HARBOR BRANCH FOUNDATION

A METHOD FOR PREDICTING THE TURNING RATE OF A SUBMERSIBLE

BY

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ABSTRACT

This paper examines the affects of various turning-thruster locations on the turning rate of the JOHNSON-SEA-LINK III Observation Submersible. A mathematical model was developed to predict the overall drag coefficient of the submersible while it was rotating with a constant angular velocity. This valve was experimentally checked by tests on a 1/12 scale model of the submersible, which was rotated in a tank of water at the corresponding Reynolds number.

The mathematical model predicted an overall drag coefficient of 0.30 and the experiments produced a C_D=0.5. The Difference is attributed to interference drag of the components and inaccuracies in the experiment and mathematical model. The results were plotted on a graph of turning rate versus thruster location on the submersible.

INTRODUCTION

The JOHNSON-SEA-LINK III submersible is to be an observation submersible with increased visibility and maneuverability at the expense of the diver lock-out compartment. This submersible will be an improvement in the design of J-S-L I & II in its location of thrusters and other external equipment. It is desirable to compact the thrusters into the "hull" of the submersible so that visibility and safety of operation will be increased. Also, this submersible will be more streamlined than the previous two. Although it is primarily a low speed submersible (1-2 knots with respect to the bottom), it should be fast enough through the water to overcome the various currents encountered. Thus, greater streamlining results in savings in power required.

For these reasons, it was decided to examine various turning thruster locations. The obvious place to put a turning thruster would be on the outermost end of the submersible where its turning moment would be the greatest. However, this would block the downward view from the observation spheres and would not help to make a streamlined body. If the turning thruster was moved inboard, the submersible would turn slower because of the smaller turning moment, but if its turning rate was comparable with JSL I & II, then it would be considered a reasonable location. The problem then became to determine the effect on turning, if these thrusters were moved inboard.

PROCEDURE

First, measurements were taken of the turning rate of the JSL II, in the channel at Link Port. The JSL II was submerged and the turning rate was measured with the use of the onboard compass and various thruster combinations. The average turning rate was found to be 8 degrees per second, with two thrusters operating at opposite ends of the submersible. This turning rate was used as a criterium for the JSL III.

The next action undertaken was to determine an overall drag coefficient for the JSL III that would allow turning rates for different thruster locations to be calculated. A simple mathematical model was formulated to get an order-of-magnitude estimate of the drag coefficient. If this theoretical valve was reasonably close to one determined by experiment, then one could be confident in the predicted turning rates.

Finally, an experiment was devised to measure the drag coefficient of a model of the JSL III. A 1/12 scale model was rotated in a tank with a system of pulleys and weights. By timing the fall of the weights over a known distance, the drag coefficient could be calculated.

MATHEMATICAL ANALYSIS

Very little was found in the literature on predicting the turning rates of submersibles, so the mathematical model presented here is a very simple analysis, intended only to give a rough estimate of the overall drag coefficient for turning. It was assumed that the JSL III would be geometrically symmetric about its vertical centerline and that two thrusters with 100 pounds force each would act at right angles to the longitudinal centerline. It was also assumed that the submersible had very quick acceleration to a constant angular velocity and that the linear velocity varied from the centerline to the end of the submersible as $V_{Linear} = WX$. (W = turning rate $^{rad}/_{sec}$). This was not the real case, but it was sufficiently accurate for this analysis.

When a submersible is turning at a constant rate, i.e., no angular acceleration, the turning moment of the thrusters must equal the drag moment of the hull. The total turning moment of the two thrusters was assumed to be 200X where X is the distance from the centerline of rotation. Here, it was also assumed that the thrust was a constant 100 pounds per thruster, which again was not the real case, since the thrust would vary with the speed of the thruster moving through the water.

In order to determine the drag moment caused by the shape of the submersible, a side view of the basic shape was divided in 4 components. These components were 2 spheres, one buoyancy tank and one battery compartment. The draf force at any location was calculated as:

$$F_D = C_D \rho/_Z AV^2, \text{ where}$$

$V = V_{Linear} - WX$

C_D = Drag Coefficient of particular component

ρ = Density of seawater

A = Area of section

This equation was used to determine the force on an infinitesimal area of one of the components. The force was then integrated over the entire length of the component to get a total drag force for the component. The integration was performed by the computer at Harbor Branch. (This program is detailed in the Appendix). The drag force for each component was summed and a total drag coefficient was determined from the formula:

$$C_{DT} = \frac{F_{tot}}{\rho/2 \ A_{tot} T^2}$$

F_{tot} = sum of drag of four components

A_{tot} = total frontal area of JSL III

V^2 = $V_{Linears}$ at X = 0.7 R

R = Distance from ℄ to end of JSL III

In this manner, a valve of 0.3 was found for the total drag coefficient.

EXPERIMENTAL

NOTATION

$\frac{\Delta X}{\Delta T}$ - velocity of weight pulling model

$T_{uncorrected}$ - weight x 0.235'. This is the moment applied to the system. 0.235' = sleeve radius

W - angular velocity of system and model

Re_D - Reynolds number of the model
D = $6.3/12$ which is diameter of model

V = (0.7 x 8.5 x W)/12
8.5 ft. is the maximum turning radius of the submersible. It was decided to take 0.7 of this radius when computing the linear velocity acting on the model. This is common in propeller design.

T system - Frictional drag of the system is represented as a moment acting against the moment applied to the system (T-uncorrected). This valve is obtained from the graph of system drag -vs- velocity. It was determined that the system drag depended on the velocity of the weight. T system = system drag X0.235.

T_{Drag} - The drag force of the model is represented by a moment, which is the difference between T-uncorrected and T-system.

F_D - The drag force is the moment due to drag, divided by the lever arm. In order to determine the lever arm, force diagrams were drawn for the model and its components that were being tested. The distances from the centerline to the centroids of the force diagrams were the lever arms.

C_D - Overall drag coefficient for the model or portion of the model being tested. $C_D = {}^{T_{Drag}}/_{(\text{lever arm})} {}^{\rho}/_{2} A_{total} V^2$

TESTING PROCEDURE

The 1/12 scale model was placed in the tank and weights ranging from 1.61 lbs to 8.01 lbs were then attached to the string. The weights were raised to a height of 11.5 ft. above the floor. Marks were placed on the wall next to the weight in two foot intervals for measuring the distance of the filling weight.

The water in the tank was allowed to come to rest, then the weight was released. It was allowed to fall four feet before timing was started. This left 7.5 feet for the weight to fall at constant velocity. Acceleration measurements were made and it was determined that the model reached constant angular velocity within the first two feet of fall.

The full model was tested 37 times with seven different combinations of weights. The weight, time and distance of each test were recorded. Next, the spheres were removed and the procedure was repeated. After removing the spheres, the batteries were removed so that the buoyancy tank and frame were tested. Finally, the spheres were tested in combination with the frame. The breakdown of the model in this manner allowed for the interference drag of the various components to be calculated.

DETERMINATION OF DRAG COEFFICIENT

As previously stated, the moment due to the drag force was calculated from the difference of the system moment and the applied moment. The drag moment was divided by its lever arm to determine the drag force. This force was used in calculating the drag coefficients. When the drag coefficients of the various components of the model were calculated, a different lever arm had to be found from the force diagram.

Except for different velocities, the term $\rho/_2 AV^2$ was kept constant. A constant valve of 0.653 ft^2 was used for the area. In this way, the drag forces on the full model and its components would be represented by the coefficients. This would allow the coefficients to be added and subtracted directly. For example:

C_D of the frame is 0.105 at $Re = 2 \times 10^5$

C_D of the buoyancy tank & frame is 0.25

C_D of the buoynacy tank is 0.125

Therefore, the interference drag coefficient is $0.25 - (0.125 + 0.105) = 0.02$. Once the overall drag coefficient of the full model was determined, it was possible to calculate a turning rate for any given thruster location. It was assumed in the calculations that two thrusters are acting at a distance (x) from the centerline with 100 pounds of thrust each. The drag moment must equal the thruster moment when the submersible is in constant angular velocity. From this relationship, the turning rate is calculated as a function of thruster location from the center line.

