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EXPERIMENTAL MEASUREMENTS OF THE SEAKEEPING CHARACTERISTICS OF FAST 4.5m DISPLACEMENT CATAMARANS IN OPEN IRREGULAR SEAS

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CONTENTS

NOMENCLATURE

Demihull	One of the hulls which make up the catamaran
LCG	Longitudinal centre of gravity
TF	Transfer function
RMS	Root mean square
Fn	Froude Number, $\left[u / \sqrt{gL}\right]$
u	Velocity [$\mathrm{ms^{-1}}$]
L, L_{BP}	Demihull length between perpendiculars [m]
A, WSA	Static wetted surface area [$\mathrm{m^2}$]
B	Demihull maximum beam [m]
T	Demihull draught [m]
S	Separation between catamaran demihull centrelines [m]
∇	Volume of displacement (demihull) [$\mathrm{m^3}$]
Δ	Mass displacement in freshwater (demihull) [kg]
C_B	Block coefficient (demihull)
$L / \nabla^{1/3}$	Length : Displacement ratio (demihull)
λ	Wavelength [m]
ζ	Wave Amplitude [m]
ω, ω_0	Wave circular frequency [$\mathrm{rads^{-1}}$]
ω_e	Wave encounter circular frequency [$\mathrm{rads^{-1}}$]
μ	Ship heading [rad] (0=following seas, π=head seas)
TF (ω_e)	Transfer function spectrum
g	Acceleration due to gravity [9.80665 $\mathrm{ms^{-2}}$]

1 INTRODUCTION

The applications of high speed commercial catamarans has increased significantly over the past few years. Progress has been made in developing techniques for the power prediction of semi-displacement catamarans, e.g. Ref. 1. At the same time there has been a need to develop techniques for the prediction of the seakeeping performance of such vessels, particularly at higher operational speeds. Earlier research, Ref. 2, has investigated the characteristics of fast displacement catamarans in head seas. The aim of the research described in this report has been to establish a better understanding of the motion characteristics of catamarans in irregular seas. This has been carried out through a programme of experimental work.

Model tests on catamarans in waves have been carried out in regular head seas in the Southampton Institute Test Tank, Ref. 2, in regular head and oblique seas in the Ocean Basin/Manoeuvring Tank at DERA Haslar, Ref. 3, and in open irregular seas in Southampton Water. This report describes the model tests in irregular seas on Southampton Water.

2 DESCRIPTION OF MODEL

One hullform was tested, designated model 5b. Details of the principal particulars of the model are given in Table 1 and its body plan is given in Fig. 1. Model 5b is the same form as that used in earlier investigations of calm water resistance and head sea tests, Refs. 1 and 2. It is of round bilge/transom stern form and based on the NPL Series.

It should be noted that, due to an increase in hull mass during construction, the model as tested was heavier than the original design displacement. The design principal particulars and those as tested are both shown in Table 1, noting that in the test condition length/displacement ratio, $L/\nabla^{1/3}$, has decreased from 8.5 to 8.3 and breadth/draught ratio, B/T, from 2.0 to 1.9.

The model has a waterline length of 4.5m, a test displacement (FW) of 324kg and is constructed in GRP. It is free running, propelled by petrol or gas fuelled internal combustion engines, radio controlled, and instrumented to record pitch, roll and vertical accelerations at LCG and 7.5% aft of FP. Radii of inertia of the models in pitch, yaw and roll are given in Table 2. For the open water tests in irregular seas the engines were run on petrol. (For the oblique sea tests in the covered Ocean Basin at DERA Haslar, the engines were run on gas). Further details of the construction, equipment and layout of the model is given in Fig. 2 and Appendix A.

3 OPEN WATER TESTS

3.1 LOCATION

The open water model tests in irregular seas were carried out on Southampton Water. An outline of the location of the test area is given in Fig. 3.

The tests were carried out over a number of days when suitable wave conditions were available. Wave properties at the test location were measured with a wave buoy designed and built for the purpose and described in Ref. 4. In all the open sea tests the model was accompanied by a high speed support boat in order to service the model and equipment and to deploy the wave buoy. A photograph of the model in typical test conditions is shown in Fig. 4.

The transfer of the one-third Tonne model from its road trailer into the water requires a robust and well organised procedure. This involves removing the hulls from the road trailer on their launch trolleys and assembling as a catamaran before launch. A number of public slips for launching the model were investigated. Ultimately, a very suitable location was found to be the privately owned University Boat Hard, about 2 miles from the University at Woodmill on the River Itchen. The model was launched at the Boat Hard and towed the 2.5 miles down the Itchen to the test area on Southampton Water, Fig. 3. This takes about 40 minutes and, taking due note of the tides, allows up to about 4 hours testing in the test area on any one day.

3.2 INSTRUMENTATION AND MEASUREMENTS

Pitch and roll were measured using a pitch/roll gyro mounted in the port hull. Accelerations were measured using piezoresistive accelerometers; these were mounted in both hulls at the LCG . Model speed was derived using a small portable GPS in the support boat which followed, and travelled at the same speed as, the model during a test run.

All measurement signals on the model were acquired using an on-board laptop computer via an analogue to digital converter. The system enabled analysis and checking of the results of each run to be carried out during the experiments.

The wave buoy, Ref. 4, is fitted with three accelerometers mounted on top of a lifebelt to measure buoy heave, pitch and roll responses to waves, together with a flux-gate compass to measure buoy heading. Power supplies to the instrumentation and output signals are carried along a 50m umbilical cable to the support boat. The buoy deployed directly to windward of the support boat at the end of the extended, but not taught, umbilical cable. During buoy deployment wind speed was monitored using a hand held wind gauge. Wind direction and the cable lead angle from the support boat to the buoy were measured with a hand bearing compass. Broadly, the wind direction and mean cable agreed within 5 to 10 degrees. Since the support boat was used to follow the model during each test run, it was not possible to test the model and measure wave properties simultaneously.

3.3 TEST CONDITIONS

The tests were carried out at separation to length ratios, (S/L) of 0.2 and 0.4 and at a nominal calm water Froude number of 0.65, (4.3m/s).

