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Resistance and flow data are summarized for models of selected surface ship hull forms. The data were obtained from more than 20 experimental facilities worldwide under the organization of the Resistance Committee of the International Towing Tank Conference (ITTC). These data were collected to provide a base for comparisons between experimental findings at several institutions under various model conditions and for validation and further development of theoretical prediction methods. The most extensive data bases presented are for the Wigley parabolic hull and the Series 60, Block 0.60 hull. These data include measurements of total resistance, wave pattern resistance and spectra, wake survey viscous resistance, hull pressure, hull shear stress, and boundary-layer velocities. More limited data for some of the global types of measurements are also reported for ATHENA, a high-speed transom stern hull. Data for one additional hull, the very full form HSVA tanker, is not reported here because of the

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limited amount of available data. Microfiche copies of all detailed data reports prepared by contributing organizations, on which the summary is based, are included as appendices. Despite differences in measurement techniques, most laboratories produce similar results for the same hull under similar test conditions; however, caution should be exercised when using very small models. It is recommended that additional experiments be conducted to complete the data bases for all four hull forms and that more detailed analyses of the available data be undertaken to identify the importance of all factors affecting the prediction of ship resistance and flow from model experiments.

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084-5000

COLLECTED EXPERIMENTAL RESISTANCE COMPONENT AND FLOW DATA FOR THREE SURFACE SHIP MODEL HULLS

Prepared by

MEMBERS OF THE RESISTANCE COMMITTEE OF THE 17th INTERNATIONAL TOWING TANK CONFERENCE

Edited by
J.H. McCarthy

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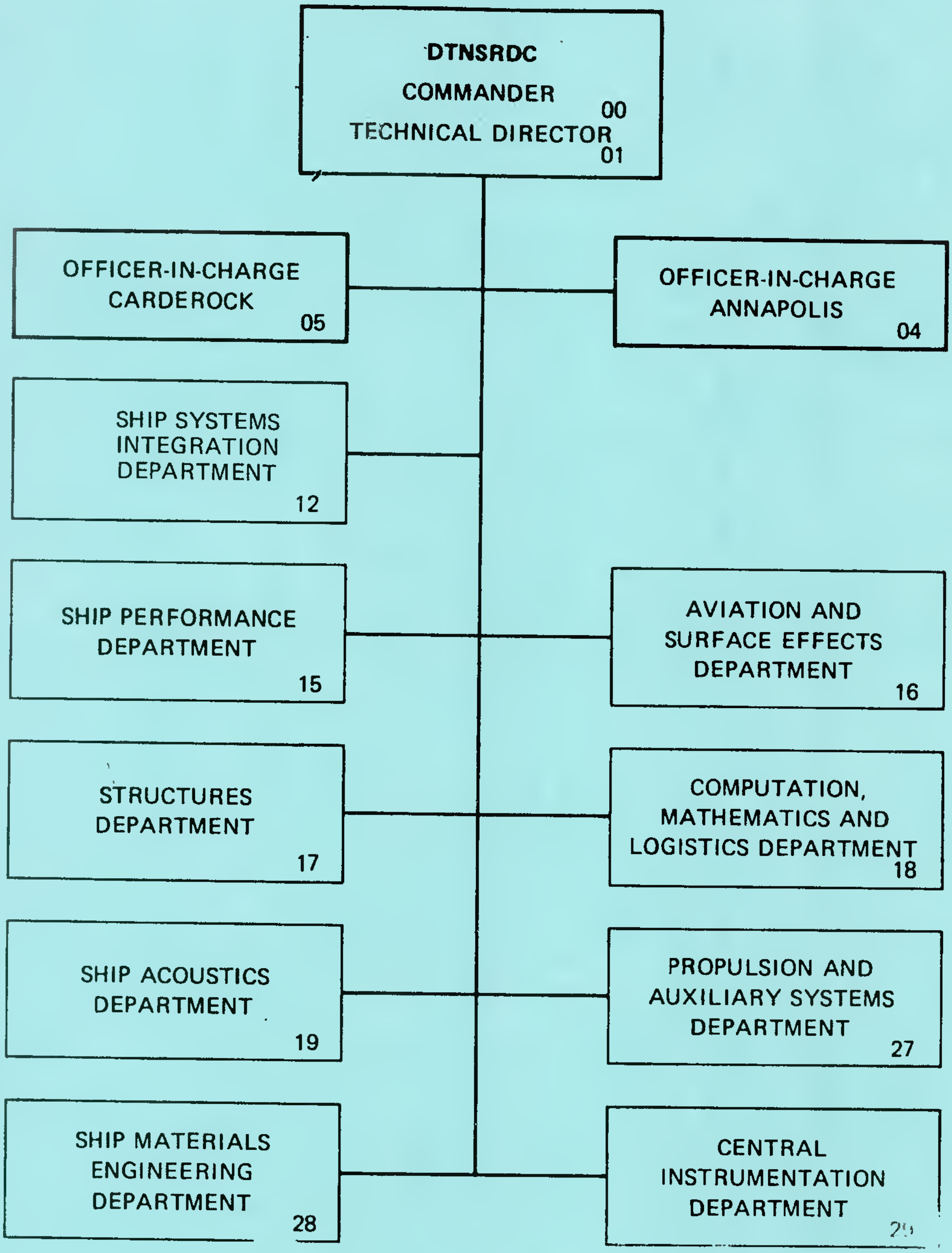
SHIP PERFORMANCE DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

September 1985

DTNSRDC-85/011

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



FOREWORD

This report publishes the complete data collected before 1984 under the Cooperative Experimental Program of the Resistance Committee of the International Towing Tank Conference (ITTC). The report has been made possible only as a result of the generous and timely support given to the program by numerous individuals at twenty member organizations of the ITTC. Their contributions are gratefully acknowledged and are reproduced (in microfiche form) as appendices to this report.

The Cooperative Experimental Program had its genesis in a 1977 suggestion by Dr. George E. Gadd, secretary of the 14th and 15th ITTC Resistance Committees from 1972 - 1978, and a member of the National Maritime Institute, England. The principal task of organizing the Program was carried out by Dr. Lars Larsson of the Swedish Maritime Research Centre SSPA, Sweden. Dr. Larsson was secretary of the 16th ITTC Resistance Committee from 1978 - 1981 and a member of the 17th ITTC Resistance Committee from 1981 - 1984. (Most of the text of the report was prepared by Dr. Larsson.) During the latter three-year period, Dr. Archibald M. Ferguson of the University of Glasgow, Scotland, with the help of Dr. Javid Ahrabian, computerized and plotted all of the "global" data received under the Program. All other members of the 17th ITTC Resistance Committee contributed to the Program by coordinating experiments at their own or nearby institutions and by assisting in the preparation and fine-tuning of the summary report. Members of the 17th ITTC Resistance Committee were:

Justin H. McCarthy (Chairman), David Taylor Naval Ship R&D Center, U.S.A.

Martin Hoekstra (Secretary), Maritime Research Institute (NSMB), the Netherlands

Eiichi Baba, Nagasaki Technical Institute, Mitsubishi Heavy Ind., Japan

Archibald M. Ferguson, University of Glasgow, U.K.

Lars Larsson, Swedish Maritime Research Center SSPA, Sweden

V.C. Patel, University of Iowa, U.S.A.

Ichiro Tanaka, Osaka University, Japan

Yovi Yovev, Bulgarian Ship Hydrodynamics Centre, Bulgaria.

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A- 3: "Cooperative Experiments on Wigley Parabolic Models in Japan," 2nd ed., I. Tanaka (Osaka University), M. Namimatsu and S. Ogiwara (Ishikawajima-Harima Heavy Industries Co., Ltd., H. Tanaka, H. Adachi, M. Hinatsu, and T. Kamikura (Ship Research Institute), H. Kajitani, H. Miyata, S. Kuzumi, Y. Tsuchiya, and M. Kanai (University of Toyko), and M. Ikehata (Yokohama National University), Dec 1983 (Osaka, Japan)

A- 4: "Study of Total and Viscous Resistance for the Wigley Parabolic Ship Form," S. Ju, IIHR Report 261, Apr 1983 (Iowa City, U.S.A.)

A- 5: "Record of a Boundary Layer Exploration on a Mathematical Ship Model," N. Hogben, NPL Ship Division Report 52, July 1964 (Feltham, England)

A- 6: "3-D Velocity Measurements Near the Stern of a 3 m Wigley Model," K. Mori, Hiroshima University, 1983 (Hiroshima, Japan)

A- 7: "Turbulence Measurements in the Flow Around a Body in a Circulating Water Channel (Part 2, Turbulence around a 3-Dimensional Body)," S. Hatano and T. Hotta, Hiroshima University, Aug 1982 (Hiroshima, Japan)

A- 8: "Pressure Coefficient and Skin Friction Coefficient Distributions for the Wigley Hull," J.H. Watmuff and P.N. Joubert, University of Melbourne, 1983 (Melbourne, Australia)

A- 9: "Boundary Layer Traverses on the Wigley Parabolic Hull," E. Baba, Nagasaki Exptl. Tank, Mitsubishi Heavy Industries Ltd., Aug 1983 (Nagasaki, Japan)

A-10: "Boundary Layer Traverses on the Wigley Parabolic Hull," M. Ikehata, Yokohama National University, Aug 1983 (Yokohama, Japan)

MF APPENDICES B-1 TO B-13 (SERIES 60, BLOCK 0.60 HULL)

B- 1: "Report on ITTC Cooperative Experiments for Series 60, $C_B = 0.60$ Hull Form," J. Zhang, Y. Feng, G. Lu, Q. Zeng, J. Lin, and G. Wu, China Ship Scientific Research Center, 1983 (Wuxi, China)

B- 2: "Trim and Sinkage Effects on Wave Resistance with Series 60, C_B = 0.60," Y-H Kim and D. Jenkins, Report/DTNSRDC SPD-1013-01, Sept 1981 (Bethesda, U.S.A.)

B- 3: "Program for Ship Flow, Wave-Making and Viscous Resistance. Series 60 Experiment," P. Hervala; Helsinki Univ. of Technical Ship Hydro. Lab., Report M-108, 1983 (Otaniemi, Finland)

B- 4: "Experimental Report for 17th ITTC Resistance Committee Cooperative Experimental Program," Y.G. Lee and B.S. Hyun, Ship Research Station, Korea Institute of Machinery and Metals, Aug 1983 (Daejeon, Korea)

B- 5: "Some Experimental Results for Resistance and Wave Pattern Measurements with Series 60, Block 0.60 Model in MARIC Tank," S. Du, Y. Li, and H. Wang, Marine Design and Research Institute of China, June 1983 (Shanghai, China)

B- 6: "Flow Examinations on a Model of Series 60 with C_B = 0.60, Model No. 675," F. Mewis and H.J. Heinke, VEB Kombinat Schiffbau, Schiffbau-Versuchsanstalt, Report 1459, July 1983 (Potsdam, GDR)

B- 7: "Experimental Results for Resistance, Wave Pattern Measurements and Wake Survey with Series 60, C_B = 0.60 Model," Y. Liu, Z. Sheng, and A. Yang, Chiao Tong Univ. Ship Hydro. Lab., Sept 1983 (Shanghai, China)

B- 8: "Wave Pattern Resistance of Model of Series 60, C_B = 0.60," F-S. Chen and T-O. Xu, Shanghai Ship and Shipping Research Inst., Dec 1982 (Shanghai, China)

B- 9: "Resistance Experiments on a 3-Meter, Series 60, C_B = 0.60 Hull," M. Ikehata; Yokohama National University, Aug 1983 (Yokohama, Japan)

B-10: "Resistance, Wave Pattern, and Wake Survey Experiments on a 2-Meter, Series 60, C_B = 0.60 Hull," M. Ikehata, Yokohama Natl. Univ., Aug 1983 (Yokohama, Japan)

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SYMBOLS AND ABBREVIATIONS

AP	After perpendicular
BL	Boundary layer or buttock line
C_B	Block coefficient
C_F	Local skin friction coefficient
C_P	Pressure resistance or pressure coefficient
C_{SF}	Sinkage fore coefficient
C_T	Total resistance coefficient
C_t	Trim coefficient
C_V	Viscous resistance coefficient
C_{WP}	Wave pattern resistance coefficient
Dim	Spatial dimension of the velocity vector
F_n	Froude number
FR	Model free to sink and trim
FS	Model free to sink
FX	Model fixed
GL	Girth line
L	Model length between perpendiculars
ℓ	L/2
R_n	Reynolds number
SL	Streamline
ST	Station
TT	Towing tank
Turb	Turbulence measurements

WC	Water channel
WT	Wind tunnel
X,Y,Z	Global coordinate system (see Figure 5)
θ_{11}	Boundary layer momentum thickness

ABSTRACT

Resistance and flow data are summarized for models of selected surface ship hull forms. The data were obtained from more than 20 experimental facilities worldwide under the organization of the Resistance Committee of the International Towing Tank Conference (ITTC). These data were collected to provide a base for comparisons between experimental findings at several institutions under various model conditions and for validation and further development of theoretical prediction methods. The most extensive data bases presented are for the Wigley parabolic hull and the Series 60, Block 0.60 hull. These data include measurements of total resistance, wave pattern resistance and spectra, wake survey viscous resistance, hull pressure, hull shear stress, and boundary-layer velocities. More limited data for some of the global types of measurements are also reported for ATHENA, a high-speed transom stern hull. Data for one additional hull, the very full form HSVA tanker, is not reported here because of the limited amount of available data. Microfiche copies of all detailed data reports prepared by contributing organizations, on which the summary is based, are included as appendices. Despite differences in measurement techniques, most laboratories produce similar results for the same hull under similar test conditions; however, caution should be exercised when using very small models. It is recommended that additional experiments be conducted to complete the data bases for all four hull forms and that more detailed analyses of the available data be undertaken to identify the importance of all factors affecting the prediction of ship resistance and flow from model experiments.

ADMINISTRATIVE INFORMATION

The publication of this report was sponsored by the Naval Sea Systems Command under the General Hydromechanics Research Program, Program Element 61153, Task Area SR0230101, administered by the David Taylor Naval Ship Research and Development Center. Copies of this report can be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, U.S.A.

INTRODUCTION

In the concluding remarks of the 15th ITTC Resistance Committee Report it was pointed out that well-documented data to validate ship flow calculation methods were scarce. It was therefore suggested that the 16th Resistance Committee should organize a cooperative effort between the member organizations of the ITTC to produce a comprehensive data base to be used when evaluating computational methods for the prediction of hull flow and resistance components. Six different types of measurements were suggested: (a) total resistance, (b) wave pattern resistance and spectra, (c) wake survey, (d) hull pressure, (e) hull shear stress, and (f) boundary-layer traverses. Later, the hull wave profile was added to the list. These measurements were to be carried out on hulls to be selected by the Committee.

