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WAVE INDUCED MOTIONS OF MARINE DECK CARGO BARGES

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Summary

The motion responses to environmental forces of a full scale marine deck cargo barge (100m x 30m) have been measured during a tow across the North Sea. Wind and wave measurements were also made enabling the response spectra and transfer functions presented in this paper to be derived. These results are compared with theoretically predicted values and the importance of roll damping is discussed.

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Introduction

Until recently there has been a general lack of knowledge concerning the motion response of marine barges (with beam/draught ratios over 4) to waves where the natural roll periods of the vessels are near those of the waves. Computer programs are known to predict unrealistic motions near resonance primarily because of their inability to simulate the viscous damping associated with barge roll motions. Furthermore there is a considerable divergence of opinion as to the correct values of equivalent linear damping terms that may be used in order to limit theoretical responses at resonance.

Physical scale model testing is the solution to which most designers resort. However the scale effects concerning the hydrodynamic damping of roll motions are not quantifiable; indeed the damping mechanism itself is not clearly understood.

The Jasmine's Turtle Experiment

In order to overcome the problems associated with small scale model testing, a full scale experiment was carried out on a marine barge in the North Sea. This barge, the Jasmine's Turtle was scheduled to carry a cargo of 3 modules for the Shell Brent C platform from Newcastle to Norway. The geometric and mass properties of the loaded and ballasted barge are given in Fig. 1.

Atkins Research and Development installed a number of instruments on the barge before tow-out, and these are listed in the next section. In view of the poor reliability of unattended instrumentation, the key components in the system were duplicated where possible. All signals were telemetered to the tug (Starmi) using the EMI telemetry system 36, where they were recorded on two tape recorders. Fig. 2 shows the instrumentation on the barge.

When the tow reached the deep waters of the Norwegian trench Jasmine's Turtle was turned into the weather and held steady whilst a waverider buoy was deployed in order to measure wave heights. The environmental conditions during this period are summarised in Fig. 3. It must be stressed that these conditions are those that were visually observed. The figures for wave height and period shown are best estimates by experienced seamen of significant wave height, period and direction. They compare reasonably with the spectrum derived from measurements made at the same time with the waverider buoy.

Data

The data transmitted from the barge and monitored and recorded on the tug were as shown in Table 1. Two orthogonal pairs of accelerometers were installed to measure surge and sway accelerations. One pair was fixed well above the barge centre of gravity, high up on the cargo, and one pair well below, down in the bilges.

Analysis

The axes systems and equations used in the analysis are given in Fig. 4. The derived data are sufficient to fully describe the motions of the barge if yawing motion can be ignored, and the accelerometer time histories can be integrated to yield the corresponding velocity time histories. This integration was performed satisfactorily in the frequency domain. Substituting the velocities in equation (2) yields the roll and pitch angular velocities, and the height of the pitch and roll centres. (These being defined as those points which have zero velocity components in the surge and sway directions respectively). The roll and pitch angular velocities derived as above with the measured accelerations are substituted into equation (3). This yields the roll and pitch angular accelerations, as well as the surge and sway components of acceleration of the C.G. To check on this analysis, the roll angular velocity time histories were numerically integrated, and compared with the gyro outputs. For most of the data, good agreement was obtained.

Results

Fig. 5 shows time histories of the roll angular velocity, the sway acceleration of the C.G. and the height of the roll centre above the C.G.

The most noticeable features of these time histories are the large excursions (to $\pm\infty$) of the roll centre. These excursions occur at zero crossing points in the roll velocity and sway acceleration time histories, and consequently have no large forces associated with them. Numerically they arise from the division of large sway velocities by near zero values for the roll angular velocity. This is to be expected when the barge follows the water surface profile of long period waves. Experience has shown that this type of motion is a characteristic of large marine barges.

Fig. 6 shows the wave spectrum derived from the wave rider buoy signal and Figs. 7 and 8 show the roll and pitch response spectra derived from the gyro outputs at the same time (tow stationary). These spectra were used to compute the transfer functions shown in Figs. 9 and 10.

Discussion

Fig. 11 shows the wave spectrum, the roll spectrum and the roll transfer function plotted together against period. The wave spectrum is clean and has most energy around 8 seconds period (as estimated by the seamen) with some evidence of the twelve second swell. However, a fairly generous estimation of the energy under this area of curve indicates a significant swell height of only 0.6m (c.f. 2m estimate by seamen).

