STATUS OF DATA BUOY DEVELOPMENT IN THE UNITED STATES

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1. In November, 1970, Captain Virgil Rinehart of the U.S. Coast Guard presented a paper at the Interocean-'70 [1] meeting in Germany on the subject of oceanographic instruments and network systems. In that paper he reported establishment of the U.S. National Data Buoy Project and outlined its objectives. At that time the project had just been established and had received its initial funds — technical goals and methods for accomplishing these goals were being formulated. Considerable progress has been made in the past two years. It is my purpose here to report that progress and attempt an assessment of the future.

2. The growing problems of low reliability and the proliferation of small-scale development programs for data gathering buoys led the United States in 1967 to establish this concentrated effort for improving the state-of-the-art. The combined difficulties of unattended operation in the ocean environment, communication over long ranges, and achieving reliable and accurate measurements are such that they can only be resolved by a significant coordinated engineering effort. This is the primary objective of the data buoy program.

3. The first task of the project, of course, was to review existing programs — something like 76 separate efforts world-wide. A concurrent analysis of the state-of-the-art [2] and needs for data buoy sensors was necessary. It was quite clear at the beginning that the major problem area would be encountered in the sensor area — and so this has become the central thrust of our first experimental program. The first major effort undertaken by the new project was to develop an integrated set of environmental sensors, match these with platforms suitable for prolonged test at sea and carry

out a rigorous series of tests to develop technical data required for a next generation of equipment.

4. It has not been expected that we would achieve a fully reliable operation in this first phase, but rather that we would learn enough about the problems to make a significant forward step in the next generation towards the goal of a completely unattended one year operation.

5. The first step, of course, was to decide what systems would be required, what parameters should be measured, and with what levels of accuracy. The parameters chosen are shown in table 1, together with desired levels of accuracy. It is important to note that the levels are those which we feel can be achieved reasonably. Also, they are goals which we expect to achieve in the next generation of equipment. Some, such as temperature and pressure, are reasonably well in hand now. Others, such as wave period and direction and water quality parameters, require considerable development.

6. How did we select these parameters to measure ? Surveys were conducted [3]. We held meetings of scientists, both oceanographic and meteorological [4] and with industrial data users [5]. We had extensive studies made of users in various sections of the country — particularly in the Gulf of Mexico [6] since this was our chosen area for tests. These included the oil industry, fishing industry, transportation, recreation, and many others. These studies not only told us what parameters were important, but told us of the particular need for information about the environment and revealed significant potential return from improved operating information or warning of hazards. In fact, comprehensive study of the Gulf of Mexico area indicates potential economic returns with a value of about 900 million dollars over a ten-year period, which can be achieved by improving real time data on cyclones, winter fronts, Gulf water circulation patterns, and general sea conditions off shore where little real time data is now available. Accordingly, our test program has been oriented to obtain the maximum possible benefit in this region.

7. An early decision was made to limit technical risks to those areas most in need of improvement. Accordingly, components for the engineering test program have been selected from those already known to be reliable insofar as possible. Examples of this philosophy are the selection of the large discus buoy at the test platform and the diesel generator as a power source. It may be that there are significant gains to be made by changing the hull configuration or by developing more reliable sources of power. We are looking at such improvements, but we are concentrating our efforts on achieving early reliable system-performance with the expectation that significant improvements can be separately developed and adopted later. Our overall plan is depicted by figure 1. You will note that we have planned three significant phases — the engineering test phase (just now starting), an engineering development phase, and a prototype development intended for general use when we feel the technology will support one year unattended deployment. This level of reliability is needed to make data buoy system costs reasonable because of the very high logistic costs

TABLE 1

Measurement requirements

LIST A

Meteorological	*Units*	*Range*	*Allowable System Error (RMS)*	
			design goal	*maximum*
Air temperature	°C	– 10 to 40	0.1	0.5
Air pressure	mb	900 to 1 100	0.1	1.0
Windspeed	m/sec	0 to 80	0.25 or 3 %	0.5 or 5 %
Wind direction	degrees	0 to 360	2.0 degrees	5.0
Dewpoint	°C	– 0 to 40	0.2°C	0.5
Global radiation	Ly/min	0 to 2	0.02	0.05
Precipitation	cm/h	0 to 20	0.025 or 1 %	0.06
Oceanographic				
Water temperature	°C	– 2 to 35	0.01	0.1
Water pressure	kg/cm^2	0.5 to 55	0.5	0.5
Salinity	‰	20 to 40	0.01	0.03
Sound speed	m/sec	1 410 to 1 580	0.3	0.5
Current speed	m/sec	0.1 to 3	0.05	0.1
Current direction	degrees	0 to 360	5.0	10.0
Significant wave height	meters	0 to 30	0.2 or 5 %	0.5 or 10 %
Wave spectrum	meters^2		0.2 or 5 %	0.5 or 10 %
Highly desired parameters whose measurement from an unmanned buoy is technically feasible.				

LIST B

Visibility	km	0 to 20	0.5 or 10 %	
Cloud base height	m			
Cloud amount	percent	0 to 100	10	
Electricity	kilo volts	0 to 10	0.01	
Ambient light	Ly/min	0 to 0.3	0.01 or 5 %	
Ambient noise	dB	– 80 to – 20	3.0	
Transparency	%/m	0 to 70	2.0	
Wave period	seconds	2 to 40	0.1	
Wave direction	degrees	0 to 360	5.0	
Water quality (dissolved oxygen, PH, chlorophl, etc.) Upper air (temperature, pressure and dewpoint) Parameters also highly desired, however, further development is needed from an unmanned buoy.				