The wind direction provided a reasonable indication of the mean wave direction and runs were made at various headings to the mean.

Prior to, and immediately after, each test run the wave properties were measured, as described in Ref. 4. For each test run the model engines were started, data acquisition started and the model released at the required heading. The correct heading was maintained manually by the radio control operator.

During each test run the support boat followed the model (at speeds of the order of 3m/s to 4m/s) in order to monitor model speed. A typical test run was of 4 or 5 minutes duration and covered some 1000m.

4 REDUCTION AND PRESENTATION OF DATA

Examples of typical result are presented in the form of RMS motions and accelerations in Tables 3 and 4. These RMS responses were obtained from a time history 165s long at a sample rate of 10Hz. In some of the time histories there were large amplitude spikes. These spikes had a large influence on the RMS values and, in order to achieve more realistic values, the data had to be windowed. The most accurate RMS values are obtained by windowing the longest section of record possible. In some cases this meant that the record had to be windowed in several successive sections and then averaged. A typical example of measured and windowed data is shown in Fig. 5.

In order to allow comparison of RMS responses with those available for a similar full scale vessel, the data was normalised. This involved dividing the RMS value at a particular heading by a reference RMS value as follows. This would then show the relative changes with heading rather than absolute values. Results of this process are shown in Figs. 6,7 and 8.

Normalised Pitch = RMS Pitch(μ) [deg] / RMS Pitch(180) [deg]

Normalised Accel. = RMS Accel.(μ) [g] / RMS Accel.(180) [g]

Normalised Roll. = RMS Roll(μ) [deg] / RMS Roll(90) [deg]

With $\mu=0^{\circ}$ for the following sea case and $\mu=180^{\circ}$ for the head sea case.

5 DISCUSSION OF RESULTS

5.1 GENERAL

Several days of open water testing took place through the spring and summer of 1998. Many of the early test days were unsuccessful, resulting in data that was not of an adequate standard, or useable. This resulted from various reasons including developing start and control methods for suitable directions and lengths of test runs, equipment failure in the hostile environment, unsatisfactory wave buoy measurements and/ or significant and rapid changes in the wind and wave conditions in the course of a chosen test period. The net number of days when successful tests were carried out, meaning satisfactory test conditions and model and wave buoy measurements, were therefore very limited.

After much initial trial and investigation a successful open water test procedure was established. The following results, for particular days in April 1998 which are presented and discussed, illustrate and confirm the satisfactory nature of the test procedures which were finally achieved and adopted.

5.2 MODEL WITH S/L=0.4

The results for this configuration are shown in Table 3 which gives RMS values and Fig. 6 which gives normalised values of pitch, roll and acceleration. The results for the open water tests in Table 3 can be compared with the RMS values in Table 5 for the regular oblique wave tests for the model, Ref. 3, representing approximately the same conditions. Other than the 180° heading, roll shows very similar levels and changes with heading. Pitch also shows similar levels and trends. Open water acceleration values are higher in head (180°) seas than the regular wave tests. The average values are however likely to be questionable since the port acceleration values seem to be in error.

The normalised curves presented in Fig. 6 show the changes in model pitch, roll and acceleration with change in heading. These can be compared with the results in Fig. 7 for a full scale vessel of similar form (at Fn=0.76). These full scale results were provided by one of the industrial sponsors of the Fast Craft Research Programme. It is seen that the roll characteristics show a very similar form. The ship pitch shows a much larger variation and with higher following sea values than for the model. The full scale ship shows a significantly larger reduction in acceleration in following seas.

5.3 MODEL WITH S/L=0.2

The results are shown in Table 4, which gives RMS values and Fig. 8 which gives the normalised values of roll. Measurements of pitch and acceleration were not available for this particular case.

Comparison of the open water results in Table 4 with those for the regular oblique sea tests in Table 6, Ref. 3, again show similar trends. Like the S/L=0.4 data, the roll values close to head sea conditions are larger in the open sea tests, although reasonable agreement is achieved as they approach beam seas. Pitch results are comparable, but the acceleration results are larger in the open sea case. Again, the port acceleration results are questionable.

The normalised values of roll in Fig. 8 show a broadly similar trend, with maximum values near beam seas, to those shown in Fig. 6 for a hull spacing of S/L=0.4.

5.4 SPEED LOSS

Model speed loss with heading is shown in Fig. 9. The results for S/L=0.4 and 178° heading is questionable. Otherwise, the results show expected trends although they are a little higher than the speed losses estimated from the regular oblique wave tests in Ref. 3.

6 CONCLUSIONS

6.1 The results of open water tests in irregular waves with a catamaran model on Southampton Water are presented. The tests were carried out at various headings and at two separation/ length ratios (S/L=0.2 and 0.4).

6.2 The results obtained from the open water tests show broadly similar trends to those for the model in controlled oblique wave tests in a test tank and to those for a similar full scale vessel in irregular waves.

6.3 The wave buoy developed and used for the open water tests was deployed from the support boat at the beginning and end of the test runs and proved satisfactory. Its effectiveness would however be improved if it could be deployed at the same time as the model test runs.

6.4 A significant amount of testing, trials and modifications occurred in developing and commissioning the open water test procedure.

The overall results obtained confirm that a suitable model test and data acquisition procedure has been developed and established for open water testing. Such tests can often provide more scope in investigating different model headings and speeds than the controlled, but sometimes limiting, seakeeping tests in a test tank.

