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by

Curtis A. Collins, James R. Clynch and Thomas A. Rago

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13. ABSTRACT *(maximum 200 words)*

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Abstract

The attitude characteristics of two small research vessels, a 539-ton monohull (*R/V Point Sur*) and a 419-ton SWATH (*R/V Western Flyer*), are compared. The comparison is based upon 134 (61) motion measurements carried out on the *R/V Point Sur (Western Flyer)* in 2003 and 2004. Measurements were made using a tilt meter and a vertical gyro. When the vessels were on station, root mean square roll on the *R/V Point Sur (Western Flyer)* increased 0.23 (0.12) degrees and pitch increased 0.12 (0.06) degrees per foot of sea height for seas between two and twelve feet. Corresponding on-station rates of increase for vertical acceleration for the stern at the side were 0.18 m/s^2 (0.03 m/s^2) per foot for the *R/V Point Sur (Western Flyer)* and reached ¼ g for the *R/V Point Sur* for 15-ft. seas. Similar accelerations were observed at full speed when seas greater than 10 ft. were forward of the bow on the *R/V Point Sur.* For *R/V Point Sur,* observed directional response at full speed and pitch and roll damping were in good agreement with values obtained from tank tests in 1979.

I. Vessels

The two vessels are shown in Figure 1. The *R/V Western Flyer* is a SWATH vessel which is owned and operated by the Monterey Bay Aquarium Research Institute

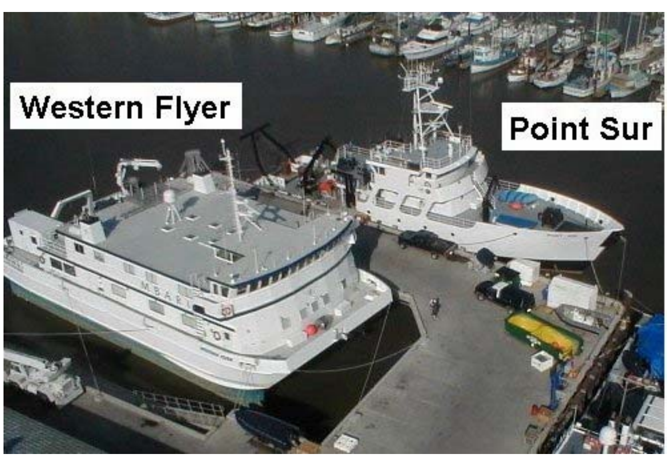


Figure 1. (left) *R/V Western Flyer* and *R/V Point Sur* alongside the MBARI Pier in Moss Landing, CA. (right) *R/V Western Flyer* in shipyard.

and *R/V Point Sur* is a monohull vessel owned by the National Science Foundation and operated by Moss Landing Marine Laboratories. The *R/V Western Flyer* is principally used with a remotely operated vehicle (ROV), although science and engineering cruises which do not require the use of a ROV are carried out on occasion. The *R/V Point Sur* is a UNOLS vessel and carries out a broad spectrum of ocean research activities in any given year. Some characteristics of the vessels are given in Table 1.

Table 1. Vessel characteristics.

Vessel	***PT. SUR***	***WESTERN FLYER***
Length	135 ft.	117 ft.
Width	32 ft.	53 ft.
Displacement, Long Tons	539 tons[1]	419 tons[2]
Daily Cost	$9,415	$23,860[3]

II. Instrumentation

Two attitude measurement systems were deployed on these vessels. An inexpensive two-axis precision tilt meter built by Applied Geomechanics[4] was used on all cruises. This measured roll and pitch to ±20° at a 4-Hz rate. On all but the first cruise on the *R/V Western Flyer,* a six-degrees-of-freedom vertical gyro built by Crossbow, Inc.[5], was used. The vertical gyro measured three accelerations and three angle rates while an internal computer estimated roll and pitch using a Kalman filter. The vertical gyro system can be sampled at a rate as high as 110 Hz. On one of the cruises on each ship the Crossbow was run at maximum rate. On the other deployments it was run at 10 Hz.

For the final cruise on the *R/V Western Flyer*, the ship's fiber optic gyro (FOG) was recorded at the same time as the tilt meter and inertial system. The FOG was installed as part of a Sperry NAVIGAT 2100/SR2100 navigation unit. Output (recording) rate was 2 Hz. and included angles and rates.

Information on sea and swell was provided by the ship's officers. Course and speed were recorded from the ship's navigation system and did not vary significantly during the period of time that ship motion was measured. Estimates of wind speed and direction were provided by the ship's officers on the *R/V Western Flyer* and by an underway data system on *R/V Point Sur.*

[1] A sister ship, *R/V Cape Hatteras,* has a displacement tonnage of 640 long tons.
[2] Design water line.
[3] Includes ROV and pilots.
[4] Applied Geomechanics (AGM) Model MD900-TW.
[5] Crossbow DMU-VGX solid state vertical gyro.

III. Deployments

The data included in this report were taken on five (four) cruises on the *R/V Point Sur (Western Flyer)*. The *R/V Western Flyer* was instrumented for a cruise from the Gulf of California to Monterey in May 2003. This cruise had only the tilt meter. In addition, the *R/V Western Flyer* was instrumented in July 2003 for a Central California hydrography cruise. The vertical gyro was also used on this cruise, sampling at its maximum rate of 110 Hz. The other two cruises on the *R/V Western Flyer* included a transit from a shipyard in Alameda to Moss Landing in November 2003 and a bathymetric mapping cruise in June 2004.

Cruises on the *R/V Point Sur* encompassed the entire year, including what are typically the worst weather conditions (during the months of March – June). In July 2003, a Central California hydrography cruise encountered similar sea conditions to those observed during the *R/V Western Flyer* July cruise. Data collected during cruises in October 2003 and January, March and June 2004 included sea conditions which forced the *R/V Point Sur* to zigzag in order to avoid heavy rolling between stations when proceeding along west-southwesterly sampling lines. *R/V Point Sur* cruises used both the tilt meter and the vertical gyro. On the first cruise, the vertical gyro was run at maximum rate; on the later cruises, it was run at 10 Hz.

Measurements were made by recording data with both instruments at the same time for about 15 minutes. Each of these 15 minute records was treated as one data sample for purposes of determining the characteristics of attitude variation. The number of samples for each cruise is shown in Table 2. Results of tilt meter measurements are tabulated in Appendix A, results of vertical gyro in Appendix B.

Table 2. Data Collection

Ship/Date	Tilt meter	Vertical Gyro	Stations	Underway
Western Flyer May 2003	27	0	13	14
Pt. Sur July 2003	45	41	15	30
Western Flyer July 2003	9	10	2	8
Pt. Sur October 2003	23	22	4	19
Western Flyer Nov. 2003	7	7	0	7
Pt. Sur January 2004	30	30	8	22
Pt. Sur March 2004	17	17	1	16
Western Flyer June 2004	18	18	9	9
Pt. Sur June 2004	19	19	4	15

IV. Data Analysis

As the first step in the analysis, the time series of roll and pitch from the two instruments were compared. The data records were similar, with the two units agreeing to within 0.2 degrees at any given time. The second step was to find the rms of the roll and pitch over each 15-minute sample. The mean rms values of roll and pitch for each of the 15-minute samples for each instrument agreed to within 0.005 degrees.

Similarly, rms accelerations were calculated for each sampling period. The coordinate system used for these measurements is shown in Figure 2. Note that x is surge and was measured along the ship's centerline with positive forward, y is sway and measured athwartships with positive starboard, and z is heave with positive downwards. Looking into these axes, a positive rotation is counterclockwise. So roll is positive when the starboard side of the vessel is moving downward, pitch is positive when the bow is moving upwards, and yaw is positive when the bow is moving to starboard.

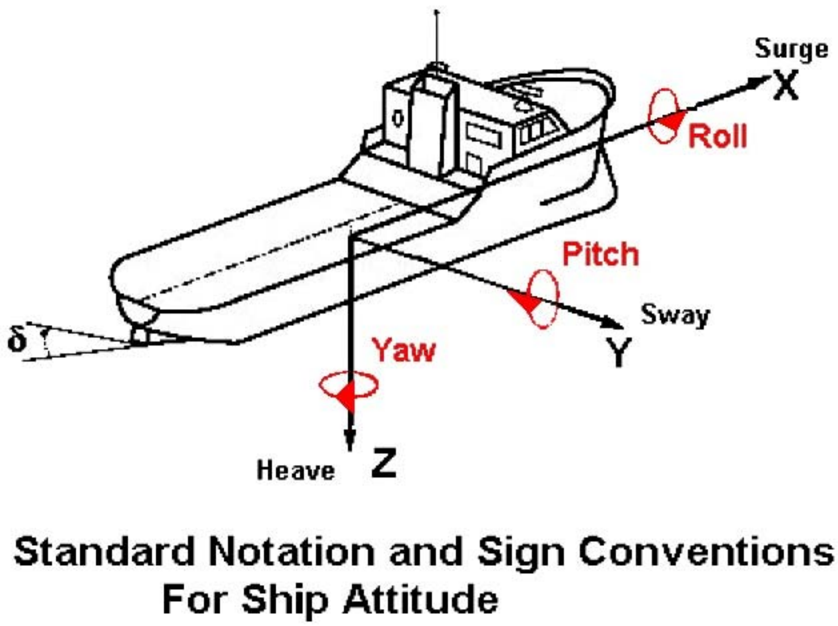


Figure 2.

On the *R/V Point Sur* the data were taken at the same location, about 1 m from the centerline and 22 m from the stern. On the *R/V Western Flyer*, two locations were used, on the centerline just in front of the moon pool and in a cabin one deck up. The data have been adjusted to a position at the outboard stern rail. This is the work area where the vertical accelerations are largest. The adjustment is made using

$$\vec{a}_L = \vec{a}_M + \dot{\vec{\omega}} \, x \, \vec{L} \, ,$$

where $\vec{a}_L = (\ddot{x}_L, \ddot{y}_L, \ddot{z}_L)$ is the acceleration at location $\vec{L}$, $\vec{L} = (L_x, L_y, L_z)$ is the offset from the measurement point, $\vec{M}$, $\vec{a}_M = (\ddot{x}_M, \ddot{y}_M, \ddot{z}_M)$ is the measured acceleration, $\dot{\vec{\omega}}$ is the time derivative of the rotation vector, $\vec{\omega} = (\omega_x, \omega_y, \omega_z)$, where ω_x is roll rate, ω_y is pitch rate, and ω_z is yaw rate in radians/s. The component equations are:

$$\ddot{x}_L = \ddot{x}_M - L_y\dot{\omega}_z + L_z\dot{\omega}_y$$
$$\ddot{y}_L = \ddot{y}_M - L_z\dot{\omega}_x + L_x\dot{\omega}_z$$
$$\ddot{z}_L = \ddot{z}_M + L_y\dot{\omega}_x - L_x\dot{\omega}_y$$

For the *R/V Point Sur,* $\vec{L}$ = (-22.0, -4.0, 0.8) m; for *R/V Western Flyer,* $\vec{L}_{moon\ pool}$ = (-22.6, -8.1, 0.0) m and $\vec{L}_{cabin}$ = (-11.3, –10.6, 4.0) m.

An alternate approach would have been to adjust the measured accelerations to the point where they are minimum, the center of gravity, $\vec{L}_{cg}$. The center of gravity represents a fixed position, which will change as equipment is moved and fuel and water consumed, through which the force of gravity acts upon a vessel. We chose the outboard stern rail in order to compare results with tank tests.

From the above, the acceleration at any point on a rigid ship can be determined from the measured acceleration as a cross product of rotation rate and distance to the measurement location. In the case of spacecraft, accelerations and rotation rates are independent and uncorrelated. But for ships, they are driven by the seas, and may be highly correlated. This means that rms values can't be substituted directly into these equations because the cross terms do not average to zero, e.g.

$$\left\langle \ddot{z}_L{}^2 \right\rangle^{0.5} \neq \left\langle \ddot{z}_M{}^2 \right\rangle^{0.5} - L_y \left\langle \dot{\omega}_x{}^2 \right\rangle^{0.5} + L_x \left\langle \dot{\omega}_y{}^2 \right\rangle^{0.5},$$

where brackets represent mean values. However, this equation can be used as a first approximation, even in the presence of high correlations, when one of the terms on the right side of the equation is much larger than the other two.

Although all accelerations were measured and listed in Appendix B, only vertical accelerations were analyzed due their relationship to habitability and working conditions on the vessel. The ratio of maximum observed acceleration to the rms acceleration was in the range 3.5 to 4.4. A ratio of 3.5 would be expected for a Gaussian distribution using the number of samples obtained during 15 minutes by the vertical gyro.

V. Sampling Issues

Two sampling issues are discussed, one dealing with the sampling rate and the other dealing with comparisons between the instruments that we used and a fiber optic gyro (FOG). The 110 Hz. data were examined to see if a lower sample rate was satisfactory. An example is shown in Figures 3 and 4, where spectra to 50 Hz. are shown for samples collected while the ship was hove to at two different stations. "On-station" data were used because motions higher than 1 Hz. were smaller than for the underway case (see below). There were spectral peaks evident at higher frequency (15, 30, and 45 Hz.), but none were at energy levels that would contaminate lower frequency roll and pitch when slower sampling was used. Note that semi-log axes are used in Figures 3 and 4 so that the frequency of the high-frequency portion of the spectrum can be easily seen.

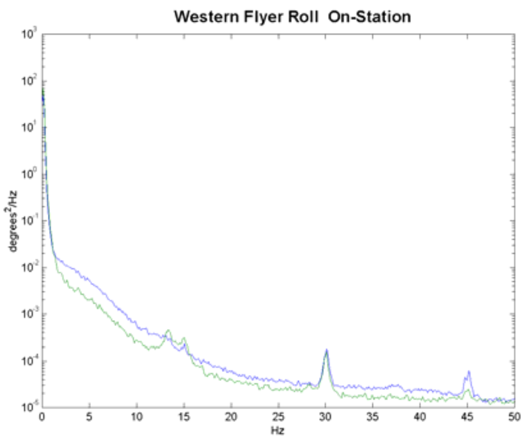


Figure 3. *R/V Western Flyer* roll to 50 Hz.

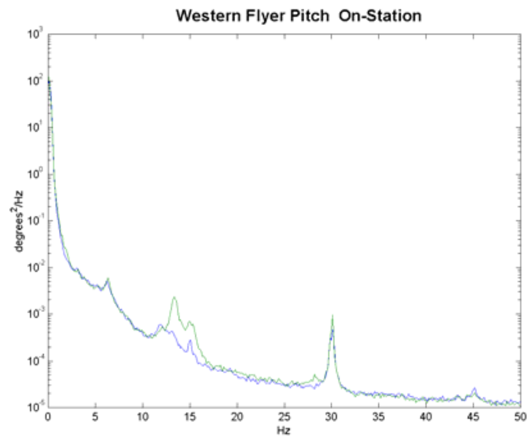


Figure 4. *R/V Western Flyer* pitch to 50 Hz.

The inertial navigation system on the *R/V Western Flyer* was replaced in 2003 with a Fiber Optic Gyro (FOG). The FOG was installed as part of a Litton Marine Systems-Sperry NAVIGAT 2100 /SR 2100. The FOG output angles and rates at 2 Hz. to an external port. The external data port had not been used prior to our cruises and it took some effort on the part of the ship's crew to get the 2-Hz. data to a computer for our use. For the June 2004 cruise, roll, pitch, roll rate, pitch rate, and yaw rate were recorded at the same time as samples were recorded by the tilt meter and vertical gyro. After removing a bias, the RMS roll and pitch in each set were determined from the three sensors. The results are shown in Figures 5 and 6 below. The three units agreed well despite the differences in sample rates. For roll, the tilt meter and vertical gyro yielded results that were somewhat greater than those of the FOG. For pitch, the tilt meter results were somewhat lower than those of the FOG, but the vertical gyro results were marginally larger.

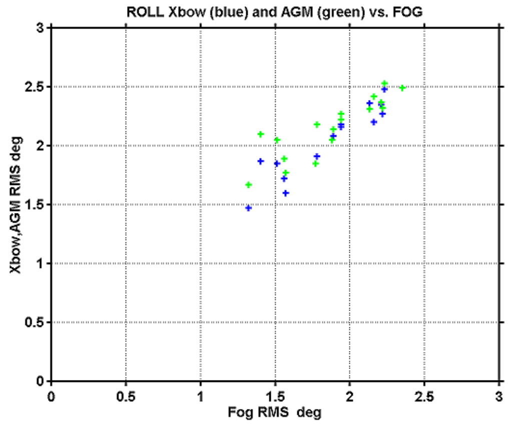


Figure 5. RMS roll from tilt meter (green) and vertical gyro (blue) vs. FOG.

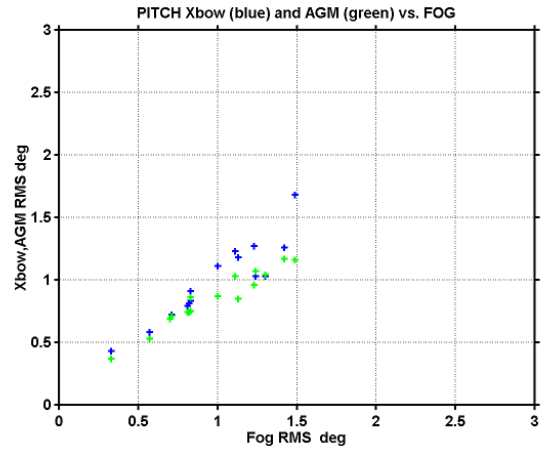


Figure 6. RMS pitch from tilt meter (green) and vertical gyro (blue) vs. FOG.

For each data set which had valid vertical gyro and FOG data, correlations were performed for five variables: roll, pitch, roll rate, pitch rate, and yaw rate. An example of the cross correlations for one data set is shown in Figures 7 and 8. The roll motion (Figure 7, blue) had notably higher correlations (>0.3) at lags greater than ± 20 s than other variables. This is due to the narrow-band character of roll, which leads to larger side bands and background levels. The pitch (Figure 7, green), roll rate (Figure 8, blue), pitch rate (Figure 8, green), and yaw rate (Figure 8, yellow) were broader band processes with small correlation values at lags greater than 5 to 10 s. For each pair, maximum correlation occurred at zero lag. These maximum correlations are tabulated in Table 3.

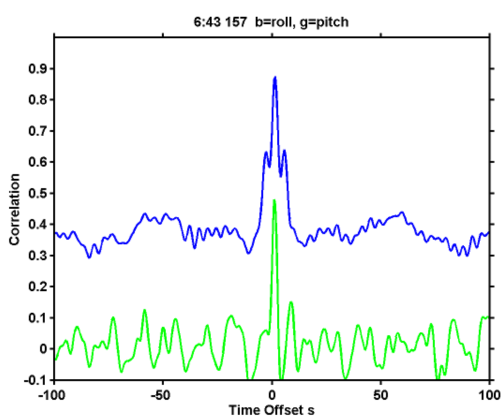


Figure 7. Cross correlation function between vertical gyro and FOG for roll (blue) and pitch (green).

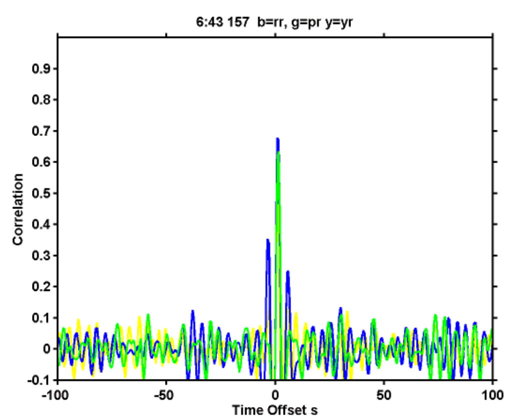


Figure 8. Cross correlation between vertical gyre and FOG for roll rate (blue), pitch rate (green) and yaw rate (yellow).

Table 3. *R/V Western Flyer* June 04 Data
Correlations between CrossBow vertical gyro and Fiber Optic Gyro

UT	Day	roll	pitch	r-rate	p-rate	y-rate
19:45	156	0.8594	0.5293	0.9517	0.9500	0.9687
21:03	156	0.9583	0.7303	0.8538	0.7311	0.6276
00:38	157	0.9417	0.6643	0.7571	0.5809	0.4422
05:01	157	0.9725	0.8094	0.9186	0.8525	0.7631
06:43	157	0.8752	0.4805	0.6778	0.6352	0.5054
16:29	157	0.9434	0.7810	0.8796	0.7913	0.6852
11:07	158	0.8832	0.5767	0.7355	0.6279	0.5273
14:34	158	0.7039	0.6518	0.5853	0.6580	0.6658
16:16	158	0.8461	0.7805	0.7893	0.7709	0.7589
17:47	158	0.7440	0.7479	0.5717	0.7304	0.7046
19:40	158	0.8244	0.8185	0.7134	0.8313	0.8284
21:39	158	0.8777	0.8369	0.8710	0.9037	0.9036
14:57	159	0.8218	0.7193	0.7971	0.7931	0.7825
15:30	159	0.7850	0.7673	0.7302	0.7232	0.6560
19:13	159	0.9032	0.6622	0.8219	0.7611	0.6365
20:43	159	0.9196	0.7100	0.8714	0.8542	0.7091

VI. Results of Pitch and Roll Measurement

Pitch and roll measurements are compared in Figure 9. The range of hull motion for the monohull was about twice that of the SWATH vessel. Roll was typically twice the pitch, but there were conditions in which the pitch exceeded the roll. For the *R/V Western Flyer* this occurred only for rms roll less than 0.5 degrees. For the *R/V Point Sur,* pitch exceeded roll when the vessel was headed directly into 3- to 5-ft seas.

