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LONG TERM UPPER OCEAN STUDY
(LOTUS)
A SUMMARY OF THE HISTORICAL DATA AND ENGINEERING TEST DATA

by

WHOI
DOCUMENT
COLLECTION

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TECHNICAL REPORT

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Abstract

Plans for the Long Term Upper Ocean Study evolved over several years. As the plans became more definite a two year period was devoted to engineering tests at the LOTUS site (34°N, 70°W). Many aspects of the proposed plans were implemented during this period in order to evaluate the performance of the equipment and instrumentation. This report presents a summary of the planning and testing periods up to but not including the first science deployments in May 1982. Historical data collected at the LOTUS site prior to the engineering tests and the data collected as part of the engineering tests are presented.

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I. INTRODUCTION

The Long Term Upper Ocean Study (LOTUS) is an experiment designed to acquire and analyse a continuous two year set of measurements of the fluctuation of currents and temperature in the upper ocean, together with the local hydrography and meteorology. Data acquisition formally began in May 1982 with the deployment of a moored array of current meters, thermistor chains and meteorological sensors.

The plans for LOTUS evolved over a number of years. As the experiment began to take form, a two year period (1980, 1981) was devoted to engineering tests to ascertain whether the goals established during early planning stages could indeed be accomplished. This report will summarize the planning and testing that were associated with LOTUS up to the first science deployment in May 1982. It will begin by presenting a brief summary of the details and questions raised by previous experiments which led to the present design of the LOTUS experiment. The site chosen for the experiment will be presented followed by a description of the cruises made during the engineering test period. Data collected prior to and during the planning and testing periods will be presented in later sections according to the type of data (i.e. current meter, XBT, CTD).

a. Background of LOTUS

Numerous past experiments like Site D, MODE, POLYMODE, and the LDE have examined low-frequency motions in the deep ocean below 500 m, sometimes extending to within 200 m of the surface, and sometimes lasting a year or more. An even larger number of upper-ocean studies like the old Site D work, MILE, and JASIN exist, usually concentrated in the top hundred meters or so and often related to air-sea interaction. All of the upper-ocean studies are short: a few weeks is typical (i.e., the length of one oceanographic cruise).

This disparity in experiment length is a consequence of two items, one scientific and one technical: the scientific reason is that the energetic, unexplored deep motions are synoptic-scale while many obvious yet not understood upper-ocean motions occur in a few hours to a few days, for example mixed-layer deepening and Ekman dynamics. Longer time-scale

upper-ocean problems such as the horizontal patchiness of thermocline formation in the Spring, or convective overturn in the Winter, are no less important but are more difficult experiments simply because they do blend the detail of upper-ocean space and time scales with the duration typical of deep-ocean experiments.

This, then, is the technical reason for short upper-ocean experiments: the required detail, accuracy, and even content of the measurements have often demanded fragile or power-hungry instrumentation and observations from ships. Upper-ocean velocity profiles and temperature-salinity relations are highly variable, yet there is often a need for density and shear measurements to describe instability processes at the base of the mixed layer and top of the thermocline. Since buoy-mounted sensors have been unable to provide these data, ship-based experiments using CTD's, velocity profilers, and towed instruments have become the norm for upper-ocean studies, and hence the experiments have been about one cruise (sometimes two!) long.

Clearly, as buoy-mounted, free-drifting, air-dropped, and even satellite sensors become able to measure the kinds of parameters needed with the accuracy, reliability, and duration required, long-term and large-area upper-ocean experiments will be planned and performed. JASIN (Pollard, 1978) was a tentative step in this direction. Meanwhile, there are a few kinds of long-term scientific questions in the upper-ocean that can be technically addressed with existing methods, for example the modulation of the internal wave field by low-frequency and seasonal processes, and the character of the low-frequency currents themselves.

The LOTUS experiment is designed to exploit present technology in the pursuit of three immediate scientific objectives:

- what is the low-frequency energy content in the upper ocean?
- what is the low-frequency modulation (envelope) of the internal wave field?
- what is the upper-ocean response to wind forcing, during different meteorological and oceanographic regimes?

The first question is mainly descriptive, but the second and third allow us to go further and ask to what extent the fluctuations and response are due

to observable quantities such as atmospheric forcing, oceanic eddies or rings acting as sources, horizontal variability such as fronts.

One motivation for LOTUS was the hypothesis of a universal level of internal wave energy of around $4 \times 10^3 \text{ J m}^{-2}$ (Garrett and Munk, 1979). In fact, the level is not exactly constant at any one location (factors of 3 variability within a few days are common, see Briscoe (1983)), and also apparently varies between locations (the Mediterranean and the Western North Atlantic seem to differ by as much as a factor of 10). As Wunsch (1975) and McComas and Müller (1981) suggest, strong clues to the dynamical balances and the sources and sinks are likely to be found in just those situations where the hypothesis of a universal level is most strongly violated. This might suggest making internal wave energy measurements all around the world, and producing energy contour plots on a Mercator projection of the globe, but first it seems advisable to sit at one location for an extended period of time and see what kind of fast (a few days) and slow (a few months) variability could occur in the internal wave field at one site. One might discover that the mean energy over one week is an excellent descriptor of the site, or that one year is necessary to give a stable result. The possibility and style of a geographical survey can then be determined.

These were the considerations which led to the formalized plans of a long term upper ocean study. The remainder of the report will be concerned with the study site and the engineering test period.

b. LOTUS Site Selection

During the planning stages the experiment site shifted from several potential locations in the North Atlantic to its final location at 34°N , 70°W . The site chosen is a 2 degree square area centered around the old WHOI "Site L" at 34°N , 70°W , which was selected for its logistic convenience and because a variety of oceanographic conditions could be expected there, namely eddies, once-in-a-while Gulf Stream rings, strong atmospheric forcing in the Fall, deep convective mixing just to the North, and a strong thermocline in the late Summer. Figure 1 shows the location with respect to the mean axis of the Gulf Stream.

The oceanography of the site is fairly homogeneous in terms of mean monthly properties. Figure 2 shows that one-degree averaged, monthly

Figure 1: Location of the Long-Term Upper-ocean Study (LOTUS) area.

Figure 2: Contoured monthly-average temperature profiles from WHOI BT atlases.

temperature profiles are similar for the four one-degree squares surrounding Site L. Seasonal thermocline formation begins in April and is complete by August. Mixed-layer deepening begins in September and terminates with deep-convective mixing in February. Figure 3 illustrates that the one-degree square monthly average sea-surface temperatures surrounding Site L are similar from year to year. (Note how cold the winter of 1977 was, a period of strong formation of "18° water".)

The bathymetry of the area is flat and featureless as the site is situated on the Hatteras abyssal plain. A bathymetric survey conducted during OCEANUS cruise 96 is shown in figure 4. The contours indicate a gentle slope to the southwest of approximately 1 meter per 10 kilometers.

Navigation throughout the engineering period and all positions shown in this report are based on Loran-C and the geographical calculation performed by the Northstar 6000 Loran-C unit.

Figure 3: Sea-surface monthly average temperatures from "Gulf Stream" monthly summaries.

SITE L BATHYMETRY SURVEY ON OCEANUS 96

CORRECTED DEPTHS

[GDR+56m(Area 13) + 5m(transducer)]

Figure 4: Measured bathymetry near Site L.

II. ENGINEERING TEST PERIOD

In preparation for the LOTUS experiment a two year period was devoted to the acquisition and testing of equipment and instrumentation. Of primary concern during this period was the mooring array to be used in the experiment. The proposed array consisted of a surface mooring, a near-surface mooring and two subsurface moorings. The surface mooring was to be used to make the very near-surface (5-100 m) current and temperature measurements as well as meteorological measurements from the buoy. The surface mooring current and temperature measurements were to be largely made by Vector Measuring Current Meters. The near-surface mooring was to be heavily instrumented in the 100 m to 500 m depth range with deeper measurements as well and the subsurface moorings were to be instrumented at several depths below 500 meters. These non-surface moorings were to be instrumented with Vector Averaging Current Meters. Confident from past experience that the subsurface moorings could survive and perform well, only the surface and near-surface moorings were tested during the engineering period. The engineering moorings carried at least one current meter and thermistor chain along with some instrumentation such as tensiometers and depth recorders for monitoring the behavior of the mooring.

In addition to the mooring work the implementation of a newly acquired internally recording CTD and shipboard processing system was also of primary concern during the engineering period. It was during this time that an in situ calibration system compatible with the CTD was designed, tested and made operational.

During the six engineering test cruises to the LOTUS site, CTD and XBT data were collected whenever possible in order to begin to compile seasonal hydrographic data from the area.

The engineering test cruises to site L are outlined in the following section, which describes the moorings that were deployed and recovered, the extent of the CTD and XBT work, and any cooperative work with other investigators. Table 1 summarizes the engineering test cruises to the LOTUS site.

Aside from the engineering data and its information about the mooring behaviour, some scientific data were obtained during the engineering mooring deployments. These data include two current meter records, and two time series of temperature data from the thermistor chains. These data are presented below along with CTD and XBT data obtained during the engineering cruises. Each type of data is presented in individual sections. The current meter data section is the only section which contains pre-engineering test data. The last data section contains some telemetered data from the second LOTUS surface buoy (LOTUS-2) including information on the track of the buoy about its watch circle.

a. Chronology

May 1980: OCEANUS cruise number 79 was the first of a series of engineering test cruises for the LOTUS experiment. During this cruise a surface mooring (Number 694) and a near-surface mooring (Number 693) were deployed near 34°N, 70°W. Mooring 693 was deployed at 34°02.8'N, 70°00.3'W and 694 was deployed at 33°59.8'N, 70°00.1'W. Mooring diagrams appear in figures A-1 and A-2. The surface mooring, designated LOTUS-1, had a buoy with an Aanderaa meteorological package and a Vector Measuring Wind Recorder sensor. The buoy was a 12 foot discus buoy previously used in IWEX (Internal Wave Experiment) in 1973 and also in earlier deployments. The surface mooring contained a prototype SEA-LINK Vector Measuring Current Meter (mechanical assembly only) and two Aanderaa thermistor chains. The near-surface mooring utilized the IWEX float; the float was at 60 m depth with a Vector Averaging Current Meter at 100 meters. Also during this cruise two expendable bathythermograph (XBT) sections were made along 70°W between 33°N and 39.7°N during the trip to and from the LOTUS area. In cooperation with D. Hurd (WHOI) a series of dissolution samples were placed on the near-surface mooring in order to evaluate the deep ocean effects.

