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NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
Washington 7, D. C.

APPROXIMATION OF SIZE OF CONTROL SURFACES FOR SUBMERGED AMPHIBIOUS TANK

by

Franklin Hawkins

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December 1948

Report C-173

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ABSTRACT

A first approximation of the proper size of the control surfaces for a submerged amphibious landing vehicle is derived based on computations of the size required when operating deeply submerged. The method of computation together with the assumptions made are explained.

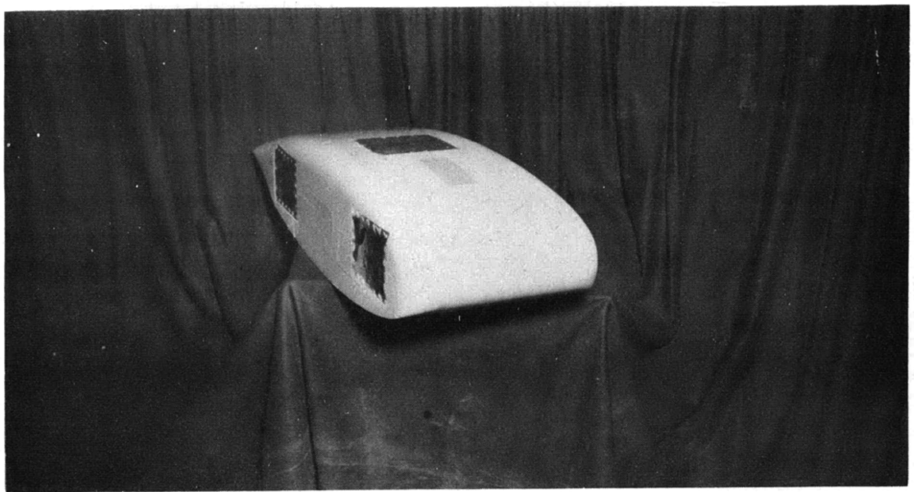
INTRODUCTION

In connection with a preliminary design study, the Bureau of Ships requested the David Taylor Model Basin to recommend the size and location of control surfaces on an amphibious landing vehicle capable of operating submerged. It was specified that the craft should submerge and remain submerged by hydrodynamic action on the hull and control surfaces rather than by the destruction of buoyancy by flooding. In addition the Bureau desired to know the maximum amount of buoyancy which could be overcome by control surfaces of reasonable size. A reasonable size of control surface was tentatively defined as one which would not protrude beyond the side of the hull more than 17 inches.

Figure 1 shows TMB Model 4066 which is a 1/10 scale model of the bare hull of the craft. The full-scale amphibian is to be thirty feet long, ten feet wide and is to have six feet nine inches maximum depth. The totally submerged displacement is 92,250 pounds. It was considered that the submerged speed of the craft should be about 13 knots and that it should carry a 10,000 pound cargo. Propulsion in the water is to be provided by twin screws. Tracks, which retract into the hull when operating in the water, will be let down for operation on land. A 750 horsepower engine will provide power to either the propellers or tracks through gearing.

GENERAL CONSIDERATIONS

The size and location of control surfaces on a given submerged body designed to remain submerged at a given speed against the action of a buoyant force of undetermined, though limited, magnitude, depend on many factors. Obviously, to obtain any solution, it is first necessary tentatively to select within the specified limit, a value for the buoyant force. Next, the hydrodynamic lift, drag, and moment characteristics of the hull and control surfaces must be determined either by experiment or by estimation from similar