It is interesting to find that the roll response spectrum has twin peaks, each being well defined. The peak 6.2 seconds corresponds to the natural roll period of the barge. The second peak at 6.9 seconds is caused by response at the wave frequency. The corresponding peak in the roll transfer function is unexpected and may indicate that there was more energy in the waves at 6.9 seconds than indicated by the wave spectrum which has been smoothed. Alternatively there may have been less energy in the waves at 6.6 seconds (an unexpected trough in the roll transfer function) than indicated, which would have the same result.

Having obtained some results for a full scale barge in real offshore conditions it is important to compare these results with existing theory. Thus in Fig. 12 the Jasmine's Turtle (JT) transfer function is compared with transfer functions predicted for a similar barge by two computer programs. Table 2 gives the properties of both JT and the computer model. The first program, TRITON, is a linear diffraction-radiation program applicable to three-dimensional bodies of arbitrary shape. The method of solving the Laplace equation is by 8 noded brick type fluid finite elements. No external damping is added to represent viscous effects. The other program, TRITIR, is a non linear simulation program. Hydrodynamic characteristics are input from the linear analysis in TRITON but are then used under less restrictive conditions. In particular non-linear effects near the free surface are considered. A surface integral of drag force proportioned to the square of the relative velocity between surface elements of the body and the fluid is computed at each time step. Hence TRITIR, to some extent, simulates the viscous roll damping forces, whilst TRITON simulates only the radiation damping arising from the generation of surface waves. TRITIR has been found to predict scale model test results on barges extremely well. TRITON, with less damping, overestimates roll response at resonance.

It is encouraging to note that the JT result is in the same region as that predicted by the theoretical models. However, the first impression given by Fig. 12 is that the JT transfer function must be for a more lightly damped system that any of the theoretical curves, although the importance of wave direction must not be underestimated. The TRITON curves are for three angles of wave attack; 30°, 60° and 90° (beam on) and for unit amplitude waves. The TRITIR curve is for beam waves only of 3m height (close to the significant height measured).

Evidently the barge response is much greater around resonance than predicted by theory for a wave attack angles of 30°-60°. Between 7.5 and 10.5 seconds response is less than predicted by theory and from 10.5 seconds upwards measured and predicted responses are close.

Conclusion

Despite the problems of directionality with the wave spectra it is concluded that the full scale barge roll response is less damped in the random sea state measured than is predicted by a theoretical computer program calibrated against model test results.

Table 1

Instrument	Signal	Unit
Colnbrook Gyro	Roll Pitch Heave	degree degree metre
B.S.R.A. Gyro	Roll Pitch Heave	degree degree metre
Strain-Gauged Shackles	Port Tension Starboard Tension	tonnes force tonnes force
Accelerometers	Accelerometer 1 (Lower Sway) Accelerometer 2 (Lower Surge) Accelerometer 3 (Upper Surge) Accelerometer 4 (Upper Sway)	m/s^2 m/s^2 m/s^2 m/s^2
Electronic Circuit	Test Voltage (2.5v)	volt
Battery Pack	Battery Supply Voltage	volt
Waverider Buoy (not on the barge)	Wave Height	metre

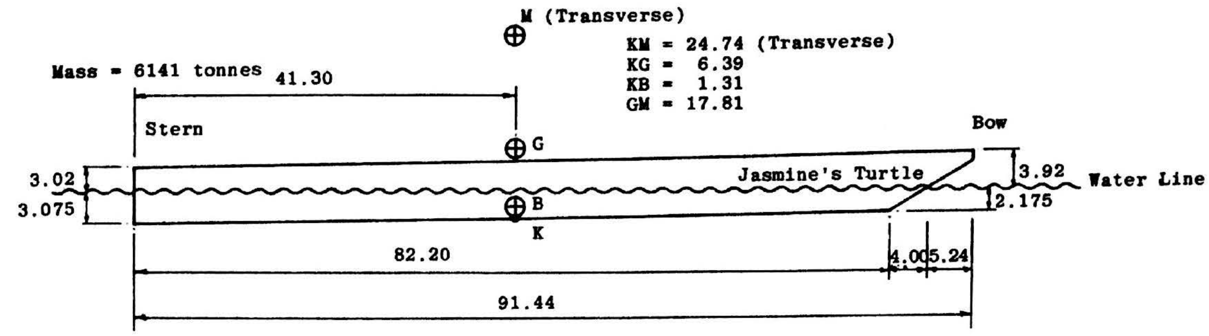
Table 2

Property/Barge	Jasmine's Turtle	Computer Model
Mass	6141 tonnes	6581 tonnes
Draught	2.62m (mean)	2.74m
Gyradius	8.92m	8.48m
KG	6.39m	4.88m
BG	5.08m	3.50m
GM	17.81m	19.36m
I_{xx}	4.89E5 tonne m^2	4.73E5 tonne m^2
T_{roll}	6.3 sec	6.0 sec