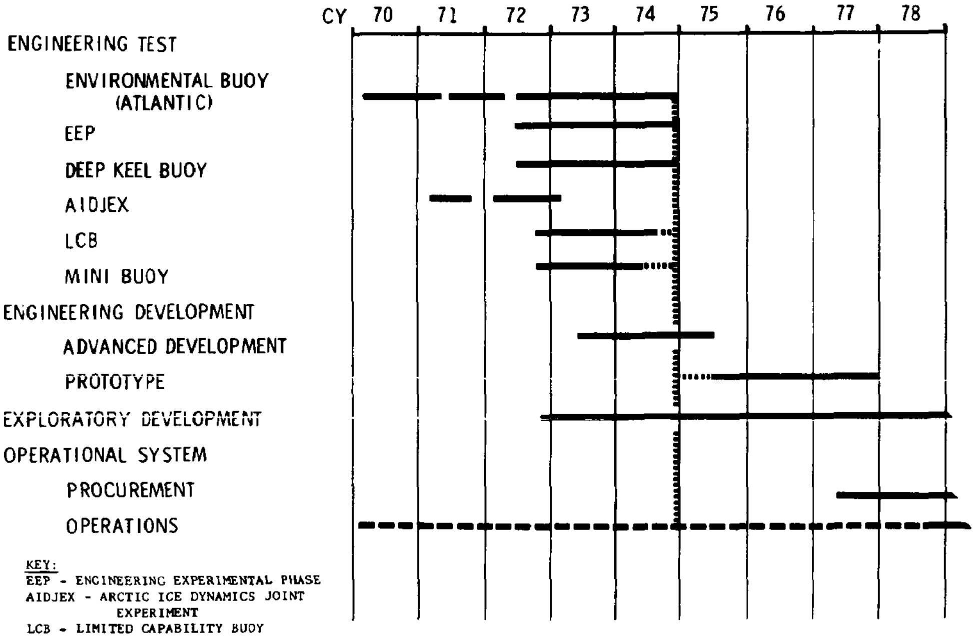


FIG. 1. — National data buoy development program.

of supporting systems at sea when they must be visited frequently. This is illustrated by the curve of costs versus service interval (figure 2) which comes from an early system analysis for a large number of high capability buoys.

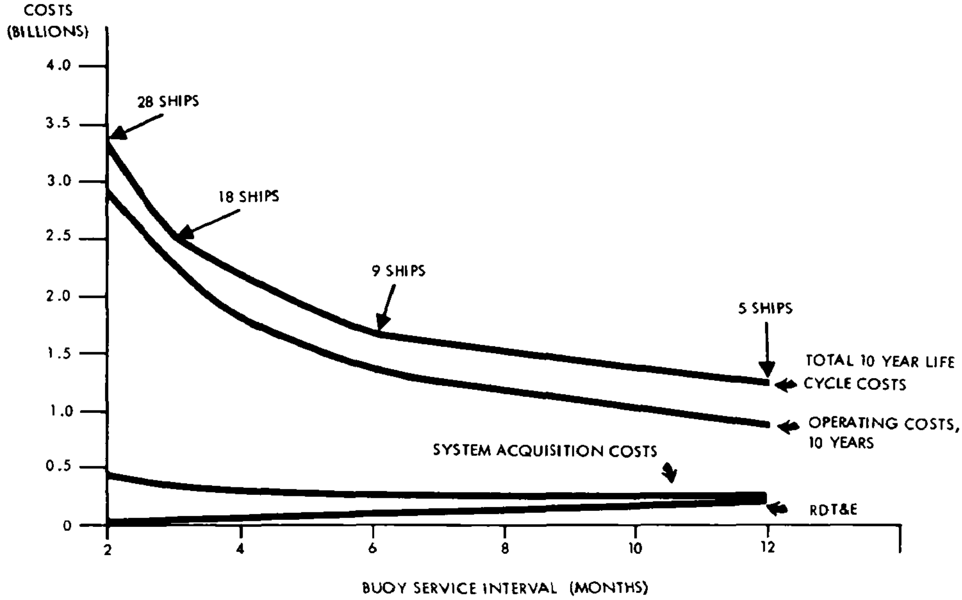


FIG. 2. — Cost vs. Buoy Service Interval for 300 Buoy System.

8. Recognizing the wide range of needs for data we are attempting to include a variety of capabilities in our development program. These range all the way from small, simple buoys measuring only a few parameters to major data acquisition systems which can handle a wide range of parameters both above and below the surface with a full communication capability. Systems developed and now undergoing test and evaluation include the large Engineering Experimental Phase (EEP) Buoy and the

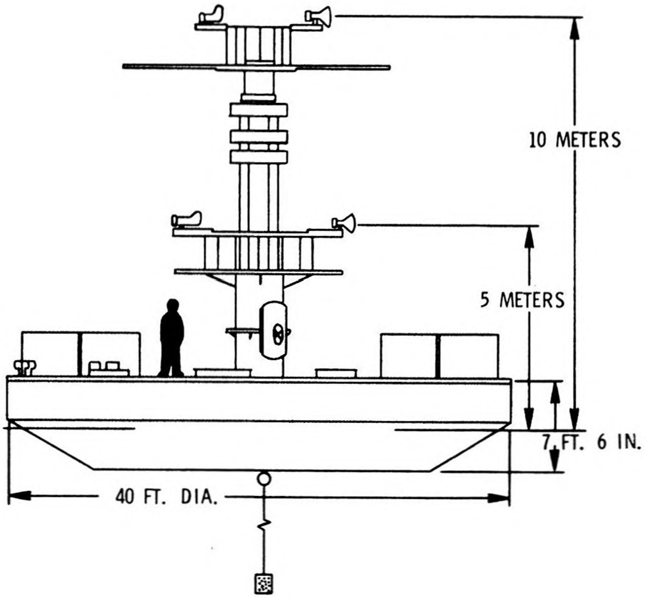


FIG. 3a. — EEP Platform Configuration.

