"Review of the 1979 and 1980 Full-Scale Experiments Onboard Containership m.v. Hollandia"

By

J.M.J. Journée

Report 1349 February 2003

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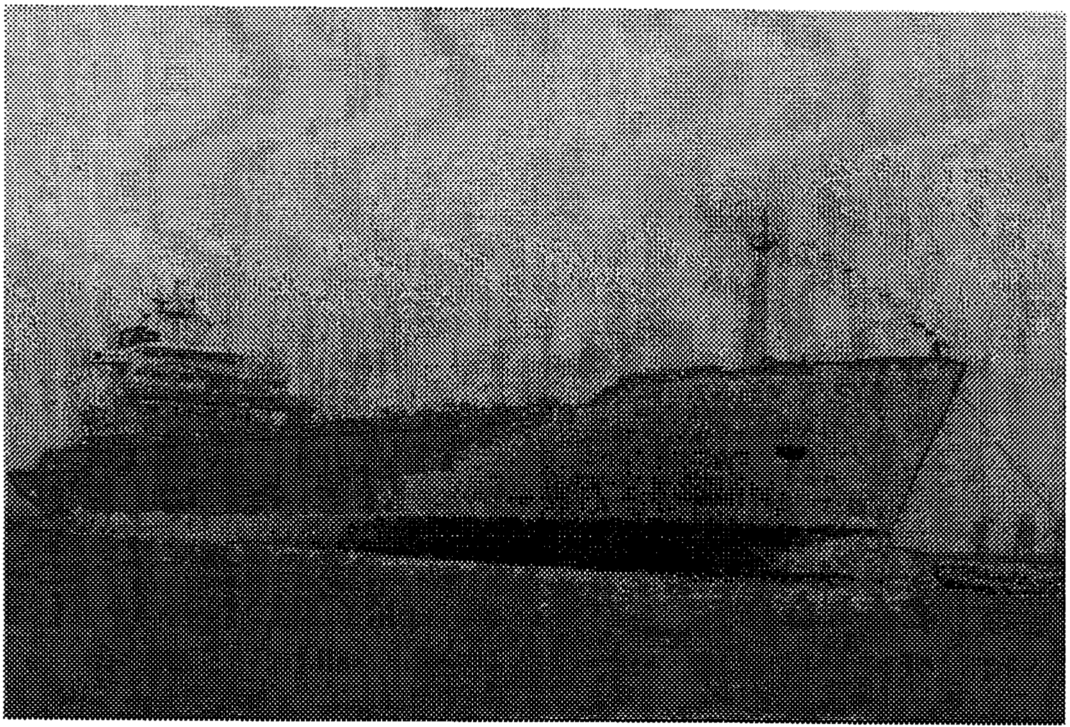

m.v. Hollandia, just before her maiden voyage in 1977

Updated: 13-03-2003

TU DELFT
Faculty of Design, Construction and Production
Ship Hydromechanics Laboratory
Delft University of Technology

Summary

After almost two years of preparations, in 1979 and 1980 extensive full-scale seakeeping tests had been carried out by the Ship Hydromechanics Laboratory of the Delft University of Technology and Lloyd's Register of Shipping in London. Subject to these tests was the 23,400 dwt container vessel, m.v. Hollandia, owned by the Royal Netherlands Steamship Company (KNSM) at Amsterdam and build by ship yard Stocznia Gdanska in Poland. A staff of up to 6 people performed these tests during three normal service voyages of the ship between Northern Europe and the Caribbean.

Lloyd's Register of Shipping had tested an Operational Performance System during a project financed by the Netherlands Maritime Institute, Lloyd's Register of Shipping and Applied Dynamics Europe. The aim of the project was to investigate the feasibility of a computer based shipboard monitoring, prediction and surveillance system, to ensure safe and economic ship operation.

The Delft Ship Hydromechanics Laboratory took part in this project by measuring the sea and wind conditions during the experiments and providing a predicted speed - rpm - power - sea state data base of the ship. Their separate research project - obtaining experimental data on ship motions, speed losses, delivered engine power and fuel consumption of a large containership in different sea states with known energy spectra - for validation purposes had been carried out simultaneously.

Test data, which were required for the project of Lloyd's Register, had been published by DUT to LR after finishing the experiments in 1980. Then, this (expensive) research project had to be stopped by order of the management of the Laboratory. Because of other urgent duties in that time, an originally intended validation study could not be carried out anymore.

However, the author had saved all experimental information and test data for almost 25 years carefully in his bookcase. It even survived two removals within the university. Being partly retired now, these test data have been reviewed and have been completed with detailed spectral information about the waves and the resulting ship motions. Also, results of some shallow and deep water manoeuvring experiments - carried out in 1979 in the Caribbean Sea - have been added to this report.

This report and all measured data can be downloaded freely from the Internet for validation or other purposes; see Section "Papers and Reports" at the author's university homepage, attainable via homepage: http://www.shipmotions.nl.

After using these measured data, a feed-back to the author will be appreciated.

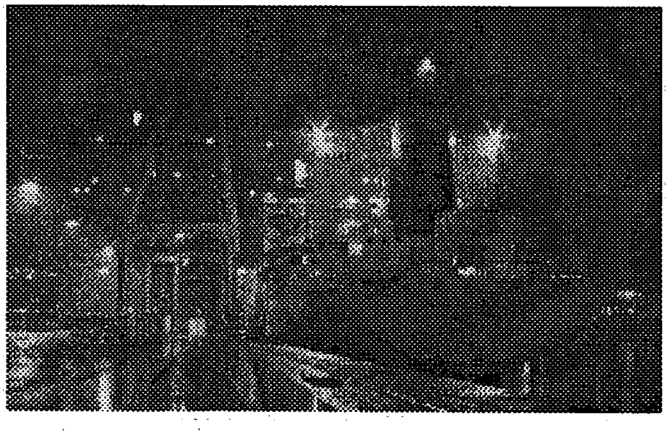

Figure 1: The vessel - renamed into m.v. Nedlloyd Hollandia in 1982 - along a quay

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1 Introduction

After almost two years of preparations, in 1979 and 1980 extensive full-scale seakeeping tests had been carried out by the Ship Hydromechanics Laboratory of the Delft University of Technology (DUT) and Lloyd's Register of Shipping (LR) in London.
Subject to these tests was the 23,4000 dwt container vessel, m.v. Hollandia, owned by the Royal Netherlands Steamship Company (KNSM) at Amsterdam and build by ship yard Stocznia Gdanska in Poland. In 1982, the ship was sold to Nedlloyd Lines and renamed to m.v. Nedlloyd Hollandia. In 1996, the ship was sold again and started old-aged sailing under the Cyprus' flag.
A staff of up to 6 people (4 from DUT and 2 from LR) performed these tests during three normal service voyages of the ship between Northern Europe and the Caribbean.

Lloyd's Register of Shipping had tested an Operational Performance System during a project financed by the Netherlands Maritime Institute, Lloyd's Register of Shipping and Applied Dynamics Europe. The aim of the project was to investigate the feasibility of a computer based shipboard monitoring, prediction and surveillance system, to ensure safe and economic ship operation.

The Delft Ship Hydromechanics Laboratory took part in this project by measuring the sea and wind conditions during the experiments and providing a predicted speed - rpm - power - sea state data base of the ship. DUT's separate research project - obtaining experimental data on ship motions, speed losses, delivered engine power and fuel consumption of a large containership in different sea states with known energy spectra - for validation purposes had been carried out simultaneously.

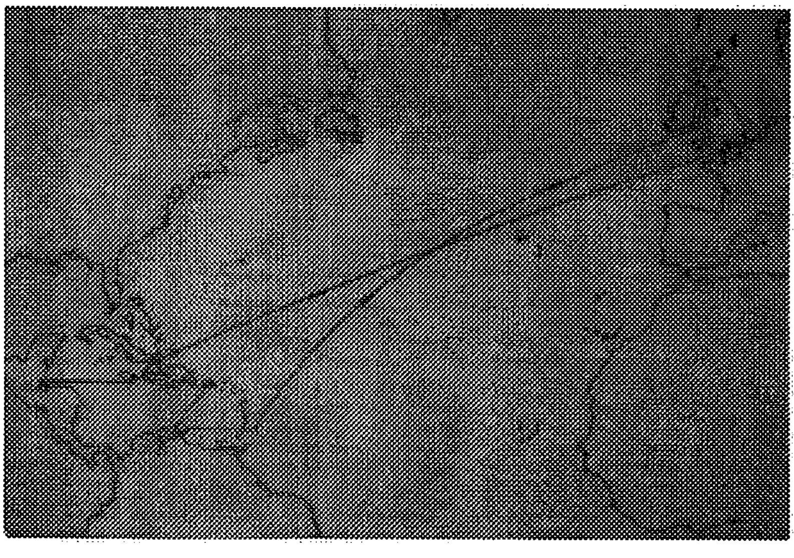

Figure 2: The ship's sailing route during the 1979 voyage

The first voyage was a double trip with an experimental staff of 6 persons (2 of LR and 4 of DUT), during January 1979 and the beginning of February 1979. The David Taylor Naval Ship Research and Development Centre in Washington D.C., USA, has offered a valuable assistance with regard to the choice of suitable wave conditions for the seakeeping trials. For this purpose wave and wind forecasts have been provided at the intended route of the ship. These forecasts - made available by the Fleet Numerical Meteorology and Oceanographic

Center at Monterey, California, USA - have been transmitted by telex to the ship through the Royal Netherlands Navy in The Hague and Scheveningen Radio.
On the outward voyage, only small head waves have been met. For a major part, following a least time route caused this. This route was advised by the Routing Office of the Royal Netherlands Meteorological Institute (KNMI), who did an undesirable perfect job. The orally obtained owner's permission to deviate significantly from the least time route had not reached the ship's captain, a misunderstanding that was noticed by the author much too late to correct. Considerable deviations from the by KNMI advised route could not be made on this voyage. Actually, it was taking a chance now, but - regretfully - this action failed signally.
On the return trip from the Caribbean to Europe however, high following seas have been met with significant wave heights up to over 11 meters.

At the end of February 1979, a new attempt during an outward voyage - with a strongly reduced staff of 3 persons (2 of LR and only 1 of DUT) - has been made to obtain the missing (this time minimal required) experimental data in head waves. But again, no suitable head waves could be met and - with the exception of 3 calm water performance tests at a new loading condition - no suitable experiments could be carried out at all during this voyage.

In January 1980, it has been tried again to obtain the missing experimental data in head waves, now with a reduced staff of 4 persons (2 of LR and 2 of DUT). Thanks to a constructive co-operation of the ship's owner, this time it was possible to choose a route with suitable head waves, when available, within a fair distance from the least time route. The last minute decision "to go or not to go" - with regard to the expected weather conditions - has been made in deliberation with the routing office of KNMI. They also have provided advises to the ship's captain for such a sailing route, that seas with a significant wave height from 5 meters up to a maximum of 7 meters could be expected. This co-operation has been very successful; the required waves have been met.

During these three voyages, the spacious owner's cabin (see Figure 3) and bed room had been placed at DUT's disposal for lodging and as an office for preparing experiments and pre-analysing measured data. The pilot's cabin has been used for lodging during the first voyage too.

Figure 3: The spacious owner's cabin, used by DUT for lodging and office

The energy spectra of the sea (point spectra) have been measured with disposable wave buoys, developed at the Delft Ship Hydromechanics Laboratory. In total, the results of 14

wave buoys have been made available during these voyages. The mean wave direction has been estimated visually. The average wind speed and direction have been measured by a cup anemometer and a wind vane, fitted in the foremast of the ship.
Ship motions were measured close to the ship's centre of gravity (heave, roll and pitch) and at the bow (heave forward). Also, results are presented of the speed, rpm, thrust, torque, power and fuel consumption measurements in calm water and in a seaway.

Test data, which were required for the project of Lloyd's Register [10], had been published by DUT [6, 7] to LR shortly after finishing the experiments in 1980. Then, this (very expensive) research project had to be stopped by order of the management of the Laboratory. Because of other urgent duties in that time, an originally intended validation study could not be carried out anymore.
However, the author had saved all written experimental information and test data for almost 25 years carefully in his bookcase. It even survived two removals within the university. Being partly retired now, an opportunity came to review all these test data and complete it with detailed spectral information about the waves and the resulting ship motions in a new report. Also, results of some shallow water manoeuvring experiments - carried out in the Caribbean Sea - have been added to this report.
Originally, the units ton(force), meter, degree, second, knot and metric horsepower were used, because most of the data should be used by LR for testing the onboard Operational Performance System, that worked with these units. But in this report, thrust, torque and power data have been transformed to the S.I. system.

Chapter 2 of this report gives an overview of general information about the ship, which had been made available by the ship's owner before carrying out the experiments.
Chapter 3 describes the experimental set-up of the Delft measuring equipment on the ship.
Chapter 4 presents the experimental results of the performance and seakeeping tests, carried out at the 3 voyages. All measured spectral wave buoy and ship motion data have been visualised in Appendix IV.
Finally, Chapter 5 presents the results of 4 manoeuvring experiments, which were carried out in 1979 under normal navigational conditions, when approaching and leaving two harbours in the Caribbean. Two additional manoeuvring tests at deep water - with initial parts of 3 turning circles - have been presented here too.

Measured data are presented in this report in tables, in figures and in polynomial forms, as complete as possible after all these years. No comparisons have been made here with results of theoretical ship motion or manoeuvring calculations. Such comparisons - for instance with the author's strip theory computer code SEAWAY [5] - are an intended future task.

This report (1349-Hollandia-03.pdf) and all measured data (1349-Hollandia-03.zip) can be downloaded freely from the Internet for validation or other purposes: see the Section "Papers and Reports" at the author's university homepage http://www.ocp.tudelft.nl/mt/journee. This web site is also attainable via the author's private homepage: http://www.shipmotions.nl.
After using these measured data, a feed-back to the author (J.M.J.Journee@wbmt.tudelft.nl) will be appreciated.

2 General Ship Information

This Chapter gives some general information about the ship's geometry, loading conditions, results of calm water model experiments and the results of the ship's trial.
Some computational constants - used in the analyses - are given below:

$$g = 9.810 \text{ m/s}^2$$

$$\rho_{\text{water}} = 1.025 \text{ ton/m}^3$$

$$\rho_{\text{air}} = 0.00125 \text{ ton/m}^3$$

$$1 \text{ nm} = 1852 \text{ m}$$

$$1 \text{ kn} = 0.5144 \text{ m/s}$$

$$1 \text{ mhp} = 0.73575 \text{ kW}$$

$$1 \text{ fathom} = 6 \text{ feet} = 1.828 \text{ m}$$

2.1 Principal Ship Data

The main dimensions of the ship are:

• Deadweight	DWT	23,400 ton
• Length over all	L_{oa}	204.00 m
• Length at design waterline	L_{dwl}	196.70 m
• Length between perpendiculars	L_{pp}	193.10 m
• Breadth	B	30.80 m
• Draught to design waterline	T	9.00 m
• Maximum draught	$T_{\max}$	10.00 m
• Block coefficient	C_B	0.585
• Centre of buoyancy to $L_{pp}/2$	L_{CB}	-1.0 % L_{pp}
• Layers of containers on deck		3

The body plan of the ship is visualised in Figure 4.

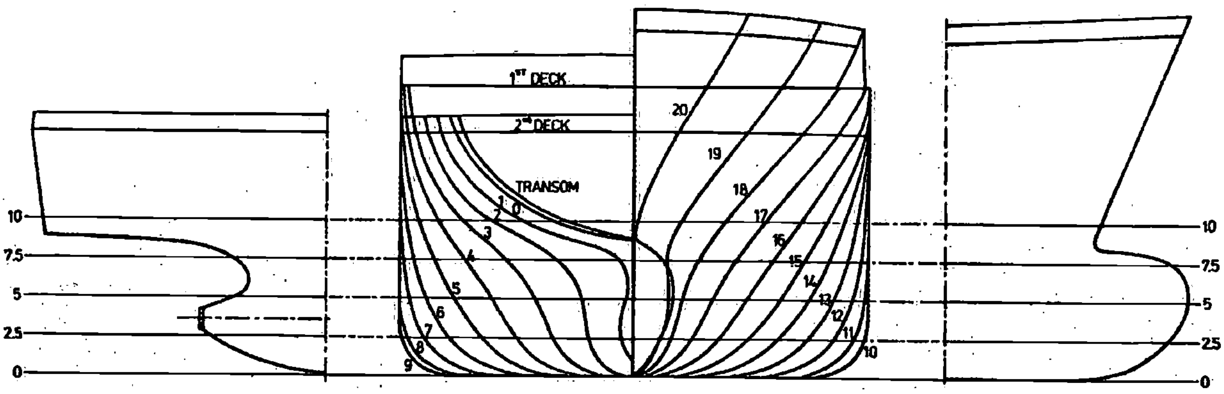

Figure 4: Body plan of m.v. Hollandia

The offsets of the body plan of the ship are given in Table 1 for an amidships draught of 10.00 meter at an even keel condition.

	WL	0.00	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
ORD																
-0.38	8.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	4.30
-0.19	8.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	4.75
0.00	8.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	5.20
0.50	8.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.66	6.23
1.00	1.10	0.00	0.00	0.00	0.00	0.00	0.33	0.63	0.86	0.71	0.52	0.30	0.69	1.55	3.88	7.35
1.50	0.10	0.00	0.30	0.70	0.99	1.16	1.49	1.69	1.90	1.83	1.86	2.00	2.63	3.67	5.64	8.37
2.00	0.00	0.38	1.04	1.56	1.88	2.15	2.53	2.80	3.03	3.11	3.32	3.66	4.40	5.60	7.27	9.42
3.00	0.00	1.28	2.40	3.25	3.70	4.10	4.68	5.11	5.50	5.88	6.38	7.00	7.89	8.90	10.02	11.25
4.00	0.00	2.72	4.09	5.11	5.64	6.11	6.76	7.30	8.03	8.68	9.33	9.98	10.74	11.47	12.18	12.86
5.00	0.00	4.52	6.06	7.21	7.80	8.32	9.01	9.59	10.46	11.17	11.80	12.35	12.88	13.35	13.76	14.12
6.00	0.00	6.60	8.09	9.22	9.85	10.40	11.12	11.72	12.58	13.16	13.64	14.03	14.33	14.59	14.81	14.98
7.00	0.00	8.89	10.27	11.30	11.84	12.31	12.95	13.46	14.10	14.47	14.74	14.90	15.06	15.18	15.27	15.32
8.00	0.00	10.95	12.06	12.90	13.36	13.75	14.23	14.60	15.03	15.23	15.35	15.40	15.40	15.40	15.40	15.40
9.00	0.00	12.11	13.09	13.80	14.15	14.45	14.81	15.09	15.37	15.39	15.40	15.40	15.40	15.40	15.40	15.40
10.00	0.00	11.90	12.81	13.50	13.86	14.18	14.60	14.94	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40
11.00	0.00	10.53	11.58	12.36	12.77	13.14	13.72	14.17	14.70	14.97	15.15	15.25	15.31	15.36	15.39	15.40
12.00	0.00	8.23	9.46	10.41	10.99	11.50	12.18	12.73	13.45	13.98	14.37	14.63	14.84	15.00	15.11	15.18
13.00	0.00	5.89	7.21	8.25	8.92	9.50	10.26	10.90	11.80	12.50	13.09	13.55	13.90	14.20	14.46	14.67
14.00	0.00	4.00	5.30	6.31	6.93	7.47	8.23	8.90	9.95	10.67	11.38	12.07	12.56	13.02	13.44	13.82
15.00	0.00	2.43	3.60	4.51	5.08	5.59	6.34	6.99	8.00	8.82	9.57	10.25	10.87	11.48	12.06	12.63
16.00	0.00	1.20	2.21	3.02	3.54	4.00	4.60	5.13	6.00	6.71	7.40	8.08	8.76	9.47	10.20	10.95
17.00	0.00	0.50	1.33	1.96	2.29	2.60	3.10	3.54	4.21	4.72	5.24	5.77	6.40	7.10	7.85	8.67
18.00	0.00	0.00	0.68	1.19	1.44	1.67	2.01	2.30	2.71	2.97	3.25	3.53	4.01	4.58	5.26	6.03
18.50	0.00	0.00	0.55	0.96	1.15	1.32	1.62	1.88	2.25	2.49	2.67	2.77	2.92	3.28	3.84	4.59
19.00	0.00	0.00	0.45	0.78	0.95	1.10	1.37	1.61	2.00	2.22	2.35	2.38	2.19	2.25	2.56	3.13
19.50	0.00	0.00	0.35	0.63	0.79	0.95	1.27	1.55	2.00	2.28	2.41	2.39	1.91	1.63	1.56	1.70
20.00	0.12	0.00	0.,21	0.55	0.76	0.95	1.27	1.55	2.00	2.39	2.58	2.59	2.02	1.45	0.88	0.30

Table 1: Body plan offsets of m.v. Hollandia

(SEAWAY data file: HOLLANDIA.HUL)

At the top of the columns in Table 1, the 15 water lines (WL x.xx) are given in meters above the base line (WL 0.00). The first column gives the 27 ordinate numbers (ORD) of the cross sections. The second column gives the distance of the keel point of each cross section above the base line; so it presents the lateral contour points. In the other columns, the half breadths at the water lines are given for each cross section.
The two ordinate intervals behind ordinate 0 (ORD 0.00) have a length 1.80 m each. The distance between ordinate 0 (ORD 0.00 = A.P.P.) and ordinate 20 (ORD 20.00 = F.P.P.) is $L_{pp} = 193.10\,\text{m}$.

The ship has been equipped with a Sulzer 10 RND 90 diesel engine having a maximum nominal output of 29000 BHP or 21350 kW at a maximum continuous engine speed $N = 122\,\text{rpm}$; see reference [1].

The main dimensions of the propeller are:

- Number of blades z = 6
- Diameter D = 6.15 m
- Pitch-diameter ratio at hub P/D = 0.7072
  at tip P/D = 1.1166
  mean P/D = 0.9626
- Expanded blade area ratio A_E/A_O = 0.9000

The diameter of the propeller shaft (at the location of the installed rpm, torque and thrust meters) is $d = 0.522$ m and the shear modulus of the propeller shaft material is approximated by $G = 8.0115 \cdot 10^7$ kN/m^2.

To reduce extreme roll motions the ship has been equipped with bilge keels and fin stabilisers. The bilge keel dimensions are lost, but a length $l_{bk} \approx 58.00$ m and a height $h_{bk} \approx 0.50$ m estimated them. The fin stabilisers have a vertical projected area of 7.2 m^2 each.

The expected draught range of the ship and the calculated wind area data of the above-water ship are given in Table 2. For three typical loading conditions of the ship the owner has provided estimated radii of inertia for pitch of the solid mass of ship and cargo, k_{yy}, which are given in this table too.

	T_m (m)	*trim* (m)	Layers Of Containers aft/fore	transverse projected wind area A_T in m^2	lateral projected wind area A_L in m^2	$\frac{k_{yy}}{L_{pp}}$
Design load	10.00	0.00	3/3	725	3735	
Full load	9.00	0.00	2/2	756	3570	
Half load	7.50	1.00	0/0	817	3163	
Ballast (empty)	6.10	2.60	0/0	885	3436	
Loading No. 09	8.42	+0.27	0/2	776	3494	0.235
Loading No. 16	9.92	- 0.37	3/3	763	3609	0.232
Loading No. 19	7.18	+0.008	3/3	848	4138	0.256

Table 2: Draught, wind area and gyradius ranges

The information in Table 2 on the gyradius for pitch, k_{yy}, is required for carrying out ship motion calculations. Information on wind areas and numbers of containers on deck is required for calculating the wind resistance of the ship.
The numbers of 20 feet containers on deck are:

- Loading No. 09: before bridge: 16 in length, 9 in breadth and 2 in height direction
  behind bridge: none
- Loading No. 16: before bridge: 14 in length, 11 in breadth and 3 in height direction
  behind bridge: 2 in length, 6 in breadth and 3 in height direction
- Loading No. 19: equal to Loading No. 16, but with empty containers

2.2 Ship Model Test Data

The parameters in the next relations:

$$V_e = V \cdot (1 - w) \qquad R = T \cdot (1 - t) \qquad Q = Q_o \cdot \eta_r$$

Equation 1

are defined by:

V ship speed

V_e	mean entrance speed of water into propeller
w	wake fraction
R	resistance
T	thrust
t	thrust deduction fraction
Q	torque of propeller behind ship
Q_o	torque of propeller in open water condition
η_r	relative rotative efficiency

An overview of the still water propulsion coefficients (thrust deduction fraction t_0, wake fraction w_0 and relative rotative efficiency η_r), as has been provided in 1977 to the author by the ship's owner for even keel conditions, is given in Table 3.

MARIN model, 1:33, small bulb, propeller 1943						
	$T_m = 9.00$ m			$T_m = 10.00$ m		
V (kn)	t_0	w_0	η_r	t_0	w_0	η_r
18.0	0.190	0.290	1.027	0.200	0.309	1.013
21.0	0.185	0.274	1.018	0.198	0.295	1.025
23.0	0.185	0.268	1.016	0.199	0.271	1.022
HSVA model, 1:30, large bulb, propeller 1783						
				$T_m = 10.00$ m		
V (kn)				t_0	w_0	η_r
20.0				-	0.323	1.046
21.0				0.185	0.310	1.045
22.0				-	0.302	1.044
23.0				-	0.299	1.051
24.0				-	0.294	1.054
24.5				-	0.294	1.055
25.0				-	0.291	1.050

Table 3: Still water propulsion data

The ship has been build with the larger bulb, with a sectional area of 11.4 % of the amidships section area, as tested by HSVA in Hamburg; see Figure 5. Forward ship speed predictions have been given in reference [4].

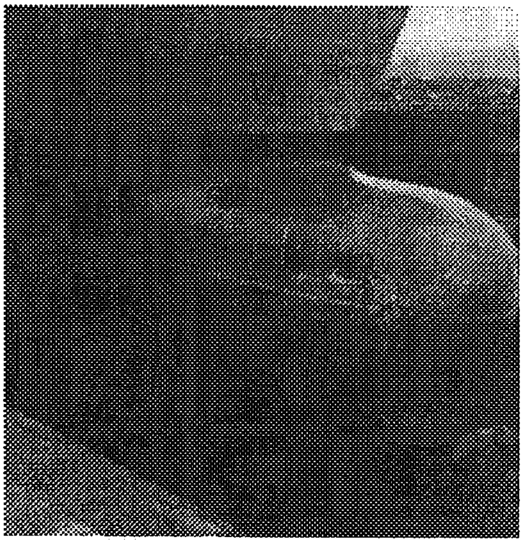

Figure 5: Bulbous bow of the ship

A graph with model experimental data in still water - extrapolated to full-scale dimensions - was given by HSVA for three loading conditions:

$$\text{effective horse power } EHP = \frac{R \cdot V}{75} \text{ as a function of ship speed } V.$$

Table 4 presents these digitised data in a tabular form. The calculated wetted areas S of the hull and the calculated (moulded) volumes of displacement ∇ are given in this table too.

V in kn	EHP in mhp at $T_m = 6.10$ m and $trim = 2.60$ m	EHP in mhp at $T_m = 9.00$ m and $trim = 0.00$ m	EHP in mhp at $T_m = 10.00$ m and $trim = 0.00$ m
19		9250	10750
20	11800	10750	12750
21	13400	12550	15250
22	15300	14900	18650
23	17700	18650	25750
24	20350	23200	27350
25	23200		
S in m^2	5059	6356	6869
∇ in m^3	19775	31282	35709

Table 4: Still water resistance test results of HSVA

2.3 Ship Trial Test Data

At 22-03-1977, full-scale trials have been carried out by the ship yard Stocznia Gdanska in the Northern zone of the Gulf of Gdansk. The draughts during these trials were 4.80 m forward and 7.40 m aft. A North-East wind with a force of Beaufort 1 and sea-state 1 was reported.

The speed was measured by a radio location method. An output reduction of 2 % was used by the ship yard in the recalculation of the measured engine output from *SHP* to *DHP*:

$$DHP = \frac{2\pi \cdot Q \cdot n}{75} = 1.02 \cdot SHP$$

The results of these full-scale measurements are specified in Table 5.

N in rpm	*V* in kn	*SHP* in mhp
123.0	21.65	22000
122.7	21.49	22030
123.0	21.87	22065
122.7	21.36	21963
Mean:		
122.9	21.64	22031

Table 5: Measured trial data by Stocznia Gdanska

The model-scale measured *EHP* data of HSVA and the full-scale measured *DHP* data of Stocznia Gdanska are presented in Figure 6.

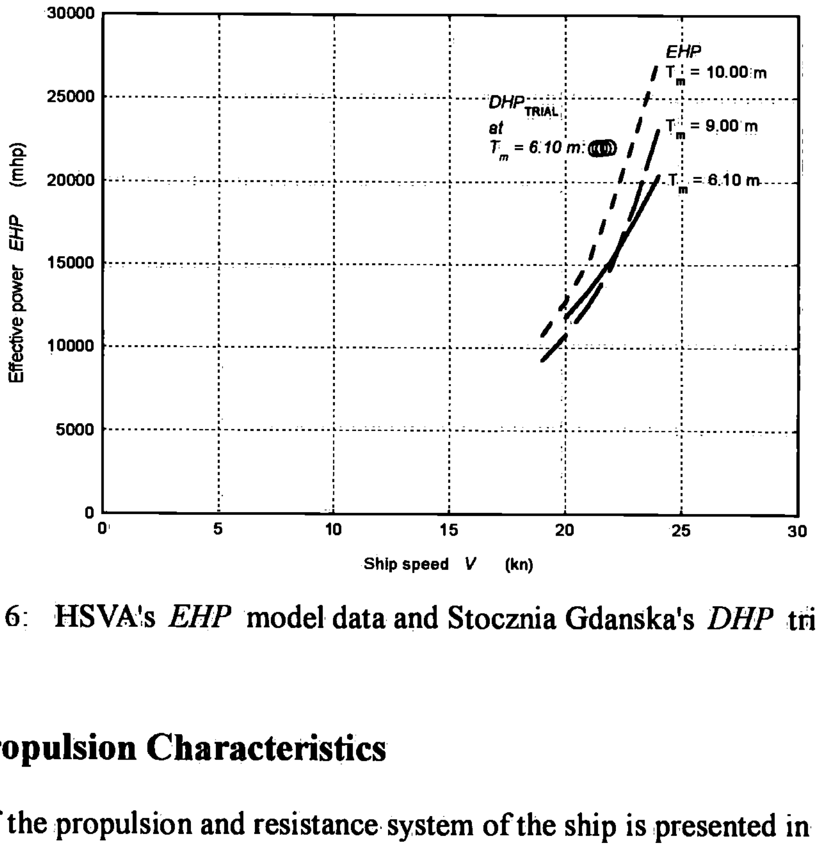

Figure 6: HSVA's *EHP* model data and Stocznia Gdanska's *DHP* trial data

2.4 Ship Propulsion Characteristics

A flow chart of the propulsion and resistance system of the ship is presented in Figure 7.

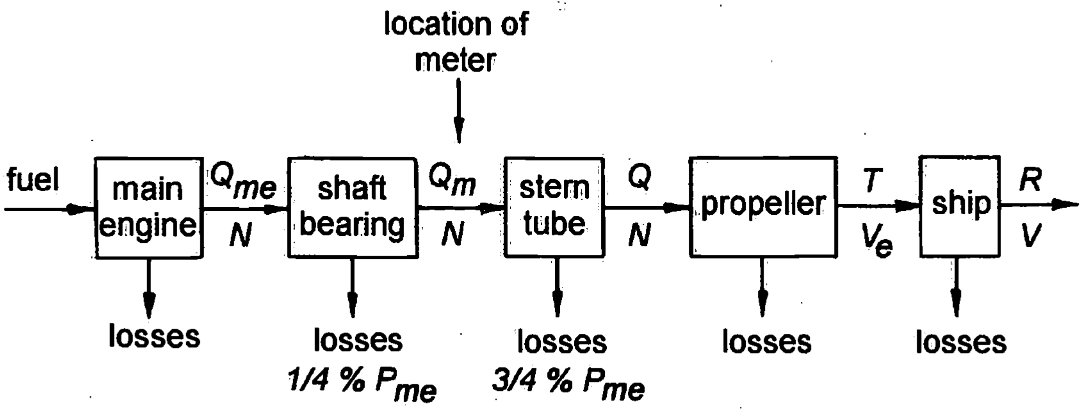

Figure 7: Flow chart of propulsion and resistance system

With respect to the power measurements the flow chart of the energy stream, the location of the torque meter and the definition of the symbols used are given here below:

P	power in kW
Q_{me}	torque delivered by the main engine in kNm
Q_m	torque at the location of the meter in kNm
Q	torque delivered to the propeller in kNm
T	thrust delivered by the propeller in kN
R	ship's resistance in kN
N	rpm of the propeller
V_e	speed of entrance in m/s
V	ship's speed in m/s

The product of the mechanical efficiency of the shaft bearings η_m, open water propeller efficiency η_p, the relative rotative efficiency η_r and the hull efficiency η_h gives the total propulsion efficiency η_t:

$$\eta_t = \frac{R \cdot V}{2\pi \cdot Q_{me} \cdot n} = \eta_m \cdot \eta_p \cdot \eta_r \cdot \eta_h \qquad \text{with} : n = \frac{N}{60}$$

Equation 2

where:

$$\eta_m = \frac{Q}{Q_{me}} \qquad \eta_{m1} = \frac{Q_m}{Q_{me}} \qquad \eta_{m2} = \frac{Q}{Q_m}$$

$$\eta_p = \frac{T \cdot V_e}{2\pi \cdot Q_o \cdot n} = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$$

$$\eta_r = \frac{Q_o}{Q}$$

$$\eta_h = \frac{R \cdot V}{T \cdot V_e} = \frac{1-t}{1-w}$$

Equation 3

The open water characteristics of the ship's propeller have been approximated by those of a Wageningen B-series propeller with $z = 6$, $P/D = 0.9626$ and $A_E/A_O = 0.9000$:

$$K_T \approx 0.476 - 0.268 \cdot J - 0.290 \cdot J^2 + 0.087 \cdot J^3$$
$$10 \cdot K_Q \approx 0.690 - 0.346 \cdot J - 0.350 \cdot J^2 + 0.091 \cdot J^3$$
$$J = \frac{V_e}{n \cdot D}$$

Equation 4

These polynomials have been obtained from reference [8].

For still water, the wake fraction w_0 and the thrust deduction fraction t_0 have been obtained from model experiments - carried out at HSVA and made available by the ship's owner - and from information given in the literature about this subject. For this particular ship, they have been determined in relation to the mean draught T_m, as shown in Figure 8 and Equation 5.

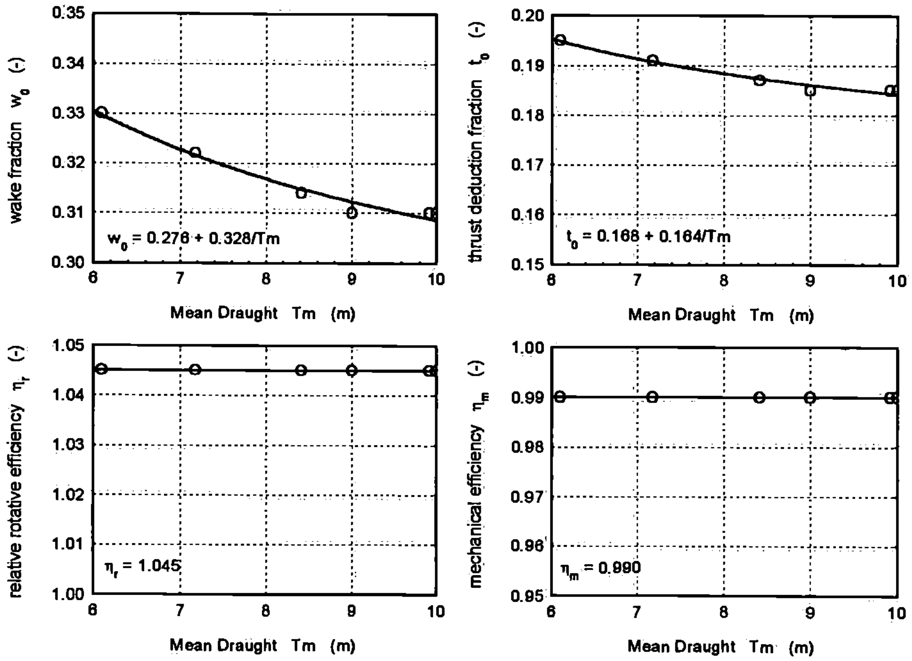

Figure 8: Still water coefficients, obtained from various sources

The approximations are:

$$w_0 \approx 0.276 + \frac{0.328}{T_m} \quad \text{and} \quad t_0 \approx 0.168 + \frac{0.164}{T_m} \quad \text{with draught } T_m \text{ in meters}$$

Equation 5

In an increasing seaway, the load of the propeller will consequently increase too.

The effect of an overloaded propeller on the wake fraction can be neglected - at least for practical purposes - thus:

$$w \approx w_0$$

Equation 6

The thrust deduction fraction however, will decrease to about 0.03-0.05 in the bollard position.
From model experiments it appeared that - except for very extreme propeller loads - a linear relation between thrust deduction fraction and speed for a constant number of revolutions could be used, at least for practical purposes:

$$t \approx t_0 \cdot \frac{V(N)}{V_0(N)}$$

Equation 7

in which $V(N)$ is the actual ship speed and $V_0(N)$ is the (to be determined) ship speed in still water at N propeller revolutions per minute.

Also, the relative rotative efficiency η_r (based here on HSVA model test data) and the (estimated) total mechanical efficiency of the shaft bearings η_m have been given in Figure 8 and Equation 8:

$$\eta_r \approx 1.045 \quad \text{and} \quad \eta_m \approx 0.99$$

Equation 8

In deliberation with one of the chief engineers of the ship, losses of 1.0% $(\eta_m \approx 0.99)$ have been estimated for the propeller shaft bearing and the stern tube: $1/4\%$ for the shaft bearing in front of the installed power measuring apparatus $(\eta_{m1} \approx 0.9975)$ and $3/4\%$ for the stern tube aft of it $(\eta_{m2} \approx 0.9925)$; see Figure 7. These estimations were based on feeling of the amount of heat, which will be developed by these engine parts.

3 Experimental Set-Up

In this Chapter, a survey is given of the experimental equipment, used to measure forward ship speed and heading, waves, wind, ship motions, propeller rpm, torque and thrust and fuel consumption of the engine. Some ship's apparatus have been used to get additional information too, of which a short survey will be given.

All Delft ship motion signals have been transmitted to recording instruments on a temporarily table between the frames against the hull in the PS gangway, amidships under the main deck. Also the wind anemometer signals were recorded here. The wave buoy signals were recorded at the aft ship and the propulsion signals have been recorded in the engine room, near the instrumented shaft.

The computer system of LR at the bridge has recorded and analysed the separately and independently measured LR transducer signals. The computer casing, as given on the picture in Figure 9, contains the DEC PDP-11/34 minicomputer, a twin disk system, an AD converter, an FFT unit and a tape drive. Results were displayed by means of a tele-type terminal and a graphical display screen.

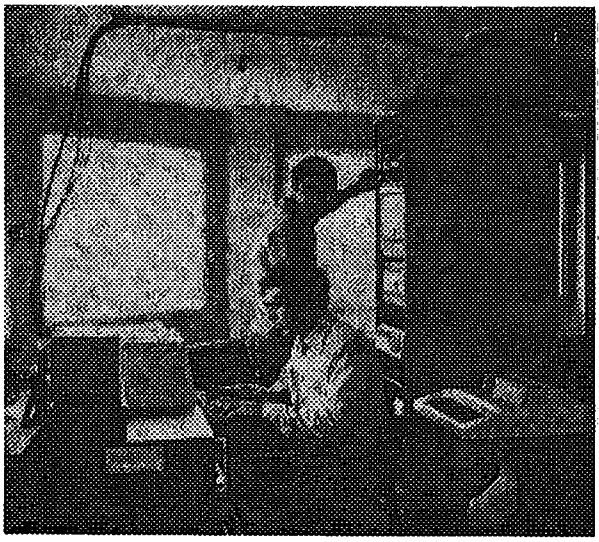

Figure 9: Operational Performance System, as installed by LR on the bridge

A short description of the first preliminary results, obtained by Lloyd's Register of Shipping with this Operational Performance System, is given in reference [10].

Before the trials, provisions have been made on the ship for a required watertight piercing of the cables through various bulkheads of the ship. The installation and calibration of all measuring equipment on the ship has been carried out at the end of December 1978 during a coastal voyage before crossing the Atlantic Ocean: from Amsterdam (via Hamburg, Bremerhafen, Tilbury, Amsterdam, Rotterdam, Zeebrugge and Le Havre) to Liverpool.

3.1 Wave Measurements

Full-scale ship motion tests require accurate information about the environmental sea- and wind conditions. The sea conditions have been measured by means of a number of disposable wave buoys, developed at the Delft Ship Hydromechanics Laboratory [2]. A scheme of the wave buoy is showed in Figure 10.

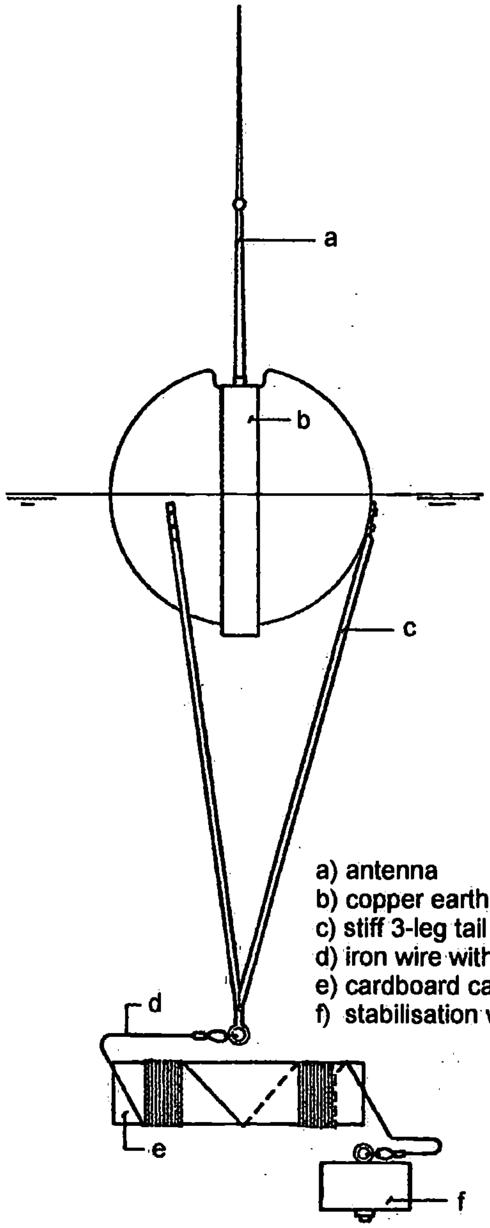

Figure 10: Disposable wave buoy of the Delft University of Technology

The disposable wave buoys are equipped with a linear vertical accelerometer of an inductive type with a natural frequency of 35 Hz. The required stabilisation - to keep the buoy continuously in a vertical position - has been achieved by means of a simple mechanic stabiliser, consisting of a tail under the buoy connected with a stabilisation weight by means of a 40 meter long wire. During transport and launching, the wire is fitted around a cardboard cylinder. The spherical buoy is half immersed when floating and follows the wave surface with sufficient accuracy.

The voltage output of the accelerometer - so in fact the acceleration signal - has been put into a voltage to frequency converter. This provides a signal that is independent of variations in the power supply, see Figure 11.

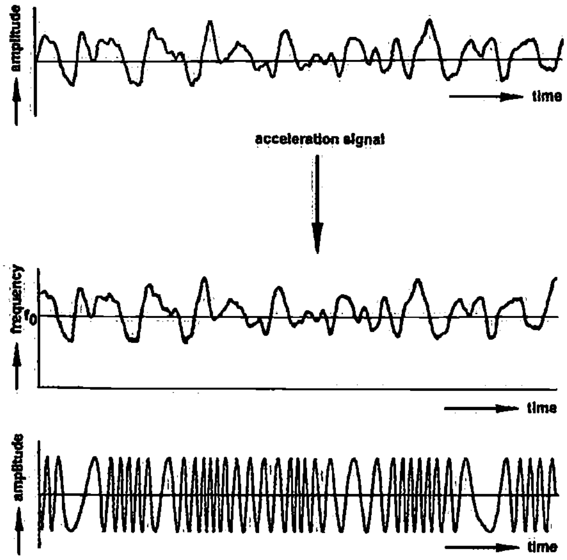

Figure 11: Frequency modulated signal

The frequency modulated signals, of which amplitudes and frequencies vary with the time, have been transmitted continuously to the ship by means of a wireless transmitter and an antenna, fitted on top of the wave buoy.

