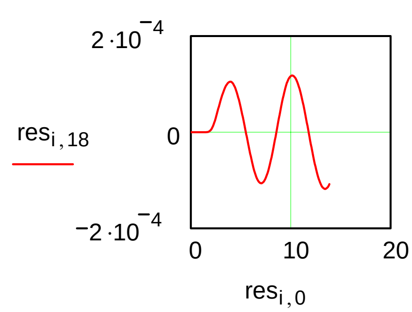
u, u'





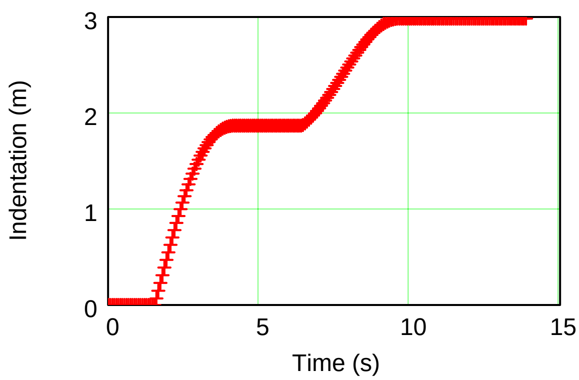
w, w'



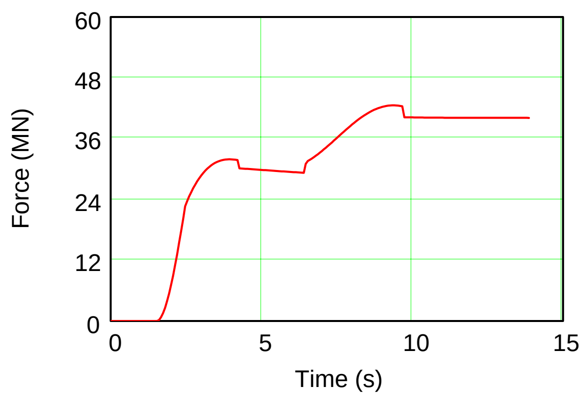


p, p'

Ice Indentation



Force time history



Max_Force = 42.55 Redge ≡ 25

Change 'var' to do new run.

var ≡

var	name	index
270	L	0
38.57	B	1
14.52	d	2
0.72	Cb	3
0.8	Cwp	4
108.67	Disp	5
39.27	P	6
4.0	vo	7
31.3	a_05	8
59	b_05	9
8.0	Hice	10
300	Dice	11
4	Po	12
−.5	ex	13

Model Parameters

L = 270 elast ≡ 1

alf = 0.546 elred ≡ .95

hice = 8 simt ≡ 100

Rice = 300

vo = 4

$Po = 4 \times 10^{6}$

imax ≡ ceil(simt·15)

$res_{1,19} = 0$

$$\frac{simt}{imax} = 0.067$$

Appendix D

Sii_3D Runs.

Base Cases for ASPPR CAC classes

	Run #	12	12	12	12	12	12
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
INPUT	**Nominal Class**	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	18.27	27.40	38.36	44.21	49.32	60.91
Speed (m/s)	**vship**	3.3	3.3	3.3	3.3	3.3	3.3
wl angles	**a_.05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_.05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	6.306	12.844	36.841	43.029	48.847	62.031
Max Velocity In X-Dir	x'	3.3	3.3	3.3	3.3	3.3	3.3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.052	0.039	0.046	0.025
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	1.45E-05	8.15E-04	7.84E-04	8.83E-04
Max Ship Pitch	θ	0.017	0.017	0.011	0.008	0.007	0.005
Max Ship Pitch Velocity	θ'	0.016	0.008	0.004	0.003	0.002	0.001
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.001	0.012	0.332	0.563	0.862	1.844
Max Ice Horizontal Velocity	u'	0.002	0.008	0.07	0.101	0.135	0.223
Max Ice Vertical Movement	w	0.001	0.003	0.007	0.008	0.009	0.013
Max Ice Vertical Velocity	w'	0.001	0.002	0.003	0.003	0.003	0.003
Max Ice Pitch	Φ	1.82E-05	4.02E-05	8.26E-05	9.93E-05	1.22E-04	1.73E-04
Max Ice Pitch Velocity	Φ'	1.61E-05	2.82E-05	3.72E-05	3.59E-05	3.69E-05	3.83E-05
Max Hull Penetration	y18	0.867	1.532	3.916	4.723	5.486	7.64
Max Force	**Fmax**	**2.923**	**6.136**	**18.096**	**22.812**	**27.385**	**41.538**

Base Cases for ASPPR CAC classes

INPUT	Run #	12	62	63	64	65	66
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	18.27	27.40	38.36	44.21	49.32	60.91
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angles	**a_.05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_.05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	7.947	16.296	46.007	53.303	59.49	73.597
Max Velocity In X-Dir	x'	4.9	4.9	4.9	4.9	4.9	4.9
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.075	0.059	0.048	0.03
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0	0	0	0
Max Ship Pitch	θ	0.02	0.022	0.015	0.012	0.01	0.007
Max Ship Pitch Velocity	θ'	0.025	0.011	0.005	0.004	0.003	0.002
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.001	0.013	0.319	0.528	0.764	1.514
Max Ice Horizontal Velocity	u'	0.002	0.01	0.087	0.125	0.161	0.253
Max Ice Vertical Movement	w	0.001	0.005	0.011	0.012	0.014	0.018
Max Ice Vertical Velocity	w'	0.002	0.003	0.004	0.004	0.004	0.004
Max Ice Pitch	Φ	2.33E-05	5.85E-05	1.24E-04	1.54E-04	1.77E-04	2.43E-04
Max Ice Pitch Velocity	Φ'	2.60E-05	4.07E-05	5.42E-05	5.30E-05	5.47E-05	5.70E-05
Max Hull Penetration	y18	1.12	2.071	6.004	7.228	8.383	11.087
Max Force	**Fmax**	**4.577**	**8.661**	**28.721**	**36.012**	**43.253**	**62.147**

Base Cases for ASPPR CAC classes

INPUT	Run #	67	68	69	70	71	72
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	18.27	27.40	38.36	44.21	49.32	60.91
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angles	**a_.05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_.05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	9.75	19.747	53.748	62.093	69.208	84.262
Max Velocity In X-Dir	x'	6.6	6.6	6.6	6.6	6.6	6.6
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.101	0.083	0.07	0.046
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0	0	0	0
Max Ship Pitch	θ	0.022	0.026	0.02	0.016	0.014	0.01
Max Ship Pitch Velocity	θ'	0.032	0.014	0.007	0.005	0.004	0.002
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.013	0.299	0.49	0.705	1.333
Max Ice Horizontal Velocity	u'	0.003	0.012	0.099	0.141	0.182	0.278
Max Ice Vertical Movement	w	0.002	0.006	0.015	0.016	0.018	0.025
Max Ice Vertical Velocity	w'	0.002	0.004	0.006	0.006	0.006	0.006
Max Ice Pitch	Φ	2.69E-05	7.90E-05	1.69E-04	1.86E-04	2.41E-04	3.02E-04
Max Ice Pitch Velocity	Φ'	3.42E-05	5.46E-05	7.38E-05	7.27E-05	7.53E-05	7.89E-05
Max Hull Penetration	y18	1.409	2.723	8.262	9.913	11.336	14.475
Max Force	**Fmax**	**5.924**	**11.902**	**41.244**	**51.4**	**60.66**	**82.899**

Base Cases for ASPPR CAC classes

INPUT	Run #	73	74	75	76	77	78
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	18.27	27.40	38.36	44.21	49.32	60.91
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angles	**a_.05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_.05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	**Po**	3.5	3.5	3.5	3.5	3.5	3.5
exponent	**ex**	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	11.32	22.569	59.178	68.403	76.087	91.664
Max Velocity In X-Dir	x'	8.2	8.2	8.2	8.2	8.2	8.2
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.126	0.107	0.092	0.065
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0	0	0	0
Max Ship Pitch	θ	0.023	0.028	0.025	0.02	0.017	0.012
Max Ship Pitch Velocity	θ'	0.038	0.018	0.008	0.006	0.005	0.003
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.014	0.272	0.446	0.636	1.166
Max Ice Horizontal Velocity	u'	0.003	0.013	0.105	0.149	0.191	0.287
Max Ice Vertical Movement	w	0.002	0.008	0.017	0.021	0.022	0.026
Max Ice Vertical Velocity	w'	0.003	0.005	0.007	0.007	0.007	0.008
Max Ice Pitch	Φ	2.97E-05	9.93E-05	2.15E-04	2.36E-04	2.54E-04	3.74E-04
Max Ice Pitch Velocity	Φ'	4.25E-05	6.83E-05	9.35E-05	9.25E-05	9.61E-05	1.01E-04
Max Hull Penetration	y18	1.71	3.333	9.814	11.854	13.555	17.04
Max Force	**Fmax**	**7.301**	**15.142**	**50.818**	**63.765**	**75.039**	**100.475**

Base Cases for IPC classes

	Run #	277	278	279	280	281	282
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
INPUT	**Nominal Class**	IPC1	IPC1	IPC1	IPC1	IPC1	IPC1
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	14.55	21.82	30.54	35.20	39.27	48.49
Speed (m/s)	**vo**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	8.0	8.0	8.0	8.0	8.0	8.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	4	4	4	4	4	4
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	4.880	12.061	38.923	45.516	51.368	64.865
Max Velocity In X-Dir	x'	4.000	4.000	4.000	4.000	4.000	4.000
Max Position In Y-Dir	y	0.000	0.000	0.000	0.000	0.000	0.000
Max Velocity In Y-Dir	y'	0.000	0.000	0.000	0.000	0.000	0.000
Max Position In Z-Dir	z	0.000	0.000	0.000	0.000	0.000	0.000
Max Velocity In Z-Dir	z'	0.000	0.000	0.074	0.056	0.044	0.028
Max Ship Roll	ϕ	0.000	0.000	0.000	0.000	0.000	0.000
Max Ship Roll Velocity	ϕ'	0.000	0.000	0.000	0.000	0.000	0.001
Max Ship Pitch	θ	0.019	0.021	0.014	0.011	0.009	0.007
Max Ship Pitch Velocity	θ'	0.027	0.010	0.005	0.003	0.003	0.002
Max Ship Yaw	Ψ	0.000	0.000	0.000	0.000	0.000	0.000
Max Ship Yaw Velocity	Ψ'	0.000	0.000	0.000	0.000	0.000	0.000
Max Ice Horizontal Movement	u	0.000	0.004	0.129	0.221	0.334	0.726
Max Ice Horizontal Velocity	u'	0.001	0.003	0.031	0.046	0.063	0.110
Max Ice Vertical Movement	w	0.001	0.003	0.008	0.011	0.014	0.018
Max Ice Vertical Velocity	w'	0.001	0.002	0.003	0.003	0.003	0.004
Max Ice Pitch	Φ	0.000	0.000	0.000	0.000	0.000	0.000
Max Ice Pitch Velocity	Φ'	0.000	0.000	0.000	0.000	0.000	0.000
Max Hull Penetration	y18	1.007	1.479	4.429	5.368	6.250	8.803
Max Force	**Fmax**	**4.669**	**7.156**	**23.329**	**29.545**	**35.504**	**54.676**

INPUT	Run #	283	284	285	286	287	288
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	IPC2	IPC2	IPC2	IPC2	IPC2	IPC2
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	14.55	21.82	30.54	35.20	39.27	48.49
Speed (m/s)	**vo**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	6.0	6.0	6.0	6.0	6.0	6.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	5.873	13.44	40.242	46.885	52.946	66.384
Max Velocity In X-Dir	x'	4	4	4.000	4	4	4
Max Position In Y-Dir	y	0	0	0.000	0	0	0
Max Velocity In Y-Dir	y'	0	0	0.000	0	0	0
Max Position In Z-Dir	z	0	0	0.000	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.062	0.047	0.037	0.023
Max Ship Roll	ϕ	0	0	0.000	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.000	0	0	2.11E-04
Max Ship Pitch	θ	0.019	0.02	0.013	0.01	0.009	0.006
Max Ship Pitch Velocity	θ'	0.023	0.009	0.004	0.003	0.002	0.001
Max Ship Yaw	Ψ	0	0	0.000	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0.000	0	0	0
Max Ice Horizontal Movement	u	6.52E-04	0.006	0.166	0.281	0.424	0.897
Max Ice Horizontal Velocity	u'	0.001	0.004	0.040	0.058	0.079	0.136
Max Ice Vertical Movement	w	7.53E-04	0.004	0.009	0.011	0.013	0.018
Max Ice Vertical Velocity	w'	9.83E-04	0.002	0.003	0.003	0.003	0.003
Max Ice Pitch	Φ	1.27E-05	5.01E-05	0.000	1.43E-04	1.59E-04	2.11E-04
Max Ice Pitch Velocity	Φ'	1.57E-05	2.69E-05	0.000	4.47E-05	4.40E-05	4.47E-05
Max Hull Penetration	y18	0.994	1.708	4.766	5.79	6.818	9.501
Max Force	**Fmax**	**3.954**	**6.91**	**22.353**	**28.363**	**34.543**	**52.81**

INPUT	Run #	289	290	291	292	293	294
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	IPC3	IPC3	IPC3	IPC3	IPC3	IPC3
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	12.40	18.60	26.03	30.00	33.47	41.33
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	5.0	5.0	5.0	5.0	5.0	5.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3	3	3	3	3	3
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	5.57	12.502	35.529	41.906	47.603	60.659
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0.042	0.041	0.05	0.038	0.018
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	6.16E-04	9.58E-04	6.87E-04	5.61E-04
Max Ship Pitch	θ	0.017	0.015	0.009	0.007	0.006	0.005
Max Ship Pitch Velocity	θ'	0.015	0.007	0.003	0.002	0.002	9.34E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	8.01E-04	0.008	0.204	0.357	0.548	1.21
Max Ice Horizontal Velocity	u'	9.78E-04	0.005	0.04	0.059	0.081	0.141
Max Ice Vertical Movement	w	8.13E-04	0.003	0.006	0.008	0.009	0.012
Max Ice Vertical Velocity	w'	7.28E-04	0.001	0.002	0.002	0.002	0.002
Max Ice Pitch	Φ	1.31E-05	3.55E-05	8.25E-05	9.36E-05	1.07E-04	1.58E-04
Max Ice Pitch Velocity	Φ'	1.12E-05	2.01E-05	3.11E-05	2.92E-05	2.80E-05	2.94E-05
Max Hull Penetration	y18	0.869	1.685	3.837	4.679	5.613	7.829
Max Force	**Fmax**	**2.53**	**5.9**	**15.33**	**19.553**	**24.441**	**37.145**

INPUT	Run #	295	296	297	298	299	300
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	IPC4	IPC4	IPC4	IPC4	IPC4	IPC4
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	7.68	11.52	16.13	18.59	20.74	25.61
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	4.0	4.0	4.0	4.0	4.0	4.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	2.5	2.5	2.5	2.5	2.5	2.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	6.171	25.402	36.879	43.557	49.452	62.661
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0.067	0.043	0.045	0.029	0.013
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	9.37E-04	3.78E-05	1.32E-04	2.61E-04	1.35E-04
Max Ship Pitch	θ	0.016	0.014	0.008	0.007	0.006	0.004
Max Ship Pitch Velocity	θ'	0.013	0.006	0.003	0.002	0.001	7.99E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	9.98E-04	0.067	0.243	0.427	0.649	1.39
Max Ice Horizontal Velocity	u'	0.001	0.019	0.047	0.07	0.095	0.159
Max Ice Vertical Movement	w	9.12E-04	0.004	0.006	0.007	0.008	0.011
Max Ice Vertical Velocity	w'	7.46E-04	0.002	0.002	0.002	0.002	0.002
Max Ice Pitch	Φ	1.42E-05	5.06E-05	6.82E-05	8.17E-05	1.01E-04	1.39E-04
Max Ice Pitch Velocity	Φ'	1.13E-05	2.61E-05	2.47E-05	2.35E-05	2.41E-05	2.49E-05
Max Hull Penetration	y18	0.915	2.683	4.233	5.276	6.311	8.646
Max Force	**Fmax**	**2.346**	**8.268**	**14.429**	**18.822**	**23.517**	**34.985**

	Run #	301	302	303	304	305	306
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
INPUT	**Nominal Class**	IPC5	IPC5	IPC5	IPC5	IPC5	IPC5
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	7.68	11.52	16.13	18.59	20.74	25.61
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	7.059	26.568	38.671	45.458	51.433	64.931
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0.054	0.042	0.032	0.02	0.009
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	3.07E-04	0	0	0	0
Max Ship Pitch	θ	0.016	0.012	0.007	0.006	0.005	0.004
Max Ship Pitch Velocity	θ'	0.012	0.005	0.002	0.002	0.001	6.58E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.001	0.085	0.308	0.526	0.786	1.631
Max Ice Horizontal Velocity	u'	0.002	0.023	0.058	0.085	0.113	0.182
Max Ice Vertical Movement	w	0.001	0.003	0.005	0.006	0.007	0.01
Max Ice Vertical Velocity	w'	7.87E-04	0.002	0.001	0.001	0.001	0.002
Max Ice Pitch	Φ	1.54E-05	4.17E-05	5.91E-05	7.67E-05	8.92E-05	1.27E-04
Max Ice Pitch Velocity	Φ'	1.17E-05	2.18E-05	1.91E-05	1.96E-05	2.00E-05	2.04E-05
Max Hull Penetration	y18	0.989	3.033	4.836	6.084	7.202	9.659
Max Force	**Fmax**	**2.213**	**7.695**	**13.524**	**17.907**	**22.12**	**32.075**

INPUT	Run #	307	308	309	310	311	312
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
	Nominal Class	IPC6	IPC6	IPC6	IPC6	IPC6	IPC6
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	7.68	11.52	16.13	18.59	20.74	25.61
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	50	50	50	50	50	50
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	19.734	29.653	42.717	50.337	57.116	72.703
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0.095	0.057	0.036	0.027	0.021	0.014
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0.011	0.02	0.012	0.009	0.007	0.004
Max Ship Pitch	θ	0.018	0.01	0.006	0.004	0.004	0.002
Max Ship Pitch Velocity	θ'	0.01	0.004	0.002	0.001	9.34E-04	5.34E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.777	2.839	7.342	10.377	13.262	20.316
Max Ice Horizontal Velocity	u'	0.265	0.57	0.881	0.97	1.027	1.13
Max Ice Vertical Movement	w	0.041	0.073	0.102	0.115	0.125	0.156
Max Ice Vertical Velocity	w'	0.025	0.038	0.043	0.045	0.045	0.047
Max Ice Pitch	Φ	0.004	0.006	0.008	0.008	0.01	0.012
Max Ice Pitch Velocity	Φ'	0.003	0.003	0.004	0.004	0.004	0.004
Max Hull Penetration	y18	1.489	2.235	3.228	3.573	3.833	4.435
Max Force	**Fmax**	**2.959**	**4.982**	**8.369**	**9.805**	**10.867**	**13.298**

	Run #	313	314	315	316	317	318
	Base Ship Name	80/20	80/20	80/20	80/20	80/20	80/20
INPUT	**Nominal Class**	IPC7	IPC7	IPC7	IPC7	IPC7	IPC7
Length (m)	**L**	100	150	210	242	270	333.4
Beam (m)	**B**	14.29	21.43	30.00	34.57	38.57	47.63
Draft (m)	**d**	5.38	8.06	11.29	13.01	14.52	17.92
Block	**Cb**	0.72	0.72	0.72	0.72	0.72	0.72
Waterplane	**Cwp**	0.8	0.8	0.8	0.8	0.8	0.8
Disp. (1000t)	**Disp**	5.52	18.63	51.13	78.24	108.67	204.60
Power (MW)	**P**	7.68	11.52	16.13	18.59	20.74	25.61
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	31.3	31.3	31.3	31.3	31.3	31.3
btk angles	**b_05**	59	59	59	59	59	59
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	25	25	25	25	25	25
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	20.454	31.393	46.178	54.664	61.879	78.339
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0.039	0.054	0.035	0.026	0.021	0.014
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0.016	0.023	0.01	0.006	0.005	0.003
Max Ship Pitch	θ	0.014	0.008	0.004	0.003	0.002	0.001
Max Ship Pitch Velocity	θ'	0.008	0.003	0.001	8.27E-04	6.34E-04	3.63E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	2.512	7.195	15.438	20.381	24.595	34.086
Max Ice Horizontal Velocity	u'	0.776	1.144	1.411	1.485	1.524	1.579
Max Ice Vertical Movement	w	0.114	0.171	0.223	0.252	0.279	0.313
Max Ice Vertical Velocity	w'	0.076	0.108	0.126	0.129	0.131	0.133
Max Ice Pitch	Φ	0.022	0.028	0.038	0.042	0.044	0.046
Max Ice Pitch Velocity	Φ'	0.014	0.018	0.021	0.021	0.022	0.022
Max Hull Penetration	y18	1.256	1.543	1.983	2.12	2.204	2.315
Max Force	**Fmax**	**2.53**	**3.705**	**5.011**	**5.68**	**6.117**	**6.736**

Base Cases for ASPPR CAC classes

	Run #	37	38	39	40	41	42
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
INPUT	**Nominal Class**	CAC4	CAC4	CAC4	CAC4	CAC4	CAC4
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
Waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	25.00	31.59	47.38	63.17	78.97	94.76
Speed (m/s)	**vship**	3.3	3.3	3.3	3.3	3.3	3.3
wl angles	**a_.05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_.05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3	3	3	3	3	3
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	7.689	10.541	45.973	66.623	84.418	102.5
Max Velocity In X-Dir	x'	3.3	3.3	3.3	3.3	3.3	3.3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.05	0.031	0.036	0.037
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.005	0	0	0
Max Ship Pitch	θ	0.024	0.019	0.016	0.01	0.007	0.005
Max Ship Pitch Velocity	θ'	0.017	0.012	0.005	0.002	0.001	7.55E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.007	3.059	5.43	7.305	10.439
Max Ice Horizontal Velocity	u'	0.002	0.005	0.212	0.308	0.384	0.453
Max Ice Vertical Movement	w	0.002	0.003	0.012	0.017	0.024	0.031
Max Ice Vertical Velocity	w'	0.001	0.002	0.004	0.004	0.004	0.004
Max Ice Pitch	Φ	2.52E-05	4.02E-05	1.47E-04	2.15E-04	2.97E-04	3.86E-04
Max Ice Pitch Velocity	Φ'	1.93E-05	2.89E-05	5.61E-05	4.97E-05	4.62E-05	5.19E-05
Max Hull Penetration	y18	0.918	1.453	5.162	7.582	10.118	12.56
Max Force	Fmax	3.599	7.049	30.372	49.048	70.802	93.529