Mass Properties:-

r = 8.92m) including cargo
I_{xx} = 4.89E5 tonne m²) and ballast
)

Mass = 6141 tonnes



Barge is of uniform width, 27.43m, with constant rectangular cross section. Bow is raked at 30°. All hull plating is flat except at corners which have a radius of approx. 400mm.

Fig. 1 Side elevation of barge (cargo not shown) with principal dimensions given for as-towed configuration.

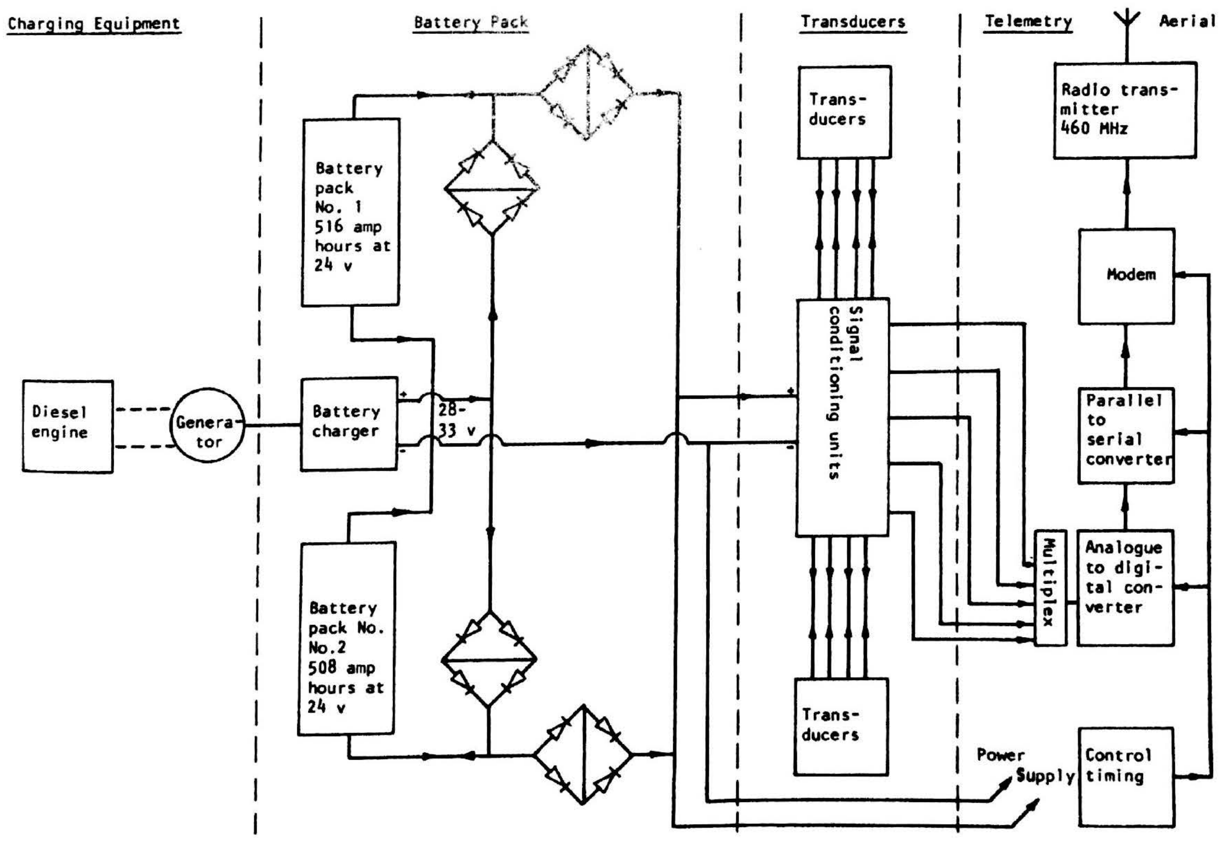


Fig. 2 General arrangement of equipment on Jasmine's Turtle.