August 1980: OCEANUS cruise number 85 was the second engineering test cruise of LOTUS. The objectives of this cruise were to test a newly acquired CTD unit and to recover the surface mooring set in May 1980. Upon arrival at 34°N, 70°W the surface buoy was not found, though both the acoustic release and acoustic tracking module were present indicating that the bulk of the mooring remained on site. Only the glass balls and acoustic release were recovered by dragging with improvised gear. Testing the CTD unit proceeded with little difficulty and a

total of 5 CTD stations were made in the LOTUS area. In addition an XBT section was made along 70°W between 34°N and 39.5°N.

November 1980: KNORR cruise 85 to 34°N, 70°W was the third engineering test cruise for LOTUS, and was cooperative with the Gulf Stream Extension project of N. Fofonoff. During this cruise the near-surface mooring (Number 693) set in May 1980 was recovered. Additional testing of the CTD system and a Fall CTD station from the LOTUS area were made. Further dragging for the LOTUS-1 surface mooring (Number 694) was attempted but was unsuccessful. As with the previous cruises an XBT section between 34°N and 39.4°N along 70°W was also completed. Additional CTD's and XBT surveys were obtained during this cruise in conjunction with the Gulf Stream Extension project.

February 1981: KNORR cruise 87 to the LOTUS area was the fourth cruise of the engineering test period. The sole purpose of this cruise was to obtain CTD data from the LOTUS site during the winter season. Ten CTD stations were made in the LOTUS area as well as several XBT sections including two sections along 70°W between 33°N and 40°N.

May 1981: OCEANUS cruise number 96 was the fifth engineering test cruise to the LOTUS area. During this cruise a second surface mooring, LOTUS-2 (mooring number 733), was deployed at 33°59.9'N, 69°59.7'W. The surface mooring buoy was a newly designed 10' diameter discus buoy. The mooring design is shown in figure A-3. It had a Vector Measuring Wind Recorder sensor, a J-tec anemometer and an ARGOS satellite transmitter which could transmit tension in the mooring line, sea and air temperature, battery and regulated voltage, water level in the buoy and the relative wind direction. From the

ARGOS and NOAA-NESS links we could monitor all the variables as well as the buoy position. For more information on the telemetered data see section II f. The surface mooring contained a Vector Measuring Current Meter at 37 m and two paralleled 100 m Aanderaa thermistor chains between 50 and 150 meters. In addition a C. S. Draper Labs Profiling Current Meter test mooring was deployed at $34^{\circ}01.8'N$, $70^{\circ}02.7'W$ in cooperation with C. Eriksen of MIT. A series of seven spring CTD stations were occupied in the LOTUS area and an XBT section was completed between $33^{\circ}N$ and $40^{\circ}N$ along $70^{\circ}W$. Additional CTD's and XBT sections were made outside the LOTUS area in cooperation with T. Joyce (WHOI) during his tests of a doppler acoustic profiler.

September 1981: OCEANUS cruise number 103 was the sixth and last engineering test cruise for LOTUS. During this cruise the second surface mooring, LOTUS-2, set in May 1981 was recovered, along with the test PCM mooring. Three CTD stations were made in the LOTUS area as well as an XBT section between $34.2^{\circ}N$ and $37.8^{\circ}N$ along $70^{\circ}W$. Additional CTD's and XBT surveys were conducted outside the LOTUS area in conjunction with cooperative work with C. Paulson of Oregon State University who was collecting towed thermistor chain data. Another attempt was made at dragging for the first failed surface mooring using modified dragging gear. The mooring was successfully recovered. Unfortunately the mooring had parted at 5 m depth below the prototype SEA Link Vector Measuring Current Meter due to a faulty master link. Everything below that point was recovered. The Aanderaa thermistor chains had been affected to varying degrees by the bottom pressure but there were recoverable data. A summary of the engineering test cruises for LOTUS appears in Table 1.

TABLE 1: A Summary of the Engineering Test Cruises for LOTUS
Showing Principal Work and Cooperative Efforts

Dates	Cruise	LOTUS Work	Other Work
1-9 May 80	OCEANUS 79	Set test surface mooring LOTUS-1, and test near-surface moorings.	Hurd (G&G) dissolution samples on near-surface mooring.
2-11 Aug 80	OCEANUS 85	Attempt LOTUS-1 recovery. Test CTD/IR.	
16 Nov-6 Dec 80	KNORR 85	Recover test near-surface mooring. Drag for LOTUS-1. Use CTD/IR.	Hurd Samples. Fofonoff CTD and mooring work.
25 Feb-4 Mar 81	KNORR 87	CTD/IR stations.	
11-21 May 81	OCEANUS 96	Set test surface mooring LOTUS-2, and make CTD/IR profiles. Test shipboard processing system.	Joyce warm core ring studies with test of doppler acoustic profiler. Set test Eriksen PCM.
10-18 Sept 81	OCEANUS 103	Recover LOTUS-2. Successful drag for LOTUS-1. CTD/IR profiles.	Paulson towed thermistor chain. Recover test Eriksen PCM.

b. Current Meter Data

Historical current meter records obtained prior to the LOTUS engineering test period are shown in figures 5-7. The current meter data presented in these figures were obtained by Geodyne Model 850 current meters. These instruments burst-sample compass, vane, and rotor values and store them plus time information on 1/4 inch two track magnetic tape cartridges. Random erroneous values and systematic errors were edited from the burst sample data, then a vector average was formed for each data burst.

The data in figure 6 and the three deep records in figure 7 are suspect since they represent rotor-vane measurements deep on a surface mooring: the time scales and relative behavior may be usable, but the amplitudes may be overestimated by a factor of 2 or more. Even the 14 m measurements (figures 5 and 7) are probably modest overestimates. Nevertheless, surface currents of 110 cm/sec (figure 7) are estimated and strong currents to 500 m (figure 6) seem possible.

During the engineering test period of LOTUS two current meter records were obtained. A Vector Averaging Current Meter (VACM) record from the near-surface mooring (Number 693) (figure A-1) deployed for 7 months starting in May 1980, and a Vector Measuring Current Meter (VMCM) record from the LOTUS-2 surface mooring (Number 733) (figure A-3) deployed in May 1981.

The VACM and VMCM differ mainly in their flow-sensing elements: the VACM uses a Savonius rotor and a vane to give speed and direction which are resolved against an internal compass to east and north components for vector averaging and recording on tape, whereas the VMCM uses orthogonal cosine-response propellers that sense directly the flow components which are then rotated relative to an internal compass to permit vector averaging and data recording. In addition the VACM had a temperature sensor (thermistor) embedded in its endcap.

Both types of current meters record on Phillips-type cassettes which are transcribed to 9 track computer compatible tapes, converted to scientific units, edited to remove launch and retrieval transients and linearly interpolated across missing and erroneous data cycles if necessary.

The near-surface test mooring gave a VACM record at a nominal 114 m depth (figure 8) from May to December 1980 that shows nearly 50 cm/s speeds, fluctuations of a factor of 3 in the energy in various high frequency bands (figure 9), factor of 10-20 fluctuations in the tidal-inertial band and a spectrum (figure 10) showing strong inertial motions and primarily clockwise M_2 tidal ellipses.

The LOTUS-2 surface mooring test from May to September 1981 provided a VMCM test record from 36 m depth. The first two weeks of the test record were perfect and are shown in figure 11. Strong inertial motions (see also peak in figure 12) occur in the middle of the record. The beginnings of the passage of a Gulf Stream ring occur at the end of the record where speeds exceed 60 cm/s.

During the same cruise on which the LOTUS-2 surface mooring was deployed, a Draper Labs-MIT profiling current meter (PCM) mooring was deployed less than 6.5 km to the northwest. The PCM profiles along the upper portion of a subsurface mooring by adjusting its buoyancy under computer control (Eriksen et al., 1982). Measurements of current, temperature, and conductivity are made while the instrument travels typically between 20 and 250 meters depth. The current measurements are made by a 10 cm diameter, two-axis Marsh-McBirney model 515 spherical electromagnetic current sensor. Temperature is sensed by a Fenwall thermistor probe and conductivity is measured by a Plessy induction type conductivity cell.

The PCM excursion bracketed the VMCM depth (36 meter) on the LOTUS-2 surface mooring. Figure 13 is a comparison of the VMCM record and the current measurements by the PCM.

Figure 5: Wind and surface currents (850 CM) from WHOI surface mooring 314 in summer 1969 at Site L.

Figure 6: Deep currents (850 CM) from WHOI surface mooring 323 in winter 1970 at Site L.

Figure 7: Surface and deep currents (850 CM) from WHOI surface mooring 334 in spring 1970 at Site L.

Figure 8: Data from the engineering deployment of a near-surface mooring at Site L from May 5 to December 2, 1980. A depth recorder at 76 m and a VACM at 114 m (nominal depths) were included to evaluate the performance of the mooring. The depth recorder failed on September 2. The current meter returned a full length record of current and temperature.

Figure 9: The time series of currents at 114 m at Site L was band pass filtered to examine the variability in various internal wave and inertial frequency bands. For each pass band, the quantity $u^2 + v^2$ is plotted. The four internal wave bands (.05 - .10, .10 - .30, .30 - 1.0, and 1.0 - 2.5 cph) were smoothed by running averages of different duration so that the bandwidth - time products for the four bands were the same and the fluctuation statistics would be similar. Temperature and 12-hour averaged current stick vectors are also shown.

Figure 10: Rotary autospectrum of currents shown in Figure 9. Solid line is clockwise, dashed counter-clockwise.

Figure 11: Currents at 36 m depth from a test VMCM on LOTUS-2 surface mooring; record covers 17-30 May 1981.

Figure 12: Rotary autospectrum of currents shown in Figure 11. Solid line is clockwise, dashed is counter-clockwise.

Figure 13: Comparison of currents measured at 36 m depth from a test VMCM on the LOTUS-2 surface mooring and the currents measured by Draper Lab's profiling current meter (PCM). LOTUS-2 and the PCM test mooring were set during OCEANUS 96 in May 1981.

c. Thermistor Chain Data

On each of the LOTUS moorings deployed during the engineering test cruises there was at least one Aanderaa thermistor cable and recording unit. For various reasons which will be discussed below there was less than 100% data return from these instruments. The instruments deployed, problems encountered and the data return will be presented in this section.

