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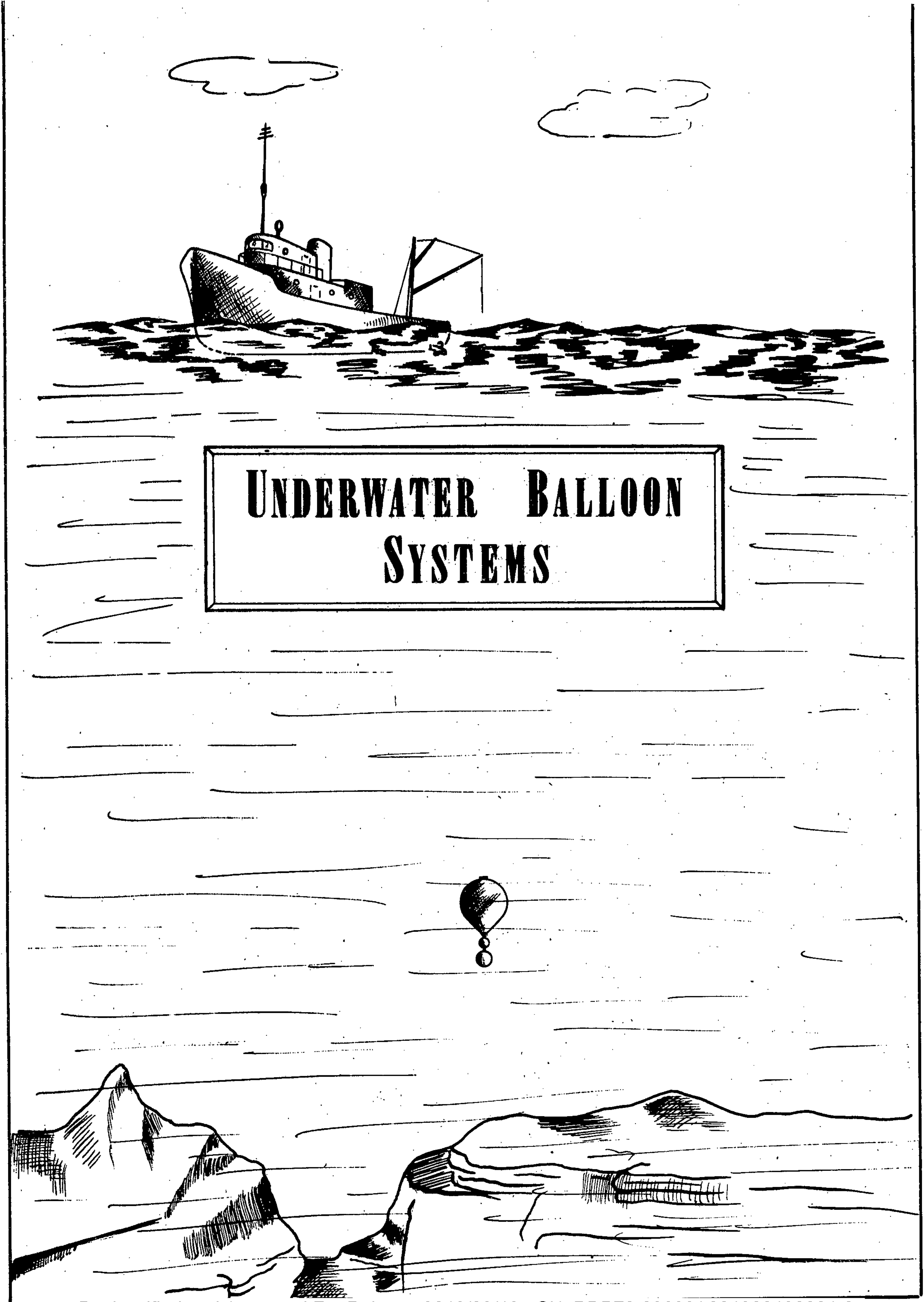

UNDERWATER BALLOON SYSTEMS

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UNDERWATER BALLOON SYSTEMS

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UNDERWATER BALLOONS

I. ABSTRACT

A program is suggested for the development of underwater balloon systems as basic research and operational vehicles. These systems would, in general, consist of a lifting vessel filled with a fluid lighter than sea water, controls necessary to program the system underwater, instruments to collect, record and/or telemeter information collected by the system, and means for tracking and recovery. The underwater balloon systems described appear to be promising both technically and economically for underwater research and operational applications.

II. INTRODUCTION

The earth's bodies of water can be considered analogous to its atmosphere. The oceans have pressure and temperature gradients and currents corresponding to those of the atmosphere.

Whereas the lower regions of the atmosphere have been studied extensively, and the upper regions to a lesser extent, the converse is true of the oceans.

Oceanography is a fertile field for scientific endeavor. An understanding of the earth's oceans can be as important as an understanding of its atmosphere.

There appear to be new military applications as well as possible increases in efficiency of present underwater weapons which could result from a better knowledge of the ocean masses.

The underwater balloon could be an important tool in utilizing and extending our knowledge of the oceans.

This report presents a general discussion of underwater balloons and some possible applications of them. The principles, as a whole, are not new. What may be new is the consideration of underwater balloon systems, as a basic tool for various types of research and operations, and some of the applications for which they may be suited.

General Mills, Inc., feels that the best approach is that of first gaining an understanding of underwater balloons. Having gained the basic knowledge, it will be straightforward to provide the necessary modifications and improvements to fit them to various specific applications.

The technical problems, operations, and applications of underwater balloons can, to some extent, be anticipated by the experience gained from atmospheric balloons.

The parallel between atmospheric balloons and underwater balloons is striking, if the present status of underwater balloons is compared to that of atmospheric balloons, fifteen years ago.

In ballooning, the elimination of the pilot has disposed of imposing problems arising from balloon sizes and safety considerations, and has led to an era of extensive and economical experimentation at altitudes previously not thought to be practical. It appears that the same evolution could take place in underwater ballooning.

By 1940 it was felt that the large, impregnated fabric, man-carrying balloon had been exploited to its limit of usefulness. The cost and technical problems associated with making routine flights of the "Explorer" type were considered to be too great for the value received. By this time, however, Dr. Jean Piccard and others, had pointed out the possibilities of making balloons from plastic materials, not previously used in balloons.

These balloons had the great advantages of being less expensive, and easier to fly than their predecessors.

Underwater balloons can be considered to be in the same state today. Experiments have been made by Dr. A. Piccard and others which established the feasibility of underwater balloon principles. To date, the vehicles built have been directed toward man-carrying applications and have therefore been large and expensive. The change to unmanned systems allowing use of new design criteria and techniques, different materials, and automated operations could make it economically feasible to greatly expand underwater activities.

Some nomenclature used in this report may not be appropriate to underwater usage. General Mills, Inc., has for some years been in the "lighter-than-air" balloon business and some of the word usage in this field has been carried over.

The word "balloon" generally is defined as being "a nonporous bag of tough, light material filled with heated air or a gas lighter than air so as to rise and float in the atmosphere". In this proposal it has been used to describe a nonporous vessel of tough, light material either rigid or non-rigid filled with a fluid lighter than water, etc.

III. APPLICATIONS

Below are listed some possible applications for underwater balloon systems. Both research and operational applications are included.

Experts in underwater research and development and various branches of science undoubtedly could conceive more uses for the basic system or variations of it, once the system has been developed and its performance determined.

A. Environmental Research

1. Study of Underwater Currents

By using a series of separate underwater balloons, maintained at various pre-set depths, a three dimensional study of ocean currents could be made.

Possible uses for the collected data would include data for submarine navigation, movement of micro-organisms in the ocean, and a better basic knowledge of oceanography.

2. Study of Temperature Gradients

Profiles of water temperature could be obtained by using underwater balloons carrying temperature sensing elements. Data for three dimensional temperature contours could be obtained by making descents at a number of geographical locations.

Possible uses for the collected data would include, a better understanding of underwater sound transmission and ocean life environment.

3. Study of Ocean Composition

Variations in ocean composition could be studied using underwater balloon systems, by carrying instruments which sense the variables being measured, or by collecting samples at various depths. Underwater photography could be used for some studies.

Possible worthy studies would include profiles of: cosmic ray intensity, light intensity, chemical composition, organism density, radio-active intensity. The latter may be of particular value after nuclear tests and around submerged waste materials.

4. Study of Ocean Bottoms

It would be possible to develop balloon systems which would descend to the ocean bottom, obtain a sample and/or photograph of the bottom, and return it to the surface.

Possible applications of this would be in obtaining data for mine laying, studying bottom plant and animal life.