To receive these signals on the ship, which could be done up to a distance of over 40 miles in 5 meter waves, a 12 meter high antenna has been installed on the aft deck. The frequency modulated signals have been recorded by an instrumentation tape recorder, together with a reference signal from a crystal oscillator to get a real time base independent of variations in the tape speed.

A digital data reduction method has been used to derive the power spectra of the vertical wave displacement; see Figure 12.

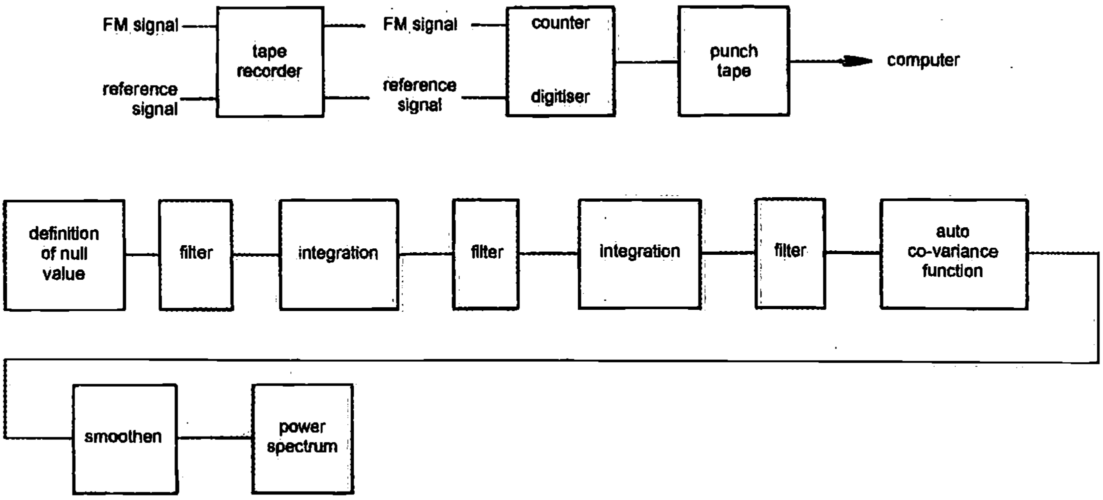

Figure 12: Flow chart of data processing for obtaining power spectra

Counting the number of zero-crossings during fixed time intervals (1.4 seconds) has derived the de-modulation of the frequency modulated signals. This digital information of the counter, transformed into punch tape data, was input to the digital IBM 370/158 computer of the Delft University of Technology Computation Centre for the calculation of the auto-covariance functions and the power spectra. A band-pass filter function has been used to cut of undesirable frequencies [9]. The transfer function of this band-pass filter is showed in Figure 13. The vertical displacement of the waves has been derived by double numerical integration of the acceleration data, using the trapezoid rule.

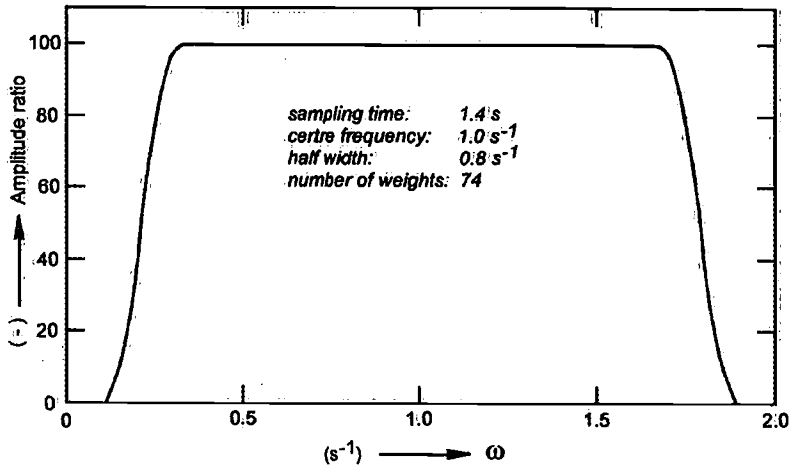

Figure 13: Transfer function of used band-pass filter

The Delft wave buoy measures only the vertical accelerations of the wave surface at the location of the buoy (point spectra). No information can be obtained with this buoy about the dominant wave directions and the directional spreading of the wave systems.
The dominant wave directions have to be estimated visually or by using radar as given in a picture in Figure 14.

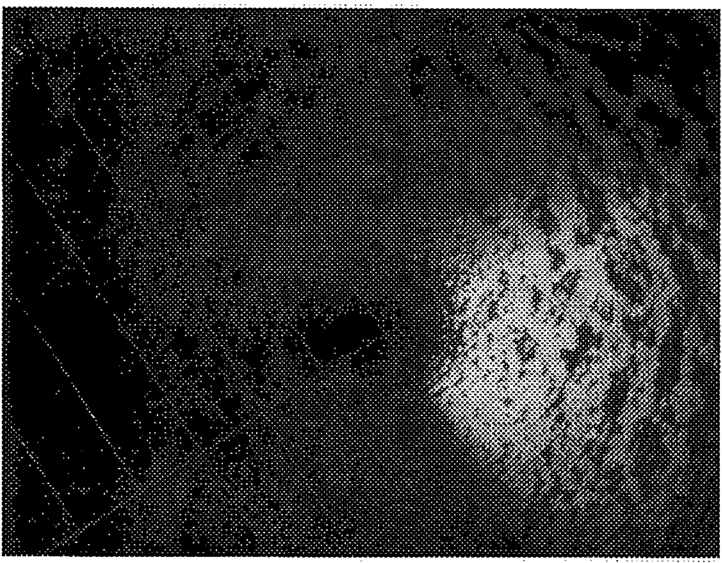

Figure 14: Radar, used as a tool to estimate the mean wave direction

Independent observations carried out by different ship's officers, show only small relative differences of 10 degrees or less. This doesn't mean that all dominant wave directions can always be distinguished visually. Hardly or not visual wave systems in bi-modal seas can have an important effect on the ship's responses.

The directional spreading of the energy of wave systems cannot be estimated visually. Sometimes a cosine-squared dividing is assumed, but this is an assumption only, which is certainly not valid for each particular sea state.

3.2 Wind Measurements

The relative wind speeds V_{rw} and directions α_{rw} have been measured by means of a cup anemometer and a wind vane (manufacturer: Lambrecht, type 1465RG). A simple pen recorder has recorded both measured signals.

The anemometer had been calibrated ashore in the wind tunnel of the Delft University of Technology and has been mounted at the top of the foremast of the ship.

The relative wind direction meter, mounted at the top of the foremast of the ship too, has been calibrated (relative direction to voltage meter output to millimetre pen recorder output) in the harbour of Le Havre, see Figure 15 and Equation 9.

$$\alpha_{rw}\,(\mathrm{deg}) = 180^0 + 2.71 \cdot \alpha_{\mathrm{recorder}}\,(\mathrm{mm})$$

Equation 9

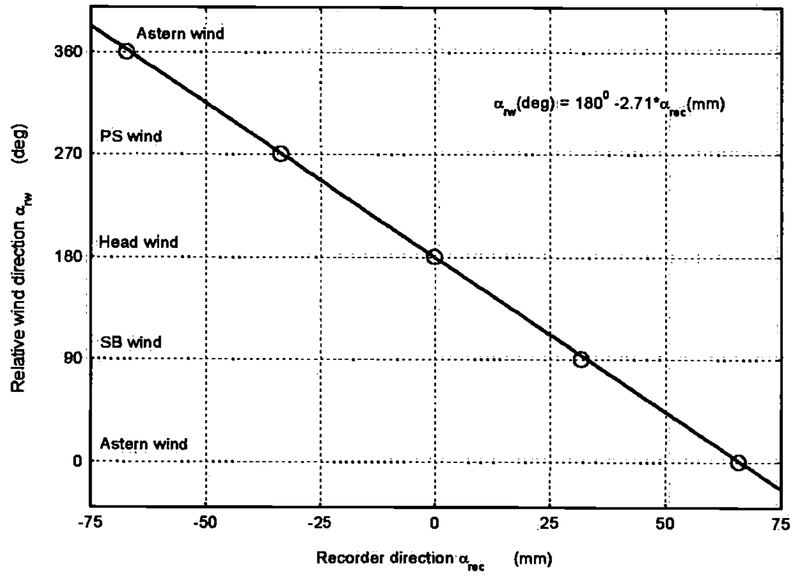

Figure 15: Calibration of relative wind direction meter

The relative wind speed has been derived in m/s. The measured relative wind direction has been defined as the direction of the wind vector relative to the ship's middle plane. Thus, astern relative wind is $\alpha_{rw} = 0$ degrees and bow relative wind is $\alpha_{rw} = 180$ degrees, while right turning is positive.

Using the from the recordings derived average values, the measured ship speed V and heading ψ, the true wind speed V_{tw} and the true wind direction α_{tw} have been determined; see Figure 16 and Equation 10.

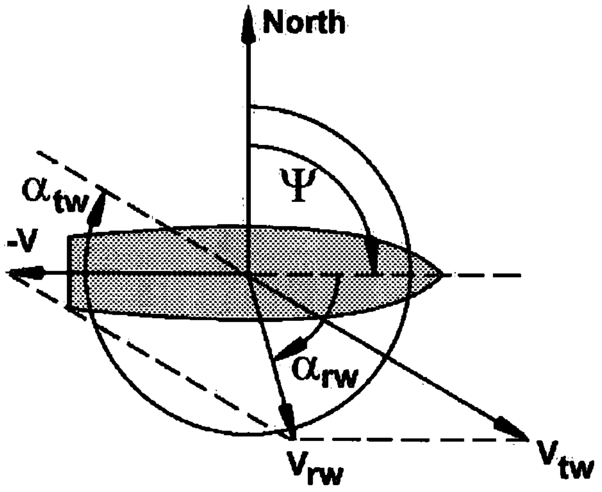

Figure 16: Relative wind and true wind

The true wind speed has been computed in knots. The true wind direction has been defined (as generally done) as the direction where the wind comes from, in a right turning earth-bound co-ordinate system with Northern wind is 000 degrees.
The true wind speed V_{tw} and true wind direction α_{tw} can be found by:

$$V_{tw} = \sqrt{(V + V_{rw} \cdot \cos\alpha_{rw})^2 + (V_{rw} \cdot \sin\alpha_{rw})^2}$$

$$\alpha_{tw} = \psi + 180 + \arcsin\left(\frac{V_{rw} \cdot \sin\alpha_{rw}}{V_{tw}}\right)$$

Equation 10

3.3 Ship Speed Measurements

The ship has been equipped with an EM speed log (Plath). The flow sensor was fitted in the pump room amidships under the keel. In operation, the distance of the flow sensor to the ship's hull is about half a meter. It develops a small AC voltage linear proportional to the rate of flow of passing seawater. This voltage is fed to the master unit that converts the input into an electric signal linear proportional to the relative speed of the water, passing the flow sensor. However, boundary layers around the ship's hull, which thickness is depending on the ship's speed, cause discrepancies between the ship's speed and the speed of the water flowing past the sensor. These errors are compensated by the use of a speed corrector circuit in the master unit. The corrector enables corrections to be applied at some points on the speed curve and it was set-up earlier at seagoing trials (measured course).
The ship's speed through the water $V_{\log}$ can be read off from the speed indicator on the bridge. Because this read off value is oscillating, especially in a seaway, for each run the average value of minimal 15 - to sometimes even 50 - read off values has been taken to obtain $V_{\log}$.
An alternative possibility was the use of the, with the speed indicator connected, miles counter (an integrator) on the bridge and a chronometer (V_{mc}). After using the least square

method - applied to all full-scale experiments that have been carried out - the next very stable relations have been found:

$$1979:\ V_{\log} \approx 1.009 \cdot V_{\mathrm{mc}}$$

$$1980:\ V_{\log} \approx 1.009 \cdot V_{\mathrm{mc}}$$

Equation 11

3.4 Ship Propulsion Measurements

Figure 17 shows pictures of the by the Delft University of Technology instrumented propeller shaft of m.v. Hollandia.

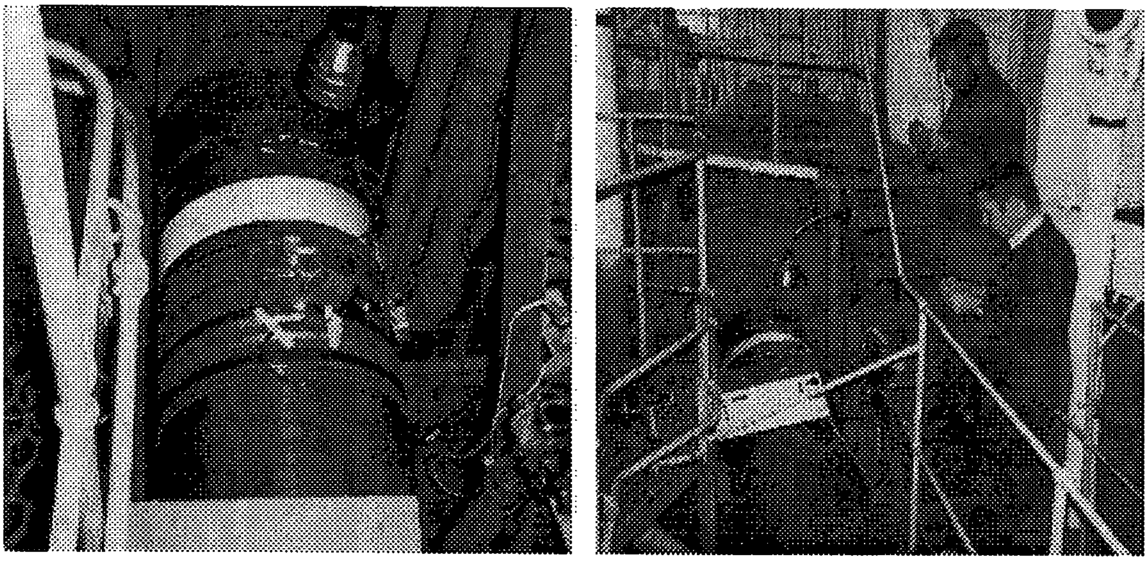

Figure 17: Instrumented propeller shaft of m.v. Hollandia

The instrumentation - which provides a continuous registration of propeller rpm, torque and thrust - was mounted on the propeller shaft several months before starting the experiments. This was done earlier for obtaining information about the zero-drift of the torque and thrust signals in a number of harbours in Europe, before starting actual the full-scale tests during an Atlantic crossing.

3.4.1 Propeller RPM

The rpm of the propeller could be measured very precisely. During the experiments, use has been made of the ship's revolution counter in the engine control room and a chronometer. The separate Delft revolution counter - mounted on the propeller shaft and providing the mean revolutions during every 10 seconds - was stand-by. The measured differences between the data of these two instruments were less than 0.05 rpm.

3.4.2 Propeller Torque

The torque delivered to the propeller shaft has been determined by measuring the deformation of the shaft surface as a result of the torsion moment by means of strain gauges.

The unit elongation ε of the propeller shaft, caused by a torsion moment Q_m is defined by:

$$\varepsilon = \frac{d \cdot Q_m}{4 \cdot G \cdot I_p} = \frac{8 \cdot Q_m}{\pi \cdot G \cdot d^3}$$

Equation 12

in which:

d diameter of propeller shaft

$I_p = \frac{\pi}{32} \cdot d^4$ polar moment of inertia of shaft cross section

G shear modulus of shaft material

The relation between the unit elongation and the relative change of the electric resistance of the strain gauges is given by:

$$\varepsilon = \frac{1}{k} \cdot \frac{\Delta R}{R}$$

Equation 13

in which:

k gauge factor

R electric resistance of the strain gauges

By using a Wheatstone bridge, it holds:

$$\varepsilon = \frac{4}{k} \cdot \frac{1}{b} \cdot \frac{U_D}{U_S}$$

Equation 14

in which:

b number of active gauges

U_D output voltage of bridge

U_S excitation voltage of bridge

This results into the relation:

$$Q_m = \frac{\pi \cdot G \cdot d^3}{8} \cdot \frac{4}{k} \cdot \frac{1}{b} \cdot \frac{U_D}{U_S}$$

Equation 15

The measuring range is determined with the next data:

$P_m = 21350\,\text{kW}$
$N = 122\,\text{rpm}$
$d = 0.522\,\text{m}$
$G = 8.0115 \cdot 10^7\,\text{kN/m}^2$
$b = 4$
$k = 2.01$

From P_m and N follows: $Q_m = 1670\,\text{kNm}$.
So, the electric measuring range has to be:

$$\frac{U_m}{U_S} = 750 \cdot 10^{-6}\,\text{V/V}$$

Equation 16

Taking into account instant peak values of the torque in a seaway, the electric measuring range has been set up at a maximum value of:

$$\frac{U_m}{U_S} = 1105 \cdot 10^{-6}\,\text{V/V}$$

Equation 17

This corresponds with a maximum torque of 2460 kNm.

The accuracy of the torque measurements is determined with the next tolerances:

k	± 1.0 %
G	± 1.0 %
linearity	± 1.0 %
d	± 0.1 %
influence of temperature	± 0.3 %
pen recorder	± 0.3 %
read off value	± 0.5 %

The accuracy of the measurements follows from these tolerances with:

$$A_m = \sqrt{\sum A_n^{\,2}} = 1.8\,\%$$

Equation 18

in which:

A_m accuracy of the measurements
A_n accuracy of the separate magnitudes

Starting from the maximum torque, one must take into account that deviations up to a maximum of about 40 kNm are possible.

A modulator, which converts the alterations of the electric resistance of the strain gauges into a frequency modulated signal, has been mounted on the shaft. The required electric feeding is transmitted by coal brushes to two trailing rings, mounted on the shaft. A wireless transmission system, an inductive pick-up, transmits the frequency modulated signal from the rotating shaft to the stationary part of the measuring system. In this part the signal is fed to a discriminator to demodulate the frequency change and provide a DC voltage whose amplitude varies in a linear proportion to the original change of the electric resistance. This is shown in Figure 18.

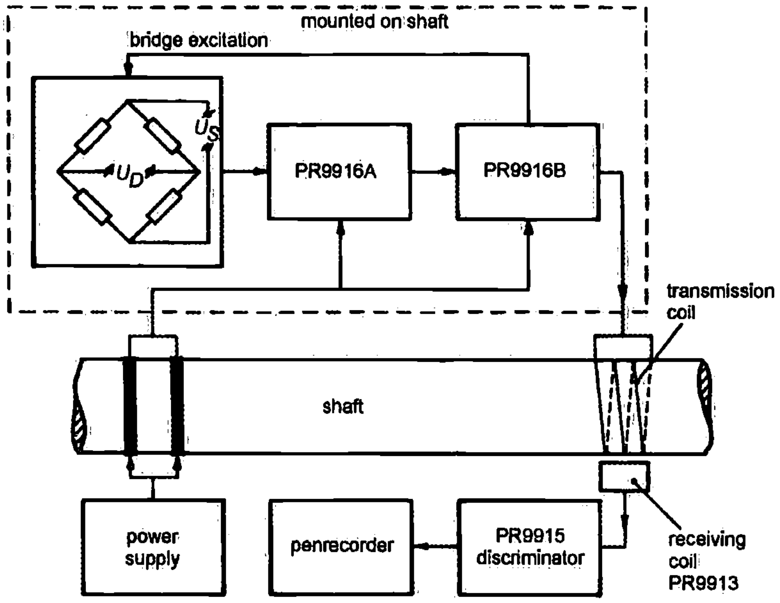

Figure 18: Experimental set-up of the torque measuring system

Use has been made of a Philips measuring system with the next specifications:

- Electrical data modulator
  - FM modulators: PR 9916A and PR9916B
  - Central freq.: 6750 Hz
  - Sweep: max. ± 30% (f_0 = ± 2025 Hz)
  - Linearity error: 0.5 %
  - Long term drift:
    - Central freq.: ≤ 0.1% per week
    - Sensitivity: ≤ 0.3% per week
- Receiving pick-up
  - Pick up: PR 9913
- Electrical data discriminator
  - FM discriminator: PR 9914
  - Accuracy of the output signal:
    - Linearity: ≤ ± 0.1 % relative to output signal
    - Zero-drift: ≤ ± 0.1 % per month
      ≤ ± 0.2 % per ^{0}C
  - Dependence of output signal:
    - On time: ≤ ± 0.1 % per day.

The output voltage is offered to a pen recorder by way of an amplifier. An example of the registration is shown in Figure 19. The output voltage is found by taking the average read off value from the paper tape at an interval time of 10 seconds during each run.

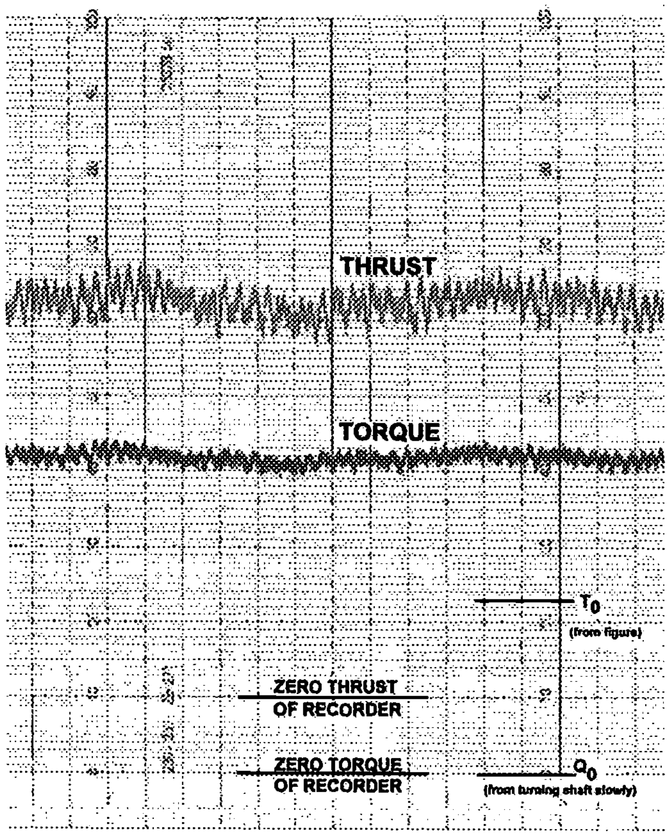

Figure 19: Example of torque and thrust recording

The output voltage at zero-torque can be found by turning the propeller shaft very slowly immediate after mooring and stopping the engine. This has been done in several ports and the differences appeared to be very small.

3.4.3 Propeller Thrust

Just like the torque, the thrust has been measured by strain gauges too and the same equipment is used as shown in Figure 18. In reference [3] it is showed that the torque would influence the thrust signal. An example is given there, from which it is clear that a difference of one degree between the axis of the propeller shaft and the axis of the strain gauges results in a contribution of the torque into the thrust signal of 53 percent of the thrust signal. A solution has been found by using a series of strain gauges, of which the axes are perpendicular on each other. This is showed in Figure 20.

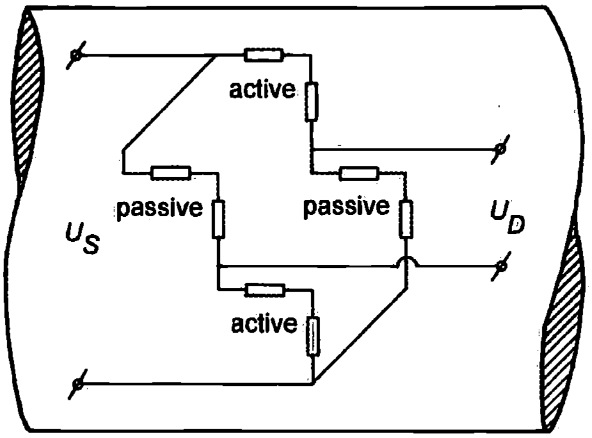

Figure 20: Measuring bridge for the thrust measurements

The sensitivity of the bridge is defined by:

$$\frac{U_D}{U_S} = \frac{1}{4} \cdot (1-\mu) \cdot k \cdot \varepsilon \text{ V/V}$$

Equation 19

with:

U_D	output voltage of bridge
U_S	excitation voltage of bridge
μ	Poisson ratio
k	gauge factor
ε	unit elongation

Assuming a linear behaviour of the shaft material, Hooke's law can be used:

$$\varepsilon = \frac{T}{A \cdot E}$$

Equation 20

in which:

T	thrust
A	sectional area of shaft
E	Young modulus

This results into:

$$T = \frac{A \cdot E \cdot 4}{k \cdot (1-\mu)} \cdot \frac{U_D}{U_S}$$

Equation 21

The measuring range is determined with the next data:

T = 1472 kN
d = 0.522 m

k = 2.01
E = 2.06 x 10^8 kN/m^2
μ = 0.28571

From these data, it follows:

$$\frac{U_D}{U_S} = 11.98 \cdot 10^{-6} \text{ V/V}$$

Equation 22

The electric measuring range has been set up at $25.94 \cdot 10^{-6}$ V/V, by using the equation given in the description of the apparatus:

$$R_3 = \frac{R}{2} \cdot \left(\frac{C \cdot V}{R + R_T} - 1 \right) \quad \text{or} \quad V = \frac{\left(R_3 + \frac{R}{2} \right) \cdot (2 \cdot R + 2 \cdot R_T)}{R \cdot C}$$

Equation 23

in which:

$R_3 = 56.2\,\Omega$
$R = (120 + 120)\,\Omega$
$R_T = 25\,\Omega$
$C = 15 \cdot 10^6$
V = inbalance of bridge per 1 Volt feeding of the bridge

From the chosen measuring range of $25.94 \cdot 10^{-6}$ V/V follows a maximum thrust of 3186 kN. This - relative to the maximum expected thrust - large value is mainly required by the necessity to have a stable measuring system. The length of the wires and the adventitious parasitically capacities of the wires have a large influence on the stability of the system.

Just as for the torque signal the output voltage of the thrust signal is offered to the pen recorder by way of an amplifier. An example of the registration of the thrust signal is shown in Figure 19 too. The output voltage is found by taking the average read off value from the paper tape at an interval time of 10 seconds during each run.

The output voltage at zero-thrust cannot be found easily. This mainly due to the influence of the temperature of the shaft material on the measurements, as will be discussed in the next.
The accuracy of the thrust measurements is determined by the same factors as given for the torque measurements. However two factors are of much more importance:

- The dimensions of a propeller shaft are highly overestimated for the thrust because it is designed to transmit a torque. The maximum thrust can cause only a very small change in length. The corresponding small measuring range of $25.94 \cdot 10^{-6}$ V/V causes an increase of stability errors. Drift of the measuring bridge and the amplifier becomes relative more important.
- The temperature drift of the thrust measuring bridge is much larger than that of the torque measuring bridge. This is caused by the temperature gradient from the surface to the centre of the shaft. This gradient is depending on the supply of heat by the engine and the

shaft bearings and the off take of heat by the air in the engine room and the propeller in the water. It causes tensions in the shaft material, which will be measured by the active strain gauges of the torque and thrust measuring bridges.

For the torque measurements this effect is of less importance, because all four strain gauges will be influenced in the same way. The total influence is almost zero.

For the thrust measurements however two active strain gauges are used. The two other gauges are mounted on a separate piece of steel, tensionless connected with the shaft surface, to compensate for the temperature at the surface of the shaft. The local temperature gradient causes tensions and elongation, which will be measured by the active gauges, by which the diagonal voltage U_D will change.

Taking these two factors into account no higher accuracy than about 10 percent of the maximum thrust - so about 300 kN - can be expected. This means that the results of the thrust measurements can only be observed as an indication of the thrust and they are of less practical value, reason why they have not been measured again during the 1980 trials. The results of the 1979 trials are given here.

The variable temperature gradient is also reason why the output voltage at zero-thrust could not be measured by turning the propeller shaft very slowly after mooring. The best way to do so should be immediately after a crash stop in open sea under normal operational circumstances and this of course is not possible. The best possible information could be obtained during the manoeuvres when entering a port. During these manoeuvres slow ahead and slow astern orders have been given. The instant read off values of the torque and thrust signals on the paper tape is plotted against each other in Figure 21.

When assuming that the thrust is zero as the torque is zero, the zero-thrust T_0 can be found at the zero-torque Q_0. This Q_0 can be obtained from turning the shaft very slowly. This has been showed in Figure 21 too.

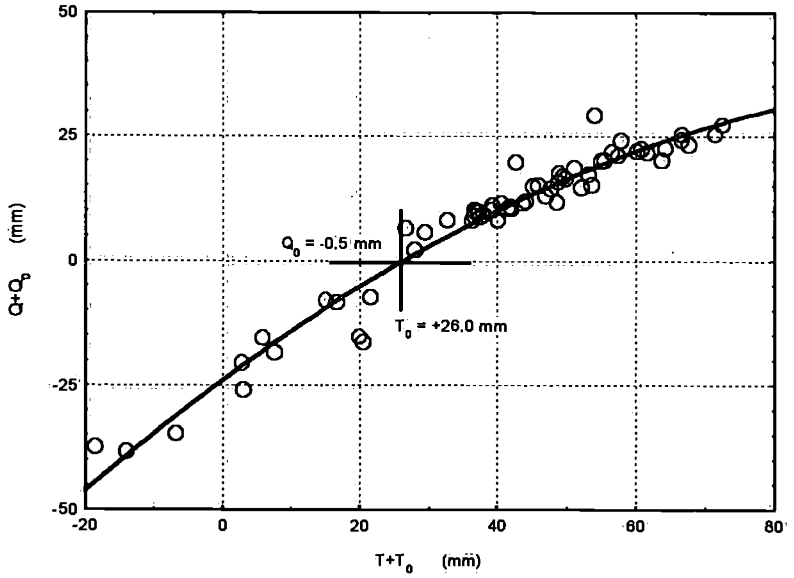

Figure 21: Zero-thrust, obtained from zero-torque

Deviations in thrust up to about 300 kN can be expected, which means that these measurements are of less practical value. So, no thrust measurements have been carried out during the 1980 voyage.

3.4.4 Fuel Consumption

The fuel consumption per unit of time had been measured with the ship's fuel meter (m^3) in the engine room and a chronometer (h). A constant fuel temperature at this location of 60 ^{0}C was specified.

No information about the accuracy of this fuel meter was available. Also, it may be noted that between the 1979 and 1980 experiments the fuel meter had been replaced; the meter was damaged by an accident in the engine room. The chief engineer testified in 1980 expressly that he had no reasons at all to mistrust the reliability and accuracy of one of these two fuel meters.

According to information obtained from the ship's owner, a specific mass of 0.952 ton/m^3 could be taken for heavy fuel with a temperature of about 60 degrees Celsius to determine the specific fuel consumption in mass units per hour. A caloric value of 9520 kCal/kg could be assumed for this heavy fuel, for comparing shipboard measurements with those on the test stand with diesel oil (10180 kCal/kg).

3.5 Ship Motion Measurements

The following ship motions have been measured by DUT:

1. Heave motions at the bow of the ship (at about FPP), in a ship bound axes system.
2. Heave motions at the bow of the ship (at about FPP), in an earth bound axes system.
3. Heave motions at the centre of gravity of the ship (at about half the ship's length), in a ship bound axes system.
4. Heave motions at the centre of gravity of the ship (at about half the ship's length), in an earth bound axes system.
5. Roll motions at the centre of gravity of the ship.
6. Pitch motions at the centre of gravity of the ship.

The ship motion items 1, 4, 5 and 6 have been measured separately by LR too. Both measured results will be presented here.

3.5.1 Heave Motions

Due to the lack of a fixed reference point aboard of a sailing ship, translations such as heave have to be measured using linear accelerometers. Also, to prevent accelerations due to roll and pitch movements to interfere with the required channels, the accelerometers have to be placed as close as possible to the ships centre of gravity. A suitable location was found at about half the ship's length between hold numbers 3A and 3B.

During the measurements two accelerometers were used to measure the heave motion. One of them was mounted on a stabilised platform that kept the sensitivity axis of the accelerometer vertical within approximately 0.6 degrees. Keeping the sensitivity axis vertical is necessary to be sure that only the vertical accelerations are measured and that the earth gravity does not introduce errors when the ship is rolling and pitching.

However, in many cases a non-stabilised accelerometer gives a very good approximation of the vertical acceleration and might be used with advantage. In particular this is the case when roll and pitch angles are not very large. Onboard of a containership this requirement is mostly met.

The accelerometers used were of the servo type. These accelerometers are rugged, can measure static accelerations, have a very low hysteresis and hence can measure extremely small and low frequency accelerations. An exact accuracy for the stabilised accelerometers is hard to get, but an accuracy within 1 percent is a conservative figure. For the non-stabilised accelerometer this figure will be higher depending on measurement conditions. But experience indicates that an accuracy within 5 percent is a safe bet.

To get the vertical displacements the acceleration signal has to be integrated twice. In order to prevent the severe pitfalls of analogue double integration and because the further processing had to be carried out by a computer the integration was done numerically.

The most important specifications of the accelerometers were:

- Manufacturer: Schaevitz Engineering
- Type: L5MP-5
- Range: ± 5 g
- Natural frequency: 100 Hz
- Damping ratio: 0.55 to 0.75
- Hysteresis: ≤ 0.02 % of full scale (10 g)
- Resolution: ≤ 0.0005 % of full scale
- Linearity: ± 0.05 % of full scale
- Power: ± 15 V @ 10 mA maximum

3.5.2 Vertical Motions of the Bow

The measurement of the vertical displacements of the bow was carried out in almost the same way as the heave measurements. The only difference was that the stabilised accelerometer was only stabilised for roll. However, the error, introduced by the pitch angles was negligible at the pitch angles that were encountered. Also, the use of a non-stabilised accelerometer for the measurements of vertical displacements of the bow will, in general, give better results as for the heave measurements. This is due to the fact that the accelerations that we want to measure are much larger in the fore ship as in the centre of gravity. The parasitic accelerations due to the earth gravity and translations are at the same at both positions and only an additional component due to local sway (caused by yaw) will be added to the acceleration signal at the bow position. Hence the relative error of the signal at the bow position is smaller than that of the heave accelerations.

A suitable location for measuring was found against the fore peak bulkhead, approximately at the forward perpendicular (FPP).

3.5.3 Roll and Pitch Motions

For the measurements of the roll and pitch angles a vertical gyro (VG) was used. The use of inclinometers for the measuring of dynamic roll and pitch angles is in general not recommended due to their sensitivity for accelerations. Even placing the inclinometer in the ship's centre of gravity gives only partial relief, because it is then still exposed to the accelerations due to the sway and surge translations. So, the use of a vertical gyro was mandatory.

The vertical gyro that was used is a type normally used in aircraft. These gyros are compact and have an excellent dynamic behaviour.

During the measurements it was placed near the centre of gravity of the ship. Although this is, at least theoretically, the most favourable place to locate a gyroscope, this location was mainly selected because the roll and pitch information was also used by a stabilised platform that had to be located at the centre of gravity. A demodulator was used to convert the three wire synchro-signals to a voltage proportional with the instantaneous value of the roll and pitch angles. The torque motors in conjunction with the liquid switches prevent the rotor from drifting away from its vertical working position. Of course, the position of the liquid is also influenced by accelerations to which the gyro is subjected. Hence it is possible that with the gyro in its midst position the switches are closed due to the accelerations, causing the torque motors to rotate the rotor away from its correct position.

To minimise this effect, the torque is kept small, keeping the erection rate at a low 2.5 degrees per minute. If the error is still too large and the measurement is of relatively short duration - for instance 5 minutes - the switches can be disabled allowing the gyro to run freely. For the measurement of ship motions the gyro is mostly operated in its slave mode (switches enabled). Under the conditions that are usually encountered during these measurements the accuracy of the gyro is approximately 0.5 degrees.

The leading particulars of the vertical gyro - used aboard m.v. Hollandia - were:

- Manufacturer: Sperry Flight Systems, Aviation Division
- Type: VG14
- Verticality error (static): ≤ 0.25 degree
- Power: 115 ± 2Vac, 400 Hz
- Starting power: ≤ 80 VA
- Operating power: ≤ 40 VA

A static inverter powered the gyro.

3.6 Additional Measurements

Some apparatus on the bridge have been used during the experiments in a seaway:

- the gyro-compass indicator
- the rate of turn indicator
- the rudder angle indicator
- the PS fin stabiliser angle indicator

These read off values are of some importance with respect to the added power in a seaway.

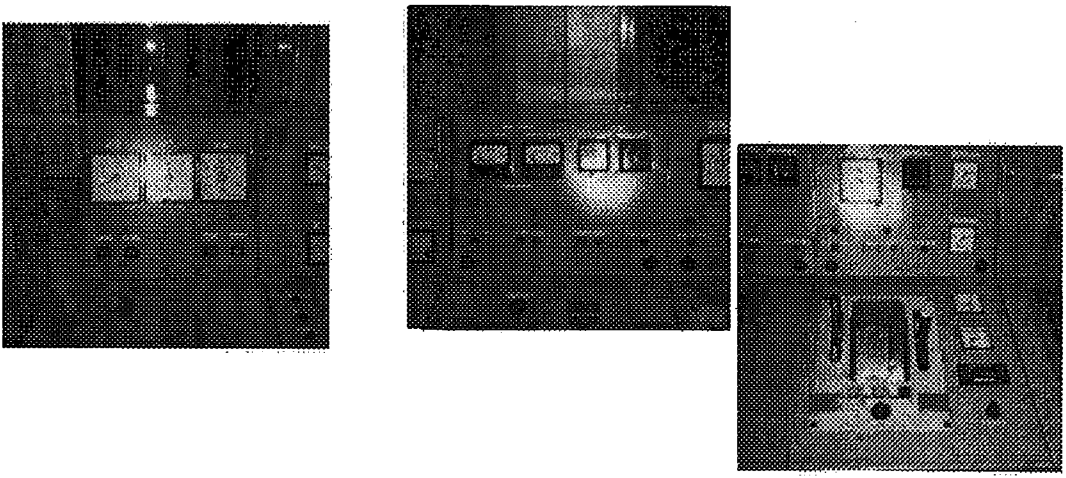

Figure 22: View of some parts of the control panel in the engine room

Other instruments which have been read off are:

- the engine load indicator on the bridge and in the engine control room (the last one only during the 1979 voyage), see the right picture in Figure 22
- the propeller revolution counter on the bridge
- the power and torque meter in the engine control room (only during the 1979 voyage), see the left picture in Figure 22

These instruments have been compared with the Delft measurements of rpm, torque and power. This could be of some use in case of an unfortunately break down of the Delft instruments, which did not occur.

4 Experimental Results

Figure 23 shows pictures of the view from the bridge to the bow of the ship in calm water and in a seaway.

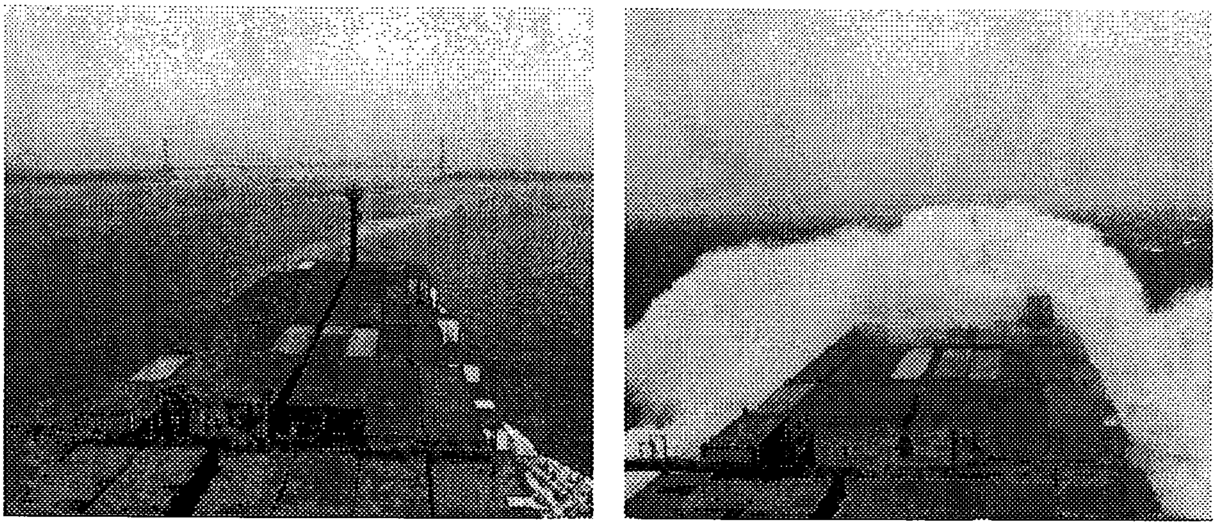

Figure 23: View from the bridge of the ship in calm water and in a seaway

The map in Figure 24 shows the locations in the Atlantic Ocean where the 1979 and 1980 sea keeping experiments - with waves measured by disposable wave buoys - have been carried out.

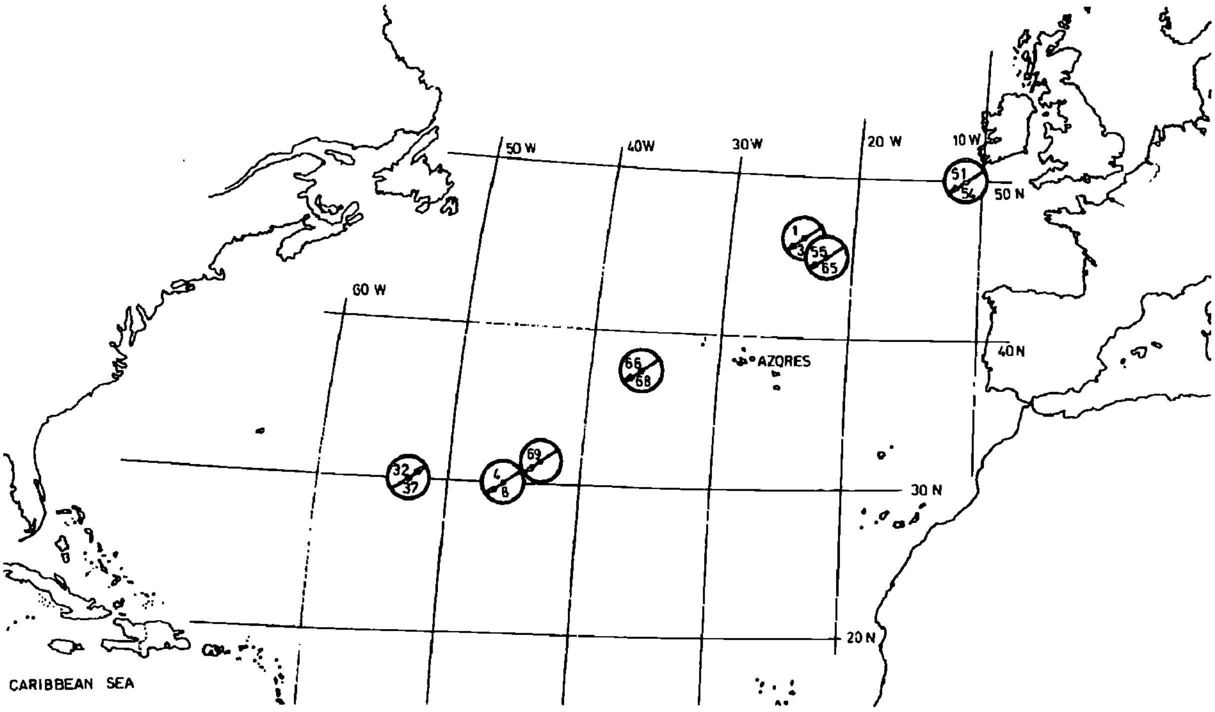

Figure 24: Main locations of experiments

The wind and sea observations during all experiments are given in Table 6 and Table 7.

