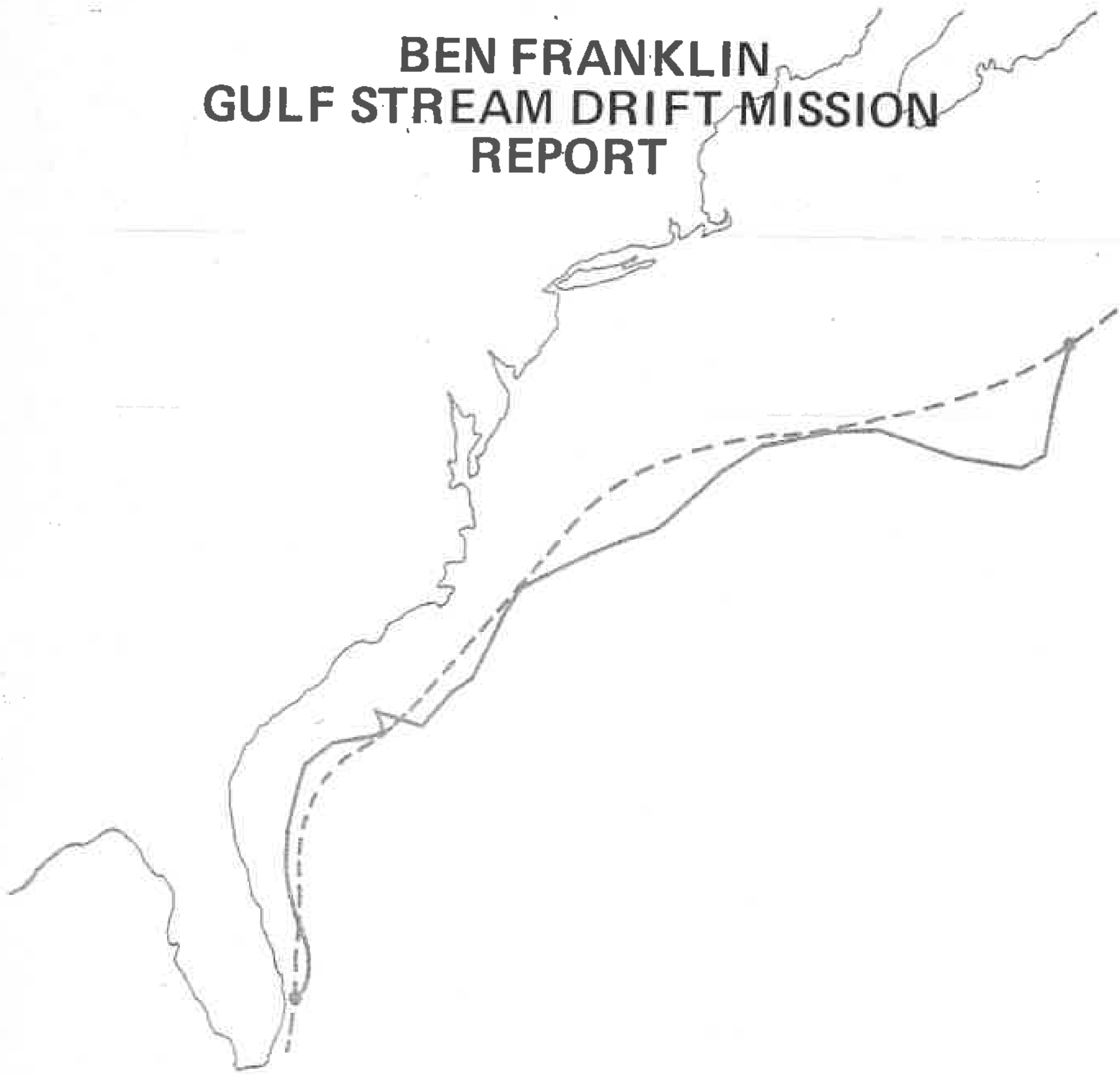
GRUMMAN

BEN FRANKLIN
GULF STREAM DRIFT MISSION
REPORT



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BEN FRANKLIN
GULF STREAM DRIFT MISSION REPORT

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Forward

Two days before Apollo 11 was launched to place two astronauts on the Moon, six oceanographers in the research submersible Ben Franklin began another mission of exploration. For thirty days they drifted in the Gulf Stream collecting millions of bits of scientific data on the stream's properties, currents, and inhabitants in what may be one of the most outstanding scientific investigations of the Gulf Stream ever attempted. This is a summary report of the mission which includes:

- A brief chronology of events during the mission
- The Ben Franklin performance
- Experiments conducted and a brief description of the results

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1 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The Gulf Stream Drift Mission was conceived by Dr. Jacques Piccard in 1965: primarily as a scientific endeavor, and secondly to demonstrate the feasability of building a submersible which could hover in mid water without the use of power. Early in 1967, following an agreement with the Grumman Corporation, construction of the mesoscaph, PX-15, began in Monthey, Switzerland. By May 1968, the nearly completed PX-15 arrived at West Palm Beach for final outfitting, and by that fall the vessel was formally christened the "Ben Franklin".

After the systems were debugged and sea trails were run, the start of the Drift Mission was scheduled for July 14, 1969. The Naval Oceanographic Office (NAVOCEANO) provided approximately 2300 pounds of scientific instrumentation, two oceanographers as crew members, as well as a logistic support ship. The National Aeronautics and Space Administration (NASA) supplied an observer to go along on the drift to evaluate crew reactions to a long stressful voyage in a completely enclosed environment.

The prime concern during the preparations for the mission was the performance of the electrical power supply system. The available power, 756 kwh, was carefully budgeted between propulsion, ships equipment, and scientific instrumentation. (See Section 4.2) Power was carefully alloted to each piece of scientific gear, lights, etc. (See the Mission Plan, Reference 1, which details every facet of the drift mission).

1.2 SUMMARY

The purpose of the Gulf Stream Drift Mission was to gather scientific data about the stream and selected sections of the sea bed beneath it. At the same time, it served to demonstrate the ability of the submersible Ben Franklin, to drift silently and maneuver for thirty days while maintaining its crew of six men and powering a large complement of scientific instrumentation. All of these goals were successfully achieved.

The drift commenced on the 14 July, 1969 when the Ben Franklin first submerged into the Gulf Stream waters off West Palm Beach, Florida. It terminated, according to plan 30 days, 11 hours later, when the Ben Franklin surfaced 360 miles south of Nova Scotia. The drift covered 1444 nautical miles at an average depth of 650 feet. Ten excursions were made to depths between 1200 and 1800 feet; five of these were ocean bottom surveys of the Blake

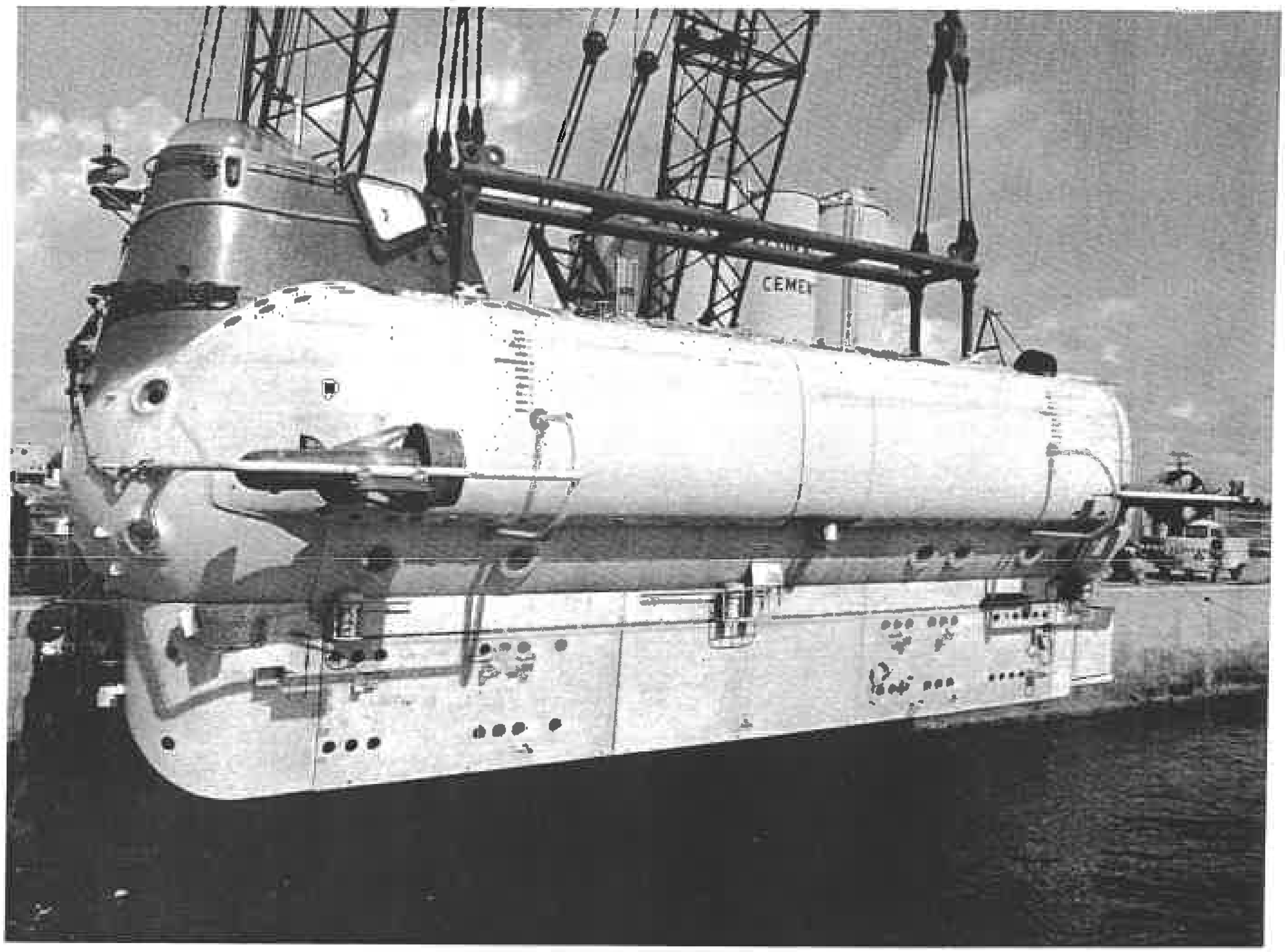
Platau. See Figure 1-1 for a comparison of the actual and predicted drift paths and bottom excursions locations.

During the course of this long silent voyage the scientists on board successfully collected:

- Over 900,000 temperature, salinity and sound velocity measurements
- 500 temperature vs depth profiles of the stream
- 50 miles of gravitational anomalies
- 60,000 photographs of crew activities in support of the NASA study.

The performance of the Ben Franklin exceeded all expectations. The variable ballast system provided excellent depth control, the life support system proved more efficient than expected, and the electrical supply system worked flawlessly. There were some equipment failures. A few of these were discomforting for the crew but they were not considered of major significance. Three of these malfunctions were:

- Failure of the toilet mascerator during the final days
- Loss of vacuum in the hot water tanks which caused the water to cool prematurely
- Failure of some scientific equipment.



Ben Franklin Launch

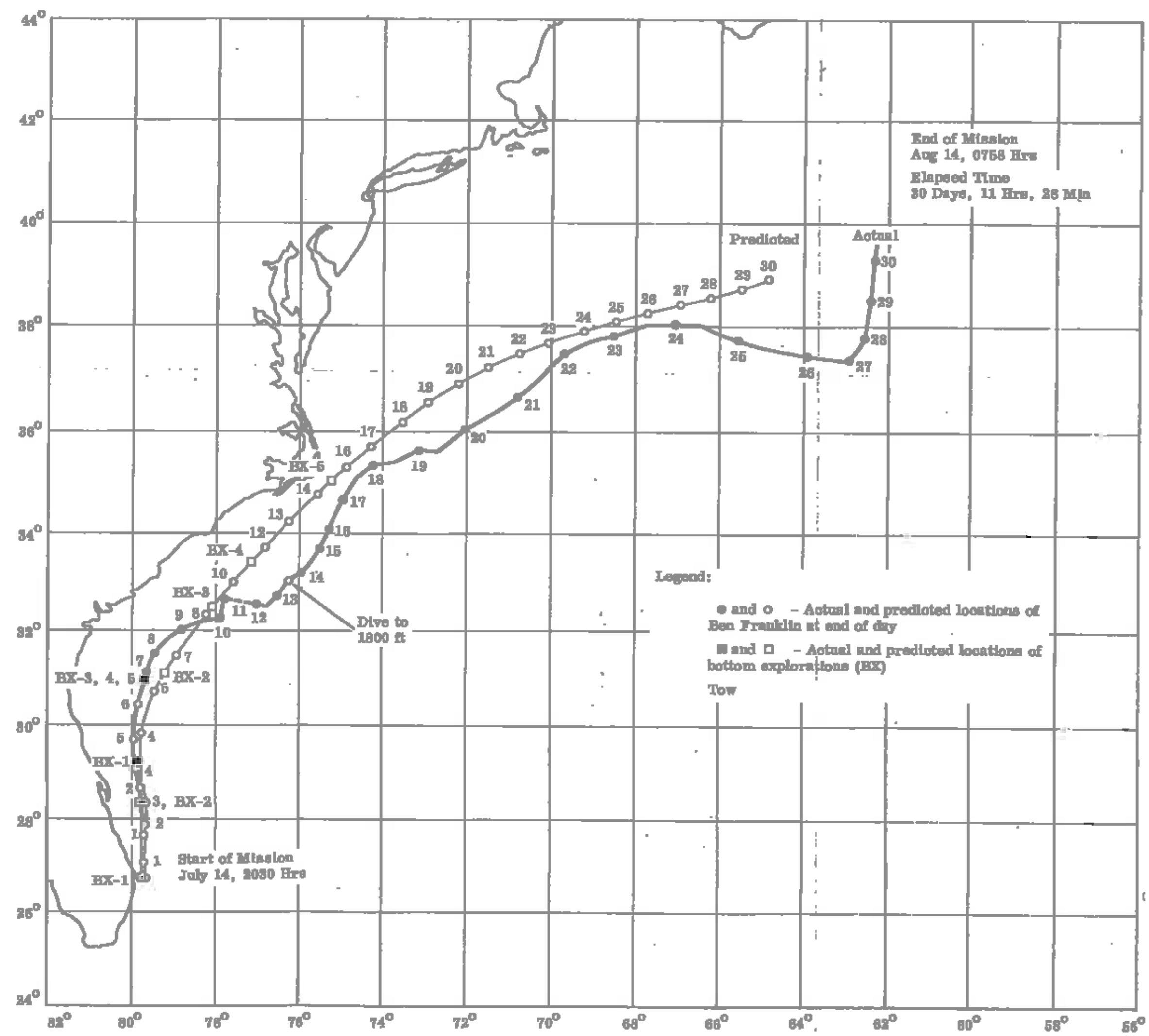


Fig. 1-1 Actual vs Predicted Mission

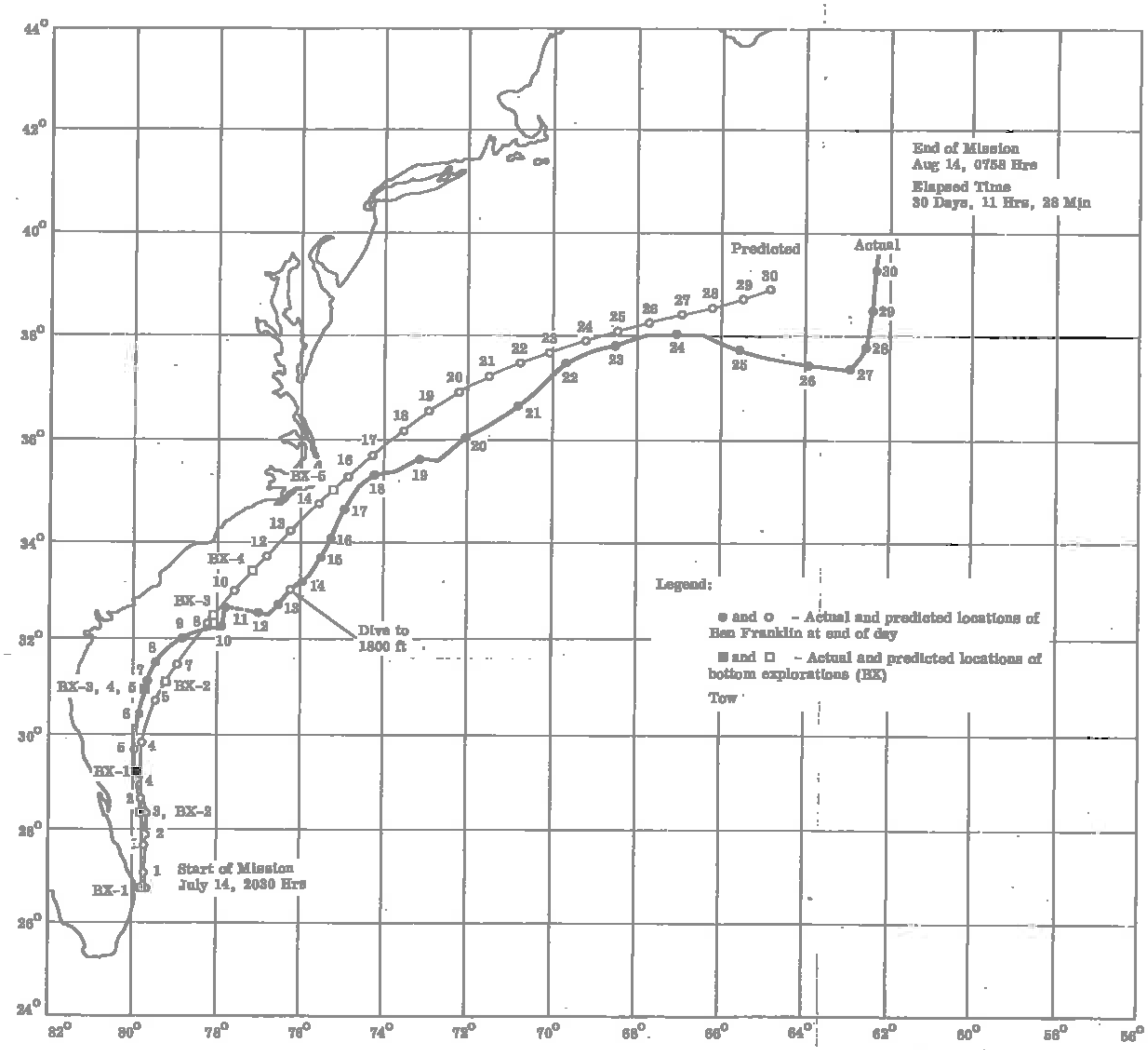


Fig. 1-1 Actual vs Predicted Mission

2 MISSION OBJECTIVES

As described in Reference 1 the Gulf Stream Drift Mission, had the following objectives.

2.1 PRIMARY OBJECTIVE

Drift with the Gulf Stream safely for 30 days performing oceanographic studies within the capabilities of Ben Franklin and support system.

2.2 SUPPLEMENTARY OBJECTIVES

- Travel a maximum distance along the core of the Gulf Stream at varying depths.
- Investigate the analog aspects between a submersible and a space station during a long duration, closed environment, stressful voyage.
- Demonstrate the engineering/operational concepts associated with long duration submersible operation.

3 SUPPORT

On Monday July 14, 1969, when the fully provisioned Ben Franklin was towed from its West Palm Beach berth to start the Drift Mission, it was supported by two ships, two land bases and a mobile support van, and several government agencies.

3.1 TRACKING THE BEN FRANKLIN

The prime support ship, the M/V Privateer, (see Figure 3-1) was supplied by NAVOCEANO. This ship was responsible for all tracking and communications with Ben Franklin. On board the Privateer were seven Grumman personnel (the Mission Director, two Mission Controllers, three trackers, and a doctor), six Navy Oceanographic Office personnel, and the ship's company of 12 men.

3.1.1 Primary Tracking System

The NAVOCEANO Tracking System was the primary means of tracking the Ben Franklin. This system comprised the following equipments:

On The Ben Franklin:

- Pinger
- Transducer

On The Privateer:

- Directional hydrophone
- Omni/directional hydrophones (2)
- 4 kHz receiver with audio output
- 18 kHz transmitter
- 16 kHz receiver with scope display
- GIFFT recorder

Referring to Figure 3-2, the following sequence of operation of the above NAVOCEANO equipment suit was used to determine the position of the Ben Franklin relative to the Privateer:

Fig. 3-1 Prime Support Ship, M/V Privateer (Atlantis II, oceanographic ship from Woods Hole in background, not part of mission)

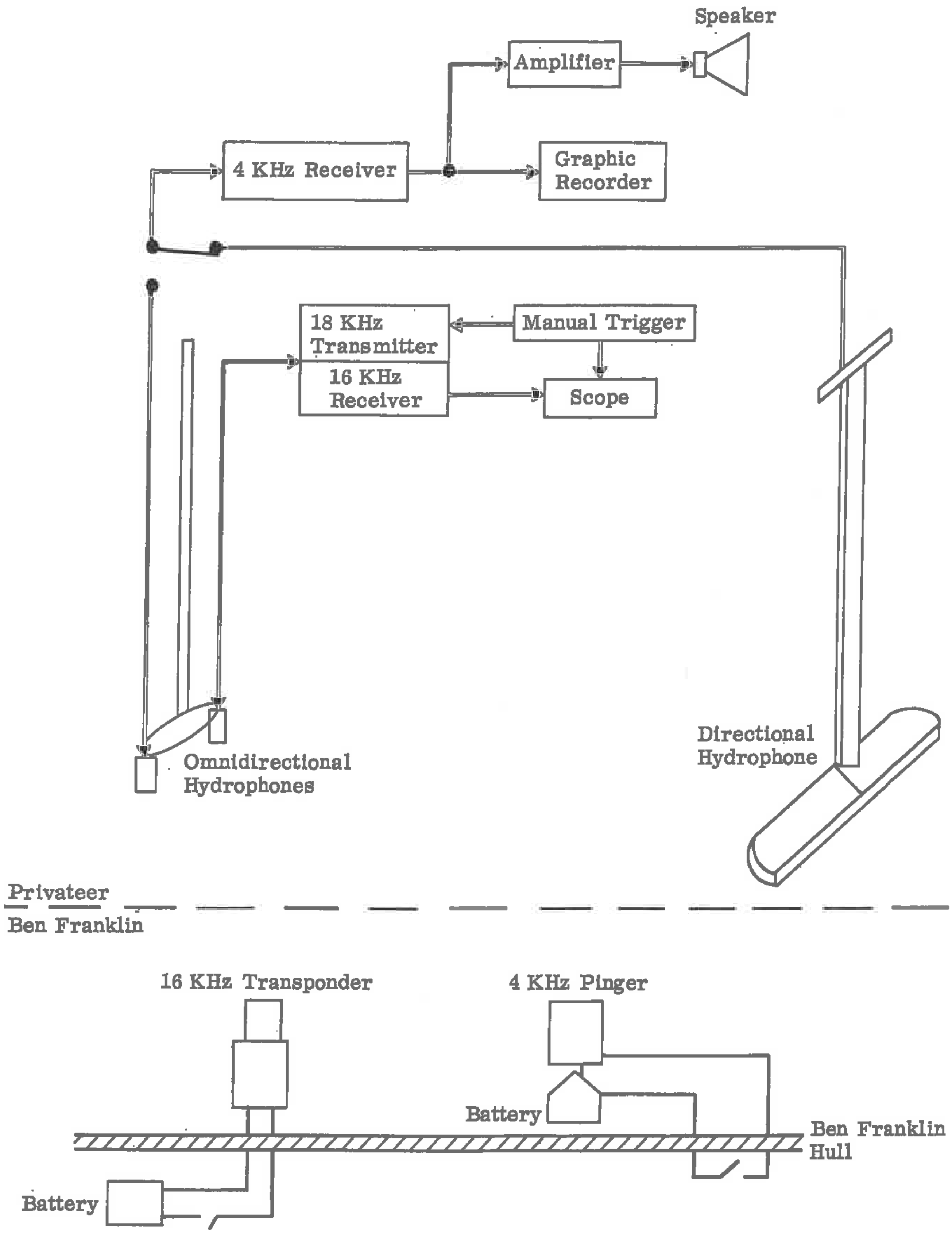


Fig. 3-2 Acoustic Tracking System

1. The 4-kHz pinger on the Ben Franklin free ran during entire mission. Its output, a two-pulse train, repeat every 2 seconds. The first pulse width is 10 msec. and the second, 3 msec. The second pulse is delayed 20-to-400 msec. as a function of pressure. This represents a 0-to-5000 psi change in pressure. The delay was used to determine Ben Franklin's depth ($\approx$ 3 ft/msec.)

2. The outputs of the pinger were detected by the use of the directional hydrophone (Harris DT-171), fed into the 4-kHz receiver and recorded on a (Gifft) graphic recorder. The recorder is calibrated so that the major divisions (vertical) on the paper represent specific distance increments since the vertical is scanned in real time and the speed of sound is considered constant.