A variation of this system might be of value in making geological surveys. An explosive charge could be implanted in the bottom and detonated to provide seismographical data.

B. Underwater Recovery

A present specialized application of underwater balloons is the recovery of experimental weapons from deep water. A project sponsored by the Naval Ordnance Laboratory is now being conducted by General Mills, Inc.

It seems possible that large underwater balloons could be attached to or placed within sunken vessels, airplanes, etc., and inflated to bring them to the surface. In this way, the balloons would replace the large metal tanks presently used for this purpose. To provide a greater lift, the balloons could be sent down empty and inflated with air supplied from compressors on the surface ship.

C. Underwater Sound Countermeasures

At present, sonar surveillence is complicated to some extent by naturally occuring ocean noises. Underwater balloons carrying sound emitters could be used to confuse underwater sound determinations. They could, for example, be dropped at random intervals from a convoy. Enemy submarines would be faced with the problem of filtering out the ship's noise from that of several other sources. A submarine could use the same technique to confuse the spotting and tracking efforts of an enemy.

D. Underwater Delivery

Making use of natural currents, underwater balloons could be used to carry a payload from one location to another.

Being noiseless and submerged, such delivery systems would be difficult to intercept. Possible uses would include remote laying of mines, remote placing of surface weather stations, and mobile listening stations. They could also carry sound transmitters which could be actuated at the proper time to conceal an actual ship movement elsewhere, or to force an enemy to tie up his forces in defense against a non-existent attack.

It is conceivable that underwater balloon systems could be used for transporting freight. During wartime, large balloons filled with jet fuel, for example, might be towed into position in the proper ocean currents, submerged and left to drift to the desired delivery point. The balloons then would be recovered and towed to shore for pumping. The empty balloons possibly could be flown back for re-use. The same technique might be used to deliver fuel to fleets at sea.

The main advantages of this method of delivery would be invulnerability to interception and a great reduction in the exposure of personnel and equipment.

A world map showing the surface currents of the oceans is included as Figure 8 in the appendix of this report.

It is interesting to note the use made of surface currents by the Kon Tiki raft in its voyage from the coast of South America to a small island in the South Pacific.

E. Underwater Testing

Underwater balloon systems could be used to test under actual conditions, underwater devices such as fuzes, hydrostatic switches, pressure vessels and cameras. The item to be tested would be carried to the desired depth, data taken on it for the desired time and returned to the surface for recovery and study.

IV. TECHNICAL DISCUSSION

The following sections discuss the basic considerations involved in developing and operating underwater balloon systems.

A. System Design

The typical system will consist of a vessel filled with a fluid lighter than water, instruments and devices to measure and control the performance of the system, and a means for carrying a payload. One possible configuration of an underwater balloon system is shown in Figure 1.

1. Lifting Vessel (Balloon)

The lifting vessel of the system could be either rigid or non-rigid. Both types would be filled with a lifting fluid and opened to ambient pressure to eliminate having to make them sufficiently strong to withstand high hydrostatic pressures.

Multiple balloons in series or parallel could be used to increase the load carrying capability of the system and may show advantages over a single larger vessel.

The lifting vessel would be equipped with the fittings required for system operation. These would include: a filling connection for introducing lifting fluid into the balloon, a filling vent located near the top of the vessel to release entrapped air during filling, a hoisting ring for handling the system prior to launching and after recovery, and a load ring for attaching the payload and instruments.

A provision would be required to allow for small changes in volume of the lifting fluid caused by compressibility or temperature differentials.

A flexible membrane at the bottom of the vessel would serve this purpose.

Non-Rigid Vessel

Although the subject must receive further analysis, it appears that the non-rigid type would have the advantages of lower manufacturing cost, greater handling ease, less shipping space, and lower tooling cost making model changes easier.

The non-rigid type could be made of two layers, one having the required strength and the other having the required impermeability and compatibility with the lifting fluid. It may be possible to find a material and lifting fluid combination which eliminates the need for two layers.

Analysis will be required to determine the best non-rigid balloon design. The "natural shape" concept developed for atmospheric balloons may apply, giving a controlled stress distribution. For certain applications the natural shape balloon formed by bringing together the ends of a cylinder and clamping them with end fittings would make a balloon economical to build.

Load tapes, wires, ropes or nylon shrouds may prove advantageous in increasing the load carrying capacity of the balloon as well as its durability.

Rigid Vessel

For some applications, a rigid lifting vessel may prove superior. It, in general, would be a light-weight tank, with the associated fittings required for underwater operation.

Analysis should be made to determine the best shapes from a stress standpoint, and best materials and methods of manufacture.

The possible materials and methods of manufacture for use in making rigid vessels include spinning or stamping sheet metal, blowing or casting plastics, and fabricating fabric-plastic laminates over a form.

2. Instrumentation, Controls, and Instrumentation Gondolas

Basic instrumentation of an underwater balloon system generally falls into two categories (a) Those required for system operation and (b) those required for collecting, recording and/or transmitting data collected by the system.

a. System Control and Operation

Rate of Descent and Ascent Control

Differential pressure across an orifice or a calibrated drag device can be used for rate sensing. These can actuate ballast and valve controls or other means provided for changing the system balance. The rate control instrument should be adjustable over the desired range of descent rates. Rate controls would not be required on simpler systems.

Depth Control

The problem of depth control would require study. It appears that the low variation in density would lead to instability, and a constantly active depth control system might be necessary. A low displacement high pressure fluid transfer system, or a pressure controlled chemical reaction, should be investigated for constant depth control.

A pressure sensitive cell might consist of a thin flexible capsule filled with a compressible fluid.

In the simple case, pressure sensing elements such as Bourdon tubes could be connected with the ballast and valve (or equivalents) to control the system at a constant depth. For maximum utilization of lifting fluid and ballast, a rate control can be connected to the depth control to anticipate changes in depth. The depth control should be adjustable over the applicable range.

Various time-depth functions could be established by special instruments. A typical programmed mission would be a step function where various pre-set depths are maintained for specified periods of time.

Controls could be developed which would maintain the balloon system at a constant distance above the bottom.

A "sounding" type operation could be accomplished by simple means. The system could be "launched" heavy and allowed to reach the ocean bottom. A release lever could drop a weight on contact with the ocean bottom and the system would return to the surface. The ocean bottom might lack firmness, but correct design would lead to a reliable detaching mechanism. This mechanism would be external and no pressurized containers would be required for any of its components.

Timer

A timer would be required to regulate the sequence of operation in some applications. In some applications, combinations of pressure-time control sequences could be combined to program the system.

Remote Control

By means of suitable ultra-sonic links, remote control of the system functions would be possible.

b. Data Collecting, Recording, and Transmitting Instruments

Instruments to collect data are varied depending on the specific task to be accomplished. These may include sensing elements such as diaphragms or Bourdon tubes for pressure, bimetels or thermisters for temperature, photo cells for transparency and light intensity, capacitance or resistance elements for conductivity and salinity, scintillations counters for cosmic ray intensity, etc.

Probably each system would carry standard instruments such as time depth and temperature recorders.

Much of this information could be telemetered. Communications problems are discussed in a later section.

c. Instrument Containers

Instrument containers using the principle of the liquid filled balloon could be developed. These would be spheres made from thin metal. They could be filled with a suitable fluid (possibly light oil) and would have an opening at the bottom to equalize internal and external pressures. This technique would eliminate the need of making instrument vessels capable of withstanding large static pressures. Each instrument component would have to be able to withstand the ambient pressure since the instrument gondola would offer no pressure protection. It might be necessary to make a small pressure vessel to contain electron tubes and other pressure critical components. A cross section of a typical gondola of this type is shown in Figure 3.

In some cases instruments could be located externally without special containers.

For moderate depths, it may be more practical to design the instrument gondola as a pressure vessel.

It appears that the pressure type gondola could be cast in two separate hemispheres. The problem of pressure sealing the equatorial seam might be solved by using the available hydrostatic pressure for clamping force. One of the abutting surfaces would have a narrow ridge which would conform to a narrow groove in the other hemisphere. By filling the groove with soft, base-metal and allowing the pressure to drive the ridge into the groove, a good seal should be obtained.

As an example, the pressure at a depth of five miles is 11,700 pounds per square inch. The compressive stress on a 30 inch diameter sphere with a one and one half inch wall thickness would be 58,000 pounds per square inch. This is a satisfactory working stress for most steels and some types of aluminum. The sphere would weigh 1085 pounds in air and would have a submerged weight of 564 pounds.

