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Technical Memorandum DS-26

Weight, Buoyancy and Stability of
DSRV ALVIN , 1967

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

Technical Memorandum DS-26

Weight, Buoyancy and Stability of DSRV ALVIN, 1967

by

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ABSTRACT

A complete weight and stability analysis for the research submarine ALVIN is presented. Weights, displacements, locations of center of gravity and center of buoyancy, and longitudinal and vertical components of the BG distance are given for the submarine in its normal condition, and in a number of emergency conditions. A computer program was set up for this purpose and results were obtained using the WHOI computer. The metacentric height GM was calculated using a semi-graphical method.

Some of the results obtained in the ALVIN dockside trials are included. Experimentally determined values of BG and GM are compared with the computed values.

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I. Introduction

The present report is divided into two main sections. The first section deals with the computed weight and stability values for ALVIN as of the beginning of diving operations in May, 1967. The second section presents results of ALVIN's post-overhaul trials performed in Woods Hole in April, 1967.

Results of the computations include: total weight and total displacement of the vehicle in its normal and various emergency conditions; weight and displacement of various subassemblies (sphere, forebody, etc.); location of center of gravity for the entire vehicle and for subassemblies; location of center of buoyancy for the vehicle and for subassemblies; BG distance for the vehicle and for subassemblies (the latter are expressed in terms of longitudinal and vertical components). Where the above named items apply to the total vehicle, the vehicle was considered in "normal submerged" condition, "normal surfaced" condition and in a total of 15 emergency conditions. In order to perform the computations, it was necessary to know the weight, displacement and locations of gravity and buoyancy centers of each of the components or packages of components which together make up the total vehicle. In cases of irregularly shaped components, or non-homogeneous packages of components, separate computations often were required to determine the locations of their centers of gravity and/or buoyancy. This information, when completely recorded, served as the "data" on which the machine computations were based. While the computations were basically simple, it was obviously necessary to repeat them a large number of times for all of the components of the submarine. Therefore, a computer program was set up, and with the assistance of members of WHOI's computation group, the results were obtained via the Institution's computer. Copies of the computer printout sheets are included in this report.

Another item of interest is the metacentric height GM for the surfaced submarine. Since it was considered necessary to determine this for the "normal surface" condition only, it was done as a separate computation and not included in the computer program. A description of the semi-graphical method used in this determination, and also the calculation itself, are included in this report.

Following the overhaul period of 1966-67 and prior to the final certification of ALVIN by the Naval Ship Systems Command of the U. S. Navy, the submarine underwent a series of dockside trials in Woods Hole. Of these trials the present report is concerned with the surface and submerged inclining experiments and the forebody stability trial. Included herein are the results obtained in those trials, as well as descriptions of the test procedures.

The final section of the report contains a comparison of the trials results with the corresponding computed values.

II. Weight and Stability Computations

- a. Explanation of Procedure. The computations for weight and stability as programmed for the WHOI computer are based on the well known principle of statical first moments. This principle states that, in any system of forces, the product of the resultant of the force system and its distance from a given reference axis is equal to the algebraic sum of the products of the individual forces and their respective distances from the same axis. For ALVIN, two separate force systems were considered. In the system of weights, the resultant, or total weight, was found, as well as its location, called the center of gravity. Similarly, in the displacement system, the resultant is the total displacement and its location is called the center of buoyancy. In both systems, moment summations were taken with respect to a transverse vertical plane through the forward end of ALVIN, called the forward perpendicular, and with respect to a horizontal plane through ALVIN's lowermost point. These operations determined the distances of the center of gravity G and the center of buoyancy B from the reference planes. Points B and G are assumed to lie in a vertical plane which passes through the longitudinal centerline of the vehicle.

For the computer run, data was obtained for 176 separate components (or packages) and a data card was punched for each component. The items were broken down into sub-groups as follows (refer to computer printout sheets):

Items 1	- 88	Pressure hull plus attachments
Items 1	- 102	Entire forebody
Items 1	- 168	Entire vehicle minus "variable" load
Items 1	- 176	Entire vehicle including "variable" load

At the end of each sub-group the weight, displacement and moment summations were made, and the locations of G and B were determined. Thus weight and stability information is known (or can be readily determined) for major subassemblies of ALVIN as well as for the total vehicle.

The results shown just following items 1 - 176 are considered to be those for the vehicle in its "normal submerged" condition. For the vehicle in this condition the main ballast tanks are flooded, the variable ballast oil is divided 25 percent to the spheres and 75 percent to the rubber bags, and the trim mercury is divided 50 percent forward and 50 percent aft.

Following the results for the normal submerged vehicle there are presented results for 16 different modifications to that condition. The first of these is designated as the "normal surface" condition, and consists of the normal submerged condition with main ballast blown. The remaining 15 modifications deal with a series of vehicle emergency conditions.

- b. Definition of Symbols. The following symbols which appear on the computer printout sheets are defined here for convenience.