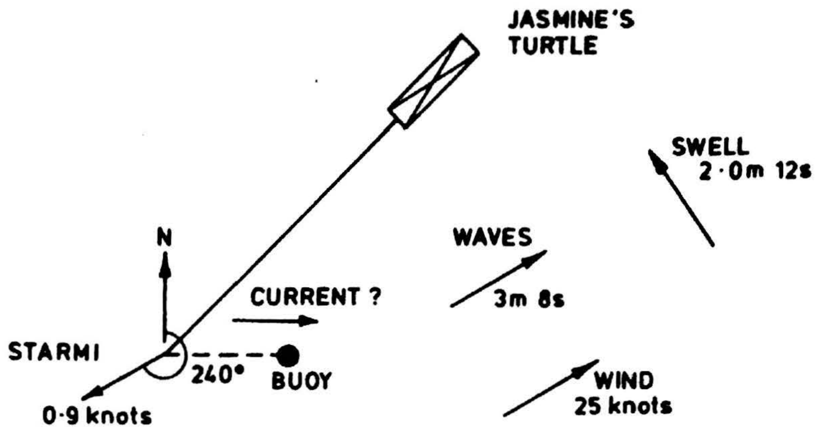
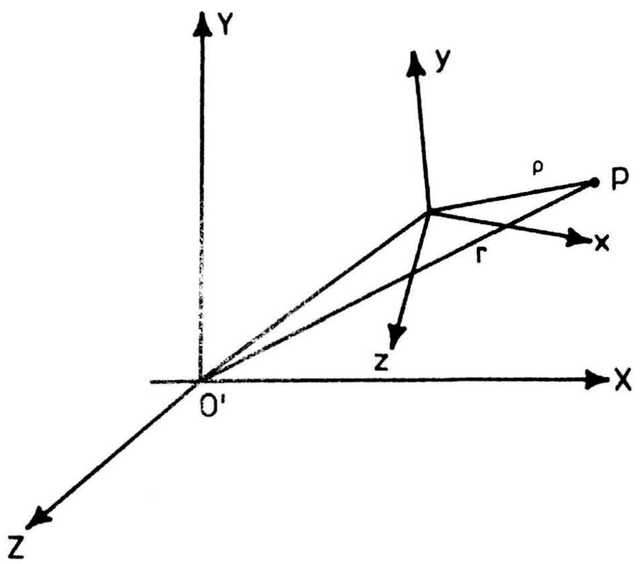


Fig. 3 The tug/barge configuration during the deployment of the waverider bouy on Wednesday 8th March, 1978.



OXYZ = is the global axis system

O'xyz = is the local (barge) axis system with angular velocity $\underset{\sim}{\omega}$ relative to OXYZ

If P is fixed relative to the barge axis system (O'xyz)

$$\underset{\sim}{r} = \underset{\sim}{R} + \underset{\sim}{\rho} \tag{1}$$

$$\dot{\underset{\sim}{r}} = \dot{\underset{\sim}{R}} + \underset{\sim}{\omega} \times \underset{\sim}{\rho} \tag{2}$$

$$\ddot{\underset{\sim}{r}} = \ddot{\underset{\sim}{R}} + \underset{\sim}{\omega} \times (\underset{\sim}{\omega} \times \underset{\sim}{\rho}) + \dot{\underset{\sim}{\omega}} \times \underset{\sim}{\rho} \tag{3}$$

Fig. 4 Axis systems for vessel motion analysis.

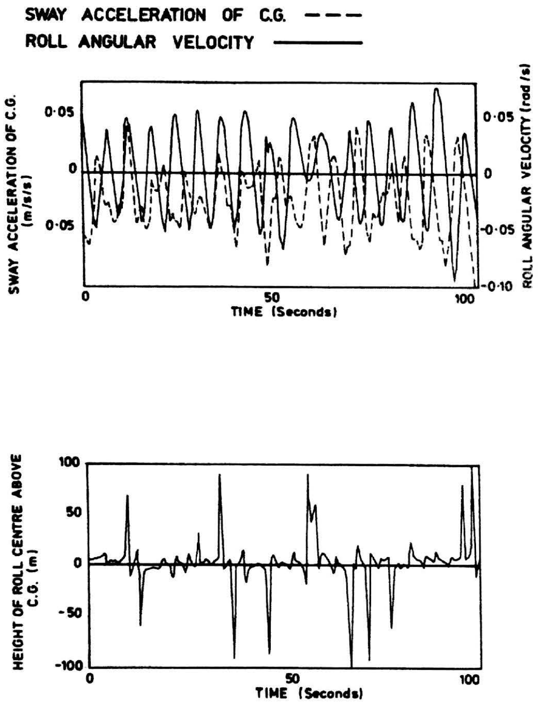


Fig. 5 Time histories of roll angular velocity, sway acceleration of C.G. and height of roll centre above C.G. (record 80, tape 3).