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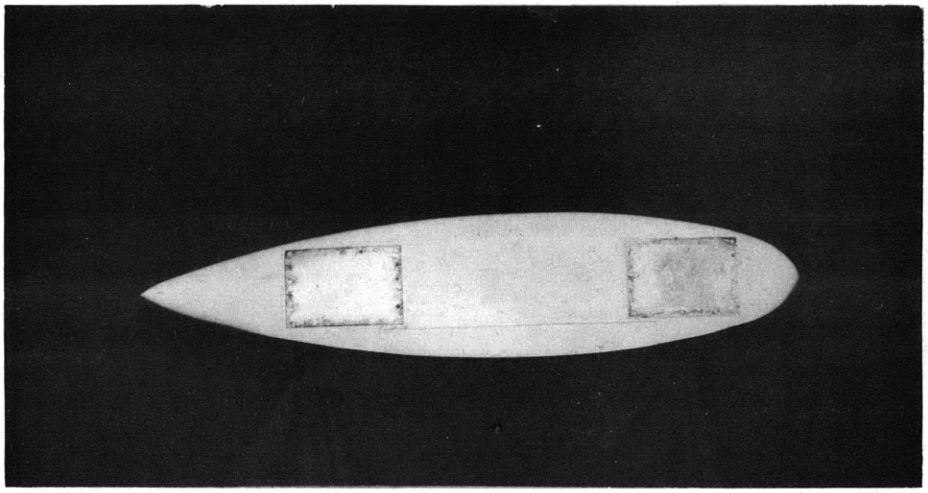
LOOKING ON STARBOARD BOW



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PROFILE

MODEL 4066
REPRESENTING SUBMERSIBLE
AMPHIBIOUS VEHICLE

FIGURE 1

forms. Having these data it is possible to write the equations of equilibrium for the body in steady motion. The problem then becomes one only of making successive changes of one design parameter in the equations in order to obtain a more satisfactory value of some other design parameter.

The largest control surface to overcome a given buoyant force at a given speed will be required when the body is on the surface because the hydrodynamic lift of the hull and control surfaces will be less than when deeply submerged. This reduction in lift will result not only from a deterioration of the lift due to surface effects, but also because of a loss in maximum speed due to a very large wave making resistance. Data were not available on the hydrodynamic characteristics to permit a solution of the problem for the surface conditon; therefore in this report only a first approximation of the necessary size of the control surfaces has been derived by computing the size necessary for the deeply submerged condition, for which hydrodynamic data were available.

METHOD OF COMPUTATION

Figure 2 is a schematic diagram of Model 4066 with control surfaces installed, showing the forces and moments which act on it. Because the body is symmetrical with respect to the plane of motion, only the forces and moments in the plane of motion need to be investigated. The equations of equilibrium were written referred to the x, z axes. The equations were simplified at the outset by assuming that:

a. Control surfaces of symmetrical section are used so that L_{bo} and L_{so} equal zero

b. The profile drags, D_{bo} and D_{so}, of the control surfaces are negligibly small.

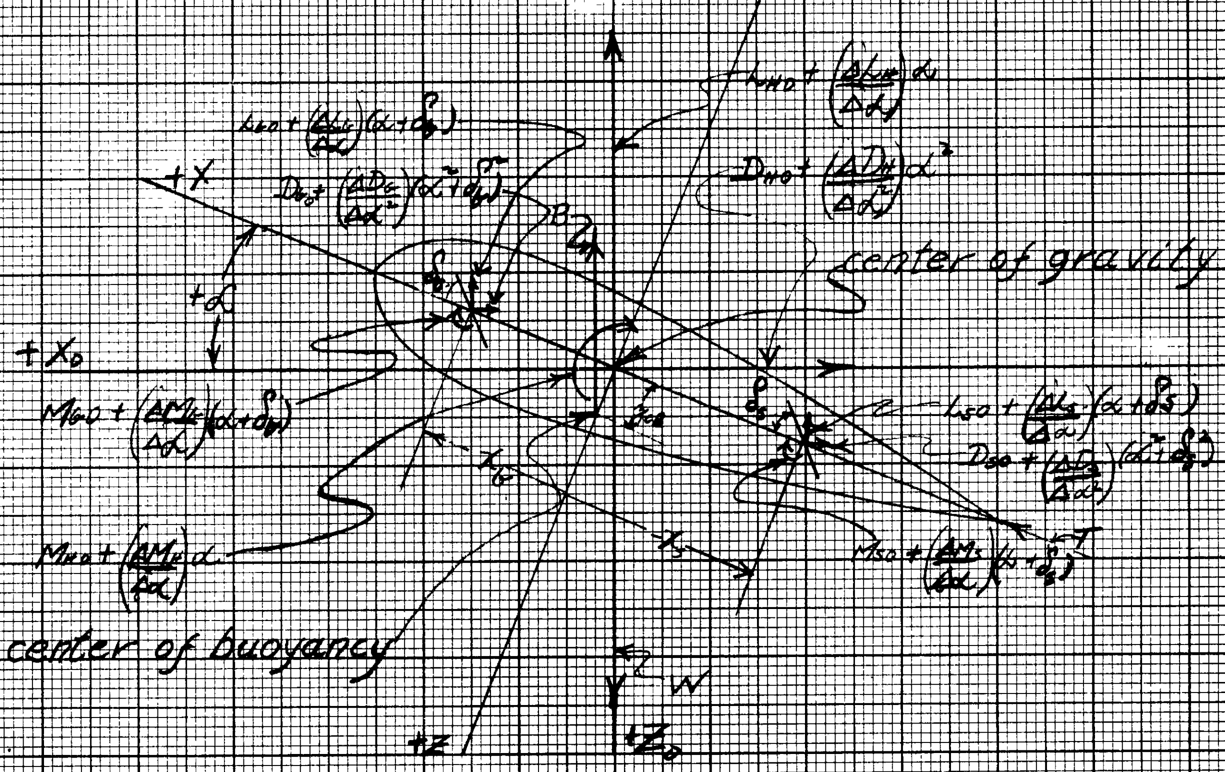
c. The moments M_b and M_s of the control surfaces about their own axes are also negligible.

