Model-scale/full-scale correlation of OCRE's model test results in supporting the CCGS Polar Icebreaker model test data evaluation

Lau, Michael; Wang, Jungyong

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21263085
Technical Report, 2012-11-01

Report Documentation Page

National Research Council Canada | Conseil national de recherches Canada

REPORT NUMBER	PROJECT NUMBER	DATE
OCRE-TR-2012-28	A1-00765	November 2012
REPORT SECURITY CLASSIFICATION		DISTRIBUTION
Unclassified		Unlimited

TITLE

MODEL-SCALE/FULL-SCALE CORRELATION OF OCRE'S MODEL TEST RESULTS IN SUPPORTING THE CCGS POLAR ICEBREAKER MODEL TEST DATA EVALUATION

AUTHOR(S)

Michael Lau and Jungyong Wang

CORPORATE AUTHOR(S)/PERFORMING AGENCY(S)

NRC Ocean, Coastal and River Engineering – St. John's, NL

PUBLICATION

SPONSORING AGENCY(S)

Canadian Coast Guard

RAW DATA STORAGE LOCATION(S)		PEER REVIEWED
MODEL #	**PROP #**	**EMBARGO PERIOD**
PROJECT	**GROUP**	**PROGRAM**
A1-00765	Research	Arctic Operations
FACILITY		
Ice Tank		

KEY WORDS	PAGES	FIGS.	TABLES
Model Test, Sea Trial, Correlation, Polar Icebreaker	iii,10	3	1

SUMMARY

This document gives a summary of the model-scale/full-scale correlation performed on model test data generated at the National Research Council Ocean, Coastal, and River Engineering (NRC-OCRE) test facility in St. John's in support of the evaluation of the full-scale prediction from the NRC-OCRE's CCGS Polar Icebreaker model test result. This correlation includes ship performance predictions, i.e., resistance, propulsion and manoeuvring. The review has shown a good agreement between NRC-OCRE model test predictions and full-scale measurements. Sensitivity analysis of flexural strength on both ice resistance and ship power shows an increase of only 9.7 and 13.7 % of ice resistance and ship power, respectively, even with a 35 % strength increase.

ADDRESSES:
NRC - Ocean, Coastal and River Engineering

St. John's
Arctic Avenue, P. O. Box 12093,
St. John's, NL A1B 3T5
Tel.: (709) 772-5185, Fax: (709) 772-2462

Ottawa
1200 Montreal Road, Building M-32
Ottawa, Ontario K1A 0R6
Tel.: (613) 991-0301, Fax: (613) 952-7679

National Research Council Canada
Conseil national de recherches Canada

Ocean, Coastal and River Engineering
Génie océanique, côtier et fluvial

MODEL-SCALE/FULL-SCALE CORRELATION OF OCRE'S MODEL TEST RESULTS IN SUPPORTING THE CCGS POLAR ICEBREAKER MODEL TEST DATA EVALUATION

OCRE-TR-2012-28

Michael Lau and Jungyong Wang

November 2012

ABSTRACT

This document gives a summary of the model-scale/full-scale correlation performed on model test data generated at the National Research Council Ocean, Coastal, and River Engineering (NRC-OCRE) test facility in St. John's in support of the evaluation of the full-scale prediction from the NRC-OCRE's CCGS Polar Icebreaker model test result. This correlation includes ship performance predictions, i.e., resistance, propulsion and manoeuvring. The review has shown a good agreement between NRC-OCRE model test predictions and full-scale measurements. Sensitivity analysis of flexural strength on both ice resistance and ship power shows an increase of only 9.7 and 13.7 % of ice resistance and ship power, respectively, even with a 35 % strength increase.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

MODEL-SCALE/FULL-SCALE CORRELATION OF OCRE'S MODEL TEST RESULTS IN SUPPORTING THE CCGS POLAR ICEBREAKER MODEL TEST DATA EVALUATION

1 INTRODUCTION

This document gives a summary of the model-scale/full-scale correlation performed on model test data generated at the National Research Council Ocean, Coastal, and River Engineering (NRC-OCRE) St. John's facility in support of the evaluation of the full-scale prediction from the NRC-OCRE CCGS Polar Icebreaker model test result. This correlation includes the ship performance predictions, i.e., resistance, propulsion and manoeuvring.

Section 2 presents the result of the model-scale/full-scale correlation of resistance, propulsion and manoeuvring trial data. The conclusion is given in Section 3. References are provided in Section 4.