Thruster moment = 200X

$$\text{Drag moment} = F_D \times \text{lever arm}$$

$$= C_D \, \rho/2 \, AV^2 \, \text{L.A.}$$

$C_D = 0.53$ by experiment ($Re = 2.0 \times 10^5$)

$\rho/2 = 0.995$

$V = 0.8 \times 8.5 \times W$

L.A. = 5.9

It can be shown with simple algebra that $W = \left(\frac{x}{51.8}\right)^{1/2}$

x = 2 ft	W = 11.3 degrees per second
x = 3 ft	W = 13.8 degrees per second
x = 4 ft	W = 15.9 degrees per second
x = 5 ft	W = 17.8 degrees per second

CONCLUSIONS

The results from this experiment compare favorably with data taken from J-S-L II. The turning rate of J-S-L II, with two thrusters acting, was found to be approximately 8 degrees per second. These measurements were taken in the Link Port Channel where wave and bottom effects would tend to slow the submersibles turning rate. Also, the present design of J-S-L III is smaller and more "streamlined" with respect to rotation than is J-S-L II. Taking these factors into consideration, the turning rates predicted by this experiment should give a good indication of what could be expected of the prototype.

The overall drag coefficient predicted by the experiment was on the order of 0.5, while the mathematical model predicted 0.3. The discrepancy can be attributed to the interference drag and errors in the experimental set up and mathematical model. However, the lower valve of drag coefficient was used to determine the curve of turning rate -vs- thruster location.