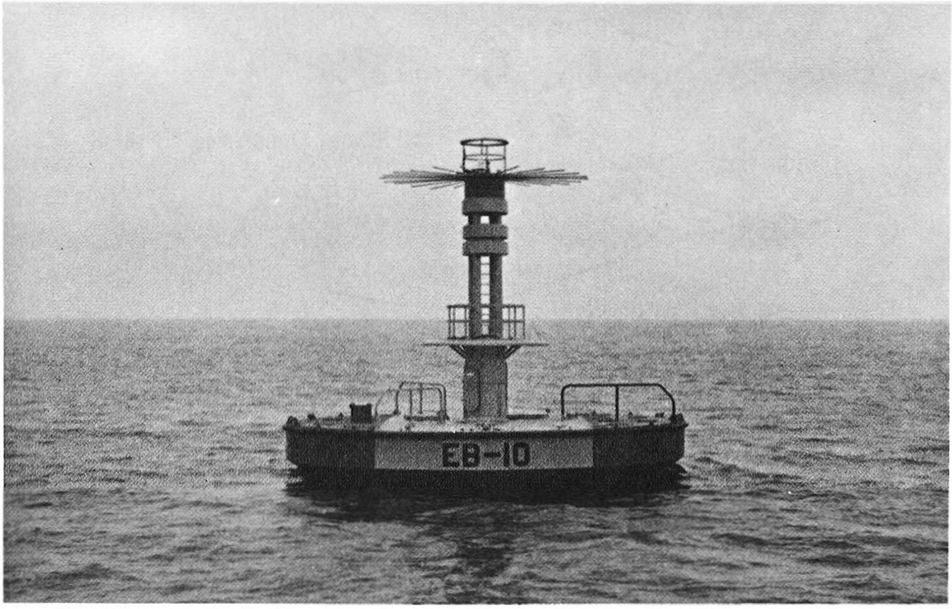


FIG. 3b. — EEP Data buoy moored in the Gulf of Mexico.

• Disc Hull Diameter	40′
• Disc Hull Depth	7′3″
• Mast Height	28′3″
• Displacement – Empty	50 Tons
• Displacement – Ballasted	100 Tons
• Draft – Ballasted	3′9″
• Mooring Line Data Line	1 700′ – 2″ Dia. Dacron + 8 Conductors

- Mooring Line for Specific Deployment Site
  - 8″ Dia. Steel Ground Plate
  - Latent Buoyancy Device
  - 2 1/8″ Dia. Nylon (Buoyed with 9 Floats)
  - Acoustic Release
  - 100′ – 2 1/8″ Nylon
  - + 90′ – 2 1/2″ Dia. Chain
  - + 2 – 7 000 # Mushroom Anchors in Parallel

Fig. 3c. — Design of EEP Hull and Mooring.

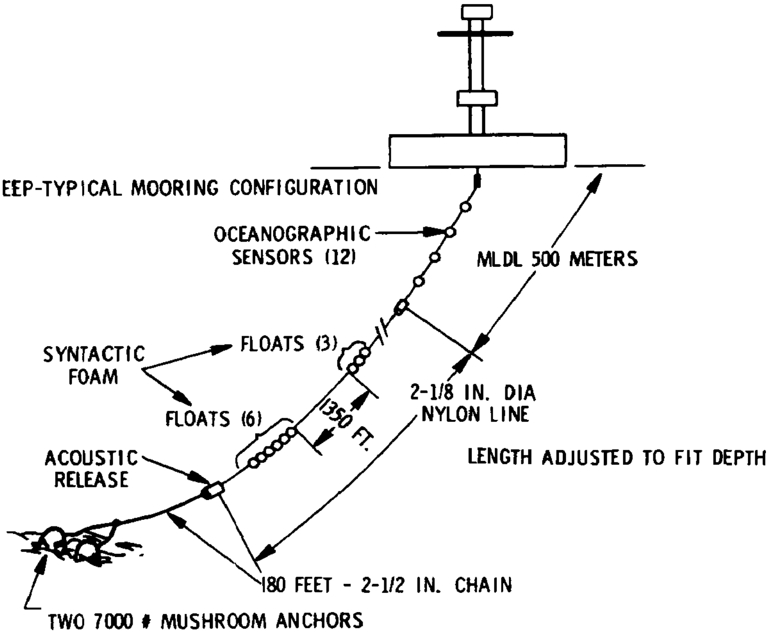


Fig. 3d. — EEP Mooring.

Limited Capability Buoys (LCB). Their characteristics are illustrated by figures 3a-i and 4a-d, respectively.

9. It is to be noted that the Limited Capability Buoys (LCB) are being developed in two versions — drifting and moored. Lockheed Missile & Space Co. is developing a moored LCB, Magnavox Inc. a drifting LCB and General Electric Corporation both drifting and moored LCB versions. Several

- Platform design : state-of-the-art
- Sensor design : improved state-of-the-art
- All digital data system
- HF communications link
- Synoptic report interval : 1, 3, 6 hours or on request
- Data averaging – 0 to 50 minutes
- Will operate under hurricane conditions
- Maintenance by module replacement
- Diesel engine/generator power system
- Performance goal : one year unattended

FIG. 3e. — EEP Design Features.

- **Meteorological**
  - Solid state (no moving parts except wind vane)
  - Self-contained electronics
    - – Data acquisition
    - – Short term data storage
- **Oceanographic**
  - Self-contained in titanium housing
    - – Inductively coupled to mooring line
  - Vaned on mooring line
  - Battery power – charged via mooring line
  - Complete electronics
    - – Some preprocessing of data

FIG. 3f. — EEP Sensor Features.

Meteorological

Parameter	*Range of measurement*	*Maximum allowable error (RMS) (see note 1)*	*Levels (meters)*
Global radiation	0–2 langleys/min	0.05 langleys/min	5–10 meters
Precipitation rate	0–20 cm/h	0.06 cm/h	10 meters
Air temperature	– 10 to 40 °C	0.5 °C	5–10 meters
Air pressure	900 to 1 100 mb	1.0 mb	5–10 meters
Dew point	– 10 to 40 °C	0.5 °C	5–10 meters
Wind velocity–N/S	0 to 80 m/sec	0.5 or 5 % of value (see note 2)	5–10 meters
Wind velocity–E/W	0 to 80 m/sec	0.5 or 5 % of value (see note 2)	5–10 meters

1. Maximum allowable system errors shown include sensor, ocean platform system, HF radio link and shore communication station errors.
2. *Whichever is greater.*

FIG. 3g. — EEP measurement requirements.