ACKNOWLEDGEMENTS

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	DESIGN	AS TESTED
Model	**5b**	**5b**
L/B	11.0	11.0
B/T	2.0	1.9
L/V^{α}	8.5	8.3
C_B	0.397	0.400
Cp	0.693	0.698
Cm	0.573	0.573
A/L^2	0.1078	0.1131
LCB [%x]	-6.4%	-6.4%

Notes: Model 5b is based on the NPL Series form.
Table 1: Principal Particulars of Model (demihull)

S/L	Pitch K_{yy}	Yaw K_{zz}	Roll K_{xx}
0.2	0.26L	0.28L	0.11L
0.4	0.26L	0.32L	0.20L

Table 2: Radii of Inertia for Model 5b
(4.5m model in catamaran configuration)

	Heading	**178**	**160**	**124**	**121**	**88**	**19**
	run no	**c079**	**C075**	**c077**	**d075**	**c078**	**c076**
deg	**Roll**	1.114	0.8027	1.499	1.841	1.9265	1.569
deg	**Pitch**	2.040	1.2642	1.598	1.684	2.0256	2.172
g	**Accel. p**	0.023	0.0106	0.020	0.026	0.0237	0.012
g	**Accel. s**	0.614	0.7236	0.523	0.425	0.6289	0.641

Table 3: RMS Motions and Accelerations for Model 5b, S/L=0.4, approx. Sea State: T_o=2.6s, $H_{1/3}$=0.2m.

	Heading	**160**	**145**	**96**	**41**	**37**
	run no	**c080**	**A078**	**e082**	**d081**	**b079**
deg	**Roll**	1.7473	0.9187	1.827	1.6089	0.6275
deg	**Pitch**	2.4915	1.3565	1.972	1.5824	1.183
g	**Accel. p**	0.1436	0.0923	0.123	0.0854	0.050
g	**Accel. s**	0.6048	0.6041	0.634	0.6438	0.575

Table 4: RMS Motions and Accelerations for Model 5b, S/L=0.2, approx. Sea State: T_o=2.6s, $H_{1/3}$=0.2m.

	Heading	**180**	**150**	**120**
deg	**Roll**	0	2.2	2.35
deg	**Pitch**	2.5	1.4	1.1
g	**Accel_lcg**	0.32	0.4	0.25

Table 5: Typical RMS Responses from Tests in Regular Oblique Waves, S/L=0.4, wave height=0.05-0.171m.

	Heading	**180**	**150**	**120**
deg	**roll**	0	2.2	2.5
deg	**pitch**	2.2	1.8	1.4
g	**Accel_lcg**	0.34	0.32	0.2

Table 6: Typical RMS Responses from Tests in Regular Oblique Waves, S/L=0.2, wave height=0.05-0.176m.

APPENDIX A: DETAILS OF MODEL

Principal Dimensions - As Tested:

	Model 5b
LOA	4.8m
LBP (=LWL)	4.5m
B	0.409m
D	0.550m
T	0.220m
C_B	0.400
∇m^3 (per hull)	0.162

CONSTRUCTION:

The hulls were constructed from GRP. Each hull has a wooden gunwale glassed in and is fitted with three 6mm plywood bulkheads. Platforms carrying the engines, shaft bearings and rudder bearings were made of 18mm plywood and glassed into the hulls.

The two cross beams joining/separating the hulls were of continuous section aluminium alloy mast material (kindly provided free of charge by Kemps Masts). These spars were bolted to each hull via a GRP fitting which was glassed to the hull and an adjacent bulkhead. This set-up allowed adjustment of the separation of the hulls, and removal of the spars for transportation of the models to test sites.

The GRP hulls were constructed outside the University and fitted out in the University Engineering Faculty Workshops.

The model was weighed prior to testing, including fuel and necessary ballast, leading to an all-up weight of 324kg.

PITCH, ROLL AND YAW INERTIAS:

Model 5b was swung in its test condition in pitch and roll to obtain the relevant radii of gyration. The radius of gyration in yaw was estimated from the inertia in pitch assuming the demi-hull inertias in pitch and yaw to be the same. A summary of the radii of gyration for Model 5b is given in Table 2.

Engines, Transmission and Propellers:

Engines: One per hull. Honda GX160QX4.
Maximum power output: 4.1kW @ 3600 rpm.
Continuous power output: 3.5 kW @ 3600 rpm.
Capable of operation on petrol or propane gas (gas used when operating under cover in the Haslar Model Basin).

Shafting: Stainless steel 19mm (3/4") diameter.

Propellers: Brass. Diameter 152mm, Pitch 178mm. One right handed, one left handed. Propellers, shafting, brass stern tubes and stuffing boxes supplied by Norris Marine Equipment Ltd.

Gear Ratios: Transmission from engine to shaft is achieved using a pulley-belt system. Vee belts and pulleys are used with three gear ratios as follows:

Ratio	**Engine Pulley Diameter**	**Prop. Shaft Pulley Diameter**
1:2.5	80mm	200mm
1:1.695	118mm	200mm
1:1	200mm	200mm

All tests to date have been carried out using the mid gear ratio (1:1.695), leading to a speed in calm water of the order of 4.40 m/s (Fn=0.67) at full engine throttle setting.

An outline drawing of the transmission arrangement is shown in Fig. 2. The electric clutch shown was not successful, due mainly to misalignment problems. It was subsequently removed at an early stage of model commissioning and replaced with a direct drive fitting.

ELECTRICAL POWER/REMOTE CONTROL:

Electrical power for instrumentation and data acquisition equipment is provided by a 12v battery.

Power for all on-board radio controlled equipment is provided by a 6v battery.

The following operations are controlled by radio: Rudder winches; Throttle servos; Engine hold; Engine off, together with channels for data acquisition trigger etc as required.

The rudder winches (one in each hull) are controlled simultaneously from a single rudder control signal. Similarly, the throttle servos (one in each hull) are controlled simultaneously.