1979 measurements			measured wind				observed sea			observed swell		
Run No.	V	ψ	V_{rw}	α_{rw}	V_{tw}	α_{tw}	$H^{(1)}_{obs}$	$T^{(1)}_{obs}$	$\mu^{(1)}_{obs}$	$H^{(2)}_{obs}$	$T^{(2)}_{obs}$	$\mu^{(2)}_{obs}$
(-)	(kn)	(deg)	(m/s)	(deg)	(kn)	(deg)	(m)	(s)	(deg)	(m)	(s)	(deg)
01	18.40	248	4.5	175	9.7	073	1.00	5.0	068	4.00	8.0	251
02	18.50	268	4.2	163	11.0	101	0.75	5.0	068	4.00	8.0	251
03	18.70	207	3.8	195	11.7	018	0.50	5.0	052	3.25	8.5	251
04	19.98	264	5.6	019	30.5	091	2.25	6.5	-	6.00	8.0	-
05	19.47	244	9.0	064	31.4	094	-	-	080	5.25	-	-
06	18.89	223	13.1	086	32.7	094	-	-	-	-	-	-
07	14.82	265	8.4	026	30.4	099	-	-	-	-	-	-
08	13.78	223	13.2	082	30.8	099	-	-	-	-	-	-
09	18.68	214	-	-	-	-	1.75	10.0	-	-	-	-
10	18.68	218	4.5	163	10.6	052	0.25	-	-	0.50	-	-
11	18.79	218	4.5	163	10.7	052	0.25	-	-	0.50	-	-
12	15.34	218	3.2	145	10.8	057	0.25	-	-	0.50	-	-
13	21.40	-	-	-	-	-	0.25	-	-	0.25	-	-
14	21.52	263	6.2	225	15.5	050	0.25	-	-	0.25	-	-
15	21.42	-	-	-	-	-	0.25	-	-	0.25	-	-
16	22.07	037	20.3	220	26.6	145	2.25	-	-	-	-	-
17	15.29	259	4.4	035	22.8	091	1.75	7.5	120	-	-	-
18	18.64	284	3.1	243	16.8	085	0.50	2.0	-	1.25	6.0	095
19	21.37	254	19.6	237	32.0	345	1.25	2.5	310	1.50	4.5	270
20	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	21.47	090	10.2	193	5.0	206	0.25	-	-	0.25	-	-
25a	21.91	092	9.2	180	4.0	272	0.25	-	-	0.25	-	-
25b	21.47	-	-	-	-	-	-	-	-	-	-	-
25c	21.34	-	-	-	-	-	-	-	-	-	-	-
26a	7.99	125	4.2	170	1.4	033	-	-	-	-	-	-
26b	-	-	-	-	-	-	-	-	-	-	-	-
27	21.12	047	-	-	-	-	1.50	-	315	-	-	-
28	20.48	066	7.1	313	31.6	227	3.00	6.0	220	3.50	8.5	300
29	19.68	065	7.6	064	29.3	272	1.50	4.0	270	4.50	6.0	250
30	19.13	065	9.5	056	33.2	272	3.50	7.0	280	4.50	10.0	300
31	18.77	064	13.0	051	39.9	274	6.00	9.0	275	6.25	9.5	285
32	19.59	095	9.2	347	37.7	269	8.50	13.5	280	-	-	-
33	18.83	075	10.7	034	37.9	273	-	-	-	-	-	-
34	18.71	056	14.3	060	40.5	272	5.75	9.5	265	9.75	10.5	285
35	13.95	095	11.7	358	36.7	274	3.00	-	265	8.00	9.0	270
36	13.77	075	13.1	034	37.7	277	-	-	-	-	-	-
37	13.50	064	13.7	048	37.1	276	-	-	-	-	-	280
38	18.66	064	6.2	006	30.7	246	4.50	8.5	250	7.75	16.5	270
39	19.02	060	8.3	037	33.4	257	3.50	8.5	290	8.00	16.5	270
40	19.65	063	9.8	314	35.6	220	4.00	7.0	220	5.75	10.5	260
41	19.11	066	5.5	356	29.8	245	2.50	6.0	220	4.75	12.0	260
42	19.78	064	10.2	280	30.3	204	2.50	6.0	190	3.50	13.0	-
43	19.52	065	9.6	290	31.3	211	1.00	5.0	230	3.50	7.5	220
44	19.89	065	2.6	026	24.5	250	1.00	-	240	2.75	8.0	240
45	18.52	065	4.3	044	25.2	258	1.00	3.5	275	3.00	9.0	260
46	17.74	075	24.2	191	29.8	237	1.75	5.5	080	0.25	-	-
47	19.20	234	18.9	167	18.5	080	1.00	-	210	1.50	-	295
48	21.18	218	11.4	204	9.1	314	0.25	-	-	0.50	-	265
49	8.10	-	3.45	102	-	-	0.25	-	-	-	-	-

Table 6: Logbook data of measured wind and observed sea during the 1979 experiments

1980 measurements			measured wind				observed sea			observed swell		
Run No. (-)	V (kn)	ψ (deg)	V_{rw} (m/s)	α_{rw} (deg)	V_{tw} (kn)	α_{tw} (deg)	$H_{obs}^{(1)}$ (m)	$T_{obs}^{(1)}$ (s)	$\mu_{obs}^{(1)}$ (deg)	$H_{obs}^{(2)}$ (m)	$T_{obs}^{(2)}$ (s)	$\mu_{obs}^{(2)}$ (deg)
50a	16.54	265	-	-	-	-	-	-	-	-	-	-
50b	16.72	265	-	-	-	-	-	-	-	-	-	-
50c	18.39	265	-	-	-	-	-	-	-	-	-	-
51	14.80	300	19.1	178	22.3	123	6.50	10.5	300	-	-	-
52	16.31	280	20.7	189	24.3	085	-	-	-	-	-	-
53	17.43	261	19.9	201	23.3	044	5.00	-	-	-	-	-
54	18.45	233	17.4	216	21.8	347	4.00	10.0	285	-	-	-
55	12.32	226	18.0	165	23.3	069	4.50	-	185	-	-	-
56	13.22	235	19.9	214	28.7	006	4.75	10.0	275	-	-	-
57	12.74	256	19.2	198	25.5	049	5.50	10.0	275	-	-	-
58	12.07	275	19.2	190	25.5	080	5.50	-	275	-	-	-
59	6.55	275	16.5	198	25.9	073	5.00	10.0	275	-	-	-
60	6.60	255	14.8	211	23.4	036	-	-	275	-	-	-
61	6.41	236	15.0	232	25.7	353	-	-	270	-	-	-
62	18.81	227	16.1	236	26.0	320	(dark)	(dark)	267	(dark)	(dark)	(dark)
63	17.45	247	15.2	217	18.8	356	(dark)	(dark)	270	(dark)	(dark)	(dark)
64	16.57	272	19.2	200	22.5	057	(dark)	(dark)	272	(dark)	(dark)	(dark)
65	18.69	226	13.5	224	18.2	317	(dark)	(dark)	268	(dark)	(dark)	(dark)
66	19.36	218	5.7	328	29.4	026	-	-	-	4.50	-	325
67	19.42	238	8.6	301	31.5	031	-	-	-	-	-	-
68	19.55	226	6.4	3287	29.5	064	-	-	-	4.00	-	325
69	20.45	223	10.7	258	26.0	351	2.50	6.0	350	4.25	12.0	350
70	20.24	219	2.0	078	21.4	049	1.00	-	080	2.50	-	015
71	20.00	-	2.2	126	-	-	1.00	3.0	040	1.00	-	000
72	19.93	211	7.1	100	22.2	069	1.00	3.0	070	1.50	5.0	080
73	17.88	-	-	-	-	-	-	-	-	-	-	-
74	17.54	-	-	-	-	-	1.75	-	-	-	-	-
75	17.59	259	3.3	302	21.7	064	1.75	-	030	1.00	-	050
76	15.10	259	1.9	286	16.5	067	1.75	-	030	1.00	-	050
77	10.04	259	3.8	326	16.7	065	1.75	-	070	1.00	-	050
78	15.82	259	1.0	307	17.1	074	0.50	0.25	-	1.75	-	025

Table 7: Logbook data of measured wind and observed sea during the 1980 experiments

The results of all experiments are discussed in the next sections and are given in Table 8 through Table 12.

4.1 Measured Wave and Wind Data

Two expressions for the significant wave height are used here:

$$H_{1/3} = 4 \cdot \sqrt{m_0} \quad \text{and} \quad H_{1/3}^{*} = 4 \cdot \sqrt{\frac{1}{2}\left(m_0 + \frac{m_2^{\,2}}{m_4}\right)}$$

Equation 24

in which:

$$m_n = \int_0^\infty \omega^n \cdot S_\zeta(\omega) \cdot d\omega \qquad \text{(spectral moment)}$$

Equation 25

where:

ω = circular wave frequency

$S_\zeta(\omega)$ = spectral value

Generally $H_{1/3}$ will be used as the significant wave height. The significant wave height $H_{1/3}^*$ includes a correction for the breadth of the spectrum and has been used by Lloyd's Register of Shipping in their operational performance system; reason why this value is given here too.

The centroid period T_1 and the average zero-crossing period T_2 of the waves are defined by:

$$T_1 = 2\pi \cdot \frac{m_0}{m_1} \quad \text{and} \quad T_2 = 2\pi \cdot \sqrt{\frac{m_0}{m_2}}$$

Equation 26

Figure 54 through Figure 60 in Chapter 11 show the results of the analyses of the 1979 and 1980 wave measurements. These results will be discussed here day by day.

1-1-1979 / 45^{0}N 23^{0}W

Between 16:20 and 19:00 GMT seakeeping trials have been carried out at normal operating power. Two wave systems have been observed: a head swell from 250 degrees with a height of 3-4 meters and a low following sea from 070 degrees with an observed height of 1 meter or less.

At 17.15 GMT wave buoy 18 has been launched. Two analyses are given here, one at 18.00 GMT and the other at 19.00 GMT. The significant wave height decreased from 4.0 to 3.7 m by a decrease of long period waves. The wave spectra are given in Figure 54.

During the experiments there was a variable wind, coming from directions between North and East, with a speed of about 11 knots.

4-1-1979 / 30^{0}N 46^{0}W

Seakeeping trials at 100 and 75 percent of the normal engine speed have been carried out between 10:30 and 16:10 GMT. A somewhat confused following sea and swell has been observed. The sea, coming from 080 degrees, had a visual height of about 2 meters and the swell was estimated on 5-6 meters, coming from 090 degrees. It may be noted that sea and swell were certainly not unidirectional. The estimated dominant wave direction was 085 degrees.

Two wave buoys have been launched; number 22 at 17:35 GMT and number 16 at 20:25 GMT. The analyses are given here at 18:10 GMT and at 21:00 GMT and show a significant wave height of 5.2 and 5.7 meter. The signal of the second wave buoy has not the quality that it should have, the energy in the low frequency part is somewhat doubtful. The wave spectra are given in Figure 55.

The measured true wind was reasonable constant, 31 knots coming from 095 degrees.

2-2-1979 / 30^{0}N 53^{0}W

The seakeeping trials have been carried out at 100 and 75 percent of the normal engine speed between 14:40 and 20:30 GMT in very high following seas. At about 14:00 the sea state was suddenly increasing up to extreme observed wave heights of 11-12 meter.

The first wave buoy, number 8 launched at 14:30 GMT, gives at 15:15 GMT a significant wave height of 11.1 meter. However an analysis 35 minutes later, shows a decreased wave height of 9.8 meter. Another wave buoy, number 9 launched at 18.00 GMT, shows also a wave height of 9.8 meter.

The visual observed sea came from 260 to 270 degrees with wave height of 4 up to even 8 meter. The swell came from 275 to 285 degrees with visual observed wave heights of 8 to 10 meters. The dominant wave direction has been estimated on 275 degrees and the waves were somewhat short-crested. The analysed wave spectra are given in Figure 56.

The true wind direction was varying between 270 and 280 degrees with a true speed of 37 to 41 knots.

5-1-1980 / 50^{0}N 11^{0}W

The seakeeping trials at normal operating power are carried out between 10:00 and 13:35 GMT in head seas. The sea state was strongly decreasing during the experiments. At 10:00 GMT 6 to 7 meter waves have been observed, coming from 300 degrees. At the end of the experiments the visual observed wave height was about 4 meter and the sea direction started to shift to 285 degrees. During the main part of the experiments the dominant wave direction was 300 degrees and no other wave systems could be observed.

Two wave buoys have been launched: number 29 at 10:55 GMT and number 15 at 12:10 GMT. The analyses of the wave buoy signals confirm the visual observations. The first wave buoy gives at 11:15 GMT a significant wave height of 6.7 meter and the second one gives at 12:30 GMT a significant wave height of 4.2 meters. The higher long period waves have been decreased considerably in a little more than one hour. The results of the wave analyses are showed in Figure 57.

The measured true wind was varying between 295 and 300 degrees with a speed of 22 to 24 knots.

6-1-1980 / 45^{0}N 22^{0}W

During this day many seakeeping trials in head waves have been carried out: at 75 and 50 percent of the normal operating engine speed during daylight between 16:25 and 19:10 GMT and at the normal operating engine speed at night between 21:35 and 23:45 GMT. The ship's officers classified the waves as constant, "unusual unidirectional" and even "off and on long crested". During daylight the visually observed wave height varied from "not more than 5 meter" to "5 meter, sometimes 6 meter" and the wave direction was estimated on 270-275 degrees. The estimated dominant wave direction during daylight was 275 degrees. At night the dominant wave direction was estimated from the sea clutter on the ship's radar: 270 degrees.

Four wave buoys have been launched: number 20 at 16:20 GMT, number 10 at 18:00 GMT, number 17 at 21:25 GMT and number 11 at 22:45 GMT. The analysed signals show significant wave heights varying between 4.6 and 5.4 meter. All spectral forms are less or more similar. This is showed in Figure 58.

During daylight the measured true wind speed was about 26 knots with a true wind direction increasing from 280 to 300 degrees. At night the wind speed was decreasing until 18 knots at a wind direction between 310 and 330 degrees.

8-1-1980 / 37^{0}N 36^{0}W

At normal operating power a few sea keeping trials in beam to quartering seas have been carried out between 12:00 and 13:45 GMT. According to the visual observations during the trials the sea consists of three wave systems:

- a swell coming from 270 degrees, decreasing from 4-5 meter to 3 meter,

- a swell coming from 330 degrees, decreasing from 4-5 meter to 4 meter and
- a coming on sea from 030 degrees.

The dominant wave direction should have been 330 degrees, but this was difficult to estimate. Two wave buoys have been launched: number 13 at 12:20 GMT and number 14 at 13:10 GMT. During the reception of buoy 13 there was a lot of radio interference. Two analyses with a time shift of 5 minutes show significant wave heights of 5.1 and 4.1 meter respectively. Considering the results of buoy 14 (5.0 meter) the first analysis seems to be the best, but certainty can't be given. The results are showed in Figure 59.
The measured true wind varied between 025 and 035 degrees, a speed of 30 to 32 knots.

9-1-1980 / 32^{0}N 43^{0}W

One experiment in quartering seas at normal operating power has been carried out between 14:15 and 14:45 GMT. According to visual observations a 4.0-4.5 meter swell was coming from 340-350 degrees and a 2-3 meter sea came from 350-355 degrees. There was also a very small swell from 270 degrees. For the dominant wave direction, 350 degrees has been estimated.
Wave buoy number 7 has been launched at 14:10 GMT. The measured significant wave height was 4.7 meter. Also the spectral form suggests that more than one wave system was present. The results are given in Figure 60.
The measured true wind came from 353 degrees with a speed 26 knots.

In total 16 wave buoys have been used for these experiments. One wave buoy was damaged when hitting the water surface and a misunderstanding during the launching procedure did lost another one. In spite of some radio interference, the other 14 wave buoys have worked well. It may be noted however, that the results of the analyses of buoy numbers 13 and 16 could give a critical reader some reasons for doubt about the reliability of these two buoys.
A survey of all measured wave buoy and wind data is given in Table 8 and Table 9 and in Figure 61 and Figure 62 in Chapter 11.

The configuration of the containers at deck during all experiments is given in Chapter 9. This configuration is mainly of importance for predicting the wind resistance with an empirical method.

Table 8: Survey of 1979 wave buoy and wind data

Date 1979	Buoy No.	Time GMT	Waves				Run No.	Time GMT	Draught		True Wind		Waves	N (rpm)
			$H_{1/3}$ (m)	$H^*_{1/3}$ (m)	T_1 (s)	T_2 (s)			T_m (m)	*trim* (m)	V_{tw} (kn)	α_{tw} (deg)	μ (deg)	
1-1-79	18	17:55-18:12	4.00	3.60	10.76	10.13	01	16:23-17:08	8.54	0.00	9.8	175 PS	000 PS	116.30
							02	17:22-18:08	8.54	0.00	11.2	163 PS	020 PS	116.39
							03	18:14-19:00	8.54	0.00	10.6	178 PS	040 PS	116.52
	18a	18:45-19:01	3.74	3.40	9.87	9.40								
4-1-79	22	18:00-18:20	5.24	4.76	10:15	9.61	04	16:32-17:17	8.44	0.00	30.4	173 PS	180 PS	116.98
							05	17:40-18:25	8.44	0.00	31.3	150 PS	160 PS	116.95
							06	18:38-19:23	8.44	0.00	32.7	129 PS	140 PS	117.44
	16	20:50-21:10	5.69	5.11	10.72	9.94	07	20:28-21:13	8.44	0.00	30.4	167 PS	180 PS	89.03
							08	21:24-22:09	8.44	0.00	30.7	124 PS	140 PS	88.87
2-2-79	08	15:00-15:35	11.06	9.73	13.87	13.00	32	14:42-15:27	8.01	0.23	37.4	174 SB	180 PS	117.33
							33	15:33-16:18	8.01	0.23	38.0	162 PS	160 PS	116.93
							34	16:25-17:10	8.01	0.23	40.6	154 PS	140 PS	117.45
	08a	15:45-15:59	9.74	8.60	13.32	12.59								
	09	18:25-18:45	9.77	8.63	13:18	12:31	35	18:05-18:50	8.01	0.23	36.8	179 SB	180 PS	90.24
							36	18:53-19:33	8.01	0.23	37.7	158 PS	160 PS	89.90
							37	19:45-20:30	8.01	0.23	37.1	148 PS	150 PS	89.97

Table 9: Survey of 1980 wave buoy and wind data

Date 1980	Buoy No.	Time GMT	Waves				Run No.	Time GMT	Draught		True Wind		Waves	N (rpm)
			$H_{1/3}$ (m)	$H^*_{1/3}$ (m)	T_1 (s)	T_2 (s)			T_m (m)	$trim$ (m)	V_{tw} (kn)	α_{tw} (deg)	μ (deg)	
5-1-'80	29	11:00-11:30	6.22	5.70	13.54	12.04	51	10:01-10:41	9.36	0.12	21.7	003 PS	000 SB	113.74
							52	10:58-11:38	9.36	0.12	23.6	015 SB	020 SB	114.87
	15	12:15-12:40	4.21	3.80	10.28	9.71	53	12:12-12:52	9.36	0.12	22.7	037 SB	040 SB	115.51
							54	12:55-13:35	9.36	0.12	21.5	067 SB	050 SB	115.62
6-1-'80	20	16:25-16:50	4.63	4.11	10.63	9.89	56	15:45-16:15	9.33	0.06	28.4	050 SB	040 SB	91.68
							57	16:15-16:45	9.33	0.06	25.0	026 SB	020 SB	91.67
							58	16:45-17:15	9.33	0.06	25.1	015 SB	000 SB	91.65
	20a	16:55-17:25	5.40	4.76	11.44	10.63								
	10	18:05-18:35	5.10	4.52	11.06	10.32	59	17:20-17:55	9.33	0.06	25.7	023 SB	000 SB	58.06
							60	18:00-18:35	9.33	0.06	23.1	040 SB	020 SB	58.10
							61	18:40-19:15	9.33	0.06	25.6	063 SB	035 SB	58.15
	10a	18:40-19:10	5.34	4.76	11.21	10.51								
	17	21:35-22:05	4.96	4.38	11.53	10.78	62	21:15-21:50	9.32	0.04	26.1	094 SB	040 SB	118.75
							63	21:50-22:25	9.32	0.04	22.8	088 SB	025 SB	117.19
	11	22:45-23:15	5.17	4.59	11.40	10.71	64	22:25-23:00	9.32	0.04	21.9	036 SB	000 SB	116.76
							65	23:00-23:35	9.32	0.04	18.2	092 SB	040 SB	118.46
	11a	23:15-23:45	4.96	4.42	11.34	10.65								
8-1-'80	13	12:20-12:35	5.10	4.36	12.49	11.11	66	12:00-12:30	9.30	0.04	30.1	168 PS	110 SB	119.78
							67	12:30-13:00	9.30	0.04	32.1	153 PS	090 SB	119.42
	13a	12:25-12:39	4.13	4.53	12.16	10.75								
	14	13:20-13:32	4.99	4.40	11.06	10.21	68	13:00-13:45	9.30	0.04	31.6	168 PS	100 SB	119.37
9-1-'80	07	14:15-14:43	4.73	4.21	10.89	10.06	69	13:50-14:35	9.27	0.06	26.4	130 SB	125 SB	121.60

4.2 Forecasted Wave and Wind Data

Figure 25 gives an example of a recent wave height and direction prediction, as can be obtained from the Internet by public access without a password nowadays from at web site http://www.fnmoc.navy.mil of the Fleet Numerical Meteorology and Oceanographic Center (FNMOC) in Monterey, California, USA. With a password, a limited or a full access to much more detailed weather information data can be obtained.

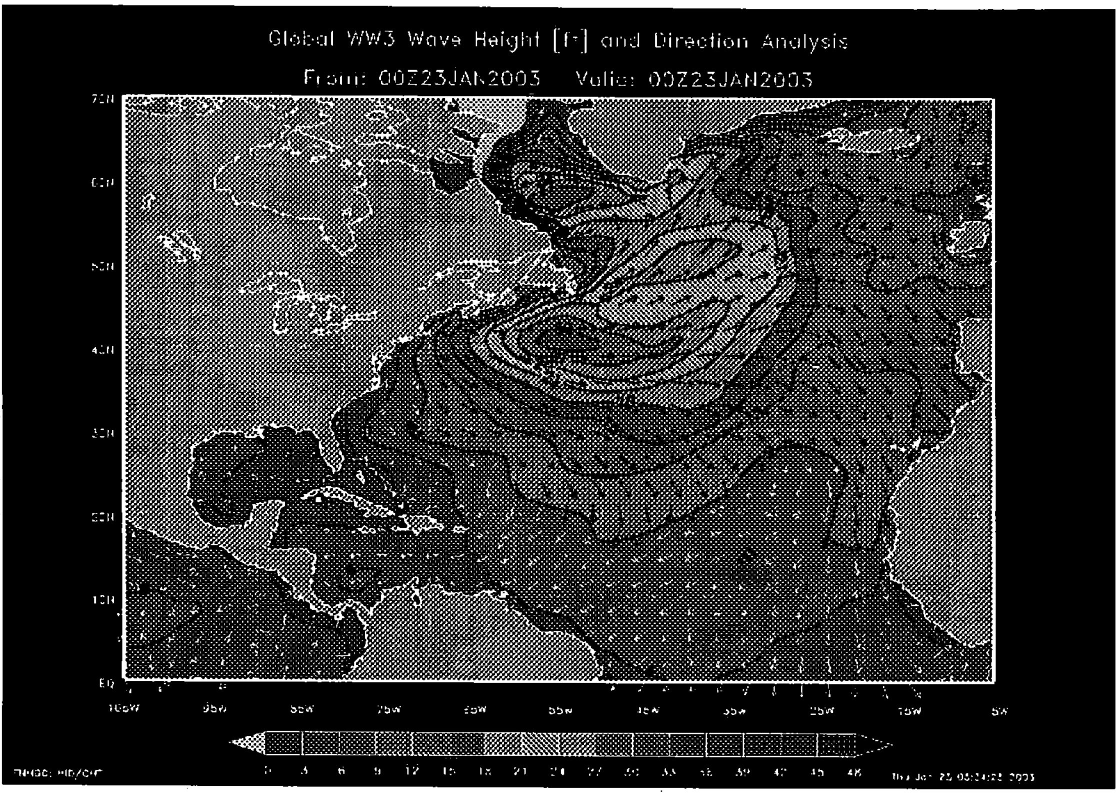

Figure 25: Example of a recent presentation of a wave height and direction prediction

These facilities were not available in that time of experiments.
However, the David Taylor Naval Ship Research and Development Centre in Washington D.C., USA, has offered during the first east- and westbound voyage (1979) a valuable assistance with regard to the choice of suitable wave conditions for the seakeeping trials. Detailed wave and wind forecasts have been made available at the route of the ship by the FNMOC, in that time called the Fleet Numerical Weather Central (FNWC). These forecasts have been transmitted by telex to the ship through the Royal Netherlands Navy in The Hague and Scheveningen Radio.
The radio officer of the ship was not very grateful to us for all this technical information by telex. Most of it arrived in the middle of the night, with a lot of noise in his cabin!

An example of onboard-received detailed wave and wind forecasts at a grid point near the route is given in Figure 26.

This assistance had not been used during the 1980 voyage, because then the ship was routed to suitable wave fields by the routing office of KNMI.

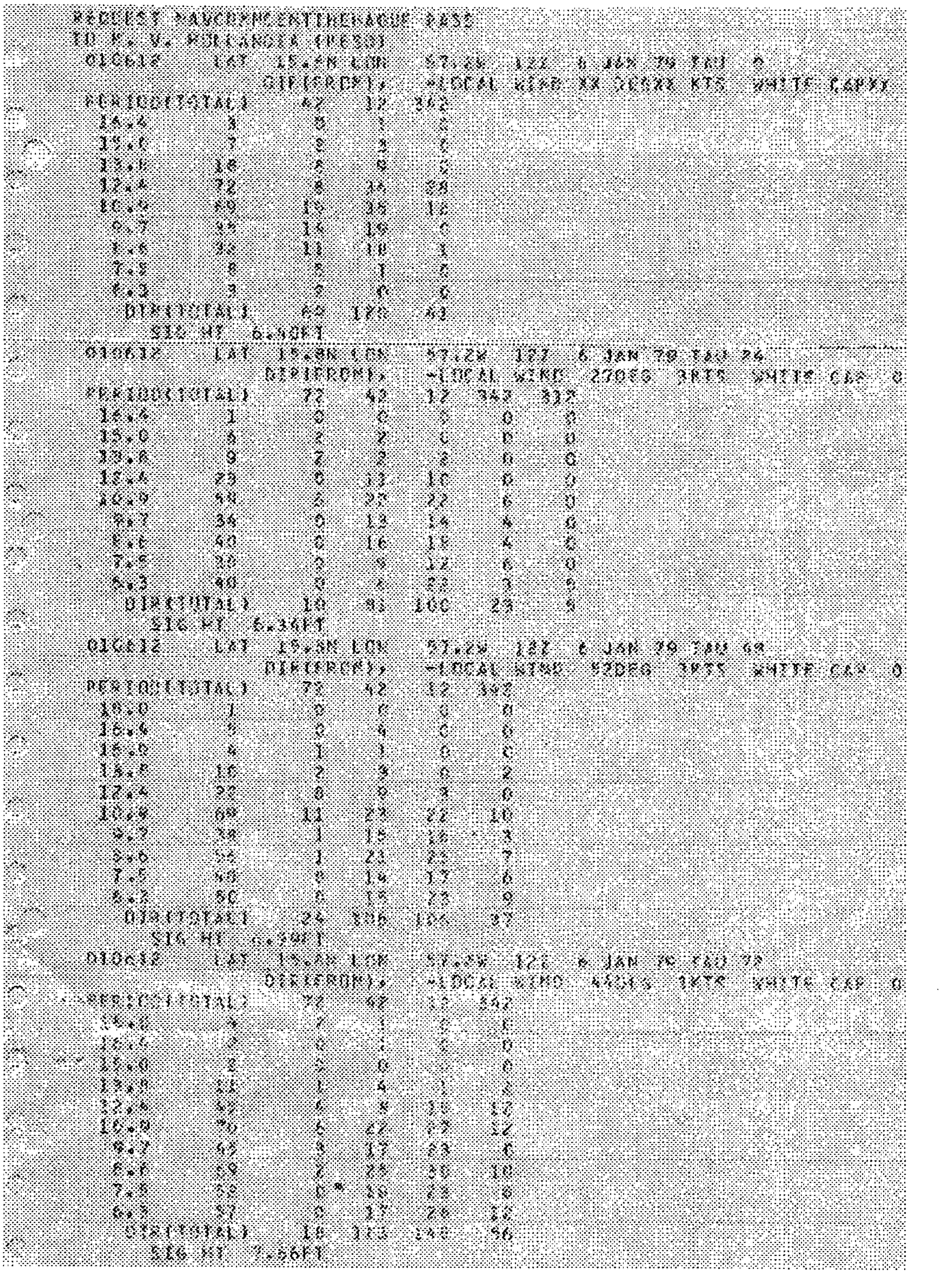

Figure 26: Example of onboard received detailed wave and wind forecasts

Expected time table data and grid points of the ship's route were transmitted to the FNWC via the Royal Netherlands Navy before leaving Liverpool on the 1979 westbound voyage and Kingston on the 1979 eastbound voyage. Using these grid points and the expected times of arrival there, detailed weather forecasts were delivered by FNWC to the ship at 12:00 GMT, together with forecasts for 24, 48 and 72 hours later.

Because the ship was deviating from its initially scheduled route without that FNWC could be informed, the schedule used by FNWC was not as close as desirable to the actual route of the ship. A straightforward communication between the (civil) researchers on the ship and the (military) FNWC was not permitted in that time. So, unfortunately, not all data delivered by FNWC to the ship were usable.

Figure 27 shows all grid points used by FNWC and marks of the suitable grid points with forecasts that could be used by DUT from the huge amount of data that was provided:

- **A-24:** 47.9 N, 23.8 W, at 01-01-1979, 12:00 GMT (forecast made 24 hours earlier)
- **A-00:** 47.9 N, 23.8 W, at 01-01-1979, 12:00 GMT
- **B-00:** 30.5 N, 44.1 W, at 04-01-1979, 12:00 GMT
- **C-24:** 29.7 N, 47.6 W, at 04-01-1979, 12:00 GMT (forecast made 24 hours earlier)
- **D-24:** 30.1 N, 57.2 W, at 02-02-1979, 12:00 GMT (forecast made 24 hours earlier)
- **E-24:** 31.1 N, 53.7 W, at 02-02-1979, 12:00 GMT (forecast made 24 hours earlier)
- **F-00:** 32.7 N, 46.6 W, at 02-02-1979, 12:00 GMT

Also, the launching co-ordinates of the disposable wave buoys have been plotted in this figure.

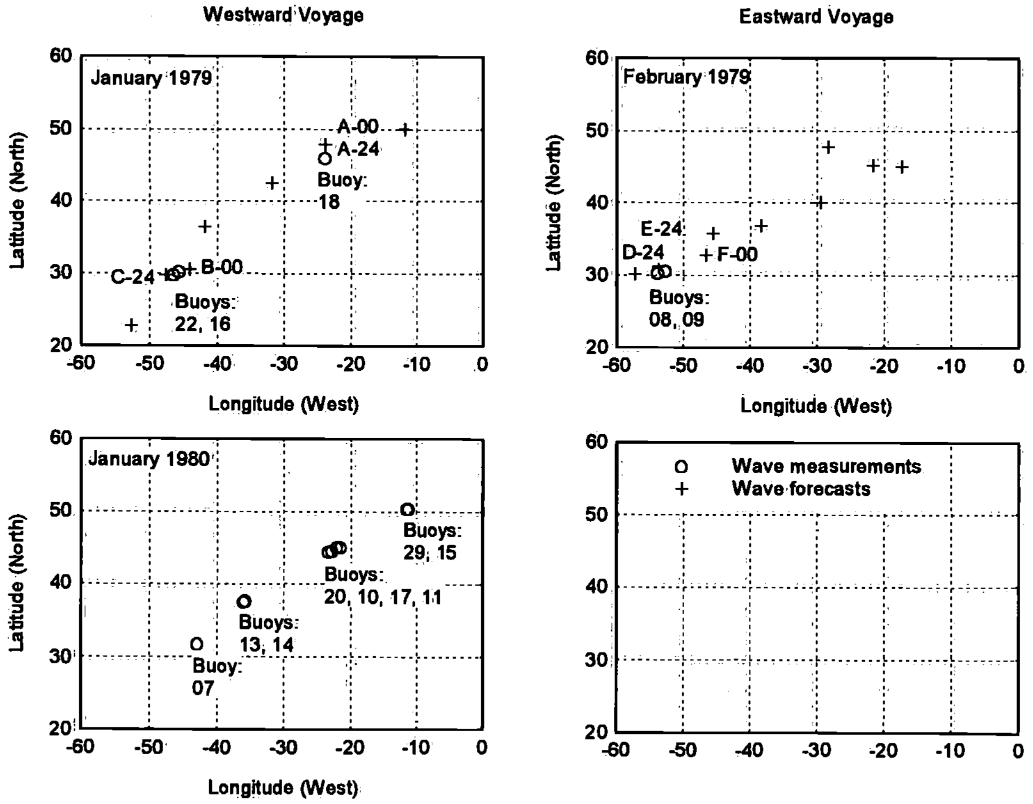

Figure 27: Grid points and wave buoy locations

The detailed weather information of FNWC at these grid points is given in tables in an appendix to this report (see Chapter 10). Note that wind and wave directions are given by the FNWC as directions where wind and waves come from.

The forecasted wave directions and spreading distributions of the wave energy are visualised in Figure 28.

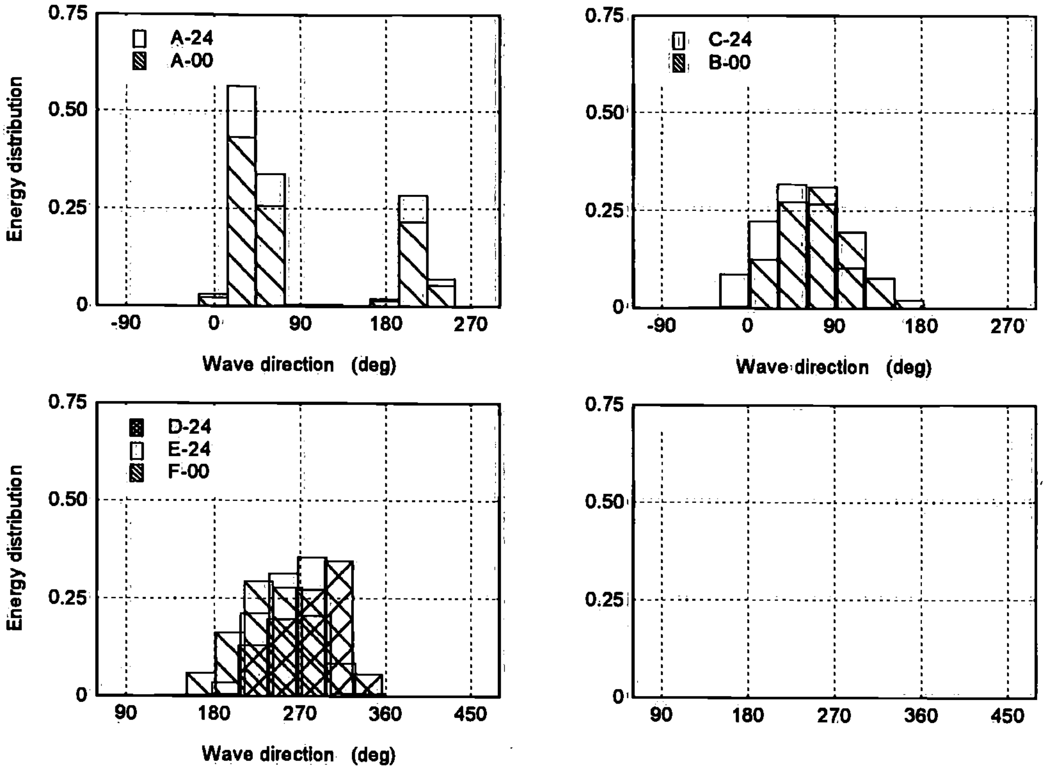

Figure 28: Forecasted wave energy spreading during the 1979 experiments

Summarized, some preliminary conclusions about these forecasts may be drawn:

- Experiments carried out at 01-01-1979:
  - Wind.

    The forecasted wind was about 7-9 knots with a variable direction. The measured wind was 10-11 knots with a variable direction too.
  - Waves.

    The forecasted wave heights were 2.92 and 3.30 meters. Wave buoy measurements 18 and 18a showed significant wave heights of 4.00 and 3.74 meters.

    The forecasted mean wave direction was about 040^0 (sea) and 220^0 (swell). The observed directions were about 070^0 and 250^0, respectively.

- Experiments carried out at 04-01-1979:
  - Wind.

    The forecasted wind was 27-36 knots, coming from 075^0-090^0. The measured wind was 30-33 knots, coming from 090^0-100^0.
  - Waves.

    The forecasted wave heights were 4.65 and 6.44 meters. Wave buoy measurements 22 and 16 showed significant wave heights of 5.24 and 5.69 meters.

    The forecasted mean wave direction was 060^0-080^0. The observed directions were 080^0-090^0.

- Experiments carried out at 02-02-1979:

  The ship had encountered a severe storm area that day.
  - Wind.

The forecasted wind was 29-44 knots, coming from 230^0-275^0. The measured wind was 37-41 knots, coming from 270^0-280^0.

- Waves.

  The forecasted wave heights in that area were 7.14, 6.50 and 10.27 meters. Wave buoy measurements 08, 08a and 09 showed significant wave heights of 11.06, 9.74 and 9.77 meters.

  The forecasted mean wave direction was 250^0-270^0. The observed directions were 265^0-285^0.

Nevertheless the fact that the schedule used by FNWC does not fit the actual schedule completely, it may be concluded here that these weather forecasts were not bad at all.

In exchange for their excellent service, DUT has provided all measured spectral wave and wind data in 1979 and 1980 to the FNWC in Monterey for their hind cast and validation studies.

4.3 Measured Performance Data

To estimate the increase of power in a seaway it is necessary to have accurate still water data at one's disposal. In particular for this ship with a large breadth-draught ratio and a large bulbous bow the available empirical methods, which can be found in the literature concerned, are inaccurate. The results of model experiments are also not accurate enough for this purpose because of a large extrapolation to full scale, an interpolation for the desired draught and in a lot of cases the effect of fouling. So it was decided - if possible - to carry out calm water experiments in the Caribbean Sea to measure speed, rpm and power.

4.3.1 Measured Performance in Calm Water

During the first 1979 voyage a lot of calm water experiments could be carried out in the Caribbean Sea. The ship called at several Caribbean ports: Bridgetown in Barbados, Willemstad in Curacao, Oranjestad in Aruba, Ponce in Puerto Rico, Rio Haina in the Dominican Republic, Port au Prince in Haiti, Kingston in Jamaica, Puerto Cortes in Honduras, Santo Thomas de Castilla in Guatemala and again Kingston in Jamaica. The mean draught was varying between 8.00 and 8.40 meter at an almost zero-trim. During these experiments there was a light to moderate breeze coming from beam to aft directions. The sea was very calm and ship motions could not be observed. Wind and draught deviations could cause a small spreading in the experimental results up to about two percent. The circumstances were the best that could be expected.
No suitable calm water conditions have been met in the Caribbean Sea during the second 1979 voyage, when sailing from Bridgetown in Barbados to Willemstad in Curacao.
During the 1980 voyage calm water experiments could only be carried out in the Caribbean Sea, when sailing from Bridgetown in Barbados to Willemstad in Curacao. The mean draught of the ship was about 9.20 meter with a small trim of 0.20 meter. There was a following wind with a true wind speed of about 20 knots. The following sea had a visual estimated height of about 1-2 meter. Small ship motions have been observed. Because the sea and the wind came from aft directions, their influence can expected to be of minor importance. However the calm water conditions during the 1979 voyage were much more ideal. The series of full-scale experiments were closed in Oranjestad in Aruba.

The results of the 1979 and 1980 performance tests in calm water are given in Table 10.

Run No.	T_m (m)	*trim* (m)	V_{log} (mV) (kn)	V_{mc} (kn)	V_{cal} (kn)	V (kn)	N (rpm)	T (kN)	Q (kNm)	P (kW)	f (m^3/h)	L_{BR} (-)
09	8.41	0.00	138.4	-	18.24	18.68	106.55	1130	1034	11537	-	-
10	8.39	0.00	138.4	-	-	18.68	106.55	1116	1015	11325	-	-
11	8.39	0.00	139.2	-	-	18.79	106.62	1091	996	11121	-	-
12	8.39	0.00	113.6	-	15.36	15.34	90.08	773	731	6896	-	-
13	8.25	0.23	158.5	-	-	21.40	118.20	1422	1202	14878	-	6.45
14	8.33	0.15	159.4	-	-	21.52	118.77	1467	1199	14913	-	-
15	8.33	0.15	158.7	-	21.83	21.42	-	-	-	-	-	-
16	8.13	0.00	23.11	-	21.33	22.07	118.11	1479	1250	15461	-	6.55
17	8.05	0.00	16.01	-	15.40	15.29	90.34	840	725	6859	1.785	4.32
18	8.04	0.02	19.52	-	18.95	18.64	106.48	1139	963	10738	2.740	5.43
19	7.32	0.05	22.38	-	21.36	21.37	117.49	1441	1248	15355	3.834	6.69
24	8.04	0.08	22.48	-	21.57	21.47	119.89	-	-	-	3.847	6.68
25	7.99	0.23	22.94	-	21.63	21.91	119.56	1454	1199	15012	3.825	6.55
25	7.99	0.23	22.48	-	21.68	21.47	119.56	1454	1199	15012	3.825	6.55
25	7.99	0.23	22.35	-	21.75	21.34	119.56	1454	1199	15012	3.825	6.55
26	8.08	0.00	8.37	-	8.05	7.99	47.84	311	180	902	-	-
27	8.08	0.00	22.11	-	-	21.12	119.44	-	-	-	3.897	-
70	9.25	0.10	21.93	21.60	-	20.24	120.66	-	1271	16060	3.963	6.83
71	9.24	0.18	-	21.34	20.41	20.00	121.00	-	1290	16346	4.006	-
72	9.20	0.00	21.69	21.27	-	19.93	120.69	-	1261	15937	3.925	6.72
73	9.23	0.14	19.26	19.08	-	17.88	-	-	-	-	-	-
74	9.23	0.18	18.88	-	-	17.54	103.14	-	925	9991	2.528	-
75	9.23	0.18	-	18.77	17.39	17.59	102.53	-	925	9932	2.470	-
76	9.23	0.20	-	16.12	15.02	15.10	89.23	-	720	6728	1.766	-
77	9.23	0.20	-	10.71	9.71	10.04	59.00	-	311	1922	0.621	-
78	9.23	0.20	17.03	16.88	-	15.82	93.20	-	780	7613	1.959	4.49

Table 10: Measured performance data in calm water

For analysing the full-scale experiments it is important to have very accurate speed data at one's disposal. So a lot of attention has been paid to the calibration of the ship's EM speed log. It was not possible to run a measured course, so consequently use has been made of a so-called "Dutchman's Log".

Red-orange painted (empty and closed) beer bottles were thrown overboard at the forecastle, as far as possible away from the ship. With respect to the visibility of the bottles and the effect of the by vertical ship motions induced waves on the bottles, this could only be carried out in very calm water. Two observers at a mutual physical distance of 134.00 meters - a distance obtained from the ship's general arrangement drawing - both equipped with a walkie-talkie and a chronometer - had measured the time interval between the instants of passing of the bottles. Both observers shouted 'stand by' and 'now' in their walkie-talkies when the bottle passed their position, marked with a squared extended wooden cross-bar on the deck. It could be assumed that the first observer would not make a significant error, when he started his watch during passing of the bottle. The same would hold too for the second observer when he stopped his watch during passing of the bottle. But the second observer had started his watch his reaction time ΔT_2 too late (actual passing time = $T_2 + \Delta T_2$), while the first observer had stopped his watch his reaction time ΔT_1 too late (actual passing time = $T_1 - \Delta T_1$). When assuming approximately equal reaction times of both observers ($\Delta T_1 \approx \Delta T_2$), the average of the two watch registrations $T \approx (T_1 + T_2)/2$ should be very reliable. This procedure was followed during these calibration experiments. At least 25 bottles were used during each experiment and the average speed found was taken as the actual forward ship speed through the water (V).