3. The 4-kHz trace on the recorder was calibrated by a trace of the 16-kHz transponder signal which was interrogated once every half hour. Since the two way travel time of the 16-kHz signal could be detected via the scope, the range to the Ben Franklin was known. The point of intersection of the 4-kHz trace and the projected 16-kHz trace defined a range scale on the 4-kHz trace. (See Figure 3-3)

4. The range to the Ben Franklin was also displayed directly on an oscilloscope from the 16-kHz transponder to provide a backup tracking system.

The directional hydrophone was operated manually; its direction determined by aural signal strength. Relative direction to the Privateer was determined by a visual readout on the hydrophone's rotational axis.

Closing and opening ranges to the Ben Franklin proved very useful in maintaining the Privateer's position relative to Ben Franklin.

3.1.2 Secondary Tracking System

A Grumman underwater ranging and tracking system (Oceanic Enterprises) was used as a backup whenever the range to Ben Franklin opened beyond the range of the NAVOCEANO gear. This system consisted of:

On Ben Franklin:

- Transponder
  - Acoustic output . . . . 20 watts
  - Range . . . . 15,000 ft (in moderate seas)

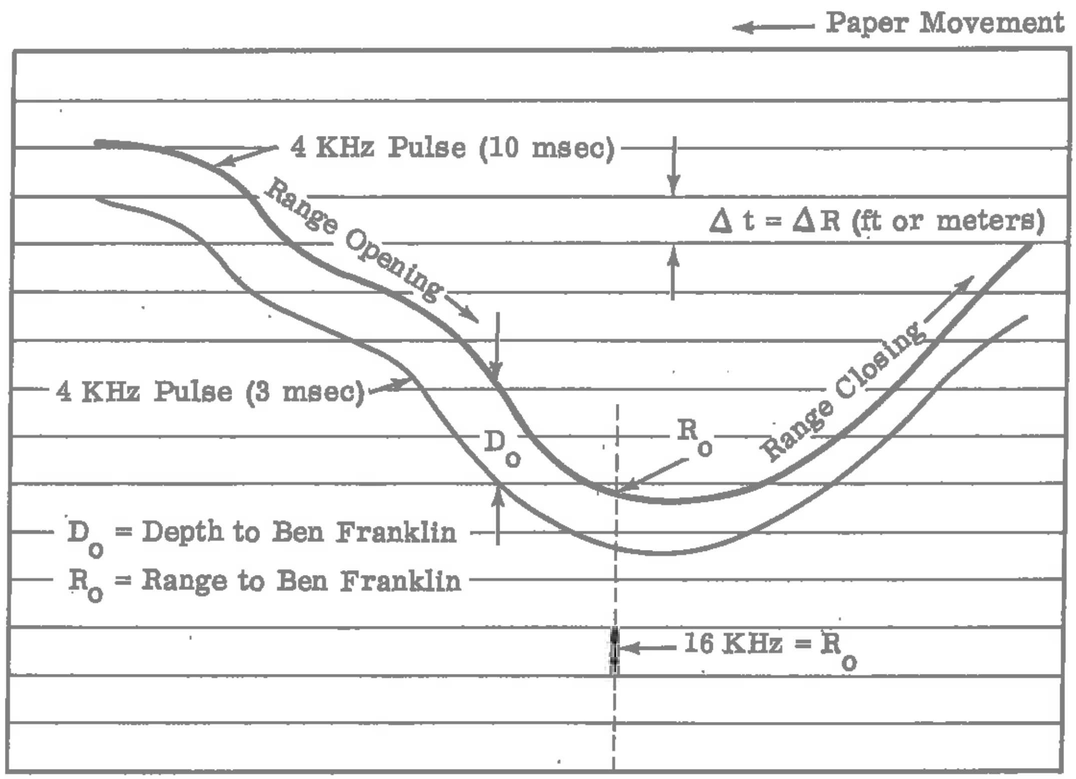


Fig. 3-3 Sample GIFFT Trace

On Privateer:

- Receiver Antenna
- Readout module
- Tracking Section:
  - Gain — 125 db
- Ranging Section
  - Acoustic outputs — 20 watts
  - Range scales — 0-1000 ft; 0-10,000 ft

3.2 TRACKING THE GULF STREAM CORE

For the first three days of the mission the yacht Grifon served as the second support ship until, on the morning of July 18th, the oceanographic ship USNS Lynch arrived on station. The Lynch's main function was to chart the course of the Gulf Stream immediately ahead of the drifting Ben Franklin. This was done by traversing the stream and dropping expendable batho thermographs (XBTs) (See Section 5.1) at regular intervals. The resulting temperature versus depth profile was used to pinpoint the submersibles location relative to the high velocity core. A sample plot of the results is shown in Section 5.

The Lynch also made a great deal of synoptic oceanographic measurements which will be coordinated with data taken aboard the Ben Franklin.

3.3 LAND-BASED SUPPORT

3.3.1 Engineering

Two land bases were set up, one designated Grumman Base South (GBS), at West Palm Beach, Florida, and the other Grumman Base North (GBN), at Bethpage, New York. These bases were staffed with engineering personnel who could provide aid in the solution to any problems which might arise.

3.3.2 Logistics

Logistics mobile support van followed the Ben Franklin up to the coast as planned in Reference 1. It had the capability to recharge the batteries and the air tanks as well as carrying spare parts. The vans movements were timed to coincide with the mission's progress in that it would proceed to the next port of option when the drift fleet crossed the point of no return for the previous port.

3.3.3 Rescue

Additional support was available from the Commander, Eastern Area, U.S. Coast Guard and the Chief of Naval Operations whose agencies maintained close surveillance of the mission.

3.4 COMMUNICATIONS

The communications link to Ben Franklin was by means of a Straza ATM-504 (100 watts) underwater telephone on Privateer and on ATM-503 (2 watts) on the Ben Franklin. The performance of this system is described in Section 5.5. This link was exercised every half hour throughout the mission by the Privateer calling Ben Franklin for a communications check and update on drift depth.

The communications network with the land bases was by single side band radio from Privateer to the GBS and GBN. Both land bases were equipped with a technical staff to provide around-the-clock watch of the radio messages from the Privateer. The scheduled contacts were as follows:

0300Q-Position report
0800Q-Situation report
1100Q-Position report to Coast Guard
2000Q-Position report

The frequencies used were 4133 kHz, 6200.5 kHz, 8273 kHz, 12410.5 kHz. Of these, 8273 kHz proved to be the best for the greater part of the mission. Communications were in general good between GBS and Privateer, but only fair-to-poor between GBN and Privateer. For this reason GBS was used as the communications center throughout the mission.

The 0800 "SITREP" was forwarded via telephone from GBS to GBN and then via telex to various interested parties as indicated in the mission plan (Reference 1).

4 CAPTAIN'S LOG

The following is a condensed version of the captain's log, describing how the mission progressed day-by-day and highlighting the significant events.

14 July 1969

At 1025 hours the "Ready for Sea" checkout was completed. It was hoped Franklin could leave port quietly with little fanfare; however, quite a crowd was on hand. Ben Franklin got underway at 1043 hours and passed the sea buoy at 1123 hours with only H. Dorr and D. Kazimir aboard to prepare the boat for diving, The remainder of the crew was aboard Privateer. At 1635 hours the LiOH was deployed. We were on station at 1844 hours, waiting for the boat Dragon Lady with additional LiOH panels that arrived after Franklin was underway. At 2030 hours the hatch was secured with the crew aboard. "Rig for Dive" was comleted, and both VBT's were empty. At 2056 hours the main ballast tank vents were opened - diving (Dive #41). The boat descended smoothly - dribbled shot occasionally to slow descent. Trim good, no propulsion needed. At 2150 hours we bottomed in 510 meters of water. Commenced checking boat and NAVOCEANO equipment. NAVOCEANO gear working well except transmissometer, sub bottom profiler and magnetometer. Side scan sonar will not operate due to high voltage provided by ships batteries. It was estimated that it would take a few days before the voltage was less than 30 volts.

15 July 1969

The checks were completed at 0100 hours; all hands settled down. Commenced dribbling the shot to achieve neutral buoyance at 20 feet altitude. Ben Franklin was underway drifting north in the Gulf Stream at 0119 hours; visibility good but the current was quite slow. Sonar in standby when not in use. One landing light used for forward visibility. At 0150 hours noticed a slight air leak in the air reducer and tightened the plug but it still leaked (very slightly) so it was decided to secure all air flasks. During this period, a few output fuses blew in the auxiliary 60-cps inverters due to operator error (too much load on the inverter). Also discovered a slight hydraulic leak around the valve stem of the depth gage. The bonnet was tightened and the leak stopped. At 0500 hours we were drifting very slowly; the boat was getting colder and colder. We dribbled shot occasionally to account for hull shrinkage as the boat cools down. At 0900 hours our position was about 19°, 19 miles from Palm Beach Inlet. Decided to terminate bottom cruise due to slow drift speed. Began ascent to 600 feet by dribbling shot. At 1135 hours noticed a small drip at NAVOCEANO's penetrator in H-6*. Penetrator tightened. During the 1200 hour routine checkoff, Drager CO_2 gage failed; shifted to the Fyrite gage which worked well throughout the 30 days. Lost communications with Privateer at 1420 hours; had to use new 504 unit (underwater telephone) at full power to regain communications. Evidently, the Privateer trackers lost us. Range checks were used to regain position. The Straza 504 paid for itself already. At 1500 hours we achieved neutral buoyancy at 300 meters with both VBT's (variable ballast tanks) empty. The cabin temperature was still about 55°F, but gradually rising. During this depth change, the current occasionally came from the north. For these first two days everyone was quite busy with very little sleep; however, spirits were quite high.

16 July 1969

We were drifting nicely at 200 meters. The ampere hour system was in operation; however, the B-2 counter occasionally counted rapidly for no apparent reason. F. Busby, D. Kazimir, C. May and J. Piccard have slight colds. The cabin temperature got up to a comfortable 66°F. C. May checked iodine concentration in the number 1 and 2 fresh water tanks and found no iodine -- cannot understand why; the concentration should be 6 ppm. The same for tanks 3 and 4. C. May was having difficulty with the bunk counters and some sleep monitoring caps. The number 1 hot water tank was cooling down fast since the vacuum was lost -- will shift tanks soon. Good luck message was sent to Apollo 11 astronauts.

17 July 1969

We were drifting at approximately 200 meters. Took the first set of battery ground readings at 0810 hours; they looked fine. The macerator needed repairs; it wouldn't stop running, so we had to defuse it. C. May and K. Haigh found a ground on the case and corrected it. At 1030 hours we deployed the LiOH panels. The motors were meggered at 1530 hours; they looked fine. The boat seems to drift with the stern pointing north. She oscillates a little to either side and occasionally turns around. Began the descent to the bottom at 1705 hours by flooding the port VBT in increments. At 1800 hours the compass was found to be unreliable; shifted to the portable compass** At 1855 hours we bottomed in 458 meters after sitting on

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*This penetrator dripped occasionally during the 30 days. It was very slight and usually dry.

**This compass worked well throughout the mission.

the guide rope and gradually reached the bottom as the hull cooled. Measured the current speed, which was quite slow, less than 0.2 knots. At 2036 we blew the port VBT slightly to ascend to cruise depth - about 20 feet off the bottom. Sat on the guide rope waiting for the current to push us, but to no avail - the current was too slow. The Privateer dropped 50 blasting caps for acoustic studies. The drift rehearsal now over -- we will go for 30 days.

18 July 1969

At 0112 hours a slow ascent was begun by blowing the port VBT in increments. The stern 250 watt light was used mainly for observations at shallow depth — it attracts quite a bit of plankton. At 0609 hours two swordfish were observed at the aft hemisphere swimming around rapidly. Once actually attacked the viewport that F. Busby was using. At 0900 hours (at 200 meters) the humidity went up to 82% and more silica gel was deployed. This reduced the level to a satisfactory 75%. Coricidin pills helped in reducing our cold symptoms. Each day we computed power usage based on the equipment logs and compared with the actual usage however, wide variations existed. We will secure the ampere hour system when the computed method becomes accurate.

19 July 1969

We were drifting routinely at approximately 230 meters; our position was 60 miles NE of New Smyrna Beach, Florida. At 1450 hours, at 187 meters, we secured all lights to check light level. Large print can be read easily. At 2014 hours we changed the LiOH panels (we were averaging about three days per set of 12). The Egan experiment was working well except for bioluminescence. The boat continues to be very stable in depth.

20 July 1969

We were drifting along nicely at 170 meters. We discovered some carbon monoxide (10 ppm) and a small amount of hydrazine and acetone during our routine checks with the Drager tubes. The four main and four positioning motors meggered out OK. We had to flood some water in the starboard VBT as the depth decreased to 142 meters. The communications with Privateer have been excellent. K. Haigh completed the seismic studies with Lynch supplying the SUS charges. The highlight of the day was the moon landing as reported by the Privateer.

21 July 1969

We continued drifting at approximately 190 meters. Our position was 90 miles east of Brunswick, Georgia. We commenced another set of SUS charges at 1340 hours for acoustic tests. At 1414 hours we began the descent to the bottom by flooding the starboard VBT in increments. By 1555 we were cruising at the 20 foot altitude in a depth of 372 meters. The current was quite strong. At 1830 hours we bottomed briefly to measure the current using our motors to hold position. At 1850 we were cruising at the 30-foot altitude. We spotted multiple sonar targets and ascended to 100 feet altitude. Decided to remain well above the bottom and then take another look at 0200 hours. We detected the first bacterial contamination, using endo and total media in petri dishes at the head sink. The Grumman movie camera malfunctioned while attempting to photograph the bottom.

22 July 1969

Drifting at 260 meters; commenced descent at 0150 hours. At 0415, at 70-foot altitude, conducted acoustic test using blasting caps which were released from the surface vessel. At 0500 hours we were cruising close to the bottom at a good speed, operating the sonar continuously. The bottom was hard and bumpy with some small escarpments seen. At 0600 we commenced ascent to a shallower depth. It would be better to study this area in three separate excursions during a 24 hour period due to the physical strain, cold and high power usage. At 1400 hours we conducted another one-hour bottom cruise in conjunction with the seismic studies. Discovered the B-2 counter* was malfunctioning; decided to rely on the computed power figures for the 110 vdc load. The ocean bottom in this area was fairly interesting. The effects of internal waves caused large, slow depth changes.

23 July 1969

Today we were drifting at 200 meters, about 100 miles east of Charleston, South Carolina. For a short period internal waves were noted at 1000 hours. The boat sometimes changes depth of 40 meters in wave periods of 15 minutes. At the end of the day decided to secure ampere hour system and rely on equipment logs to compute the power usage (saves power).

24 July 1969

At approximately 200 meters today. We were having fits again due to internal waves. The boat oscillated between 180 and 220 meters. Changed the bacteria filters and replaced the purafil in the head blower. Had to drain some fresh water into the mini-waste tank for flushing. The sinks were clear of contaminants - possibly due to changing of the bacteria filters. The mission has gone well - the crew and boat in good shape.

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*This counter in the ampere-hour system monitored the power used from the B-2 battery string.

25 July 1969

Drifting at 270 meters approximately 90 miles south of Cape Fear, North Carolina. Motors meggered OK at 1112 hours. At 1123 hours Privateer reported that we broke through the north wall of the Gulf Stream; we then commenced running on two motors at 60 amps to power back into the Stream, on a course of 100°. At 1705 hours we completed the transit. Today we observed endo and total contamination of water at the head sink.

26 July 1969

At 233 meters at 0400 hours, it was quite clear that we did not make our way back into the Stream. At 0928 hours we commenced the ascent to the surface. The decision was made to have Privateer tow Franklin. We ascended slowly in order to prevent battery gas from escaping too fast. We saw many sharks and a barracuda enroute to the surface. We also heard gas escaping from the batteries. Sometimes it would escape more rapidly from one side and actually cause a very small roll. At 1205 we surfaced. We then blew the MBT's only slightly. Divers used scuba air to blow the MBT's and then added shot to ensure negative buoyancy on the next dive. While under tow, we listened to "News Radio 88" - the CBS radio station from New York City. The boat got quite warm while on the surface and the sea was calm. The boat was left sealed during the surfacing and towing in order not to disturb the "closed environment" which was important to the NASA study.

27 July 1969

At 0313 hours Franklin arrived at the dive site in the Gulf Stream core. Divers re-rigged the noise boom, removed the magnetometer and disconnected the tow line. Dive number 42 commenced at 0401 hours. Franklin submerged rapidly while shot was dribbled to slow the descent. Several battery vent valve salt water sensors came "ON". It took several hours for the boat to stabilize in the temperature and she finally settled out at approximately 200 meters at about noon. Megger readings taken in the evening showed quite a drop for the number 2 main motor but the reading is still OK. At this point in the mission, two crew members picked up a rash, probably due to perspiration and the fact that underwear was changed every three days (not often enough). The carbon monoxide level was now up to 15 ppm. The acetone and hydrazine levels had not increased.

28 July 1969

We drifted today quite nicely at 200 meters. High bacteria counts throughout the boat necessitated a thorough wash down with microguard. Also, a routine setup to wash down the galley, shower and head areas daily was instituted. At 1222 hours we began the descent to 565 meters to measure the ambient light and to conduct acoustic tests for mid-water scatterers and bottom reflectivity. Commenced the ascent at 1944 hours. The boat was very stable, no internal waves. F. Busby and E. Aebersold repaired the wobbly wardroom table with two C-clamps, one "Vise Grip" and two butter knives for shims.

29 July 1969

Drifting at shallow depths approximately 85 miles SSE of Cape Lookout, North Carolina. We passed the halfway point in the mission at 2030 hours.

30 July 1969

Drifting at 165 meters. The boat was rising slowly. The carbon monoxide level was up to 20 ppm. We ran the contaminant removal system for one hour. The mission was getting to be quite routine now with plenty of sleep for everyone.

31 July 1969

Today we drifted at shallow depths. We went past Cape Hatteras and headed out to the open sea. The hot water was heated for 2.5 hours in tank number 3.

1 August 1969

Again we drifted at shallow depths approximately 35 miles east of Cape Hatteras. At 2055 hours we released a SAS ball with urine and feces samples in it. The ball was retrieved immediately by Privateer. Surprise for someone if it wasn't retrieved. The galley, shower and head faucets all show contamination. This is no problem since cold water was used only for washing.

2 August 1969

Drifting again at shallow depths today. Motor number 2 meggered - holding steady at 5 megohms. Had to heat the hot water for 2.5 hours. The carbon monoxide level was at 20 ppm. Swiss National Day was celebrated by lighting a match in front of the United States and Swiss flags.

3 August 1969

Approximately 120 miles east of Cape Hatteras, we drifted at shallow depths. Our drift speed has increased to close to 3 knots. J. Piccard caught a salp in the plankton sampler.

4 August 1969

At approximately the 200-meter depth, we drifted 300 miles south of Block Island. Internal waves made life interesting. The drift speed was up to 3 knots. Plenty of power available as the batteries continue to hold up well.

5 August 1969

Drifting at shallow depths (200 meters) again at a good speed approximately 270 miles south of Martha's Vineyard. During the day many tuna were sighted. The USS Lapon (SSN661) transited the area on the surface. Franklin and Privateer had underwater phone contact with her as she passed through the area. The carbon monoxide level was up to 30 ppm; ran the contaminant removal system for 4 hours. Drager readings before and after running the system indicated no change in the level.

6 August 1969

Again drifted at shallow depths approximately 165 miles south of Nantucket Shoals Lightship. Had difficulty blowing the starboard VBT for depth-keeping - the lines seemed to be plugged. Cleared the system by building air pressure up to 10 atmospheres over sea pressure. Many whales and porpoises have been heard on sonar for the past few days. Internal waves continue to plague us; however, the experience level in trimming the boat has increased to a point where it is no problem. Ran the contaminant removal system for 4 hours. The carbon monoxide level was at 30 ppm.

7 August 1969

Drifted at 298 meters, moving up and down with no need for accurate depth keeping. Our position is now about 195°, 320 miles from Cape Sable, Nova Scotia. Heated hot water tank number 3 for 8 hours. Ran the contaminant removal system again for 4 hours.

8 August 1969

Proceeded nicely at shallow depths at a good speed. Meggered the motors - all OK. The batteries are in good shape also.

9 August 1969

Drifted at 265 meters. At 1811 hours commenced the descent to 500 meters. At this level conducted acoustic work using SUS charges. Vibrations could be felt through the hull even though the charges were set to explode at 60 feet.

10 August 1969

Drifted at 500 meters. Completed the deep excursion at 0030 hours. The carbon monoxide level was up to 40 ppm. The crew is getting restless. We still have not seen the deep scattering layer.

11 August 1969

Again drifted at shallow depths. Our speed slowed to less than 2 knots. At 2007 hours commenced the descent to 500 meters for acoustic work.

12 August 1969

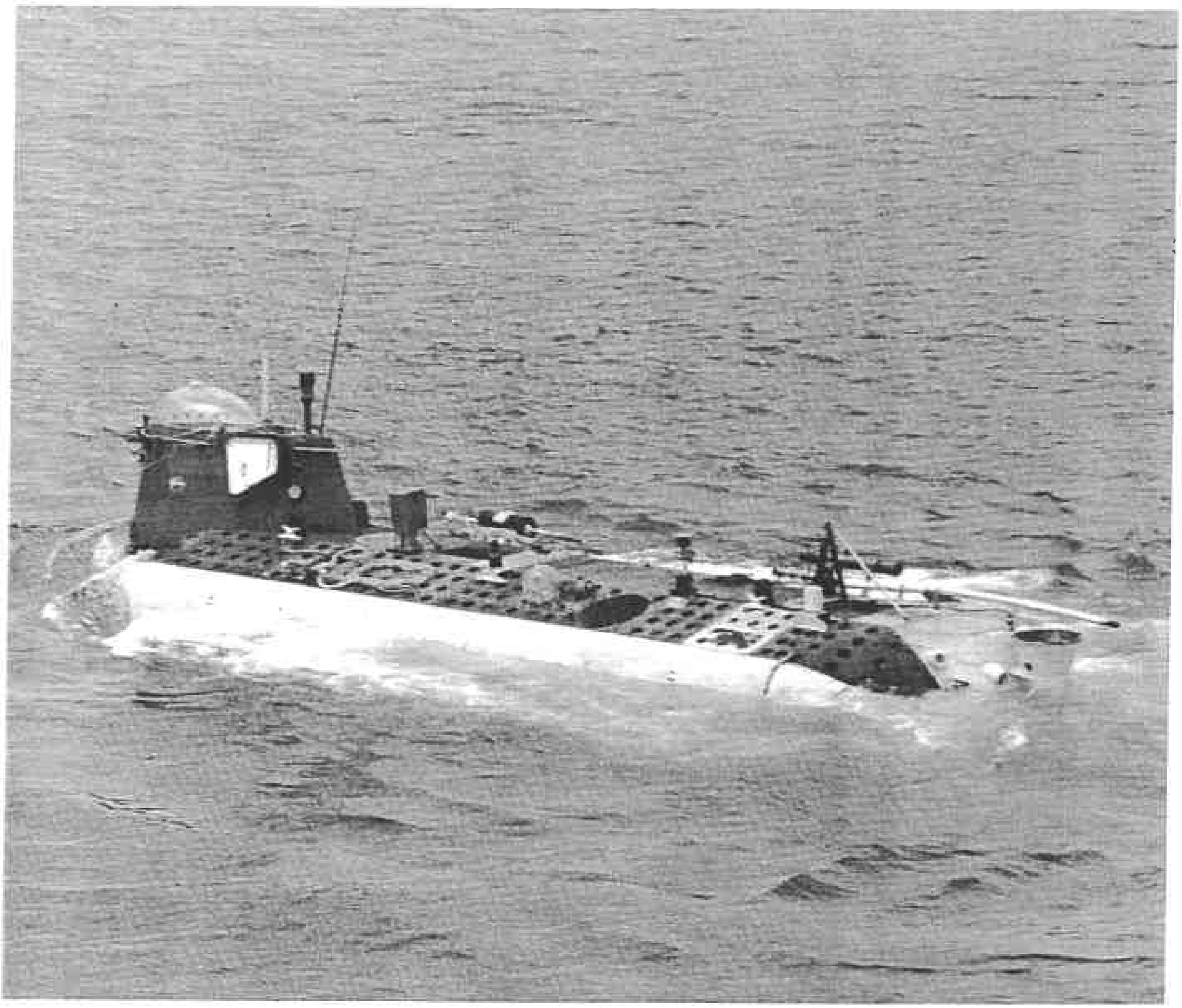
Conducted acoustic experiments at 500 meters. Commenced return to shallow depths at 0028 hours. The mascerator switch burned out; the system can be used without the mascerator. Heated the hot water tank number 3. The crew has channel fever -- quite anxious to surface. Conducted another descent to 500 meters, commencing at 2017 hours. Ran the contaminant removal system for four hours.