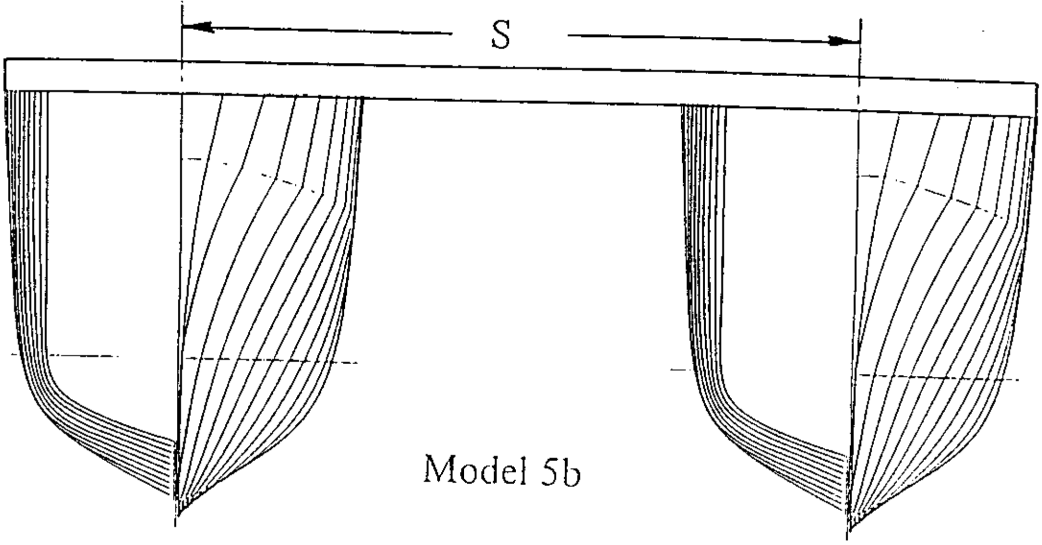

Fig.1 Body Plan of Model

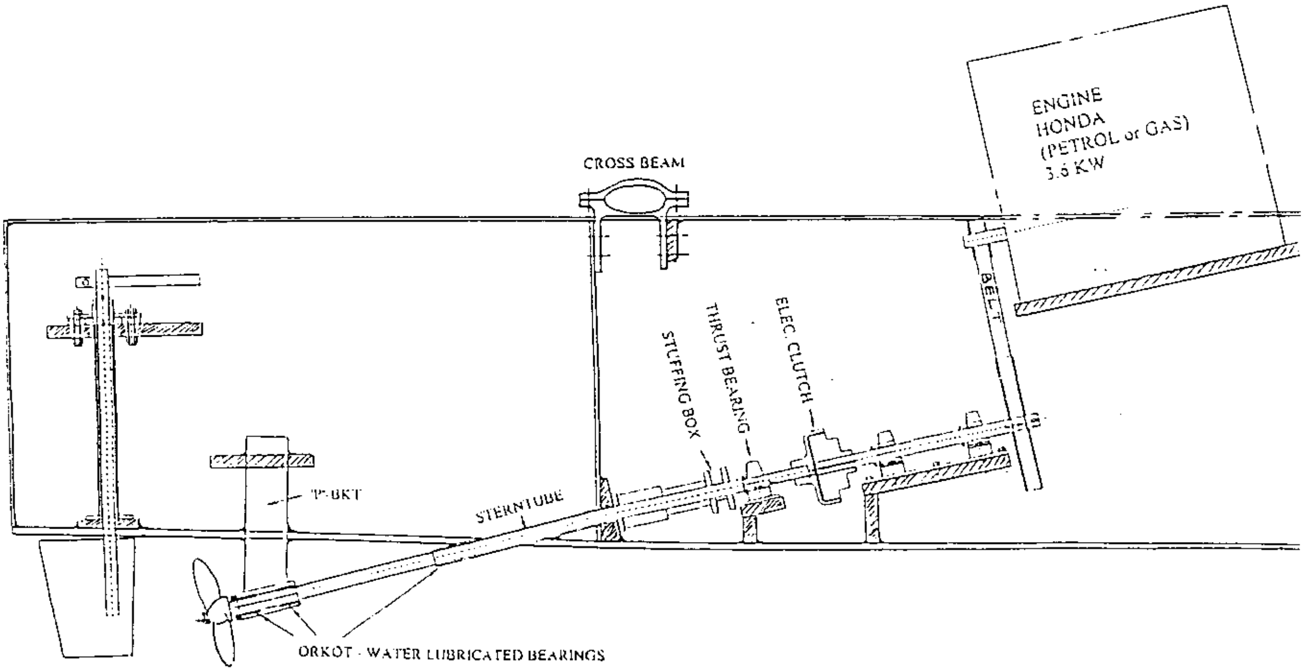

Fig.2 Outline of Transmission and Rudder Arrangements

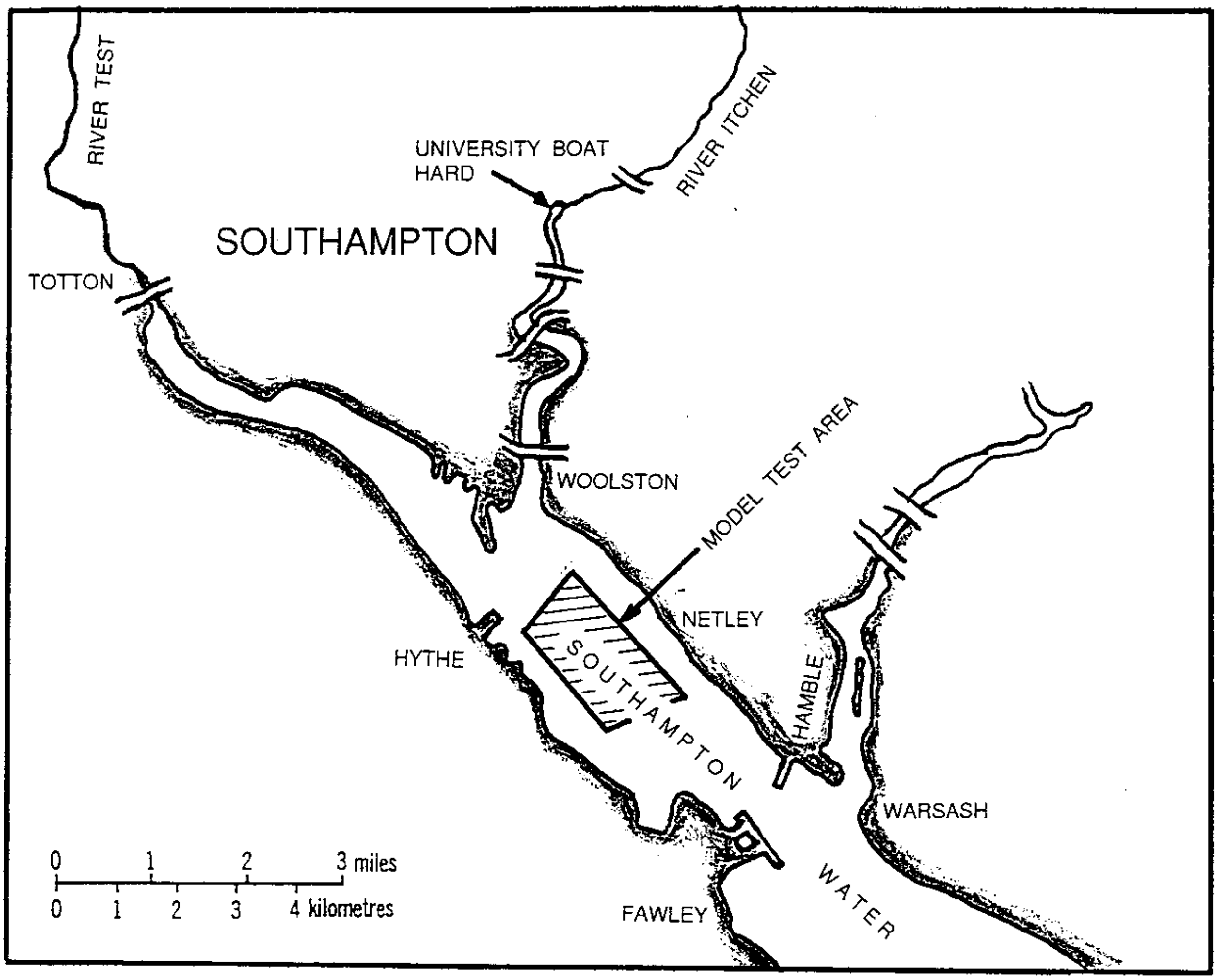

Fig.3 Location of Test Area on Southampton Water