B. Performance

In general, it will be required to send the system at a controlled rate of descent, to some pre-determined depth, maintain it there for a specified time, and return it to the surface. The system will move with the currents and will trace out a trajectory while it is in the water.

A typical (hypothetical) time-depth curve is shown in Figure 3. Information that might be included on the record of an underwater experiment has been given as an example.

The time-depth program could, of course, be changed to fit special applications.

For some applications it may be desirable to allow the system to sink to the bottom, and then inflate the balloon to bring it back to the surface. Gas generation devices or compressed gas containers could be used for this.

1. Effects of Lifting Fluid on Performance

With but small error, water can be considered incompressible over the depths occurring in the ocean. (See table below.) Likewise, the pressure can be assumed to vary linearly with depth.

COMPRESSIBILITY OF WATER

(Ref: Lange's Handbook of Chemistry, 1946)

The table below gives the relative volumes of water at various temperatures and pressures. The volume at 0°C and one normal atmosphere (760 mm of H_g) is taken as unity. (NOTE: This table is for pure water).

P, atm	Depth, ft. (approx.)	-10°C	0°C	10°C	20°C	40°C	60°C
1	0	1.0017	1.000	1.001	1.0016	1.0076	1.0168
500	18,064	0.9788	0.9767	0.9778	0.9804	0.9867	0.9967
1000	36,164	0.9581	0.9566	0.9591	0.9619	0.9689	0.9780
1500	54,156	0.9399	0.9394	0.9424	0.9456	0.9529	0.9617
2000	72,220	0.9223	0.9241	0.9277	0.9312	0.9386	0.9472

If a gas is used as the buoyant force, it will compress as the system descends, and since the water density remains nearly constant, the lifting force will decrease. As a rough example, an air-inflated balloon that has a lift of 1,000 lbs. at sea level would have a lift of approximately 1 lb. at a depth of 36,000 feet, presenting an impractical control situation.

Deviations from the perfect gas law should be considered for exact figures.

This has led past investigators to use as a lifting medium, a liquid having a specific gravity less than water. The lift of the system then remains nearly constant with depth, the only change being that due to the difference between the compressibility coefficients for water and the lifting liquid.

Dr. A. Piccard, in his bathyscaphe, used a hydrocarbon as the lifting medium.

Using gasoline as an example (others may be better from a safety standpoint), the specific lift is:

specific gravity of gasoline = 0.66

wt. per ft^3 of gasoline = 41 lb.

specific gravity of sea water = 1.025

wt. per ft^3 of sea water = 63.86 lb.

Thus, the lift per cubic foot of gasoline in sea water is 21.85 lb. per ft^3. A 100 ft^3 balloon (5.76 ft. diameter) would have a lift of 2185 lb. Figure 4 shows the relationship between gross lift and balloon diameter, for gasoline in sea water.

The weight of the system and payload considered should be the effective weight in water. Balloon materials which have a specific gravity near one, for example, would be nearly self-supporting and would not contribute to the load that the lifting fluid must support. A solid aluminum body which weighs 150 lbs. in air would weigh about 100 lbs. in sea water.

There are a number of liquids which are potential lifting fluids. The following table lists some of these:

Liquid	Specific Gravity	Weight Lb/ft^3	Lift in Sea Water Lbs/ft^3
Methyl alcohol	.791	49.3	14.56
Ethyl alcohol	.788	49.2	14.66
Heptane	.684	42.7	21.16
Octane	.70	43.7	20.16
Pentane	.62	38.7	25.16
Fuel Oil	.80	49.9	13.96
Acetone	.791	49.4	14.46

The final choice of lifting fluid should include considerations of cost, safety (inflammability, toxicity, corrosiveness, etc.) availability, compatibility with balloon materials, and viscosity, as well as the specific gravity.

2. Ascent and Descent

Because of the negligible variation of density with depth, the system will have no equilibrium floating depth. If the system is weighed-off heavy, (i.e., that the total weight exceeds the buoyant force) so as to cause it to descend, it will proceed at a nearly constant rate to the bottom.

One method of changing the rate of descent and ascent, and controlling the system at a constant level would be by using ballast and a valve in the balloon. If the rate of descent were too great, ballast could be dropped. If the rate of descent were too small, lifting medium could be valved. A constant level would be maintained by alternate dropping of ballast and valving of lifting medium, so as to approach equilibrium.

More efficient methods of maintaining a constant depth have been developed for other applications and may be adaptable to underwater balloons.

3. Duration

The duration capability of the balloon will depend primarily upon its leakage rate. Since a given stratum of sea water is nearly iso-thermal, there will be no appreciable loss of lifting medium due to "pumping" caused by temperature variations. A membrane could be used at the bottom of the balloon, so that internal and external pressures would be equalized, without allowing mixing of sea water with the lifting medium.

E. Communications

1. General

The communication requirements of an underwater balloon system result from the need to transmit data from the instruments to a receiver, and the need to locate or track the balloon.

Underwater sonic communication is suitable for short range data transmission from the balloon to a shipborne or floating buoy receiver, or for long range communication to an underwater receiver located at the proper depth. Radio frequency communication is required to re-transmit data from floating buoys over long distances to a central land or ship station.

2. Water Communications

Underwater sonic wave propagation is influenced by the inevitable process of attenuation, and also by the acoustical impedance discontinuities which result from stratification of water layers. Clearly defined strata may exist with significant differences in temperature or saline content. Ocean currents may produce similar discontinuities in a vertical plane.

At the boundary between two layers of water of different acoustical impedance, an incident sound wave is refracted and reflected.

For sound transmission at angles close to the perpendicular to the boundary plane, the principal effect is loss of amplitude due to reflection. Therefore, it may be expected that relatively low power sonic or ultrasonic communication links will be reliable and effective for transmission of data from the balloon to a receiver located nearby on the surface.

For long distance communication, the sound waves are incident on the horizontal boundary layers at small angles. With significant discontinuities of acoustic impedance, total reflection may occur at such angles and the sound wave may be trapped in the layer. Many instances of extremely long range communication have been observed due to this effect. Of course, the receiver should be located in the same layer of water as the source, for longest range.

3. Radio Communication

For data transmission in excess of 100 miles it would be desirable to use a floating buoy transmitter. Many beacon transmitters have developed already, and it is possible that one of them now in existence may be suitable. The transmitter would probably be a pulsed ultra-sonic generator. The methods for putting sound energy into the water are: magneto-striction, quartz crystals, Rochelle salts, and ceramics.

The information rate requirements for underwater ballooning are similar to those of airborne vehicles. In order to conserve power and bandwidth, it might be advisable to design special transducers with low power consumption and a communication link with continuous and commutated channels.

A small radio beacon, used commonly in rescue operations today would be of great help in locating the balloon after re-surfacing. This could be located on the balloon top and could be actuated by a pressure switch or by a timer.

The antenna pattern of the underwater transmitter may be adjusted by proper design for the particular function desired. If data is to be transmitted up to the surface, it will be coupled to the water by means of a conventional large flat plate whose surface is driven by crystal or magnetostriction transducers in phase. If horizontal beam action, or pencil beam is desired, other transducer arrays can be used.

The balloon program can be controlled by command signals transmitted from the surface down to the balloon, if necessary.

4. Summary

It appears to be feasible to perform all of the data transmission and communication functions of underwater balloon systems by application of components and techniques which are now known. Much underwater signaling equipment would be adaptable with little change, while other requirements may only be provided by new engineering designs.

F. Power Supply

The power supply to operate instruments, devices to perform underwater functions, and possibly to propel the system itself could be supplied from batteries. Because of the potentially large loads that could be carried by underwater balloon systems, the weight of a battery power supply will present no great problem.

When balloon descents of long duration are attempted, it will be necessary to devote considerable attention to economy in use of power. Chemical battery storage appears to be the most suitable power supply since temperatures underwater are not extreme. Internal combustion or pneumatic power sources are unsuitable because of their need for intake and exhaust connections.

The pressure inside and outside the batteries could be equalized by using a flexible membrane to separate the battery electrolyte from sea water. The battery case then would not have to be built as a pressure vessel. It may be possible to design a battery to withstand the high pressures involved.

G. Launching and Recovery

Probably most underwater balloons would be launched from a boat or ship. Some applications could dictate special launching methods to be used from helicopters, aircraft, submarines, or large ships. These special techniques and the associated devices would best be developed as the applications dictate.

In launching an underwater balloon, it will be necessary to: (a) ready and attach the system instruments and payload; (b) inflate the balloon so as to give it the proper balance in the water; (c) place the system in the water; (d) release it.

