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# Centre for Marine Science and Technology

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## Preliminary sea trials on Sea Gyro

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# 1 OBJECTIVES

The main objective of the trials was to assess the effectiveness of the Sea Gyro in reducing roll motion in beam seas at low Froude number. The trials were also intended to establish the nature of the relationship between gyro rotational speed and vessel response, and also to provide insight to the influence of the Sea Gyro on other vessel motions.

# 2 METHODOLOGY

The influence of the Sea Gyro on motions in beam seas was assessed by orienting the vessel to the waves and recording the vertical accelerations at two transverse locations on the vessel, repeating the process for different gyro speeds. The length of each run was a compromise between acquiring a data set long enough for low statistical uncertainties, but of sufficiently short duration and distance to reduce the temporal and spatial variation of the wave field to acceptable levels. Temporal variation of the wave field could be compensated for to some extent by obtaining statistical estimates of the wave height and period during each run and using these data to normalise the motions data. Spatial variation of the wave field was minimised firstly by choosing a region where visual observation indicated very little variation, and by using the same start point for each run. The run length chosen was 15 minutes.

Response Amplitude Operators were not calculated because of the comparatively high statistical uncertainties in the spectral ordinates for runs of such short duration.

The use of just two accelerometers required the assumption that any pitch contamination of the signal was consistent across all runs, and that the roll angles would be small enough to justify neglecting the change in the gravitational component of the accelerometer signals when the very not aligned vertically.

# 3 EQUIPMENT

The vessel of opportunity used was *Sea Airs,* a 17m heavy displacement single screw motor yacht with large bilge keels. Principal characteristics are shown in *Table 10-1*.

The vessel was equipped with two contra-rotating prototype Sea Gyros each weighing 450kg bolted down to the aft deck. The gyro spin was driven by a 240V motor with variable speed controller. Each Sea Gyro was fitted with two non-linear dampers on its precession motion. Each damper was adjustable, with the adjustment set to maximum for the trials.

Wave surface elevation was measured using two CMST wave recorders. These are portable pressure sensors attached to data loggers. They are pre-programmed and downloaded from a PC via the serial port. The recorders can be deployed either on the seabed, or surface-suspended from a float. They were deployed in surface-suspended mode for these experiments. They are stand-alone, with no method of accurate synchronisation. They were set at 2Hz sample rate and in this mode can record approximately 9 hours of data.

A pair of Schaevitz accelerometers were installed on the main deck just aft of amidships, separated 4.63m transversely. They provided an analogue voltage output with a frequency range of 0-30Hz. The accelerometer signals were acquired using the Daqbook system IOtech (2000), with analogue low pass 3rd order Butterworth filters set at 20 Hz. The signals were acquired at 100Hz sample rate.

The ship supply at 240V DC was used to power the laptop PC and data acquisition rack; the accelerometers and Daqbook were driven from a 12V power supply (fed from the ship supply).

Ship's compass was used to measure wind and wave encounter angles.

# 4 PROCEDURE

The data acquisition system was first set up in the laboratory and a series of measurements were taken to check for noise and channel cross-talk. The equipment was then installed on the vessel .

The trials was conducted in Cockburn Sound, Fremantle (*Figure 9-1*) in conditions of moderate winds and low seas. A pair of CMST recorders were programmed prior to departure and deployed in surface-suspended mode at S 32° 08.65' E 115° 42.7'. The gyro motor speed was set and the gyros allowed to spin up as the vessel steamed to a position approximately 1M east of the recorders. When the gyro speed had stabilised the vessel was turned towards the recorders, then data was recorded for 15 minutes with the vessel engines on idle – corresponding to a vessel speed of approximately 3 kn or Froude number of 0.1. The run was completed with the vessel a few hundred metres past the wave recorders. On completion of the run, the vessel headed back to the run start point whilst the gyro speed was altered. When the gyro speed had reached its desired setting and the vessel was in position, the next run was started. All runs were in the same direction relative to the dominant wave direction.

Visual observations of wind and wave conditions were recorded at regular intervals (*Table 10-2*). At the end of the last run, the wave recorders were recovered and downloaded.