d. The velocity of flow in the region of the control surfaces is equal in magnitude and direction to the velocity of motion and hence, also there is no interference between the bow and stern planes.

e. The bow and stern planes are identical in shape and section.

By virtue of the last two assumptions it is permissible to write:

$$\frac{\Delta L_b}{\Delta \alpha} = \frac{\Delta L_s}{\Delta \alpha} = \frac{\Delta L_b}{\Delta \delta_b} = \frac{\Delta L_s}{\Delta \delta_s} \qquad \frac{\Delta D_b}{\Delta \alpha^2} = \frac{\Delta D_s}{\Delta \alpha^2} = \frac{\Delta D_b}{\Delta \delta_b^2} = \frac{\Delta D_s}{\Delta \delta_s^2}$$



L_H - Lift of hull alone
L_b - Lift of 2 bow planes
L_s - Lift of 2 stern planes
L_{H0} - Lift of hull for $\alpha = 0$
L_{b0} - Lift of 2 bow planes, $\alpha = 0$
L_{s0} - Lift of 2 stern planes, $\alpha = 0$
D_H - Drag of hull alone
D_b - Drag of 2 bow planes
D_s - Drag of 2 stern planes
D_{H0} Drag of hull for $\alpha = 0$
D_{b0} Drag of 2 bow planes, $\alpha = 0$
D_{s0} Drag of 2 stern planes, $\alpha = 0$
W - Weight of hull
α - Angle of attack of hull

M_H - Moment of hull about c.g.
M_b - Moment of 2 bow planes about own axes
M_s - Moment of 2 stern planes about own axes
M_{H0} Moment of hull about c.g. for $\alpha = 0$
M_{b0} - Moment of 2 bow planes about own axes for $\alpha = 0$
M_{s0} - Moment of 2 stern planes about own axes for $\alpha = 0$
B - Bouyancy of hull
T - Propeller thrust
δ_b - Bow plane angle
δ_s - Stern plane angle

$\frac{\Delta L}{\Delta \alpha}$ signifies rate of change of Lift with angle
$\frac{\Delta M}{\Delta \alpha}$ signifies rate of change of Moment with angle
$\frac{\Delta D}{\Delta \alpha^2}$ signifies rate of change of Drag with square of angle

FIGURE 2

Accordingly the equations of equilibrium are:

(1)
$$\Sigma Z = 0 = -L_{H0}\cos\alpha - D_{H0}\sin\alpha - \left(\frac{\Delta L_H}{\Delta\alpha}\right)\alpha\cos\alpha - \left(\frac{\Delta L_b}{\Delta\alpha}\right)(\alpha+\delta_b)\cos\alpha - \left(\frac{\Delta L_s}{\Delta\alpha}\right)(\alpha+\delta_s)\cos\alpha - \left(\frac{\Delta D_H}{\Delta\alpha^2}\right)\alpha^2\sin\alpha - \left[\left(\frac{\Delta D_b}{\Delta\alpha^2}\right)(\alpha^2+\delta_b^2)+\left(\frac{\Delta D_s}{\Delta\alpha^2}\right)(\alpha^2+\delta_s^2)\right]\sin\alpha - (B-W)\cos\alpha$$