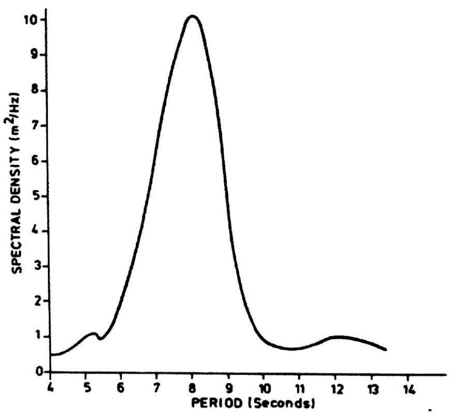


Fig. 6 Wave spectrum obtained using wavender buoy on Wednesday 8th March, 1978.

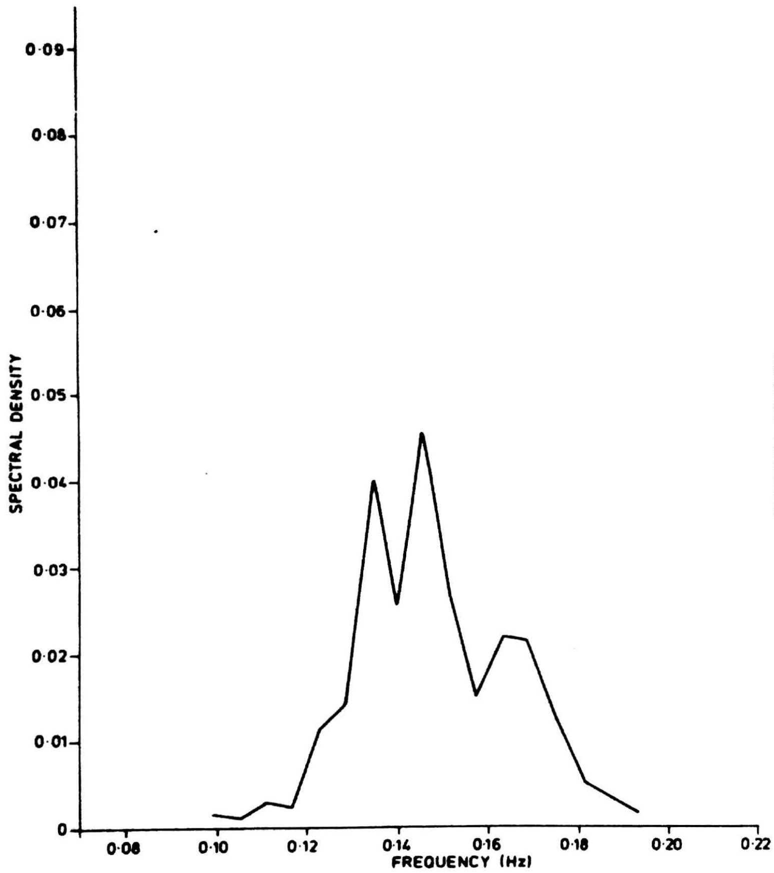


Fig. 7 Roll response spectrum for Jasmine's Turtle on Wednesday 8th March, 1978.