13 August 1969

Today we drifted routinely at 408 meters ascending to shallow depths. We checked the number 2 motor and it meggers OK. The carbon monoxide level was at 40 ppm. Commenced preparations for surfacing. The Coast Guard Cutter, Cook Inlet, arrived and will standby in order to transport personnel to Portland, Maine. Since no deep scattering layer was found during the drift, Ben Franklin will surface with excess power available.

14 August 1969

Drifted at 288 meters while preparations continued for surfacing. The boat was rigged for heavy weather, all data packaged for transfer to Cook Inlet. Commenced slow ascent at 0432 hours. Surfaced at 0757 hours. Lynch, Cook Inlet, Privateer, two vessels from WHOI and two rubber boats stood by. The crew and data was transferred to the Cook Inlet. Franklin was taken in tow by the Privateer after the Privateer received fuel and provisions. from Lynch.



Ben Franklin at End of Mission

5 VEHICLE SYSTEMS AND PERFORMANCE

Each of the vehicles systems was subjected to a post mission analysis to evaluate how each performed compared to what was expected. The results of these analyses are presented below

5.1 BALLASTING AND TRIM CONTROL

The Ben Franklin's depth stability was demonstrated during the mission by drifting at constant depth ± 15 meters for as long as 62 hours without changing ballast.

The data taken from the Ben Franklin log and Dr. Piccard's personnal log provide a time history of the Gulf Stream Drift Mission depth-keeping and trim control capability. This data is plotted in Figure 5-1 which also shows when dive or rise commands were given. These commands represent the dropping of shot or expulsion of water from the variable ballast tanks (VBTs). Each arrow on the chart may represent a large number of commands whereby the boat's weight was varied to provide the desired control. The time scale does not permit the presentation of all the individual commands. According to Dr. Piccard's log, 492 entries were made with reference to trim and ballast changes, however, in many cases a dive or climb command actually consisted of a number of small changes in buoyancy until the desired effect was achieved. For example, the initial dive was slowed by four discharges of iron shot over a two minute period and lift off from the bottom was achieved by nine separate commands over 44 minutes.

Figure 5-1 shows six long periods during which no control actions were taken. In only one of these periods did the boat go through an extreme change of depth. This took place between the 18th and 19th of July, where the boat rose from 235 meters to 150 meters. During this time, water was taken into the VBT. Weight changes due to VBT control can only be roughly estimated, because no means is available for measuring water levels in the VBT. Weight changes due to shot ballast ejection can be estimated by measuring the length of time the shot ballast switch is depressed. Figure 5-2 is a plot of outside temperature versus time.

The initial dive and ascent are plotted in Figure 5-3 on an expanded time scale. Ballast control commands and the amount of shot dropped are also indicated. The boat descended at an average rate of 0.7 feet/second. As the boat approached the bottom, approximately 400 pounds shot was dropped. This appeared to be too much and some water was taken into the VBT. The boat then settled to the bottom where it rested for approximately 3 1/2 hours.

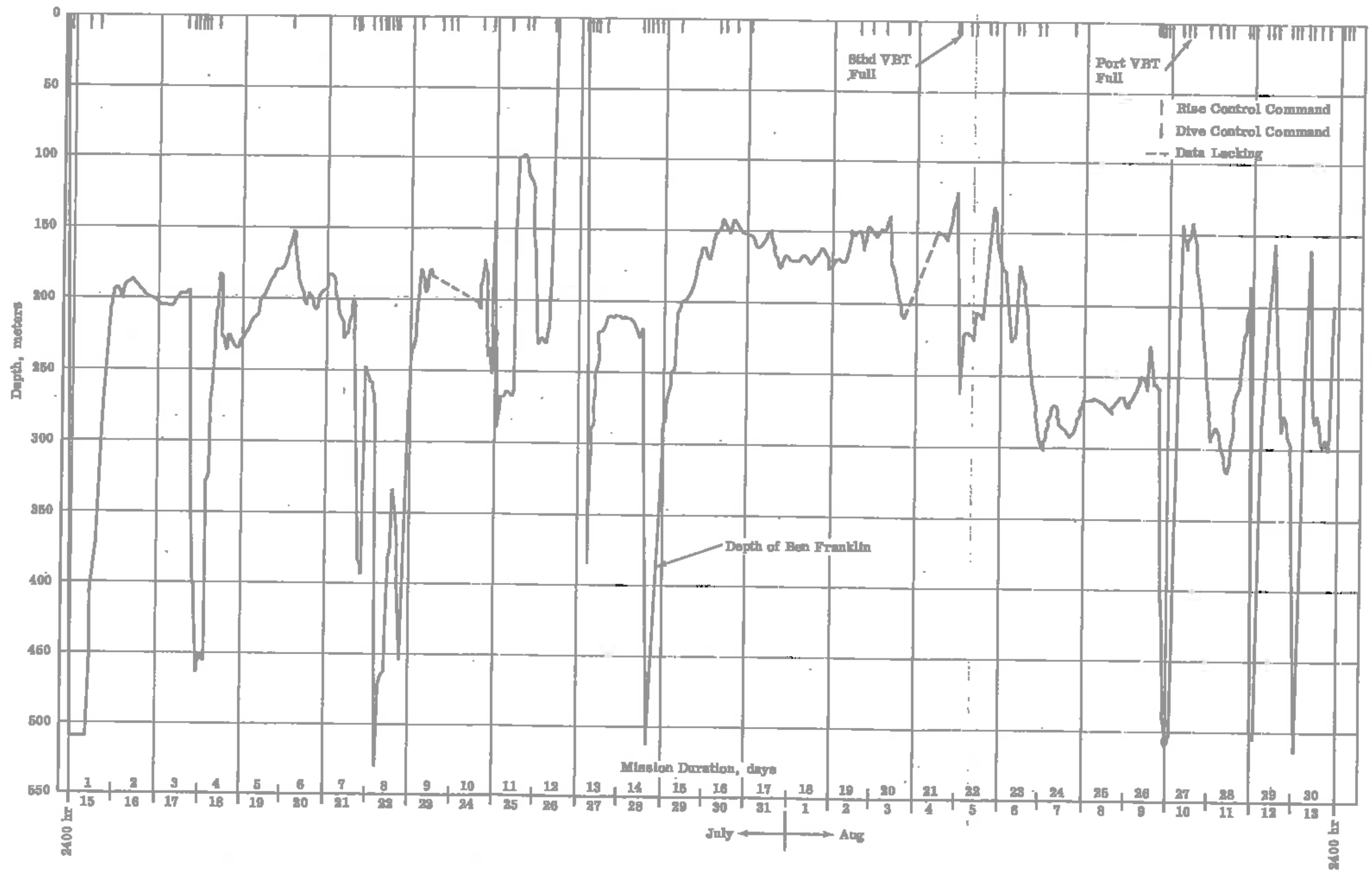


Fig. 5-1 Depth Log, Entire Mission

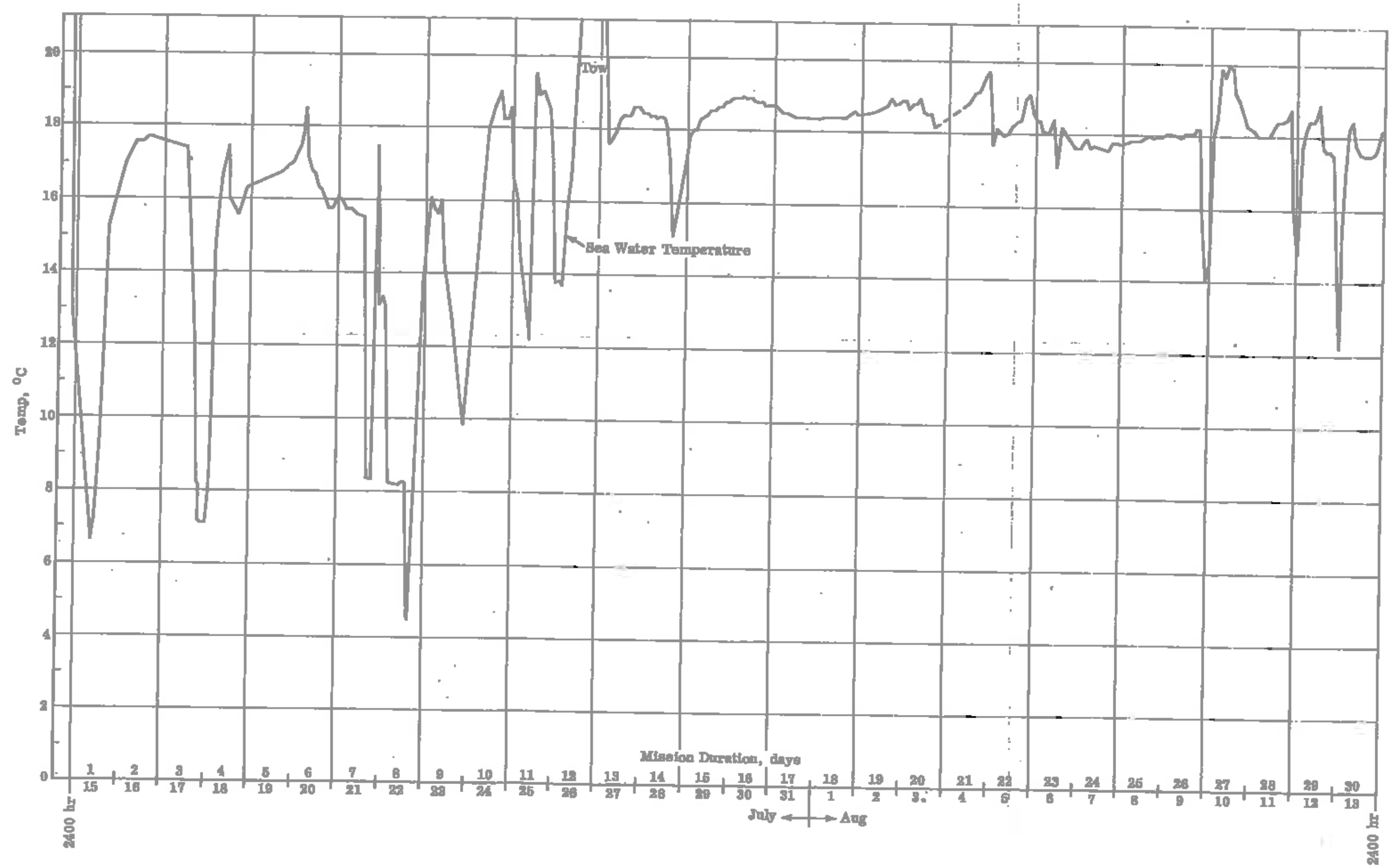


Fig. 5-2 Temperature Log, Entire Mission

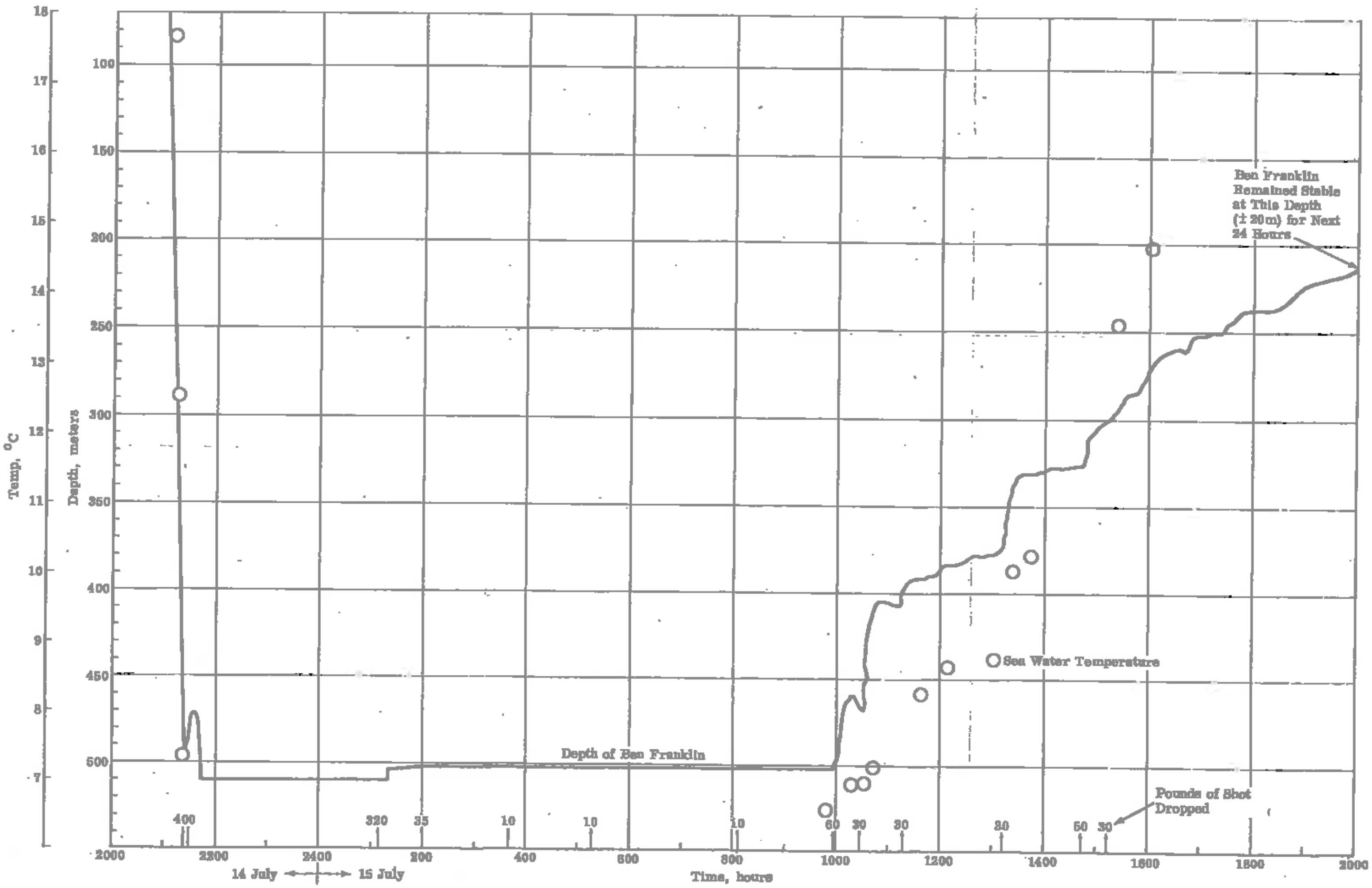


Fig. 5-3 Depth and Temperature Log, Initial Dive and Ascent

At this time approximately 320 pounds of shot was dropped and the boat rose from the bottom and trimmed to 18 feet where it drifted on the guide rope. The boat drifted for approximately nine hours. During this time shot was dribbled to maintain depth. This was necessary because the boat was becoming heavier due to the cold soak effect.

At the end of this time,60 pounds of shot were dropped and the boat began to rise. Additional shot was dribbled until a total of 230 pounds were released. The boat was then allowed to stabilize to its trim depth of 200 meters.

Initially, the boat was ballasted heavy at the surface, and it was still slightly heavy when it settled to the bottom. After 13 hours on the bottom it was necessary to release 445 pounds of shot to allow the boat to start rising. Hence the boat became heavier by approx. 400 while it was at the bottom. This again is attributed to the cold soak effects. As an example of this effect the following estimate can be made, based on 1280 cubic feet of entrapped water in the main ballast tanks and in the sail. It is assumed that a difference of density exists between this entrapped water and the external water and this difference is due to temperature effects.

The incremental change in sea water density from 30° C to 6° C is estimated as 0.32 pounds cubic feet. Further it is assumed that the temperatures of the entrapped water is essentially the same as at the surface, and therefore, the weight of the boat will increase by 0.32 x 1280 (or 410 pounds) as the water temperature equalizes to the ambient. During this time the boat's volume changed due to temperature variations causing a further decrease in bouyancy and thereby account for some of the additional shot which was dropped.

A portion of the overall trajectory, and the command indicators is shown in Figure 5-4. Of chief interest on this portion is the large excursion in depth with no change in temperature. This effect is attributed to the temperature profile of the stream at this portion of the mission.

Temperature profiles were taken by USNS Lynch during the mission. The Lynch made numerous crossings of the Gulf Stream, upstream of the Ben Franklin. During each crossing it dropped expendable bathy-thermographs (XBT), at 20-minute intervals while the ship maintained its heading automatically.

Figure 5-5 is a sample XBT graph taken while the Lynch travelled at constant speed. Data from graphs taken during a run were used to plot composite profiles, such as Figure 5-6.

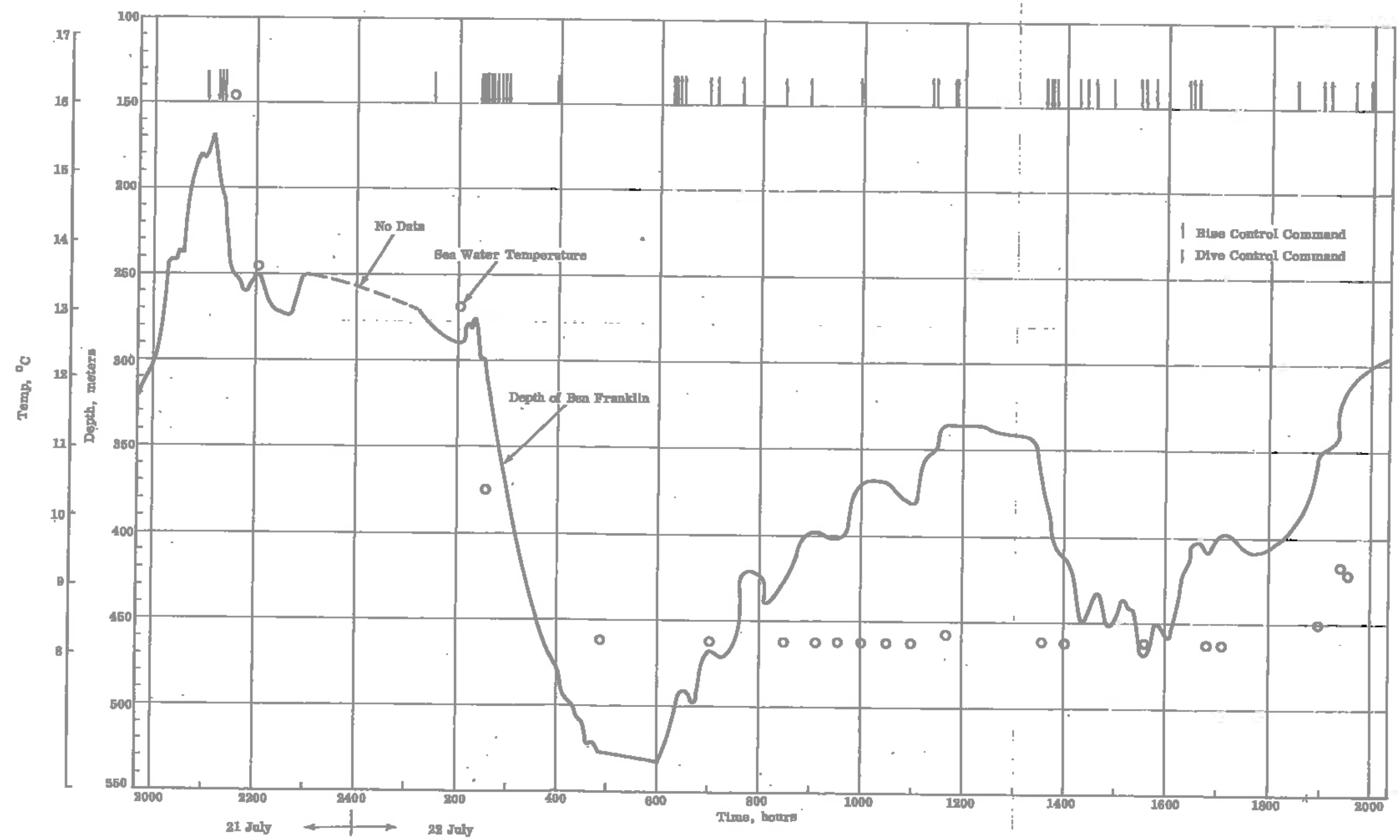


Fig. 5-4 Depth and Temperature Log, Bottom Excursion

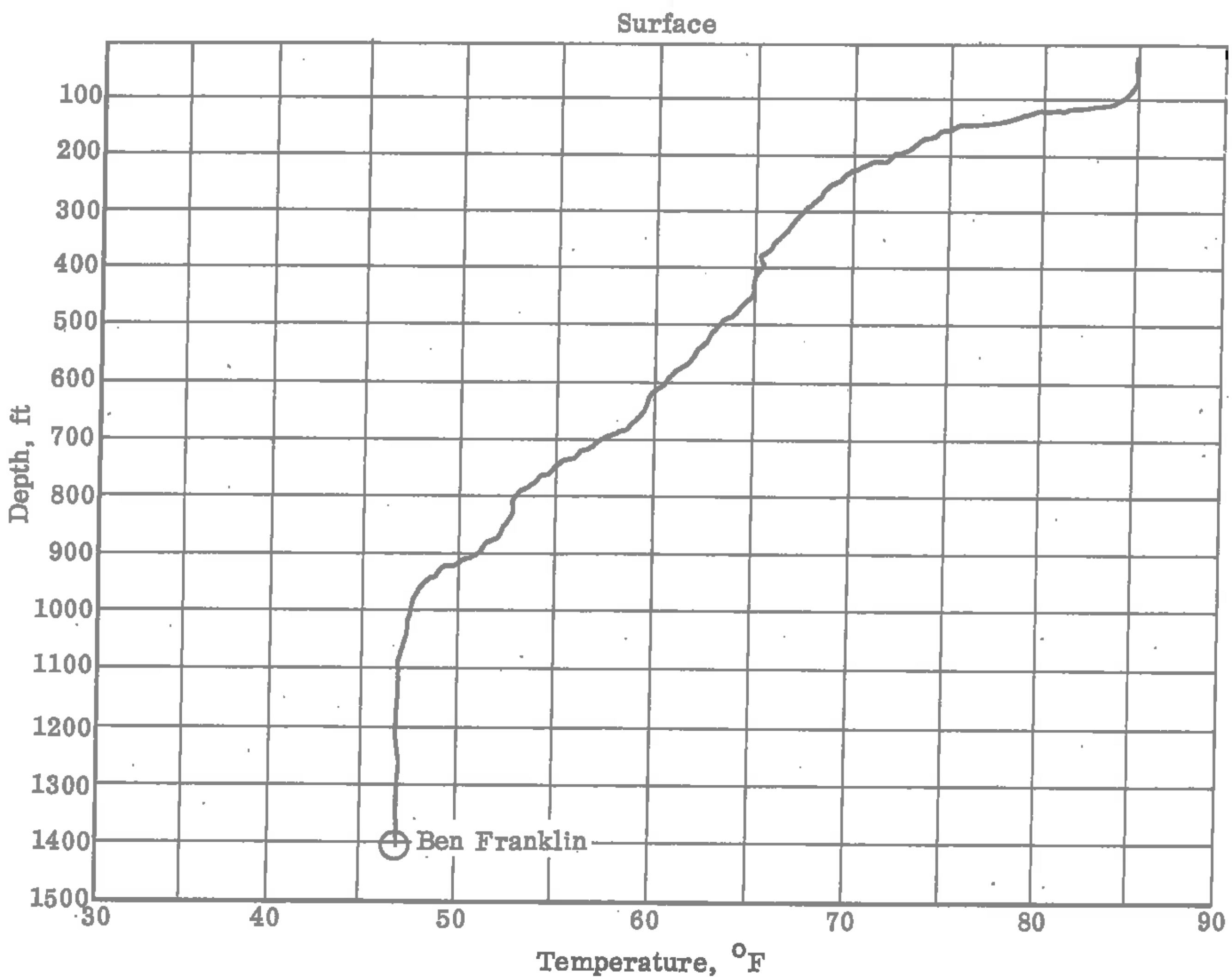


Fig. 5-5 Bathythermograph Trace

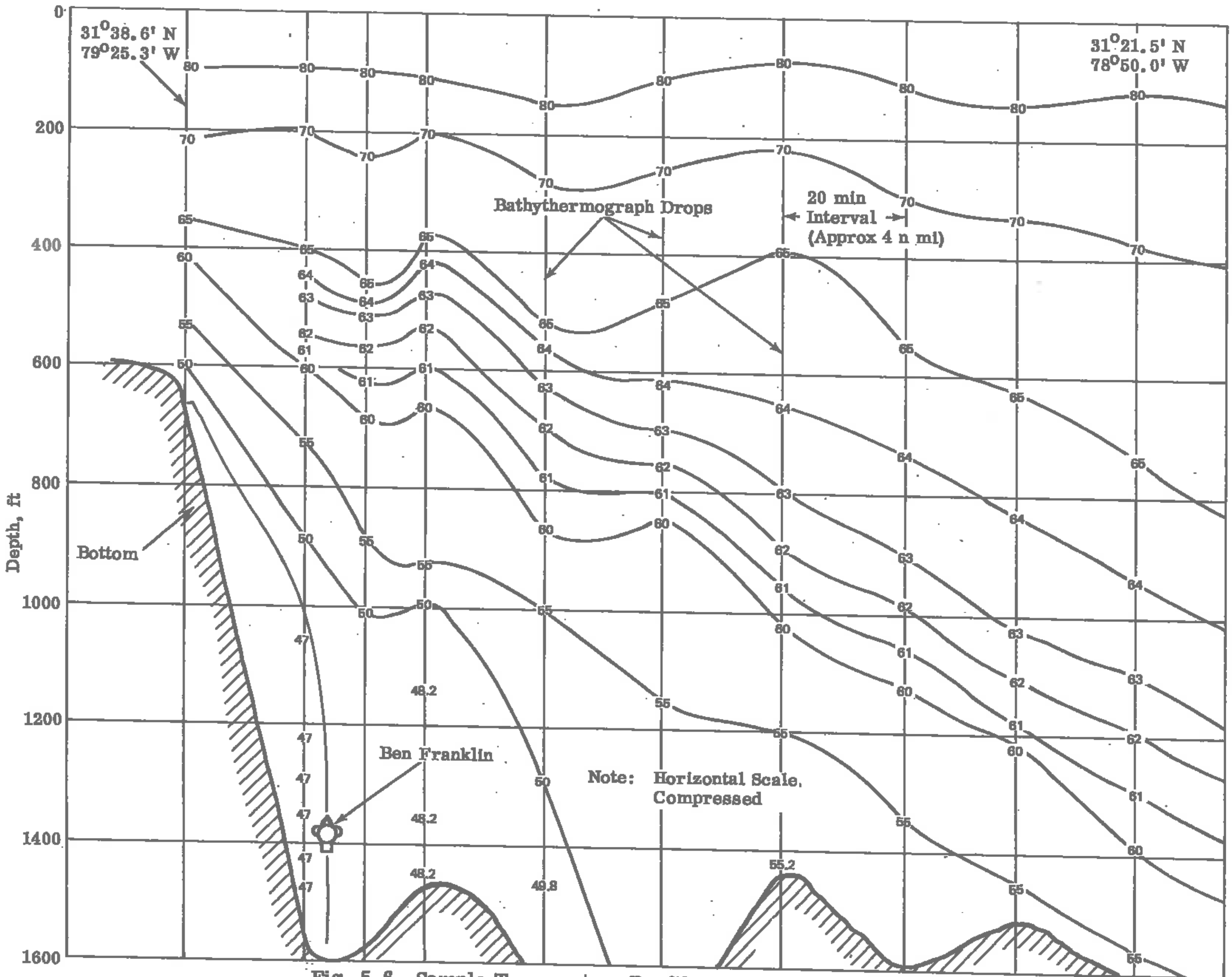


Fig. 5-6 Sample Temperature Profile of Gulfstream Plotted from Expendable Bathythermograph Data