W	- weight of item in air, lbs.
X	- distance of center of gravity of item from forward perpendicular, feet (positive x means aft of F.P. See Figure 1.).
Y	- distance of center of gravity of item above base plane, feet (See Figure 1.).
MX	- product of W times X, foot-lbs.

MY - product of W times Y, foot-lbs.

D - displacement of item, lbs. of seawater

XP - distance of center of buoyancy of item from forward perpendicular, feet

YP - distance of center of buoyancy of item above base place, feet

MXP - product of D times XP, foot-lbs.

MYP - product of D times YP, foot-lbs.

BG longitudinal - distance between center of buoyancy B and center of gravity G, longitudinal component, feet (negative value indicates tendency for up-angle of trim. See Figure 2.).

BG vertical - distance between center of buoyancy B and center of gravity G, vertical component, feet (positive value indicates vertical stability of vehicle. See Figure 2.).

The following additional terms and symbols appear in various places in this report:

Forward Perpendicular - vertical plane passing through foremost edge of front window cone of ALVIN. (See Figure 1).

Base Plane - horizontal plane passing through bottom of skids of ALVIN. (See Figure 1).

B' - new position of center of buoyancy B. Lateral shift occurs due to change of underwater form when vehicle is inclined on the surface. (See Figure 3).

Metacenter M - point found by extending line of action of vertical buoyancy force through B' to intersect with original vertical centerline of vehicle inclined on the surface. (See Figure 3).

GM - vertical distance from center of gravity G to meta-center M (M above G indicates positive stability of surfaced vehicle. See Figure 3).

c. Outline of Programmed Computations

1. Total weight = summation W

2. Total displacement = summation D

3. Distance to center of gravity, longitudinal

$$XW = (\text{summation } MX) / (\text{summation } W)$$

4. Distance to center of gravity, vertical

$$YW = (\text{summation } MY) / (\text{summation } W)$$

5. Distance to center of buoyancy, longitudinal

$$XPD = (\text{summation } MXP) / (\text{summation } D)$$

6. Distance to center of buoyancy, vertical

$$YPD = (\text{summation } MYP) / (\text{summation } D)$$

7. BG longitudinal = XPD - XW

8. BG vertical = YPD - YW

Figure 1 Longitudinal Section of ALVIN Showing Sample of Data Used in Computations

Figure 2 Longitudinal Section of ALVIN Showing Components of BG Distance

Figure 3 Transverse Section of ALVIN Showing Locations of Points K, G, B, B' and M

