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WOODS HOLE OCEANOGRAPHIC INSTITUTION

TECHNICAL MEMORANDUM #DS--17

WHOI COMMENTS ON DSRV ALVIN DESIGN

Review by
Bureau of Ships

WOODS HOLE, MASSACHUSETTS

WHOI Tech.
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January 12, 1965

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1. Personnel Sphere

The comments use the term "factor of safety" with two different meanings. It should be noted that one,

$$F.S. = \frac{\text{test depth}}{\text{design operating depth}},$$

which equals 1.61 for Hull No.1 compares with a value of 1.00 or less for combat submarines.

WHOI concurs that the strength of the personnel sphere is adequate. This conclusion, however, must be based on more than a review of the references (a) and (b) noted.

2. Personnel Sphere Windows, Hatch and Penetrations

WHOI concurs that the ultimate strength of the plexiglas windows is unknown, and the d/t of 1.43 is larger than that found on the TRIESTE spheres. For this reason, WHOI is planning the test of full scale windows seated in a tank test block simulating the hull. Facilities are available for test to 11,500 psi which is expected to be close to that required for failure. It is planned to determine the effect on performance of mismatch of window and seat, as well as cracks and crazing.

An ALVIN window was strain gaged for the 2500 and 3300 psi tests of Hull No.1. Data from these tests is presented in SWRI report "Experimental Strain Analysis for ALVIN Hull No.1" by E. M. Briggs and R. C. Dehart, May 1964. However, a WHOI review of the original strain data has shown a data reduction error. The data is replotted correctly in the attached brief report. In summary, the maximum stress observed at 3300 psi pressure was 6500 psi biaxial compressive stress at the center of the outside of the window.

3. The variable ballast and buoyancy spheres are discussed in a report entitled "Summary Report on Fabrication, Inspection, and WHOI TM-DS-15 by J. W. Mavor, Jr.

4. Subject: Buoyancy Materials.

Bureau Comments: "Insufficient data available to judge adequacy."

WHOI concurs that, as of the time of the BUSHIPS design review, there was little data available on the characteristics and performance of the buoyancy material. Considerable data has

been accumulated since that time, some of which (Litton reports on ALVIN buoyancy material) has been forwarded to the Bureau. In addition, much information has been gained on the same type of material from tests conducted by other activities (U.S. Navy Applied Science Laboratory, Southwest Research Institute and General Motors Inland Division). Also, WHOI is preparing a long-term (1000 hours) exposure and cycling test on samples of the buoyancy material cored out of the ALVIN buoyancy packages. A summary of the significant information on syntactic foams, comprised of epoxy binder and microballons, such as in ALVIN is as follows:

- a. The material does not fail catastrophically in compression. When yield occurs (14 - 15,000 psi for present formulations) the material deforms to less than 10% loss of volume.
- b. The typical failure is a gradual loss of buoyancy by water absorption after long, or cyclic exposure to high pressure (over 1000 psi). The "better" formulations (those of uniform density which have been oven-cured) level-off in their water absorption so that water weight does not go beyond about 1%, even after 1000 hours. Some of the poor formulations may increase water absorption rapidly after about 500 hours exposure. It is this latter fact which induced WHOI to run a 1000-hour test on cored samples from ALVIN - not because of concern over safe performance, but to permit prediction of the life of the material.
- c. Short-term (56 hours) tests of cored samples from ALVIN at pressure up to 3300 psi showed a net percentage weight increase of 120 samples of about 1%.
- d. A test of the same 120 samples to determine change in buoyant force from 0 to 3000 psi due to compressibility showed a net loss of 7.75 lbs. for all of the material in ALVIN. (Sample buoyancy was extrapolated to complete package buoyancy).
- e. The results noted in c. and d. above are pessimistic because:
 - 1) Water absorption varies directly with the ratio of surface/volume, which is large for the samples and small for the complete buoyancy packages.
 - 2) The samples are uncoated, but the major packages are coated with a rubber coating similar to Thiokol. Such coatings have proved beneficial in reducing water absorption.

- 3) The compressibility samples were uncoated, which resulted in an initial, apparent compression during pressurization from 0 - 500 psi due to compression of surface-entrapped air.

In summary, WHOI considers the buoyancy material, installed in ALVIN, to be safe for repetitive operations to 6000 ft. depth. Such failure as may occur will be gradual loss of buoyancy due to water absorption, compensation for which is well within the capacity of the variable ballast system.

5. Weight and Stability

A preliminary report has been submitted. Notably, this does not include clear definitions of the loading conditions, longitudinal stability calculations, or calculations of stability and buoyancy in some emergency conditions of interest.

Some explanation of loading conditions is an order with respect to the Bureau comments. The normal condition of the submarine includes, in addition to the basic operating craft fixed weights, the following variable load:

<u>Item</u>	<u>Weight (lbs.)</u>	<u>Displ.(lbs.)</u>
1. Scientific Payload	1200	100
2. Crew and effects	500	---
3. Variable Ballast Reservoir Oil	514	603

Normal surface condition is diving trim. Normal submerged condition differs from normal surface only in the addition of weight of main ballast water.