5.1.1 Compressed Air Usage

The pneumatic flasks were filled with 1023 pounds of air prior to the mission. This was 73 pounds over the nominal weight of stored air in the Ben Franklin. This air was used to blow water out of the variable ballast tanks (VBTs), main ballast tanks (MBTs) and the SAS. Only one half (514 pounds) of the air was consumed during the mission. This can be attributed largely to the ability of the crew, especially Capt. Kazimir and Erwin Aebersold since there was no gaging device to determine the quantity of water in the VBTs. The response of the Ben Franklin to changes in buoyancy and the sound of air bubbles being discharged was the only means for operating the variable buoyancy system. Prior to the mission, engineering calculated that it would be possible to limit air consumption to 600 pounds. Including 60 pounds of externally supplied air to blow the MBT's prior to the tow back into the Gulf Stream, the mission was actually completed using 574 pounds. A little more than half of the total supply for blowing the VBTs was used in the first nine days to accomplish 5 of the 10 bottom excursions in this period. See Figure 5-7.

External leakage at the bottom fitting of the pressure reducing valve was isolated and reduced by shutting off all the air flask valves whenever the pneumatic system was not being used. Until these valves were closed, eight pounds of air was discharged in to the hull. This accounts for the hull pressure increases.

Insufficient data was recorded to establish the actual daily air consumption from July 23 to 28, however, the total amount of air used during this period is known. Daily approximations are shown by dashed lines, in Figure 5-7.

5.1.2 Droppable Shot Usage

The droppable shot system is essentially an emergency means of providing six tons of positive buoyancy. Additional steel shot can be carried in this system to augment the variable ballast system during initial submergence and to maintain the required buoyancy during this dive until vehicle temperature has stablized to ambient at the desired depth. An additional 1500 pounds of shot was carried by the Ben Franklin at the start of the drift mission for the latter use. During the first two days of the mission,950 pounds of shot were used for this purpose, as shown in Figure 5-7. After surfacing on July 26th for the tow, an additional 1950 pounds of steel shot were added (providing 2500 pounds in excess of the emergency system requirements).

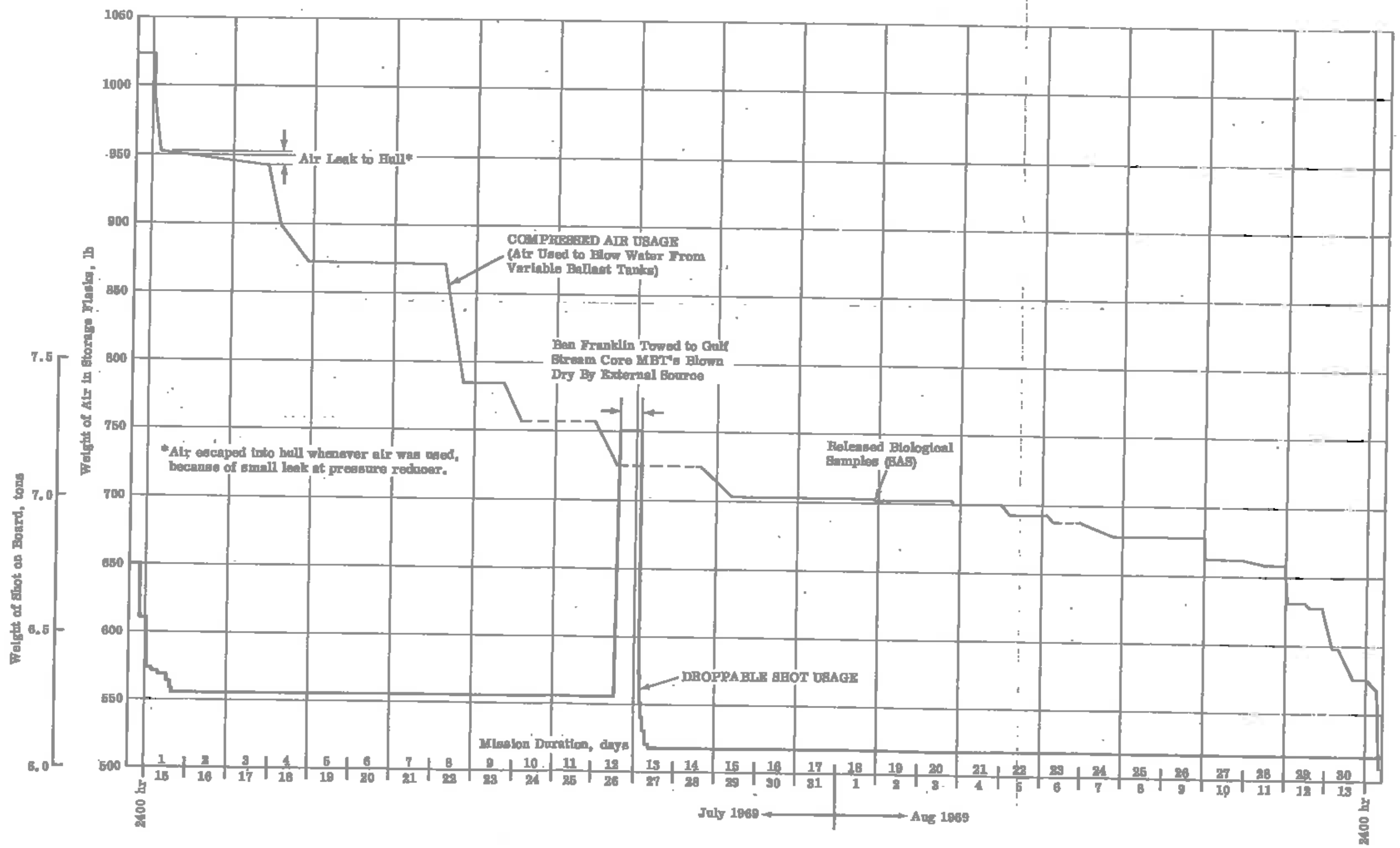


Fig. 5-7 Compressed Air and Droppable Shot Usage

This variable buoyancy system augmentation was only used during a dive from the surface. At no time during the mission was there less than 12,000 pounds of positive buoyancy available for an emergency.

To assure that a gradual loss of magnetism in the permanent magnets of the shot release valves would not result in dribbling shot inadvertantly, the permanent magnets were remagnetized regularly during the mission.

The hydraulic system, used to release the shot in case of an emergency, functioned flawlessly, as demonstrated by the release of a SAS ball (a small plastic sphere which floats to the surface) and the final dumping of shot thru a hydraulicly released trap door at the end of the mission.

5.2 LIFE SUPPORT

The mission demonstrated that the passive systems (natural convection) for ventilation, carbon dioxide removal, and temperature and humidity control were satisfactory. In this system, fans, blowers, heaters, etc. are not used and the life support system required essentially no electrical power. It was demonstrated that the present Ben Franklin life support system could perform for 60 days (compared with the 42 day design mission) with only slight modification.

5.2.1 Oxygen Storage and Supply

The oxygen consists of two liquid oxygen dewars which contained 250 pounds of oxygen each and were allowed to boil off at a preselected rate thru a regulator. This system, in general, worked as designed without any problems.

Figure 5-8 shows how the oxygen level was maintained throughout the mission. All major corrections were made manually with the flow meter. Nine major corrections were made in the first 12 days during which 0_2 levels varied 2 1/2 percent, ranging between 19.5 and 22 percent. In the remaining 18 days only 3 major reversals were made and the 0_2 level varied 1 1/2 percent, holding between 19.5 and 21 percent. Finer control could have been obtained if it were desired. The automatic control, originally part of the system, was disconnected prior to the mission to eliminate an inverter and conserve electrical energy.

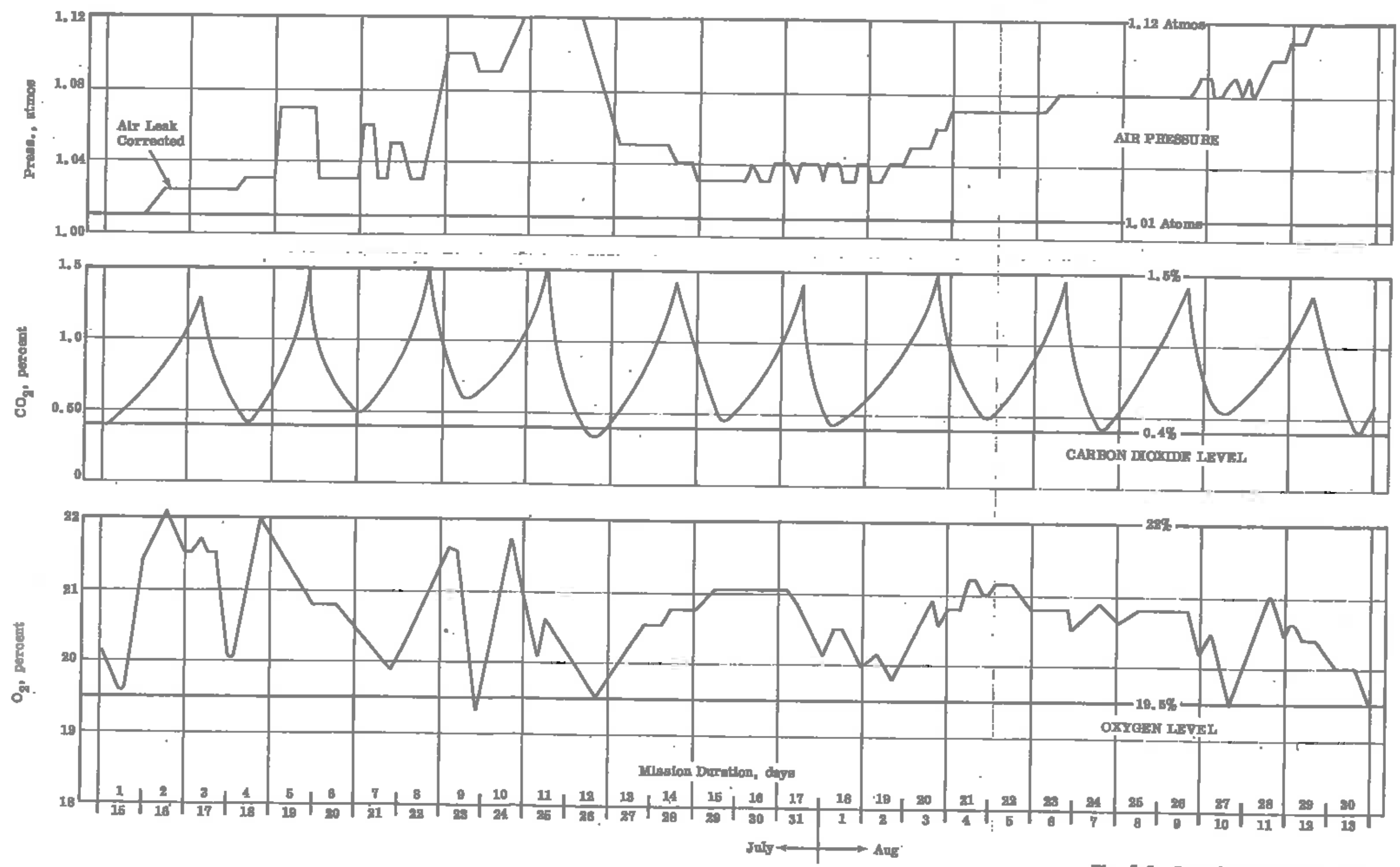


Fig. 5-8 Log of Air Pressure, CO_2, and O_2 Inside Ben Franklin

By the end of the mission, approximately one half of the original oxygen supply was left. This corresponds to an average consumption of 1.4 to 1.5 pounds of oxygen and a metabolic rate of 8750 BTU (2200 calories) per day per man. Based on crew activities this number seems to be fairly accurate.

5.2.2 Carbon Dioxide Removal

The carbon dioxide removal system, which consisted of 12 lithium hydroxide (LiOH) panels deployed throughout the boat, worked better than anticipated. As shown in Figure 4-6, the CO_2 level was maintained between .4 and 1.5 percent. All 12 LiOH panels were changed whenever CO_2 levels exceeded 1.3 percent. The anticipated buildup rate was calculated such that panels were to be changed every 2 1/2 days, however, in actual practice changes were required about every 3 days. For a daily oxygen consumption of 1.5 pounds, the corresponding CO_2 generation rate is 1.7 pounds per day. Thus, the efficiency of the LiOH panels was approximately 75 percent. The panels worked so well that greater use could have been obtained from them if desired.

5.2.3 Atmospheric Pressure Control

Air pressure in the vessel ranged between a low of 1.01 atmospheres at the start of the mission to a high of 1.12 atmospheres. (See Figure 5-8.) The highs occurred twice, once when the boat surfaced and was undertow, and again at the end of the mission. The net variation of 0.11 atmospheres or 1.6 psi was well within safe operational levels. After the first day, a slight air leak in the pressure reducing valve for the VBTs was noticed and corrected. Cabin pressure had by this time risen to 1.025. The next series of variations shown in Figure 5-8 correspond to cabin temperature. When the temperature rose, the pressure rose and vice-versa. This accounts for the pressure increasing to its highest level when the vessel was on the surface under tow. After resubmerging, the vessel cooled down and the pressure remained between 1.03 and 1.04. This variation is so slight that it can be explained as an error in reading the pressure gage. The rise in pressure from 1.04 on day 20 to 1.12 on day 30 is explained by a slight air leak into the boat, from the reducing valve during VBT operation

5.2.4 Relative Humidity Control

Maintaining a satisfactory relative humidity throughout the drift mission was a questionable item. Due to power limitations 3600 pounds of silica gel, were stowed aboard the vessel for the drift mission. Figure 5-9 shows that except for a few short intervals, the relative humidity was maintained between 70 and 80 percent. Roughly 2400 of the 3600 pounds of silica gel was used. The mission started with approximately 600 pounds exposed. Additional silica gel was exposed periodically as recorded. Relative humidity appears to have fluctuated randomly; however, there is an obvious relation to temperature. In general, whenever the vessel cooled down the relative humidity rose, and whenever the temperature increased, the relative humidity decreased. There also seems to be a correlation between humidity and carbon dioxide level. The CO_2 lows tend to correspond to a decrease in relative humidity. This may be explained by an immediate pickup of moisture by freshly exposed LiOH panels.

5.2.5 Temperature Control

Both sea water and cabin temperatures are plotted in Figure 5-9. Except for those relatively short intervals during which the vessel sat on the bottom or made deep dives, sea water temperatures varied between 62^{o}F and 66^{o}F. The corresponding cabin temperature range was 64 to 68^{o}F. This period which represente more than half of the mission was quite comfortable for the crew. On the deep dives sea water temperatures reached as low as 41^{o}F, cabin temperatures got down to the mid fifties and the vessel became uncomfortable. The crew complained that much warmer clothing is needed to make operation in this environment bearable. There were also two instances when the boat became to warm; the first occurring while the vessel was trying to power itself back into the Gulf Stream, and the second time when the vessel was on the surface under tow. Temperature at these times rose to 73^{o}F and 84^{o}F respectively.

The vessel reached equilibrum after approximately six hours with cabin temperature running 3 1/2^{o}F above sea temperature. This was a much lower temperature difference than had been expected. In previous dives, a difference of 5^{o}F to 7^{o}F was experienced. Obvious explanations for this deviations are:

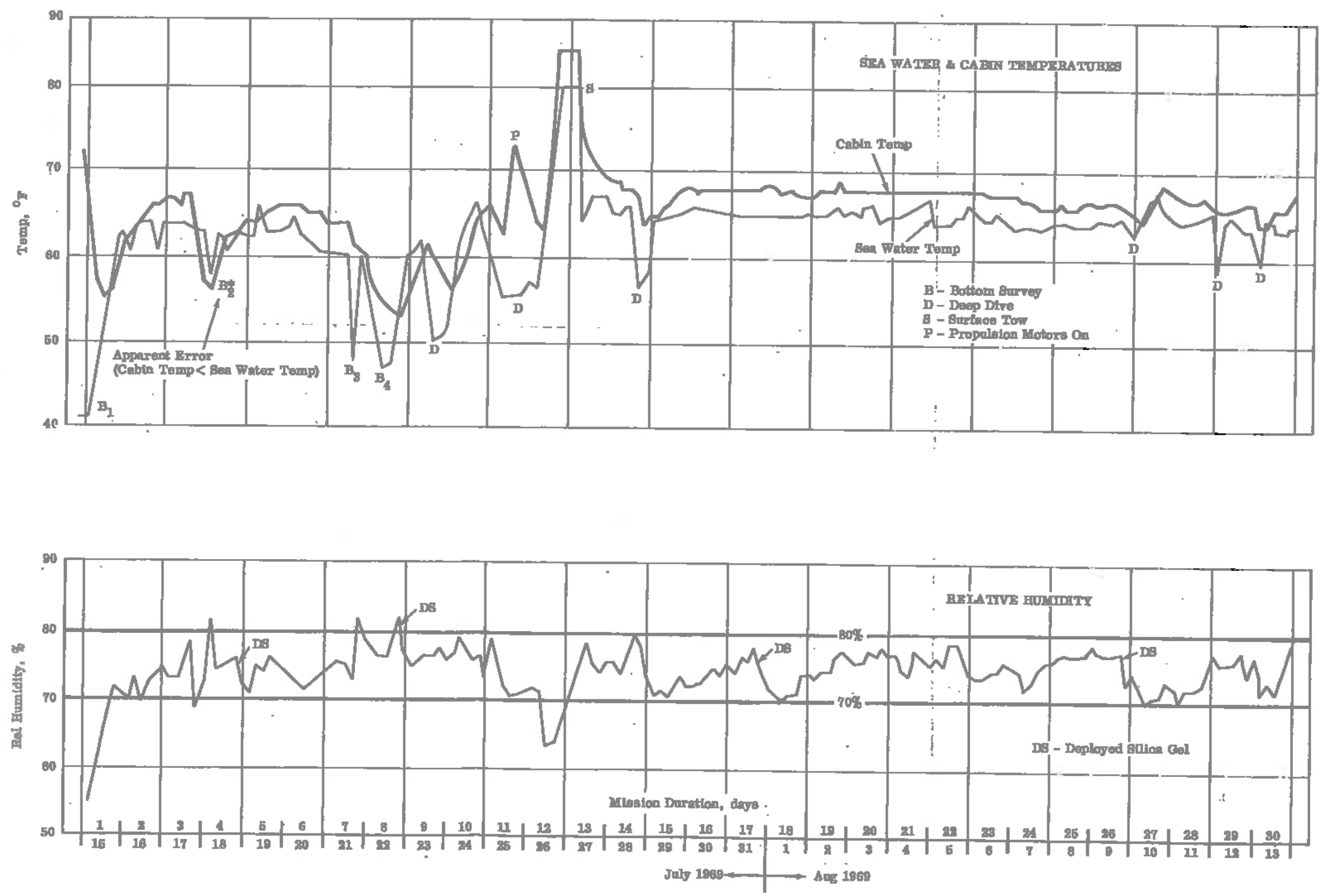


Fig. 5-9 Log of Temperature and Relative Humidity

- Lower internal electrical power consumption on the drift mission than on previous dives, particularly lights.

- Activity level of the crew was somewhat lower than on previous dives.

Passive temperature control of the Ben Franklin was only possible because of warm temperatures of the Gulf Stream. Any operation of the vessel in colder waters will require insulating the boat and use of a heat source. Work is now under way to come up with requirements for making Ben Franklin operational in all sea water temperatures.

5.2.6 Air Contaminant Removal

The most probable metabolic contaminants were looked for daily, making use of Drager gas detector tubes. These gases included NH_3, CO, H_2S, NO_2, H_2, and SO_2. Twenty eight other contaminants were looked for on a weekly basis also using Drager Tubes. After approximately five days, eight ppm of carbon monoxide appeared. The CO level continued to rise as anticipated and, at a level of 20 ppm, the active contaminant removal system was operated with no effect. As shown in Figure 5-10, the CO level continued to rise and by mission end was 40 ppm. (The level of CO for a 6-man 30-day mission was calculated to be approximately 27 ppm).

The first full contaminat check made on the eighth day, revealed, .2 ppm hydrazine and 200 ppm of acetone. Periodic rechecking of these two contaminants throughout the mission showed similar levels. It is believed that the hydrazine indication was due to ammonia or an amine because no source of hydrazine was on board. The acetone could also represent a ketone or an aldehyde.

Ten atmosphere samples were taken during the mission, one every three days. Post mission analysis of these samples indicate that a small amount of methane was present throughout the mission (less than 200 ppm).

A gas chromatograph was operated periodically as part of the NASA program. The data from this instrument was not available at the time this report was written, however, it will be available in the NASA report.

