Proudman Oceanographic Laboratory

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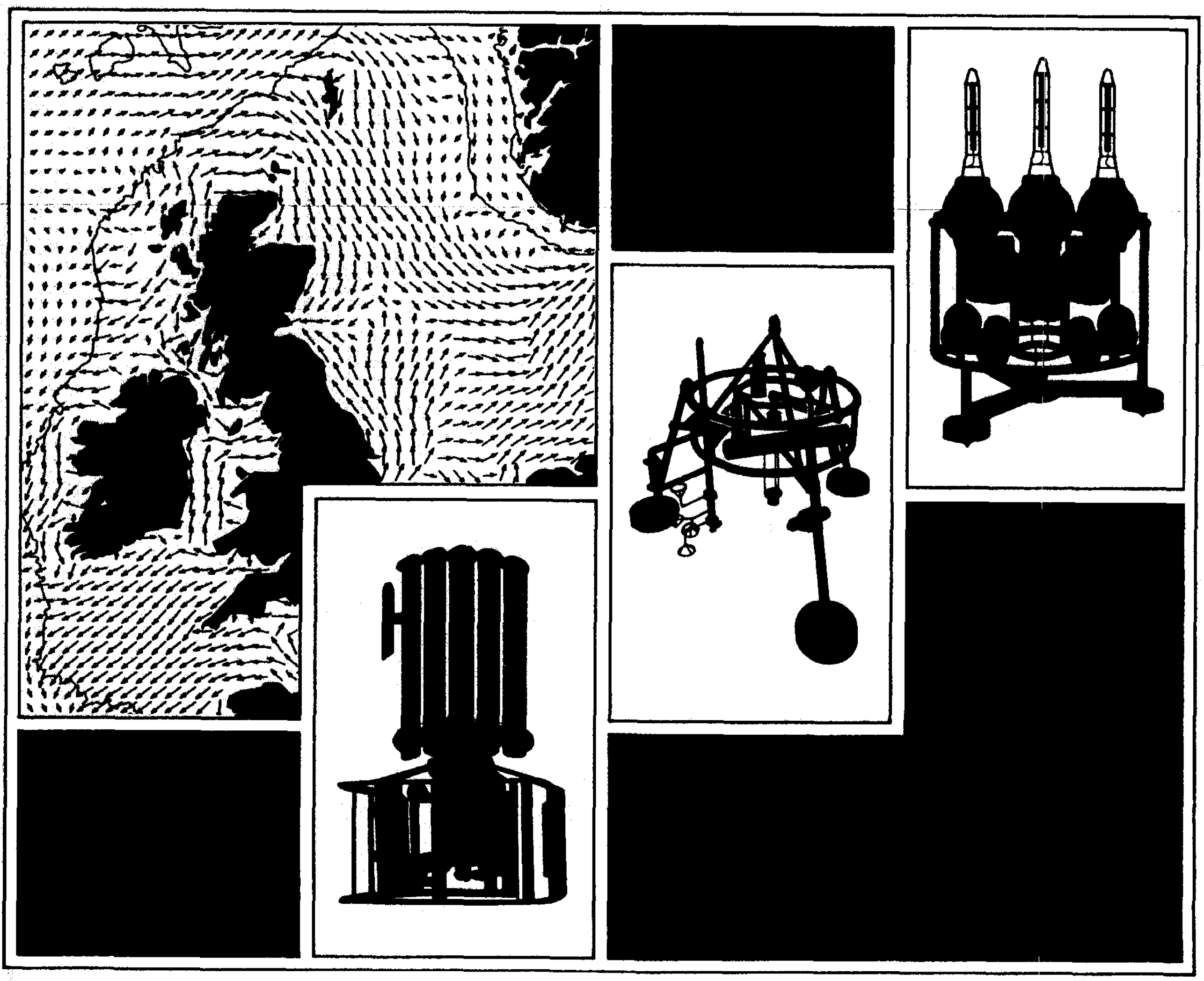
JD Humphery and SP Moores

Report No. 37 1994



Natural Environment Research Council

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# Description and Interpretation of Data Recorded by STABLE II During Charles Darwin Cruise 84, OMEX, Goban Spur, January, 1994.

J.D. Humphery and S.P. Moores

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**ABSTRACT**

This report describes how STABLE II was used during Charles Darwin cruise 84, to the Goban Spur during January, 1994. This deployment was part of the physics component of the OMEX programme, funded by the CEC. The format of the data as archived by the British Oceanographic Data Service is described and details of sensor-calibration and the disposition of sensors on the STABLE apparatus are given.

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# 1 INTRODUCTION

A deployment of the pop-up (deepwater) version of STABLE II was requested by Dr J M Huthnance of POL as part of the OMEX programme of the European Commission. It was to take place during Charles Darwin cruise 84, on the Goban Spur to the southwest of Ireland, during January, 1994. Analysis of the data was to be performed by Paul Chatwin of Plymouth University.

This report describes the equipment as used on the Goban Spur, how the data were obtained, mentions some of the ancillary data, details calibration procedures and explains how the data as archived by the British Oceanographic Data Centre (BODC) should be interpreted.

# 2 THE EQUIPMENT

When this work was requested, STABLE II existed only in its shallow-water, heavy form. However, the instrumentation was designed from the outset to be capable of working to 1000m depth. Accordingly, development of a lightweight vehicle suitable for free-fall and free-recovery was completed.

Pop-up STABLE II consists of a large aluminium frame standing on tripod legs, (see Figure 1); it is fitted with syntactic foam buoyancy, two Benthos transponding releases, mechanical releases and disposable ballast. When the Benthos releases receive a coded acoustic command from the mother ship, the ballast is released and the instrument pops up to the surface.

The frame carries a large number of sensors, (Humphery and Moores, 1994). Three-dimensional turbulent currents and rapidly-changing pressures are logged at 8Hz for twenty minutes every hour by a "burst" logger. Each burst record contains 9600 scans. Tidal currents and their direction, tidal pressures, rig-attitude and orientation and seawater temperature are all measured once a minute by a "mean" logger. Four simple settlement traps collect samples of suspended sediment during the course of experiments. An ABS (Acoustic Backscatter System) measures suspended sediment profiles concurrently with the burst logging periods. During CD84, the suspended sediment concentrations were very low and generally below the threshold of the ABS system; consequently ABS results are not described further here and have not been archived. Other sensors are still under development.

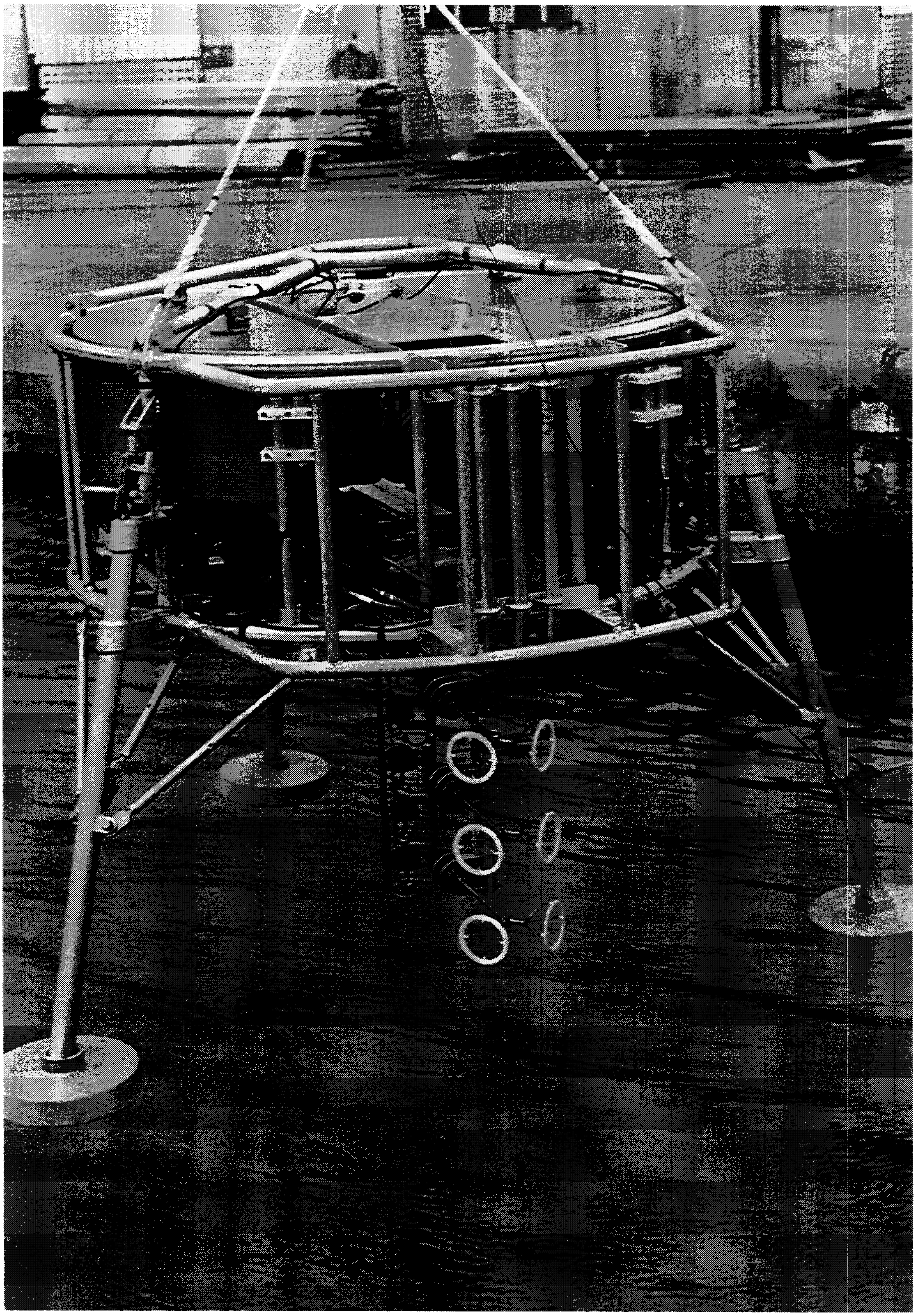

Figure 1.

POP-UP STABLE II undergoing flotation trials in Vittoria Dock, Birkenhead, on 29th November, 1993.

## 3 DEPLOYMENT OF STABLE II

STABLE II was taken to RVS Barry on 12th January, 1994, and was assembled and tested in the equipment store. It was loaded onto the Charles Darwin by crane in a fully working condition on the 17th January, and the ship sailed for the Goban Spur on the 18th. Logger-performance was checked periodically up to the moment of sailing; thereafter, poor conditions on deck precluded any further checks. The cruise was primarily to investigate marine chemistry and the Principal Scientist was Dr P Statham of Southampton Universtiy.

Objectives for the deployment had been determined before sailing. STABLE II was to be deployed on the Goban Spur near the top of the Continental Slope on the transect formed by a line of three suspended sediment trap moorings, (the "OMEX transect", see Cruise Report, Poseidon 200, Leg 7). For a chart of the STABLE II position, see Figure 2, below. Depth was to be about 800m. It was hoped that this depth would coincide with a maximum slope, a weak thermocline and a poorly-defined nepheloid layer. When the ship reached the area, CTD measurements were made at 200m and 1000m to assess the situation.

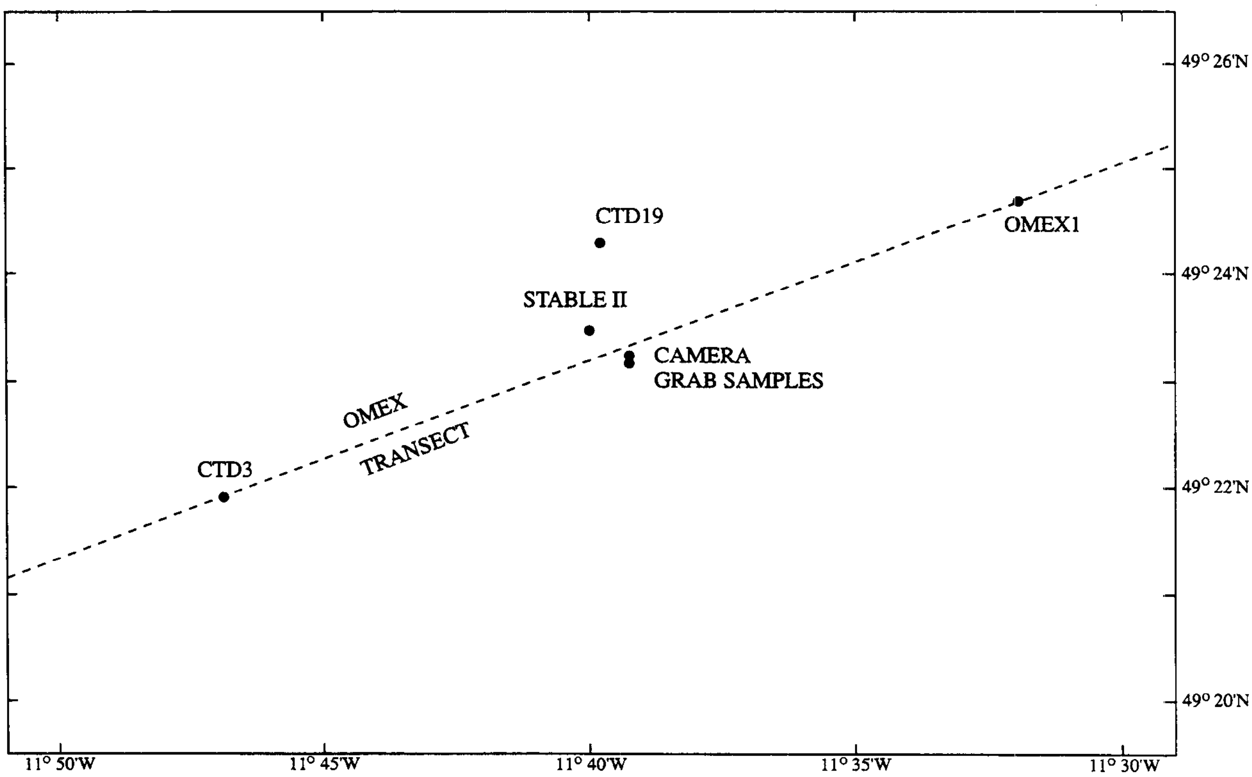


Figure 2.