The Aanderaa thermistor chain consists of a recording unit and thermistor cable. The thermistor cables used during the LOTUS engineering period were of two types. The older type used were 30 meter long oil filled PVC hose with 11 thermistors built-in along its length (thermistor spacing = 3 meters). Cables of newer design also used during this period were 100 meter long polyurethane cables with 11 thermistors molded to the outside of the cable (thermistor spacing = 10 meters).

The recording unit is mated with the thermistor cable by a watertight connector. All the thermistor cables deployed during the engineering tests of LOTUS were connected to Aanderaa model TR-1 recorders which record the temperature data on 1/4 inch reel to reel magnetic tape. The temperature range the instruments were capable of measuring was 10.08 to 36.04°C. The resolution of the temperature measurements is .1% of the temperature range or .025°C.

The recording units were held in stainless steel brackets with strength members that fastened in line with the mooring. The thermistor cables were attached to the mooring wire by clamps manufactured by the Stauff Corporation. These clamps independently grasp the mooring wire and thermistor cable and hold the two in a parallel configuration.

The near-surface mooring (Number 693) (figure A-1) deployed in May 1980 had a single 30 m thermistor chain between 125 and 155 meters depth. Upon recovery it was determined that this instrument had experienced a tape transport problem which appeared to have occurred during deployment. Tape from the full supply spool slipped off the spool and fell behind it. As the tape continued to advance it tightened up on the supply spool shaft and prevented any further tape advancement.

The surface mooring (Number 694) (figure A-2) also deployed in May 1980 had two 30 m thermistor chains between 13.5 and 43.5 and between 53.5 and 83.5 m. Loss of the surface buoy caused the entire mooring to fall to the bottom (5360 m depth). Unfortunately the recording unit pressure cases were only rated to 2000 m. Recovery of the mooring during dragging operations from OCEANUS cruise number 103 revealed that the upper instrument had been crushed by the water pressure which prevented any recovery of the data tape. The lower instrument however was deformed but had continued to operate throughout the duration. The data obtained from this instrument is shown in figure 14. The data are truncated part way through the deployment because the temperature measurements went off scale when the mooring fell to the bottom.

The surface mooring (Number 733) (figure A-3) deployed in May 1981 had two paralleled 100 m thermistor chains between 45 and 150 meter depth. This was done so that in the event of failure of either thermistor chain there would be a back up unit in the same depth range. The two thermistor chains were offset by 5 m to give a 5 m sensor spacing. This configuration proved useful because one of the two instruments experienced an encoder bearing failure, which prevented any data from being recorded by that instrument. The other instrument recorded good data from approximately 75% of the deployment. The data from this instrument appear in figure 15.

Figure 14: Time series of temperature data from the 30 m long Aanderaa thermistor chain located between 53.5 and 83.5 meters depth on the LOTUS-1 surface mooring. Thermistor spacing is 3 meters. Each temperature series has been offset by 1°C from the previous deeper series for ease of presentation.

Figure 15: Time series of temperature data from the 100 m long Aanderaa thermistor chain located between 50 and 150 meters depth on the LOTUS-2 surface mooring. Thermistor spacing is 10 meters. Each temperature series has been offset by 1°C from the previous deeper series for ease of presentation.

d. Expendable Bathythermograph Data

During each LOTUS cruise one and sometimes two XBT sections were made along 70°W between Site L and nominally 40°N. This section of the report presents for each cruise a chart showing individual XBT locations and the corresponding XBT section. Since the cruises were planned for each season beginning in the spring of 1980 (OCEANUS 79) the transitions which occur from season to season can be observed. Table 2 is a list of the XBT sections included in this report with the corresponding figure numbers (figure 16-31) of the location chart and section. Of note are the strong cold-core ring in early May 1980 (OCEANUS 79) and the thick "18° water" region in all sections.

Two XBT time series were made at Site L during the test cruises. A 25-hour time series in May 1980 (figure 32) shows very little internal tidal motion. The other time series, which is only 7 hr long (figure 33), was obtained in February 1981.

Table 2: A summary of the XBT sections made during the LOTUS engineering test cruises.

Figure Numbers	Vessel	Cruise Number	Date	Description
16-17	OCEANUS	79	2-3 May 1980	70°W, 39.1°-33.8°N
18-19	OCEANUS	79	7-8 May 1980	70°W, 39.7°-33°N
20-21	OCEANUS	85	3-4 Aug. 1980	70°W, 39.5°-34°N
22-23	KNORR	85	4-6 Dec. 1980	70°W, 39.4°-34.1°N
24-25	KNORR	87	26-28 Feb. 1981	70°W, 40°-33°N
26-27	KNORR	87	28 Feb.-3 Mar. 1981	70°W, 40°-33°N
28-29	OCEANUS	96	19-21 May 1981	70°W, 40.1°-33°N
30-31	OCEANUS	103	16-17 Sept. 1981	70°W, 37.8°-34.2°N

Figure 16: Chart showing the locations of the XBT's taken during OCEANUS cruise 79, 2-3 May 1980.

Figure 17: XBT section along 70°W between 39.1°N and 33.8°N, 2-3 May 1980.

Figure 18: Chart showing the locations of the XBT's taken during OCEANUS cruise 79, 7-8 May 1980.

Figure 19: XBT section along 70°W between 39.7°N and 33°N, 7-8 May 1980.

Figure 20: Chart showing the locations of the XBT's taken during OCEANUS cruise 85, 2-4 Aug. 1980.

Figure 21: XBT section along 70°W between 39.5°N and 34°N, 2-4 Aug. 1980.

Figure 22: Chart showing the locations of the XBT's taken during KNORR 85, 4-6 Dec. 1980.

Figure 23: XBT section along 70°W between 39.4°N and 34.1°N, 4-6 Dec. 1980.

Figure 24: Chart showing the locations of the XBT's taken during KNORR 87, 26-28 Feb. 1981.

Figure 25: XBT section along 70°W between 40°N and 33°N, 26-28 Feb. 1981.

Figure 26: Chart showing the location of the XBT's taken during KNORR 87, 28 Feb. - 3 Mar. 1981.

Figure 27: XBT section along 70°W between 40°N and 33°N, 28 Feb. - 3 Mar. 1981.

Figure 28: Chart showing the locations of the XBT's taken during OCEANUS 96, 19-21 May 1981.

Figure 29: XBT section along 70°W between 40.1°N and 33°N, 19-21 May 1981.

Figure 30: Chart showing the locations of the XBT's taken during OCEANUS 103, 16-17 Sept. 1981.

Figure 31: XBT section along 70°W between 37.8°N and 34.2°N, 16-17 Sept. 1981.

Figure 32: XBT time series from OCEANUS 79 at Site L, 3-4 May 1980.

Figure 33: XBT time series from KNORR 87 at Site L, 28 Feb. 1981.

e. CTD Data

The LOTUS CTD program evolved considerably during the engineering test period. It began with the acquisition of a new Neil Brown Instrument Systems internal-recording CTD (CTD/IR). This CTD/IR is battery powered and has the capability to record its data on a cassette tape within the CTD/IR. Since there is no need for the conventional electromechanical cable the CTD/IR is lowered using the ship's hydro-wire. This however does not permit any real time output of data on-board ship. Depth information is obtained by monitoring the distance the instrument is from the bottom using a Benthos pinger (attached to the CTD/IR) in conjunction with a precision depth recorder (PDR).

The CTD/IR was first used during OCEANUS cruise number 85. Calibration water samples were obtained using Nansen bottles attached to the hydro-wire. This method proved to be awkward and difficult to interpret. With the experience gained from the first cruise a better calibration scheme was developed, modified and tested during the cruises that followed. In turn the quality of the calibration samples from later cruises improved.

The new sampling scheme, fashioned after a rosette sampler, was designed for use with the CTD/IR. It differs from the rosette sampler in that it is a simple messenger actuated system in which all the sample bottles close at the same time. The use of a messenger actuated system eliminates the need of any conducting cable and preserves the flexibility of the internally recording CTD which can be lowered using any standard hydrographic wire. The system consists of three 1.7 liter Niskin bottles attached to the pressure case of the CTD/IR. The bottles are tripped by a mechanism mounted above the CTD/IR on a small tripod. The hydro-wire passes through a hole in the tripping mechanism and is shackled to a swivel attached to the end plate of the CTD/IR. Since the tripping mechanism is above the hydro-wire termination there are no obstructions in the way of the messenger. With the messenger impact the lanyards from the three Niskin bottles are released and all three bottles are closed at the same time and at the same depth as the CTD/IR. In order to obtain a time mark as to when the bottles closed, the Benthos Pinger is switched to a double ping rate when the bottles are tripped. The change in ping rate is

detected using the ship's PDR. This not only gives an indication of the time when the samples are taken but also verifies that the messenger has reached the CTD/IR and has activated the tripping mechanism. Mechanical and operational details of the CTD/IR and its in situ calibration scheme can be found in Trask (1981).

The temperature and pressure CTD/IR data are taken directly from the instrument applying only the manufacturers calibration coefficients. The conductivity sensor is calibrated with the water samples collected at depth. Water sample salinities were determined using a Guildline "Autosal" salinometer. A conductivity calibration coefficient (cell factor, K) was determined for each CTD/IR cast based on a comparison of the water sample salinities and the corresponding CTD/IR calculated salinities. The salinity computations are based on the 1978 Practical Salinity Scale (Lewis and Perkins, 1978) as recommended by the Joint Panel on Oceanographic Tables and Standards (JPOTS).

The cell factor is the scaling factor the measured conductivity must be multiplied by to obtain the "true" conductivity. The proper value of K was determined by an iterative process in which the CTD/IR conductivity values (in the region where the water samples were taken) were multiplied by K which is adjusted until the calculated CTD/IR salinities and bottle salinities were matched within reasonable limits ($\pm .003$ psu). The conductivity values of the entire cast were then multiplied by the appropriate K to obtain the "true" conductivities.

Preliminary processing of the CTD/IR data was accomplished using a Hewlett-Packard 85 desk-top computer. The preliminary processing involves taking the raw down-cast data from cassette and applying the appropriate calibration coefficients, editing wild points, and applying a sensor time lag correction. This correction is applied to the pressure and conductivity data since these sensors respond to sudden changes considerably faster than does the platinum temperature sensor. The recursive filter, which in effect slows down the conductivity and pressure sensors to match the temperature sensor, is described in Millard (1981). The data were then pressure averaged over a two decibar pressure range. Salinities were calculated and then the averaged pressure, temperature,

conductivity, and salinity were stored on flexible disc. The pressure averaged data are then available for computing a number of other oceanographic variables.