Due to the preliminary nature of this investigation, only selected works from NRC-OCRE publications, i.e., Jones and Lau (2006) on the USCGC icebreaker Healy, Wang and Jones (2008) on the CCGS icebreaker Terry-Fox, Spencer and Jones (2002) on the CCGS R-Class icebreakers Pierre Radisson and Sir John Franklin and Spencer (1992) on the CCGS icebreaker Louis S. St. Laurent, were reviewed and summarized.

The model tests were conducted at OCRE ice tank with the correct density (CD) EGADS model ice that is also used for the CCGS Polar Icebreaker model test.

2 MODEL-SCALE/FULL-SCALE CORRELATION

2.1 Principle of the Correlation

This correlation is based on the concept that a "correlation friction coefficient" (CFC) can be used to predict full-scale ship icebreaking resistance from model test data. This concept is analogous to the correlation allowance used in clear-water testing. If the CFC falls in a narrow band of values for all ships of similar hull surface condition, it is assumed that full-scale performance for another similar hull can be predicted from model tests based on the same CFC.

The CFCs have been compared for correlation studies using good-quality full-scale information for five icebreaker models in the NRC-OCRE model test database. Table 1 gives the CFC obtained from each of these studies. From these studies, good correlation is evident for a smooth-hulled ship breaking snow-free ice in most cases with a coefficient of 0.05. The CFC of 0.05 is adopted in the CCGS Polar Icebreaker model test.

For details of the NRC-OCRE friction correlation procedure, the reader is referred to Spencer and Jones (2002).

2.2 Full-Scale Trial and Model Test Data

The model tests and associated sea trials summarized in Table 1 are briefly described as follows. For details, please refer to the cited publications.

CCGS R-Class icebreakers

Several full-scale speed-power icebreaking trials have been conducted with the R-class icebreakers CCGS Pierre Radisson and CCGS Sir John Franklin.

The CCGS Pierre Radisson was tested soon after delivery in 1978 during transit in the Central Arctic with ice thickness in the range of 0.8 to 1.3 m and ice flexural strength estimated at 200 kPa. In February 1979, further tests were conducted in thinner but stronger ice in the St. Lawrence River where ice thickness ranged from 0.2 to 0.7 m and ice flexural strength varied from 400 to 500 kPa (Edwards et al, 1979).

Tests were conducted on the CCGS Sir John Franklin in Notre Dame Bay, Newfoundland in February 1991, where ice thickness was between 0.5 and 0.6 m, and flexural strength ranged between 200 and 300 kPa (Williams et al, 1991 and 1992).

Model level ice resistance tests were conducted at NRC (St. John's) on a 1:20 scale model covering a wide range of speed, ice thickness and strength with two hull-ice friction coefficients: 0.03 (Spencer et al, 1992) and 0.09 (Newbury, 1988). Newbury and Williams (1986) summarized R-Class icebreaker model test results.

CCGS icebreaker Terry-Fox

The full-scale trial for the CCGS Terry-Fox used in this study was conducted in 1990 by Fleet Technology Limited (Cowper, 1991). The ice thickness was 1.55 m and the flexural strength was 150 kPa. In this trial, the Terry-Fox was towed by the MV Ikaluk to measure resistance directly. Self propulsion tests were also conducted to measure power and thrust.

A 1:21.8 scale model has been tested with three different hull-ice friction coefficients (0.11, 0.045 and 0.005) and several ice conditions over a period of more than 20 years. The datasets used in this review were from Spencer et al (1988) with a hull-ice friction of 0.11 and Nordco Ltd. (1989) with a hull-ice friction coefficient of 0.045.

CCGS icebreaker Louis S. St. Laurent

Full-scale data was obtained from ARCTEC Canada (Noble and Comfort, 1979) in its July 1979 Strathcona Sound trials. Immediately prior to these trials, a new

INERTA 160 coating was applied over the ship's bow and waterline regions; thus the hull condition during these trials may be similar to a new ship on its maiden voyage. Ice thickness varied from 0.76 m to 1.36 m, and mean flexural strength was only 150 kPa averaged over five cantilever beam tests. Snow cover was very light and was not a factor in these trials. Shipboard measurements were shaft speed (RPM) and ship speed. Ship resistance was estimated from RPM only in model overload tests.