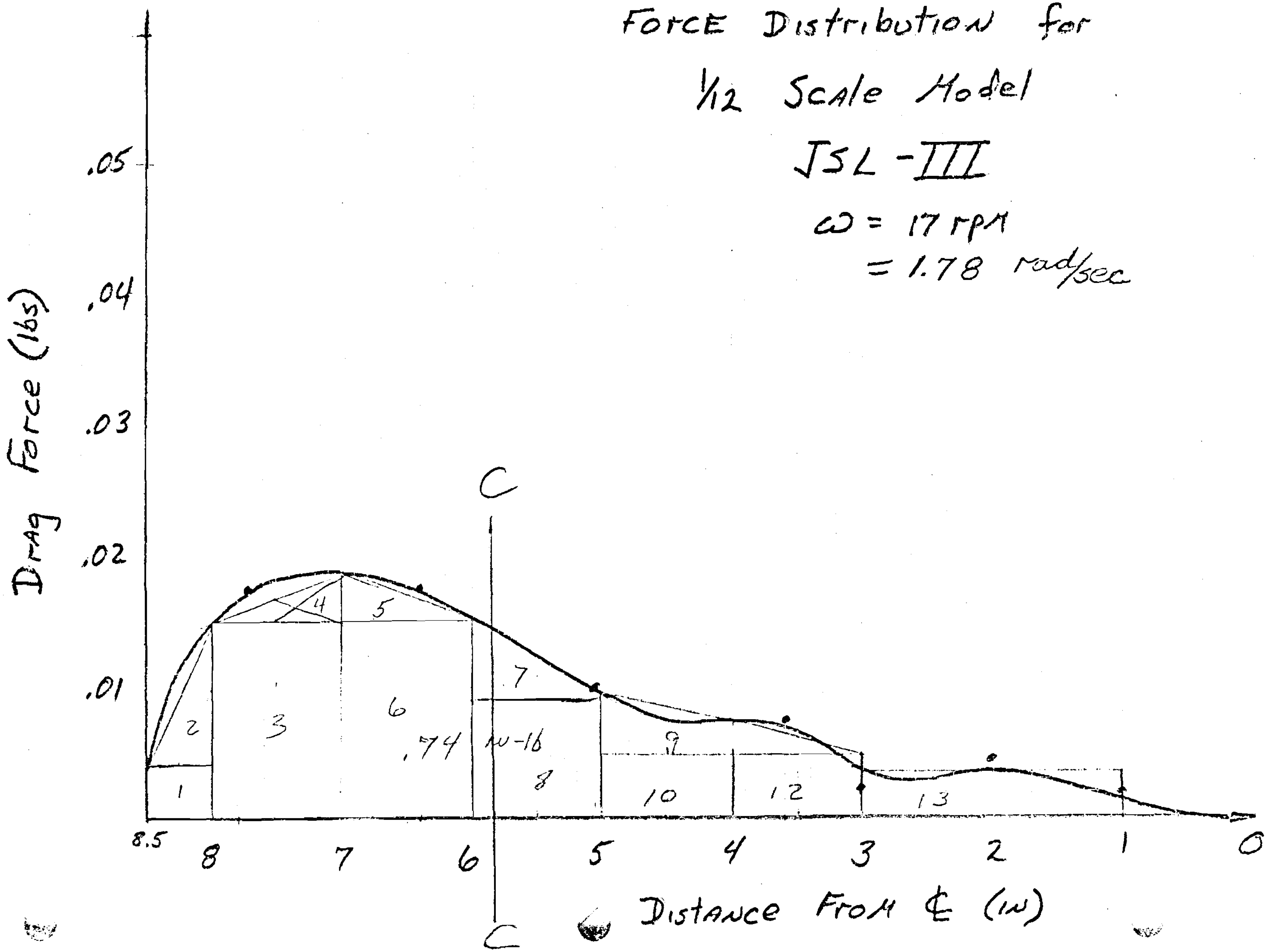
Force Distribution for

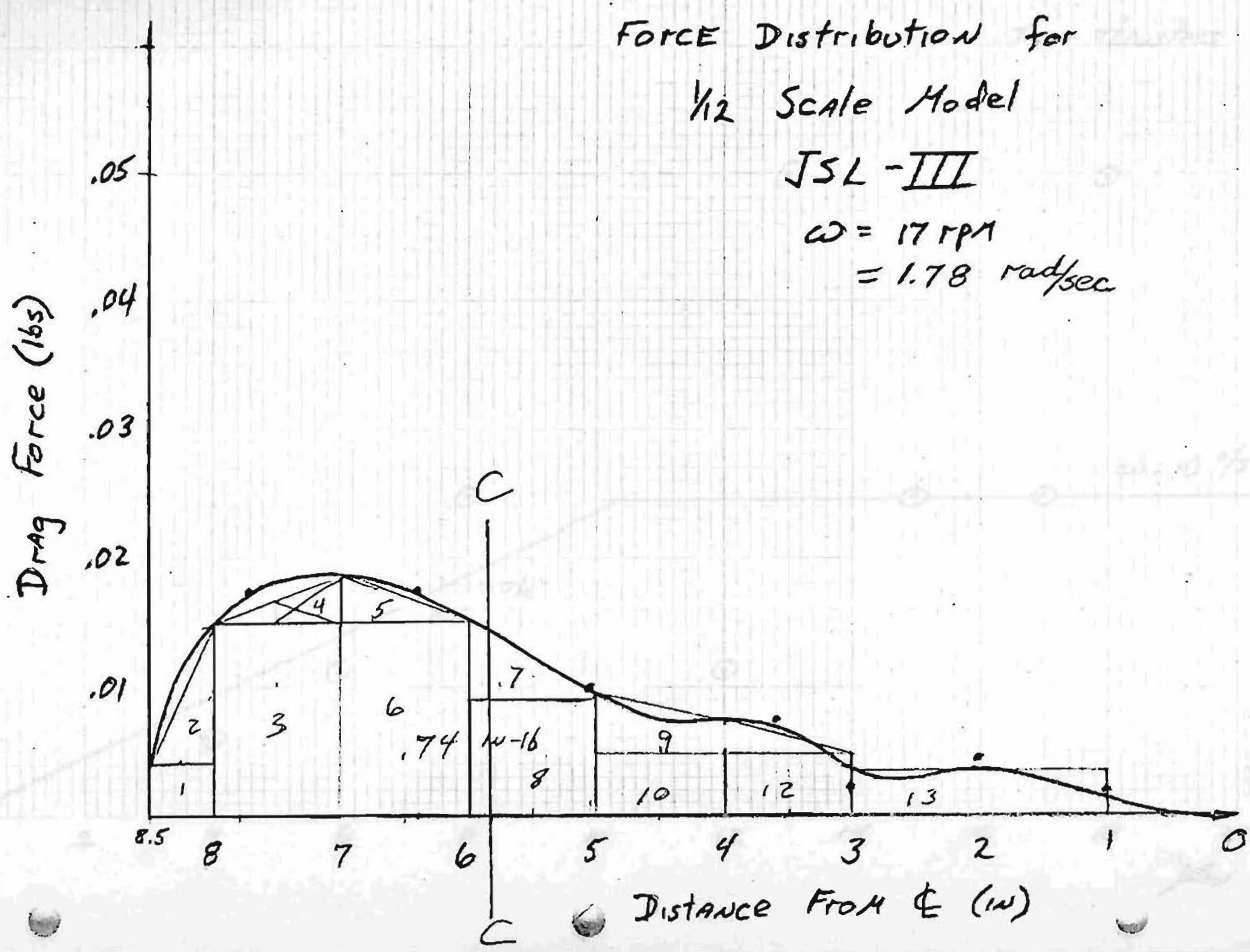
1/12 Scale Model

JSL-III

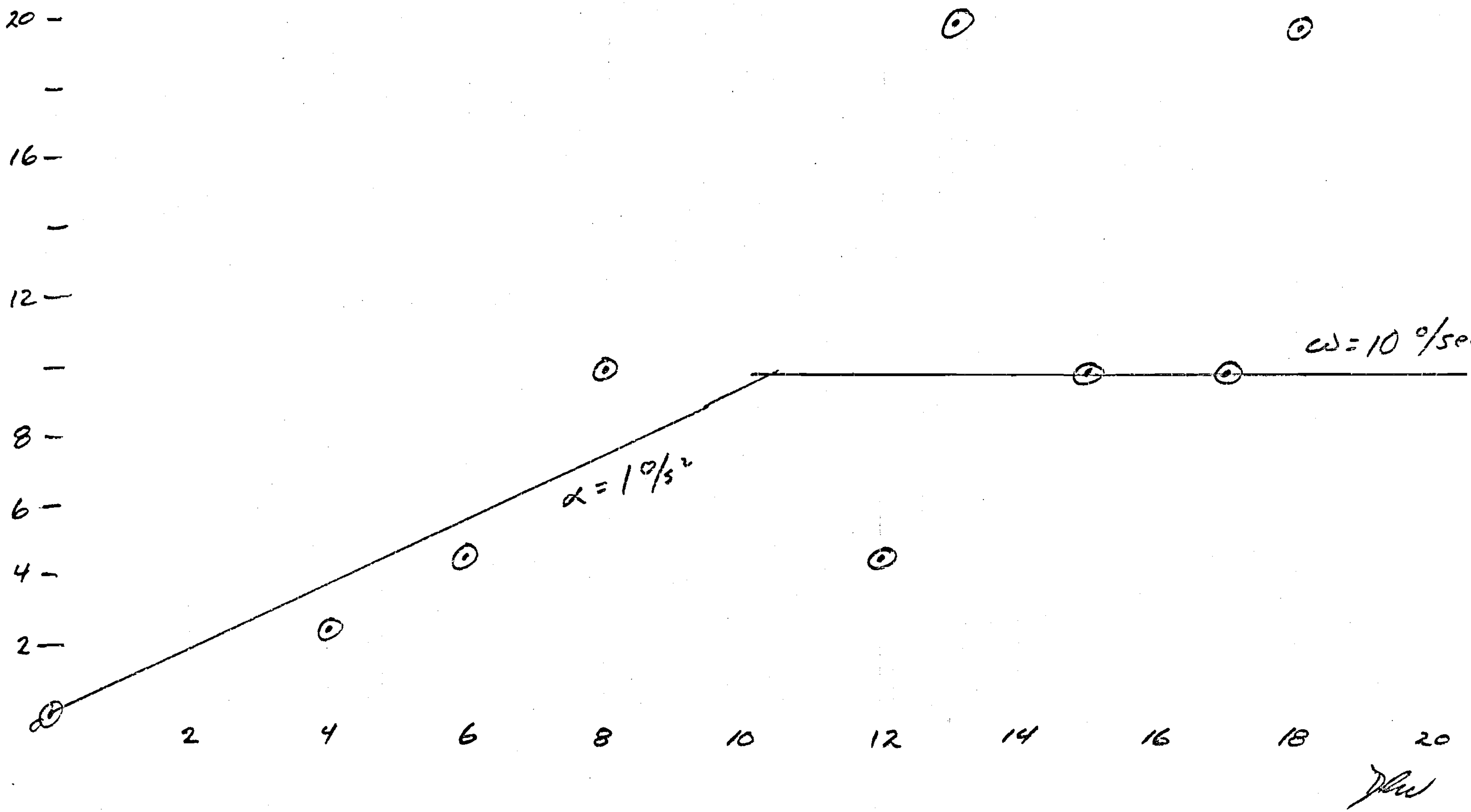
ω = 17 rpm

= 1.78 rad/sec

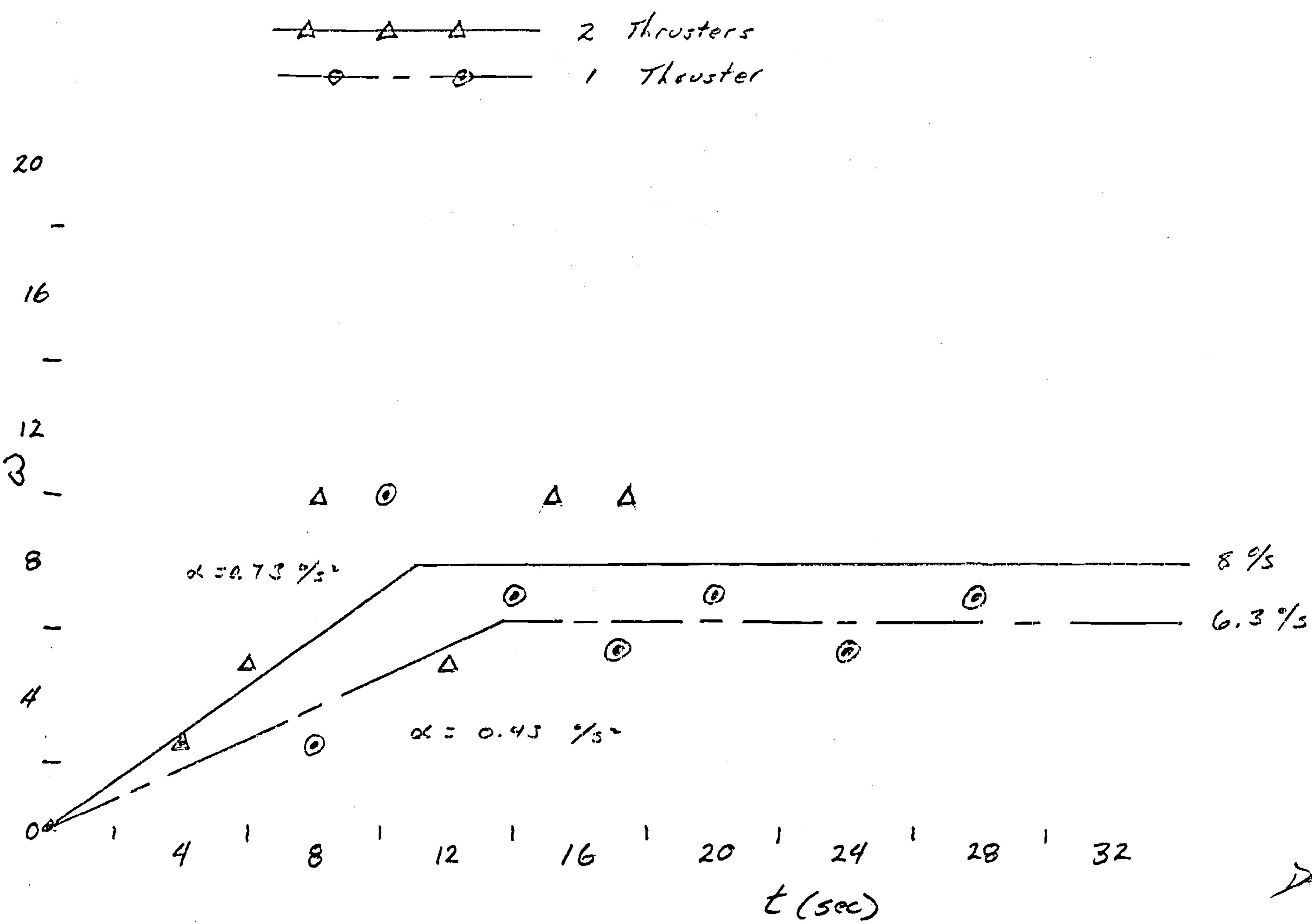



Force Distribution for
1/12 Scale Model
JSL - III
ω = 17 rpm
= 1.78 rad/sec
Drag Force (lbs)
.05
.04
.03
.02
.01
8.5
8
7
6
5
4
3
2
1
0
Distance From ℄ (in)
C
C
1
2
3
4
5
6
.74
7
8
w-16
9
10
12
13