Base Cases for ASPPR CAC classes

INPUT	Run #	43	44	45	46	47	48
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC3	CAC3	CAC3	CAC3	CAC3	CAC3
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
Waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	40.97	51.77	77.66	103.55	129.44	155.32
Speed (m/s)	**vship**	4.9	4.9	4.9	4.9	4.9	4.9
wl angles	**a_.05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_.05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3	3	3	3	3	3
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	9.6	13.4	62.1	82.9	98.5	114.0
Max Velocity In X-Dir	x'	4.9	4.9	4.9	4.9	4.9	4.9
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.07	0.057	0.037	0.021
Max Ship Roll	φ	0	0	0	0	0	0
Max Ship Roll Velocity	φ'	0	0	0.01	0	0	0
Max Ship Pitch	θ	0.032	0.027	0.02	0.013	0.009	0.006
Max Ship Pitch Velocity	θ'	0.027	0.017	0.007	0.003	0.002	0.001
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.007	1.582	3.176	4.574	6.349
Max Ice Horizontal Velocity	u'	0.003	0.006	0.212	0.337	0.437	0.53
Max Ice Vertical Movement	w	0.002	0.004	0.018	0.025	0.034	0.045
Max Ice Vertical Velocity	w'	0.002	0.003	0.006	0.006	0.005	0.005
Max Ice Pitch	Φ	3.63E-05	5.84E-05	2.10E-04	3.15E-04	4.27E-04	5.48E-04
Max Ice Pitch Velocity	Φ'	3.14E-05	4.19E-05	8.08E-05	7.25E-05	6.73E-05	6.87E-05
Max Hull Penetration	y18	1.098	1.824	7.658	11.154	14.701	18.217
Max Force	Fmax	5.289	9.048	46.549	74.089	105.061	138.916

Base Cases for ASPPR CAC classes

INPUT	Run #	49	50	51	52	53	54
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC2	CAC2	CAC2	CAC2	CAC2	CAC2
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
Waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	59.45	75.13	112.69	150.26	187.82	225.38
Speed (m/s)	**vship**	6.6	6.6	6.6	6.6	6.6	6.6
wl angles	**a_.05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_.05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3	3	3	3	3	3
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	11.3	16.1	68.1	88.1	105.0	119.7
Max Velocity In X-Dir	x'	6.6	6.6	6.6	6.6	6.6	6.6
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.109	0.091	0.065	0.04
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.012	0.002	0	0
Max Ship Pitch	θ	0.036	0.032	0.022	0.015	0.01	0.008
Max Ship Pitch Velocity	θ'	0.035	0.021	0.009	0.004	0.002	0.002
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.007	0.899	1.864	2.973	4.159
Max Ice Horizontal Velocity	u'	0.003	0.007	0.197	0.326	0.439	0.534
Max Ice Vertical Movement	w	0.003	0.006	0.024	0.033	0.045	0.056
Max Ice Vertical Velocity	w'	0.003	0.004	0.008	0.008	0.007	0.007
Max Ice Pitch	Φ	4.23E-05	7.85E-05	2.75E-04	4.18E-04	5.38E-04	6.88E-04
Max Ice Pitch Velocity	Φ'	4.20E-05	5.59E-05	1.09E-04	9.88E-05	9.24E-05	9.50E-05
Max Hull Penetration	y18	1.438	2.296	10.245	14.797	18.861	22.356
Max Force	Fmax	6.851	11.745	63.182	99.868	138.579	177.389

Base Cases for ASPPR CAC classes

INPUT	Run #	55	56	57	58	59	60
	Base Ship Name	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
	Nominal Class	CAC1	CAC1	CAC1	CAC1	CAC1	CAC1
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
Waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	77.98	98.55	147.82	197.09	246.36	295.64
Speed (m/s)	**vship**	8.2	8.2	8.2	8.2	8.2	8.2
wl angles	**a_.05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_.05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3	3	3	3	3	3
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Flex strength	**sigf**	0.8	0.8	0.8	0.8	0.8	0.8
OUTPUT							
Max Position In X-Dir	x	12.9	18.1	36.4	95.1	103.5	118.2
Max Velocity In X-Dir	x'	8.2	8.2	8.2	8.2	8.2	8.2
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0	0.002	0.001	7.04E-04
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0	1.56E-04	0	0
Max Ship Pitch	θ	0.038	0.035	0.024	0.015	0.011	0.008
Max Ship Pitch Velocity	θ'	0.042	0.026	0.01	0.005	0.003	0.002
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.007	0.061	1.496	1.836	2.677
Max Ice Horizontal Velocity	u'	0.004	0.008	0.039	0.326	0.385	0.483
Max Ice Vertical Movement	w	0.00	0.006	0.013	0.039	0.052	0.06
Max Ice Vertical Velocity	w'	0.00	0.005	0.007	0.01	0.009	0.009
Max Ice Pitch	Φ	4.60E-05	9.26E-05	1.61E-04	4.93E-04	5.91E-04	7.77E-04
Max Ice Pitch Velocity	Φ'	0.00	6.97E-05	9.77E-05	1.25E-04	1.18E-04	1.22E-04
Max Hull Penetration	y18	1.78	2.715	6.681	17.405	20.387	23.772
Max Force	Fmax	8.496	14.318	43.255	119.512	158.671	198.317

Base Cases for IPC classes

INPUT	Run # / Base Ship Name / Nominal Class	151 Robert Lemeur IPC1	152 Robert Lemeur IPC1	153 Robert Lemeur IPC1	154 Robert Lemeur IPC1	155 Robert Lemeur IPC1	156 Robert Lemeur IPC1
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	8.0	8.0	8.0	8.0	8.0	8.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	4	4	4	4	4	4
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	6.361	9.662	50.231	71.821	90.371	106.964
Max Velocity In X-Dir	x'	4	4	4	4	4	4
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.056	0.042	0.041	0.053
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.011	0	0	0
Max Ship Pitch	θ	0.035	0.025	0.02	0.013	0.009	0.007
Max Ship Pitch Velocity	θ'	0.03	0.017	0.007	0.003	0.002	0.001
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	8.45E-04	0.002	1.063	2.271	3.645	5.271
Max Ice Horizontal Velocity	u'	0.001	0.002	0.107	0.191	0.279	0.368
Max Ice Vertical Movement	w	0.001	0.003	0.012	0.021	0.032	0.043
Max Ice Vertical Velocity	w'	0.001	0.002	0.003	0.004	0.004	0.005
Max Ice Pitch	Φ	1.98E-05	4.36E-05	1.75E-04	2.95E-04	4.16E-04	5.50E-04
Max Ice Pitch Velocity	Φ'	1.92E-05	2.52E-05	4.22E-05	5.48E-05	6.55E-05	6.90E-05
Max Hull Penetration	y18	0.993	1.375	5.894	8.749	11.908	15.038
Max Force	**Fmax**	**5.426**	**7.401**	**39.506**	**64.614**	**95.212**	**128.576**

Base Cases for IPC classes

INPUT	Run # / Base Ship Name / Nominal Class	157	158	159	160	161	162
		Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur	Robert Lemeur
		IPC2	IPC2	IPC2	IPC2	IPC2	IPC2
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	4.0	4.0	4.0	4.0	4.0	4.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	6.0	6.0	6.0	6.0	6.0	6.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3.5	3.5	3.5	3.5	3.5	3.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	7.366	10.847	53.404	74.852	91.871	108.166
Max Velocity In X-Dir	x'	4	4	4	4	4	4
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.049	0.04	0.049	0.05
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.008	0	0	0
Max Ship Pitch	θ	0.03	0.023	0.018	0.012	0.008	0.006
Max Ship Pitch Velocity	θ'	0.024	0.015	0.006	0.003	0.002	9.35E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.001	0.003	1.295	2.609	3.884	5.627
Max Ice Horizontal Velocity	u'	0.001	0.003	0.13	0.222	0.308	0.4
Max Ice Vertical Movement	w	0.001	0.003	0.013	0.022	0.03	0.04
Max Ice Vertical Velocity	w'	0.001	0.002	0.003	0.004	0.004	0.005
Max Ice Pitch	Φ	2.29E-05	4.79E-05	1.75E-04	2.83E-04	3.88E-04	4.95E-04
Max Ice Pitch Velocity	Φ'	1.88E-05	2.67E-05	4.48E-05	5.80E-05	6.04E-05	5.99E-05
Max Hull Penetration	y18	0.971	1.586	6.319	9.372	12.605	15.799
Max Force	**Fmax**	**4.477**	**7.731**	**37.824**	**61.595**	**89.621**	**119.887**

Base Cases for IPC classes

INPUT	Run # / Base Ship Name / Nominal Class	163 Robert Lemeur IPC3	164 Robert Lemeur IPC3	165 Robert Lemeur IPC3	166 Robert Lemeur IPC3	167 Robert Lemeur IPC3	168 Robert Lemeur IPC3
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	5.0	5.0	5.0	5.0	5.0	5.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	3	3	3	3	3	3
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	6.823	9.969	43.701	63.202	82.066	99.842
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0	0.036	0.032	0.041	0.021
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0	0.002	4.93E-04	0	2.65E-04
Max Ship Pitch	θ	0.022	0.017	0.014	0.009	0.006	0.005
Max Ship Pitch Velocity	θ'	0.016	0.011	0.004	0.002	0.001	6.07E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.001	0.004	1.844	3.73	5.781	8.488
Max Ice Horizontal Velocity	u'	0.001	0.003	0.135	0.225	0.308	0.386
Max Ice Vertical Movement	w	0.001	0.003	0.009	0.015	0.022	0.028
Max Ice Vertical Velocity	w'	8.73E-04	0.001	0.002	0.003	0.003	0.003
Max Ice Pitch	Φ	2.04E-05	3.64E-05	1.32E-04	2.00E-04	2.68E-04	3.45E-04
Max Ice Pitch Velocity	Φ'	1.34E-05	2.05E-05	3.61E-05	4.24E-05	3.92E-05	3.83E-05
Max Hull Penetration	y18	0.952	1.622	5.118	7.681	10.314	12.888
Max Force	**Fmax**	**3.365**	**6.959**	**26.155**	**43.237**	**62.867**	**83.236**

INPUT	Run # Base Ship Name Nominal Class	169 Robert Lemeur IPC4	170 Robert Lemeur IPC4	171 Robert Lemeur IPC4	172 Robert Lemeur IPC4	173 Robert Lemeur IPC4	174 Robert Lemeur IPC4
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	4.0	4.0	4.0	4.0	4.0	4.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	2.5	2.5	2.5	2.5	2.5	2.5
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	7.422	28.235	47.054	67.369	85.288	102.871
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0.043	0.03	0.04	0.038	0.012
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0.023	0.003	0	0	6.12E-04
Max Ship Pitch	θ	0.021	0.021	0.012	0.008	0.005	0.004
Max Ship Pitch Velocity	θ'	0.014	0.009	0.003	0.002	8.46E-04	5.11E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.757	2.018	3.719	5.686	8.353
Max Ice Horizontal Velocity	u'	0.002	0.069	0.148	0.233	0.31	0.384
Max Ice Vertical Movement	w	0.001	0.004	0.009	0.014	0.019	0.025
Max Ice Vertical Velocity	w'	9.13E-04	0.001	0.002	0.003	0.002	0.002
Max Ice Pitch	Φ	2.11E-05	6.34E-05	1.20E-04	1.73E-04	2.40E-04	3.11E-04
Max Ice Pitch Velocity	Φ'	1.38E-05	2.57E-05	3.39E-05	3.32E-05	3.18E-05	3.13E-05
Max Hull Penetration	y18	1.06	3.212	5.647	8.407	11.165	13.935
Max Force	**Fmax**	**3.425**	**12.399**	**24.614**	**40.35**	**57.817**	**76.028**

INPUT	Run # Base Ship Name Nominal Class	175 Robert Lemeur IPC5	176 Robert Lemeur IPC5	177 Robert Lemeur IPC5	178 Robert Lemeur IPC5	179 Robert Lemeur IPC5	180 Robert Lemeur IPC5
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	300	300	300	300	300	300
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	8.168	30.772	51.626	70.405	87.344	103.987
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0	0.034	0.025	0.045	0.017	0.017
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	0.018	0.003	0	5.97E-04	4.18E-04
Max Ship Pitch	θ	0.02	0.019	0.011	0.007	0.005	0.003
Max Ship Pitch Velocity	θ'	0.013	0.008	0.003	0.001	6.89E-04	4.14E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	0.002	0.928	2.266	3.492	5.406	7.754
Max Ice Horizontal Velocity	u'	0.002	0.083	0.164	0.236	0.309	0.374
Max Ice Vertical Movement	w	0.002	0.004	0.008	0.012	0.017	0.022
Max Ice Vertical Velocity	w'	9.71E-04	0.002	0.002	0.002	0.002	0.002
Max Ice Pitch	Φ	2.05E-05	6.61E-05	1.04E-04	1.55E-04	2.14E-04	2.75E-04
Max Ice Pitch Velocity	Φ'	1.41E-05	4.09E-05	2.77E-05	2.55E-05	2.48E-05	2.68E-05
Max Hull Penetration	y18	1.196	3.624	6.334	9.31	12.297	15.286
Max Force	**Fmax**	**3.181**	**11.512**	**22.66**	**36.672**	**51.803**	**68.157**

INPUT	Run # / Base Ship Name / Nominal Class	187 Robert Lemeur IPC7	188 Robert Lemeur IPC7	189 Robert Lemeur IPC7	190 Robert Lemeur IPC7	191 Robert Lemeur IPC7	192 Robert Lemeur IPC7
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	25	25	25	25	25	25
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	27.864	36.047	57.057	78.942	100.858	122.994
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0.077	0.04	0.02	0.014	0.011	0.008
Max Ship Roll	φ	0	0	0	0	0	0
Max Ship Roll Velocity	φ'	0.005	0.003	0.002	9.13E-04	5.22E-04	3.39E-04
Max Ship Pitch	θ	0.012	0.008	0.004	0.002	0.001	7.84E-04
Max Ship Pitch Velocity	θ'	0.008	0.004	0.001	5.99E-04	3.38E-04	2.12E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	7.452	11.794	23.774	36.537	49.429	62.37
Max Ice Horizontal Velocity	u'	1.184	1.339	1.516	1.603	1.662	1.702
Max Ice Vertical Movement	w	0.203	0.244	0.35	0.4	0.426	0.451
Max Ice Vertical Velocity	w'	0.084	0.103	0.125	0.134	0.138	0.14
Max Ice Pitch	Φ	0.03	0.035	0.045	0.052	0.056	0.058
Max Ice Pitch Velocity	Φ'	0.015	0.018	0.021	0.022	0.023	0.023
Max Hull Penetration	y18	1.627	1.828	2.127	2.275	2.367	2.415
Max Force	**Fmax**	**4.269**	**5.302**	**7.192**	**8.272**	**8.928**	**9.279**

INPUT	Run # Base Ship Name Nominal Class	181 Robert Lemeur IPC6	182 Robert Lemeur IPC6	183 Robert Lemeur IPC6	184 Robert Lemeur IPC6	185 Robert Lemeur IPC6	186 Robert Lemeur IPC6
Length (m)	**L**	79.13	100	150	200	250	300
Beam (m)	**B**	19.03	24.05	36.08	48.10	60.13	72.15
Draft (m)	**d**	5.50	6.95	10.43	13.91	17.39	20.86
Block	**Cb**	0.7	0.7	0.7	0.7	0.7	0.7
waterplane	**Cwp**	0.9	0.9	0.9	0.9	0.9	0.9
Disp. (1000t)	**Disp**	5.54	11.18	37.75	89.47	174.75	301.97
Power (MW)	**P**	22.19	28.04	42.06	56.08	70.10	84.12
Speed (m/s)	**vo**	3.0	3.0	3.0	3.0	3.0	3.0
wl angle	**a_05**	36.2	36.2	36.2	36.2	36.2	36.2
btk angles	**b_05**	70.5	70.5	70.5	70.5	70.5	70.5
Ice thk (m)	**Hice**	3.0	3.0	3.0	3.0	3.0	3.0
Floe Dia (m)	**Dice**	50	50	50	50	50	50
Pressure	Po	2	2	2	2	2	2
exponent	ex	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
OUTPUT							
Max Position In X-Dir	x	26.553	33.94	52.606	72.804	93.514	114.863
Max Velocity In X-Dir	x'	3	3	3	3	3	3
Max Position In Y-Dir	y	0	0	0	0	0	0
Max Velocity In Y-Dir	y'	0	0	0	0	0	0
Max Position In Z-Dir	z	0	0	0	0	0	0
Max Velocity In Z-Dir	z'	0.04	0.053	0.039	0.021	0.015	0.012
Max Ship Roll	ϕ	0	0	0	0	0	0
Max Ship Roll Velocity	ϕ'	0	8.20E-04	0	9.32E-05	3.73E-04	5.28E-05
Max Ship Pitch	θ	0.02	0.014	0.007	0.004	0.002	0.002
Max Ship Pitch Velocity	θ'	0.011	0.007	0.002	0.001	5.36E-04	3.23E-04
Max Ship Yaw	Ψ	0	0	0	0	0	0
Max Ship Yaw Velocity	Ψ'	0	0	0	0	0	0
Max Ice Horizontal Movement	u	3.985	6.475	14.22	23.764	33.975	45.114
Max Ice Horizontal Velocity	u'	0.613	0.795	1.048	1.185	1.286	1.372
Max Ice Vertical Movement	w	0.066	0.101	0.168	0.211	0.251	0.282
Max Ice Vertical Velocity	w'	0.03	0.04	0.049	0.052	0.054	0.054
Max Ice Pitch	Φ	0.006	0.008	0.012	0.015	0.017	0.018
Max Ice Pitch Velocity	Φ'	0.003	0.004	0.004	0.004	0.004	0.004
Max Hull Penetration	y18	2.156	2.808	3.936	4.74	5.315	5.804
Max Force	**Fmax**	**5.769**	**8.264**	**13.385**	**17.537**	**20.777**	**23.443**

POPOV Model - Force vs. Displacement

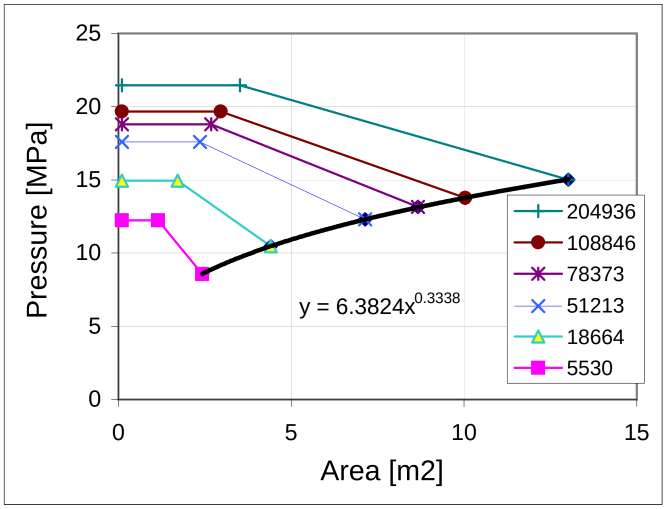
by C.Daley, March 1997

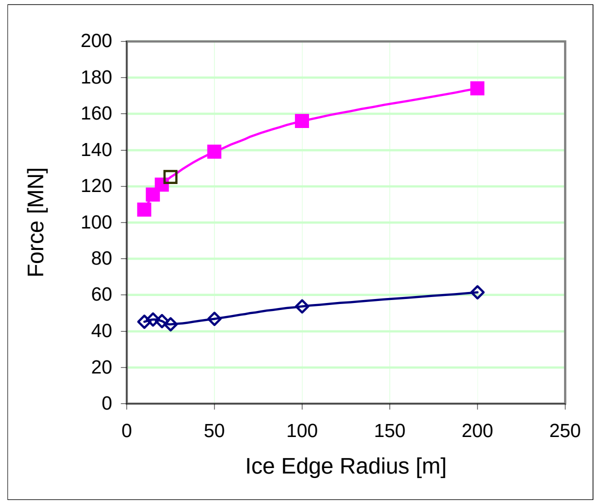
IPC1, 5.1 m/s, varrying ship length, displacement, 12 m ice