# 5 RESULTS

## 5.1 Data processing

The accelerometer time series were decimated down to 10Hz sampling, yielding 9,000 data points per run. They were then Fourier transformed by the Welch method using a Hanning window on 512 data point segments with 50% overlap. Upper and lower frequency limits of 1Hz and 0.05Hz respectively were used, though investigative processing using other limits yielded only small differences to the results. The roll angular acceleration time series was obtained from the difference between the zero-meaned, calibrated, port and starboard accelerometer signals, divided by their transverse separation. Heave acceleration time series were obtained from the average of the zero-meaned, calibrated, accelerometer signals. The statistical characteristics of the spectra were obtained from the spectral moments.

The wave surface elevation time series (2Hz sampling) from the wave recorders were split into hourly segments of 7,200 points and Fourier transformed by the Welch method using a

Hanning window on 256 data point segments with 50% overlap. Upper and lower frequency limits of 0.5Hz and 0.1Hz respectively were used.

The slight temporal change in wave climate over the period of the trials was partially corrected for by creating an attenuation factor for each motion parameter. This was achieved by dividing the significant motion (or acceleration) height by the significant wave height for the wave data segment corresponding closest to the trial run time period. Period attenuation factors were derived by dividing the motion period by the wave period.

These attenuation factors were normalised with respect to their maximum occurring value. Significant amplitudes were calculated without broadness corrections, in accordance with industry practice.

## 5.2 Wave data

The statistical summary of the wave data from each wave recorder is shown in *Table 10-3*. The mean uncorrected significant wave height was 0.50m and the mean modal period was 3.11s. Representative wave spectra from the two wave recorders are shown in *Figure 9-2*. The agreement between the two recorders is very good, and the variation of the wave field over time is low, with the exception of the last hour when the significant wave height increased by nearly 50%. This increase did not correspond with visual observations. There was a modest increase in measured heave motion over this period, though not as great as might be expected from the wave height change. There is the possibility of a deployment malfunction in the wave recorders over this last hour, though the similar behaviour of both recorders rules out a sensor or data logger error.

## 5.3 Motion response in irregular waves

Motion time series for run 0 and run 4 are shown in *Figure 9-2* with equivalent roll motion spectra in *Figure 9-4*. Motion spectral statistics are shown in *Table 10-4* and *Table 10-5*.

The effect of the Sea Gyro on the roll motions and accelerations is shown in *Figure 9-5*. The presentation format in this figure allows for the small changes in wave height between runs. The effect on roll amplitude and acceleration modal periods is shown in *Figure 9-6*. Equivalent data for heave are shown in *Figure 9-7* and *Figure 9-8*.

The results show that the Sea Gyro reduced roll motion amplitude and roll acceleration amplitudes by approximately 60% with the gyro at half maximum speed. The effect of the gyro was approximately linear from 5% maximum speed to 50% maximum speed.

There was generally no discernible influence of the Sea Gyro on the modal period of roll amplitude, or the heave motion. There was an indicative trend for the modal period of the roll acceleration to decrease with increasing gyro speed. However, the changes are close to the limits of experimental error. Further testing at higher gyro speeds is required to verify this trend.

# 6 ERRORS

The principle source of error was due to the assumption that the accelerometers remained vertical. A typical roll angle of 3° induces a change in the measured gravitational component of 0.013ms$^{-2}$. The maximum vertical acceleration induced by such a roll angle for a typical 3 second roll period is 0.55ms$^2$. The maximum error from this source is therefore 2.4%. Signal to noise ratio was typically 0.2% in the acceleration time series, which amplified in the amplitude time series to a worst case of 0.5% at 0.1Hz. Changes to significant motion amplitude resulting from reducing the length of the data sets from 15 minutes to 7 minutes were up to 3%.

The heave motion measurement was subject to error from the assumption that there was no pitch. However, pitch-induced vertical accelerations were generally lower than those from roll and heave, and were likely to be consistent across all runs.

The accelerometers were calibrated with a non-linearity standard error of 0.21%

Wave height and period estimates were subject to larger instrumentation error. The mean difference between wave amplitude estimates from the two recorders was 2%. This did not take into account errors incurred as a consequence of assumptions made in the data processing e.g. the use of linear wave theory, or errors due to deployment configuration e.g. any variation from unity of the surface buoy response transfer function. Previous experience of these wave recorders when deployed in the vicinity of other types of wave recorder suggests absolute errors in wave height of approximately 20% and relative errors of 5%.

