SESSION ON PERFORMANCE IN ICE-COVERED WATERS

Chairman: Mr. D.C. Murdey

Performance in Ice-Covered Waters Committee Memberships: J.C. Tatinclaux (Chairman) - S. Narita (Secretary) - V.A. Beljashov - R. Ettema - J.H. Hellmann - S.J. Jones - V. Kostilainen - V. Likhomanov - K. Takekuma.

Discussion of the Report and the Draft Recommendations of the Report of the Performance in Ice-Covered Waters Committee (cf. Proceedings, Volume 1, pp.525-575)

I. DISCUSSIONS

N. Bose - Memorial University of Newfoundland, St. Johns, Newfoundland, Canada.

This discussion is mainly concerned with two sections of the report: 1. Comparative test program with R-class model; and 5. Model propulsion tests in ice.

Figure 1.1 shows plots of regression analyses of resistance results for an R-class model tested at different laboratories. Some of the symbols used on the plots are not clearly defined and it would be useful to know what these are. The measured resistance of the roughened model from Lab. 2 is almost 50% higher than that from the other laboratories; for the smooth model the results from this source are less than from other laboratories. Is there a reason for this?

A plot of the actual data points, as well as the regression lines, would indicate whether the differences between the curves are significant or whether all curves lie within the scatter from the experiments. The report states that most test results lie within + or - 25% of the overall average, but as stated, test conditions are difficult to repeat exactly and the time and cost involved in making ice sheets reduces the amount of tests that can be done. The regression line for each test may be significantly influenced by scatter from a small number of runs. Therefore, all lines are probably valid, and the nature of these tests means that, at present, model icebreaker resistance cannot be measured to an accuracy greater than, say, about + or - 25%. On the other hand, if it was known that a certain type of model ice, or test technique, always gave lower or higher readings than other types, then this would also be a useful conclusion; does the original data exhibit any of these trends?

The regression lines show finite resistance at zero Froude number. What was the lowest speed actually tested and what is the true shape of the curves as speed is reduced? Is the extrapolation to zero speed justified; does it indicate a component of resistance?

On Figure 1.2, the lines shown are not fully explained. The solid lines look like the regression curves for the data, but a dotted line is also shown in one of the plots; could these be clarified? The data are compared with the propeller characteristics in open water and I think that it would be useful to show the open-water characteristics as lines on these plots. The results seem to show that at zero advance coefficient thrust and torque coefficient are close to their open water values, but that as advance coefficient increases, the torque coefficient does not reduce as it would in open water; is this so?

Although the thrust coefficient against advance coefficient relationship is similar to that in open water and may be similar to the full-scale propeller, the actual operating advance coefficient may be different between model and ship. Levels of thrust from the model propellers may mean a different operating thrust coefficient at a corresponding speed from those required of the full-scale propellers. In many conventional open-water, self-propulsion tests, some of the model resistance is off loaded from the model propeller to allow for the larger proportion of frictional resistance to total resistance on the model than on the full-scale ship. For tests in ice, fluid friction is a much smaller component of the total resistance, but are there any justifications for doing self-propulsion tests at propeller loadings other than those required to obtain a balance between net propeller thrust and total resistance?

Finally, in Figure 1.3 the method for the full-scale extrapolations shown has not been explained. What method was used and how would different methods affect conclusions drawn from the comparisons with full-scale data?

H. Kitagawa - Ship Research Institute, Tokyo, Japan

The committee is to be congratulated for the valuable contribution to the development of ice tank technologies in adverse circumstances.

As for the comparative testings with the R-class model, the report has suggested the likely causes of the discrepancies in ice resistance between the facilities. The committee should make redoubled efforts, however, to clarify their definite effects on ice resistance, which will be fulfilled through active and well-planned cooperative studies between the ice tanks. Effect of length of averaging, for instance, has been once discussed and was found to be serious on ship models with parallel body if the averaging length is shorter than twice the model length[1]. Another example is on the ice ingestion effect on thrust of a propeller. Ice-propeller interaction has surely various scenarios, and although it will not often occur, ice ingestion by the propeller disks affects markedly the propeller thrust. Such a mode of interaction can be recognized by analyzing the fluctuations of thrust and torque of a propeller[2].