ALVIN has usually operated in the normal loaded condition, that is variable ballast in the normal condition, half in the spheres and half in the bags. In this condition, sum of scientific payload and crew and effects must be 1700 lbs. When less than this figure was on board, the balance was made up with lead ballast carried inside the sphere. The V.B. system was used primarily to make the boat heavy for diving or sitting on the bottom.

However, at other times, during later operations, the variable ballast capacity was used for static compensation rather than lead ballast and close to the full range of loading was experienced from the light loading of $1700 - 400 = 1300$ lbs. to a heavy loading of $1700 + 450 = 2150$ lbs.

which were experienced during the dives conducted this past summer:

- a) To compensate for removal or retention of the mechanical arm (350# in water) and the PGR (248# - all in sphere).
- b) Accomodate load changes for one or two observers (up to 250#).
- c) Expedite normal diving and surfacing by changing displacement on the order of $\pm 200 - 400\#$ from "neutral trim" after compensation for (a) - (c).
- d) Adjust for heavy trim on bottom to counteract mechanical arm forces, take sensitive gravity measurements (+600# was used to get a LaCoste gravimeter reading on a soft bottom), etc.
- e) To compensate for samples taken on board. As many rock or water samples as is safe to do so will probably be picked up on any given dive for that purpose.
- f) To compensate for emergency loss of buoyancy to things other than this system where the maximum amount available will be used, such as the Main Ballast System and to aid other emergency systems if the V.B. system is available.
- g) To provide a useful payload. With one-half of oil in spheres, and one-half in the rubber bags, the measured payload of the vehicle is 1200#. Any reduction in this system is a direct reduction in payload unless spheres are left empty (and therefore subject to flooding even if not part of the V.B. system).

The variable ballast system is subject to several kinds of failures as follows:

- a) Failure of pump or motor -
If nothing else in the system fails, this can be negligible or compensated for by using other methods (main ballast, dropping arm, mercury or batteries - usually science battery).
- b) Failure of valve -
If valve fails shut, same applies as in (a). If valve fails open and rest of system is intact, pump can be used to maintain equilibrium during return to surface.

- c) Rupture of rubber bags -
The total displacement between the maximum amount of oil that can be in the bags, and the sea water which would replace it is only about 200#, easily compensated for by dropping the science battery. Any lesser failure can be all or partially compensated for by pumping oil to sea.
- d) Rupture of all spheres simultaneously -
The seriousness of this failure is the worst case but the maximum loss of buoyancy-spheres empty of oil - will be approximately 1260#. This requires dropping the mercury (600#), science battery (320#), and arm (350#). This would also be an extreme emergency and dropping these items, while retaining propulsion would be the normal procedure for return to the surface. This is an unlikely occurrence.
- e) Leakage or failure of "hard" piping -
The seriousness of this failure is directly proportional to the amount of oil in the spheres as all piping is to the bottom of same. Thus the sea water will flood only to the extent the entrapped air and water will permit and likewise will be partially expelled as the vehicle decreases depth.

An isolation valve in the line to any sphere or spheres would still leave the possibility of failure that existed prior to its installation, but to a lesser degree. However, the decrease in changes available for operations would outweigh the advantages. The safety of the system is still not 1.0 but something less. There is a pressure indicating system to measure the amount of oil in the "hard" side of this system which has been used with satisfactory results during the first 77 dives. Further, it is impossible to overfill the rubber bags if proper filling procedures are used, as their capacity (300 gal.) is well in excess of the oil used in the system (165 gal.). It is therefore not considered necessary to indicate that the bags are extended.

Conclusions.

1. The capacity of the V.B. System is not so large that in the event of any but catastrophic failure compensatory action cannot be taken.
2. The system capacity now available is necessary for efficient and safe use of the vehicle.

3. Indication of the extension of the rubber bags is not deemed necessary because an indication of the amount of oil in the spheres is available and the capacity of the bags is considerably in excess of the oil in the system. Proper procedures for filling and calibrating the system are being carefully followed. (See Page 3.6.1.1, Vol.III, of the Instruction Manual).

8. Subject: Mercury Trim System

Bureau Comment: "Capacity is minimum and reliability can be improved."

WHOI concurs with the comment, and is making some improvements in the system. Such concurrence assumes that "minimum" applies to the demonstrated capacity of the system compared to the specified trim capability of $\pm 30^\circ$. The specified trim capability was not, and is not, a controlling factor in the safe operation of ALVIN; rather it was an arbitrarily selected range to facilitate scientific observations and collection of specimens. The achieved range of trim, as tested in shallow water trials, in the normal-load condition was a total of 45° . The difference between the specified range of 60° and the achieved range is attributed to the late addition of buoyancy material in the forebody, resulting in the vehicle being heavy by the stern, unless the mercury is unequally distributed. Actually, this condition will permit collecting a greater load of specimens than anticipated.