Position of STABLE II and associated measurement sites during Charles Darwin cruise CD84.

CTD cast 1 went to a depth of approx 175m, in position 49deg 29.80min North, 11deg 00.18min West, during the morning of 20th January. The water was well mixed, with near-constant salinity and temperature to the depth of the cast. Temperature was about 10.9deg C. (CD84 CTD information is held by the British Oceanographic Data Centre, BODC, at the Proudman Oceanographic Laboratory, Birkenhead.)

CTD cast 3 went to a depth of approx 980m in position 49deg 21.92min North, 11deg 46.92min West at about 1730GMT on the 20th. There was little evidence of a thermocline, but a slightly more rapid temperature change occurred at about 850m. A weak nepheloid layer started at about 900m. The weak thermocline at 850m coincided with the lower limit of a steeper slope: it was decided to deploy STABLE II in about 850m. Temperature at this depth was about 9.66deg C.

Two small Shipek grab samples of silty mud were obtained in 860m water in position 49deg 23.25min North, 11deg 39.22min West at 20.34GMT on the 20th.

The POL bed-hopping camera was deployed in 860m water in position 49deg 23.28min North, 11deg 39.24min West, at 22.17GMT. The film, which was developed on the Charles Darwin later, showed a muddy bottom without current-induced features, but with some bioturbation, (see Figure 3).

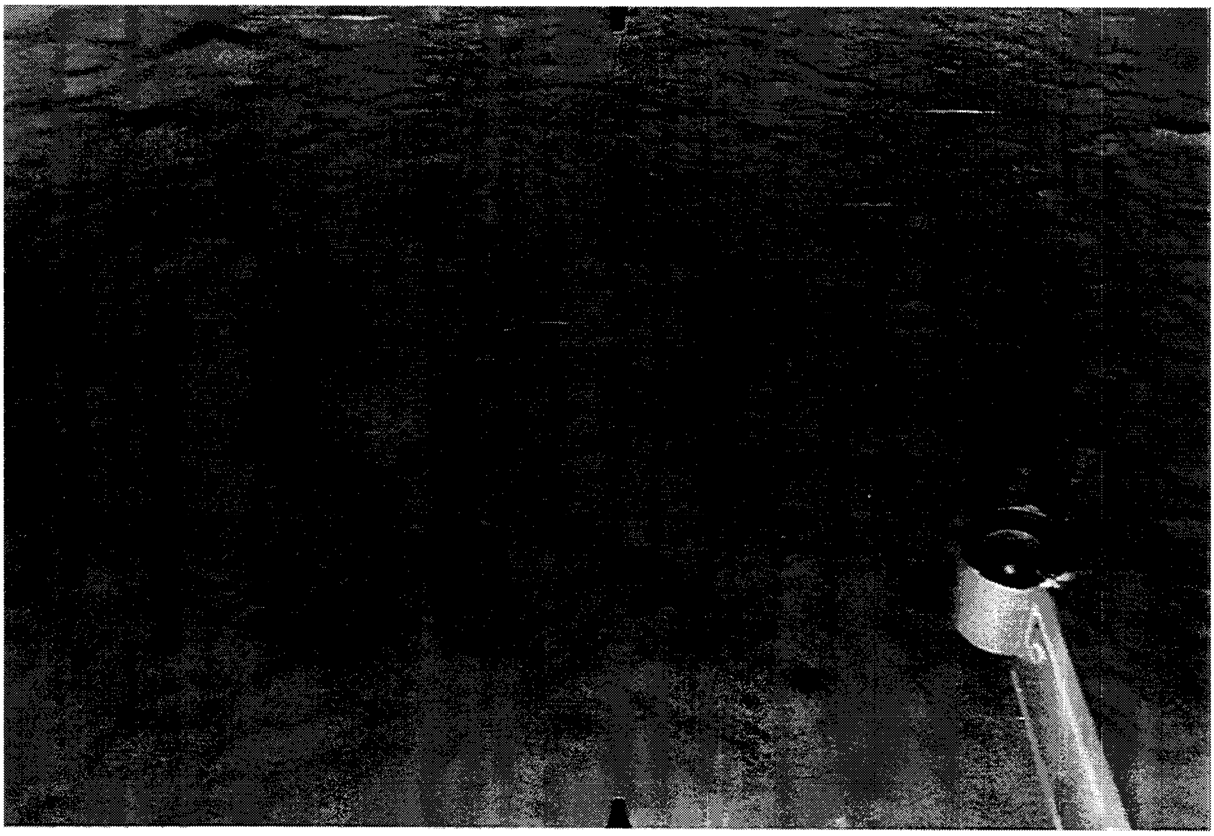

Figure 3.

Photograph of the seabed near the STABLE site. Note the feeding-tracks of sea urchins - see example, top right.

STABLE II was deployed immediately after the camera-drop; (for collated details of deployment, see below). The frame was lowered into the water on a slip-hook from the A-frame; the slip-hook was released with some difficulty in the moderate sea. STABLE's descent to the seabed was monitored on the Benthos deck unit; slant range was 933m when the rig reached the bottom.

From time and pressure information obtained later from the STABLE II mean logger, the descent-rate was 1.04m/s.

## 4 CHECK ON STATUS

The STABLE II site was visited at 1517GMT on 26th January. The Benthos transponders were interrogated and both gave a slant-range reading of about 950m. As the ship was drifting in strong winds at the time, these readings were considered acceptable. (Note that recovery was scheduled for this time, but high winds and heavy seas prevented any attempt.)

## 5 RECOVERY OF STABLE II

The STABLE II site was visited again on the 31st January 1994, at the end of the cruise, to afford a second attempt at recovery. The apparatus was interrogated at 0653GMT and gave a slant range of 935m from both transponders. Weather conditions were not good for a recovery. The wind was blowing a steady 20kt from 230deg with some sea and swell and with the occasional wave coming up over the transom onto the after deck. This was to be the last possibility of recovery during the cruise however, and it was decided that an attempt should be made.

The Benthos system was interrogated again at 0807GMT and gave a slant range of 1125m. The ship was positioned downwind (ie approx NE) of the STABLE II position, and about 1km distant. The release command was transmitted and the range display was watched while the rig started for the surface: the transponding function ceased abruptly when the transponders broke clear of the surface. The rig was spotted by the bridge, the ship was manoeuvered alongside, and the rig lifted onto the after deck by the strayline . The time was 0856GMT. There was no rig-damage.

STABLE II floated with very little freeboard and looked like an orange pancake floating on the surface. Rise-rate during ascent was later computed to have been 0.69m/s.

CTD 19 was taken in position 49deg 24.33min North, 11deg 39.78min West, (within a mile of the STABLE site), at 0955GMT, ie, shortly after rig-recovery. This was done to provide corroborative temperature information to compare with the STABLE II data.

## 6 COLLATED DEPLOYMENT INFORMATION

| | |
|---|---|
| Date deployed: | 20th January, 1994. |
| Time deployed: | 23.17GMT. |
| Position: | 49deg 23.49N,<br>11deg 40.03W. |
| Depth (by echo-sounder): | 879m. |
| Descent rate: | 1.04m/s. |
| Date recovered: | 31st January, 1994. |
| Time released: | 0809GMT |
| Time recovered on deck: | 0856GMT |
| Ascent rate: | 0.69m/s. |
| First mean scan: | 23:17:35GMT on<br>20th January, 1994. |
| First mean scan on bottom: | 23:32:35GMT on<br>20th January, 1994. |
| Last mean scan on bottom: | 08:09:35GMT on<br>31st January, 1994. |
| Total number of mean scans: | 14,978. |
| First burst record: | Burst 001, on<br>20th January,1994, at<br>22:00:01GMT. |
| First burst record on bottom: | Burst 003, on<br>21st January, at<br>00:00:01GMT. |
| Last burst record on bottom:<br>(part-burst only) | Burst 251, on<br>31st January, at<br>08:00:01GMT. |
| Total number of bursts: | 251. |

## 7 THE DATA

For convenience, and because the data-types are very different, the mean and burst data are archived separately. However, regardless of the type of sensor and the logger to which data were written, all sensors have been calibrated, and the data have had the relevant calibration coefficients applied to them to give parameters in engineering units.

STABLE II is one of the few oceanographic instruments where the disposition of sensors is important. Diagrams showing the positions of instruments, relevant dimensions and the directions of vector quantities may be found in the relevant appendices.

### 7.1 Mean data

Mean data are presented in a single large file of scans recorded at one minute intervals. The data are presented in fourteen columns of information, and the information contained in each column is described below. The first 20 scans of mean data are shown below in Table 1 as an example; the changing values at the top of Column 3 indicate that the rig was falling towards the seabed. Note that the last digits in Column 14 have sometimes been truncated due to insufficient space.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200194 | 231635 | 1.2612 | 10.981 | 11.057 | 0.68 | 0.69 | 0.63 | 0.80 | 5.00 | -0.20 | 2.35 | 165.7 | 65.9 |
| 200194 | 231735 | 3.0730 | 10.986 | 11.057 | 0.27 | 0.28 | 0.32 | 0.37 | 5.00 | -0.39 | 0.20 | 152.2 | 335. |
| 200194 | 231835 | 9.1296 | 10.988 | 11.061 | 0.15 | 0.14 | 0.17 | 0.24 | 5.00 | -0.29 | 0.20 | 79.9 | 272.6 |
| 200194 | 231935 | 15.4175 | 10.992 | 11.067 | 0.14 | 0.13 | 0.12 | 0.26 | 5.00 | -0.20 | 0.49 | 12.8 | 208. |
| 200194 | 232035 | 21.7096 | 10.997 | 11.071 | 0.13 | 0.13 | 0.10 | 0.25 | 5.00 | -0.20 | 0.49 | 317.8 | 144 |
| 200194 | 232135 | 28.0033 | 11.003 | 11.075 | 0.14 | 0.13 | 0.10 | 0.24 | 5.00 | -0.20 | 0.49 | 118.0 | 85. |
| 200194 | 232235 | 34.3375 | 11.006 | 11.063 | 0.14 | 0.13 | 0.09 | 0.25 | 5.00 | -0.10 | 0.49 | 167.7 | 22. |
| 200194 | 232335 | 40.7164 | 11.006 | 10.997 | 0.15 | 0.12 | 0.00 | 0.26 | 5.00 | 0.00 | 0.20 | 122.8 | 315. |
| 200194 | 232435 | 47.0502 | 10.992 | 10.882 | 0.14 | 0.13 | 0.03 | 0.26 | 5.00 | 0.00 | 0.49 | 52.1 | 249.0 |
| 200194 | 232535 | 53.3799 | 10.968 | 10.762 | 0.15 | 0.13 | 0.10 | 0.24 | 5.00 | 0.00 | 0.49 | 323.8 | 179. |
| 200194 | 232635 | 59.6924 | 10.930 | 10.635 | 0.14 | 0.13 | 0.10 | 0.25 | 5.00 | -0.10 | 0.49 | 297.2 | 124 |
| 200194 | 232735 | 65.9560 | 10.883 | 10.495 | 0.15 | 0.12 | 0.05 | 0.25 | 5.00 | -0.10 | 0.49 | 104.4 | 73. |
| 200194 | 232835 | 72.2019 | 10.821 | 10.312 | 0.15 | 0.13 | 0.00 | 0.25 | 5.00 | -0.10 | 0.20 | 179.2 | 14. |
| 200194 | 232935 | 78.4745 | 10.743 | 10.123 | 0.14 | 0.13 | 0.00 | 0.25 | 5.00 | -0.10 | 0.20 | 35.4 | 302. |
| 200194 | 233035 | 84.6957 | 10.656 | 9.983 | 0.14 | 0.14 | 0.00 | 0.24 | 5.00 | 0.10 | 0.59 | 18.6 | 240.8 |
| 200194 | 233135 | 89.4178 | 10.570 | 9.893 | 0.14 | 0.15 | 0.05 | 0.21 | 5.00 | -0.88 | -0.78 | 286.1 | 225 |
| 200194 | 233235 | 89.6829 | 10.481 | 9.850 | 0.14 | 0.11 | 0.07 | 0.12 | 5.00 | -0.88 | -1.08 | 89.2 | 225. |
| 200194 | 233335 | 89.6830 | 10.400 | 9.825 | 0.18 | 0.16 | 0.09 | 0.16 | 5.00 | -0.88 | -1.08 | 90.8 | 225. |
| 200194 | 233435 | 89.6819 | 10.327 | 9.809 | 0.15 | 0.14 | 0.09 | 0.14 | 5.00 | -0.88 | -1.08 | 53.0 | 226. |
| 200194 | 233535 | 89.6821 | 10.260 | 9.798 | 0.13 | 0.09 | 0.07 | 0.12 | 5.00 | -0.88 | -1.08 | 285.2 | 226 |

Table 1.