Data Presentation

During each engineering test cruise at least one CTD/IR station was made in the LOTUS area. All of the CTD/IR stations are not presented in this report. Many of the stations made during individual cruises are in close proximity to each other. In those instances a single representative station has been selected for presentation here. Several cruises had sufficient time to make some stations throughout the 2 degree square LOTUS area. Where available those stations which were made at the intersection of whole degrees of latitude and longitude in the LOTUS area are also presented for spatial considerations. The presentation consists of tabular listings of pressure (PRESS) in decibars, in situ temperature (TEMP) in degrees centigrade, salinity (SALIN) in practical salinity units, sigma-t in kg/m^3 , sound speed (SSPEED) in meters/second, dynamic height (DYNHGT) in dynamic meters, potential temperature (POTEMP) in degrees centigrade, potential temperature gradient (POTGRD) in millidegrees centigrade/decibar, potential density (POTDEN) in kg/m^3 and Brunt Väisälä frequency (BR-V) in cycles per hour at standard pressures along with graphical profiles of potential temperature and salinity. The heading of the listings include an abbreviated ship name (OC = OCEANUS and KN = KNORR) and cruise number, CTD number, year, day of year and time, latitude and longitude and the depth of the water.

Table 3 summarizes the LOTUS CTD/IR work conducted during the engineering test period. The page numbers refer to the CTD sections corresponding to each cruise.

As a graphic summary of the seasonal variability of potential temperature and salinity at 34°N , 70°W , a composite plot of four CTD/IR stations, one from each season, are presented in figure 50.

Table 3: A summary of the CTD/IR work conducted during the LOTUS engineering test period.

CRUISE	DATE	No. of CTDs in LOTUS area	Page No.
OCEANUS 85	Aug. 1980	5	60
KNORR 85	Nov. 1980	1	64
KNORR 87	Feb. 1981	10	68
OCEANUS 96	May 1981	7	78
OCEANUS 103	Sept. 1981	3	86

OCEANUS 85

AUGUST 1980

CTD STATIONS SITE L

8-9 AUGUST 1980

Figure 34: Chart showing the locations of CTD stations made during OCEANUS 85, Aug. 1980.

DC 85	CTD 002	1980 221 1313Z	34 00.26N	69 59.85W	POTGRD	SIGMA-t	POTDEN	BR-V	SSPEED	DYNHGT
PRESS	TEMP	SALIN	POTEMP	POTGRD	SIGMA-t	POTDEN	BR-V	SSPEED	DYNHGT	
dbar	°C	psu	°C	m ² /db	kg/m**3	kg/m**3	cph	m/s	dyn m	
2.	27.572	36.208	27.571	0.00	23.464	23.446	0.00	1541.7	0.0000	
6.	27.556	36.205	27.555	9.99	23.467	23.449	4.42	1541.7	0.0186	
10.	27.322	36.171	27.319	113.79	23.517	23.499	10.90	1541.2	0.0347	
16.	26.288	36.145	26.284	99.11	23.827	23.810	10.54	1538.9	0.0613	
20.	26.092	36.190	26.087	54.78	23.923	23.906	7.56	1538.6	0.0762	
26.	25.802	36.204	25.796	85.28	24.024	24.008	11.57	1538.0	0.0998	
30.	25.061	36.268	25.054	266.87	24.301	24.285	14.37	1536.4	0.1160	
36.	23.991	36.376	23.983	203.92	24.705	24.690	13.73	1534.0	0.1374	
50.	21.878	36.546	21.868	74.57	25.445	25.432	10.30	1529.1	0.1770	
66.	20.974	36.582	20.961	82.18	25.723	25.711	5.94	1527.0	0.2165	
75.	20.535	36.599	20.520	31.13	25.856	25.844	7.32	1526.0	0.2372	
100.	19.547	36.601	19.528	8.30	26.119	26.109	4.40	1523.7	0.2873	
126.	18.896	36.594	18.874	23.13	26.283	26.274	3.44	1522.3	0.3352	
150.	18.667	36.578	18.640	11.22	26.330	26.321	2.06	1522.0	0.3776	
200.	18.483	36.568	18.448	.72	26.369	26.363	1.38	1522.3	0.4645	
250.	18.390	36.561	18.346	2.43	26.387	26.383	1.14	1522.8	0.5516	
300.	18.276	36.552	18.223	2.52	26.408	26.407	1.25	1523.3	0.6379	
350.	18.147	36.535	18.085	1.59	26.428	26.428	1.19	1523.8	0.7243	
400.	18.052	36.525	17.982	2.30	26.443	26.446	1.13	1524.3	0.8102	
450.	17.766	36.477	17.688	8.63	26.478	26.482	1.69	1524.3	0.8964	
500.	17.508	36.441	17.422	2.66	26.514	26.520	1.48	1524.3	0.9814	
550.	17.126	36.371	17.033	5.88	26.553	26.560	1.83	1523.9	1.0650	
600.	16.539	36.270	16.440	9.21	26.616	26.624	2.16	1522.8	1.1475	
650.	15.740	36.132	15.636	21.76	26.695	26.703	2.13	1521.1	1.2268	
700.	14.806	35.971	14.698	14.59	26.780	26.788	2.67	1518.8	1.3029	
750.	13.770	35.807	13.660	6.57	26.876	26.883	2.54	1516.1	1.3743	
800.	12.630	35.632	12.519	10.96	26.974	26.980	2.76	1512.9	1.4416	
900.	10.383	35.332	10.272	14.25	27.163	27.165	2.19	1506.5	1.5617	
1000.	8.354	35.141	8.245	27.37	27.350	27.348	2.82	1500.5	1.6635	
1100.	6.849	35.092	6.740	5.48	27.533	27.527	2.19	1496.3	1.7451	
1200.	5.846	35.066	5.735	7.55	27.645	27.639	1.88	1494.0	1.8121	
1300.	5.238	35.048	5.123	6.97	27.707	27.699	1.39	1493.2	1.8703	
1400.	4.886	35.033	4.765	3.79	27.736	27.729	.89	1493.4	1.9244	
1500.	4.650	35.025	4.522	1.16	27.757	27.750	.93	1494.1	1.9767	
1600.	4.412	35.006	4.278	1.07	27.768	27.762	.83	1494.8	2.0275	
1800.	4.136	34.994	3.986	4.06	27.788	27.783	.67	1497.0	2.1272	
2000.	3.971	34.992	3.804	.10	27.804	27.800	.58	1499.6	2.2258	
2200.	3.757	34.986	3.574	-.25	27.822	27.819	.73	1502.1	2.3231	
2400.	3.590	34.985	3.389	.98	27.838	27.836	.64	1504.8	2.4186	
2500.	3.505	34.979	3.296	1.63	27.841	27.840	.56	1506.1	2.4658	
2600.	3.427	34.975	3.209	.67	27.846	27.845	.60	1507.4	2.5129	
2800.	3.233	34.962	2.998	.97	27.854	27.855	.63	1510.0	2.6069	
3000.	3.088	34.952	2.835	.19	27.861	27.862	.48	1512.8	2.6998	
3200.	2.937	34.942	2.666	1.01	27.866	27.869	.62	1515.5	2.7923	
3400.	2.792	34.933	2.503	.93	27.872	27.876	.51	1518.3	2.8840	
3600.	2.677	34.926	2.369	.64	27.877	27.882	.57	1521.2	2.9748	
3800.	2.569	34.921	2.242	1.18	27.882	27.888	.50	1524.2	3.0650	
4000.	2.482	34.915	2.134	.01	27.885	27.893	.47	1527.3	3.1550	
4200.	2.409	34.910	2.040	1.17	27.888	27.897	.39	1530.4	3.2447	
4400.	2.375	34.904	1.984	.40	27.888	27.896	.29	1533.7	3.3357	
4600.	2.352	34.899	1.937	.74	27.884	27.896	.31	1537.1	3.4281	
4800.	2.340	34.896	1.901	.14	27.882	27.896	.28	1540.5	3.5218	
5000.	2.335	34.892	1.871	.16	27.880	27.896	.26	1543.9	3.6177	
5200.	2.334	34.890	1.845	-.03	27.878	27.896	.27	1547.4	3.7151	
5400.	2.293	34.880	1.779	.02	27.873	27.893	0.00	1550.7	3.8151

Figure 35: Profiles of potential temperature and salinity from OCEANUS 85, CTD number 2, 8 Aug. 1980.

KNORR 85

DECEMBER 1980

CTD STATIONS SITE L

4 DECEMBER 1980

Figure 36: Chart showing the locations of CTD stations made during KNORR 85, Dec. 1980.