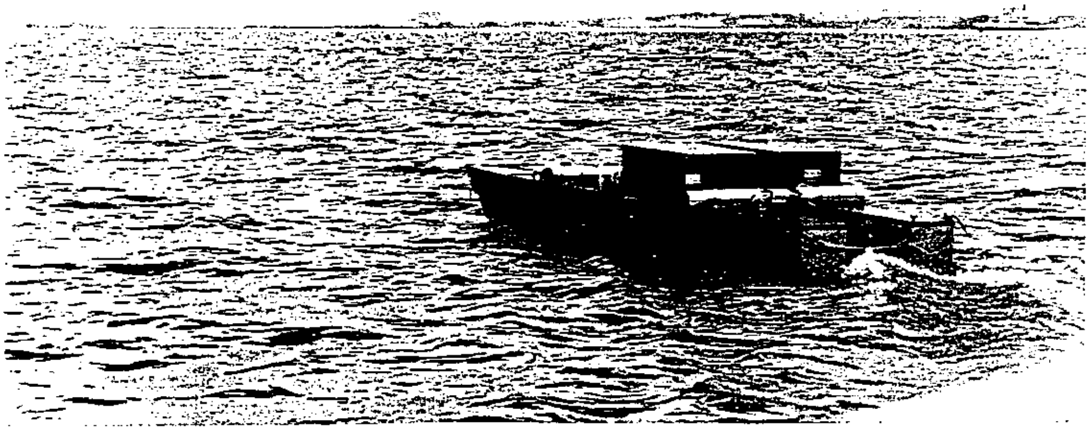

Fig.4 Photograph of Model in Typical Test Conditions
On Southampton Water

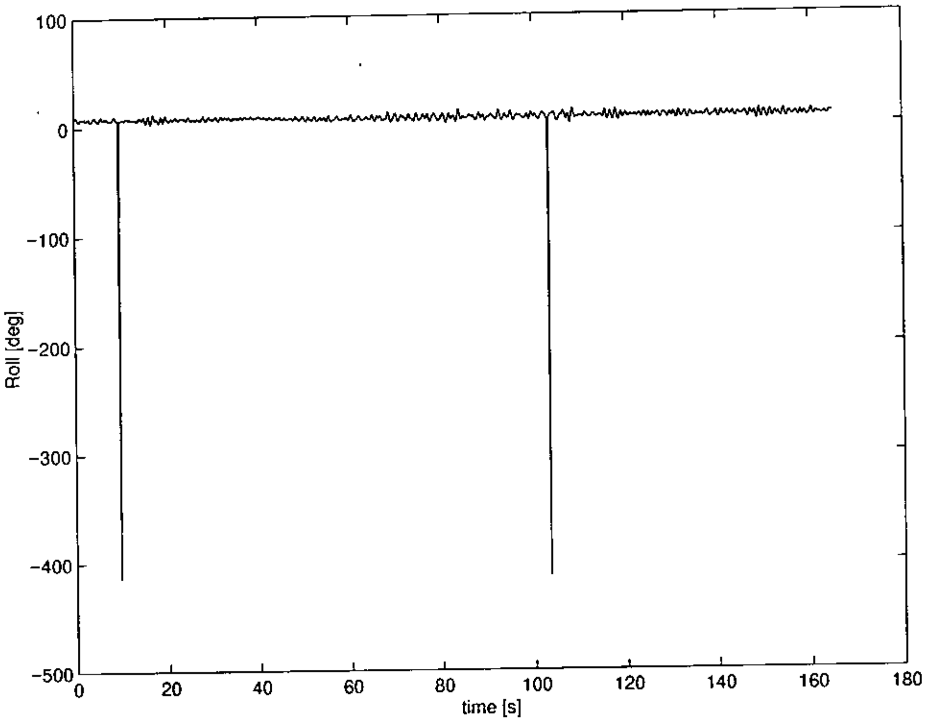

Fig. 5a: Typical Roll Time History