JSC-II
6/25/76
Two Thrusters

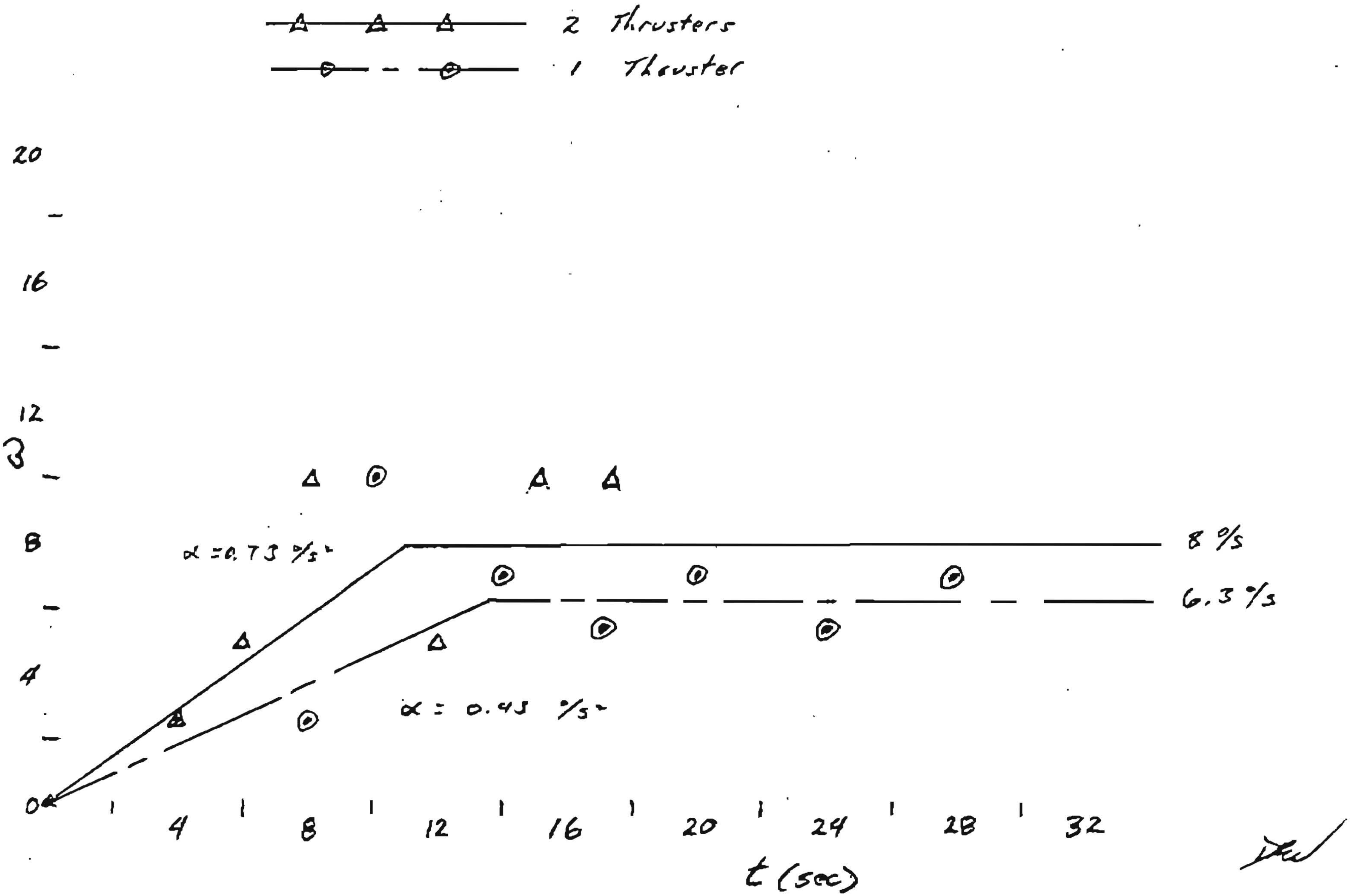


√SL II
6/25/76

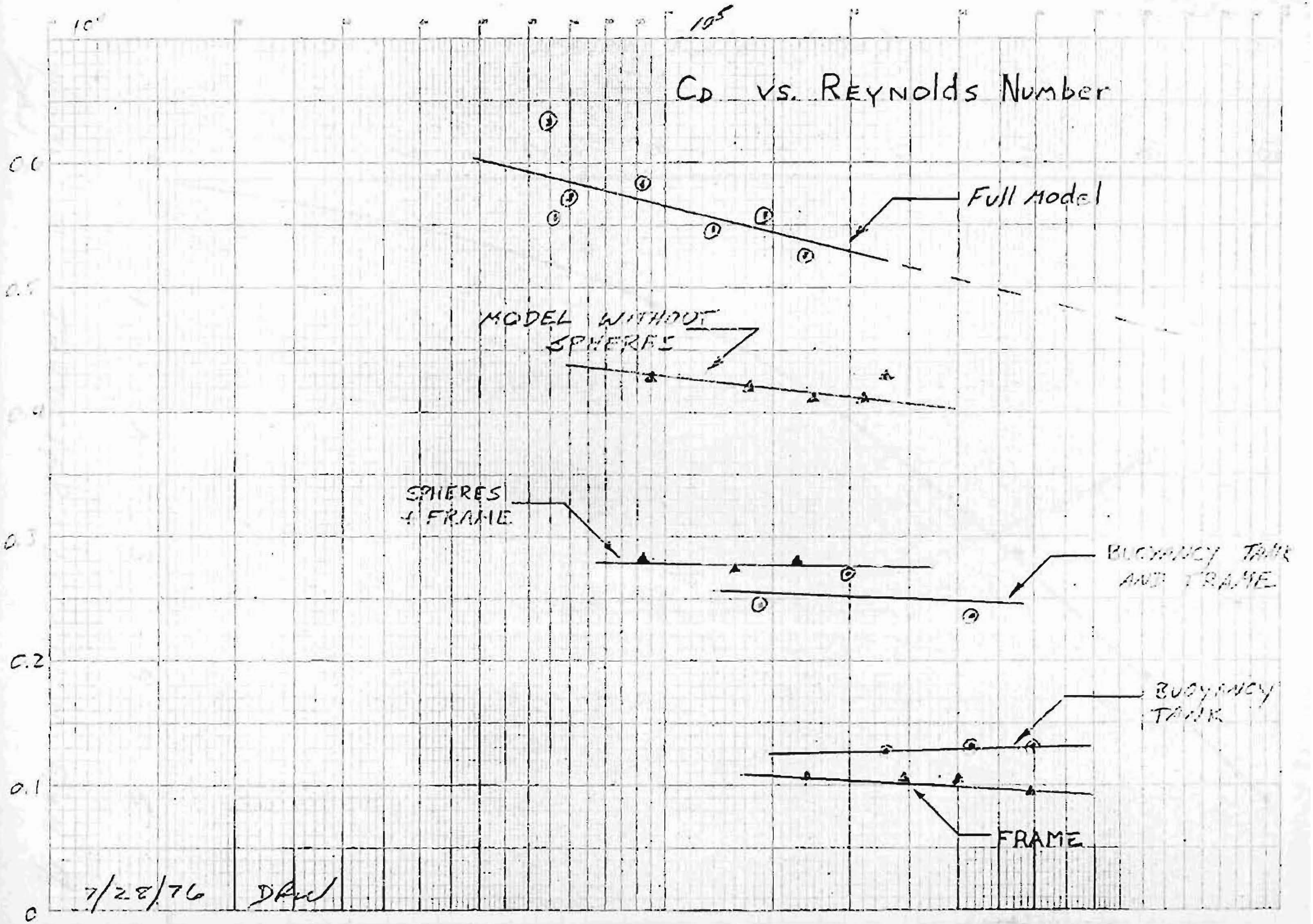


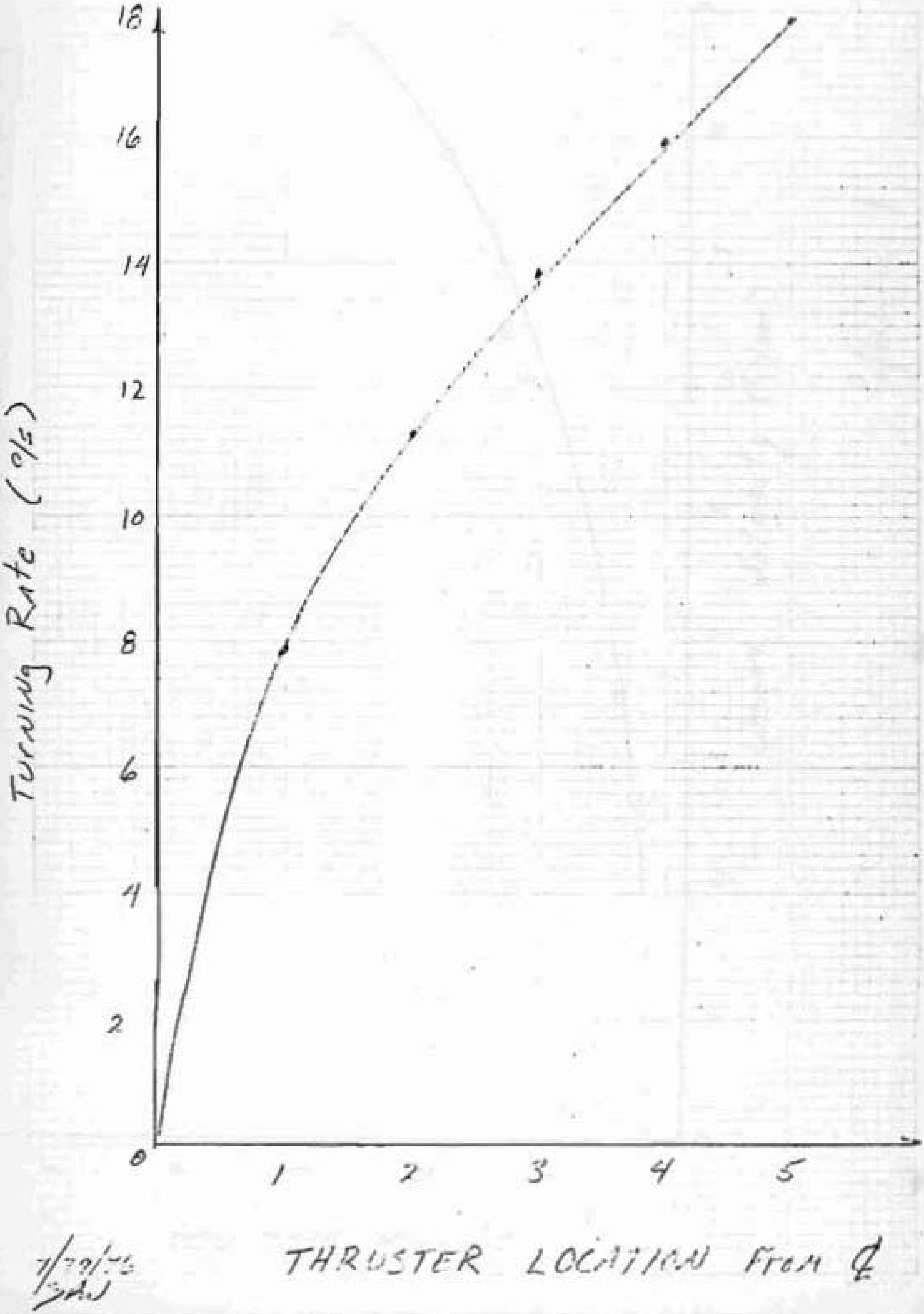
2 Thrusters
1 Thruster
20
16
12
3
8
4
0
4
8
12
16
20
24
28
32
t (sec)
α = 0.73 °/s²
α = 0.43 °/s²
8 °/s
6.3 °/s

ISL II
6/25/76

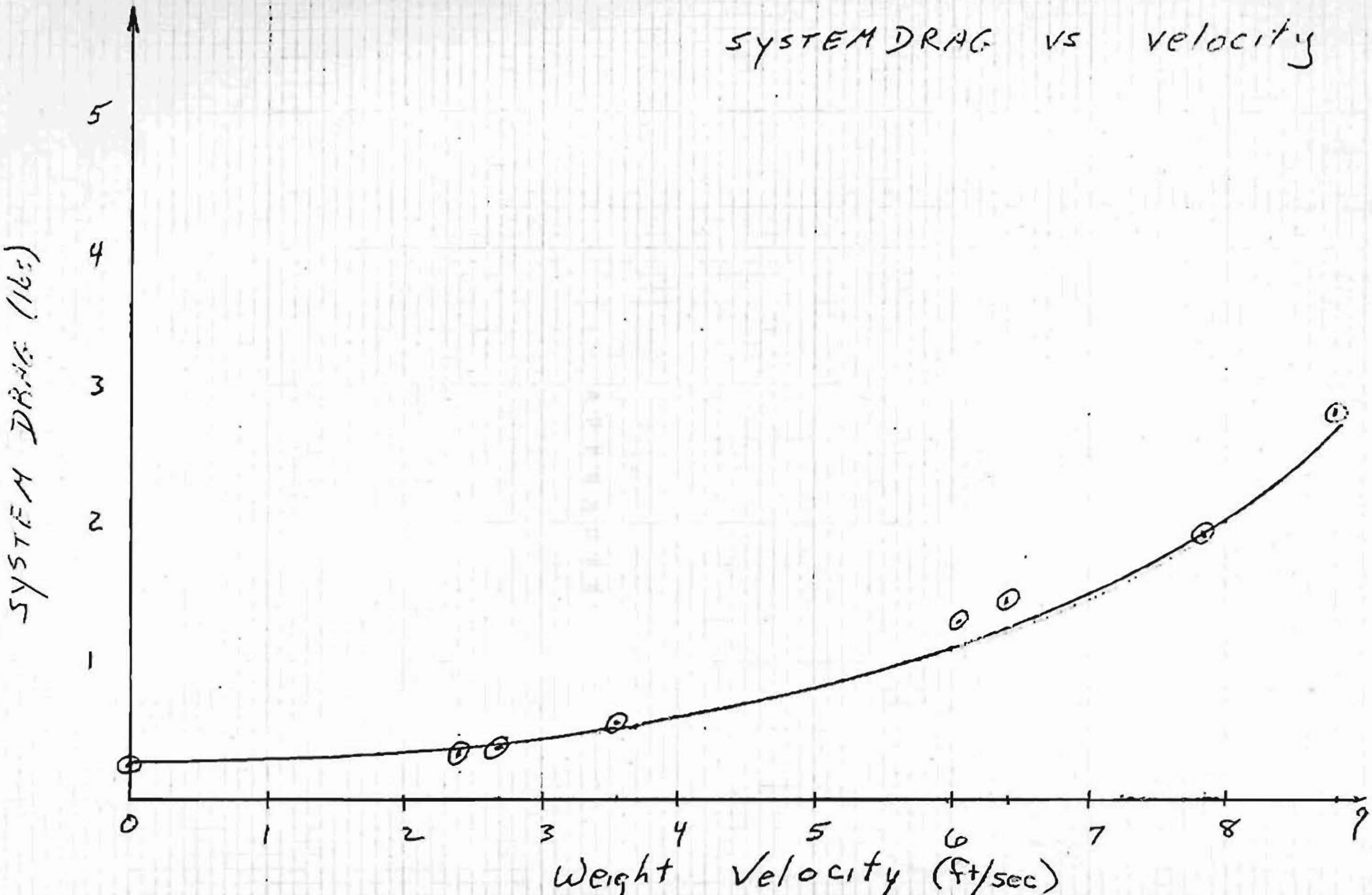


2 Thrusters
1 Thruster
20
16
12
8
4
0
α = 0.73 °/s²
α = 0.45 °/s²
8 °/s
6.3 °/s
4
8
12
16
20
24
28
32
t (sec)


Cd vs. Reynolds Number
10⁴
10⁵
0.6
0.5
0.4
0.3
0.2
0.1
0
Full Model
MODEL WITHOUT SPHERES
SPHERES + FRAME
BUOYANCY TANK AND FRAME
BUOYANCY TANK
FRAME
7/28/76 DAW



Turning Rate (°/s)
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
THRUSTER LOCATION From ℄


SYSTEM DRAG VS velocity
SYSTEM DRAG (lbs)
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
Weight Velocity (ft/sec)