Resistance of the 1:15 scale model of Louis S. St. Laurent was extensively measured at NRC (St. John's) (Spencer, 1987) with a hull-ice friction coefficient of 0.13 and ice thicknesses of 47, 67 and 100 mm corresponding to 0.7, 1.0 and 1.5m full-scale for the ship. The target ice strength was 30 kPa corresponding to 450 kPa full-scale. It was subsequently refinished and tested with a 0.07 hull-ice friction coefficient (Fleet Technology Ltd., 1992) and the same target ice thickness and ice strength.

USCGC icebreaker Healy

Extensive full-scale ice trials of USCGC Healy (Sodhi et al., 2001) were performed in 2000 shortly after its delivery to the US Coast Guard with ice thickness in the range of 0.6 to 1.75 m and ice flexural strength from 190 to 400 kPa. Snow depth ranged from 3 to 20 cm. At full power of about 28,800 HP, the ship broke 1.75 m level ice with an average flexural strength of 360 kPa at 2 knots, and the ship achieved 4.66 to 5.33 knots in 1.37 m level ice with the same flexural strength. Besides continuous icebreaking, the Healy trials also included manoeuvring.

Following the full-scale trials, a complete set of resistance, propulsion and manoeuvring model tests with a 1:23.7 scale model of the ship were performed in scaled ice conditions for correlation with the full-scale data. Jones (2005) has summarized the results of the resistance and propulsion model tests, and Lau (2006) the manoeuvring tests. Two hull-ice friction coefficients of 0.014 and 0.034 were used.

Table 1 Summary of Model-Scale/Full-Scale Studies. The CFC is the friction coefficient with which a perfect correlation is achieved between the model-scale and full-scale data (see Section 2.1).

	Sea Trial					Model Test	Correlation	
Ship	Date	Location	Thickness (m)	Flexural Strength (kPa)	Reference	Reference	Correlation Friction Coefficient	Reference
CCGS Pierre Radisson	July & August 1978	Central Arctic	0.8 - 1.3	200	Edwards et al, 1979	Newburg and Williams, 1986	0.05	Spencer and Jones, 2002
CCGS Pierre Radisson	Feb. 1979	St. Lawrence River	0.2 - 0.7	400 - 500	Edwards et al, 1979	Newburg and Williams, 1986	0.06	Spencer and Jones, 2002
CCGS Sir John Franklin	Feb. 1991	Notre Dame Bay, NL	0.5 - 0.6	200 - 300	Williams et al, 1991 & 1992	Newburg and Williams, 1986	0.065	Spencer and Jones, 2002
CCGS Louis S. St. Laurent	1979	Strathcona Sound	0.8 - 1.4	150	Noble and Comfort, 1979	Spencer, 1987; Spencer 1992	0.05-0.07	Spencer, 1992
CCGS Terry-Fox	1991	Central Arctic	1.55	150	Cowper, 1991	Spencer et al, 1988; Nordco Ltd, 1989	0.05	Wang and Jones, 2008
USCGC Healy	April & May 2000	Baffin Bay	0.6 - 1.75	190 - 400	Sodhi et al, 2001	Jones and Moores, 2002; Jones and Lau, 2006	0.05	Jones and Lau, 2006

2.3 Resistance and Power

The resistance correlation was performed for five sets of full-scale data, including the trials for the CCGS Louis S. St. Laurent, CCGS Terry-Fox, CCGS Pierre Radisson and CCGS Sir John Franklin. Since each model was at least tested at two hull-ice friction correlations, the resistance data can be adjusted to 0.05, which is the correlation friction coefficient prior to comparison. For this adjustment we assumed a linear relationship between resistance and friction.

The result of the ship resistance correlation is given in Figure 1. The 1:1 fit line indicates perfect correlation. The figure shows a good correlation between the model test prediction and the sea trial measurement. Correlation is even better with thicker ice, i.e., the range of interest, which corresponds to higher resistance. There is substantial uncertainty on ice thickness and ice strength within the full scale data sets that contributes to data scattering. A 1:15 fit line is plotted on the figure that envelopes most data points. This suggests a conservative estimate can be obtained to address this uncertainty reasonably by increasing the model prediction by 15%.