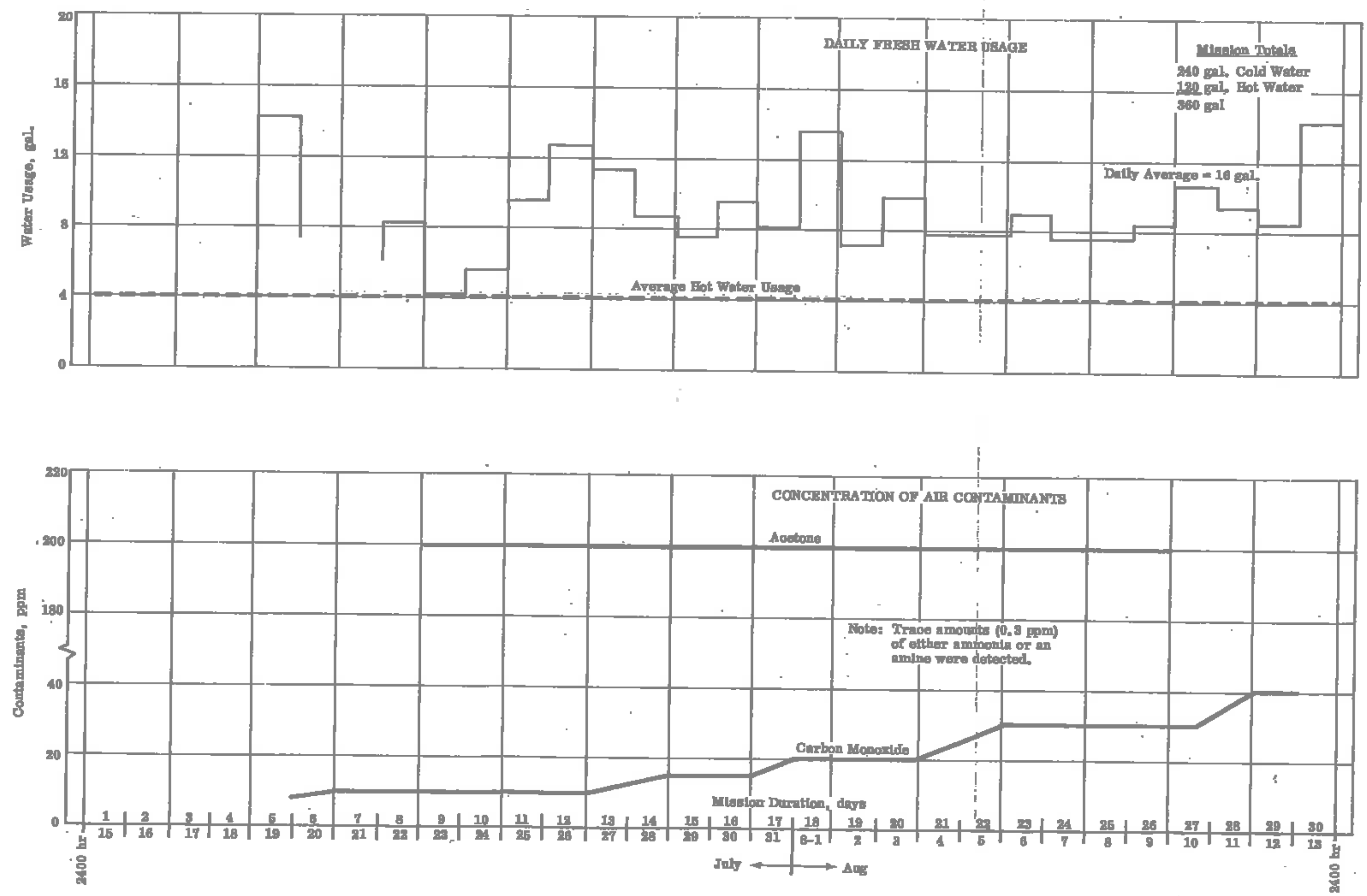


Fig. 5-10 Log of Water Usage and Air Contaminats

5.2.7 Water Management

Approximately 500 gallons of potable water was loaded onboard the vessel at the start of the mission, 165 gallons of hot water in 4 vacuum jacketed tanks and 335 gallons of cold water in 4 saddle tanks. The crew used 250 gallons of cold water and 120 gallons of hot water during the mission. Thus the daily consumption per man averaged of 5.5 pounds of hot water and 11 pounds of cold water.

5.2.8 Cold Water

Cold water was used primarily for personal hygiene and washing dishes. Very little cold water was consumed in drinking or food preparation primarily because of the cool temperature of the vessel, the repugnant taste of the iodine treated water, and the efforts of the crew to conserve the supply. In fact cold water consumption was so low that periodically cold water was run just to keep the miniwaste tank from running dry. Biological measurements were taken throughout the mission as part of NASA Program and a detailed report in this area will be forthcoming.

5.2.9 Hot Water

The mission was started with two of the four hot water tanks not working properly, i.e., the vaccuum had been lost and the tanks cooled down rapidly. All four tanks were heated initially. Water was initially drawn from one of the deffective tanks. After the second day, the switch was made to the two good tanks.

After approximately 20-to-22 days, it was necessary to periodically use electrical power to heat some water. By design, hot water could only be drawn from the galley sink. No hot water was used in the shower in order to conserve this comodity. More detailed information will be forthcoming in the NASA report.

5.3 ELECTRICAL POWER

The total power available on the Ben Franklin for this mission was 756 kilowatt hours. The source of this power comprised 378, 2-volt, 1000-ampere-hour, lead acid batterys located in the keel external to the pressure hull. This power was distributed to three basic electrical systems:

- 28 VDC, 308 kwhr
- 110 VDC, 112 kwhr
- 336 VDC propulsion, 336 kwhr

Due to the long duration of this mission and the amount of equipment to be operated, it was necessary to allocate operating times and duty cycles for each piece of equipment. (See Reference 1)

Since the ampere-hour system was not operated continuously throughout the mission, power usage was calculated from the following data:

- Equipment daily usage
- Battery terminal voltages
- Ampere-hour data
- Battery-to-hull resistance measurements

These calculations indicate a total power consumption during the mission of between 55 and 65 percent of the original allocation.

Figures 5-11, 5-12, 5-13 show a comparison between the data taken and the predicted usage.

It should be noted that the power consumption derived from both the daily power consumption log and the terminal voltage data represents only the power consumed subsequent to day one: it does not include the power used during the initial tow, the first dive or the equipment check-out during the first bottom-sit. The ampere-hour data represents all power used subsequent to the zeroing of the system at the dock before the initial tow to the dive site. The data presented in these curves was obtained as follows:

Ampere-Hour Values:

The absolute ampere hour readings were converted to kwh using the appropriate conversions contained in the curves of section 3.2.2.2. "Power "Profile" of the Mission Plan (Reference 1). The ampere-hour system operation was terminated prematurely and the very low data for battery B_2 has not been fully explained. A post mission system checkout indicates low B_2 readings but not as low as shown on Figure 15.

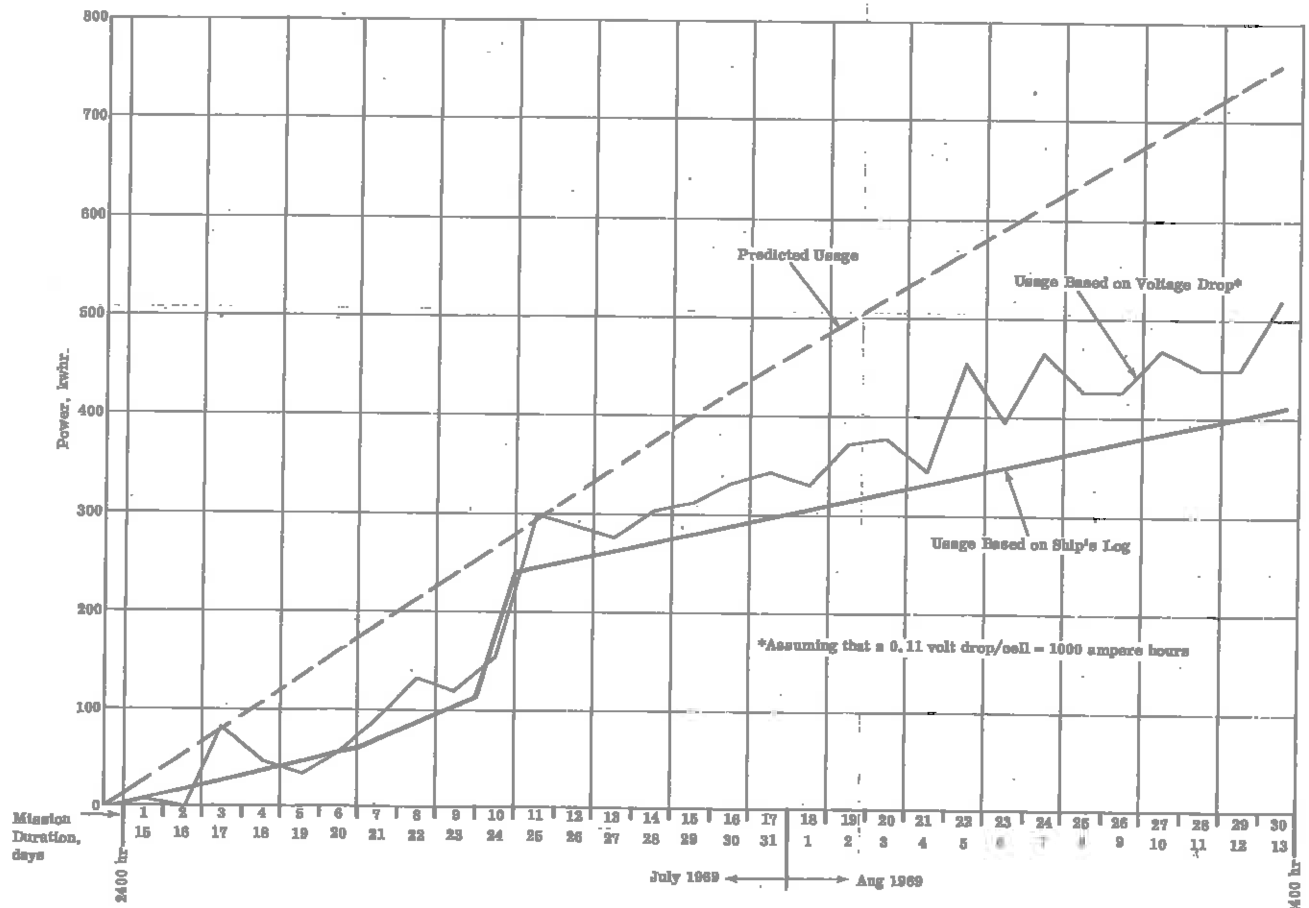


Fig. 5-11 Log of Total Power Consumption Curves

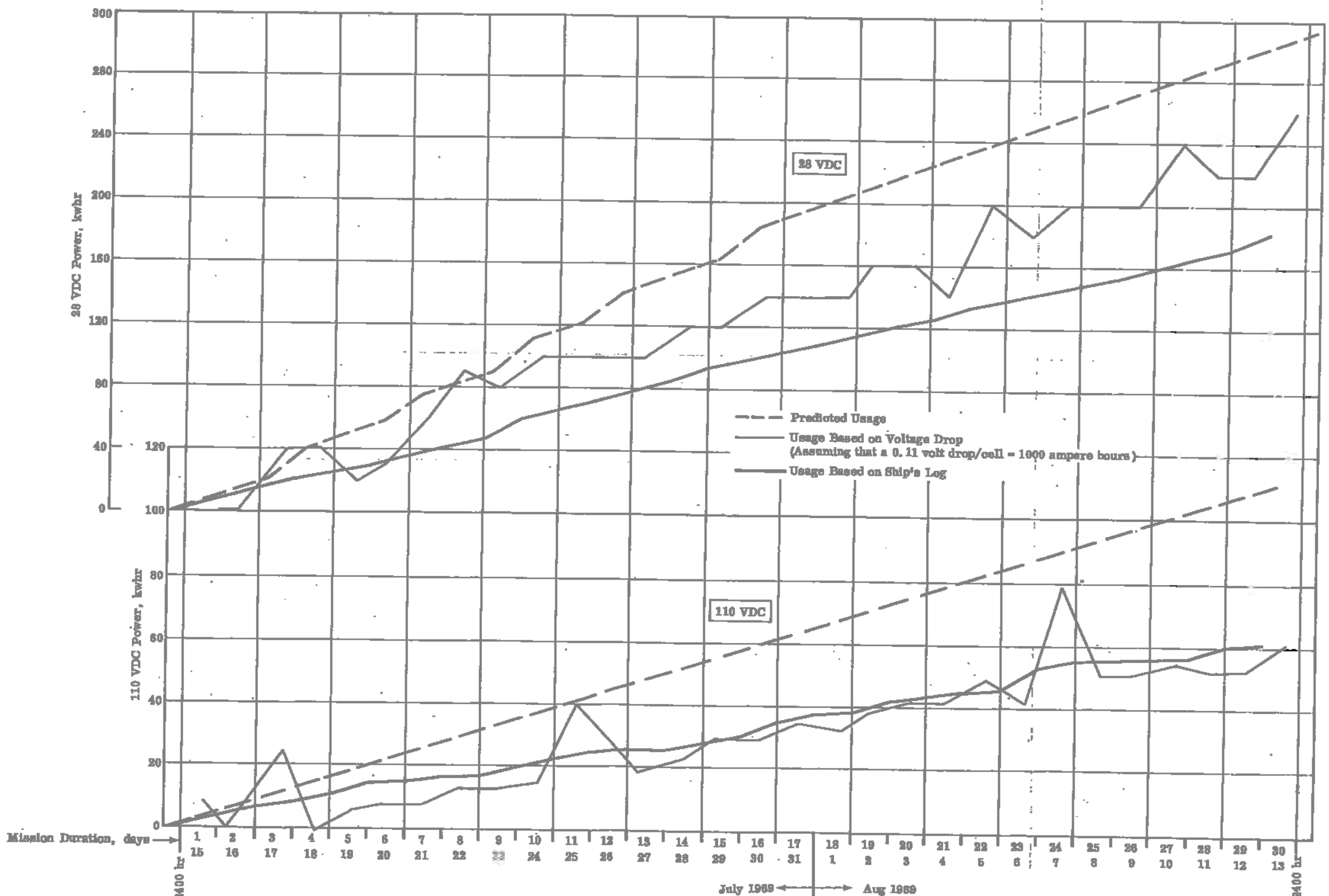


Fig. 5-12 Log of 28V and 110V DC Power Consumption

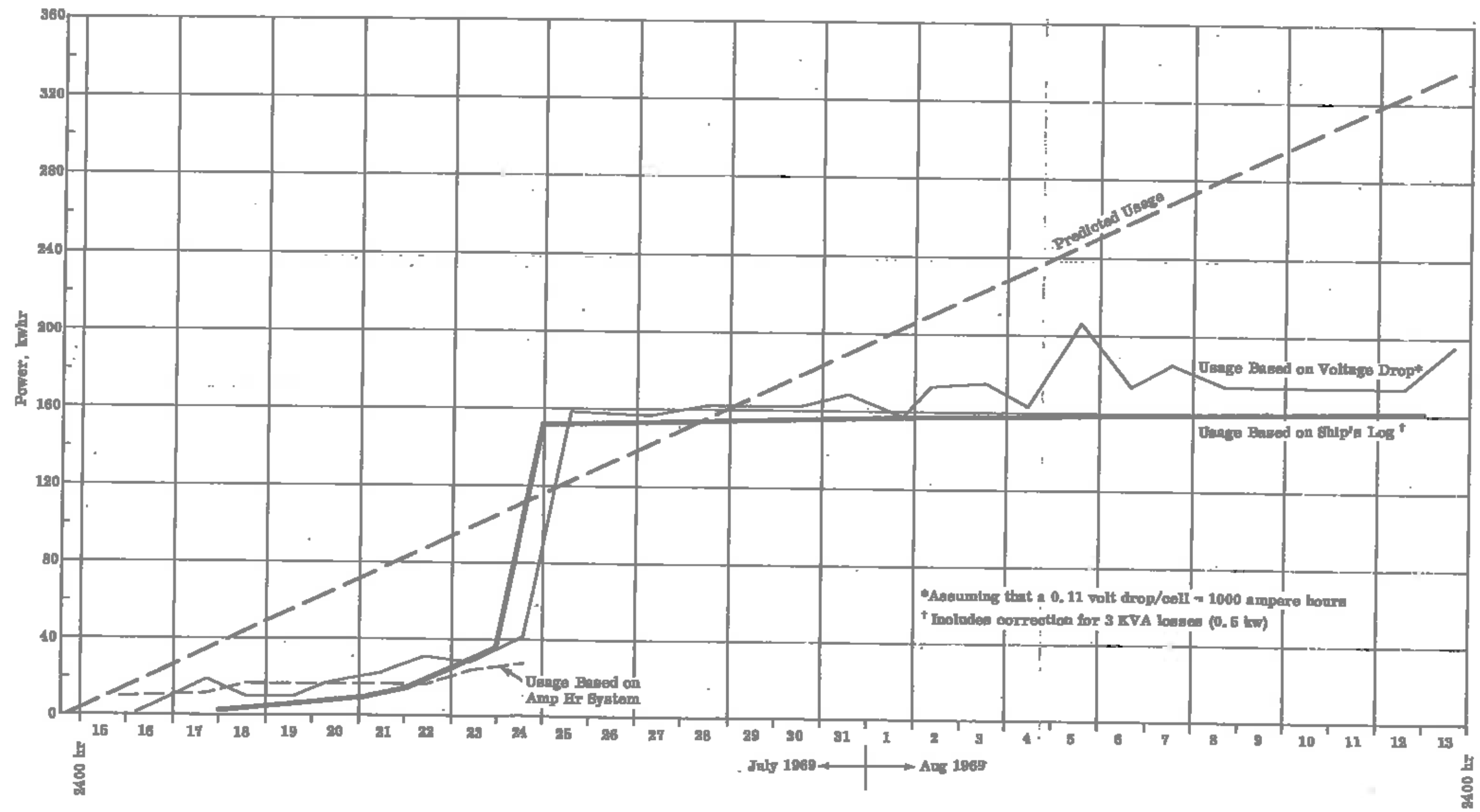


Fig. 5-13 Propulsion Power Consumption

Ship's Log Entries:

The daily kwh usage contained in the power consumption sheets of the Mission Log was plotted directly.

Terminal Voltage Change:

Power consumption was also calculated based on a cell voltage change of 0.055 volts per kwhr. This nominal value was derived from the limited cell discharge tests conducted at West Palm Beach, Florida. The kwhr calculation for a given battery reduced to the following:

$$KWH = (V_O - V_t)\ 18.2$$

Figures 5-14, 5-15, and 5-16 reflect a power usage which was less than originally predicted. This difference can be generally accounted for as follows:

- Decreases from the original predictions (approximately 250 kwhr)

– Propulsion compensation for drifting out of the core was used only once	156 kwhr
– Some equipments inoperative	30 kwhr
– Bottom time approximately 25% of the original plan	21 kwhr
– Deep Scatter layer not encountered	35 kwhr
– Amperehour-system used approximately 50% of allocation	11 kwhr

- Additions for equipments which originally had no allocation

Additions for equipments which originally had no allocation	18.5 kwhr
– Hot water heater	16.0 kwhr
– Hot plate	0.6 kwhr
– Ship-to-shore radio	1.2 kwhr
– Running lights	0.5 kwhr

A detailed accounting of equipment usage, as based onthe ship's log data, is shown in Figures 5-15, and 5-16.