The 16th ITTC Resistance Committee distributed a questionnaire to member organizations requesting their participation in the Program. Seven candidate hull forms were identified, and existing data for these hulls were requested. After reviewing the responses, four hulls were chosen for the Program:

a. The Wigley hull having parabolic waterlines and sections (Figure 1).

b. The Series 60, C_B = 0.60, parent model (Figure 2).

c. A high-speed hull, ATHENA (Figure 3).

d. A tanker tested at the Hamburg Ship Model Basin (HSVA), referred to as the HSVA tanker (Figure 4).

Since a large number of organizations reported their willingness to participate, and the objective of the work was to produce well-documented test cases covering a range of Froude and Reynolds numbers, specific recommendations were given about the

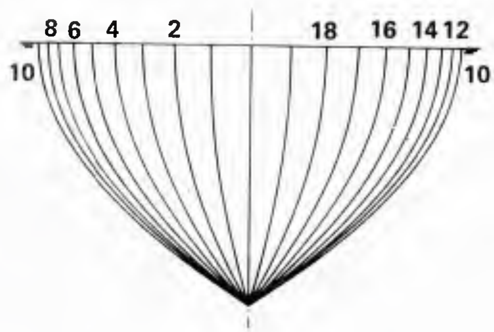


Figure 1 - Wigley Hull

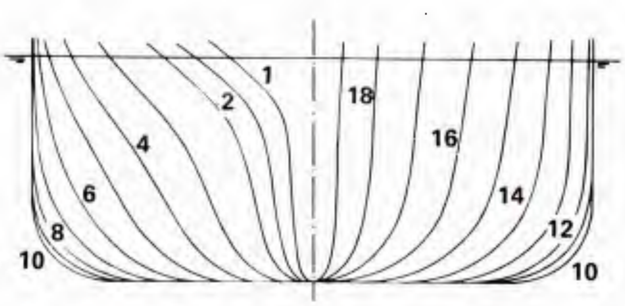


Figure 2 - Series 60, C_B = 0.60 Hull

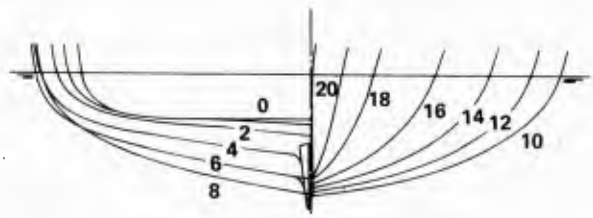


Figure 3 - ATHENA Hull

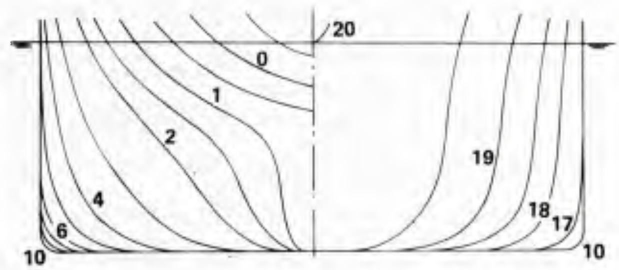


Figure 4 - HSVA Tanker Hull

test conditions and the report preparation. The reports were to include offset measurements on the hull, information about test conditions (type of facility, dimensions, blockage, wave damping devices, turbulence level, time between runs, tripping device, etc.), instrumentation (principle of operation, accuracy, calibration, etc.), recording and processing equipment, and corrections.

The test results were to include information about Reynolds and Froude numbers, hull attitude (sinkage and trim), resistance components measured, and velocity components at measurement points. Formats were specified for all graphic information.

It soon became clear that this Program would have to be extended over two ITTC sessions, i.e., over a period of six years, so that the final report could be presented at the 17th ITTC in 1984. This report summarizes the status of the work as of 1 December 1983. Extensive local and global data are available for only the Wigley and Series 60 hulls. Some global data are also reported for the ATHENA hull. At this stage, 20 organizations have provided data obtained either since the 15th ITTC or previously. These are in alphabetical order:

Bulgarian Ship Hydro. Centre (BSHC)
Centro Stud. di Tecnica Navale (CETENA)
China Ship Scientific Res. Center (CSSRC)
David Taylor Naval Ship R&D Cen. (DTNSRDC)
Glasgow University (Glasgow)
Helsinki University (Helsinki)

Hiroshima University (Hiroshima M) [Mori] or
(Hiroshima H) [Hatano and Hotta]
Ishikawajima-Harima Heavy Ind. (IHI)
University of Iowa (Iowa)
Korea Research Institute of Ships [(KRIS);
now Korea Inst. Mech. and Metals (KIMM)]
Marine Des. and Res. Inst. of China (MARIC)
Univ. of Melbourne (Melbourne)
Mitsubishi Heavy Industries (MHI)
National Maritime Institute (NMI)
VEB Kombinat Schiffbau (Rostock)
Shanghai Chiao Tong University (CTU)
Ship Research Institute (SRI)
Shanghai Ship and Shipping Res. Inst. (SSSRI)
Univ. of Tokyo (Tokyo)
Yokohama National Univ. (Yokohama)

The total number of pages issued under the Program thus far is about 1,000. All reports issued prior to, or as part of, the Cooperative Experimental Program are reproduced in microfiche form as appendices to this report to make more generally available the detailed experimental findings of all Program participants. The main text of the report is confined to a summary of the overall findings and conclusions and discussions of the Program presented at the 17th International Towing Tank Conference in September 1984 (see main appendix).

In the next section, the "global" measurements comprising total resistance, as well as wave, viscous, and pressure resistance components, are summarized.

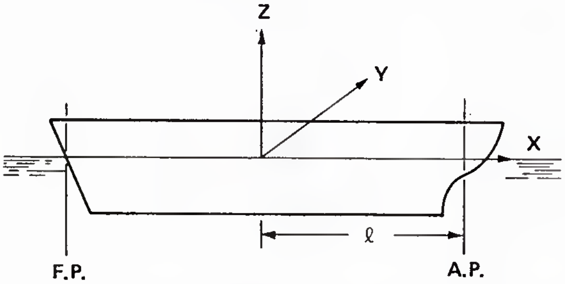


Figure 5 - Coordinate System for Global Measurements

The wave profile is also discussed there. Most of the global data have been compiled in a computer data bank at the University of Glasgow. This will allow easy access for future analysis. "Local" measurements, i.e., wall pressure, shear stress, and boundary layer and near-wake traverses, are summarized in a following section, and a limited analysis of the data is presented.

Figure 5 shows the coordinate system used in this report.

THE GLOBAL MEASUREMENTS

The available global measurements are summarized in Table 1. Model lengths and dimensions of the towing tanks are given first. Thereafter, the five different types of measurements are listed. For each quantity, the Froude number F_n range and the hull attitude (FX, FS, or FR) are specified. In Figures 6 to 8, plots are given of the measured total resistance, wave pattern resistance, and wave profiles. Some sinkage and trim measurements are shown in Figure 9.

To allow a sensible comparative study of the total resistance, the results for each model were brought to a common temperature (15°C) and a common length, using the 1957 ITTC correlation line. The length for the Series 60 and Wigley hulls was 121.92 m, and for the ATHENA hull, 42.04 m. The other measurement results were not changed, except that some reanalysis has been made to allow the presentation to be consistent with the committee recommendations.

TOTAL RESISTANCE

There is very little scatter between most tanks for all three hulls in the model-free condition (Figure 6). The data furthest from the mean line are those from the smallest models. The total resistance is generally less for the fixed models than for the free models. This is not surprising since the sinkage and trim of the free models will increase both wavemaking and frictional resistance. The amount of scatter between tanks is greater for the fixed models, probably due to the restrictions placed on the dynamometer by having the model fixed.

WAVE PATTERN RESISTANCE

With the exception of the results for the smallest models, the scatter between the wave pattern resistance curves is reasonably small (Figure 7). This is very encouraging, considering the fact that a variety of wave-resistance measurement techniques have been used. The wave pattern resistance for the fixed models is less

TABLE 1 - OVERVIEW OF THE GLOBAL MEASUREMENTS ON HULLS

Organization	Model Length L (m)	Tank Dimen. (m^3)	Experimental Values										Complete Data on Microfiche (MF) No.†
			C_T*		Wave Profile		C_{WP}*		C_V*		C_P*		
			F_n	Hull Attitude	F_n	Hull Attitude	F_n	Hull Attitude	F_n	Hull Attitude	F_n	Hull Attitude	
			Wigley Hull										
BSHC	6.1	200×16×6.5	0.10–0.49	FR,FX	—		0.27–0.42	FR,FX	—		—		A- 1
CETENA	4.9	136.5×9×4.1	0.12–0.20	FR	—		—		0.35	FR	—		A- 2
IHI	6.0	210×10×5	0.08–0.36	FR	0.25–0.32	FR	0.08–0.36	FR	0.27,0.32	FR	0.25–0.32	FR	A- 3
Iowa	3.0	91.4×3×3.1	0.10–0.40	FR,FX	—		—		0.16–0.34	FX	—		A- 4
NMI	6.1	152×9.1×3.7	0.16–0.42	FR	0.16–0.32	FR	—		—		—		A- 5
SRI	4.0	400×18×8	0.08–0.40	FR,FX	0.25–0.32	FR,FX	0.21–0.40	FR,FX	0.25–0.32	FR	0.25–0.32	FR	A- 3
Tokyo	2.5	86×3.5×2.4	0.10–0.41	FR,FX,FS	0.25–0.41	FR,FX,FS	0.25–0.41	FR,FX,FS	0.25–0.32	FR	0.25–0.32	FR,FX	A- 3
Yokohama	2.0	100×8×3.5	0.11–0.42	FR,FX	—		0.23–0.38	FR	0.23–0.38	FR	—		A- 3
			Series 60, C_B = 0.6 Hull										
BSHC	7.0	200×16×6.5	0.11–0.36	FR,FX	—		0.22–0.31	FR,FX	—		—		A- 1
CSSRC	6.0	474×14×7	0.20–0.36	FR,FX	0.22–0.35	FR,FX	0.22–0.36	FR,FX	0.23–0.35	FR	0.25–0.38	FR	B- 1
DTNSRDC	6.1	256×15.5×6.7	0.22–0.35	FR,FX	0.22–0.35	FR,FX	0.22–0.35	FR,FX	—		—		B- 2
Glasgow	3.0	77×4.6×2.4	0.22–0.36	FR,FX	—		0.22–0.35	FX,FR	0.25,0.28	FR	—		—
Helsinki	5.0	130×11×5.5	0.22–0.35	FR,FX	—		0.25–0.35	FR	0.35 (vel. distr.)		—		B- 3
KRIS	4.9	200×16×7	0.22–0.35	FR,FX	0.22–0.35	FR,FX	0.22–0.35	FR,FX	0.28	FR	—		B- 4
MARIC	2.5	70×5×2.5	0.22–0.35	FR,FX,FS	0.22–0.35	FR,FX,FS	0.22–0.35	FR,FX,FS	—		—		B- 5
Rostock	5.0	280×9×4.5	0.22–0.35	FR,FX	—		0.22–0.35	FR,FX	0.22	FX	—		B- 6
CTU	2.5	110×6×3	0.21–0.37	FR,FX	0.22–0.35	FR,FX	0.21–0.37	FR,FX	0.22,0.28	FR	—		B- 7
SSSRI	1.8	50×6×2	0.10–0.43	FR	—		0.25–0.43	FR,FX	—		—		B- 8
Yokohama 3	3.0	100×8×3.5	0.10–0.37	FR			0.25–0.35	FR	0.23–0.33	FR	—		B- 9
Yokohama 2	2.0	100×8×3.5	0.15–0.43	FR,FS	—		—		—		—		B-10
			ATHENA Hull										
DTNSRDC	5.7	256×15.5×6.7	0.28–1.00	FR,FX	0.28–0.65	FR,FX	0.28–1.00	FR,FX	—		—		C- 1
NMI	3.2	152×9.1×3.7	0.18–0.66	FR	0.28–0.65	FR	0.28–0.65	FR	0.28–0.65	FR	—		C- 2
			HSVA Hull										
CETENA	5.1	136.5×9×4.1	0.09–0.19	FR	0.13–0.19	FR	0.13–0.19	FR	0.17	FR	—		A- 2

*Resistance coefficients: C_T = total, C_{WP} = wave pattern, C_V = viscous, and C_P = pressure.

†Inside back cover.