d. Computer Printout Sheets

ALVIN STABILITY PROGRAM

PAGE 1

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
HULL MINUS INSTS.	6152.35	4.97	4.89	30577.18	30084.99	10668.99	4.50	4.75	48010.45	50677.70
HULL INSERT -FWD	500.00	1.14	4.75	570.00	2375.00	16.79	1.14	4.75	19.14	79.75
HULL INSERT -BOTTOM	500.00	3.72	1.42	1860.00	710.00	16.79	3.72	1.42	62.46	23.84
HULL INSERTS -PANDS	1000.00	2.39	3.46	2390.00	3460.00	33.58	2.39	3.46	80.26	116.19
HATCH INSERT	266.00	4.50	8.11	1197.00	2157.26	12.92	4.50	8.11	58.14	104.78
WINDOW -FWD	9.81	1.14	4.75	11.18	46.60	0.	0.	0.	0.	0.
WINDOW -BOTTOM	9.81	3.72	1.44	36.49	14.13	0.	0.	0.	0.	0.
WINDOWS -P AND S	19.62	2.39	4.36	46.89	85.54	0.	0.	0.	0.	0.
WINDOW RET RING-FWD	8.37	1.14	4.75	9.54	39.76	1.09	1.14	4.75	1.24	5.18
WINDOW RET RING BOTTOM	8.69	3.72	1.30	32.33	11.30	1.14	3.72	1.30	4.24	1.48
WIN RET RING-P AND S	16.74	2.39	3.46	40.01	57.92	2.18	2.39	3.46	5.21	7.54
SPHERE REL-UPPER	59.04	4.50	1.33	265.68	78.52	5.49	4.50	1.21	24.70	6.64
HATCH	220.00	4.50	8.11	990.00	1784.20	0.	0.	0.	0.	0.
HINGE ARMS	8.00	4.21	8.28	33.68	66.24	1.04	4.21	8.28	4.38	8.61
HINGE SHAFT	5.68	4.00	8.28	22.72	47.03	0.74	4.00	8.28	2.96	6.13
INSIDE HANDLE	4.50	4.91	7.94	22.09	35.73	0.	0.	0.	0.	0.
OUTSIDE HANDLE	9.00	4.91	8.28	44.19	74.52	1.17	4.91	8.28	5.74	9.69
SPRING RETAINER	4.67	4.14	8.28	19.33	38.67	0.61	4.14	8.28	2.53	5.05
INT SWING CLAMPS	2.66	4.60	7.94	12.24	21.12	0.	0.	0.	0.	0.
MISC	1.19	4.50	8.11	5.35	9.65	0.	0.	0.	0.	0.
HINGE SPRINGS	11.25	4.00	8.28	45.00	93.15	1.47	4.00	8.28	5.88	12.17
HATCH WINDOW	1.19	4.50	8.19	5.35	9.75	0.	0.	0.	0.	0.
HATCH WIND RET RING	3.78	4.50	8.10	17.01	30.62	0.49	4.50	8.10	2.20	3.97
HINGE BLOCKS	11.50	3.92	8.05	45.08	92.57	1.50	3.92	8.05	5.88	12.07
PENETRATORSX7 FWD	72.45	1.06	4.75	76.80	344.14	4.43	1.06	4.75	4.70	21.04
PENETRATORSX5 BOTTOM	51.75	4.29	1.42	222.01	73.48	3.16	4.29	1.42	13.56	4.49
TV RECVR	24.00	2.75	6.95	66.00	166.80	0.	0.	0.	0.	0.
STRAZA MOD 100	30.00	3.13	5.53	93.90	165.90	0.	0.	0.	0.	0.
STRAZA MOD 200	32.00	4.04	5.96	129.28	190.72	0.	0.	0.	0.	0.
STRAZA MOD 300	40.00	4.37	6.67	174.80	266.80	0.	0.	0.	0.	0.
UHER 4000	8.50	4.13	7.08	35.10	60.18	0.	0.	0.	0.	0.
DRAWER SHEET METAL	2.00	5.54	5.88	11.08	11.76	0.	0.	0.	0.	0.
O2 ANALYSER	3.50	5.38	6.70	18.83	23.45	0.	0.	0.	0.	0.
FLARE BOX	8.00	5.38	5.87	43.04	46.96	0.	0.	0.	0.	0.
TEMP ° HUMID GAGE	1.00	5.38	6.70	5.38	6.70	0.	0.	0.	0.	0.
O2 SUPPLY INDICATOR	1.70	5.38	6.37	9.15	10.83	0.	0.	0.	0.	0.
ALTIMETER	1.50	5.38	6.03	8.07	9.04	0.	0.	0.	0.	0.
AL RACK TRAYS STEPS	15.00	5.83	5.21	87.45	78.15	0.	0.	0.	0.	0.
GYRO COMPASS	23.25	5.50	2.46	127.87	57.19	0.	0.	0.	0.	0.
GYRO POWER SUPPLY	14.00	6.33	2.46	88.62	34.44	0.	0.	0.	0.	0.
SCUBA BOTTLES X2	40.00	6.62	3.63	264.80	145.20	0.	0.	0.	0.	0.
O2 BOTTLE	33.00	6.71	3.79	221.43	125.07	0.	0.	0.	0.	0.
STATIC INVERTER	39.00	6.67	3.54	260.13	138.06	0.	0.	0.	0.	0.
SCUBA BOTTLE XHORIZ	20.00	5.92	3.54	118.40	70.80	0.	0.	0.	0.	0.
LIOH CANNISTERS X2	20.00	6.29	5.71	125.80	114.20	0.	0.	0.	0.	0.
AIR REGEN UNIT	13.30	6.38	4.50	84.85	59.85	0.	0.	0.	0.	0.
FIRE EXTING	5.20	5.57	4.50	28.96	23.40	0.	0.	0.	0.	0.
FIRST AID KIT	2.50	6.20	2.79	15.50	6.97	0.	0.	0.	0.	0.
CABIN LIGHT	1.00	5.67	6.79	5.67	6.79	0.	0.	0.	0.	0.
PHONE XMTR	27.50	4.29	6.75	117.97	185.62	0.	0.	0.	0.	0.

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
FRONT WINDOW CONE	102.00	0.75	4.75	76.50	484.50	154.00	0.75	4.75	115.50	731.50
FIBREGLASS CLAMP	4.00	2.39	3.46	9.56	13.84	2.22	2.39	3.46	5.31	7.68
SONAR UNIT	130.00	0.50	8.00	65.00	1040.00	50.00	0.50	8.00	25.00	400.00
MAIN BALLAST CONTR	65.00	7.93	7.43	515.45	482.95	42.00	7.93	7.43	333.06	312.06
NDT PLUGS X8	6.40	4.50	1.33	28.80	8.51	0.83	4.50	1.33	3.73	1.10
MAGNETIC COMPASS	9.07	7.00	10.13	63.49	91.88	8.33	7.10	10.13	59.14	84.38
EXTERIOR LIGHTS	24.00	2.50	5.40	60.00	129.60	8.00	2.50	5.40	20.00	43.20
SEVONIUS ROTOR	8.00	3.50	13.20	28.00	105.60	2.00	3.50	13.20	7.00	26.40
PREC DEPTH TRANS	14.00	6.50	7.30	91.00	102.20	5.00	6.50	7.30	32.50	36.50
BOW BUOYANCY NEW	863.00	0.38	7.00	327.94	6041.00	1505.00	0.38	7.00	571.90	10535.00
SAIL, ETC	1323.35	4.64	7.02	6140.34	9289.92	1714.00	4.34	6.65	7438.76	11398.10
LG BUOYANCY RING	1135.00	4.42	3.43	5016.70	3893.05	1570.00	4.42	3.43	6939.40	5385.10
MAIN BALLAST TANKS	1493.76	4.50	6.00	6721.92	8962.56	1493.76	4.50	6.00	6721.92	8962.56
TV CAMERA AFT	12.00	7.68	11.10	92.16	133.20	3.00	7.68	11.10	23.04	33.30