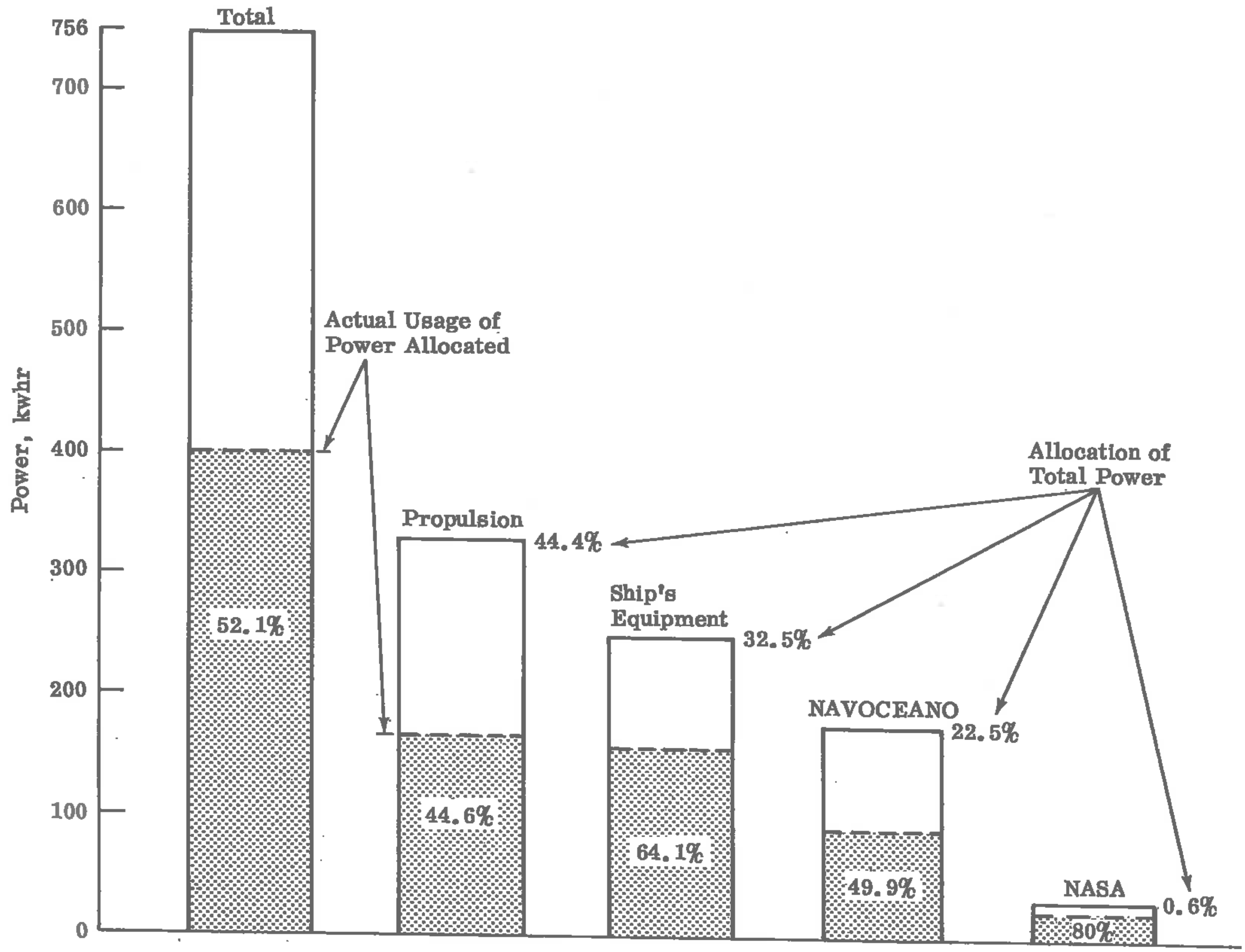


Fig. 5-14 Summary of Power Allocated and Power Used

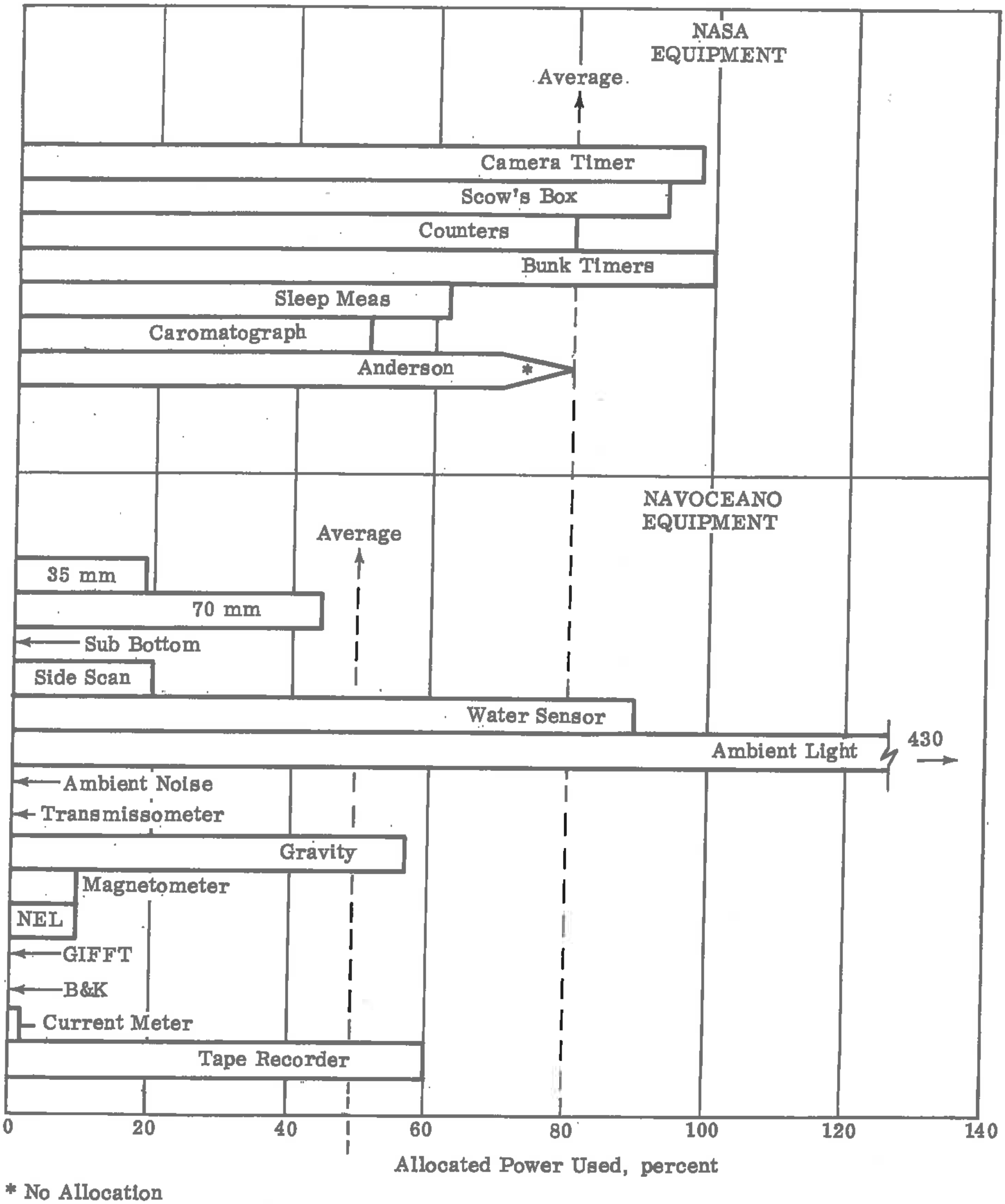
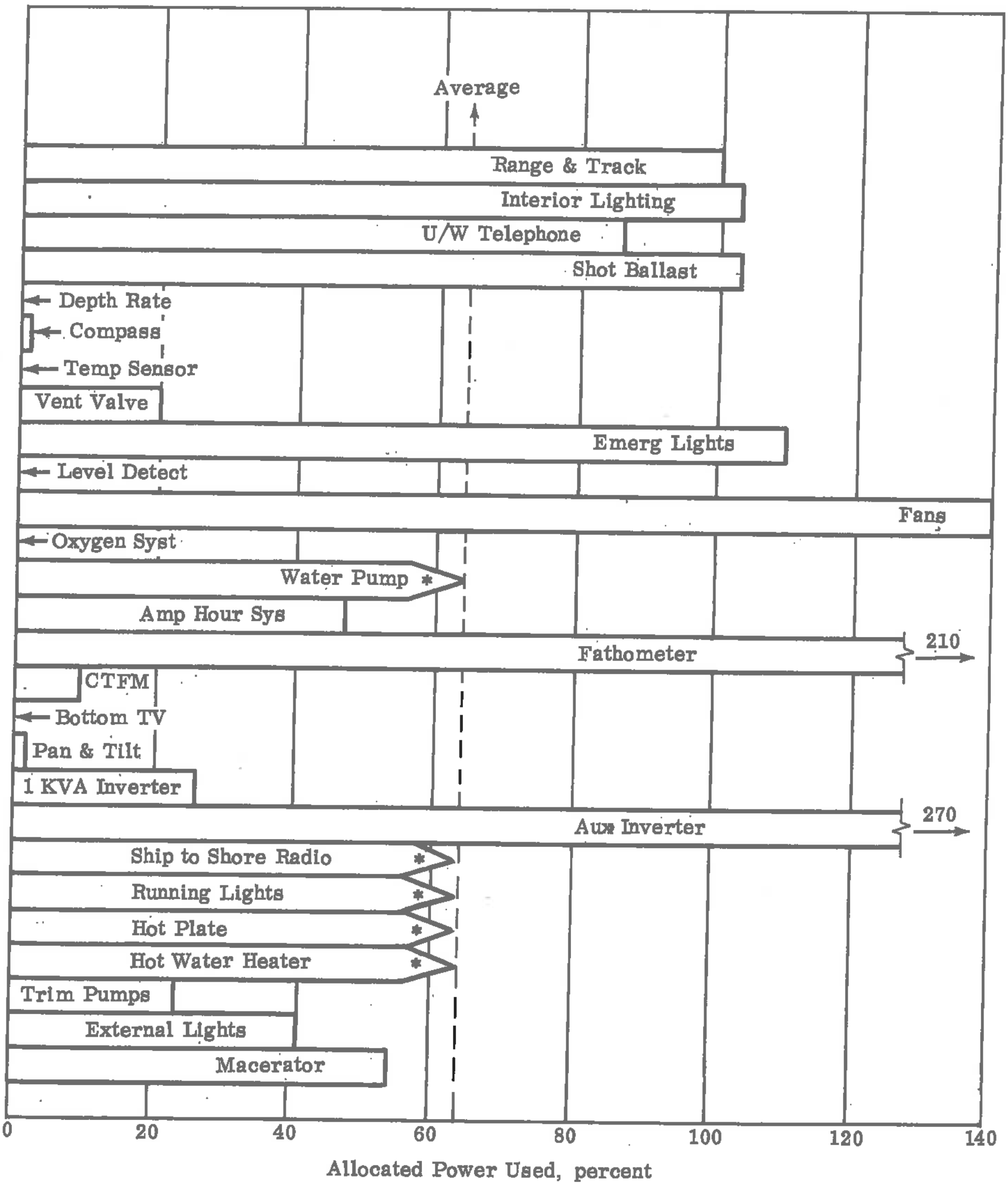


Fig. 5-15 Analysis of Power Consumed by Scientific Equipment



*No Allocation

Fig. 5-16 Analysis of Power Consumed by Ship's Equipment

Losses asociated with the leakage resistance between the batteries and the hull appear to be very small. A "worst case" calculation indicates a maximum leakage loss for the entire mission, of 2.70 kwhr. Actual losses for the mission are estimated to be less than 1 kwh.

Figures 5-17 (Sheets 1 to 3) show the battery resistance to hull measurements taken during the mission. These readings were closely watched as the drift progressed, and in general showed no deterioration of the batteries due to grounding thru the sea water to the hull.

5.4 COMMUNICATIONS AND INSTRUMENTATION

5.4.1 Communication System

This system provided communications with:

- The support ship via underwater telephone
- A diver or observer in the sail
- Shore station via marine radio

The underwater telephone consisted of two (one primary, one redundant) 2.5 watt single sideband, suppressed carrier units, and higher power (100 watt) backup unit. The support ship Privateer followed a zigzag pattern over Ben Franklin, with the slant range between the two rarely exceeding 3000 feet at the extremes of the pattern. Except for one instance, when the slant range to the support ship opened up to 15,000 feet and the high power unit was used, the low power unit performed satisfactorily. The other components of this system worked satisfactorily throughout the mission.

5.4.2 Instrumentation

The instrumentation system on board provided status data on the batteries, power distribution system, propulsion system, shot ballast system, and various other systems.

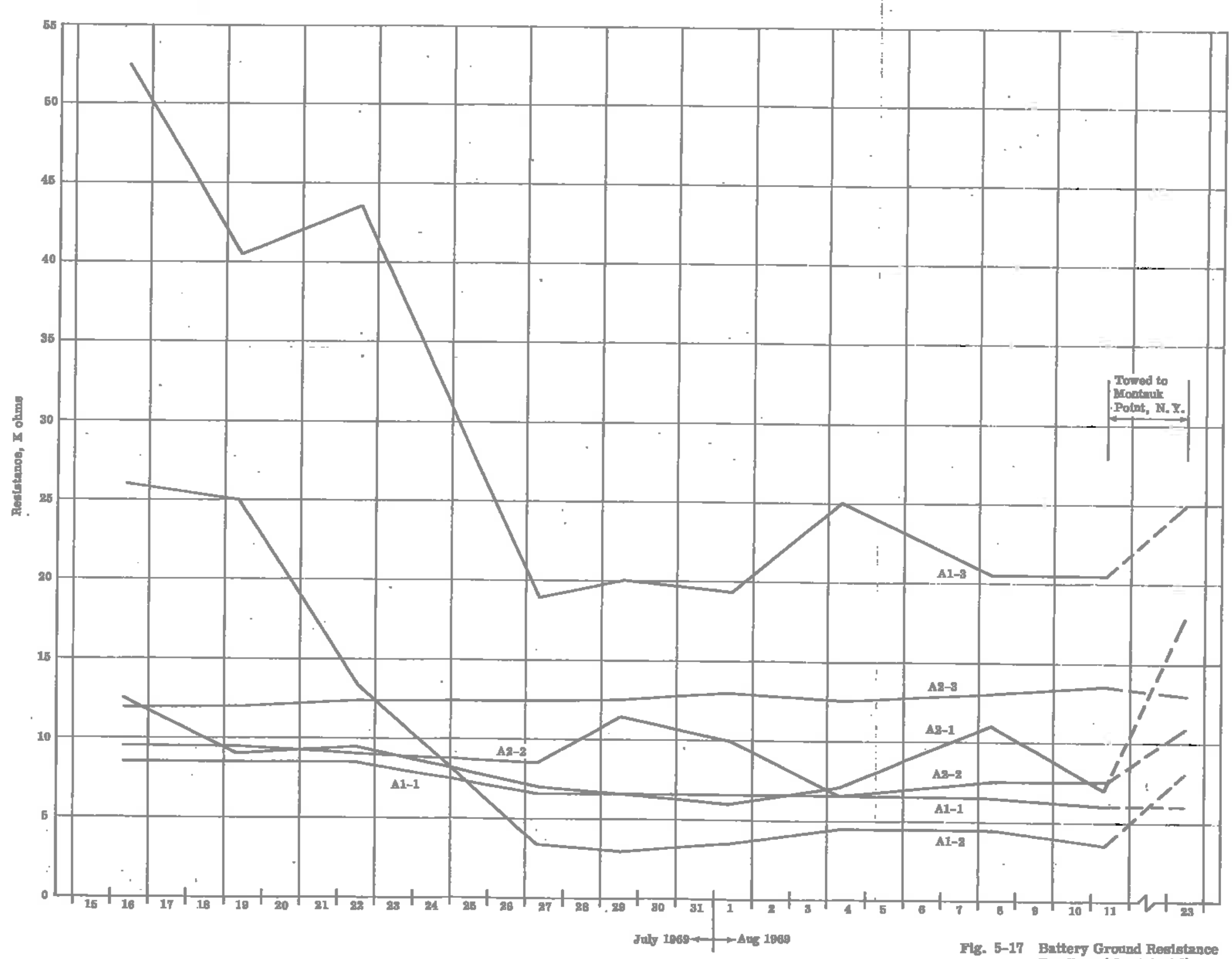


Fig. 5-17 Battery Ground Resistance Readings (Sheet 1 of 3)

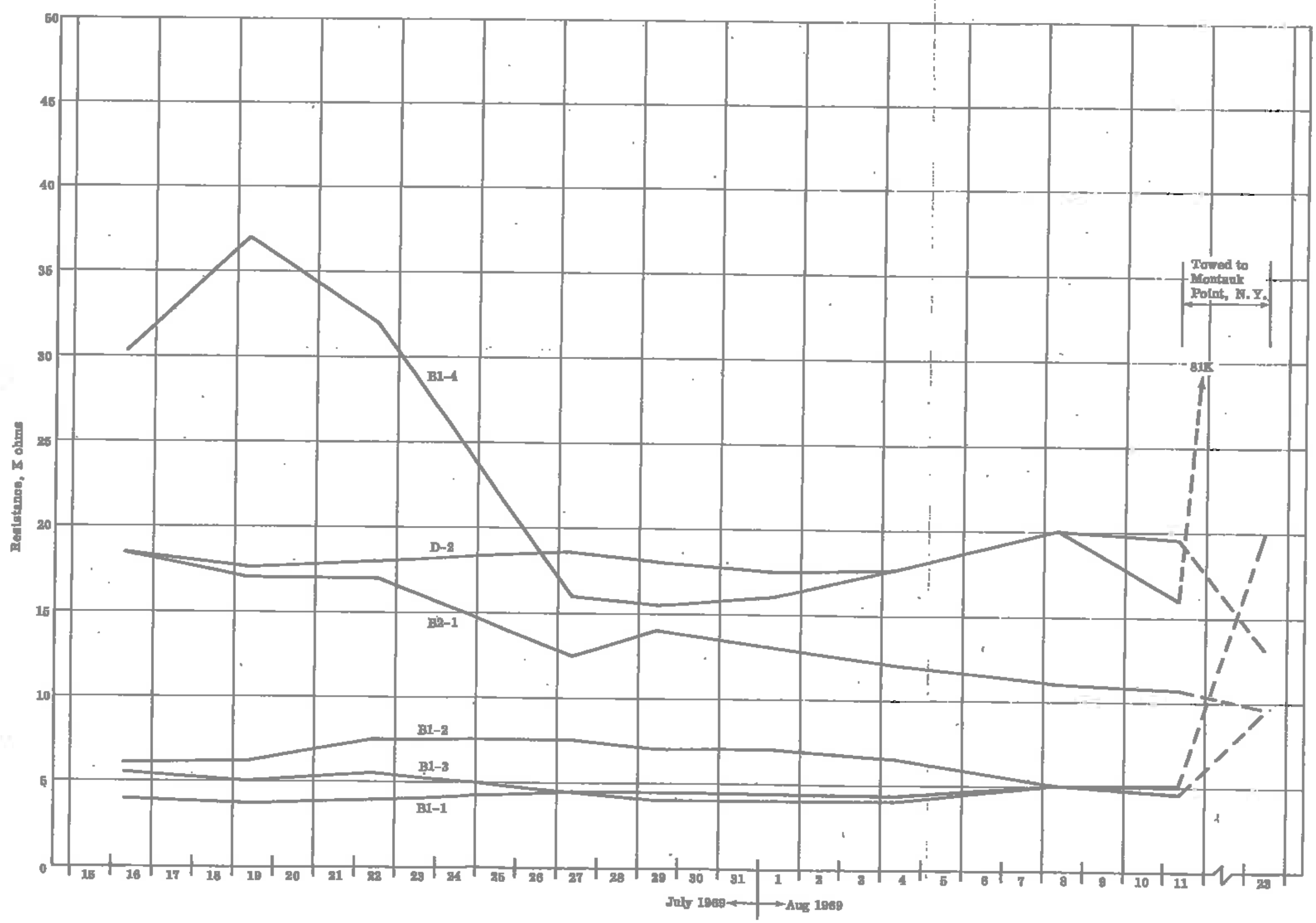


Fig. 5-17 Battery Ground Resistance Readings (Sheet 2 of 3)

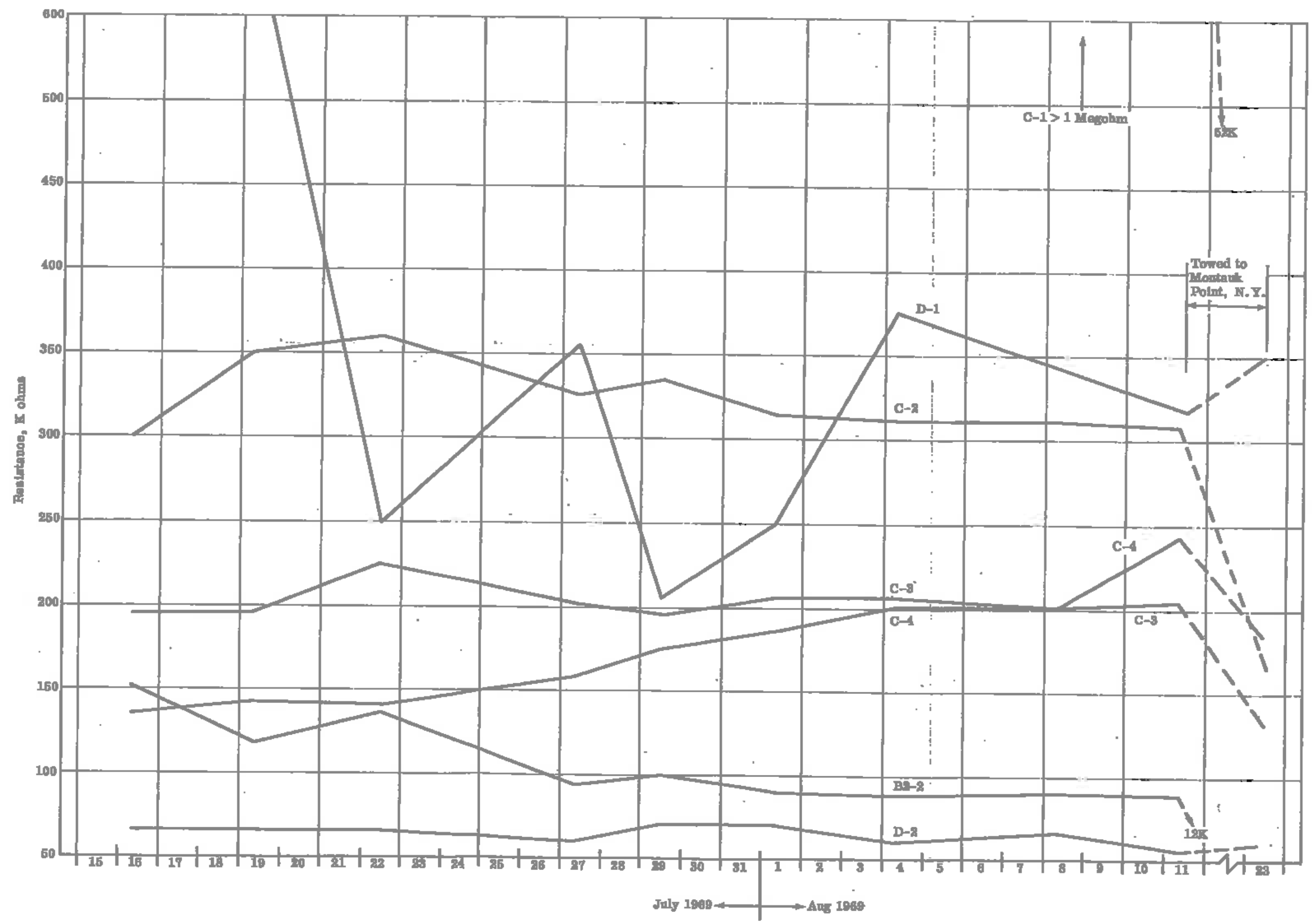


Fig. 5-17 Battery Ground Resistance Readings (Sheet 3 of 3)

6 NAVOCEANO EXPERIMENTS AND RESULTS

The basic scientific mission of the Ben Franklin was to perform synoptic oceanographic, geologic and biologic measurements of the Gulf Stream. Because of the varying depth of the Gulf Stream, the mission's scientific program was divided into two phases:

Phase I Drift and bottom excursions at pre-determined areas between Miami and Cape Hatteras.

Phase II Water column excursions and sampling experiments (acoustic, visual, water sampling, etc.) between Cape Hatteras and the mission termination point.

The experiments were scheduled for use as follows:

6.1 BEN FRANKLIN MEASUREMENTS AND EXPERIMENTS

Phase I - Miami to Cape Hatteras

- Continuous Measurements
  - a) Water sensor POD - (WASP) Sound Velocity, Temperature, Salinity
- Periodic Measurements
  - Ambient light
  - Light Transmission
  - Gravity
  - Magnetic Field
  - Current Velocity and Direction
  - Ambient Noise
- Periodic or One-Time Measurements
  - Sub-Bottom Structure - Sub Bottom Profiler
  - Bottom Topography
    - Side Scan Sonar
    - 35 mm Stereo Photography
    - 70 mm Stereo Photography
    - Visual Observations During Bottom Excursions
  - Biological Observation and sampling

Phase II - Cape Hatteras to Mission Termination

- Continuous Measurements
  - Water Sensor POD

- Periodic Measurements
  - Gravity
  - Magnetic Field
  - Ambient Light
  - Light Transmission
  - Water Current and Direction
  - Ambient Noise

- Periodic or One-Time Measurements
  - Water Column Observations
  - 70 mm Camera Photography
  - Visual Observations

  - Volume Reverberation Studies - NEL Acoustic System
  - False Target Studies

6.2 SURFACE SHIP (USNS LYNCH) SURVEYS/MEASUREMENTS

The USNS Lynch was equipped with an XBT temperature probe system. This system, utilizing surface-dropped thermistor probes allows rapid determination of temperature in the vertical axis to depths of about 500 meters.

Personnel aboard the Lynch were kept informed of the rate and direction of the Ben Franklin's drift as well as the temperature at the drift depth. Once or twice per day Lynch would leave the tracking ship, Privateer, to make a tempertaure section across the Gulf Stream. Temperature transect positions were selected based on the Ben Franklin's drift rate and directions. The timing of these temperature recording runs was planned to coincide with the Ben Franklin drifting through the section just as it was being completed. See figure 5-6. Thus, meaningful positional information could be relayed to the submersible. This temperature-based positioning method was successful, and played a key role in operational decisions made throughout the mission.

The geographic scale of the Gulf Stream Drift Mission precluded placement of a network of navigational or positioning transponders. Thus it was necessary to devise a method of, not only tracking the submersible, but, also insuring that the Ben Franklin remained within the Gulf Stream. Instruments on the submersible allowed the crew to measure temperature, salinity, pressure and sound velocity. Studies showed that the temperage change rate in all dimensions was the most sensitive indicator of the Ben Franklin's lateral movement within the Gulf Stream.

6.3 DATA COLLECTION AND PROCESSING

Almost all of the NAVOCEANO program was accomplished and the data, at this time in the raw stages, indicates that a substantial increase in the understanding of the Gulf Stream System will result. In addition to the measurements conducted by the Ben Franklin, the USNS LYNCH and pursued an oceanographic research program of her own which was designed to assist and augment the Ben Franklin program.

The following data were collected during the 30-day drift mission:

- Approximately 900,000 temperature, sound velocity and salinity measurements were recorded with time and depth. The water sensor POD recorded on magnetic tape each parameter every two seconds. The data has been "dumped" and at least 80 percent looks good. The problem with the other 20 percent appears to be due to uneven tape take-up on tape recorder, however, this portion of data may still be salvaged. The rest of the data is being screened and reduced to a more workable number on a digital computer. The screening program will also calculate water density and rate of change of the parameters along the drift track. Correlation of this insitu data with surface collected water column measurements (XBTs, etc), will allow analysis of the Ben Franklin performance in terms of the changing ocean environment.

- Three miles of the bottom were mapped by the side scan sonar and 848 stero-photographs of the bottom were taken at five different locations.

- The Gulf Stream current was measured continuously by tracking the Ben Franklin over the entire 30-day mission. In addition, a total of six hours of insitu current measurements were made while the Ben Franklin was bottomed.

- Over 371 hours of ambient light measurements from the Ben Franklin and the Privateer were recorded on the Wasp's mag tape.

- Two hours (4 miles) of magnetic anomalies were recorded on paper strip charts.

  Over 1,100 bottom reflectivity and volume reverberation measurements were made by setting off explosive charges from both the Privateer (blasting caps) and the USNS Lynch (SUS charges). The direct and bottom reflected pulses were recorded on magnetic tape on board the Ben Franklin. Based on preliminary analysis of the tape the data looks very good.

- Approximately 24 hours (50 miles) of gravitational anomalies were recorded on strip chart recorder aboard the Ben Franklin.

- The USNS Lynch traversed the Gulf Stream 41 times dropping expendable bathythermographs resulting in 500 temperature depth profiles. See Figures 5-5 and 5-6, for examples of the data obtained.

- Three surface temperatures transits were made using an airborne radiation thermometer to assist in positioning Ben Franklin in the Gulf Stream.

  The Ben Franklin crew spent a minimum of 360 hours directly viewing and selectively photographing the organisms within the water column. Surprisingly few fish were sighted during the mission. Figure 6-1 shows a photograph of a passing school of tunafish taken in ambient light at 600 feet. Twenty-four plankton sampling tows were made from the USNS Lynch. Twenty-four Deep Nansen casts were also made to assist in positioning Ben Franklin.

- The sub-bottom profiler did not operate at any time during GSDM or test dives. The reason for this failure will be determined when the Ben Franklin is hauled from the water.

- The strobes on the 70 mm camera system seemed to be "out of sync"; a bad external wire-splice is suspected. Films are being processed, but no images expected.