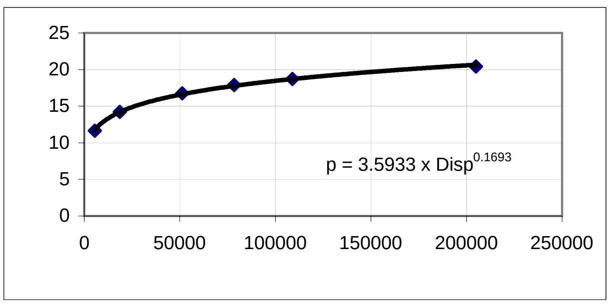
MAIN	**Lenth (m)**	**L**	**100**	**150**	**210**	**242**	**270**	**333.4**	
PARTICULARS	Beam (m)	B	**14.29**	**21.43**	**30.00**	**34.57**	**38.57**	**47.63**	
	Draft (m)	T	**5.38**	**8.06**	**11.29**	**13.01**	**14.52**	**17.92**	
	Height (m)	H	**8.63**	**12.945**	**18.123**	**20.8846**	**23.301**	**28.7724**	
	Cwp	Cwp	**0.800**	**0.800**	**0.800**	**0.800**	**0.800**	**0.800**	
	Cm	Cm	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**	
	Cb	Cb	**0.720**	**0.720**	**0.720**	**0.720**	**0.720**	**0.720**	
	Displacement (t)	Disp	**5530**	**18664**	**51213**	**78373**	**108846**	**204936**	
	Speed (m/s)	v	**4**	**4**	**4**	**4**	**4**	**4**	
	Power (MW)	Pow	**6.2**	**10.5**	**11.5**	**12.5**	**18**	**34**	
	Stem Angle (deg)	gama	**30**	**30**	**30**	**30**	**30**	**30**	
CONSTANTS:	radians	deg	0.01745						
	t/m^3	ro	1						
	m/s^2	g	9.81						
	m	Rice	25						
HULL	Station		**1**	**1**	**1**	**1**	**1**	**1**	
FORM	m	x	**45**	**67.5**	**94.5**	**108.9**	**121.5**	**150.03**	
	deg	alfa	**31**	**31**	**31**	**31**	**31**	**31**	
	m	y	**2.6**	**3.9**	**5.4**	**6.2**	**7.0**	**8.6**	
	deg	beta	**59**	**59**	**59**	**59**	**59**	**59**	
	rad	betap	**0.959**	**0.959**	**0.959**	**0.959**	**0.959**	**0.959**	55
ICE	Floe mass (t)	Dice	**5.7E+05**	**5.7E+05**	**5.7E+05**	**5.7E+05**	**5.7E+05**	**5.7E+05**	
PROPERTIES	Ice thickness (m)	Hice	**8**	**8**	**8**	**8**	**8**	**8**	
	Flex Strength (MPa)	sigf	**10**	**10**	**10**	**10**	**10**	**10**	
	dynamic strength	ap	**894**	**894**	**895**	**896**	**894**	**894**	
GY. RADIUS (m)	roll	Ix	**20.8**	**46.8**	**91.8**	**121.9**	**151.8**	**231.4**	
	pitch	Iy	**560.0**	**1260.0**	**2469.6**	**3279.6**	**4082.4**	**6224.7**	
	yaw	Iz	**625**	**1406**	**2756**	**3660**	**4556**	**6947**	
ADDED	surge	L_11	**0**	**0**	**0**	**0**	**0**	**0**	
MASSES	sway	L_22	**0.753**	**0.753**	**0.753**	**0.753**	**0.753**	**0.753**	
	heave	L_33	**0.875**	**0.875**	**0.875**	**0.875**	**0.875**	**0.875**	
	roll	L_23	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**	
	pitch	L_13	**0.863**	**0.863**	**0.863**	**0.863**	**0.863**	**0.863**	
	yaw	L_12	**0.650**	**0.650**	**0.650**	**0.650**	**0.650**	**0.650**	
COLLISION	Station		**1**	**1**	**1**	**1**	**1**	**1**	
POINT	dir	l_1	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	
	cosines	m_1	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	
		n_1	**0.82**	**0.82**	**0.82**	**0.82**	**0.82**	**0.82**	
	moment arms	la_1	**2.11**	**3.17**	**4.44**	**5.11**	**5.70**	**7.04**	
		mu_1	**-36.85**	**-55.27**	**-77.38**	**-89.17**	**-99.49**	**-122.85**	
		nu_1	**21.38**	**32.07**	**44.89**	**51.73**	**57.72**	**71.27**	

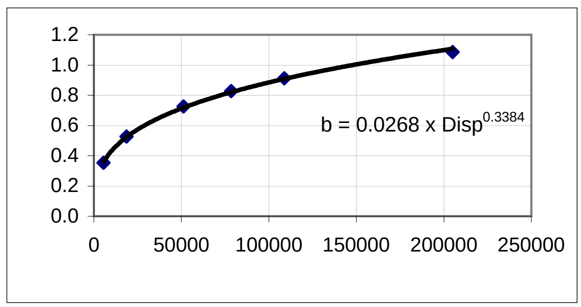
MASS	ice	C_1	**2.03**	**2.03**	**2.03**	**2.03**	**2.03**	**2.03**
REDUCTION	ship	C_0	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**
COEFFICIENTS	total	Ct	**2.52**	**2.57**	**2.68**	**2.78**	**2.89**	**3.23**
LOAD		Cp	**0.511**	**0.509**	**0.506**	**0.503**	**0.499**	**0.490**
COEFFICIENTS		Ch	**0.480**	**0.477**	**0.470**	**0.464**	**0.459**	**0.442**
(form)		Cq	**0.245**	**0.243**	**0.238**	**0.233**	**0.229**	**0.216**
		Cf	**0.154**	**0.152**	**0.147**	**0.144**	**0.140**	**0.130**
COLLISION	mass	M	**564**	**1903**	**5220**	**7989**	**11095**	**20891**
RESULTS	loads (inf)	pmax	**12.25**	**14.95**	**17.58**	**18.78**	**19.67**	**21.45**
		bmax	**0.38**	**0.57**	**0.79**	**0.90**	**0.99**	**1.17**
		qmax	**4.12**	**7.49**	**12.15**	**14.77**	**17.05**	**22.12**
		fmax	**19.14**	**42.54**	**80.97**	**105.05**	**127.34**	**180.11**
	length	l_rec	**6.33**	**7.73**	**9.08**	**9.69**	**10.17**	**11.09**
		Area	**2.42**	**4.41**	**7.14**	**8.67**	**10.03**	**13.01**
		p_bar	**8.57**	**10.47**	**12.31**	**13.15**	**13.77**	**15.01**
		Aro	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
		po	**12.25**	**14.95**	**17.58**	**18.78**	**19.67**	**21.45**
		Ari	**1.15**	**1.71**	**2.36**	**2.69**	**2.96**	**3.52**
		pi	**12.25**	**14.95**	**17.58**	**18.78**	**19.67**	**21.45**
	L x B x pbar	F	**20.77**	**46.15**	**87.86**	**113.98**	**138.16**	**195.42**
	bending force	Fflx	**1040**	**1040**	**1040**	**1040**	**1040**	**1040**
	Force	Ratio	**1**	**1**	**1**	**1**	**1**	**1**
	lookup	k	**0.41**	**0.41**	**0.41**	**0.41**	**0.41**	**0.41**
	factors	fp	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**
		fb	**0.92**	**0.92**	**0.92**	**0.92**	**0.92**	**0.92**
		fq	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
		ff	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**
	pressure [MPa]	p	**11.7**	**14.2**	**16.7**	**17.9**	**18.7**	**20.4**
	load height [m]	b	**0.35**	**0.53**	**0.73**	**0.83**	**0.91**	**1.08**
	line load [MN/m]	Q	**4.1**	**7.5**	**12.1**	**14.8**	**17.1**	**22.1**
	total force [MN]	F_tot	**18.4**	**40.9**	**77.8**	**101.0**	**122.4**	**173.1**
		FT_Sii_Circ	**16.7**	**37.9**	**75.4**	**100.4**	**125.1**	**190**
		FT_Sii_Circ	**8.49**	**17.9**	**31.6**	**36.5**	**43.7**	**72.1**
		FT_Sii_Circ					**139**	
		FT_Sii_Circ					**156**	
		FT_Sii_Circ					**174**	
		FT_Sii_Circ					**120.9**	
		FT_Sii_Circ					**115.3**	

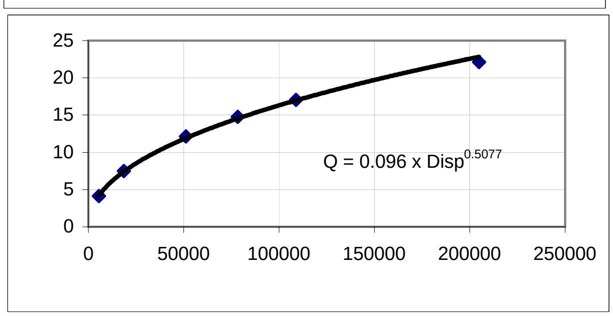
p=8, Re=25	Redge	F_8	F_4A.4
p=4A^-.4	10	**107**	**45.3**
p=8, Re=50	15	**115.3**	**46.4**
p=8, Re=100	20	**120.9**	**45.6**
p=8, Re=200	25	**125.1**	**43.8**
p=8, Re=20	50	**139**	**46.9**
p=8, Re=15	100	**156**	**53.7**
	200	**174**	**61.5**

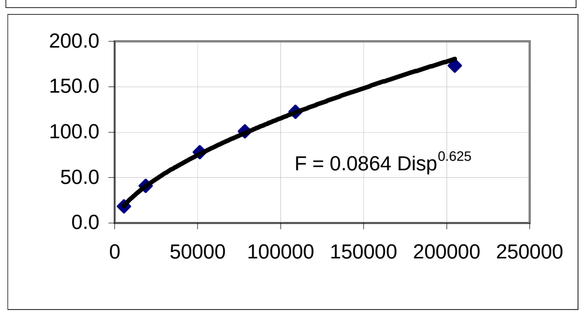

Pressure [MPa]
Area [m2]
204936
108846
78373
51213
18664
5530
y = 6.3824x^0.3338

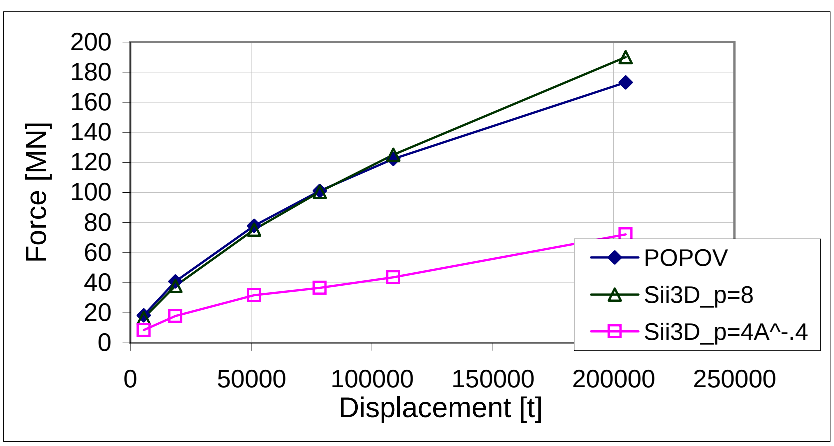

Force [MN]
Ice Edge Radius [m]


p = 3.5933 x Disp^0.1693


b = 0.0268 x Disp^0.3384


Q = 0.096 x Disp^0.5077


F = 0.0864 Disp^0.625


Force [MN]
Displacement [t]
POPOV
Sii3D_p=8
Sii3D_p=4A^-.4

Appendix E

Popov Model Calculations.

POPOV Model - Russian 100 m ship

by C.Daley, March 1997

IPC1, 100

MAIN PARTICULARS	Lenth	m	100	
	Beam	m	17	
	Draft	m	6.7	
	Height	m	8.5	
	Cwp		0.835	
	Cm		0.98	
	Cb		0.65	
	Displacement	tonnes	7404	
	Speed	m/s	5.1	
	Power	MW	6.4	
	Stem Angle	deg (vert)	30	0.524

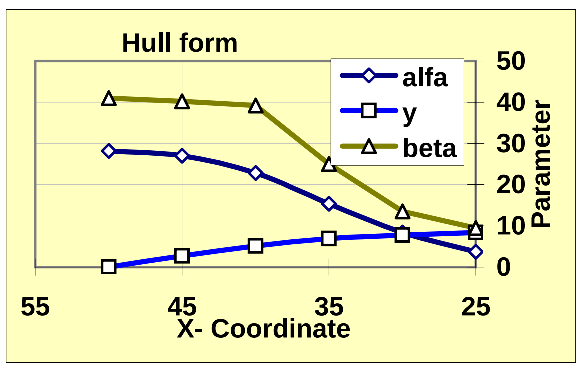
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.78824
	heave	L_33	0.9888
	roll	L_23	0.25
	pitch	L_13	0.88118
	yaw	L_12	0.59412

GY. RADIUS	m	
roll	Ix	27.62082
pitch	Iy	584.5
yaw	Iz	625

HULL FORM	Station		0	1	2	3	4	5
	x	m	50	45	40	35	30	25
	alfa	deg	28.2	27	22.8	15.4	8.4	3.7
	y	m	0	2.7	5.1	6.9	7.8	8.4
	beta	deg	41	40.2	39.2	25	13.5	9.5
	betap	rad	0.65373	0.645	0.645	0.422	0.233	0.165

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	8
	Flex Strength	Mpa	1.45
	dynamic strength	~	894

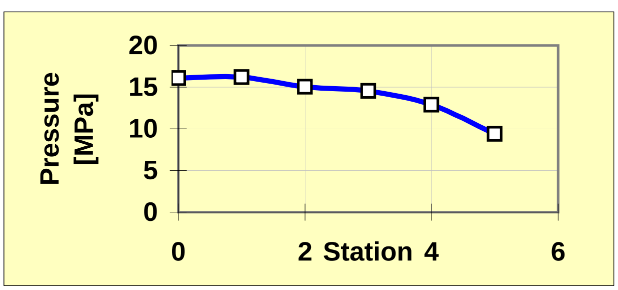


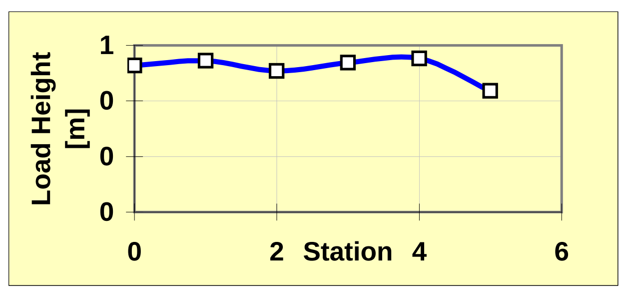
COLLISION POINT	Station		0	1	2	3	4	5
	dir cosines	l_1	0.38	0.36	0.31	0.24	0.14	0.06
		m_1	0.70	0.71	0.74	0.88	0.96	0.98
		n_1	0.61	0.60	0.60	0.41	0.23	0.16
	moment arms	la_1	0.00	1.62	3.06	2.83	1.80	1.38
		mu_1	-30.41	-27.07	-24.04	-14.35	-6.93	-4.12
		nu_1	34.98	31.05	27.89	29.11	27.77	24.07

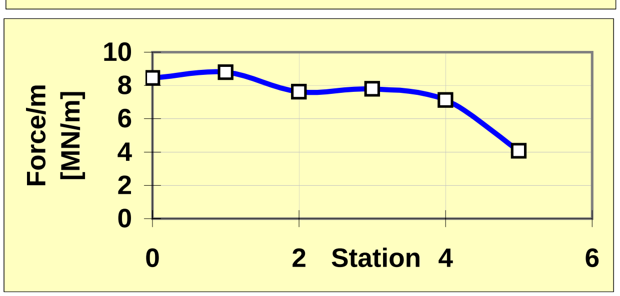
MASS	ice	C_1	1.60	1.58	1.56	1.25	1.08	1.04
REDUCTION	ship	C_0	2.67	2.31	2.16	1.84	1.48	1.21
COEFFICIENTS	total	Ct	2.67	2.31	2.16	1.84	1.48	1.21

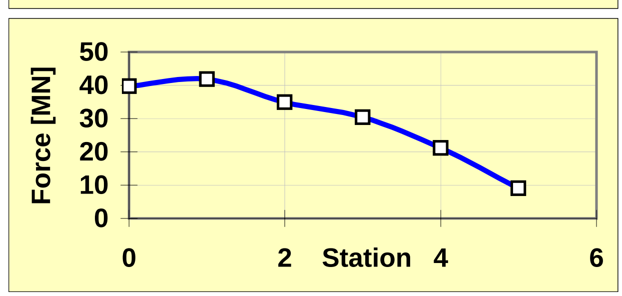
LOAD	Cp	0.587	0.592	0.550	0.532	0.472	0.343
COEFFICIENTS	Ch	0.563	0.582	0.543	0.574	0.591	0.466
(form)	Cq	0.331	0.345	0.298	0.305	0.279	0.160
	Cf	0.194	0.204	0.170	0.148	0.103	0.044

COLLISION	mass	M	755	755	755	755	755	755
RESULTS	loads (inf)	pmax	16.86	16.99	15.78	15.26	13.55	9.84
		bmax	0.57	0.59	0.55	0.58	0.60	0.47
		qmax	8.45	8.80	7.62	7.79	7.12	4.07
		fmax	41.34	43.49	36.35	31.59	21.97	9.43
	length	l_rec	6.66	6.73	6.50	5.52	4.21	3.15
	L x B x pbar	F	44.86	47.19	39.44	34.28	23.84	10.23
	bending force	Fflx	203	205	205	301	534	749
	Force	Ratio	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96
	pressure	p	16.1	16.2	15.0	14.5	12.9	9.4
	load height	b	0.53	0.54	0.51	0.54	0.55	0.44
	line load	Q	8.5	8.8	7.6	7.8	7.1	4.1
	total force	F	39.7	41.8	34.9	30.4	21.1	9.1









POPOV Model - Russian 150 m ship

by C.Daley, March 1997

IPC1, 150

MAIN PARTICULARS	Lenth	m	150	
	Beam	m	22	
	Draft	m	8.5	
	Height	m	13	
	Cwp		0.845	
	Cm		0.98	
	Cb		0.67	
	Displacement	tonnes	18794	
	Speed	m/s	5.1	
	Power	MW	10.5	
	Stem Angle	deg (vert)	30	0.524

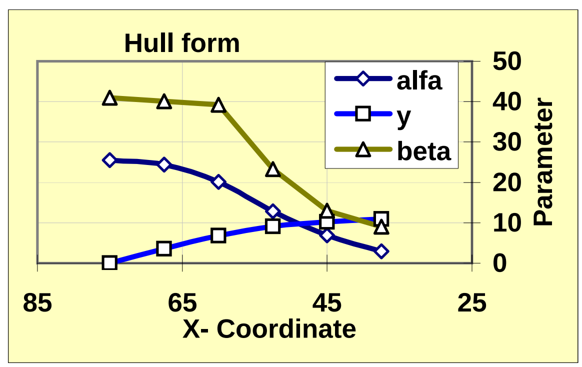
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.77273
	heave	L_33	0.99668
	roll	L_23	0.25
	pitch	L_13	0.91682
	yaw	L_12	0.64091

GY. RADIUS	m	
roll	Ix	50.69092
pitch	Iy	1330.875
yaw	Iz	1406.25

HULL FORM	Station		0	1	2	3	4	5
	x	m	75	67.5	60	52.5	45	37.5
	alfa	deg	25.5	24.4	20.1	12.8	6.9	2.9
	y	m	0	3.6	6.8	9.1	10.2	10.9
	beta	deg	41	40.1	39.2	23.3	13	9
	betap	rad	0.66528	0.654	0.654	0.398	0.225	0.157

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	8
	Flex Strength	Mpa	1.45
	dynamic strength	~	894

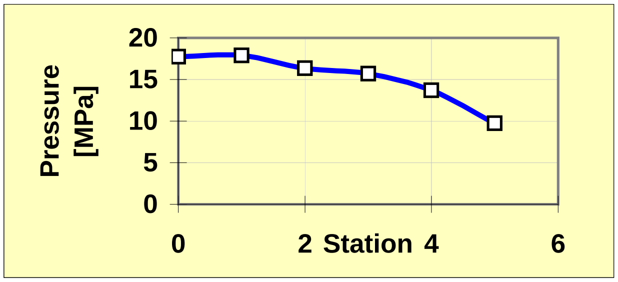


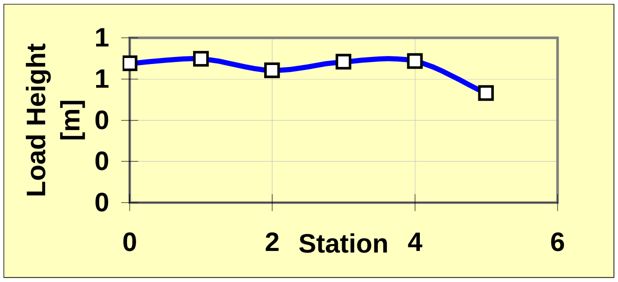
COLLISION POINT	Station		0	1	2	3	4	5
	dir cosines	l_1	0.34	0.33	0.27	0.20	0.12	0.05
		m_1	0.71	0.72	0.75	0.90	0.97	0.99
		n_1	0.62	0.61	0.61	0.39	0.22	0.16
	moment arms	la_1	0.00	2.19	4.13	3.52	2.28	1.70
		mu_1	-46.30	-41.08	-36.48	-20.33	-10.05	-5.86
		nu_1	53.26	47.60	42.88	45.34	42.35	36.45

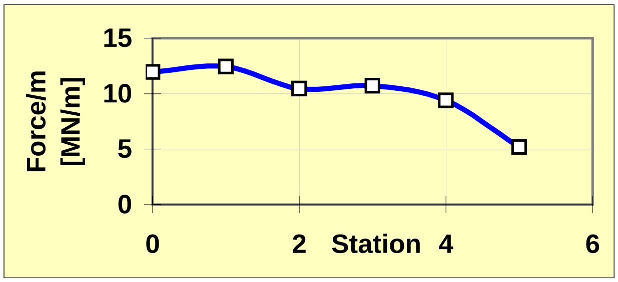
MASS	ice	C_1	1.60	1.58	1.56	1.22	1.07	1.03
REDUCTION	ship	C_0	2.66	2.31	2.16	1.82	1.47	1.20
COEFFICIENTS	total	Ct	2.66	2.31	2.16	1.82	1.47	1.20

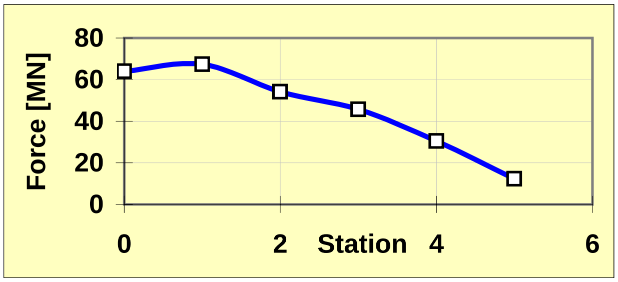
LOAD	Cp	0.555	0.560	0.512	0.492	0.429	0.305
COEFFICIENTS	Ch	0.529	0.547	0.502	0.535	0.538	0.416
(form)	Cq	0.294	0.306	0.257	0.263	0.231	0.127
	Cf	0.168	0.176	0.142	0.120	0.080	0.032

COLLISION	mass	M	1916	1916	1916	1916	1916	1916
RESULTS	loads (inf)	pmax	18.61	18.76	17.17	16.49	14.38	10.23
		bmax	0.73	0.75	0.69	0.74	0.74	0.58
		qmax	11.95	12.44	10.46	10.71	9.38	5.17
		fmax	66.64	70.06	56.41	47.58	31.73	12.87
	length	l_rec	7.60	7.67	7.35	6.05	4.61	3.39
	L x B x pbar	F	72.30	76.01	61.20	51.63	34.42	13.96
	bending force	Fflx	200	203	203	319	552	790
	Force	Ratio	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96
	pressure	p	17.7	17.9	16.4	15.7	13.7	9.7
	load height	b	0.68	0.70	0.64	0.68	0.69	0.53
	line load	Q	11.9	12.4	10.5	10.7	9.4	5.2
	total force	F	64.1	67.3	54.2	45.7	30.5	12.4