On-station hull performance is shown in Figure 10. For rms wave heights of 4 feet, roll was about three times pitch. For seas greater than 4 feet, the mean motion of the *R/V Point Sur* exceeded that of the *R/V Western Flyer*, and the discrepancy increased with increasing sea height. The lines shown in Figure 10 are least squares fits. The slope of these lines is a measure of the performance of the hull, at least for seas from 2 to 12 feet. For the *R/V Point Sur (Western Flyer)* rms roll increased 0.23 (0.12) degrees per foot of sea height, while rms pitch increased 0.14 (0.06) degrees per foot of sea height (Table 4). This means that the SWATH performed about twice as well as the monohull.

Table 4. Rate of increase in rms angles with sea height. Values are in degrees per ft. These are the slopes of the least square fit lines in Figure 10.

	Slope of Roll	**Slope of Pitch**
Pt. Sur	0.23	0.14
Western Flyer	0.12	0.06

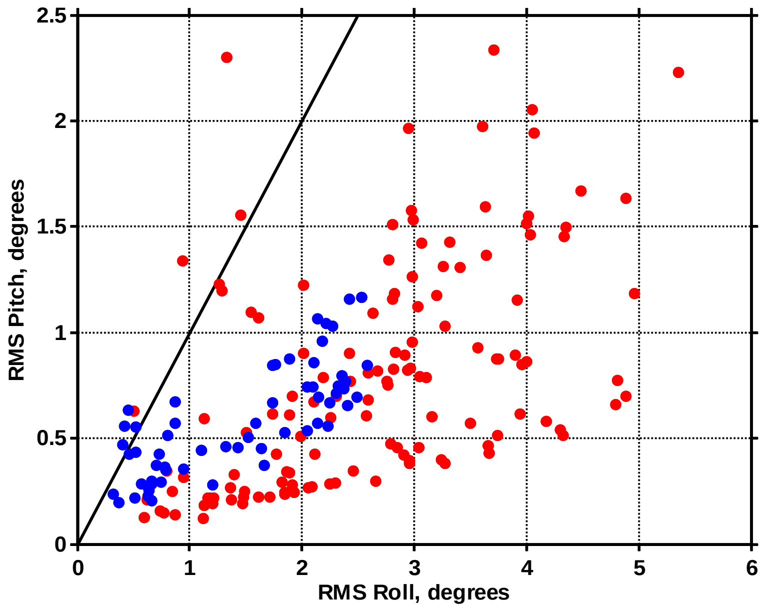


Figure 9. Pitch vs. roll. *R/V Point Sur* measurements are blue and *R/V Western Flyer* measurements are red. The black line indicates equal pitch and roll.

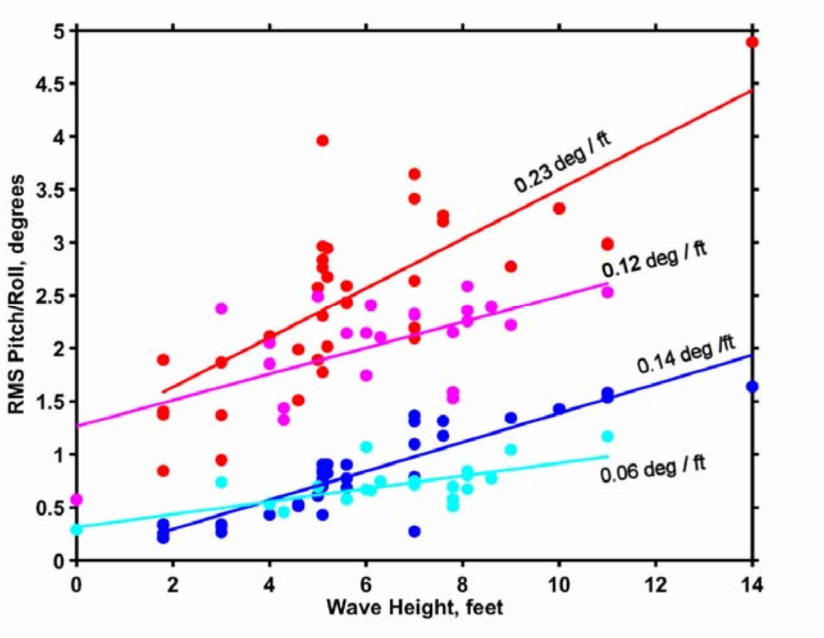


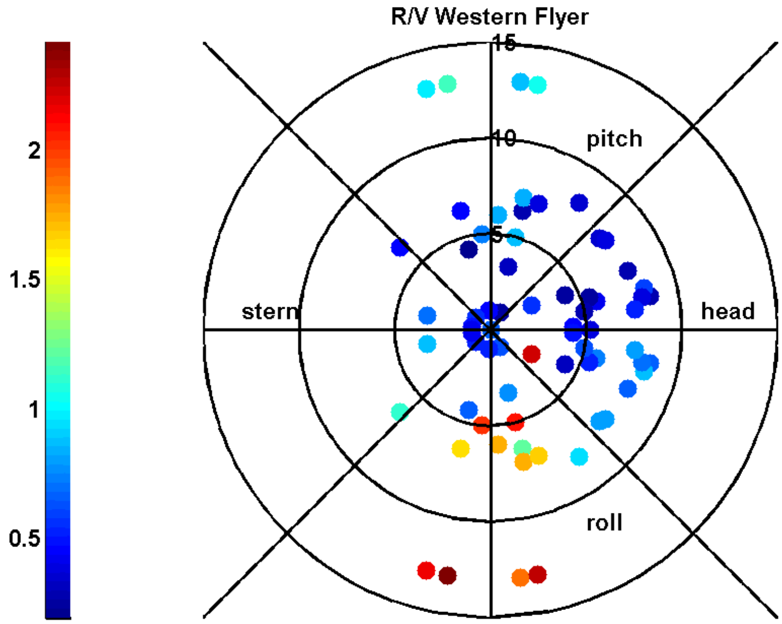
Figure 10. On-station performance. RMS pitch and roll as a function of combined wave and swell height while vessels were hove to with their heads into the seas. *R/V Point Sur* pitch measurements are blue and roll measurements are red. *R/V Western Flyer* pitch measurements are cyan and roll measurements are magenta. Lines were fitted to data using the method of least squares.

Figure 11 compares the motion of the two vessels while underway at cruising speed. The scales for the two ships shown at the left in Figure 11 differ by a factor of 2 (2.5° for the *R/V Western Flyer,* 5° for the *R/V Point Sur*). Note that symmetric response has been assumed, so that waves and swell on the port bow are represented using the same angle as those on the starboard bow. The maximum rms roll for the *R/V Western Flyer* measurements (Figure 11, upper) was 1.6°, about one third the maximum rms roll, 4.5°, for the *R/V Point Sur*, (Figure 11, lower). As seas approach 10 feet, the *R/V Point Sur* cannot move into the seas at full speed and, similarly, riding in the trough is extremely uncomfortable. In these conditions, the *R/V Point Sur* "tacks" between stations, moving into the seas at reduced speed, then putting the seas on the ship's quarter while increasing to full speed. Figure 11 (lower) reflects this practice: although large rms roll was shown, the period of the motion is long enough that the ride is quite comfortable.

Mean spectra for pitch and roll for the May *R/V Western Flyer* cruise are shown in Figure 12 (upper). These further illustrate the change in motion behavior that occurred between the on-station and underway conditions. The amplitude of the pitch and roll while on station exceeded that while underway by a factor of about ten for frequencies lower than 0.2 Hz. Both the inertia of the vessel and the action of canards (mounted inboard of the subsurface hulls: see Figure 1, right panel) dampen underway motion. Roll spectra were close to behaving in a decreasing monotonic manner with frequency, while pitch spectra show a distinct peak. On this cruise, the *R/V Western Flyer* was always moving into the seas, but the shift of the pitch from 0.08 Hz. to 0.2 Hz. was too great to ascribe to the increased frequency of wave encounter (which would increase the frequency about 0.01 Hz.). When moving through the water, pitch increased, and to a lesser extent roll also increased, at frequencies higher than 0.2 Hz. relative to on-station measurements. As a practical matter, the higher frequency motion was noticeable only on the *R/V Western Flyer* stern.

The period of roll in seconds, T_r, is related to the natural period of the vessel. For a monohull, the natural period is approximated by $T_r = fB/\sqrt{GM}$ where B is beam and GM is metacentric height, both in meters, and f is a constant which is about 0.75 $sm^{-0.5}$ (IMO, 2002). The frequency of pitch is controlled by the frequency of encounter of waves.

The spectra for *R/V Point Sur* show well-developed peaks at 0.11 Hz. for roll and 0.18 Hz. for pitch. Unlike the *R/V Western Flyer,* the *R/V Point Sur* roll at frequencies <0.06 Hz. was larger while the vessel was underway, a consequence of putting the seas on the ship's head when the vessel was on station. Like the *R/V Western Flyer,* the energy levels of the underway spectrum exceeded those for on-station at higher frequencies. Underway and on-station pitch spectra were similar with slightly larger energy densities for underway conditions except in the 0.09 to 0.15 Hz. band. The spectral peak for pitch was only slightly shifted to higher frequency, as predicted in the previous paragraph.



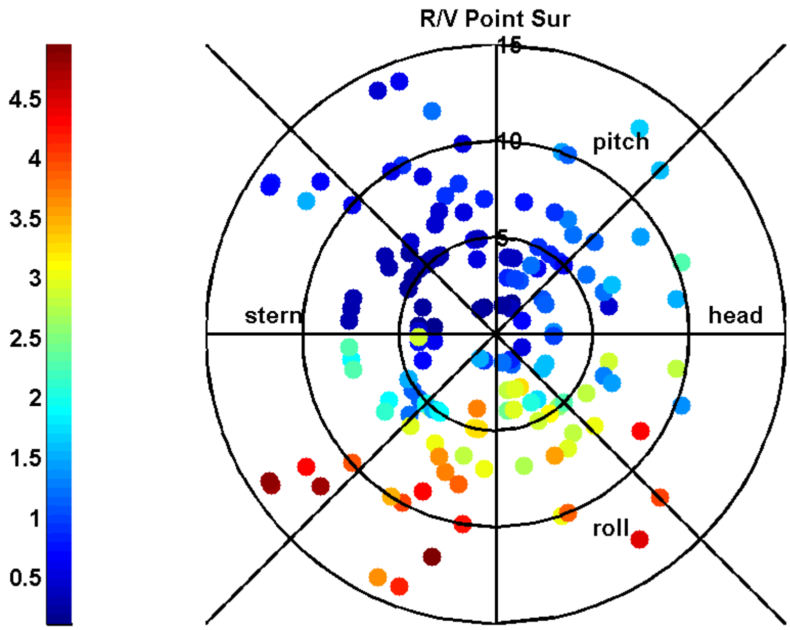


Figure 11. RMS pitch and roll at cruising speed. Data points are plotted at the head of a vector. The magnitude of the vector is the combined wave and swell height, which is zero at the origin and increases to 15 feet at the outer circle. The direction of the seas is relative to the ship's head, with symmetric response assumed. Pitch results are shown in the upper hemisphere and roll in the lower hemisphere. (upper) *R/V Western Flyer.* (lower) *R/V Point Sur.*

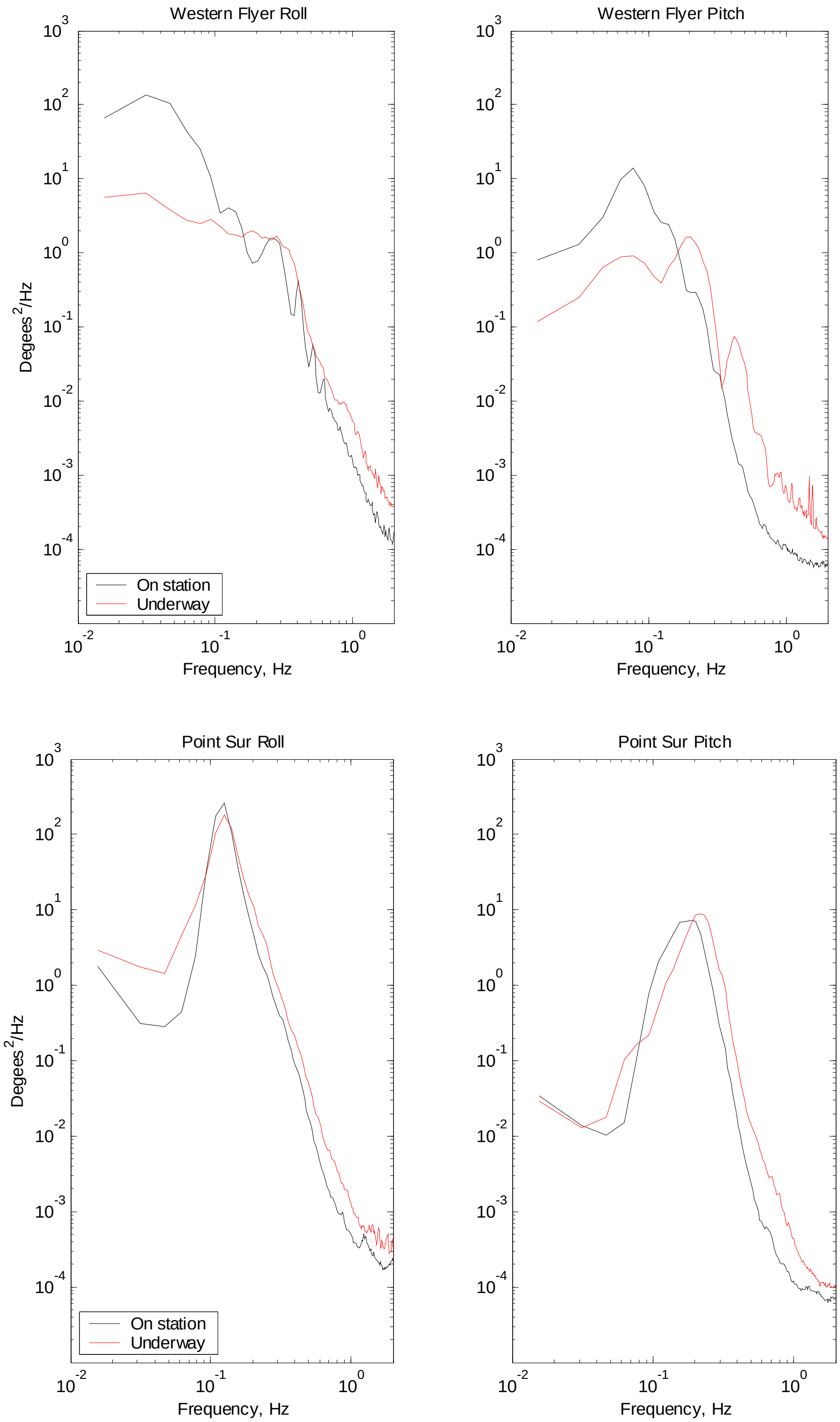


Figure 12. Mean spectra. May 2003 *R/V Western Flyer* (upper). July 2003 *R/V Point Sur* (lower). The underway spectrum is shown in red, the on-station spectrum in black. (left) Roll. (right) Pitch.

VII. Vertical Acceleration

The measured accelerations were adjusted to the outboard stern location as described above. As with the pitch and roll data, the vertical acceleration data were placed in two categories: data collected while the ship was on station and data collected while the ship was moving through the water at speeds greater than 5 knots. The vertical accelerations (maximum vertical accelerations) observed while the ships were hove-to on station are shown in the left (right) panel of Figure 13. For the vertical acceleration (maximum vertical acceleration), the minimum observed on the *R/V Point Sur*, about 0.3 m/s^2 (1.2 m/s^2), was only slightly less than the maximum observed on the *R/V Western Flyer*, about 0.4 m/s^2 (1.7 m/s^2). The contrast between the two vessels was especially marked at the largest wave heights, where both the vertical acceleration and the maximum vertical acceleration were about six times greater on the *R/V Point Sur* than on the *R/V Western Flyer*.

The least squares regression for a line that fit vertical acceleration to sea height is also shown in Figure 13. The slope of this line for vertical acceleration for the *R/V Point Sur (Western Flyer)* was 0.18 $m/(s^2$ ft.) (0.03 $m/(s^2$ ft.)) (Table 5). For maximum vertical acceleration, the slope for the *R/V Point Sur (Western Flyer)* was 0.6 $m/(s^2$ ft.) (0.1 $m/(s^2$ ft.)) (Table 5). This means that for the range of seas observed the vertical accelerations on the monohull increased at six times the rate as those on the SWATH. Since the distance from the center of gravity to the outboard stern rails of the two vessels differs, the effect of moving to another location would lower the accelerations. But the observed rate of change with increasing sea height would remain the same.

Table 5. Rate of increase of vertical acceleration with sea height. Values are in m/s^2 per ft. These are the slopes of the least squares fit lines in Figure 13.

	Slope of RMS Vertical Acceleration	**Slope of Maximum Vertical Acceleration**
Pt. Sur	0.18	0.60
Western Flyer	0.03	0.10

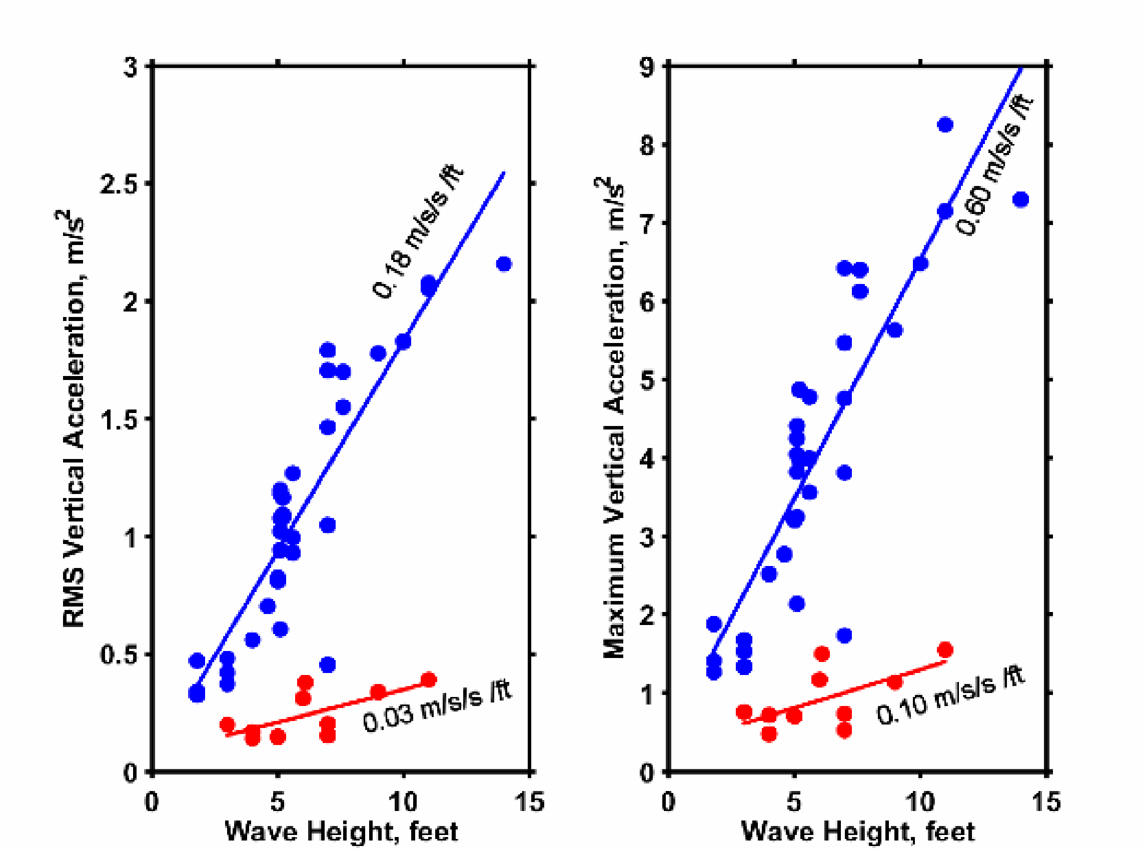


Figure 13. On-station measurements of vertical acceleration at the outboard stern rail. *R/V Point Sur* measurements are blue, *R/V Western Flyer* measurements are red. Lines were fitted to the data using the method of least squares. (left) RMS vertical acceleration as a function of combined wave and swell height while vessels were hove to with their heads into the seas. (right) Maximum vertical acceleration as a function of combined wave and swell height while vessels were hove-to with their heads into the seas.

Data collected while the ship was moving through the water are shown in Figure 14. The same scale was used for both ships. There were no observations available from the *R/V Western Flyer* for seas greater than five feet from forward of the bow or aft of the quarter. As for the on-station vertical acceleration measurements, the *R/V Western Flyer* seemed relatively unaffected by increase in sea state. In contrast, the *R/V Point Sur* was more sensitive to seas forward of the bow than aft of the quarter.