The best sequence of the above steps will depend upon the type of launching vessel used, the size of balloon system, and the conditions of the sea and weather.

For small systems, the steps above could be carried out in the order given. The entire system less lifting medium would be weighed to provide data for proper weigh-off. The lifting fluid then would be pumped or poured into the balloon, the proper amount determined by weighing or volumetric metering. The system would be hoisted over the side, eased into the water and released.

The filling of the balloon may be accomplished in the water during moderate or calm sea conditions. The weigh-off in this case would be direct, the balloon being filled until the system weight exceeds the buoyancy by the amount required to give the proper rate of descent.

Flexible attachments would be necessary to allow for the roll of the ship. A sequence of this launching procedure is shown in Figure 5.

This method of inflation in the water has the advantage of reducing the stress which the balloon must withstand. As an example, 100 cubic feet of gasoline weighs 4100 pounds in air and will provide a lift of 2100 pounds in the water. It would be inefficient to design a balloon which must both support the 4100 pounds of gasoline and also withstand the lifting force of 2100 pounds underwater.

One launching system which could be used to combine the advantage of the two systems mentioned above, would be to use a tank large enough to contain the balloon, which could be hoisted aboard ship. The deflated balloon would be placed in the tank, the tank filled with water, and the balloon filled. The launching tank, containing the balloon then would be hoisted into the water and separated from the balloon. A sequence of this launching procedure is shown in Figure 6.

Another possible launching system would make use of a specially designed launching craft which has an inboard opening to the water. A hoist would be provided over the opening. The balloon system could then be supported by the hoist during the readying period, lowered into the water and inflated. This craft would provide a convenient working area around the system and would provide a buffer to rough sea surface conditions. A raft which could be hoisted aboard a mother ship could also be considered as a launching craft.

The above techniques would apply (in reverse) to system recovery. The system would be made captive by connecting a cable to the upper load ring, then hoisted aboard and the lifting fluid pumped out or the fluid could be pumped out while the balloon is in the water. In some cases the balloon or all of the system can be considered expendable and, therefore, requires no recovery.

V. POWERED UNDERWATER VEHICLE

An extension of the underwater balloon concept would be in supplying a means of propulsion to the vehicle. This would enable the positioning and movement of the system to be controlled without depending solely on the natural currents.

It may be desirable in the applications for underwater balloon systems previously mentioned to consider a powered system. In addition there may be some applications requiring an unmanned powered system. Prescribed courses may be traveled, including a return to the launching base.

To illustrate the general feasibility of such a system, a specific example is presented.

A streamlined shape vessel, powered by electrically driven propellers is considered. Assuming a frontal area of 25 sq. ft., a gross load of 2000 lbs., 500 lbs. of batteries, a drag coefficient of .05 and a speed of 2 ft/sec. (1 3/8 miles per hour) it can be shown that the system would have a range of approximately 400 miles and a duration of about 23 days. This calculation is based on a propulsive efficiency of 50% and batteries having a capacity of 1 watt hour per ounce (lead acid).

This is an example and does not indicate a limit in either range or speed. Figure 6 illustrates how the vehicle might appear. Various other forms may be more practical depending upon the task to be accomplished.

Previous discussion on communications, instrumentation, and control also apply to this vehicle. Rudders could be used to provide horizontal and verticle control.

VI. SUGGESTED PROGRAM

It is suggested that a research and development contract be undertaken to study, develop and test a basic underwater system.

The objective of this program would be to study the feasibility of an underwater balloon system outlining the problems and directing the development effort. The effort would then be aimed at building a balloon, control and tracking instruments, launching and recovery equipment, and making a series of underwater tests.

As part of the program, a survey would be made to determine what existing equipment and facilities are adaptable to underwater balloon use.

The program is proposed in three phases:

1. Preliminary Study of Underwater Balloon Systems and Operation

The objective of this phase would be to study and investigate all phases of the system and operation, and establish a target specification for a basic underwater balloon system.

2. Design and Construction of a Basic Underwater Balloon System

A detailed design would be made based on knowledge gained from phase 1. A series of test systems meeting the specifications established in phase 1 would be built for test.

3. Underwater Balloon System Testing

A series of underwater tests would be made on the test systems. Performance data of the system and operation of its component parts would be determined and compared to the theoretical analysis. A revision of the specifications would be made.

Upon completion of phase 3, enough data and experience should be available to allow underwater balloon systems to be designed to meet the requirements of specific applications.

A more detailed description of the work proposed in each phase follows:

Phase 1. Preliminary Study of Underwater Balloon Systems and Operation

a. System Design

A study would be made to determine the most promising materials and methods of construction for underwater balloons. Laboratory tests would be made to determine the properties of candidate materials. Sample balloons would be made and laboratory tested. A study of balloon configuration and stresses would be made.

This study would provide criteria for underwater balloon design.

b. Performance and Control

A study would be made to establish the performance characteristics of underwater balloon systems. Included would be a study of rates of descent and ascent, load carrying capability, duration, and control forces required.

A study would be made to determine the best ways to control the system. Valving and ballast, thrust pumps and compressed gas devices would be included in the study of controlling floating levels and descent rates. A study would be made of various types of instrument containers including pressure vessels and pressure equalized containers. The pressure resistance of instrument components would be considered. A study would be made of pressure resistant seals and connections.

This study would provide basic performance data for designing underwater balloon systems and control devices.

c. Lifting Fluid

A study would be made to determine the best lifting fluid for underwater balloons. Included would be considerations of the cost, safety, availability, compatibility with other materials, handling, and specific lift of each fluid.

This study would provide data on the relative merits of each candidate lifting fluid.

d. Instrumentation

A study would be made of the instruments required to control and record underwater balloon performance. The study would cover underwater telemetering, pressure and temperature recording, constant level and rate of descent controls, timers, and radio telemetering for surface recovery.

This study would provide data for designing underwater balloon system instrumentation.

e. Power Supply

A study would be made of power supplies to determine the most promising ones. This would include an evaluation of different types of batteries and a consideration of compressed gas power systems. The evaluation will include factors of cost, weight, reliability and duration.

This study will provide data for designing power supplies for underwater use.

f. Launching and Recovery

A study would be made of the problems of launching and recovery, and possible solutions. Launching and recovery devices and techniques would be evaluated.

This study would provide data for design of launching and recovery equipment required as well as specifying shore and ship facilities required.

Having established the basic design and operational criteria for underwater balloon systems, in cooperation with the sponsor, the specifications for a system could be established. An attempt should be made to specify a system which will be satisfactory for operational test purposes and be adaptable to some particular application of interest.

Phase 2. Design and Construction of a Basic Underwater Balloon System

Using data and the target specifications established in phase 1, a detailed design of an underwater balloon system will be made. Functional tests of all parts of the system will be made to establish their suitability under salt water environment and high pressure. Launching and recovery equipment needed will be designed and built. Shipboard equipment needed for the communication link will be procured. Several complete underwater balloon systems will be readied for open water tests.

Phase 3. Underwater Balloon System Testing

Preliminary tests may be carried out locally. Full scale tests should be carried out in cooperation with the U. S. Navy.

Since these tests will require extensive use of Government personnel and facilities, it is recommended that a representative of the Sponsor participate in the tests and coordinate the activities.

The choice of the best location for testing depends largely upon the Government facilities available.

It is estimated that a 65' vessel equipped with a 5 ton crane would be adequate for launching and recovery. The vessel should have a speed considerably greater than the water current speeds which will be encountered.*

Sonar or other special equipment may be required for underwater tracking and radio direction finding equipment for surface recovery.

The water depth in the test area should be great enough to provide desired pressures. The bottom should be regular enough that the systems can be tested without becoming entangled. (The problems of coping with irregular bottoms could be part of a longer range program.)

Since it would appear that underwater balloons will have greatest application in the oceans, it would be better to test the systems in the ocean.

In some cases, testing in fresh water lakes may be more convenient. Lake Superior, for example, would be a possible test area, having a maximum depth of 2302 feet. U. S. Coast Guard vessels and facilities adequate for testing purposes exist there.

Some of the major ocean deeps are located near Cuba. Figure 7 in the Appendix shows the major ocean deeps.

The open water tests may uncover some difficulties and shortcomings in the system. These would be overcome so that phase 3 would end having demonstrated a workable underwater balloon system.

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* It is possible that underwater currents do not have the same direction and velocity as surface currents. Thus, the surface vessel may have to go "counter current" in tracking the underwater balloon.

FACILITIES REQUIRED

As part of phase 1, it is intended to purchase or build test equipment required for underwater balloon systems and components. It is believed that this equipment is required for development of the underwater equipment and will, throughout the proposed and possible subsequent programs, be justifiable when the alternate method of extensive open water testing is considered.