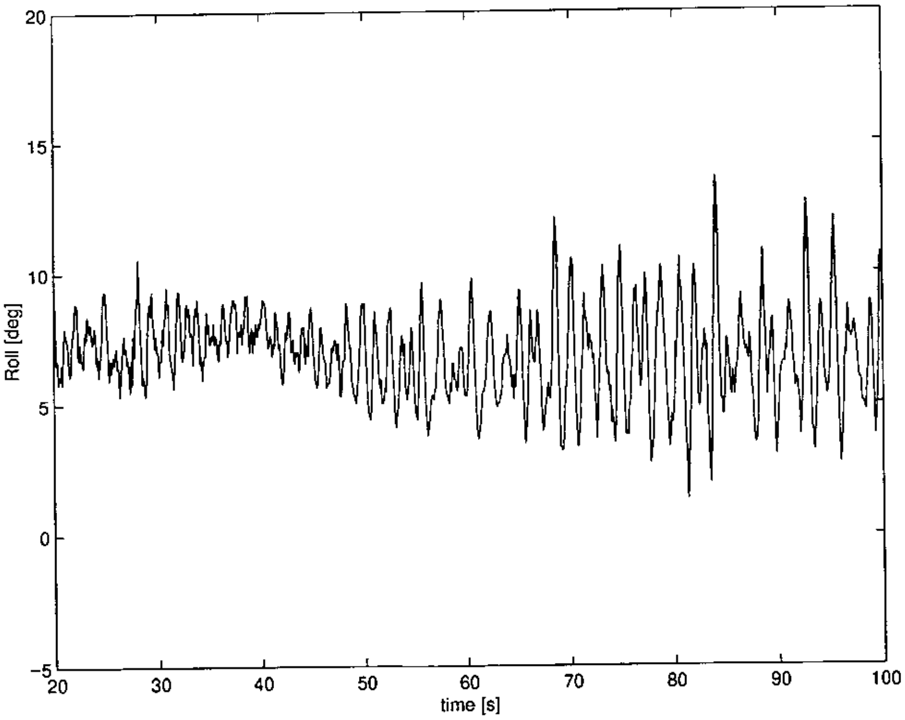

Fig. 5b: Windowed Roll Data

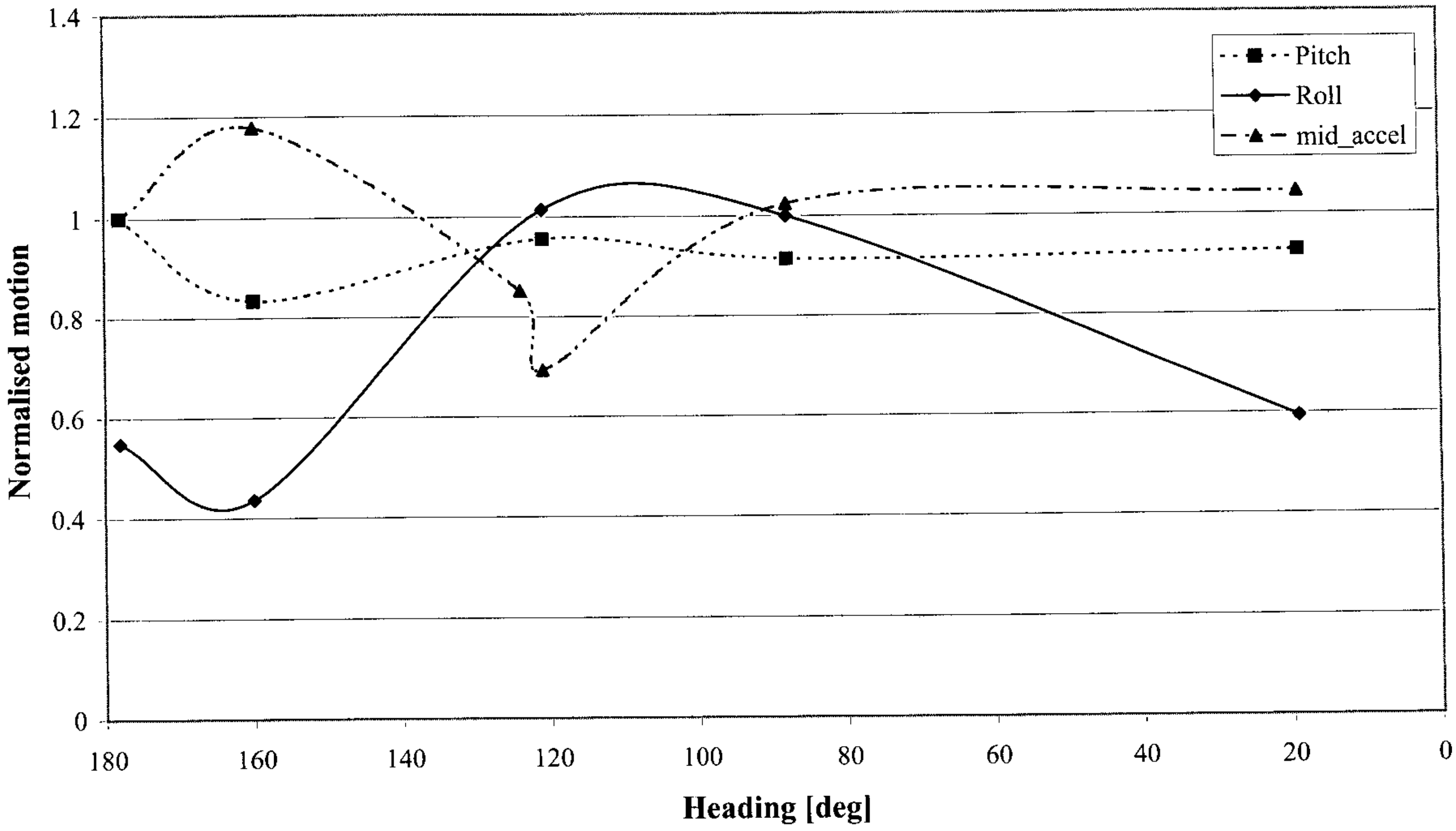

Fig. 6: Normalised RMS Pitch, Roll and Acceleration for Model 5b, S/L=0.4, in Irregular Seas, approx. Sea State: T_0=2.6s, $H_{1/3}$=0.2m.