The *R/V Point Sur* acceleration can be approximated by a simple model using just the rms pitch as an independent variable. For the vertical acceleration at the side of the stern on the *R/V Point Sur,* consider a simple model that ignores roll and considers only the pitch. If the pitch, φ, consists of simple harmonic motion, $\varphi = A\sin\theta t$, then the time derivative of the rotation rate is $\dot{\omega}_y = \ddot{\varphi} = -\theta^2 A \sin t\theta$ and the rms of the vertical acceleration should be proportional to the product of L_y and θ^2. Figure 12, lower right,

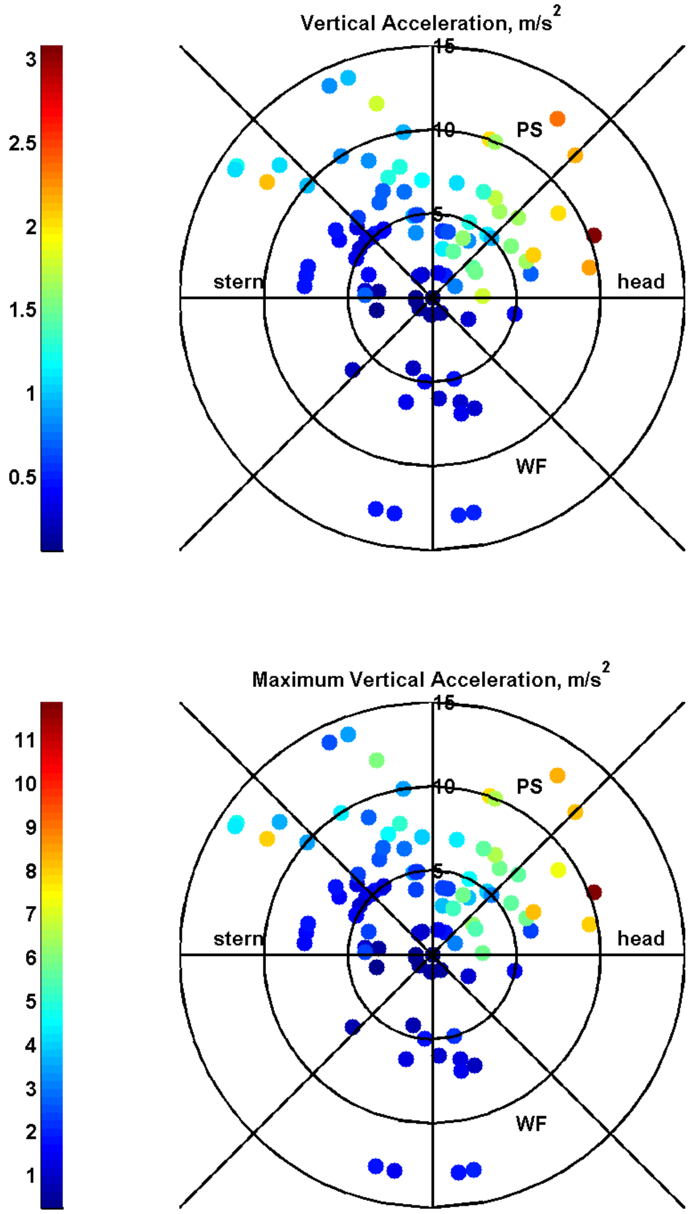


Figure 14. Vertical accelerations at cruising speed. The upper hemisphere shows *R/V Point Sur* data, the lower hemisphere *R/V Western Flyer* data. Data points are plotted at the head of a vector. The magnitude of the vector is the combined wave and swell height, which is zero at the origin and increases to 15 feet at the outer circle. The direction of the seas is relative to the ship's head, with symmetric response assumed. (upper) Vertical acceleration. (lower) Maximum vertical acceleration.

indicates that the frequency of pitch is about 4 s. Using half the ship length for L, one obtains $\theta^2 L_y$=(1.57 radian/s)^2 x 20 m = 50 (m/s^2)/radian = 0.9 m/s^2/degree-pitch-rms. (The corresponding quantity for the 8-s roll is smaller by more than an order of magnitude, $\theta^2 L_x$=(0.78 radian/s)^2 x 5 m = 3.1 (m/s^2)/radian = 0.05 m/s^2/degree-pitch-rms.) Figure 15 shows rms vertical acceleration for the stern at the side for the *R/V Point Sur* along with the predicted rate of increase of vertical acceleration due to pitch. The slope of the line that is fitted to the data using the method of least squares had a slope of 1.3 m/s^2/degrees-pitch-rms. The difference, 0.4 m/s^2/degree-pitch-rms must be dominated by the vertical motion of the center of gravity. Hence, the vertical motion at the side of the stern of the *R/V Point Sur* can be approximated as $\ddot{z}_{PtSurStern} = 1.3$ *degrees-pitch-rms.

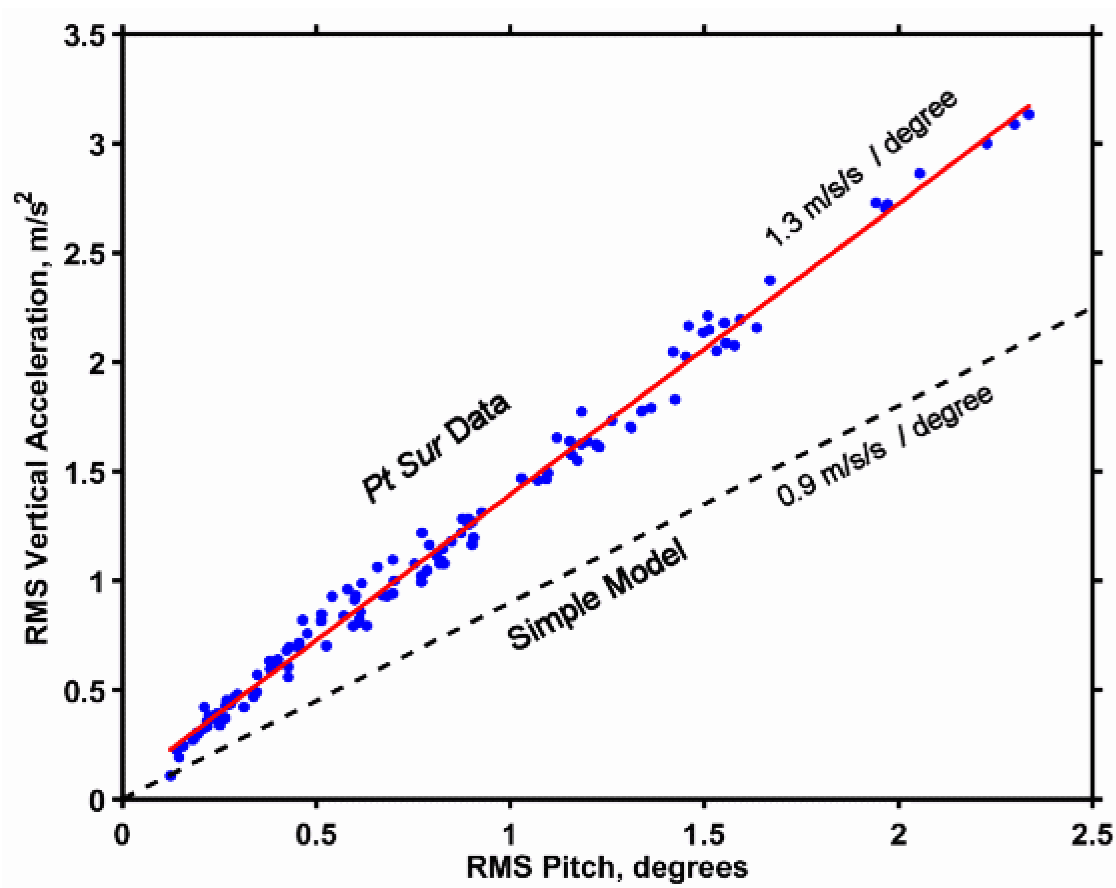


Figure 15. *R/V Point Sur* vertical acceleration at the outboard side of the stern vs. pitch. The dashed black line shows the rms vertical acceleration due to pitch predicted from 4-s seas and the red line shows a least squares fit through the data.

Data from the *R/V Western Flyer* do not seem to fit any simple model as data from the *R/V Point Sur*. The smaller water plane area and the submerged pontoons clearly reduce the buoyancy forces, the increased transverse moment of inertia acts to reduce roll, and the underwater canards reduce pitch when moving through the water. The net effect is not only to reduce the amplitude of motion, but also to shift it to lower frequency. So the ratio

$$\ddot{z}_{PtSur} / \ddot{z}_{WesternFlyer} \propto \theta^2_{PtSur} / \theta^2_{WesternFlyer},$$

which was 2.4 for roll and 64 for pitch, contribute to the reduced effectiveness of a given sea condition on vertical accelerations on the *R/V Western Flyer* relative to the *R/V Point Sur*, as seen in Figures 13 and 14.

VIII. Comparison with Tank Tests

Model tests were conducted at Stevens Institute (DeSaix and Numata, 1979) and MIT (Chryssostomidis, 1979) for the Matzer-designed hull that served as the basis for the Cape Class research vessels. The Stevens' tests produced an average period and damping factor of 7.9 s and 0.041, respectively, for a vertical center of gravity 12.9 ft. above baseline and a transverse metacentric height of 4.22 ft. The observed roll period for the *R/V Point Sur* was 8.3 s (Figure 12, lower left) and the damping factor 0.06. (The method calculating the damping factor is based upon that described by Cartwright and Rydill, 1957.) Observed pitch period was 5.3 s and damping factor 0.09 (Figure 12, lower right). Note that tank tests did not include bilge keels.

The MIT seakeeping tests measured absolute vertical acceleration at the side of the stern deck at four speeds (0, ¼, ½, and full speed), five headings (head, bow, beam, quartering and stern), and significant wave heights of 6, 9, and 12 feet.[6] Results of the MIT tests were that (1) angular acceleration was largely independent of speed, (2) the Matzer 120 exceeded ¼ g (2.5 m/s^2) acceleration 82 % of the time for seas greater than 6 feet at design speed, and (3) the hull characteristics fell between those of the *R/V Iselin* and *R/V Oceanus*, which were considered sea-kindly vessels. The ¼-g criterion relates to ability to work on deck. Summary curves of vertical acceleration at the side in 12-ft. seas at zero and full speed were taken from the Gilbert Associates report (1979), and are shown in Figure 16.

Since the *R/V Point Sur* always hove-to with the seas almost dead ahead, there is only one point from Figure 13 for comparison with tank results. This showed 6.5 $ft./s^2$ observed versus 5 $ft./s^2$ predicted. A full speed curve was generated from the data shown in Figure 13 for seas greater than 9 ft. by fitting a parabola to the observed data. This parabola is shown in Figure 16 as a blue line. Both model tests and vessel measurements at full speed clearly show the reduction in vertical accelerations that were associated with lowering of the frequency of encounter that occurred when the model or ship was moving in the same direction as the waves,

[6] The MIT tests included a 120-ft. and a 160-ft. version of the Matzer design. It concluded that "unless the ships are involved in a mission where operating ability is of paramount importance, a difference of less than 6% in operating ability resulting from a 40-ft. increase in length is usually not justified."

$$\sigma_D = \sigma - (\frac{V\sigma^2}{g})\cos\theta,$$

where σ is the frequency of the waves, V the ship speed, g the gravitational acceleration, θ the angle of incidence of the waves, and σ_D the frequency of encounter (Cartwright and Rydill, 1957). While it is tempting to associate the greater observed stability for bow and beam seas to bilge keels, it is difficult to understand why this didn't occur for quartering seas as well. There were no observations for the case when seas were on the stern of the *R/V Point Sur*.

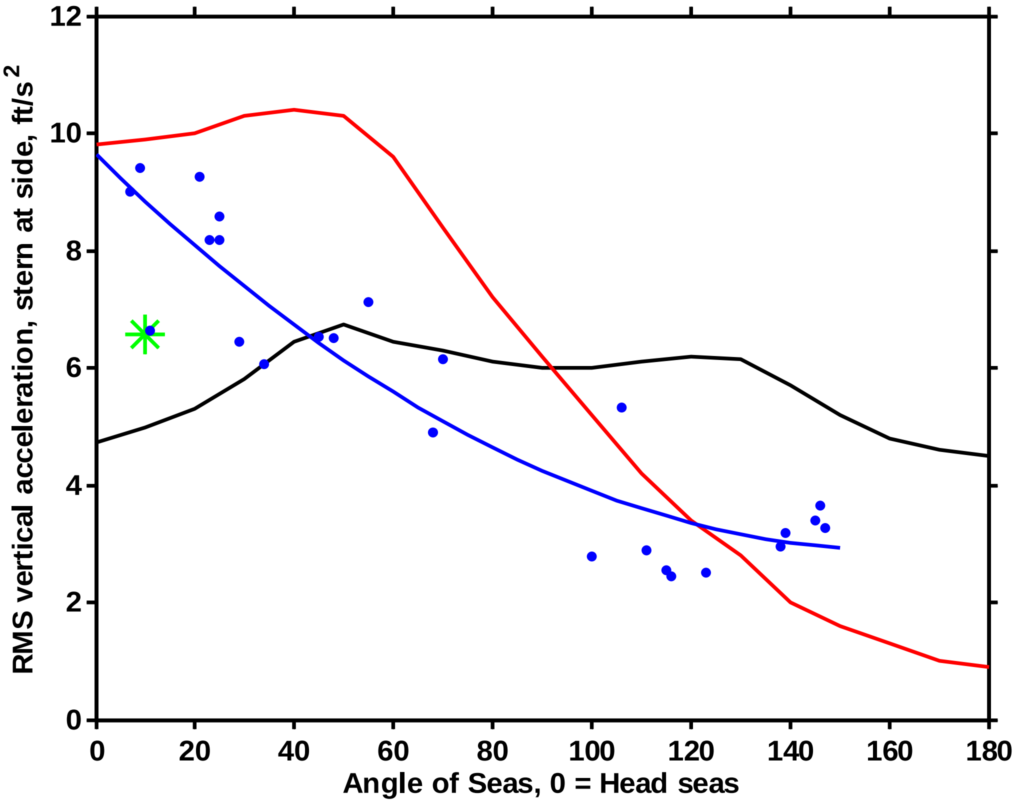


Figure 16. RMS vertical accelerations, stern at side, for 12-foot seas from tank tests performed on the Matzer 120 hull compared to observed vertical accelerations measured on *R/V Point Sur* in similar seas. The black line represents performance when the model was hove-to and the red line represents full speed. *R/V Point Sur* measurements when hove-to (full speed) are shown by the green asterisk (blue dots). The blue line is the least squares fit of a parabola to the full speed data.

The only available model test for the *R/V Western Flyer* focused on the relative perturbations to hull performance that would be caused by three different modifications to sponsons and struts that were under consideration to strengthen the vessel (Muselet et al., 1997). Hence, there are few comparisons that can be made with measurements. For 2.3-m head seas and a stationary model, vertical accelerations of 1.0 m/s^2 were measured, but observed vertical accelerations (Figure 13) were only 0.3 m/s^2 for this sea state. The *R/V Western Flyer* tests also produced estimates of roll (pitch) and decay of 0.39 (0.54). The value for the *R/V Western Flyer* pitch decay calculated from Figure 12 (upper right) was 1.25, about twice that from the tank test.

IX. Discussion

The objective of this study was to compare the motion of SWATH and monohull research vessels of about the same size in typical Central California sea conditions. It is well known that SWATH vessels have a smoother ride, and the first clues of the degree to which this is true are the glasses and cups, often partially filled, that are left on tables and desks, and the vials and beakers sitting on lab benches, all unsecured. This study documented a quantitative measure of how much better the ride on the SWATH is: for on-station work, with increasing seas, rms pitch and roll (vertical acceleration) increase on the monohull at three (six) times the rate of the SWATH. Dinsmore (2001) reported a ratio of about 4 for the vertical acceleration of a 95-ft. USCG cutter compared to the 89-ft. SWATH *Kaimalino*.

The ¼-g criterion suggests that on-station work on the stern of the *R/V Point* Sur will become difficult as sea heights approach 15 ft. Usually at about 12 ft. conditions on the after deck become difficult, because water coming over the stern is sufficient that operations which involve removal of the safety lines are unwise. Two of the authors have launched XBTs at the leeward side of the stern with seas greater than 15 ft. and have found the ride acceptable, although it was necessary to use one hand to hold onto the rail. If the ship is not rolling too heavily, it is possible to launch and recover CTDs (from midships) with an experienced crew in 15-ft. seas. But the problem is getting from one station to the next, especially when the course lies in the trough, as is usually the case. Even with 9- to 10-ft. seas, the motion is sufficiently uncomfortable that the ship's officers must steer into the seas at reduced speed and, when the course to station places the seas a few points abaft the beam, change course to the station while resuming full speed. The net result is that running time between stations is doubled or tripled.

The shortcomings of a SWATH are not related to its ride: when moving at full speed into either 15-ft. head or beam seas there is very little increase in motion. Disadvantages are that the costs of building and maintaining a SWATH are greater than those for a monohull. The working deck on the *R/V Western Flyer* is about four times as far from the sea surface as on the *R/V Point Sur*, which can be a complicating factor in getting some kinds of equipment on and off the deck, especially when the sea surface is rough. Finally, when the scientific payload is large, as for mooring cruises, it might take a SWATH several trips to carry out the work that a monohull could do in a single cruise. In an ideal world, the researcher would have both kinds of vessels available and use the one that is best adapted to his research program.

The measurements reported here were piggybacked on existing cruises, so we felt we could not ask to modify courses purely for the sake of observing attitude response. This led to some gaps in the directional responses presented in Figures 11 and 14. Data regarding sea conditions were obtained from visual observations made by the ship's officers. Observations at night were problematic, and observations during both day and night lacked information on wave frequency. Better characterization of sea (forcing) conditions is essential for better understanding of the physical reasons for the responses observed. The use of the ship's radar to provide this information would be ideal. It would have been better to obtain more samples from the *R/V Western Flyer*, but unexpected repairs took it out of service in late winter/early spring 2004.

Acknowledgements

This project was sponsored by the Office of Naval Research, and we very much appreciate the interest and encouragement of John Freitag. Steve Etchemendy and Chris Grech provided access to the *R/V Western Flyer,* helped arrange for measurements, and provided reports of tank tests. Dan Chamberlain arranged for collection of FOG data on the *R/V Western Flyer.* Captain Steve Bliss gave advice regarding operating characteristics of *R/V Point Sur*. Mike Prince tracked down tank test results for the Cape class vessels. Bruce Hutchinson of Glosten, Inc., assisted in interpreting tank tests for *R/V Western Flyer*.

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Appendix A. Pitch and Roll Observations.

Tables of pitch and roll observations are given in this appendix. The ship, month, and year for each set of observations are stated prior to the appropriate set. Time is given as either UT or Local Time (PST = UT-8 or PDT = UT-7, depending on the time of year), while day is the yearday. Units are degrees rms for roll and pitch, knots for ship and wind speeds, and feet for sea height, seas, and swell. The direction of the winds and seas is the geographic direction from which each is coming. UW identifies when the ship is on station (UW=0). NPts is the number of samples collected for that observation. Details regarding environmental data collection are given in Section III of this report.