Clear understanding of mechanism of ice friction is undoubtedly important both in model and full scale. Model ice, in particular, of columnar structure, is generally much more fragile than real ice. The model ice has quite an amount of brine which rapidly flows down onto the sliding surface in case of plank experiments, and the weak bottom layer of model ice is easily crushed even under usual normal loads. The committee will be then requested to pursue a particular study of model ice friction.

We do not have suitable model ice which will satisfy the scaled-down mechanical properties. The committee will be naturally expected to play an important role in finding more reasonable model ice to make every possible effort to write out an effective scenario.

Standardizations of model test and analysis procedures will be strongly demanded as the committee states in the report. Standardizations require tremendous substantial data of high reliability. The committee, we are afraid, however, has been lacking satisfactory data. The committee should first make a reasonable proposal to perform systematic and determine cooperative studies between the facilities to accumulate necessary data and information to standardize the tests and analyses at the ice tanks.

[1] H. Kitagawa et al, "Some model experiments on ship performance in ice," Autumn Meeting of the Ship Research Institute, No. 38, 1981.

[2] H. Kitagawa et al, "A study on ship performance in ice-covered waters (1st Report)," Autumn Meeting of the SRI, No. 40, 1982.

S. T. Mathews - Coldstream Maritime Inc., Ottawa, Ontario, Canada

I have read the report with a great deal of interest and find the facts presented indisputable. For the most part I am in agreement with the comments. The comment in the Concluding Reports that: "The current state of the art in ship model propulsion testing leaves much to be desired." is unfortunately only too true. It should be emphasized here that the reference is to propulsion in ice. The follow-on statement regarding 'good correlation with full scale measurements only when there is minor propeller/ice interaction at both model and full scales' needs a great deal of qualification. This may well be a requirement for good correlation but I have yet to see any good model/ship correlation. In my experience on the evidence of the data examined "much to be desired" is still the state of the art situation.

I am in full agreement that the state of the art in ice resistance testing has reached a satisfactory level for useful research and design investigation purposes. The work of the committee to further improve this situation and to gain a better understanding of the mechanisms involved is to be commended.

I am enclosing a copy (extracted from a more comprehensive report) of analyses carried out with model R Class data (low friction level) as reported in the ITTC Proceedings. I would particularly like to call the committee's attention to the method of plotting ice resistance data. This is associated with a Law of Comparison for the Dynamic Similarity of Ship's Ice Resistance which I developed some eight years ago. The work has been summarized in various reports but has not been generally published. The use of the LOC allows for the correction from <u>model</u> ice Modulus of Elasticity (E) values to <u>full scale</u> values. In my findings it is the otherwise lack of such a correction capability that does not currently allow the profession to make useful full scale ice resistance predictions. I should like to add here that some major ice tanks do not present their E values as was agreed in early days of the Ice Committee. This is a terrible pity since I have not been able to use so much otherwise valuable data.

I realize that there probably is not time for the present committee to study and reply to all the various aspects of the enclosed analyses. I would however be happy to correspond, on a continuing basis, with the Ice Committee and its individual members.

The high quality work of the committee is much appreciated.

R. Abdelnour - Fleet Technology, Ltd., Kanata, Ontario, Canada

Ice Density and Propulsion Performance

Correct scaling of density is very important. This did not receive enough emphasis by the ITTC.

Propulsion performance tests of icebreaking vessels in ice depend significantly on the trajectory of the broken ice pieces moving along the ship's hull. Denser model ice is expected to be less likely to surface than a lighter ice during its passage from the bow to the stern.

Recent tests carried out for the National Research Council at Fleet Technology lab in Calgary using MOD-ICE, demonstrated clearly that the number of broken ice pieces that reached the propeller was influenced significantly by the ice density. During the tests the density was varied between 0.80 and 0.90. The work was published by S. Jones et al [1].

As per your concluding remarks, section 1.4, page 6, the above confirms the statement made about the appearance of greater ice propeller interaction at model scale than at full scale.