Just before starting the first 1979 outward voyage experiments, the speed log indicator and its integrator (miles counter) received suddenly no signals anymore. No speed data could be measured during the runs 01, 02 and 03, due to an electric short circuit in the transformer of the EM log measuring unit aboard. Later that day, the electronic team found a very practical and successful solution for this experimental disaster. The output voltage of the EM speed log had to be measured directly during the coming experiments and additional calibrations of "voltage to knots" had to be carried out before repair in the Caribbean.
These additional EM speed log calibrations with bottles have been carried out at 3 speeds (runs 09, 12 and 15) in the Caribbean Sea, see Figure 29.

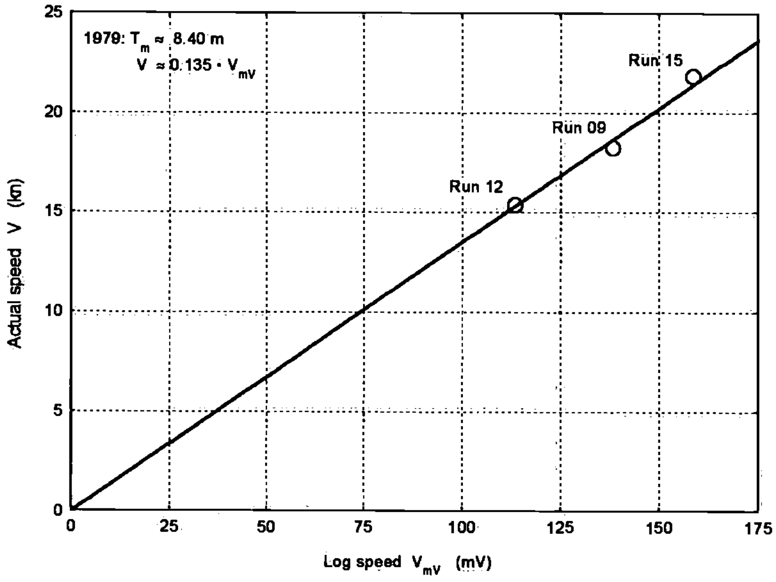

Figure 29: Calibration of damaged EM speed log

The next practical relation was found:

$$V\,(\text{in kn}) \approx 0.135 \cdot V_{\text{mV}}\,(\text{in mV}) \qquad \text{at } T_m \approx 8.40\text{ m}$$

After calibration-run 15, the ship's EM log was successfully repaired in the Caribbean with ordered and received new electronic parts.
For the intended calm water trials and the experiments during the return voyage, the calibration of the (now repaired) EM log speed indicator has been carried out with bottles at 5 speeds (runs 16, 17, 18, 19 and 24) in the Caribbean Sea.
Also use has been made of the ship's radar for calibration purposes. From charts of several ports it appeared that the deviation of the distance on the ship's radar screen was about -0.8 per cent, which percentage could be used as a correction coefficient. At a log speed of about 22.5 knots an oil drum - partly filled with water - was thrown overboard on the forecastle (run 25a). The time since passing the bridge was measured at 0.5 nautical mile intervals on the radar screen. The drum was visible on the screen up to a distance of over 2 miles. The linearity between distance and time showed that the drum was outside the ship's influence and the corrected radar distance and a chronometer gave the actual speed of the ship through the

water. At the same time, the speed indicator was read off. After this experiment the speed was measured with bottles (run 25b) and after that again with the radar and another oil drum (25c). Finally, the radar has been used with a checkpoint ashore at a low speed (run 26).
Because of a lack of chronometers during these calibrations - 4 were used already: two by the "bottle observers", one for the rpm measurements and one for the fuel consumption measurements - the very stable speed indicator was read off about 30 to 50 times during each calibration experiment for determining $V_{\log}$.

During the 1980 experiments, the calibration of the EM speed log with bottles has been carried out at 4 speeds (runs 71, 75, 76, and 77), again in the Caribbean Sea. Mainly, the miles counter at the bridge and a chronometer have been used now.

The experimental data are presented in Figure 30.

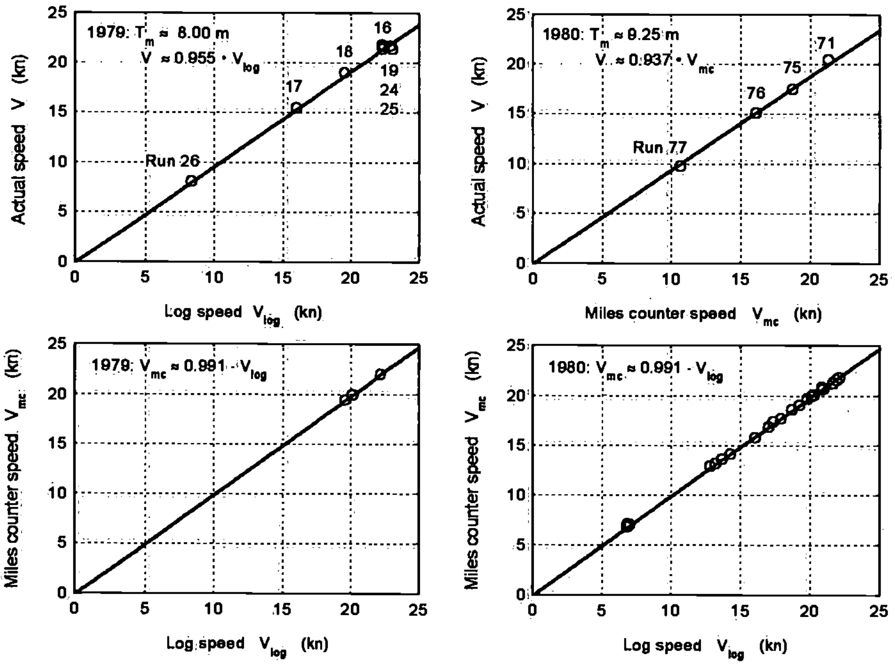

Figure 30: Calibration of EM speed log

From using a least square method and the relation $V_{\log} \approx 1.009 \cdot V_{\mathrm{mc}}$, it follows:

$$1979,\ T_m \approx 8.00\,\mathrm{m}: \quad V \approx 0.955 \cdot V_{\log} \approx 0.964 \cdot V_{\mathrm{mc}}$$

$$1980,\ T_m \approx 9.20\,\mathrm{m}: \quad V \approx 0.929 \cdot V_{\log} \approx 0.937 \cdot V_{\mathrm{mc}}$$

Equation 27

The 2.5 % difference in calibration (so about 0.50 knots at full speed) coefficient can easily be explained by a difference in boundary layer thickness of the two loading conditions.
To get an impression of the influence of the boundary layer on the measured EM log speed, the distance of the flow sensor to the ship's hull has been varied. The actual ship speed at an amidships draught of 8.02 m was about 21.3 knots (run 27). Alternately, the flow sensor has been situated at the normal maximum displacement of 0.495 meter and at three shorter distances to the hull. The influence of these variations on the measured speed is shown in Figure 31.

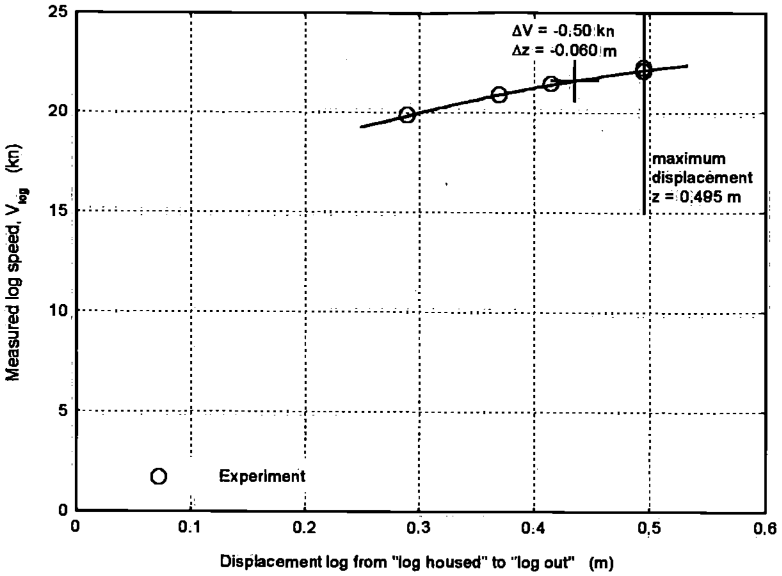

Figure 31: Effect of boundary layer on measured log speed

Figure 31 shows that a position of the log only 0.060 meter closer to the hull will cause this deviation in measured speed of 0.50 knots.

The thickness of the boundary layer at the position of the EM log is depending on the draught and the ship's speed. Also, fouling and vertical ship motions in a seaway will influence it. It will be clear that changes in draught and vertical ship motions, which cause variations in the thickness of and the speed in the boundary layer, will cause variations in the read off of the speed indicator. The corrected speed can differ slightly from the actual speed, but no better measuring system was available during these experiments.

The influence of the fin stabilisers (each with a vertical projected are of 7.2 m^2) on the propulsion characteristics can be neglected. At a constant engine speed of 106.60 rpm in calm water, the measured difference in speed caused by the outboard fins was within the accuracy of the measurements; it was less than 0.10 knots.

The "measured" open water propeller characteristics can be found by:

$$K_T = \frac{T}{\rho \cdot D^4 \cdot n^2} \qquad K_Q = \eta_r \cdot \eta_{m2} \cdot \frac{Q}{\rho \cdot D^5 \cdot n^2} \qquad J = \frac{V \cdot (1-w)}{n \cdot D} \qquad n = \frac{N}{60}$$

Equation 28

where V, N, T and Q are the measured speed, rpm, thrust and torque data from Table 10 and η_r, η_{m2} and w are coefficients as defined in Section 2.4.

These "measured" data have been compared in Figure 32 with the B-series propeller characteristics, as given by Equation 4 in Section 2.4. Nevertheless a large spreading in the "measured" torque data, the average value fits the B-series prediction surprisingly well. The average "measured" thrust value is about 10 % higher than the B-series value.

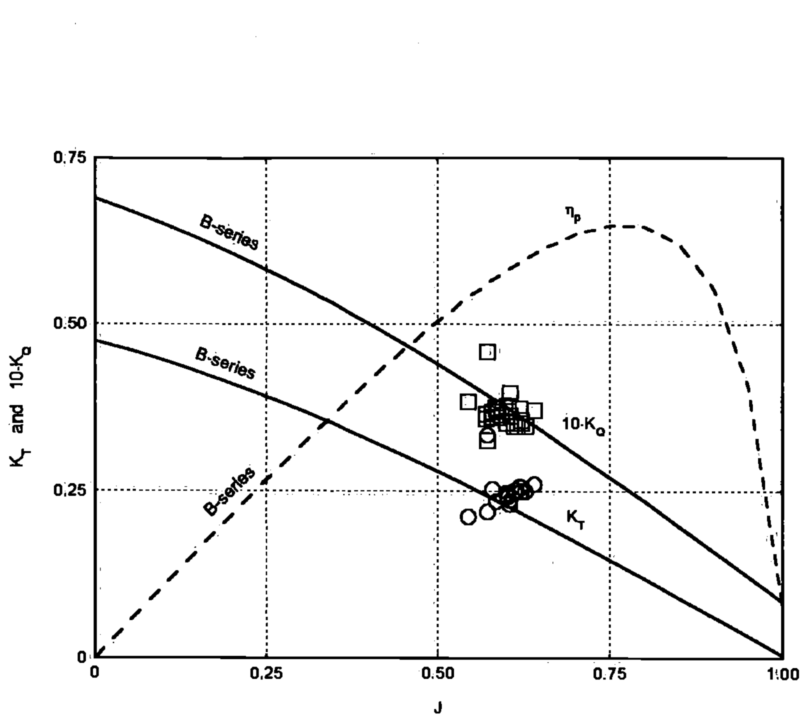

Figure 32: Open water propeller characteristics in calm water

The 1979 and 1980 experimental results with respect to the measured rpm to ship speed relations in calm water are shown in Figure 33.

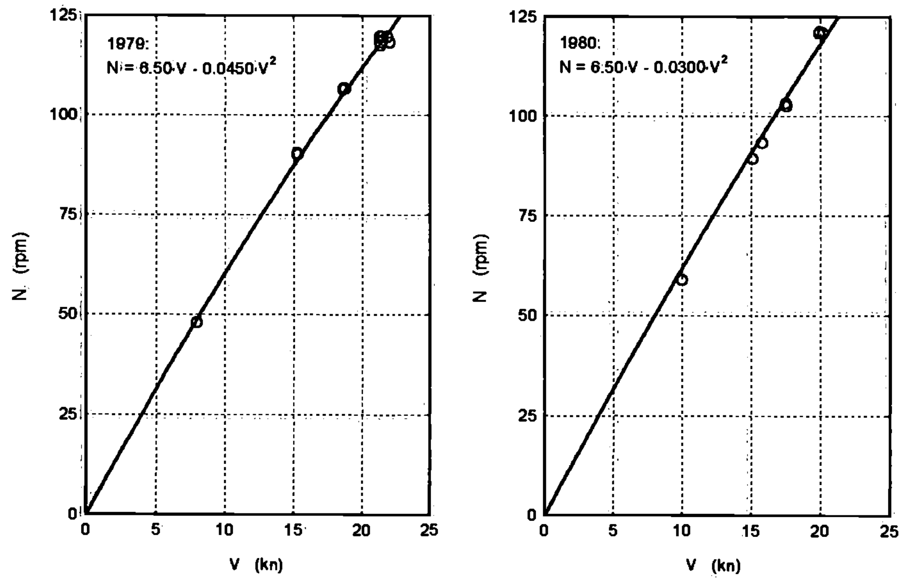

Figure 33: Measured relation between propeller rate and ship speed in calm water

These relations can be approximated by:

1979: $T_m \approx 8.20\,\mathrm{m}$ $N_0 \approx 6.50 \cdot V_0 - 0.0450 \cdot V_0^{\,2}$

1980: $T_m \approx 9.20\,\mathrm{m}$ $N_0 \approx 6.50 \cdot V_0 - 0.0300 \cdot V_0^{\,2}$

Equation 29

with N_0 in rpm and V_0 in knots, where the index $_0$ means calm water.

As showed in Figure 33, depending on the draught, a forward ship speed between 20.5 and 22.0 knots can be achieved in calm water at the nominal maximum propeller rate of $N = 122$ rpm.

The measured relations between the propeller thrust and the ship speed or rpm in the 1979 calm water conditions are given in Figure 34. The theoretical relation - obtained from the propulsion characteristics given in Section 2.4 and the measured speed-rpm relations of Equation 29 - is given in the figure too.

As has been discussed in Section 3.4.3, the thrust measurements are expected to be not very reliable. About 10 % lower predicted thrust data have been found in calm water conditions.

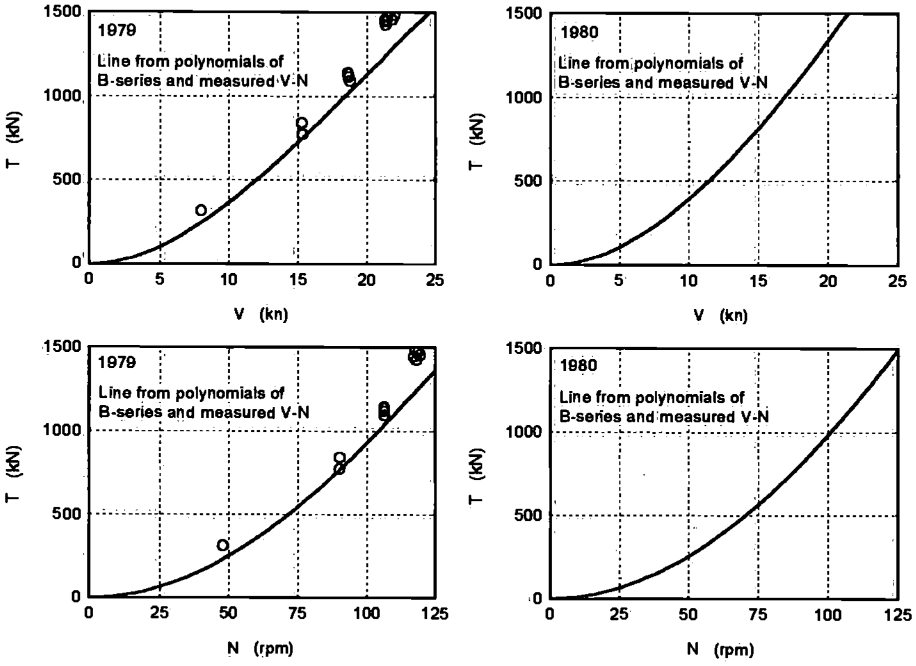

Figure 34: Relation between measured propeller thrust and ship speed or rpm in calm water

The measured relations between the propeller torque and power and the ship speed or rpm in calm water conditions are given in Figure 35 and Figure 36. The theoretical relations - obtained from the Wageningen B-series propulsion characteristics as given in Section 2.4 and from the measured speed-rpm relations of Equation 29 - are given in these figures too. Fairly well agreements between predictions and experiments have been found.

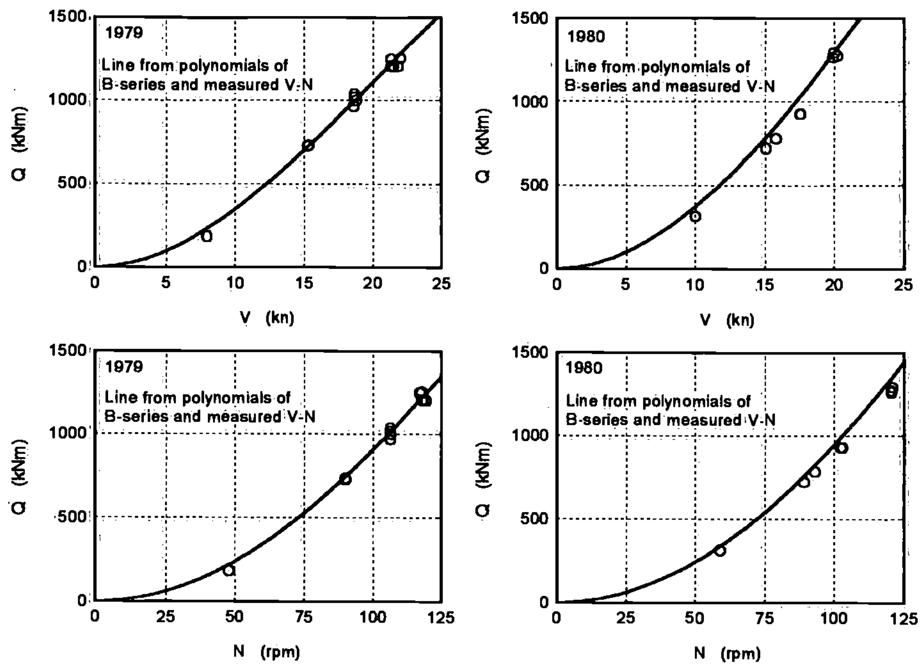

Figure 35: Relation between measured propeller torque and ship speed or rpm in calm water

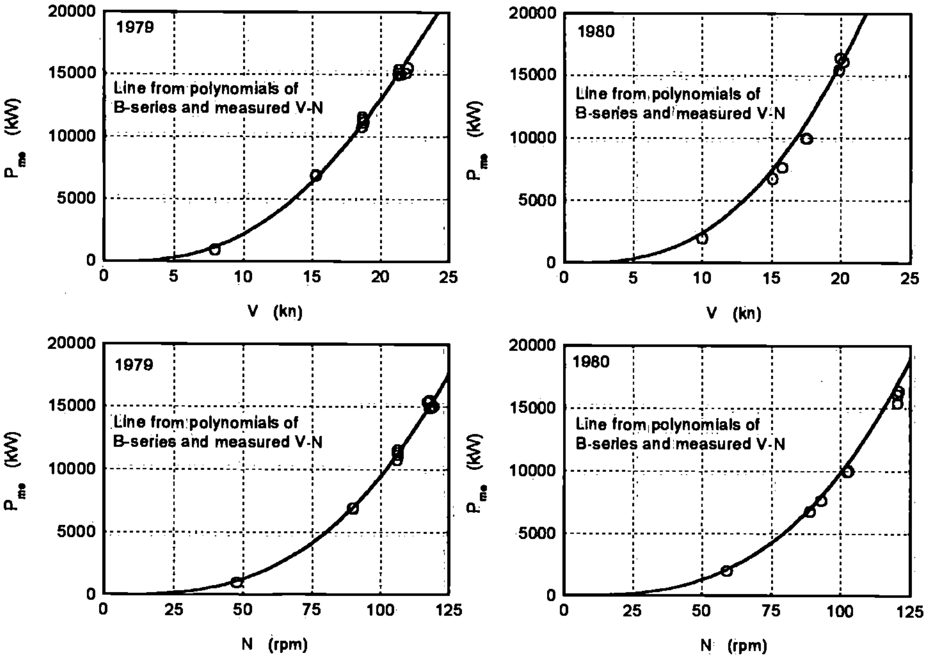

Figure 36: Relation between measured engine power and ship speed or rpm in calm water

4.3.2 Measured Performance in Waves

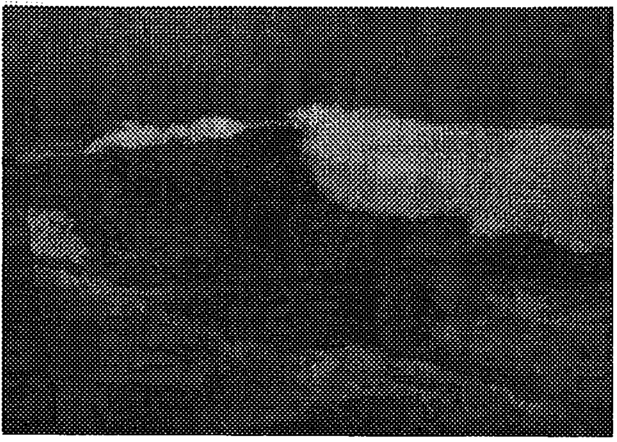

Figure 37: Full-scale experiments in a seaway

The results of the 1979 and 1980 performance measurements with measured sea conditions (experiments using wave buoys and measuring the ship's motions) are given in Table 11.

Run No.	T_m (m)	*trim* (m)	$\overline{GM}$ (m)	α_p (deg)	α_n (deg)	$V_{\log}$ (mV) (kn)	V_{mc} (kn)	V (kn)	N (rpm)	T (kN)	Q (kNm)	P (kW)	f (m^3/h)	L_{BR} (-)
01	8.54	0.00	0.84	0	0	-	-	18.40	116.29	1357	1364	16611	4.133	7.11
02	8.54	0.00	0.84	0	0	-	-	18.50	116.39	1320	1344	16381	4.124	6.94
03	8.54	0.00	0.84	0	0	-	-	18.70	116.50	1265	1314	16031	3.914	6.84
04	8.44	0.00	0.84	6.9	6.2	148.0	-	19.98	116.91	1323	1250	15303	3.719	6.43
05	8.44	0.00	0.84	8.6	7.3	144.2	-	19.47	116.89	1315	1244	15227	3.716	6.42
06	8.44	0.00	0.84	10.0	8.6	139.9	-	18.89	117.20	1360	1268	15562	3.777	6.41
07	8.44	0.00	0.84	10.3	9.8	109.8	-	14.82	89.01	766	734	6842	1.782	4.39
08	8.44	0.00	0.84	10.5	7.4	102.1	-	13.78	88.87	800	764	7110	1.793	4.39
32	8.01	0.23	1.60	10.6	9.1	20.51	-	19.59	117.38	1277	1248	15340	3.908	6.55
33	8.01	0.23	1.60	11.7	9.9	19.72	-	18.83	116.81	1268	1242	15193	3.863	6.60
34	8.01	0.23	1.60	13.7	13.7	19.59	-	18.71	117.26	1314	1254	15398	3.934	6.69
35	8.01	0.23	1.60	15.4	13.9	14.61	-	13.95	90.24	776	749	7078	1.930	4.62
36	8.01	0.23	1.60	18.1	17.3	14.42	-	13.77	89.90	734	740	6967	1.907	4.56
37	8.01	0.23	1.60	17.2	17.3	14.14	-	13.50	89.92	759	752	7081	1,902	4.45
51	9.36	0.12	0.30	0	0	16.08	15.80	14.80	113.74	-	1414	16842	4.177	7.55
52	9.36	0.12	0.30	0	0	17.38	17.41	16.31	114.87	-	1409	16949	4.114	7.47
53	9.36	0.12	0.30	0	0	18.72	18.60	17.43	115.51	-	1377	16656	3.982	7.20
54	9.36	0.12	0.30	0	0	19.81	19.69	18.45	115.62	-	1300	15740	3.803	6.81
56	9.33	0.06	0.30	0	0	14.29	14.11	13.22	91.68	-	898	8621	2.150	4.98
57	9.33	0.06	0.30	0	0	13.70	13.60	12.74	91.67	-	917	8803	2.205	5.03
58	9.33	0.06	0.30	0	0	12.87	12.88	12.07	91.65	-	927	8897	2.264	5.09
59	9.33	0.06	0.30	0	0	7.01	6.99	6.55	58.06	-	425	2584	0.821	3.11
60	9.33	0.06	0.30	0	0	6.86	7.04	6.60	58.10	-	436	2653	-	3.14
61	9.33	0.06	0.30	0	0	6.84	6.84	6.41	58.15	-	431	2625	0.695	3.12
62	9.32	0.04	0.30	0	0	20.31	20.08	18.81	118.75	-	1372	17061	4.185	7.41
63	9.32	0.04	0.30	0	0	18.71	18.62	17.45	117.19	-	1420	17426	4.271	7.58
64	9.32	0.04	0.30	0	0	17.93	17.68	16.57	116.76	-	1417	17326	4.250	7.60
65	9.32	0.04	0.30	0	0	20.15	19.95	18.69	118.46	-	1380	17119	4.162	7.42
66	9.30	0.04	0.30	5.0	4.3	20.88	20.67	19.36	119.78	-	1341	16821	4.103	7.12
67	9.30	0.04	0.30	5.7	5.3	21.00	20.73	19.42	119.42	-	1339	16745	4.097	6.96
68	9.30	0.04	0.30	5.4	4.2	20.87	20.86	19.55	119.37	-	1328	16601	4.027	6.97
69	9.27	0.06	0.30	5.3	5.1	22.12	21.82	20.45	121.60	-	1327	16898	4.170	7.16

Table 11: Measured performance data during the seakeeping tests

Because of the technical failure mentioned earlier, no accurate speed data are available for run numbers 01, 02 and 03. These speed data are probably around 18.4, 18.5 and 18.7 knots respectively, which data have been used in this report.

The initial metacentric height data of the vessel during the seakeeping tests were provided by the first mate. Unfortunately, the notes of these data during the 1980 westbound voyage could not be recovered. However, the author still remembers the large roll amplitudes with very low lateral accelerations (due to large periods of roll) in beam waves on the bridge during this voyage. This behaviour was caused by an extreme low metacentric height of the ship. According to the first mate, the metacentric height was about 0.29 meter when leaving Liverpool harbour. Based upon these memories, $\overline{GM} = 0.30$ meter is assumed to be a very responsible measure for the 1980 experiments.

The mean upwards and downwards extreme nose angles (α_p and α_n, respectively) of the PS anti-roll fin can be found in Table 11 too. The marks "0" in these tables mean that the fins were housed during that run. During all other runs with the vessel, the fins were housed too. Information about observed rudder angles is given in Table 17 and Table 18.

The results of all other 1979 and 1980 performance measurements with visually estimated sea conditions (experiments without measuring the ship's motions) are given in Table 12.

Run No.	T_m (m)	*trim* (m)	$V_{\log}$ (kn)	V_{mc} (kn)	V (kn)	N (rpm)	T (kN)	Q (kNm)	P (kW)	f (m^3/h)	L_{BR} (-)
28	8.03	0.00	21.45	-	20.48	119.35	1410	1222	15273	3.928	6.65
29	8.03	0.00	20.61	-	19.68	119.17	1351	1225	15287	3.932	6.54
30	8.03	0.00	20.03	-	19.13	119.02	1397	1235	15393	3.978	6.78
31	8.01	0.00	19.65	-	18.77	117.28	1303	1272	15622	3.967	6.44
38	7.98	0.00	19.54	-	18.66	115.84	1223	1215	14739	3.748	6.39
39	7.98	0.00	19.92	-	19.02	116.80	1279	1239	15155	3.861	6.58
40	7.96	0.00	20.58	-	19.65	116.15	1186	1208	14693	3.726	6.41
41	7.96	0.00	20.01	-	19.11	115.13	1121	1183	14263	3.576	6.15
42	7.94	0.00	20.72	-	19.78	115.69	1159	1188	14393	3.666	6.21
43	7.98	0.00	20.44	-	19.52	114.18	1122	1161	13882	3.535	6.13
44	7.95	0.00	20.83	-	19.89	118.33	1211	1242	15390	3.815	6.33
45	7.89	0.00	19.39	-	18.52	114.38	1109	1158	13870	3.485	6.12
46	7.89	0.00	18.58	-	17.74	114.07	1004	1208	14430	3.634	6.36
47	8.95	0.00	20.10	-	19.20	121.56	1270	1371	17452	4.095	-
48	8.88	0.00	-	21.97	21.18	120.63	1363	1396	17635	4.016	-
49	8.75	0.00	-	8.41	8.10	48.72	212	263	1342	0.209	-
50	9.10	0.00	17.80	-	16.54	106.80	-	954	10670	-	-
50	9.10	0.00	18.00	-	16.72	107.70	-	966	10895	2.694	-
50	9.10	0.00	19.80	-	18.39	117.20	-	1135	13930	3.456	-
55	9.33	0.00	13.23	13.15	12.32	91.53	-	852	8166	2.163	4.83

Table 12: Other measured performance data

4.3.3 Measured Fuel Consumption

The use of fuel per hour has been measured with the ship's fuel meter (m^3) in the engine room and a chronometer. The measured data during the 1979 and 1980 experiments appeared to be very similar; see Figure 38.

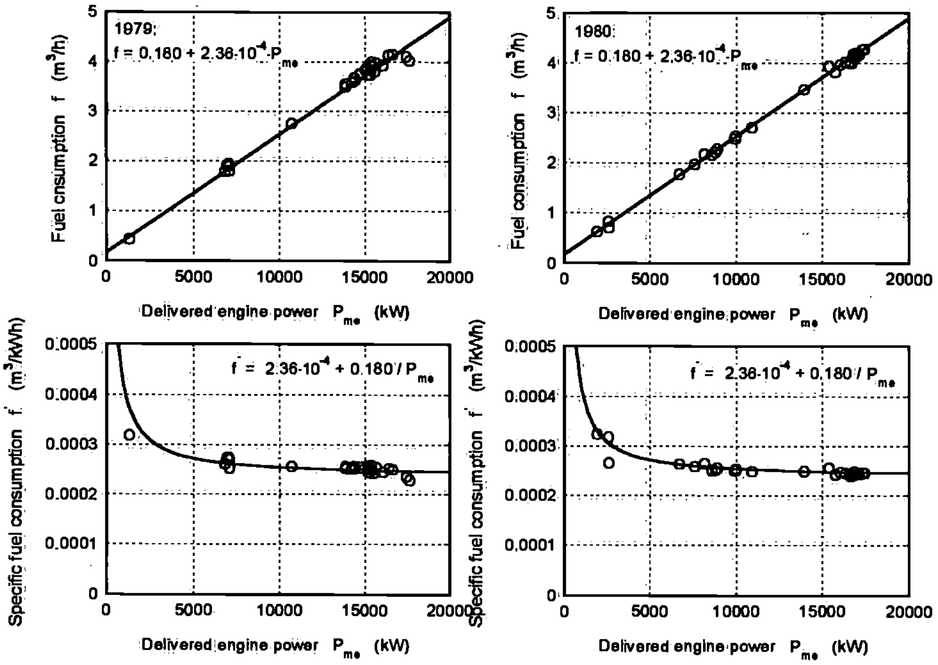

Figure 38: Measured relation between fuel consumption and engine power

The average measured fuel consumption to engine power ratio - obtained during three voyages by these two independent fuel meters - are given in Equation 30:

$$f = 0.180 + 2.36 \cdot 10^{-4} \cdot P_{me} \quad (\mathrm{m^3/kWh})$$

Equation 30

The specific fuel consumption is given in Equation 31:

$$f^{*} = 0.236 + 180 / P_{me} \quad (\mathrm{liter/kWh})$$

Equation 31

The fuel temperature in the fuel meter appeared to be very constant (about 60 ^{0}C) during all experiments.

4.4 Measured Ship Motion Data

Validation of computer codes with these data, was one of the initial targets of DUT for these full-scale experiments. For this, all measured spectral data are given in the file 1349-Hollandia-03.zip at the Internet: http://www.shipmotions.nl.

The energy spectra of the measured ship motions are presented in a large number of figures: Figure 63 through Figure 94 in Chapter 11. Four figures are presented for each of the 32 runs, containing the measured spectral data of both DUT (solid lines) and LR (dotted lines). The vertical scale of each figure is chosen such that the spectral peaks lie in the upper half of each figure. So, the figures are not meant for mutual comparisons, its purpose is to judge the individual spectra itself.

The computed significant amplitudes and mean periods of the ship motions, obtained from the measured spectra of both institutes, have been compared in Table 13 through Table 16 and in Figure 95 through Figure 98. The *x*-axis in the four figures is simply counting from 1 to 32, the total number of runs in waves.

The statistics in these figures and tables are coded by:

- Vertical displacements of the bow at the FPP (heave forward), as $S_{zf}(\omega_e)$ in m^2s
  - Measured on deck by DUT, code DUT-2
  - Measured on deck by LR, code LR-2
  - Measured on a gyro-stabilised platform by DUT, code DUT-3

- Vertical displacements of the centre of gravity (heave), as $S_z(\omega_e)$ in m^2s
  - Measured on deck by DUT, code DUT-4
  - Measured on a gyro-stabilised platform by DUT, code DUT-5
  - Measured on a gyro-stabilised platform by LR, code LR-5

- Angular roll displacements, as $S_\phi(\omega_e)$ in deg^2s
  - Measured by DUT, code DUT-6
  - Measured by LR, code LR-6

- Angular pitch displacements, as $S_\theta(\omega_e)$ in deg^2s
  - Measured by DUT, code DUT-7
  - Measured by LR, code LR-7

The definition of the significant amplitudes and mean periods is equivalent to those as given for the wave statistics in Section 4.1.

Heave forward

Run No.	$z_{fa1/3}$ (m)			$z^*_{fa1/3}$ (m)			T_{1zf} (s)			T_{2zf} (s)		
	DUT-2	LR-2	DUT-3	DUT-2	LR-2	DUT-3	DUT-2	LR-2	DUT-3	DUT-2	LR-2	DUT-3
1	2.52	2.97	2.59	2.43	2.84	2.49	8.33	8.44	8.31	8.08	8.14	8.05
2	2.35	2.46	2.41	2.25	2.32	2.30	8.47	8.77	8.47	8.17	8.36	8.17
3	2.31	2.76	2.35	2.21	2.61	2.26	8.55	9.06	8.56	8.28	8.66	8.29
4	1.48	1.60	1.49	1.25	1.35	1.27	17.60	16.55	17.43	15.81	14.85	15.68
5	1.90	1.87	1.93	1.64	1.59	1.67	18.25	17.49	18.19	17.01	16.12	16.93
6	2.40	2.65	2.42	2.10	2.27	2.11	15.32	15.58	15.15	14.25	14.37	14.09
7	1.69	1.69	1.74	1.53	1.51	1.58	13.97	13.75	13.98	13.18	12.87	13.19
8	2.40	2.38	2.47	2.19	2.14	2.25	12.22	11.93	12.20	11.59	11.22	11.56
32	4.95	4.51	5.01	4.31	3.79	4.38	22.11	22.58	22.08	21.01	20.93	21.01
33	5.01	5.14	4.86	4.37	4.44	4.27	20.25	20.19	19.73	19.03	18.89	18.69
34	5.15	5.32	5.36	4.53	4.61	4.68	17.15	17.14	17.23	16.18	16.05	16.23
35	5.13	4.95	5.23	4.61	4.37	4.71	19.68	19.38	19.55	18.86	18.43	18.76
36	5.49	6.01	5.62	4.97	5.38	5.09	18.96	18.93	18.88	18.26	18.23	18.18
37	4.83	4.92	4.84	4.29	4.33	4.34	17.07	17.13	16.97	16.21	16.19	16.15
51	6.61	7.03		5.65	6.12		15.50	14.00		12.91	11.91	
52	4.06	4.86		3.95	4.67		8.92	9.22		8.79	9.00	
53	3.07	4.13		2.98	3.92		8.76	9.51		8.61	9.18	
54	2.68	2.89		2.50	2.67		10.20	10.08		9.57	9.43	
56	3.40	3.70		3.08	3.36		11.93	11.35		10.94	10.49	
57	3.40	3.85		3.24	3.65		10.22	10.22		9.96	9.93	
58	3.21	3.95		3.06	3.73		9.67	9.82		9.42	9.49	
59	2.75	2.99		2.58	2.78		10.81	10.84		10.26	10.26	
60	3.25	3.55		3.08	3.32		10.91	11.19		10.58	10.73	
61	3.41	3.78		3.24	3.55		10.66	10.92		10.36	10.51	
62	3.97	3.93		3.79	3.69		9.53	9.86		9.25	9.46	
63	4.06	4.86		3.89	4.62		9.62	9.51		9.39	9.20	
64	4.34	5.07		4.14	4.73		9.63	10.24		9.32	9.75	
65	3.80	4.75		3.60	4.45		10.03	10.83		9.66	10.40	
66	2.62	3.27		2.46	3.02		9.96	10.59		9.50	9.94	
67	2.58	3.04		2.47	2.87		9.09	9.29		8.79	8.89	
68	2.37	2.66		2.21	2.47		10.10	10.14		9.54	9.56	
69	4.07	3.93		3.25	3.14		23.60	23.02		19.62	18.67	

Table 13: Statistics of heave motions forward

Heave												
Run No.	$z_{a1/3}$ (m)			$z^{*}_{a1/3}$ (m)			T_{1z} (s)			T_{2z} (s)		
	DUT-4	DUT-5	LR-5	DUT-4	DUT-5	LR-5	DUT-4	DUT-5	LR-5	DUT-4	DUT-5	LR-5
1	0.85	0.86		0.80	0.83		8.96	8.81		8.57	8.49	
2	0.83	0.84		0.78	0.79		9.15	9.09		8.73	8.70	
3	1.11	1.13	1.37	1.07	1.09	1.32	8.87	8.94	8.77	8.63	8.67	8.54
4	0.63	0.64	0.71	0.56	0.57	0.64	13.22	13.06	11.48	12.14	12.05	10.68
5	0.62	0.63	0.69	0.54	0.56	0.59	14.93	14.87	13.77	13.71	13.67	12.53
6	0.94	0.94	1.00	0.83	0.83	0.88	13.68	13.53	12.93	12.73	12.59	11.95
7	0.77	0.79	0.87	0.72	0.74	0.80	12.10	12.12	11.64	11.52	11.54	11.02
8	1.02	1.05	1.15	0.95	0.97	1.05	11.87	11.87	11.24	11.37	11.37	10.69
32	2.61	2.72	2.68	2.26	2.37	2.18	22.80	22.79	21.35	21.67	21.72	19.68
33	2.74	2.84	3.32	2.40	2.51	2.92	20.08	20.04	19.35	18.98	19.07	18.50
34	3.43	3.48	3.72	3.06	3.11	3.23	17.34	17.11	16.21	16.47	16.27	15.20
35	2.77	2.66	2.78	2.50	2.40	2.37	20.90	20.69	19.53	20.11	19.91	18.43
36	3.14	3.27	4.14	2.85	2.97	3.51	19.39	19.38	18.43	18.69	18.68	17.47
37	3.11	3.14	3.64	2.81	2.83	3.13	17.40	17.23	16.87	16.60	16.43	15.76
51			1.73			1.66			9.01			8.83
52			1.81			1.74			9.00			8.82
53			1.69			1.61			9.06			8.85
54			1.70			1.61			9.86			9.61
56			1.72			1.60			10.71			10.36
57			1.70			1.61			10.92			10.65
58			1.54			1.44			10.30			9.96
59			1.18			1.09			11.08			10.64
60			1.25			1.16			11.50			11.08
61			1.68			1.56			12.03			11.59
62			1.97			1.84			10.21			9.84
63			2.03			1.93			9.90			9.63
64			1.86			1.74			9.79			9.45
65			2.30			2.16			10.50			10.19
66			1.69			1.54			11.32			10.44
67			1.52			1.41			9.48			9.03
68			1.60			1.50			10.37			9.95
69			1.20			1.08			12.37			11.52

Table 14: Statistics of heave motions

Roll								
Run No.	$\phi_{a1/3}$ (deg)		$\phi^{*}_{a1/3}$ (deg)		$T_{1\phi}$ (s)		$T_{2\phi}$ (s)	
	DUT-6	LR-6	DUT-6	LR-6	DUT-6	LR-6	DUT-6	LR-6
1	0.50	0.62	0.39	0.47	18.57	22.52	15.86	16.61
2	0.47	0.61	0.36	0.46	18.51	22.86	15.78	16.76
3	0.59	0.68	0.47	0.52	18.69	22.07	15.84	16.44
4	1.55	1.63	1.41	1.26	25.73	25.69	24.44	22.24
5	1.83	1.97	1.67	1.58	22.50	22.75	21.63	20.50
6	2.12	2.42	1.97	2.04	20.07	20.94	19.33	19.53
7	1.23	1.27	1.15	1.06	18.18	20.03	17.63	18.44
8	1.43	1.40	1.36	1.21	15.91	17.19	15.47	15.88
32	2.49	2.65	2.27	2.19	20.55	20.92	19.74	19.18
33	3.57	3.84	3.28	3.26	19.69	19.93	19.01	18.70
34	5.08	5.28	4.81	4.55	17.87	17.99	17.47	16.98
35	2.94	3.35	2.74	2.90	17.07	17.01	16.61	15.98
36	5.01	5.99	4.80	5.34	17.41	17.96	17.06	17.33
37	5.41	5.47	5.18	4.76	17.14	17.29	16.80	16.54
51		1.76		1.34		24.14		19.63
52		1.67		1.26		23.42		19.55
53		1.55		1.17		25.19		20.06
54		1.93		1.48		20.95		17.42
56		1.30		1.00		20.52		16.85
57		1.55		1.18		23.13		19.53
58		1.71		1.30		23.23		19.17
59		1.61		1.23		22.84		19.14
60		1.79		1.35		24.02		20.25
61		1.73		1.32		24.70		20.68
62		1.52		1.19		23.06		19.87
63		1.26		0.96		25.18		20.89
64		1.44		1.10		22.42		19.11
65		1.45		1.14		22.22		18.93
66		1.33		0.97		39.62		26.63
67		1.29		0.95		37.85		24.87
68		1.45		1.06		40.60		28.20
69		1.27		0.94		30.62		22.03

Table 15: Statistics of roll motions

Pitch								
Run No.	$\theta_{a1/3}$ (deg)		$\theta^*_{a1/3}$ (deg)		$T_{1\theta}$ (s)		$T_{2\theta}$ (s)	
	DUT-7	LR-7	DUT-7	LR-7	DUT-7	LR-7	DUT-7	LR-7
1	1.46	1.70	1.40	1.63	8.21	8.18	7.97	7.91
2	1.34	1.49	1.28	1.39	8.38	8.68	8.08	8.25
3	1.29	1.35	1.22	1.28	8.74	8.45	8.32	8.11
4	1.06	0.90	0.88	0.74	18.72	17.04	16.88	14.91
5	1.29	1.13	1.10	0.93	18.92	17.46	17.66	15.85
6	1.40	1.47	1.20	1.25	15.27	15.00	14.07	13.63
7	1.05	1.08	0.93	0.93	14.73	14.33	13.80	13.24
8	1.44	1.39	1.30	1.23	12.60	11.60	11.89	10.77
32	2.72	2.70	2.19	2.19	20.71	20.58	19.01	18.81
33	2.56	2.60	2.09	2.16	18.98	18.44	17.37	17.05
34	2.32	2.50	1.91	2.08	16.18	16.45	14.62	15.01
35	2.85	3.09	2.35	2.62	18.30	18.09	16.97	16.93
36	2.90	3.56	2.39	3.00	17.96	18.38	16.70	17.29
37	2.53	2.39	2.11	2.02	16.40	15.83	15.17	14.53
51		2.85		2.73		8.76		8.58
52		2.65		2.54		8.73		8.56
53		2.05		1.95		8.49		8.27
54		1.32		1.24		8.39		8.09
56		1.71		1.59		9.53		9.18
57		2.07		1.94		9.87		9.57
58		2.10		1.97		9.31		9.02
59		1.56		1.44		9.81		9.44
60		1.89		1.76		10.35		9.96
61		2.00		1.86		10.02		9.63
62		1.90		1.77		9.10		8.74
63		2.48		2.36		8.98		8.73
64		2.46		2.32		9.09		8.78
65		2.19		2.05		9.57		9.26
66		1.48		1.39		9.08		8.69
67		1.54		1.46		8.38		8.12
68		1.37		1.28		9.14		8.71
69		1.22		1.04		13.06		11.43

Table 16: Statistics of pitch motions

The spectra of the 1979 DUT motion experiments show (as expected) hardly any influence of roll and pitch on the independent recordings of the vertical motions of the centre of gravity and of the bow of the ship. These agreements suggest at least that the measured vertical acceleration signals itself of DUT are reliable.
The independently measured and analysed DUT and LR motion spectra show some (however still acceptable) differences.