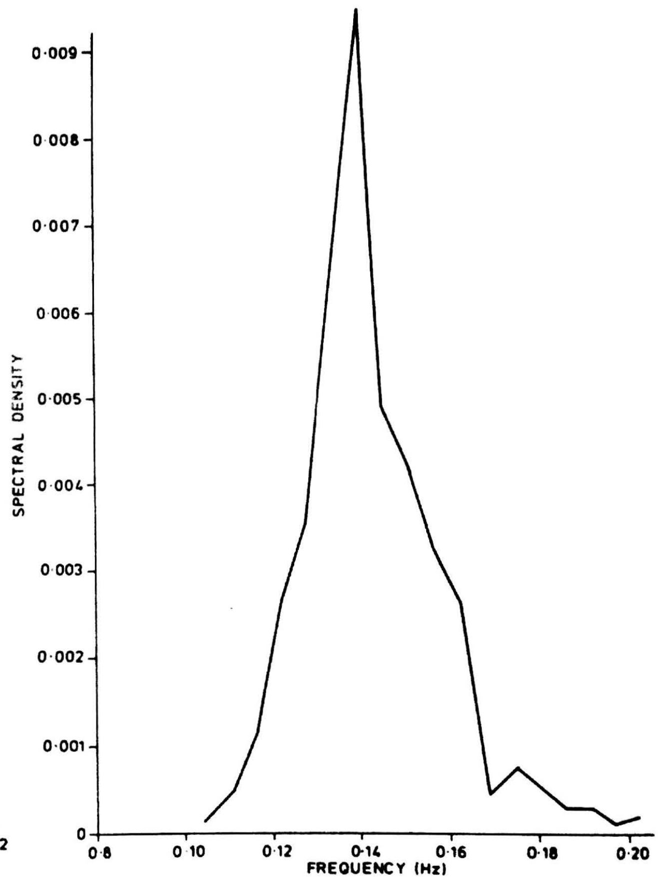


Fig. 8 Pitch response spectrum for Jasmine's Turtle on Wednesday 8th March, 1978.

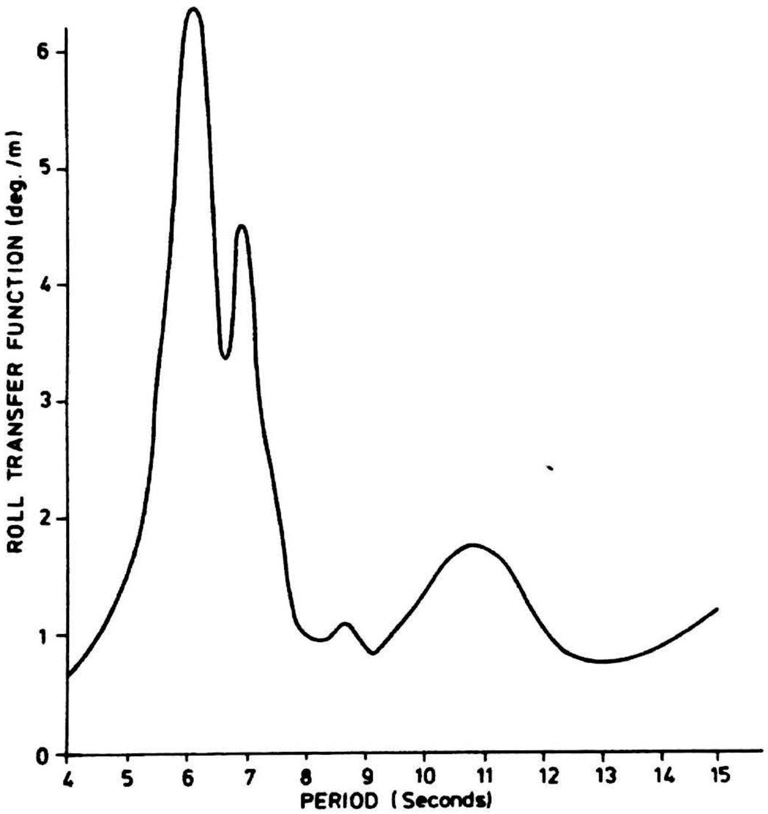


Fig. 9 Roll transfer function for Jasmine's Turtle on Wednesday 8th March, 1978.

