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MORAY TV-1A BUOYANCY
MATERIAL.

by

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INTRODUCTION

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A basic precept of the MORAY TV-1A design is that the vehicle be positively buoyant at all times. Weight and balance estimates indicated that the hull, with its components, would have a net negative buoyancy and a center of gravity too far aft of the center of buoyancy. It was realized that a low-density material, located in the after-section of the vehicle, would compensate for the buoyancy deficit and trim. Accordingly, a search for a suitable low density material was initiated.

BUOYANCY MATERIAL STATUS REPORT

Syntactic foam is the only material, of those considered in this study, which fulfills all of the requirements for MORAY TV-1A. A syntactic foam is one in which the density and other physical properties are controlled by the percentage of lightweight filler used in the formulation. The particular formulation for TV-1A is comprised of an epoxy base, its hardener and minute hollow glass spheres as the filler. It has a density of approximately 40.5 lb/ft^3, and will lose less than 1.0% of its buoyant force when subjected to a hydrostatic pressure of 1500 psi for a period of 24 hours.

BACKGROUND

A low density material data collection and measurement program was initiated in June 1960. In some instances, measurements were performed on materials which were felt to be unlikely to satisfy current requirements, but which might be of interest if requirements should change. A summary of several materials studied is shown in Table 1. The particular reasons for rejection, as useable materials for TV-1A, are briefly presented in the following paragraphs:

1. Liquids

(a) Since maneuverability is basic in MORAY's design criteria, the everchanging pressures upon the relatively compressible low density liquids would have created a trim stability problem.

(b) Low density liquids would have been a fire hazard, both aboard the test vehicle as well as the mothership.

(c) The loss of the bulk of a liquid system, due to leakage or hull rupture, could not have been compensated for by an emergency buoyancy system.

2. Petroleum Jelly - A minimum density on the order of 51 lb/ft3 eliminated this material from further consideration.

3. Waxes

(a) This material has a relatively high density (46-48 lb/ft^3).

(b) The best of the wax samples tested for volume change, while being subjected to 1500 psi hydrostatic load, compressed 5.5%. Because of the material's high density, approximately 100 ft3 would have been required for TV-1A in order to provide a positive buoyancy of 350 lbs. This 5.5 ft^3 of sea water to be added to the overall weight. This additional sea water would have been a sufficient amount (352 lbs) to completely eliminate the vessel's initial positive buoyancy (350 lbs).

4. Wood - All of a variety of common woods proved to have low resistance to hydrostatic compressive loads. Most failed at pressures below 1,000 psi. They all failed to re-expand to their original volumes after being returned to atmospheric pressure (see Fig. 1). The mahogany block on the right, originally the same size as the one on the left, was coated with Polyvinalchloride and subjected to 1500 psi, hydrostatic pressure.

5. Aluminum Spheres

(a) This system of providing buoyancy was complex with respect to sphere distribution and retention.

(b) The fabrication of sufficiently strong spheres made this the most expensive of the materials investigated.

(c) Several sizes of spheres would have been required for maximum packing density - therefore becoming an even more expensive system.

6. Glass Spheres and Cylinders - Although these items possessed many buoyancy material attributes, in particular their high compressive strengths (above 10,000 psi in most cases), they proved to be an extreme safety hazard. In isostatic press tests, as well as in a deep ocean test, it was found that "sympathetic implosion" occurs in a cluster of these items. That is, the implosion of one sphere or cylinder triggers a chain reaction among the remaining items - resulting in complete failure of all items in the cluster.

7. Syntactic Foams (Microballoon filled plastics) - The extremely low true density range (10-16 lb/ft^3) of minute hollow spheres made them attractive as a buoyant material early in this study (see Fig. 2). However, the "state-of-the-art" samples, plastic encased glass micro-

spheres furnished by Emerson and Cuming, Inc., failed to withstand pressures without either absorbing too much of the liquid medium or compressing an unacceptable amount. These materials were necessarily forced into the background while more promising materials were investigated.