It is a pity (now almost 25 years later) that DUT and LR have exchanged no motion signals for mutual analyses during this project. However, when comparing experimental motion data of different institutes, it is the author's opinion that - generally - the measured data itself are much more comparable than the spectral analysed data.

4.5 Measured Additional Data

As could be expected, the revolution counter of the ship and of DUT provided almost exact equal data. The ship's revolution counter data have been used when analysing the experimental data.

For obtaining alternatives in case of an unfortunately break down of the Delft instruments, a number of ship indicators have been read of during the 1979 DUT torque and power measurements too:

- the torque meter in the engine room (Q_{ER}) with the torque data of DUT (Q_{DUT})
- the power meter in the engine room (P_{ER}) with the power data of DUT (P_{DUT})
- the load indicator in the engine room (L_{ER}) with the load indicator at the bridge (L_{BR})

These data have been compared mutually in Figure 39.

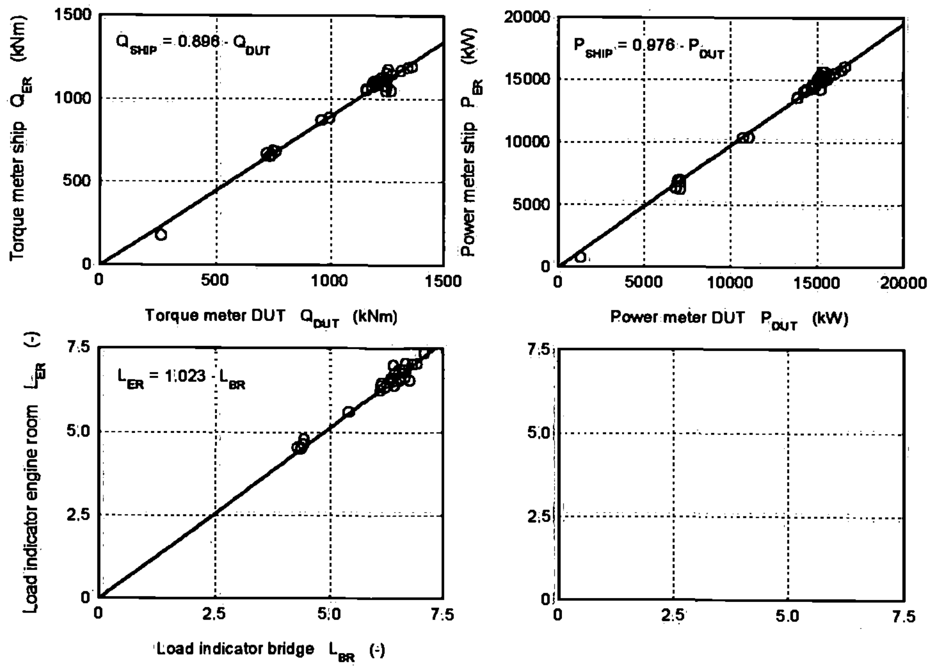

Figure 39: Comparison of various 1979 main engine indicator data

The next relations have been found:

$$
\begin{aligned}
Q_{\mathrm{BR}} &= 0.896 \cdot Q_{\mathrm{DUT}} \\
P_{\mathrm{BR}} &= 0.976 \cdot P_{\mathrm{DUT}} \\
L_{\mathrm{BR}} &= 1.023 \cdot L_{\mathrm{BR}}
\end{aligned}
$$

Equation 32

It is showed in Equation 32 that the ship's torque meter in the engine room appeared to have a deviation of over 10 %, while the power meter there deviate only 2.4 %. The load indicators in the engine room and on the bridge deviates 2.3 %.

A fairly stable relation had been found between the load indicator on the bridge and the by DUT measured engine power.

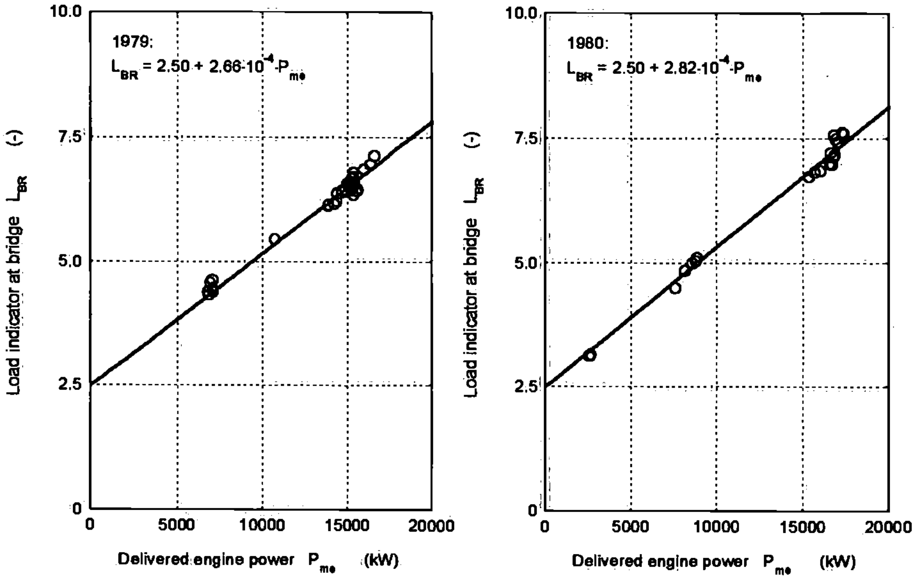

Figure 40: Measured relation between load indicator at bridge and engine power

$$
\begin{aligned}
1979: \quad & L_{\mathrm{BR}} = 2.50 + 2.66 \cdot 10^{-4} \cdot P_{me} \quad (\mathrm{kW}^{-1}) \\
1980: \quad & L_{\mathrm{BR}} = 2.50 + 2.82 \cdot 10^{-4} \cdot P_{me} \quad (\mathrm{kW}^{-1})
\end{aligned}
$$

Equation 33

The differences between the data of the two series of load indicator comparisons in Figure 40 and Equation 33 were less than 4 %.

During all voyages in 1979 and 1980, the performance measuring instruments of DUT have worked very well. No break downs occurred and, consequently, the emergency-relations in Equation 32 and Equation 33 have not been used. They have been presented here for the sake of giving a complete description of the experiments done only.

5 Manoeuvring Experiments

Nevertheless this was not a part of the official measuring schedule, a few manoeuvring experiments at deep and shallow water have been carried out too. Moreover, this was done as a kind turn for colleagues at the Manoeuvring Simulator Section of the former Ship Research Centre of TNO (Foundation for Applied Research in the Netherlands) in Delft. They had some lack of data information on the manoeuvrability of larger container vessels at low speeds in shallow water. Kind co-operation of the captain allowed these additional tests with the ship in the Caribbean. The ship's measuring tools on the bridge were used for data collection.

When approaching and leaving two harbours in the Caribbean - Puerto Cortes in Honduras and Santo Thomas de Castilla in Guatemala - the ship's path and performance at shallow water have been recorded under normal navigation conditions. The performance data (water depth under keel h, speed V, rudder angle δ, heading ψ, rate of turn $\dot{\psi}$, rpm N, thrust T, and torque Q) have been measured during about 1 hour at time intervals down to 10 seconds. The sign conventions here were:

- rudder angle, δ : PS rudder angle is positive and SB is negative,
- rate of turn, $\dot{\psi}$: PS rate of turn is negative and SB is positive.

Also, the wind speed and direction data have been recorded. These manoeuvres at shallow water include a few turning circles, each maintained as long as possible from a navigational point of view.

Being at open sea after leaving Santo Thomas de Castilla, a part of a turning circle - with nominal 10 degrees SB rudder angle - has been recorded too. Finally, two parts of turning circles at deep water - with nominal 20 degrees SB and PS rudder angles - have been performed, when leaving Kingston in Jamaica for sailing back to Europe.

The ship's officers on the bridge have plotted the path over the ground on nautical charts, by using satellite navigation.

At fixed time intervals, the water depth under the keel, the ship's speed, the rudder angle, the heading and rate of turn of the ship and the propeller rpm have been read off from the ship's instruments on the bridge. The staff of DUT and LR has written down all data on paper.
At time intervals of 10 seconds, an electronic device on the bridge produced a short and loud whistle and the DUT team leader announced each passed full minute. Paper-pen recordings of thrust, torque and wind were marked manually at the beginning and the end of the measurements. Changes of rudder angle or heading and propeller rpm have been started at the beginning of a time interval, so at a whistle sound. Because a large staff with 6 people of DUT and LR was available, this simple but very labour-intensive procedure could be followed easily.

All measured performance data are given in ASCII files at the Internet and the visualisations of the performance data are given in the next figures:

- Approaching Puerto Cortes in Honduras at 21-01-1979:
  Run 20, $T_m = 7.30$ m, *trim* = 0.00 m, Figure 48
  Start of experiment at: 20:00:06 GMT (zero at recordings).
- Leaving Puerto Cortes in Honduras at 25-01-1979:
  Run 21, $T_m = 7.34$ m, *trim* = 0.16 m, Figure 49.

Start of experiment at: 00:34:06 GMT (zero at recordings).

- Approaching SantoThomas de Castilla in Guatemala at 25-01-1979:
  Run 22, $T_m = 7.34\,\mathrm{m}$, *trim* = 0.16 m, Figure 50.

  Start of experiment at: 04:45:05 GMT (zero at recordings).
- Leaving SantoThomas de Castilla in Guatemala at 28-01-1979:
  Run 23a, $T_m = 8.04\,\mathrm{m}$, *trim* = 0.08 m, Figure 51.

  Start of experiment at: 06:43:08 GMT (zero at recordings).
- Part of a turning circle near Santo Thomas de Castilla in Guatemala at 28-01-1979:
  Run 23b, $T_m = 8.04\,\mathrm{m}$, *trim* = 0.08 m, Figure 52.

  Start of experiment at: 06:43:08 GMT (zero at recordings).
- Two parts of turning circles in deep water near Kingston in Jamaica at 30-01-1979:
  Run 26b, $T_m = 8.08\,\mathrm{m}$, *trim* = 0.00 m, Figure 53.

  Start of experiment at: 08:40:30 GMT (zero at recordings).

Figure 41 compares the measured torque and (less reliable) thrust during these maneuvering experiments with the approximated still and deep-water data at stationary rpm and speed. These comparisons have been carried out here only to verify - after these about 25 years - correctly used zero-offsets of the torque and thrust recordings on the pen-recorder.

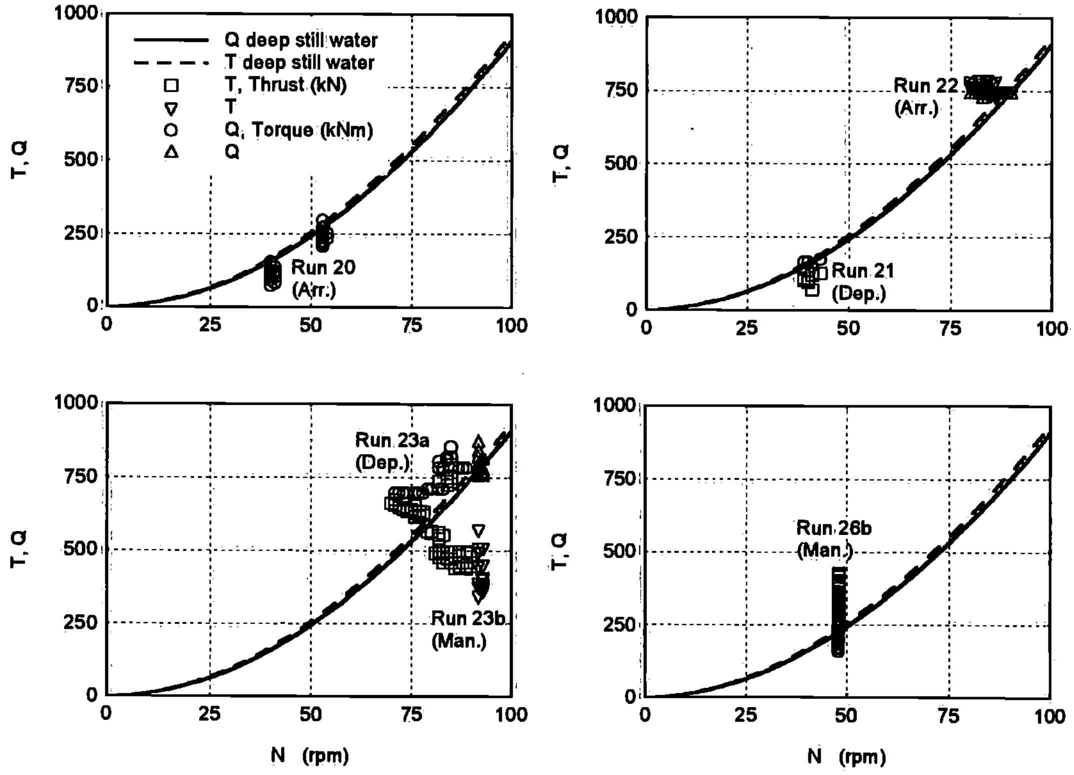

Figure 41: Measured torque and thrust during the maneuvering experiments

It may be noted that, nevertheless the fact the torque, thrust and wind data have been recorded continuously during these experiments, unfortunately only a restricted (however the most important) part of these data could be recovered from the archive of this. The box with the large number pen-recordings of these 3 phenomena itself has been lost during the removals within the university, but the selected data from these recordings - which were delivered to TNO in that time - have been survived.

Local water depths could be measured at keel clearances exceeding 3.60 meter.
Being in deeper waters, as the keel clearance exceeded about 12-18 meters, the captain activated the speed log.

As has been reported back afterwards by Ben Jaspers, head of the Maneuvering Simulator Section of TNO, the provision of these (limited) maneuvering data appeared to be a very valuable supplement to their database.

5.1 Approaching and Leaving Two Harbours

During arrival and departure of two harbours - Puerto Cortes and Santo Thomas de Castilla - the navigation officer has been asked to plot a number of path co-ordinates on the navigation chart. After finishing each run, this chart has been copied manually on rice-paper. Processed scans of these rice-paper copies have been presented here.

Figure 42 and Figure 43 show the navigation charts of the sea (as it is nowadays) near these two harbours.
Full-scale images of each chart can be found in NavigationCharts.zip: Chart-PuertoCortes.pcx and Chart-SantoThomasDeCastilla.pcx.

Figure 44 through Figure 47 show an overview of the 4 plots of the paths over the ground of the ship at the bridge.
Full-scale images of each path-plot can be found in the zip-file NavigationCharts.zip too: Chart-Run20.pcx, Chart-Run21.pcx, Chart-Run22.pcx and Chart-Run23.pcx.

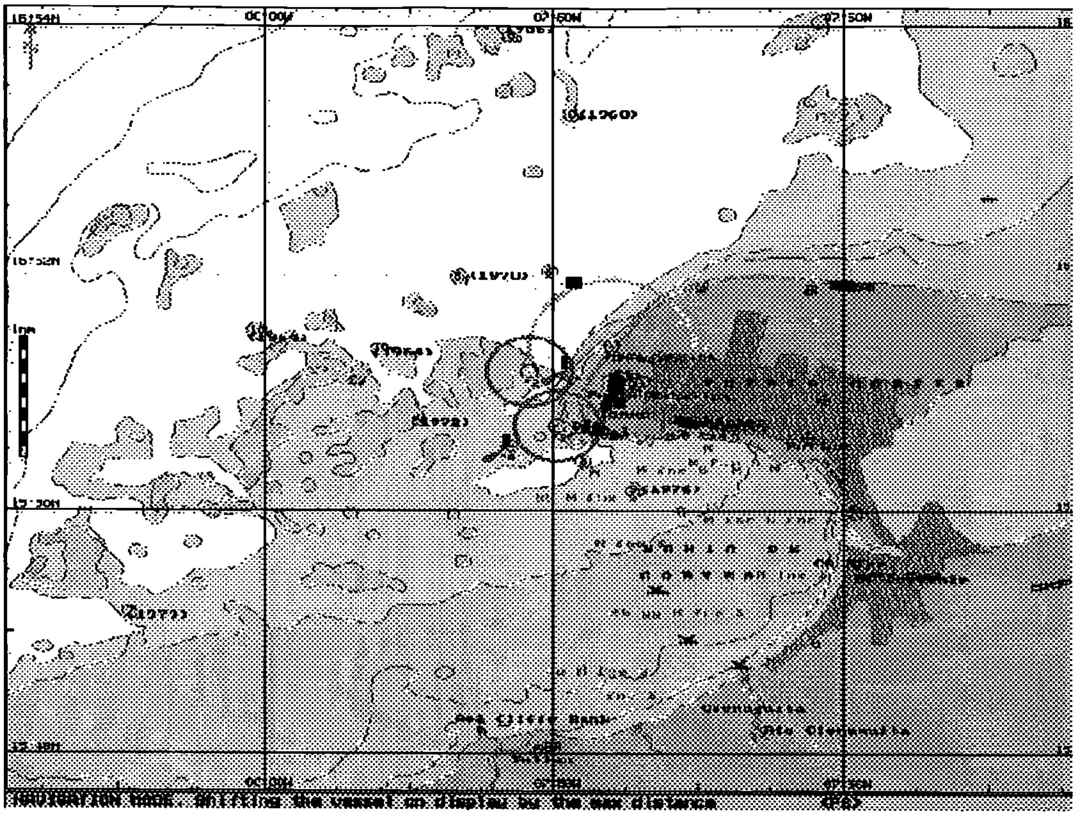

Figure 42: Navigation chart of sea near Puerto Cortes (Run 20 and 21)

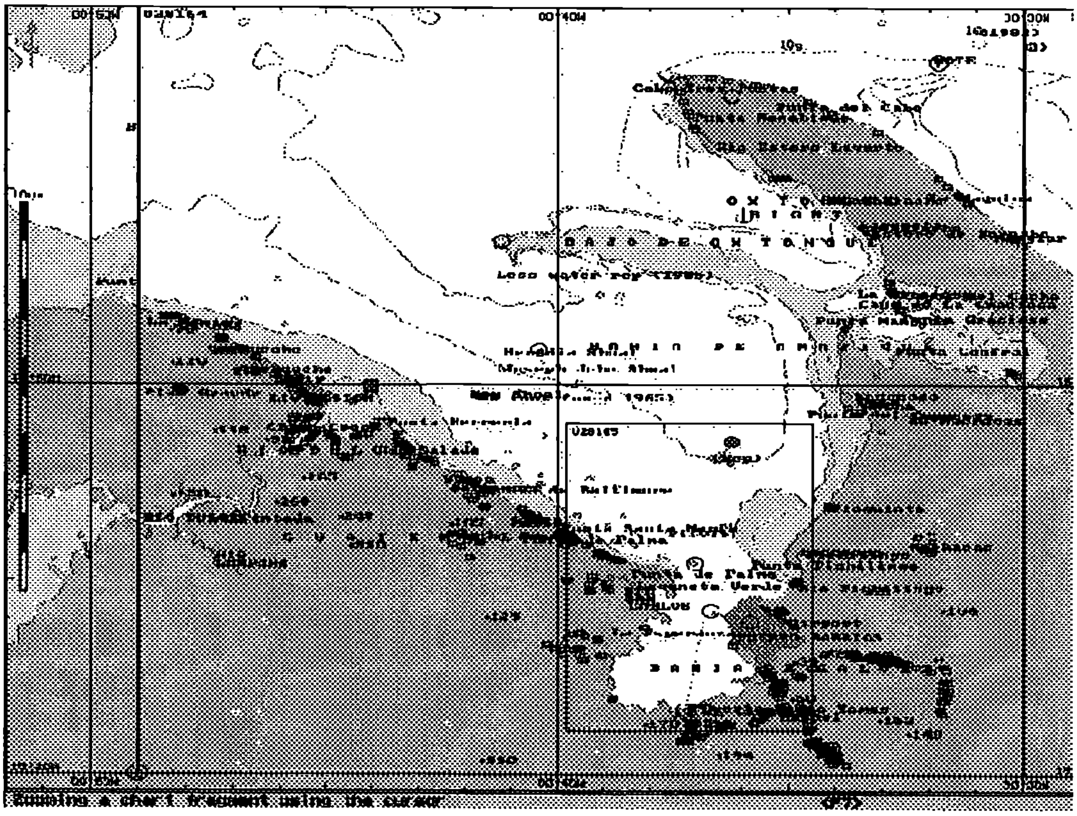

Figure 43: Navigation chart of sea near Santo Thomas de Castilla (Run 22 and 23)

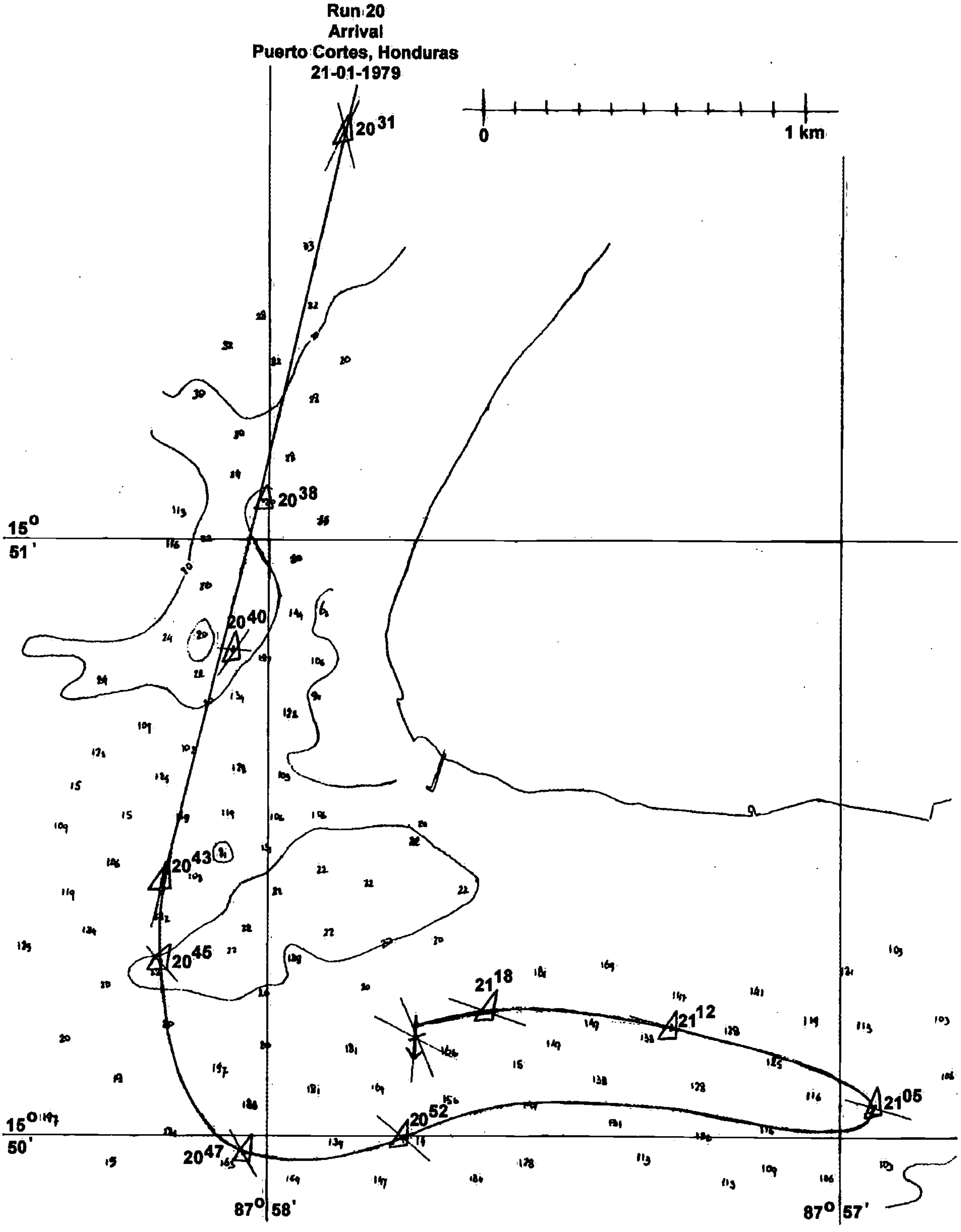

Figure 44: Plotted path over the ground of Run 20

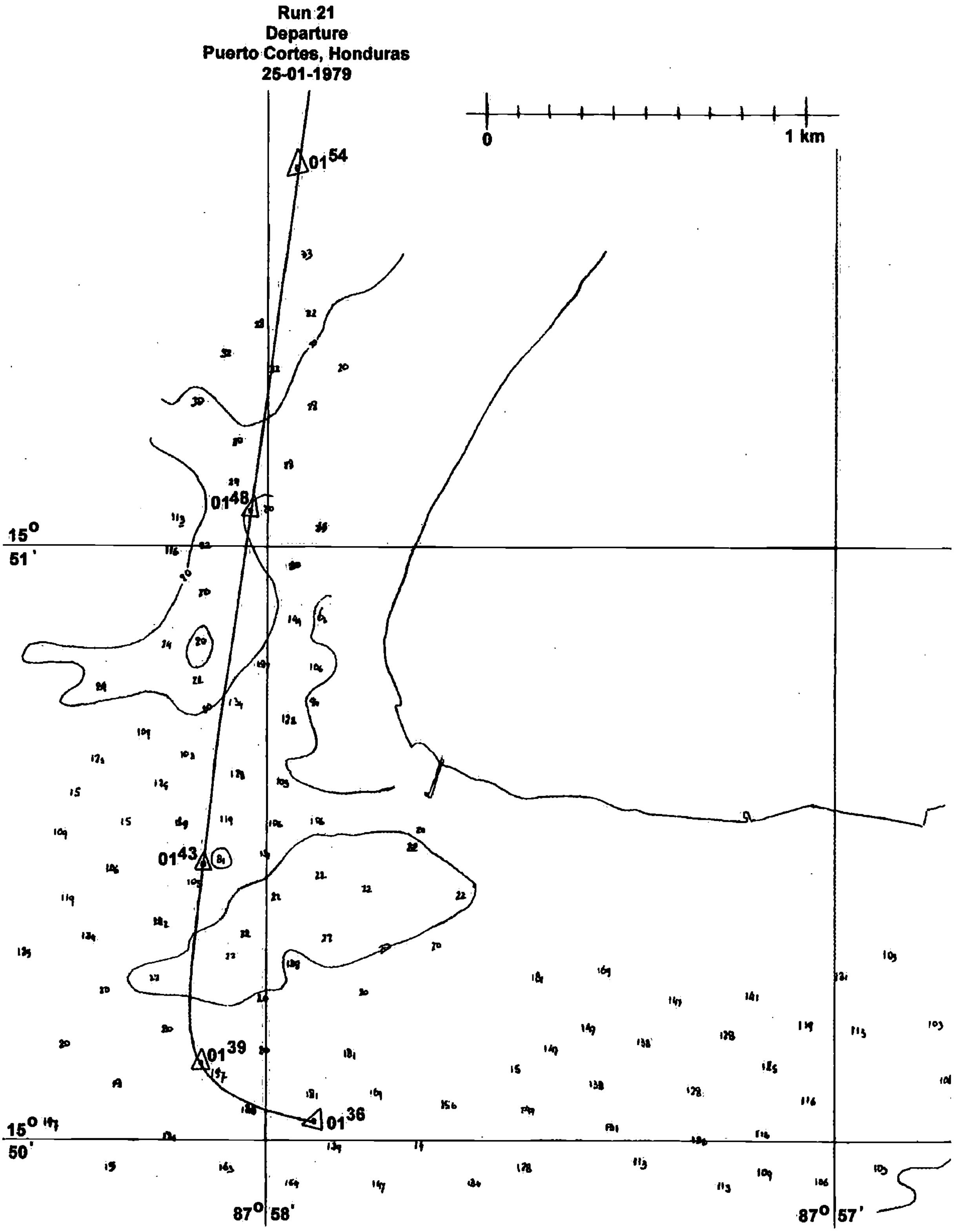

Figure 45: Plotted path over the ground of Run 21

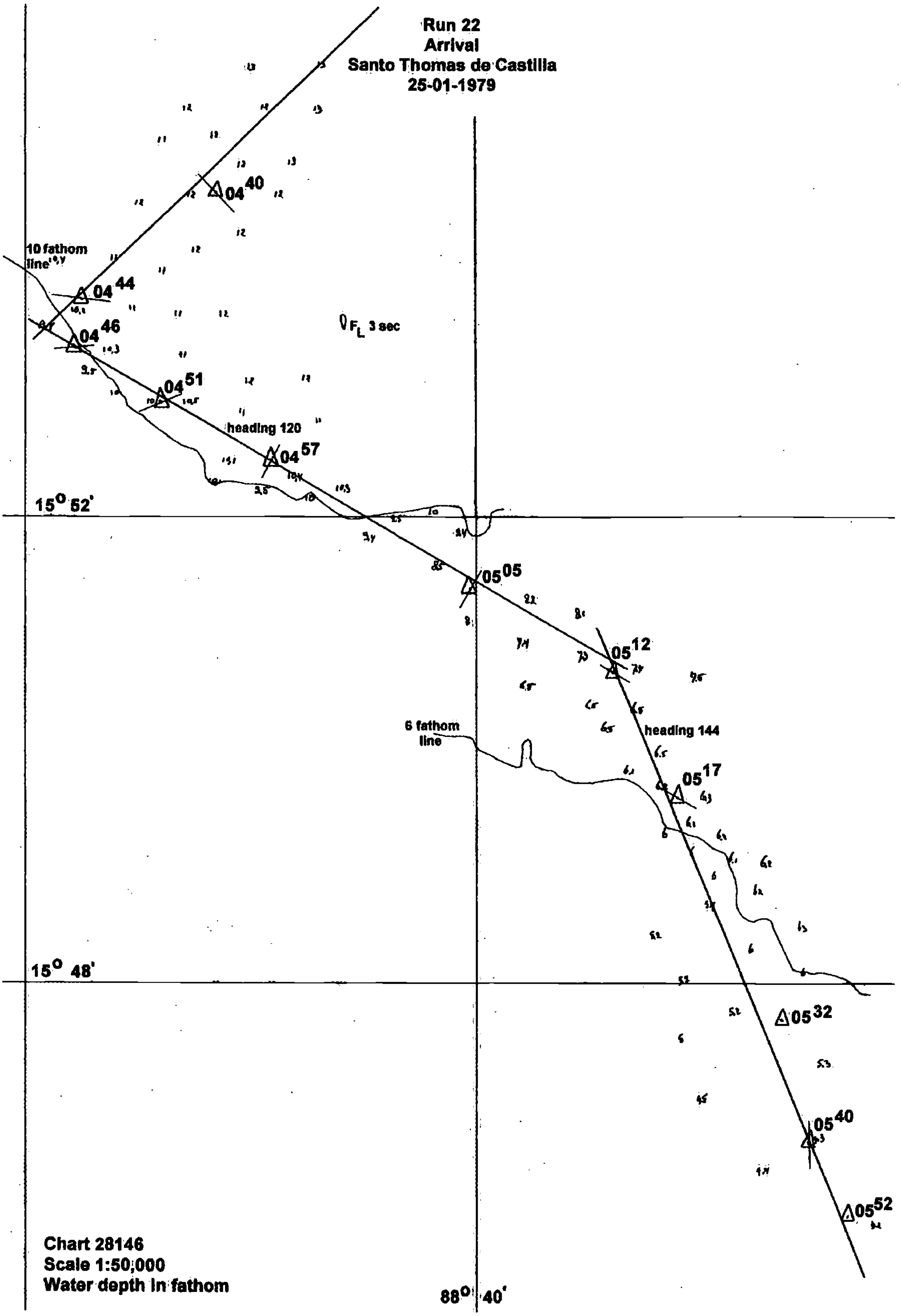

Figure 46: Plotted path over the ground of Run 22

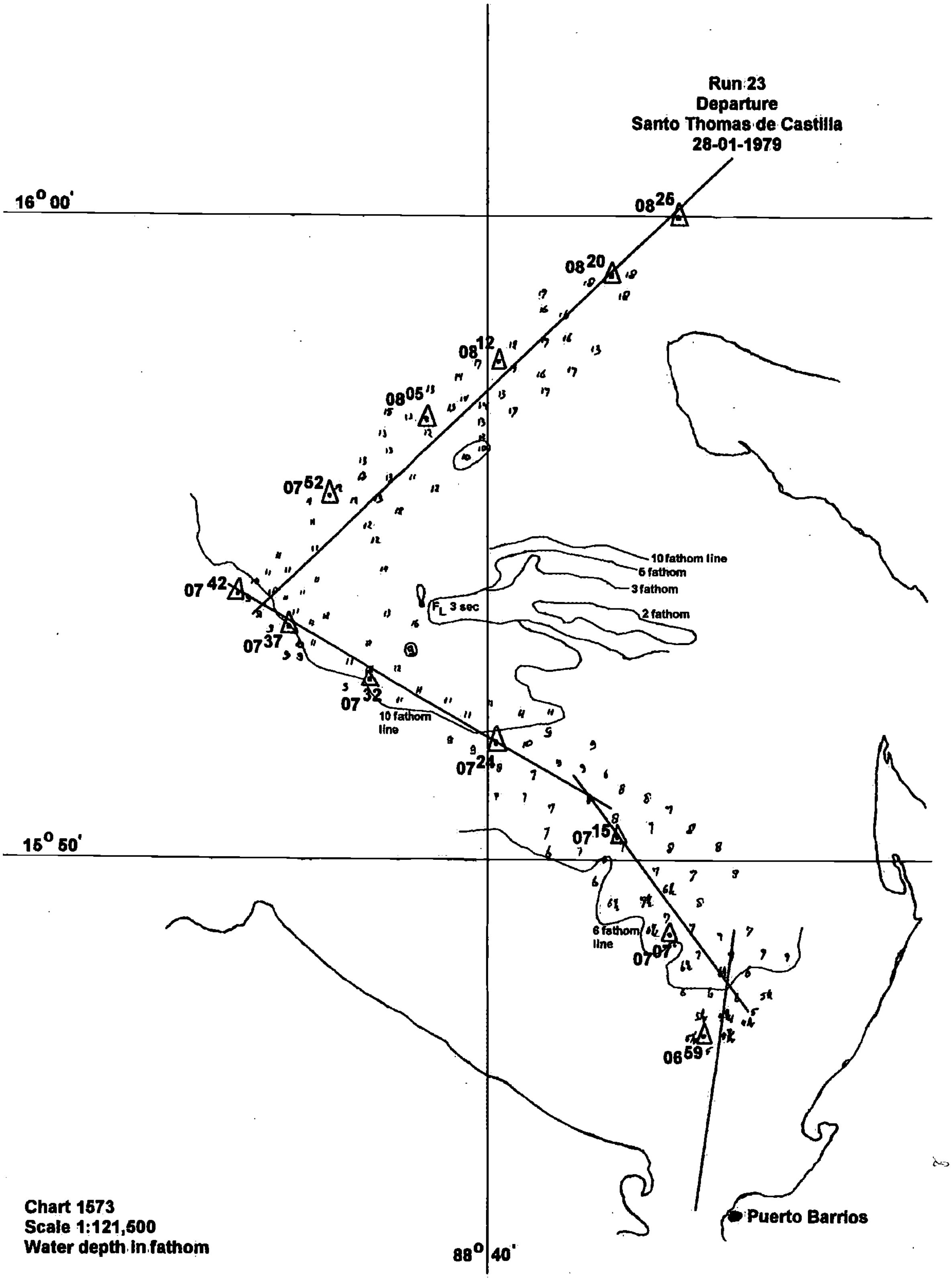

Figure 47: Plotted path over the ground of Run 23a

The measured time histories of these four manoeuvring experiments are given in Figure 48 through Figure 51.

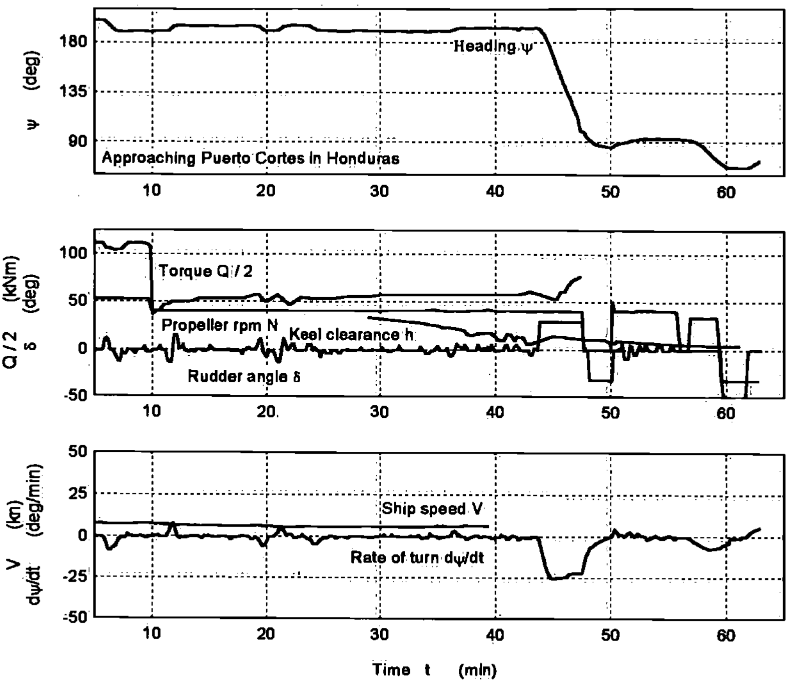

Figure 48: Performance when approaching Puerto Cortes (Data file: 20-MAN.EXP)

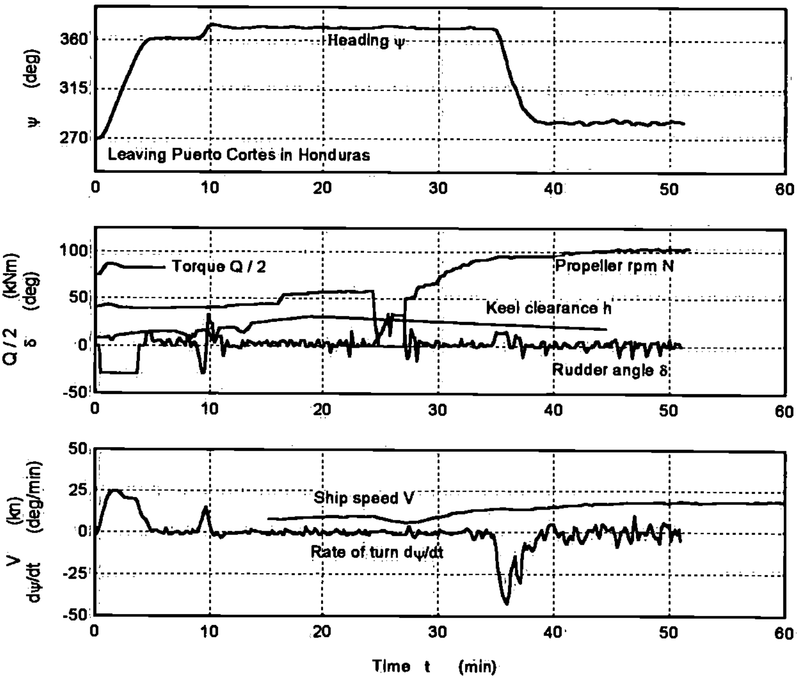

Figure 49: Performance when leaving Puerto Cortes (Data file: 21-MAN.EXP)

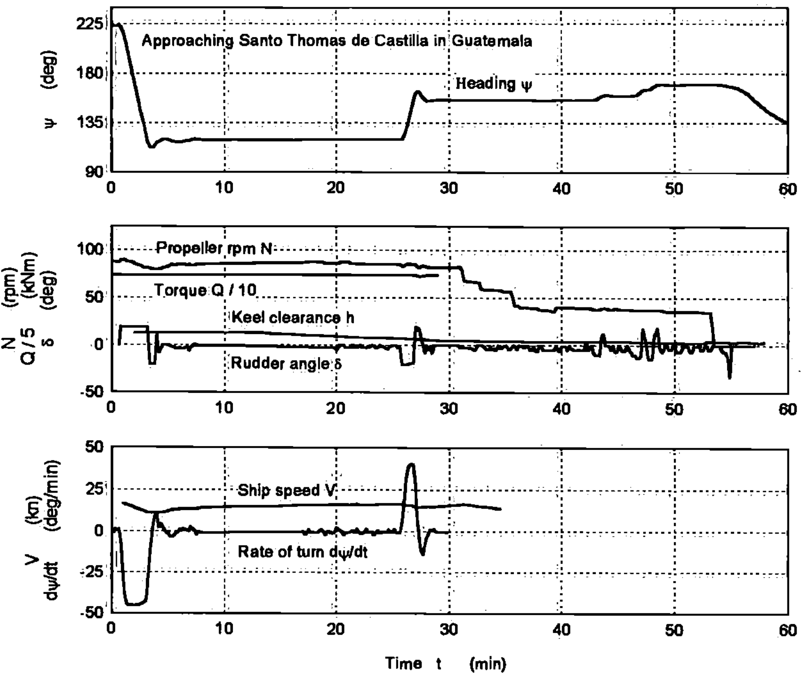

Figure 50: Performance when approaching Santo Thomas de Castilla (Data file: 22-MAN.EXP)

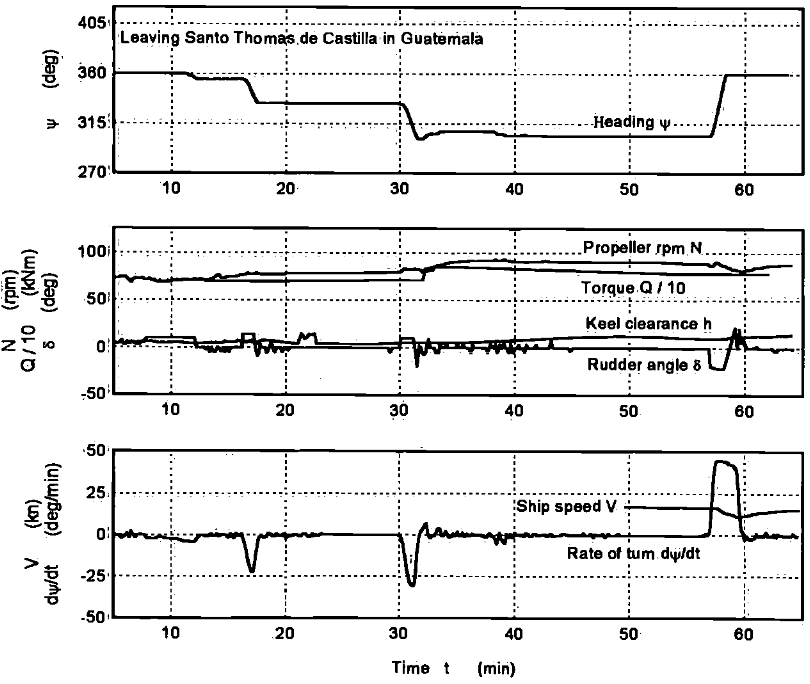

Figure 51: Performance when leaving Santo Thomas de Castilla (Data file: 23a-MAN.EXP)

5.2 Parts of a Few Turning Circles

The measured time histories of the turning circle experiments at deeper water are given in Figure 52 and Figure 53.