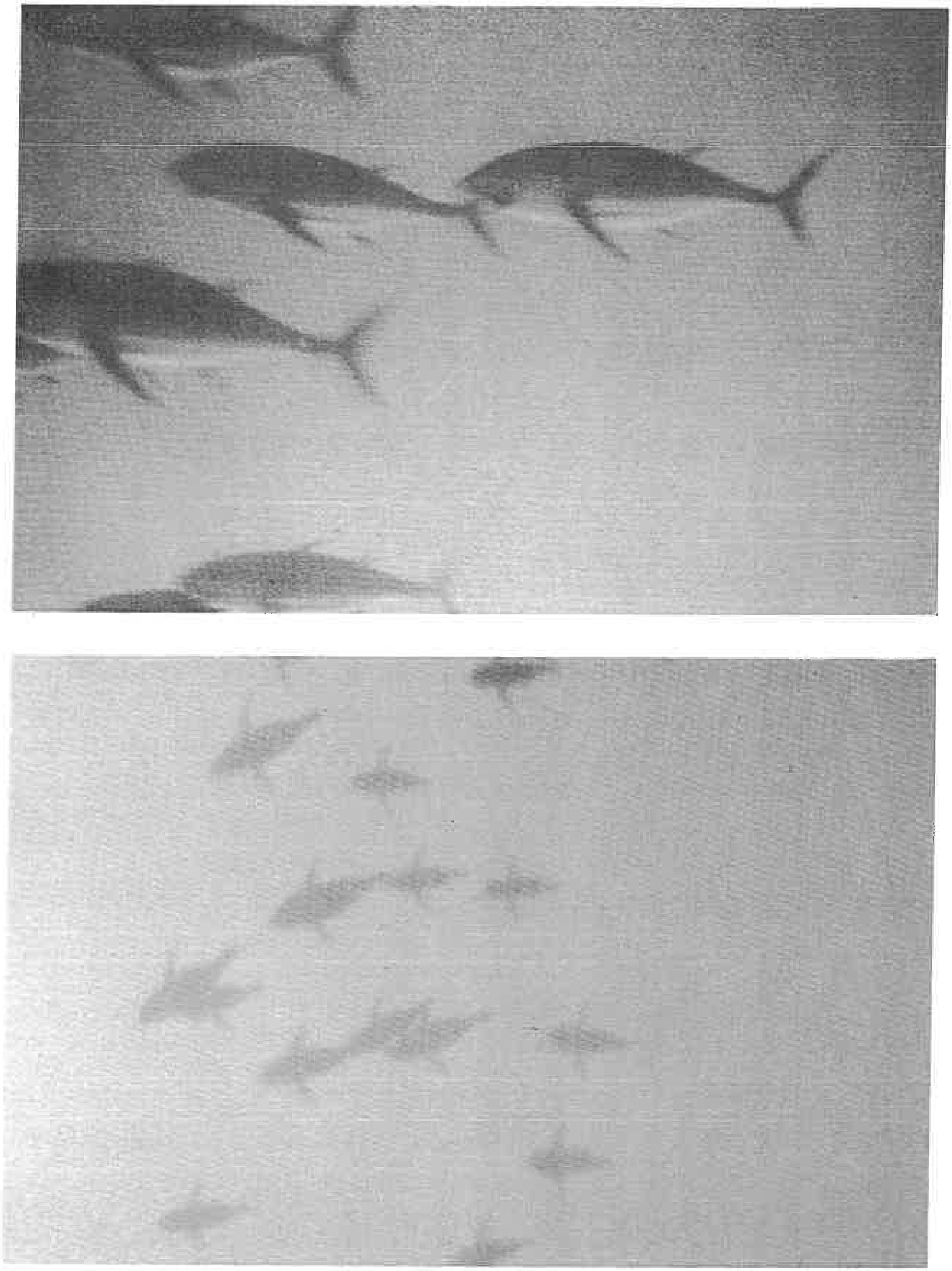


Fig. 6-1 Photographs of School of Tunafish Taken in Ambient Light at 600-foot Depth

The following general comments concerning the NAVOCEAN experiments were made by F. Busby:

- No deep scattering layer was detected along the path followed by Ben Franklin
- A notable scarcity of any form of sea life observed
- When the submersible was trimmed for a selected depth, vertical displacements of up to 100 meters were experienced as the vessel followed undulating isotherms
- A swordfish was observed to attack the vessel, reluctantly accept defeat, and retreat (similar to an occurrence experienced by ALVIN).

All the above data is being processed and analyzed, and will be reported on by NAVOCEANO in the following months.

7 NASA EXPERIMENT AND RESULTS

The operational activities of a submersible in performing research and living in the sea have commonality with space stations. System engineering studies have revealed that a submersible such as Ben Franklin could serve in the development of space station design criteria. NASA and Grumman jointly explored these commonalities during the drift mission.

Equipment and procedures were developed in preparation for the study and these were used to gather data about the onboard operations and crew performance. The following is an outline of the specific data collected.

Psychological Data Collected

- A tape recording of one hour of meal-time conversation each day and all the Ben Franklin-to-surface-ship communications
- A continuous photographic record of crew movements (one frame every two minutes) from three fixed cameras inside the vessel
- Measurement of sensori-motor performance by means of a device which timed a series of hand-foot-eye coordination tests
- A record of crew movements past selected key locations
- An organized diary of crew morale, health, and observations (kept by each crew member)
- A record of the ambient noise levels at selected locations on the vessel
- A record of the ambient light conditions at selected locations
- A daily record of the time each crew member spent in his bunk

Psychological Data Collected

- Tests of strength using a hand dynamometer
- Sleep measurements
- Pulse rate before and after exercise

Environmental Data Collected

- Hot water usage
- Cold water usage
- Gas chromatograph readings of atmosphere content

  Note: This data supplemented the environmental data required for crew safety (i.e., oxygen content, temperature, humidity, and carbon dioxide level)

Maintainability Data Collected

- Repair times were recorded as well as
  - Who did the work
  - What was done
  - What tools used

Since the completion of the Gulf Stream Drift Mission the data has been collated and the analysis started. Debriefings were held as soon after surfacing as possible. Baselines rechecked were:

- Personal profiles through individual interviews
- Physical fitness index
- Hand strength

The results of this study will be a detailed report to NASA.

8 GRUMMAN EXPERIMENTS AND RESULTS

8.1 SAMPLING FOR PHYTOPLANKTON

Two experiments were undertaken to establish the existence of phytoplankton in the Gulf Stream. The Egan experiment (Reference 3) was conducted aboard the Ben Franklin, by optically sampling the marine environment in situ. The Walker Experiment, conducted from the support ship Lynch consisted of physically sampling Gulf Stream water, with Nansen bottles or a Sears bucket and analyzing the samples in a lab aboard ship. Both experiments sought to detect bioluminescence and yellow substance. It was also suggested that some dissolved minerals in suspension might be detected along with the minute plant and organic material.

8.1.1 Optical Sampling Method

Irradiation of phytoplankton with near-ultraviolet light results in the emission of red light from chlorophyll cells in some phytoplankton. With a high-gain photomultiplier tube and a suitable amplifier, it is possible to record the fluorescence. The Egan experiment used ultraviolet lamps externally mounted on the Ben Franklin as radiation sources. When the lamps were turned on , Egan's photomultiplier tubes were powered and the resultant emission from fluorescing chlorophyll cells, yellow substance, and minerals could be detected. With judicious use of interference filters, the photomultiplier tubes were set up to discriminate between chlorophyll fluorescence, yellow substance, and mineral fluorescence.

The signals from the output of the photomultipliers were fed to a dc field-effect transistor amplifier, then recorded on a strip chart.

The long optical path length available to the photomultiplier detectors, and the in situ sampling arrangement (detectors mounted outside the Ben Franklin) are the salient features of the Egan Experiment.

8.1.2 Physical Sampling Method

The Walker Experiment took advantage of a laboratory environment and the availability of regulated a-c power. This gave the experimentor flexibility in choosing the amplifier, light sources and ancillary equipment necessary to make high spectral resolution measurements of the sea water in search of fluorescence and unusual absorption lines and bands.

Distilled water was used to calibrate the instruments prior to each spectral measurement. The absorption data on distilled water was normalized to 1, and the seawater data was then compared to the distilled water data. On the average, five water samples were optically examined daily from the outset of the mission until August 10, 1969. After the samples were examined with the spectral instruments, they were put under a microscope to determine visually if there was any particulate matter in the water.

A water sample taken from a Nansen bottle (cast from 0-300 meters) was put into a 12-centimeter cuvette. A xenon arc lamp (75 watts) irradiated the water sample through a quartz window in one end of the cuvette. A ground glass window at the other end of the cuvette, integrated the scattered radiation before it passed into a monochrometer for spectral analysis and detection by a photomultiplier tube. The resulting signals were then processed by an ac amplifier and recorded on a chart. Fluorescence and absorption data could be obtained by this method even if the signal levels were very low.

There were two disadvantages to the laboratory approach: (1) optical path length was limited to the 12 cm of the cuvette; (2) the water sampling with Nansen bottles was necessarily random as opposed to in situ sampling.

8.1.3 Results

Data from the Walker experiment is presented in Figures 8-1 and 8-2. During the mission, some discernable difference had been found spectrally between the distilled water standard and the seawater from various depths, but little in the red region where chlorophyll fluoresces. Common emission by all sea water sources at the sodium D line's wavelengths is notable. Examination of the Gulf Stream water samples under the microscope revealed no particulate matter, bearing out the belief that the Gulf Stream is probably phytoplankton poor (insofar as the sampling technique is efficacious.)

On August 4, 1969, the USNS Lynch headed into coastal waters and a surface seawater sample was taken (the bucket). Phytoplankton visibly abounded in the water and definite broadband absorption and emission of visible radiation was noted in the sample taken (See Figure 8-1). The sample was saved and the experiment was run again about four days later (See Figure 8-1). Stronger absorption bands were noted. The analysis of this data is continuing.

The data from the Egan experiment is not yet available.

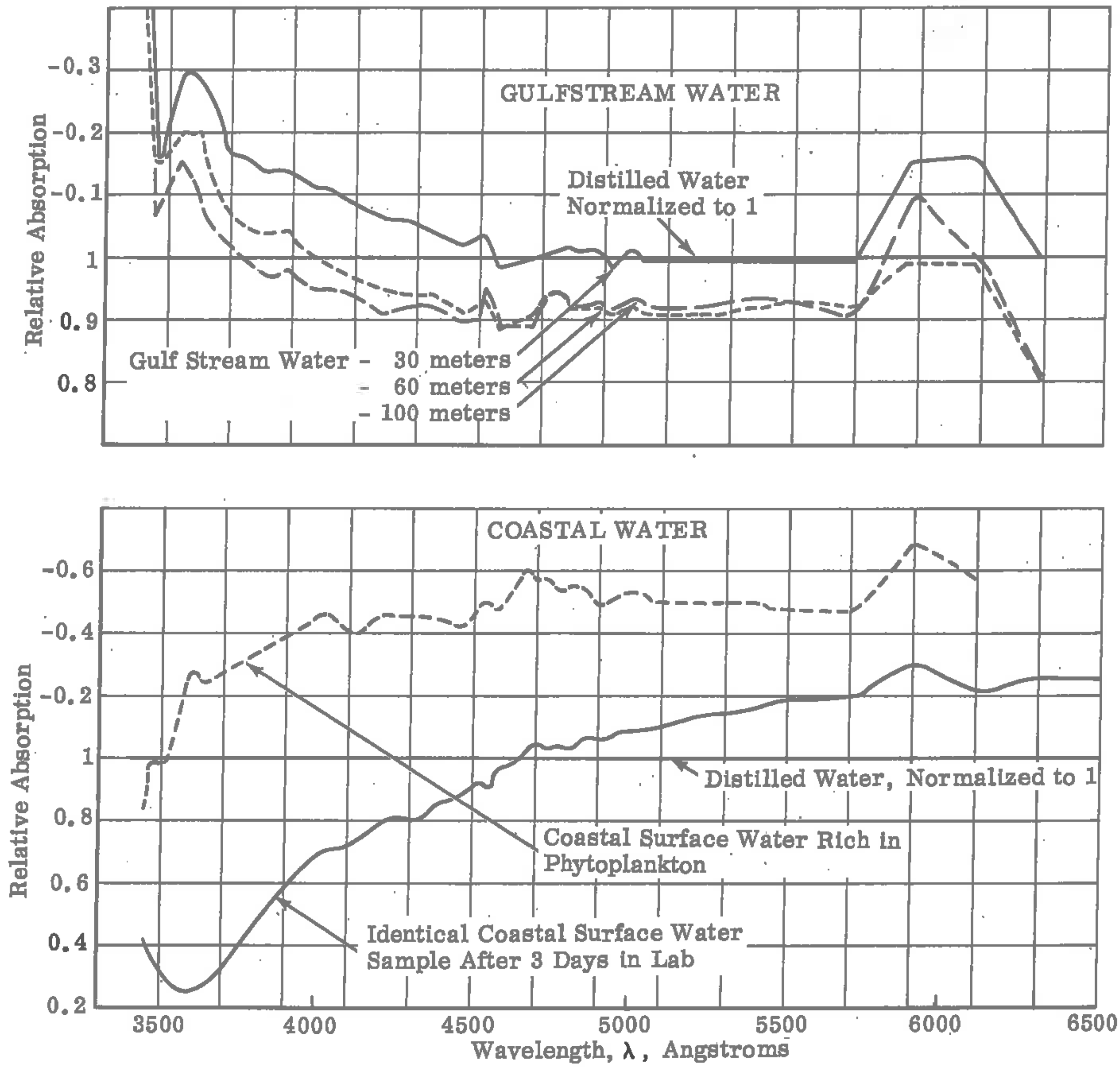


Fig. 8-1 Absorption of Visible Radiation by Coastal Water and Gulfstream Water

8.2 MICROBIOLOGY STUDY

A microbiology study of the crew and Ben Franklin was conducted as part of the investigation of space station and a submersible similarities. Special procedures were developed during test dives prior to the mission to enable the crew to monitor and control microbiological contamination. The NASA observer onboard was trained to monitor:

- Human Flora (using swabs and Rodacs)
- Environmental Flora (using Rodacs)
- Atmosphere (using Anderson Sampler and Gas Chromatograph)
- Water Flora (using Millipore field monitors)

A total of 2700 microbiological samples were taken during the premission, mission, and postmission phases. (During the mission, 1900 samples were obtained.) The last samples taken are still being developed in the microbiological and analytical laboratories at Grumman. A detailed report is being compiled on the findings, however some preliminary observations are described below:

Human Flora: Microbial counts on the crew garments, performed after termination of the mission, showed less than 20 organisms per plate with the exception of socks and undershorts which ranged from 20 to "too numerous to count". The organisms most frequently observed were gram positive cocci. The garments had all been pretreated with the antimicrobial agent, "Microgard" to minimize the growth of micro organisms on the skin and fabric. Results of skin swab samples from the crew during the drift show a reduction of the number of organisms after each change of garments. See Figures 8-2 and 8-3.

Food Monitoring: Microbiological testing by standard plate count method resulted in two sets of data: one indicative of the food loaded on board; the other indicative of the food recovered after the drift. In general the foods examined showed microbial counts ranging from 5-to-500 organisms/gram, with Bacillus being the dominant genus. Of 30 foods tested, only three were over 500 organisms/gram. There was no noticeable increase in the microbial count from the food during the mission, nor a change in the type of flora.

Atmosphere Monitoring: An Anderson air sampler, which draws 2 cfm of air through a stack of seven plates with different micron size holes, was used to monitor the cabin atmosphere. It was operated eight times during the mission in different locations in the

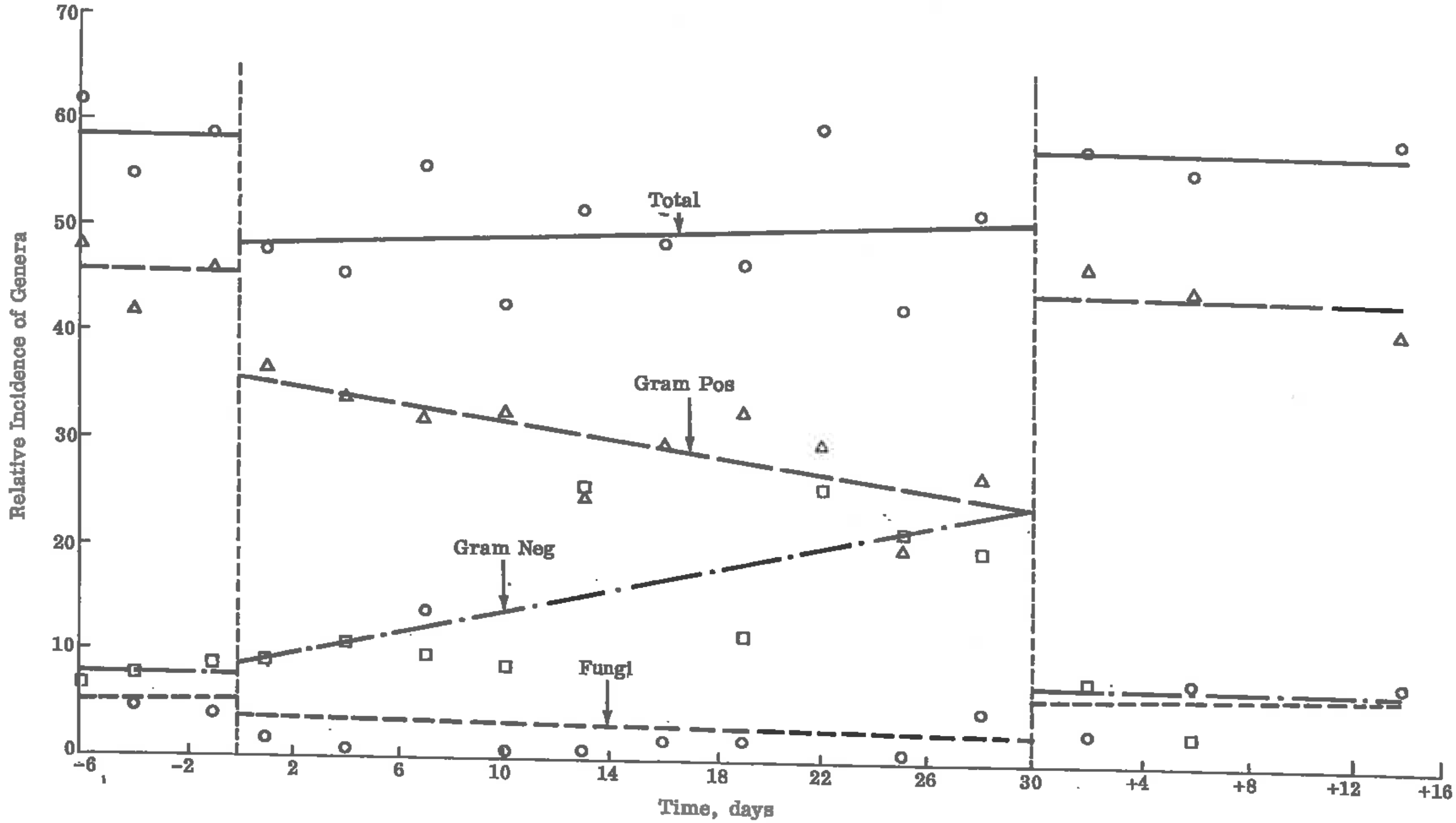


Fig. 8-2 Total Body Shift

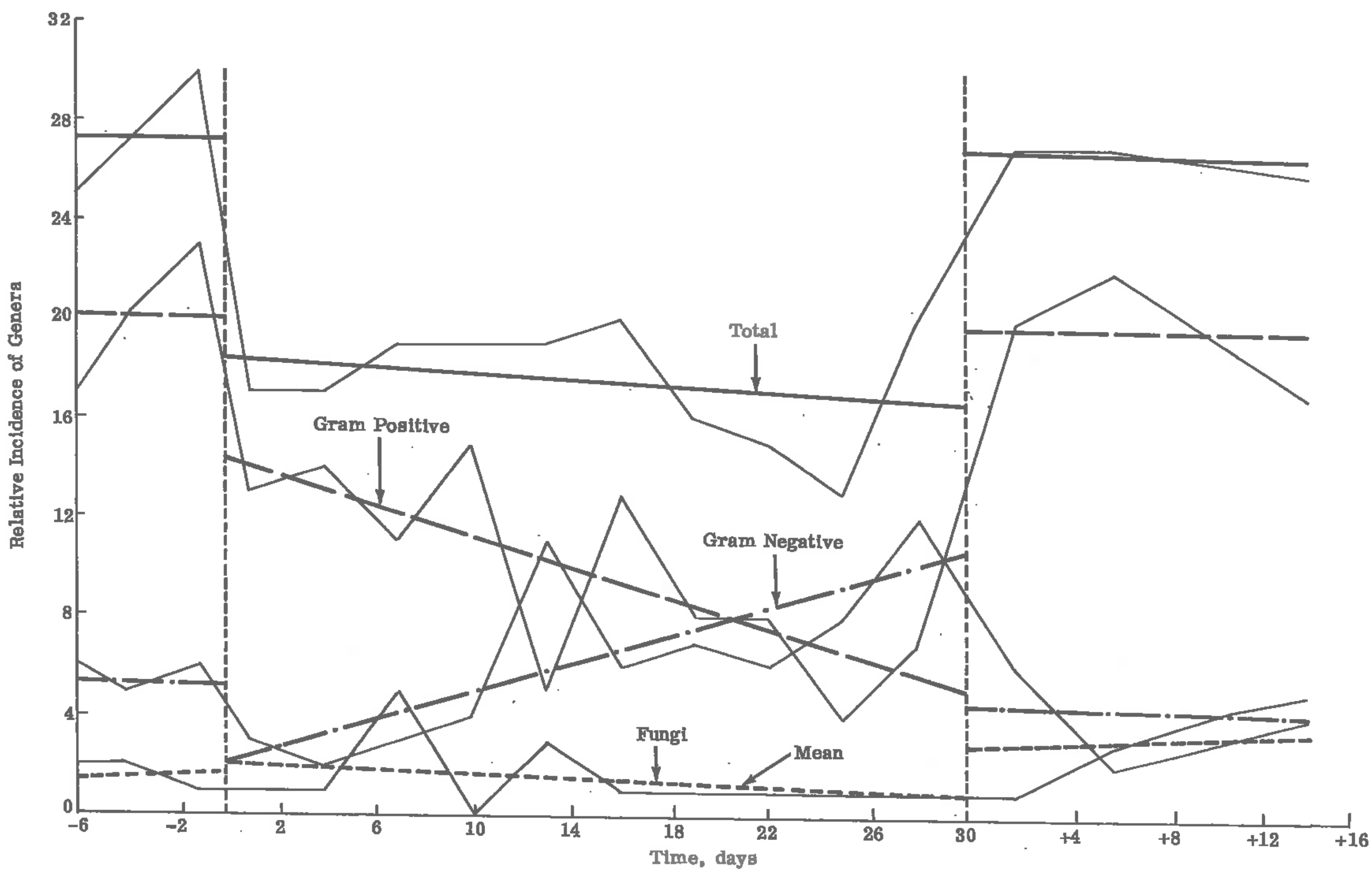


Fig. 8-3 Nose, Throat and Ear Shift

vehicle. Total counts ranged from 3 to 314 organism/cu ft. Aspergillus and Micrococcus were the predominant organisums. Aspergillus was expected since it had been discovered once before in its sporulating form at the end of a 3-day test dive. Pseudomonus was also present in the air as well as the water system.

Water System Monitoring: Microbial protection of the cold water system by means of a 7-to-8 ppm concentration of iodine was attempted, but after several days, no iodine could be detected, and contamination resulted. Pseudomonis was found predominent in the cold water system and shortly thereafter appeared on the crew members skin. The hot water remained sterile throughout the mission.

9 REFERENCES

1. Grumman/Piccard Ben Franklin Gulf Stream Drift Mission (Plan) OSR-69-14

2. Ben Franklin System Description, Ocean Systems Department, Grumman Aerospace Corporation

3. RM455J, Manned Submersible Optical Remote Sensing Within The Gulf Stream, W. J. Eagan, 1969

A APPENDIX

BEN FRANKLIN DESCRIPTION*

A.1 GENERAL

The Ben Franklin is a large submersible displacing 150 tons, and providing over 3500 cubic feet of internal volume. Payloads of more than 18,000 lb can be carried to depths of 2000 feet. Batteries provide 756 kwh of energy, while the life support system has been designed for missions of four weeks or greater. The propulsion system, 100 hp in four propulsion pods, is capable of providing speeds up to 5 knots. The interior arrangement and instrumentation for the drift mission are shown in Figures A-1 and A-2.

The interior is basically divided into the following three areas.