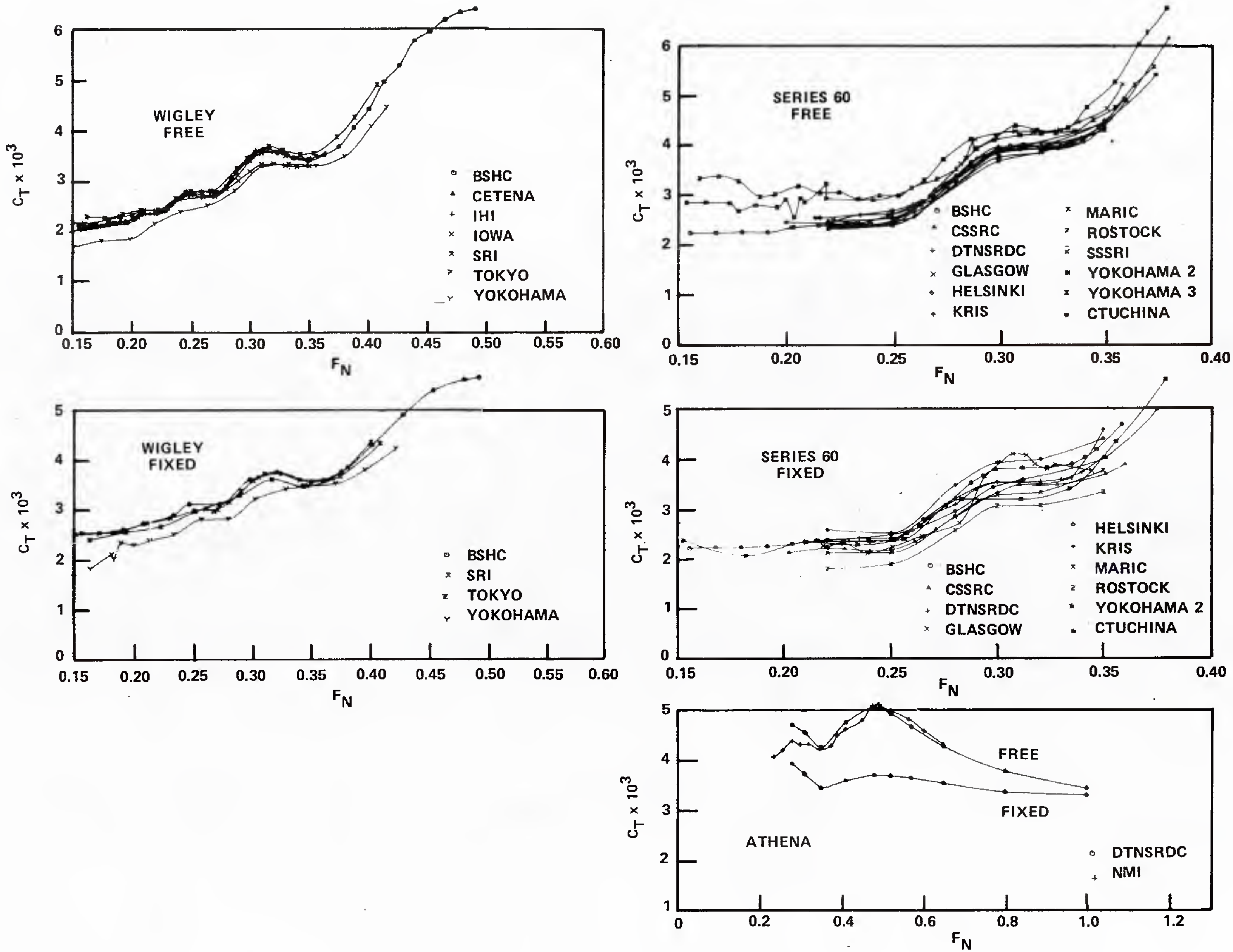


Figure 6 - Total Resistance C_T for All Hulls

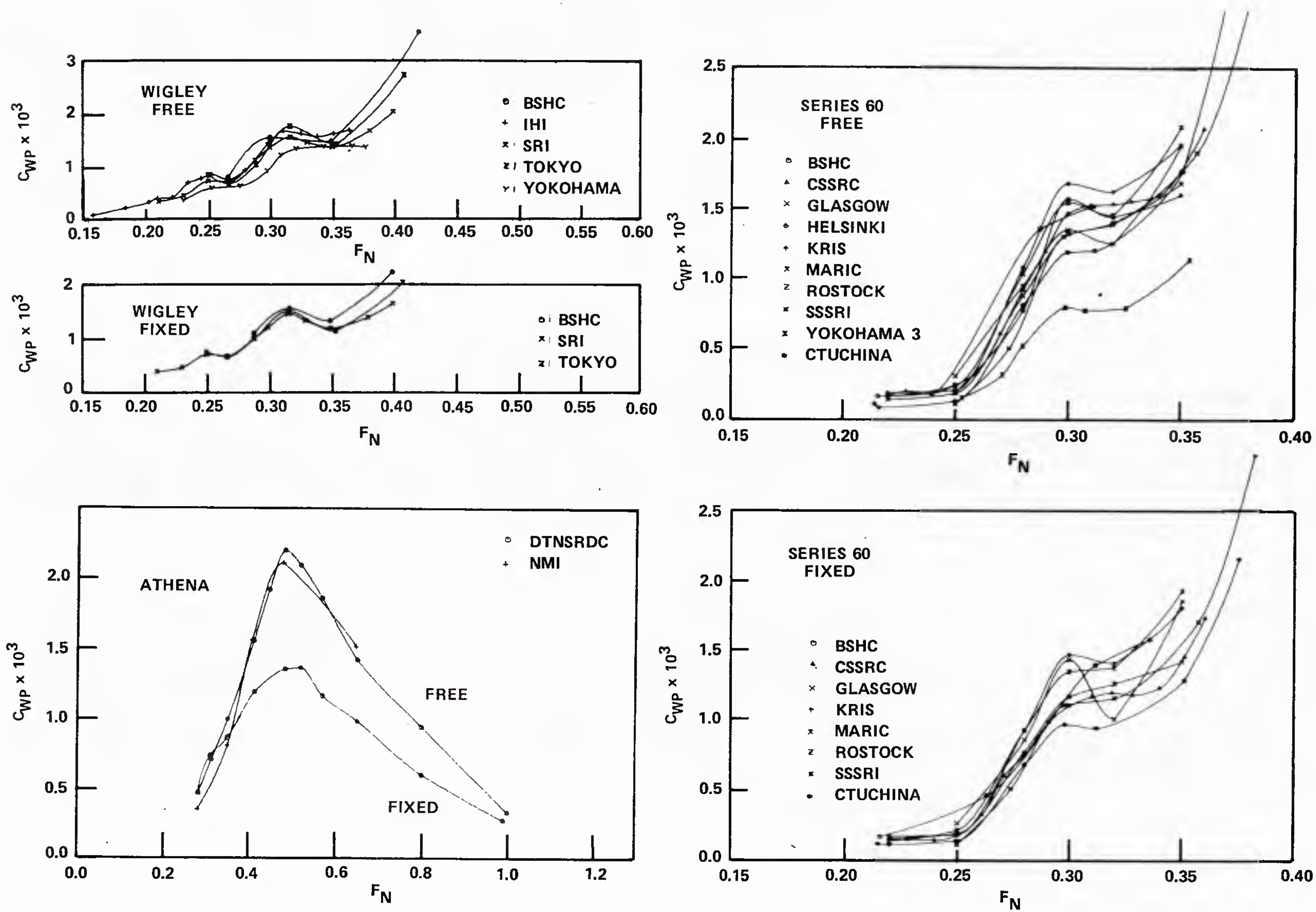


Figure 7 - Wave Pattern Resistance C_{WP} for All Hulls

than that for the free models, for the Series 60 and the ATHENA hulls; and, the scatter is much the same as for the free models. This is understandable since, unlike the total resistance measurements, the wave measuring techniques are not affected by fixing the model.

WAKE SURVEY VISCOUS RESISTANCE

Values of the viscous resistance coefficients C_V are given in Table 2. As these results are for models at different Reynolds numbers, they cannot be compared directly. It is recognized, however, that a great deal of valuable further analysis is possible from the detailed wake survey results, and it is hoped that this will be part of a continuing analysis program.

WAVE PROFILES

Typical wave profiles for the three hulls are given in Figure 8. With the exception of the ATHENA results, the data scatter is commendably small.

SINKAGE AND TRIM

Results are available only for the Series 60 and Wigley hulls, and for the latter only one set of data has been obtained for the sinkage. The sinkage and trim coefficients are shown in Figure 9.

THE LOCAL MEASUREMENTS

A summary of the local measurements is presented in Table 3 for the Wigley and Series 60, C_B = 0.60, hulls. The type of test facility (towing tank TT, wind tunnel WT, or water channel WC) is indicated first, followed by the model length L, the Reynolds R_n and Froude F_n numbers, and the hull attitude. The three types of measurements are summarized in the subsequent columns. For the static pressure C_P and skin friction C_F, the measurement points were selected at locations along waterlines, streamlines, buttocks, or "girthlines." The latter is defined as a line along the hull at a constant fraction of the girth, measured from the keel. In most cases, measurements were made at specified longitudinal stations.

The locations of the boundary layer traverses may be seen in Figure 10 where the symbols represent the base points of the lines along which the traverses have been made. Such a line may be either in the normal direction (Hiroshima H, MHI, NMI,

TABLE 2 - MEASURED VISCOUS RESISTANCE COEFFICIENTS C_V FOR ALL HULLS*

Series 60 Hull — Viscous Resistance Coefficient $10^3\ C_V$

Froude No. F_n	CSSRC (B-1)†	Glasgow (-)	KRIS (B-4)	Rostock (B-6)	Yokohama 3 (B-9)	CTU (B-7)
Hull Attitude	FR	FR	FR	FX	FR	FR
Hull Length (m)	6.0	3.0	4.9	5.0	3.0	2.5
Water Temp. (°C)	15.1	-	-	-	15.0	21.4
0.220				3.092		4.293
0.226	3.276					
0.234					3.946	
0.250	3.255	2.250				
0.253					3.776	
0.271					3.565	
0.276	3.316					
0.280		2.866	3.400			4.187
0.299					3.623	
0.300	3.256					
0.326	3.465					
0.327					3.618	
0.350	3.446					

Wigley Hull

Froude No. F_n	Iowa (A-4)†	Yokohama 2 (A-3)
Hull Attitude	FX	FR
Hull Length (m)	3.0	2.0
Water Temp. (°C)	18.3	15.0
0.16	4.01	
0.17	3.97	
0.18	3.93	
0.19	3.89	
0.20	3.84	
0.21	3.78	
0.22	3.75	
0.23	3.79	5.948
0.24	3.83	
0.25	3.80	
0.26	3.76	
0.27	3.76	
0.276		5.460
0.28	3.76	
0.29	3.74	
0.30	3.69	
0.309		5.312
0.31	3.63	
0.32	3.58	
0.33	3.59	
0.34	3.62	
0.343		5.103
0.377		5.083

Athena Hull

Froude No. F_n	NMI (C-2)†
Hull Attitude	FR
Hull Length (m)	3.2
Water Temp. (°C)	21.0
0.28	4.73
0.35	3.91
0.41	4.50

†Complete data on microfiche by same number, inside back cover.

*Several organizations have reported wake contours but no viscous resistance.

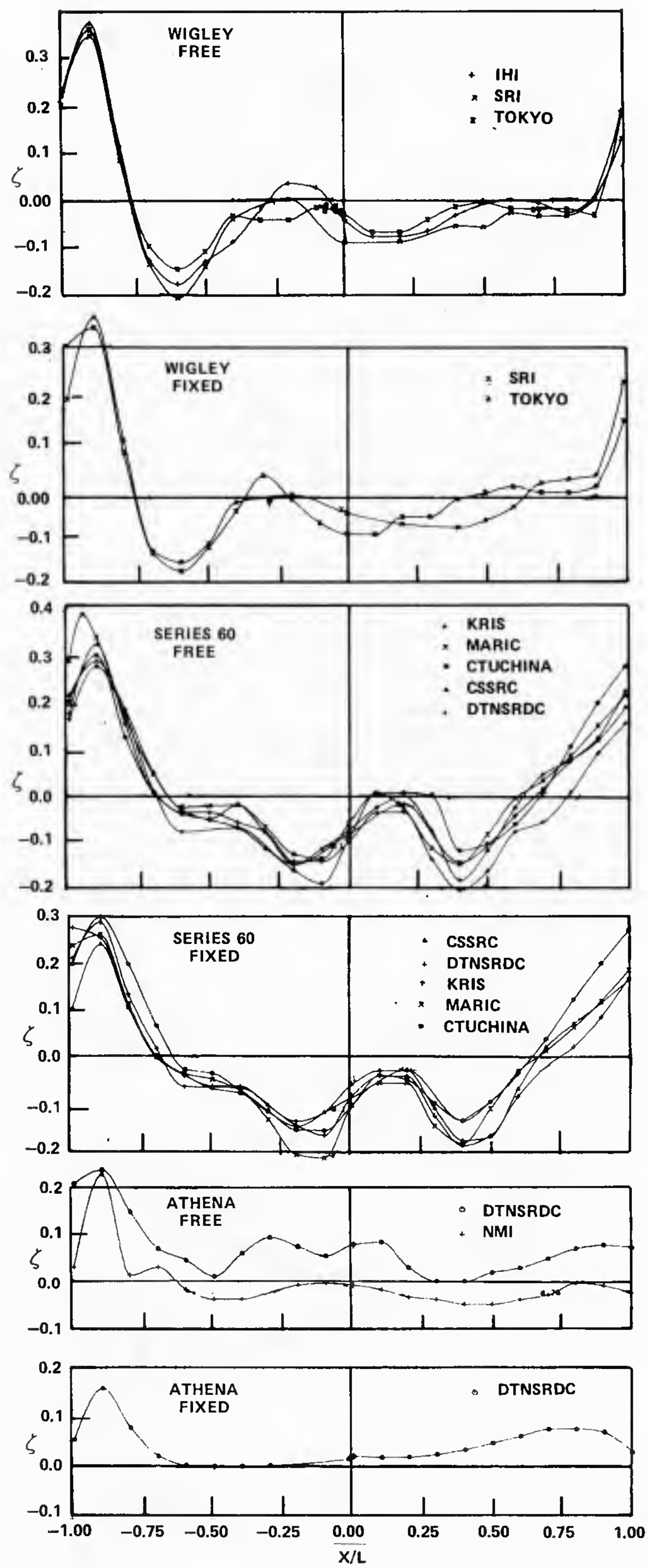


Figure 8 - Wave Profiles for All Hulls

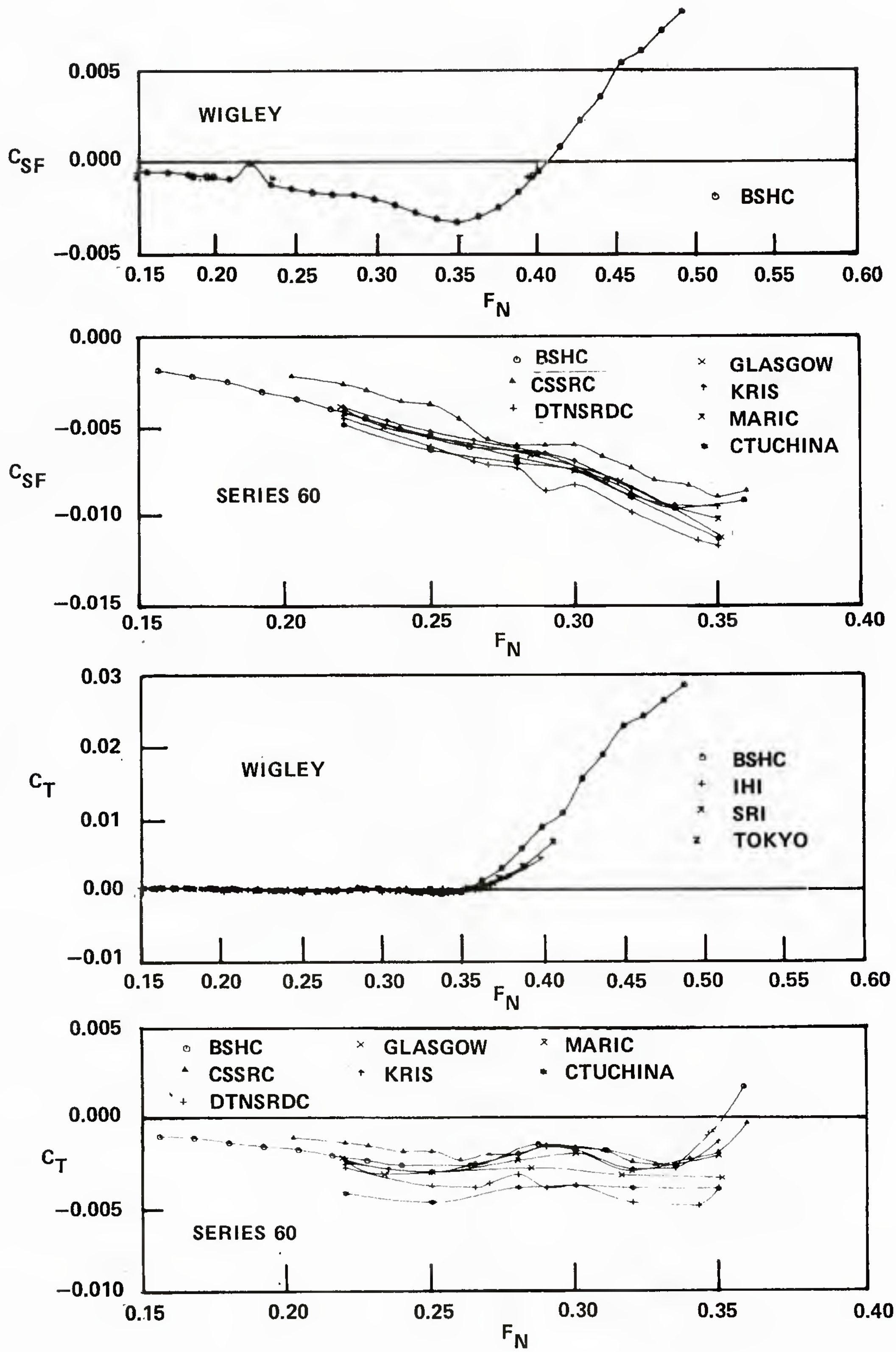


Figure 9 - Forward Sinkage and Trim

and Yokohama) or at X = const, Z = const (BSHC, Hiroshima M, and Rostock). It turns out, however, that the differences between these types of lines are small for the major part of the stern profiles for the Wigley and Series 60, $C_B = 0.60$, hulls.