SUMMARY	NR. ITEMS	SUM W	SUM X	SUM Y	SUM D	SUM XP	SUM YP	SUM MXP	SUM MYP
102		14949.18	4.13	5.11	17338.37	4.07	5.14	70639.86	89096.08

BG LONGITUDINAL -0.05

BG VERTICAL 0.02

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
BATT BOX RES	182.50	7.00	1.40	1277.50	255.50	215.10	7.00	1.40	1505.70	301.14
MOUNTS PLUMB AFT	23.50	17.50	3.92	411.25	92.12	3.08	17.50	3.92	53.90	12.07
BATT REL BOXES	184.00	10.23	3.03	1882.32	557.52	75.00	10.23	3.03	767.25	227.25
RUBBER GASKETS %3	10.00	4.50	2.60	45.00	26.00	8.33	4.50	2.60	37.48	21.66
BATT RES BOX BAG	32.00	7.00	1.40	224.00	44.80	17.80	7.00	1.40	124.60	24.92
BATT RES BOX BRACKET	1.40	7.00	1.40	9.80	1.96	0.37	7.00	1.40	2.59	0.52
V/B BOX BRACKET	1.50	17.50	5.00	26.25	7.50	0.56	17.50	5.00	9.80	2.80
TAIL RING SPACER	4.00	18.80	4.63	75.20	18.52	1.85	18.80	4.63	34.78	8.57
SS MANIP ADAPT %22	6.00	0.19	2.50	1.14	15.00	0.78	0.19	2.50	0.15	1.95
CONTR CENT BRACKET	3.00	10.21	4.50	30.63	13.50	1.11	10.21	4.50	11.33	4.99
STIFF IN LIP %4	0.50	0.19	1.75	0.09	0.87	0.28	0.19	1.75	0.05	0.49
STIFF IN SIDE %4	0.75	4.50	1.75	3.37	1.31	0.42	4.50	1.75	1.89	0.73
V/B BOX COMP	58.00	10.10	3.67	585.80	212.86	32.20	10.10	3.67	325.22	118.17
MISC PLUMBING	24.00	10.10	3.67	242.40	88.08	3.14	10.10	3.67	31.71	11.52
WEIGHT DROPPER %1	40.00	0.39	2.75	15.60	110.00	10.00	0.39	2.75	3.90	27.50
WEIGHT DROPPERS %2	80.00	6.55	2.75	524.00	220.00	20.00	6.55	2.75	131.00	55.00

SUMMARY	NR.	ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
	168		31813.19	7.79	4.44	247829.99	141238.49	32857.95	7.54	4.77	247787.60	156836.90

BG LONGITUDINAL -0.25

BG VERTICAL 0.33

PAGE 1

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MP
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
BLOW MAIN BALAST	-1493.76	4.50	6.00	-6721.92	-8962.56	0.	0.	0.	0.	0.

SUMMARY	NR.	ITEMS	SUM W	S4XW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
	2		31556.98	7.75	4.32	244463.70	136460.70	33053.45	7.50	4.76	247900.87	157334.42

PAGE 1

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MP
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.

SUMMARY	NR.	ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMYPD	SMYP	SUM MXP	SUM MYP
	3		32460.74	7.56	4.43	245495.07	143706.36	33053.45	7.50	4.76	247900.87	157334.42

PAGE 1

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	NORMAL CONDITION MODIFIED AS INDICATED									
	W	X	Y	MX	MY	D	XP	YP	MXP	MP
NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
DROP MID BATT	-1495.00	10.00	2.80	-14950.00	-4186.00	-929.00	10.00	2.80	-9290.00	-2601.20

SUMMARY	NR.	ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
	2		31555.74	7.49	4.48	236235.62	141237.26	32124.45	7.43	4.82	238610.87	154733.22

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP	PAGE 1
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42	
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.	
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.	
DROP FWD BATT	-1495.00	8.68	2.80	-12976.60	-4186.00	-929.00	8.68	2.80	-8063.72	-2601.20	
DROP AFT BATT	-1495.00	11.40	2.80	-17043.00	-4186.00	-929.00	11.40	2.80	-10590.60	-2601.20	
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP	
5	29470.74	7.31	4.59	215475.47	135334.36	31195.45	7.35	4.88	229246.55	152132.02	
BG LONGITUDINAL	0.04			BG VERTICAL	0.28						