Reference 1

A P P E N D I X

Run	V/2c (ft/sec)	T (lb-ft) (uncorrected)	ω (rad/sec)	R_E	T_{wire}	T_{dyn}	F_D (lbs)	C_D = T/(...)	Model
11	0.721	0.427	3.068	7.59 × 10⁴	0.068	0.359	(.736)	0.491	Full model
12	0.682	"	2.902	7.18 "	"	"		0.549	
13	0.697	"	2.966	7.34 "		"		0.525	
14	0.702	"	2.987	7.39 "		"		0.518	
15	0.676	"	2.577	7.12 "		"		0.558	
16	0.625	"	2.659	6.58 "	"	"		0.653	
17	0.625	"	2.659	6.58 "	"	"		0.653	
18	0.654	"	2.783	6.89 "	"	"		0.597	
						AVG		**0.568**	
(avg)	0.673								
19	0.597	0.427	2.531	6.26 × 10⁴	0.068	0.359	(0.236)	0.721	
20	0.625	"	2.650	6.56 "	"	"		0.658	
21	0.597	"	2.531	6.26 "	"	"		0.721	
22	0.678	"	2.825	7.11 "	"	"		0.559	
23	0.678	"	2.825	7.11 "	"	"		0.559	
						AVG		**0.644**	
(AVG)	0.635								
24	0.635	0.278	2.692	6.66 × 10⁴	0.068	0.210	(0.636)	0.551	
25	0.635	"	2.692	6.66 "	"	"		0.551	
26	0.635	"	2.692	6.66 "	"	"		0.551	
27	0.617	"	2.616	6.47 "	"	"		0.583	
28	0.635	"	2.692	6.66 "	"	"		0.551	
						AVG		**0.557**	
29	0.872	0.705	3.697	9.14 × 10⁴	0.071	0.634	(1.300)	0.597	
30	0.887	"	3.761	9.31 "	"	"		0.577	
31	0.893	"	3.787	9.37 "	"	"		0.569	
32	0.877	"	3.719	9.20 "	"	"		0.590	
33	0.887	"	3.761	9.31 "	"	"		0.577	
						AVG		**0.582**	

Rivet A/M = 0.48

Run	%/Σ(%)	T (ft-lb)	ω (rpm)	Re = [illegible]	T_{spin} ([illegible])	T_{prop}	(T_p)	G	model
34	1.162	1.053	4.949	1.22×10^5	0.071	1.012	(2.01)	0.532	Full model
35	1.196	"	4.534	1.20 "	"	"	"	0.557	
36	1.195	"	4.872	1.21 "	"	"	"	0.549	
37	1.128	"	4.880	1.19 "	"	"	"	0.565	
38	1.154	"	4.911	1.22 "	"	"	"	0.540	Lever Arm = 0.46
							AVG	0.548	
39	1.359	1.498	5.911	1.46×10^5	0.072	1.426	(2.93)	0.552	
40	1.376	"	5.855	1.45 "	"	"	"	0.562	
41	1.376	"	5.855	1.45 "	"	"	"	0.562	
42	1.376	"	5.855	1.45 "	"	"	"	0.562	
43	1.377	"	5.911	1.46 "	"	"	"	0.552	
							AVG	0.555	
44	1.571	1.883	6.515	1.61×10^5	0.073	1.810	(3.71)	0.571	
45	1.667	"	7.094	1.76 "	"	"	"	0.492	
46	1.563	"	6.651	1.65 "	"	"	"	0.545	
47	1.667	"	7.094	1.76 "	"	"	"	0.482	
							AVG	0.521	
									model I sphere
48	2.174	1.883	9.251	2.29×10^5	0.082	1.801	(5.63)	0.423	
49	2.174	"	9.251	2.29 "	"	"		0.423	
50	2.206	"	9.387	2.32 "	"	"		0.411	LA - 0.52
51	2.113	"	8.991	2.23 "	"	"		0.448	
52	2.174	"	9.251	2.29 "	"	"		0.423	
							AVG	0.426	

Run	$\frac{\Delta x}{\Delta t}$ (ft/sec)	T (lb-ft)	ω (rad/sec)	$R_e = 0.2475\omega$	T_{system}	T_{drag}	(F_D)	C_D	Model
53	2.000	1.498	8.511	2.11×10^5	0.082	1.416	(4.43)	0.393	3 spheres
54	1.948	"	8.259	2.05 "	"	"	"	0.414	
55	1.974	"	8.466	2.05 "	"	"	"	0.404	
56	1.923	"	8.123	2.03 "	"	"	"	0.425	
57	1.948	"	8.289	2.05 "	"	"	"	0.415	
							AVG	0.410	
58	1.655	1.053	7.170	1.77×10^5	0.078	1.005	(3.14)	0.393	
59	1.648	"	7.013	1.74 "	"	"	"	0.411	
60	1.667	"	7.094	1.75 "	"	"	"	0.402	
61	1.648	"	7.013	1.74 "	"	"	"	0.411	
62	1.613	"	6.864	1.70 "	"	"	"	0.429	
							AVG	0.409	
63	1.316	0.705	5.600	1.39×10^5	0.073	0.632	(1.98)	0.405	
64	1.316	"	5.600	1.39 "	"	"	"	0.405	
65	1.282	"	5.455	1.35 "	"	"	"	0.427	
66	1.282	"	5.455	1.35 "	"	"	"	0.427	
67	1.271	"	5.409	1.34 "	"	"	"	0.435	
68	1.293	"	5.502	1.36 "	"	"	"	0.420	
							AVG	0.420	
69	0.915	0.378	3.594	0.96×10^5	0.071	0.307	(.96)	0.407	
70	0.888	"	3.779	0.94 "	"	"	"	0.432	
71	0.882	"	3.753	0.93 "	"	"	"	0.438	
72	0.888	"	3.779	0.94 "	"	"	"	0.432	
73	0.882	"	3.753	0.93 "	"	"	"	0.438	
							AVG	0.429	

[V.A. = 0.33?]

Run	$\frac{\Delta x}{\Delta t}$ (ft/sec)	T (lb-ft)	ω (rad/sec)	R_{e_D}=0.2875ω	T_{system}	T_{drag} (F_D)	C_D	Model
53	2.000	1.492	8.511	2.11 ×10	0.082	1.416 (4.93)	0.393	3 spheres
54	1.998	"	8.239	2.05 "	"	" "	0.414	
55	1.974	"	8.466	2.05 "	"	" "	0.404	
56	1.923	"	8.183	2.03 "	"	" "	0.475	
57	1.948	"	8.259	2.05 "	"	" "	0.415	
						AVG	0.410	
58	1.655	1.653	7.170	1.77 ×10^5	0.078	1.005 (3.14)	0.393	
59	1.648	"	7.013	1.74 "	"	" "	0.411	
60	1.667	"	7.094	1.75 "	"	" "	0.402	
61	1.648	"	7.013	1.74 "	"	" "	0.411	
62	1.613	"	6.864	1.70 "	"	" "	0.429	
						AVG	0.409	
63	1.316	0.705	5.600	1.39 ×10^5	0.073	0.632 (1.98)	0.405	
64	1.316	"	5.600	1.39 "	"	" "	0.405	
65	1.282	"	5.455	1.35 "	"	" "	0.427	
66	1.282	"	5.455	1.35 "	"	" "	0.427	
67	1.271	"	5.409	1.34 "	"	" "	0.435	
68	1.293	"	5.502	1.36 "	"	" "	0.420	
						AVG	0.420	
69	0.915	0.378	3.894	0.96 ×10^5	0.071	0.307 (.96)	0.407	
70	0.888	"	3.779	0.94 "	"	" "	0.432	
71	0.882	"	3.753	0.93 "	"	" "	0.438	
72	0.888	"	3.779	0.94 "	"	" "	0.432	
73	0.882	"	3.753	0.93 "	"	" "	0.438	
						AVG	0.429	

7/7?/??