During the fabrication of MORAY TV-1A fiberglass hull, a need existed for a material which could be cast to a given configuration, to become a rib and fin cores (see Fig. 3). The function of the material was to change the rib and fin components from pressure vessels to solid members - thereby removing the possibility of the ambient pressure imploding them. At this time limited testing was being conducted on two commercially available syntactic foams - "Ren" (Ren Plastics, Inc.) and "Epocast 169" (Furane Plastics, Inc.). The more promising of the two, "Epocast 169", was tested for the specific application and incorporated into the hull ribs and fins. This limited use of syntactic foam, as well as a glass microballoon, which had recently been developed by the 3M Co., re-vitilized interest in this approach to the buoyancy problem. A series of syntactic foam formulations and tests followed. Zenith Plastics Co., a division of Minnesota Mining and Manufacturing Co., attempted to perfect the use of the 3M Co. microballoons in a plastic matrix, while this Station was engaged in a general study of various microballoons encased in a limited number of plastics.

To date, low compressive strengths or variations in true density have narrowed the useable microballoon field to one item - "Eccosphere SI", manufactured by Emerson & Cumming, Inc. This filler material will be used in TV-1A.

The plastic matrix, selected for system compatibility, is an epoxy resin "EPON 815" with DEAPA, Diethylamino Propylamine, hardener. Both resin and hardener are supplied by the Shell Chemical Company.

BUOYANT FILLER MATERIAL UTILIZED IN MORAY TV-1A FRAME STIFFENERS AND MOVABLE FINS

The total internal volume of MORAY's four movable fins and nine frame stiffeners, is approximately eight cubic feet. These components, if constructed as pressure vessels, could upon failure, whether by leakage or implosion, alter the initial positive buoyancy of the vessel by approximately 500 pounds - an amount greater than the initial positive buoyancy. To overcome this safety hazard, as well as to provide added strength to these members, the internal volumes have been filled with a low density Epoxy formulation. This filler represents a 175 pound buoyant force gain over the "Free Flooded" condition.

The buoyant material chosen as the frame and fin filler was "Epocast 169". This is an "off-the-shelf" item, manufactured by Furane Plastics, Incorporated, Los Angeles, California.

Tests conducted on this material at NOTS have produced the following data:

1. Density Range. . . . . 40-44 lb/ft^3
2. Tensile Strength, Avg. Ult. . . . . 1,765 psi
3. Compressive Strength Avg. Ult. . . . . 8,000 psi
4. Percent Buoyant Force loss due to isostatic compression at 900 psi for six hours 1.40%
5. Percent liquid absorption after 6 hours at 2,675 psi isostatic pressure 0.00%
6. Percent permanent volume change after 5 hours at 2,675 psi isostatic pressure. . . 0.63%

This permanent volume change was noted to occur only during the initial test. The specimen did not sustain additional permanent volume change in subsequent tests.

At the limited depth of 2,000 feet for TV-1A, failure of the frames and fins to remain watertight would subject the internal buoyant material to a hydrostatic force such that only 1.4% loss of buoyant force, due to compression of the material, would result. This would be 1.4% of the total eight cubic feet and amounts to only 2.45 pounds. Therefore, the buoyant-filler material in the ribs and fins of MORAY TV-1A will be safe and should present no operational problems at the limited depth of 2,000 feet (see Fig. 3).

PRINCIPAL MASS OF BUOYANT MATERIAL FOR MORAY TV-1A

A total volume of 74.5 cubic feet of buoyant material, with a density of 40.5 lb/ft3, will be required to provide MORAY with 350 pounds of initial positive buoyancy. Of this volume 23.7 cubic feet will be located in the tail casting and 50.8 cubic feet in the main body above the battery case. This material in TV-1A will be a microsphere filled epoxy (syntactic foam) which has been formulated and tested at this Station. It is referred to as NOTS Foam 7-A by the Underwater Weapons Systems Branch.

The formulation is as follows:

EPON 815 EPOXY RESIN.	75.0% by wt.
DEAPA HARDENER	5.0%
ECCOSPHERE SI FILLER	20.0%

EPON 815 EPOXY RESIN is manufactured by the Shell Chemical Corporation. It was selected for use in this formulation because it's viscosity is only 5-9 poises and yet has a compressive strength comparable to other epoxy resins (18,000 psi). It's liquid absorption is negligible.