The first 20 scans of mean data recorded by STABLE II during the OMEX experiment, Goban Spur, January, 1994.

Column 1: Date - A column comprised of six figures:
First and second figures - day-number in the month;
Third and fourth figures - month-number in the year, (01 = Jan.);
Fifth and sixth figures - year number, (94 = 1994).
Date is derived from the crystal-controlled system clock and logger set-up information.

Column 2: Time in GMT, (24-hour clock) - A column comprised of six figures:
First and second figures - hours, (00 = midnight);
Third and fourth figures - minutes, (00 = "on the hour");
Fifth and sixth figures - seconds, (00 = "on the minute").
Time is derived from the crystal-controlled system clock and logger set-up information.

Column 3: Digiquartz Pressure (D/Q Press) in Bar - measures tidal pressure variations.
Note: 1Bar = 0.1MPa, and 1Pa (Pascal) = 1Newton per square metre, and that one bar is equivalent to approx 10m of seawater. This sensor is an absolute pressure gauge and measures the sum of all pressure components; thus to obtain the pressure due to water depth, atmospheric pressure must be deducted first. This pressure has been corrected for temperature effects, (see Column 4, below), and normal calibration coefficients have been applied. Readings are integrated over one minute.

For mean D/Q Press calibration information, see Appendix A.

Column 4: Digiquartz Temperature (D/Q Temp) in degrees Celsius - measures the temperature of the D/Q pressure sensor.
Note: Digiquartz pressure sensor number 52861 contains a thermistor to measure temperature: this temperature information is then used to apply corrections to the pressure signal, (see Column 3, above). D/Q Temp can be used as a rough measure of seawater temperature, but note that the sensor has an uncertain thermal time-constant which is possibly of the order of a few minutes. Readings are integrated over one minute.
This sensor was calibrated both before and after deployment; agreement was good and readings are probably accurate to within plus or minus 20 mdeg C.

For mean D/Q Temp calibration information, see Appendix A.

Column 5: Quartz Crystal Temperature (Qts Temp) in degrees Celsius - measures seawater temperature.
Note: The mean logger end-cap houses a temperature sensitive crystal with a thermal time-constant of a few tens of seconds. It therefore gives a better indication of rapid changes in seawater temperature than the D/Q Temp sensor. Readings are integrated over one minute.
Temperature agreement with Column 4 (D/Q Temp) is quite good, (discrepancy is approx 30mdeg C, with Qts Temp generally reading higher) after initial settling.

For mean Qts Temp calibration information, see Appendix B.

Column 6: Rotor 4, (R4), metres per second - measures tidal currents using a Savonius rotor.
Note: R4 measures omnidirectional tidal currents at a height of 762mm above the seabed (assumed plane). Readings are integrated over one minute.

For R4 calibration information, see Appendix C. For R4 siting information, see Appendix I.

Column 7: Rotor 3, (R3), metres per second - measures tidal currents using a Savonius rotor. Note: R3 measures omnidirectional tidal currents at a height of 582mm above the seabed (assumed plane). Readings are integrated over one minute.

For R3 calibration information, see Appendix C. For R3 siting information, see Appendix I.

Column 8: Rotor 2, (R2), metres per second - measures tidal currents using a Savonius rotor. Note: R2 measures omnidirectional tidal currents at a height of 402mm above the seabed (assumed plane). Readings are integrated over one minute.

For R2 calibration information, see Appendix C. For R2 siting information, see Appendix I.

Column 9: Rotor 1, (R1), metres per second - measures tidal currents using a Savonius rotor. Note: R1 measures omnidirectional tidal currents at a height of 222mm above the seabed (assumed plane). Readings are integrated over one minute.

For R1 calibration information, see Appendix C. For R1 siting information, see Appendix I.

Column 10: 5V Reference, (5V Ref), Volts - measures the reference voltage applied to the pitch and roll sensors.
Note: A fixed reference voltage is applied to the pitch and roll sensors; any variation in this voltage will cause the pitch and roll outputs to vary, and this could be interpreted as rig-instability. 5V Ref also checks the performance of the A/D converter, assuming that the reference is constant. These are spot readings.

Column 11: Pitch, degrees relative to horizontal - measures whether rig attitude is nose-up or nose-down.
Note: Rig-attitude has implications for "vertical" and "horizontal" currents as measured by the electromagnetic current meters, (see burst data information). Seabed irregularities usually mean that STABLE II is not level during deployments, and so the instrument is fitted with attitude sensors. Positive readings indicate a stern-down attitude, (see diagrams, Appendix I), negative readings indicate a nose-down attitude. These are spot readings.

Note that the orientation of the pitch sensor is determined by the orientation of the mean logger case in the STABLE II frame and cannot be adjusted. The pitch reading was checked when the frame was level prior to deployment; the reading was 521 counts, corresponding to a pitch of about 0.1deg nose-down.

For Pitch calibration information, see Appendix D.

Column 12: Roll, degrees relative to horizontal - measures rig attitude from side to side.
Note: See Note, (Column 11), regarding the effect of rig attitude on electromagnetic current

meter readings. Positive roll readings indicate that the port side of the apparatus is down with respect to the centre-line, (see diagrams, Appendix I); negative readings indicate that the starboard side is down. These are spot readings.
Note that the orientation of the roll sensor is determined by the initial setting-up of the mean logger tube in the STABLE II frame; this is aided by a small spirit level. The roll reading was checked when the frame was level prior to deployment; the reading was 482 counts, corresponding to a roll of about 0.1deg, starboard side down.

For Roll calibration information, see Appendix E.

Column 13: Current direction, (Vane), degrees relative to magnetic North - measures the direction TOWARDS WHICH a tidal current flows.
Note: The tidal current direction sensor, (vane), is sited 907mm above the seabed, (assumed plane), (see diagrams, Appendix I). It is mounted on the same vertical axis as the Savonius rotor column. The raw vane output gives current direction relative to frame-heading; this is then combined with the heading-sensor reading, (see Column 14), to give current direction relative to magnetic North. For True current direction, it is necessary to add or subtract local Magnetic Variation which can be obtained from the appropriate Admiralty chart. These are spot readings.

For information on how the vane readings are derived, see Appendix F. For information on how to interpret the vane readings, see Appendix I.

Column 14: Rig Heading, (Compass), degrees relative to magnetic North - measures the direction towards which the rig faces, (see diagrams, Appendix I).
Note: The heading sensor, (a KVH Azimuth 314 digital compass), is aligned with the centreline of STABLE II, and gives a zero output when the rig faces towards magnetic North. These are spot readings.
Note that the compass itself is factory-calibrated. When the sensor is installed in the frame however, perturbations are caused to the readings. It is very difficult to quantify these errors. The frame has to be instrumented fully, and turned about its vertical axis while the compass is interrogated. The ground underneath must have no perturbing magnetic influences.

The STABLE compass has been calibrated in the POP-UP frame, but not under ideal conditions. However, there was no indication that the compass did not give a correct reading, ie the frame and instruments did not cause any appreciable perturbation.

## 7.2 Burst data

Because of the large amount of data recorded during each burst, and because of the temporal discontinuities between bursts, each 20-minute burst of 9600 scans is archived as a separate file with its own header information.

### 7.2.1 Header Information

This is given at the beginning of each burst file.

Apparatus Name: POP-UP STABLE2

Burst Number: The number of the burst in question, (between 001 and 251). (Note that STABLE was deployed near the end of burst 001, and was released from the seabed near the end of burst 251.)

Start Date: Date on which the burst in question was recorded, eg 20:01:94, ie 20th January, 1994.

Start Time: Time at which the burst in question started, eg 22:00:01, ie 1 second after 22 hours, GMT.

Deployment Reference: OMEX-CD84.

Logging Frequency: 8Hz.

### 7.2.2 Logged Data

Data are arranged in thirteen columns. The first 12 columns display spot readings of current velocity in metres per second as measured by the six electromagnetic current meters, (EMCMs). The last column displays pressure variations which are integrated over 0.125s. An example of burst data is shown in Table 2, below. For disposition of sensors see diagrams in Appendices G and I.

Outside the zero-current offset ranges, UPWARD-FLOWING vertical currents have positive values, (columns 2, 4, 6, 8, 10, and 12.)

For horizontal currents measured by the Port heads, (columns 1, 5, and 9), positive values indicate flows from left to right across the front face of the head, ie flows which move generally from FRONT to BACK of STABLE, (but note any zero-current offset).

For horizontal currents measured by the Starboard heads, (columns 3, 7,and 11), positive values indicate flows from left to right across the front face of the head, ie flows which move generally from BACK to FRONT of STABLE, (but note any zero-current offset).

Note that STABLE was on deck during burst 001 and for most of burst 002, and that EMCMs do not give sensible readings in air. Erratic readings were obtained while the rig was in the water before let-go during burst 002, but settled down to a steady drop-rate while the rig descended to the seabed. Note also that STABLE was released from the seabed near the end of burst 251.