R/V Western Flyer, May 2003

					Ship		Sea		Wind				
PDT	Day	Roll	Pitch	UW	Heading	Speed	Height	Dir.	Speed	Dir.	NPts	Seas	Swell
2100	143	0.746	0.295	1	299	9.8	3.4	225	8	248	7070	1.5	3
1400	144	0.732	0.424	1	300	9.8	5.7	315	26	315	5881	4	4
1800	144	2.148	0.694	0	315	0	7.8	315	25	315	6699	5	6
0200	145	2.252	0.668	0	315	0	8.1	315	28	315	7389	4	7
1100	145	0.664	0.284	1	327	9.8	8.5	315	28	315	6264	6	6
1400	145	1.586	0.573	0	330	0	7.8	315	22	315	8054	5	6
2200	145	0.868	0.569	1	330	9.8	8.3	315	32	315	9814	4.5	7
1000	146	2.392	0.771	0	50	0	8.6	315	18	315	5608	5	7
1500	146	0.943	0.355	1	10	10.5	8.1	315	25	315	7988	4	7
1900	146	2.585	0.843	0	305	0	8.1	315	31	315	8014	4	7
2200	146	0.706	0.373	1	327	8.5	8.1	315	32	315	5868	4	7
0300	147	2.355	0.797	0	340	0	8.1	315	27	315	6709	4	7
1100	147	0.641	0.254	1	338	10.7	7.8	315	22	315	6904	3.5	7
1300	147	1.525	0.506	0	265	0	7.8	315	18	315	6402	3.5	7
1600	147	0.510	0.218	1	333	9.7	5.4	315	16	315	7617	2	5
2000	147	1.322	0.459	0	310	0	4.3	315	16	315	7650	1.5	4
0100	148	0.374	0.197	1	315	9.7	5.2	315	11	315	6738	1.5	5
0800	148	0.569	0.286	0	307	0	0.0	315	3	68	6988	0	0
1200	148	0.320	0.235	1	290	10	4.3	315	13	292	7262	1.5	4
1700	148	1.433	0.456	0	290	0	4.3	292	18	270	10433	1.5	4
2200	148	0.462	0.427	1	290	10.7	4.3	292	20	292	8202	1.5	4
0000	149	2.140	0.572	0	300	0	5.6	292	15	292	7286	2.5	5
1000	149	1.741	0.666	0	293	0	6.0	315	12	315	8872	2.5	5.5
1500	149	0.787	0.351	1	355	10.5	7.4	315	13	315	8059	2.5	7
1800	149	0.780	0.364	1	353	10	7.6	315	27	315	7592	3	7
1900	149	2.101	0.745	0	310	0	6.3	315	27	315	8324	2	6
2200	149	0.806	0.513	1	323	9.7	7.6	315	16	325	6886	3	7

R/V Western Flyer, July 2003

					Ship		Sea		Wind				
PDT	Day	Roll	Pitch	UW	Heading	Speed	Height	Dir.	Speed	Dir.	NPts	Seas	Swell
0301	189	1.206	0.281	1	240	9.9	6.4	315	17	315	13600	4	5
0925	189	2.406	0.655	0	237	0	6.1	315	1	315	11145	3.5	5
0509	190	1.742	0.845	1	239	10.2	7.1	315	29	315	6720	5	5
1632	190	0.634	0.270	1	326	10	5.0	315	19	315	6708	3	4
1552	191	0.660	0.207	1	60	10	4.3	315	16	338	6472	1.5	4
0340	192	1.637	0.450	1	59	10	6.4	315	27	315	6374	4	5
0506	192	1.102	0.442	1	177	10.4	6.4	315	27	315	8939	4	5
1125	192	0.868	0.674	1	122	12.3	3.4	315	22	315	10564	1.5	3

R/V Western Flyer, November 2003

UT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
1718	328	0.665	0.297	1	277	10	0.0	270	4.3	317	7723	0	0
1824	328	0.629	0.226	1	209	12.5	1.0	270	9	309	5927	1	0
1915	328	0.518	0.434	1	174	13.7	1.0	270	6	200	7425	1	0
2019	328	0.521	0.552	1	160	14	1.0	300	11	320	5435	1	0
2130	328	0.455	0.631	1	130	14	1.0	300	12	293	6640	1	0
2226	328	0.423	0.559	1	119	14	1.0	300	12	293	5317	1	0
2319	328	0.401	0.471	1	112	13.5	1.0	300	10	315	6105	1	0

R/V Western Flyer, June 2004

UT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
1747	156	2.236	0.559	1	245	10.2	2.5	275	18	275	1783	2.5	0
2103	156	2.373	0.735	0	318	0.0	3.0	300	24	300	6630	3.0	0
0038	157	2.323	0.748	0	325	0.0	7.0	315	24	317	7321	7.0	0
0500	157	2.308	0.711	0	322	0.0	7.0	315	25	322	6025	7.0	0
0642	157	1.666	0.372	1	241	7.4	7.0	310	27	310	6271	7.0	0
1628	157	2.049	0.534	0	305	0.0	4.0	315	16	315	6365	4.0	0
2010	157	1.849	0.525	0	305	0.0	4.0	314	20	314	6771	4.0	0
2346	157	2.487	0.693	0	324	0.0	5.0	338	26	333	4702	5.0	0
1106	158	2.531	1.165	0	335	0.0	11.0	327	32	327	8828	11.0	0
1434	158	1.890	0.874	1	50	10.5	13.0	327	27	327	13515	13.0	0
1605	158	2.272	1.029	1	46	9.5	13.0	327	27	327	7374	13.0	0
1746	158	2.182	0.958	1	75	8.5	13.0	330	30	330	9072	13.0	0
1940	158	2.422	1.158	1	70	9.5	13.0	330	30	330	5543	13.0	0
2138	158	1.766	0.847	1	56	9.2	6.0	330	24	300	6061	6.0	0
1456	159	2.103	0.857	1	250	12.7	5.0	325	20	325	3979	5.0	0
1530	159	2.049	0.744	1	230	12.9	5.0	325	20	325	5991	5.0	0
1913	159	2.144	1.066	0	315	0.0	6.0	316	24	316	6003	6.0	0
2042	159	2.218	1.041	0	317	0.0	9.0	317	26	317	6223	9.0	0

R/V Point Sur, July 2003

PDT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
1105	202	2.106	0.671	1	252	9.1	4.0	315	7.3	211	5399	0	4
1152	202	1.863	0.340	0	106	0.9	3.0	315	4.9	211	4800	0	3
1441	202	2.817	0.826	1	237	9.2	3.0	315	10	164	6160	0	3
1832	202	3.732	0.874	1	228	8.9	5.0	292	7.4	193	7457	0	5
1934	202	1.886	0.611	0	293	1.2	5.0	292	4.9	218	5158	0	5
2034	202	2.589	0.810	1	243	9.6	5.0	292	5.2	219	6401	0	5
2119	202	2.572	0.607	0	300	0.7	5.0	292	2.8	236	6143	0	5
0003	203	3.107	0.788	1	236	9.3	5.0	292	4.3	283	8207	0	5
0239	203	2.761	0.771	0	304	1.2	5.1	292	8.1	319	8303	1	5
0446	203	2.964	0.829	0	305	1.6	5.1	292	11.8	319	6832	1	5
0741	203	1.614	0.223	1	156	9.4	5.2	292	11.3	323	9217	1.5	5
0838	203	2.943	0.823	0	312	1.0	5.2	292	11.1	325	5886	1.5	5
0929	203	1.719	0.222	1	157	9.1	5.1	292	10.3	332	8375	1	5
1218	203	1.204	0.194	1	155	9.3	6.1	292	13.2	324	5357	1	6
1301	203	2.434	0.771	0	298	0.8	5.6	292	13.6	325	5398	1	5.5
1805	203	2.673	0.818	0	293	1.0	5.2	292	15.4	309	6351	1.5	5
1851	203	1.134	0.182	1	153	9.2	5.2	292	16	321	9583	1.5	5
1959	203	2.013	0.902	0	316	1.4	5.2	292	16.1	315	7186	1.5	5
2059	203	1.131	0.184	1	146	9.1	5.2	292	15.6	331	9121	1.5	5
0150	204	1.215	0.220	1	140	8.9	5.1	292	11.4	326	7706	1	5
0249	204	2.837	0.905	0	311	1.5	5.1	292	13.5	311	5767	1	5
0809	204	3.961	0.848	0	325	1.8	5.1	292	9.6	331	5828	1	5
0809	204	3.961	0.848	0	8	1.8	5.1	292	9.6	331	5828	1	5
0857	204	1.483	0.221	1	139	8.9	5.1	292	8.1	327	7591	1	5
1323	204	2.661	0.297	1	64	9.1	5.1	292	9.3	325	8910	1	5
1617	204	2.304	0.697	0	322	1.0	5.1	292	9.1	327	5629	1	5
1910	204	1.930	0.244	1	67	9.8	5.1	292	10.7	321	5998	1	5
2017	204	1.771	0.427	0	310	0.7	5.1	292	7	320	5061	1	5
2046	204	1.491	0.251	1	62	10.0	5.1	292	11.2	319	5562	1	5
0214	205	1.134	0.594	1	295	2.4	3.0	292	4	117	8156	0	3
2118	205	1.264	1.229	1	294	9.5	3.0	292	3.3	245	8590	0	3
0015	206	1.612	1.071	1	329	9.3	3.0	292	1.8	195	6820	0	3
0302	206	1.547	1.096	1	323	9.3	3.0	292	2	310	6123	0	3
0845	206	0.941	1.339	1	290	9.6	3.0	292	8.4	122	8334	0	3
1221	206	3.275	1.029	1	358	9.5	3.0	292	10.7	188	5021	0	3
1303	206	2.983	0.955	1	3	9.2	3.0	292	7.4	274	5725	0	3
1038	207	1.366	0.265	0	237	0.9	3.0	292	6.2	269	8047	0	3
1310	208	0.946	0.314	0	278	0.8	3.0	292	6.7	269	6813	0	3
1525	208	0.844	0.251	0	269	0.7	1.8	292	7.9	248	5346	1	1.5
0055	209	1.372	0.211	0	174	2.1	1.8	292	3.4	253	5884	1	1.5
0316	209	1.163	0.219	1	356	1.9	1.8	315	4.3	278	7289	1	1.5
1219	210	1.887	0.338	0	186	0.6	1.8	270	4.1	295	7648	1	1.5
1347	210	1.399	0.330	0	164	0.8	1.8	270	8	230	8222	1	1.5
1502	210	1.125	0.121	1	62	10.0	1.8	-1	8	258	8771	1	1.5

R/V Point Sur, October 2003

PST	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
0905	302	2.852	0.457	1	239	9.2	6.0	225	10.9	265	6306	6.0	0
1312	302	2.770	0.753	1	237	8.2	7.0	315	14.6	355	6166	7.0	0
1605	302	4.298	0.540	1	215	9.1	10.0	315	22	344	4772	10.0	0
1735	302	3.321	1.425	0	325	1.6	10.0	315	26	340	13911	10.0	0
1827	302	4.001	0.863	1	196	8.6	10.0	315	28	350	4672	10.0	0
2139	302	2.976	1.578	0	335	1.3	11.0	315	28	340	6936	11.0	0
2305	302	3.706	2.335	1	324	5.5	12.0	315	35	347	9109	12.0	0
0144	303	3.661	0.464	1	199	9.1	14.0	315	31	356	6652	14.0	0
0520	303	5.354	2.227	1	308	5.4	14.0	315	35	341	10190	14.0	0
0741	303	4.177	0.580	1	204	8.0	14.0	315	28	342	6352	14.0	0
0910	303	4.888	1.635	0	340	1.9	14.0	315	29	337	5989	14.0	0
1105	303	4.807	0.772	1	101	9.2	14.0	315	28	334	8001	14.0	0
1618	303	4.883	0.697	1	102	9.1	14.0	315	28	340	7068	14.0	0
1855	303	4.790	0.657	1	94	8.7	12.0	315	20	338	10609	12.0	0
2029	303	2.991	1.532	0	333	1.3	11.0	315	20	335	3697	11.0	0
2203	303	3.947	0.617	1	93	8.7	10.0	315	15	327	6637	10.0	0
0144	304	3.504	0.571	1	78	9.2	10.0	315	22	321	4950	10.0	0
0425	304	3.069	1.420	1	25	8.1	10.0	315	21	323	7154	10.0	0
0759	304	3.037	1.120	1	358	9.0	7.0	315	8	345	4557	7.0	0
1015	304	1.286	1.199	1	294	7.8	6.0	315	5	111	6906	6.0	0
1203	304	2.261	0.598	1	0	8.1	5.0	315	4	168	5717	5.0	0
1539	304	1.826	0.294	1	165	7.3	5.0	292	20	83	5426	5.0	0
1918	304	0.736	0.158	1	84	9.4	4.0	270	10	105	7414	4.0	0

R/V Point Sur, January 2004

UT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
0140	28	2.812	1.159	1	237	9.1	5.6	270	9	308	5707	2.5	5
0452	28	2.827	1.183	1	240	9.0	6.5	292	17	326	10923	2.5	6
1241	28	1.850	0.245	1	152	10.2	6.5	300	21	343	5325	2.5	6
1556	28	1.915	0.279	1	145	9.3	7.6	315	20	338	7378	3	7
1957	28	2.249	0.284	1	140	8.7	7.6	315	19	347	5646	3	7
2300	28	3.197	1.173	0	336	1.0	7.6	310	20	340	6523	3	7
0152	29	2.053	0.266	1	144	8.9	7.6	310	21	340	6135	3	7
0426	29	3.257	1.312	0	333	0.9	7.6	310	22	328	7723	3	7
0618	29	2.301	0.289	1	144	9.1	7.6	310	22	338	5696	3	7
1412	29	3.631	1.593	1	9	5.1	7.6	310	20	349	6388	3	7
1632	29	3.749	0.876	1	60	8.5	7.6	310	21	349	5726	3	7
2113	29	1.453	1.556	1	292	8.0	6.5	315	16	330	4784	2.5	6
2232	29	2.959	0.393	1	88	8.4	6.5	315	19	332	6763	2.5	6
0201	30	3.045	0.455	1	74	8.9	6.5	315	22	332	6368	2.5	6
0502	30	2.790	0.476	1	60	8.4	6.5	315	22	318	12452	2.5	6
2108	30	2.423	0.901	0	336	1.5	5.6	315	17	302	6109	2.5	5
0413	31	1.331	2.299	1	294	6.9	10.3	315	26	312	6983	5	9
0706	31	4.055	2.054	1	340	5.0	10.3	315	25	319	8104	5	9
1240	31	2.952	1.964	1	322	5.6	7.2	340	10	348	13911	1.5	7
1745	31	2.810	1.509	1	326	6.4	9.5	315	24	298	12903	3	9
2140	31	4.004	1.513	1	344	5.7	9.5	315	22	331	5975	3	9
2322	31	4.068	1.941	1	340	5.1	9.7	315	25	322	4895	3.5	9
0019	32	3.608	1.971	1	338	5.2	9.7	315	27	312	5565	3.5	9
0235	32	4.036	1.460	1	3	5.3	9.7	315	24	318	6362	3.5	9
0754	32	1.507	0.525	0	270	1.0	4.6	275	7	90	13941	1	4.5
0847	32	1.987	0.510	0	86	1.1	4.6	275	6	65	8526	1	4.5
0323	34	2.588	0.682	0	150	1.7	5.6	270	16	235	5869	2.5	5
2107	35	2.190	0.785	0	280	0.9	7.0	275	12	303	4070	2.5	6.5
2319	35	2.092	0.269	0	60	9.4	7.0	275	21	305	13369	2.5	6.5
2242	36	0.599	0.124	1	83	9.6	3.2	270	10	280	3838	1	3

R/V Point Sur, March 2004

UT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
1643	69	0.794	0.346	1	330	9.9	1.5	270	5	298	4366	0	1.5
1746	69	0.776	0.146	1	146	9.6	1.5	270	3	290	5701	0	1.5
1817	69	0.868	0.141	1	155	9.5	1.5	270	5	303	5599	0	1.5
1953	69	1.181	0.217	1	194	9.8	1.5	270	4	267	6277	0	1.5
2028	69	0.505	0.630	1	297	9.1	1.5	270	11	285	7181	0	1.5
2130	69	1.469	0.194	1	33	9.7	1.5	270	15	291	5580	0	1.5
1730	72	1.918	0.701	1	333	9.1	4.0	270	3	170	6409	0	4
1830	72	2.112	0.427	0	235	0.8	4.0	270	5	262	5636	0	4
1930	72	1.740	0.613	1	328	9.3	4.0	270	9	286	5659	0	4
2016	72	2.458	0.348	1	189	9.9	4.0	270	12	276	8277	0	4
2051	72	2.961	0.380	1	193	9.9	4.0	270	12	292	6384	0	4
2116	72	2.908	0.423	1	92	10.0	4.0	270	10	292	6648	0	4.5
2212	72	3.740	0.512	1	14	8.9	4.0	270	7	281	1634	0	4.5
2222	72	0.622	0.211	1	110	9.7	4.0	270	8	277	5621	0	4.5
2257	72	3.160	0.601	1	13	9.2	5.0	270	12	270	5356	1	4.5
2318	72	3.245	0.400	1	10	9.0	5.0	270	10	258	5324	1	4.5
2349	72	3.276	0.382	1	11	9.4	5.0	270	9	239	5358	1	4.5

R/V Point Sur, June 2004

UT	Day	Roll	Pitch	UW	Ship Heading	Ship Speed	Sea Height	Sea Dir.	Wind Speed	Wind Dir.	NPts	Seas	Swell
1925	160	2.012	1.222	1	252	8.3	4.0	315	24	275	6105	4.0	0
2234	160	1.851	0.237	1	80	9.5	5.0	315	17	275	5963	5.0	0
0132	161	2.983	1.262	1	257	8.0	7.0	315	14	280	8130	7.0	0
0638	161	3.412	1.309	0	292	1.1	7.0	292	20	298	4554	7.0	0
0916	161	3.643	1.363	0	298	1.0	7.0	315	22	306	5583	7.0	0
1642	161	4.339	1.453	1	258	6.2	9.0	292	20	307	11450	9.0	0
2023	161	4.016	1.552	1	270	6.7	12.0	315	18	305	5308	12.0	0
0555	162	3.916	1.154	1	247	8.1	10.0	315	16	325	6873	10.0	0
1032	162	3.566	0.926	1	251	8.7	7.0	315	16	335	13930	7.0	0
1428	162	2.915	0.892	1	251	9.1	5.0	315	14	335	6040	5.0	0
1915	162	2.635	1.093	0	341	0.8	7.0	315	16	346	6967	7.0	0
2314	162	3.046	0.791	1	50	8.7	7.0	315	20	330	9297	7.0	0
0215	163	3.899	0.892	1	59	8.8	8.0	315	22	329	13233	8.0	0
0435	163	2.773	1.341	0	330	1.1	9.0	315	24	336	5840	9.0	0
0617	163	4.961	1.184	1	61	9.0	12.0	315	26	332	5364	12.0	0
1324	163	4.349	1.497	1	100	8.8	12.0	315	25	324	5697	12.0	0
1351	163	4.485	1.670	1	10	6.8	13.0	315	26	323	8020	13.0	0
1444	163	4.327	0.513	1	70	8.9	9.0	315	25	329	5136	9.0	0
1547	163	3.668	0.430	1	70	9.4	7.0	315	21	325	9624	7.0	0

Appendix B. Acceleration Measurements.

Tables of the acceleration measurements are given in this appendix. The ship, month, and year for each measurement set are given prior to each appropriate data listing. The distance L (in meters) from the measurement location to the outboard stern rail is also given prior to the data listing. Time is given as either UT or Local Time (PST = UT-8 or PDT = UT-7, depending on the time of year), while day is yearday. Units are m/s^2 for measured and adjusted accelerations (which are rms values) as well as for maximum accelerations, and are $degrees/s^2$ for rms angle rates. Coordinate systems are shown in Figure 2 above. Details regarding environmental data collection are given in Section III of this report.

R/V Western Flyer, July 2003
Distance L to outboard stern rail (meters) -22.600 -8.100 0.000

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
PDT	Day	x	y	z	x	y	z	x	y	z	x	y	z
0305	189	0.049	0.200	0.153	0.093	0.305	0.276	0.315	1.429	1.168	1.004	0.411	0.530
0927	189	0.114	0.350	0.172	0.161	0.469	0.376	0.631	1.503	1.499	0.765	0.748	0.720
2113	189	0.121	0.284	0.168	0.169	0.403	0.320	0.610	1.729	1.208	1.156	0.488	0.646
0510	190	0.146	0.296	0.190	0.202	0.439	0.359	0.690	1.744	1.436	1.205	0.577	0.713
1632	190	0.047	0.111	0.128	0.093	0.271	0.376	0.366	1.034	1.387	0.810	0.596	0.622
1552	191	0.035	0.116	0.098	0.075	0.238	0.200	0.265	0.860	0.714	0.696	0.358	0.484
0259	192	0.142	0.394	0.167	0.172	0.486	0.431	0.717	1.607	1.496	0.665	0.777	0.674
0340	192	0.078	0.282	0.195	0.104	0.364	0.358	0.421	1.430	1.262	1.598	0.492	0.513
0506	192	0.071	0.193	0.133	0.111	0.286	0.210	0.377	1.212	0.701	0.727	0.332	0.425
1125	192	0.119	0.154	0.043	0.122	0.165	0.080	0.409	0.558	0.340	0.177	0.134	0.149

R/V Western Flyer, November 2003
Distance L to outboard stern rail (meters) -22.600 -8.100 0.000

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
UT	Day	x	y	z	x	y	z	x	y	z	x	y	z
1718	328	0.031	0.078	0.019	0.036	0.094	0.067	0.151	0.395	0.291	0.168	0.149	0.139
1824	328	0.038	0.107	0.109	0.045	0.122	0.127	0.238	0.550	0.534	0.405	0.221	0.170
1915	328	0.075	0.089	0.073	0.086	0.115	0.117	0.332	0.413	0.483	0.304	0.196	0.189
2019	328	0.093	0.089	0.067	0.101	0.118	0.116	0.347	0.468	0.442	0.304	0.198	0.184
2130	328	0.109	0.078	0.050	0.113	0.097	0.097	0.401	0.344	0.389	0.204	0.181	0.147
2226	328	0.096	0.072	0.038	0.098	0.089	0.082	0.302	0.383	0.321	0.186	0.166	0.133
2319	328	0.081	0.069	0.029	0.085	0.083	0.072	0.294	0.370	0.272	0.156	0.146	0.122

R/V Western Flyer, June 2004
Distance L to outboard stern rail (meters) -11.300 -10.600 +4.000