Two essential items of test equipment are:

(1) High pressure, temperature controlled test chamber; for pressure testing of components.

(2) A tank 12 feet in diameter and 30 feet high in which the control characteristics of underwater balloon systems can be determined. This tank would be equipped with instrumentation for measuring lifting forces, rates of rise and descent, and accelerations. It would be used also for studies on balloon configuration and stress analysis.

UNDERWATER BALLOON SYSTEM

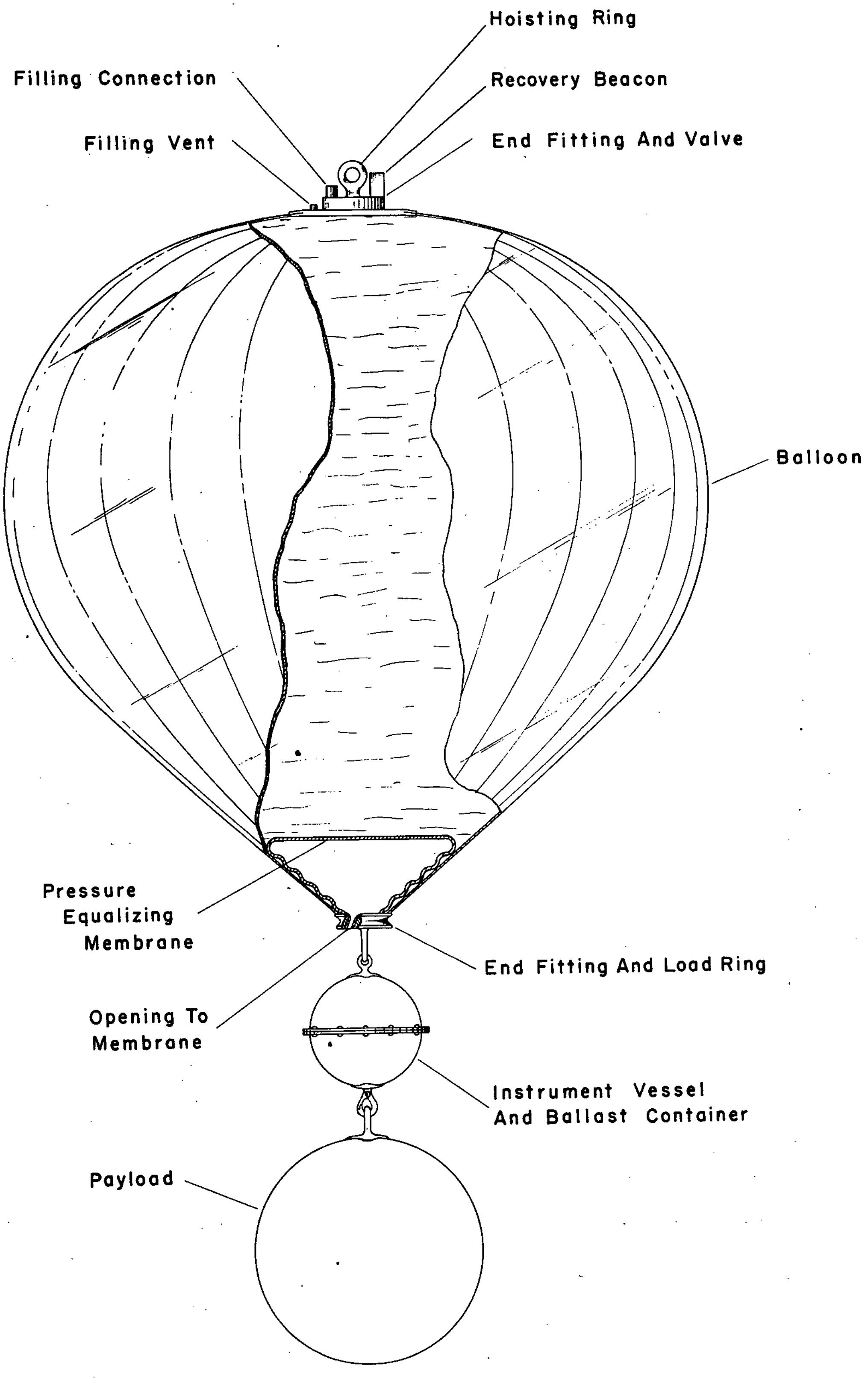


Figure 1

INSTRUMENT GONDOLA
(NON-PRESSURIZED TYPE)