DIETHYLAMINO PROPYLAMINE HARDENER (DEAPA, Epon Curing Agent "A") is manufactured by various chemical companies including Shell Chemical Corporation. It's principle advantages are long pot life and low exotherm - permitting relatively large batches to be mixed and cast.

ECCOSPHERE SI MICROSPHERES are manufactured by Emerson and Cuming, Inc. The manufacturer lists the following physical properties:

Physical Form	Free flowing powder
Particle Size	30 to 125 microns
Wall Thickness	About 2 microns
Chemical Composition	Over 95% SiO_2
Bulk Density	11 lbs/cu ft (0.18 g/cc)
True Particle Density	About 16.2 lbs/cu ft (0.28 g/cc)
Temperature Capability	2500°F (1400°C)
Permeability of Particle Wall	Impermeable to water and other liquids
Thermal Conductivity of Loosely Packed Material	0.03 BTU/hr/ft^2/°F/ft at 0°F 0.04 BTU/hr/ft^2/°F/ft at 300°F
Compressive Strength under Hydrostatic Loading	At least 1000 psi
Dielectric Constant (dry) 1 mc to 8600 mc	Approximately 1.16
Dissipation Factor (dry) 1 mc to 8600 mc	Approximately 0.0005

Tests conducted on this material have produced the following data:

1. Density Range.	40-41 lb/ft3
2. Percent buoyant force loss due to isostatic compression at 1500 psi for 24 hours	1.0% maximum

3. Percent buoyant force loss after 100 cycles from 0 to 1500 psi plus 6 hour hold time. . . . . 1.0% maximum

4. Percent liquid absorption . . . . 0.1% by wt. maximum

See Fig. 4.

No commerical instrumentation capable of measuring the changes in buoyancy with the precision required and with the necessary stability, is available. An instrument was designed, in this branch, for performing this test. Strain gages are used to measure the deflection of a cantilever beam. The buoyant body and a weight exert opposing ambient pressure. Changes in buoyant force introduces a force imbalance with a corresponding beam deflection and strain gage indication. The strain gage network consists of a bridge network to provide temperature compensation. See Fig. 5.

Fabrication is to some extent an art, as is formulation. Some of the more important factors are as follows:

1. The consistency of a mix is governed by the percentage of microspheres used. A lower density mix may be obtained by the addition of more microspheres, but will result in a mix which can not readily be poured. If a mix requires packing or tamping, there will very likely be air included. Heat may be applied to the epoxy to lower its viscosity, but care must be taken not to create a condition whereby the exotherm will "set" the mix prematurely.