POPOV Model - Russian 200 m ship

by C.Daley, March 1997

IPC1, 200

MAIN PARTICULARS	Lenth	m	200	
	Beam	m	26.8	
	Draft	m	11	
	Height	m	18	
	Cwp		0.875	
	Cm		0.98	
	Cb		0.73	
	Displacement	tonnes	43041	
	Speed	m/s	5.1	
	Power	MW	18	
	Stem Angle	deg (vert)	30	0.524

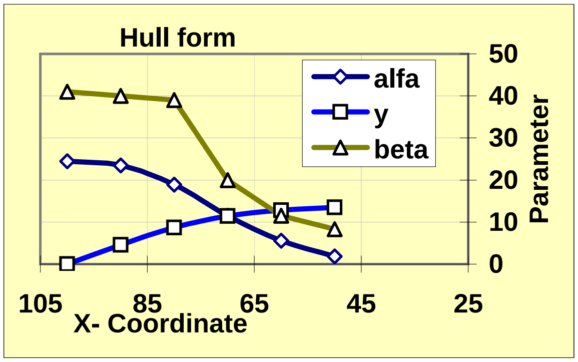
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.8209
	heave	L_33	0.90854
	roll	L_23	0.25
	pitch	L_13	0.91722
	yaw	L_12	0.67313

GY. RADIUS	m	
roll	Ix	83.25313
pitch	Iy	2450
yaw	Iz	2500

HULL FORM	Station		0	1	2	3	4	5
	x	m	100	90	80	70	60	50
	alfa	deg	24.5	23.5	18.9	11.5	5.6	1.8
	y	m	0	4.6	8.7	11.4	12.8	13.5
	beta	deg	41	40	39	20	11.5	8.3
	betap	rad	0.66924	0.656	0.654	0.343	0.2	0.145

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	8
	Flex Strength	Mpa	1.45
	dynamic strength	~	894



COLLISION POINT	Station		0	1	2	3	4	5
	dir cosines	l_1	0.33	0.32	0.26	0.19	0.10	0.03
		m_1	0.71	0.73	0.75	0.92	0.98	0.99
		n_1	0.62	0.61	0.61	0.34	0.20	0.14
	moment arms	la_1	0.00	2.81	5.29	3.83	2.54	1.95
		mu_1	-62.04	-54.89	-48.65	-23.52	-11.91	-7.21
		nu_1	71.37	63.96	57.84	62.47	57.30	49.03

MASS	ice	C_1	1.60	1.58	1.55	1.16	1.06	1.03
REDUCTION	ship	C_0	2.62	2.28	2.14	1.75	1.43	1.17
COEFFICIENTS	total	Ct	2.62	2.28	2.14	1.75	1.43	1.17

LOAD		Cp	0.544	0.549	0.497	0.488	0.397	0.242
COEFFICIENTS		Ch	0.518	0.537	0.486	0.550	0.510	0.331
(form)		Cq	0.282	0.295	0.242	0.269	0.203	0.080
		Cf	0.160	0.169	0.131	0.115	0.064	0.017

COLLISION	mass	M	4387	4387	4387	4387	4387	4387
RESULTS	loads (inf)	pmax	20.93	21.15	19.12	18.80	15.29	9.30
		bmax	0.94	0.98	0.89	1.00	0.93	0.60
		qmax	17.35	18.16	14.87	16.54	12.47	4.92
		fmax	110.24	116.44	90.64	79.67	44.48	12.04
	length	l_rec	8.66	8.73	8.30	6.56	4.86	3.33
	L x B x pbar	F	119.61	126.34	98.34	86.44	48.26	13.07
	bending force	Fflx	199	202	203	367	622	855
	Force	Ratio	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96
	pressure	p	19.9	20.1	18.2	17.9	14.6	8.9
	load height	b	0.87	0.90	0.82	0.93	0.86	0.56
	line load	Q	17.3	18.2	14.9	16.5	12.5	4.9
	total force	F	106.0	111.9	87.1	76.6	42.8	11.6

POPOV Model - Russian 250 m ship

by C.Daley, March 1997

IPC1, 250

MAIN PARTICULARS	Lenth	m	250	
	Beam	m	38	
	Draft	m	16	
	Height	m	21	
	Cwp		0.9	
	Cm		0.98	
	Cb		0.78	
	Displacement	tonnes	118560	
	Speed	m/s	5.1	
	Power	MW	34	
	Stem Angle	deg (vert)	30	0.524

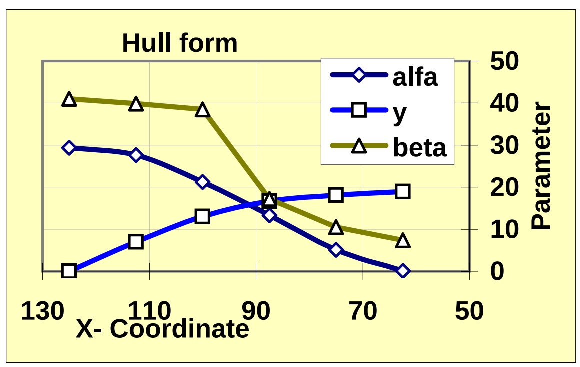
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.84211
	heave	L_33	0.86538
	roll	L_23	0.25
	pitch	L_13	0.94246
	yaw	L_12	0.62895

GY. RADIUS	m	
roll	Ix	153.0765
pitch	Iy	3937.5
yaw	Iz	3906.25

HULL FORM	Station		0	1	2	3	4	5
	x	m	125	112.5	100	87.5	75	62.5
	alfa	deg	29.4	27.6	21.2	13.3	5.1	0.1
	y	m	0	7	13	16.7	18.1	18.96
	beta	deg	41	39.9	38.5	17.2	10.5	7.4
	betap	rad	0.64818	0.638	0.638	0.293	0.183	0.129

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	8
	Flex Strength	Mpa	1.45
	dynamic strength	~	894



COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.39	0.37	0.29	0.22	0.09	0.00
	cosines	m_1	0.69	0.71	0.75	0.93	0.98	0.99
		n_1	0.60	0.60	0.60	0.29	0.18	0.13
	moment arms	la_1	0.00	4.17	7.74	4.82	3.29	2.44
		mu_1	-75.47	-66.98	-59.57	-25.24	-13.62	-8.05
		nu_1	86.81	77.50	71.11	77.86	71.88	61.95

MASS	ice	C_1	1.60	1.58	1.54	1.12	1.05	1.02
REDUCTION	ship	C_0	2.54	2.22	2.15	1.72	1.44	1.19
COEFFICIENTS	total	Ct	2.54	2.22	2.15	1.72	1.44	1.19

LOAD		Cp	0.607	0.605	0.532	0.553	0.386	0.052
COEFFICIENTS		Ch	0.589	0.600	0.525	0.652	0.505	0.065
(form)		Cq	0.357	0.363	0.279	0.361	0.195	0.003
		Cf	0.213	0.217	0.156	0.156	0.059	0.000

COLLISION	mass	M	12086	12086	12086	12086	12086	12086
RESULTS	loads (inf)	pmax	27.65	27.58	24.24	25.21	17.60	2.36
		bmax	1.50	1.53	1.34	1.66	1.29	0.16
		qmax	36.49	37.09	28.53	36.86	19.91	0.34
		fmax	288.56	294.11	211.66	212.09	79.93	0.41
	length	l_rec	10.77	10.80	10.11	7.84	5.47	1.65
	L x B x pbar	F	313.09	319.11	229.65	230.12	86.73	0.45
	bending force	Fflx	204	207	207	428	680	958
	Force	Ratio	0.70845	0.705	0.979	1	1	1
	lookup	k	0.77	0.77	0.48	0.41	0.41	0.41
	factors	fp	0.98	0.98	0.98	0.95	0.95	0.95
		fb	0.72	0.72	0.90	0.92	0.92	0.92
		fq	0.80	0.80	1.00	1.00	1.00	1.00
		ff	0.68	0.68	0.94	0.96	0.96	0.96
	pressure	p	27.1	27.1	23.7	24.0	16.8	2.3
	load height	b	1.08	1.10	1.20	1.54	1.19	0.15
	line load	Q	29.1	29.6	28.4	36.9	19.9	0.3
	total force	F	194.8	198.6	199.5	203.9	76.8	0.4

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC1, all

MAIN	Lenth (m)	L	**100**	**150**	**200**	**250**	
PARTICULARS	Beam (m)	B	**17**	**22**	**26.8**	**38**	6.80272
	Draft (m)	T	**6.7**	**8.5**	**11**	**16**	16.5837
	Height (m)	H	**8.5**	**13**	**18**	**21**	11.5875
	Cwp	Cwp	**0.835**	**0.845**	**0.875**	**0.9**	
	Cm	Cm	**0.98**	**0.98**	**0.98**	**0.98**	
	Cb	Cb	**0.65**	**0.67**	**0.73**	**0.78**	
	Displacement (t)	Disp	**7404**	**18794**	**43041**	**118560**	
	Speed (m/s)	v	**5.1**	**5.1**	**5.1**	**5.1**	
	Power (MW)	Pow	**6.4**	**10.5**	**18**	**34**	
	Stem Angle (rad)	gama	**30**	**30**	**30**	**0.5236**	
			7.4035	**18.7935**	**43.0408**	**118.56**	

GY. RADIUS (m)						
	roll	Ix	**27.6208**	**50.6909**	**83.2531**	**153.077**
	pitch	Iy	**584.5**	**1330.88**	**2450**	**3937.5**
	yaw	Iz	**625**	**1406.25**	**2500**	**3906.25**

ADDED	surge	L_11	**0**	**0**	**0**	**0**
MASSES	sway	L_22	**0.78824**	**0.77273**	**0.8209**	**0.84211**
	heave	L_33	**0.9888**	**0.99668**	**0.90854**	**0.86538**
	roll	L_23	**0.25**	**0.25**	**0.25**	**0.25**
	pitch	L_13	**0.88118**	**0.91682**	**0.91722**	**0.94246**
	yaw	L_12	**0.59412**	**0.64091**	**0.67313**	**0.62895**

HULL	Station		**1**	**1**	**1**	**1**
FORM	x	m	**45**	**67.5**	**90**	**112.5**
	alfa	deg	**27**	**24.4**	**23.5**	**27.6**
	y	m	**2.7**	**3.6**	**4.6**	**7**
	beta	deg	**40.2**	**40.1**	**40**	**39.9**
	betap	rad	**0.645**	**0.654**	**0.656**	**0.638**

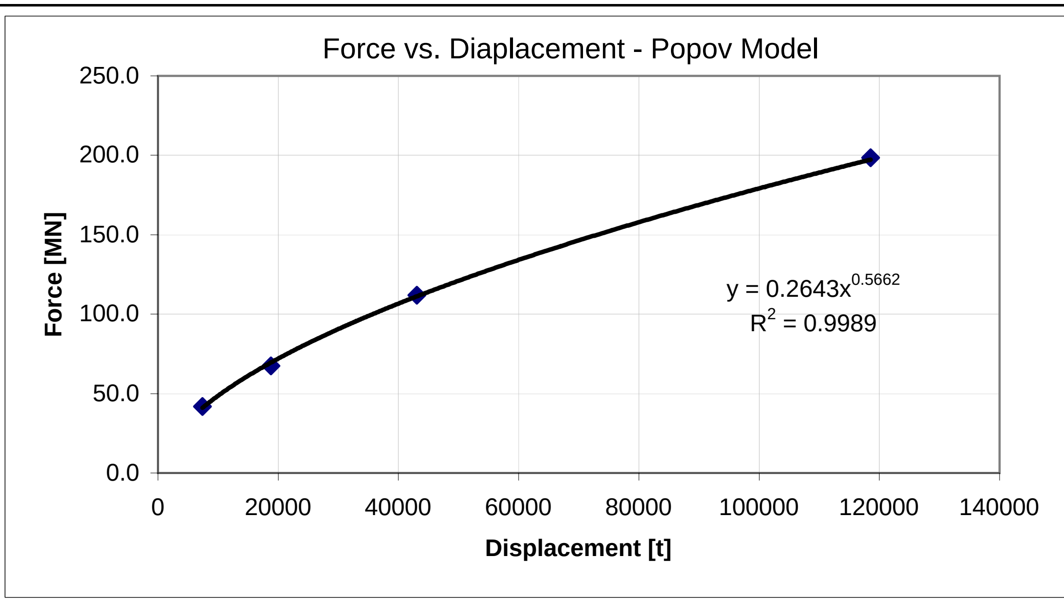
ICE	Floe mass (t)	Dice	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**
PROPERTIES	Ice thickness (m)	Hice	**8**	**8**	**8**	**8**
	Flex Strength (MPa)	sigf	**1.45**	**1.45**	**1.45**	**1.45**
	dynamic strength	ap	**894**	**894**	**894**	**894**

COLLISION	Station		**1**	**1**	**1**	**1**
POINT	dir	l_1	**0.36**	**0.33**	**0.32**	**0.37**
	cosines	m_1	**0.71**	**0.72**	**0.73**	**0.71**
		n_1	**0.60**	**0.61**	**0.61**	**0.60**
	moment arms	la_1	**1.62**	**2.19**	**2.81**	**4.17**
		mu_1	**-27.07**	**-41.08**	**-54.89**	**-66.98**
		nu_1	**31.05**	**47.60**	**63.96**	**77.50**

MASS	ice	C_1	**1.58**	**1.58**	**1.58**	**1.58**
REDUCTION	ship	C_0	**2.31**	**2.31**	**2.28**	**2.22**
COEFFICIENTS	total	Ct	**2.31**	**2.31**	**2.28**	**2.22**

LOAD		Cp	**0.592**	**0.560**	**0.549**	**0.605**
COEFFICIENTS		Ch	**0.582**	**0.547**	**0.537**	**0.600**
(form)		Cq	**0.345**	**0.306**	**0.295**	**0.363**
		Cf	**0.204**	**0.176**	**0.169**	**0.217**

COLLISION	mass	M	**755**	**1916**	**4387**	**12086**
RESULTS	loads (inf)	pmax	**16.99**	**18.76**	**21.15**	**27.58**
		bmax	**0.59**	**0.75**	**0.98**	**1.53**
		qmax	**8.80**	**12.44**	**18.16**	**37.09**
		fmax	**43.49**	**70.06**	**116.44**	**294.11**
	length	l_rec	**6.73**	**7.67**	**8.73**	**10.80**
	L x B x pbar	F	**47.19**	**76.01**	**126.34**	**319.11**
	bending force	Fflx	**205**	**203**	**202**	**207**
	Force	Ratio	**1**	**1**	**1**	**0.70489**
	lookup	k	**0.41**	**0.41**	**0.41**	**0.77**
	factors	fp	**0.95**	**0.95**	**0.95**	**0.98**
		fb	**0.92**	**0.92**	**0.92**	**0.72**
		fq	**1.00**	**1.00**	**1.00**	**0.80**
		ff	**0.96**	**0.96**	**0.96**	**0.68**
	pressure [MPa]	p	**16.2**	**17.9**	**20.1**	**27.1**
	load height [m]	b	**0.54**	**0.70**	**0.90**	**1.10**
	line load [MN/m]	Q	**8.8**	**12.4**	**18.2**	**29.6**
	total force [MN]	F	**41.8**	**67.3**	**111.9**	**198.6**
						197.001



POPOV Model - Force vs. Displacement

by C.Daley, March 1997

IPC1, 5.1 m/s, varrying ship length, displacement, 12 m ice

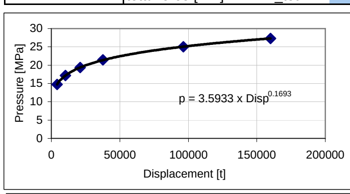
MAIN	**Lenth (m)**	**L**	**90**	**120**	**150**	**180**	**240**	**280**
PARTICULARS	Beam (m)	B	**13.239**	**17.652**	**22.065**	**26.478**	**35.304**	**41.188**
	Draft (m)	T	**5.562**	**7.416**	**9.27**	**11.124**	**14.832**	**17.304**
	Height (m)	H	**7.767**	**10.356**	**12.945**	**15.534**	**20.712**	**24.164**
	Cwp	Cwp	**0.830**	**0.845**	**0.860**	**0.875**	**0.905**	**0.925**
	Cm	Cm	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**
	Cb	Cb	**0.631**	**0.658**	**0.685**	**0.712**	**0.766**	**0.802**
	Displacement (t)	Disp	**4182**	**10336**	**21017**	**37748**	**96264**	**160048**
	Speed (m/s)	v	**5.1**	**5.1**	**5.1**	**5.1**	**5.1**	**5.1**
	Power (MW)	Pow	**5.5**	**10.5**	**11.5**	**12.5**	**18**	**34**
	Stem Angle (deg)	gama	**30**	**30**	**30**	**30**	**30**	**30**
CONSTANTS:	radians	deg	0.0174533					
	t/m^3	ro	1					
	m/s^2	g	9.81					
	m	Rice	25					
HULL	Station		**1**	**1**	**1**	**1**	**1**	**1**
FORM	m	x	**40.5**	**54**	**67.5**	**81**	**108**	**126**
	deg	alfa	**27**	**27**	**27**	**27**	**27**	**27**
	m	y	**2.3**	**3.1**	**3.9**	**4.6**	**6.2**	**7.2**
	deg	beta	**40**	**40**	**40**	**40**	**40**	**40**
	rad	betap	**0.642**	**0.642**	**0.642**	**0.642**	**0.642**	**0.642**
ICE	Floe mass (t)	Dice	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**
PROPERTIES	Ice thickness (m)	Hice	**12**	**12**	**12**	**12**	**12**	**12**
	Flex Strength (MPa)	sigf	**1.45**	**1.45**	**1.45**	**1.45**	**1.45**	**1.45**
	dynamic strength	ap	**894**	**894**	**895**	**896**	**894**	**894**
GY. RADIUS (m)	roll	Ix	**18.0**	**32.5**	**51.4**	**75.0**	**136.7**	**189.1**
	pitch	Iy	**470.6**	**851.8**	**1354.5**	**1984.5**	**3649.0**	**5076.4**
	yaw	Iz	**506**	**900**	**1406**	**2025**	**3600**	**4900**
ADDED	surge	L_11	**0**	**0**	**0**	**0**	**0**	**0**
MASSES	sway	L_22	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**
	heave	L_33	**0.947**	**0.933**	**0.921**	**0.910**	**0.891**	**0.879**
	roll	L_23	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**
	pitch	L_13	**0.819**	**0.843**	**0.869**	**0.896**	**0.955**	**0.997**
	yaw	L_12	**0.640**	**0.640**	**0.640**	**0.640**	**0.640**	**0.640**
COLLISION	Station		**1**	**1**	**1**	**1**	**1**	**1**
POINT	dir	l_1	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**
	cosines	m_1	**0.71**	**0.71**	**0.71**	**0.71**	**0.71**	**0.71**
		n_1	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**
	moment arms	la_1	**1.39**	**1.85**	**2.32**	**2.78**	**3.71**	**4.33**
		mu_1	**-24.25**	**-32.33**	**-40.42**	**-48.50**	**-64.67**	**-75.45**
		nu_1	**28.06**	**37.41**	**46.76**	**56.11**	**74.82**	**87.29**

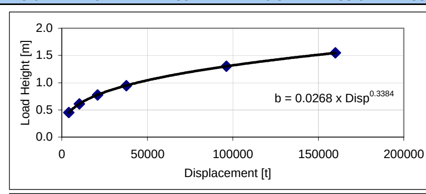
k_table:

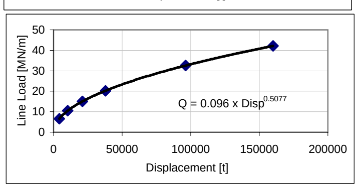
fP	k
0	1
0.097784	0.99
0.15444	0.98
0.201344	0.97
0.242661	0.96
0.280128	0.95
0.314685	0.94
0.346913	0.93
0.377204	0.92
0.405838	0.91
0.433026	0.9
0.458928	0.89
0.483673	0.88
0.507365	0.87
0.53009	0.86
0.55192	0.85
0.572917	0.84
0.593131	0.83
0.612609	0.82
0.63139	0.81
0.649508	0.8
0.666995	0.79
0.683877	0.78
0.700179	0.77
0.715923	0.76
0.731128	0.75
0.745813	0.74
0.759993	0.73
0.773683	0.72
0.786897	0.71
0.799646	0.7
0.811942	0.69
0.823796	0.68
0.835216	0.67
0.846211	0.66
0.856788	0.65
0.866956	0.64
0.876721	0.63
0.886088	0.62
0.895063	0.61
0.903652	0.6
0.911858	0.59
0.919686	0.58
0.92714	0.57
0.934222	0.56
0.940935	0.55
0.947283	0.54

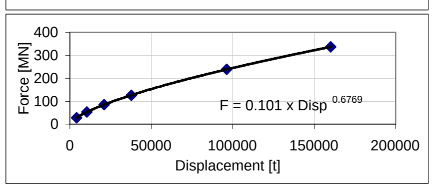
MASS	ice	C_1	1.58	1.58	1.58	1.58	1.58	1.58
REDUCTION	ship	C_0	2.31	2.29	2.27	2.25	2.21	2.19
COEFFICIENTS	total	Ct	2.31	2.29	2.27	2.25	2.21	2.19
LOAD		Cp	0.593	0.594	0.595	0.596	0.597	0.599
COEFFICIENTS		Ch	0.583	0.585	0.587	0.588	0.592	0.594
(form)		Cq	0.346	0.347	0.349	0.350	0.354	0.356
		Cf	0.204	0.206	0.207	0.208	0.210	0.212
COLLISION	mass	M	426	1054	2142	3848	9813	16315
RESULTS	loads (inf)	pmax	15.48	18.02	20.34	22.48	26.30	28.68
		bmax	0.49	0.66	0.84	1.02	1.41	1.67
		qmax	6.63	10.48	15.02	20.23	32.54	42.20
		fmax	29.78	54.78	88.49	131.58	248.26	351.08
	length	l_rec	6.11	7.12	8.03	8.86	10.39	11.33
		Area	2.98	4.71	6.74	9.07	14.63	18.98
		p_bar	10.83	12.62	14.24	15.74	18.41	20.07
		Aro	0.10	0.10	0.10	0.10	0.10	0.10
		po	15.48	18.02	20.34	22.48	26.30	28.68
		Ari	1.46	1.98	2.52	3.07	4.23	5.02
		pi	15.48	18.02	20.34	22.48	26.30	28.68
	L x B x pbar	F	32.31	59.44	96.01	142.77	269.36	380.92
	bending force	Fflx	464	464	464	464	464	464
	Force	Ratio	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96
	pressure [MPa]	p	14.7	17.2	19.4	21.4	25.0	27.3
	load height [m]	b	0.45	0.61	0.78	0.95	1.30	1.55
	line load [MN/m]	Q	6.6	10.5	15.0	20.2	32.5	42.2
	total force [MN]	F_tot	28.6	52.7	85.1	126.5	238.6	337.5