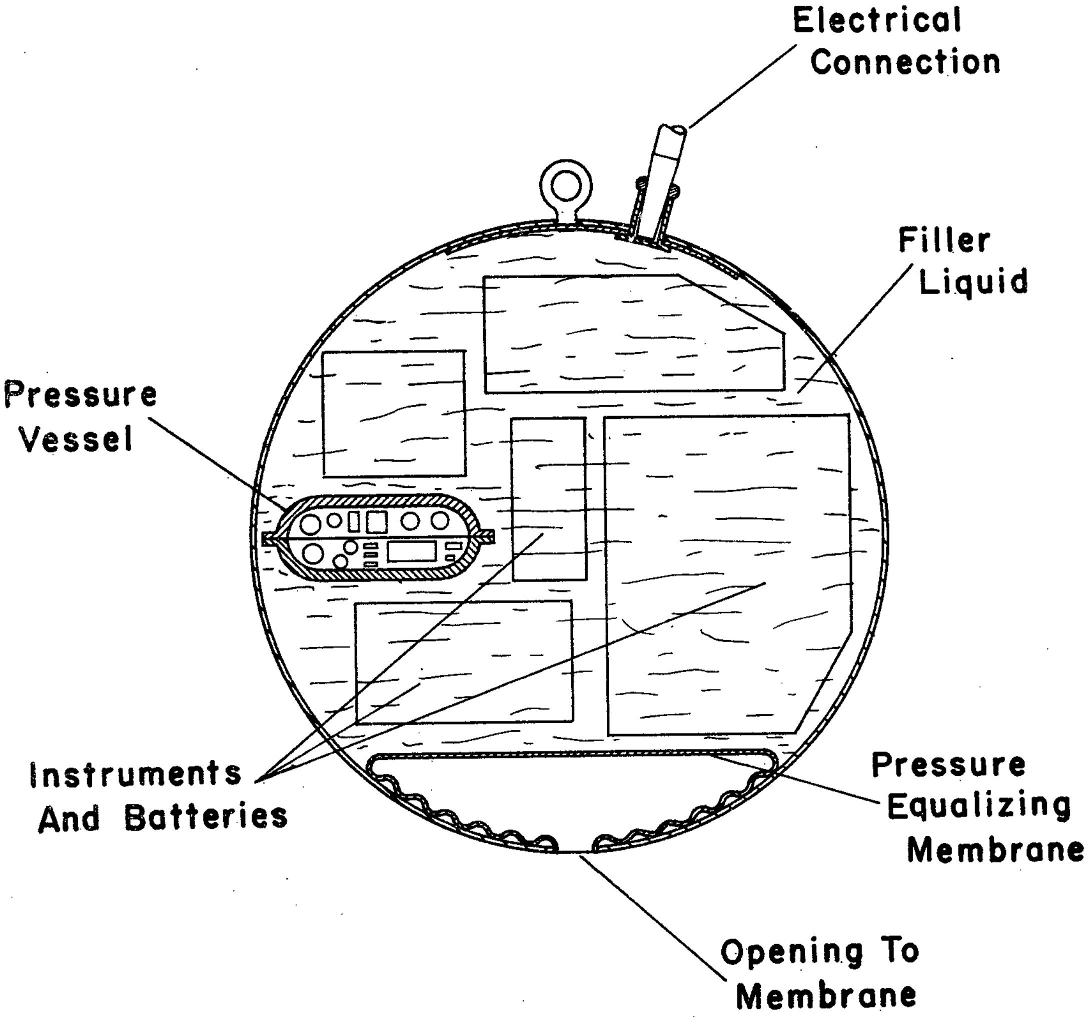


Figure 2

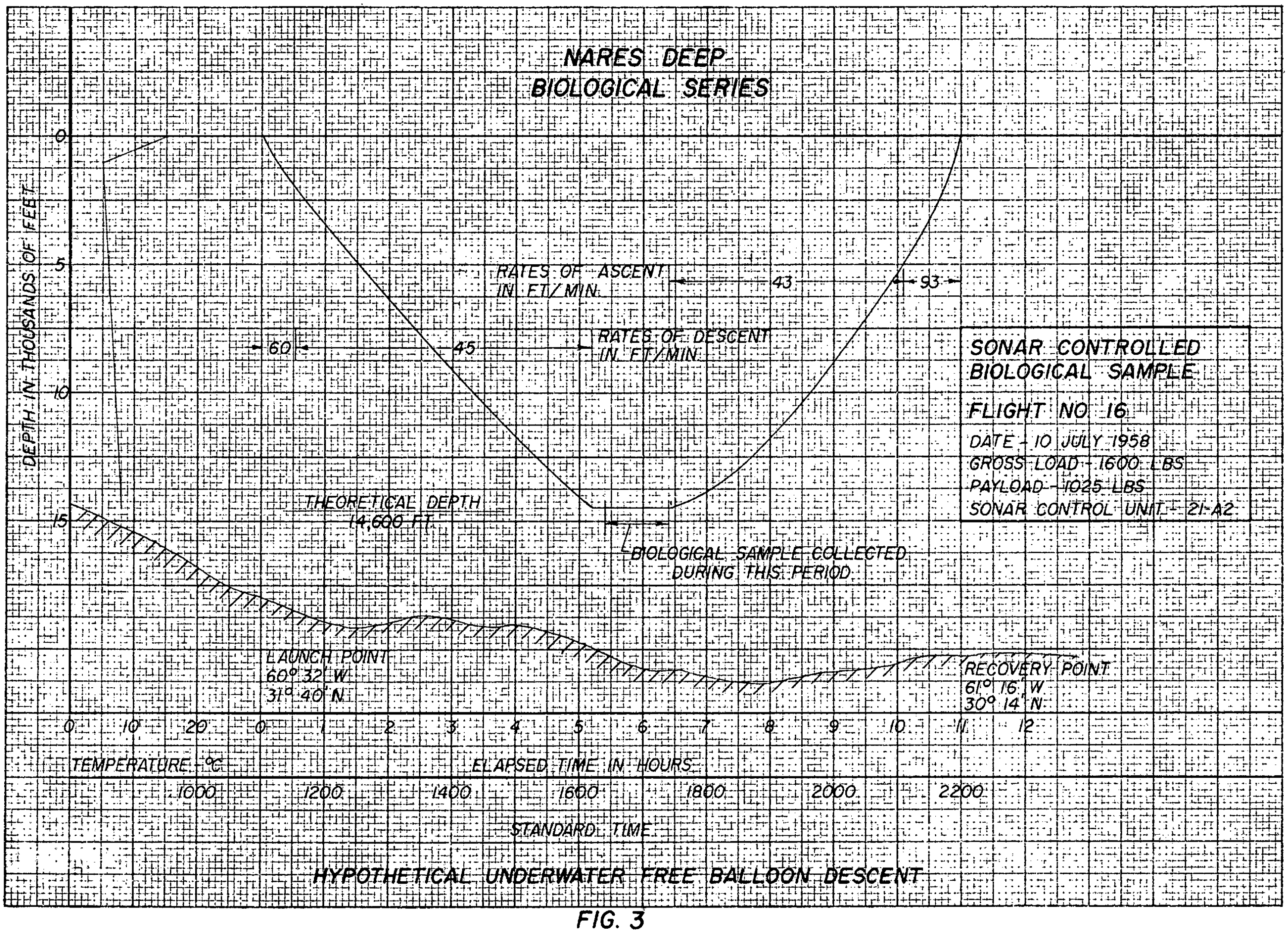

NARES DEEP
BIOLOGICAL SERIES
DEPTH IN THOUSANDS OF FEET
0
5
10
15
RATES OF ASCENT
IN FT/MIN
43
93
60
45
RATES OF DESCENT
IN FT/MIN
THEORETICAL DEPTH
14,600 FT
BIOLOGICAL SAMPLE COLLECTED
DURING THIS PERIOD
SONAR CONTROLLED
BIOLOGICAL SAMPLE
FLIGHT NO 16
DATE - 10 JULY 1958
GROSS LOAD - 1600 LBS
PAYLOAD - 1025 LBS
SONAR CONTROL UNIT - 21-A2
LAUNCH POINT
60° 32' W
31° 40' N
RECOVERY POINT
61° 16' W
30° 14' N
0
10
20
0
1
2
3
4
5
6
7
8
9
10
11
12
TEMPERATURE °C
ELAPSED TIME IN HOURS
1000
1200
1400
1600
1800
2000
2200
STANDARD TIME
HYPOTHETICAL UNDERWATER FREE BALLOON DESCENT

FIG. 3

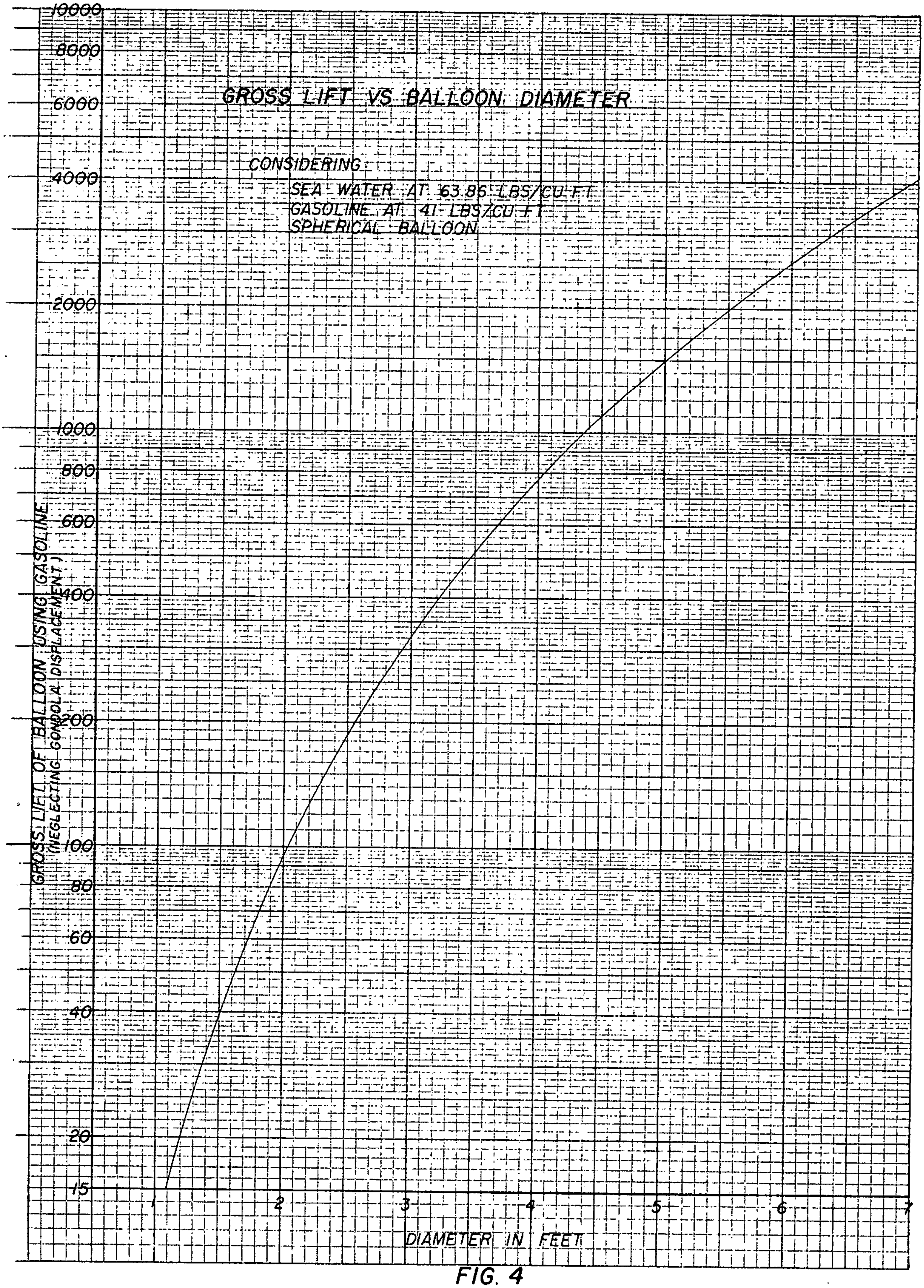

GROSS LIFT VS BALLOON DIAMETER
CONSIDERING:
SEA WATER AT 63.86 LBS/CU FT
GASOLINE AT 41 LBS/CU FT
SPHERICAL BALLOON
GROSS LIFT OF BALLOON USING GASOLINE
(NEGLECTING GONDOLA DISPLACEMENT)
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
15
1
2
3
4
5
6
7
DIAMETER IN FEET
K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