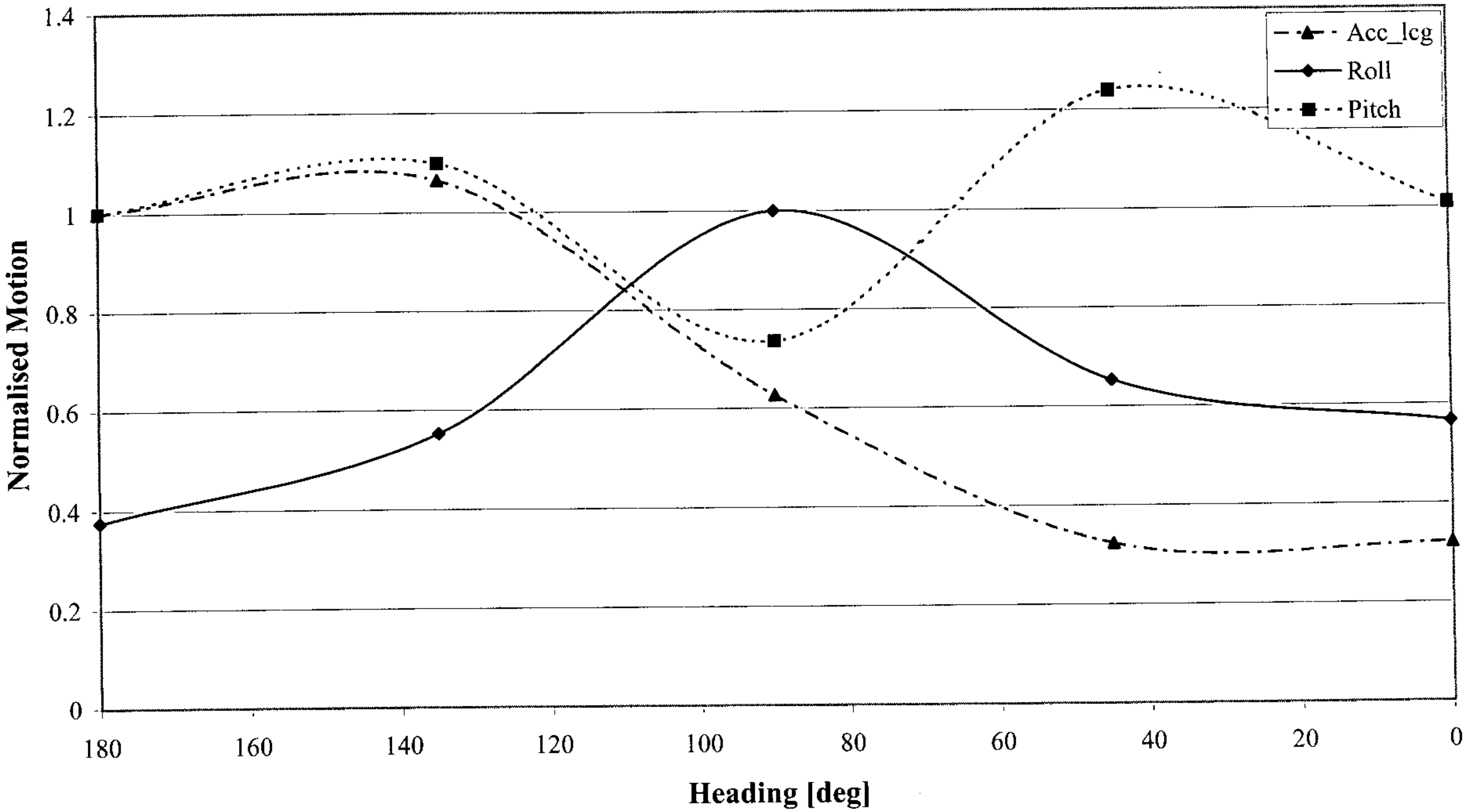

Fig. 7: Normalised RMS Roll, Pitch and Acceleration for FBM 35m Solent Class Catamaran Tricat at 33 Knots, $H_{1/3}$=1.5m, T_0=4.5s.