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
UT	Day	x	y	z	x	y	z	x	y	z	x	y	z
1900	156	0.052	0.200	0.119	0.172	0.198	0.245	1.978	2.470	1.228	0.946	0.515	0.735
1948	156	0.075	0.298	0.146	0.181	0.300	0.278	0.707	1.021	0.963	1.176	0.592	0.694
2103	156	0.126	0.393	0.162	0.209	0.394	0.198	0.748	1.173	0.754	0.578	0.757	0.642
0038	157	0.128	0.391	0.170	0.211	0.393	0.202	0.882	1.171	0.730	0.632	0.808	0.669
0501	157	0.123	0.395	0.133	0.186	0.400	0.153	0.758	1.109	0.525	0.521	0.628	0.532
0643	157	0.066	0.263	0.128	0.162	0.277	0.263	0.641	1.189	0.908	1.044	0.482	0.618
1629	157	0.091	0.340	0.107	0.159	0.341	0.167	0.578	1.170	0.715	0.603	0.531	0.615
2011	157	0.090	0.300	0.086	0.145	0.301	0.139	0.584	1.112	0.475	0.457	0.405	0.486
2347	157	0.120	0.423	0.115	0.188	0.426	0.147	0.698	1.250	0.704	0.471	0.586	0.570
1107	158	0.204	0.437	0.364	0.304	0.452	0.389	1.352	1.455	1.549	0.871	1.084	0.850
1434	158	0.149	0.328	0.380	0.263	0.349	0.494	1.063	1.324	1.814	1.543	0.914	0.850
1606	158	0.173	0.373	0.390	0.301	0.393	0.503	1.313	1.696	1.949	1.486	0.994	0.921
1747	158	0.167	0.375	0.354	0.266	0.411	0.444	1.040	1.682	1.778	1.353	0.907	0.861
1940	158	0.202	0.425	0.299	0.255	0.478	0.439	1.206	1.779	1.435	1.564	0.769	0.805
2139	158	0.146	0.303	0.170	0.162	0.360	0.278	0.925	1.464	0.997	0.923	0.540	0.627
1457	159	0.138	0.358	0.373	0.226	0.374	0.430	1.124	1.569	2.188	1.373	0.922	0.724
1530	159	0.131	0.358	0.369	0.211	0.379	0.403	0.925	1.455	1.726	1.462	0.843	0.650
1913	159	0.186	0.365	0.297	0.255	0.374	0.309	0.873	1.210	1.168	0.751	0.859	0.705
2043	159	0.181	0.383	0.328	0.257	0.395	0.335	0.942	1.528	1.134	0.843	0.925	0.749

R/V Point Sur, July 2003
Distance L to outboard stern rail (meters)   -22.000   -4.000   +0.800

		Raw Acceleration			Adjusted to L — Acceleration			Adjusted to L — Max. Acceleration			Angle dot_dot=dot_w		
PDT	Day	x	y	z	x	y	z	x	y	z	x	y	z
1110	202	0.115	0.391	0.415	0.135	0.486	0.932	0.509	1.692	3.559	1.600	1.529	0.316
1154	202	0.058	0.316	0.184	0.069	0.337	0.478	0.227	1.093	1.673	1.415	0.914	0.239
1443	202	0.139	0.497	0.516	0.168	0.612	1.145	0.560	2.567	3.854	2.042	1.861	0.450
1834	202	0.148	0.644	0.580	0.165	0.775	1.217	0.630	3.047	4.309	2.673	1.997	0.567
1936	202	0.103	0.330	0.306	0.130	0.394	0.823	0.485	1.008	3.234	1.296	1.511	0.288
2036	202	0.137	0.438	0.506	0.155	0.530	1.112	0.523	1.902	3.968	1.833	1.823	0.403
2121	202	0.102	0.445	0.303	0.125	0.535	0.807	0.499	1.674	3.199	1.683	1.488	0.354
0241	203	0.132	0.486	0.358	0.163	0.595	1.021	0.721	2.441	3.822	1.825	1.907	0.427
0448	203	0.139	0.516	0.376	0.175	0.630	1.076	0.773	2.172	4.250	1.968	2.008	0.502
0743	203	0.039	0.278	0.197	0.052	0.316	0.366	0.204	1.046	1.506	1.125	0.562	0.409
0840	203	0.140	0.514	0.393	0.173	0.630	1.091	0.634	2.297	3.995	1.943	2.030	0.504
0931	203	0.039	0.303	0.206	0.049	0.338	0.380	0.201	1.061	1.363	1.278	0.568	0.374
1220	203	0.034	0.209	0.141	0.051	0.234	0.306	0.183	0.820	1.158	0.852	0.523	0.378
1302	203	0.132	0.419	0.352	0.157	0.520	0.993	0.621	1.771	3.559	1.605	1.877	0.412
1806	203	0.140	0.471	0.378	0.163	0.590	1.077	0.632	2.071	3.968	1.772	2.003	0.496
1852	203	0.031	0.198	0.127	0.045	0.214	0.270	0.169	0.841	1.148	0.710	0.464	0.394
2000	203	0.153	0.352	0.390	0.186	0.448	1.164	0.846	2.020	4.870	1.377	2.193	0.479
2101	203	0.033	0.191	0.126	0.046	0.227	0.274	0.167	0.856	1.004	0.715	0.489	0.427
0152	204	0.038	0.211	0.150	0.054	0.262	0.333	0.189	0.906	1.435	0.835	0.592	0.466
0251	204	0.152	0.497	0.420	0.190	0.622	1.196	0.766	1.943	4.039	1.872	2.214	0.556
0811	204	0.142	0.695	0.485	0.184	0.814	1.179	0.703	2.899	4.406	2.757	2.145	0.636
0859	204	0.038	0.257	0.171	0.054	0.300	0.356	0.199	1.275	1.632	1.077	0.604	0.441
1325	204	0.049	0.467	0.315	0.072	0.533	0.478	0.249	2.013	1.829	1.923	0.707	0.414
1618	204	0.117	0.403	0.349	0.144	0.473	0.940	0.511	2.009	3.247	1.576	1.705	0.335
1912	204	0.040	0.338	0.224	0.055	0.389	0.364	0.239	1.335	1.301	1.416	0.575	0.335
2019	204	0.072	0.308	0.246	0.092	0.363	0.604	0.331	1.320	2.138	1.192	1.068	0.252
0216	205	0.101	0.198	0.267	0.128	0.239	0.792	0.568	0.904	3.324	0.823	1.441	0.238
2120	205	0.207	0.218	0.656	0.248	0.292	1.611	1.036	0.976	6.070	0.887	2.749	0.320
0017	206	0.181	0.283	0.598	0.229	0.359	1.457	1.034	1.439	6.181	1.178	2.433	0.390
0304	206	0.187	0.270	0.617	0.233	0.360	1.491	0.746	1.271	5.463	1.099	2.513	0.402
0847	206	0.228	0.162	0.684	0.275	0.236	1.773	0.970	0.977	5.838	0.723	3.035	0.342
1222	206	0.173	0.564	0.661	0.227	0.709	1.468	0.878	2.426	5.341	2.200	2.401	0.596
2153	206	0.054	0.253	0.149	0.064	0.284	0.416	0.256	1.056	1.501	1.043	0.785	0.212
1040	207	0.044	0.225	0.154	0.057	0.257	0.370	0.248	0.999	1.531	0.933	0.664	0.229
1311	208	0.054	0.164	0.138	0.067	0.197	0.420	0.221	0.928	1.334	0.678	0.794	0.197
1527	208	0.043	0.144	0.116	0.054	0.172	0.337	0.196	0.698	1.408	0.595	0.639	0.174
1926	208	0.041	0.197	0.114	0.050	0.219	0.323	0.214	1.335	1.364	0.832	0.623	0.172
0057	209	0.037	0.240	0.129	0.043	0.256	0.324	0.151	0.911	1.268	1.045	0.577	0.230
0318	209	0.037	0.198	0.152	0.054	0.236	0.355	0.195	0.918	1.157	0.783	0.583	0.217
1221	210	0.059	0.331	0.174	0.067	0.355	0.468	0.258	1.271	1.880	1.435	0.892	0.299
1419	210	0.065	0.237	0.182	0.078	0.265	0.501	0.345	1.210	2.305	0.994	0.954	0.259

R/V Point Sur, October 2003
Distance L to outboard stern rail (meters) -22.000 -4.000 +0.800

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
PST	Day	x	y	z	x	y	z	x	y	z	x	y	z
0907	302	0.077	0.508	0.337	0.081	0.570	0.691	0.259	1.692	2.254	2.091	1.057	0.363
1314	302	0.128	0.490	0.510	0.132	0.604	1.076	0.569	2.172	4.369	1.980	1.780	0.628
1606	302	0.091	0.743	0.484	0.112	0.791	0.927	0.394	3.091	3.345	3.077	1.389	0.836
1736	302	0.229	0.566	0.644	0.286	0.744	1.828	1.133	3.560	6.478	2.167	3.382	0.860
2141	302	0.262	0.518	0.711	0.324	0.675	2.075	1.333	2.397	8.249	2.018	3.845	0.800
2306	302	0.388	0.648	1.169	0.473	0.908	3.133	1.918	4.233	10.277	2.441	5.607	1.027
0145	303	0.079	0.639	0.422	0.104	0.647	0.818	0.358	2.564	2.565	2.467	1.271	0.903
0521	303	0.361	0.923	1.193	0.446	1.248	3.000	1.789	5.151	10.387	3.447	5.233	1.178
0742	303	0.097	0.720	0.492	0.119	0.745	0.959	0.448	2.312	3.352	2.884	1.488	0.949
0911	303	0.273	0.861	0.766	0.332	1.088	2.157	1.219	4.731	7.292	3.185	4.003	1.051
1105	303	0.130	0.825	0.665	0.183	0.918	1.218	0.642	2.930	4.782	3.261	1.906	0.868
1619	303	0.117	0.848	0.606	0.170	0.926	1.094	0.681	3.115	4.269	3.405	1.752	0.884
1855	303	0.111	0.827	0.597	0.161	0.886	1.061	0.604	3.127	3.562	3.287	1.669	0.891
2029	303	0.258	0.526	0.701	0.312	0.685	2.051	1.184	2.268	7.145	2.047	3.834	0.823
2203	303	0.102	0.683	0.538	0.151	0.744	0.986	0.541	2.955	3.343	2.682	1.544	0.800
0144	304	0.089	0.603	0.460	0.129	0.663	0.837	0.584	2.409	4.298	2.404	1.346	0.686
0425	304	0.237	0.534	0.828	0.301	0.688	2.047	1.157	2.517	7.904	2.094	3.441	0.708
0759	304	0.188	0.529	0.736	0.246	0.678	1.653	0.880	2.250	5.698	2.051	2.715	0.620
1015	304	0.199	0.225	0.634	0.238	0.316	1.638	0.995	1.349	5.885	0.944	2.864	0.398
1203	304	0.099	0.390	0.424	0.134	0.486	0.912	0.450	1.486	3.039	1.534	1.470	0.433
1539	304	0.049	0.323	0.233	0.069	0.388	0.470	0.271	1.625	1.828	1.373	0.758	0.436
1918	304	0.028	0.127	0.110	0.035	0.158	0.243	0.138	0.550	1.094	0.480	0.414	0.272

R/V Point Sur, January 2004
Distance L to outboard stern rail (meters) -22.000 -4.000 +0.800

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
UT	Day	x	y	z	x	y	z	x	y	z	x	y	z
0141	028	0.194	0.479	0.684	0.234	0.606	1.574	0.806	2.683	5.609	1.976	2.608	0.521
0453	028	0.201	0.481	0.713	0.235	0.623	1.625	0.835	2.386	5.847	1.965	2.701	0.598
1241	028	0.042	0.319	0.202	0.062	0.351	0.390	0.207	1.211	1.495	1.244	0.642	0.578
1557	028	0.048	0.333	0.206	0.068	0.378	0.435	0.226	1.251	1.474	1.369	0.752	0.582
1958	028	0.048	0.389	0.222	0.066	0.428	0.454	0.237	1.875	1.610	1.659	0.758	0.549
2301	028	0.198	0.557	0.530	0.246	0.675	1.548	1.039	2.421	6.399	2.144	2.826	0.583
0152	029	0.046	0.357	0.189	0.070	0.410	0.426	0.275	1.385	1.645	1.527	0.741	0.672
0426	029	0.220	0.556	0.571	0.267	0.690	1.698	1.040	2.386	6.121	2.146	3.138	0.701
0619	029	0.049	0.397	0.222	0.073	0.446	0.464	0.256	1.553	1.707	1.655	0.787	0.654
1413	029	0.266	0.642	0.808	0.339	0.809	2.194	1.337	2.972	8.537	2.525	3.796	0.769
1633	029	0.145	0.654	0.597	0.199	0.753	1.282	0.745	3.013	4.597	2.666	2.079	0.714
2114	029	0.262	0.255	0.823	0.312	0.388	2.086	1.299	1.878	8.201	1.073	3.632	0.543
2233	029	0.065	0.514	0.331	0.099	0.570	0.610	0.509	1.998	2.285	2.158	1.004	0.652
0202	030	0.075	0.529	0.417	0.113	0.594	0.713	0.410	1.986	2.477	2.188	1.130	0.655
0502	030	0.081	0.500	0.408	0.123	0.561	0.756	0.481	2.014	2.939	2.095	1.218	0.652
2108	030	0.149	0.426	0.441	0.199	0.529	1.268	0.826	2.069	4.774	1.718	2.223	0.567
0414	031	0.388	0.239	1.127	0.479	0.401	3.087	1.941	2.074	11.902	1.046	5.474	0.616
0707	031	0.342	0.713	1.049	0.434	0.925	2.863	1.416	3.643	10.011	2.786	4.970	0.974
1241	031	0.326	0.500	0.985	0.422	0.673	2.703	1.804	3.942	11.442	1.933	4.702	0.780
1746	031	0.259	0.499	0.853	0.339	0.677	2.211	1.240	2.676	8.063	1.948	3.752	0.768
2141	031	0.250	0.710	0.877	0.322	0.879	2.148	1.261	2.926	7.820	2.763	3.654	0.742
2323	031	0.322	0.707	1.021	0.411	0.889	2.729	1.523	3.331	9.043	2.811	4.690	0.863
0019	032	0.326	0.633	1.002	0.411	0.811	2.723	1.527	3.416	9.261	2.494	4.717	0.828
0235	032	0.240	0.709	0.891	0.319	0.895	2.165	1.172	3.421	7.434	2.734	3.545	0.859
0755	032	0.089	0.248	0.249	0.112	0.284	0.701	0.463	1.428	2.766	1.051	1.333	0.247
0323	034	0.113	0.443	0.325	0.145	0.485	0.929	0.564	2.575	3.991	1.988	1.771	0.500
2107	035	0.131	0.382	0.375	0.162	0.468	1.046	0.664	1.809	3.807	1.518	1.930	0.402
2320	035	0.048	0.381	0.233	0.073	0.413	0.452	0.259	1.526	1.728	1.612	0.787	0.620
2243	036	0.012	0.056	0.048	0.017	0.083	0.106	0.064	0.306	0.367	0.202	0.194	0.156

R/V Point Sur, March 2004
Distance L to outboard stern rail (meters)   -22.000   -4.000   +0.800

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
UT	Day	x	y	z	x	y	z	x	y	z	x	y	z
1644	069	0.059	0.142	0.207	0.083	0.198	0.488	0.298	0.653	1.808	0.597	0.795	0.264
1746	069	0.024	0.132	0.090	0.030	0.157	0.190	0.150	0.543	0.750	0.576	0.322	0.207
1817	069	0.024	0.151	0.098	0.034	0.164	0.222	0.112	0.589	0.791	0.691	0.370	0.245
1953	069	0.037	0.206	0.203	0.041	0.245	0.353	0.144	0.959	1.430	0.842	0.508	0.235
2028	069	0.102	0.140	0.317	0.121	0.182	0.793	0.498	1.194	3.128	0.577	1.354	0.245
2130	069	0.034	0.255	0.174	0.048	0.291	0.297	0.177	0.941	0.964	1.074	0.488	0.307
1731	072	0.114	0.336	0.444	0.161	0.449	1.000	0.585	1.754	3.677	1.302	1.584	0.488
1830	072	0.072	0.372	0.198	0.084	0.436	0.558	0.347	1.894	2.517	1.458	1.064	0.296
1930	072	0.099	0.300	0.371	0.138	0.392	0.855	0.671	1.462	3.854	1.186	1.376	0.408
2016	072	0.059	0.426	0.313	0.064	0.480	0.568	0.223	2.159	2.302	1.751	0.810	0.323
2051	072	0.064	0.510	0.358	0.070	0.565	0.631	0.235	2.252	2.221	2.129	0.880	0.366
2116	072	0.072	0.505	0.367	0.081	0.550	0.680	0.276	1.897	2.306	2.117	1.005	0.446
2212	072	0.082	0.654	0.491	0.119	0.778	0.815	0.378	2.108	2.329	2.479	1.185	0.572
2222	072	0.053	0.226	0.165	0.068	0.269	0.420	0.350	1.489	2.239	0.842	0.728	0.257
2257	072	0.099	0.550	0.500	0.141	0.665	0.930	0.490	2.624	3.328	2.162	1.421	0.527
2318	072	0.066	0.567	0.397	0.095	0.650	0.638	0.324	2.057	2.211	2.267	0.965	0.454
2349	072	0.063	0.572	0.370	0.092	0.653	0.595	0.322	2.269	2.032	2.282	0.905	0.453

R/V Point Sur, June 2004
Distance L to outboard stern rail (meters) -22.000 -4.000 +0.800

		Raw Acceleration			Adjusted to L: Acceleration			Adjusted to L: Max. Acceleration			Angle dot_dot=dot_w		
UT	Day	x	y	z	x	y	z	x	y	z	x	y	z
0111	160	0.170	0.286	0.331	0.175	0.491	0.554	0.638	2.269	2.972	1.035	0.918	0.743
1925	160	0.203	0.347	0.669	0.236	0.481	1.621	0.887	2.145	5.752	1.355	2.766	0.516
2235	160	0.040	0.321	0.214	0.056	0.343	0.380	0.238	1.357	1.281	1.319	0.621	0.416
0134	161	0.211	0.522	0.757	0.244	0.662	1.732	0.956	2.164	6.602	1.982	2.863	0.518
0639	161	0.224	0.593	0.600	0.272	0.748	1.705	0.863	2.385	5.471	2.187	3.198	0.734
0917	161	0.233	0.642	0.636	0.280	0.813	1.789	1.221	3.046	6.420	2.341	3.303	0.813
1642	161	0.243	0.749	0.861	0.287	0.921	2.025	1.031	3.001	7.255	2.936	3.387	0.775
2023	161	0.260	0.704	0.941	0.311	0.894	2.178	1.121	3.947	8.215	2.666	3.598	0.729
0557	162	0.196	0.686	0.725	0.230	0.819	1.637	0.903	3.238	6.578	2.715	2.717	0.738
1033	162	0.153	0.637	0.602	0.176	0.757	1.311	0.611	2.581	5.665	2.528	2.108	0.604
1429	162	0.150	0.508	0.579	0.167	0.625	1.256	0.638	2.530	4.521	1.987	2.078	0.572
1916	162	0.181	0.462	0.489	0.228	0.573	1.463	0.759	2.060	4.757	1.755	2.668	0.569
2315	162	0.130	0.525	0.544	0.176	0.618	1.162	0.592	2.172	3.917	2.074	1.857	0.563
0217	163	0.141	0.669	0.639	0.195	0.774	1.282	0.794	3.078	5.142	2.619	2.037	0.732
0437	163	0.224	0.489	0.598	0.277	0.615	1.778	0.934	2.316	5.627	1.862	3.264	0.648
0619	163	0.194	0.853	0.851	0.263	0.976	1.772	0.908	4.282	6.035	3.256	2.804	0.924
1325	163	0.247	0.753	0.877	0.319	0.934	2.135	1.379	3.736	8.036	2.743	3.569	0.944
1352	163	0.273	0.782	0.966	0.350	0.995	2.374	1.537	3.836	8.307	2.890	3.946	0.916
1445	163	0.085	0.733	0.520	0.126	0.772	0.845	0.434	3.014	2.700	2.809	1.291	0.760
1548	163	0.072	0.637	0.419	0.108	0.679	0.694	0.478	2.422	2.672	2.468	1.109	0.722

APPENDIX C. Sampling Procedures

<u>Instructions for AGM Tiltmeter and Xbow Gyro</u>

<u>AGM Tiltmeter:</u>

1. Use the old laptop (in the bigger blue case). [*<u>Note:</u> Use the power pack for this computer.*]
2. There is a parallel port Zip drive, as well as a Zip disk (labeled "AGM (Tiltmeter)"), in one of the front pockets of the case. Use the drive and the disk.
3. Connect the Zip drive to the computer's parallel port. Connect the AGM to the computer's serial port.
4. Turn on the computer. (There will be six times that you need to hit <Enter> during the boot up process.) If the computer hangs up in booting, find a paper clip and press the reset button.
5. Open a DOS window.
6. Set the date and time. ("date" and "time")
7. Change to the Zip drive (d:\), and cd to agm. (*Obviously, make sure the Zip disk is in the drive.*)
8. Type "seriop".
9. Type "agm4" to start collecting data.
10. Type "|quit" to stop data collection.

The file naming convention is g<hhmm>.<yearday>

<u>Xbow Gyro:</u>

1. Plug the USB-to-Serial adapter into the middle USB port.
2. Connect the Xbow Gyro to "serial 1".
3. If you want to use the external mouse, connect it to the front USB port.
4. Turn on the computer. Log into SEA2 (<u>not</u> NPGS) as "tarry" (no password).
5. Set the date and time.
6. Double click on "gyroview".
7. Set up gyroview as follows:
   a) Open the Graph and Navigation windows.
   b) Set the logging rate to 10 samples/sec.
   c) Packet Type = angle mode
   d) erection rate = 50
   e) zero avg. time = 200
   f) Set the filename. Use the convention g,<hhmm*yearday*>.txt

(Click on the E and Z buttons after the instrument has been plugged in ~half an hour and before the ship has left the dock.)

Start (and Stop) data collection with the Start (Stop) Logging toggle switch.

It's probably best to bring a power strip with you, as well as a good clock. Periodically check (but do not correct) the computer clocks against the correct time.