A review of the scaling laws regarding the effect of ice density was published by Abdelnour et al [2]. It was concluded that in order to simulate in laboratory the sea ice density (0.90) and the sea water density (1.02), the model ice density should be 0.88 (the water density in the lab is assumed to be close to 1.00). Considering that the average refrigerated model ice density is 0.94, an error of 100% in simulating the buoyancy force could be made.

The results of model tests and full scale tests of the Kulluk floating offshore structure was presented in the same paper. A comparison of the model scale results obtained from two modelling materials, MOD-ICE and Urea ice, with full scale results was made. The forces obtained in Urea ice was significantly lower than the one measured on the prototype. However, the results obtained in MOD-ICE were along the same order of magnitude of the full scale results.

Attempts to produce new model ices that correctly simulate the ice properties including the ice density are progressing. Beside the IMD attempt to introduce air within the crystallographic structure of the ice, synthetic model ices such as the SYG Ice, Beltaos et al [3] and the BEADS-ICE, Abdelnour et al [4], are also available.

I would like to note the inconsistency of two statements made in page 5, section 1.3.b. In the first paragraph it says "The model propulsion test results of all facilities showed that the propeller thrust coefficient in level ice was practically the same as in ice free water." and in the last paragraph "Overall, the thrust deduction factor in level ice was found to be approximately constant equal to 0.18 +/- 0.07, rather than increasing with ship speed as in clear water."

Comparative Tests with Basic Offshore Structure Model

I have reviewed the results of the tests carried out by towing a standard cylinder through level ice. The test is an excellent idea and I hope it will be as successful as the R-Class model tests. I suggest that the standard cylinder be circulated to other model testing facilities for testing. Fleet technology would accept testing the cylinder in both MOD-ICE and Beads-Ice.

To make these test results more useful, I suggest to carefully document the model of failure of the model ice for future comparison of the resulting forces and associated failure modes with full scale observations. Modeling ice/structure interaction is a relatively complex test to perform due to the lack of information on how the ice fails in nature. However, recent full scale observations from ice interaction events in the Canadian Arctic and the Baltic Sea provided useful visual records that may assist in better understanding the mode of ice failure. A major project is being carried out by the Canadian Government to develop a numerical model for ice interaction with offshore structures. These reports (under five contracts) will be available in November 1990. Other experimental and analytical studies related to the mode of ice failure are progressing at the University of Helsinki.

It is essential to closely look at the outcome of these studies to come up with a reliable method to simulate the ice failure modes including flaking, fracturing, buckling, bending and crushing to obtain results that agrees with the overall behavior of the ice in full scale.

Specific comments:

Section 3.3.2, "cantilever beam crushing tests": Unless the is low (about 1 to 1.5), it is very unlikely that the model ice would break by crushing. Because the ice is relatively thin, buckling failure would occur before crushing unless the ice fails by shearing or splitting (see last comment).

Section 3.3.3, "4 cm indentor tests": It was noted that the method of testing by towing a 4-cm cylindrical indentor through the ice seemed to be termed as "unreliable" test unless "assurance of no buckling" is provided. My concern here, that if a 4 cm indentor is causing the ice to buckle, what would be the mode of failure when a much wider indentor (215 mm diameter) is towed through the same ice sheet?

From past experience and literature, it is well established that ice crushing failure mode will increase along the ice/structure contact while buckling failure mode will decrease when the ratio of the indentor width to the ice thickness decreases. This presumes that the mode of ice failure observed during the tests with the 215 mm wide indentor should have been mostly by buckling since it was for the 4 cm cylindrical indentor. However, based on the description of the ice failure during the tests with the 215 mm cylinder, buckling failure was not the dominant mode of failure with the 215 mm cylinder. This again brings the importance of stressing the careful documentation and description of the mode of ice failure during model tests.

Section 3.4, "ratio of ice strength": The value of the ratio obtained from each facility seems well within the expected level but one. HSVA ratio should have a value in the same order of magnitude as SRIJ and MHI. However, as mentioned in their report, the HSVA ice failed by splitting and shear rather than crushing. These results reinforce the need to question the validity of this crushing test and come up with a more reliable method to obtain the crushing strength.