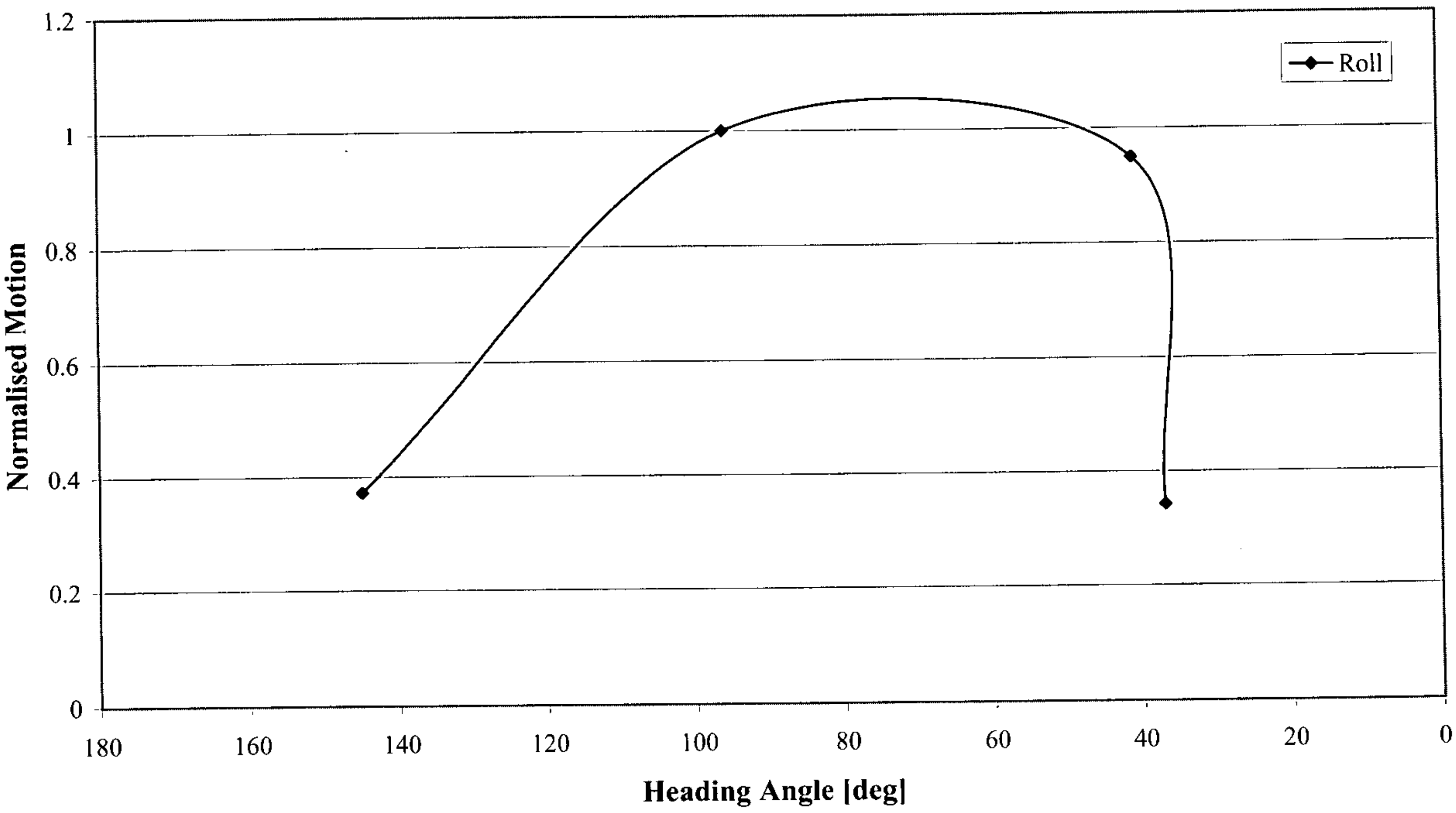

Fig. 8: Normalised RMS Roll Motion for Model 5b, S/L=0.2, in Irregular Seas, approx. Sea State: T_0=2.6s, $H_{1/3}$=0.2m

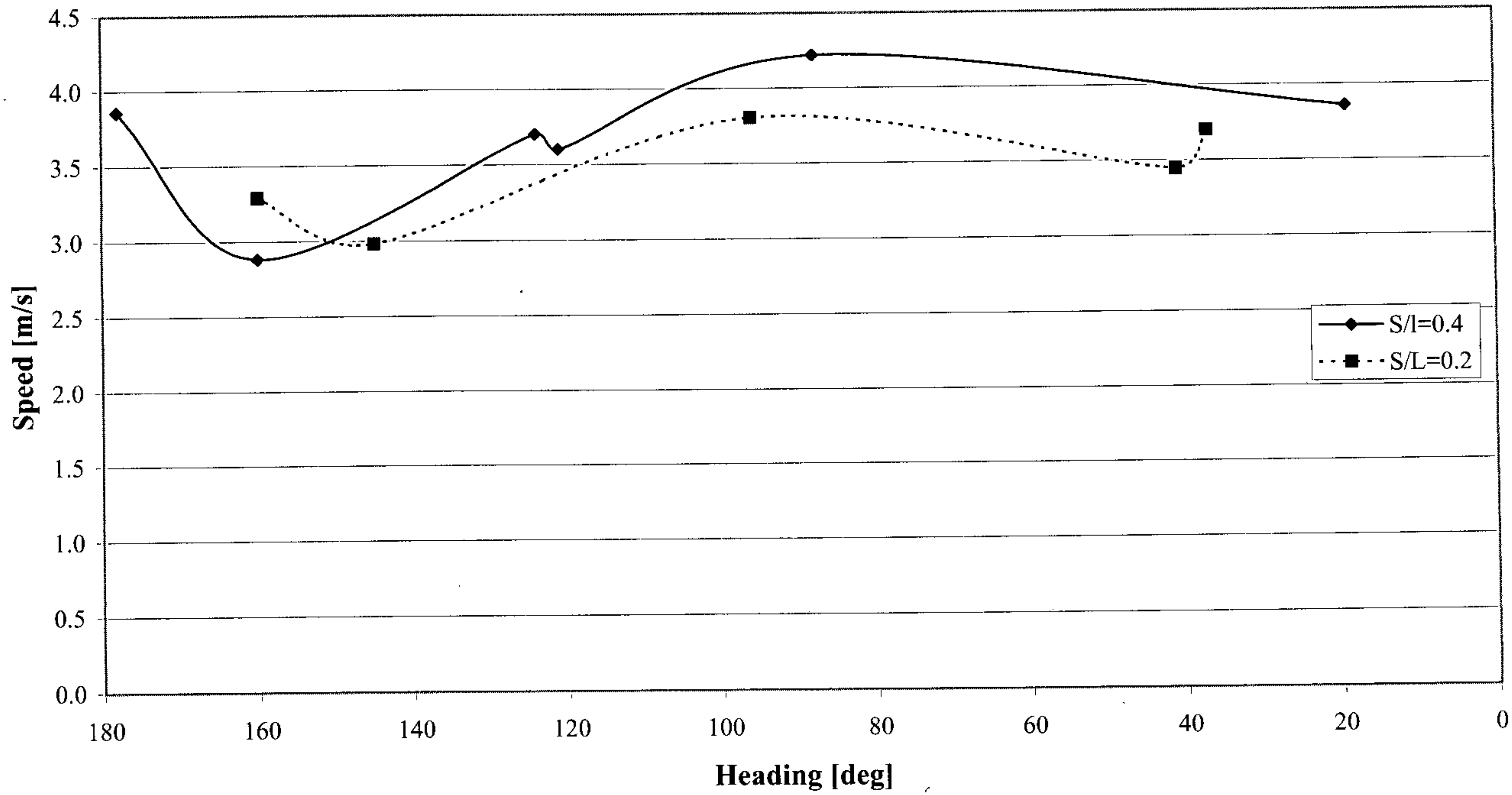

Fig. 9: Speed Loss with Heading for Model 5b, in Irregular Seas.