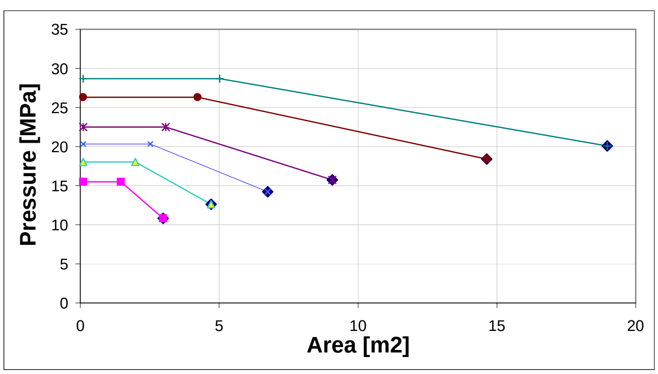
0.953267	0.53
0.958888	0.52
0.964149	0.51
0.969049	0.5
0.973591	0.49
0.977774	0.48
0.981598	0.47
0.985063	0.46
0.988168	0.45
0.990912	0.44
0.993294	0.43
0.995311	0.42
0.99696	0.41
0.99696	0.41
0.99696	0.41
0.99696	0.41
0.99696	0.41











<u>POPOV Model in Russian Approach</u>

by C.Daley, March 1997

IPC1, 120m, varying speed, 8m ice

MAIN PARTICULARS	Lenth (m)	L	200	200	200	200	200	200
	Beam (m)	B	29.42	29.42	29.42	29.42	29.42	29.42
	Draft (m)	T	12.36	12.36	12.36	12.36	12.36	12.36
	Height (m)	H	17.26	17.26	17.26	17.26	17.26	17.26
	Cwp	Cwp	0.885	0.885	0.885	0.885	0.885	0.885
	Cm	Cm	0.980	0.980	0.980	0.980	0.980	0.980
	Cb	Cb	0.730	0.730	0.730	0.730	0.730	0.730
	Displacement (t)	Disp	53090	53090	53090	53090	53090	53090
	Speed (m/s)	v	2	3	4	5	6	7
	Power (MW)	Pow	18.8	10.5	11.5	12.5	18	34
	Stem Angle (deg)	gama	30	30	30	30	30	30

CONSTANTS:	radians	deg	0.01745
	t/m^3	ro	1
	m/s^2	g	9.81
	m	Rice	25

HULL FORM	Station		1	1	1	1	1	1
	m	x	90	90	90	90	90	90
	deg	alfa	27	27	27	27	27	27
	m	y	5.2	5.2	5.2	5.2	5.2	5.2
	deg	beta	40	40	40	40	40	40
	rad	betap	0.642	0.642	0.642	0.642	0.642	0.642

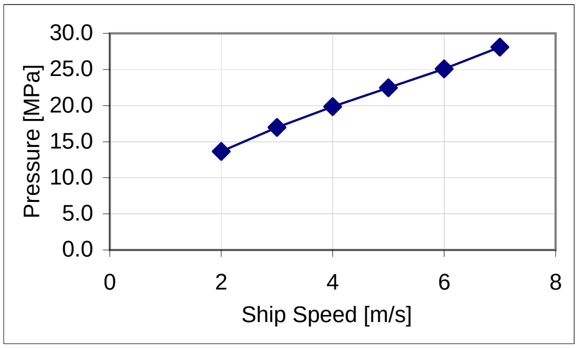
ICE PROPERTIES	Floe mass (t)	Dice	1.0E+12	1.0E+12	1.0E+12	1.0E+12	1.0E+12	1.0E+12
	Ice thickness (m)	Hice	8	8	8	8	8	8
	Flex Strength (MPa)	sigf	1.45	1.45	1.45	1.45	1.45	1.45
	dynamic strength	ap	894	894	895	896	894	894

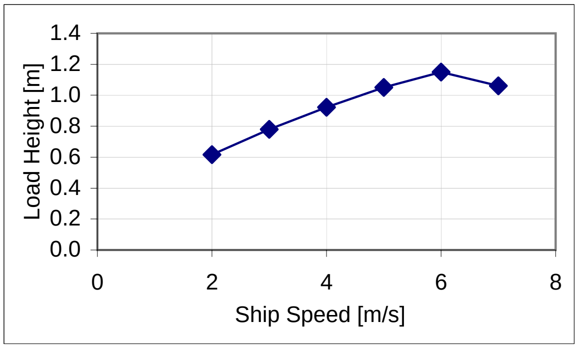
GY. RADIUS (m)	roll	Ix	93.4	93.4	93.4	93.4	93.4	93.4
	pitch	Iy	2478.0	2478.0	2478.0	2478.0	2478.0	2478.0
	yaw	Iz	2500	2500	2500	2500	2500	2500

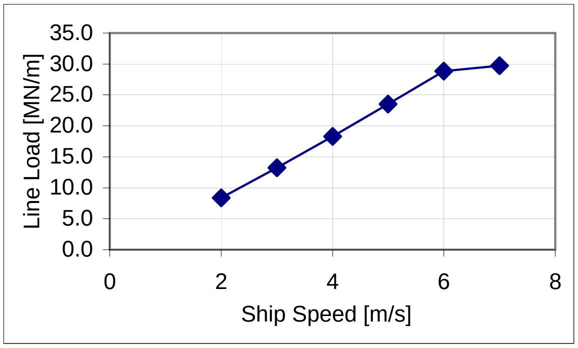
ADDED MASSES	surge	L_11	0	0	0	0	0	0
	sway	L_22	0.840	0.840	0.840	0.840	0.840	0.840
	heave	L_33	0.903	0.903	0.903	0.903	0.903	0.903
	roll	L_23	0.250	0.250	0.250	0.250	0.250	0.250
	pitch	L_13	0.915	0.915	0.915	0.915	0.915	0.915
	yaw	L_12	0.640	0.640	0.640	0.640	0.640	0.640

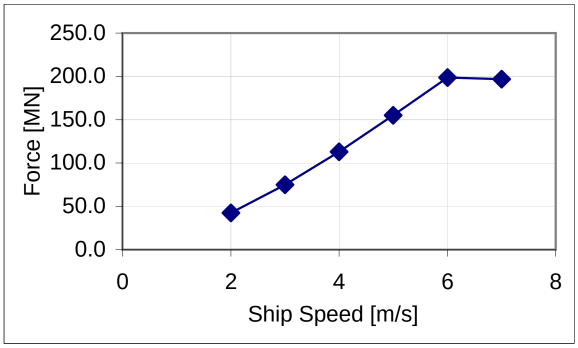
COLLISION POINT	Station		1	1	1	1	1	1
	dir	l_1	0.36	0.36	0.36	0.36	0.36	0.36
	cosines	m_1	0.71	0.71	0.71	0.71	0.71	0.71
		n_1	0.60	0.60	0.60	0.60	0.60	0.60
	moment arms	la_1	3.09	3.09	3.09	3.09	3.09	3.09
		mu_1	-53.89	-53.89	-53.89	-53.89	-53.89	-53.89
		nu_1	62.35	62.35	62.35	62.35	62.35	62.35

MASS	ice	C_1	1.58	1.58	1.58	1.58	1.58	1.58
REDUCTION	ship	C_0	2.24	2.24	2.24	2.24	2.24	2.24
COEFFICIENTS	total	Ct	2.24	2.24	2.24	2.24	2.24	2.24
LOAD		Cp	0.596	0.596	0.596	0.596	0.596	0.596
COEFFICIENTS		Ch	0.590	0.590	0.590	0.590	0.590	0.590
(form)		Cq	0.351	0.351	0.351	0.351	0.351	0.351
		Cf	0.209	0.209	0.209	0.209	0.209	0.209
COLLISION	mass	M	5412	5412	5412	5412	5412	5412
RESULTS	loads (inf)	pmax	14.31	17.83	20.86	23.57	25.95	28.21
		bmax	0.67	0.84	1.00	1.14	1.26	1.38
		qmax	8.38	13.23	18.29	23.53	28.85	34.31
		fmax	43.99	78.12	117.48	161.23	208.57	259.47
	length	l_rec	7.15	8.04	8.75	9.33	9.85	10.30
	L x B x pbar	F	47.73	84.76	127.47	174.94	226.29	281.52
	bending force	Fflx	206	206	206	206	206	206
	Force	Ratio	1	1	1	1	0.98828	0.7944
	lookup	k	0.41	0.41	0.41	0.41	0.45	0.71
	factors	fp	0.95	0.95	0.95	0.95	0.97	1.00
		fb	0.92	0.92	0.92	0.92	0.91	0.77
		fq	1.00	1.00	1.00	1.00	1.00	0.87
		ff	0.96	0.96	0.96	0.96	0.95	0.76
	pressure [MPa]	p	13.6	17.0	19.9	22.4	25.1	28.1
	load height [m]	b	0.62	0.78	0.92	1.05	1.15	1.06
	line load [MN/m]	Q	8.4	13.2	18.3	23.5	28.8	29.7
	total force [MN]	F_tot	42.3	75.1	112.9	155.0	198.7	196.9









POPOV Model in Russian Approach

by C.Daley, March 1997

IPC1, 120m, varying speed, 12 m ice

MAIN	Lenth (m)	L	**120**	**120**	**120**	**120**	**120**	**120**
PARTICULARS	Beam (m)	B	**17.652**	**17.652**	**17.652**	**17.652**	**17.652**	**17.652**
	Draft (m)	T	**7.416**	**7.416**	**7.416**	**7.416**	**7.416**	**7.416**
	Height (m)	H	**10.356**	**10.356**	**10.356**	**10.356**	**10.356**	**10.356**
	Cwp	Cwp	**0.845**	**0.845**	**0.845**	**0.845**	**0.845**	**0.845**
	Cm	Cm	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**	**0.980**
	Cb	Cb	**0.658**	**0.658**	**0.658**	**0.658**	**0.658**	**0.658**
	Displacement (t)	Disp	**10336**	**10336**	**10336**	**10336**	**10336**	**10336**
	Speed (m/s)	v	**2**	**3**	**4**	**5**	**6**	**7**
	Power (MW)	Pow	**7.7**	**10.5**	**11.5**	**12.5**	**18**	**34**
	Stem Angle (deg)	gama	**30**	**30**	**30**	**30**	**30**	**30**

CONSTANTS:	radians	deg	0.01745
	t/m^3	ro	1
	m/s^2	g	9.81
	m	Rice	25

HULL	Station		**1**	**1**	**1**	**1**	**1**	**1**
FORM	m	x	**54**	**54**	**54**	**54**	**54**	**54**
	deg	alfa	**27**	**27**	**27**	**27**	**27**	**27**
	m	y	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**
	deg	beta	**40**	**40**	**40**	**40**	**40**	**40**
	rad	betap	**0.642**	**0.642**	**0.642**	**0.642**	**0.642**	**0.642**

ICE	Floe mass (t)	Dice	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**	**1.0E+12**
PROPERTIES	Ice thickness (m)	Hice	**12**	**12**	**12**	**12**	**12**	**12**
	Flex Strength (MPa)	sigf	**1.45**	**1.45**	**1.45**	**1.45**	**1.45**	**1.45**
	dynamic strength	ap	**894**	**894**	**895**	**896**	**894**	**894**

GY. RADIUS (m)	roll	Ix	**32.5**	**32.5**	**32.5**	**32.5**	**32.5**	**32.5**
	pitch	Iy	**851.8**	**851.8**	**851.8**	**851.8**	**851.8**	**851.8**
	yaw	Iz	**900**	**900**	**900**	**900**	**900**	**900**

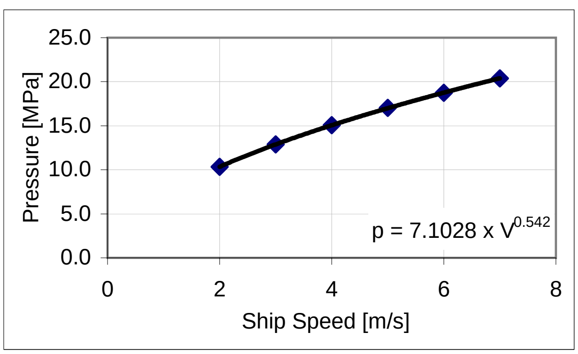
ADDED	surge	L_11	**0**	**0**	**0**	**0**	**0**	**0**
MASSES	sway	L_22	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**
	heave	L_33	**0.933**	**0.933**	**0.933**	**0.933**	**0.933**	**0.933**
	roll	L_23	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**	**0.250**
	pitch	L_13	**0.843**	**0.843**	**0.843**	**0.843**	**0.843**	**0.843**
	yaw	L_12	**0.640**	**0.640**	**0.640**	**0.640**	**0.640**	**0.640**

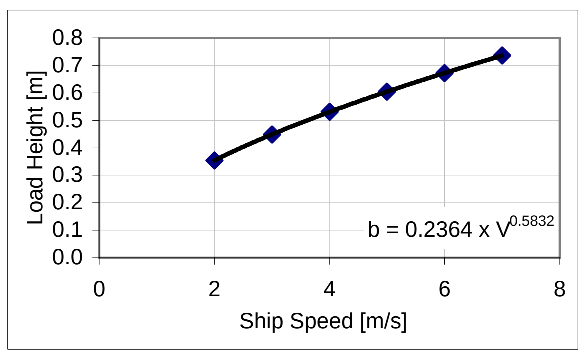
COLLISION	Station		**1**	**1**	**1**	**1**	**1**	**1**
POINT	dir	l_1	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**
	cosines	m_1	**0.71**	**0.71**	**0.71**	**0.71**	**0.71**	**0.71**
		n_1	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**
	moment arms	la_1	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**	**1.85**
		mu_1	**-32.33**	**-32.33**	**-32.33**	**-32.33**	**-32.33**	**-32.33**
		nu_1	**37.41**	**37.41**	**37.41**	**37.41**	**37.41**	**37.41**

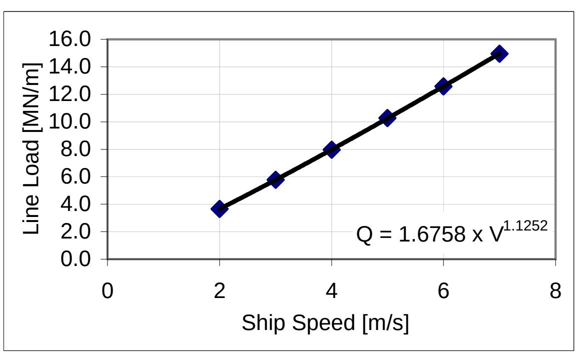
MASS REDUCTION COEFFICIENTS	ice	C_1	1.58	1.58	1.58	1.58	1.58	1.58
	ship	C_0	2.29	2.29	2.29	2.29	2.29	2.29
	total	Ct	2.29	2.29	2.29	2.29	2.29	2.29

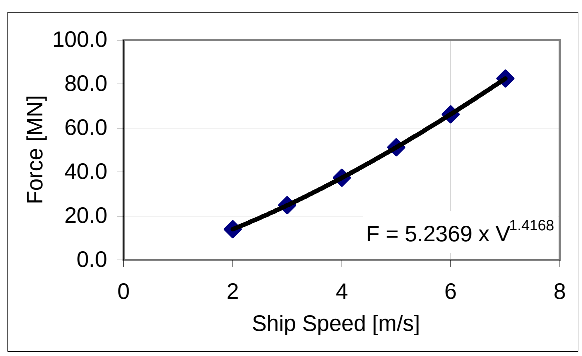
LOAD COEFFICIENTS (form)		Cp	0.594	0.594	0.594	0.594	0.594	0.594
		Ch	0.585	0.585	0.585	0.585	0.585	0.585
		Cq	0.347	0.347	0.347	0.347	0.347	0.347
		Cf	0.206	0.206	0.206	0.206	0.206	0.206

COLLISION RESULTS	mass	M	1054	1054	1054	1054	1054	1054
	loads (inf)	pmax	10.85	13.52	15.82	17.87	19.68	21.40
		bmax	0.38	0.49	0.57	0.65	0.73	0.80
		qmax	3.65	5.77	7.98	10.26	12.58	14.96
		fmax	14.54	25.83	38.85	53.31	68.96	85.79
	length	l_rec	5.42	6.10	6.63	7.08	7.47	7.81
		Area	2.08	2.96	3.81	4.62	5.43	6.22
		p_bar	7.60	9.46	11.07	12.51	13.78	14.98
	L x B x pbar	F	15.78	28.03	42.15	57.84	74.82	93.08
	bending force	Fflx	464	464	464	464	464	464
	Force	Ratio	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96
	pressure [MPa]	p	10.3	12.9	15.1	17.0	18.7	20.4
	load height [m]	b	0.35	0.45	0.53	0.60	0.67	0.74
	line load [MN/m]	Q	3.7	5.8	8.0	10.3	12.6	15.0
	total force [MN]	F_tot	14.0	24.8	37.3	51.2	66.3	82.5









POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 100

MAIN PARTICULARS	Lenth	m	100	
	Beam	m	17	
	Draft	m	6.7	
	Height	m	8.5	
	Cwp		0.8	
	Cm		0.98	
	Cb		0.65	
	Displacement	tonnes	7404	
	Speed	m/s	2.6	
	Power	MW	4.2	
	Stem Angle	deg (vert)	45	0.785

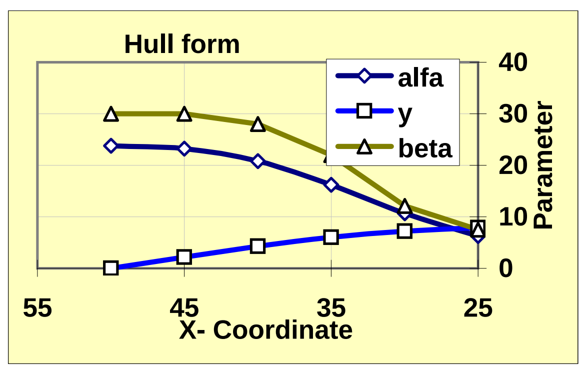
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.78824
	heave	L_33	0.92529
	roll	L_23	0.25
	pitch	L_13	0.8238
	yaw	L_12	0.59412

GY. RADIUS	m	
roll	Ix	26.71543
pitch	Iy	560
yaw	Iz	625

HULL FORM	Station		0	1	2	3	4	5	6
	x	m	50	45	40	35	30	25	20
	alfa	deg	23.8	23.2	20.8	16.2	10.7	6.3	3.87
	y	m	0	2.2	4.3	6	7.2	7.9	8.3
	beta	deg	30	30	28	22	12.1	7.5	4.38
	betap	rad	0.48599	0.488	0.461	0.37	0.208	0.13	0.076

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	3
	Flex Strength	Mpa	0.523
	dynamic strength	~	196



COLLISION POINT	Station		0	1	2	3	4	5	6
	dir cosines	l_1	0.36	0.35	0.32	0.26	0.18	0.11	0.07
		m_1	0.81	0.81	0.84	0.90	0.96	0.99	0.99
		n_1	0.47	0.47	0.45	0.36	0.21	0.13	0.08
	moment arms	la_1	0.00	1.03	1.91	2.17	1.48	1.03	0.63
		mu_1	-23.35	-21.09	-17.80	-12.66	-6.18	-3.24	-1.52
		nu_1	40.45	35.77	32.12	29.77	27.54	23.78	19.34

MASS	ice	C_1	1.35	1.35	1.31	1.20	1.06	1.02	1.01
REDUCTION	ship	C_0	2.78	2.36	2.05	1.77	1.44	1.17	0.95
COEFFICIENTS	total	Ct	2.78	2.36	2.05	1.77	1.44	1.17	0.95

LOAD	Cp	0.596	0.604	0.595	0.572	0.557	0.489	0.445
COEFFICIENTS	Ch	0.594	0.618	0.627	0.641	0.727	0.724	0.764
(form)	Cq	0.354	0.373	0.373	0.367	0.405	0.354	0.340
	Cf	0.186	0.201	0.197	0.177	0.157	0.108	0.082

COLLISION	mass	M	755	755	755	755	755	755	755
RESULTS	loads (inf)	pmax	2.60	2.64	2.60	2.50	2.43	2.13	1.95
		bmax	0.74	0.77	0.79	0.80	0.91	0.91	0.96
		qmax	1.70	1.80	1.80	1.76	1.95	1.70	1.64
		fmax	8.35	8.99	8.83	7.91	7.01	4.85	3.68
	length	l_rec	6.67	6.82	6.69	6.10	4.90	3.88	3.06
	L x B x pbar	F	9.06	9.76	9.58	8.58	7.61	5.26	3.99
	bending force	Fflx	13	13	14	17	30	48	82
	Force	Ratio	1	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96	0.96
	pressure	p	2.5	2.5	2.5	2.4	2.3	2.0	1.9
	load height	b	0.69	0.72	0.73	0.74	0.84	0.84	0.89
	line load	Q	1.7	1.8	1.8	1.8	1.9	1.7	1.6
	total force	F	8.0	8.6	8.5	7.6	6.7	4.7	3.5

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 150

MAIN PARTICULARS	Lenth	m	150	
	Beam	m	22	
	Draft	m	8.5	
	Height	m	13	
	Cwp		0.816	
	Cm		0.98	
	Cb		0.67	
	Displacement	tonnes	18794	
	Speed	m/s	2.6	
	Power	MW	7.2	
	Stem Angle	deg (vert)	45	0.785