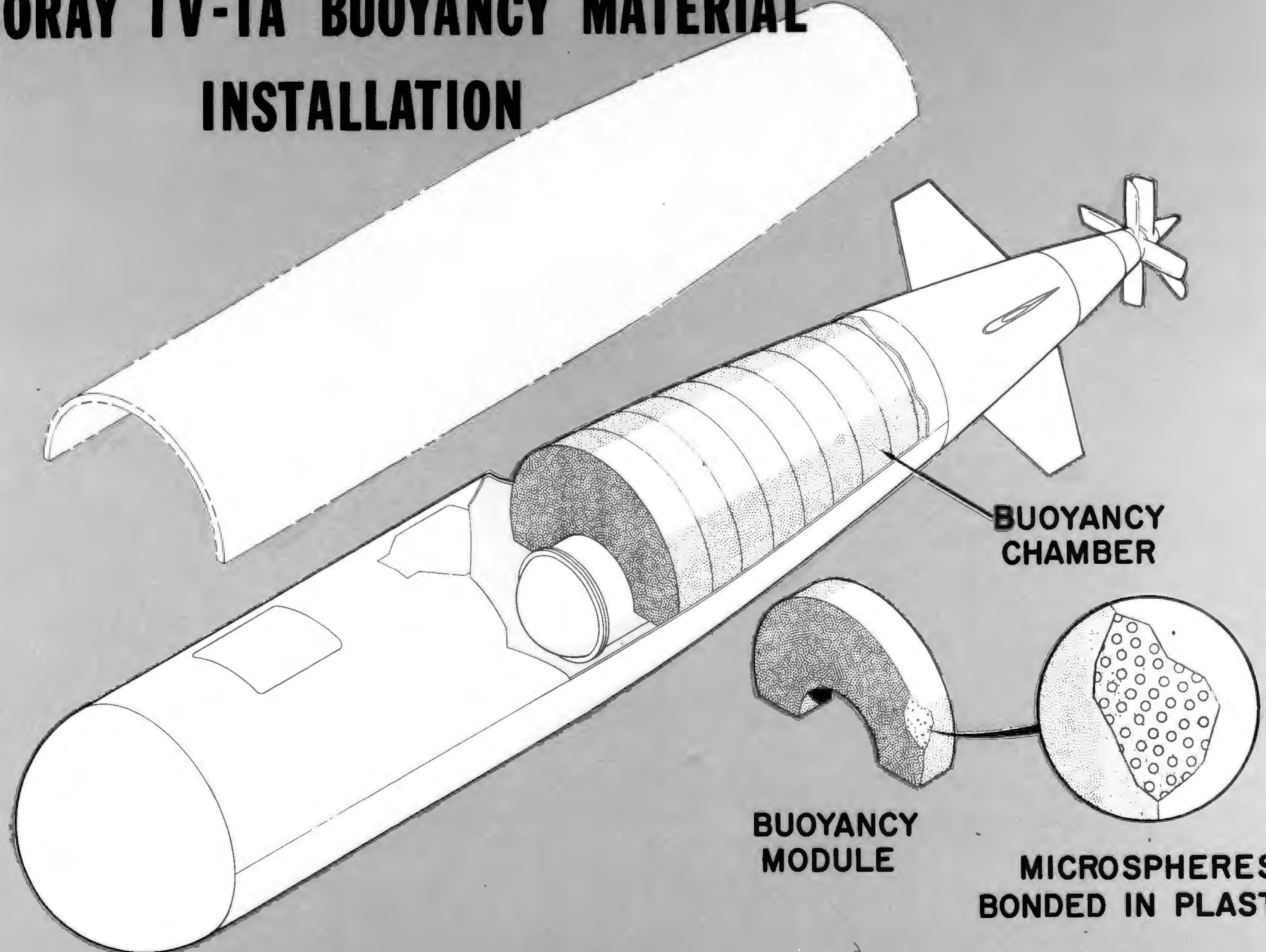
2. Pulling a vacuum of approximately 20 in. Hg, during the last few minutes of mixing, will generally exclude most air from a mix.

3. Mix time is governed by the quantity being mixed. That is, the larger the quantity, the shorter the time before the exotherm makes the material "set". Complete mixing of quantities of 1/2 gallon or less present no problem. Larger quantities may require that the microspheres be mixed with the epoxy followed by a short mix time with the curing agent.

4. The size of casting is primarily set by the depth of the material and the exotherm involved. The formulation described in this report will be cast in layers which will not exceed 3 inches. Casting excessively deep sections results in "burn areas" created by high exotherms. These areas contain air pockets and thereby reduce the compressive strength of the finished product.

The buoyant material, other than that in the ribs and frames, will be cast into the hull and fabricated into modules as illustrated in Fig. 6. The ribs and thickened hull at the centerline provide contoured matching surfaces which permit accurate placement of the modules and prevent shifting.

MORAY TV-1A BUOYANCY MATERIAL INSTALLATION



MATERIAL	BUOYANT FORCE/Ft^3 OF PACKING SPACE (lbs) 0 5 10 15 20 25	ESTIMATED COST PER 100 LB NET POSITIVE BUOYANCY (DOLLARS) 0 100 200 300	SPECIFIC WEIGHT	RESISTANCE TO PRESSURE EFFECT	RESISTANCE TO SEAWATER EFFECT	SAFETY	COST	HANDLING	SPACE CONFORMITY	INSTALLATION	MAINTENANCE
Liquids (In container)			Good	Fair	N.A.	Poor*	Excel.	Fair	Excel.	Good	Fair
Petroleum Jelly (In container)			Poor*	Good	N.S.	Good	Excel.	Fair	Excel.	Good	Excel.
Waxes			Poor*	Good	Excel.	Good	Excel.	Good	Excel.	Good	Excel.
Woods			Good	Poor*	Fair	Poor*	Excel.	Good	Good	Fair	Fair
Aluminum Spheres (4 in. diameter)			Good	Excel.	Poor*	Ukn+	Poor*	Good	Fair	Fair	Fair
Glass Spheres (3 in. diameter)			Fair	Excel.	Excel.	Poor*	Good	Fair	Fair	Fair	Good
Glass Cylinders (4" dia. x 8" lg)			Good	Excel.	Excel.	Poor*	Poor*	Fair	Fair	Fair	Good
Micro Balloon Filled Plastics			Excel.	Good	Excel.	Excel.	Fair	Good	Excel.	Good	Excel.