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP	PAGE 1
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42	
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.	
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.	
DROP FWD BATT	-1495.00	8.68	2.80	-12976.60	-4186.00	-929.00	8.68	2.80	-8063.72	-2601.20	
DROP MID BATT	-1495.00	10.00	2.80	-14950.00	-4186.00	-929.00	10.00	2.80	-9290.00	-2601.20	
DROP AFT BATT	-1495.00	11.40	2.80	-17043.00	-4186.00	-929.00	11.40	2.80	-10590.60	-2601.20	
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP	
6	27975.74	7.17	4.69	200525.47	131148.36	30266.45	7.27	4.94	219956.55	149530.82	
BG LONGITUDINAL	0.10			BG VERTICAL	0.25						

ALVIN STABILITY PROGRAM
NORMAL CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP	PAGE 1
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42	
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.	
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.	
DROP MID BATT	-1495.00	10.00	2.80	-14950.00	-4186.00	-929.00	10.00	2.80	-9290.00	-2601.20	
DROP ARM	-438.55	-0.30	2.70	131.56	-1184.08	-143.00	0.	2.70	0.	-386.10	
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP	
5	30527.19	7.56	4.53	230676.64	138336.27	31981.45	7.46	4.83	238610.87	154347.12	
BG LONGITUDINAL	-0.10			BG VERTICAL	0.29						

ALVIN STABILITY PROGRAM
CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
V/B OIL TO BAGS	0.	0.	0.	0.	0.	290.00	10.10	3.67	2929.00	1064.30
FLOOD V/B SPHERES	1416.00	9.43	4.75	13352.88	6726.00	0.	0.	0.	0.	0.
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.
DROP FWD BATT	-1495.00	8.68	2.80	-12976.60	-4186.00	-929.00	8.68	2.80	-8063.72	-2601.20
DROP AFT BATT	-1495.00	11.40	2.80	-17043.00	-4186.00	-929.00	11.40	2.80	-10590.60	-2601.20
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
7	30886.74	7.41	4.60	228828.35	142060.36	31485.45	7.37	4.87	232175.55	153196.32

BG LONGITUDINAL -0.03

BG VERTICAL 0.27

ALVIN STABILITY PROGRAM
CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
V/B OIL TO BAGS	0.	0.	0.	0.	0.	290.00	10.10	3.67	2929.00	1064.30
FLOOD V/B SPHERES	1416.00	9.43	4.75	13352.88	6726.00	0.	0.	0.	0.	0.
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.
DROP FWD BATT	-1495.00	8.68	2.80	-12976.60	-4186.00	-929.00	8.68	2.80	-8063.72	-2601.20
DROP MID BATT	-1495.00	10.00	2.80	-14950.00	-4186.00	-929.00	10.00	2.80	-9290.00	-2601.20
DROP AFT BATT	-1495.00	11.40	2.80	-17043.00	-4186.00	-929.00	11.40	2.80	-10590.60	-2601.20
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
8	29391.74	7.28	4.69	213878.35	137874.36	30556.45	7.29	4.93	222885.55	150595.12

BG LONGITUDINAL 0.02

BG VERTICAL 0.24

ALVIN STABILITY PROGRAM
CONDITION MODIFIED AS INDICATED

IDENTIFICATION	W	X	Y	MX	MY	D	XP	YP	MXP	MYP
IN NORMAL CONDITION	33050.74	7.60	4.40	251185.62	145423.26	33053.45	7.50	4.76	247900.87	157334.42
V/B OIL TO BAGS	0.	0.	0.	0.	0.	290.00	10.10	3.67	2929.00	1064.30
FLOOD V/B SPHERES	1416.00	9.43	4.75	13352.88	6726.00	0.	0.	0.	0.	0.
DROP HG FWD	-295.00	1.79	1.90	-528.05	-560.50	0.	0.	0.	0.	0.
DROP HG AFT	-295.00	17.50	3.92	-5162.50	-1156.40	0.	0.	0.	0.	0.
DROP FWD BATT	-1495.00	8.68	2.80	-12976.60	-4186.00	-929.00	8.68	2.80	-8063.72	-2601.20
DROP MID BATT	-1495.00	10.00	2.80	-14950.00	-4186.00	-929.00	10.00	2.80	-9290.00	-2601.20
DROP AFT BATT	-1495.00	11.40	2.80	-17043.00	-4186.00	-929.00	11.40	2.80	-10590.60	-2601.20
DROP ARM	-438.55	-0.30	2.70	131.56	-1184.08	-143.00	0.	2.70	0.	-386.10
SUMMARY NR. ITEMS	SUM W	SMXW	SMYW	SUM MX	SUM MY	SUM D	SMXPD	SMYPD	SUM MXP	SUM MYP
9	28953.19	7.39	4.72	214009.92	136690.27	30413.45	7.33	4.94	222885.55	150209.02

BG LONGITUDINAL -0.06

BG VERTICAL 0.22

e. Calculation of Metacentric Height GM

The present method for determining the GM distance for the research submarine ALVIN is based on the fact that when the vehicle is inclined on the surface, the change of underwater shape is due almost entirely to the relative change of position of the external buoyancy material (sponsons, decks, newly installed bow buoyancy block). Most of this material is near the waterline, partly above the surface and partly below, and it is equally distributed port and starboard. When the vehicle is inclined, a greater amount of this buoyancy material is submerged on one side, and a smaller amount, on the other side. This causes a lateral shift in the position of the center of buoyancy for the whole vehicle, which in turn establishes the position of the metacenter M.