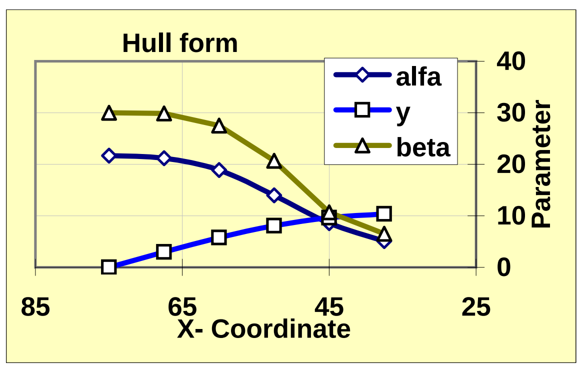
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.77273
	heave	L_33	0.94428
	roll	L_23	0.25
	pitch	L_13	0.86629
	yaw	L_12	0.64091

GY. RADIUS	m	
roll	Ix	49.43457
pitch	Iy	1285.2
yaw	Iz	1406.25

HULL FORM	Station		0	1	2	3	4	5	6
	x	m	75	67.5	60	52.5	45	37.5	30
	alfa	deg	21.7	21.2	18.9	14	8.6	5.1	0.10
	y	m	0	3	5.8	8.1	9.6	10.4	11
	beta	deg	30	29.9	27.5	20.7	10.7	6.5	6
	betap	rad	0.49237	0.492	0.458	0.351	0.185	0.113	0.105

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	3
	Flex Strength	Mpa	0.523
	dynamic strength	~	196



COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.33	0.32	0.29	0.23	0.15	0.09
	cosines	m_1	0.82	0.82	0.85	0.91	0.97	0.99
		n_1	0.47	0.47	0.44	0.34	0.18	0.11
	moment arms	la_1	0.00	1.42	2.56	2.79	1.76	1.17
		mu_1	-35.45	-31.89	-26.51	-18.07	-8.26	-4.23
		nu_1	61.41	54.51	49.24	45.99	42.33	36.19

MASS	ice	C_1	1.35	1.35	1.30	1.17	1.05	1.02
REDUCTION	ship	C_0	2.76	2.34	2.04	1.76	1.43	1.16
COEFFICIENTS	total	Ct	2.76	2.34	2.04	1.76	1.43	1.16

LOAD	Cp	0.567	0.575	0.568	0.538	0.511	0.452
COEFFICIENTS	Ch	0.562	0.586	0.598	0.607	0.681	0.689
(form)	Cq	0.319	0.337	0.340	0.327	0.348	0.312
	Cf	0.164	0.178	0.175	0.149	0.123	0.087

COLLISION	mass	M	1916	1916	1916	1916	1916	1916
RESULTS	loads (inf)	pmax	2.89	2.94	2.90	2.75	2.61	2.31
		bmax	0.96	1.00	1.02	1.04	1.16	1.18
		qmax	2.44	2.59	2.60	2.51	2.67	2.39
		fmax	13.69	14.80	14.54	12.45	10.26	7.23
	length	l_rec	7.63	7.79	7.61	6.76	5.23	4.12
	L x B x pbar	F	14.85	16.06	15.77	13.50	11.13	7.85
	bending force	Fflx	13	13	14	18	34	56
	Force	Ratio	0.96748	0.895	0.975	1	1	1
	lookup	k	0.51	0.61	0.49	0.41	0.41	0.41
	factors	fp	0.98	1.00	0.98	0.95	0.95	0.95
		fb	0.88	0.83	0.89	0.92	0.92	0.92
		fq	0.99	0.95	0.99	1.00	1.00	1.00
		ff	0.93	0.86	0.94	0.96	0.96	0.96
	pressure	p	2.8	2.9	2.8	2.6	2.5	2.2
	load height	b	0.85	0.84	0.91	0.96	1.08	1.09
	line load	Q	2.4	2.4	2.6	2.5	2.7	2.4
	total force	F	12.7	12.8	13.6	12.0	9.9	7.0

POPOV Model in Russian Approach
by C.Daley, March 1997

IPC5, 200

MAIN PARTICULARS	Lenth	m	200	
	Beam	m	26.8	
	Draft	m	11	
	Height	m	18	
	Cwp		0.85	
	Cm		0.98	
	Cb		0.73	
	Displacement	tonnes	43041	
	Speed	m/s	2.6	
	Power	MW	12.6	
	Stem Angle	deg (vert)	45	0.785

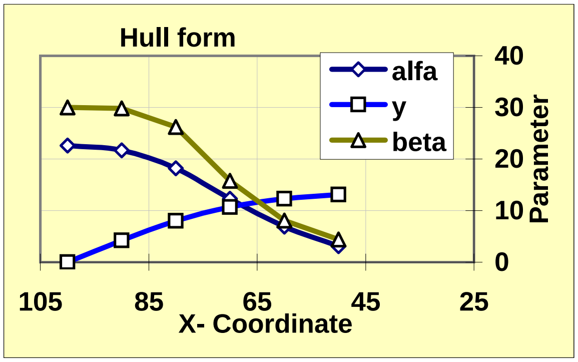
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.8209
	heave	L_33	0.86895
	roll	L_23	0.25
	pitch	L_13	0.87169
	yaw	L_12	0.67313

GY. RADIUS	m	
roll	Ix	81.6459
pitch	Iy	2380
yaw	Iz	2500

HULL FORM	Station		0	1	2	3	4	5
	x	m	100	90	80	70	60	50
	alfa	deg	22.6	21.7	18.2	12.3	6.9	3.1
	y	m	0	4.2	8	10.7	12.3	13.1
	beta	deg	30	29.8	26.2	15.8	8.1	4.4
	betap	rad	0.48971	0.489	0.437	0.27	0.14	0.077

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	3
	Flex Strength	Mpa	0.523
	dynamic strength	~	196



COLLISION POINT	Station		0	1	2	3	4	5
	dir cosines	l_1	0.34	0.33	0.28	0.21	0.12	0.05
		m_1	0.81	0.82	0.86	0.94	0.98	1.00
		n_1	0.47	0.47	0.42	0.27	0.14	0.08
	moment arms	la_1	0.00	1.97	3.39	2.85	1.72	1.00
		mu_1	-47.04	-42.28	-33.88	-18.65	-8.39	-3.83
		nu_1	81.47	72.45	66.58	63.72	57.52	49.07

MASS	ice	C_1	1.35	1.35	1.27	1.10	1.03	1.01
REDUCTION	ship	C_0	2.68	2.29	2.01	1.70	1.39	1.14
COEFFICIENTS	total	Ct	2.68	2.29	2.01	1.70	1.39	1.14

LOAD		Cp	0.582	0.586	0.566	0.544	0.489	0.383
COEFFICIENTS		Ch	0.582	0.601	0.602	0.653	0.694	0.630
(form)		Cq	0.339	0.352	0.341	0.355	0.340	0.241
		Cf	0.177	0.187	0.172	0.148	0.106	0.053

COLLISION	mass	M	4387	4387	4387	4387	4387	4387
RESULTS	loads (inf)	pmax	3.41	3.43	3.32	3.19	2.87	2.24
		bmax	1.31	1.35	1.36	1.47	1.56	1.42
		qmax	3.93	4.08	3.96	4.12	3.94	2.80
		fmax	25.68	27.05	24.92	21.45	15.31	7.67
	length	l_rec	8.89	9.02	8.58	7.09	5.29	3.73
	L x B x pbar	F	27.87	29.35	27.03	23.27	16.62	8.32
	bending force	Fflx	13	13	15	23	45	82
	Force	Ratio	0.5182	0.493	0.593	1	1	1
	lookup	k	0.87	0.88	0.83	0.41	0.41	0.41
	factors	fp	0.93	0.92	0.95	0.95	0.95	0.95
		fb	0.60	0.59	0.65	0.92	0.92	0.92
		fq	0.63	0.61	0.71	1.00	1.00	1.00
		ff	0.49	0.47	0.57	0.96	0.96	0.96
	pressure	p	3.2	3.1	3.2	3.0	2.7	2.1
	load height	b	0.79	0.79	0.89	1.36	1.45	1.31
	line load	Q	2.5	2.5	2.8	4.1	3.9	2.8
	total force	F	12.6	12.6	14.2	20.6	14.7	7.4

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 200

MAIN PARTICULARS	Lenth	m	250	
	Beam	m	38	
	Draft	m	16	
	Height	m	21	
	Cwp		0.875	
	Cm		0.98	
	Cb		0.78	
	Displacement	tonnes	118560	
	Speed	m/s	2.6	
	Power	MW	26.6	
	Stem Angle	deg (vert)	45	0.785

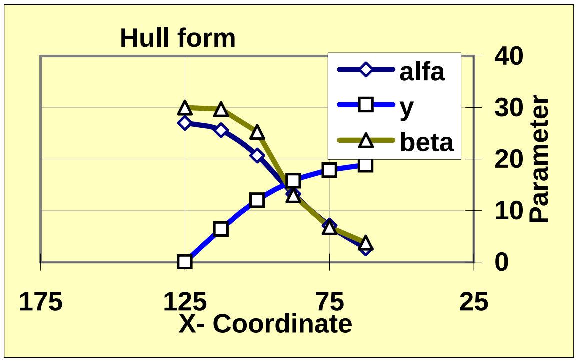
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.84211
	heave	L_33	0.82888
	roll	L_23	0.25
	pitch	L_13	0.89412
	yaw	L_12	0.62895

GY. RADIUS	m	
roll	Ix	149.8452
pitch	Iy	3828.125
yaw	Iz	3906.25

HULL FORM	Station		0	1	2	3	4	5
	x	m	125	112.5	100	87.5	75	62.5
	alfa	deg	27	25.6	20.7	13.2	7.1	2.7
	y	m	0	6.4	12	15.8	17.8	18.9
	beta	deg	30	29.7	25.3	13	6.8	3.8
	betap	rad	0.47512	0.475	0.416	0.221	0.118	0.066

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	3
	Flex Strength	Mpa	0.523
	dynamic strength	~	196



COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.40	0.38	0.32	0.22	0.12	0.05
	cosines	m_1	0.79	0.80	0.86	0.95	0.99	1.00
		n_1	0.46	0.46	0.40	0.22	0.12	0.07
	moment arms	la_1	0.00	2.93	4.85	3.46	2.09	1.25
		mu_1	-57.18	-51.46	-40.44	-19.19	-8.81	-4.14
		nu_1	99.04	87.76	81.67	79.59	71.72	61.41

MASS	ice	C_1	1.35	1.34	1.26	1.07	1.02	1.01
REDUCTION	ship	C_0	2.61	2.23	1.99	1.68	1.39	1.15
COEFFICIENTS	total	Ct	2.61	2.23	1.99	1.68	1.39	1.15

LOAD	Cp	0.647	0.646	0.616	0.597	0.519	0.368
COEFFICIENTS	Ch	0.658	0.673	0.666	0.755	0.770	0.624
(form)	Cq	0.425	0.435	0.410	0.451	0.400	0.230
	Cf	0.233	0.241	0.213	0.183	0.120	0.047

COLLISION	mass	M	12086	12086	12086	12086	12086	12086
RESULTS	loads (inf)	pmax	4.48	4.48	4.27	4.14	3.60	2.55
		bmax	2.08	2.13	2.11	2.39	2.43	1.97
		qmax	8.19	8.38	7.90	8.68	7.71	4.42
		fmax	66.35	68.66	60.57	52.14	34.24	13.28
	length	l_rec	11.03	11.16	10.44	8.18	6.05	4.09
	L x B x pbar	F	71.99	74.50	65.72	56.57	37.15	14.41
	bending force	Fflx	14	14	15	29	53	95
	Force	Ratio	0.20626	0.199	0.256	0.547	1	1
	lookup	k	0.97	0.98	0.96	0.86	0.41	0.41
	factors	fp	0.75	0.70	0.78	0.93	0.95	0.95
		fb	0.37	0.33	0.41	0.61	0.92	0.92
		fq	0.32	0.26	0.37	0.65	1.00	1.00
		ff	0.19	0.15	0.23	0.51	0.96	0.96
	pressure	p	3.4	3.2	3.4	3.9	3.4	2.4
	load height	b	0.78	0.69	0.86	1.47	2.25	1.82
	line load	Q	2.6	2.2	2.9	5.7	7.7	4.4
	total force	F	12.9	10.2	14.2	26.7	32.9	12.8

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 100

MAIN PARTICULARS	Lenth	m	100	
	Beam	m	17	
	Draft	m	6.7	
	Height	m	8.5	
	Cwp		0.755	
	Cm		0.98	
	Cb		0.65	
	Displacement	tonnes	7404	
	Speed	m/s	1.35	
	Power	MW	2.1	
	Stem Angle	deg (vert)	45	0.785

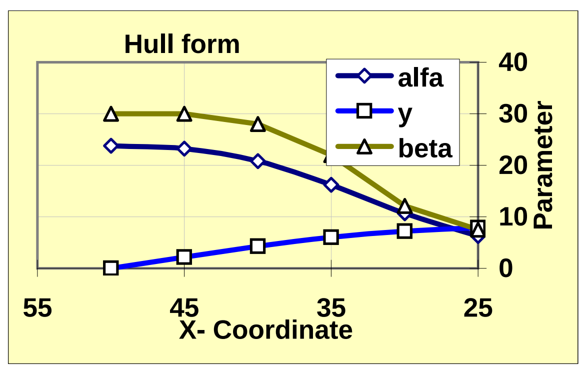
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.78824
	heave	L_33	0.84525
	roll	L_23	0.25
	pitch	L_13	0.75853
	yaw	L_12	0.59412

GY. RADIUS	m	
roll	Ix	25.55136
pitch	Iy	528.5
yaw	Iz	625

HULL FORM	Station		0	1	2	3	4	5	6
	x	m	50	45	40	35	30	25	20
	alfa	deg	23.8	23.2	20.8	16.2	10.7	6.3	3.50
	y	m	0	2.2	4.3	6	7.2	7.9	8.3
	beta	deg	30	30	28	22	12.1	7.5	4.5
	betap	rad	0.48599	0.488	0.461	0.37	0.208	0.13	0.078

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	2
	Flex Strength	Mpa	0.35
	dynamic strength	~	140



COLLISION POINT	Station		0	1	2	3	4	5	6
	dir cosines	l_1	0.36	0.35	0.32	0.26	0.18	0.11	0.06
		m_1	0.81	0.81	0.84	0.90	0.96	0.99	1.00
		n_1	0.47	0.47	0.45	0.36	0.21	0.13	0.08
	moment arms	la_1	0.00	1.03	1.91	2.17	1.48	1.03	0.65
		mu_1	-23.35	-21.09	-17.80	-12.66	-6.18	-3.24	-1.57
		nu_1	40.45	35.77	32.12	29.77	27.54	23.78	19.40

MASS	ice	C_1	1.35	1.35	1.31	1.20	1.06	1.02	1.01
REDUCTION	ship	C_0	2.84	2.41	2.09	1.80	1.44	1.18	0.95
COEFFICIENTS	total	Ct	2.84	2.41	2.09	1.80	1.44	1.18	0.95

LOAD	Cp	0.594	0.602	0.593	0.571	0.556	0.488	0.418
COEFFICIENTS	Ch	0.590	0.614	0.623	0.638	0.726	0.723	0.710
(form)	Cq	0.350	0.369	0.370	0.364	0.404	0.353	0.297
	Cf	0.184	0.198	0.195	0.175	0.156	0.108	0.070

COLLISION	mass	M	755	755	755	755	755	755	755
RESULTS	loads (inf)	pmax	1.30	1.32	1.30	1.25	1.22	1.07	0.92
		bmax	0.58	0.60	0.61	0.62	0.71	0.71	0.69
		qmax	0.66	0.69	0.70	0.69	0.76	0.66	0.56
		fmax	2.84	3.06	3.01	2.71	2.41	1.67	1.08
	length	l_rec	5.88	6.00	5.89	5.38	4.33	3.43	2.64
	L x B x pbar	F	3.09	3.32	3.26	2.94	2.62	1.82	1.17
	bending force	Fflx	4	4	4	5	9	14	24
	Force	Ratio	1	1	1	1	1	1	1
	lookup	k	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	factors	fp	0.95	0.95	0.95	0.95	0.95	0.95	0.95
		fb	0.92	0.92	0.92	0.92	0.92	0.92	0.92
		fq	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		ff	0.96	0.96	0.96	0.96	0.96	0.96	0.96
	pressure	p	1.2	1.3	1.2	1.2	1.2	1.0	0.9
	load height	b	0.53	0.56	0.56	0.58	0.66	0.65	0.64
	line load	Q	0.7	0.7	0.7	0.7	0.8	0.7	0.6
	total force	F	2.7	2.9	2.9	2.6	2.3	1.6	1.0

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 150

MAIN PARTICULARS	Lenth	m	150	
	Beam	m	22	
	Draft	m	8.5	
	Height	m	13	
	Cwp		0.773	
	Cm		0.98	
	Cb		0.67	
	Displacement	tonnes	18794	
	Speed	m/s	1.35	
	Power	MW	4.5	
	Stem Angle	deg (vert)	45	0.785

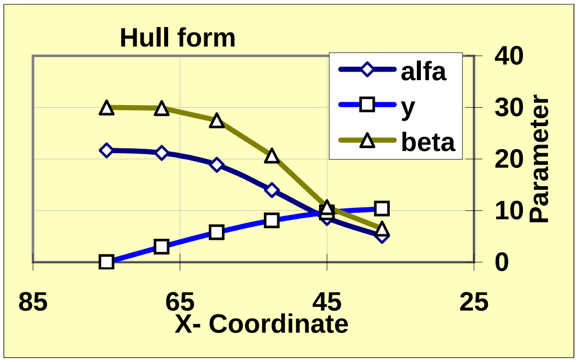
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.77273
	heave	L_33	0.86794
	roll	L_23	0.25
	pitch	L_13	0.79932
	yaw	L_12	0.64091

GY. RADIUS	m	
roll	Ix	47.5717
pitch	Iy	1217.475
yaw	Iz	1406.25

HULL FORM	Station		0	1	2	3	4	5	6
	x	m	75	67.5	60	52.5	45	37.5	30
	alfa	deg	21.7	21.2	18.9	14	8.6	5.1	2.40
	y	m	0	3	5.8	8.1	9.6	10.4	10.9
	beta	deg	30	29.9	27.5	20.7	10.7	6.5	3.9
	betap	rad	0.49237	0.492	0.458	0.351	0.185	0.113	0.068

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	2
	Flex Strength	Mpa	0.35
	dynamic strength	~	140



COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.33	0.32	0.29	0.23	0.15	0.09
	cosines	m_1	0.82	0.82	0.85	0.91	0.97	0.99
		n_1	0.47	0.47	0.44	0.34	0.18	0.11
	moment arms	la_1	0.00	1.42	2.56	2.79	1.76	1.17
		mu_1	-35.45	-31.89	-26.51	-18.07	-8.26	-4.23
		nu_1	61.41	54.51	49.24	45.99	42.33	36.19

MASS	ice	C_1	1.35	1.35	1.30	1.17	1.05	1.02
REDUCTION	ship	C_0	2.81	2.39	2.08	1.78	1.43	1.17
COEFFICIENTS	total	Ct	2.81	2.39	2.08	1.78	1.43	1.17

LOAD		Cp	0.565	0.574	0.566	0.537	0.511	0.452
COEFFICIENTS		Ch	0.559	0.583	0.595	0.605	0.680	0.688
(form)		Cq	0.316	0.334	0.337	0.325	0.347	0.311
		Cf	0.162	0.175	0.173	0.148	0.123	0.087

COLLISION	mass	M	1916	1916	1916	1916	1916	1916
RESULTS	loads (inf)	pmax	1.44	1.47	1.45	1.37	1.31	1.16
		bmax	0.75	0.78	0.79	0.81	0.91	0.92
		qmax	0.95	1.00	1.01	0.97	1.04	0.93
		fmax	4.67	5.04	4.96	4.27	3.53	2.50
	length	l_rec	6.72	6.86	6.70	5.97	4.62	3.64
	L x B x pbar	F	5.06	5.47	5.39	4.63	3.83	2.71
	bending force	Fflx	4	4	4	5	10	17
	Force	Ratio	0.84407	0.781	0.849	1	1	1
	lookup	k	0.67	0.72	0.66	0.41	0.41	0.41
	factors	fp	1.00	0.99	1.00	0.95	0.95	0.95
		fb	0.80	0.76	0.80	0.92	0.92	0.92
		fq	0.90	0.86	0.91	1.00	1.00	1.00
		ff	0.81	0.75	0.82	0.96	0.96	0.96
	pressure	p	1.44	1.46	1.45	1.31	1.24	1.10
	load height	b	0.59	0.59	0.64	0.75	0.84	0.85
	line load	Q	0.85	0.86	0.92	0.97	1.04	0.93
	total force	F	3.8	3.8	4.0	4.1	3.4	2.4

POPOV Model in Russian Approach

by C.Daley, March 1997

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MAIN PARTICULARS	Lenth	m	200	
	Beam	m	26.8	
	Draft	m	11	
	Height	m	18	
	Cwp		0.818	
	Cm		0.98	
	Cb		0.73	
	Displacement	tonnes	43041	
	Speed	m/s	1.35	
	Power	MW	8.6	
	Stem Angle	deg (vert)	45	0.785

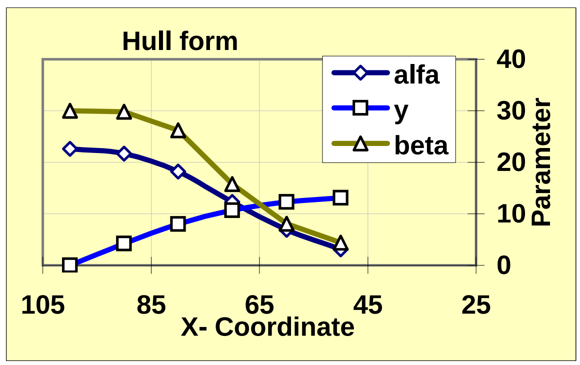
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.8209
	heave	L_33	0.81892
	roll	L_23	0.25
	pitch	L_13	0.8186
	yaw	L_12	0.67313

GY. RADIUS	m	
roll	Ix	79.58864
pitch	Iy	2290.4
yaw	Iz	2500

HULL FORM	Station		0	1	2	3	4	5
	x	m	100	90	80	70	60	50
	alfa	deg	22.6	21.7	18.2	12.3	6.9	3.1
	y	m	0	4.2	8	10.7	12.3	13.1
	beta	deg	30	29.8	26.2	15.8	8.1	4.4
	betap	rad	0.48971	0.489	0.437	0.27	0.14	0.077

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	2
	Flex Strength	Mpa	0.35
	dynamic strength	~	140



COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.34	0.33	0.28	0.21	0.12	0.05
	cosines	m_1	0.81	0.82	0.86	0.94	0.98	1.00
		n_1	0.47	0.47	0.42	0.27	0.14	0.08
	moment arms	la_1	0.00	1.97	3.39	2.85	1.72	1.00
		mu_1	-47.04	-42.28	-33.88	-18.65	-8.39	-3.83
		nu_1	81.47	72.45	66.58	63.72	57.52	49.07

MASS	ice	C_1	1.35	1.35	1.27	1.10	1.03	1.01
REDUCTION	ship	C_0	2.72	2.32	2.04	1.70	1.39	1.14
COEFFICIENTS	total	Ct	2.72	2.32	2.04	1.70	1.39	1.14

LOAD	Cp	0.581	0.584	0.565	0.544	0.489	0.383
COEFFICIENTS	Ch	0.580	0.598	0.600	0.652	0.694	0.630
(form)	Cq	0.337	0.349	0.339	0.354	0.339	0.241
	Cf	0.176	0.185	0.171	0.148	0.106	0.053

COLLISION	mass	M	4387	4387	4387	4387	4387	4387
RESULTS	loads (inf)	pmax	1.70	1.71	1.66	1.59	1.44	1.12
		bmax	1.02	1.05	1.06	1.15	1.22	1.11
		qmax	1.53	1.59	1.54	1.61	1.54	1.09
		fmax	8.79	9.26	8.54	7.38	5.28	2.65
	length	l_rec	7.84	7.95	7.56	6.26	4.68	3.30
	L x B x pbar	F	9.54	10.04	9.27	8.01	5.73	2.87
	bending force	Fflx	4	4	4	7	13	24
	Force	Ratio	0.45043	0.428	0.515	0.946	1	1
	lookup	k	0.9	0.91	0.87	0.55	0.41	0.41
	factors	fp	0.90	0.88	0.93	0.99	0.95	0.95
		fb	0.55	0.53	0.60	0.87	0.92	0.92
		fq	0.56	0.54	0.63	0.98	1.00	1.00
		ff	0.42	0.39	0.49	0.91	0.96	0.96
	pressure	p	1.5	1.5	1.5	1.6	1.4	1.1
	load height	b	0.56	0.56	0.63	0.99	1.13	1.03
	line load	Q	0.9	0.8	1.0	1.6	1.5	1.1
	total force	F	3.7	3.6	4.2	6.7	5.1	2.5

POPOV Model in Russian Approach

by C.Daley, March 1997

IPC5, 200

MAIN PARTICULARS	Lenth	m	250	
	Beam	m	38	
	Draft	m	16	
	Height	m	21	
	Cwp		0.855	
	Cm		0.98	
	Cb		0.78	
	Displacement	tonnes	118560	
	Speed	m/s	2.6	
	Power	MW	13.9	
	Stem Angle	deg (vert)	45	0.785

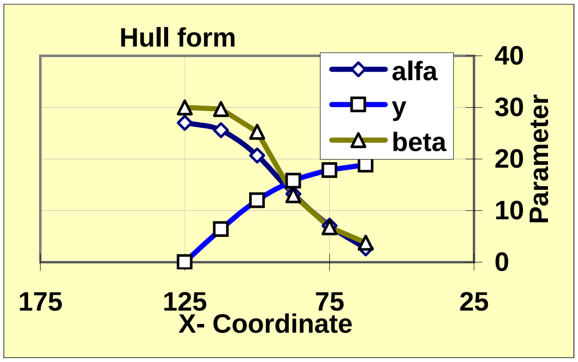
CONSTANTS:		
deg	0.017	radians
ro	1	t/m^3
g	9.81	m/s^2
Rice	25	m

ADDED MASSES	surge	L_11	0
	sway	L_22	0.84211
	heave	L_33	0.79996
	roll	L_23	0.25
	pitch	L_13	0.85831
	yaw	L_12	0.62895

GY. RADIUS	m	
roll	Ix	147.2602
pitch	Iy	3740.625
yaw	Iz	3906.25

HULL FORM	Station		0	1	2	3	4	5
	x	m	125	112.5	100	87.5	75	62.5
	alfa	deg	27	25.6	20.7	13.2	7.1	2.7
	y	m	0	6.4	12	15.8	17.8	18.9
	beta	deg	30	29.7	25.3	13	6.8	3.8
	betap	rad	0.47512	0.475	0.416	0.221	0.118	0.066

ICE PROPERTIES	Floe mass	tonnes	1.0E+12
	Ice thickness	m	2
	Flex Strength	Mpa	0.35
	dynamic strength	~	140

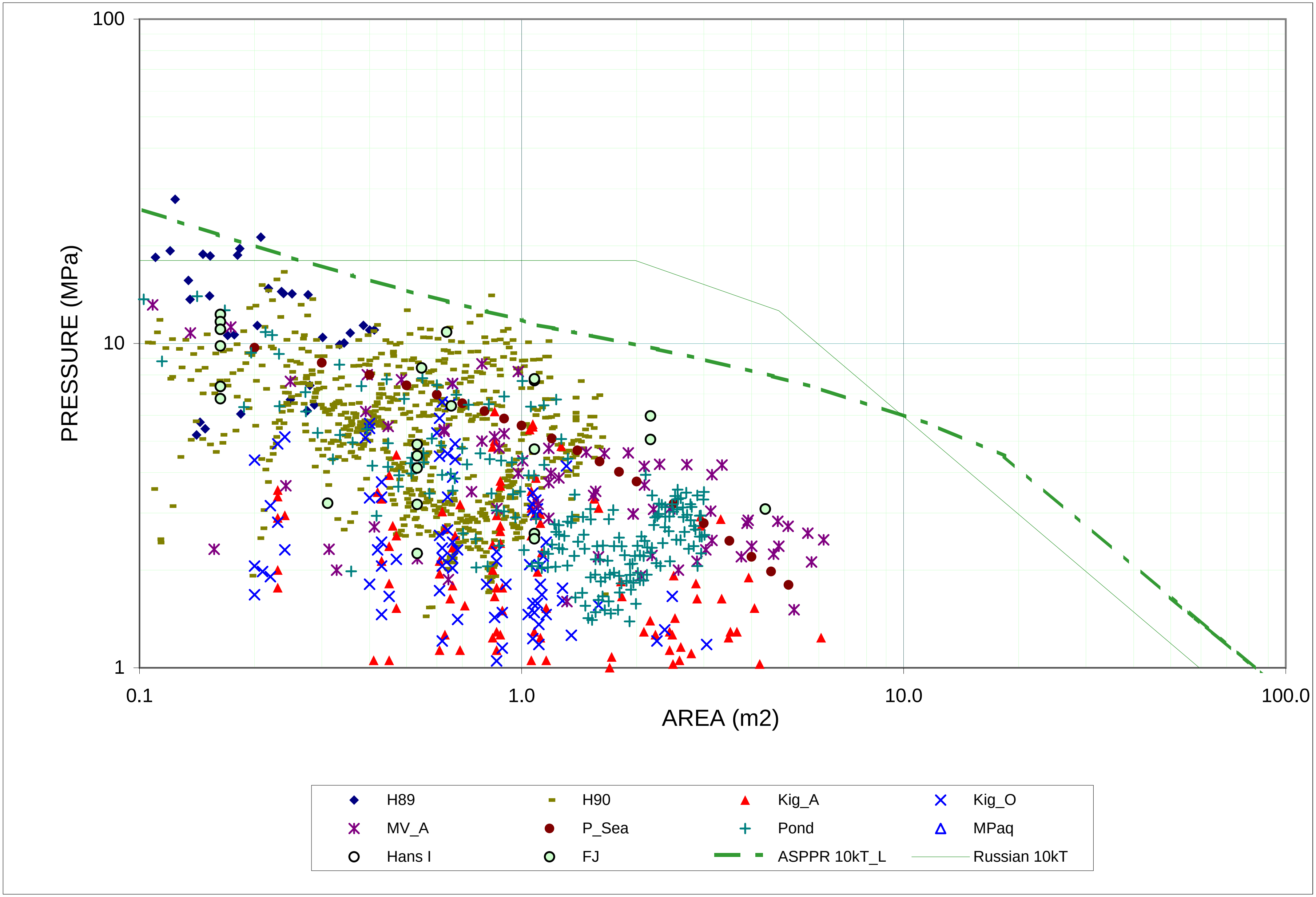


COLLISION POINT	Station		0	1	2	3	4	5
	dir	l_1	0.40	0.38	0.32	0.22	0.12	0.05
	cosines	m_1	0.79	0.80	0.86	0.95	0.99	1.00
		n_1	0.46	0.46	0.40	0.22	0.12	0.07
	moment arms	la_1	0.00	2.93	4.85	3.46	2.09	1.25
		mu_1	-57.18	-51.46	-40.44	-19.19	-8.81	-4.14
		nu_1	99.04	87.76	81.67	79.59	71.72	61.41

MASS	ice	C_1	1.35	1.34	1.26	1.07	1.02	1.01
REDUCTION	ship	C_0	2.63	2.25	2.00	1.68	1.39	1.15
COEFFICIENTS	total	Ct	2.63	2.25	2.00	1.68	1.39	1.15

LOAD	Cp	0.646	0.645	0.615	0.597	0.519	0.368
COEFFICIENTS	Ch	0.656	0.672	0.665	0.754	0.770	0.624
(form)	Cq	0.424	0.433	0.409	0.450	0.400	0.230
	Cf	0.232	0.240	0.212	0.183	0.120	0.047

COLLISION	mass	M	12086	12086	12086	12086	12086	12086
RESULTS	loads (inf)	pmax	3.20	3.20	3.05	2.96	2.57	1.82
		bmax	2.37	2.43	2.40	2.73	2.78	2.26
		qmax	6.67	6.82	6.44	7.08	6.30	3.61
		fmax	57.68	59.69	52.71	45.51	29.91	11.61
	length	l_rec	11.78	11.92	11.15	8.75	6.47	4.37
	L x B x pbar	F	62.59	64.76	57.19	49.38	32.45	12.59
	bending force	Fflx	4	4	5	8	16	28
	Force	Ratio	0.07057	0.068	0.087	0.187	0.53	1
	lookup	k	0.994	0.995	0.992	0.975	0.88	0.41
	factors	fp	0.58	0.56	0.61	0.73	0.92	0.95
		fb	0.22	0.21	0.24	0.35	0.59	0.92
		fq	0.14	0.13	0.17	0.29	0.61	1.00
		ff	0.07	0.06	0.08	0.17	0.47	0.96
	pressure	p	1.8	1.8	1.8	2.2	2.4	1.7
	load height	b	0.52	0.50	0.58	0.96	1.63	2.09
	line load	Q	1.0	0.9	1.1	2.1	3.8	3.6
	total force	F	3.9	3.6	4.3	7.8	13.9	11.2



100
10
1
PRESSURE (MPa)
0.1
1.0
10.0
100.0
AREA (m2)
H89
H90
Kig_A
Kig_O
MV_A
P_Sea
Pond
MPaq
Hans I
FJ
ASPPR 10kT_L
Russian 10kT

Appendix F

Ice Data. Extracted from: Burden, R., Timco, G.; A Catalogue of Sea Ice Ridges; National Research Council; 1995.

4.0 ICE RIDGE DATA

4.1 First-year Ice Ridge Data

The information on the one hundred and seventy-six ice ridges was divided into first-year, and multi-year tables. The following first-year ridge information is given in Table 1:

RIDGE -	A symbol to identify each ridge (ex. F1). If the symbol is followed by ' then the ridge has a cross-section profile in Appendix A.
SOURCE -	A coded symbol to represent the ridge's reference source (see Section 3.1).
LIT -	The level ice thickness on both sides of the ridge.
WD -	The water depth at the ridge. If it is followed by * then the ridge is grounded.
SAIL HEIGHT -	
MAX. -	The maximum sail height at any point of the ridge.
CS -	The maximum sail height along a ridge cross-section.
AVG. -	The average sail height along a ridge cross-section.
KEEL DEPTH -	
MAX. -	The maximum keel depth at any point of the ridge.
CS. -	The maximum keel depth along a ridge cross-section.
AVG. -	The average keel depth along a ridge cross-section.
KSR -	The ratio of maximum keel depth to maximum sail height.
SAIL ANGLE -	The angle of incline for each side of the sail.
KEEL ANGLE -	The angle of decline for each side of the keel.
SW MAX. -	The maximum width of the sail.

KW MAX. -	The maximum width of the keel.
AREA -	
SAIL (A_s) -	The measured cross-sectional area of the sail.
KEEL CONS (A_c) -	The measured cross-sectional area of the consolidated keel region.
KEEL TOTAL (A_k) -	The measured cross-sectional area of the entire keel.
SNOW (A_s) -	The measured cross-sectional area of snow on the ridge.
SNOW -	
MIN. -	The minimum snow cover depth along the ridge.
MAX. -	The maximum depth of the snow cover.
CONSOLIDATED DEPTH -	
MIN. -	The minimum depth to the bottom of the consolidated zone.
MAX. -	The maximum depth to the bottom of the consolidated zone.
AVG. -	The average depth to the bottom of the consolidated zone.
SA. -	The average measured salinity of the ridge. If two values are given, then they represent the maximum and minimum.
EL. -	The measured elasticity of the ridge.

STRENGTH OF -	
ICE SHEET -	The average measured strength of the ice sheet near the ridge.
SAIL AVG. -	The average measured strength of the sail.
KEEL MAX. -	The maximum measured strength of the keel.
POROSITY -	
SAIL -	The measured porosity of the sail.
KEEL -	The measured porosity of the keel.
AVG. -	The average measured porosity of the entire ridge.
MAX. -	The maximum measured porosity of the entire ridge.

Table 1. First-Year Ice Ridge Data

Ridge	Source	LIT 1 (m)	LIT 2 (m)	WD (m)	Sail Height Max (m)	Sail Height CS (m)	Sail Height Avg (m)	Keel Depth Max (m)	Keel Depth CS (m)	Keel Depth Avg (m)	KSR	Sail Angle 1 (deg)	Sail Angle 2 (deg)	Keel Angle 1 (deg)	Keel Angle 2 (deg)	Sail Width (m)	Keel Width (m)
F1'	FA1			9	0.5	0.5	0.2	2.7	2.7		5.9						
F2'	FA1			8.9	1.4	1.4	0.3	7.7	7.7		5.3						
F3'	FA1			9.5	1.9	1.9	0.4	7.8	7.8		4.1						
F4'	FA1			10	1.1	1.1	0.2	3.2	3.2		3.0						
F5'	FA1			9.5	1.7	1.7	0.4	5.6	5.6		3.2						
F6'	FA1			9.8	2.1	2.1	0.4	8.0	8.0		3.8						
F7'	FA1			8.5*	2.6	2.6	0.6										
F8A'	FA2	0.3			0.6	0.6	0.3	5.3	5.3	3.4	8.9						
F8B'	FA2	0.6			0.6	0.6	0.2	4.5	4.5	3.2	7.4						
F9A'	FA3	0.5	1.0			1.7	0.6		10.6	2.6		23	16	17	14	9.0	50.0
F9B'	FA3	1.0	1.5		1.7	1.4	0.4	10.6	9.7	2.5	6.4	23	7	39	37		
F9C'	FA3	1.0	1.8			1.2	0.3		9.4	2.9		16	6	29	18		
F10A'	FA3	1.0	1.5			1.2	0.6		7.6	4.3		45	11	10	14		
F10B'	FA3	1.0	2.0		2.0	0.8	0.2	9	9	3.7	4.6	10	6	51	16		
F10C'	FA3	1.0	2.5			2.0	0.6		8.7	4.3		17	27	20	21		
F11A'	FA3	1				1.8	0.6		12	6.7		15	10	21	23		
F11B'	FA3	1			2.4	2.4	0.9	12.0	12	6.3	4.9	17	21	17	20		
F11C'	FA3	1				2.0	0.6		12	6.7		3	58	37	31		
F12A'	FA3	2				4.2	1.1					20	32	24			
F12B'	FA3	1.3			4.2	2.9	0.8					32	26	20			
F12C'	FA3	2				3.8	1.1					24	20	42			
F13	FA4			6.7*	4.6	4.6										30.5	42.7
F14A'	FA4			21.9*	7.0	5.2										29.0	99.1
F14B'	FA4					7.0										29.0	106.7
F15'	FA4			23.8	3.4	3.4		14.3	14.3							27.4	85.3
F16'	FA4			21.3*	4.9	2.4										36.6	96.0
F17A'	FA4			11.9	2.0	2.0		10.1	10.1		5.1					21.3	33.5
F17B'	FA4			12.2		1.4			7.9							9.1	18.3
F18A'	FA4			14.6	1.2	1.2		8.5	8.5		7.0					10.7	33.5
F18B'	FA4			14.6		1.2			7.6							10.7	25.9
F19A'	FA4			21.3	2.1	2.1		12.8	12.8		6.0					22.9	44.2

Table 1. First-Year Ice Ridge Data

Ridge	Area				Snow Cover		Consolidation Layer			SA.	EL.	Strength of			Porosity			
	Sail	Keel		Snow	Min	Max	Min	Max	Avg			Ice Sheet	Sail Avg	Keel Max	Sail	Keel	Avg	Max
		Cons	Total															
	(m^2)	(m^2)	(m^2)	(m^2)	(m)	(m)	(m)	(m)	(m)	(ppt)	(MPa)	(MPa)	(MPa)	(MPa)	(%)	(%)	(%)	(%)
F1'						0.04	0.6	1.3	0.86									
F2'						0.35	0.5	1.5	0.85									
F3'						0.31	0.7	1.2	0.93									
F4'						0.02	0.2	0.5	0.32									
F5'						0.03	0.4	1.5	0.82									
F6'						0.04	0.7	1.3	0.91									
F7'						0.27	0.5	1.2	0.80									
F8A'						0.13	0.3	1.2	0.62								27	55
F8B'						0.60	0.6	1.4	0.97								20	56
F9A'	34		210	12		0.70					1.4			14.1				
F9B'	22		234	11		0.90												
F9C'	19		222	15		1.05												
F10A'	19		276	16		0.80												
F10B'	14		236	18		0.60												
F10C'	25		275	17		0.70												
F11A'	38		445	17		0.70												
F11B'	44		414	25		1.20												
F11C'	35		438	21		0.90												
F12A'	55			22		0.90					1.4			8.2				
F12B'	44			22		1.85												
F12C'	64			17		1.00												
F13						1.21		1.8		3 , 5								
F14A'								1.5		3 , 5			27.6	27.6				
F14B'								2.1						27.6				
F15'								1.8		4 , 7.5								
F16'								2.0										
F17A'								2.0										
F17B'								1.8										
F18A'								2.4										
F18B'								2.4										
F19A'								4.9										
F19B'								3.4		4 , 8								

Table 1. First-Year Ice Ridge Data

Ridge	Source	LIT 1 (m)	LIT 2 (m)	WD (m)	Sail Height Max (m)	Sail Height CS (m)	Sail Height Avg (m)	Keel Depth Max (m)	Keel Depth CS (m)	Keel Depth Avg (m)	KSR	Sail Angle 1 (deg)	Sail Angle 2 (deg)	Keel Angle 1 (deg)	Keel Angle 2 (deg)	Sail Width (m)	Keel Width (m)
F20A'	FA4			23.8		2.4			16.5							10.7	48.8
F20B'	FA4			21.6	3.0	3.0		17.4	17.4		5.7					19.8	38.1
F21'	FA4			25.6	4.6	3.7		19.2	17.4							13.4	
F22'	FA4			15.2*	5.3	5.3										44.2	59.4
F23A'	FA4			23.5	3.4	3.4		15.5	15.5		4.6					32.0	76.2
F23B'	FA4			22.9		3.0			15.5							8.2	
F24'	FA4			26.5	3.8	3.8		19.2	19.2		5.1					73.2	85.3
F25A'	FA4			20.4	2.1	1.8		15.5	15.5		7.4					27.4	57.9
F25B	FA4			19.2		2.1			11.9							9.1	
F26'	FA4			30.2	2.7	2.7		13.1	13.1		4.9					12.2	56.4
F27'	FA5	1.5		33.5	7.5	6.4		26.8	26.8		3.6	25	41	15	29	23.8	149.4
F28'	FA5	0.9		17.1	3.0	2.1		9.4	9.4		3.1	22	36	23	28	9.1	36.0
F29'	FA5			29.0	6.3	6.3		22.9	22.9		3.6	26	36	40	21	23.8	57.9
F30'	FA5	1.2		40.8	3.7	3.2		14.3	10.1		3.9	36	48	18	18	9.1	37.5
F31'	FA5	1.5		35.1	5.7	5.7		23.2	23.2		4.1	24	41	24	27	13.4	96.9
F32'	FA5	0.6	1.5	56.7	5.4	5.4		23.8	21.0		4.4	27	31	23	70	18.3	69.8
F33'	FA5	0.9		56.7	2.7	2.0		13.4	13.4		4.9	19	32	29	59	7.9	49.4
F34'	FA5			31.4	3.7	3.5		17.4	17.4		4.8	49	40	37	23	11.0	80.5
F35'	FA5	1.8		11.9*	2.7	2.7						35	35	22	40	7.3	38.7
F36'	FA5	2.4		12.5*	8.6	8.1						32	17	30		36.6	87.8
F37'	FA5	0.9	1.5	61.0	4.5	4.5		21.9	16.5		4.9	18	44	23	27	15.8	87.8
F38'	FA5	1.2		39.6	5.8	5.8		23.8	23.8		4.1	40	30	46	28	23.2	71.3
F39	FA5			16.8*	9.7	8.8						30	37			33.5	23.2
F40'	FA6	1.8		17.2*	6.9	5.1											
F41	FA7	0.7			1.1	1.1		2.9	2.9		2.6					5	20
F42	FA7	0.5			1.7	1.7		6.5	6.5		3.8					4	15
F43	FA7	0.4			1.2	1.2		4.6	4.6		3.8					4.5	24.5
F44'	FA7	0.3			0.6	0.6		5.1	5.1		8.5					4	22.7
F45	FA7				0.7	0.7		4.2	4.2		6.0					5.6	15.0
F46'	FA7	0.7			1.8	1.8		14.9	14.9		8.3					24	59
F47'	FA8				1.7	1.7	0.5	8.5	6.7	3.9	4.9						
F48'	FA8	0.1	0.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							