Of particular concern for these trials was a change in the mean value of the pressure signal, accompanied by an increased signal variance, during the last hour of deployment. This did not correspond with an increase in heave motion – a crude indicator of wave height. This only affected the attenuation factors for runs 6 and 7.

Wave direction estimates were also subject to error. Whilst the measurement accuracy of direction was within +-5°, the value recorded was the mean for the perceived dominant frequency. The directional spread of that dominant frequency was not measured, nor were the directions of the subsidiary frequencies.

An indication of repeatability is given by the repeat runs at 20% maximum gyro speed (runs 2 and 5), for which the roll amplitude reduction differed by 7%.

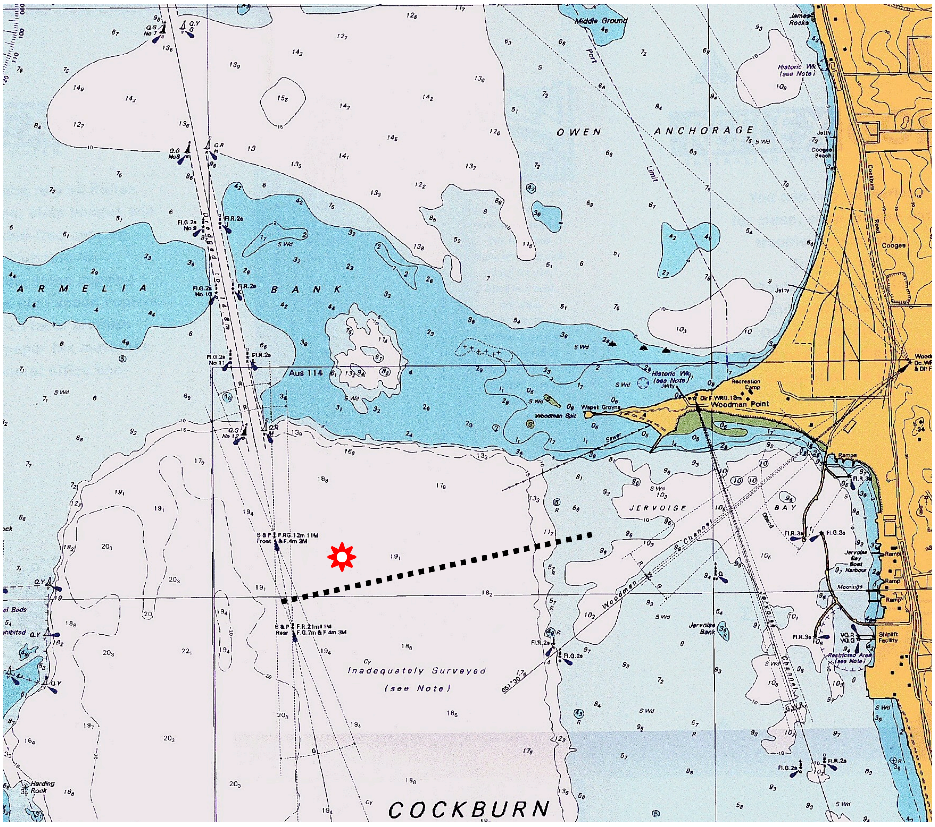
# 7 CONCLUSIONS

Trials were conducted on a 40 tonne vessel to assess the performance of Sea Gyro in beam seas at low vessel speed. At a Froude number of approximately 0.1 in 0.5m significant wave height the Sea Gyro reduced the significant roll amplitude and angular acceleration by approximately 60% with gyro speed at 50% maximum. The roll reduction was approximately linear with gyro speed increasing from 5% to 50% of maximum. The Sea Gyro had no discernible influence on roll period, or heave motion, over the range of conditions investigated. There was a possible decrease in roll acceleration period with increasing gyro speed.