As appears from Table 3 and Figure 10, the locations for the local measurements are quite different from case to case. Therefore, it is not possible, without interpolation, to present extensive comparisons. Some results may, however, be compared easily, and these are presented in Figure 11. The most complete comparisons can be made for the boundary-layer measurements near the stern of the Wigley model. At $X/\ell = 0.7$, results are available from MHI, NMI, and Yokohama (wind tunnel and towing tank). At $X/\ell = 0.9$, the two sets of results from Hiroshima and those from Yokohama can be compared. Comparisons are also possible at sections $X/\ell = 1.0$ (AP), 1.1, and 1.2. At the after perpendicular (AP), results are also available from NMI. In the figures, the longitudinal momentum thickness is plotted as a function of the arc length, measured along the girth from the keel. Where several measurements of the same kind are available, these have been connected by smooth lines.

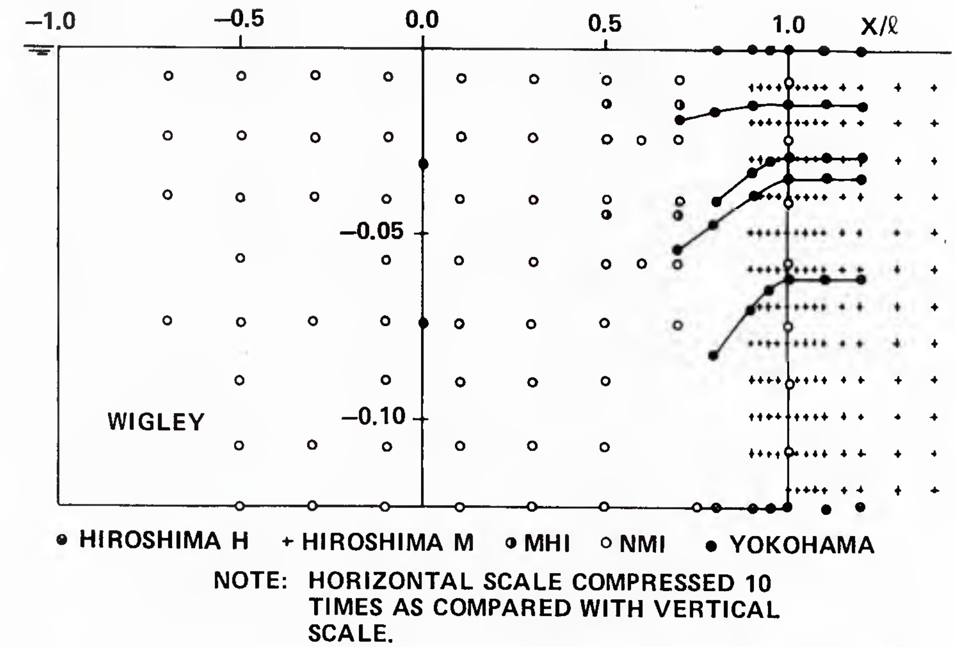
The comparisons between the different results might have been expected to display both Froude and Reynolds number dependence and experimental scatter. However, the only obvious difference in this respect, which can be judged from Figure 11, is the relatively large momentum thickness from the Hiroshima H data, no doubt due to a factor of 10 spread between the values of the NMI and the Hiroshima H Reynolds numbers. The Froude number influence can be judged by comparing the results from NMI. Figure 12 shows the momentum thickness distribution at $Z/D = 0.2$ and wave profiles at three values of F_n. Although the waterline in question is quite close to the free surface, the effects of the waves on momentum thickness are quite small. This is somewhat surprising in view of the very strong influence of the waves on the pressure distribution, as shown in Figure 13. The good correlation between the towing-tank pressure data at different scales indicate no stern Reynolds number effects. More analysis of the data is required to arrive at detailed findings. Since the boundary-layer measurements for the Series 60 model were carried out along the horizontal lines at BSHC and Rostock, momentum thicknesses were not evaluated. Different locations have also been used for the pressure tappings, so it is not possible, without interpolation, to make pressure comparisons.

TABLE 3 - OVERVIEW OF THE LOCAL MEASUREMENTS

Organization	Facility	Model Length L (m)	Experimental Values: Reynolds No. 10^{-6} R_n	Froude No. F_n	Hull Attitude	Measurement Locations: C_P*	C_F	BL Traverses: Dim	Turb	Complete Data on Microfiche (MF) No.†
			Wigley Hull							
Hiroshima M	TT	3	3.2	0.2	FX	--	--	3D	--	A- 6
Hiroshima H	WC	1.2	0.8	double model	--	--	--	3D	yes	A- 7
IHI	TT	6	8.9-11.2	0.25-0.32	FR	12 WL,23 ST	--	--	--	A- 3
Melbourne	WT	3	5	double model	--	7 WL,31 ST	7 WL,25 ST	--	--	A- 8
MHI	TT	8	12.5	0.17	FS	--	--	3D	--	A- 9
NMI	TT	6	7.4-14.8	0.16-0.32	FR	--	--	1D	--	A- 5
SRI	TT	4	5.5-6.9	0.25-0.32	FR	12 WL,23 ST	--	--	--	A- 3
Tokyo	TT	2.5	3.4-4.3	0.25-0.32	FR,FX	9 WL,17 ST	--	--	--	A- 3
Yokohama 2	TT	2	1.4	0.21	FR	--	--	3D	X	A-10
Yokohama 2	WT	2	1.4	(unconventional)	--	--	--	3D	X	A-10
			Series 60, C_B = 0.60 Hull							
BSHC	TT	7	9.6	0.18		--	--	3D	--	B-11
CSSRC	TT	6	16.0	0.35	FR	7 WL,11 BL	--	--	--	B- 1
DTNSRDC	TT	6	10.1-14.7	0.22-0.32	FR	4 SL,17 ST +1 WL	4 SL,17 ST +1 WL	--	--	B-12
Rostock	TT	5	7.7	0.22	FR,FX	10 GL,13 ST	--	3D	--	B- 6
Yokohama 3	TT	3	3.4	0.21	FR	--	--	3D	yes	B-13

*Resistance coefficients: C_P = pressure and C_F = skin friction.

†Inside back cover.



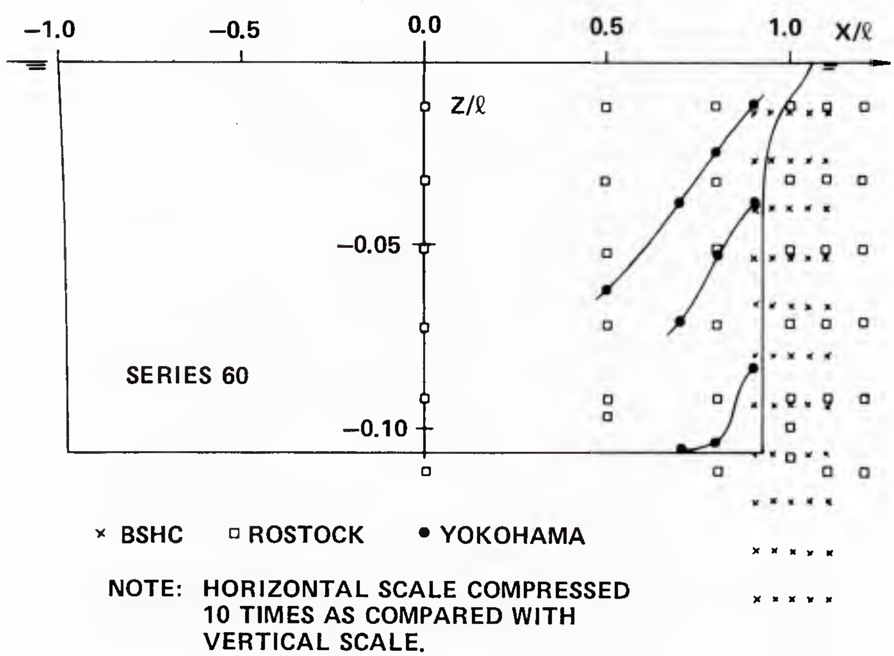
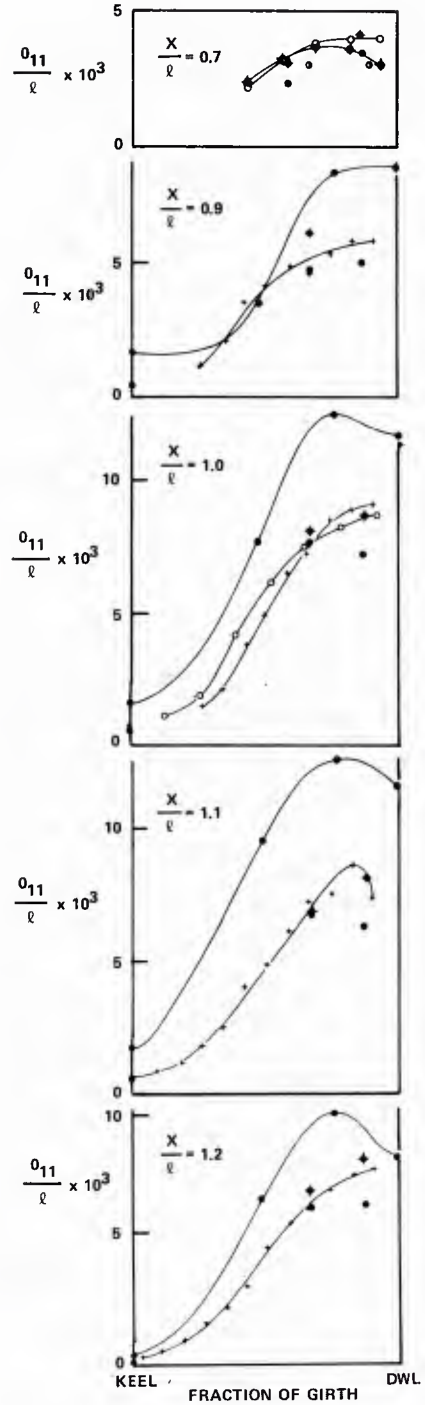


Figure 10 - Locations of the Boundary Layer (BL) Traverses



	⊗ HIROSHIMA H	+ HIROSHIMA M	⊙ MHI	○ ⊖ NMI	● ◆ YOKOHAMA 2
F_n		0.20	0.17	0.16 0.32	0.21
$R_n \times 10^{-6}$	0.8	3.2	12.5	7.4 14.8	1.4 1.4

Figure 11 - The Girthwise Distribution of the Momentum Thickness on the Wigley Hull

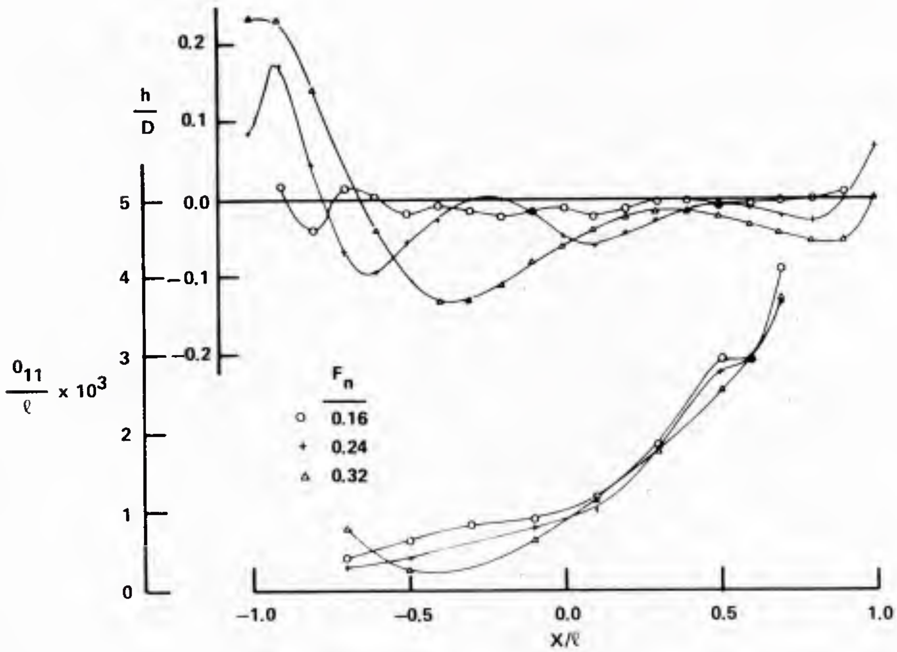


Figure 12 - Wave Profiles and Momentum Thickness on the Wigley Hull for Z/D = 0.2 (NMI Results)

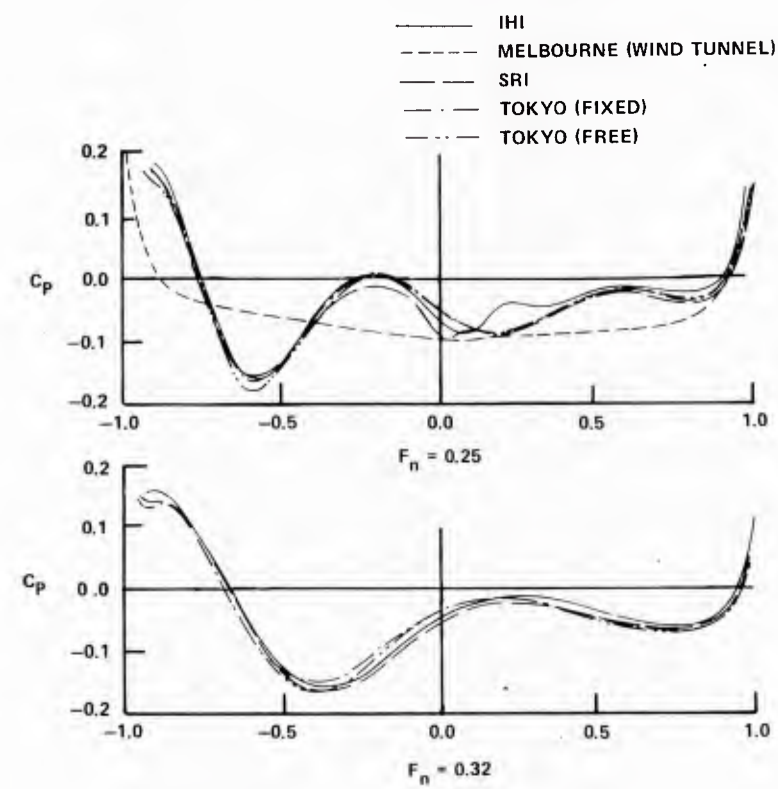


Figure 13 - Pressure Distributions on the Wigley Hull for Z/D = 0.2

SUMMARY

From the brief review presented here it is apparent that the Cooperative Experimental Program has been successful in establishing a valuable data base which can be used for the validation and further development of theories for the prediction of fluid flow over model hulls and values of resistance components. Many experiments initiated under this program are still in progress. The participating organizations should be encouraged to carry their work through to completion. It is recognized that a great deal of detailed analysis of the data can still be done to identify the relative importance of the Froude and Reynolds numbers, test conditions, model scale and attitude, and measurement techniques. However, even from the limited analysis presented here, it is encouraging to note that, despite differences in measurement techniques, most laboratories produce similar results for the same hull under similar conditions. A general point worth noting is that caution should be exercised when using very small models. It is evident that some results from the smaller models tend to be different from those obtained from larger models.