Section 3.5.1, "test results": The results reported by NKK and SRIJ (as reported at the end of the section) show that in thinner ice (25 mm thick) simultaneous buckling failure was frequently observed, while NKK reported crushing as almost the only mode of failure in all cases.

A theoretical 2D formula that calculates the buckling force (static force) of an ice sheet interaction with a vertical wall showed that an ice sheet with a ratio σ_c/σ_f of about 3 will fail by buckling rather than crushing for a 50 mm ice sheet thickness. A 25 mm thick ice sheet will also fail by buckling if σ_c/σ_f is about 1. Therefore, for all three model ices used by SRIJ, MHI and HSVA, a 25 mm thick ice sheet should fail by buckling (at relatively low speed, close to 0.5 knots full scale. Assuming these experiments are being conducted at a scale of 1:20, buckling failure would never occur and crushing will be the prevailing mode of failure. This is a serious modeling problem where considerable effort must be allocated to find an acceptable solution.

References:

[1] S. J. Jones, K. C. Hardiman, R. Ritch and R. Abdelnour, "The Effect of Density of the Trajectory on Ice Pieces Around a Ship's Hull." IAHR Ice Symposium 1990, Espoo, Finland.

[2] R. Abdelnour, G. Comfort, R. Pilkington and B. D. Wright, "Ice Forces on Offshore Structures; Model and Full Scale Comparison and Future Improvement" Ocean 87 Halifax, 1987.

[3] S. Beltaos, J. Wong, W. J. Moody, "A Model Material for River Ice Breakup Studies." IAHR Ice Symposium 1990, Espoo, Finland.

[4] R. Abdelnour, G. Comfort and H. El-Tahan, "Recent Development in Modelling of Offshore Structures and Vessels in Ice Covered Waters." ISCORD 88, International Conference on Cold Region, Harbin, China August 1988.

Per Aren - KaMewa Marine Laboratory, Sweden

A recommendation is given on scanning frequency while measuring rpm and propeller forces. The objective with the recommendation is to "obtain a sufficiently detailed picture of ice/propeller interaction." While testing propellers operating in ice conditions it is of utmost importance to record dynamic loads. In order to measure these dynamic loads a much higher sampling frequency than recommended is required.

M. Schmiechen - VWS, Berlin Model Basin, Berlin, Germany

The uncertainty in the determination of the thrust deduction fraction mentioned can be completely avoided, if the method developed by the present discusser is applied. As explained earlier during the conference the systems identification method proposed is based on only consistent data sets derived from propulsion tests alone, i.e., requiring no extra resistance tests, and can be applied on full scale as well as model scale. The results shown in the report of the committees confirm the findings of the present discusser from full and model scale tests with the research vessel METEOR.

II. REPLY BY THE PERFORMANCE IN ICE-COVERED WATERS COMMITTEE

The committee greatly appreciates the interest shown by the discussers. **Dr. Bose** should find the answers to most of his questions in the paper [ref. 3] presented at the 1989 Annual Meeting of the Society of Naval Architects and Marine Engineers and recently published in Vol. 97 of the SNAME Transaction, p. 31-52. Because of this previous publication of the results, the section of the committee report on the R-class cooperative test program was purposely brief, possibly too brief, to leave a maximum space for the other topics of the report.

Because of scatter in the actual resistance test data, both at each facility and between facilities, Dr. Bose's comment that all regression lines, except one, in Figure 1.1a,b are probably valid is indeed true. Lab 2 changed the type and manufacturing process of its model ice between the tests with the smooth model and those with the roughened one. This may at least partially explain that its regression line in Figure 1.1b differs significantly from the other lines.

The ice resistance at zero speed is actually undefined. But its limit as V or F_n goes to 0_+ is non-zero, for even at creeping speed ice deflection and eventually ice breaking take place.

Regarding Figure 1.2a, the dashed line in the plot of K_q vs J_v represents the regression equation through Lab 4 data which were obtained from tests in presawn ice rather than level ice. Also, the propeller characteristics in level ice are compared with those in ice-free water in the figure below which is reproduced from the aforementioned SNAME paper.

As in model tests in ice-free water, overload propulsion tests in level ice are performed to determine the variations of K_t and K_q with J_v. However, the differences in frictional or viscous resistance coefficients, C_F or C_V, between model scale and full scale are usually neglected in ice tests.