# 8 REFERENCES

IOtech (2000) *DaqBook Series*, 9 July 2003, http://www.iotech.com/catalog/daq

# 9 DIAGRAMS




Wave recorders ·························· Nominal vessel track

*Figure 9-1.* Trials location – Woodman Point

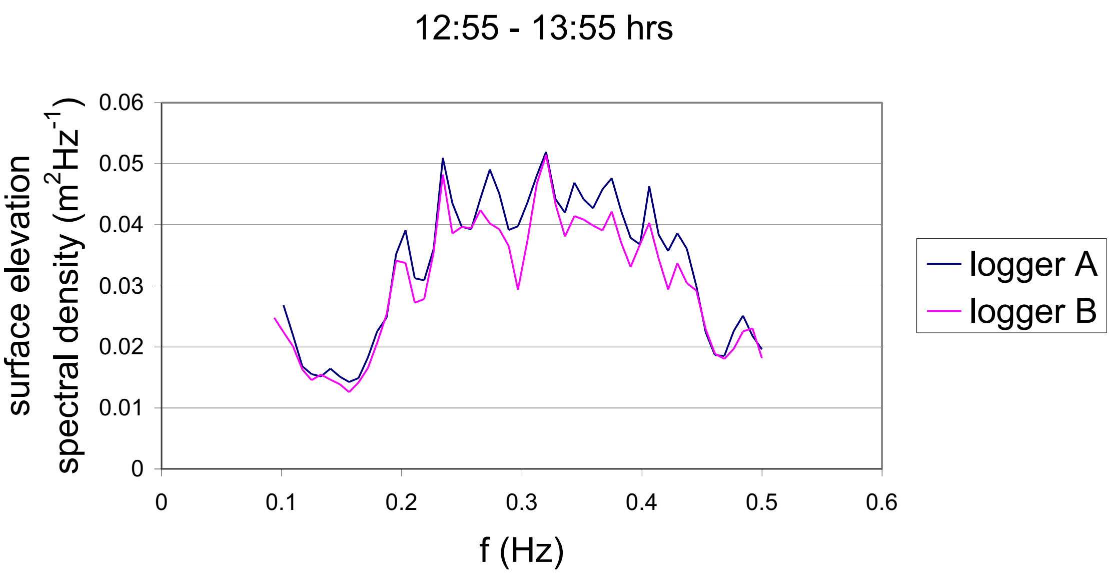



*Figure 9-2.* Sample wave spectra

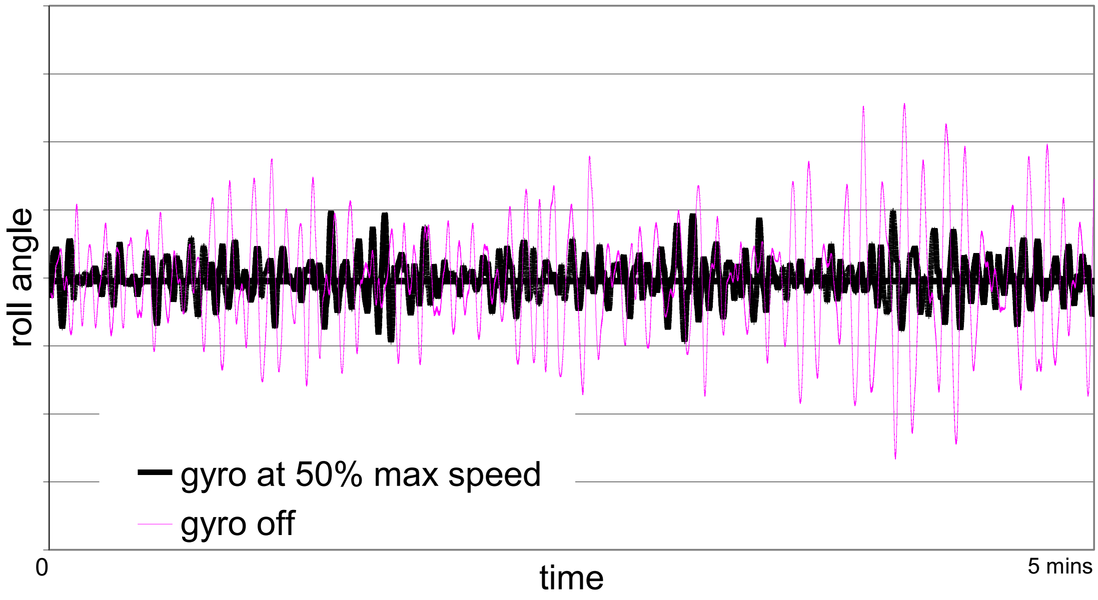



*Figure 9-3.* Roll motion time series - effect of Sea Gyro