Further, note that the EMCMs went faulty during burst 218. This is shown by numerous noise-spikes in the data, which get worse and more numerous towards the end of the deployment. Integrity of EMCM data from burst 218 to 251 should be questioned.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.24 | 0.19 | -0.02 | 0.05 | 0.30 | 0.09 | 0.07 | -0.05 | 0.24 | 0.04 | 0.06 | -0.18 | 89.636 |
| 0.24 | 0.19 | -0.01 | 0.05 | 0.29 | 0.07 | 0.08 | -0.04 | 0.24 | 0.05 | 0.06 | -0.18 | 89.636 |
| 0.25 | 0.19 | -0.01 | 0.04 | 0.29 | 0.06 | 0.09 | -0.05 | 0.24 | 0.04 | 0.07 | -0.18 | 89.636 |
| 0.25 | 0.19 | -0.01 | 0.05 | 0.30 | 0.05 | 0.08 | -0.04 | 0.25 | 0.04 | 0.07 | -0.18 | 89.641 |
| 0.25 | 0.19 | 0.00 | 0.05 | 0.30 | 0.04 | 0.08 | -0.04 | 0.25 | 0.03 | 0.07 | -0.18 | 89.641 |
| 0.25 | 0.19 | -0.01 | 0.05 | 0.30 | 0.03 | 0.08 | -0.04 | 0.25 | 0.03 | 0.07 | -0.18 | 89.636 |
| 0.25 | 0.19 | -0.02 | 0.05 | 0.30 | 0.02 | 0.08 | -0.03 | 0.24 | 0.03 | 0.07 | -0.18 | 89.636 |
| 0.25 | 0.19 | -0.02 | 0.05 | 0.30 | 0.02 | 0.06 | -0.03 | 0.24 | 0.03 | 0.08 | -0.18 | 89.636 |
| 0.26 | 0.19 | -0.02 | 0.05 | 0.30 | 0.02 | 0.08 | -0.03 | 0.24 | 0.03 | 0.07 | -0.18 | 89.641 |
| 0.26 | 0.18 | -0.02 | 0.05 | 0.30 | 0.02 | 0.08 | -0.03 | 0.24 | 0.03 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.18 | -0.02 | 0.05 | 0.29 | 0.01 | 0.08 | -0.03 | 0.24 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.18 | -0.02 | 0.05 | 0.29 | 0.01 | 0.07 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.641 |
| 0.26 | 0.18 | -0.03 | 0.05 | 0.30 | 0.00 | 0.07 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.641 |
| 0.26 | 0.18 | -0.02 | 0.05 | 0.30 | 0.00 | 0.07 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.18 | -0.03 | 0.05 | 0.29 | 0.00 | 0.06 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | 0.00 | 0.06 | -0.03 | 0.24 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.06 | -0.03 | 0.24 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.30 | -0.01 | 0.07 | -0.03 | 0.25 | 0.03 | 0.06 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.04 | 0.29 | -0.02 | 0.06 | -0.03 | 0.25 | 0.03 | 0.06 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.04 | 0.29 | -0.02 | 0.06 | -0.03 | 0.25 | 0.03 | 0.07 | -0.20 | 89.636 |
| 0.25 | 0.18 | -0.02 | 0.04 | 0.30 | -0.02 | 0.06 | -0.03 | 0.25 | 0.03 | 0.07 | -0.19 | 89.636 |
| 0.26 | 0.17 | -0.03 | 0.04 | 0.29 | -0.02 | 0.06 | -0.03 | 0.25 | 0.03 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.04 | 0.29 | -0.02 | 0.05 | -0.03 | 0.25 | 0.03 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.29 | -0.03 | 0.06 | -0.02 | 0.25 | 0.03 | 0.08 | -0.19 | 89.641 |
| 0.26 | 0.17 | -0.02 | 0.05 | 0.30 | -0.02 | 0.06 | -0.03 | 0.25 | 0.03 | 0.07 | -0.19 | 89.636 |
| 0.24 | 0.18 | -0.03 | 0.05 | 0.29 | -0.02 | 0.06 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.26 | 0.18 | -0.03 | 0.05 | 0.29 | -0.01 | 0.06 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.26 | 0.18 | -0.03 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.641 |
| 0.26 | 0.17 | -0.03 | 0.05 | 0.29 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.26 | 0.17 | -0.02 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.09 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.02 | 0.06 | 0.29 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.29 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.24 | 0.17 | -0.02 | 0.05 | 0.29 | -0.01 | 0.08 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | -0.01 | 0.08 | -0.03 | 0.24 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.30 | 0.00 | 0.08 | -0.03 | 0.24 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.29 | 0.00 | 0.09 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.02 | 0.05 | 0.30 | 0.00 | 0.09 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.29 | -0.01 | 0.09 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.25 | 0.17 | -0.03 | 0.05 | 0.29 | -0.01 | 0.09 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.24 | 0.17 | -0.03 | 0.05 | 0.29 | 0.00 | 0.09 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |
| 0.24 | 0.17 | -0.03 | 0.05 | 0.30 | 0.00 | 0.09 | -0.03 | 0.24 | 0.02 | 0.08 | -0.19 | 89.641 |
| 0.24 | 0.17 | -0.03 | 0.05 | 0.29 | 0.00 | 0.09 | -0.03 | 0.25 | 0.02 | 0.07 | -0.19 | 89.636 |
| 0.25 | 0.17 | -0.03 | 0.04 | 0.29 | 0.00 | 0.09 | -0.03 | 0.25 | 0.02 | 0.08 | -0.19 | 89.636 |

Table 2.

An example of burst data recorded by STABLE II during the OMEX experiment, Goban Spur, January, 1994.

Column 1: Horizontal flow component measured by the "port" head of array A. Units are m/s; spot readings.

Column 2: Vertical flow component, w1, measured by the "port" head of array A. Units are m/s; spot readings.

Column 3: Horizontal flow component measured by the "starboard" head of array A. Units are m/s; spot readings.

Column 4: Vertical flow component, w2, measured by the "starboard" head of array A. Units are m/s; spot readings.

Column 5: Horizontal flow component measured by the "port" head of array B. Units are m/s; spot readings.

Column 6: Vertical flow component, w1, measured by the "port" head of array B. Units are m/s; spot readings.

Column 7: Horizontal flow component measured by the "starboard" head of array B. Units are m/s; spot readings.

Column 8: Vertical flow component, w2, measured by the "starboard" head of array B. Units are m/s; spot readings.

Column 9: Horizontal flow component measured by the "port" head of array C. Units are m/s; spot readings.

Column 10: Vertical flow component, w1, measured by the "port" head of array C. Units are m/s; spot readings.

Column 11: Horizontal flow component measured by the "starboard" head of array C. Units are m/s; spot readings.

Column 12: Vertical flow component, w2, measured by the "starboard" head of array C. Units are m/s; spot readings.

Column 13: Pressure measured by the "waves" Digiquartz pressure transducer, (D/Q Waves). Units are Bar; readings are integrated over 0.125s. (Note that there are about 15 noise spikes in each D/Q waves burst record. These are easy to pinpoint in the CD84 pressure dataset because normal readings only occupy a very narrow pressure range.)

For EMCM calibration and supplementary information, (including information on a right-handed coordinate system for the OMEX EMCM data set), see Appendix G.

For D/Q Waves calibration and supplementary information, see Appendix H.

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Staff at the Proudman Oceanographic Laboratory who helped to design, build and test STABLE II.

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## APPENDIX A

Calibration details for the mean or "Tides" Digiquartz pressure sensor, D/Q Press, serial number 52861, and the Digiquartz temperature sensor, D/Q Temp.

The Paroscientific Digiquartz pressure sensors used on STABLE II are contained within their own pressure housings, and both have a maximum working depth of 1400m. The D/Q Press sensor has serial number 52861 and contains both a pressure sensor, (giving D/Q Press data), and a temperature sensor, (giving D/Q Temp data): the latter is used for correcting the pressure signal for temperature effects. Both sensors produce a signal which varies in frequency according to the parameter being measured. The frequency of both sensors is integrated over a period of one minute and then recorded by the mean logger.

During calibration, the whole sensor is kept at a steady temperature in a water-bath while the pressure is varied using a dead-weight tester. Output signals from the pressure and temperature sensors are monitored by frequency counters. Bath temperature is monitored by a precision thermometer.

When analysing the experimental data, the temperature of the sensors is computed first from the D/Q Temp data using the equation under "Temperature Sensor", (see below). This information is then used to evaluate the coefficients A(temp), B(temp), C(temp) and D(temp), which are then substituted into the pressure equation under "Temperature Compensation Equation". This provides pressure information which has been compensated for temperature effects. Note that the pressure calculated is an absolute pressure, and includes a component due to the atmosphere, (approximately equal to 1Bar). This component should be subtracted before trying to calculate water depth from the pressure information contained in the data set. STABLE II cannot of course measure atmospheric pressure accurately while underwater.

The temperature data provided by the D/Q Temp sensor agreed with the Qts Temp data, (see Appendix B), to within about 30mdeg C during the Charles Darwin cruise. The D/Q Temp sensor recorded lower temperatures. During periods of rapid temperature-change, (for example, during deployment), the D/Q Temp sensor took longer to settle down than the Qts Temp sensor, (by about eleven minutes).

## Digiquartz SN52861 (1400metre Depth Sensor)

**CALIBRATION DATE CAL283** 21-24/9/1993 along with DQ 36626
Dual Range DWT Fig280D P/U L209 Weight Set 672 Accuracy 0.01%.
Tx calibrated in a vertical position with a 54 mb oil head.

**PRESSURE SENSOR CALIBRATION EQUATIONS**

$$P = a + b X + c X^2 + d X^3 \text{ Bars}$$

$$F = a' + b' Y + c' Y^2 + d' Y^3 \text{ Hz}$$

where X = (2*Pressure Frequency- B - A)/(B - A) Y = (2 Pressure - B'- A')/(B' - A')

Limits A = 32640 Hz B= 36420 Hz
A'=0.5 Bars B'= 137 Bars(Absolute

| Temperature Degrees C | Coefficient a | Coefficient b | Coefficient c | Coefficient d |
|---|---|---|---|---|
| 0.334 | +66.353531 | +68.017895 | 2.314819 | 0.028114 |
| 4.040 | +66.370897 | +68.010505 | 2.314718 | 0.032356 |
| 9.474 | +66.400967 | +68.009163 | 2.316529 | 0.028378 |
| 14.488 | +66.436319 | +67.999884 | 2.318556 | 0.033837 |
| 19.806 | +66.479548 | +67.996352 | 2.318215 | 0.030739 |

Coeffs a,b,c,d in Bars SDs 3.21,2.96,3.65,3.17,3.32 mbs respectively.

| Temperature Degrees C | Coefficient a' | Coefficient b' | Coefficient c' | Coefficient d' |
|---|---|---|---|---|
| 0.334 | +34596.53615 | +1891.90636 | -64.610222 | +3.633961 |
| 4.040 | +34596.05976 | +1892.14481 | -64.624332 | +3.514868 |
| 9.474 | +34595.22947 | +1892.23542 | -64.690311 | +3.634530 |
| 14.488 | +34594.25530 | +1892.55524 | -64.769662 | +3.491514 |
| 19.806 | +34593.06138 | +1892.73458 | -64.782315 | +3.580661 |

Coeffs a',b',c',d' in Counts SDs 0.106,0.099,0.122,0.104,0.107 Hz respectively.

**TEMPERATURE COMPENSATION EQUATION.**

Pressure=A(temp)+B(temp)*X+C(temp)*X^2+D(temp)*X^3 Bars
A(temp)=66.352299+4.0319E-03*temp+1.2093E-04*temp^2
B(temp)=68.017147-1.0788E-03*temp
C(temp)=2.314482+2.166E-04*temp
D(temp)=2.9475E-02+1.2570E-04*temp
X=(2*PRESS FREQ-69060)/3780

where temp is the temperature in Degrees C

Pressure Frequency=A'(temp)+B'(temp)*Y+C'(temp)*Y^2+D'(temp)*Y^3 Hz
A'(temp)=34596.5704-0.1107899*temp-3.35462E-03*temp^2
B'(temp)=1891.911419+4.16568E-02*temp
C'(temp)=-64.599607-9.9457E-03*temp
D'(temp)=3.593493-2.325E-03*temp
Y=(2*BARS-137.5)/136.5

**TEMPERATURE SENSOR.**

T=10.013034+10.355604*Z-0.075143*Z^2 Degrees C
where Z=(2*TEMP FREQ-341365)/155

## APPENDIX B

Calibration details for the quartz crystal temperature sensor, Qts Temp.

The Qts Temp sensor is a very small crystal device, type IQTS-156, which, together with its drive circuit, is mounted in a block of copper. This block penetrates the mean logger end-cap so that it is in contact with the sea-water; it is thermally isolated with plastic spacers. No measurements of the thermal time-constant of the device while mounted in the end-cap have been made, but it is expected to be of the order of a few tens of seconds.

It proved difficult to perform an accurate calibration of the device while it was mounted in the end-cap: the cap is large and heavy, and the device itself cannot function when wet. A special waterproof housing was therefore made which enabled the device to be immersed in a water bath; signals were taken out via an underwater connector. The temperature of the water bath was monitored with a precision thermometer and the output from the Qts Temp sensor was measured with a frequency counter.

When the experimental data are read from the logger, the calibration coefficients are applied using the temperature equation under "Quartz Temperature Sensor", (see below). The temperature information obtained from this device during the Charles Darwin cruise agreed with that provided by the D/Q Temp sensor to within about 30mdeg C, (Qts Temp was higher).

## QUARTZ TEMPERATURE SENSOR CALIBRATIONS.(CAL307)

**Calibration Date: 6th-9th June 1994**

**Calibration Data (NB Frequency data corrected for Counter errors.)**

| Temperature | QT "A" Output |
|---|---|
| Degrees C. | Hz. |
| 2.535 | 261905.687 |
| 4.649 | 261923.953 |
| 5.275 | 261928.993 |
| 7.32 | 261946.581 |
| 9.368 | 261964.013 |
| 11.844 | 261985.236 |
| 16.159 | 262022.218 |
| 21.168 | 262065.522 |
| 25.503 | 262103.104 |

**Calibration Equations.**

Temperature = a + b*X + c*(X^2) Degrees C. where X = (2*temp.freq - B-A)/ (B-A)

Frequency = a' + b'*Y + c'*(Y^2) Hz where Y =(2*Temp - B'-A')/(B'-A')

A, B Upper and Lower Limits Hz. A',B' Upper and Lower Limits Degrees C

**Quartz Temperature Sensor**

Temp = 14.730539 + 12.796862*X -0.079964*(X^2) SD=12 milli-degrees C

Freq = 262008.0187 + 107.428965*Y + 0.655228*(Y^2) SD=0.104 Hz

A = 262120Hz B = 261900Hz A' = 2 B' = 27 Degrees C

**APPENDIX C**

Calibration details for the Savonius rotors R1, R2, R3 and R4.

The Savonius rotors used on STABLE II are mounted vertically one above another in a stainless steel frame, (see Figure 4 below and Appendix I). The frame is mounted under the instrument platform, hanging vertically towards the seabed. It is arranged so that the lowest rotor is as close to the seabed as is practicable. The framework is guyed to reduce vibration to a minimum and to give support during deployment and recovery.