Oceanographic

Parameter	*Range of measurement*	*Maximum allowable error (RMS) (see note 1)*	*Levels (meters)*
Water temperature	−2 to 40°C	0.1 °C	12 levels down to 500 m
Salinity	20 to 40 parts per thousand (‰)	0.03‰	" " " "
Current velocity–N/S	0.1 to 3.0 m/sec	0.07 m/sec	" " " "
Current velocity–E/W	0.1 to 3.0 m/sec	0.07 m/sec	" " " "
Water pressure	0.5 to 55 kg/cm^2	0.5 kg/cm^2	" " " "
Sound speed	1 410 to 1 580 m/sec	0.4 m/sec	" " " "

1. Maximum allowable system errors shown include sensor, ocean platform system, HF radio link and shore communication station errors.

FIG. 3h. — EEP measurement requirements (Cont'd).

	Tropical	Sub polar
Surface current	3.2 m/sec (6.2 kts)	1.0 m/sec (1.94 kts)
Subsurface current	1 kt at 300 m	1 kt at 300 m
Wind	80 m/sec (155 kts) for 5 minutes	40 m/s (77.6 kts) for 5 minutes
Wave height (average height highest 1/3 of waves)	14 m (46 ft) for 6 hours	17 m (56 ft) for 6 hours
Ice	None	130 kg/m^2 (5 inch equivalent thickness)

FIG. 3i. — EEP survival environment.

models of each will be delivered this winter for test and evaluation. The LCB's differ from the EEP buoys principally in their reduced size, power capacity, sensor number and accuracy, data storage and processing capability, life (three months, drifting; six months, moored), survival and operating conditions and, of course, cost. It is expected that the LCB will be about one tenth the acquisition cost of the EEP buoy. In an attempt to further reduce the cost for special applications, "minimum" capability buoys are being developed by Nova University (figure 5), and Woods Hole Oceanographic Institution. These small buoys should be about one tenth the cost of the LCB. The costs are of course most sensitive to the sophistication of the on board data processing and the number of buoys to be procured. While we are unable to place exact costs at this point it looks like the range of acquisition costs will be upward from about $ 5000 for the small drifting buoy in the approximate ratio indicated above.

10. An experimental spar buoy shown by figure 6, for polar applications, has also been developed. Six buoys are being tested as part of the Arctic

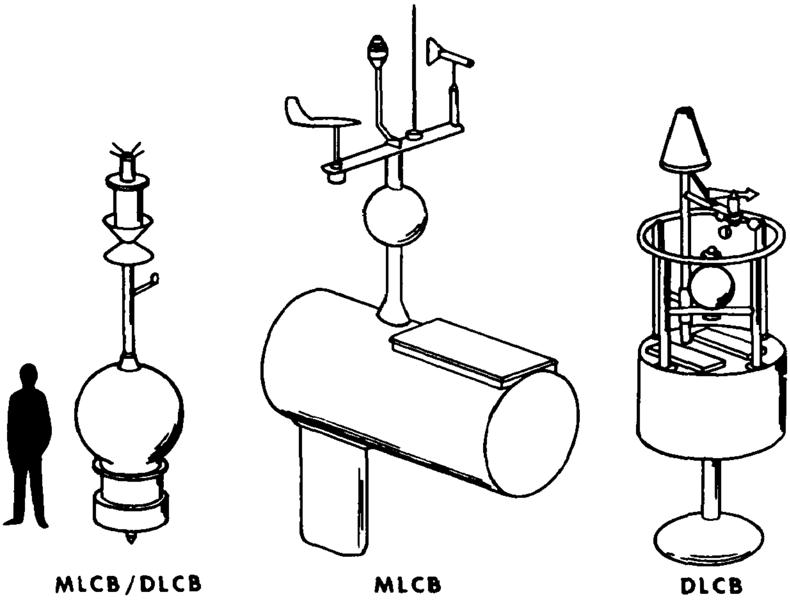


FIG. 4a. — LCB platform configuration.

- Drifting Limited Capability Buoys (DLCB) require position fixing system
  - Developing equipment to utilize both Omega and Navy Navigational Satellite System
  - Ship-deployed now, air-deployed later
- Moored Limited Capability Buoys (MLCB)
  - Automatic mooring techniques
- DLCB's and MLCB's
  - Reporting interval : 6 hours synoptic, 1 hour interrogated
  - Performance goal : Delivery of 80 % environmental data for any synoptic report
  - Communications : HF now, UHF satellite later

FIG. 4b. — LCB Design features.

Ice Dynamics Joint Experiment. The NIMBUS D satellite is used for environmental data relay (atmospheric pressure and temperature) and position location. This specialized buoy is a spar set in holes drilled in the ice — batteries and electronics are below the surface, protected from temperature extremes, and the buoys will float free if the ice melts.

11. Our primary test area is the Gulf of Mexico as shown on figure 7. The communication from the buoys is by high frequency communication to the Coast Guard radio station at Miami. In the course of conducting our tests we are naturally generating a considerable amount of data both environmental and system engineering. The data is reduced at Miami and the environmental data is sent by direct wire to the National Weather Service in Suitland, Maryland where it will be put on the national and world weather nets. These data, together with engineering test data, are also sent by land line to the Mississippi Test Facility where they are given

Measurand	*Units*	*Location relative to D.W.1. (meters)*	*Range*	*Allowable errors (RMS)*	
				Design goal(2)	*Maximum*(2)
Meteorological data					
Air pressure	MB	2 (minimum)	900 to 1 100	0.33	1.0
Air temperature	°C	2 (minimum)	− 10 to 40	0.15	0.5
Wind speed-North	m/sec	2 (minimum)	1 to 50(1)	0.5 m/sec or 3 % of the reading whichever is greater	1.0 or 5 % whichever is greater
Wind speed-East	m/sec	2 (minimum)			
Oceanographic data					
Water temperature	°C	0 to 2	− 2 to 40	0.067	0.2
Water temperature	°C	10 to 200 5 lvls (MLCB only)	− 2 to 40	0.03	0.1
Water pressure	kg/cm^2	200 (MLCB only)	15 to 23	0.15	0.5

1. 0.5 to 80 meters/sec is a design goal
2. *Includes buoy motion.*

FIG. 4c. — LCB measurement requirements.