Cross-sections of the external buoyancy material were examined at stations one foot apart. Areas of these sections were obtained by graphical integration. Each area (sq. ft.) was multiplied by one (1) to give the average volume (cu. ft.) at each station. That portion of each volume increment submerged (for the given draft and angle of inclination) was determined graphically, port and starboard.

An angle of inclination of 10 degrees was selected in an effort to minimize the error associated with graphical work involving small angles. The axis of roll was assumed to be the longitudinal centerline of the faired vehicle shape (this is a line passing through the center of the forward window and the center of the stern propeller - see Figure 1). The moment arm for the buoyancy material, each side, was estimated to be 3.5 feet measured from a vertical plane passing through the longitudinal axis. Since the buoyancy material lies generally above the axis, the arm length varies as the vehicle inclines.

For the 10 degree angle the arm length was corrected to give values d_1 and d_2 (see appendix). With the displacements known for external buoyancy and for the total vehicle, a moment summation was set up with respect to the axis of roll. This led to the location of the new center of buoyancy B' and thus to the metacenter M . The complete calculation and an accompanying diagram are presented in the appendix.

The results of the calculation are summarized here:

Condition of Vehicle:	Normal Surface
Total Displacement:	$D = 31,570$ lbs.
Draft (approx.):	7 ft. 2 in.
Calculated GM:	.92 ft.
Righting Moment:	3125 ft.-lbs.

III. ALVIN Dockside Trials

- a. Description of Test Procedures. Post-overhaul dockside trials for ALVIN were held in Woods Hole, Massachusetts on April 14 - 21, 1967, and on October 27, 1967. Of those tests, the present report is concerned with the following:

1. Surface inclining experiment
2. Submerged inclining experiment
3. Forebody stability trial

The surface inclining experiment was performed in Eel Pond, Woods Hole, Massachusetts on April 17, 1967, and, at the request of the U. S. Naval Ship Systems Command, was repeated on October 27, 1967. The submerged inclining experiment was performed in Eel Pond, Woods Hole, Massachusetts on April 17, 1967, and the forebody stability trial was done in the same location on April 20, 1967.

Surface and submerged inclining experiments were done in the usual manner, i.e., by moving known weights, already aboard, through a known distance perpendicular to a vertical plane through the vehicle's longitudinal axis. After the submarine had settled in an equilibrium position, the angle of inclination was measured. Draft readings were taken, as well as the temperature and density of the water. Along with each inclining experiment, a roll period test was conducted, as an alternative means for determining the metacentric height GM.

On October 27, 1967, when the surface inclining experiment was repeated, wind and sea surface conditions in Woods Hole harbor were such as to necessitate a sheltered location for the test. Therefore, ALVIN was placed between the two hulls of the catamaran support vessel, and a barrier was placed across the end of the catamaran facing open water. Water surface within the enclosure was smooth but there was some swell due to harbor traffic. The vehicle was not "sallied" for determination

of roll period on this date, because under the adverse conditions of the test there would be a risk of injury to swimmers and damage to ALVIN. The results of the sally done in April, 1967 are included in this report.

On April 20, 1967, ALVIN's forebody was removed and lowered into the water by crane. With two pilots aboard, and main ballast tanks completely flooded, draft readings were taken. With swimmers rocking the forebody, maximum pitch and roll were estimated. Inclinator readings were taken for list and trim. Water temperature and specific gravity were measured.

b. Experimental Results

1. Surface Inclining Experiment

GM (transverse) = 0.81 ft. (by inclining)

GM (transverse) = 1.20 ft. (from roll period)

2. Submerged Inclining Experiment

BG (vertical) = 0.35 ft. (by inclining)

BG (vertical) = 0.41 ft. (from roll period)

3. Forebody Stability Trial

Draft: Port - 7 ft. 4 in.; Starboard - 6 ft. 11 in.

Pitch: 12 - 15 degrees

Roll: 12 - 15 degrees

Trim: 3 3/4 degrees bow down

List: 1/4 degree port

Remarks: Hatch 12 inches above water level at all times; man can emerge.

All deck surfaces out of water. Maximum list estimated

30 - 40 degrees with two swimmers on deck in maximum

off-center position.

Figure 4 Photograph Showing Surface Inclining Experiment

Figure 5 Photograph Showing Submerged Inclining Experiment

IV. Discussion

Weights, displacements, and stability values were computed for the complete vehicle and for major subassemblies. A number of normal and emergency conditions were examined which, it is felt, would cover most situations likely to be encountered in the operation of ALVIN. As can be seen from the computed results, positive stability is predicted (B above G) for the total vehicle and for all subassemblies. The computed value of the metacentric height GM indicates positive stability of the total vehicle on the surface.