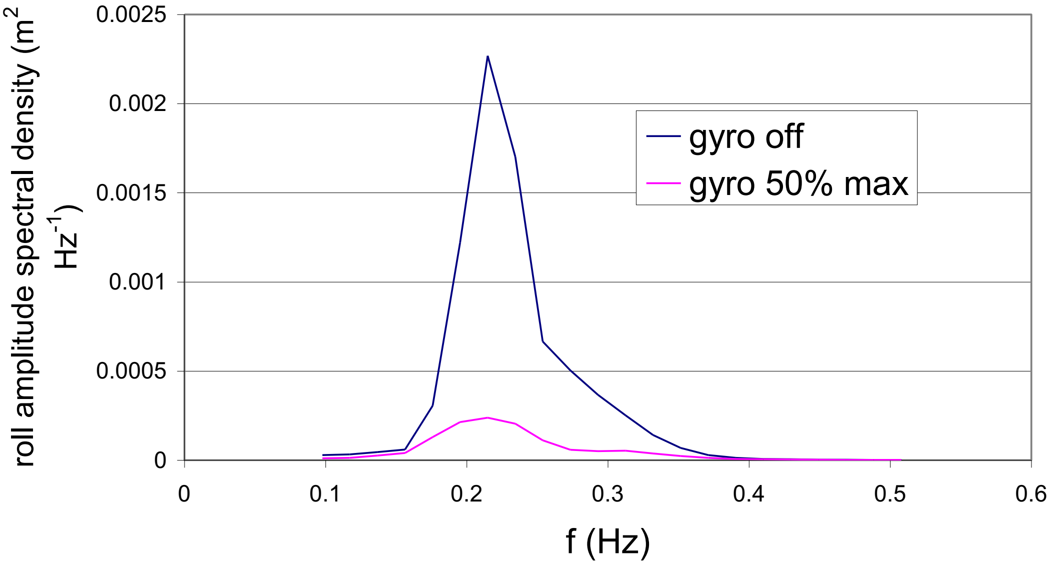



*Figure 9-4.* Effect of Sea Gyro on roll motion spectrum

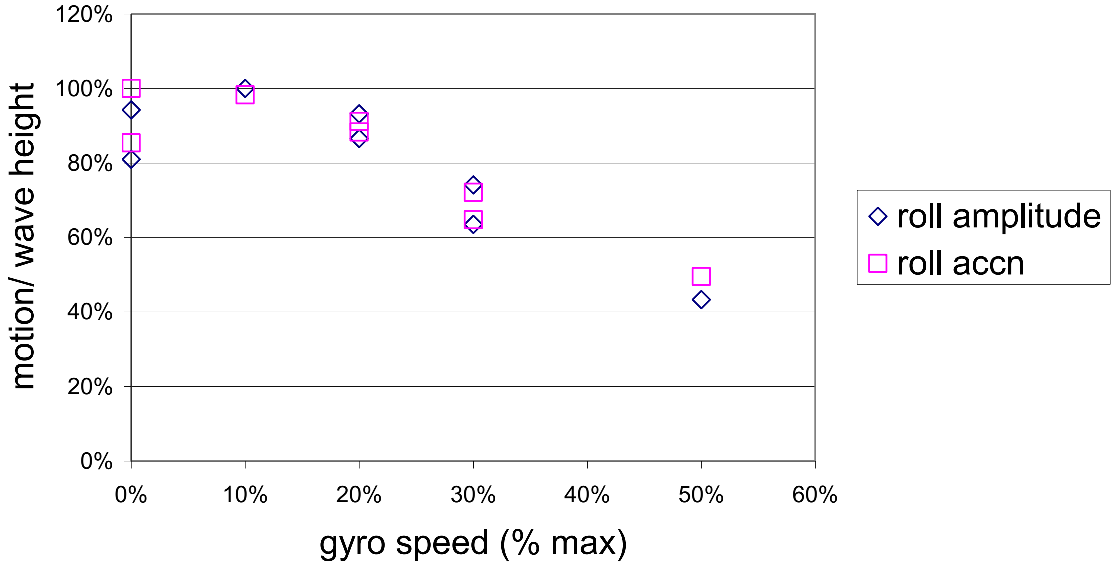



*Figure 9-5.* Influence of Sea Gyro on roll amplitude

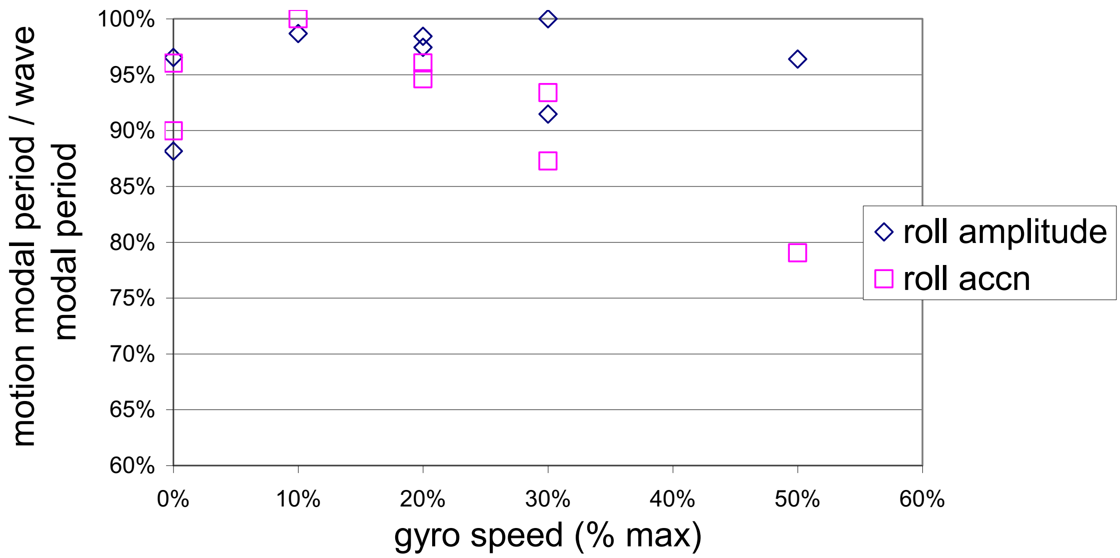



*Figure 9-6.* Influence of Sea Gyro on roll period

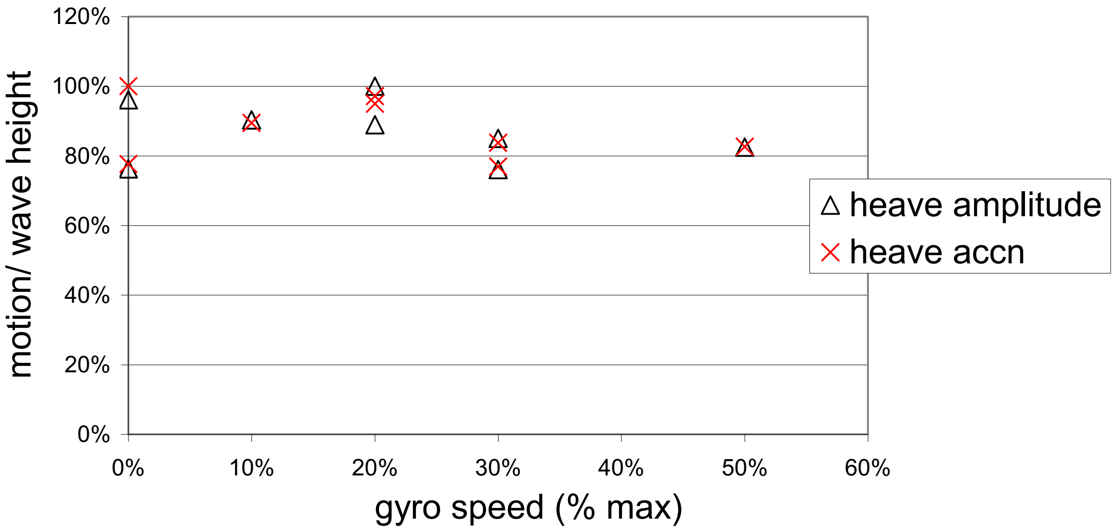



*Figure 9-7.* Influence of Sea Gyro on heave amplitude