TABLE I

COMPARISON OF BUOYANT MATERIALS

*"Poor" rating is reason for eliminating material from usable material list.

+ Deep Ocean testing of aluminum spheres for sympathetic implosion has not been conducted.

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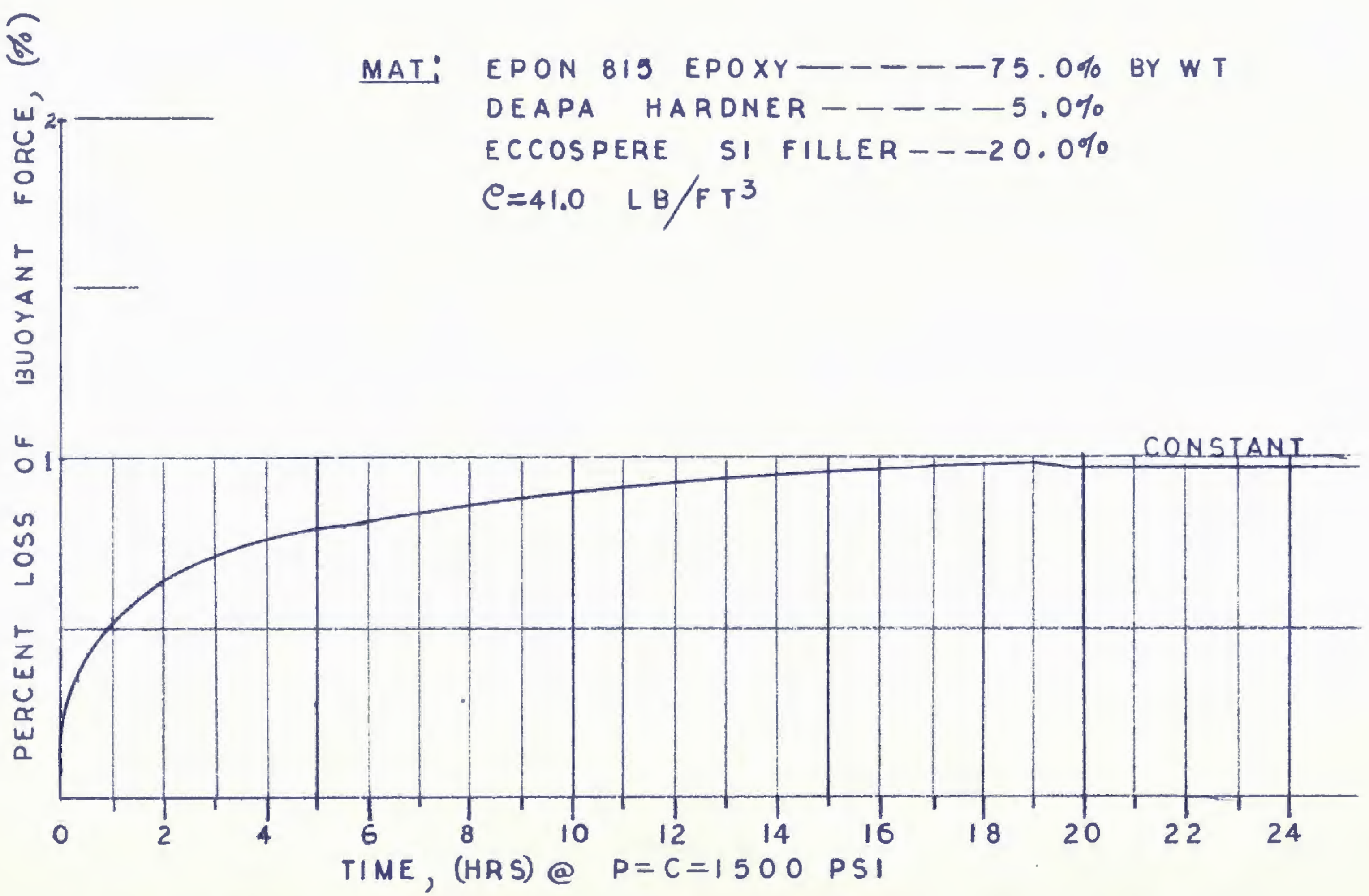