APPENDIX

DISCUSSIONS OF THE RESISTANCE COMMITTEE COOPERATIVE EXPERIMENTAL PROGRAM AT THE 17th ITTC

(Gothenburg, Sept 1984)

Discussion A.1

"On Data and Presentation of the Cooperative Experimental Program"

Masaaki Namimatsu and Ryo Tasaki
(Ishikawajima-Harima Heavy Industries Co., Ltd.,
Yokohama, Japan)

The authors would like to correct a misprint in a table of the pressure distribution in the report presented to the Resistance Committee, entitled "1983 Report on the Cooperative Experiments on Wigley Parabolic Models in Japan." The C_P value of IHI model at Z/D = -0.20, x/(L/2) = 0.2, for F_n = 0.25 on p. 6-6 should be corrected from "-0.40" to "-0.93." Figure A.1.1 is the corrected figure corresponding to Figure 13 of the Committee Report. It is found that the agreement of the results is much improved.

The trim coefficients for Wigley hulls are plotted in Figure 9 of the Committee Report. In the figure, the half values are plotted for the Japanese models. The trim coefficients of the Japanese models are, however, nondimensionalized by the model length. All the data of Wigley models are plotted in Figure A.1.2. The results of the four models are in good agreement with each other.

The sinkage of a ship is caused by the velocity increase around the hull, and the trim is caused by the longitudinal asymmetry of the force including the effect of ship waves and skin friction. Figure 9 of the Committee Report shows the sinkage at the fore end. However, it may be better to plot the mean value of fore and aft sinkage, considering the above physical meaning of the sinkage.

Figure A.1.3 shows the reanalyzed data of sinkage for Wigley hulls expressed by

$$\sigma = \frac{g}{U^2} (\delta_A + \delta_F) \qquad (A.1.1)$$

where δ_F and δ_A are the sinkage of the fore and aft ends, respectively, g is the gravitational acceleration, and U is the ship speed. This expression seems to be rational from the view point of hydrodynamical forces acting on the hull surface and has been used in the Workshop on Ship Wave-Resistance Computations.[1] The values of sinkage at the lower Froude numbers scatter because of errors in the measurement. An error in the sinkage measurement can be evaluated as the effect of seiche in towing tanks.[2]

In Figure A.1.3 the solid line is the sinkage calculated by using the wave potential. The wave potential is expressed by Michell's thin ship approximation, and the vertical pressure force can be calculated as

$$F_z = - \rho U \iint \frac{\partial \phi}{\partial x} \frac{\partial f}{\partial z} \, dx \, dz \tag{A.1.2}$$

where ϕ is the wave potential of thin ship approximation, and f is the hull offset $y = f(x,z)$.

The calculated result has humps and hollows and qualitatively agrees with the experimental results. The dotted line is the sinkage estimated by using the double model flow.[3] The calculation gives a constant value of σ and corresponds well to the experimental value at the lower Froude numbers where the sinkage is very small. Behavior of the sinkage at the low speed has been discussed by Kajitani et al. taking into account the viscous effect.[4]

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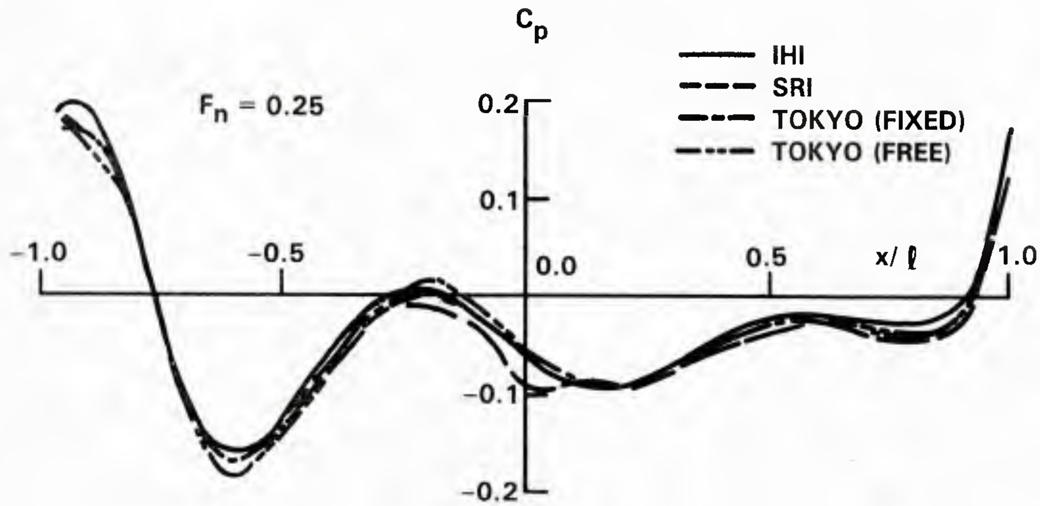

Figure A.1.1 - Pressure Distribution on the Wigley Hull for Z/D = 0.2

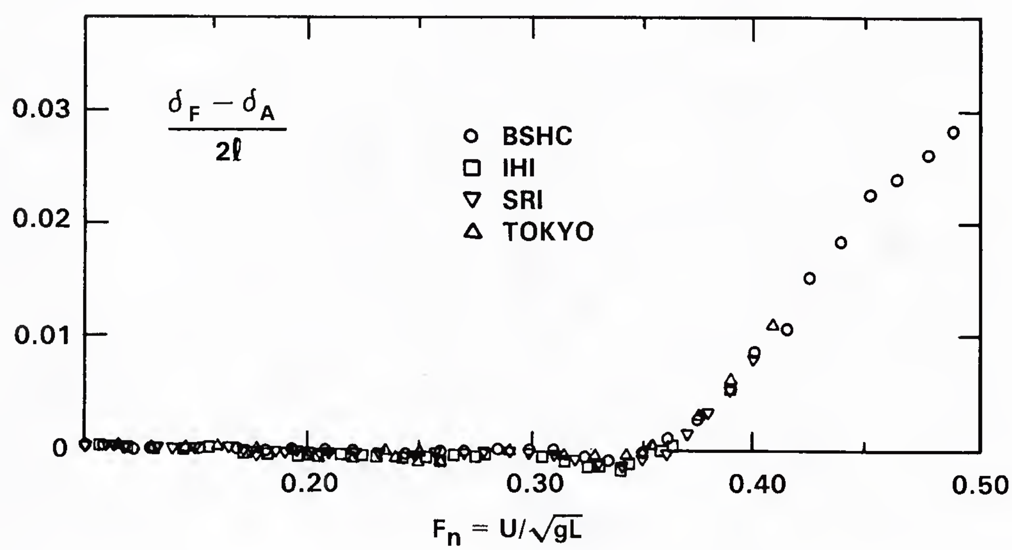

Figure A.1.2 - Trim Coefficients of the Wigley Hull

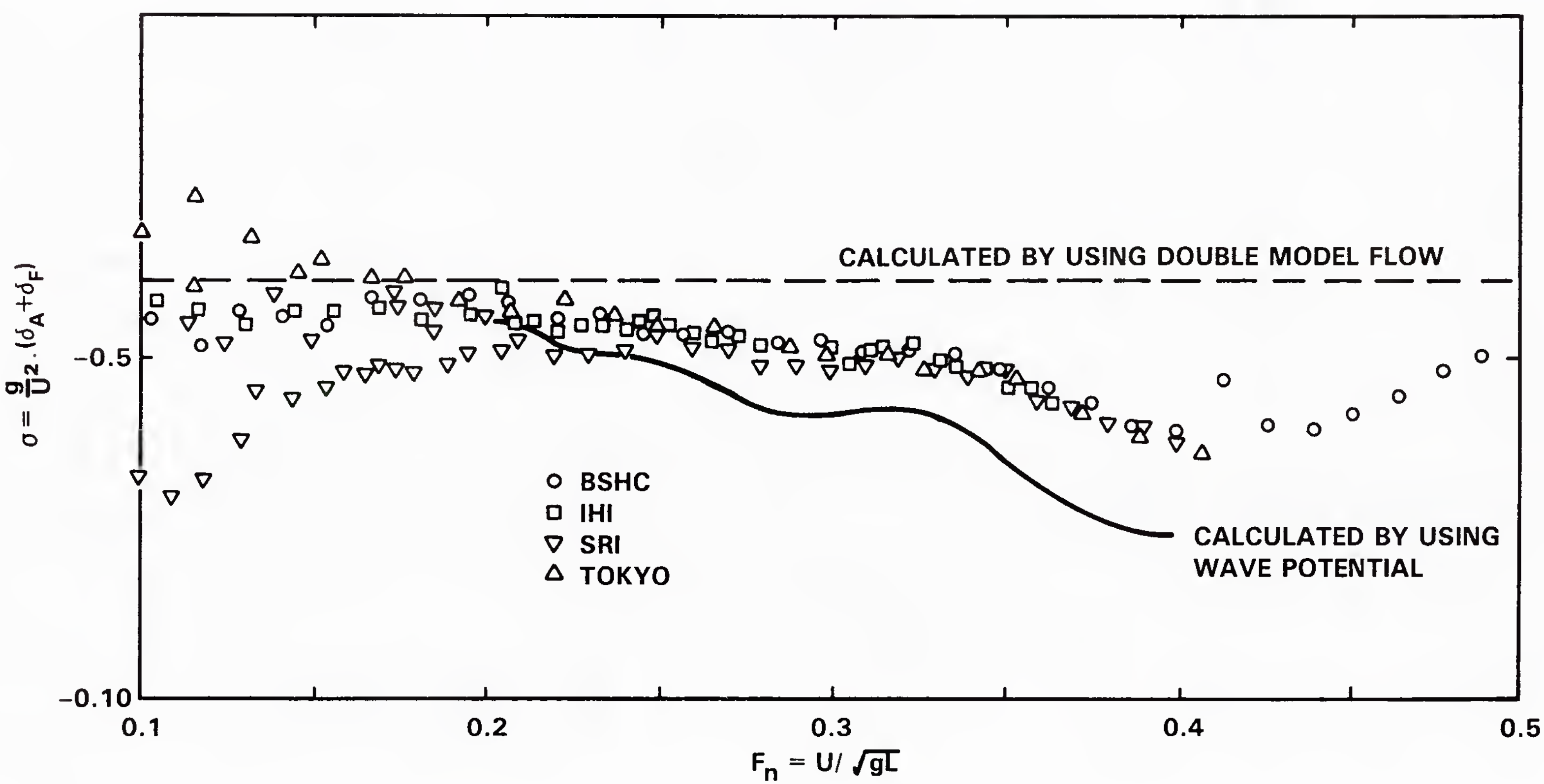

Figure A.1.3 - The Sinkage of Wigley Hull

Discussion A.2

"Effect of Seiche on Measurement of Sinkage in Towing Tanks"

Ryo Tasaki and Seikoo Ogiwara
(Ishikawajima-Harima Heavy Industries Co., Ltd.,
Yokohama, Japan)

INTRODUCTION

The Resistance Committee reports on the attitude of model ships in the comparative experimental program. The sinkage was presented by the nondimensional expression

$$\sigma = \frac{g}{V^2} (\delta_A + \delta_F) \tag{A.2.1}$$

in the Workshop on Ship Wave-Resistance Computations.[1] Here g is the acceleration of gravity, V is the model speed, and δ_A and δ_F are the aft and fore sinkage, respectively. The Japanese report of Wigley models also uses this expression.[2] The expression exaggerates values at the low speed where the sinkage is small itself and errors are liable to occur in the measurement. The expression tends, however, to a limiting value for V = 0 and gives a clue to examine the validity of mathematical models.[3,4]

Herewith the authors show that the effect of seiche is predominant in the error of sinkage measurement in towing tanks and suggest a cure to remove it.