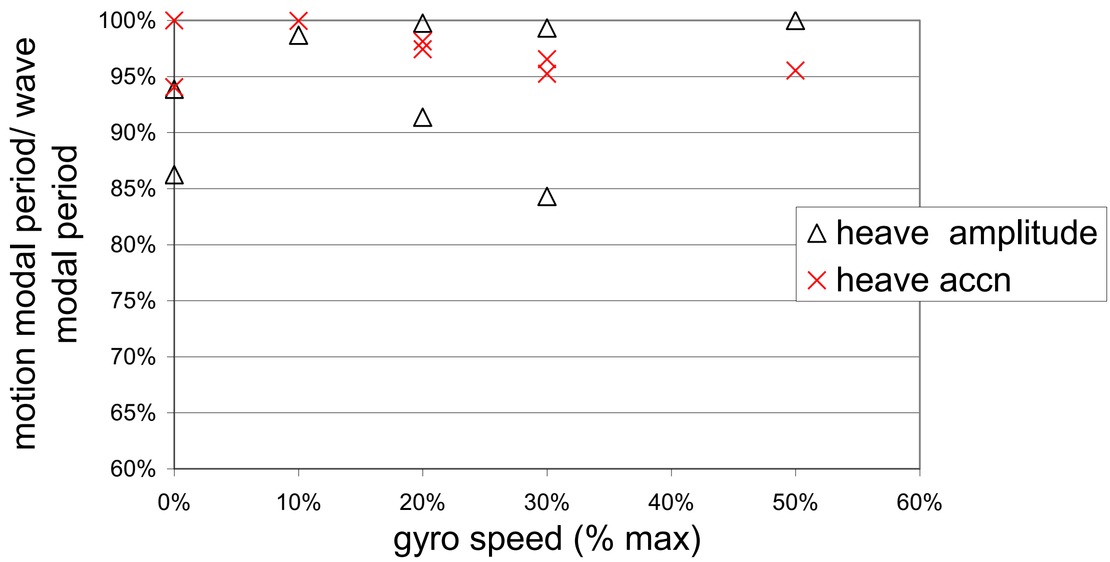



*Figure 9-8.* Influence of Sea Gyro on heave period

# 10 TABLES

| | |
|---|---|
| LOA (m) | 17.4 |
| Beam (m) | 5 |
| Draft (m) | 1.4 |
| Canoe body draft (m) | 0.55 |
| Mass (trials trim) (tonnes) | 40 |

*Table 10-1.* Main vessel particulars

| Run no. | Gyro motor setting (Hz) | Vessel hdg | Wave dir | Wind speed (kn) | Wind dir | Start time |
|---|---|---|---|---|---|---|
| 0 | 0 | 240 | 330 | 15 | 338 | 1213 |
| 1 | 5 | 240 | 330 | 15 | 338 | 1243 |
| 2 | 10 | 240 | 330 | 12 | 338 | 1312 |
| 3 | 15 | 240 | 330 | 7 | 338 | 1343 |
| 4 | 25 | 240 | 330 | 7 | 338 | 1413 |
| 5 | 10 | 230 | 320 | 10 | 325 | 1451 |
| 6 | 0 | 220 | 310 | 12 | 325 | 1522 |
| 7 | 15 | 210 | 300 | 11 | 320 | 1553 |