The lowest computed value of BG (vertical) obtained was that for the forebody, a value of 0.02 ft. This is for the forebody on its way to the surface after release from the afterbody, but still submerged. Because of this slight tendency to remain upright, the drag of the conning tower may invert the forebody as it moves upward through the water. In a similar stability analysis done in 1965, it was indicated that the forebody might possibly reach the surface in an upside down attitude. However, it is believed that the submerged stability of the forebody is now greater than it was at that time. On the surface, vehicle behavior depends upon GM rather than on BG, and it is felt that GM for the forebody also has been increased over its 1965 value. This idea is substantiated by the fact that GM values for the complete vehicle are now 20 - 30 percent greater than those reported in 1965. An inclining experiment for the forebody alone would remove any uncertainty on this point. It should be noted that during the forebody stability trial done on April 20, 1967, an attempt was made to heel the forebody. With two swimmers standing on deck in the maximum off-center position, the list was 30 - 40 degrees. All deck surfaces were out of water, and the hatch cover was estimated to be 12 inches above water level at all times.

Table 1. presents a summary of results, both computed and experimental. Values of BG (vertical) are in good agreement, particularly the computed value and that from the static inclining experiment. Values of GM (transverse) agree fairly well, with the computed value lying between the two experimental values. BG and GM values are generally higher than those reported in 1965. This is probably the result of the addition of new buoyancy material to the forebody in 1967. It can also be seen that values of BG and GM obtained from the roll period are somewhat greater than those obtained in the static inclining tests. The probable reason for this is the difficulty encountered in determining the radius of gyration of the vehicle with accuracy.

For the computation of GM (transverse), an angle of list of 10 degrees was selected in an effort to obtain maximum graphical accuracy. However, it is recognized that many authorities feel that the position of the metacenter M remains fixed only for angles up to about 7 degrees. The limiting angle may be even less for vehicles which, like ALVIN, have an abrupt change of shape near the waterline.

Table 1

ALVIN Stability: Computed and Experimental Values

	Total Vehicle		Forebody Only		Sphere Only	
	BG ¹ vertical feet	GM ² transverse feet	BG vertical feet	GM transverse feet	BG vertical feet	GM transverse feet
Computed	.36	.92	.02	-	.06	-
Experimental (M-θ)	.35	.81	-	-	-	-
Experimental (roll period)	.41	1.20	-	Stable	-	-

(1) Vehicle in "normal submerged" condition

(2) Vehicle in "normal surface" condition

V. Appendix

Miscellaneous Data and Calculations

Volumes of Exterior Buoyancy Material
Used for Computing Distance GM
Draft: 7' 2"

Station No.	Old material V cu.ft.	New material V cu.ft.	Total V ea. side cu.ft.	V Subm. 10° incl. low side cu.ft.	V Subm. 10° incl. high side cu.ft.
X		3.36	3.36	3.00	1.68
$\frac{1}{2}$		5.35	5.35	5.00	3.60
$1\frac{1}{2}$	.47	1.87	2.34	2.34	1.20
$2\frac{1}{2}$	1.60	.48	2.08	2.08	1.10
$3\frac{1}{2}$	1.86	.22	2.08	2.08	1.30
$4\frac{1}{2}$	1.59		1.59	1.59	1.00
$5\frac{1}{2}$	1.22		1.22	1.22	.66
$6\frac{1}{2}$	.81		.81	.81	.43
$7\frac{1}{2}$	.52		.52	.52	.43
$8\frac{1}{2}$	.62		.62	.62	.56
$9\frac{1}{2}$	.65		.65	.65	.65
$10\frac{1}{2}$	.62		.62	.62	.56
$11\frac{1}{2}$	.97		.47	.47	.40
$12\frac{1}{2}$	.27		.27	.27	.22
Totals			21.98	21.27	13.69

A-I. Calculation of Metacentric Height GM
(Distances in Feet, Forces in Pounds)

1. Displacements of Submerged Buoyancy Material

$$\text{Low Side} \quad D = 21.27(64) = 1361$$

$$\text{High Side} \quad D = 13.69(64) = 876$$

2. Corrected Moment Arms for Inclined Vehicle

$$\text{Low Side} \quad d_1 = 3.5 \cos 10 + 2.5 \sin 10 = 3.89$$

$$\text{High Side} \quad d_2 = 3.5 \cos 10 - 2.5 \sin 10 = 3.01$$

3. Summation of Moments about Axis 0 (See Fig.A-1)

$$31570(AB^t) = 1361(3.89) + 29333(AB) - 876(3.01)$$

$$AB = OB \sin 10$$

$$= (KB-KO)\sin 10$$

$$= (4.76-4.67) \cdot .174$$

$$= (.09)(.174) = .016$$

$$\text{Then } AB^t = \frac{1361(3.89) + 29333(.016) - 876(3.01)}{31570} = .099$$

4. Find BB^t , BM, and GM

$$BB^t = AB^t - AB$$

$$= .099 - .016 = .083$$

$$BM = BB^t / \sin 10 = .083 / .174 = .98$$

$$GM = BG + BM$$

$$= .44 + .48$$

$$= .92$$

5. Righting Moment

$$M = D(AB^t)$$

$$= 31570(.099)$$

$$= 3125 \text{ ft.-lbs.}$$

Figure A-1 Force Diagram Used in Calculation of Distance GM

A-II. Surface Inclining Experiment
Data and Calculations

The following information is taken from the original data sheets for this experiment. The experiment was performed in Woods Hole on April 17, 1967 and October 27, 1967.