FIG. 4 NOTS FOAM 7-A COMPRESSIBILITY TEST

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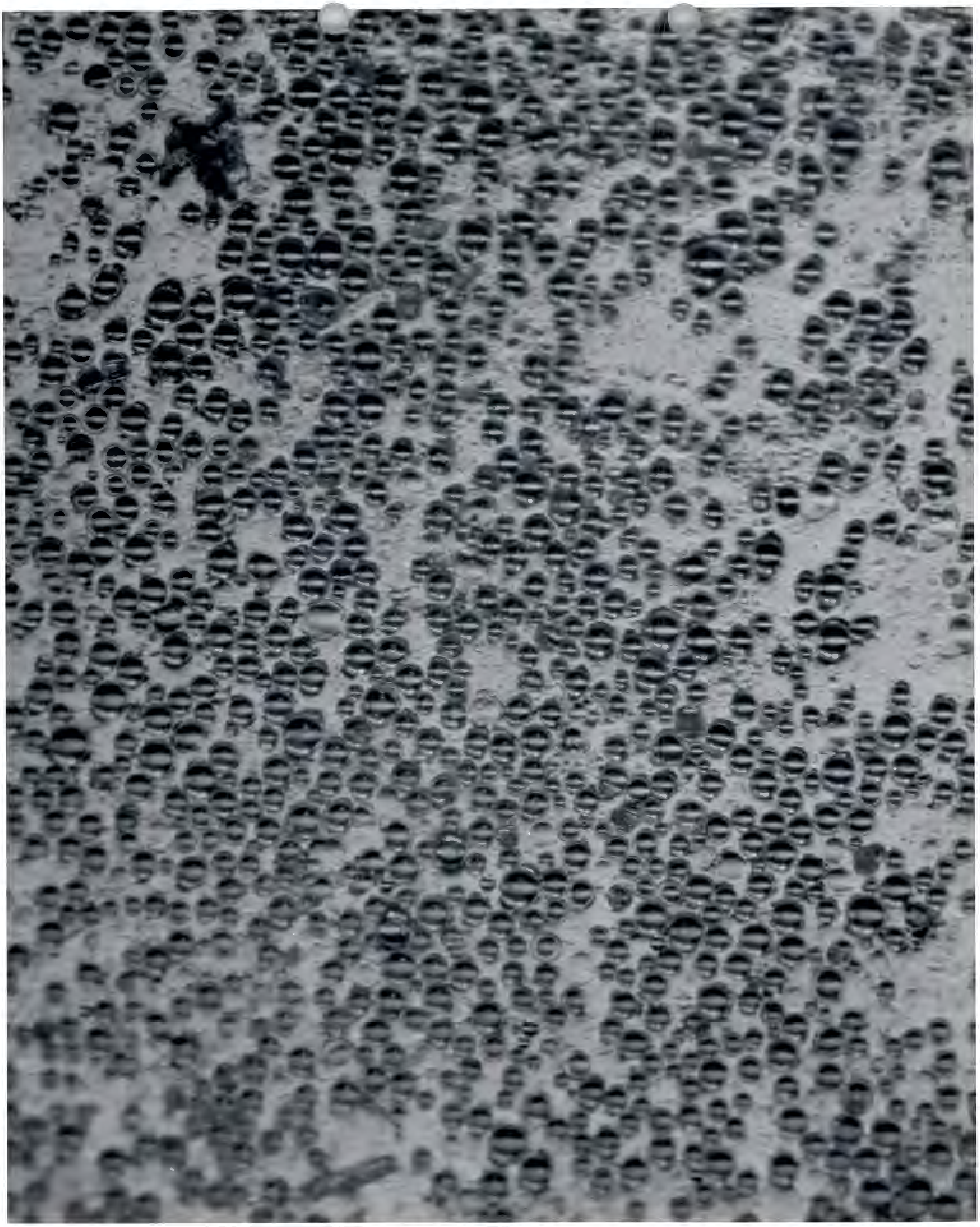