- **Deployed operational**

Surface current : 2.5 kts constant down to 10 m

Subsurface current (assumed profile) : $V = 6.30 \times (D)^{-0.4}$ kts where D is depth in meters from $D \geqslant 10$ m

Wind : 90 kts for period of 1 hour and 50 kts for period of 16 hrs.

Wave height : 30 ft. for period of 6 hours

Ice : Ice buildup shall be assumed on all exposed surfaces to thickness of five inches

Temperature : − 10°C to 40°C

Temperature, Sea : − 2°C to 40°C

Vibration : As generated by sea environment

Shock : As generated by sea environment

- **Deployed survival**

Surface current : 4 kts constant down to 10 meters

Subsurface current (assumed profile) : $U = 2.52\ U_s X D^{-0.4}$ kts. where U_s = surface current and D = depth in meters $\geqslant$ 10 meters

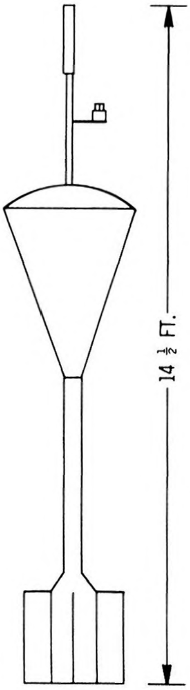
Wind : 100 kts

Wave height : 45 ft for period of 6 hours

Buoy submergence depth Dependent on other design parameters

FIG. 4d. — LCB operational and survivability requirements.

a complete analysis and evaluated in terms of the test program objectives. The environmental data are also processed there for transmittal to the national environmental data repositories.



DESIGN FEATURES

- LOW COST EXPENDABLE DRIFTING DESIGN
- RAMS
- DURATION - 6 MONTHS TO 1 YEAR

MEASUREMENTS

- WIND SPEED
- BAROMETRIC PRESSURE
- AIR TEMPERATURE
- SEA SURFACE TEMPERATURE
- WATER TEMPERATURE 5-100 METERS

DEPLOYMENT

- 2 MINI-BUOYS IN GULF OF MEXICO FALL '72

FIG. 5. — Nova mini-buoy.

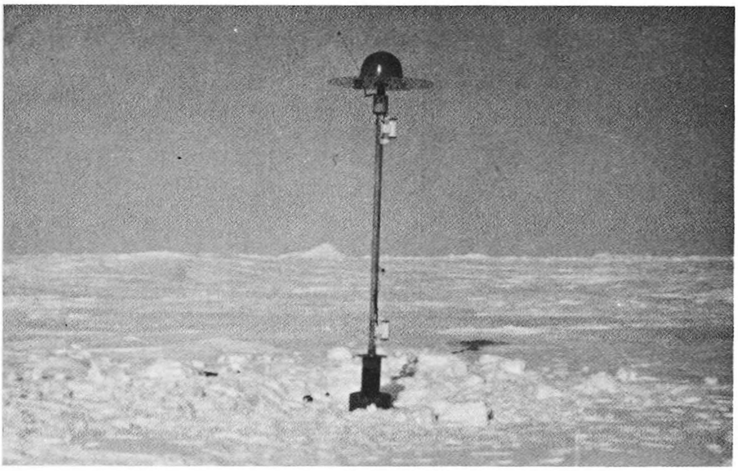


FIG. 6. — Experimental Polar data buoy deployed in the Arctic.

12. We do not think it necessary to wait for operational application until all of our goals are achieved. Our test areas are being expanded, in part because of the pressure for more data, and in part because of the need to test in other environments. The most significant immediate expansion is taking place in the Gulf of Alaska as shown on figure 8. As indicated on this chart, the high capability test buoy has been deployed about 180 miles southeast of Kodiak, Alaska. This buoy will provide valuable data from a relatively inaccessible area and should tell us a great deal about the

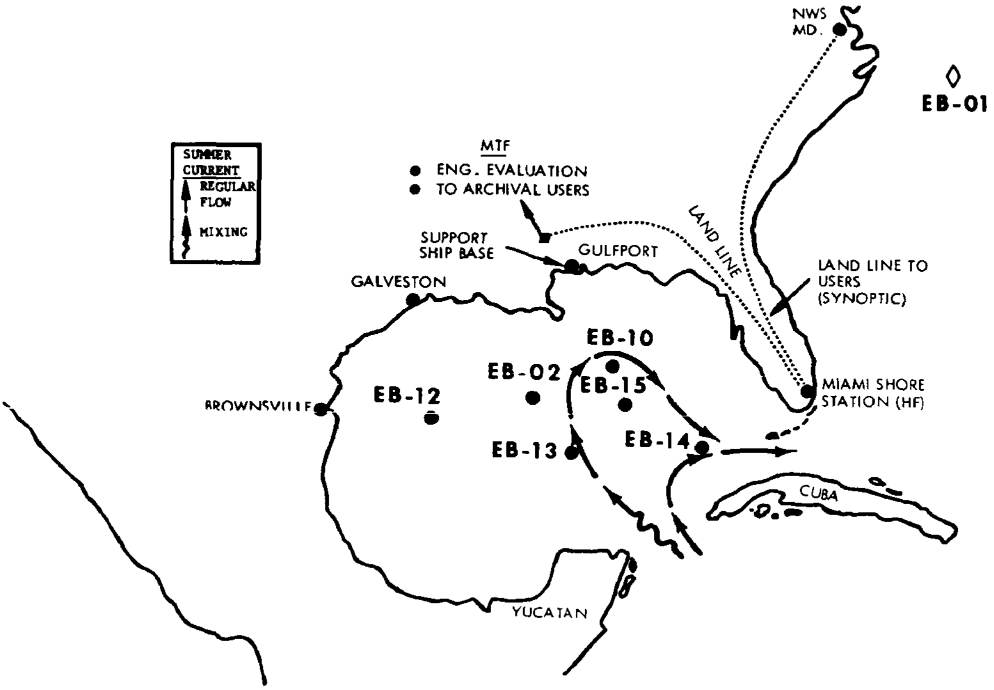


Fig. 7. — Initial Gulf of Mexico deployment.