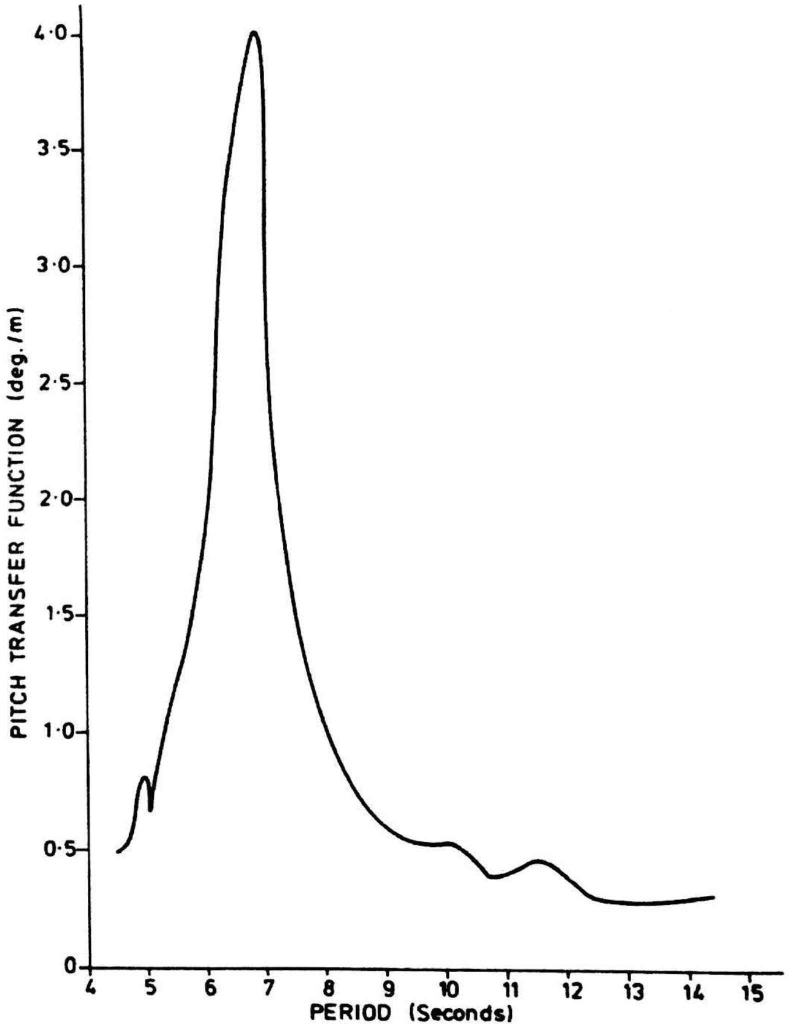


Fig. 10 Pitch transfer function for Jasmine's Turtle on Wednesday 8th March, 1978.