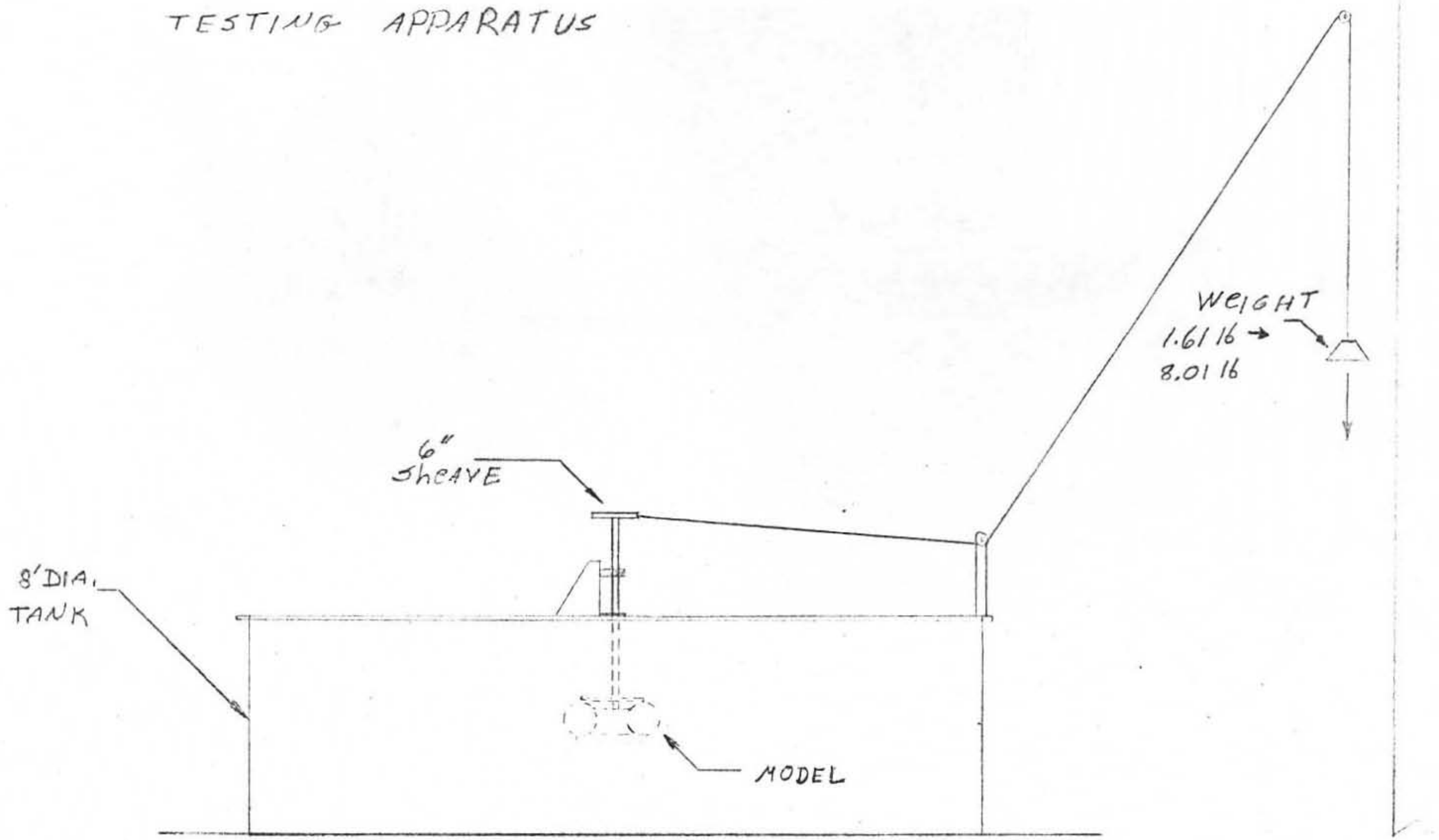
RUN	$\frac{\Delta X}{\Delta t}$	T (lb-ft)	ω (rad/sec)	R_{e_y}	T_{system}	T_{drag}	(f_0)	C_0	Model
95	2.671	1.023	11.366	2.81 x10^5	0.103	0.980	(2.51)	0.125	Frame Only
96	3.000	"	12.766	3.16 "	"	"	"	0.099	
97	3.000	"	12.766	3.16 "	"	"	"	0.099	
98	3.061	"	13.025	3.22 "	"	"	"	0.095	
99	3.061	"	13.025	3.22 "	"	"	"	0.095	
							AVG	0.103	
100	2.419	0.705	10.291	2.55 x10^5	0.082	0.623	(1.60)	0.097	L.A. = 0.39
101	2.308	"	9.821	2.43 "	"	"	"	0.107	
102	2.344	"	9.974	2.47 "	"	"	"	0.103	
103	2.308	"	9.821	2.43 "	"	"	"	0.107	
104	2.308	"	9.821	2.43 "	"	"	"	0.107	
							AVG	0.104	
105	1.596	0.378	6.791	1.68 x10^5	0.078	0.300	(0.77)	0.107	
106	1.613	"	6.864	1.70 "	"	"	"	0.105	
107	1.613	"	6.864	1.70 "	"	"	"	0.105	
108	1.667	"	7.094	1.75 "	"	"	"	0.098	
109	1.613	"	6.864	1.70 "	"	"	"	0.105	
							AVG	0.104	
110	2.174	0.378	9.251	2.29 x10^5	0.082	0.296	(1.64)	0.124	Buoyancy T.
111	2.174	"	9.251	2.29 "	"	"	"	0.124	L.A. = 0.18
112	2.206	"	9.387	2.32 "	"	"	"	0.120	
113	2.174	"	9.251	2.29 "	"	"	"	0.123	
114	2.143	"	9.120	2.26 "	"	"	"	0.127	
							AVG	0.124	

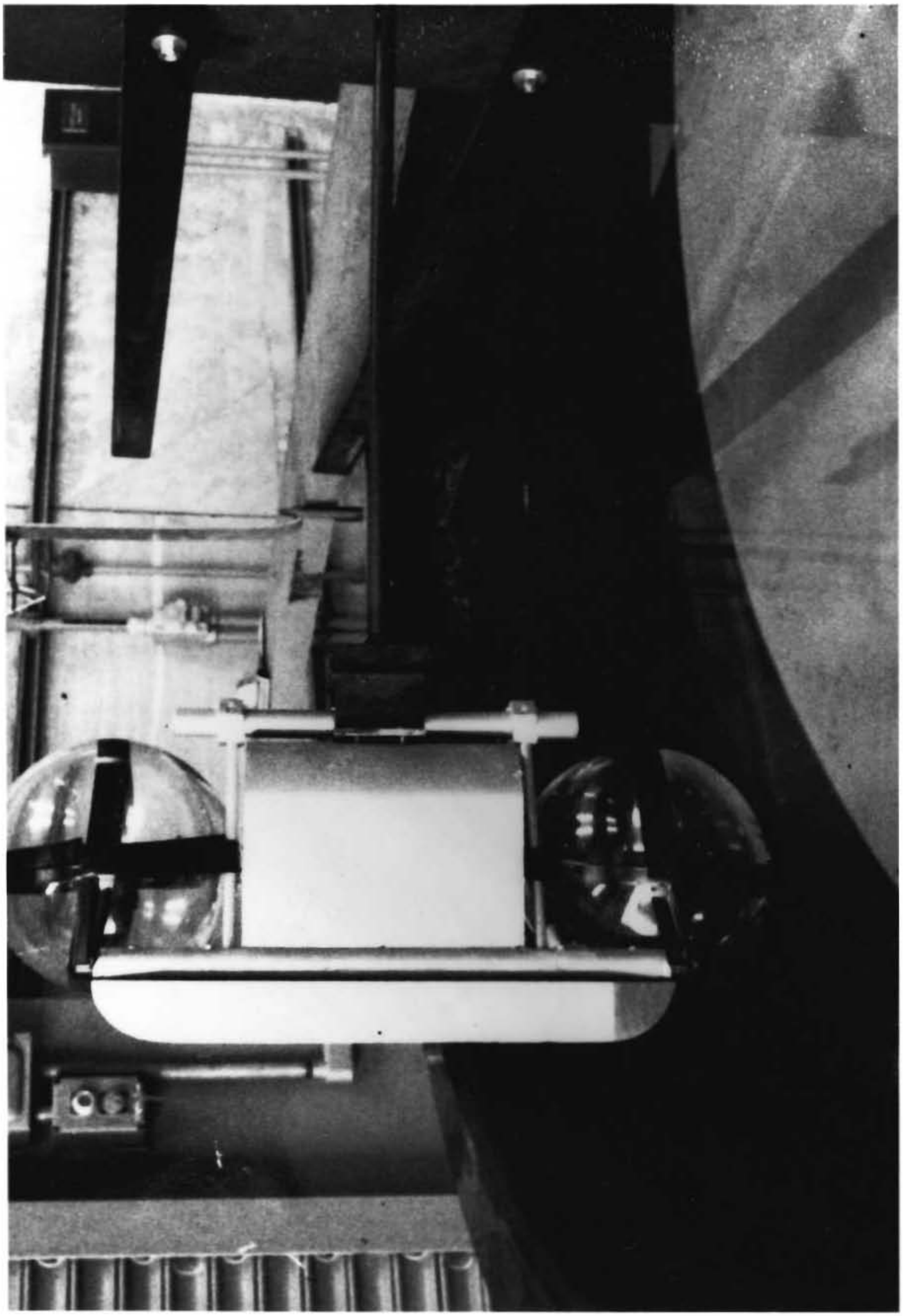
RUN	$\frac{\Delta x}{\Delta t}$	T (lb-ft)	ω (rad/sec)	Re_D	T_{system}	T_{Drag}	(F_D)	C_D	Model
115	3.659	1.053	15.570	3.85×10^5	0.129	0.954	(5.30)	0.141	Buoyancy Tan[k]
116	3.659	"	15.570	3.85 "	"	"	"	0.141	
117	3.750	"	15.957	3.95 "	"	"	"	0.134	L.A. = 0.18
118	3.846	"	16.366	4.05 "	"	"	"	0.127	
119	3.846	"	16.366	4.05 "	"	"	"	0.127	
							AVG	0.134	
120	3.000	0.705	12.766	3.16×10^5	0.101	0.604	(3.35)	0.133	
121	3.061	"	13.025	3.22 "	"	"	"	0.127	
122	3.125	"	13.298	3.29 "	"	"	"	0.122	
123	3.061	"	13.025	3.22 "	"	"	"	0.127	
124	3.125	"	13.298	3.29 "	"	"	"	0.122	
							AVG	0.126	
125	1.25	0.705	5.319	1.32×10^5	0.071	0.634	(1.21)	0.275	Spheres & Fra[me]
126	1.25	"	5.319	1.32 "	"	"	"	0.275	
127	1.26	"	5.360	1.33 "	"	"	"	0.270	
128	1.26	"	5.360	1.33 "	"	"	"	0.270	
129	1.26	"	5.360	1.33 "	"	"	"	0.270	
							AVG	0.272	
130	0.872	0.378	3.711	9.20×10^4	0.068	0.310	(0.59)	0.276	
131	0.872	"	3.711	9.20 "	"	"	"	0.276	L.A. = 0.526
132	0.862	"	3.668	9.10 "	"	"	"	0.283	
133	0.852	"	3.625	9.00 "	"	"	"	0.289	
134	0.862	"	3.625	9.00 "	"	"	"	0.289	
							AVG	0.283	
135	1.579	1.083	6.719	1.66×10^5	0.075	1.008	(1.92)	0.274	
136	1.546	"	6.579	1.63 "	"	"	"	0.286	
137	1.562	"	6.647	1.64 "	"	"	"	0.280	
							AVG	0.280	