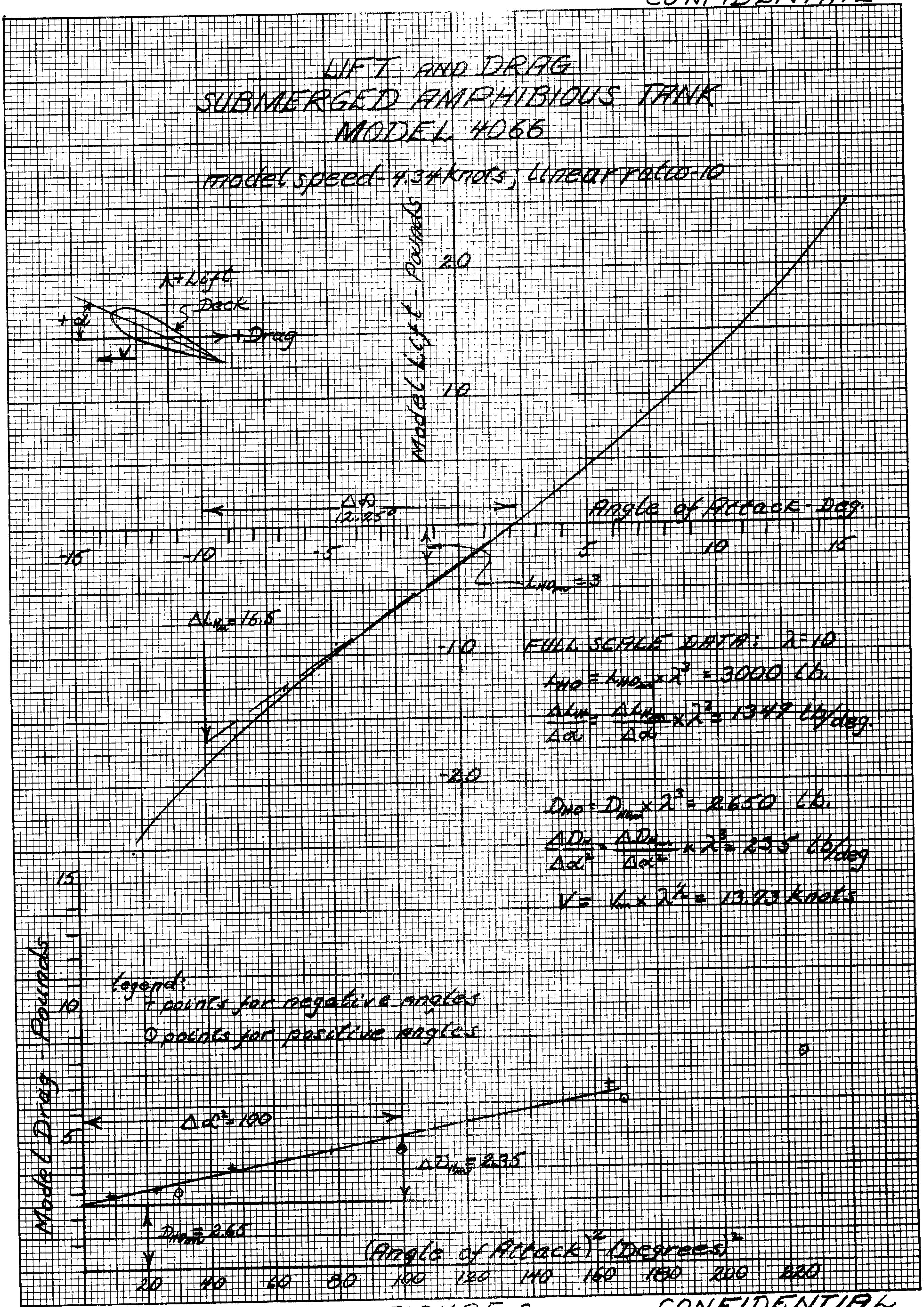
(2)
$$\Sigma X = 0 = -D_{H0}\cos\alpha + L_{H0}\sin\alpha - \left(\frac{\Delta D_H}{\Delta\alpha^2}\right)\alpha^2\cos\alpha - \left[\left(\frac{\Delta D_b}{\Delta\alpha^2}\right)(\alpha^2+\delta_b^2)+\left(\frac{\Delta D_s}{\Delta\alpha^2}\right)(\alpha^2+\delta_s^2)\right]\cos\alpha + \left(\frac{\Delta L_H}{\Delta\alpha}\right)\alpha\sin\alpha + \left[\left(\frac{\Delta L_b}{\Delta\alpha}\right)(\alpha+\delta_b)+\left(\frac{\Delta L_s}{\Delta\alpha}\right)(\alpha+\delta_s)\right]\sin\alpha + T + (B-W)\sin\alpha$$