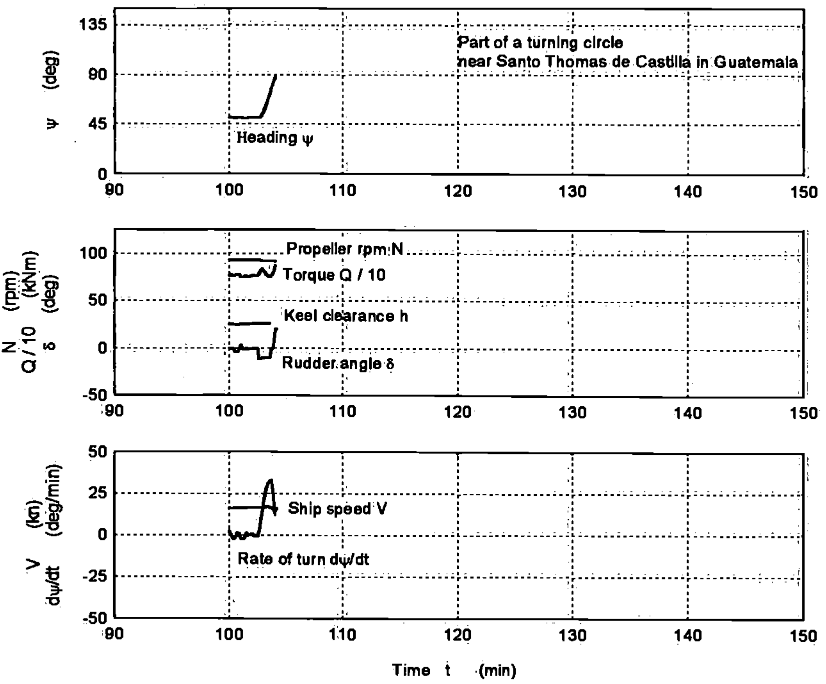

Figure 52: Part of a turning circle near Santo Thomas de Castilla (Data file: 23b-MAN.EXP)

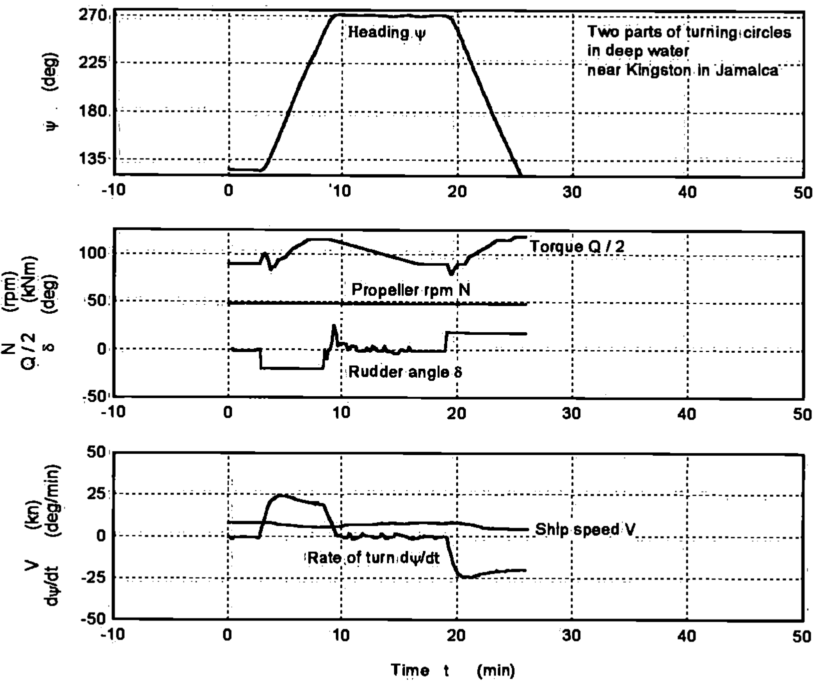

Figure 53: Two parts of turning circles in deep water near Kingston (Data file: 26b-MAN.EXP)

6 Acknowledgements

Nevertheless the fact that these full-scale experiments took place already a long time ago, the author likes repeating to express his appreciation here to:

- The ship owner (former KNSM), the ship's captains Brunt and Laatsch and the officers and crew of m.v. Hollandia for their very constructive co-operation and personal interest during the preparation and the execution of the three full-scale trials,
- Lloyd's Register of Shipping, especially Tony Hancock and Dave Robinson of the Specialists Services Section in London for their fruitful and amicable co-operation during the three common voyages and the project as a whole,
- CMO - especially Ton Pijcke - for making funds available for financing the Operational Performance Project, being carried out by Lloyd's Register of Shipping in London,
- DTNSRDC - especially Susan Bales - for offering detailed weather forecasts during the 1979 voyage and
- KNMI Routing Office for supplying excellent routing advises during the 1980 voyage.

Also, the author thanks his then-colleagues from the Ship Hydromechanics Laboratory of the Delft University of Technology. Being members of only a small Laboratory, all contributed very well to this relatively large and very stressful project. Especially Maarten Buitenhek, Lex Goeman, Cees Jorens, Hans Ooms and Aad van Strien gave their full technical and personal support before, during and after these extensive full-scale experiments.
In particular, Maarten Buitenhek was very essential by preparing, co-ordinating, guiding and executing the technical part of all these experiments.

The numerous graphs in this report have been made with EasyPlot, a very handsome tool of Spiral Software in the USA and originally designed by Stuart Karon at MIT. The author is very much indebted to Stuart Karon for supporting him with an updated version of his program, to create WMF files of all graphs in a very convenient and fast way. Information about this very valuable tool can be found at the Internet: http://www.SpiralSoftware.com.

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This paper is enclosed in the 1349-Hollandia-03.zip file.

8 Appendix I: Tables with Experimental Data

All logbook data are given in Table 17 and Table 18, with a definition of the symbols above the columns as given below:

NR	-	Run number
IC	-	Code for main goal of experiments: IC = 1: Calibration of speed log in calm water IC = 2: Performance tests in calm water IC = 3: Ship motion tests in waves IC = 4: General performance tests IC = 5: Manoeuvring tests
Tm	m	Mean draught in meter
trim	m	Trim in meter
V	kn	Forward ship speed in knots
N	rpm	Number of propeller revolutions per minute
T	kN	Thrust in propeller shaft in kN
Q	kNm	Torque in propeller shaft in kNm
P	kW	Power in kW
f	m^3 / h	Fuel consumption in m^3 per hour
L	-	Read off of load indicator at bridge
y.1	o / '	Mean yaw rate amplitude in degrees per minute
y.2	o / '	RMS of yaw rate amplitude in degrees per minute
ym	o	Mean yaw angle amplitude in degrees
Ty	o	Mean yaw period in seconds
dps	o	Mean maximum rudder angle to PS in degrees
dsb	o	Mean maximum rudder angle to SB in degrees
dg	o	Mean absolute value of rudder angle in degrees
ap	o	Mean maximum upwards nose angle of PS fin in degrees
an	o	Mean maximum downwards nose angle of PS fin in degrees
Vw	kn	True wind speed in knots
Muw	o	True wind vector direction in degrees
WB	-	Wave buoy number
H1s	m	Significant wave height $H_{1/3}$ in meter
H2s	m	Significant wave height $H_{1/3}^*$ in meter
T1s	s	Mean wave period T_1 in seconds
T2s	s	Mean zero-crossing wave period T_2 in seconds
Mus	o	Wave vector direction in degrees

Note: -1 in Table 17 and Table 18 means that no data about that subject are available or that the subject is a variable during the test.

NR	IC	Tm	trim	V	N	T	Q	P	f	L	y.1	y.2	ym	Ty	dps	dsb	dg	ap	an	W	Mw	WB	H1s	H2s	T1s	T2s	Ms
-	-	m	m	kn	rpm	kN	kNm	kW	m3/h	-	o/'	o/'	o	s	o	o	o	o	o	kn	o	-	m	m	s	s	o
01	3	8.54	0.00	18.40	116.29	1357	1364	16611	4.133	7.11	6.5	7.5	-1	-1	1.1	0.6	-1	-1	-1	9.8	355	18	4.00	3.60	10.76	10.13	180
02	3	8.54	0.00	18.50	116.39	1320	1344	16381	4.124	6.94	6.6	6.7	-1	-1	0.8	1.2	-1	-1	-1	11.2	343	18	4.00	3.60	10.76	10.13	200
03	3	8.54	0.00	18.70	116.50	1265	1314	16031	3.914	6.84	7.5	8.4	-1	-1	2.2	0.9	-1	-1	-1	10.6	358	18	4.00	3.60	10.76	10.13	220
04	3	8.44	0.00	19.98	116.91	1323	1250	15303	3.719	6.43	14.0	16.2	-1	-1	4.9	5.1	-1	6.9	6.2	30.4	353	22	5.24	4.76	10.15	9.61	360
05	3	8.44	0.00	19.47	116.89	1315	1244	15227	3.716	6.42	16.6	18.8	-1	-1	3.6	7.3	-1	8.6	7.3	31.3	330	22	5.24	4.76	10.15	9.61	340
06	3	8.44	0.00	18.89	117.20	1360	1268	15562	3.777	6.41	24.1	26.5	-1	-1	3.8	9.4	-1	10.0	8.6	32.7	309	22	5.24	4.76	10.15	9.61	320
07	3	8.44	0.00	14.82	89.01	766	734	6842	1.782	4.39	10.5	11.4	-1	-1	2.2	2.8	-1	10.3	9.8	30.4	347	16	5.69	5.11	10.72	9.94	360
08	3	8.44	0.00	13.78	88.87	800	764	7110	1.793	4.39	14.9	17.3	-1	-1	-3.2	9.0	-1	10.5	7.4	30.7	304	16	5.69	5.11	10.72	9.94	320
09	1	8.41	0.00	18.68	106.55	1130	1034	11537	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
10	2	8.39	0.00	18.68	106.55	1116	1015	11325	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
11	2	8.39	0.00	18.79	106.62	1091	996	11121	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
12	1	8.39	0.00	15.34	90.08	773	731	6896	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
13	2	8.25	0.23	21.40	118.20	1422	1202	14878	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
14	2	8.33	0.15	21.52	118.77	1467	1199	14913	-1	6.45	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
15	1	8.33	0.15	21.42	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
16	1	8.13	0.00	22.07	118.11	1479	1250	15461	-1	6.55	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
17	1	8.05	0.00	15.29	90.34	840	725	6859	1.785	4.32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
18	1	8.04	0.02	18.64	106.48	1139	963	10738	2.740	5.43	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
19	1	7.32	0.05	21.37	117.49	1441	1248	15355	3.834	6.69	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
20	5	7.30	0.00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
21	5	7.34	0.16	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
22	5	7.34	0.16	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
23	5	8.04	0.08	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
24	1	8.04	0.08	21.47	119.89	-1	-1	-1	3.847	6.68	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
25	1	7.99	0.23	21.91	119.56	1454	1199	15012	3.825	6.55	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
25	1	7.99	0.23	21.47	119.56	1454	1199	15012	3.825	6.55	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
25	1	7.99	0.23	21.34	119.56	1454	1199	15012	3.825	6.55	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
26	1	8.08	0.00	7.99	47.84	311	180	902	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
26	5	8.08	0.00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
27	1	8.08	0.00	21.12	119.44	-1	-1	-1	3.897	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
28	4	8.03	0.00	20.48	119.35	1410	1222	15273	3.928	6.65	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
29	4	8.03	0.00	19.68	119.17	1351	1225	15287	3.932	6.54	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
30	4	8.03	0.00	19.13	119.02	1397	1235	15393	3.978	6.78	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
31	4	8.01	0.00	18.77	117.28	1303	1272	15662	3.967	6.44	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
32	3	8.01	0.23	19.59	117.38	1277	1248	15340	3.908	6.55	26.2	28.0	1.6	22	8.4	7.3	-1	10.6	9.1	37.4	6	8	11.06	9.73	13.87	13.00	360
33	3	8.01	0.23	18.83	116.81	1268	1242	15193	3.863	6.60	28.6	31.7	1.8	23	6.6	8.8	-1	11.7	9.9	38.0	342	8	11.06	9.73	13.87	13.00	340
34	3	8.01	0.23	18.71	117.26	1314	1254	15398	3.934	6.69	23.9	29.0	1.5	23	3.6	8.1	-1	13.7	13.7	40.6	334	8	11.06	9.73	13.87	13.00	320
35	3	8.01	0.23	13.95	90.24	776	749	7078	1.930	4.62	22.4	24.9	1.2	20	6.9	4.3	-1	15.4	13.9	36.8	1	9	9.77	8.63	13.18	12.31	360
36	3	8.01	0.23	13.77	89.90	734	740	6967	1.907	4.56	29.4	32.1	1.7	22	3.3	6.4	-1	18.1	17.3	37.7	338	9	9.77	8.63	13.18	12.31	324
37	3	8.01	0.23	13.50	89.92	759	752	7081	1.902	4.45	25.2	28.8	1.3	19	2.1	7.6	-1	17.2	17.3	37.1	328	9	9.77	8.63	13.18	12.31	330
38	4	7.98	0.00	18.66	115.84	1223	1215	14739	3.748	6.39	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
39	4	7.98	0.00	19.02	116.80	1279	1239	15155	3.861	6.58	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
40	4	7.96	0.00	19.65	116.15	1186	1208	14693	3.726	6.41	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
41	4	7.96	0.00	19.11	115.13	1121	1183	14263	3.576	6.15	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
42	4	7.94	0.00	19.78	115.69	1159	1188	14393	3.666	6.21	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
43	4	7.98	0.00	19.52	114.18	1122	1161	13882	3.535	6.13	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
44	4	7.95	0.00	19.89	118.33	1211	1242	15390	3.815	6.33	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
45	4	7.89	0.00	19.52	114.38	1109	1158	13870	3.485	6.12	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
46	4	7.89	0.00	17.74	114.07	1004	1208	14430	3.634	6.36	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
47	2	8.95	0.00	19.20	121.56	1270	1371	17452	4.095	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
48	2	8.88	0.00	21.18	120.63	1363	1396	17635	4.016	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
49	2	8.75	0.00	8.10	48.72	212	263	1342	0.425	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Table 17: Logbook data of 1979 experiments

NR	IC	Tm	trim	V	N	T	Q	P	f	L	y.1	y.2	ym	Ty	dps	dsb	dg	ap	an	W	Mw	WB	H1s	H2s	T1s	T2s	Ms
-	-	m	m	kn	rpm	kN	kNm	kW	m3/h	-	o/'	o/'	o	s	o	o	o	o	o	kn	o	-	m	m	s	s	o
50	4	9.10	0.00	16.54	106.80	-1	954	10670	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
50	4	9.10	0.00	16.72	107.70	-1	966	10895	2.694	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
50	4	9.10	0.00	18.39	117.20	-1	1135	13930	3.456	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
51	3	9.36	0.12	14.80	113.74	-1	1414	16842	4.177	7.55	6.4	7.0	0.2	12	-1	-1	1.3	-1	-1	21.7	183	29	6.72	5.70	13.54	12.04	180
52	3	9.36	0.12	16.31	114.87	-1	1409	16949	4.114	7.47	6.4	6.9	0.8	44	-1	-1	2.1	-1	-1	23.6	165	29	6.72	5.70	13.54	12.04	160
53	3	9.36	0.12	17.43	115.51	-1	1377	16656	3.982	7.20	7.2	8.0	0.2	10	-1	-1	-1	-1	-1	22.7	143	15	4.21	3.80	10.28	9.71	140
54	3	9.36	0.12	18.45	115.62	-1	1300	15740	3.803	6.81	9.0	10.2	0.4	17	-1	-1	-1	-1	-1	21.5	113	15	4.21	3.80	10.28	9.71	130
55	4	9.33	0.00	12.32	91.53	-1	852	8166	2.163	4.83	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
56	3	9.33	0.06	13.22	91.68	-1	898	8621	2.150	4.98	7.1	7.3	0.4	19	-1	-1	-1	-1	-1	28.4	130	20	4.63	4.11	10.63	9.89	140
57	3	9.33	0.06	12.74	91.67	-1	917	8803	2.205	5.03	5.5	5.9	0.4	24	-1	-1	-1	-1	-1	25.0	154	20	4.63	4.11	10.63	9.89	160
58	3	9.33	0.06	12.07	91.65	-1	927	8897	2.264	5.09	5.6	6.0	0.3	17	-1	-1	-1	-1	-1	25.1	165	20	4.63	4.11	10.63	9.89	180
59	3	9.33	0.06	6.55	58.06	-1	425	2584	0.821	3.11	4.4	4.9	0.3	21	-1	-1	-1	-1	-1	25.7	157	10	5.10	4.52	11.06	10.32	180
60	3	9.33	0.06	6.60	58.10	-1	436	2653	-1	3.14	6.3	6.7	0.3	15	-1	-1	-1	-1	-1	23.1	140	10	5.10	4.52	11.06	10.32	160
61	3	9.33	0.06	6.41	58.15	-1	431	2625	0.695	3.12	9.6	10.6	0.5	20	-1	-1	-1	-1	-1	25.6	117	10	5.10	4.52	11.06	10.32	145
62	3	9.32	0.04	18.81	118.75	-1	1372	17061	4.185	7.41	8.5	9.4	0.4	16	-1	-1	-1	-1	-1	26.1	86	17	4.96	4.38	11.53	10.78	140
63	3	9.32	0.04	17.45	117.19	-1	1420	17426	4.271	7.58	8.0	9.0	0.4	16	-1	-1	-1	-1	-1	22.8	92	17	4.96	4.38	11.53	10.78	155
64	3	9.32	0.04	16.57	116.76	-1	1417	17326	4.250	7.60	5.7	6.2	0.2	13	-1	-1	-1	-1	-1	21.9	144	11	5.17	4.59	11.40	10.71	180
65	3	9.32	0.04	18.69	118.46	-1	1380	17119	4.162	7.42	10.8	11.8	0.6	19	-1	-1	-1	-1	-1	18.2	88	11	5.17	4.59	11.40	10.71	140
66	3	9.30	0.04	19.36	119.78	-1	1341	16821	4.103	7.12	8.2	9.3	0.4	16	-1	-1	2.7	5.0	4.3	30.1	12	13	5.10	4.36	12.49	11.11	70
67	3	9.30	0.04	19.42	119.42	-1	1339	16745	4.097	6.96	5.8	6.3	0.4	26	-1	-1	3.1	5.7	5.3	32.1	27	14	4.99	4.40	11.06	10.21	90
68	3	9.30	0.04	19.55	119.37	-1	1328	16601	4.027	6.97	8.4	9.7	0.5	20	-1	-1	2.3	5.4	4.2	31.6	12	14	4.99	4.40	11.06	10.21	80
69	3	9.27	0.06	20.45	121.60	-1	1327	16898	4.170	7.16	11.7	13.0	0.8	26	-1	-1	2.5	5.3	5.1	26.4	50	7	4.73	4.21	10.89	10.06	55
70	2	9.25	0.10	20.24	120.66	-1	1271	16060	3.963	6.83	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
71	1	9.24	0.18	20.00	121.00	-1	1290	16346	4.006	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
72	2	9.20	0.00	19.93	120.69	-1	1261	15397	3.925	6.72	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
73	2	9.23	0.14	17.88	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
74	2	9.23	0.18	17.54	103.14	-1	925	9991	2.528	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
75	1	9.23	0.18	17.59	102.53	-1	925	9932	2.470	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
76	1	9.23	0.20	15.10	89.23	-1	720	6728	1.766	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
77	1	9.23	0.20	10.04	59.00	-1	311	1922	0.621	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
78	2	9.23	0.20	15.82	93.20	-1	780	7613	1.959	4.49	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Table 18: Logbook data of 1980 experiments

All relevant experimental and other data - suitable for post-processing - have been given at the Internet at web site http://www.ocp.tudelft.nl/mt/journee, also attainable via web site http://www.shipmotions.nl, in Section "Papers and Reports" in a zipped file, named **1349-Hollandia-03.zip**.

The files in here have been coded as follows:

- **ReadMe.doc**, this section of Report No. 1349. Additions and modifications since the first release of the Report at 14-02-2003 are described at the end of this document at the Internet too.

- **PaperTaylor.zip**, with 10 scanned Zsoft Paintbrush (pcx) files of a 1980 paper of K.V. Taylor about the Operational Performance Project of Lloyd's Register of Shipping onboard m.v. Hollandia.

- **PaperSulzer.zip**, with 11 scanned Zsoft Paintbrush (pcx) files of a 1977 paper of M.J. Briner, R. Stoffel and H. Zehnder about Sulzer RN...M engines.

- **Seaway.hul**, an ASCII file with the under water hull form of the ship, to be used as input file for the ship motions computer code SEAWAY.

- **TablesReport.zip** with XXXXXX.doc, 15 Word'97 documents with relevant tables of the report:
  - Table-BodyPlan.doc, as given in Table 1.
  - Table-WindSeaObsData-1979.doc, as given in Table 6.
  - Table-WindSeaObsData-1980.doc, as given in Table 7.
  - Table-WaveBuoyData-1979.doc, as given in Table 8.
  - Table-WaveBuoyData-1980.doc, as given in Table 9.
  - Table-PerformanceCalmWater.doc, as given in Table 10.
  - Table-PerformanceWaves.doc, as given in Table 11.
  - Table-PerformanceOther.doc, as given in Table 12.
  - Table-Motions-23.doc, as given in Table 13.
  - Table-Motions-45.doc, as given in Table 14.
  - Table-Motions-6.doc, as given in Table 15.
  - Table-Motions-7.doc, as given in Table 16.
  - Table-LogBook-1979.doc, as given in Table 17.
  - Table-LogBook-1980.doc, as given in Table 18.
  - Table-Forecasts-1979.doc, as given in Appendix III.

  ASCII files can easily be derived from these documents.

- **WaveSpectra.zip** with BUOY-XX.EXP, 14 ASCII files with the wave buoy spectra (where XX is the serial number of the buoy) in the next sequence:
  - Column 1: $\omega =$ circular wave frequency in rad/s
  - Column 2: $S_\zeta(\omega) =$ wave spectral value in m^{2}s of first time history
  - Column 3: $S_\zeta(\omega) =$ if available, wave spectral value in m^{2}s of second time history

- **MotionSpectra-1.zip** with XX-DUT.EXP, 32 ASCII files with the ship motion spectra of DUT (where XX is the run number) in the next sequence:
  - Column 1: $\omega_e =$ circular frequency of encounter in rad/s
  - Column 2: $S_{zf}(\omega_e) =$ spectral value of ship-bound heave motion forward in m^2s
  - Column 3: $S_{zf}(\omega_e) =$ spectral value of earth-bound heave motion forward in m^2s
  - Column 4: $S_z(\omega_e) =$ spectral value of ship-bound heave motion at centre of gravity in m^2s
  - Column 5: $S_z(\omega_e) =$ spectral value of earth-bound heave motion at centre of gravity in m^2s
  - Column 6: $S_\phi(\omega_e) =$ spectral value of roll motion in deg^2s
  - Column 7: $S_\theta(\omega_e) =$ spectral value of pitch motion in deg^2s

  Above run number 37, columns 1 and 2 are given only; the other phenomena had not been measured by DUT.

- **MotionSpectra-2.zip** with XX-LR.EXP, 32 ASCII files with the ship motion spectra of LR (where XX is the run number) in the next sequence:
  - Column 1: $\omega_e =$ circular frequency of encounter in rad/s
  - Column 2: $S_{zf}(\omega_e) =$ spectral value of ship-bound heave motion forward in m^2s
  - Column 3: $S_z(\omega_e) =$ spectral value of earth-bound heave motion at centre of gravity in m^2s
  - Column 4: $S_\phi(\omega_e) =$ spectral value of roll motion in deg^2s
  - Column 5: $S_\theta(\omega_e) =$ spectral value of pitch motion in deg^2s

- **Maneuvering.zip** with XX-MAN.EXP, 6 ASCII files with the time histories of the manoeuvring experiments (where XX is the run number) in the next sequence:
  - Column 1: $t_m =$ time in integer minutes
  - Column 2: $t_s =$ additional time in integer seconds
  - Column 3: $h =$ keel clearance in m
  - Column 4: $V =$ ship speed in knots
  - Column 5: $\delta =$ rudder angle in degrees
  - Column 6: $\psi =$ heading in degrees
  - Column 7: $\dot{\psi} =$ rate of turn in deg/min
  - Column 8: $N =$ propeller rate in rpm
  - Column 9: $Q =$ torque in kNm
  - Column 10: $T =$ thrust in kN
  - Column 11: $V_{tw} =$ true wind speed in knots
  - Column 12: $\alpha_{tw} =$ true wind direction in degrees

  Note: -111 in these files means that the data concerned has not been determined at that time instant.

- **NavigationCharts.zip**, with Zsoft Paintbrush (pcx) files of 2 navigation charts (Puerto Cortes and Santo Thomas de Castilla) and 4 scanned plots of the paths over the ground during the manoeuvring experiments.

9 Appendix II: Overview of Containers at Deck

The next schemes show the available information about the number of containers at deck during the experiments, when sailing between the harbours mentioned. The schemes represent a top view of the ship, while the data in here represent the number of layers of 20 or 40 feet length containers at deck. One cell presents a number of stapled containers with length of 40 feet.

At run numbers 47 and 48-49 (so the second outward voyage), the numbers "1.5" represent a steel structure and two railway wagons as deck load between the containers. Its height varied between 1.00 and 3.75 meters. Unfortunately, at a few runs (numbers 13, 14, 15, 21 and 22) no deck load information has been recorded.

The draughts aft (T_A) and forward (T_F), measured in the harbours of departure and arrival respectively, are given in the schemes too.

Run 01 - 12:

2 2
2 2
2 2
2 2
3 3
2 2

T_A	T_F
(m)	(m)
8.80	8.70
8.73	8.31

Liverpool to Bridge Town

Crane	.	.	1	.	2 2	.	
1 1	2 1	2 2	2 2	.	3 3	1 1	2 1
.	2 2	2 2	2 2	.	3 3	2 1	2 2
1	2 2	2 2	2 2	.	3 3	2 1	2 2
1	. 2	1 1	1 2	2 2	2 2	. 1	2 2
2	. 2	1 1	1 2	2 2	2 2	. 1	2 2
2	1 2	. 2	2 2	2 2	2 2	. 1	2 2
.	2 2	2 3	2 2	.	3 3	2 2	2 2
1 2	2 2	2 2	2 2	.	2 3	2 2	2 2
1 1	2 1	2 2	2 2	. 1	2 2	2 .	2 2
Crane	.	.	. 1	.	2 2	.	

Run 13 - 15:

T_A	T_F
(m)	(m)
8.36	8.13
8.40	8.25

Bridge Town to Willemstad

Crane							
	Information not recorded						
Crane							

Run 16:

2 2
2 2
2 2
2 2
3 3
2 2

T_A (m)	T_F (m)
8.13	8.13
8.13	8.13

Oranjestad to Ponce

Crane	.	.	.	.	.	.	
1 1	.	2 2	2 2	.	. 1	1 1	2 .
. 1	.	. 2	2 2	2	1 1	2 1	2 2
.	.	1 2	2 2	2	1 2	2 1	2 2
2 2	.	2 2	2 2	2 2	1 1	. 1	2 2
2 1	.	2 2	1 2	2 2	1 1	. 1	2 2
2 2	.	. 2	2 2	2 2	1 1	. 1	2 2
. 2	.	. 1	2 2	2	2 2	2 2	2 2
1 2	.	. 1	2 2	2	2 2	1 2	2 2
1 1	.	. 2	2 2	. 1	2 2	2 .	2 2
Crane	.	.	.	.	.	.	

Run 17:

2 2
2 2
2 2
2 2
3 3
2 2

T_A (m)	T_F (m)
8.05	8.05
8.05	8.05

Ponce to Rio Haina

Crane	.	.	.	.	.	.	
1 .	.	2 2	2 2	.	. 1	1 1	2 .
. 1	.	. 2	2 2	1 1	. 1	2 2	2 2
. 1	.	2 2	2 2	.	1 2	2 2	2 2
2 2	.	2 2	2 2	2 2	2 .	. 1	2 2
2 2	.	2 2	2 2	2 2	2 .	. 1	2 2
2 2	.	1 2	2 2	2 2	2 .	. 1	2 2
2 2	.	. 2	2 2	.	2 2	. 2	2 2
2 .	.	. 1	2 2	.	2 2	1 1	. 2
2 2	.	. 2	2 2	.	2 2	. 2	. 2
Crane		.	.	.	.	.	

Run 18:

2 2
2 2
2 2
2 2
3 3
2 2

T_A (m)	T_F (m)
8.05	8.03
8.08	8.00

Rio Haina to Port au Prince

Crane	.	.	.	.	.	.	
. 1	.	2 2	2 2	.	2 2	1 1	2 .
.	.	. 2	2 2	1	2 2	1 2	2 2
.	.	2 2	2 2		2 2	1 2	2 2
2 2	.	2 2	2 2	2	2 2	.	2 2
2 2	.	2 2	2 2	2	2 2	.	2 2
2 2	.	1 2	2 2	2	2 2	.	2 2
2 2	2	. 2	2 2	.	2 2	.	2 2
2	2 1	. 2	2 2	.	2 2	.	1 2
2	.	. 2	2 2	.	2 2	2 .	. 2
crane	.	.	.	.	.	.	

Run 19 - 20:

.
.
.
.
.
.

T_A (m)	T_F (m)
7.34	7.29
7.42	7.26

Kingston to Puerto Cortes

crane	.	.	.	.	.	.	
.	.	2 2	.	.	2 2	.	.
.	.	. 1	.	.	2 2	. 2	1 2
.	.	2 2	.	.	2 2	. 2	2 2
2 2	.	2 2	. 2	. 2	2 2	.	2 2
2 2	.	2 2	1 2	1 2	2 2	.	2 2
2 2	.	2 2	2 2	2 2	2 2	.	2 2
2 2	2	2 2	.	.	2 2	.	.
2 .	2 1	2 2	.	.	2 2	.	.
2	.	2 2	.	.	1 2	.	. 2
crane	.	.	.	.	.	.	

Run 21 - 22:

T_A (m)	T_F (m)
7.42	7.26
7.42	7.26

Puerto Cortes to Sto Thomas de Castilla

crane							
		Information not recorded					
crane							

Run 23 - 25:

.
.
.
2
1
.

T_A (m)	T_F (m)
8.08	8.00
8.10	7.87

Santo Thomas de Castilla to Kingston

crane	.	.	.	.	.	.	
.	.	2 .	.	.	. 2	1 .	.
.	.	2 .	.	.	. 2	2 1	1 .
.	.	2 .	.	.	. 2	2 1	1 .
.	.	2 .	.	1 2	2 2	.	.
.	.	2 1	.	2 2	2 2	.	.
.	. 1	2 1	.	2 2	2 2	.	.
2	.	2 .	.	2	2 2	1 .	.
2	.	2 2	.	2	2 2	1 .	.
2	.	2 2	.	2	1 2	.	.
crane	.	.	.	.	.	.	

Run 26 - 46:

4 4
4 4
4 4
2
3
.

T_A (m)	T_F (m)
8.10	7.87

Kingston to Amsterdam

crane	.	.	.	.	3 3	3 .	
.	.	2 2	2 .	2 2	3 3	3 2	2 .
.	.	2 2	2 .	2 2	3 3	3 2	2 .
.	.	2 2	2 .	2 2	3 3	3 2	2 .
.	.	2 2	2 1	1 2	2 2	. 3	.
.	.	2 2	2 1	2 2	2 2	. 3	.
.	. 1	2 2	2 .	2 2	2 2	. 3	.
2	.	2 2	2 .	2	2 2	2 3	2 .
2	.	2 2	2 .	2	2 2	2 3	2 .
2	.	2 2	2 .	2	2 2	2 3	2 .
crane	.	.	.	.	.	. 3	

Run 47:

3 2
3 2
2 3
3
3
3

T_A (m)	T_F (m)
8.95	8.95

Liverpoool to Bridge Town

crane	.	.	2 2	2 2	2 .	2 .	
1 2	2	1 .	1.5	2 2	2 2	2 2	2 2
2	2 2	2 .	1.5	2 2	2	2 1	2 2
1 1	2 2	1 .	1.5	1 2	2	2 2	2 2
2 2	2 2	2 2	1.5	2 2	2	2 2	2 2
2 2	2	2 1	1.5	1 2	1 2	2 2	2 2
2 2	2	2 1	1.5	2	2	2 1	2 2
2 2	2	2 1	1.5	2 2	2	2 2	2 3
2 2	2 2	2 .	1.5	2 2	2 2	2 2	2 3
2 1	2 2	2 .	1.5	2 2	2 2	2 2	2 3
Crane	.	.	2 2	2 2	.	2 .	

Run 48 - 49:

3 2
3 2
2 3
3
3
3

T_A (m)	T_F (m)
8.88	8.88
8.75	8.75

Bridge Town to Willemstad

crane	.	.	.	2 2	2 .	2 .	
1 2	2	1 .	1.5	1 2	2 2	2 2	2 2
2	2 2	2 .	1.5	1 2	2	2 1	2 2
1 1	2 2	1 .	1.5	2 2	2	2 2	2 2
2 2	2 2	2 2	1.5	2 2	2	2 2	2 2
2 2	2	2 1	1.5	2 2	1 2	2 2	2 2
2 2	2	2 1	1.5	2	2	2 1	2 2
2 2	2	2 1	1.5	2 2	2	2 2	2 3
2 2	2 2	2 .	1.5	2 2	2 2	2 2	2 3
2 1	2 2	2 .	1.5	2 2	2 2	2 2	2 3
Crane	.	.	.	1	.	2 .	

Run 50 - 69:

3	3
3	3
3	2
3	3
2	3
4	3

T_A (m)	T_F (m)
9.42	9.30
9.30	9.24

Liverpool to Bridge Town

crane	.	2 3	2 2	2 2	.	2 .	
2 2	2 2	2 3	2 2	2 2	2 2	2 3	2 3
2 2	2 2	2 3	2 2	3 2	2 2	2 3	3 3
2 2	1 1	2 3	2 2	3 2	2 2	2 3	3 3
2 2	2 2	2 2	2 2	2 2	2 2	3 3	3 3
2 2	2 2	3 2	2 2	2 2	2 3	2 3	3 3
1 1	2 2	2 2	2 2	2 2	2 2	2 3	3 3
2 1	2 2	2 3	2 2	2 2	2 3	3 3	3 3
2 2	2 2	2 3	2 2	2 2	2 2	2 3	3 3
2 2	2 2	2 3	2 2	2 2	2 2	2 3	2 3
crane	.	2 2	2 2	2 2	. 2	2 2	

Run 70 - 78:

3	3
3	3
3	2
3	3
2	3
4	3

T_A (m)	T_F (m)
9.31	9.20
9.33	9.13

Bridge Town to Willemstad

Crane	.	.	. 2	2 2	.	2 .	
2 2	2 2	2 2	2 2	2 2	2 2	2 3	2 3
2 2	2 2	2 2	2 2	3 2	2 2	2 3	3 3
2 2	1 1	2 2	2 2	3 2	2 2	2 3	3 3
2 2	2 2	2 2	2 2	2 2	2 2	3 3	3 3
2 2	2 2	2 2	2 2	2 2	2 3	2 3	3 3
1 1	2 2	2 2	2 2	2 2	2 2	2 3	3 3
2 2	2 2	2 2	2 2	2 2	2 3	3 3	3 3
2 2	2 2	2 2	2 2	2 2	2 2	2 3	3 3
2 2	2 2	2 2	2 2	2 2	2 2	2 3	2 3
crane	.	.	.	2 2	. 2	2 2	

10 Appendix III: Tables with 1979 Weather Forecasts

Wave and wind forecasts at grid point A-24

47.9 N, 23.8 W		01-01-1979, 12:00 GMT, τ = -24 h						V_w = 9 kn, μ_w = 108^0	
	μ^* =	089^0	059^0	029^0	359^0	239^0	209^0	179^0	119^0
T (s)	total								
22.5									
20.0									
18.0	3	0	0	0	0	1	1	0	0
16.4	9	0	0	0	2	5	0	0	0
15.0	26	0	3	5	4	9	0	0	0
13.8	62	0	18	19	4	11	5	0	0
12.4	123	0	36	46	4	11	12	9	0
10.9	105	0	44	54	1	0	3	0	0
9.7	132	0	27	44	0	0	59	0	0
8.6	96	0	35	57	0	0	1	0	0
7.5	86	0	13	35	0	0	36	0	0
6.3	70	0	0	36	0	0	32	0	0
4.8	0	0	0	0	0	0	0	0	0
3.2	8	2	1	0	0	0	0	0	2
Total	720								
Total	687	2	177	296	15	37	149	9	2

$H_{1/3}$ = 10.82 ft = 3.30 m

Wave and wind forecasts at grid point A-00

47.9 N, 23.8 W		01-01-1979, 12:00 GMT, τ = 0 h						V_w = 7 kn, μ_w = 235^0	
	μ^* =	059^0	029^0	359^0	299^0	269^0	239^0	209^0	179^0
T (s)	total								
22.5									
20.0									
18.0	3	0	0	0	0	0	1	1	0
16.4	11	0	0	1	0	0	4	1	0
15.0	19	0	0	1	0	0	9	3	2
13.8	50	4	14	0	0	1	12	9	3
12.4	106	4	30	0	0	0	33	27	8
10.9	49	2	30	0	0	0	12	0	2
9.7	73	0	18	0	0	0	13	28	11
8.6	120	0	78	0	0	0	4	19	16
7.5	95	0	53	0	0	0	4	25	10
6.3	32	0	0	0	0	0	0	32	0
4.8	0	0	0	0	0	0	0	0	0
3.2	2	0	0	0	0	0	0	0	0
Total	560								
Total	525	10	223	2	0	1	92	145	52

$H_{1/3}$ = 9.57 ft = 2.92 m

Wave and wind forecasts at grid point B-00

30.5 N, 44.1 W — 04-01-1979, 12:00 GMT, τ = 0 h — V_w = 27 kn, μ_w = 091^0

	μ^* =	168^0	138^0	108^0	078^0	048^0	018^0	348^0		
T (s)	total									
22.5										
20.0										
18.0										
16.4	4	0	0	0	0	1	0	0		
15.0	14	0	0	3	3	2	1	1		
13.8	52	0	0	18	12	12	6	0		
12.4	184	0	0	16	64	75	21	3		
10.9	248	0	9	45	88	75	26	0		
9.7	224	0	15	45	77	61	22	0		
8.6	256	0	26	53	79	62	31	0		
7.5	172	11	20	35	45	35	21	0		
6.3	178	16	23	34	39	33	28	0		
4.8	86	0	10	18	20	20	14	0		
3.2	22	0	3	5	5	3	2	0		
Total	1440									
Total	1392	27	106	272	432	379	172	4		

$H_{1/3}$ = 15.24 ft = 4.65 m

Wave and wind forecasts at grid point C-24

29.7 N, 47.6 W — 04-01-1979, 12:00 GMT, τ = -24 h — V_w = 36 kn, μ_w = 075^0

	μ^* =	136^0	106^0	076^0	046^0	016^0	346^0	316^0		
T (s)	total									
22.5										
20.0										
18.0										
16.4	93	0	5	19	43	17	5	0		
15.0	246	0	15	66	104	44	13	0		
13.8	263	0	20	85	90	50	15	0		
12.4	599	2	51	173	181	142	45	0		
10.9	467	2	44	125	143	111	38	0		
9.7	335	0	36	83	100	78	30	2		
8.6	312	0	40	75	89	71	32	0		
7.5	182	0	26	42	47	39	25	0		
6.3	165	0	29	38	41	35	18	0		
4.8	87	0	13	20	21	18	11	0		
3.2	32	0	3	6	8	7	4	0		
Total	2781									
Total	2735	4	282	732	867	612	236	2		

$H_{1/3}$ = 21.14 ft = 6.44 m

Wave and wind forecasts at grid point D-24

30.1 N, 57.2 W

02-02-1979, 12:00 GMT, τ = -24 h

V_w = 29 kn, μ_w = 275^0

	μ^* =	251^0	221^0	191^0	011^0	341^0	311^0	281^0		
T (s)	total									
22.5	1	0	0	0	0	0	1	0		
20.0	56	0	0	0	0	8	32	14		
18.0	270	0	0	0	0	68	139	60		
16.4	294	0	0	0	0	27	184	80		
15.0	303	30	13	0	0	26	157	77		
13.8	312	64	20	0	0	28	123	73		
12.4	629	143	81	0	0	13	194	194		
10.9	480	134	89	7	0	0	114	131		
9.7	337	93	67	2	0	0	79	92		
8.6	294	84	68	0	0	0	55	83		
7.5	164	45	39	0	0	0	32	45		
6.3	159	40	37	0	0	8	30	40		
4.8	87	21	18	0	0	8	15	21		
3.2	29	6	4	0	0	3	5	7		
Total	3415									
Total	3371	660	436	9	0	189	1160	917		

$H_{1/3}$ = 23.44 ft = 7.14 m

Wave and wind forecasts at grid point E-24

31.1 N, 53.7 W

02-02-1979, 12:00 GMT, τ = -24 h

V_w = 31 kn, μ_w = 259^0

	μ^* =	253^0	223^0	193^0	163^0	343^0	313^0	283^0		
T (s)	total									
22.5										
20.0	19	3	0	0	0	0	5	9		
18.0	159	27	0	0	0	0	44	85		
16.4	178	28	27	0	0	1	40	77		
15.0	219	66	28	0	0	1	27	93		
13.8	277	102	34	0	0	1	35	101		
12.4	570	195	119	0	1	6	28	216		
10.9	444	157	125	0	0	3	16	138		
9.7	287	104	85	0	0	0	3	92		
8.6	284	89	77	31	0	0	0	84		
7.5	168	47	44	25	0	0	4	45		
6.3	167	40	39	25	0	0	19	40		
4.8	83	21	17	10	0	0	12	19		
3.2	29	7	5	3	0	0	4	6		
Total	2884									
Total	2835	886	600	94	1	12	237	1005		

$H_{1/3}$ = 21.33 ft = 6.50 m

Wave and wind forecasts at grid point F-00										
32.7 N, 46.6 W			02-02-1979, 12:00 GMT, τ = 0 h					V_w = 44kn, μ_w = 230^0		
	μ^* =	257^0	227^0	197^0	167^0	137^0	317^0	287^0		
T (s)	total									
22.5	25	6	3	1	0	0	0	10		
20.0	270	84	67	27	7	0	0	81		
18.0	757	238	217	104	16	0	6	170		
16.4	931	279	307	128	41	1	0	170		
15.0	898	26 7	294	135	25	1	4	166		
13.8	785	223	267	106	33	1	1	148		
12.4	1309	316	369	242	109	7	21	239		
10.9	752	194	190	147	55	0	3	158		
9.7	453	116	120	79	36	0	0	98		
8.6	382	95	95	70	33	0	0	85		
7.5	204	50	50	38	19	0	0	45		
6.3	177	43	42	32	17	0	0	39		
4.8	96	22	25	20	12	0	0	13		
3.2	40	9	10	8	4	0	0	5		
Total	6879									
Total	7014	1942	2056	1137	407	10	35	1427		
$H_{1/3}$ = 33.69 ft = 10.27 m										

11 Appendix IV: Figures with Spectral Data

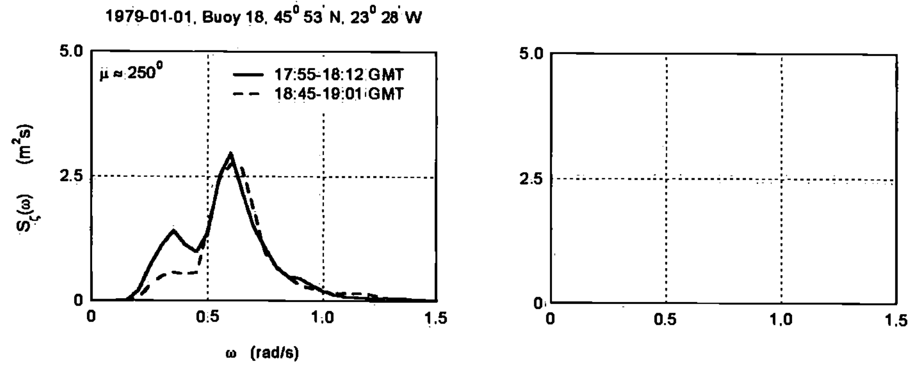

Figure 54: Measured wave spectra at 01-01-1979
(Data file: BUOY-08.EXP)