INVESTIGATION WITH A MATHEMATICAL MODEL

MATHEMATICAL MODEL

The coordinate system is shown in Figure A.2.1 where a is the tank length, h is the water depth, and x is the position of a carriage measured from the starting end of the tank. The elevation of water surface observed from the carriage running at a speed V is written for the seiche of unit amplitude with a single node as

$$Z = \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi\sqrt{gh}}{V} \frac{x-x_0}{a} + \phi\right)$$

$$= \cos (\pi\xi) \cos (\pi f\xi + \Phi) \tag{A.2.2}$$

where x_0 is the point from which the carriage runs with a constant speed ($x = x_0$) and ϕ is the arbitrary phase of seiche at $x = x_0$; also,

$$\xi = x/a, \quad \xi_0 = x_0/a, \quad \Phi = \phi - \pi f \xi_0$$

$$f = \sqrt{gh}/V = 1/F_h = \sqrt{h}/L\ (1/F_n)$$

where F_h is the water depth Froude number, and F_n is the ship length Froude number. When the sinkage measurement is done over a measuring range between $x = x_1 = \xi_1 a$ and $x_2 = \xi_2 a$, the mean elevation of water surface over the range is expressed as

$$S = \frac{1}{\xi_2 - \xi_1} \int_{\xi_1}^{\xi_2} \cos \pi\xi \cos (\pi f \xi + \Phi)\, d\xi$$

$$= P \cos \Phi + Q \sin \Phi \tag{A.2.3}$$

where P and Q are functions of f, ξ_1 and ξ_2, and Φ is to be an arbitrary phase. The amplitude of S is defined as the seiche amplitude factor

$$S_F = |S| = \sqrt{P^2 + Q^2}$$

$$= \frac{1}{\pi\lambda(f^2-1)} \{(f^2+1)\ (1-\cos \pi\lambda \cos \pi f\lambda) - 2f \sin \pi\lambda \sin \pi f\lambda$$

$$+ (f^2-1)\ (\cos \pi\lambda - \cos \pi f\lambda) \cos 2\pi\varepsilon\}^{1/2} \tag{A.2.4}$$

where

$$\lambda = \xi_2 - \xi_1 \text{ and } 2\varepsilon = \xi_1 + \xi_2 - 1$$

The seiche factor S_F presents the effect of seiche on the sinkage measurement and is a function of the three parameters:

a. the water depth Froude number $F_h = V/\sqrt{gh}$

b. the ratio of the length of measuring range to the tank length λ

c. the position of the range, that is, the ratio of the distance between the middle point of the range and the tank to the tank length ε

CHARACTERISTICS OF SEICHE AMPLITUDE FACTOR

Effect of the Length of Measuring Range

The effect of the length of the measuring range is shown in Figure A.2.2 for the case where the middle point of the measuring range coincides with that of the tank length. The effect is noticeable, and the shorter measuring range has the smaller effect. It is recommended for making accurate measurement of the sinkage to use the mean value of sinkage over one-half the length of the tank for $F_n \simeq F_h < 0.2$, and one-quarter the length for $F_h > 0.2$.

Effect of the Position of the Measuring Range

The effect of the position of measuring range, ε is shown in Figure A.2.3 for the case where the length of the measuring range is half the tank length. It is concluded that the effect is negligible when the range includes the middle point of the tank as the usual towing tank practice.

Humps and Hollows of the Amplitude Factor

The amplitude factor has humps and hollows dependent upon the water depth Froude number. Froude numbers which correspond to humps and hollows are roughly estimated by the formulae

Humps at $F_h = \lambda/2n$

and

Hollows at $F_h = \lambda/(2n-1)$, $n = 1, 2, 3, \ldots$

Effect of Seiche in a Progressive Test

Frequently in long towing tanks progressive speed tests are run. This is, however, unfavorable for the sinkage measurement because a calculation shows that in the low-speed range, the error due to seiche of a progressive test can be 10 times as large as that of a speed test in a run.[5]

PRACTICAL EXAMPLES

Because the sinkage is proportional to V^2, the differences between the experimental σ's at the two successive Froude numbers may be regarded as a variation in the data when the differences of the Froude numbers are small. Figure A.2.4 shows an example of the variation of σ for a Wigley model. In the figure the solid lines are the σ's calculated by S_F for the seiches of given amplitudes ξ(mm) and the dotted lines by the given uniform vertical displacement z(mm). The scattering of the data is the variation due to seiche.

The effect of seiche on the sinkage measurement for practical ship forms is given in Table A.2.1. The seiche of amplitude 1 mm which is assumed in Table A.2.1, is usually observed in towing tanks and brings about the following order of variations in the sinkage measurement in towing tanks:

0.1 mm for $F_n < 0.07$

0.2 mm for $0.07 < F_n < 0.16$

0.4 mm for $0.16 < F_n < 0.20$

0.6 mm for $0.20 < F_n < 0.40$

These variations are not more than 10% of the values to be measured and can be neglected in usual tests. Attention should be paid however to the latent influence of seiche as the amplitude grows possibly even up to more than 3 mm.[6] The effect of seiche on the sinkage measurement is relatively large for a fine ship form. Further, the periods of seiche in the towing tanks are the order of a minute. Attention should be paid when adjusting the zero for sinkage measurement.

CONCLUSION

The effect of seiche on the sinkage measurement in towing tanks is investigated by using a simple mathematical model and practical examples; it is shown that attention should be paid to the effect when doing elaborate experiments such as comparative experiments and geosim tests. Recently, numerical methods and new tank test techniques have brought rapid progress and many interesting and useful findings. These findings should be finally examined through rather conventional tank tests. It seems that greater development in ship hydrodynamics requires more accurate tank work. It is desired that more tank problems be added to the committee's discussions.

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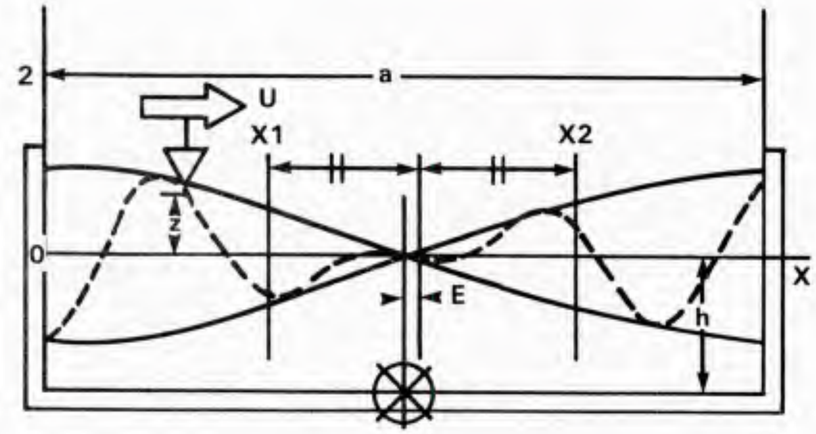


Figure A.2.1 - Coordinate System

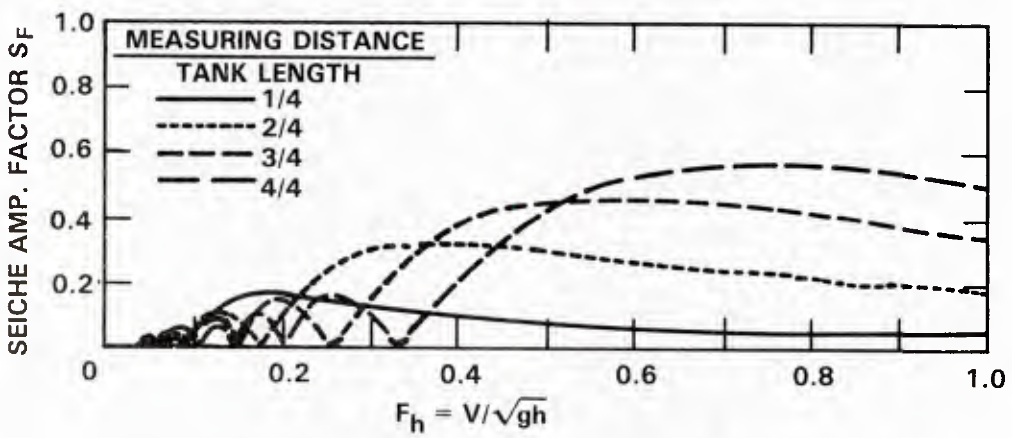


Figure A.2.2 - Seiche Amplitude Factor (Effect of Measuring Distance)

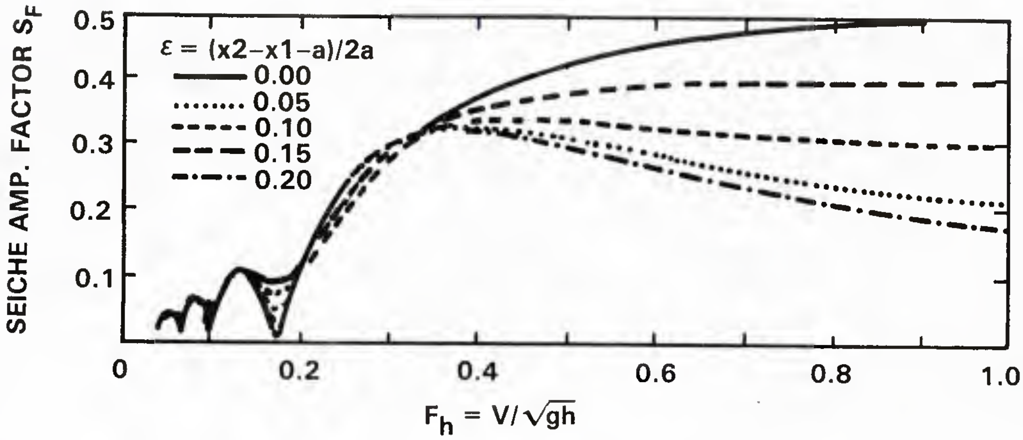


Figure A.2.3 - Seiche Amplitude Factor (Effect of Measuring Position ε)

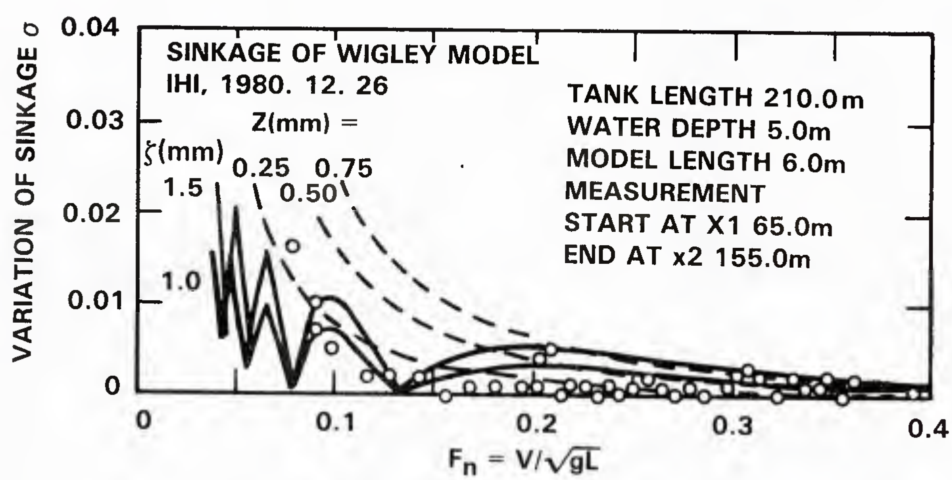


Figure A.2.4 - Variation of σ of a Wigley Model

TABLE A.2.1 - EXAMPLES OF THE EFFECT OF SEICHE ON THE MEASUREMENT OF SINKAGE

$F_n = V/\sqrt{(gL)}$ $F_h = V/\sqrt{(gh)}$	0.10 0.11				0.20 0.22				0.25 0.27				0.30 0.33			
Var. Due to Seiche σ (mm)	0.20 0.007				0.44 0.004				0.55 0.003				0.56 0.002			
Kind of Ship*	T	M	C	W	T	M	C	W	T	M	C	W	T	M	C	W
Sinkage σ (mm)	3.7 0.12	2.6 0.09	2.2 0.07	1.0 0.03	14.6 0.12	10.6 0.09	9.0 0.08	5.0 0.04	-- --	-- --	14.6 0.08	8.4 0.04	-- --	-- --	-- --	13.5 0.05
Percentage Due to Seiche	5	8	9	20	3	4	5	9	--	--	4	7	--	--	--	4

*T = Tanker, M = Medium-speed ship, C = Container ship, and W = Wigley model.

Remarks: Amplitude of seiche is assumed to be 1.0 mm. Length of tank = 210 m. Depth of water = 5.0 m, Length of model = 6 m. Measuring range = 65-155 m.

Discussion A.3

"Wave-Pattern Resistance of Geosims"

Fu-sheng Chen and Tong-quan Xu
(Shanghai Ship and Shipping Research Institute)

The wave-pattern measurement of the 1.8-m, Series 60, $C_B = 0.60$, 4210W model were carried out in tank No. 1 of SSSRI in July 1981 and April 1982; the results were submitted to the Resistance Committee of the 17th ITTC. In Nov. 1983, the same work was done on a 3.84-m wood model of the same lines in the No. 2 tank of SSSRI.

MODEL AND TANK

THE MODEL

Lines:	Parent model 4210W of Series 60, $C_B = 0.60$
Lbp × B × T:	$3.84 \times 0.512 \times 0.205\ m^3$
Wetted surface:	$2.514\ m^2$
Displacement:	241.6 kg
Trip wire:	1 mm at stn. 19

THE TANK

L × B × H:	$192 \times 10 \times 4.5\ m^3$
Water depth:	4.2 m

TEST CONDITION AND RESULT

The wave pattern and wave profile along the hull's side were measured in Nov. 1983. The water temperature was 15.8°C. The signal of wave height was picked up by a wave probe of the KGY-2 type and recorded on the XWT-type recorder. The signal of a photocell indicating the position of the model relative to the generated wave was also recorded on the XWT recorder. The wave probe was placed at a transverse distance Y = 1.096 m from the center line of the model, for which Y/L = 0.285. The calculation according to Sharma's method was used. Figure A.3.1 shows the amplitude functions F and G for twelve F_n numbers. The curves of C_{WP} versus F_n are shown in Figure A.3.2 together with the results of the 1.8-m model tested in tank No. 1 in July 1981. It is clear that there is a certain effect of the size of the model on wave-pattern resistance, the smaller model giving the smaller value of resistance.

In order to study the effect of the transverse position of the probe on the measured wave-pattern resistance, five positions (Y/L = 0.185, 0.235, 0.285, 0.335, and 0.385) were used; the results are shown in Figure A.3.3. It can be seen that the result is similar to that obtained on the 1.8-m model in the smaller tank, and the effect of the value of Y on wave-pattern resistance is slightly significant at higher F_n numbers only.

Figure A.3.4 shows the wave profile along the hull surface at the above-mentioned twelve F_n, where ζ is the nondimensional wave height relative to the undisturbed water surface (nondimensioned with $U^2/2g$).

By comparing Figure A.3.2 with Figure 7 on p. 82 of the proceedings of the 17th ITTC, it can be concluded that the effect of the size of the model on the value of C_{WP} is not very large, and the effect of the accuracy of the measuring instruments may be an important factor.