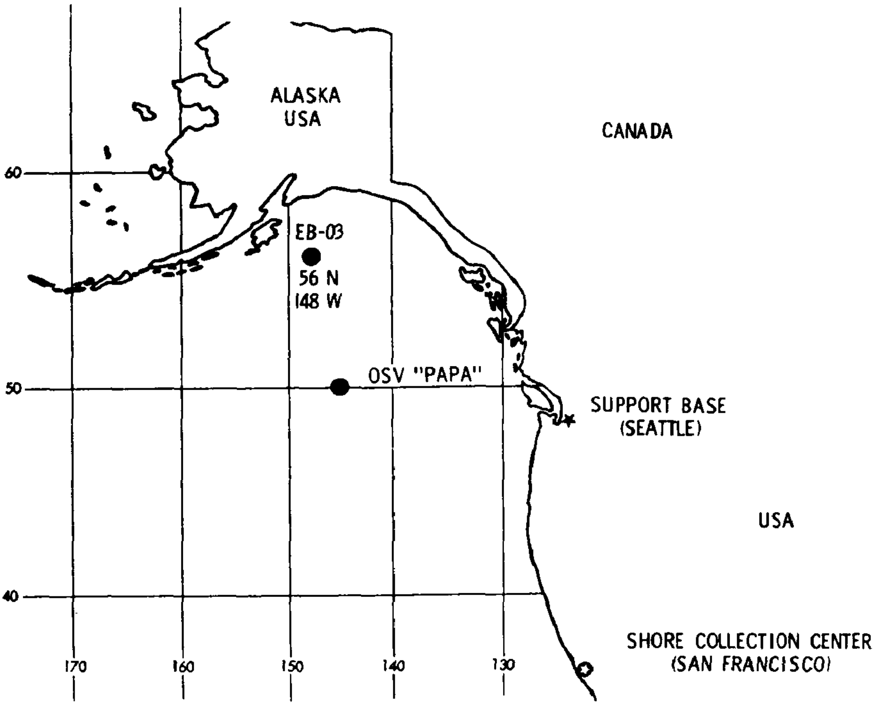


Fig. 8. — Initial Gulf of Alaska deployment.

operational requirements for subarctic conditions. Its communications will be directed to the Coast Guard station in San Francisco. We hope to supplement this buoy with selected small buoys from the LCB group once they have passed their initial trials in the Gulf of Mexico. This probably will take place late next summer. We are also planning for considerable field use in the forthcoming GARP Atlantic Tropical Experiment which will be conducted under the auspices of the WMO, beginning in 1974. [7] [8]. Final plans for the use of buoys to obtain essential surface and subsurface data are not yet complete, but we expect the emphasis for this type of short-term experiment to be on the low cost buoys which will be made to obtain surface sea and air temperature, wind velocity, current, conductivity, and temperature with depth from dispersed locations.

13. I noted earlier that we have concentrated on development of reliable instrumentation, so a few remarks are in order on this aspect of the program. We circulated to industry our requirements, as outlined in table 1, and solicited proposals to build fully engineered systems for an experimental buoy. Following evaluation of proposals, we awarded a contract to Westinghouse Electric Corporation for the development of a complete set of buoy instruments (six high capability buoys). In order to insure that alternatives would not be overlooked we required that a separate set of oceanographic instruments be developed by a different contractor. We are thus obtaining 50 oceanographic sensor packages from Westinghouse and a like number from E.G. & G. These must, of course,

TABLE 2

EEP SENSOR TYPES

Measurand	*Measurement Technique*
Meteorological :	
Wind Speed	Vortex-Shedding Anemometer
Wind Direction	Flux-gate Compass and Wind Vane
Air Temperature	Platinum Resistance Thermometer
Dew Point	Thermoelectrically Cooled Mirror
Atmospheric Pressure	Capacitive Pressure Gauge
Precipitation	Volumetric Gauge
Global Radiation (short wave)	Spectral Pyranometer
(long wave)	Infrared Radiometer
Oceanographic :	
Water Temperature	Platinum Resistance Thermometer
Conductivity	Inductive Coupling
Water Pressure	Bonded Strain Gauge
Current Speed	1. Acoustic Doppler 2. Electromagnetic
Current Direction	1. Flux-gate Compass 2. (Not selected)
Sound Speed	Acoustic (Sing-Around)