The minimum practical vertical separation of the rotors is 180mm, with R1 at the bottom, and R4 540mm above it. Each rotor is a standard Aanderaa device, without shroud, and is responsive to currents from any horizontal direction. The bearings are of tungsten carbide and are arranged so that the cups face downward so that they do not collect sediment, which could lead to degraded performance. Encapsulated reed-switches are actuated twice every revolution, and the logging system simply counts the number of closures in every minute. These data are converted to current speeds in the data-reading process.

The rotor stack was calibrated in the high-velocity recirculating flume in the Mechanical Engineering Department of the University of Liverpool on 2nd February, 1993. The arrangement was as shown in the diagram below. The output from each rotor was logged by a simple counting device - the number of counts at each water-speed setting was recorded over a period of two minutes. No check was made on stalling or threshold speeds. A warning was given by the flume operator that the bottom rotor might be within the flume boundary layer; there is no obvious sign from the calibration data that this was the case, although correlation coefficients get better from R1 to R4.

Calibration Results:

| ROTOR NUMBER | INTERCEPT counts | GRADIENT counts per m/sec | CORRELATION COEFFICIENT |
|---|---|---|---|
| 1 | -9.33 | 278.79 | 0.9987 |
| 2 | -6.38 | 280.27 | 0.9992 |
| 3 | -6.84 | 282.74 | 0.9994 |
| 4 | -5.05 | 279.74 | 0.9995 |

Current speeds during the deployment are computed from the rotor data using:

(Data Counts - Intercept) / Gradient,

giving an answer directly in metres per second.

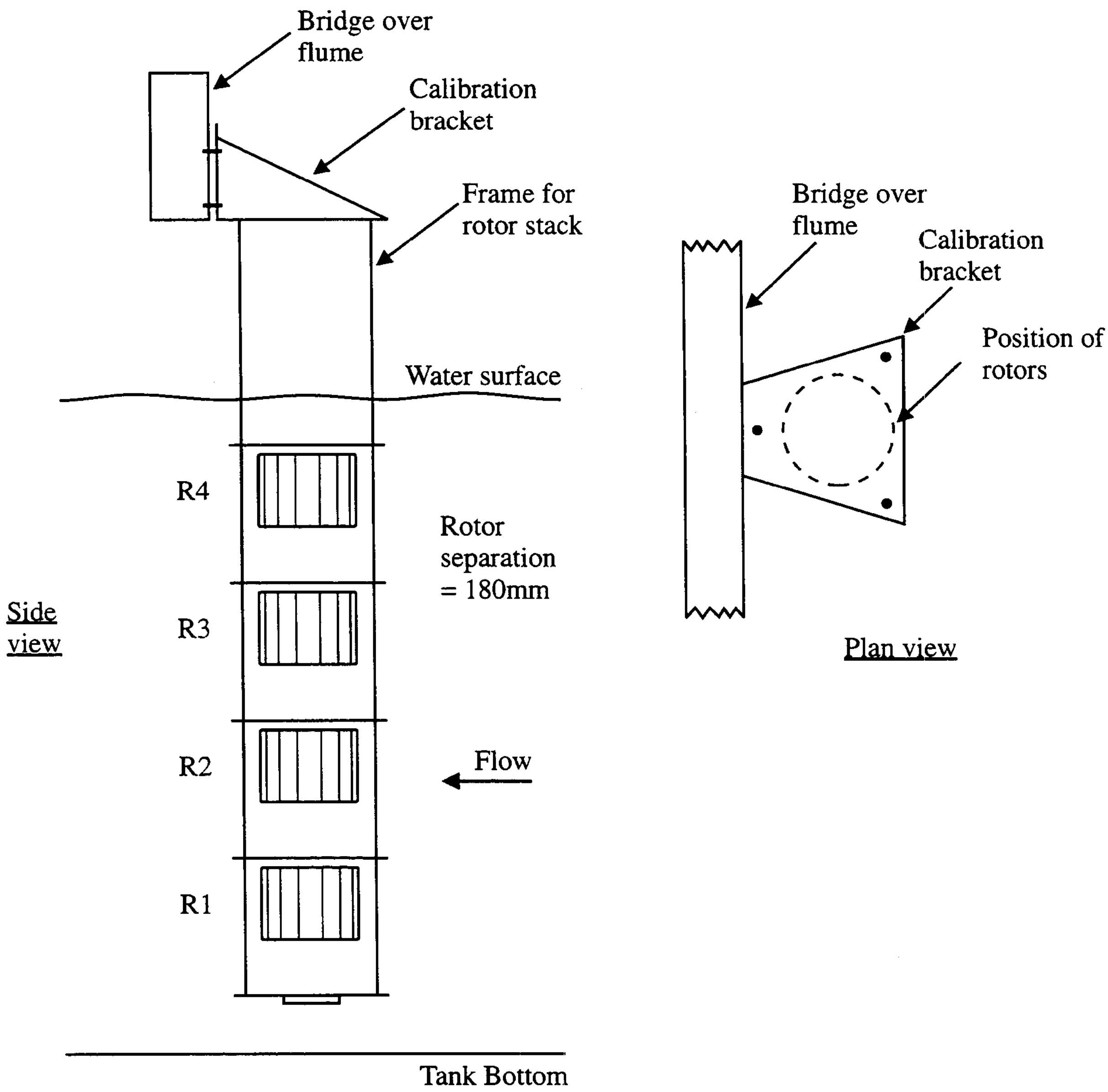



Figure 4.

Experimental Arrangement Used to Calibrate the Savonius Rotor Stack.

**APPENDIX D**

Calibration details for the pitch sensor.

The pitch sensor is a TI55 device, made by Penny and Giles. It consists of a small, heavy pendulum which wipes an electrode across a resistive plastic track when there is rotational movement in the plane of the track. This varies the voltage between the electrode and the end of the track; this varying voltage is fed into the A/D converter in the mean logger, and is recorded in counts. Unless there is settlement during the course of the experiment, there are likely to be only small changes in these readings after deployment onto the seabed.

The pitch sensor measures departures from a nominal level condition in the fore and aft direction of the STABLE II frame, and this is arranged to be in the same direction as the long axis of the mean logger tube. No adjustment of the tube in the frame is possible, and it is necessary to take a reading of the pitch output when the frame is level before deployment. See explanatory diagrams below and Appendix I.

During calibration, the mean logger was set up on the bench in a working condition, and was interrogated by a bench-top computer to get readings of the pitch sensor. One end of the mean logger chassis was then jacked up until the pitch reading changed no more - this was the limit in that direction. The actual pitch angle was read with a direct-reading precision inclinometer, (resolution 0.1deg, linearity 0.1deg up to 10deg and 1.5% of reading between 10deg and 45deg). The inlination of the chassis was reduced in steps towards zero and increased in the other direction until the readings stopped changing again.

From the information obtained:

| | |
|---|---|
| Intercept, (ie zero-pitch reading) | = 520.0145 counts. |
| Gradient, (ie sensitivity) | = -10.2273 counts per deg. |
| Correlation coefficient | = -0.9999. |

To obtain rig-pitch from any reading in counts obtained from the raw data set,

Pitch in degrees = (Counts - Intercept) / Gradient.

Positive pitch-angles indicate a stern-down attitude, negative pitch-angles indicate a bow-down attitude.

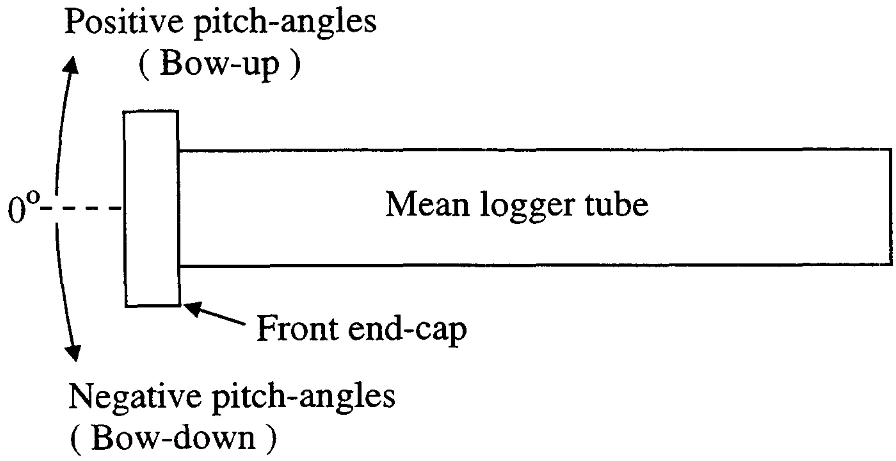



Figure 5.

Calibration-Arrangement for the Pitch Sensor.

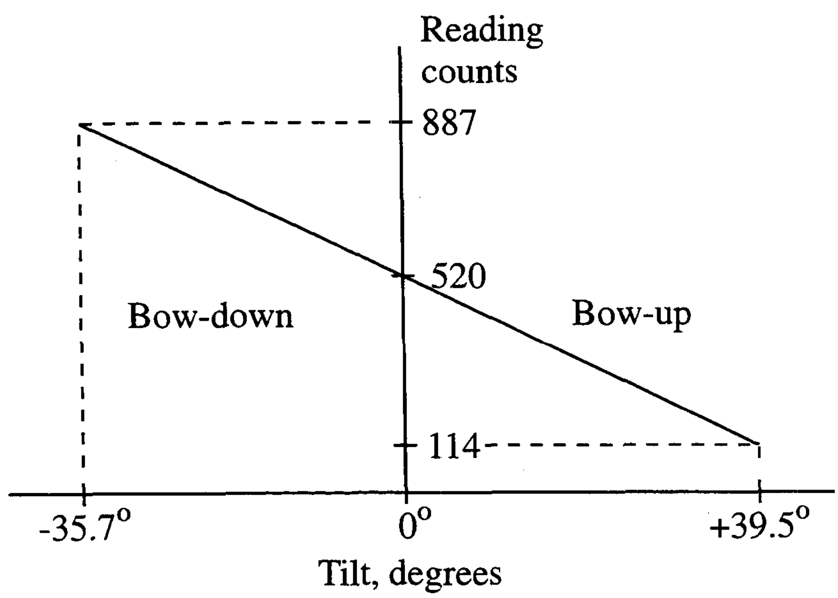



Figure 6.

Results from the Pitch Sensor Calibration.

**APPENDIX E**

Calibration details for the roll sensor.

The roll sensor is similar to the pitch sensor in all respects except that it responds to lateral rotation of the rig about the fore-and-aft axis, (see diagrams below and Appendix I). The calibration of the roll sensor was carried out in the same way too, except that the rotation took place around the long axis of the mean logger tube. (For a more complete description of sensor-function, see Appendix D regarding the pitch sensor.)

From the information obtained:

Intercept, (ie zero-roll reading) = 482.9837 counts.

Gradient, (ie sensitivity) = 10.2254 counts per deg.

Correlation coefficient = 1.0000.

To obtain rig-roll from any reading in counts obtained from the raw data set,

Roll in degrees = (Counts - Intercept) / Gradient.

Positive roll-angles indicate a port-side down attitude, negative roll-angles indicate a starboard-side down attitude.

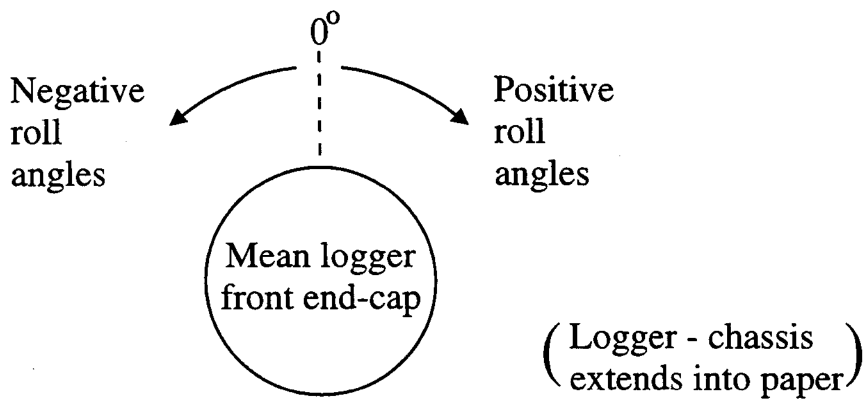



Figure 7.

Calibration-Arrangement for the Roll Sensor.