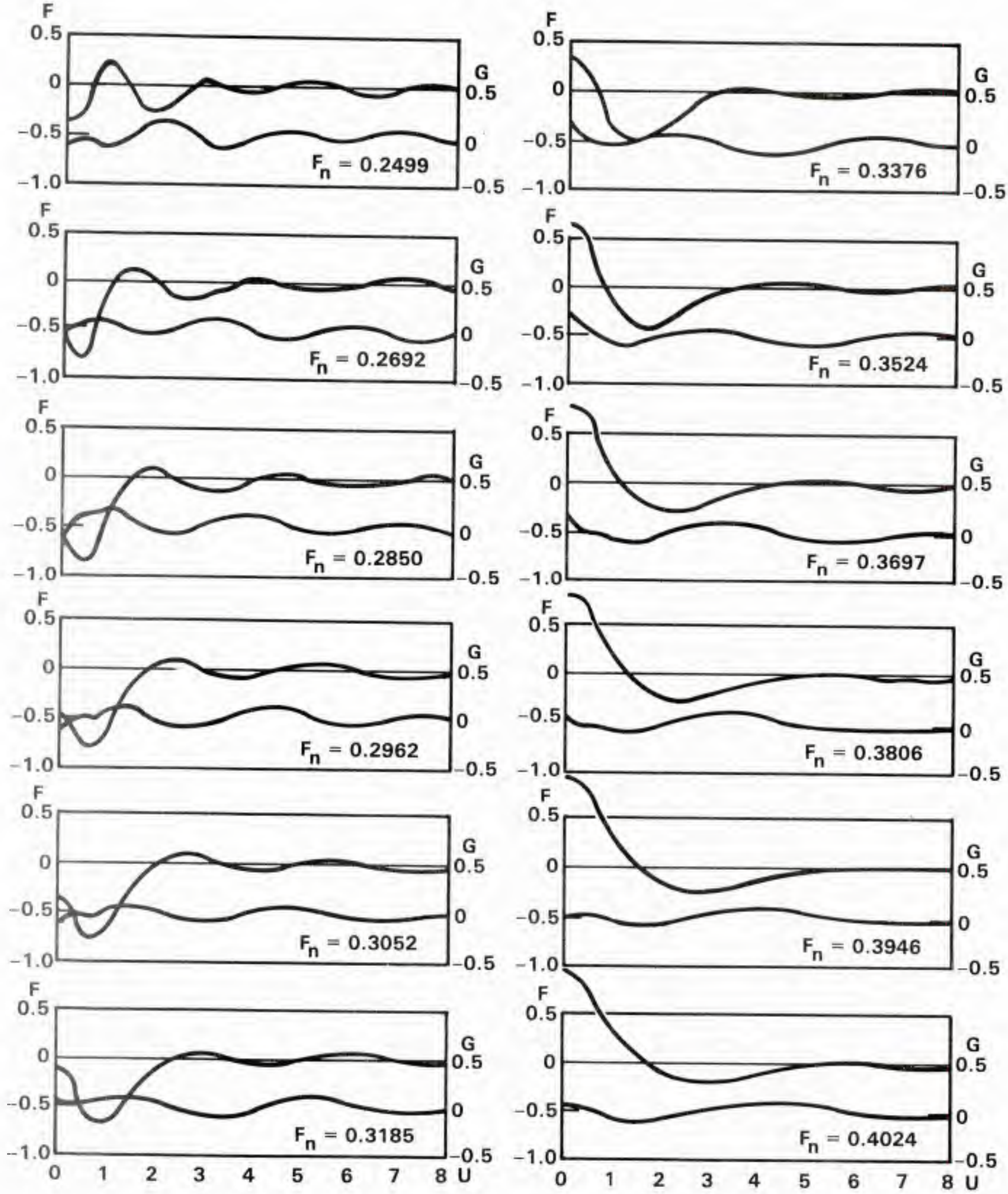


Figure A.3.1 - Amplitude Functions F and G for Twelve Values of F_n

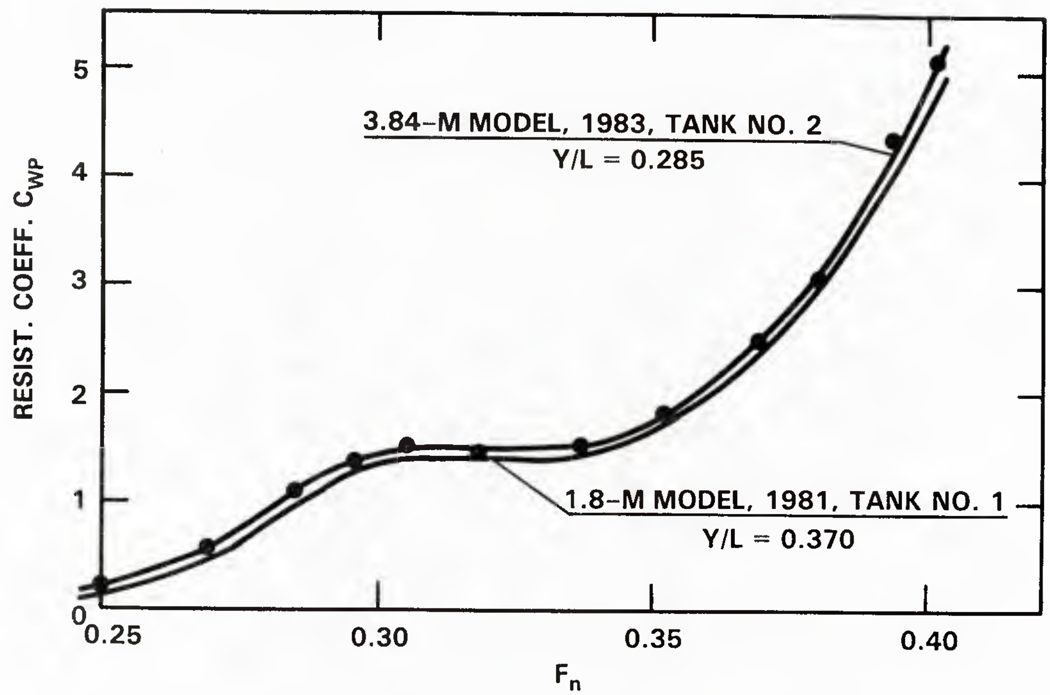


Figure A.3.2 - C_{WP} Curve of Geosims

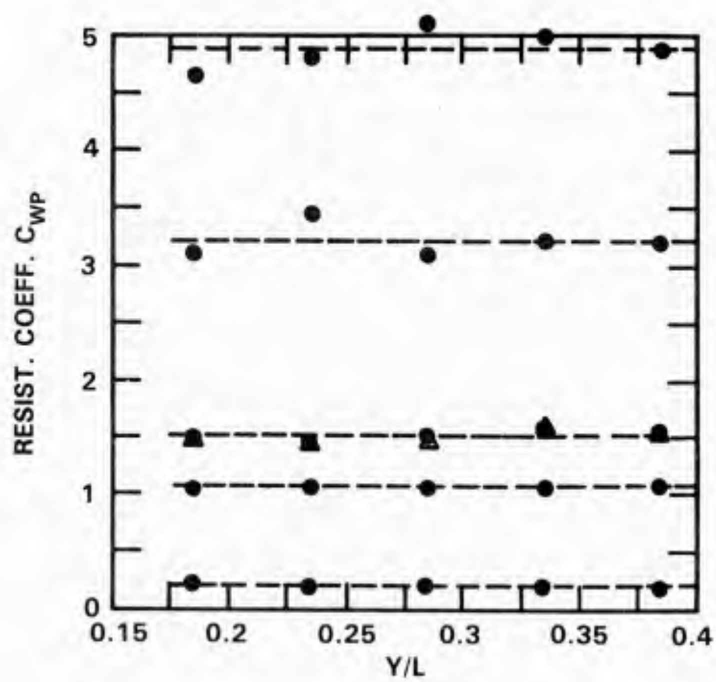


Figure A.3.3 - C_{WP} at Different Values of Y/L

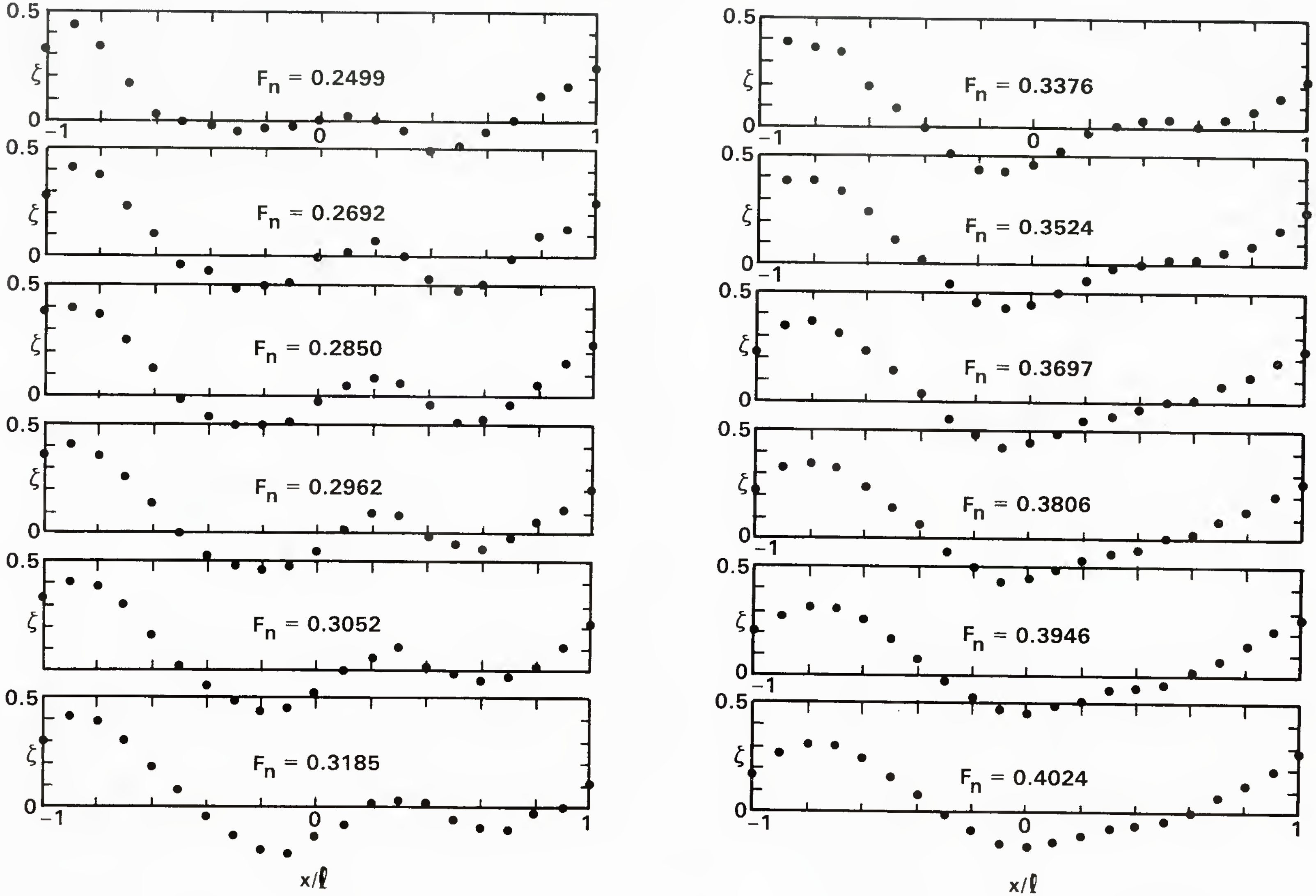


Figure A.3.4 – Wave Profile Alongside the Hull Surface

Discussion A.4

"Written Contribution to the Resistance Committee Reports"

K. Mori
(Hiroshima University)

The report of the Cooperative Experimental Program is invaluable. The data base which is published will contribute much toward future developments in related fields. The contributors are to be thanked.

Let me make a comment on one of the conclusions drawn: "A general point worth noting is the danger of using too small a model." This conclusion seems to come from the results of the 2.0-m Yokohama model, the 1.8-m SSSRI model (both for global measurements), and the 1.2-m Hiroshima H model (for local measurements). It is true that the Yokohama model is a little isolated in the Wigley resistance test, and so is the SSSRI model in the Series 60 wave-pattern resistance test. These differences, however, should not be attributed solely to the size of models. Experimental errors, which can be included in the larger models also, must be carefully examined before drawing such a "warning." Even larger models show different curves.

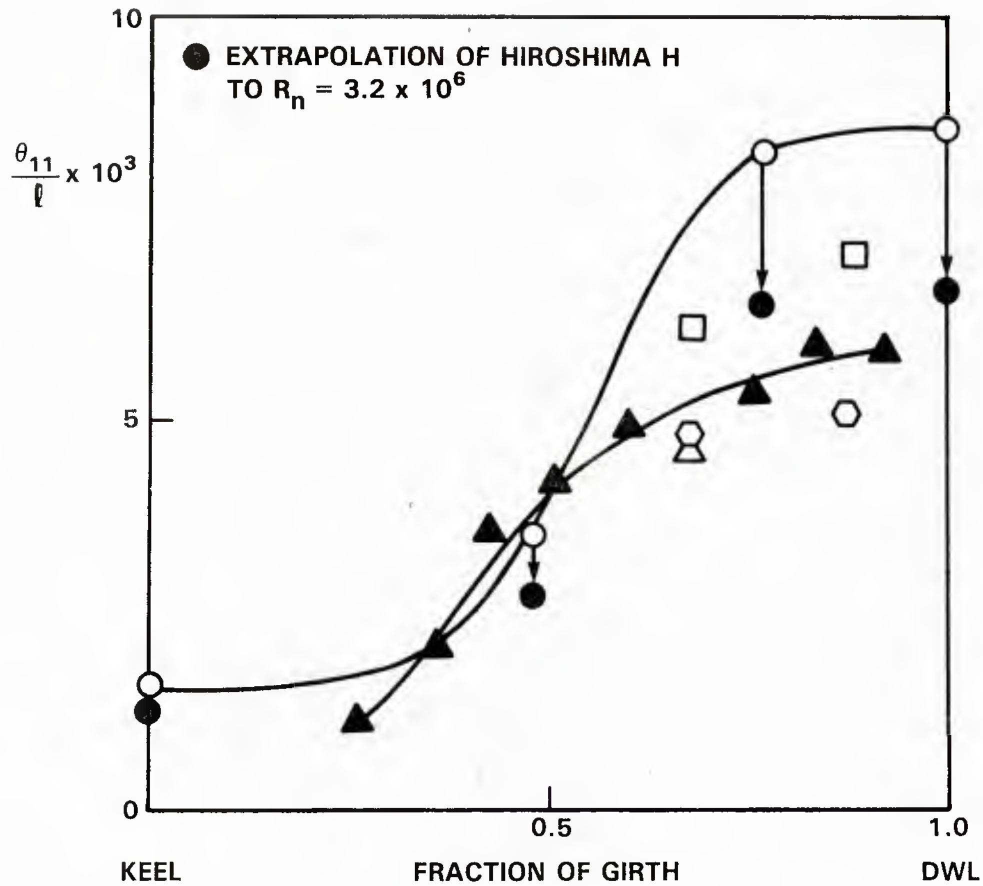
As mentioned briefly in the above report, the Reynolds number effects are included in the results. The results of Hiroshima H, shown in Figure 11 of that report, are examined from this standpoint.