AGM Tiltmeter (older laptop)

1. Set the computer date and time (UTC).
2. Open a DOS window
3. Change drives to d: *(the zip drive)*, then type "cd agm"
4. If this is the first time running the program after opening the DOS window, type "seriopc"
5. To start recording data, type "agm4" *(Program automatically names the data file g<hhmm.yearday>.)*
6. To stop recording data, type "|quit"

Xbow Gyro

1. Log onto computer (SEA2) as tarry. There is no password.
2. Set the computer date and time (UTC).
3. Open the program "gyroview."
4. Under view, open "graph" and "navigation" windows.
5. Set the packet type to "angle mode".
6. Before the ship leaves the dock, set erection rate to 50, then run that. *(Use the switch "E".)*
7. Before the ship leaves the dock, set zero to 200, then run that. *(Use the switch "Z".)*
8. Set the logging rate to 10 Hz.
9. Open the file to which to record the data. (Filename = <AGM filename>.txt) *(e.g., if AGM filename is g1023.064, then make Xbow filename g1023064.txt)*
10. Start logging the data. *(Toggle switch.)*
11. To stop recording, end logging the data. *(Same toggle switch as step 10.)*

APPENDIX D. Sample logs.

<u>Gyro/Tiltmeter Conditions, CalCOFI Line 67 Cruise, Oct. 2003 (*R/V Pt. Sur*)</u>

Date (2003)	File Name	AGM Begin (UTC)	Xbow Begin (UTC)	End (UTC)	Speed, SOG (knots)	Heading (degrees)	True Wind Speed (knots)	True Wind Direction (degrees)	Estimated Seas/Swell (feet)	Oper-ator
x/29	g0905302	0905:30	0908:00	0929	9.2	239.35	10.89	264.63	4-7, SW	TAR
	g1312302	1312:30	1314:15	1336	8.2	237.15	14.61	354.92	6-8, NW	TAR
	g1605302	1605	1607	1623	9.05	215	22	344	8-11, NW	CAC
	g1735302	1735	1736	1845	1.55	325	26	340	8-11, NW	CAC
		(1820)	(1820)	(1845)	8.6	196	28	350	8-11, NW	CAC
	g2139302	2139:45	2142:00	2206	1.30	334.50	28	340	9-13, NW	TAR
	g2305302	2305:30	2306:18	2340	5.50	324.25	35	347.23	9-14, NW	TAR
x/30	g0144303	0144:00	0145:20	0209	9.05	199.2	31	356	11-16,NW	TAR
	g0520303	0520	0521	0558	5.4	308	35	341	11-16,NW	CAC
	g0741303	0741	0742	0805	8.0	204	28	342	11-16,NW	CAC
	g0910303	0910:10	0911:26	0933	1.90	340.10	29	337	11-16,NW	TAR
	g1105303	1105:00	1106:00	1135	9.2	101	28	334	11-16,NW	TAR
	g1618303	1618:30	1619:40	1645	9.1	102	28	340	11-16,NW	CAC
	g1855303	1855:00	1856:00	1934	8.7	094	20	338	11-13,NW	CAC
	g2029303	2029:00	2030:00	2043	1.3	333	20	335	10-13,NW	CAC
	g2203303	2203:15	2204:00	2228	8.7	092.5	15	327	9-13, NW	TAR
x/31	g0144304	0144:05	0144:45	0202	9.15	078	22	321	8-11, NW	TAR
	g0425304	0425:00	0426:00	0452	8.05	025	21	323	8-11, NW	CAC
	g0759304	0759:00	0800:00	0816	9.00	358	8	345	6-8, NW	CAC
	g1015304	1015:00	1015:45	1041	7.80	294	5	111	5-7, NW	TAR
	g1203304	1203:00	1203:30	1224	8.10	000	4	168	4-6, NW	TAR
	g1539304	1539:00	1540:00	1559	7.3	165	20	083	4-6, WNW	CAC
	g1918304	1918:00	1919:00	1946	9.4	084	10	105	3-6, W	CAC

Notes:

1. The file names apply to both the AGM and the Xbow. For the AGM, place a dot before the last three digits (302, 303 or 304) to make those digits the file extension. For the Xbow, add ".txt" to each file name.
2. Other than the start and end times, all the data were taken from the UDAS, usually at the start of each data collection period. Where the precision is given to more than the units place, that really only applies to the 30-second UDAS ensemble from which the numbers were copied.
3. For the case of files g1735302, Curt forgot to stop data collection after ~20 minutes. The second line of values applies to that data collection from 1820 to 1845 UTC.
4. The computer clocks for the AGM and Xbow were set and started at 1550 UTC on 28 October. The following time checks were made subsequently:
   a) On 29 Oct. at 1339 UTC, Xbow = 1338:58
   b) On 29 Oct. at 1340:15 UTC, AGM = 1340:40.01
   c) On 30 Oct. at 2229:00 UTC, AGM = 2228:59.57
   d) On 30 Oct. at 2230:00 UTC, Xbow = 2229:56
   e) On 31 Oct. at 1043:00 UTC, AGM = 1043:00.21
   f) On 31 Oct. at 1045:00 UTC, Xbow = 1044:56
   g) On 31 Oct. at 1947:00 UTC, AGM = 1946:58.37; at 1948:30 UTC, AGM = 1948:28.44
   h) On 31 Oct. at 1950:00 UTC, Xbow = 1949:55; at 1952:00 UTC, Xbow = 1951:55

Gyro/Tiltmeter Conditions, Return from Shipyard, Nov. 2003 (*R/V Western Flyer*)

Date (2003)	**File Name**	**AGM Begin (UTC)**	**Xbow Begin (UTC)**	**End (UTC)**	**Speed, SOG (knots)**	**Heading (degrees)**	**True Wind Speed (knots)**	**True Wind Direction (degrees)**	**Estimated Seas/Swell (feet)**	**Oper-ator**
xi/24	g1718328	1718:00	1718:20	1747	8.7	277	4.3	317 (Rel)	0	TAR
		(1734)	(1734)		12	300				
		(1746)	(1746)		11	253				
	g1824328	1824:00	1824:15	1846	12-13	209	9	309	1 from W	TAR
	g1915328	1915:00	1915:10	1943	13.7	174	6	200	1 from W	TAR
	g2019328	2019:00	2019:10	2039	14	160	11	320	1 from 300	TAR
	g2130328	2130:00	2130:05	2155	14	130	12	293	1 from 300	TAR
	g2226328	2226:00	2226:05	2246	14	119	12	293	1 from 300	TAR
	g2319328	2319:00	2319:05	2342	13.5	112	10	315	1 from 300	TAR

Notes:

1. The file names apply to both the AGM and the Xbow. For the AGM, place a dot before the last three digits (328) to make those digits the file extension. For the Xbow, add ".txt" to each file name.
2. Wind data are problematic, as the wind vane was not working and directions were estimated by eye. We think the speeds are correct.
3. For the case of file g1718328, I forgot to set the Xbow to sample at 10 Hz. It therefore sampled at its highest rate.
4. Also for file g1718328, the ship's course and speed were varying as the *R/V Western Flyer* made its way through San Francisco Bay from the shipyard in Alameda, behind Alcatraz, and through the Golden Gate. I tried to note these changes along the way.
5. The computer clocks for the AGM and Xbow were set and started at 1622:30 and 1626:55 UTC, respectively, on 24 November. The following time checks were made subsequently:
    a) At 2044:30 UTC, Xbow = 2044:29.49
    b) At 2045:45 UTC, Xbow = 2045:44.58
    c) At 2040:45 UTC, AGM = 2040:44.53
    d) At 2042:00 UTC, AGM = 2041:59.44
    e) At 2222:30 UTC, Xbow = 2222:29.52
    f) At 2223:30 UTC, Xbow = 2223:29.39
    g) At 2224:00 UTC, Xbow = 2223:59.38
    h) At 2220:30 UTC, AGM = 2220:28.99
    i) At 2221:15 UTC, AGM = 2221:13.92
    j) At 2221:45 UTC, AGM = 2221:43.85
    k) At 2345:30 UTC, Xbow = 2345:29.75
    l) At 2346.10 UTC, Xbow = 2346:09.38
    m) At 2347.00 UTC, Xbow = 2346:59.44
    n) At 2344.00 UTC, AGM = 2343:58.74
    o) At 2344:30 UTC, AGM =2344:28.73
    p) At 2345:00 UTC. AGM = 2344:58.67

Gyro/Tiltmeter Conditions, OC3570 and OC4270*, Winter 2004 (*R/V Pt. Sur*)

Date (2004)	File Name	AGM Begin (UTC)	Xbow Begin (UTC)	End (UTC)	Speed, SOG (knots)	Heading (degrees)	True Wind Speed (knots)	True Wind Direction (degrees)	Estimated Seas/Swell (feet)	Direction of Sea/Swell	Oper-ator
i/28	g0139.028	0139		0201	9.11	236.9	9.25[2]	307.6	2-3/4-6	W/W	TAR
	g0139028.txt		0141	0201	9.11	236.9	9.25[2]	307.6			
	g0452.028	0452		0534	8.96	240.2	17.48	326.5	2-3/5-7	WNW/WNW	Marla
	g0452028.txt		0454	0534	8.96	240.2	17.48	326.5			

	g1241.028	1241		1301	10.19	151.7	20.59	343.1	2-3/5-7	NW/WNW	TAR
	g1241028.txt		1242	1301	10.19	151.7	20.59	343.1			
	g1556.028	1557		1624	9.28	145.4	20.38	338.4	2-4/6-8	NW/NW	Marla
	g1556028.txt		1556	1624	9.28	145.4	20.38	338.4			
	g1956.028	1956		2018	8.72	139.6	18.63	347.1	2-4/6-8	NW/NW	CAC
	g1956028.txt		1958	2018	8.72	139.6	18.63	347.1			
	g2300.028	2259		2325	1.04	336.4	20.37	340.0	2-4/6-8	NNW/NW	CAC
	g2300028.txt		2301	2325	1.04	336.4	20.37	340.0			
i/29	g0152.029	0152		0215	8.90	144.3	21.47	338.9	2-4/6-8	NNW/NW	TAR
	g0152029.txt		0153	0215	8.90	144.3	21.47	338.9			
	g0426.029	0426		0455	0.93	333.1	21.90	327.7	2-4/6-8	NNW/NW	TAR
	g0426029.txt		0427	0455	0.93	333.1	21.90	327.7			
	g0618.029	0618		0640	9.12	144.1	21.60	337.2	2-4/6-8	NNW/NW	Marla
	g0618029.txt		0619	0640	9.12	144.1	21.60	337.2			
	g1412029	1413		1437	5.15	009.0	20.13	349.1	2-4/6-8	NNW/NW	TAR
	g1412029.txt		1414	1437	5.15	009.0	20.13	349.1			
	g1632.029	1632		1654	8.54	059.6	20.98	349.3	2-4/6-8	NNW/NW	Marla
	g1632029.txt		1633	1654	8.54	059.6	20.98	349.3			
	g2113.029	2114		2131	8.04	291.8	16.23[3]	330.6	2-3/5-7	NW/NW	CAC
	g2113029.txt		2116	2131	8.04	291.8	16.23[3]	330.6			
	g2232.029	2232		2258	8.42	087.9	19.10	332.6	2-3/5-7	NW/NW	CAC
	g2232029.txt		2232	2258	8.42	087.9	19.10	332.6			
i/30	g0201.030	0201		0225	8.93	073.8	22.00	332.2	2-3/5-7	NW/NW	TAR
	g0201030.txt		0202	0225	8.93	073.8	22.00	332.2			
	g0502.030	0502		0549	8.35	059.6	21.97	317.9	2-3/5-7	NW/NW	Marla
	g0502030.txt		0503	0549	8.35	059.6	21.97	317.9			
	g2108.030	2108		2131	1.50	336.5	16.63	301.8	2-3/4-6	NW/NW	TAR
	g2108030.txt		2109	2131	1.50	336.5	16.63	301.8			
i/31	g0413.031	0413		0440	6.94	294.0	26.48	311.7	4-6/8-10	NW/NW	Marla
	g0413031.txt		0414	0440	6.94	294.0	26.48	311.7			
	g0706.031	0706		0737	4.96	339.6/345.3[5]	24.92	318.8	4-6/8-10	NW/NW	CAC
	g0706031.txt		0707	0737	4.96	339.6/345.3[5]	24.92	318.8			
	g1240.031	1241		(1332)	5.65	320.3/325.4[6]	7.23/15.74[7]	348.2[8]	1-2/6-8	N/NW	TAR
	(g1333.031)[4]	(1333)		1406	5.71/1.26[9]	323.8/333.7[9]	12.72[10]	345.5[10]	2-3/7-9	N/NW	
	g1240031.txt		1241	1406	-----[11]	--------[11]	------[11]	-------[11]			
	g1745.031	1745		1834	6.46	326.5	24.21	298.1	2-4/8-10	NW/NW	Marla
	g1745031.txt		1746	1834	6.46	326.5	24.21	298.1			
	g2140.031	2140		2202	5.68	344.0	22.23	330.9	2-4/8-10	NW/NW	CAC
	g2140031.txt		2141	2202	5.68	344.0	22.23	330.9			
	g2322.031	2322		2341	5.14	346.4/333.2[12]	25.14	322.0	3-4/8-10	NW/NW	CAC
	g2322031.txt		2323	2341	5.14	346.4/333.2[12]	25.14	322.0			
ii/1	g0019.032	0019		0040	5.17	338.3	27.25	311.9	3-4/8-10	NW/NW	TAR
	g0019032.txt[13]		0020	0040	5.17	338.3	27.25	311.9			

	g0235.032	0235		0259	5.26	002.5	23.69	317.5	3-4/8-10	NW/NW	TAR
	g0235032.txt		0236	0259	5.26	002.5	23.69	317.5			
	g0754.032	0754		(0846)	0.64/2.46[15]	274.9/106.5[16]	6.49	090.8[17]	1/4-5	W/WNW	CAC
	(g0847.032)[14]	(0847)		0919	1.07[18]	085.6[19]	6.47	064.6[20]	1/4-5	W/WNW	
	g0754032.txt		0755	0919	------[21]	--------[21]	------[21]	------[21]			
ii/3	g0323.034	0323		0345	1.70[22]	252.3/089.5[23]	16.07	235.6[24]	2-3/4-6	W/W	TAR
	g0323034.txt		00324	0345	1.70[22]	252.3/089.5[23]	16.07	235.6[24]			
ii/4*	g2107.035	2107		2122	0.87	281.5	12.22	302.6	2-3/5-8	NW/WNW	CAC
	g2107035.txt		2108	2122	0.87	281.5	12.22	302.6			
	g2319.035	2319		0010	9.41	058.4/063.3[25]	21.12	305.0	2-3/5-8	NW/WNW	CAC
	g2319035.txt		2320	0010	9.41	058.4/063.3[25]	21.12	305.0			
ii/5*	g2242.036	2242		2257	9.62[26]	082.7[26]	9.78	280.1	1/2-4	W/W	CAC
	g2242036.txt		2243	2257	9.62[26]	082.7[26]	9.78	280.1			

Notes:

1. Time Checks (UTC): The initial time was 18:14:58.

DATE	AGM	XBOW
27 January 2004	18:14:52.97	18:14:50.70
28 January 2004	20:58:37.28 20:59:28.96 21:00:21.03	20:58:35.15 20:59:26.84 21:00:18.89
29 January 2004	21:45:41.49 21:46:45.97 21:47:35.95	21:45:38.92 21:46:43.40 21:47:31.20
30 January 2004	21:32:06.72 21:32:53.63 21:33:38.01	21:32:01.33 21:32:48.25 21:33:32.64
1 February 2004	00:43:11.71 00:44:09.11 00:44:54.09	00:43:05.41 00:44:02.87 00:44:47.80
2 February 2004	23:02:39.95 23:03:37.74 23:04:17.78	23:02:31.92 23:03:29.70 23:04:09.74

2. Wind speeds were steadily dropping through this period.
3. There were two distinct wind speeds during this period.
4. Forgot to stop recording data after ~20 minutes. Instruments ran through CTD #35.
5. Heading changed ~19 minutes into the sampling period.
6. Heading changed ~13 minutes into the sampling period.
7. Wind speed changed ~37 minutes into the sampling period.
8. This is only a mean wind direction. Actual UDAS data (w01312004.mdf) should be examined.
9. CTD #35 was between ~12 and ~24 minutes into sampling period. (This was the lower speed, the ship's second heading value.)
10. These are the average wind speed and direction. The speed steadily dropped during the sampling period from ~18 to ~8 knots, while the direction veered from about NNW to N.
11. See notes 6-10, above.
12. Ship's heading changed ~14 minutes into the sampling period.
13. It looked as if the gyro had tumbled during this sampling period. I reset the erection rate to 100—it had been set to 50—at 0041 UTC on 1 February.
14. Forgot to stop recording data after ~20 minutes.
15. The lower speed applies except for the time from ~20 to ~30 minutes during the sampling period.
16. Ship headings apply to the first and second halves (respectively) of the sampling period.
17. The wind steadily backed from ~110^o to ~80^o during the sampling period.
18. The ship's speed slowly edges up from ~0.7 to ~1.2 knots.
19. This ship's heading applies to the first ~20 minutes of the sampling period. After that, the ship turned initially to a heading of ~300^o, but never really steadied up, ending at ~240^o.
20. During the sampling period, the wind direction backed from ~080^o to ~060^o.
21. See notes 15-20, above.
22. Ship's speed slowly climbed from ~1.2 to ~2.1 knots during the sampling period.
23. Ship changed its heading ~7 minutes into the sampling period.
24. Winds steadily veered from ~222^o to ~246^o during the sampling period.
25. Ship's heading changes ~17 minutes into the sampling period.
26. The ship is still on station for the first ~2 minutes of the sampling period.

<u>Gyro/Tiltmeter Conditions, OC4210, March 2004 (*R/V Pt. Sur*)</u>

Date (2004)	**File Name**	**AGM Begin (UTC)**	**Xbow Begin (UTC)**	**End (UTC)**	**Speed, SOG (knots)**	**Heading (degrees)**	**True Wind Speed (knots)**	**True Wind Direction (degrees)**	**Estimated Seas[0]/Swell (feet)**	**Direction of Sea/Swell**	**Oper-ator**
iii/9	g1643.069	1643:30		1700	9.87	330.2	4.84	298.3	R/1-2	---/W	TAR
	g1643069.txt		1644:17	1700	9.87	330.2	4.84	298.3			
	g1746.069	1746:00		1807	9.55	145.8	2.85	289.5[1]	R/1-2	---/W	TAR
	g1746069.txt		1746:50	1807	9.55	145.8	2.85	289.5[1]			
	g1817.069	1817:00		1838	9.45	154.7	5.36	302.8	R/1-2	---/W	TAR
	g1817069.txt		1817:45	1838	9.45	154.7	5.36	302.8			
	g1953.069	1953:00		2016	9.78	194.3	4.46	266.8[2]	R/1-2	---/W	TAR
	g1953069.txt		1953:35	2016	9.78	194.3	4.46	266.8[2]			
	g2028.069	2028:00		2055	9.08	297.0[3]	10.50[4]	285.3	R/1-2	---/W	TAR
	g2028069.txt		2028:27	2055	9.08	297.0[3]	10.50[4]	285.3			
	g2130.069	2130:00		2151	9.66	032.8	14.68	291.0	Wvt/1-2	---/W	TAR
	g2130069.txt		2130:18	2151	9.66	032.8	14.68	291.0			
iii/12	g1730.072	1730:07		1754	9.07	332.7	3.42	169.6	R/3-5	---/W	TAR
	g1730072.txt		1731:05	1754	9.07	332.7	3.42	169.6			
	g1830.072[5]	1830:00		1851	0.76	234.6[5]	5.37	262.4	R/3-5	---/W	TAR
	g1830072.txt[5]		1830:45	1851	0.76	234.6[5]	5.37	262.4			
	g1930.072	1930:01		1951	9.31	327.7	9.06	285.8	R/3-5	---/W	TAR
	g1930072.txt		1930:33	1951	9.31	327.7	9.06	285.8			
	g2016.072	2016:00		2047	9.92	188.7	11.53[6]	275.5	R/3-5	---/W	TAR
	g2016072.txt		2016:30	2047	9.92	188.7	11.53[6]	275.5			
	g2051.072	2051:00		2115	9.85	193.3	12.49	291.6	R/3-5	---/W	TAR
	g2051072.txt		2051:30	2115	9.85	193.3	12.49	291.6			
	g2116.072	2116:05		2141	9.98	192.3	10.22	292.4	R/3-6	---/W	TAR
	g2116072.txt		2116:50	2141	9.98	192.3	10.22	292.4			
	g2212.072	2212:02		2218	8.93	013.9	7.07	280.6	R/3-6	---/W	TAR
	g2212072.txt		2212:29	2218	8.93	013.9	7.07	280.6			
	g2222.072	2222.00		2243	9.69	109.7	8.07	276.7[7]	R/3-6	---/W	TAR
	g2222072.txt		2222:10	2243	9.69	109.7	8.07	276.7[7]			
	g2257.072	2257:00		2317	9.20	013.3	11.83[8]	269.6	>1/3-6	W/W	TAR
	g2257072.txt		2257:30	2317	9.20	013.3	11.83[8]	269.6			
	g2318.072	2318:00		2338	9.02	010.1	9.70	258.4	>1/3-6	W/W	TAR
	g2318072.txt		2318:00	2338	9.02	010.1	9.70	258.4			
	g2349.072	2349:00		0009	9.36	011.1	8.61[9]	238.6[10]	>1/3-6	W/W	TAR
	g2349072.txt		2349:03	0009	9.36	011.1	8.61[9]	238.6[10]			

Notes:

0. R = Ripples, Wvt = Wavelets
1. Wind direction veered steadily through the sampling period from 265^o to 315^o.
2. Wind direction was very variable over the first few minutes of the sampling period.
3. The ship was turning at the end of the sampling period.
4. Wind speed steadily increased during the sampling period from 7.5 to 15 knots.
5. Ship was effectively hove to: a mooring line was wrapped in the propeller.
6. Wind speed steadily increased during the sampling period from 9 to 13.5 knots.
7. Wind direction veered steadily through the sampling period from 255^o to 290^o.
8. Wind speed steadily decreased during the sampling period from 13.5 to 9.5 knots.
9. Wind speed steadily decreased during the sampling period from 10.5 to 6 knots.
10. This is an average direction. The wind direction was veering during the second half of the sampling period from 243^o to 225^o.