KN 85	CTD 003	1980 339 1155Z	34 00.83N	70 01.43W	SSPEED	DYNHGT
PRESS	TEMP	SALIN	POTGRD	SIGMA-t	BR-V	dyn m
dbar	°C	psu	m ² /db	kg/m ³	cph	m/s
2.	21.116	36.553	0.00	25.662	0.00	1526.3
6.	21.133	36.548	-1.36	25.654	-1.93	1526.4
10.	21.139	36.547	.30	25.651	-79	1526.4
16.	21.140	36.548	.66	25.651	.59	1526.5
20.	21.140	36.548	-84	25.651	-46	1526.6
26.	21.145	36.547	-1.13	25.650	-1.00	1526.7
30.	21.150	36.547	-91	25.648	-70	1526.8
36.	21.149	36.547	.39	25.648	.71	1526.9
50.	21.151	36.547	.94	25.648	.16	1527.2
66.	21.156	36.547	.94	25.647	.63	1527.4
76.	21.154	36.547	.07	25.647	.25	1527.6
100.	21.128	36.549	14.09	25.656	4.32	1527.9
126.	19.486	36.607	16.53	26.140	4.29	1523.9
150.	19.026	36.590	7.53	26.246	3.04	1523.0
150.	18.551	36.560	3.78	26.345	1.92	1522.5
200.	18.349	36.545	4.19	26.385	1.43	1522.7
300.	18.186	36.529	3.79	26.414	1.57	1523.0
350.	17.995	36.508	2.91	26.445	1.33	1523.3
400.	17.772	36.476	6.29	26.476	1.57	1523.4
450.	17.581	36.452	6.38	26.505	1.53	1523.7
500.	17.360	36.415	4.77	26.530	1.74	1523.8
550.	16.812	36.317	10.73	26.587	2.25	1522.9
600.	16.140	36.200	11.73	26.655	2.22	1521.6
650.	15.391	36.071	7.58	26.727	2.15	1519.9
700.	14.477	35.918	11.68	26.811	2.46	1517.7
750.	13.615	35.782	12.65	26.889	2.38	1515.5
800.	12.726	35.653	15.67	26.971	2.52	1513.3
900.	10.538	35.369	16.73	27.165	2.64	1507.1
1000.	8.590	35.178	12.90	27.343	2.35	1501.4
1100.	7.129	35.086	16.21	27.489	2.47	1497.4
1200.	5.887	35.051	4.19	27.629	1.90	1494.1
1300.	5.210	35.032	5.77	27.697	1.45	1493.1
1400.	4.879	35.026	4.758	27.731	1.16	1493.4
1500.	4.661	35.018	3.20	27.750	.87	1494.1
1600.	4.430	35.002	4.19	27.763	.77	1494.8
1800.	4.147	34.986	1.48	27.781	.64	1497.0
2000.	3.965	34.983	.19	27.798	.61	1499.6
2200.	3.809	34.980	1.39	27.812	.63	1502.3
2400.	3.638	34.978	.26	27.827	.64	1504.9
2500.	3.550	34.974	1.92	27.833	.66	1506.3
2600.	3.471	34.972	1.25	27.839	.66	1507.6
2800.	3.277	34.961	.69	27.849	.68	1510.2
3000.	3.118	34.952	1.54	27.857	.59	1512.9
3200.	2.952	34.942	.69	27.865	.63	1515.6
3400.	2.640	34.923	1.33	27.872	.59	1518.3
3600.	2.522	34.915	1.11	27.878	.60	1521.1
3800.	2.436	34.909	-.38	27.881	.47	1524.0
4000.	2.373	34.904	.68	27.885	.44	1527.1
4200.	2.341	34.900	.51	27.886	.39	1530.2
4400.	2.324	34.895	.24	27.885	.31	1533.6
4600.	2.319	34.892	-.19	27.883	.23	1536.9
4800.	2.317	34.889	-.06	27.881	.23	1540.4
5000.	2.317	34.889	.20	27.878	.24	1543.9

Figure 37: Profiles of potential temperature and salinity from KNORR 85, CTD number 3, 4 Dec. 1980.

KNORR 87

FEBRUARY - MARCH 1981

CTD STATIONS
SITE L
27 FEB - 2 MAR 1981

Figure 38: Chart showing the locations of CTD stations made during KNORR 87, Feb. 1981.

KN 87	CTD 002	1981 058 2032Z	33 59.99N	69 59.76W	PRESS	TEMP	SALIN	POTEMP	POTGRD	SIGMA-t	POTDEN	BR-V	SSPEED	DYNHGT
					dbar	°C	psu	°C	m	kg/m**3	kg/m**3	cph	m/s	dyn m
2.	18.444	36.550	18.444	0.00	26.365	26.350	0.00	1518.9	0.0000					
6.	18.443	36.550	18.443	2.15	26.365	26.350	-1.17	1518.9	0.0063					
10.	18.457	36.550	18.455	-2.03	26.361	26.347	.35	1519.0	0.0128					
16.	18.446	36.550	18.444	.14	26.364	26.349	-.27	1519.1	0.0234					
20.	18.448	36.550	18.444	-.29	26.363	26.349	-.57	1519.2	0.0298					
26.	18.449	36.549	18.445	-.01	26.363	26.349	.41	1519.3	0.0403					
30.	18.449	36.550	18.444	.07	26.363	26.349	.25	1519.3	0.0464					
36.	18.450	36.549	18.444	.55	26.363	26.349	.52	1519.4	0.0571					
50.	18.448	36.551	18.440	.16	26.364	26.351	.10	1519.7	0.0805					
66.	18.451	36.550	18.440	-.01	26.363	26.351	.64	1519.9	0.1075					
76.	18.452	36.551	18.439	-.03	26.363	26.351	-.84	1520.1	0.1244					
100.	18.459	36.551	18.442	.19	26.361	26.350	-.16	1520.5	0.1650					
126.	18.462	36.550	18.440	-.16	26.360	26.351	-.16	1521.0	0.2094					
150.	18.458	36.552	18.432	-.17	26.362	26.354	.33	1521.4	0.2505					
200.	18.462	36.551	18.427	.13	26.361	26.355	.74	1522.2	0.3367					
250.	18.442	36.555	18.398	.42	26.369	26.365	.61	1523.0	0.4242					
300.	18.400	36.555	18.348	.92	26.379	26.378	.89	1523.7	0.5118					
350.	18.339	36.548	18.277	2.99	26.389	26.390	1.12	1524.3	0.5998					
400.	18.244	36.535	18.174	.82	26.403	26.406	1.51	1524.9	0.6878					
450.	17.914	36.493	17.836	10.01	26.453	26.458	1.94	1524.7	0.7753					
500.	17.545	36.442	17.459	.22	26.506	26.512	1.21	1524.4	0.8604					
550.	17.139	36.372	17.046	23.91	26.550	26.558	2.18	1523.9	0.9454					
600.	16.646	36.286	16.547	11.49	26.603	26.611	2.14	1523.2	1.0279					
650.	15.797	36.140	15.693	20.31	26.688	26.696	2.36	1521.3	1.1079					
700.	14.985	36.004	14.877	32.25	26.766	26.774	2.68	1519.4	1.1838					
750.	13.704	35.800	13.594	29.90	26.885	26.891	2.81	1515.9	1.2554					
800.	12.497	35.615	12.387	20.59	26.987	26.992	2.78	1512.5	1.3220					
900.	9.888	35.283	9.781	15.30	27.211	27.211	2.54	1504.6	1.4390					
1000.	8.127	35.140	8.020	6.89	27.384	27.381	2.71	1499.6	1.5361					
1100.	6.608	35.088	6.502	19.93	27.562	27.566	2.42	1495.4	1.6150					
1200.	5.526	35.044	5.419	11.78	27.668	27.660	1.79	1492.7	1.6787					
1300.	5.118	35.040	5.004	.16	27.714	27.707	1.37	1492.7	1.7352					
1400.	4.752	35.021	4.633	5.50	27.742	27.734	.94	1492.9	1.7882					
1500.	4.502	35.004	4.376	1.97	27.757	27.750	.84	1493.5	1.8397					
1600.	4.284	34.990	4.152	1.99	27.769	27.762	.72	1494.2	1.8898					
1800.	4.058	34.983	3.909	10.19	27.788	27.782	.66	1496.6	1.9892					
2000.	3.969	34.993	3.802	1.22	27.805	27.801	.64	1499.6	2.0875					
2200.	3.796	34.988	3.612	.83	27.819	27.817	.62	1502.3	2.1850					
2400.	3.609	34.984	3.408	1.78	27.835	27.834	.69	1504.8	2.2812					
2500.	3.519	34.979	3.310	2.61	27.840	27.839	.57	1506.1	2.3287					
2600.	3.439	34.976	3.221	1.42	27.846	27.845	.64	1507.5	2.3762					
2800.	3.268	34.966	3.032	.72	27.854	27.855	.61	1510.1	2.4703					
3000.	3.110	34.955	2.857	1.49	27.860	27.862	.60	1512.9	2.5636					
3200.	2.938	34.945	2.668	.57	27.869	27.872	.57	1515.5	2.6560					
3400.	2.803	34.937	2.514	.64	27.874	27.878	.60	1518.4	2.7473					
3600.	2.669	34.928	2.362	.71	27.879	27.884	.58	1521.2	2.8380					
3800.	2.550	34.922	2.223	.90	27.885	27.891	.53	1524.1	2.9278					
4000.	2.456	34.914	2.109	.73	27.886	27.894	.47	1527.2	3.0168					
4200.	2.392	34.908	2.024	.12	27.887	27.896	.38	1530.3	3.1059					
4400.	2.354	34.905	1.963	.02	27.888	27.898	.32	1533.6	3.1959					
4600.	2.334	34.900	1.920	.28	27.886	27.898	.30	1537.0	3.2874					
4800.	2.325	34.897	1.887	.07	27.884	27.898	.25	1540.4	3.3807					
5000.	2.322	34.894	1.858	.08	27.882	27.898	.25	1543.9	3.4758

KN 87 CTD 002

KN 87 CTD 002

Figure 39: Profiles of potential temperature and salinity from KNORR 87, CTD number 2, 27 Feb. 1981.

Figure 40: Profiles of potential temperature and salinity from KNORR 87, CTD number 7, 28 Feb. 1981.