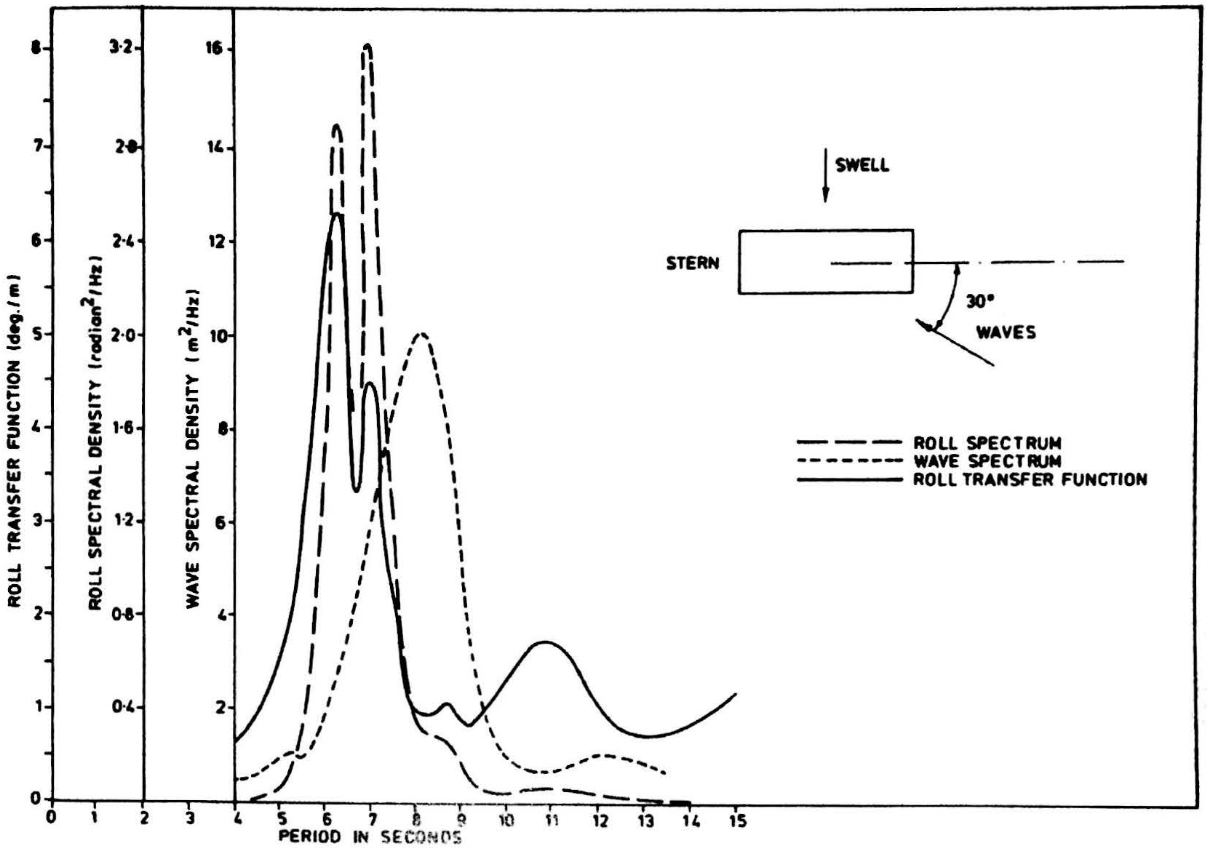


Fig. 11 Wave spectrum, roll spectrum and roll transfer function.

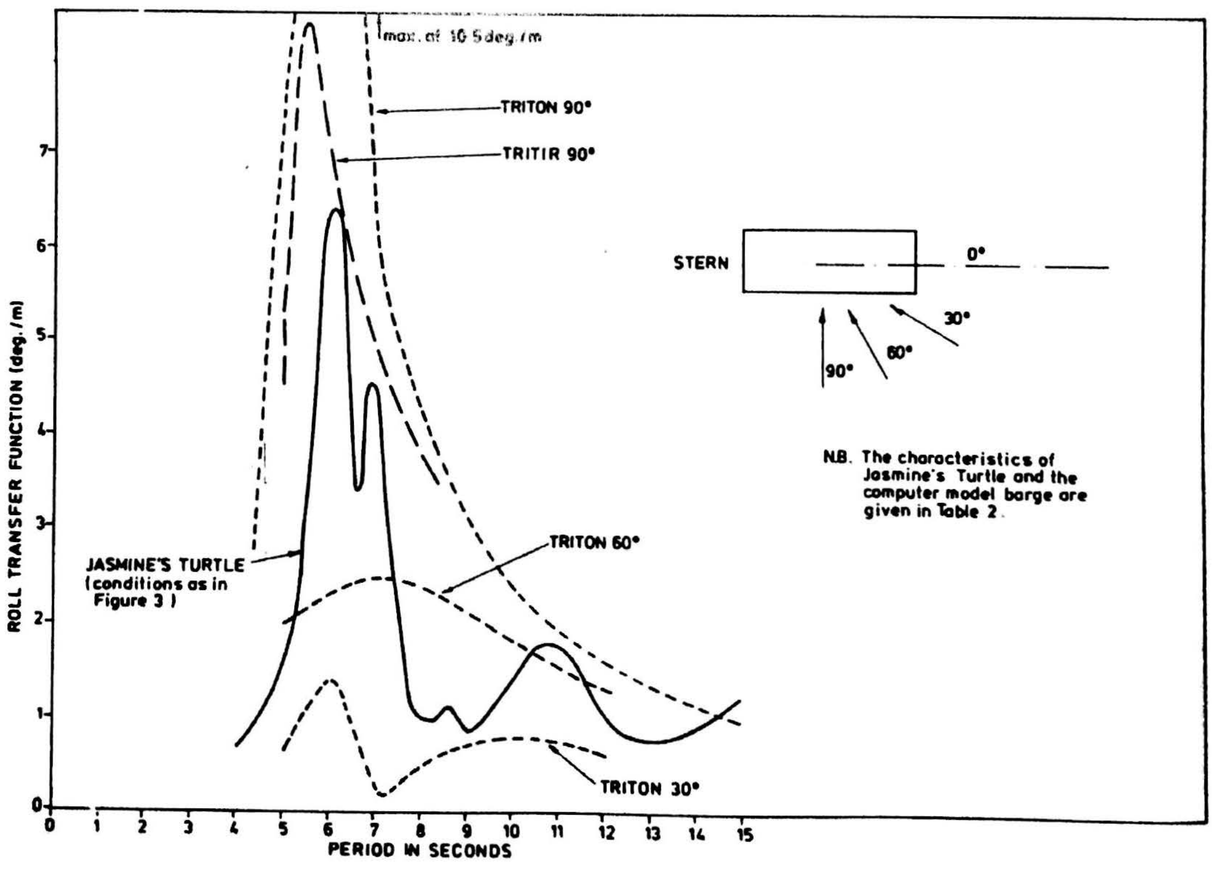


Fig. 12 Roll transfer function from Jasmine's Turtle and transfer functions predicted by programs TRITON & TRITIR.