Gyro/Tiltmeter/FOG Conditions, June 2004 (*R/V Western Flyer*)

Date (2004)	File Name (*g*.* = AGM, f*.* = FOG, *.txt = Gyro)*	AGM Begin (UTC)	Xbow Begin (UTC)	End (UTC)	Speed, SOG (knots)	Heading (degrees)	True Wind Speed (knots)	True Wind Direction (degrees)	Estimated Seas/Swell (feet)	Direction of Sea/Swell	FOG Begin (UTC)
vi/4 [2]	(g1859156.txt)		1900	1944	10.20	245	18	275	2-3	275	
	g1945.156	1945		1946	10.20	245	18	275	2-3	275	
	f1209.156				10.20	245	18	275	2-3	275	1909
	f1226.156				10.20	245	18	275	2-3	275	(1926)
	f1244.156			1946(?)	10.20	245	18	275	2-3	275	(1944)
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vi/4	g1947.156	1947		1954	10.20	245	18	275	2-3	275	
	g1947156.txt		1948	1954	10.20	245	18	275	2-3	275	
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	g2103.156	2102:45		2128	0.00	318	24	300	2-4	300	
	g2103156.txt		2103:50	2128	0.00	318	24	300	2-4	300	
	f1400.156			(2117)	0.00	318	24	300	2-4	300	2100
	f1418.156			2126	0.00	318	24	300	2-4	300	(2118)
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vi/5	g0038.157	0038		0105	0.00	325	24	317	6-8	315	
	g0038157.txt		0038	0105	0.00	325	24	317	6-8	315	
	f1735.156			(0052)	0.00	325	24	317	6-8	315	0035
	f1753.156			0059	0.00	325	24	317	6-8	315	(0053)
	--------------	--------	--------	-------	--------	-------------	---------	---------	--------	---------	--------
	g0500.157	0500		0524	0.00	322	25	318	6-8	315	
	g0500157.txt		0501	0524	0.00	322	25	318	6-8	315	

	f2157.156			(0514)	0.00	322	25	318	6-8	315	0457
	f2215.156			0521	0.00	322	25	318	6-8	315	(0515)
	--------------	-------	--------	-------	--------	-------------	---------	---------	-------	---------	--------
	g0642.157	0642		0706	7.4	241	27	310	6-8	315	
	g0642157.txt		0643	0706	7.4	241	27	310	6-8	315	
	f2340.156			(0657)	7.4	241	27	310	6-8	315	0640
	f2358.156			0703	7.4	241	27	310	6-8	315	(0658)
	--------------	-------	--------	-------	--------	-------------	---------	---------	-------	---------	--------
	g1628.157	1628		1652	0.00	305	16	315	3-5	315	
	g1628157.txt		1629	1652	0.00	305	16	315	3-5	315	
	f0926.157			(1643)	0.00	305	16	315	3-5	315	1626
	f0944.157			1650	0.00	305	16	315	3-5	315	(1644)
	--------------	-------	--------	-------	---------	-------------	---------	---------	-------	---------	--------
	g2010.157	2010		2036	0.00	305	20	314	3-5	315	
	g2010157.txt		2010	2036	0.00	305	20	314	3-5	315	
	f1308.157			(2025)	0.00	305	20	314	3-5	315	2008
	f1326.157			2033	0.00	305	20	314	3-5	315	(2026)
	--------------	-------	--------	-------	--------	-------------	---------	---------	-------	---------	--------
	g2346.157	2346		0004	0.00	324	26	333	4-6	337.5	
	g2346157.txt		2347	0004	0.00	324	26	333	4-6	337.5	
	f1645.157			0002	0.00	324	26	333	4-6	337.5	2345
--------	--------------	-------	--------	-------	--------	-------------	---------	---------	-------	---------	--------
vi/6	g1106.158	1106		1139	0.00	335	32 (G 40)	327	10-12	327	
	g1106158.txt		1107	1139	0.00	335	32 (G 40)	327	10-12	327	
	f0404.158			(1121)	0.00	335	32 (G 40)	327	10-12	327	1104
	f0422.158			1137	0.00	335	32 (G 40)	327	10-12	327	(1122)
	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	--------
	g1434.158	1434		1525	10.50	050/030/075[3]	27	327	12-14	327	
	g1434158.txt		1435	1525	10.50	050/030/075	27	327	12-14	327	
	f0732.158			(1449)	10.50	050/030/075	27	327	12-14	327	1432
	f0750.158			(1507)	10.50	050/030/075	27	327	12-14	327	(1450)
	f0808.158			1523	10.50	050/030/075	27	327	12-14	327	(1508)
	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	--------
	g1605.158	1605		1633	9.50	046	27	327	12-14	327	
	g1605158.txt		1606	1633	9.50	046	27	327	12-14	327	
	f0909.158			(1626)	9.50	046	27	327	12-14	327	1609
	f0927.158			1630	9.50	046	27	327	12-14	327	(1627)
	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	--------
	g1746.158	1746		1820	8.50	005/110/075[4]	30	330	12-14	330	
	g1746158.txt		1747	1820	8.50	005/110/075	30	330	12-14	330	
	f1049.158			(1806)	8.50	005/110/075	30	330	12-14	330	1749
	f1107.158			1817	8.50	005/110/075	30	330	12-14	330	(1807)
	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	---------

	g1940.158	1940		2001	9.50	070	30	330	12-14	330	
	g1940158.txt		1941	2001	9.50	070	30	330	12-14	330	
	f1238.158			(1954)	9.50	070	30	330	12-14	330	1938
	f1255.158			2003	9.50	070	30	330	12-14	330	(1955)
	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	--------
	g2138.158	2138		2201	9.20	056	24	301	5-7	330	
	g2138158.txt		2139	2201	9.20	056	24	301	5-7	330	
	f1435a.158			(2152)	9.20	056	24	301	5-7	330	2135
	f1453.158			2203	9.20	056	24	301	5-7	330	(2153)
--------	--------------	-------	-------	-------	-------	-------------	---------	---------	-------	---------	--------
vi/7	g1456.159	1456		1512	12.70 [5]	249	20	325	4-6	325	
	g1456159.txt		1457	1512	12.70	249	20	325	4-6	325	
	f0754.159			1510	12.70	249	20	325	4-6	325	1454
	--------------	-------	-------	------	-------	-------------	---------	---------	-------	---------	--------
	g1530.159	1530		1553	12.90	230	20	325	4-6	325	
	g1530159.txt		1531	1553	12.90	230	20	325	4-6	325	
	f0827.159			(1544)	12.90	230	20	325	4-6	325	1527
	f0845.159			1551	12.90	230	20	325	4-6	325	(1545)
	--------------	-------	-------	------	-------	-------------	---------	---------	-------	---------	--------
	g1913.159	1913		1935	0.00	315	24	316	5-7	316	
	g1913159.txt		1914	1935	0.00	315	24	316	5-7	316	
	f1211.159			(1928)	0.00	315	24	316	5-7	316	1911
	f1229.159			1934	0.00	315	24	316	5-7	316	(1929)
	--------------	-------	-------	------	-------	-------------	---------	---------	-------	---------	--------
	g2042.159	2042		2106	0.00	317	26.5	317	8-10	317	
	g2042159.txt		2043	2106	0.00	317	26.5	317	8-10	317	
	f1341.159			(2058)	0.00	317	26.5	317	8-10	317	2041
	f1359.159			2104	0.00	317	26.5	317	8-10	317	(2059)
--------	--------------	-------	-------	------	-------	-------------	---------	---------	-------	--------	--------
vi/8	g0110160.txt [6]		0110	0132	9.30	345/140 [7]	25	330	10-12	325	
	f1808a.159			(0125)	9.30	345/140	25	330	10-12	325	0108
	f1826.159			0131	9.30	345/140	25	330	10-12	325	(0126)

Notes:

1. Time Checks (UTC): The initial time—AGM and Xbow-- was 1723:45 on 4 June 2004. (I had no authority to set the time on the FOG computer. However, that computer seemed to be accurately set to local—PDT—time, with minor drift.)

DATE	AGM	XBOW	FOG (PDT)
5 June 2004			
@ 0107:05	0107:02.02	0107:04.89	
@ 1653:30	1653:23.21	1653:29.25	
@ 1655:30	1655:23.16	1655:29.11	
6 June 2004			
@ 0837:00 (PDT)			0836:56.59
@ 0837:50 (PDT)			0837:46.49
@ 0838:30 (PDT)			0838:26.51
@ 1551:10	1550:51.14	1551:08.24	
@ 1554:45	1554:26.31	1554:43.35	
7 June 2004			
@ 0903:45 (PDT)			0903:39.43
@ 0904:30 (PDT)			0904:24.54
@ 0905:00 (PDT)			0904:54.49
@ 1554:15	1553:42.64	1554:12.33	
@ 1556:00	1555:27.76	1555:57.35	

2. Initial problems abounded. a) The AGM tiltmeter computer, started at 1859:45 UT, crashed, losing all those data. The replacement computer was started at 1945 UT, but was immediately (at 1946 UT) stopped to correctly reset the clock (to UT from PDT). The AGM tiltmeter was restarted at 1947, only to be stopped at 1954, when we had arrived at station. b) The FOG computer locked up when I tried to restart it at 1947 UT. (I hadn't yet determined and solved this problem with the FOG computer.) **Bottom Line:** We had concurrent Xbow and FOG data from 1909 UT; we had concurrent Xbow and AGM data from 1948 UT; but we did not have all three instruments concurrently until after 1954 UT on 4 June 2004.
3. The initial heading was 050. At 1503 UT the heading was changed to 030. Finally, at 1513 UT the heading was changed to 075.
4. The initial heading was 005. At 1802 UT the heading was changed to 110. Finally, at 1812 UT the heading was changed to 075.
5. The ship stopped on station at 1510 UT.
6. The second AGM computer crashed: no AGM data file here. (I eventually got the computer back on line for the *R/V Point Sur* cruise that followed the next day.)
7. The initial heading was 345. At 0123 UT the heading was changed to 140.
8. The version of "george" running on the FOG computer imposed a hard limit on the size of the files generated. This is why there often is more than a single FOG file per data set.

Gyro/Tiltmeter Conditions, CalCOFI Line 67, June 2004 (*R/V Pt. Sur*)

Date (2004)	File Name	AGM Begin (UTC)	Xbow Begin (UTC)	End (UTC)	Speed, SOG (knots)	Heading (degrees)	True Wind Speed (knots)	True Wind Direction (degrees)	Estimated Seas/Swell (feet)	Direction of Sea/Swell	Oper-ator
vi/8	g01925.160	1925:20		1948	8.30	251.8	23.82	275.7	3-5	NW	TAR
	g01925160.txt		1925:56	1948	8.30	251.8	23.82	275.7			
	g2234.160	2234:11		2256	9.53	080.7	16.66[2]	277.5	4-6	NW	TAR
	g2234160.txt		2235:35	2256	9.53	080.7	16.66[2]	277.5			
vi/9	g0132.161	0132		0203	7.98	256.8	14.19[3]	279.5	6-8	NW	CAC
	g0132161.txt		0134	0203	7.98	256.8	14.19[3]	279.5			
	g0638.161	0638		0655	1.10	292.1	20.44	298.0	6-8	WNW	CAC
	g0638161.txt		0639	0655	1.10	292.1	20.44	298.0			
	g0916.161	0916		0937	1.04	297.6	21.96	306.0	6-8	NW	TAR
	g0916161.txt		0917	0937	1.04	297.6	21.96	306.0			
	g1642.161	1642		1725	6.21	257.7	20.41	307.0	8-10	WNW	CAC
	g1642161.txt		1643	1725	6.21	257.7	20.41	307.0			
	g2023.161	2023		2043	6.72	269.4	18.13	305.3	10-14	NW	TAR
	g2023161.txt		2023	2043	6.72	269.4	18.13	305.3			
vi/10	g0555.162	0555		0622	8.10	247.0	16.00[4]	325.2	9-11	NW	CAC
	g0555162.txt		0557	0622	8.10	247.0	16.00[4]	325.2			
	g1032.162	1033:00		1220[5]	8.69	251.4	16.32[6]	335.0	6-8	NW	TAR
	g1032162.txt		1033:45	1220[5]	8.69	251.4	16.32[6]	335.0			
	g1428.162	1428		1451	9.06	250.9	13.81	334.6[7]	4-6	NW	CAC
	g1428162.txt		1429	1451	9.06	250.9	13.81	334.6[7]			
	g1915.162	1915		1942	0.81	340.9[8]	16.48	346.2	6-8	NW	CAC
	g1915162.txt		1916	1942	0.81	340.9[8]	16.48	346.2			
	g2314.162	2314:45		2349	8.67	050.4	20.39	330.2	6-8	NW	TAR
	g2314162.txt		2315:40	2349	8.67	050.4	20.39	330.2			
vi/11	g0215.163	0215		0305	8.83	059.2	22.37	329.2	7-9	NW	CAC
	g0215163.txt		0217	0305	8.83	059.2	22.37	329.2			
	g0435.163	0436:20		0458	1.13	330.0	23.63	336.5	8-10	NW	TAR
	g0435163.txt		0437:15	0458	1.13	330.0	23.63	336.5			
	g0617.163	0617		0637	8.98	061.4	26.40	332.5	9-13	NW	CAC
	g0617163.txt		0619	0637	8.98	061.4	26.40	332.5			
	g1324.163	1325		1346	8.77/7.04[9]	101.7/009.3[9]	25.11	324.5	11-14	NW	TAR
	g1324163.txt		1325	1346	8.77/7.04[9]	101.7/009.3[9]	25.11	324.5			
	g1351.163	1352		1422	6.85	010.1	26.36	323.1	11-14	NW	TAR
	g1351163.txt		1352	1422	6.85	010.1	26.36	323.1			
	g1444.163	1444		1504	8.91	069.2	24.82	328.8	8-10	NW	CAC
	g1444163.txt		1446	1504	8.91	069.2	24.82	328.8			
	g1547.163	1548		1624	9.39	070.5	20.98	325.6	6-8	NW	CAC
	g1547163.txt		1549	1624	9.39	070.5	20.98	325.6			

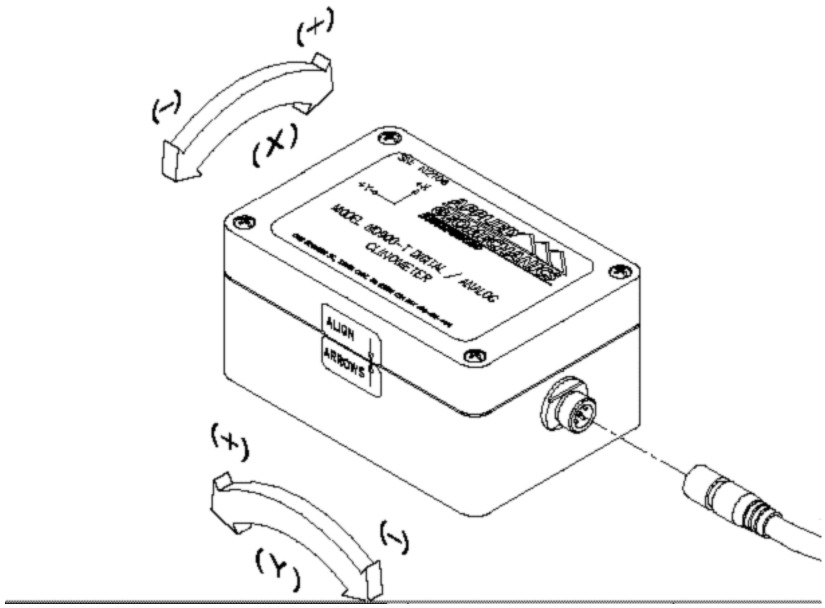
Notes:

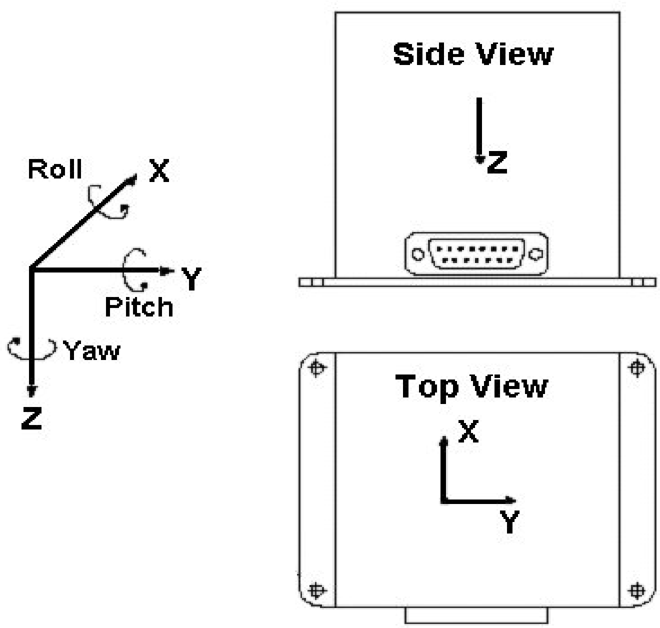
1. Time Checks (UTC): The initial time was 1922:30 on 8 June 2004.

DATE	AGM	XBOW
9 June 2004 @ 2020:00	2019:45.94	2019:59.37
@ 2021:15	2021:00.95	2021:14.11
@ 2022:00	2021:45.93	2021:59.07
10 June 2004 @ 1028:45	1028:19.37	1028:43.67
@ 1030:00	1029:34.38	1029:58.56
@ 1031:10	1030:44.26	1031:08.45
11 June 2004 @ 1348:00	1347:19.78	1347:57.88
@ 1349:15	1348:34.62	1349:12.35
@ 1350:55	1350:14.64	1350:52.37

2. During the sampling period the wind steadily increased from ~12 knots to ~19 knots.
3. During this sampling period the wind steadily increased from ~12 knots to ~16 knots.
4. During this sampling period the wind steadily decreased from ~19 knots to ~14 knots.
5. I forgot to stop the data recording after 20 minutes. Fortunately, course/speed/etc. were steady for this transit time.
6. This is a good average wind speed. However, there was a brief period (~20 minutes) where the winds kicked up to 25 knots.
7. Approximately over the first half of the sampling period the wind swung around from 345^o to the average direction listed here.
8. During this sampling period the ship's heading steadily changed from ~330^o to ~355^o.
9. The ship altered course and speed at 1333 UT during this sampling period.

APPENDIX E. Instrument Axes.





Crossbow DMU Orientation

Appendix F. *R/V Point Sur* Sampling

The yellow square in Figure F1 below shows the mounting location for the vertical gyro and tiltmeter in the main laboratory on the *R/V Point Sur*. The green square shows the location of the outboard stern rail for which vertical accelerations have been tabulated.

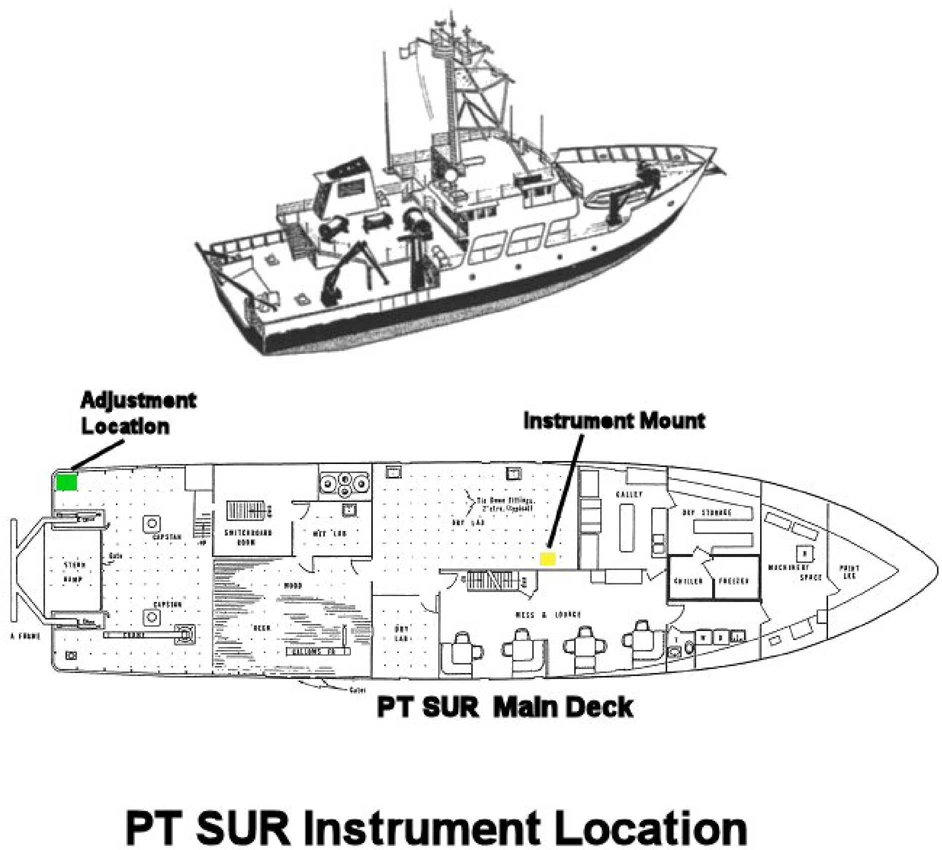


Figure F1. Instrument location on the *R/V Point Sur*. Instruments were set up on the work bench along the inboard side of the main laboratory as indicated by the yellow square. This was just aft of the ship's gyro repeater compass. The green square shows the outboard stern rail location for which vertical acceleration was calculated.