KN 87	CTD 008	1981 060 0246Z	33 00.17N	68 59.98W	BR-V	SSPEED	DYNHGT
PRESS	TEMP	POTEMP	POTGRD	SIGMA-t	POTDEN	m/s	dyn m
dbar	°C	°C	m°C/db	kg/m**3	kg/m**3		
2.	18.301	18.301	0.00	26.410	26.395	0.00	0.0000
6.	18.306	18.305	-0.57	26.408	26.393	-1.15	1518.5
10.	18.311	18.310	-0.11	26.407	26.392	-0.19	1518.5
16.	18.306	18.304	-0.02	26.408	26.393	-0.61	1518.6
20.	18.308	18.304	-0.08	26.408	26.393	-0.79	1518.7
26.	18.316	18.311	-0.87	26.405	26.391	-0.65	1518.8
30.	18.317	18.312	-0.22	26.405	26.391	-0.68	1518.9
36.	18.325	18.319	-1.15	26.403	26.389	-0.88	1519.0
50.	18.328	18.319	-0.39	26.402	26.389	-0.59	1519.1
66.	18.331	18.320	-0.15	26.401	26.389	-0.59	1519.3
76.	18.332	18.319	-0.07	26.400	26.389	-0.17	1519.6
100.	18.335	18.318	-0.10	26.400	26.389	-0.37	1519.8
126.	18.339	18.317	-0.32	26.399	26.389	-0.28	1520.2
150.	18.344	18.318	-0.28	26.397	26.389	-0.12	1520.6
200.	18.354	18.319	-0.36	26.395	26.388	-0.19	1521.0
250.	18.359	18.315	-0.08	26.393	26.389	-0.20	1521.9
300.	18.328	18.276	3.80	26.396	26.394	1.29	1522.7
350.	18.100	18.039	4.70	26.428	26.429	1.37	1523.5
400.	17.903	17.834	-0.12	26.457	26.454	1.35	1523.6
450.	17.719	17.642	8.64	26.483	26.487	1.66	1523.8
500.	17.483	17.397	7.02	26.515	26.521	1.54	1524.1
550.	17.139	17.046	7.30	26.553	26.560	1.58	1524.2
600.	16.722	16.623	10.06	26.591	26.599	2.47	1523.9
650.	15.920	15.816	21.51	26.673	26.682	2.81	1521.7
700.	14.834	14.726	27.49	26.778	26.786	2.91	1521.7
750.	13.968	13.857	19.28	26.859	26.867	2.31	1518.9
800.	12.715	12.604	12.92	26.969	26.974	2.80	1516.8
900.	10.135	10.026	45.00	27.182	27.182	3.18	1513.2
1000.	8.118	8.011	19.34	27.383	27.379	2.97	1505.5
1100.	6.591	6.485	5.48	27.559	27.553	2.03	1499.6
1200.	5.768	5.659	5.10	27.654	27.647	1.80	1493.7
1300.	5.258	5.143	2.18	27.711	27.703	1.27	1493.3
1400.	4.869	4.749	2.71	27.738	27.730	.95	1493.3
1500.	4.660	4.532	7.19	27.755	27.748	.88	1494.1
1600.	4.153	4.274	-0.12	27.766	27.760	.74	1494.8
1800.	3.964	3.990	.74	27.786	27.780	.70	1494.8
2000.	3.792	3.797	-0.25	27.803	27.799	.67	1497.0
2200.	3.575	3.608	.67	27.820	27.818	.71	1499.6
2400.	3.486	3.479	.86	27.835	27.833	.67	1502.2
2500.	3.372	3.377	3.24	27.841	27.840	.72	1504.7
2600.	3.172	3.155	.53	27.845	27.845	.54	1506.0
2800.	2.992	2.939	1.61	27.856	27.856	.66	1507.2
3000.	2.837	2.741	.73	27.864	27.866	.58	1509.7
3200.	2.667	2.569	1.90	27.871	27.873	.64	1512.3
3400.	2.530	2.426	.60	27.877	27.881	.56	1515.1
3600.	2.422	2.226	1.35	27.883	27.887	.56	1517.8
3800.	2.366	2.021	.19	27.886	27.892	.47	1520.6
4000.	2.328	1.961	.25	27.887	27.894	.40	1523.6
4200.	2.308	1.918	.51	27.886	27.895	.30	1526.8
4400.	2.294	1.881	.12	27.883	27.895	.23	1530.0
4600.	2.294	1.881	.09	27.881	27.895	.15	1533.4
4800.	2.303	1.840	.13	27.878	27.894	.19	1536.8
5000.	2.293	1.805	.22	27.875	27.893	.00	1540.3
5200.							1543.8
							1547.2
							3.5506

Figure 41: Profiles of potential temperature and salinity from KNORR 87, CTD number 8, 28 Feb. 1981.

KN 87	CTD 010	1981 061 0541Z	35 00.25N	69 59.97W	POTDEN	BR-V	SSPEED	DYNHGT	
PRESS	TEMP	SALIN	POTEMP	POTGRD	SIGMA-t	POTDEN	BR-V	SSPEED	DYNHGT
dbar	°C	psu	°C	m °C/db	kg/m**3	kg/m**3	cph	m/s	dyn m
2.	19.060	36.562	19.060	0.00	26.217	26.202	0.00	1520.6	0.0000
6.	19.059	36.563	19.059	-.24	26.217	26.202	.37	1520.7	.0074
10.	19.062	36.563	19.060	-.79	26.217	26.202	.28	1520.8	.0143
16.	19.060	36.563	19.058	-.13	26.217	26.203	.57	1520.9	.0255
20.	19.060	36.563	19.057	.05	26.217	26.203	.54	1520.9	.0326
26.	19.058	36.563	19.054	.09	26.218	26.204	.36	1521.0	.0433
30.	19.058	36.563	19.053	.07	26.218	26.204	.43	1521.1	.0507
36.	19.054	36.563	19.048	.03	26.219	26.205	1.11	1521.2	.0617
50.	19.001	36.560	18.992	7.86	26.230	26.217	2.06	1521.3	.0872
66.	18.714	36.555	18.703	22.88	26.300	26.288	3.68	1520.7	.1158
76.	18.670	36.554	18.657	.28	26.310	26.299	.36	1520.7	.1333
100.	18.625	36.547	18.607	5.38	26.316	26.306	2.10	1521.0	.1752
126.	18.554	36.544	18.532	3.77	26.332	26.323	1.94	1521.2	.2202
150.	18.503	36.546	18.477	1.22	26.346	26.338	1.15	1521.5	.2621
200.	18.475	36.547	18.440	.27	26.354	26.348	.54	1522.2	.3488
250.	18.480	36.553	18.436	-.67	26.358	26.354	.76	1523.1	.4366
300.	18.482	36.556	18.430	.18	26.360	26.358	.49	1523.9	.5248
350.	18.465	36.555	18.403	1.18	26.363	26.364	.96	1524.7	.6139
400.	18.244	36.536	18.174	1.53	26.405	26.407	1.71	1524.9	.7027
450.	18.018	36.511	17.940	4.65	26.442	26.446	1.70	1525.0	.7902
500.	17.738	36.471	17.652	3.00	26.481	26.487	1.33	1525.0	.8768
550.	17.454	36.428	17.360	7.57	26.517	26.525	1.48	1524.9	.9627
600.	16.869	36.327	16.769	12.10	26.581	26.589	2.33	1523.9	1.0464
650.	16.090	36.189	15.985	8.10	26.658	26.667	2.34	1522.2	1.1282
700.	15.153	36.031	15.044	6.43	26.750	26.759	2.23	1519.9	1.2053
750.	14.136	35.868	14.024	6.53	26.846	26.854	2.47	1517.3	1.2789
800.	13.097	35.705	12.983	13.96	26.937	26.944	1.85	1514.6	1.3477
900.	10.557	35.356	10.445	9.55	27.151	27.153	3.01	1507.1	1.4715
1000.	8.357	35.143	8.248	24.36	27.352	27.349	2.90	1500.5	1.5723
1100.	6.398	35.066	6.293	20.80	27.574	27.567	2.23	1494.5	1.6524
1200.	5.572	35.044	5.464	6.17	27.663	27.655	1.55	1492.9	1.7160
1300.	5.113	35.041	4.999	3.11	27.715	27.708	.97	1492.7	1.7726
1400.	4.869	35.035	4.749	8.88	27.739	27.732	1.21	1493.4	1.8262
1500.	4.635	35.024	4.507	2.19	27.757	27.750	.87	1494.0	1.8780
1600.	4.457	35.016	4.322	.19	27.771	27.764	.78	1495.0	1.9289
1800.	4.138	34.994	3.988	.18	27.788	27.783	.66	1497.0	2.0288
2000.	3.954	34.990	3.787	3.02	27.804	27.800	.78	1499.6	2.1272
2200.	3.787	34.989	3.603	-1.23	27.821	27.818	.70	1502.2	2.2245
2400.	3.597	34.982	3.396	.83	27.835	27.834	.66	1504.8	2.3204
2500.	3.520	34.980	3.310	.23	27.841	27.840	.44	1506.1	2.3679
2600.	3.455	34.977	3.237	.73	27.845	27.844	.65	1507.6	2.4154
2800.	3.243	34.964	3.008	1.11	27.855	27.856	.61	1510.0	2.5095
3000.	3.074	34.955	2.822	.09	27.864	27.866	.60	1512.7	2.6021
3200.	2.910	34.946	2.640	1.10	27.872	27.875	.70	1515.4	2.6935
3400.	2.726	34.936	2.439	.36	27.881	27.884	.57	1518.0	2.7832
3600.	2.566	34.926	2.261	1.17	27.886	27.891	.61	1520.8	2.8710
3800.	2.431	34.917	2.107	.87	27.891	27.897	.50	1523.6	2.9576
4000.	2.363	34.911	2.019	-.01	27.892	27.899	.37	1526.8	3.0437
4200.	2.321	34.907	1.955	.45	27.892	27.901	.36	1530.0	3.1307
4400.	2.306	34.903	1.917	.12	27.890	27.901	.20	1533.4	3.2190
4600.	2.298	34.900	1.884	.09	27.889	27.901	-.10	1536.8	3.3092
4800.	2.299	34.896	1.861	.04	27.886	27.900	.16	1540.3	3.4013

KN 87 CTD 010

Figure 42: Profiles of potential temperature and salinity from KNORR 87, CTD number 10, 2 Mar. 1981.

OCEANUS 96

MAY 1981

CTD STATIONS
SITE L
17-19 MAY 1981

Figure 43: Chart showing the locations of CTD stations made during OCEANUS 96, May 1981.

Figure 44: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 7, 17 May 1981.

Figure 45: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 12, 19 May 1981.