FIG. 4

LAUNCHING TECHNIQUE

(USING UNDERWATER FILLING)

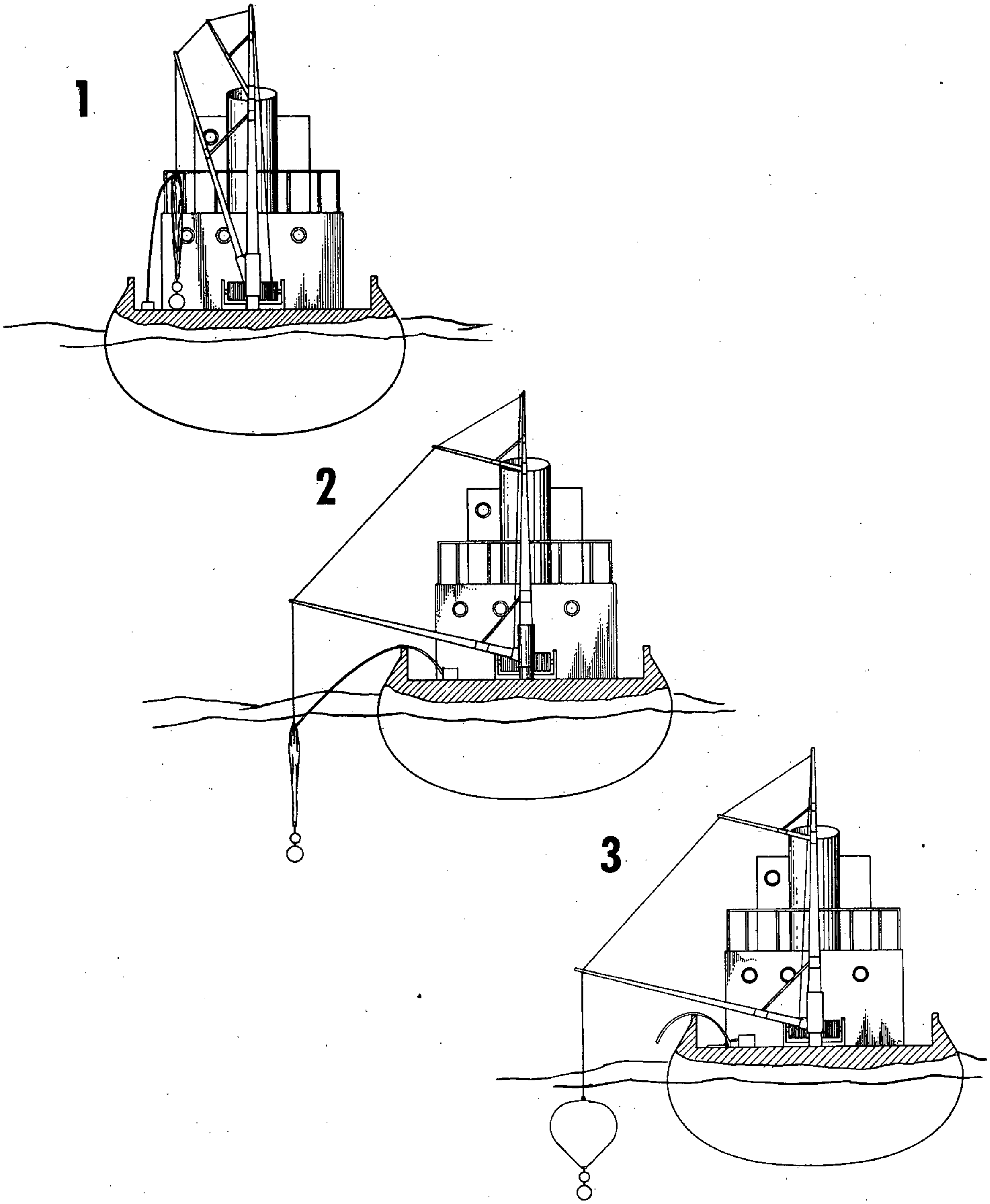


Figure 5

LAUNCHING TECHNIQUE
(UTILIZING A LAUNCHING TANK)

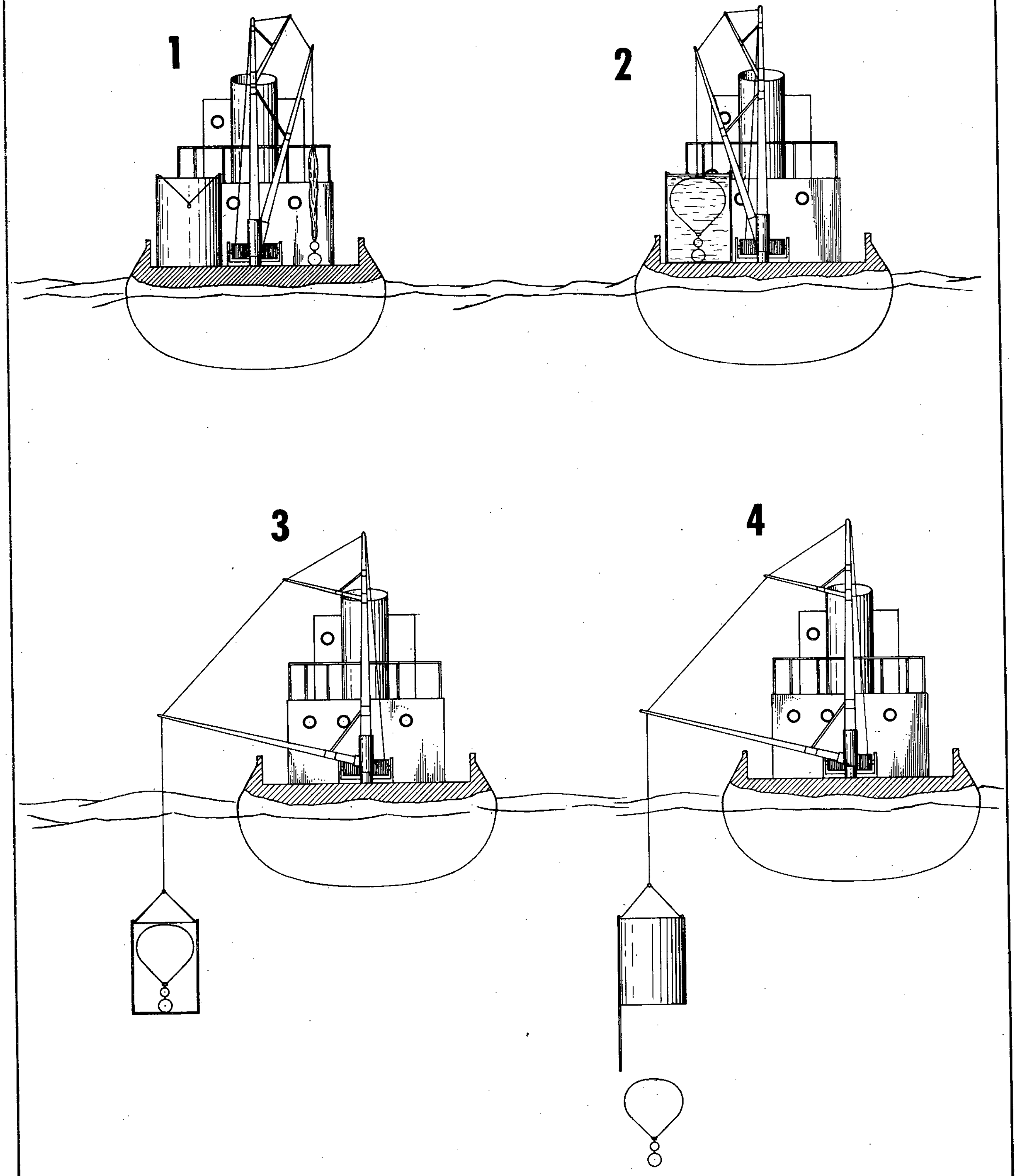
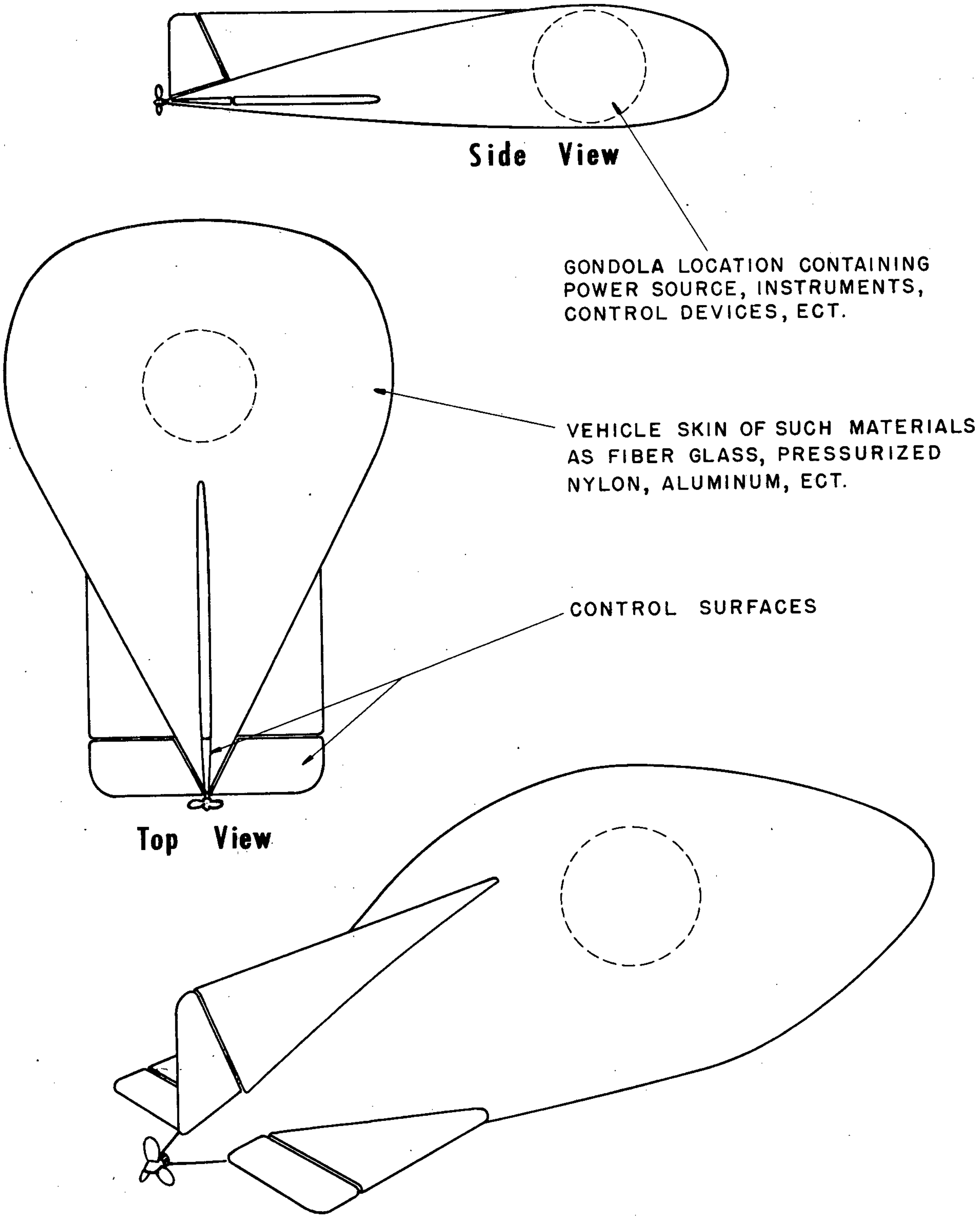