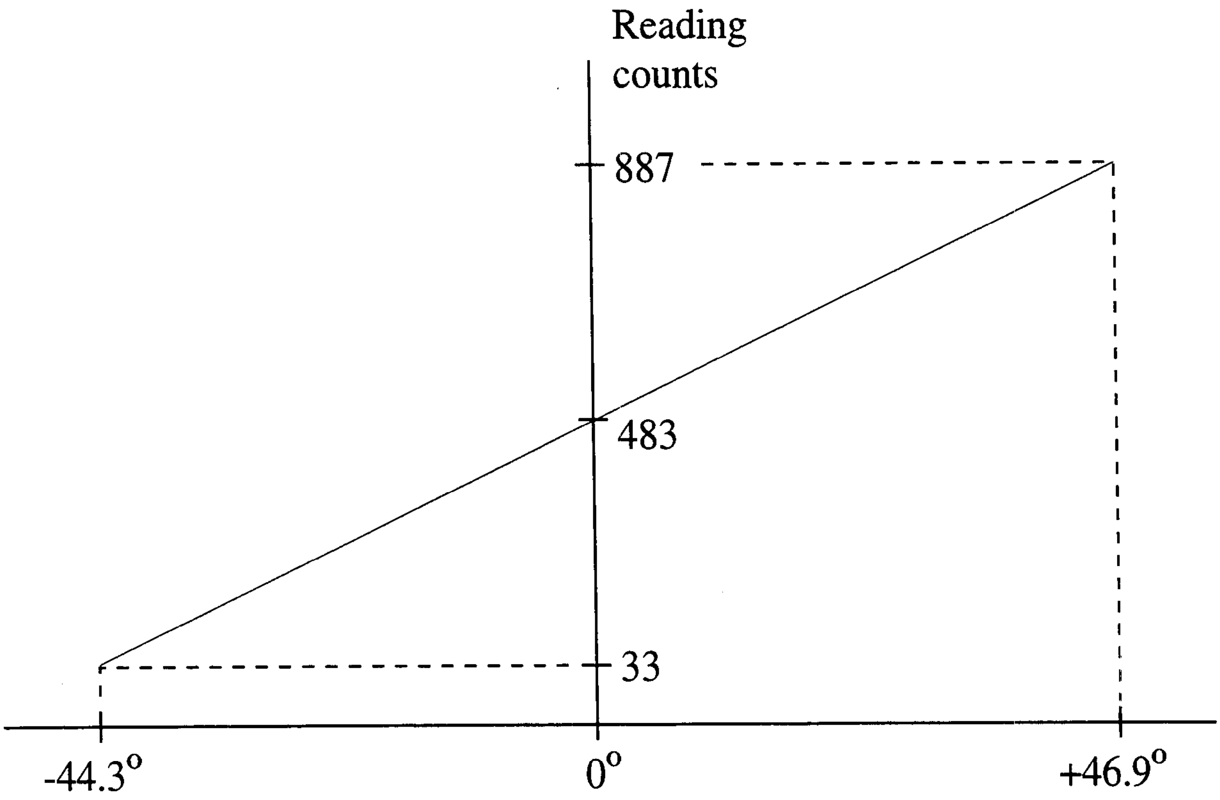


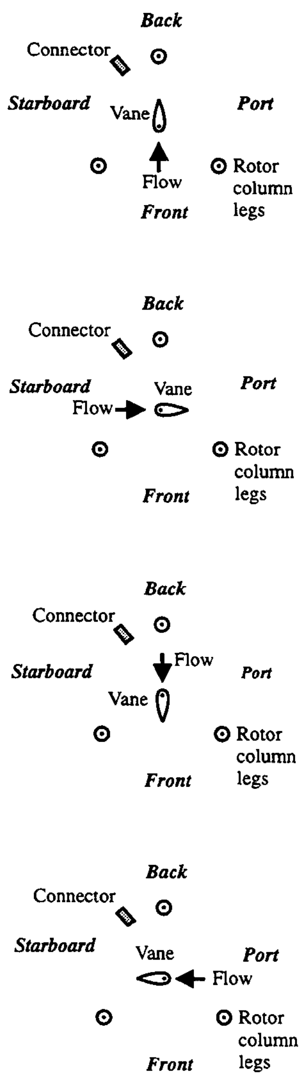

Figure 8.

Results from the Roll Sensor Calibration.

## APPENDIX F

Derivation of vane readings.

The vane sensor is enclosed within a pressure-proof case and consists of a magnetic compass carrying an encoded disc: the compass is a Digicourse model 218, which is no longer made. An external polythene vane carries a powerful samarium-cobalt magnet: the orientation of the vane and compass are locked together by magnetic coupling. In turn, the vane is orientated by the current. It should be noted that the output of the vane-compass is effectively reversed because it is driven by an external magnet; thus the 0deg and 180deg readings are recorded correctly, but the 90deg and 270deg readings are reversed. This is demonstrated in the four diagrams below, showing the experimental set-up used in the laboratory to test the output of the system.




Flow from front to back
(ie. Rearward-flowing current)
Vane output = 180° relative to rig

Flow from starboard to port
Vane output = 90° relative to rig

Flow from back to front
(ie. Forward-flowing current)
Vane output = 0° relative to rig

Flow from port to starboard
Vane output = 270° relative to rig

Figure 9.

Diagrams Showing the Orientation of the Vane in the Stack Together with Corresponding System-Output Readings.

The system-output is summarised in Figure 10 below:

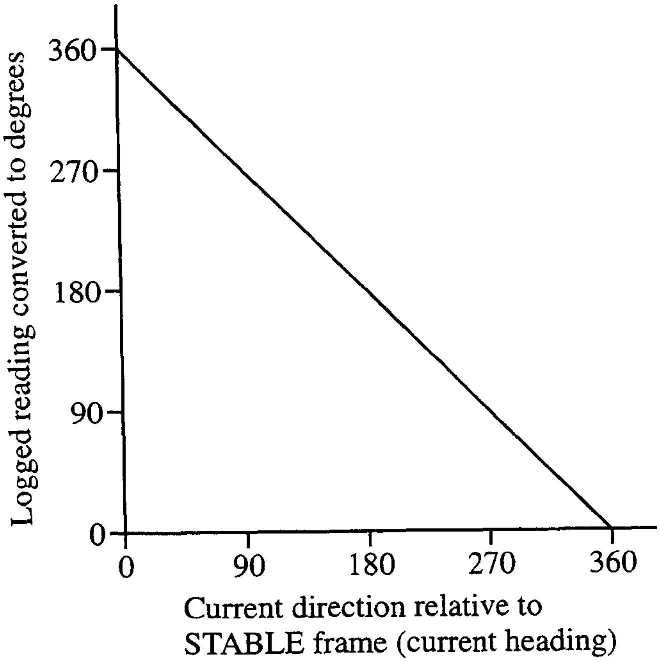



Figure 10.

Shows the Relation Between Current-Heading Relative to the STABLE Frame and the Logged Reading.

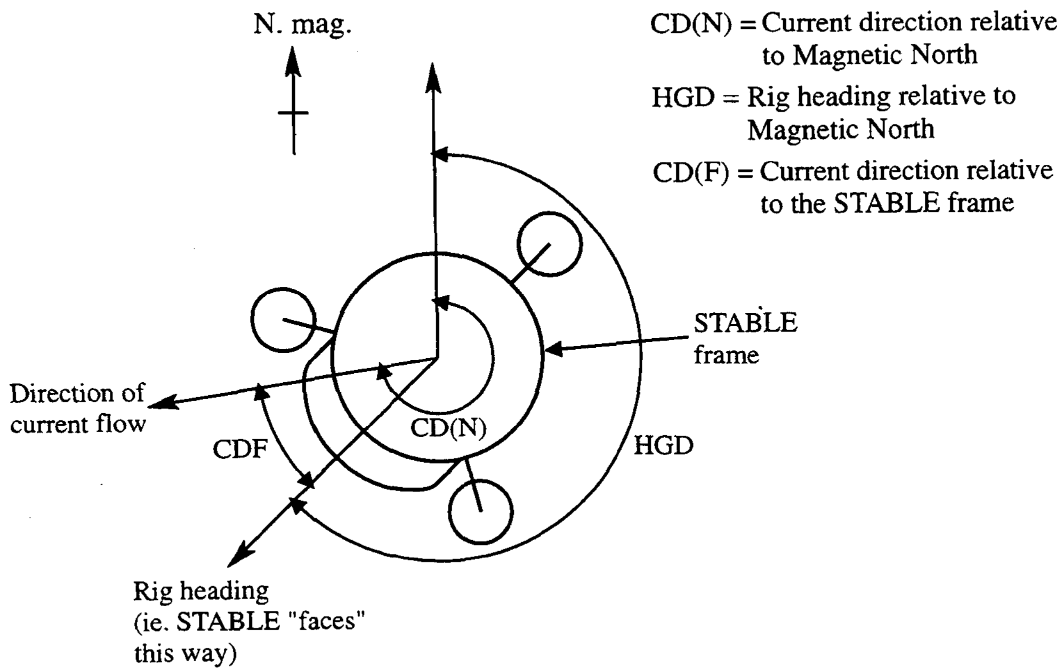



Figure 11.

Shows the Relationship Between Current Directions Relative to the STABLE Frame and Magnetic North.

The coded disc within the vane-sensor carries eight-bit Gray code markings which are recorded by the mean logger. The logged readings have therefore to be converted as follows: a) the readings are converted to decimal values, b) then they are multiplied by 360/256 to give an answer in degrees. This value, (VANE - see below), is then used to calculate the current direction relative to magnetic north, CD(N).

To calculate CD(N), (ie Column 13 in the mean data set), it is necessary to know the values of (1) HDG - the frame-heading relative to magnetic north (Column 14 in the mean data set), (2) CD(F) - the current-direction relative to the STABLE frame, and (3) VANE - the output from the vane sensor in degrees, (refer to Figure 11, above).

To calculate CD(N):

Let CD(F) = 360 - VANE degrees.

Then, let Q = HDG + CD(F) degrees.

If Q > 359.9 degrees, subtract 360 degrees.

This gives CD(N), ie the direction towards which the current flows, (current heading), relative to magnetic north. This information is shown in Column 13 in the mean data set.

## APPENDIX G

Calibration details for the electromagnetic current meters (EMCMs).

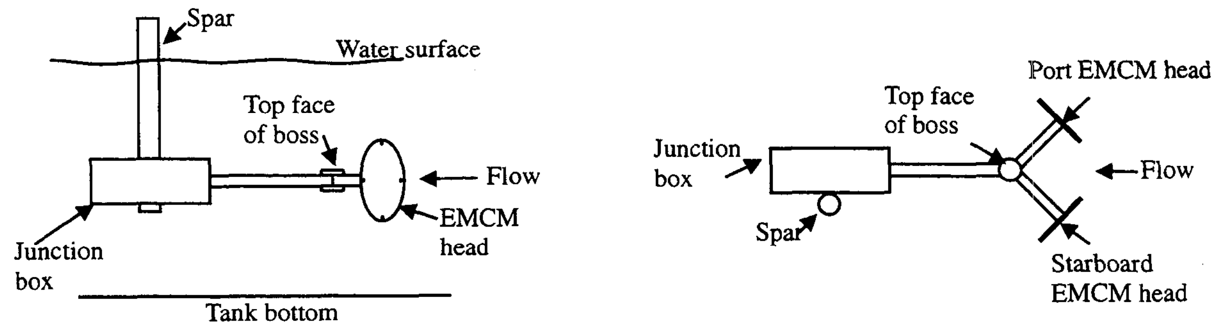
In order to provide high-resolution flow information in all three directions at any given height above the seabed, pairs of EMCM heads are mounted on Y-shaped stems to form arrays. Each head in an array carries two pairs of electrodes; one pair is orientated vertically, the other pair horizontally. Each array thus provides one estimate of u, one estimate of v and two estimates of the w flow-component.

The EMCMs are 800-series devices made by Valeport. Each system consists of a head, two pre-amplifiers, a coil-drive circuit, amplifiers and output filters with a 4Hz cutoff. Annular heads are used; their open construction means that reversing flows are measured with little hydrodynamic interference from the sensor itself. Each head is about 170mm in diameter, with an electrode-spacing of 100mm. Each head-pair is separated laterally by about 230mm when mounted into an array, and arrays are stacked with a vertical interval of about 300mm, (see the white circular devices in Figure 1). This is close enough to cause electrical interference between arrays which usually manifests itself as an offset in the output: corrections for these offsets may have to be made during analysis. Note that the calibration apparatus is not big enough to accommodate the complete EMCM apparatus; each array has to be calibrated separately.

Each array is calibrated for both horizontal and vertical currents, (see Figures 12 and 13 below). To avoid having to perform two horizontal runs, (one in the plane of each head), the array is mounted so that the stem looks straight towards the oncoming current and the apparent horizontal sensitivity of each head is multiplied by 1.414, (the square-root of 2), to give the absolute sensitivity. Extreme care must be taken at the time to note the senses of the outputs and the experimental layout, to avoid confusion when interpreting the results.