(3)
$$\Sigma M_{cg} = 0 = M_{H0} + \left(\frac{\Delta M_H}{\Delta\alpha}\right)\alpha + \left[\left(\frac{\Delta L_b}{\Delta\alpha}\right)(\alpha+\delta_b)\cos\alpha + \left(\frac{\Delta D_b}{\Delta\alpha^2}\right)(\alpha^2+\delta_b^2)\sin\alpha\right]x_b - \left[\left(\frac{\Delta L_s}{\Delta\alpha}\right)(\alpha+\delta_s)\cos\alpha + \left(\frac{\Delta D_s}{\Delta\alpha^2}\right)(\alpha^2+\delta_s^2)\right]x_s + B z_{cB}\sin\alpha$$

It will be noted that any solution which satisfies equations 1 and 3 will also be a solution for equation 2 if the term T, is adjusted to suit. The propeller thrust, T, is adjustable up to a certain maximum defined by the available power and the efficiency of the propulsion means. Therefore, it is not necessary to solve all these equations in every case but only when it appears that the available maximum thrust may be exceeded.

Evaluation of the terms defining the hydrodynamic characteristics of the hull in these equations was done by use of data for the deeply submerged condition obtained from tests of Model 4066 on a three component dynamometer. These data together with the values of the hydrodynamic characteristics of the hull are shown on Figures 3 and 4. It will be noted that the assumption of linear relationships between the lift and angle of attack and drag and angle of attack is valid only for small angles.

For the hydrodynamic characteristics of the control surfaces data on a spade-type rudder reported in Reference (1) were used. See Figure 5. Since these data were obtained by tests of a model of the rudder under a simulated hull it was not necessary to correct them for the effect of the hull. It was necessary to correct the rudder data from an aspect ratio of 1 to ½. This was done using the correction factors given in Reference (2), but because the data included the hull effect, factors for correcting from aspect ratio 2 to 1 instead of from 1 to ½ were used. Thus some account was



LIFT AND DRAG
SUBMERGED AMPHIBIOUS TANK
MODEL 4066

model speed - 4.34 knots; linear ratio - 10

FULL SCALE DATA: $\lambda = 10$

$L_{H0} = L_{H0_m} \times \lambda^3 = 3000$ lb.

$\frac{\Delta L_H}{\Delta \alpha} = \frac{\Delta L_{H_m}}{\Delta \alpha} \times \lambda^3 = 1347$ lb/deg.

$D_{H0} = D_{H0_m} \times \lambda^3 = 2650$ lb.

$\frac{\Delta D_H}{\Delta \alpha^2} = \frac{\Delta D_{H_m}}{\Delta \alpha^2} \times \lambda^3 = 235$ lb/deg