Table 1. First-Year Ice Ridge Data

Ridge	Area				Snow Cover		Consolidation Layer			SA.	EL.	Strength of			Porosity			
	Sail	Keel Cons	Keel Total	Snow	Min	Max	Min	Max	Avg			Ice Sheet	Sail Avg	Keel Max	Sail	Keel	Avg	Max
	(m^2)	(m^2)	(m^2)	(m^2)	(m)	(m)	(m)	(m)	(m)	(ppt)	(MPa)	(MPa)	(MPa)	(MPa)	(%)	(%)	(%)	(%)
F20A'								1.5										
F20B'								2.0										
F21'								1.2		1.5 , 6.5								
F22'								1.5										
F23A'								1.2		3 , 6.5								
F23B'								1.8										
F24'								3.7										
F25A'								2.4		3 , 9								
F25B								1.2										
F26'								1.7										
F27'					0.03	0.61	0.8	6.7		5	1505.0	17.97		18.0				
F28'					0.03	0.46	1.3	5.1	2.93		722.3	17.28		20.7				
F29'							0.5	1.9	1.06	3.2 , 4.5	305.8			14.5				
F30'							1.4	2.7	1.78	0.9 ,4.5		16.59		18.7				
F31'							1.0	6.3	2.26	1 , 8.3		16.59		18.0				
F32'							1.0	6.7	2.56			13.82		16.6				
F33'							0.5	1.8	1.10			13.82		15.9				
F34'							0.9	2.1	1.39	4.1 ,7.1	320.0			20.0				
F35'							2.2	2.9	2.49		449.3	17.28		17.3				
F36'					0.01	0.01	0.0	4.6	2.53	3 , 7	988.4	19.35		19.4				
F37'							1.1	3.1	2.14	3 , 6.4		21.43		19.4				
F38'							4.2	4.2	4.19	0.9 , 4.5	194.9	13.13		15.2				
F39					0.01	0.03	1.7	4.4	3.33									
F40'																		
F41								1.0							31	30	30	
F42								1.0							14	23	23	
F43								0.5							17	28	27	
F44'							0.1	0.8	0.41						19	32	32	
F45								0.4							23	33	33	
F46'								0.8							9	28	28	
F47'							0.8	3.8	2.18						10			
F48'							1.1	3.7	2.18						20			

Table 1. First-Year Ice Ridge Data

Ridge	Source	LIT 1 (m)	LIT 2 (m)	WD (m)	Sail Height Max (m)	Sail Height CS (m)	Sail Height Avg (m)	Keel Depth Max (m)	Keel Depth CS (m)	Keel Depth Avg (m)	KSR	Sail Angle 1 (deg)	Sail Angle 2 (deg)	Keel Angle 1 (deg)	Keel Angle 2 (deg)	Sail Width (m)	Keel Width (m)
F49'	FA8				1.3	1.3	0.5	5.9	4.8	4.0	4.5						
F50'	FA8				0.8	0.8	0.3	5.6	4.8	3.0	7.1						
F51'	FA8				1.4	1.4	0.3	6.2	6.2	3.4	4.6						
F52'	FA9				0.6	0.6		4.7	4.7		7.9	31	30	38	27	2.0	16.5
F53'	FA9	0.4			1.7	1.7		8.4	8.4		4.8	35	38	64	37	5.0	12.9
F54'	FA9	0.4			1.0	1.0		7.5	7.5		7.7	26	14	8	64	6.0	42.7
F55'	FA9	0.4			0.9	0.9		3.5	3.5		4.1	19	16	21	24	5.3	15.0
F56'	FA9	0.4			1.6	1.6		12.3	12.3		7.7	8	12	45	38	10.5	22.0
F57'	FA9				1.2	1.2		4.6	4.6		3.8	26	32	17	25	5.0	27.0
F58'	FA9	0.4			0.6	0.6		5.1	5.1		8.6	17	17	27	12	4.0	24.0
F59'	FA9	0.3			0.7	0.7		4.3	4.3		6.6	9	12			6.0	
F60'	FA10				1.1	0.9	0.8	9.7	7.6	7.8	8.8						
F61'	FA10				2.0	1.6	1.5	2.8	9.2	8.2	1.4						
F62'	FA11			8.2*	5.0	5.0						32	39				38.1
F63'	FA11			24.4	4.7	3.9		17.2	15.6		3.7	27	25	17	19		
F64'	FA11			26.8	3.2	3.2		13.7	13.7		4.3	20	59	7	23		
F65'	FA11			14.9	3.1	3.1		11.0	11.0		3.6	23	39	13	22	12.2	
F66'	FA11				3.0	3.0		11.6	11.6		3.8	36	34	17	16	12.2	
F67'	FA11			11.0*	5.4	5.4		11.6	11.6		2.2	38	30	14	17		
F68'	FA11			5.5	2.0	2.0		4.6	4.6		2.3	23	41	13	13		
F69	FA11				4.6	4.6		15.8	15.8		3.5						
F70'	FA12	0.6			1.6	1.6	0.3	4.0	4.0	2.5	2.4					44.2	50.0
F71'	FA12				2.3	2.3	0.9	10.2	10.2	6.1	4.5					32.6	37.2
F72'	FA12	2.3	5.2		4.3	4.3	2.0	7.7	7.7	0.6	1.8					38.7	45.1
F73	FA13	0.6	0.4		1.1	1.1		4.4	4.4		4.0					7.6	9.1
F74	FA13	0.4	0.4		1.1	1.1		2.9	2.9		2.7					7.3	16.5
F75	FA13	0.3	0.5		0.6	0.6		1.8	1.8		3.0					3.0	10.7
F76	FA13	0.9	0.5		1.4	1.4		4.3	4.3		3.1					9.8	22.9
F77	FA13	1.6	0.5		1.7	1.7		9.8	9.8		5.6					15.2	19.8
F78	FA13	0.8	0.4		1.7	1.7		7.3	7.3		4.2					29.6	48.2
F79	FA13	0.8	1.2		0.4	0.4		2.1	2.1		5.7					1.8	10.4

F77	FA13	1.6	0.5		1.7	1.7		9.8	9.8		5.6					15.2	19.8
F78	FA13	0.8	0.4		1.7	1.7		7.3	7.3		4.2					29.6	48.2
F79	FA13	0.8	1.2		0.4	0.4		2.1	2.1		5.7					1.8	10.4
F80	FA13	0.9	0.7		1.2	1.2		3.4	3.4		2.8					4.6	15.2

Table 1. First-Year Ice Ridge Data

Ridge	Area				Snow Cover		Consolidation Layer			SA.	EL.	Strength of			Porosity			
	Sail	Keel		Snow	Min	Max	Min	Max	Avg			Ice Sheet	Sail Avg	Keel Max	Sail	Keel	Avg	Max
		Cons	Total															
	(m^2)	(m^2)	(m^2)	(m^2)	(m)	(m)	(m)	(m)	(m)	(ppt)	(MPa)	(MPa)	(MPa)	(MPa)	(%)	(%)	(%)	(%)
F49'					0.00	0.47	0.1	3.5	2.39						20			
F50'					0.10	0.10	0.3	2.8	1.75	1.03								
F51'					0.00	0.19	0.0	4.0										
F52															5	22	20	
F53'															41	37	38	
F54'															20	34	33	
F55'															20	29	29	
F56'															13	24	23	
F57'															17	28	27	
F58'															19	32	32	
F59'															23	33	33	
F60'													5.9	3.9			35	31
F61'												6.70	7.7	4.0			38	33
F62'																		
F63'																	30	
F64'																		
F65'								0.6										
F66'								4.6									30	
F67'																		
F68'																		
F69																		
F70'	9	56	105	4				2.2	1.31									
F72'	50		227	3														
F71'	16		153	2				5.5										
F73	9	20					2.6	2.6										
F74	8	16	23				2.9	2.9										
F75	3	8	10				1.2	1.2										
F76	9	29	48				2.9	2.9										
F77	18	62					5.7	5.7										
F78	41	223																
F79	3	11					2.1	2.1										
F80	4	13	32				1.5	1.5										

Table 1. First-Year Ice Ridge Data

Ridge	Source	LIT		WD	Sail Height			Keel Depth			KSR	Sail Angle		Keel Angle		Sail Width	Keel Width
		1	2		Max	CS	Avg	Max	CS	Avg		1	2	1	2		
		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)		(deg)		(deg)		(m)	(m)
F81	FA13	1.1	0.8		0.7	0.7		2.3	2.3		3.4					7.6	21.3
F82	FA13	0.4	0.5		0.5	0.5		1.5	1.5		2.9					6.4	12.5
F84	FA13	0.6	0.6		1.0	1.0		3.3	3.3		3.3					6.1	16.8
F85	FA13	2.1	2.3		1.4	1.4		5.0	5.0		3.6					2.4	
F86	FA13	1.1	0.5		0.9	0.9		1.9	1.9		2.1					6.1	7.6
F87	FA13	0.4	0.4		1.0	1.0		2.9	2.9		3.0						
F88	FA13	1.1	1.1		1.4	1.4										9.1	
F89	FA13	0.4	0.5		0.8	0.8		2.4	2.4		3.2					8.2	12.5
F90	FA13	0.8	0.7		1.9	1.9		3.4	3.4		1.7					11.3	35.1
F91	FA13	1.3	0.8		1.7	1.7		4.2	4.2		2.5					8.8	24.4
F92	FA13	1.0	0.9		0.8	0.8		3.0	3.0		3.8					4.3	19.2
F93	FA13	0.5	0.8		0.4	0.4		3.2	3.2		7.5					6.4	12.5
F94	FA13	0.5	1.0		1.0	1.0		4.6	4.6		4.7					7.6	23.2
F95	FA13	0.5	0.7		1.4	1.4		3.5	3.5		2.5					7.9	20.4
F96	FA13	1.1	1.1		1.1	1.1										7.3	18.3
F97	FA13	1.1	1.1		0.9	0.9										3.7	14.0
F98	FA13	0.4	0.4		1.0	1.0		2.7	2.7		2.8						
F99	FA13	0.7	0.4		2.2	2.2		7.0	7.0		3.2					10.1	25.9
F100	FA13				1.9	1.9		6.2	6.2		3.3					8.2	
F101	FA13	0.4	0.6		1.7	1.7		5.2	5.2		3.0					7.9	18.6
F102	FA13	0.6	0.4		1.9	1.9		5.3	5.3		2.8					7.3	22.6
F103	FA13	0.8	0.8		1.7	1.7		5.3	5.3		3.1					5.8	
F104	FA13	0.5	0.8		0.5	0.5		0.9	0.9		1.8					4.3	10.7
F105	FA13	0.9	0.9		0.6	0.6		2.4	2.4		4.0					3.0	10.4
F106	FA13	0.6	0.6		0.9	0.9		3.7	3.7		4.0					6.1	21.0
F107	FA13	1.4	0.4		0.7	0.7		2.7	2.7		4.1					6.4	19.8
F108	FA13	0.6	0.3		0.7	0.7		2.2	2.2		3.2					4.3	19.2
F109	FA13	0.6	0.4		1.8	1.8		3.4	3.4		1.8					2.7	18.3
F110	FA13	0.3	0.6		0.5	0.5		2.4	2.4		5.3					3.0	12.8
F111	FA13	0.9	0.9		0.9	0.9		3.4	3.4		3.7					3.0	
F112	FA13	0.8	0.6		0.7	0.7		2.1	2.1		3.0					4.3	19.2

Table 1. First-Year Ice Ridge Data

Ridge	Area				Snow Cover		Consolidation Layer			SA.	EL.	Strength of			Porosity			
	Sail	Keel Cons	Keel Total	Snow	Min	Max	Min	Max	Avg			Ice Sheet	Sail Avg	Keel Max	Sail	Keel	Avg	Max
	(m^2)	(m^2)	(m^2)	(m^2)	(m)	(m)	(m)	(m)	(m)	(ppt)	(MPa)	(MPa)	(MPa)	(MPa)	(%)	(%)	(%)	(%)
F81	6	27					2.3	2.3										
F82	4	14					1.5	1.5										
F84	8	19	30				1.6	1.6										
F85	9	54	178				3.8	3.8										
F86	3	14					1.9	1.9										
F87							1.3	1.3										
F88							3.4	3.4										
F89			11				0.9	0.9										
F90	53	43	80				2.9	2.9										
F91	15	40	59				4.2	4.2										
F92	5	19	30				1.5	1.5										
F93	1	10	20				3.2	3.2										
F94	12	21	38				1.7	1.7										
F95	7	30	41				2.7	2.7										
F96	9	17					1.9	1.9										
F97	9	22					1.2	1.2										
F98							0.8	0.8										
F99			96									0.22						
F100			92															
F101			53															
F102	11	18	66				1.5	1.5										
F103			79															
F104	2	7	9				0.9	0.9										
F105	2	8	13				0.9	0.9										
F106	5	14	51				1.1	1.1										
F107	4	21	34				1.5	1.5				0.39						
F108	4	11	27				0.9	0.9										
F109	7	14	37				2.1	2.1										
F110	5	8	17				1.5	1.5										
F111	4	20	53				1.3	1.3										
F112	3	15	16				1.6	1.6										

4.2 Multi-Year Ice Ridge Data

For multi year ridges, much of the information listed in Table 1 was not measured during field operations. For example, there was no data on the keel angle, and sail width. The following multi-year information is given in Table 2:

RIDGE - A symbol to identify each ridge (ex. M1). If the symbol is followed by ' then the ridge has a cross-sectional profile in Appendix B.

SOURCE - A coded symbol to represent the ridge's reference source (see Section 3.2).

RL - The length of the ridge.

LIT - The level ice thickness on both sides of the ridge.

WD - The water depth at the ridge. If it is followed by * then the ridge is grounded.

SAIL HEIGHT (H_s) -

- MAX. - The maximum sail height at any point on the ridge.
- CS. - The maximum sail height along a ridge cross-section.
- AVG. - The average sail height along a ridge cross-section.

KEEL DEPTH (H_k)

- MAX. - The maximum keel depth at any point on the ridge.
- CS. - The maximum keel depth along a ridge cross-section.
- AVG. - The average keel depth along a ridge cross-section.

KSR -	The ratio of maximum keel depth to maximum sail height.
SAIL ANGLE (α_s) -	The angle of incline for each side of the sail.
KW MAX. (W_k) -	The maximum width of the keel.
AREA -	
SAIL (A_s) -	The measured cross-sectional area of the sail.
KEEL (A_k) -	The measured cross-sectional area of the entire keel.
CONS. DEPTH -	The maximum depth to the bottom of the consolidated zone.
SA. -	The measured salinity of the ridge. If two values are given, they represent the maximum and minimum.
EL. -	The measured elasticity of the ridge.

ble 2. Multi-Year Ice Ridge Data

idge	Source	RL	LIT		WD	Sail Height			Keel Depth			KSR		Sail Angle		Keel Width		Area		Cons. Depth	SA.	EL.
			1	2		Max	CS	Avg	Max	CS	Avg	Max	Width	1	2	Max	Avg	Sail	Keel			
			(m)		(m)	(m)			(m)					(deg)		(m)		(m^2)		(m)	(ppt)	(MPa)
M43A	MA9					5.0	5.0		27.0	27.0		5.4									1.7	
M43B	MA9						3.5			22.5											1.7	
M44	MA10					2.5	2.5		9.3	9.3		3.7		20	20							
M45	MA10					3.1	3.1		11.1	11.1		3.6		19	19							
M46	MA10					2.4	2.4		9.6	9.6		4.0										
M47	MA10					3.2	3.2		10.8	10.8		3.4										
M48'	MA10					1.8	1.8		6.7	6.7		3.7		22	13							
M49'	MA10					3.4	3.4		9.8	9.8		2.9		25	19							
M50	MA10					4.1	4.1		12.2	12.2		3.0		24								
M51'	MA10					4.1	4.1		8.7	8.7		2.1		24	28							
M52'	MA10					2.0	2.0		5.8	5.8		2.9		8	10							
M53'	MA10					2.8	2.8		8.5	8.5		3.0		24	31							
M54	MA10					3.0	3.0		8.5	8.5		2.8										
M55	MA11		1.2	3.4		1.9		0.8	15.5		9.4	8.1				78.9	65.5	51	618	12.2		
M56'	MA11		1.9	3.0		2.4		0.6	6.7		4.3	2.8				49.4	40.8	26	177	6.4		
M57	MA11		2.7	2.7		2.5		1.4	7.4		4.9	3.0										
M58	MA11		6.1	6.1		3.4		1.4	8.0		7.3	2.4				40.8	33.8			8.9		
M59'	MA11		4.0	5.9		2.0		0.6	6.6		5.4	3.3				51.8	47.9	32	259	6.8		
M60'	MA11		2.4	3.2		1.5		0.9	5.9		4.9	4.0				35.1	27.4	26	134			
M61'	MA11		4.4	4.4		1.8		0.6	6.0		5.3	3.4				38.7	35.7	21	189	4.9		
M62'	MA11		4.2	4.2		2.2		1.3	9.7		7.5	4.4				35.7	24.4	33	183			
M63'	MA11		6.1	6.1		4.5		1.1	13.1		9.3	2.9				36.0	28.6	31	265	7.7		
M64	MA11		1.8	1.8		3.2		0.9	12.7		9.1	4.0				43.0	39.3	33	359	9.6		

Table 2. Multi-Year Ice Ridge Data

Ridge	Source	RL	LIT		WD	Sail Height			Keel Depth			KSR		Sail Angle		Keel Width		Area		Cons. Depth	SA.	EL.
			1	2		Max	CS	Avg	Max	CS	Avg	Max	Width	1	2	Max	Avg	Sail	Keel			
			(m)		(m)	(m)			(m)					(deg)		(m)		(m^2)		(m)	(ppt)	(MPa)
M1'	MA1		2.4	5.2	11.6	3.7	3.7		8.3	8.3		2.2									0, 8	
M2'	MA1				12.2	2.3	2.3		7.9	7.9		3.4									0, 5	
M3'	MA1				13.4*	5.3	5.3															
M4'	MA1				13.4	3.4	3.4		12.8	12.8		3.8		34	32							
M5'	MA2	250	2.3	2.3	42.7	10.6	10.6		31.1	31.1		2.9		27	26							
M6'	MA2		1.2	1.2	37.6	8.0	6.6		24.4	24.4		3.0		22	22							
M7'	MA2					5.8	4.5		19.2	19.2		3.3		20	20							
M8'	MA2		1.5	1.5		3.9	3.9		11.6	11.6		2.9		27	29							
M9'	MA2				39.6	6.0	6.0		17.4	17.4		2.9		27	20							
M10'	MA2		1.5	1.5		5.7	5.7		18.3	18.3		3.2		22	22							
M11'	MA2	122				6.4	6.4		19.5	19.5		3.0		30	15							
M12'	MA2					2.9	2.9		10.4	10.4		3.6		17	18							
M13'	MA2	61				6.3	6.3		23.2	23.2		3.7		17	19							
M14'	MA2	69				2.3	2.3		7.3	7.3		3.2		20	13							
M15A'	MA2	500					4.1			13.7				18	15							
M15B'	MA2	500				5.7	5.7		21.9	21.9		3.9		14	26							
M16	MA2					5.4	5.4		18.6	18.6		3.4										
M17	MA2	35				8.5	8.5		25.6	25.6		3.0										
M18	MA2				18.3*	12.5	12.5															
M19	MA2	38			22.6*	8.8	8.8															
M20	MA2	69			14.0*	12.5	12.5															
M21A'	MA3	91				3.6	3.6		12.5	12.5		3.5	4.4	23	16							
M21B'	MA3	91					1.7			7.6			3.4	4	3						0.7	1984
M21C'	MA3	91					2.5			11.3			2.9	15	13							
M22'	MA3	46				3.5	3.2		9.8	9.8		2.8	3.8	21	22						0.6	1864
M23'	MA3	46				3.2	3.2		12.2	12.2		3.8	3.3	27	23						1.5	6745
M24	MA4					0.9	0.9		2.9	2.9		3.3		11	11							

M23'	MA3	46				3.2	3.2		12.2	12.2		3.8	3.3	27	23						1.5	6745
M24	MA4					0.9	0.9		2.9	2.9		3.3		11	11							

Table 2. Multi-Year Ice Ridge Data

Ridge	Source	RL	LIT (m)		WD (m)	Sail Height (m)			Keel Depth (m)			KSR		Sail Angle (deg)		Keel Width (m)		Area (m^2)		Cons. Depth (m)	SA. (ppt)	EL. (MPa)
			1	2		Max	CS	Avg	Max	CS	Avg	Max	Width	1	2	Max	Avg	Sail	Keel			
M25	MA5					1.3	1.3		3.9	3.9		3.0										
M26	MA5					2.7	2.7		8.5	8.5		3.1										
M27	MA5					3.0	3.0		8.5	8.5		2.8										
M28A'	MA6						3.9			12.0				16	19							
M28B'	MA6					3.9	3.9		13.1	13.1		3.4		20	18							
M28C'	MA6						3.3			11.0				13	28							
M29	MA7				14.3*	4.3	4.3							28	41							
M30	MA8					2.4	2.4		8.5	8.5		3.6		2	2							
M31	MA8					2.7	2.7		8.3	8.3		3.1		2	2							
M32	MA9					4.8	4.8		26.0	26.0		5.4									1.7	
M33	MA9					3.7	3.7		26.0	26.0		7.0									1.7	
M34	MA9					2.6	2.6		15.0	15.0		5.8									1.7	
M35	MA9					4.0	4.0		9.5	9.5		2.4									1.7	
M36	MA9					2.8	2.8		6.5	6.5		2.3									1.7	
M37	MA9					3.3	3.3		12.5	12.5		3.8									1.7	
M38A	MA9					5.9	5.9		31.0	27.0		5.3									1.7	
M38B	MA9						3.2			31.0											1.7	
M39A	MA9					2.6	2.6		14.5	14.5		5.6									1.7	
M39B	MA9						2.3			8.0											1.7	
M39C	MA9						2.6			13.0											1.7	
M40	MA9					4.5	4.5		16.0	16.0		3.6									1.7	
M41A	MA9					5.5	5.5		22.5	22.5		4.1									1.7	
M41B	MA9						3.3			14.0											1.7	
M42A'	MA9						5.3			22.0				24	16						1.7	
M42B'	MA9					6.4	6.4		37.0	37.0		5.8		19	29						1.7	
M42C	MA9						3.0			32.0				6	44						1.7	
M42D'	MA9						3.7			31.8				11	18						1.7	