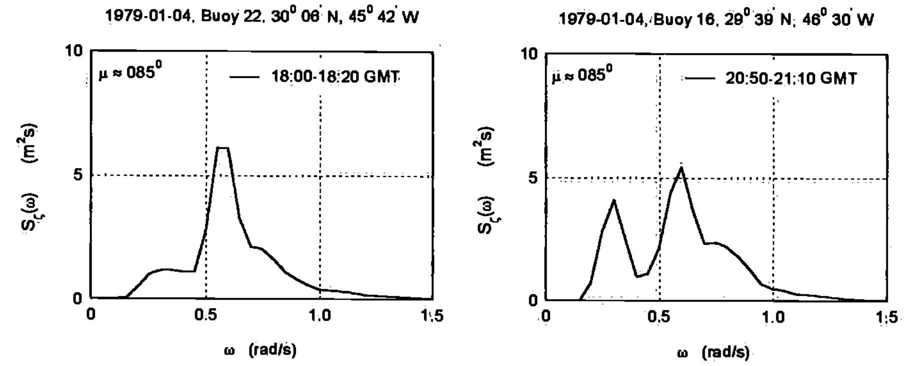

Figure 55: Measured wave spectra at 04-01-1979
(Data files: BUOY-22.EXP and BUOY-16.EXP)

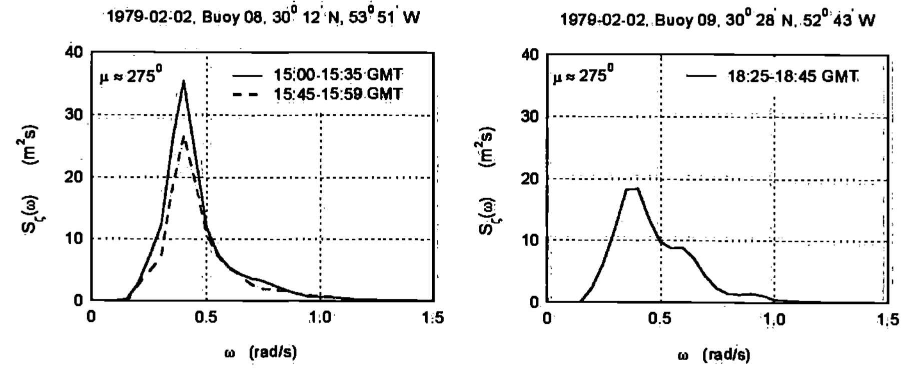

Figure 56: Measured wave spectra at 02-02-1979
(Data files: BUOY-08.EXP and BUOY-09.EXP)

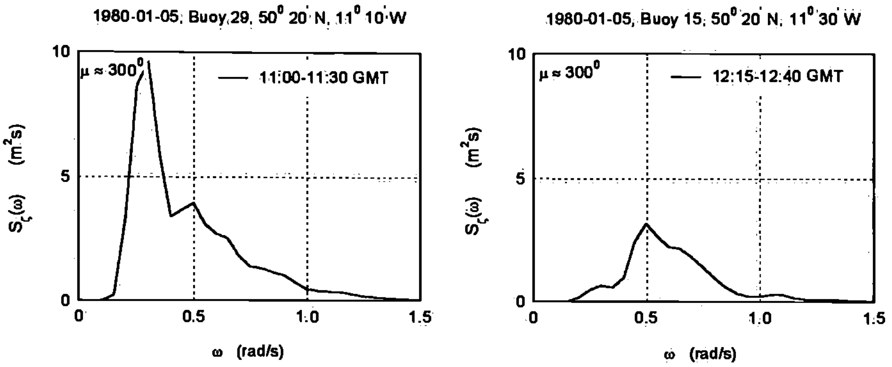

Figure 57: Measured wave spectra at 05-01-1980
(Data files: BUOY-29.EXP and BUOY-15.EXP)

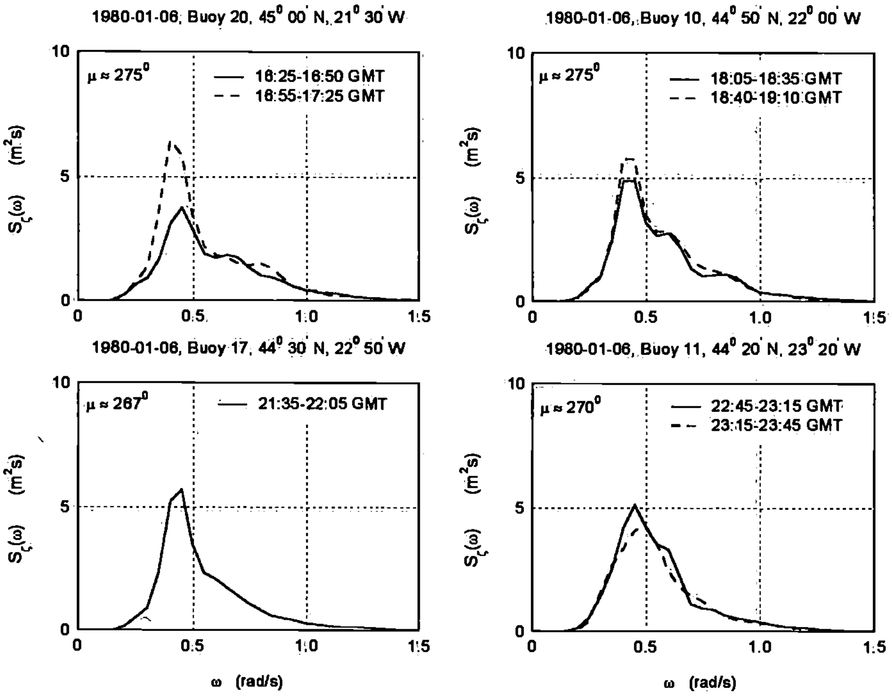

Figure 58: Measured wave spectra at 06-01-1980
(Data files: BUOY-20.EXP, BUOY-10.EXP, BUOY-17.EXP and BUOY-11.EXP)

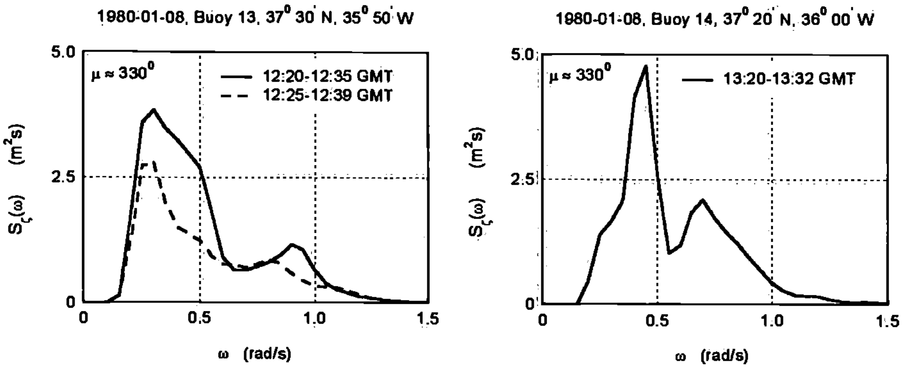

Figure 59: Measured wave spectra at 08-01-1980
(Data files: BUOY-13.EXP and BUOY-14.EXP)

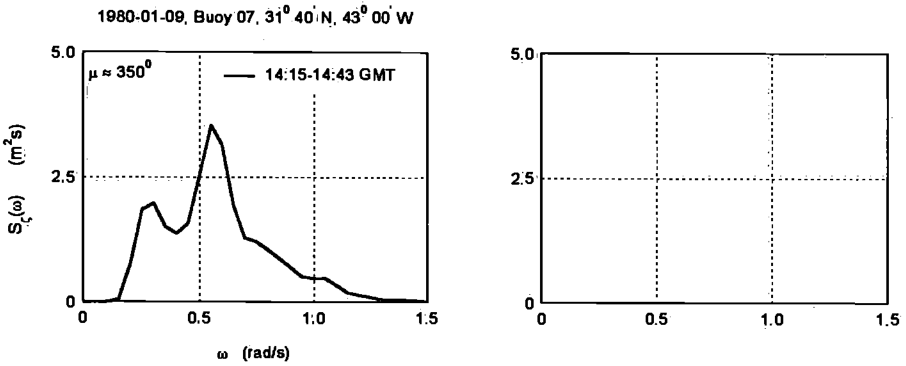

Figure 60: Measured wave spectra at 09-01-1980
(Data file: BUOY-07.EXP)

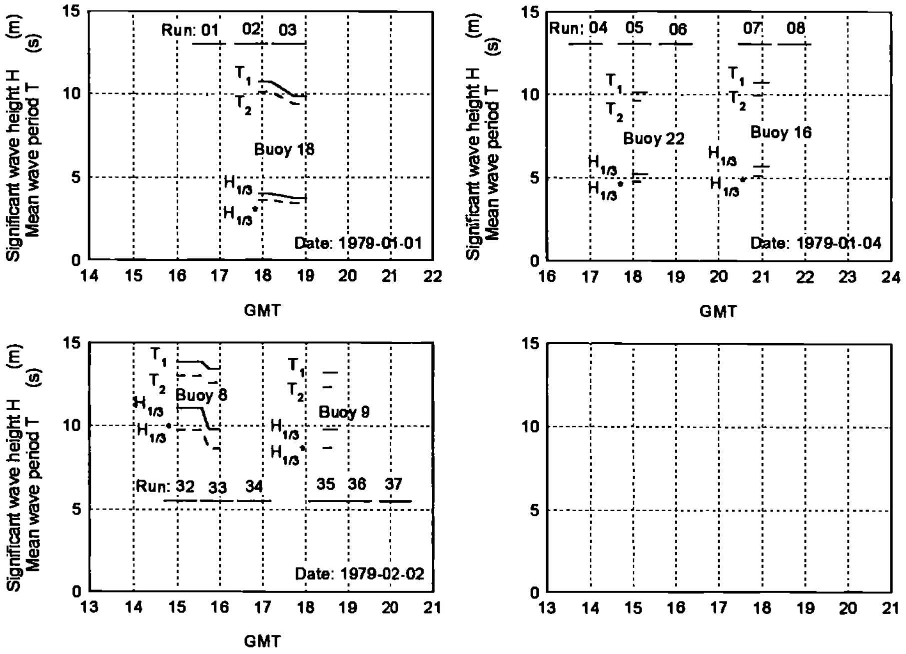

Figure 61: Significant wave heights and mean wave periods of 1979 experiments

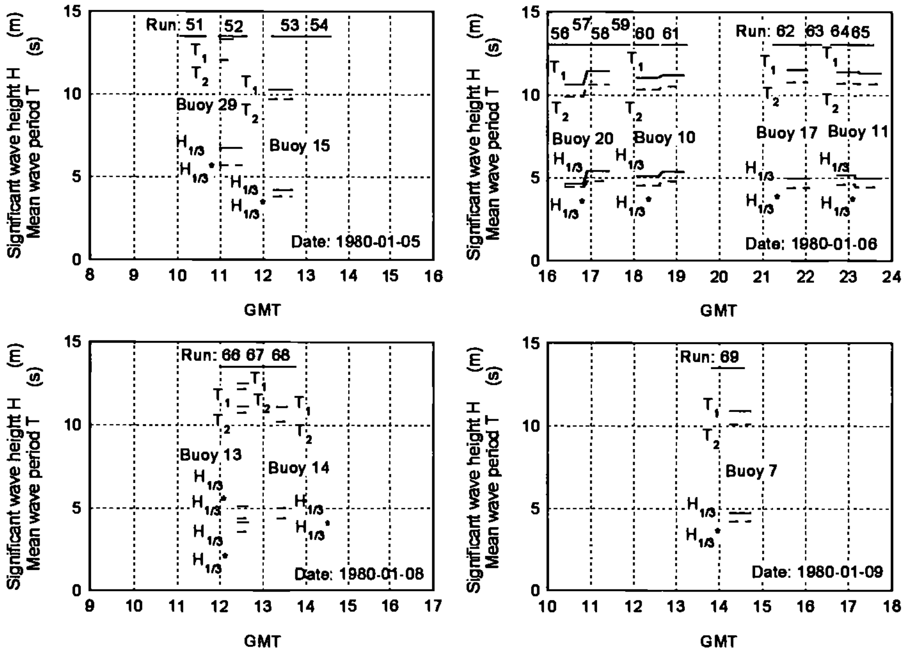

Figure 62: Significant wave heights and mean wave periods of 1980 experiments

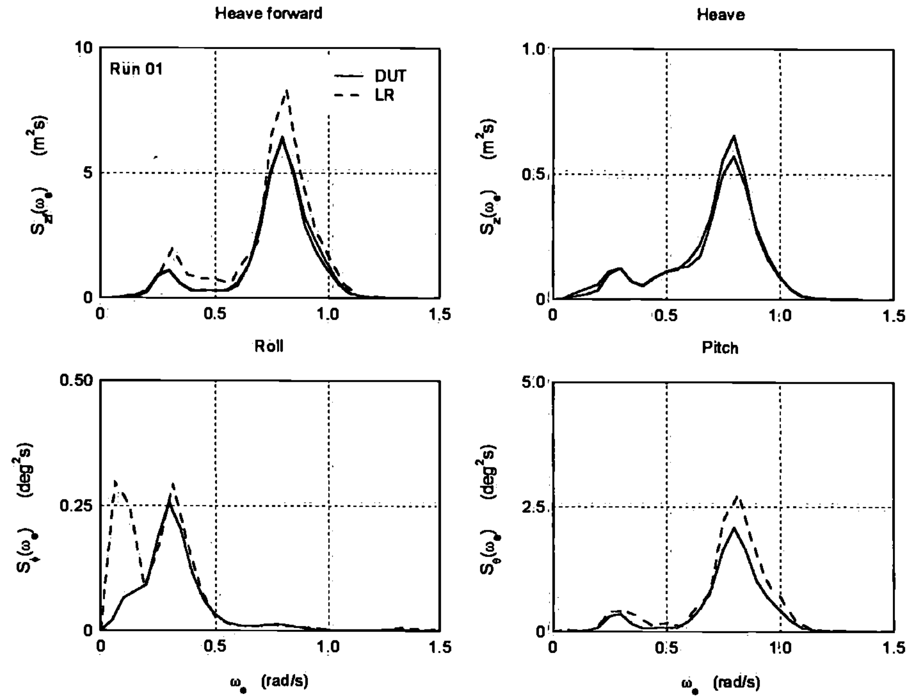

Figure 63: Measured ship motion spectra during run 01
(Data files: 01-DUT.EXP and 01-LR.EXP)

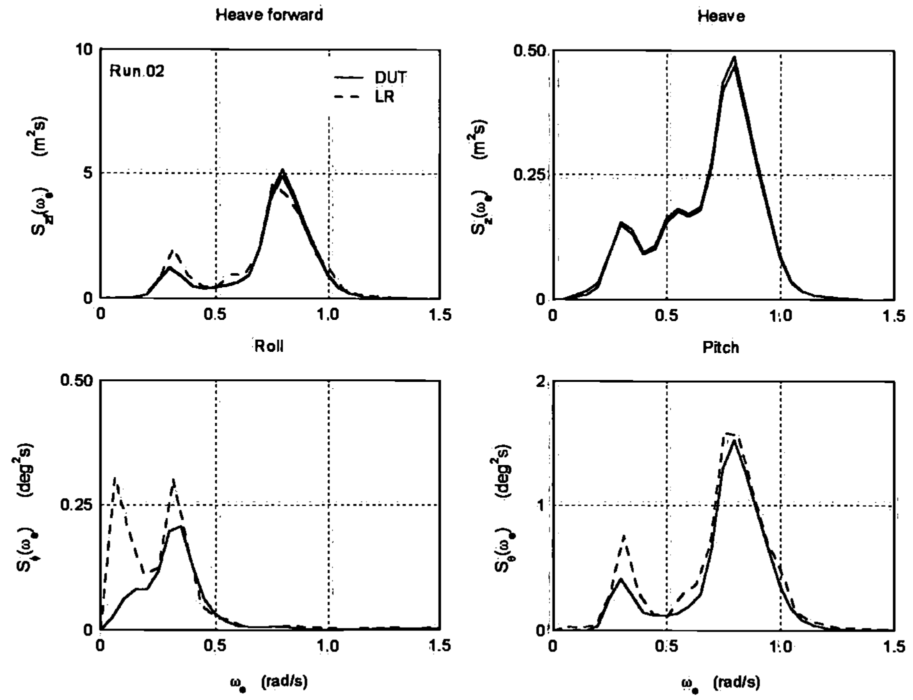

Figure 64: Measured ship motion spectra during run 02
(Data files: 02-DUT.EXP and 02-LR.EXP)

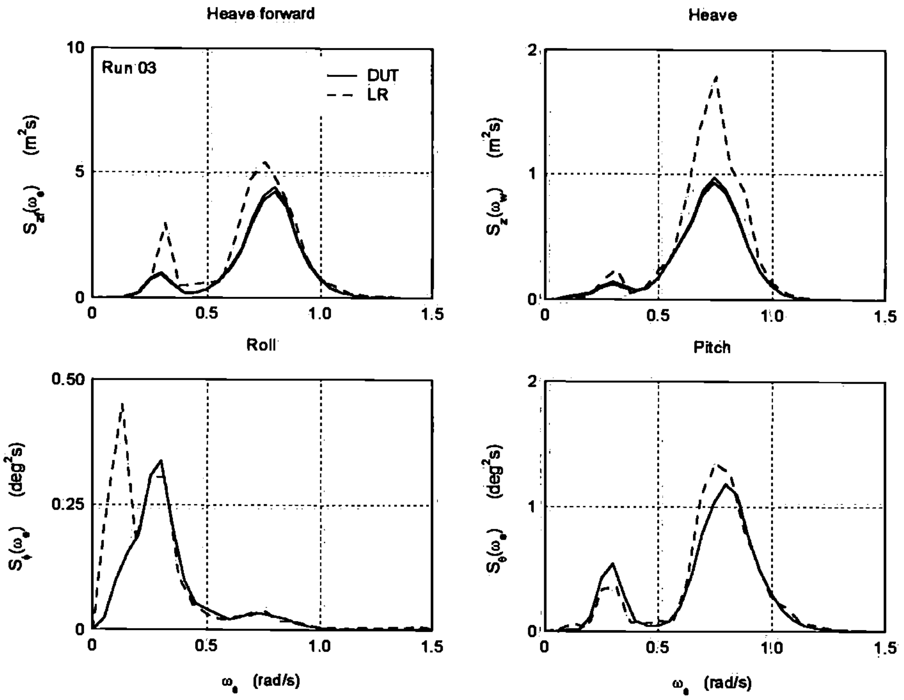

Figure 65: Measured ship motion spectra during run 03
(Data files: 03-DUT.EXP and 03-LR.EXP)

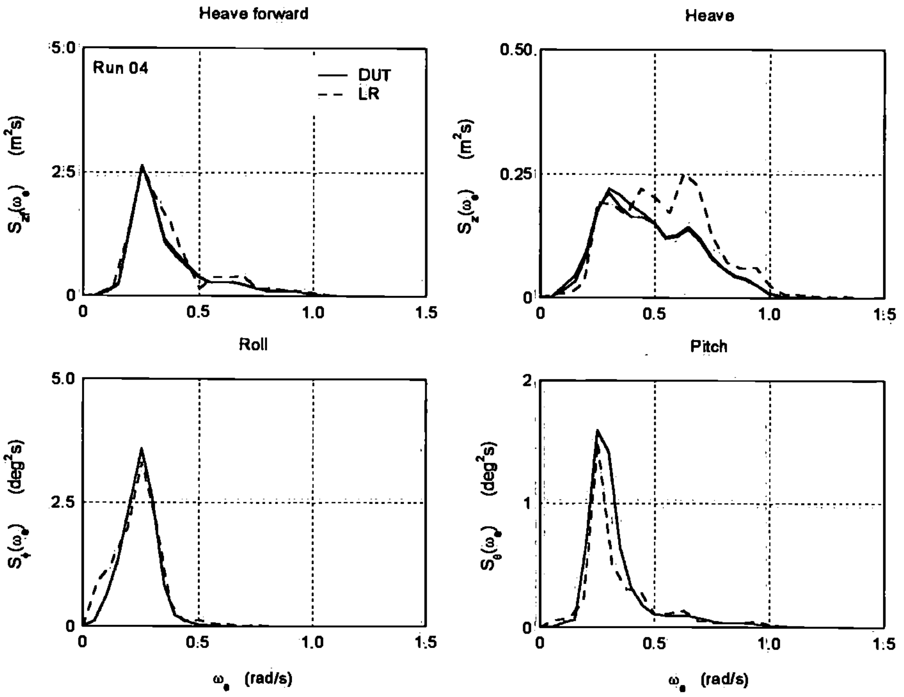

Figure 66: Measured ship motion spectra during run 04
(Data files: 04-DUT.EXP and 04-LR.EXP)

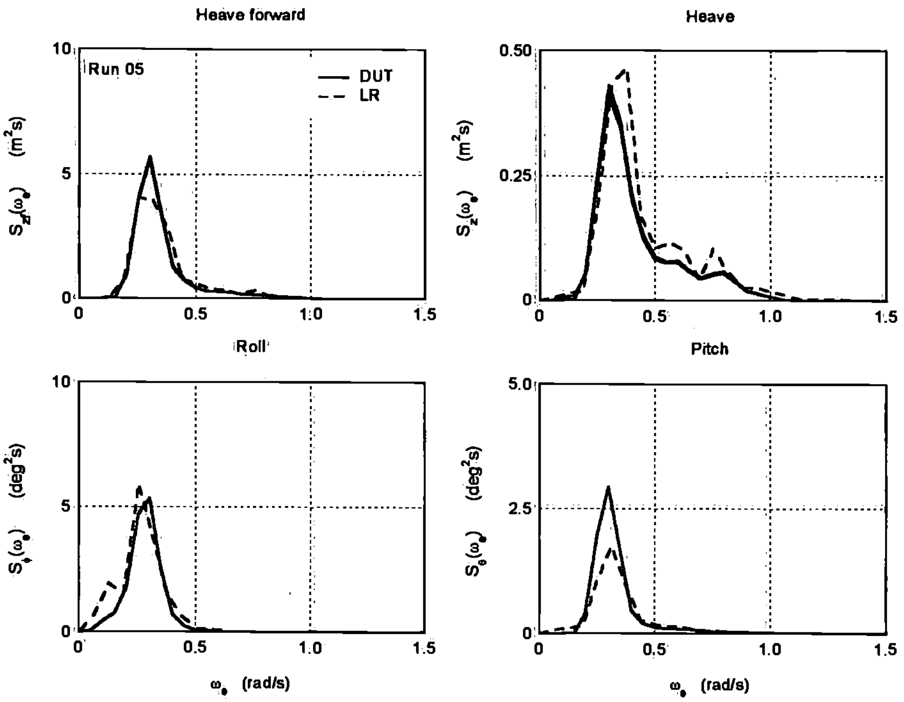

Figure 67: Measured ship motion spectra during run 05 (Data files: 05-DUT.EXP and 05-LR.EXP)

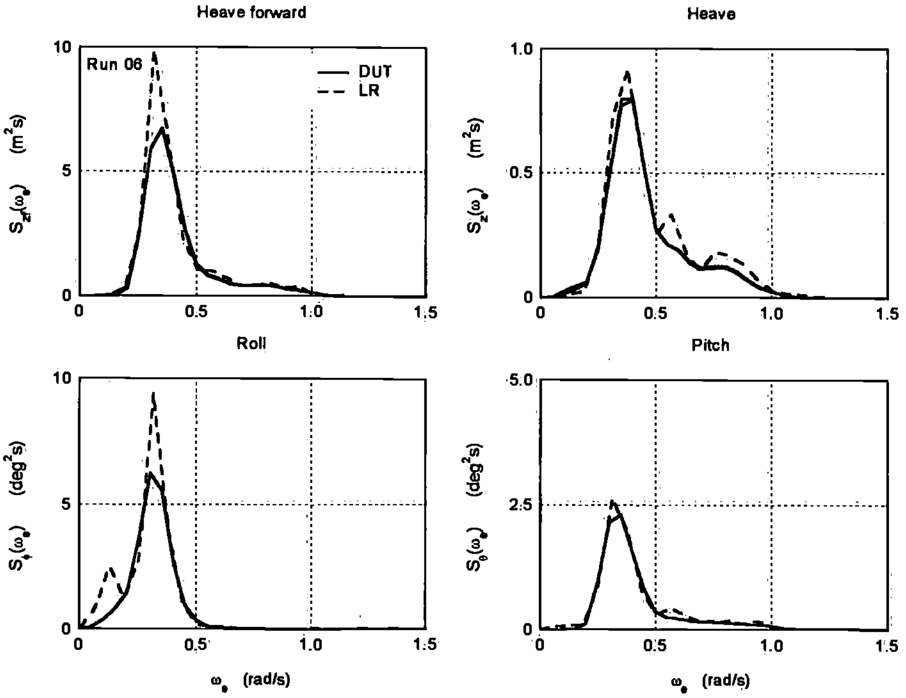

Figure 68: Measured ship motion spectra during run 06 (Data files: 06-DUT.EXP and 06-LR.EXP)

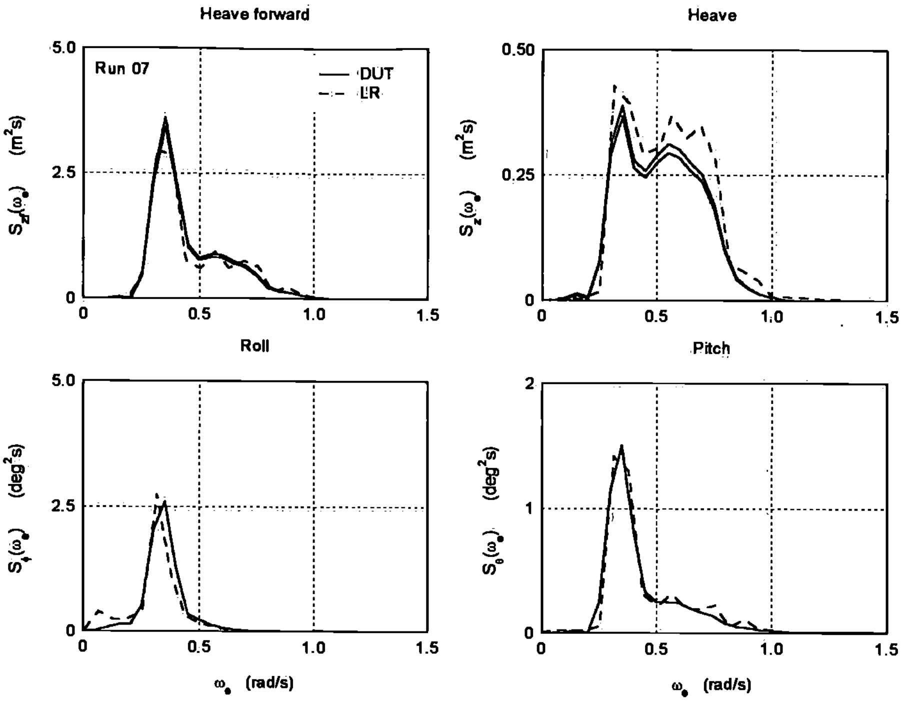

Figure 69: Measured ship motion spectra during run 07
(Data files: 07-DUT.EXP and 07-LR.EXP)

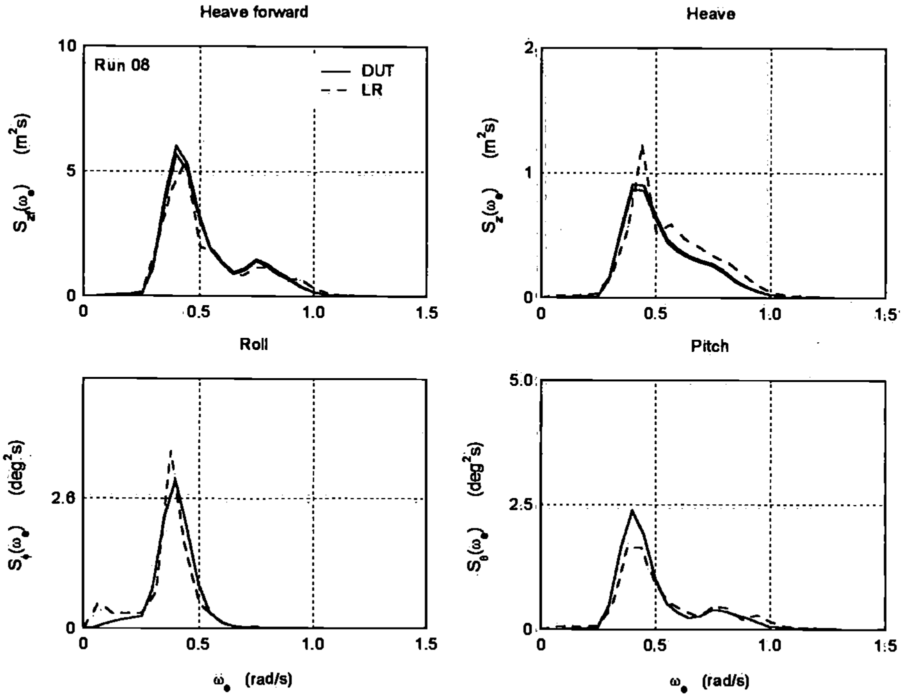

Figure 70: Measured ship motion spectra during run 08
(Data files: 08-DUT.EXP and 08-LR.EXP)

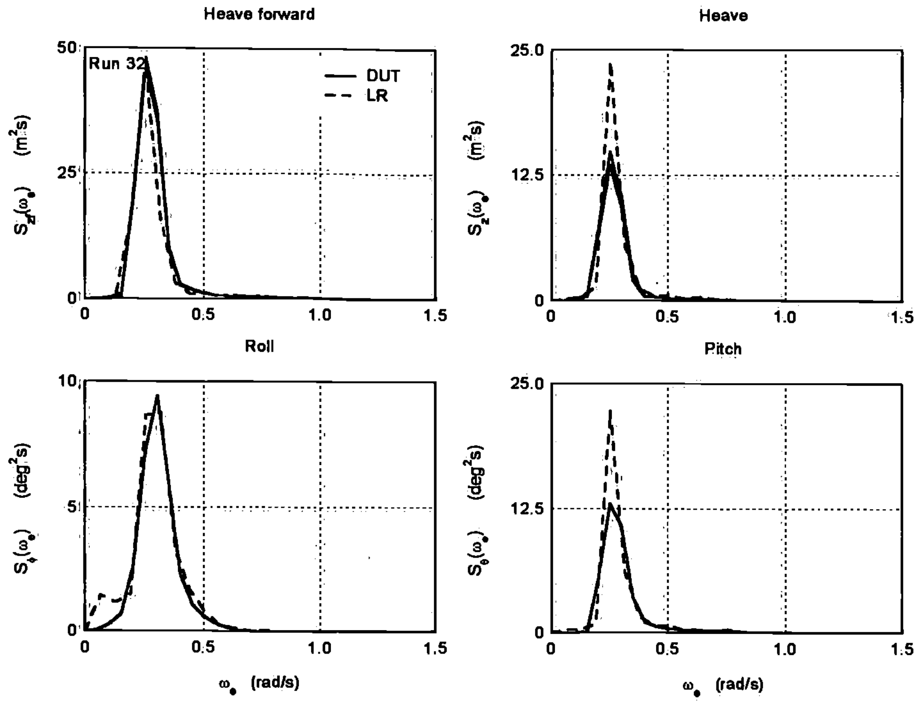

Figure 71: Measured ship motion spectra during run 32
(Data files: 32-DUT.EXP and 32-LR.EXP)

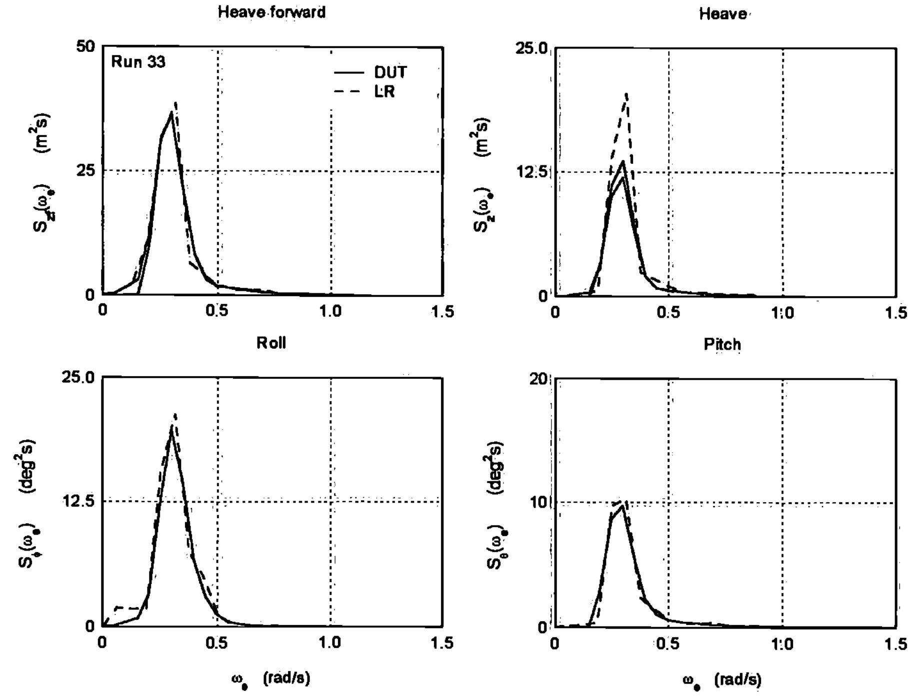

Figure 72: Measured ship motion spectra during run 33
(Data files: 33-DUT.EXP and 33-LR.EXP)

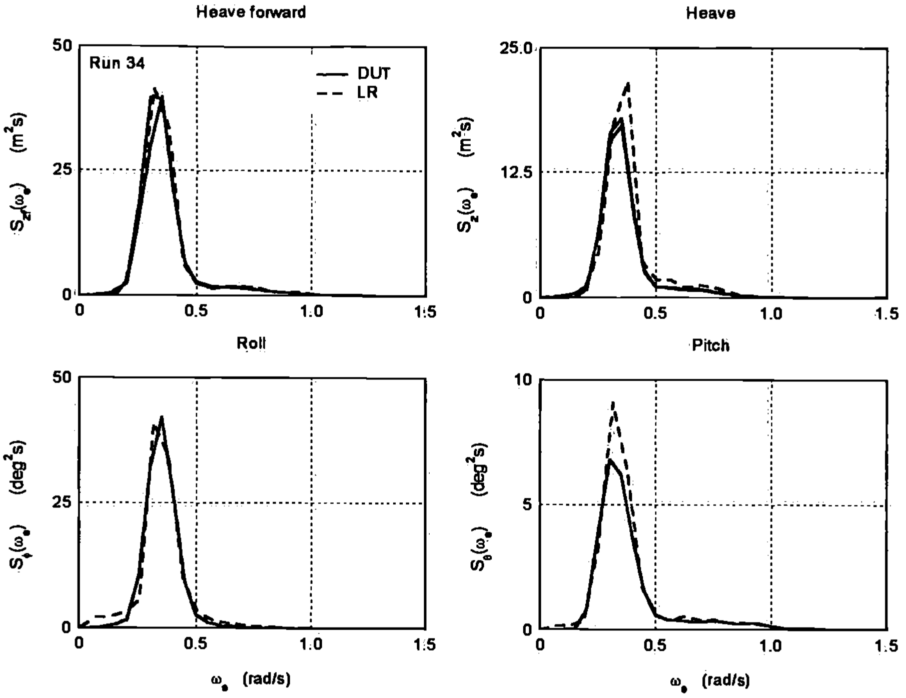

Figure 73: Measured ship motion spectra during run 34 (Data files: 34-DUT.EXP and 34-LR.EXP)

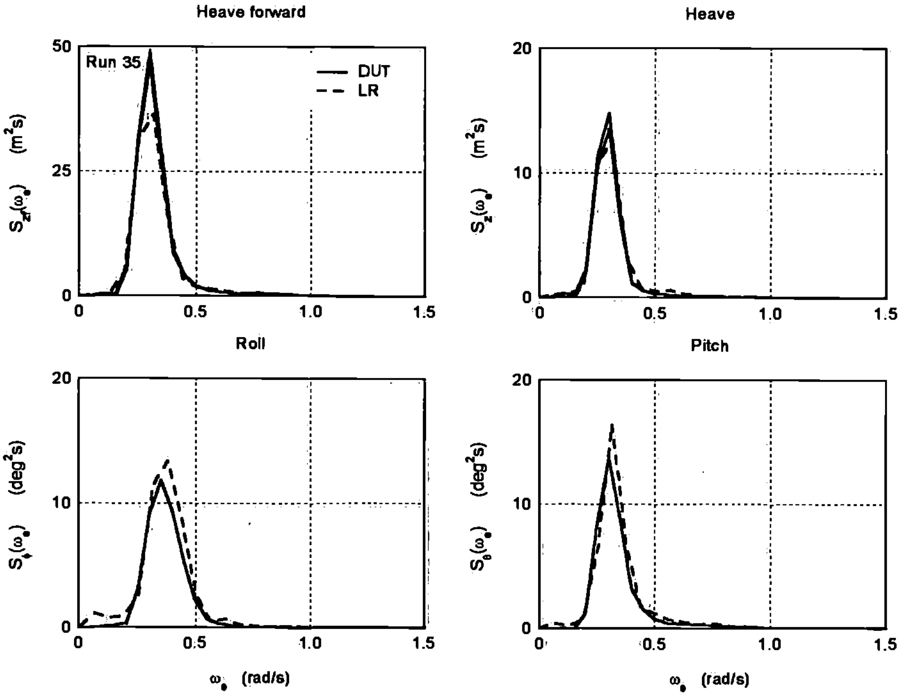

Figure 74: Measured ship motion spectra during run 35 (Data files: 35-DUT.EXP and 35-LR.EXP)

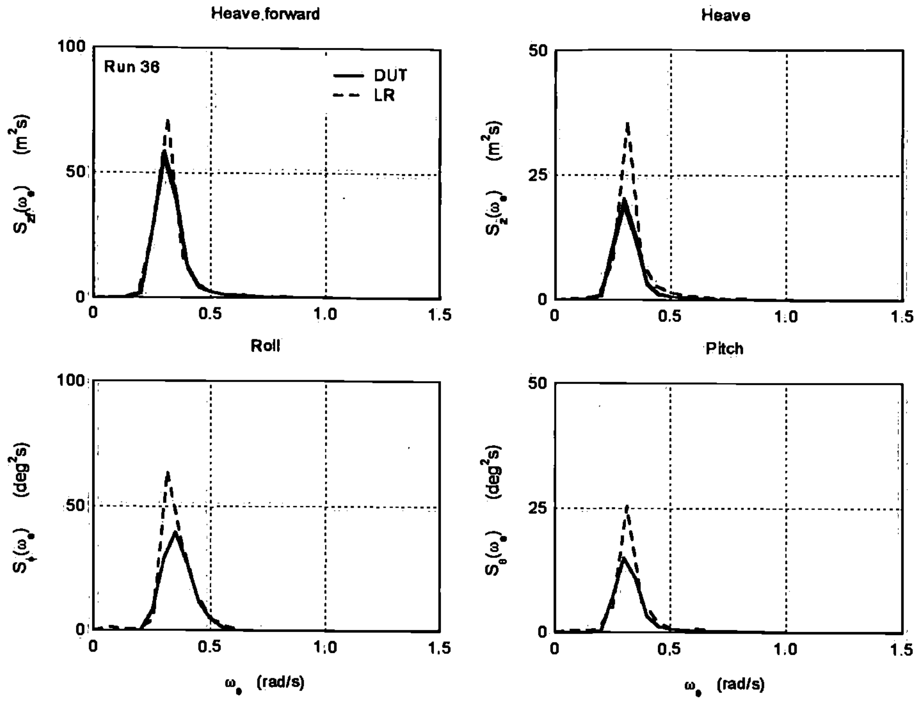

Figure 75: Measured ship motion spectra during run 36

(Data files: 36-DUT.EXP and 36-LR.EXP)

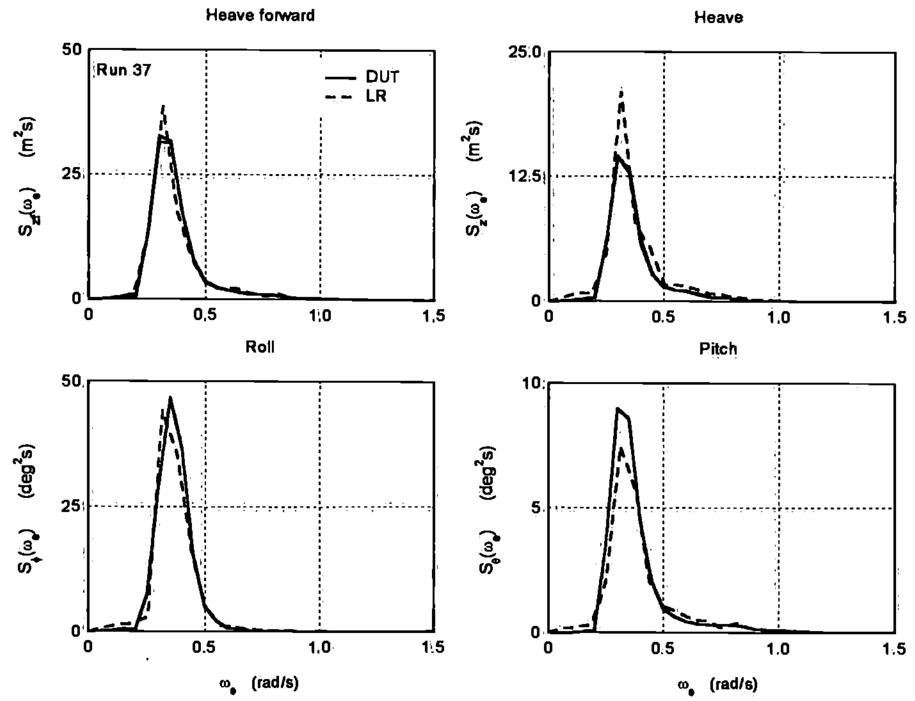

Figure 76: Measured ship motion spectra during run 37

(Data files: 37-DUT.EXP and 37-LR.EXP)

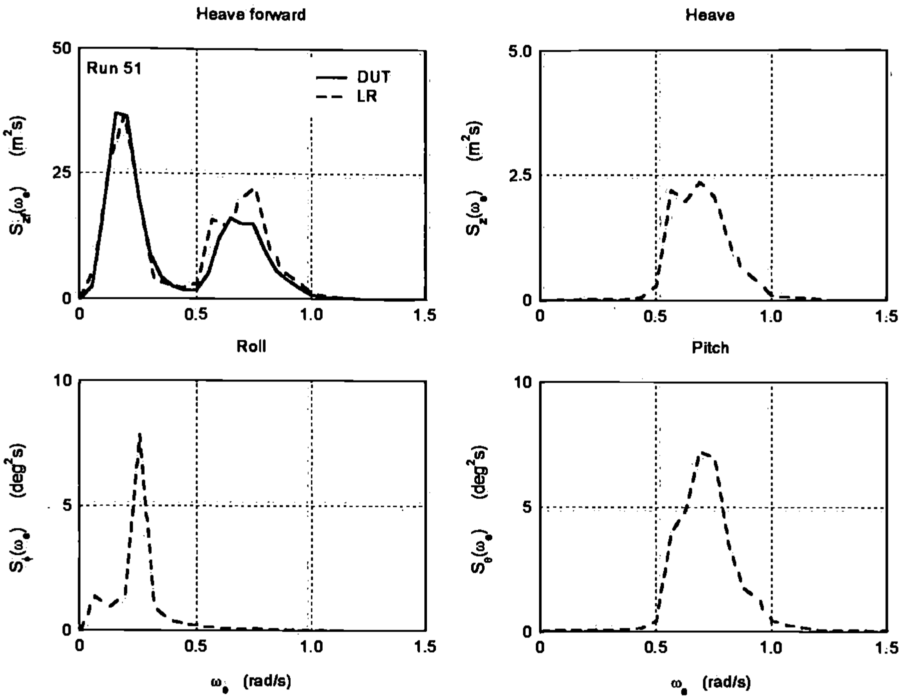

Figure 77: Measured ship motion spectra during run 51 (Data files: 51-DUT.EXP and 51-LR.EXP)