- Observation, Mess and Vehicle Control Area (forward)
- Life support, Sanitary Facilities, and Electrical Conversion and Distribution Equipment area (amidships)
- Scientific Equipment and Crew Berthing Area (aft). A total of six berths are provided

VEHICLE CHARACTERISTICS

Submerged displacement	299,000 lb
Lightship weight	264,000 lb
Length	48 ft 9 in.
Beam – without motors	13 ft 4 in.
– with motors	18 ft 6 in.
Height	20 ft 0 in.
Draft – hullborne	11 ft 8.5 in.
Pressure hull interior diameter	10 ft 1 in.
Access hatches	30 in. dia. (2)
Maximum operational depth	2000 ft
Collapse depth	4000 ft

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* See Reference 2 for a complete systems description

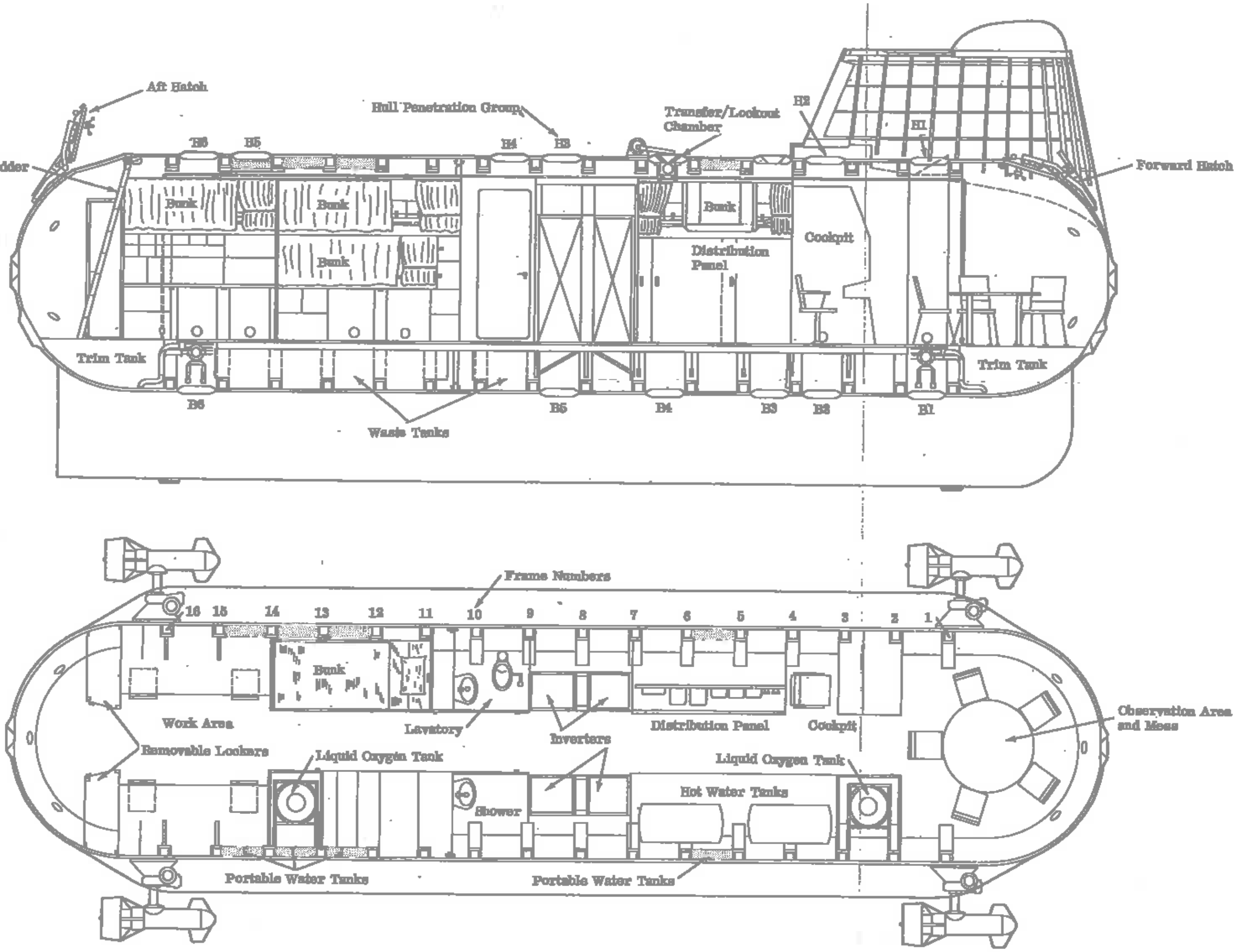


Fig. A-1 Ben Franklin Inboard Profile

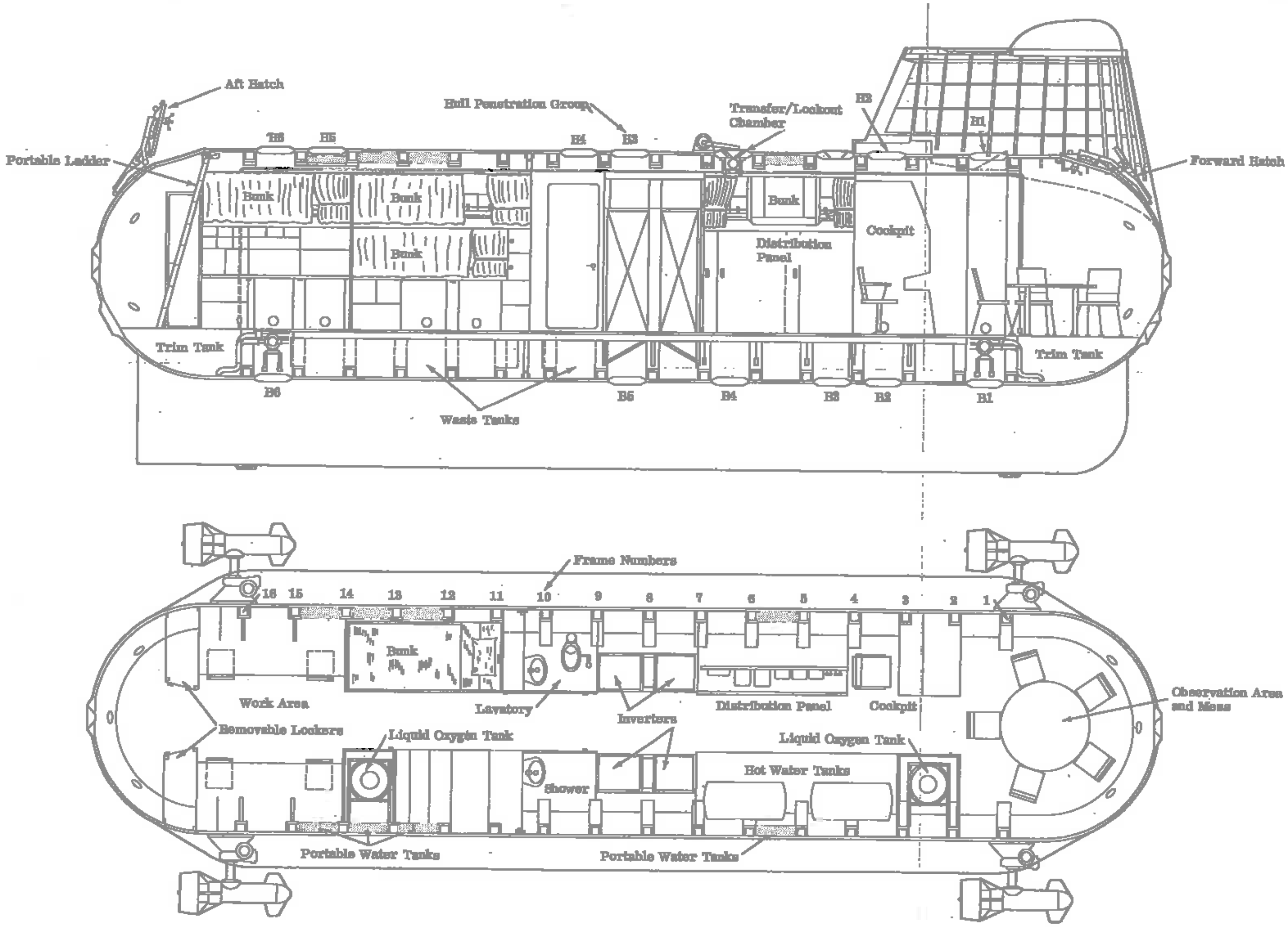
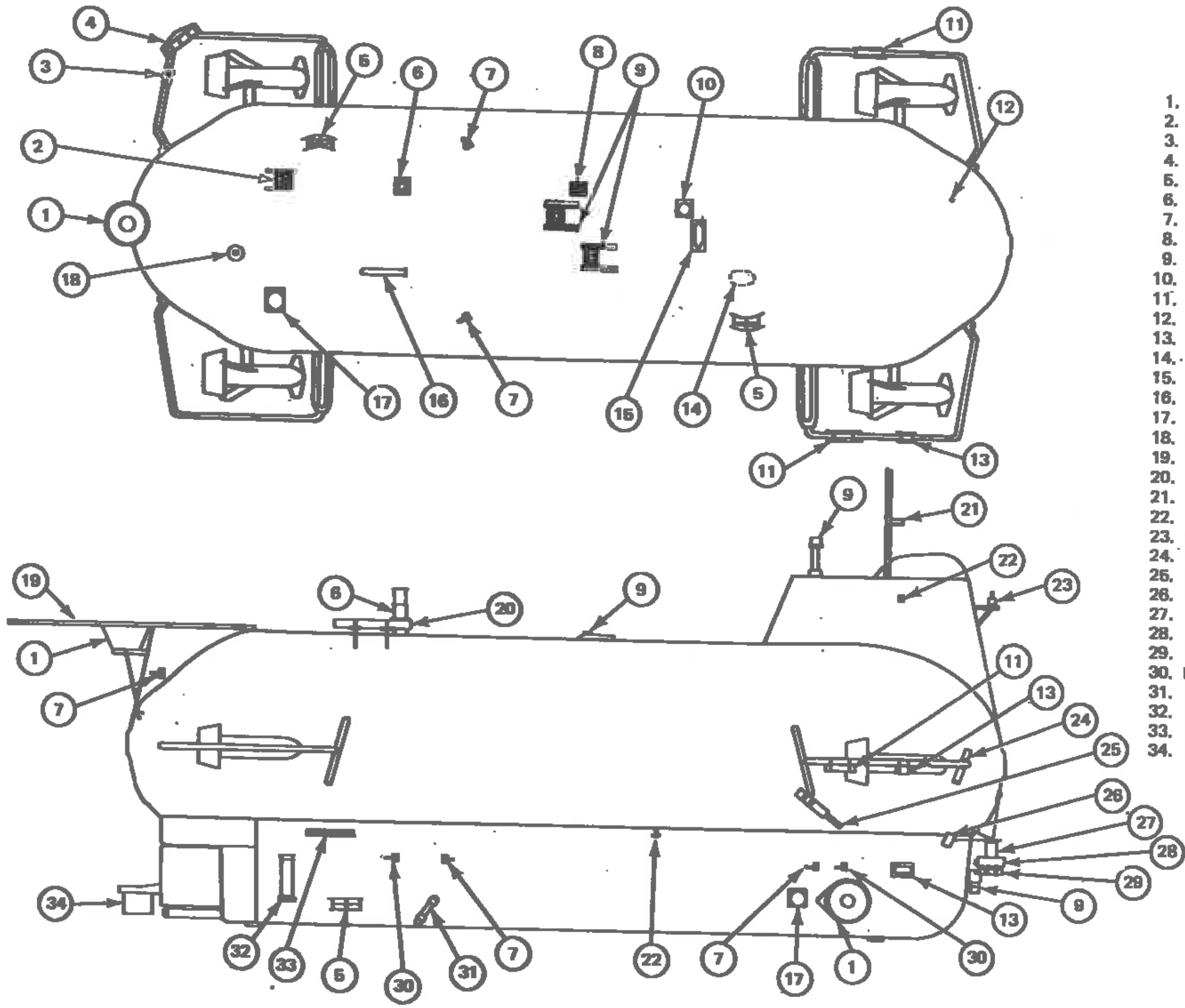


Fig. A-1 Ben Franklin Inboard Profile



KEY

1. 3.5-KHZ TRANSDUCER
2. WET AMBIENT SENSOR PACKAGE
3. ULTRAVIOLET LIGHT
4. PHOTO MULTIPLIER
5. ANEMOMETER CLUSTER
6. CURRENT METER
7. 250-WATT HALOGEN LAMP (10)
8. 16-KHZ TRANSPONDER
9. UNDERWATER TELEPHONE
10. 4-KHZ TRACKING BEACON
11. 1000-WATT MIXED GAS ARC LIGHT (2)
12. CTFM TEST TRANSDUCER
13. 1000-WATT HALOGEN LAMP (6)
14. MIXED GAS LAMP BALLAST
15. FATHOMETER
16. AMBIENT LIGHT SENSOR
17. 12-KHZ TRANSDUCER
18. 27-KHZ PINGER (RANGING & TRACKING)
19. AMBIENT NOISE SENSOR
20. TRANSMISSOMETER
21. VELOCITY PROBE
22. TEMPERATURE SENSOR
23. CTFM SCANNER
24. 70-MM STROBE LIGHT
25. SEA-ARC LIGWT
26. 350-WATT THALLIUM IODIDE LIGHT (3)
27. PAN & TILT MECHANISM
28. 70-MM CAMERA
29. TV CAMERA
30. 500-WATT HALOGEN LAMP (6)
31. 35-MM STROBE LIGHT
32. 35-MM CAMERA
33. SIDE-SCAN SONAR
34. SUB BOTTOM PROFILER

Fig. A-2 Gulfstream Drift Mission Oceanographic Instrumentation

Battery capacity (1000 hr rate) — 756 kwhr total

Consisting of:

- Group A, ± 168 volts (336 volts total) - - - - 336 kwhr
- Group B, ± 112 volts (224 volts total) - - - - 224 kwhr
- Group C, 28 volts - - - - - - - - - - - - - - - - 112 kwhr
- Group D, 28 volts - - - - - - - - - - - - - - - - 84 kwhr

A.2 PRESSURE HULL

The structural arrangement of the pressure hull consists of a ring-stiffened cylinder with hemispherical end closures. The internal dimensions are approximately 10 feet 1 inch by 48 feet 6 inches. Two 30-inch diameter hatches with viewports are provided, one at the upper portion of each hemisphere. A small lockout/transfer chamber with viewport is located on the vertical centerline amidships. In addition, 12 viewports are provided in the hemispherical ends, and 15 viewports along the cylindrical section - 29 in all. Twelve multipenetration reinforcements are available; six along the upper centerline and six along the lower. A substantial number of hull penetrations are reserved for future uses (e.g., cable, pipe and coaxial lines).

The hull is fabricated of 1-3/8 inch thick steel plate having a yield strength of 78,500 psi. Structural rings spaced uniformly along and inside the hull provide sufficient support to the shell to permit safe operation to depths of 2,000 feet while maintaining a margin of safety of two on hull collapse. The box frames are 6.3 inches by 5.7 inches deep and are spaced 27.5 inches apart. The combination of hull plating and reinforcement provides a hull bulk modulus in excess of 400,000 psi.

With the exception of a hull mechanical joint located in the amidships area, the basic structure is completely welded. After fabrication, the two hull sections were stress relieved. To preserve the stress relief, no future weldings may take place on the pressure hull; however, additional attachment clips have been provided on the hemispherical ends.

A.3 LIFE SUPPORT SYSTEMS

With the possible exception of temperature, humidity control and oxygen masks; the life support systems, as presently configured, are adequate for a complement of up to 12 persons for short periods.

A.3.1 Waste Management

The waste management system chemically treats and stores metabolic wastes on board. In this manner, minimum power is required and there are no hull penetrations. The system requires no power except for the odor removal unit and a macerator, both of which are operated for very short intervals. All pumping and flushing is accomplished by manually-powered mechanisms. Wastes are stored in tanks located below the floor between ring sections. The six tanks have a capacity in excess of 6000 pounds.

A.3.2 Air Purification

Purification of air requires control of CO_2, odor, and contaminant levels, the latter being generated by man's metabolic process and by the equipment and materials within the hull. Lithium hydroxide (LiOH) is used for CO_2 absorption. To conserve electrical power, LiOH panels are located throughout the vehicle so that the natural convective currents within the cabin circulate through them. These panels also contain activated charcoal for odor and certain contaminant removal.

Required LiOH panel weight has been calculated at four pounds/man day. Contaminants which are not processed by the charcoal are neutralized by a portable, active odor removal unit which consists of a blower, a chemical absorbing section and a chemical oxidizing section. This unit will be activated periodically whenever the contaminants reach significant levels.

A.3.3 Temperature and Humidity Control

Temperature control of the Ben Franklin is accomplished passively. Heat generated internally passes through the uninsulated hull of the vessel and is picked up by the sea water. Control in this manner is only possible in water warmer than 50°F (e.g., the Gulf Stream). Operation in cooler water down to 30°F; will require a combination of boat insulation, proper clothing and a separate heat source. The specific combination of these items is dependent on the sea water temperature and the operational profile of mission equipments.

Humidity is controlled passively with a desicant (silica gel). Silica gel is deployed throughout the vessel to maintain the relative humidity between 50 and 65 percent.

A. 3.4 Emergency Equipment

In addition to first aid equipment, an emergency O_2 supply and fire-fighting equipment are provided. The emergency O_2 supply is provided in the event smoke or any other irritant enters the vehicle atmosphere. Though only minutes are required to surface and open the hatch, provision has been made for a four hour emergency oxygen supply. Six masks are provided. The masks are fueled with super oxide which simultaneously removes CO_2 and generates O_2.

Standard, wall-mounted chemical type fire-extinguishers are provided.

A.4 BALLAST AND BALLAST CONTROL SYSTEMS

Two systems of ballast control are provided; the main ballast (MB) system for maintaining freeboard on the surface and the variable ballast (VB) system for ascent/descent and precise depth control.

MB compressed air is vented to the sea after use. VB air is normally vented to the sea, but alternatively may be vented into the hull interior. An on-board compressor can then recompress it and return it to the circuit.

An emergency droppable shot ballast system provides emergency ascent capability in the event of power failure, the vessel is "stuck" on the bottom, or complete exhaustion of the compressed air supply.

Major external elements of the ballast systems can be removed from the hull to facilitate overland transportation.

A.4.1 Main Ballast System

Four "soft" fiberglass main ballast tanks are mechanically attached to the hull, two on each side, to provide additional buoyancy when the vessel is surfaced. The additional buoyancy provides adequate freeboard for ingress/egress through either of the vehicle's two hatches. These main ballast tank assemblies are normally completely flooded during submerged operations. Diving from the surface is accomplished by permitting water to enter these tanks from the bottom while air is vented off at the top.

When surfacing, the top vents are closed and compressed air used to blow the tanks. The compressed air is carried in high pressure tanks located in the deck section.

A.4.2 Variable Ballast System

The limited compressibility of the hull and the use of compressed air and water in the VB system permits the crew to operate the vehicle at any desired depth without expending any electric power and with a minimum of subsequent ballast adjustments.

Variable buoyancy control is provided by pressure-resistant (hard) tanks located beneath the hull in the lower keel section. The vehicle is neutrally buoyant near the surface when these tanks are half full of water. Allowing water to enter, or blowing water out by compressed air gives vertical maneuvering capability for the vehicle within its operational depth limits. To arrive at a predetermined depth, sea water will be taken into the VB tanks. The actual amount of water ballast required to effect a change in depth is a function of pressure and salinity, as well as the ambient sea temperature and heat generated within the vehicle.

To reduce the boat's displacement, compressed air is let into one or more of the tanks, and water is driven out. To increase the displacement, this procedure is reversed and ambient sea water enters the tanks; the air thus displaced is normally vented overboard.

A.4.3 Emergency Ballast System

The emergency ballast system provides for the quick release of six tons of iron shot for positive buoyancy in the event of difficulty in surfacing by normal procedures. The shot is stored in bins between the forward and aft main ballast tanks and the release of shot ballast can be controlled either electrically or manually. The electromagnetic shot valves are divided into two sections. The upper section is made of steel having high magnetic retentivity. This section becomes magnetized when the field coils are briefly energized with 110V current. It retains its magnetic property for extended periods of time (like a permanent magnet), thus restricting the flow of shot without expending electrical energy. The lower section of the valve is a control coil which prevents the dropping of shot only when current flows through the coil. Shot ballast can be dropped at a constant rate by the electrical demagnetization of the upper section or in a small quantity by the demagnetization of the upper section and the intermittant activation of the control coil. In either case, shot drop is stopped by the remagnetization of the upper section.

In addition to the shot valve, a door is located at the bottom of each shot bin. This door is held closed by a hydraulically controlled system. Manual release of trapped oil on one side of each cylinder and/or oil pressure ported to the other side of each of two cylinders in the system will open the doors and all of the shot will be dropped. This system is totally independent of electrical power.

A.4.4 Pneumatic System

The pneumatic system is used to control the variable ballast tanks, to blow the main ballast tanks, and to blow the lockout/transfer chamber. High pressure air, stored external to the hull, in six 3000-psi flasks, totals 76 cubic feet. An electrically driven air compressor is provided inside the hull for added system flexibility. It is not normally used because of the electrical power required to compress a large quantity of air. Except for the solenoid vent valves on the main ballast tanks, all the valves controlling the pneumatic system are manual and are located within the pressure hull with tubes penetrating through the pressure hull.

A.4.5 Hydraulic System

A manually actuated hydraulic system pressurizes accumulators to operate the emergency ballast system and the lockout/transfer chamber hatch. The manual pump, reservoir, accumulators, shutoff and selectro valves are located within the submersible. Hull tube penetrations connect the actuators to the system.

The emergency ballast steel shot is contained in a hopper in each side of the vehicle, between the main ballast tanks. In an emergency, doors at the bottom of the emergency ballast hopper can be released. A manual selector valve ports the pump to wither the emergency ballast system or to the transfer chamber release hatch. A reversible rotary actuator outside the hull is used to open and close the transfer chamber hatch.

A.5 TRIM SYSTEM

The pitch-trim system enables the pilot to cope with changes in pitch by transferring water between two tanks located at the extreme ends of the hull. The system holds enough water (about 50 cu ft) to fill either of the tanks completely, and can correct pitch conditions as large as 10 degrees. The two tanks, transfer pipe, and transfer pumps are all located beneath the floor, and the two tanks are also connected by a vent line which passes overhead within the hull. The two 80-gpm electric transfer pumps are pilot actuated.

Careful attention is placed on the distribution of payload to ensure that full payload allowance is available for equipment and stores. Although no system is designated primarily for static list control, this can be achieved by asymmetric loading of the shot (emergency ballast) tanks.

A.6 RUDDERS

The rudders are located at the aft end of the keel. They are conventional, electronically operated, flat spade rudders. The rudders will normally only be operated while the boat is surfaced, but their position while submerged may be adjusted to act as a trim tab to compensate for current and drift.

A.7 PROPULSION SYSTEM

Propulsion is accomplished with four 25-hp motors. These motors are 220V, 3 phase, 50 Hz units manufactured by Pleuger. They are fresh water filled, pressure compensated, and operated by the two main solid-state inverters.

This configuration provides vehicle speed control and sufficient power or propulsion for a maximum speed of approximately four knots. In addition, the propulsion motors can be fully reversed and rotated in the vertical plane, thus providing up, down and reverse thrust capability. By applying forward thrust with the motors on one side of the vehicle and reverse thrust with the motors on the other side of the vehicle, the Ben Franklin can make still-water turns within its own length.

A.8 ELECTRICAL SYSTEM

A.8.1 Primary Batteries

Electrical power is supplied by lead acid batteries housed in the keel section. The system is pressure compensated to sea ambient. The battery consists of 378 two-volt cells which may be connected in series/parallel combinations and are subdivided into four basic groups. The total battery capacity is 756 kwh.

- Group A consists of six, 56-volt strings connected inside the pressure hull to provide ± 168 volts (336 volts total).

- Group B consists of two, 56-volt strings and four, 28-volt strings connected inside the pressure hull to provide 112 vdc power and either 28 vdc power or 224 volts, in series with Group C, for propulsion power.

- Group C consists of four 28-volt strings connected inside the pressure hull to provide either 28 vdc power or 112 volts, in series with Group B, for propulsion power.

- Group D consists of three 28-volt strings connected in parallel within the pressure hull to supply 28 vdc power.

A.8.2 Emergency Battery System

A separate battery system is installed inside the pressure hull to supply 28 volt power to the 28 volt dc bus in the event of loss of power from the external batteries. This power source consists of fourteen, 2-volt cells with lead calcium grids, having a capacity of 192 ampere-hours at 12-hour rate to 1.75 volts. Activation of this system is manual and disconnects all other sources of power from the bus prior to connecting the emergency battery.

A.8.3 Distribution System

The manual, six-position, master mode switch controls the primary selection and combinations of battery elements and directs these outputs to the boat's inverters and other equipment. Secondary selection capability is provided through the B-battery switch.

The primary load for dc power is the pair of variable-frequency, solid-state inverters which supply the main motors with ac power. The next heaviest load consists of the two fixed-frequency, solid-state inverters which power the pod positioning motors. The dc system also includes a 112-volt supply for the exterior lights and a 28-volt supply for onboard equipment, including general lighting.

The five basic loads are:

- Port, 60-kva propulsion inverter (Inverter 1)

- Starboard, 60-kva propulsion inverter (Inverter 2)

- Propulsion motor positioning system inverters (Inverters 3 and 4)

- 112 vdc lighting (external) and auxillary equipment
- 28 vdc lighting and internal equipment. Internal equipment includes two, 28 vdc-to-115 vac, 60 Hz inverters for limited use.

A.8.4 Inverters

Two solid-state static inverters, operating on 336 volts dc, power the four main motors. Two static inverters convert 168 volts dc to 115 volts ac for the pod positioning motors. The inverters are located amidships, but are controlled from the pilots station.

The main inverters are three phase and permit the reversing of the main motors. The output of the main inverters can be varied from 5 Hz at 70 volts ac to 50 Hz at 220 volts ac.

The secondary inverter's output is 115 volts ac at 60 Hz.

A.10 Lockout/Transfer System

The transfer system which is capable of passing parcels up to 5.5 inches in diameter, enables the crew to send exposed film or other objects of interest to the surface for pickup by support vessels. The system consists of the following:

- A hydraulically-operated hatch, flush with the top of the hull, opening outward
- A hull-strength pressure chamber bolted beneath it to the inside of the hull
- Pipes and fittings for blowing and flooding the chamber
- A supply of hollow, two-piece aluminum spheres.

To use the lockout system, the sphere is loaded, taped together with rubber tape, and put into the chamber through the bottom hatch, which is then dogged tight. The chamber is then flooded and the top hatch is opened. A window in the bottom hatch enables an observer to see that the sphere floats clear. The top hatch is then closed and the entrapped water blown out through a pipe to the sea by compressed air.