The integrity and reliability of the system is being improved by internal changes in the system to prevent carry-over of mercury and improvement of the dump solenoid circuitry. Welded connections are not being considered for use until greater experience with the system has been gained. In the meantime, ease of assembly and disassembly is considered more desirable than the greater integrity of welded connections. Further, the fittings being used have proved to be very reliable in service to date.

In summary, WHOI agrees that achieved trim capability does not meet that specified; however, the resultant condition should actually enhance operations rather than hamper them. The mercury isolation features of the system need improvement and are the subject of active negotiations with Litton at present.

9. Subject: Main Ballast System.

Bureau Comment: "Adequate for surface."

WHOI concurs that the main ballast blowing system, even as modified with an additional air flask, is not a factor for any significant flooding casualty; except in water depths less than about 600 feet. The main ballast blowing system was designed primarily to provide freeboard on the surface and to permit "riding the vents" while in diving trim. Other recovery features are provided to counter flooding casualties in deep water. Even in shallow-water casualties, the first consideration will be to make a controlled ascent. In normal surfacing procedure the main ballast tanks are not blown until the vehicle is on the surface. The air flow rate is intentionally kept small in order to avoid the possibility of over-pressurizing the main ballast tanks.

10. Subject: Electrical System.

Bureau Comment: "Circuit reliability should be improved."

WHOI concurs that the reliability of the electrical system should be improved; and is currently making numerous modifications to accomplish this objective.

Comment is made below on the various conclusions noted in the Bureau's review of the electrical system:

- 1) Battery disconnects are being installed in the control centers. These will be 300 amp. contactors, initially closed with power from Emergency Battery No.2. The operator may open the contactor from inside the pressure hull in case of an overload. Since the battery charging leads have separate terminals and caps, about three feet apart; both caps would have to leak to provide a salt water path across the battery. In addition, salt water is a relatively high resistance circuit. The danger of shorting the battery is therefore considered very small.
- 2) Insofar as it is reasonable to do so, without the addition of many new thru-hull penetrators, individual circuit protection is being provided for the control circuits.

- 3) (a) Battery release circuits are being split into three separate circuits with no common lead.
- (b) The release switches for the mercury, manipulator, and three main batteries are being changed to interrupt both control leads of the unit concerned.
- (c) The recommended splitting of the mercury release solenoids into two independent circuits, and the addition of a second mechanical arm release solenoid are not considered necessary because the hazards involved are not sufficient to warrant the added complexity and new through-hull leads. Accidental dumping will be minimized by changing the switches to double pole. Reasonable assurance of proper operation will be provided by pre-dive circuit checks.

11. Subject: Life Support Systems.

Bureau Comment: "Adequate".

WHOI concurs that the system is adequate for the service intended.

12. Recovery Features

Four Methods

The power of the propulsion system, while low, does generate 200 lbs. of lift. The main ballast tanks, while ineffective at 6000 feet, are capable of considerable lift at shallower depths.

Angles

It is planned to make a test battery drop. The maximum trim angle for mercury drop is a variable and can be calculated.

Mercury System

Explosive valves will be tested.

Battery Release System

WHOI is making numerous changes in the electrical system and these are discussed under item 10.

Sphere Release

An O-ring seal between the "through hull bushing" and

the sphere was not used because of concern over the stress concentration factor of over 5 in a standard O-ring groove and a minimum of 3 in a specially designed one. The "through hull bushing" itself is made of heat treated 174PH to accomodate the S.C.F. of 2 present at the interior clearance. However, an O-ring seal has been used in the hatch with success where frequent complete inspection is possible. Experimental stress analysis of the hulls has shown the nominal stress to be less near the outside of the hatch seat than in way of the hull release shaft. Note that the existing O-rings between bushing and shaft are located outboard and inboard of the sphere.

WHOI does not consider the existing design satisfactory until deficiencies arising from past testing have been corrected and further testing accomplished. It is planned to strain gage the release shaft to determine bending stresses encountered in service.

The matter of a high pressure seal lock in the rubber seating ring is a possibility. It is planned to observe whether clearance exists between the sphere and the ring when ALVIN is submerged. If a problem exists, steps will be taken to correct it. During hull release test of September 1964 in 30 ft. of water, it is estimated sealing force would have been 6000 lbs. if a lock existed. Forebody was 900 lbs. buoyant and ejected smoothly and quickly upon release of mechanism as observed by divers.

Comments on Conclusions

1. The effect of trim angles on performance of release systems should be ascertained. Concur.
2. Battery release system test. Concur.
3. Manipulator maintenance. Concur.
4. WHOI believes sphere release seal adequate. Seal lock possibility exists. Release mechanism has been tested with pressure on the sea water side.