DC 96	CTD 013	1981 139 2310Z	35 04.00N	69 59.37W	SSPEED	DYNHGT
PRESS	TEMP	SALIN	POTGRD	SIGMA-t	BR-V	dyn m
dbar	°C	psu	m ² /db	kg/m ³	cph	m/s
2.	20.469	36.546	0.00	25.833	25.817	0.00
6.	20.470	36.546	-0.67	25.832	25.817	1524.5
10.	20.473	36.545	-0.79	25.831	25.816	1524.6
16.	20.450	36.544	-1.73	25.837	25.822	1524.7
20.	20.450	36.543	-1.37	25.835	25.821	1524.7
26.	20.372	36.539	11.47	25.854	25.839	1524.8
30.	20.086	36.521	70.54	25.916	25.902	1524.6
36.	19.699	36.515	10.87	26.014	26.001	1524.6
50.	19.487	36.524	31.91	26.077	26.064	1522.9
66.	19.102	36.550	21.38	26.196	26.184	1522.6
76.	18.893	36.553	31.13	26.252	26.241	1521.8
100.	18.646	36.555	6.88	26.317	26.307	1521.4
126.	18.445	36.552	8.72	26.366	26.357	1521.1
150.	18.336	36.553	4.96	26.394	26.386	1520.9
200.	18.213	36.543	1.33	26.418	26.411	1521.0
250.	18.153	36.539	8.48	26.429	26.425	1521.5
300.	18.070	36.539	1.26	26.450	26.448	1522.1
350.	17.961	36.527	2.43	26.468	26.468	1522.7
400.	17.899	36.519	-0.01	26.477	26.479	1523.2
450.	17.815	36.506	1.09	26.488	26.493	1523.9
500.	17.716	36.488	0.98	26.499	26.505	1524.4
550.	17.604	36.468	3.01	26.511	26.519	1524.9
600.	17.374	36.427	6.32	26.536	26.546	1525.4
650.	16.519	36.252	29.80	26.606	26.616	1525.5
700.	15.525	36.079	17.98	26.703	26.713	1523.6
750.	14.588	35.926	11.71	26.794	26.803	1521.2
800.	13.291	35.722	19.58	26.911	26.918	1518.9
900.	10.781	35.373	21.95	27.124	27.127	1515.2
1000.	8.638	35.156	11.25	27.317	27.316	1507.9
1100.	6.754	35.069	14.81	27.528	27.522	1501.6
1200.	5.505	35.021	5.43	27.652	27.644	1495.9
1300.	4.921	34.990	5.51	27.698	27.690	1492.6
1400.	4.714	34.978	3.15	27.728	27.720	1491.8
1500.	4.609	35.002	2.84	27.743	27.736	1492.7
1600.	4.414	34.994	1.03	27.758	27.752	1493.9
1800.	4.130	34.978	0.91	27.776	27.771	1493.9
2000.	3.962	34.977	0.62	27.793	27.789	1494.8
2200.	3.795	34.974	1.09	27.808	27.806	1496.9
2400.	3.629	34.969	0.28	27.821	27.820	1499.6
2500.	3.541	34.967	0.68	27.828	27.827	1502.2
2600.	3.423	34.961	3.32	27.835	27.835	1504.9
2800.	3.242	34.952	0.24	27.846	27.846	1506.2
3000.	3.058	34.942	0.11	27.855	27.857	1507.4
3200.	2.865	34.930	0.87	27.863	27.865	1510.0
3400.	2.700	34.922	0.75	27.871	27.875	1512.6
3600.	2.576	34.914	1.05	27.876	27.881	1515.2
3800.	2.444	34.906	1.16	27.881	27.887	1517.9
4000.	2.390	34.901	0.65	27.882	27.889	1520.8
4200.	2.330	34.894	0.11	27.881	27.890	1523.7
4400.	2.306	34.892	0.18	27.881	27.892	1526.9
4600.	2.300	34.887	0.15	27.878	27.890	1530.0
						1533.4
						1536.8
						3.3594

Figure 46: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 13, 19 May 1981.

OCEANUS 103

SEPTEMBER 1981

CTD STATIONS

SITE L

13-14 SEPTEMBER 1981

Figure 47: Chart showing the locations of CTD stations made during OCEANUS 103, Sept. 1981.

Figure 48: Profiles of potential temperature and salinity from OCEANUS 103, CTD number 1, 13 Sept. 1981.

DC103	CTD 003	1981 257 1845Z		35 00.02N		70 00.09W		DYNHGT
PRESS	TEMP	SALIN	POTEMP	POTGRD	SIGMA-t	POTDEN	BR-V	SSPEED
dbar	°C	psu	°C	m	kg/m***	kg/m***	cph	m/s
2.	26.423	36.310	26.423	0.00	23.909	23.891	0.00	1539.2
6.	26.255	36.303	26.254	52.01	23.957	23.939	4.96	1538.9
10.	26.224	36.306	26.222	4.81	23.969	23.951	2.93	1538.9
16.	26.176	36.311	26.173	8.40	23.987	23.971	2.92	1538.8
20.	26.158	36.314	26.153	5.72	23.995	23.979	2.14	1538.9
26.	26.139	36.312	26.134	2.39	24.000	23.984	1.80	1538.9
30.	26.129	36.314	26.123	2.99	24.004	23.988	1.93	1539.0
36.	26.101	36.312	26.093	5.79	24.012	23.996	5.68	1539.0
50.	23.260	36.523	23.250	459.93	25.032	25.018	17.42	1532.6
66.	20.992	36.571	20.980	74.58	25.710	25.697	9.76	1527.0
76.	20.293	36.581	20.279	65.80	25.906	25.895	7.23	1525.3
100.	19.560	36.610	19.542	17.04	26.123	26.112	3.90	1523.7
126.	19.048	36.583	19.026	21.63	26.236	26.226	3.32	1522.7
150.	18.722	36.574	18.695	9.18	26.313	26.304	2.99	1522.1
200.	18.275	36.541	18.241	7.78	26.400	26.394	2.06	1521.7
250.	18.057	36.521	18.014	2.03	26.440	26.436	1.44	1521.8
300.	17.939	36.520	17.887	4.00	26.468	26.466	1.36	1522.3
350.	17.763	36.498	17.703	3.05	26.495	26.495	1.16	1522.6
400.	17.655	36.484	17.586	2.29	26.511	26.513	1.18	1523.1
450.	17.407	36.439	17.331	3.84	26.537	26.540	1.48	1523.2
500.	17.001	36.360	16.918	7.36	26.574	26.579	1.96	1522.7
550.	16.280	36.224	16.191	7.29	26.641	26.646	2.21	1521.2
600.	15.454	36.080	15.360	12.30	26.720	26.725	2.03	1519.3
650.	14.576	35.934	14.477	7.82	26.802	26.808	2.48	1517.2
700.	13.663	35.794	13.561	26.99	26.889	26.894	2.50	1514.9
750.	12.535	35.629	12.432	15.16	26.991	26.994	2.60	1511.8
800.	11.422	35.475	11.318	4.74	27.086	27.088	2.20	1508.6
900.	9.400	35.223	9.295	28.63	27.247	27.245	2.77	1502.8
1000.	7.570	35.108	7.467	8.95	27.442	27.438	2.17	1497.5
1100.	5.981	35.052	5.879	2.14	27.617	27.609	2.38	1492.9
1200.	5.278	35.041	5.172	7.56	27.696	27.687	1.41	1491.7
1300.	4.955	35.031	4.843	-1.24	27.726	27.718	1.21	1492.0
1400.	4.652	35.016	4.534	4.27	27.749	27.741	.76	1492.4
1500.	4.477	35.009	4.352	.10	27.763	27.756	.75	1493.4
1600.	4.333	35.004	4.200	1.39	27.775	27.768	.79	1494.4
1800.	4.071	34.989	3.922	6.73	27.792	27.786	.75	1496.7
2000.	3.912	34.989	3.745	.52	27.808	27.804	.64	1499.4
2200.	3.751	34.987	3.568	.54	27.823	27.820	.68	1502.1
2400.	3.617	34.984	3.416	.84	27.834	27.833	.71	1504.9
2500.	3.482	34.977	3.273	.14	27.842	27.841	.66	1506.0
2600.	3.373	34.970	3.156	2.46	27.847	27.847	.77	1507.2
2800.	3.178	34.959	2.944	.64	27.857	27.858	.50	1509.8
3000.	3.000	34.948	2.750	.38	27.865	27.867	.73	1512.4
3200.	2.840	34.939	2.572	-.04	27.873	27.875	.77	1515.1
3400.	2.672	34.930	2.386	-.03	27.881	27.884	.56	1517.8
3600.	2.524	34.921	2.220	-.26	27.887	27.891	.54	1520.6
3800.	2.422	34.918	2.099	.13	27.893	27.898	0.00	1523.6

Figure 49: Profiles of potential temperature and salinity from OCEANUS 103, CTD number 3, 14 Sept. 1981.

Figure 50: Seasonal profiles of potential temperature and salinity for the upper 500 meters (a and b respectively) and for the entire cast (c and d respectively). Summer = OC 85 station 2; Fall = KN 85 station 3; Winter = KN 87; Spring = OC 96 station 7.

f. Telemetered Data

After losing the LOTUS-1 surface buoy deployed in May 1980 plans for another surface buoy required a means of monitoring the buoy position, the mooring tension and sea conditions. Telemetry of that information via satellite seemed a viable solution. To accomplish this an ARGOS satellite based data collection and platform location system was chosen. This section of the report will briefly describe that system and present an example of the data telemetered from the LOTUS-2 buoy.

The ARGOS system consists of two TIROS satellites in orbit, each equipped with a data collection system (DCS), a platform (in our case the LOTUS-2 buoy) with a transmitter terminal, and several ground data processing centers. The platform transmitter terminal (PTT) provides the link between the platform and the satellites. The sensors on the platform are linked directly to the PTT which periodically transmits the data without the need for satellite interrogation. The DCS on board the satellite receives the data when the platform is within the satellite's coverage. The DCS records the time and date, measures the carrier frequency and demodulates the platform identification number and data. These data are then formatted and stored by one of the onboard magnetic tape recorders. Each time the satellite passes over one of the three telemetry stations, the data recorded on tape are read out and transmitted to the earth. On earth the received data are transmitted to the National Environmental Satellite Service (NESS) Center at Suitland, Maryland, from which it is transmitted to the Centre National d'Etudes Spatiales, Toulouse Space Center, France, where the ARGOS Data Processing Center is located. The processing performed at the Center permits the determination of platform position and the extraction of sensor data. From France the data is returned to Suitland, Maryland, where the most recent information received by NESS can be accessed by remote terminals over the commercial telephone lines. Data in the form of listings and computer compatible 9 track tapes are available from the ARGOS Data Processing Center.

The sensors onboard the LOTUS-2 buoy included a tensiometer for monitoring the tension in the mooring line, sea and air temperatures,

barometric pressure, relative wind direction, battery and regulated voltages and water level in the buoy. On the average there were ten satellite passes per day with as many as ten transmissions per satellite pass.

Throughout the LOTUS-2 deployment the telemetered data were accessed daily by phone. Figure 51 is a plot of four telemetered variables including mooring line tension, barometric pressure, and sea and air temperature obtained during the LOTUS-2 deployment.

Mooring Motion

Figure 52 shows the daily positions of the LOTUS-2 surface mooring as calculated by the ARGOS system; some of the jitter is from the accuracy of the satellite location system (about $\pm 1/2$ km), the rest is the buoy actually moving around. The slow drift of the buoy around its watch circle is clear; it took about two months for the buoy to circle around its anchor position. Note that the buoy does not go around its watch circle each inertial period, rather it sets over to some position determined by the mean, depth-integrated current profile and then jitters around that position according to tides and inertial oscillations.