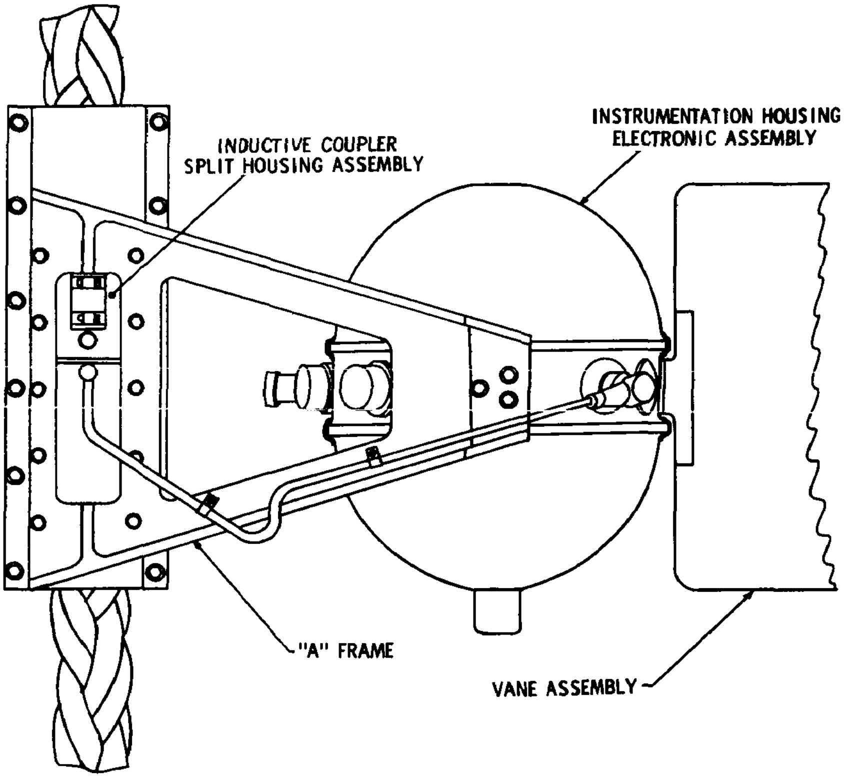


FIG. 9. — Inductively coupled oceanographic sensor.

be integrated into the buoy system with common interface requirements. We are obtaining some significantly different approaches for evaluation, e.g., Westinghouse will provide an acoustic current sensing system; E.G. & G. will provide electromagnetic sensors. The sensor measurement techniques are indicated in table 2. We believe that the tests of these different systems will provide valuable guidance for further development, as well as help to insure system operation through the test phase. The Westinghouse instrument package is shown as it is attached to the data line in figure 9.

14. You will note from the descriptions that the initial systems use high frequency communication. The present systems are designed to utilize a preset frequency from a choice of three different bands, upon command, to suit transmission conditions. Frequency bands are chosen for the particular geographic region based on propagation studies and operating experience from the six bands (4, 6, 8, 10, 12, 16 & 22 mHz) set aside for transmission of environmental data. This has well recognized disadvantages in power consumption and in range of reliable operation because of diurnal variation of transmission characteristics, etc. We are designing our systems to use satellite communication for relay of information from remotely located buoys. This, of course, depends upon availability of suitable satellites, and it is expected that our systems will work with the NOAA Geostationary Operational Environmental Satellite (GOES) which

is to be launched in the fall of 1973. These systems will work in the 400 mHz range : 402.0 mHz buoy-to-satellite; 468.825 mHz satellite-to-buoy.

15. A parallel problem which applies to the drifting buoys is that of position fixing. At the present time, our approach is to utilize the world-wide Omega navigational system or the navigational satellite system. In each of these cases the buoy will receive and record the radio signals and retransmit these with the environmental data to the shore station. We are also developing a buoy application for use with the Random Access Measurement System of the Tropical Wind, Energy Conversion and Reference Level Experiment known as TWERLE-RAMS [9]. The buoy signal is received and recorded by the NIMBUS F satellite, retransmitted to a shore readout station, and position is calculated by the doppler effect. The system, while potentially much smaller, lighter, and less expensive, is less accurate and remains to be tested at sea. This system is expected to be used in the small buoy configuration being developed by Nova University.

16. Mention was made earlier of the cost of buoy servicing. Since these test buoys are not reliable for long unattended deployment and since the

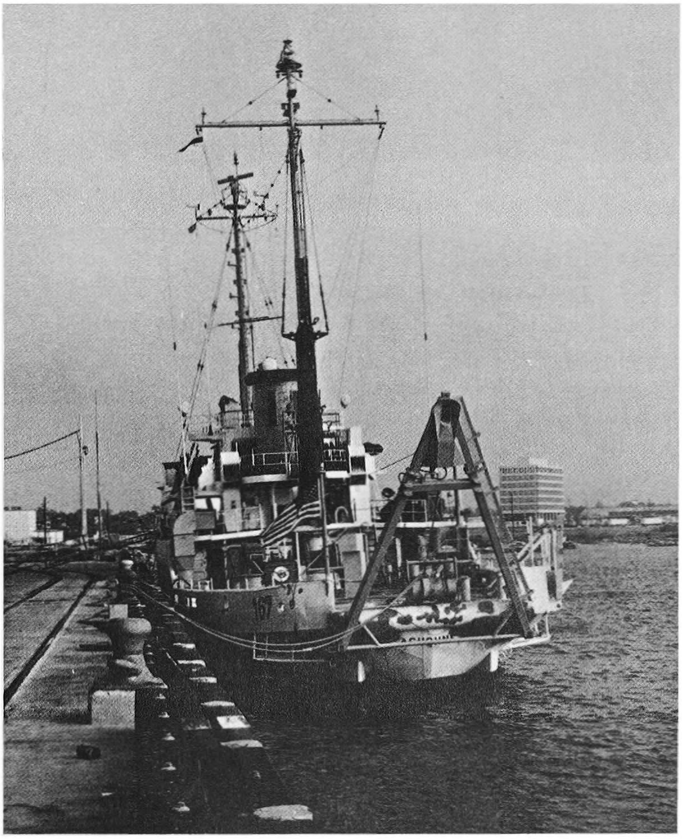


FIG. 10. — Support ship buoy handling arrangement.