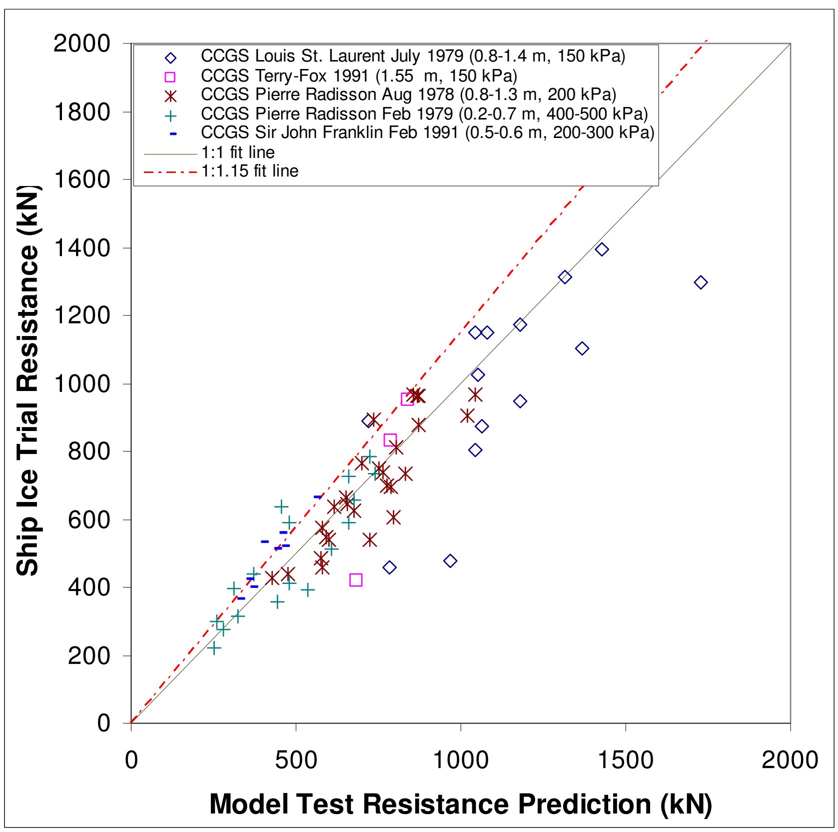

Figure 1 Result of the ship resistance correlation.

Sensitivity analysis of flexural strength on ice resistance over the range of full-scale trial conditions was performed on the data sets by increasing the flexural strength of the model ice by 25 and 35 %. On average the full-scale ice resistance increases by 5.6 and 9.7 % for the 25 and 35 % strength increase, respectively.

The power correlation was performed for 5 sets of full-scale data, including the trials for the USCGC Healy, CCGS Terry-Fox, CCGS Pierre Radisson and CCGS Sir John Franklin. Again, the power data were adjusted to 0.05, the correlation friction coefficient, prior to comparison by assuming a linear relationship between resistance and friction.

The result of the ship power correlation is given in Figure 2. Again, the figure shows a good correlation between the model test prediction and the sea trial measurement. Again, the 1:15 fit line envelopes most data points, that suggests a conservative estimate can be obtained by increasing the model prediction by 15%.