The photograph below (Figure F2) shows the instruments mounted on the forward end of the bench that runs along the midship bulkhead in the main lab. The top of the ship's gyro repeater can be seen behind the chair. The laptop computer in the left of the photograph was used to record data from the vertical gyro. A close-up of the tiltmeter and vertical gyro is shown in Figure F3.

Figure F2. Arrangement of sampling equipment on *R/V Point Sur*.

Figure F3. Close-up of the vertical gyro (left) and tiltmeter (right) mounted on a lab bench in the main lab of *R/V Point Sur*.

Figure F4 shows the layout of the main deck and upper deck for the *R/V Western Flyer*. The instrument locations are indicated by the green square on the ship's centerline just forward of the moon pool and in a cabin on the upper deck on the port side aft of the location of the moon pool. Vertical accelerations discussed above were calculated for the port side of the stern, as shown by the black square.

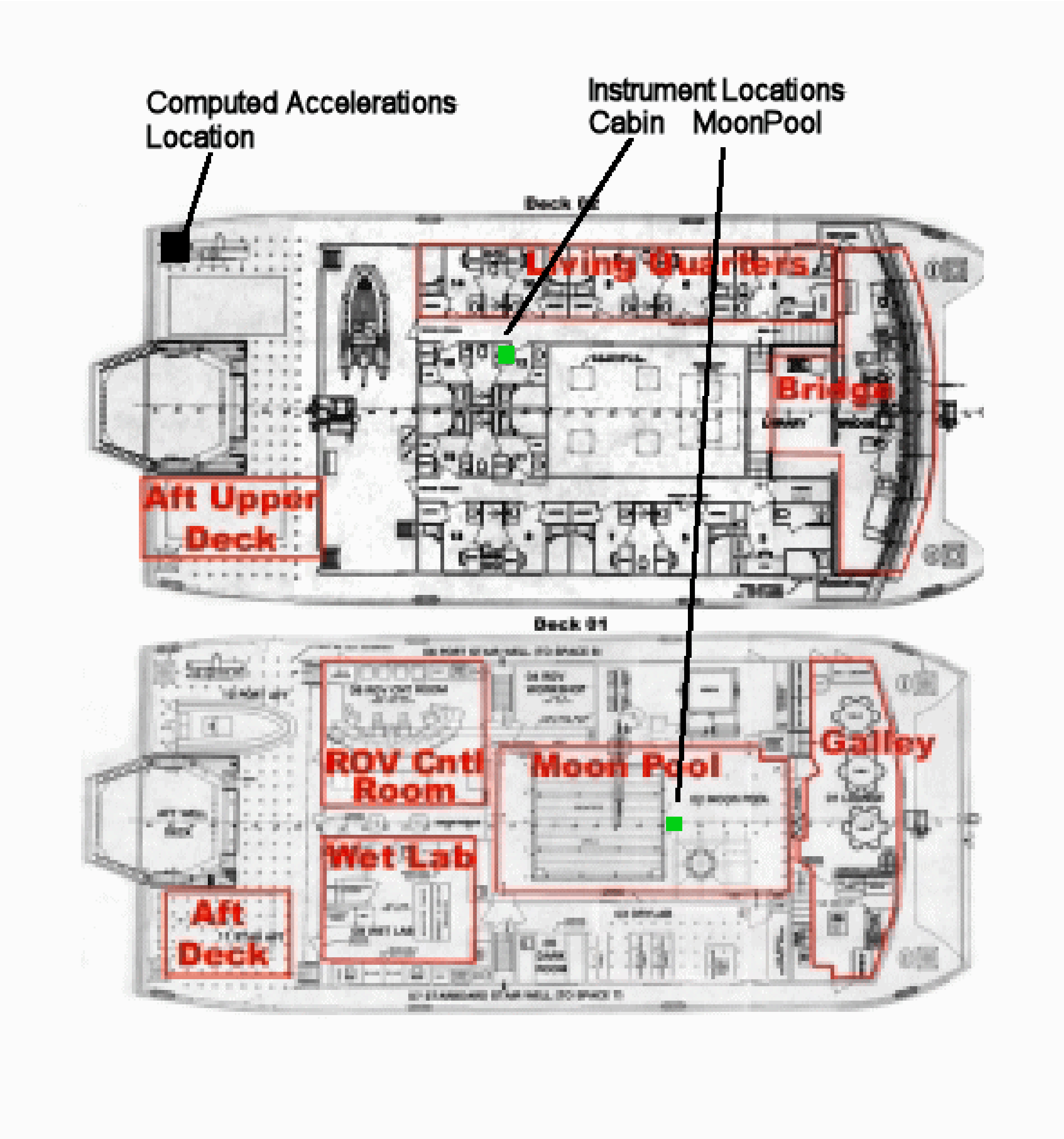


Figure F4. Plan view of the Upper and Main Decks on *R/V Western Flyer*. The green squares show the measurement locations and the black square indicates the location for which vertical accelerations where calculated.

Figure F5 shows the instruments as mounted in the cabin, while Figure F6 shows the AGM tiltmeter mounted forward of the moon pool, of the *R/V Western Flyer*.

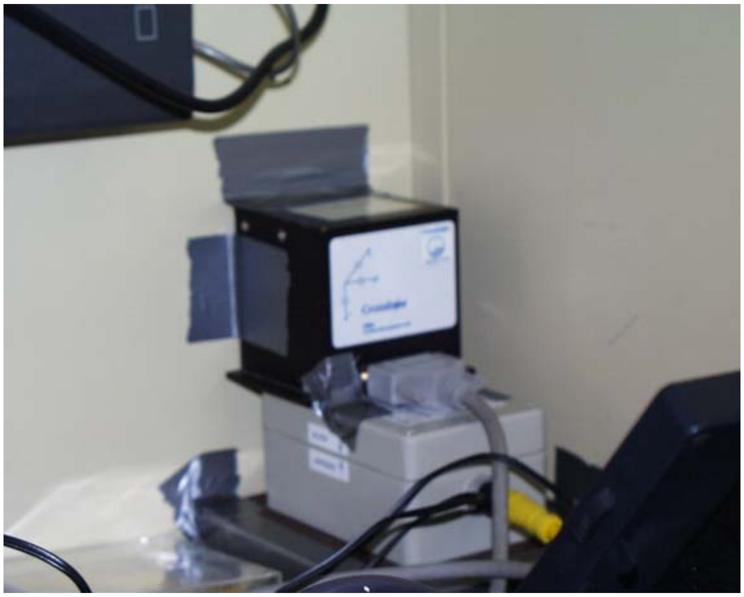


Figure F5. Tiltmeter and vertical gyro mounted in cabin on *R/V Western Flyer*.

Figure F6. Tiltmeter mounted forward of the moon pool on *R/V Western Flyer*.

APPENDIX G. Evaluation of GPS Attitude System on *R/V Point Sur*

An attempt was made to evaluate the ability of two different attitude systems on the *R/V Point Sur* in a known wave field in November 2002. The experiment was done in conjunction with a set of wave measurements made by Prof. Tom Herbers.

The *R/V Point Sur* has a permanently installed GPS-based attitude system, the Thales (Ashtech). This unit takes GPS measurements from four antennas and computes the heading, pitch, and roll. The antennas are shown in the photograph below (Figure G1). The photograph shows the mast area about 15 m above the water line. (Some of the other antennas shown, such as the 4 geodetic GPS antennas, were not present during the November 2002 experiment.)

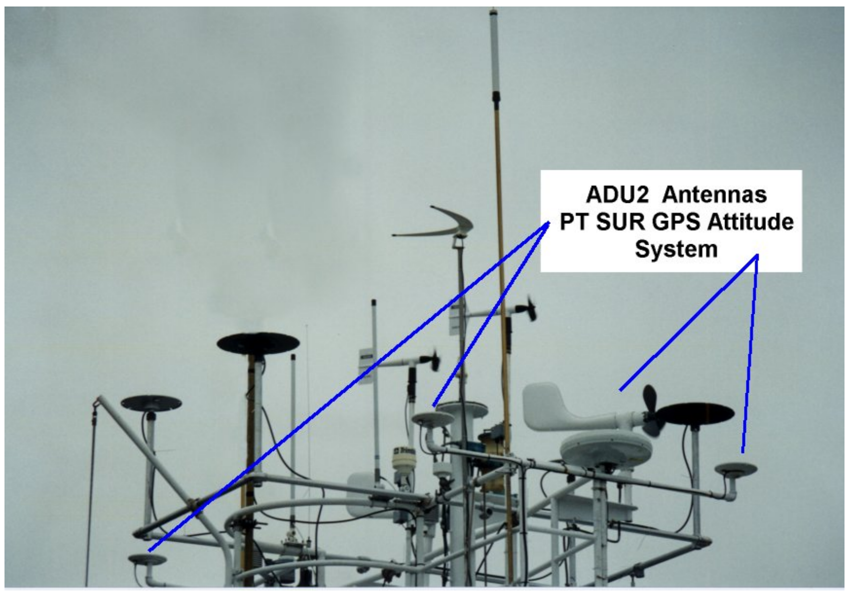


Figure G1. Upper portion of *R/V Point Sur* mast showing location of GPS antennas used by the attitude measuring system.

The Ashtech unit outputs data at 2 Hz. (Later models can go to 5 Hz.) The accuracy is a function of the antenna separation. For the *R/V Point Sur* unit, the manufacture quotes an accuracy of 0.15° in a low multipath environment, 0.3° in a high multipath environment. Clearly there is considerable multipath in the *R/V Point Sur* case. The Ashtech unit cost about $25,000, but now (with a considerable GSA discount) has a price of $17,000.

In addition to the Ashtech measurements, an Applied Geomechanics[7] (AGM) Model MD900-T precision tiltmeter was installed below decks within about 1 m of the

[7] The unit was purchased to measure ice deflection associated with aircraft landings.

center of motion of the ship. This unit measures roll and pitch. It has a resolution of 0.01° and a quoted accuracy of 0.03°, outputting data at 4 Hz. It is about 2 x 3 x 5 inches, and was bolted to the ship's structure. The unit cost about $1000.

Data were acquired on 21 and 22 November 2002 during two student cruises of about 8 hours each. The ship stayed close to shore in Monterey Bay. The seas were calm, with a 1.5- to 2-m swell from 270° with a period of 15-18 s. Only data from 21 November (yearday 325) were examined in any detail. The swell period peaked at 18 s during this time.

The data from both units were converted to simple text files with columns of time and attitude components. The GPS unit had heading, pitch and roll at 2 Hz. The tiltmeter had only roll and pitch. The real data rate of the tiltmeter was 4.44 Hz. The instrument response for the tiltmeter was measured in the laboratory.

The means and standard deviations of all the attitude components from both units were computed in 1-minute windows. The standard deviations are shown in Figures G2 and G3 below.

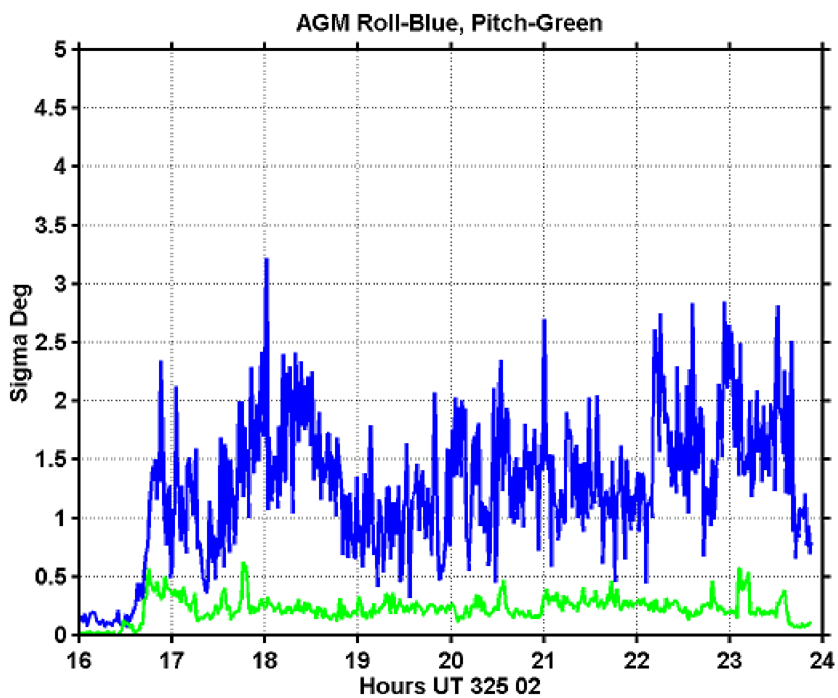


Figure G2. Standard deviation of one-minute samples of pitch and roll obtained from AGM tiltmeter.

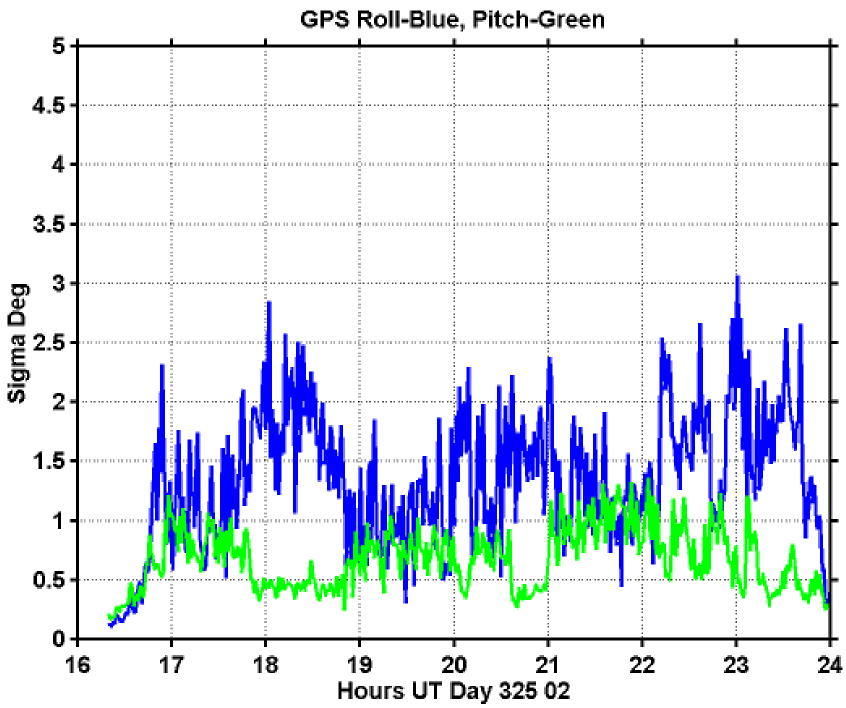
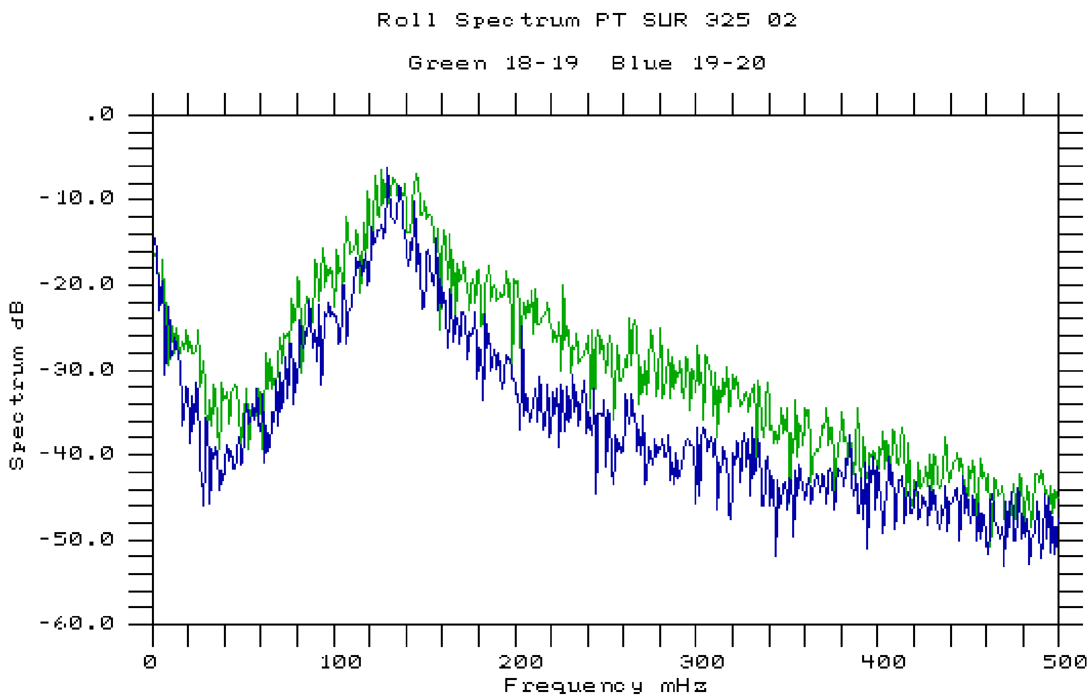


Figure G3. Standard deviation of one-minute samples of pitch and roll obtained from GPS attitude system on *R/V Point Sur.*

It appears that the GPS unit agrees well in roll with the AGM. At low magnitudes this is also true of the pitch. At pitch amplitudes above about 0.5°, the GPS unit shows larger values than the AGM. The origins of this have not been established, but it may be vibration of the pipes that support the GPS antennas which are parallel to the fore-aft centerline of the vessel.

Spectra for hours 18 and 19 were computed for the roll component (Figure G4). These hours show slightly different character in the 1-minute statistics, e.g. the standard deviation of the roll during hour 18 is about twice that for hour 19. The AGM spectra are shown below followed by the GPS data. The levels are with respect to 1° $(mHz.)^{-1/2}$.

The AGM unit shows larger high frequency values (100 - 400 mHz.) in hour 18, when there was more roll energy. This is not the case for the GPS spectra. There is more low frequency energy in both hours of the GPS data.



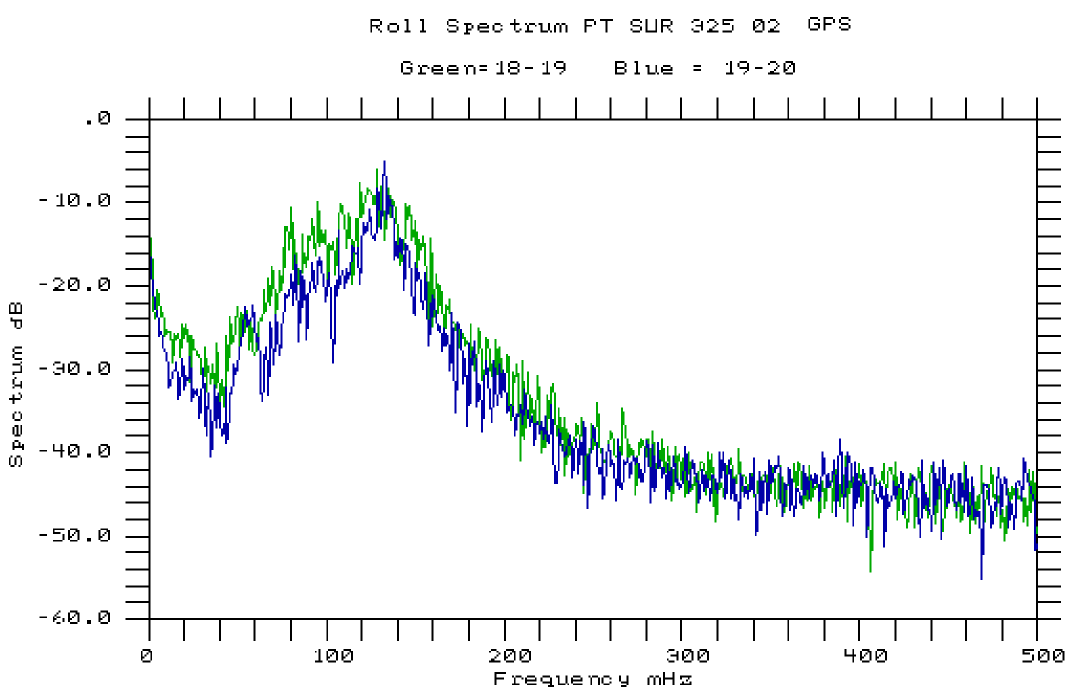


Figure G4. Spectrum of roll measurements on *R/V Point Sur* for 1800 (green) and 1900 (blue) UT on 21 November 2002. *Upper.* AGM tiltmeter measurements. *Lower.* GPS attitude measurements.

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