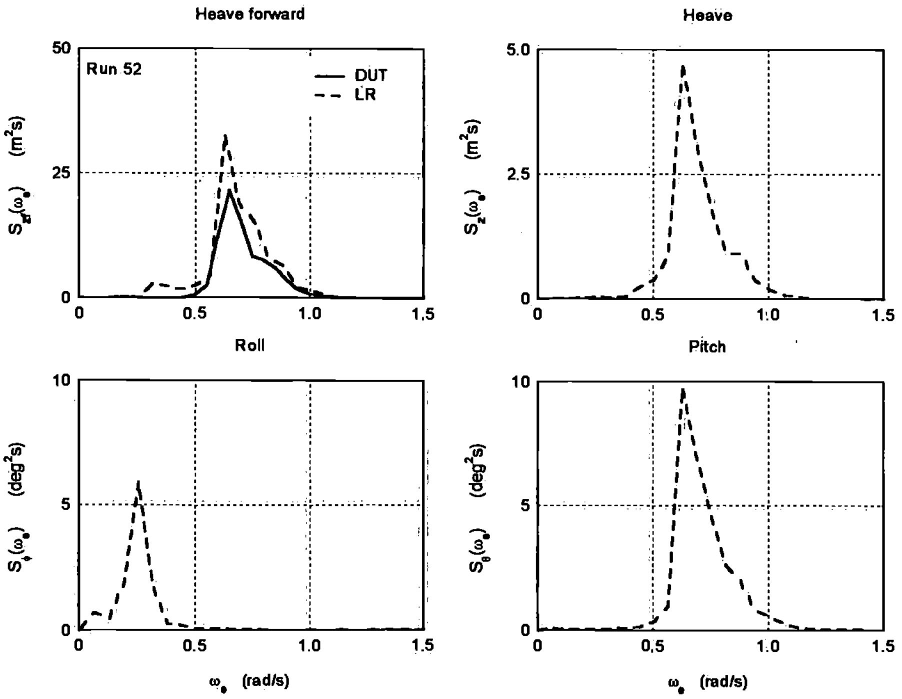

Figure 78: Measured ship motion spectra during run 52 (Data files: 52-DUT.EXP and 52-LR.EXP)

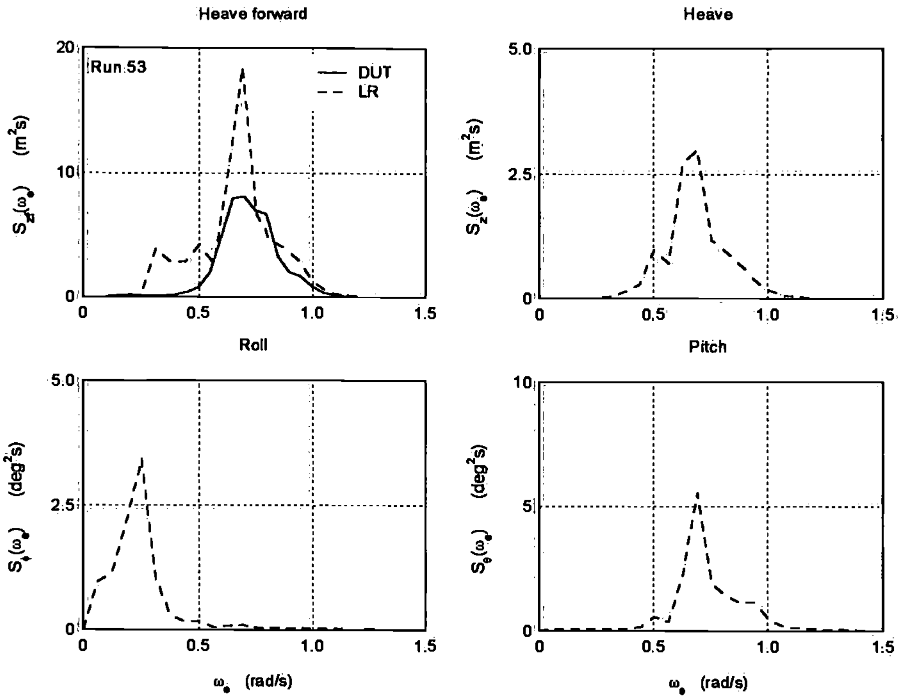

Figure 79: Measured ship motion spectra during run 53
(Data files: 53-DUT.EXP and 53-LR.EXP)

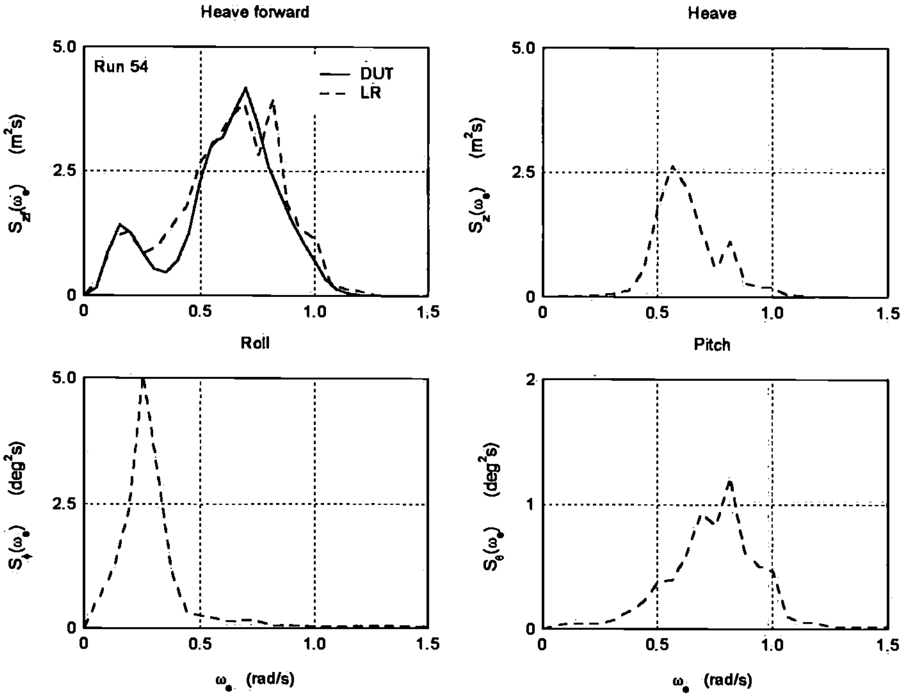

Figure 80: Measured ship motion spectra during run 54
(Data files: 54-DUT.EXP and 54-LR.EXP)

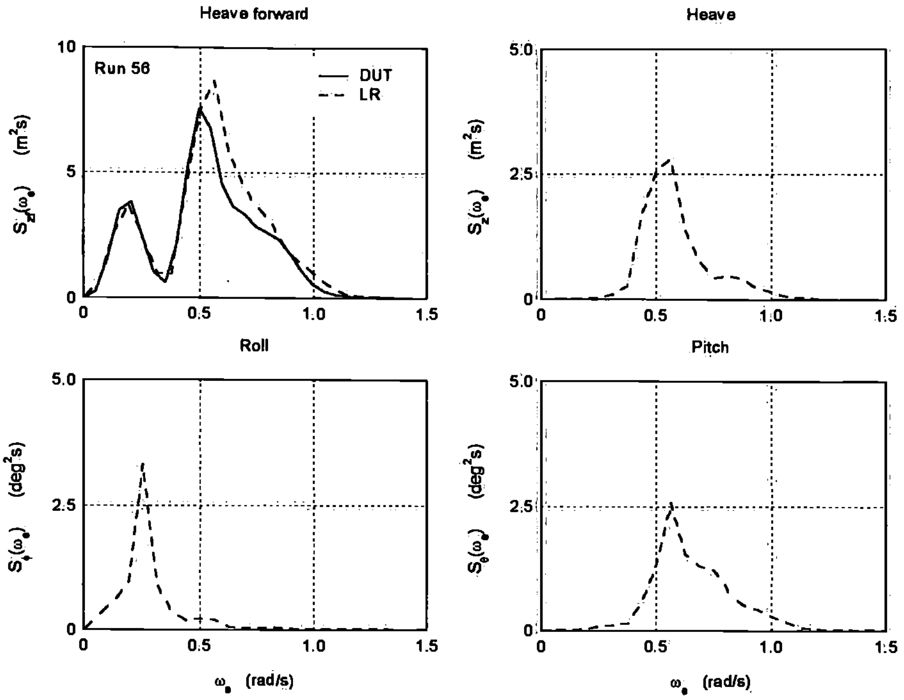

Figure 81: Measured ship motion spectra during run 56
(Data files: 56-DUT.EXP and 56-LR.EXP)

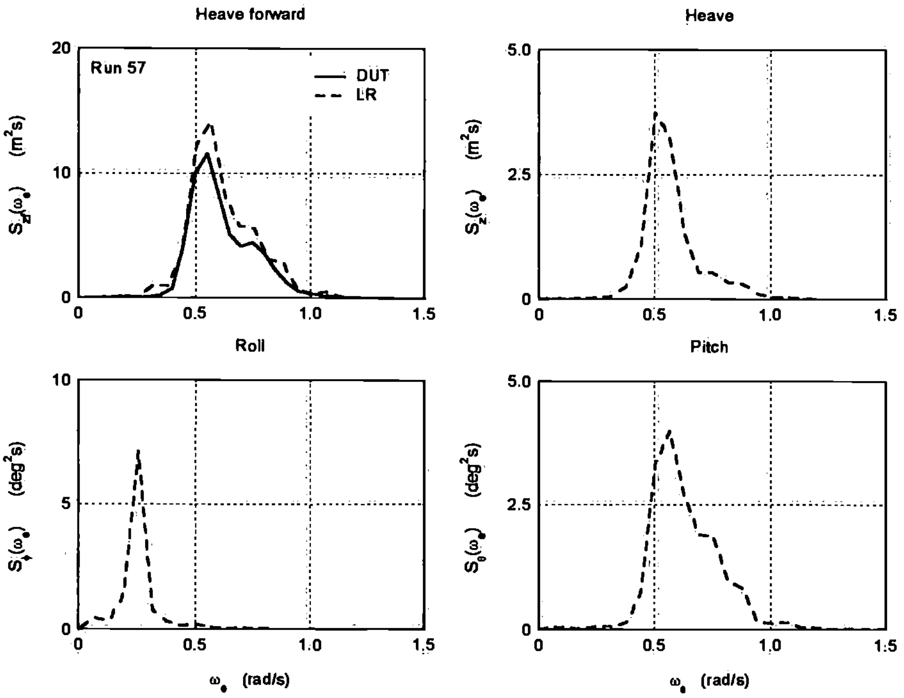

Figure 82: Measured ship motion spectra during run 57
(Data files: 57-DUT.EXP and 57-LR.EXP)

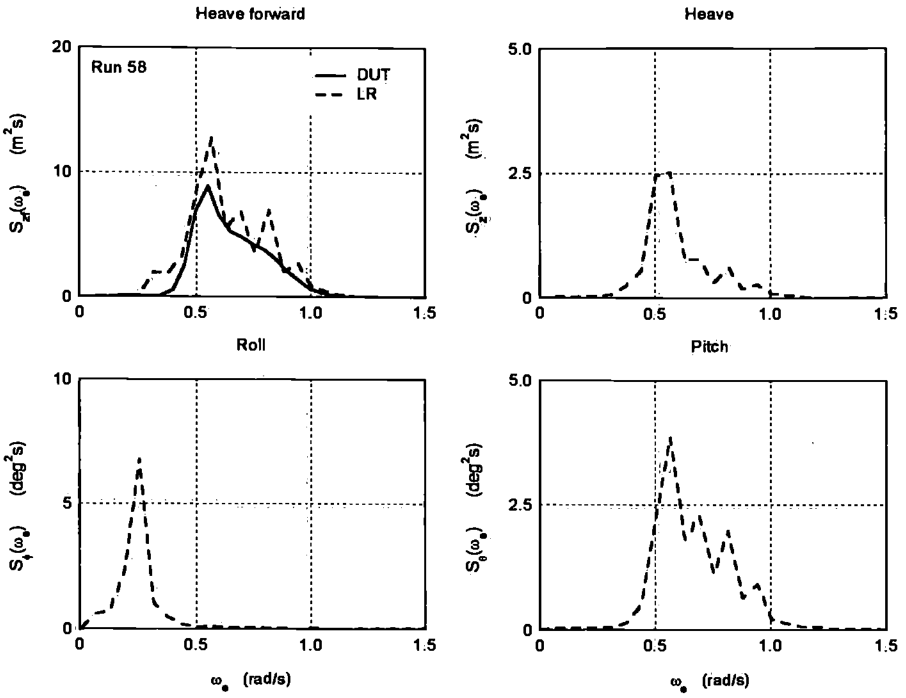

Figure 83: Measured ship motion spectra during run 58
(Data files: 58-DUT.EXP and 58-LR.EXP)

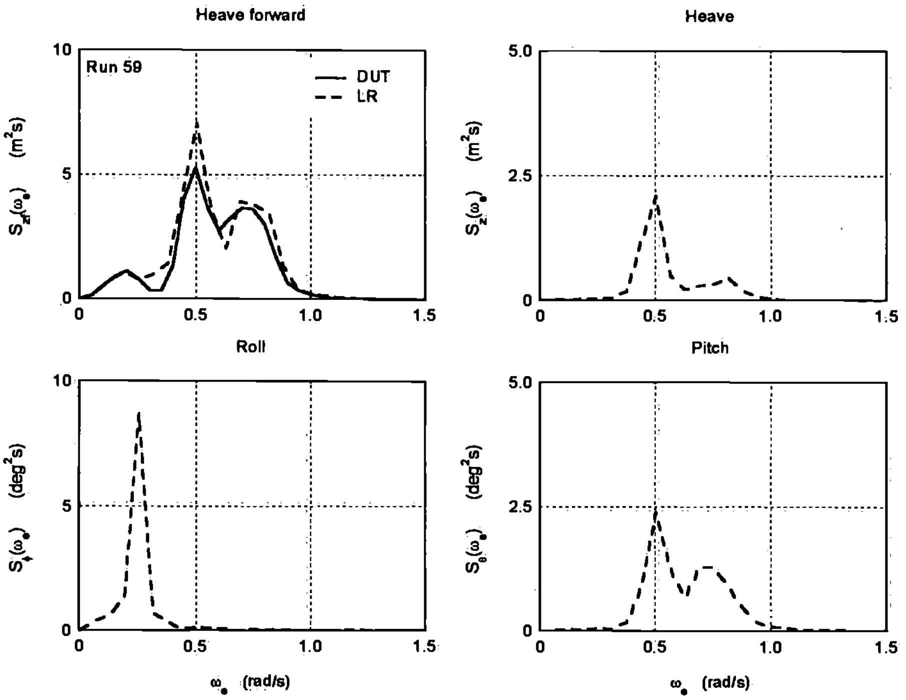

Figure 84: Measured ship motion spectra during run 59
(Data files: 59-DUT.EXP and 59-LR.EXP)

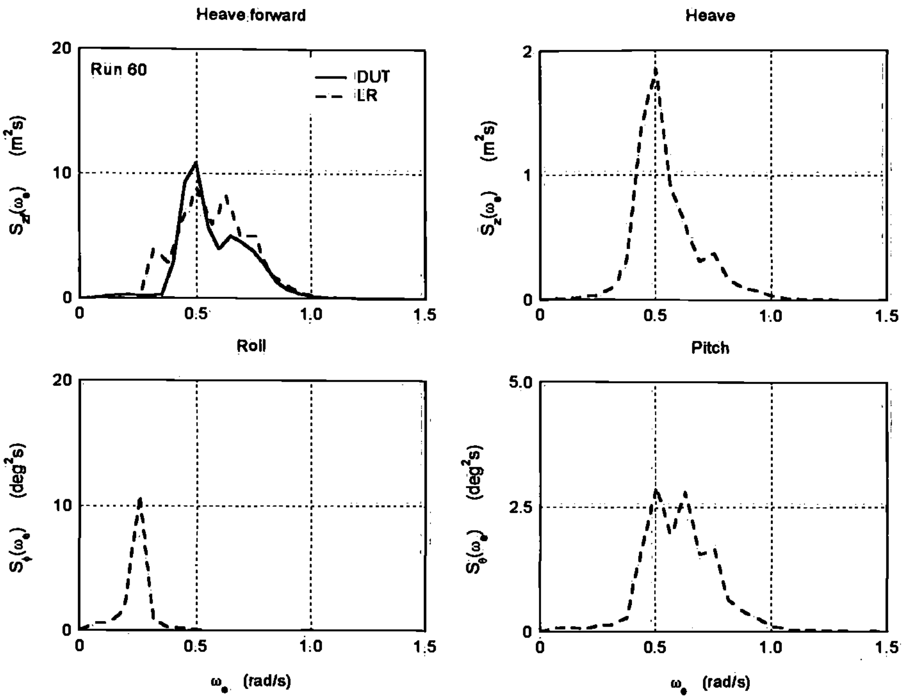

Figure 85: Measured ship motion spectra during run 60 (Data files: 60-DUT.EXP and 60-LR.EXP)

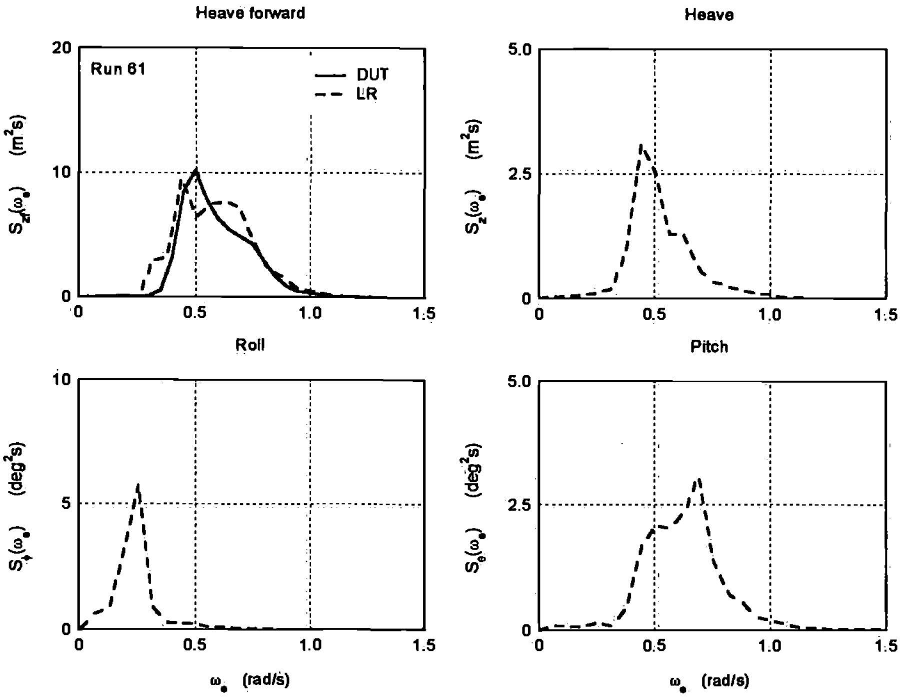

Figure 86: Measured ship motion spectra during run 61 (Data files: 61-DUT.EXP and 61-LR.EXP)

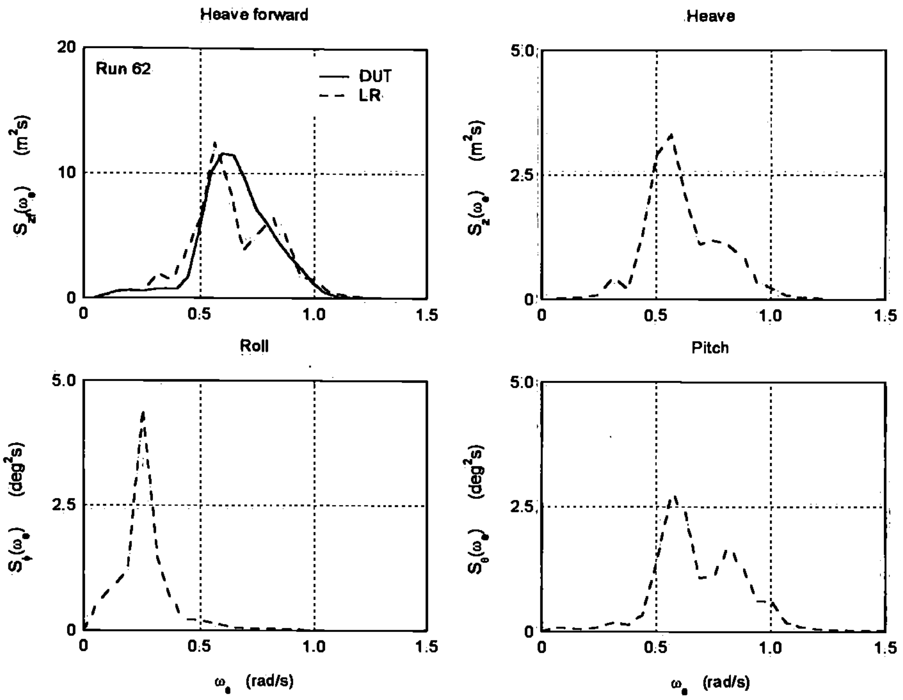

Figure 87: Measured ship motion spectra during run 62 (Data files: 62-DUT.EXP and 62-LR.EXP)

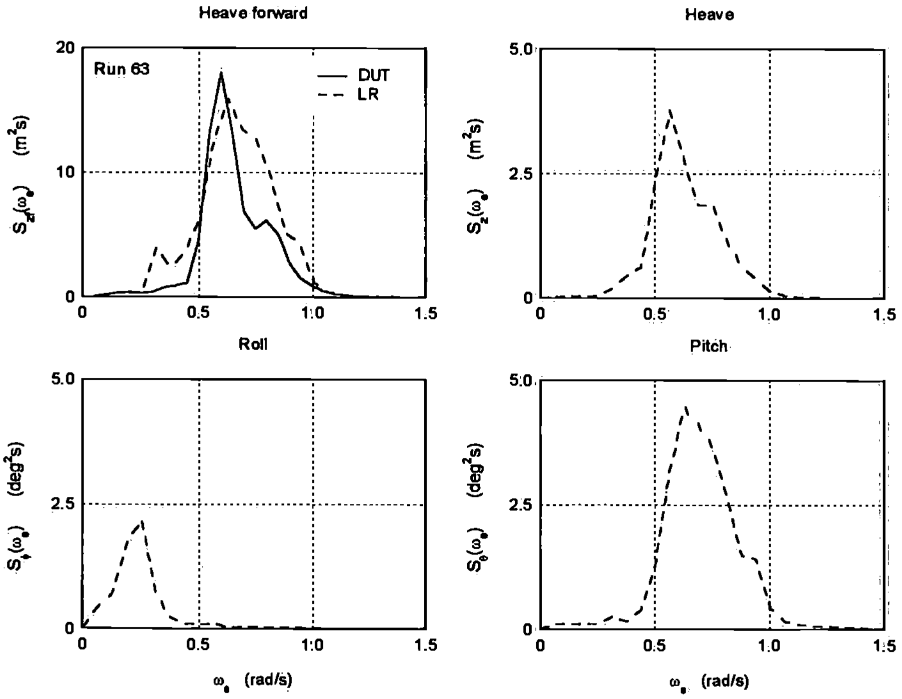

Figure 88: Measured ship motion spectra during run 63 (Data files: 63-DUT.EXP and 63-LR.EXP)

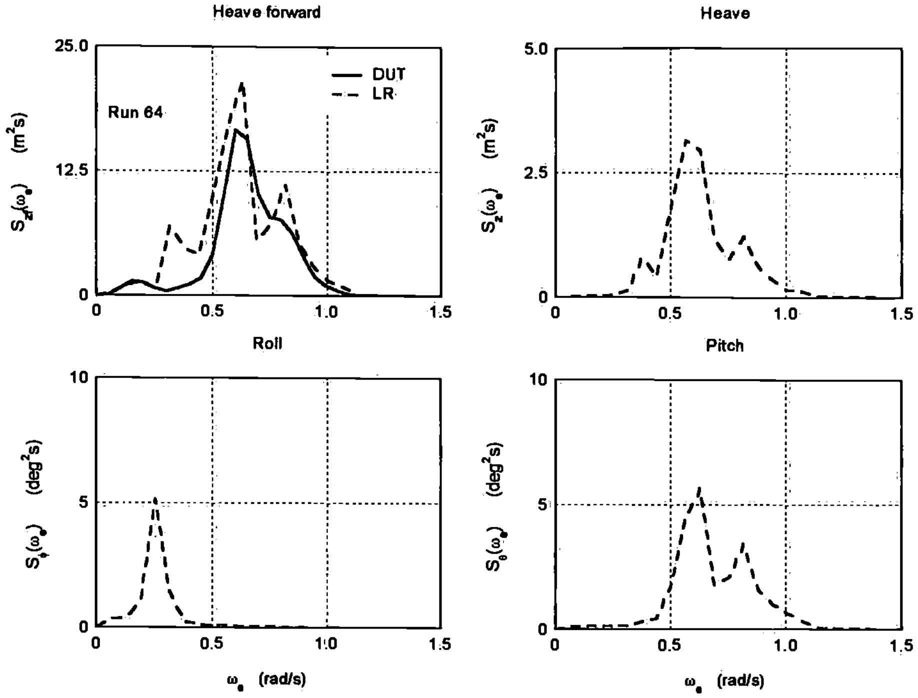

Figure 89: Measured ship motion spectra during run 64
(Data files: 64-DUT.EXP and 64-LR.EXP)

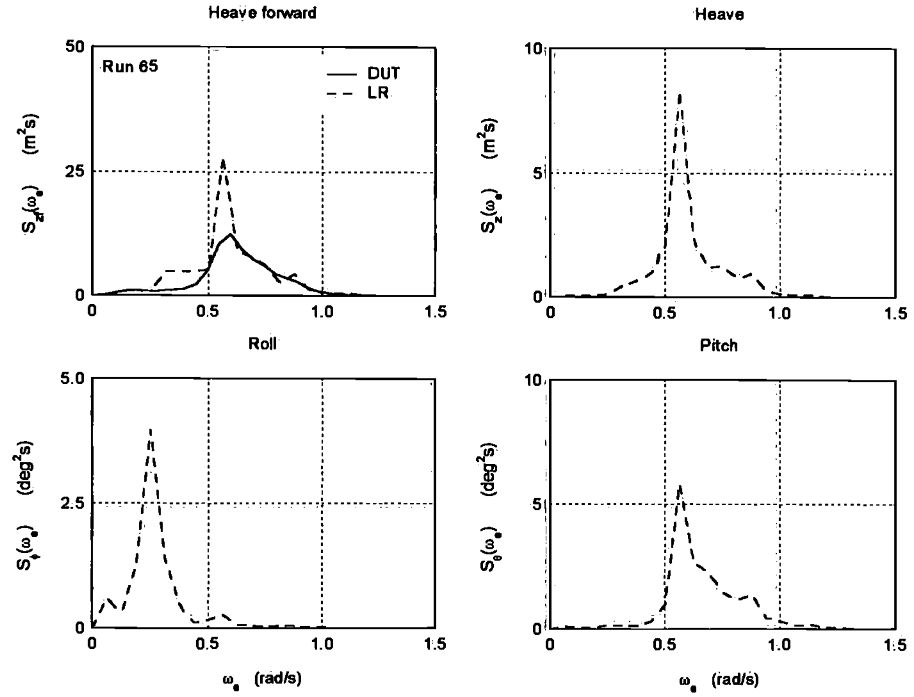

Figure 90: Measured ship motion spectra during run 65
(Data files: 65-DUT.EXP and 65-LR.EXP)

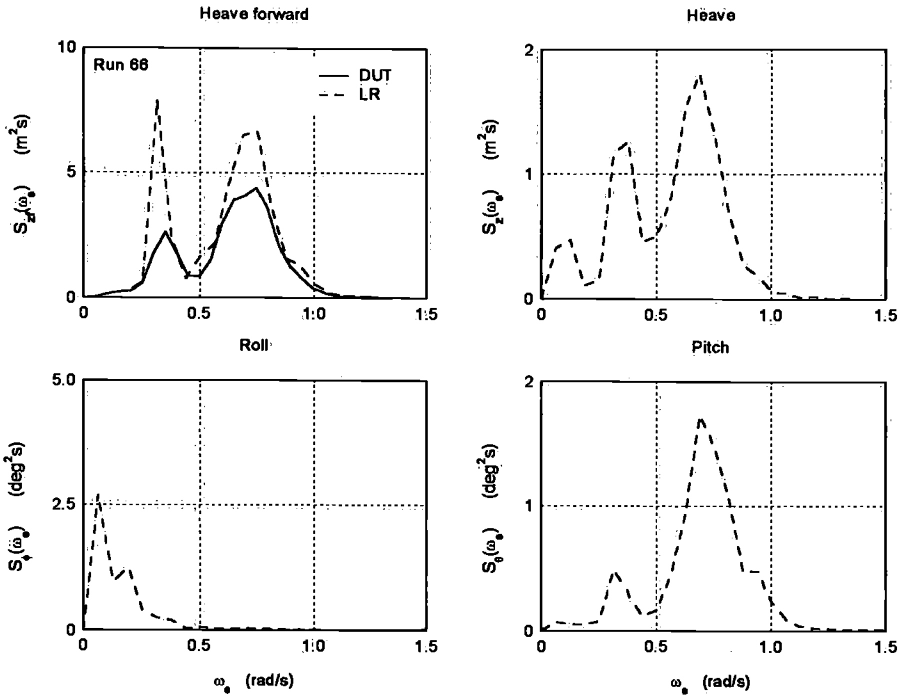

Figure 91: Measured ship motion spectra during run 66
(Data files: 66-DUT.EXP and 66-LR.EXP)

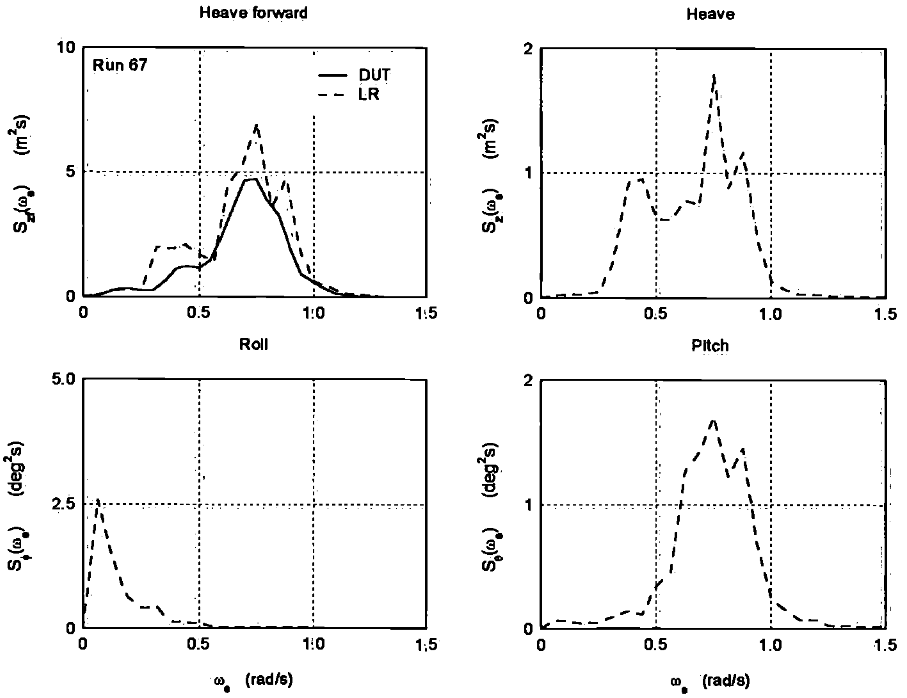

Figure 92: Measured ship motion spectra during run 67
(Data files: 67-DUT.EXP and 67-LR.EXP)

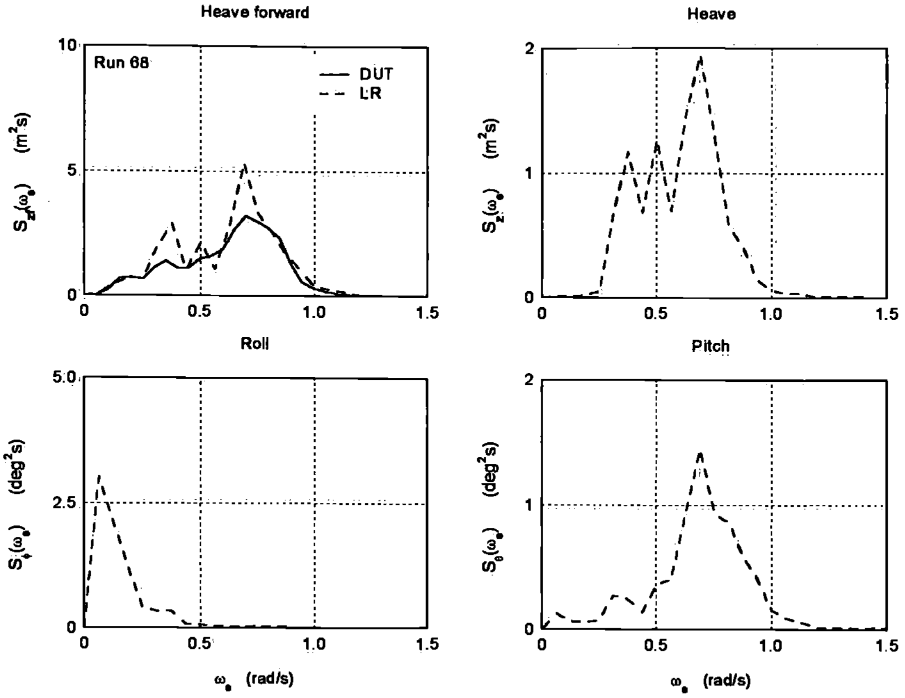

Figure 93: Measured ship motion spectra during run 68
(Data files: 68-DUT.EXP and 68-LR.EXP)

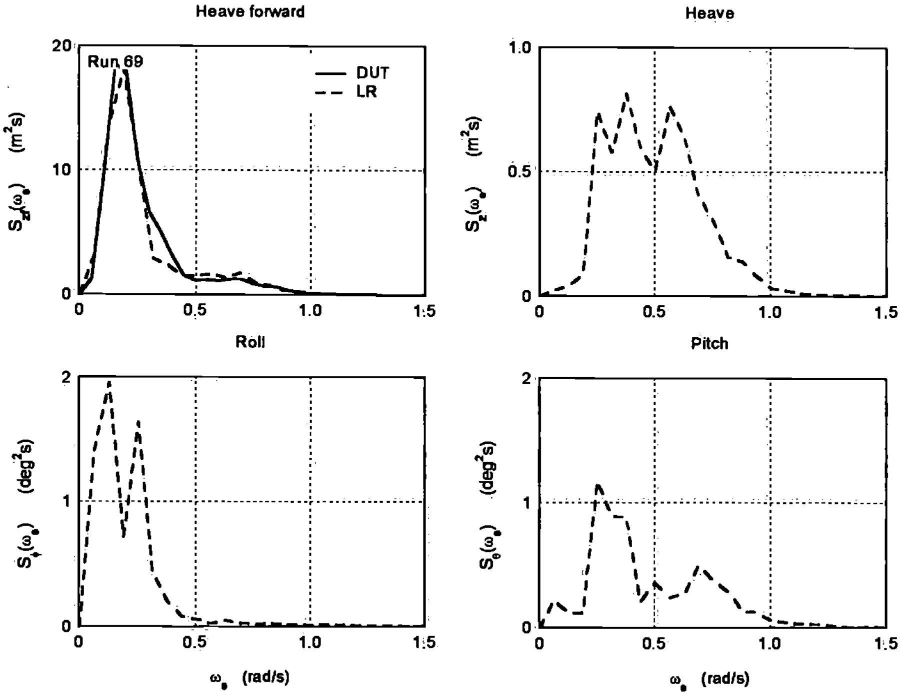

Figure 94: Measured ship motion spectra during run 69
(Data files: 69-DUT.EXP and 69-LR.EXP)

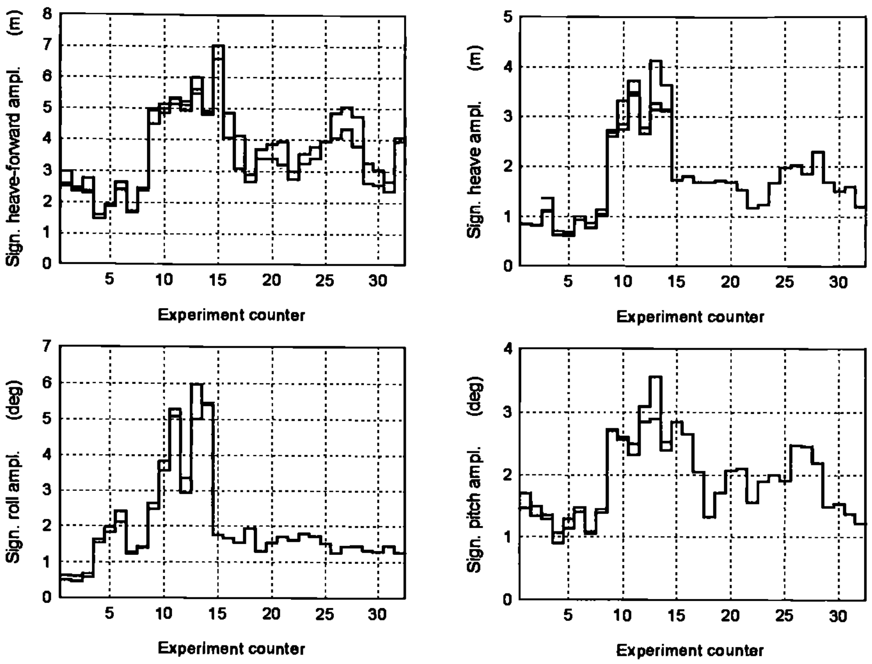

Figure 95: Overview of measured significant motion amplitudes (1/3) during 32 runs

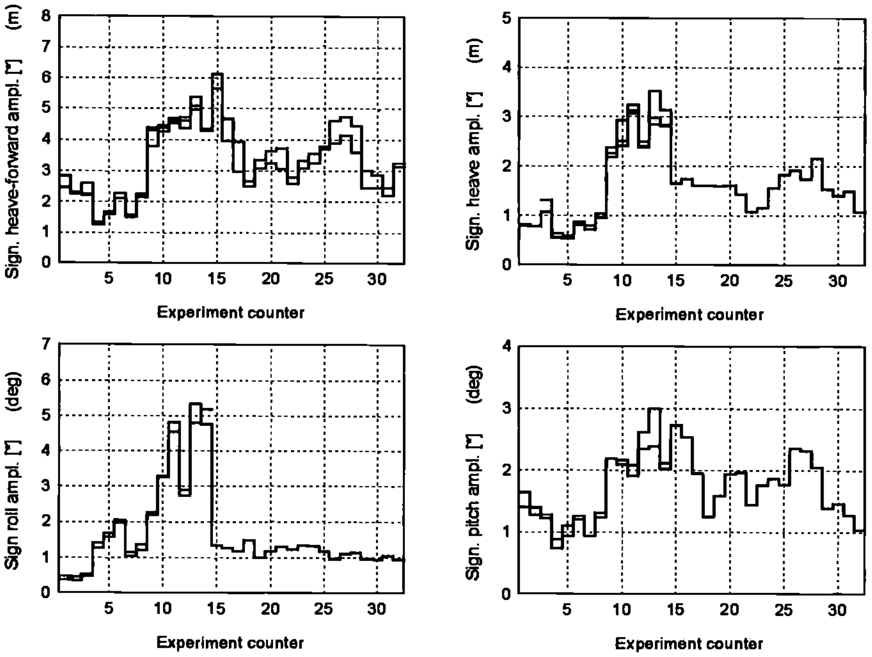

Figure 96: Overview of measured significant motion amplitudes (1/3*) during 32 runs

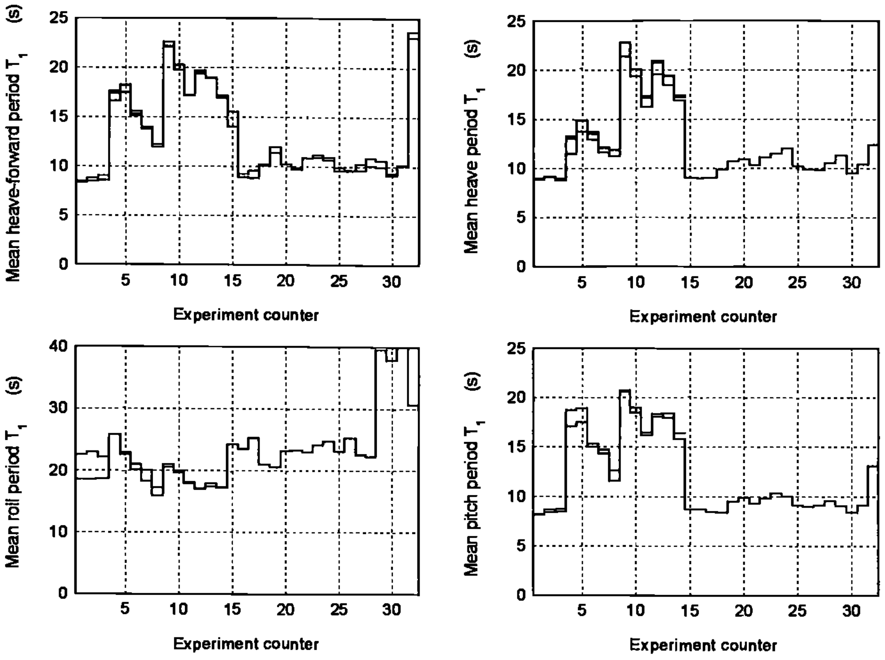

Figure 97: Overview of measured average motion periods (T_1) during 32 runs

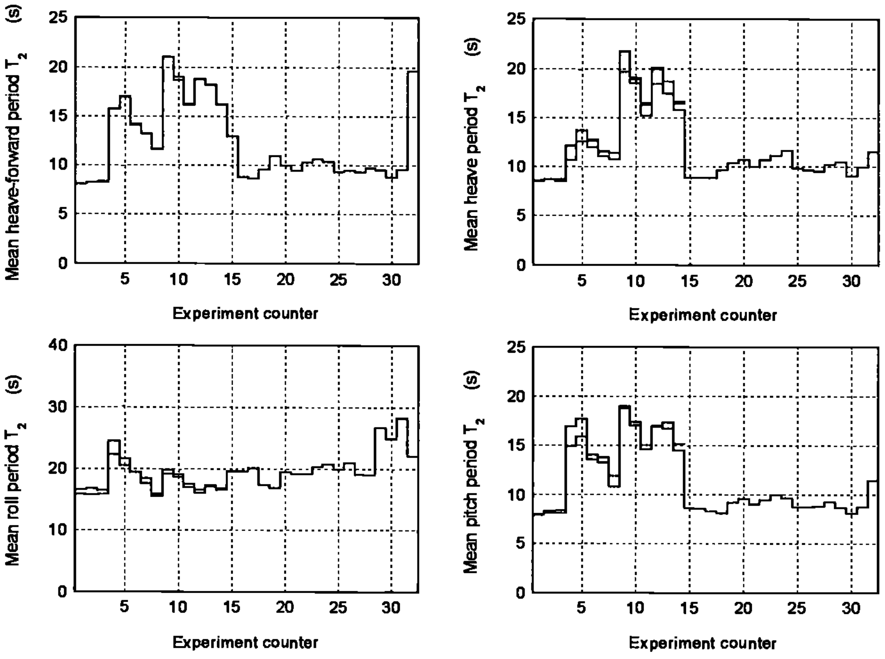

Figure 98: Overview of measured average motion periods (T_2) during 32 runs