1. Preliminary Data

- a. Inclining Weights: 10 lead pigs weighing each 22.0 lbs. air weight, 20.25 lbs. water weight. Total weight in air 220 lbs.; in water, 202.50 lbs.
- b. Three persons aboard -- weight: 500 lbs.
- c. Inclinator mounted inside pressure hull.
- d. No ascent weights installed.
- e. Arm compensator weight: 372 pounds of lead (water weight).
- f. Stern propeller wedged.
- g. Variable ballast oil: 25 percent in spheres, 75 percent in bags.
- h. Mercury trim: equally divided fore and aft.
- i. Main ballast blown.
- j. Water sample: April 17, 1967: temp. 41°F, sp. gr. 1.0242
October 27, 1967: temp. 57°F, sp. gr. 1.0230
- k. Displacement of Vehicle ("normal surface" condition with corrections):
 - D = 31,570 lbs.
- l. Draft (at start of test, zero trim angle): Port: 7 ft. 3 in.
Starboard: 7 ft. 1 in.
- m. Moment arm to location of weights: 3.5 ft.

2. Moments and Angles (data taken October 27, 1967)

Movement	Net Weight Lbs.	Moment Arm feet	Moment ft-lbs	Tan θ
10 wts -P	202.5 P	3.5	-708.75	.0275 R
2 wts P-S	121.5 P	3.5	-425.25	.0180 R
2 wts P-S	40.5 P	3.5	-141.75	.0039 R
1 wt. P-S	0	3.5	0	.0007 R
1 wt. P-S	40.5 S	3.5	+141.75	.0052 G
2 wts P-S	121.5 S	3.5	+425.25	.0184 G
2 wts P-S	202.5 S	3.5	+708.75	.0280 G
10 wts S-P	202.5 P	3.5	-708.75	.0267 R
0	0	3.5	0	.0019 G

3. Calculation of GM

$$GM = \frac{w \times d}{W \times \tan \theta} = \frac{1}{W} \times (\text{slope of plot of tangents})^*$$

$$= \frac{25,450}{31,570} = .81 \text{ ft.}$$

4. GM from Roll Period (data taken April 17, 1967)

<u>Trial No.</u>	<u>Period T (sec.)</u>
1	4.0
2	4.0
3	3.95
4	4.0

Total 15.95

Avg. T = 3.98, and $T^2 = 15.84$

if K = radius of gyration, feet

= 3.94 ft., estimated,

$$\text{then } GM = \frac{1.23 K^2}{T^2}$$

$$= \frac{1.23(15.5)}{15.84}$$

$$= 1.205 \text{ ft.}$$

* See Fig.A-2 for slope

DSRV ALVIN
SURFACE INCLINING
EXPERIMENT
OCTOBER 27, 1967

Figure A-2 Plot of Tangents for Surface Inclining Experiment

A-III. Submerged Inclining Experiment
Data and Calculations

The following information is taken from the data form for this experiment, which is part of a separate report on the inclining experiments dated April 17, 1967. That report gives full preliminary details, which are essentially the same as those for the surface inclining experiment.

1. Moments and Angles

<u>Movement</u>	<u>Net Weight lbs.</u>	<u>Moment Arm feet</u>	<u>Moment foot lbs.</u>	<u>Tanθ</u>
2 wts. P-S	81	3.5	+283.5	.0248
2 wts. P-S	162	3.5	+567.0	.0476
2 wts. S-P	81	3.5	+283.5	.0250
2 wts. S-P	0	3.5	0	0
2 wts. S-P	81	3.5	-283.5	.0259
2 wts. S-P	162	3.5	-567.0	.0479

2. Calculation of BG

$$BG = \frac{w \times d}{W \times \tan \theta} = \frac{1}{W} \times (\text{slope of plot of tangents})^*$$

$$= \frac{11700}{33068} = .35 \text{ ft.}$$

*See Fig. A-3 for slope

3. BG from Roll Period

<u>Trial no.</u>	<u>Period T (sec.)</u>
1	7.0
2	8.0
3	7.5
4	<u>8.0</u>

Total 30.5

$$\text{Avg. } T = 7.62, \text{ and } T^2 = 58.1$$

if K = radius of gyration, feet

$$= 4.4 \text{ ft., estimated,}$$

$$\text{then } BG = \frac{1.73 K^2}{T^2}$$

$$= \frac{1.23(19.4)}{58.1}$$

$$= 0.41 \text{ ft.}$$

DSRV ALVIN
SUBMERGED INCLINING
EXPERIMENT
APRIL 17, 1967

Figure A-3 Plot of Tangents for Submerged Inclining Experiment