Finally, the full-scale extrapolations shown in Figure 1.3 of the committee report were calculated by the standard thrust identify method (without any corrections for wake fraction or otherwise) on the basis of the regression resistance equations from the resistance test data at all laboratories (except Lab 2 for the roughened model) and using the model propulsion characteristics (K_t, K_q and

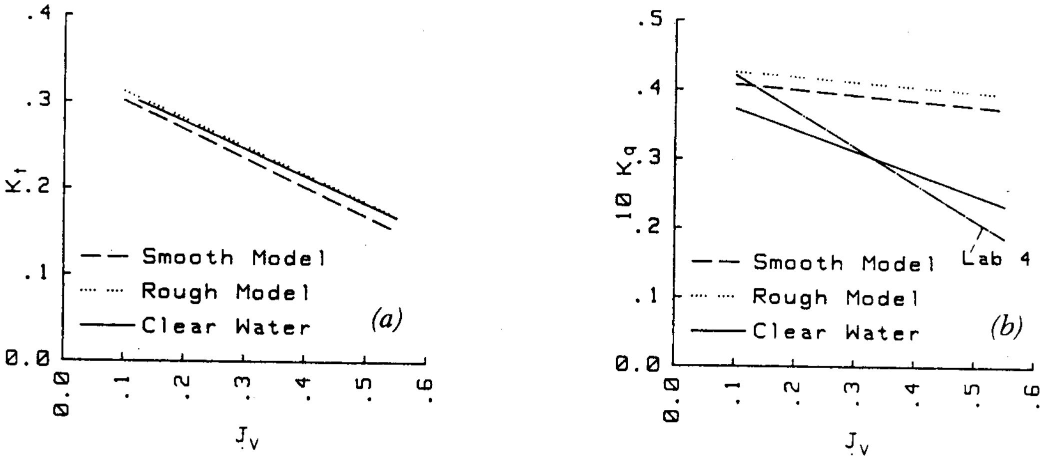

Fig. 1: Comparison between propulsion test results with smooth and roughened models (a) thrust coefficient; (b) torque coefficient (Ref. 3 in Committee report)

t) measured in either ice-free tests or level ice tests.

We thank **Dr. Kitagawa** for his contribution in which he points out a number of areas for possible future work.

The committee agrees that a resistance value must be averaged over a sufficient length of ice sheet to be representative, but does not agree that it is always necessary to use "twice the model length" as a criterion. This averaging length may vary with the hull form, and sometimes one to one and a half model lengths is sufficient, especially for the new bow shapes which include reamers.

Also, the committee cannot entirely agree with Dr. Kitagawa's statement "ice ingestion by the propeller disks affects markedly the propeller thrust." We believe that under realistic conditions of operation, ice ingestion by the propeller disks has little effect on the mean thrust (at least for unducted propellers), but a significant effect on mean torque. However, the peak values of thrust and its time record are clearly affected.

The committee agrees that ice friction is still important to understand both in model and full scale. The committee report does point out some interesting work in progress [refs. 17 and 21] on friction of ice during crushing. The committee is aware of the problems of brine drainage in relatively weak model ice and, therefore has recommended in previous ITTC reports that friction testing be done with a wet plate, and with the ice top surface in contact with the friction board.

The search for improved model ices, which correctly model all full-scale mechanical properties, is an on-going one, and the committee is well aware that the perfect model ice does not exist. In the past, improvements have been made by individual tanks, which have later become of widespread use. The committee believes that this will continue and encourages the publication of such improvements.

The committee does agree that some standardization of model tests in ice is important and refers to paragraph 2.1 of its "Recommendations for future work." The recent co-operative work with the R-class model and the on-going one with the basic offshore cylindrical structure are a step in this direction.

Mr. Mathews was the founding father and the first chairman of the ITTC Ice Committee. The current committee deeply appreciates his kind words and welcomes his contribution. The committee has not had sufficient time to study the summary of Mr. Mathews' proposed method of plotting ice resistance data but will certainly do so. The committee also welcomes further communications with Mr. Mathews on this particular topic, and would like to take this opportunity to urge him to publish a detailed account of his method in the open literature.