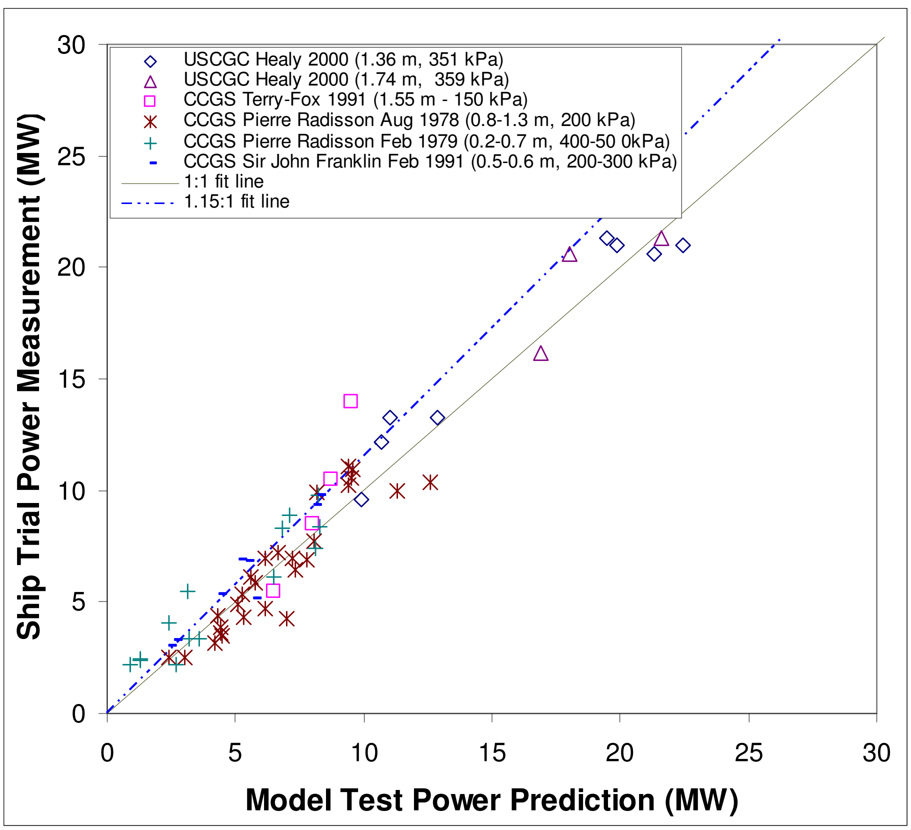

Figure 2 Result of the ship power correlation...

Sensitivity analysis of flexural strength on power was only performed on the R-Class data sets, i.e., CCGS Pierre-Radisson and CCGS Sir John Franklin, due to the partial availability of raw data at the time of analysis. Nevertheless, the result was in consistent with the resistance analysis. On average the full-scale ship power increases by 7.8 and 13.7 % for the 25 and 35 % strength increase, respectively.

2.4 Manoeuvring

Limited correlation was also performed for the USCGC Healy icebreaker (Jones and Lau, 2006) for manoeuvring in ice. Selected test conditions from the sea trials were duplicated for the manoeuvring tests and turning diameters were measured from the arcs of partial circles made in the ice tank. Performance predictions were then compared to the full-scale data previously collected. The tests were conducted at a target full-scale ice thickness of 0.75 m and 1 m with an ice strength ranging from 483 to 1,081 kPa. The rudder angle was kept at 30 degrees as used in the sea trials. The delivered power was kept at around 30,000 hp, which was consistent with the delivered power employed during the full-scale trials.

Figure 3 shows the comparison of the non-dimensional turning diameter as a function of non-dimensional ice thickness for the sea trial and model test data. Despite some discrepancy in ice strength and power level between the model tests and sea trial, the model data agree well with the sea trial data except for the three data points identified in the figure. These three points were seen as outliers in the full-scale report. Otherwise, the manoeuvring data show a good correlation between the model test and sea trial results.

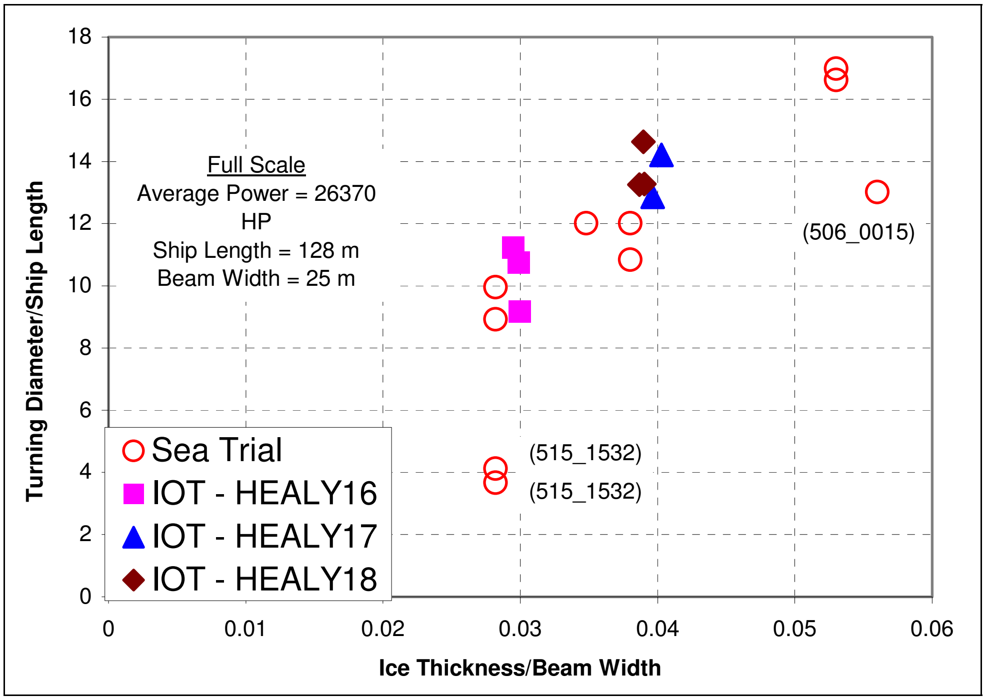

Figure 3 The non-dimensional turning diameter as a function of non-dimensional ice thickness for the USCSC Healy sea trial and model test data