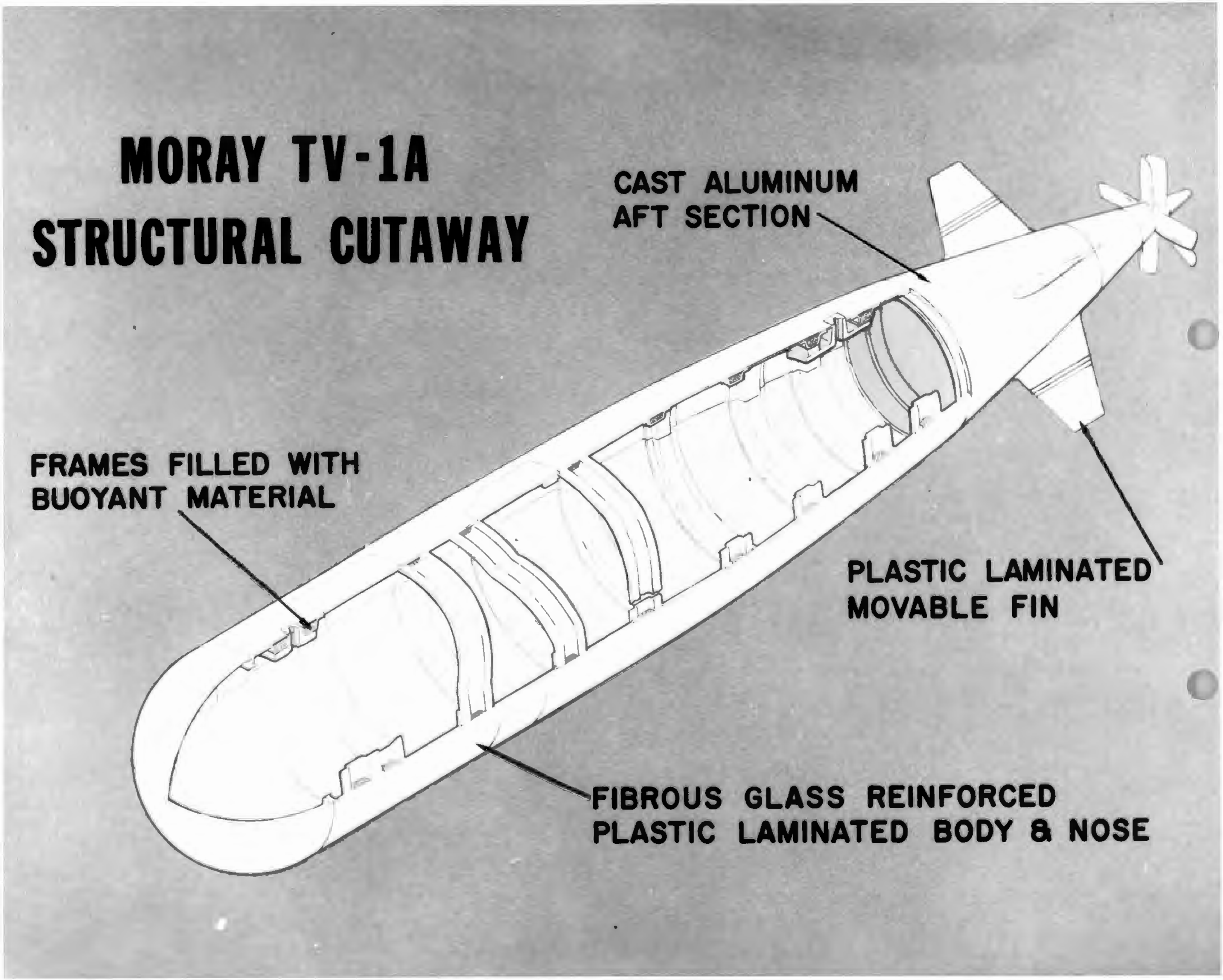
MORAY TV-1A
STRUCTURAL CUTAWAY
CAST ALUMINUM
AFT SECTION
FRAMES FILLED WITH
BUOYANT MATERIAL
PLASTIC LAMINATED
MOVABLE FIN
FIBROUS GLASS REINFORCED
PLASTIC LAMINATED BODY & NOSE