The committee agrees in general with **Dr. Abdelnour's** comments on the importance of ice density on the trajectory of submerged ice floes, their interaction with the propellers and, consequently, their effect on model propulsion test results. The committee welcomes the development of model ices that better model the ice density without sacrificing the critical ice properties. Since the propulsion coefficients at both model and full scale are likely to be affected by other parameters such as ice floe size and ice resistance to fracture, elastic modulus, fracture toughness, crystal size are ice characteristics that, ideally, should also be correctly modeled. However, it is unlikely that a model ice will ever be developed that will model all ice properties accurately. Therefore, methods of correcting model test results as well as estimating the confidence level of test data need to be developed. These areas of research are indeed to be addressed in the immediate future by the committee. Contrary to Dr. Abdelnour's comment, the fact that the thrust deduction factor from model tests in ice is approximately constant is not necessarily inconsistent with a thrust coefficient nearly equal to that in ice-free water. The thrust deduction factor is the <u>small</u> relative difference between two large measured quantities, the delivered thrust and the total resistance in ice. These two quantities are measured in separate tests. While the accuracy in the thrust measurement is usually quite good, the uncertainty in the ice resistance can be significant. It is therefore not entirely surprising that the resulting uncertainty in the thrust deduction factor overwhelms its variation with the advance coefficient.

In reply to the comments by Dr. Abdelnour on the comparative tests with a basic model offshore structure, the following can be said:

1. The committee welcomes the offer by Fleet Technology Ltd. to participate in this comparative test program.

2. The test program specifically requires careful and detailed documentation of the mode of ice failure during the tests.

3. The indentor is an attempt at measuring an index of the ice crushing strength in a quick but reliable and consistent manner. Should the ice fail in buckling ahead of the indentor, then the data would be disregarded.

The committee wishes to emphasize that it is nowhere stated in this report that the ice failed in crushing ahead of the large-cylinder while failing in buckling ahead of the indentor, as Dr. Abdelnour appears to have inferred.

4. The short cantilever beam method to measure ice crushing was also applied for comparison with the indentor technique. The test program is yet to be completed at all facilities, and detailed analysis of the results remains to be done.

5. The committee is well aware that ice may fail by buckling at model scale while it would fail by crushing at full scale, a very serious scale effect indeed. This and other modeling problems are the concern of and are being addressed by the committee.

The committee agrees with **Mr. Per Aren** that if <u>dynamic loads</u> on propeller blades are to be investigated a higher sampling frequency than the one recommended in the committee report should be used. In fact at least one propeller blade should be instrumented specifically rather than rely on measurements of the overall propeller thrust and torque.

Finally, the committee members are not sufficiently familiar with the analysis method championed by **Dr. Schmiechen** to comment on his remarks. But the committee welcomes any method which can provide additional information, especially if it does not require additional tests or measurements.

III. COMMITTEE REPORT ERRATA

Page/Column	Line	Instead of	Read
526-R	23	maneauverability	maneuverability
527-L	8	1.20	1:20
540-R	8 from bottom	changed of model	changed model
541-L	19	impovement	improvement
542-L	15	should described	should be described
542-R	13	properrty	property
542-R	3 from bottom	has be treated	has been treated
546-R	12	icomparative	comparative
546-R	15	as much as twice	as little as half
547-R	1	5.4 Concluding remarks	5.5 Concluding remarks
548-L	14-15 from bottom	had .... testing.	have .... tests.
549-Table 6.1	7	Institute of Marine	Institute for Marine
549-Table 6.1	12	Masa-Yara	Masa-Yard
550-L	10 from bottom	it is to early	it is too early
550-L	7 from bottom	is complicated	are complex
550-R	4 from bottom	Motozuana	Motozuna
552-L	23	Delete sentence "Table 2	.... in ice."
554	3	Institute of Marine	Institute for Marine
556-L	19	"MW Baltic	"1.6MW Baltic
569	Table A.1:	Width of IMD ice tank is	12m, not 10m as indicated
570	last 2 lines	Gora Wilkman Anita Nortla Hoikanen	Goran Wilkman Anita Nortala Hoikanen