The EMCMs were calibrated in the high-velocity recirculating flume at the Mechanical Engineering Department of Liverpool University on 18th November, 1993. This is a large device which produces virtually non-turbulent flow over a section 140cm wide by 84cm deep. The working section is about 6m long and the maximum water velocity is about 6m/sec, although the EMCMs are only calibrated up to a maximum of 2m/sec. An adjustable bed over the working section is used to tune out standing waves. A bridge over the working section is used to support the EMCMs on a scaffold-pole spar.

The array being calibrated is set up carefully to ensure correct orientation; the other two arrays are set up to work in the water where their wakes do not interfere with the array under test. All arrays have to be working during calibration, otherwise unpredictable offsets are caused.



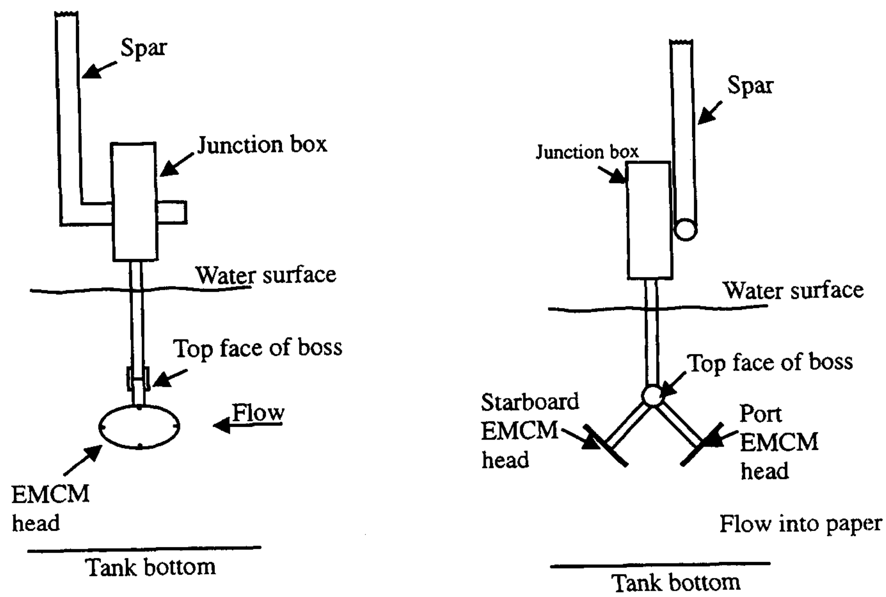

Side view, i.e. view onto side of starboard head

Plan view, looking onto top face of heads as installed on STABLE.

Figure 12.

Experimental Arrangement for the Calibration of the Horizontal Channels of the Electromagnetic Current Meters.

Note: "Top Face" faces upwards when array is fitted to STABLE.




Side view, i.e. view onto side of starboard head.

View from "upstream".

Figure 13.

Experimental Arrangement for the Calibration of the Vertical Channels of the Electromagnetic Current Meters.

Note: "Top Face" faces upwards when array is fitted to STABLE.

The EMCM outputs are logged for two minutes at 8Hz at water speeds of 0, 10, 20, 30, 40, 50, 75, and 100cm/sec for both horizontal and vertical flows; additionally, horizontal flows are logged at 150 and 200cm/sec. Higher water velocities cause too much aeration and are potentially dangerous to the heads and flume if parts should drop off.

Special calibration software has been developed to compute maximun, minimum and average outputs, and standard deviation of readings at each current speed. When readings have been logged at all current speeds, the gradient (sensitivity), offset and correlation coefficient of each set of readings is computed. The figures obtained during calibrations are shown in Table 3, below.

## Horizontal responses

| Head | Port | Stbd | Offset | Gradient* | Corr/Coef |
|---|---|---|---|---|---|
| A | √ | | -3.1473 | 3.5190 | 0.99996 |
| A | | √ | 1.1445 | -3.3502 | -0.99937 |
| B | √ | | -9.0012 | 3.4231 | 0.99992 |
| B | | √ | -17.4415 | -3.1468 | -0.99993 |
| C | √ | | -46.8294 | 3.6563 | 0.99976 |
| C | | √ | -46.1286 | -3.0286 | -0.99983 |

## Vertical responses

| Head | Port | Stbd | Offset | Gradient* | Corr/Coef |
|---|---|---|---|---|---|
| A | √ | | 30.7359 | -5.0031 | -0.99995 |
| A | | √ | -21.0177 | -4.6064 | -0.99995 |
| B | √ | | 27.7477 | -5.0197 | -0.99995 |
| B | | √ | -35.2387 | -4.4628 | -0.99998 |
| C | √ | | 40.4008 | -5.1594 | -0.99996 |
| C | | √ | -75.3244 | -4.3142 | -0.99997 |

*** Units in counts per cm $s^{-1}$.**

Table 3.

Coefficients Obtained During the Calibrations Performed on 18th November, 1993.

Offsets are in counts and gradients are in counts per cm/sec. Multiply horizontal gradients by 1.414 to get true sensitivities.

To obtain the curent velocities shown in Columns 1 - 12 inclusive in the burst data files, the following equations were used:

For horizontal currents:

Current speed in m/sec = Counts - Offset / 141.4 x Gradient.

For vertical currents:

Current speed in m/sec = Counts - Offset / 100 x Gradient.

In both cases, "counts" is the value logged by a particular channel, "offset" is the offset obtained at calibration and "gradient" is the sensitivity of that channel, obtained from the calibration data. Note that the offset values might have changed between calibration and the OMEX deployment; it might become necessary to use an average value for all burst readings of a particular channel as the correct offset value.

The EMCM arrays were set up on STABLE II as shown in Figure 21, Appendix I, during the OMEX deployment.

The signs on the gradient figures are important, especially when computing angles of current-incidence. Generally, horizontal currents produce a positive output when currents flow from left to right across the front face of the heads: vertical currents produce a positive output when currents flow upwards past the heads. From the diagram below, Figure 14, it may be seen that the currents measured by STABLE II can be regarded as a right-handed set of coordinates with the correct signs if the starboard head output is taken as u, the port head output is taken as v and the vertical outputs from the two heads are taken as w1 and w2, (port and starboard respectively). Other frames of reference can be employed at the user's discretion.

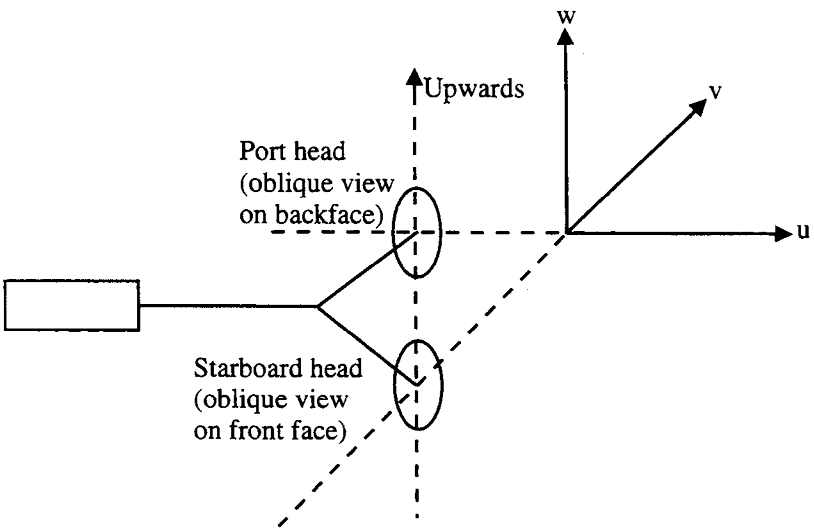



Figure 14.

An EMCM Array and a Corresponding Set of Right-handed Coordinates.

**APPENDIX H**

Calibration details for the burst Digiquartz pressure sensor, D/Q Waves, serial number 36626.

The burst pressure sensor is similar to the D/Q Press (mean) sensor, except that it does not contain a temperature sensor; both sensors have a maximum working depth of 1400m.

The calibration method is very similar to that used for the D/Q Press sensor, except that temperature corrections have to be made using data collected at the time of calibration rather than using temperature readings collected during the course of the experiment. In the OMEX data, an average temperature derived from the D/Q Press sensor was used to provide the temperature correction information used to compute the D/Q Waves information. This average value was taken to be 9.5deg C.

Coefficients A(temp), B(temp), C(temp) and D(temp) are calculated using the temperature 9.5deg C. Pressure is then calculated from the expression given under "Temperature Compensation Equation", see below. Note that the pressure calculated is an absolute pressure, and includes a component due to the atmosphere, (approximately equal to 1Bar).

## Digiquartz SN36626 (1400metre Depth Sensor)

CALIBRATION DATE CAL282 21-24/9/1993 along with DQ 52861
Dual Range DWT Fig280D P/U L209 Weight Set 672 Accuracy 0.01%.
Tx calibrated in a vertical position with a 54 mb oil head.

PRESSURE SENSOR CALIBRATION EQUATIONS

P = a + b X + c X^2 + d X^3 Bars

F = a' + b' Y + c' Y^2 + d' Y^3 Hz

where X = (2*Pressure Frequency- B - A)/(B - A) Y = (2 Pressure - B'- A')/(B' - A')

Limits A = 31650 Hz B= 36060 Hz

A'=0.5 Bars B'= 137 Bars(Absolute

| Temperature Degrees C | Coefficient a | Coefficient b | Coefficient c | Coefficient d |
|---|---|---|---|---|
| 0.334 | +65.877455 | +67.990213 | 2.630843 | 0.016676 |
| 4.040 | +65.922120 | +67.987480 | 2.628476 | 0.016123 |
| 9.474 | +65.990446 | +67.987968 | 2.631220 | 0.012976 |
| 14.488 | +66.057511 | +67.974033 | 2.643648 | 0.035860 |
| 19.806 | +66.135103 | +67.973727 | 2.640703 | 0.029710 |

Coeffs a,b,c,d in Bars SDs 1.79,2.42,2.12,4.25,4.11 mbs respectively.

| Temperature Degrees C | Coefficient a' | Coefficient b' | Coefficient c' | Coefficient d' |
|---|---|---|---|---|
| 0.334 | +33948.06490 | +2206.188361 | -85.716706 | +6.147976 |
| 4.040 | +33946.62506 | +2206.393946 | -85.662702 | +6.157524 |
| 9.474 | +33944.41772 | +2206.542335 | -85.775978 | +6.276053 |
| 14.488 | +33942.25230 | +2207.140945 | -86.204955 | +5.572153 |
| 19.806 | +33939.74411 | +2207.362580 | -86.125180 | +5.734597 |

Coeffs a',b',c',d' in Counts SDs 0.066,0.080,0.095,0.170,0.166 Hz respectively.

**TEMPERATURE COMPENSATION EQUATION.**

Pressure=A(temp)+B(temp)*X+C(temp)*X^2+D(temp)*X^3 Bars
A(temp)=65.873316+1.19777E-02*temp+1.938E-05*temp^2+2.181E-06*temp^3
B(temp)=67.99176-9.4260E-04*temp
C(temp)=2.628067+7.178E-04*temp
D(temp)=1.3242E-02+9.3750E-04*temp
X=(2*PRESS FREQ-67710)/4410

where temp is the temperature in Degrees C

Pressure Frequency=A'(temp)+B'(temp)*Y+C'(temp)*Y^2+D'(temp)*Y^3 Hz
A'(temp)=33948.2224-3.667388E-01*temp-3.11881E-03*temp^2
B'(temp)=2206.12095+6.28019E-02*temp
C'(temp)=-85.628802-2.78657E-02*temp
D'(temp)=6.25603-2.89113E-02*temp
Y=(2*BARS-137.5)/136.5

NO TEMPERATURE SENSOR. FITTED

## APPENDIX I

Disposition of instruments and interpretation of vector data.