Figure 6

CONCIEVABLE UNDERWATER POWERED VEHICLE CONFIGURATION



Side View

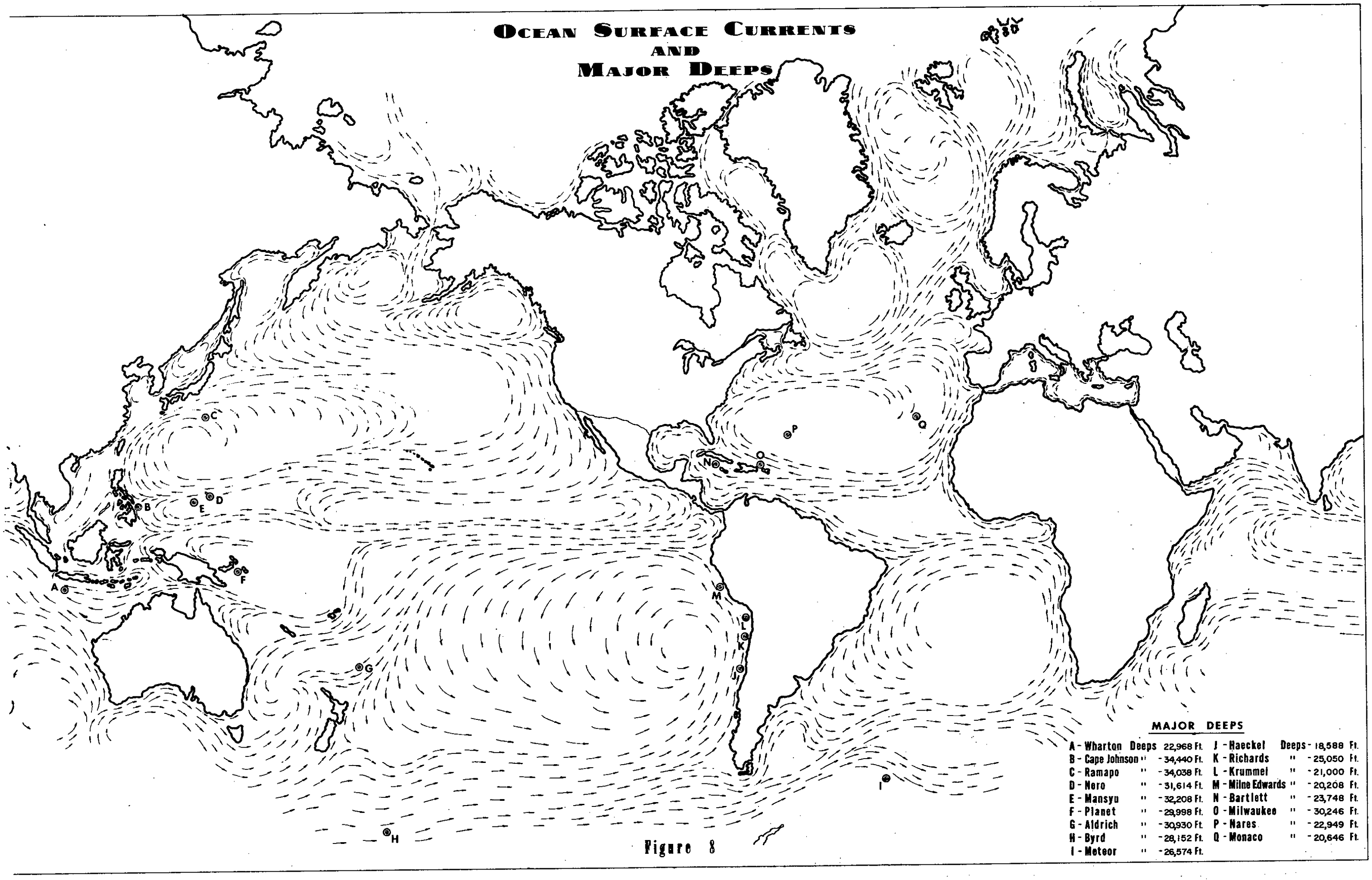
GONDOLA LOCATION CONTAINING POWER SOURCE, INSTRUMENTS, CONTROL DEVICES, ECT.

VEHICLE SKIN OF SUCH MATERIALS AS FIBER GLASS, PRESSURIZED NYLON, ALUMINUM, ECT.

CONTROL SURFACES

Top View

FIGURE 7



OCEAN SURFACE CURRENTS AND MAJOR DEEPS

MAJOR DEEPS

A - Wharton Deeps	22,968 Ft.	J - Haeckel	Deeps - 18,588 Ft.
B - Cape Johnson "	- 34,440 Ft.	K - Richards	" - 25,050 Ft.
C - Ramapo "	- 34,038 Ft.	L - Krummel	" - 21,000 Ft.
D - Nero "	- 31,614 Ft.	M - Milne Edwards	" - 20,208 Ft.
E - Mansyu "	- 32,208 Ft.	N - Bartlett	" - 23,748 Ft.
F - Planet "	- 29,998 Ft.	O - Milwaukee	" - 30,246 Ft.
G - Aldrich "	- 30,930 Ft.	P - Nares	" - 22,949 Ft.
H - Byrd "	- 28,152 Ft.	Q - Monaco	" - 20,646 Ft.
I - Meteor "	- 26,574 Ft.		

Figure 8