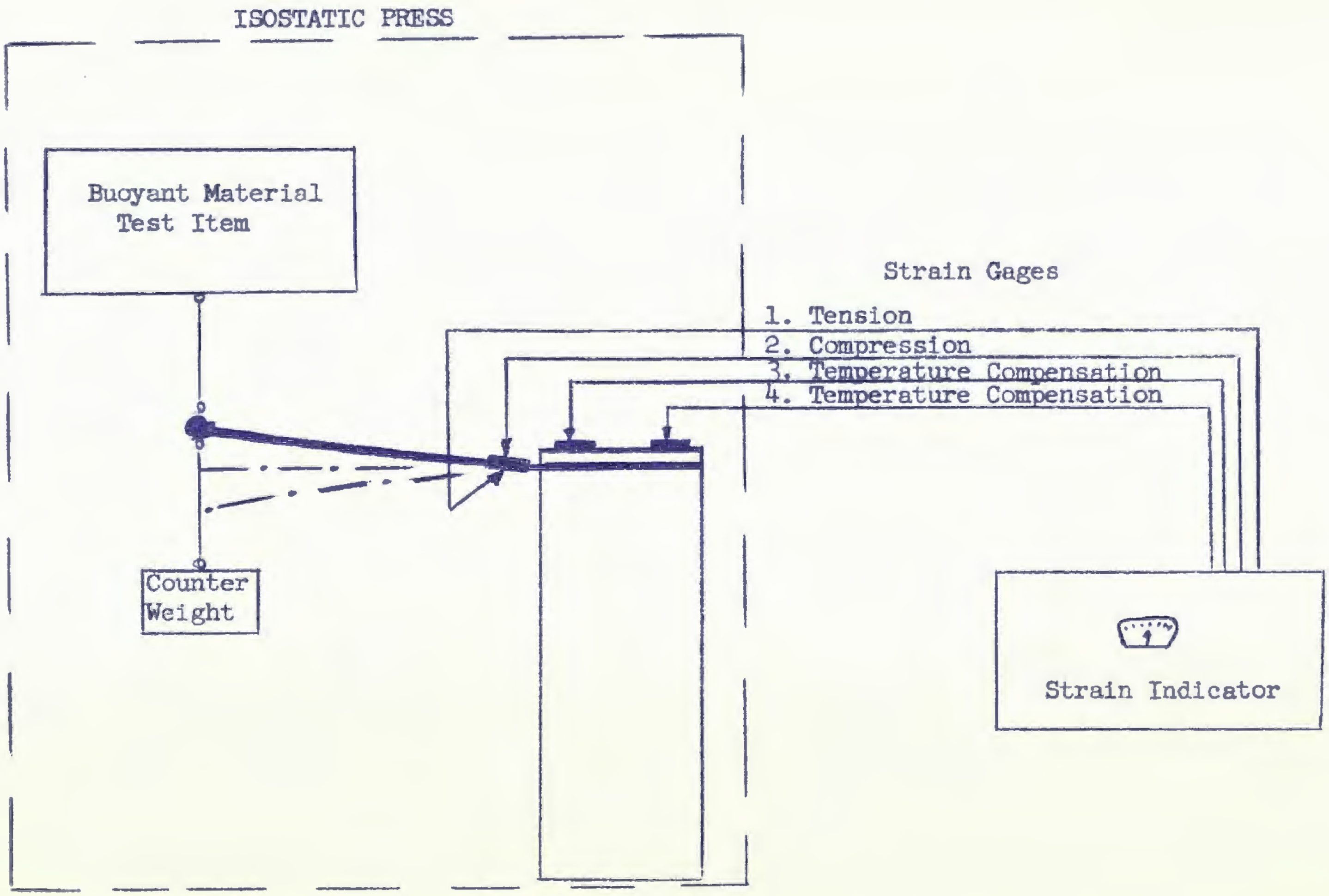

FIG. 5 INSTRUMENTATION FOR MEASURING BUOYANCY CHANGE