The flat plate boundary layer theory tells us that the momentum thickness is proportional to $R_n^{-1/5}$; R_n is the Reynolds number. Under this assumption, we extrapolated Hiroshima H (R_n=0.8×10^6) to $R_n = 3.2 \times 10^6$, at which value Hiroshima M is carried out.

The calculated results are shown in Figures A.4.1 through A.4.4 by darkened circles. They show rather good agreement with Hiroshima M, except for $x/\ell = 1.1$ (Figure A.4.3). The discrepancies still remaining should be regarded as experimental errors which are possible in other results, also.

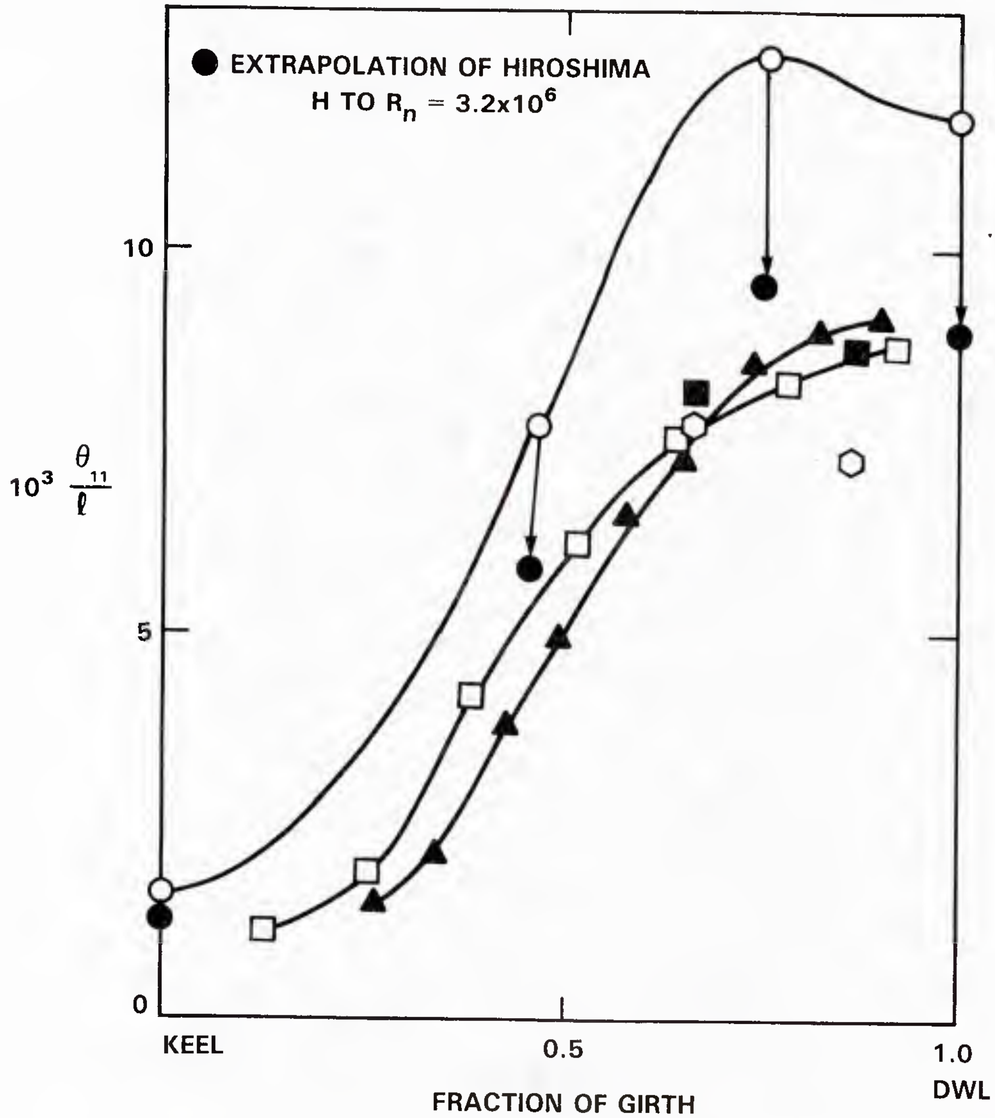
The wave-pattern resistance of Series 60 measured by SSSRI must also be defended. The wave-analysis method and the position of wave-recordings and truncation sometimes brings forth significant differences in the final resistance results, although those differences are not mentioned precisely.

As one of the researchers who is undertaking experiments by making use of rather small models, ranging from 1.2 m to 3.0 m, I strongly urge deleting the word "danger." I hope to draw a positive conclusion for small models through the present cooperative program.



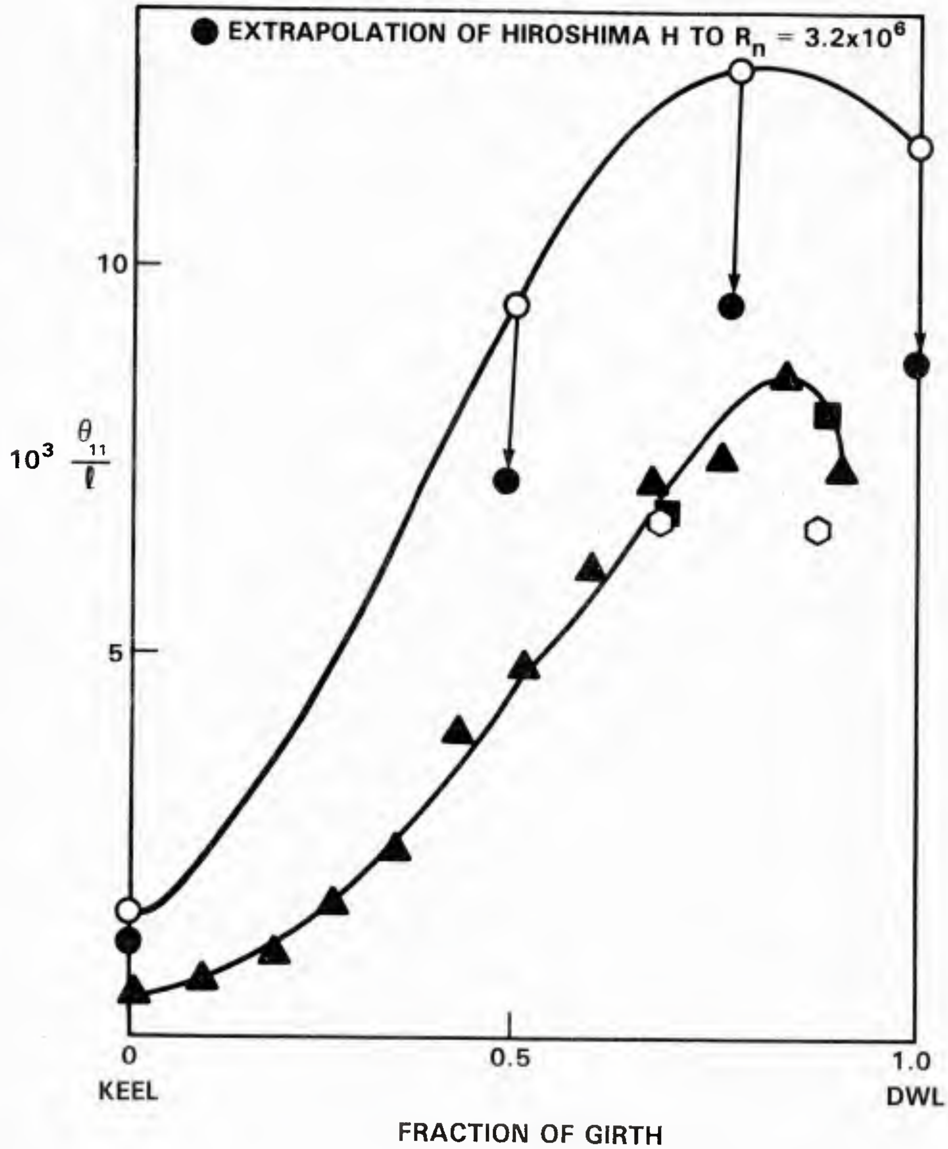
	○ HIROSHIMA H	▲ HIROSHIMA M	⬡	□ YOKOHAMA 2
F_n	—	0.20	0.21	—
$R_n \times 10^{-6}$	0.8	3.2	1.4	1.4

Figure A.4.1 - Momentum Thickness for Wigley Hull Models ($x/\ell = 0.9$)



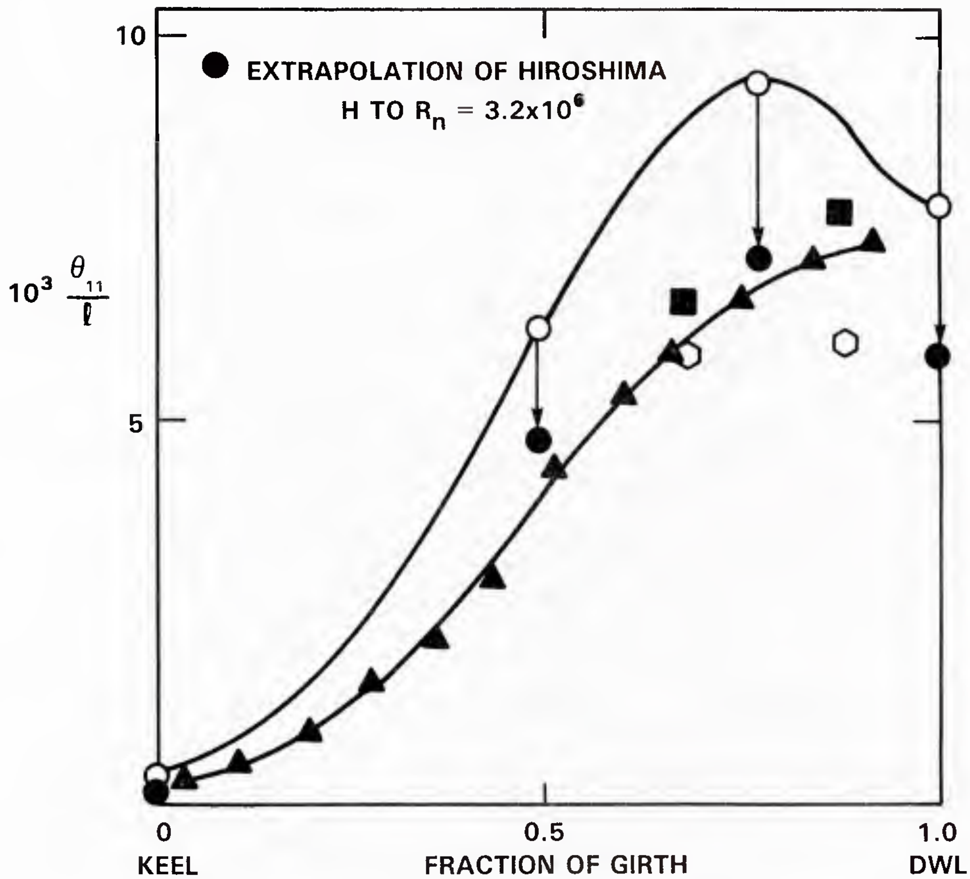
PARAMETER	○ HIROSHIMA H	▲ HIROSHIMA M	□ NMI	⬡	■ YOKOHAMA 2
F_n	—	0.20	0.16	0.21	—
$10^{-6} R_n$	0.8	3.20	7.4	1.40	1.40

Figure A.4.2 - Momentum Thickness for Wigley Hull Models (x/ℓ = 1.0 (AP))



PARAMETER	○ HIROSHIMA H	▲ HIROSHIMA M	⬡	■ YOKOHAMA 2
F_n	—	0.20	0.21	—
$10^{-6} R_n$	0.8	3.20	1.40	1.40

Figure A.4.3 - Momentum Thickness for Wigley Hull Models (x/ℓ = 1.1)



PARAMETER	○HIROSHIMA H	▲HIROSHIMA M	⬡	■YOKOHAMA 2
F_n	–	0.20	0.21	–
10^{-6} R_n	0.8	3.20	1.40	1.40

Figure A.4.4 - Momentum Thickness for Wigley Hull Models (x/ℓ = 1.2)

17th ITTC RESISTANCE COMMITTEE REPLY TO DISCUSSIONS

Mr. NAMINATSU and Dr. TASAKI point out a misprint in a table of pressure values which they supplied earlier to the Committee. We shall take due notice of this modification which indeed gives a much improved agreement of the results. We also thank the discussers for drawing our attention to an error in the plotting of the Japanese Wigley trim data (Figure 9 in main text). The correct results will be included in the final report on the Cooperative Experiments.

Mr. Naminatsu and Dr. Tasaki go on to discuss the merits of presenting curves of mean sinkage. The report gives curves of sinkage at the bow and curves of the change in trim from which it is possible, of course, to derive curves of mean sinkage. Mean sinkage would be expected to correlate better between tanks because the main source of errors is the detection of change in trim. As one of the Committee's briefs was to highlight inconsistencies in tank testing techniques, we thought it best to present the results as we did. However, since more than one delegate has made the request, curves of mean sinkage will be added in the final reporting.

Dr. TASAKI and Dr. OGIWARA raise the question of the effect of seiche on measurement of sinkage and trim. The Resistance Committee is fully aware of this phenomenon, but it is grateful to the discussers for offering a method of making corrections for it. We agree that experimentalists should make sure that effects of a seiche do not spoil their results.

Mr. FU-SHENG CHEN and Mr. TONG-QUAN XU provide us with new results for the Cooperative Experimental Program, which is a most valuable addition to the data already supplied. Experiments have been carried out for a geosim model about twice as large as the original 1.8-m model, using the same equipment. The spread between the results of the respective models is considerably less than the spread between results of models of similar size but tested in different towing tanks. This seems to indicate that the warning given in the Committee's report concerning the use of small models is somewhat premature. However, some other results have been obtained with small models which depart to some extent from the bulk of the other data. In view of anticipated scale effects on the resistance components, this is not surprising, so it is still the opinion of the Committee that considerable caution is necessary when analysing the results of small models.

The new results presented in the discussion will be included in the final report on the Cooperative Experiments.

The topic of small-model testing is also taken up by Prof. MORI. He is quite right in pointing out that the momentum thickness results of the Hiroshima H experiments can be shown to be consistent with those of the Hiroshima M experiments by employing a simple flat-plate boundary layer extrapolation method. In fact, the same exercise has been carried out by the Committee and the same conclusions were drawn. The warning concerning the use of small models was rather motivated by some of the results in the global measurements. Although admittedly the word "danger" should better have been avoided, the Committee still feels that extra caution is needed when interpreting tests with small models.

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