3 CONCLUSIONS

A brief review of the model-scale/full-scale correlation studies on the USCGC icebreaker Healy, CCGS icebreaker Terry-Fox, CCGS R-Class icebreakers Pierre Radisson and Sir John Franklin and CCGS icebreaker Louis S. St. Laurent by NRC-OCRE (St. John's) ice tank has shown a good agreement between NRC-OCRE model test predictions and full-scale measurements in resistance, power and manoeuvring. Sensitivity analysis of flexural strength on both ice resistance and ship power shows an increase of only 9.7 and 13.7 % of ice resistance and ship power, respectively, even with a 35 % strength increase.

4 REFERENCES

Cowper, B., 1991. *Resistance and populsive performance trials of the MV Terry-Fox and MV Ikaluk in level ice*, Transport Canada, Report Number TP10845E.

Edwards, R.Y. Jr., et al, 1979. *Result of trials in ice and open water of CCGS Pierre Radisson*, Report 245C-8, 2 vols, ARCTEC Canada Ltd.

Fleet Technology Ltd., 1992. *Low friction coefficient CCG Louis St. Laurent – Test report*, NRC-OCRE report CR-1992-01, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Jones, S. J. and Lau, M., 2006. *Propulsion and maneuvering model tests of the USCGC Healy in ice and correlation with full-scale*, 7th International Conference and Exhibition on Performance of Ships and Structures in Ice, 16-19 July 2006, Banff, Alberta. Paper 104.

Jones, S.J. and Moores, C., 2002. *Resistance tests in ice with the USCGC Healy*, IAHR 16th International Symposium on Ice, Dunedin, New Zealand, Vol. 1, p. 410-415.

Newbury, S., 1988*. Icebreaking experiments with 1:20 and 1:40 scale models of the CCG R-class vessels*, NRC-OCRE report TR-AVR-10, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Newbury, G.S. and Williams, F.M., 1986. *"R-class" icebreaker model experiment results*, <u>Ice Technology</u>, Computational Mechanics, Springer-Verlag, Berlin, p. 333-348.

Noble, P. and Comfort, G., 1979. *Ice trials to evaluate low friction coating on C.C.G.S. Louis S. St. Laurent*, ARCTEC Canada report FR357C-4.

Nordco Ltd, 1989. *Report on resistance tests of Model 417 (Terry-Fox/Kalvik) in the ice tank*, NRC-OCRE report CR-1989-25, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Spencer, D., 1992. *Model-scale/Full-scale ice resistance correlation for the CCGS Louis St. Laurent - Part II*. NRC-OCRE report LM-1992-05, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Spencer, D.S., 1987. *Ice model tests on CCG Louis St. Laurent – Phase I: Models M395A, M395B, and M395C*, NRC-OCRE report TR-AVR-01, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Spencer, D. and Jones, S.J., 2002. *Model-scale/Full-scale correlation in open water and ice for Canadian Coast Guard 'R-class' icebreakers*, NRC-OCRE report IR-2002-05, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Spencer, D., Molynuex, D. and Keinonen, A., 1988. *Model tests of M.V.'s "Terry-Fox"/"Kalvik" and their correlation to full scale*, NRC-OCRE report TR-AVR-12, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Spencer, D., Williams, F. M. and Newbury, S., 1992. *Model-scale/Full-scale ice resistance correlation for the CCG R-class icebreakers*, NRC-OCRE report LM-1992-20, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Sodhi, D.S., Griggs, D.B. and Tucker, W.B., 2001. *Healy ice trials: Performance tests in ice*, Proc. 16th International Conference on Port and Ocean Engineering under Arctic Conditions, Vol. 2, pp.893-907,

Wang, J. and Jones, S. J., 2008. *Resistance and propulsion of CCGS Terry Fox in ice from model tests to full scale correlation*, 8th International Conference and Exhibition on Performance of Ships and Structures in Ice, 20-23, Banff, AB.

Williams, F.M. et al, 1991. *Full-scale icebreaker trials CCGS Sir John Franklin Indian Arm/Little Burnt Bay 1991*, NRC-OCRE report TR-1991-03, Ocean, Coastal and River Engineering, National Research Council Canada, St. John's, Newfoundland and Labrador.

Williams, F.M. et al, 1992. *Full-scale trials in level ice with Canadian R-class icebreaker*, *Trans*. SNAME, 100, 293.