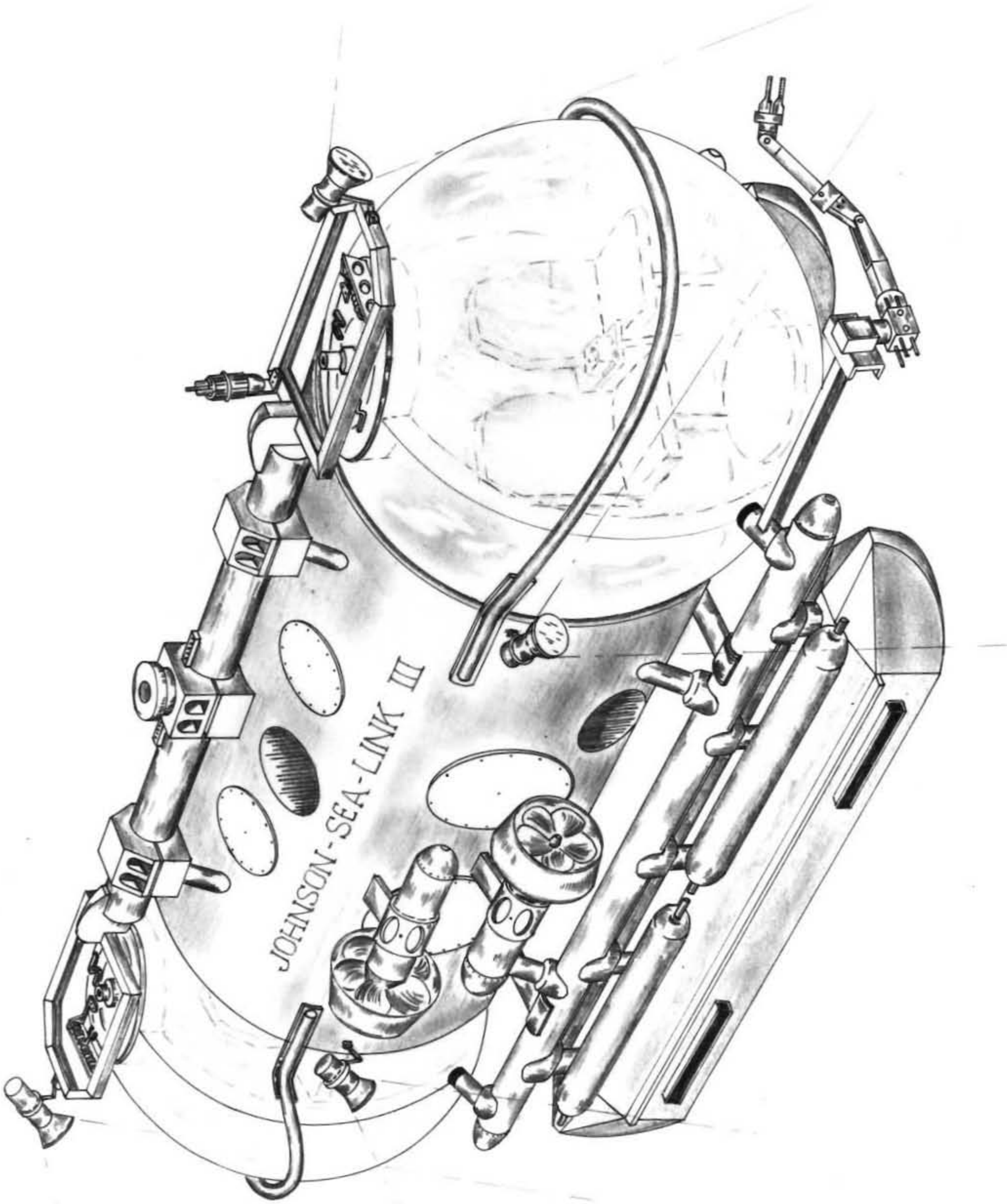
```
C        PROGRAM 1  DRAG COEFFICIENT CALCULATION
C     THIS PROGRAM BY DAVID WILLIAMS IS FOR CALCULATING THE TOTAL DRAG COEFFICIENT
C     FOR THE JSL 3
         DIMENSION X(100), Y(100), R(100), RX(100)
         KAM=4
         DO 25 M=1,KAM
         READ (2,10) N,W1,W2,V,H1,H2,CD1,CD2,CD3,TLFCL
      10 FORMAT (I4, 10F5.2)
         B= 120*TLFCL
      22 A=20.0
         DX=W1/A
         DX2=W2/A
         DR=5.5/A
         AREA1=0
         Y(1)=0
         AREA2=0
         FORC1=0
         FORC2=0
         FORC3=0
         DO 14 I=2,N
         L=I-1
      14 X(I)=X(L)+DX
         E=V**2/72.25
         DO 15 I=1,N
         VELSQ= E*X(I)**2
         AREA1= 2*DX*H1*VELSQ*.995*CD1
      15 FORC1= FORC1+AREA1
C        FORCE ON BATTERIES
         DO 16 I=2,N
         L=I-1
      16 Y(I)=Y(L)+DX2
         DO17 I=1,N
         Z=Y(I)+DX/2.0
         VELSQ2=E*Z**2
         AREA2= 2*DX2*H2*VELSQ2*0.995*CD2
      17 FORC2= FORC2+ AREA2
C        SPHERE CALCULATIONS
         DO 21 I=1,N
         K=I
      21 R(I)= 3+DR*K
         DO 18 I=1,N
         RX(I)=R(I)-5.75
         HEIGHT = SQRT((2.75)**2-RX(I)**2)
         DAREA= DR*HEIGHT
         VELSQ=E*R(I)**2
         FSPHE= 4*DAREA*VELSQ*0.995*CD3
      18 FORC3=FORC3+FSPHE
C        FORCE AND MOMENT CALCULATIONS
         FTOT=FORC1 + FORC2+ FORC3
         MTOT=FTOT*6.375
         IF (MTOT.GT.B) GO TO 23
         V=V +0.05
         GO TO 22
```

```
0048      23 B=V/8.5
0049         ANGVEL=ATAN(B)
0050         ANGVEL= ANGVEL*57.2958
0051         CDTOT= FTOT/(0.995*46.42*0.707*V**2)
0052         WRITE (3,24) MTOT, FTOT, FORC1, FORC2, FORC3, ANGVEL, CDTOT
0053      24 FORMAT(2X,14HDRAG MOMENT = ,F10.4,7H FT-LB ,/,13H DRAG FORCE= ,F10
        X.4,2HLB,/,22H BOUYANCY TANK DRAG = ,F10.4,3H LB,/,16H BATTERY DRAG
        X = ,F10.4,/,15H SPHERE DRAG = ,F10.4,2HLB,/,20H ANGULAR VELOCITY =
        X ,F10.4,16H DEGREES PER SEC./,26H TOTAL DRAG COEFFICIENT V ,F10.4)
0054      25 CONTINUE
0055         STOP
0056         END
```

TESTING APPARATUS






JOHNSON-SEA-LINK II