Acoustic tracking of the LOTUS-1 surface buoy showed about 100 m rms horizontal excursions on a day-by-day basis, superimposed on a slow 1.5 km total horizontal excursion during the first two weeks; figure 8 shows the strongest currents during this time. This confirms the LOTUS-2 satellite-positioning result that daily excursions of the surface buoy are small relative to the size of the watch circle and slow excursions.

Figure 51: Telemetered data from the LOTUS-2 surface buoy.

Figure 52: ARGOS system satellite tracking of the LOTUS-2 surface buoy during May-September 1981.

III. SUMMARY

The engineering test period was extremely valuable in preparing for the LOTUS science period. The opportunity to deploy moorings and instrumentation on site and then evaluate their performance with the option of making design changes prior to their science commitment will definitely improve the science data return. How representative the engineering test period was of conditions that will be encountered during the science period will only be known at the end of the experiment. This section will present a summary of the significance of the engineering period with respect to each major component of the experiment discussed in section II.

Surface Mooring Design

The almost complete recovery of the LOTUS-1 surface mooring accomplished by several dragging operations and the recovery of LOTUS-2 yielded much information that was valuable in planning future deployments. Several design changes that were incorporated as a result of observations made during the engineering test period are discussed below.

The loss of LOTUS-1 has been attributed to the failure of a Crosby-Laughlin A-342 1/2 inch master link located immediately below the VMCM at 5 meters depth. Evidence indicates that the failed master link was one of a batch of master links received in 1979 in which some were found to be cracked and broken. The master links are an alloyed steel and had been galvanized after proof testing. The failed links were returned to the manufacturer for examination. After laboratory analysis the probable cause of failure was stated as "liquid metal embrittlement". This occurred during the galvanizing process and after the stressing of the link during the proof test. The failure of the master link on LOTUS-1 occurred during a period of low to moderate tension suggesting that the mode of failure was fatigue (R. Walden, personal communication).

Evidence indicates that alloy master links can be safely used if not galvanized or if galvanized before stressing. Since neither of these alternatives appeared attractive to our mooring applications 1/2 inch galvanized steel pear rings have been substituted at all locations where master links were previously used. Pear rings were selected because they

are made of steel which unlike the alloyed steel is unaffected by "liquid metal embrittlement".

Recovery of the LOTUS-1 surface mooring after it had parted required dragging since the backup buoyancy was not capable of bringing the mooring to the surface. Several factors were responsible for the insufficient buoyancy. Since the upper 13 meters of the mooring consisted largely of 1/2 inch diameter chain and only two instruments an assumption was made that if the mooring was to part it would do so below this point. Backup buoyancy was therefore calculated not considering the weight of the chain and instruments in the upper 13 meters. In addition the buoyancy did not take into consideration the potential weight increase that would occur should any instruments become flooded. Since the mooring parted at 5 meters the increased weight of the 1/2 inch chain plus one flooded instrument decreased the available buoyancy by 117 pounds.

A less obvious complication became apparent when modelling the mooring in the configuration it assumed after the mooring was released from its anchor. When the parted mooring was released from the anchor, the backup buoyancy approached the surface. The chain, wire rope and instruments that were originally near the top became the new "anchor". In this configuration the mooring resembled a poorly buoyed subsurface mooring. In the presence of a 20 cm/sec current (typical for the area at this time) the vertical component of tension approaches zero. Thus the mooring could not come to the surface (P. Clay, personal communication).

Another factor which contributed to the lack of buoyancy was discovered at the time the mooring was recovered. One glass ball was missing from the backup buoyancy cluster. The glass ball had probably broken away from the mooring during deployment.

Following the loss of the LOTUS-1 buoy a new buoy was designed. The basic improvement made to the LOTUS-1 design was a stronger and smaller hull. In the design of the LOTUS-1 buoy the 12-foot hull consisted of butt welded aluminum plate. Previous experience with this form of construction had shown that these welded joints could easily split open if the buoy should hit against the ship during deployment or recovery. For this reason the new 10-foot buoy design included rolled 3 inch aluminum channel at the

intersection of the top deck plate and the side of the hull. The channel provided a large surface to weld the aluminum plates to, strengthened the outermost perimeter of the hull, and provided a place for a rubber bumper. The new buoy design was first used in LOTUS-2, and a second such buoy was built for LOTUS-3.

Inspection of the LOTUS-2 buoy after recovery revealed signs of wear at the bolts connecting the rigid bridle to the buoy hull. Bolt diameters were therefore increased to one inch at these locations.

Failure of the telemetered tensiometer on LOTUS-2 necessitated a redesign of the tensiometer so that it could withstand the constant buoy motion. The tensiometer, located at the apex of the rigid bridle, had received all the flexure between the buoy and the mooring line resulting in its failure. A universal joint was added just below the rigid bridle in order to minimize the flexing occurring at the tensiometer. The flexure occurring between the buoy and the mooring line is due largely to the tilting of the buoy as it follows the slope of wind generated waves. Since the buoy aligns itself with the wind by means of a large vane it is also aligned in the propagation direction of the wind waves. The tilting motion of the buoy is therefore in the same plane as that of the vane. The pivot pin of the universal joint was placed perpendicular to the vane such that the flexure between the rigid bridle and the mooring line would occur in the same plane as that of the pivotal direction of the universal joint. This in turn reduced the flexing that was originally occurring at the base of the tensiometer.

Breaking strength tests conducted on the nylon line recovered from LOTUS-2 indicated that the upper 1000 meters had undergone a significant decrease in breaking tension. The breaking tension of the 3/4 inch diameter nylon line is normally approximately 14500 pounds. On LOTUS-2 the nylon line at and greater than 1000 meters from the top of the nylon had breaking tensions of nearly 14300 pounds. Test samples taken from the top of the nylon broke at only 11000 pounds tension. The decrease in breaking strength is believed to have occurred because the upper part of the mooring (wire rope and instruments) is essentially rigid whereas the nylon immediately below is compliant and absorbs most of the vertical motions

transmitted by the buoy. To compensate for the degradation, the diameter of the nylon line in the upper 1000 meters was increased to 13/16 inch.

Current Meters

Since the upper 100 meter current measurements made from the surface mooring are strongly dependent on the VMCM, experience with these instruments was needed. The engineering test period not only provided the opportunity to deploy two of these relatively new instruments at the LOTUS site but also provided a period of time whereby experience was gained through other experiments which were dependent on their use.

During the engineering test period there were several changes made to the VMCM both mechanically and electronically. One area of particular concern has been the propellor assemblies and their survivability during a deployment period. One design change that has occurred has been with the propellor shaft and the method for holding the propellers on the shaft. Earlier shafts had a tapped hole in the end which would accept a screw that retained the propellor. The screws were found to back out allowing the propellers to fall off the shaft. The newer design shaft has a threaded end on which two nuts can be placed and tightened against each other.

Other changes have occurred in the sensor hub assembly. In several instruments the screws which held the end caps on the hubs backed out which resulted in the loss of the internal hub components and the subsequent flooding of the entire sensor assembly. Upon discovery of this defect the hub assembly procedures were modified to include the use of an adhesive on the threads of the screws to prevent them from backing out. The use of more suitable hardware is planned for future deployments.

Several different types of bearings have been used in the VMCM sensor assembly. Excessive wear has been a problem in past deployments. Different combinations of materials and bearing designs continue to be tested in search of a bearing that can survive without hindering the performance of the instrument.

The first commercially available VMCM's had propellor blades made of Noryl, a phenylene oxide, chosen for its extremely low water absorption characteristic. The Noryl blades however were susceptible to breaking at the base of the blades. Previous experience with several Delrin pieces

(an acetal homopolymer) used on the VACM's suggested that it could possibly be a good material for the VMCM propellers. The use of Delrin blades in several deployments appears to have reduced the incidence of broken blades, however the problem has not been totally eliminated.

Aanderaa Thermistor Chains

Aanderaa thermistor chains were deployed on three occasions during the engineering test period. Problems encountered during their deployments included tape transport failures, encoder bearing problems, and seawater leakage into the thermistor cables. Each malfunction was evaluated and with the exception of the cable problems a scheme for either preventing the problem in the future or for detecting it before deployment was devised. Instrument checkout procedures were modified in order to address these malfunctions. Prior to each instrument's predeployment checkout it is set at a fast sampling rate and run for approximately one week in a cold (4°C) environment. Problems resulting from the cold temperatures or wear (major causes of previous failures) can become apparent in this time frame and be corrected. The thermistor cables were returned to the manufacturer and repaired by an improved method which made use of a more flexible potting material. The deployments during the engineering period also provided an opportunity to try several different methods of attaching the thermistor cables to the mooring wire and to select that method which best secured the cables. The clamps manufactured by the Stauff Corporation, which firmly grasp both the mooring wire and the thermistor cable, have been used on several occasions with satisfactory results.

CTD

The LOTUS CTD was acquired early in the engineering test period, which provided adequate time to become familiar with it and its operation at sea. During the engineering test period the CTD was used on five cruises. Based on the experience gained during these cruises additions and modifications were made to the system in order to facilitate the handling and data processing. Additions to the CTD included a pinger for depth determination, a messenger activated water sampling system for conductivity calibration,

and two underwater switches for turning the CTD off at the bottom to conserve battery power and for switching the pinger to a double ping rate when the sample bottles are tripped. Modifications included the placement of a file gap on the cassette tape each time the CTD is turned on and the rearrangement of several components in the internal recording module of the CTD to facilitate tape removal and overall handling at sea.

Aside from evaluating the instrumentation the engineering period provided a time for collecting background data from the LOTUS site in order to become familiar with the types of features and conditions that might be expected there such as strong inertial motions and occasional Gulf Stream rings.

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APPENDIX I: Mooring Drawings

MOORING 693

Figure A-1: Mooring diagram of mooring number 693 set in May 1980.

Figure A-2: Mooring diagram of mooring number 694 set in May 1980.

MOORING 733

Figure A-3: Mooring diagram of mooring number 733 set in May 1981.

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Plans for the Long Term Upper Ocean Study evolved over several years. As the plans became more definite a two year period was devoted to engineering tests at the LOTUS site (34°N, 70°W). Many aspects of the proposed plans were implemented during this period in order to evaluate the performance of the equipment and instrumentation. This report presents a summary of the planning and testing periods up to but not including the first science deployments in May 1982. Historical data collected as part of the engineering tests are presented.