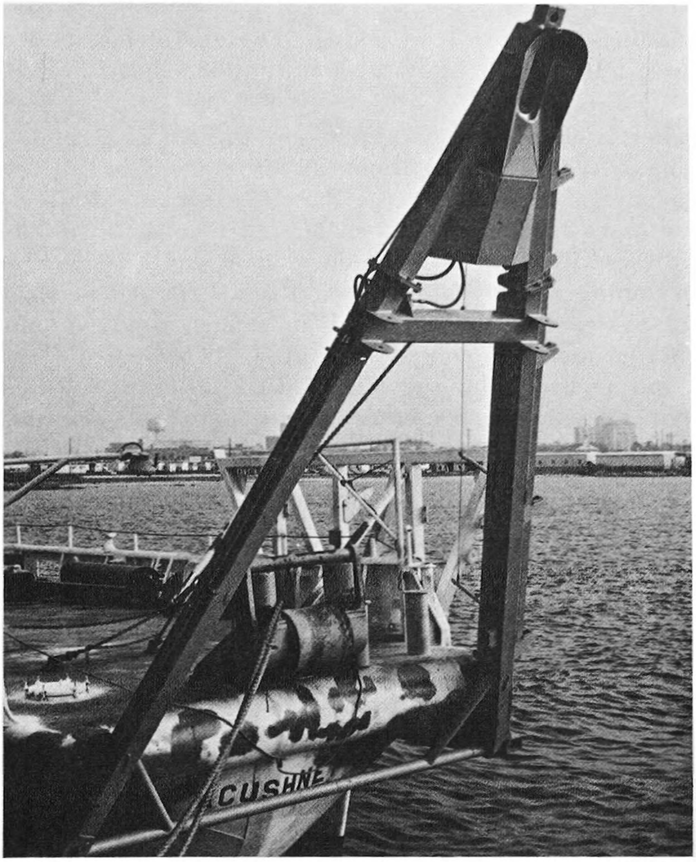


FIG. 11. — Support ship A-frame and billboard.

test program requires special servicing we have arranged for this portion of the tests to be performed by our buoy tending experts — the U.S. Coast Guard. One ship — the 1745-ton *Acushnet* — has been detailed full time to the job. She is twin screw, Diesel drive, and had been specifically fitted to tow and service the buoys. Figures 10 and 11 show the special billboard provided on the starboard quarter for launching the anchor assembly and the large A-frame with swivel which is used to attach the buoy to the ship during servicing operations at sea.

17. Engagement between buoy and ship is accomplished by lowering the A-frame from its vertical stowed position to a horizontal plane and subsequent interlock between a 10″ ball mounted on the deck of the buoy and a socket hitch mounted at the apex of the A-frame. The securing process is completed by two cable arrests from the ship to bitts mounted outboard of the ball and on each side of the buoy. A catwalk on one side of the A-frame provides easy access from ship to buoy and a working area to manoeuver the mooring line data line MLDL through the center of the A-frame. An additional piece of equipment essential to retrieval of the MLDL is a crane, mounted in close vicinity of the A-frame, soon to be added to the equipage of the *Acushnet*.

18. In a typical operation, a pennant attached to the top of the MLDL is detached from the buoy and routed through the eye of the A-frame and over the ship's roller chock to the capstan and winch. The MLDL is slowly winched aboard, until the upper-most of the eye splices, located 15 feet above each sensor on the MLDL, breaks the water's surface. The splice is then picked up by the ship's crane, and the MLDL is raised until the sensor is above deck level. The crane is then slewed inboard and the MLDL is stopped off at a point just below the sensor, permitting sensor removal from the now slack portion of MLDL. Tension is then put on the MLDL by the capstan and winch, and retrieval continues until the next splice breaks water. The above process is then repeated for each of the sensors. To return the MLDL to its operational configuration, the above process is reversed.

19. The engineering development program requires optimization of hull size and configuration. Of the numerous proposals evaluated the boat shape with a deep keel appears to offer the best prospect of attaining equal performance with reduced size (about 1/5 the size of the large EEP platforms). This leads to improved station keeping, easier handling in tow or on board ship and even introduces the capability of cross-country transportation by truck. This concept is shown in figure 12 and it will be deployed at Station EB-02 in the Gulf of Mexico in November of this year.

FIG. 12. — Deep keel hull environmental buoy.

20. Eventually, when large numbers of buoys are deployed, it is probable that specially designed support ships will be a necessity. I do not expect that we will be ready to design such seagoing buoy tenders until we have finished a large part of our engineering development program — probably about 1974. By that time, we should have not only a reasonably clear idea of the characteristics of the buoys themselves but a much better idea of the areas of deployment and the number needed. There is also a need for a small, seagoing, high speed servicing unit to make adjustments and repairs not involving the heavy handling gear problems of deployment. Helicopters, hydrofoils, and surface effect ships are likely candidates for this function.

21. Experience to date has shown us that we can put buoys at sea and hold them in place, solving the problems of weather, currents, waves and fish bites. We can reliably communicate their intelligence ashore via HF, ultimately UHF satellite links. We are improving the quality of the sensing systems for standard parameters and by statistical analysis we are improving the validity of measurement when obtained in a rapidly changing environment. We are just beginning to look at the need for better environmental quality sensors — our data systems are designed to accommodate such when they are developed — as they must be.

22. In Captain Rinehart's paper in 1970, he predicted that a pilot operational network should be possible off the U.S. coast by 1977. The need for data will not wait that long — particularly in areas which cannot be covered by other means, such as satellites. The Gulf of Alaska is such an area. I feel these areas to be of such importance that we will keep the experimental networks in operation with improved components and they will evolve into regular monitoring networks. Today we actually have data coming into the National Weather Service regularly from the experimental buoy off the U.S. East Coast, one of the six planned buoys in the Gulf of Mexico and the one in the Gulf of Alaska. These will be supplemented by additional buoys during the coming year. Separately, our environmental monitoring specialists have been examining the needs for better coverage of the oceans which includes the requirements for additional buoy networks. Particular areas of interest include the U.S. Middle Atlantic and Pacific coastal areas. The problems of numbers, locations, and balance with other systems, such as satellites and ships of opportunity, need considerable development. But by the time these questions are resolved — hopefully by 1975 — we expect to be ready with proven data buoy systems for a wide spectrum of users.

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