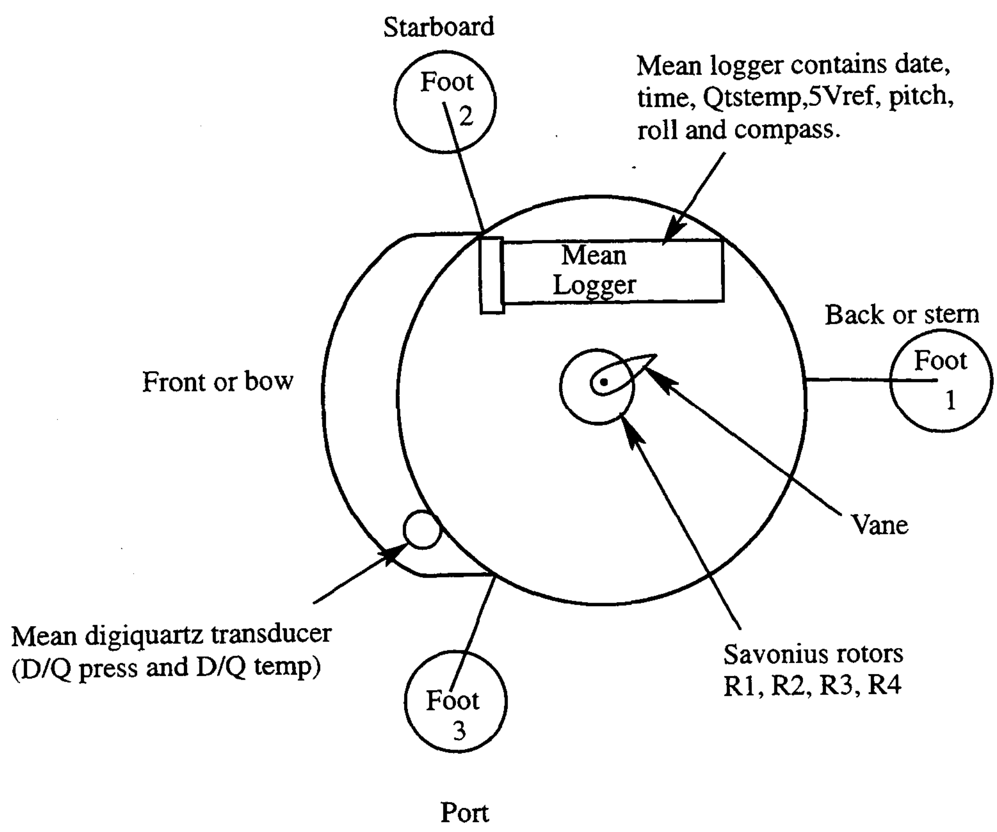



Figure 15.

Plan View of STABLE II Showing Mean Sensors.

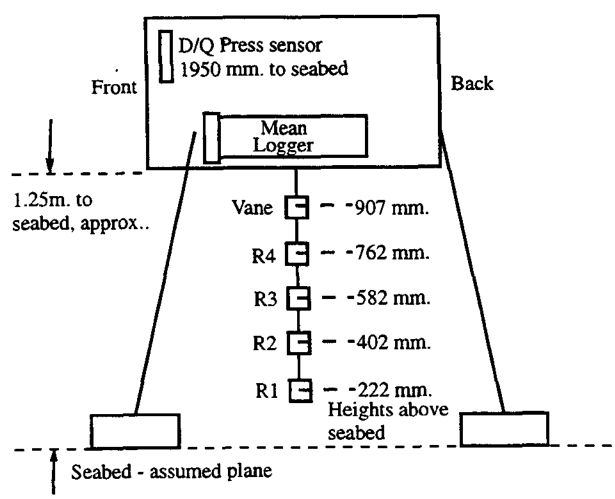



Figure 16.

View onto Port side of STABLE II.

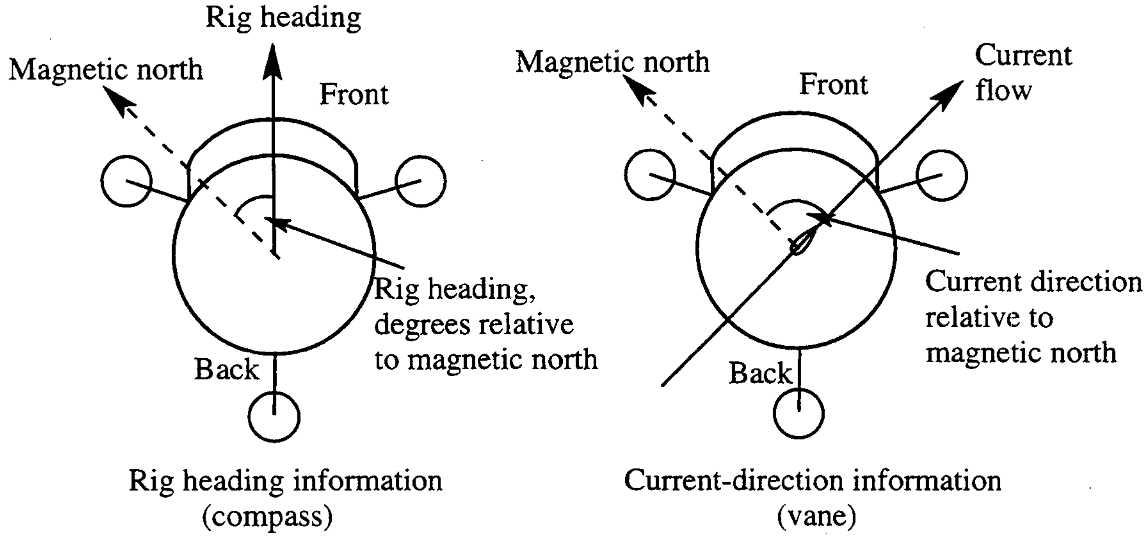



Figure 17.

Rig-Heading Information, (left), and Current-Direction Information, (right), Both Relative to Magnetic North.

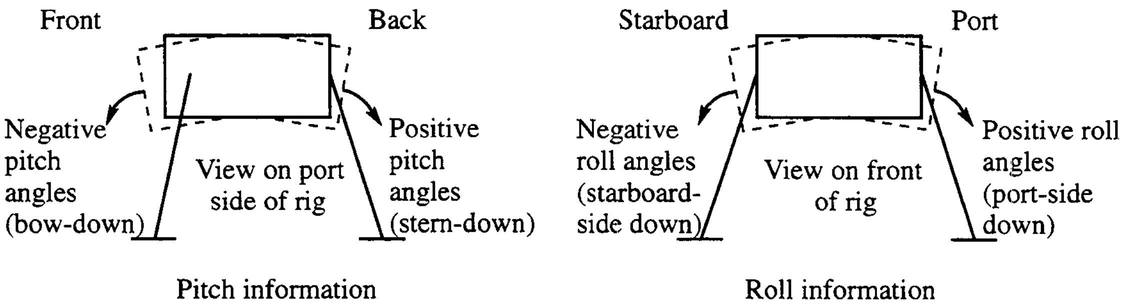



Figure 18.

Pitch and Roll Information with Indications of Positive and Negative Angles.

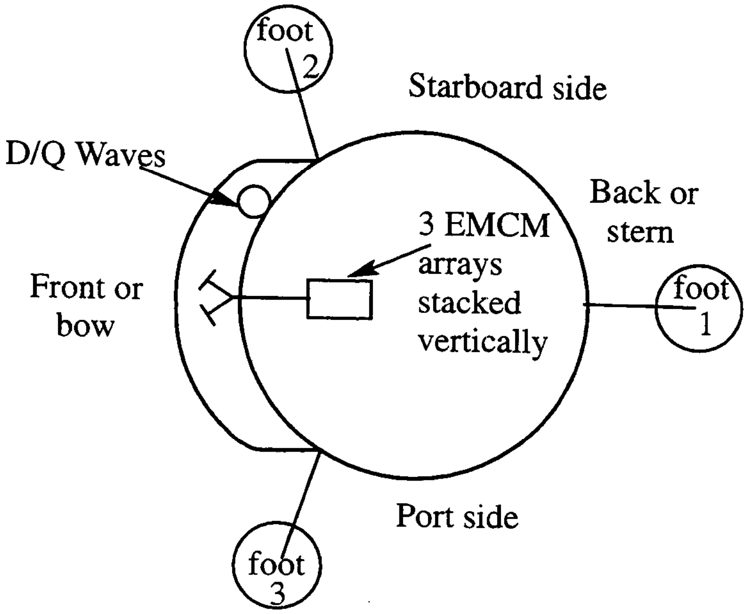



Figure 19.

Plan View of STABLE II Showing Burst Sensors.

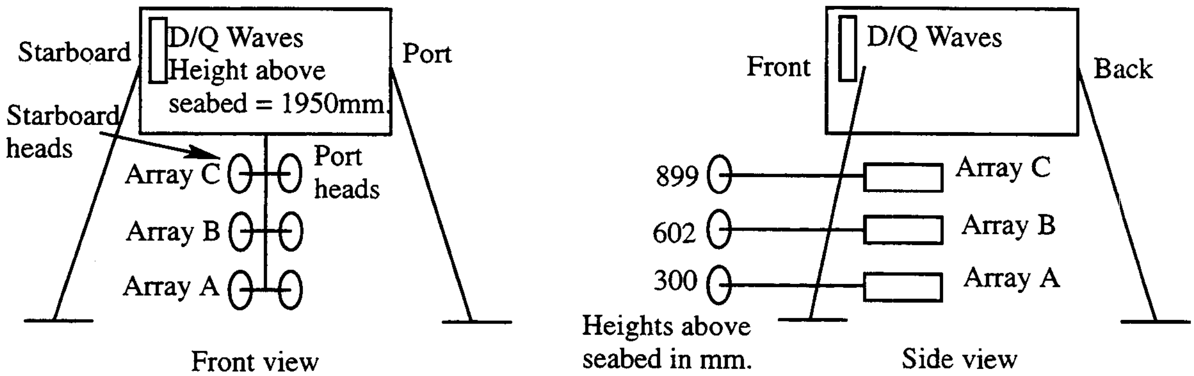



Figure 20.

View on Front of STABLE II, (left), and View onto Port Side.

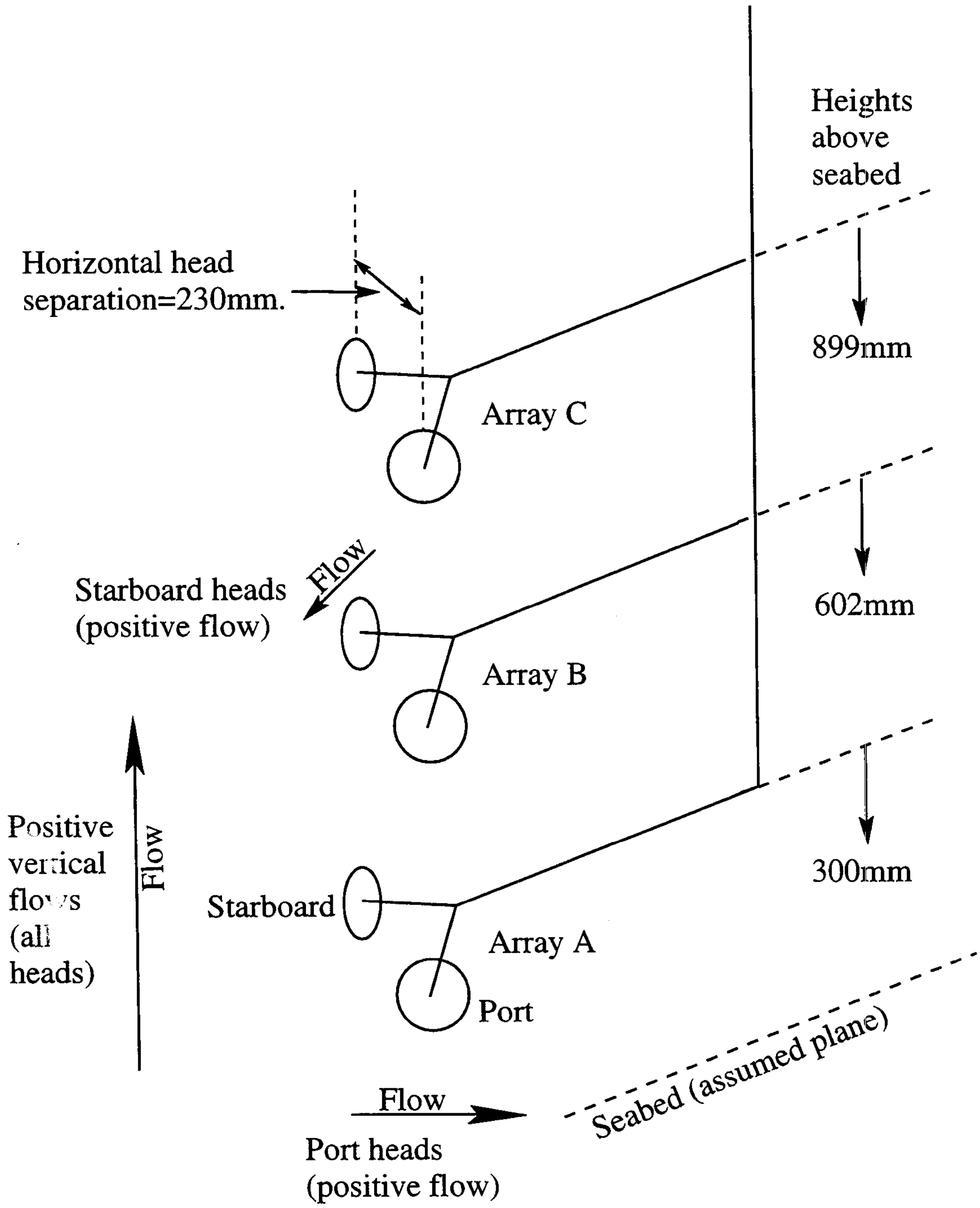



Figure 21.

Diagram Showing Arrangement of EMCM Heads, Principal Dimensions and Polarities of Outputs.