*Table 10-2.* Trials runs

| logger number | 040615A | 040615A | 040615A | 040615A | 040615b | 040615b | 040615b | 040615b |
|---|---|---|---|---|---|---|---|---|
| data segment | 5277-12477 | 12477-19677 | 19677-26877 | 30653-35142 | 5700-12900 | 12900-20100 | 20100-27300 | 30185-35177 |
| time segment | 11:55 - 12:55 | 12:55 - 13:55 | 13:55 - 14:55 | 15:12 - 16:12 | 11:55 - 12:55 | 12:55 - 13:55 | 13:55 - 14:55 | 15:12 - 16:12 |
| lower frequency limit [Hz] | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| upper frequency limit [Hz] | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| rms amplitude [m] | 0.13 | 0.12 | 0.11 | 0.15 | 0.12 | 0.11 | 0.11 | 0.15 |
| sig height - uncorr [m] | 0.50 | 0.46 | 0.45 | 0.61 | 0.49 | 0.44 | 0.44 | 0.60 |
| sig height - corr [m] | 0.47 | 0.43 | 0.42 | 0.57 | 0.46 | 0.41 | 0.41 | 0.57 |
| broadness parameter (epsilon) | 0.49 | 0.50 | 0.49 | 0.45 | 0.48 | 0.50 | 0.48 | 0.45 |
| mean period [s] | 3.15 | 3.21 | 3.19 | 3.31 | 3.13 | 3.21 | 3.16 | 3.30 |
| zero crossing period [s] | 3.00 | 3.06 | 3.05 | 3.20 | 2.99 | 3.06 | 3.02 | 3.19 |
| peak to peak period [s] | 2.62 | 2.66 | 2.66 | 2.85 | 2.62 | 2.65 | 2.64 | 2.85 |
| modal period [s] | 2.91 | 3.12 | 3.05 | 3.66 | 2.91 | 3.12 | 3.05 | 3.05 |

*Table 10-3.* Wave statistics

| run | gyro speed (Hz) | % max speed | wave (m) | roll (rad) | roll acc (rads^-2) | hve (m) | hve acc (ms^-2) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0% | 0.125 | 0.049 | 0.116 | 0.417 | 1.275 |
| 1 | 5 | 10% | 0.125 | 0.052 | 0.114 | 0.392 | 1.141 |
| 2 | 10 | 20% | 0.113 | 0.044 | 0.096 | 0.394 | 1.125 |
| 3 | 15 | 30% | 0.113 | 0.035 | 0.076 | 0.335 | 0.97 |
| 4 | 25 | 50% | 0.111 | 0.02 | 0.051 | 0.318 | 0.936 |
| 5 | 10 | 20% | 0.111 | 0.04 | 0.091 | 0.343 | 1.076 |
| 6 | 0 | 0% | 0.151 | 0.051 | 0.12 | 0.401 | 1.2 |
| 7 | 15 | 30% | 0.151 | 0.04 | 0.091 | 0.4 | 1.188 |

*Table 10-4.* Significant (uncorrected) motion amplitudes

| | | | Tmodal (To) (s) | | | | |
|---|---|---|---|---|---|---|---|
| run | gyro speed (Hz) | % max speed | wave | roll | roll acc | hve | hve acc |
| 0 | 0 | 0% | 2.62 | 4.33 | 3.67 | 4.47 | 2.97 |
| 1 | 5 | 10% | 2.62 | 4.43 | 3.82 | 4.70 | 2.97 |
| 2 | 10 | 20% | 2.66 | 4.47 | 3.72 | 4.82 | 2.96 |
| 3 | 15 | 30% | 2.66 | 4.54 | 3.62 | 4.79 | 2.91 |
| 4 | 25 | 50% | 2.65 | 4.37 | 3.05 | 4.82 | 2.87 |
| 5 | 10 | 20% | 2.65 | 4.42 | 3.66 | 4.40 | 2.93 |
| 6 | 0 | 0% | 2.85 | 4.30 | 3.74 | 4.47 | 3.04 |
| 7 | 15 | 30% | 2.85 | 4.46 | 3.63 | 4.37 | 3.08 |

*Table 10-5.* Motion modal periods

| | 1200 | 1500 |
|---|---|---|
| Garden Island | N14kts | NW14 |
| Swanbourne | N14 | NW14 |

*Table 10-6.* Wind data 15 June 2004. Source: www.seabreeze.com.au!

| | Hs (m) | Tmean (s) |
|---|---|---|
| sea | 0.75 | 4 |
| swell | 0.6 | 13 |
| total | 1.0 | 6 |

*Table 10-7.* Cottesloe wave data 1200hrs 15 June 2004. Source: DPI marine website