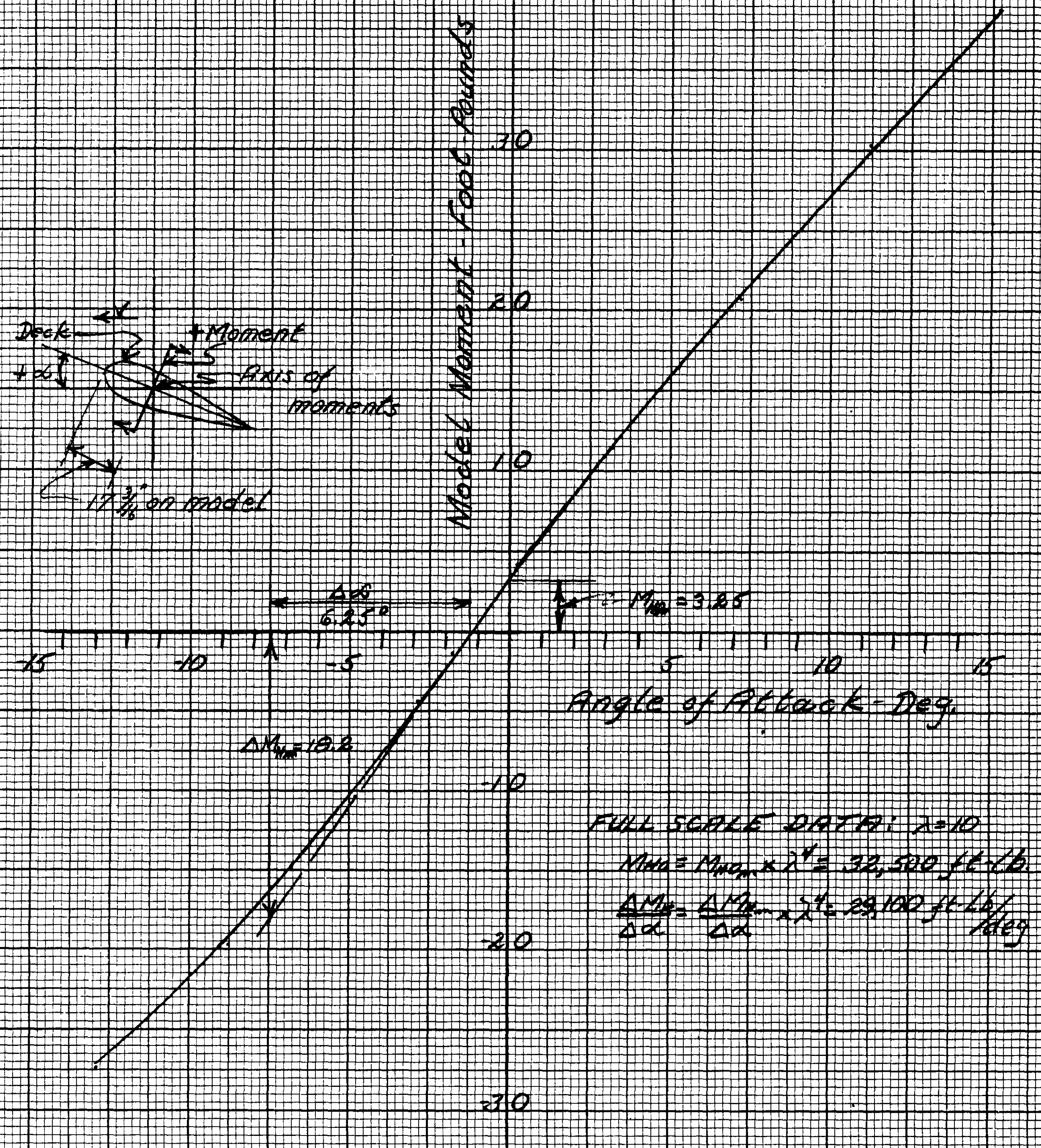
$V = V_m \times \lambda^{1/2} = 13.73$ knots

legend:
+ points for negative angles
⊙ points for positive angles

FIGURE 3

MOMENT
SUBMERGED AMPHIBIOUS TANK
MODEL 4066

model speed - 4.34 knots ; linear ratio - 10



FULL SCALE DATA: $\lambda = 10$

$M_{Ho} = M_{Ho_m} \times \lambda^4 = 32{,}500$ ft-lb.

$\frac{\Delta M_H}{\Delta \alpha} = \frac{\Delta M_{H_m}}{\Delta \alpha} \times \lambda^4 = 29{,}100$ ft-lb/deg

FIGURE 4

LIFT AND DRAG COEFFICIENTS OF SPADE RUDDER

Data for Rudder U from TMB RESTRICTED Report - C-125

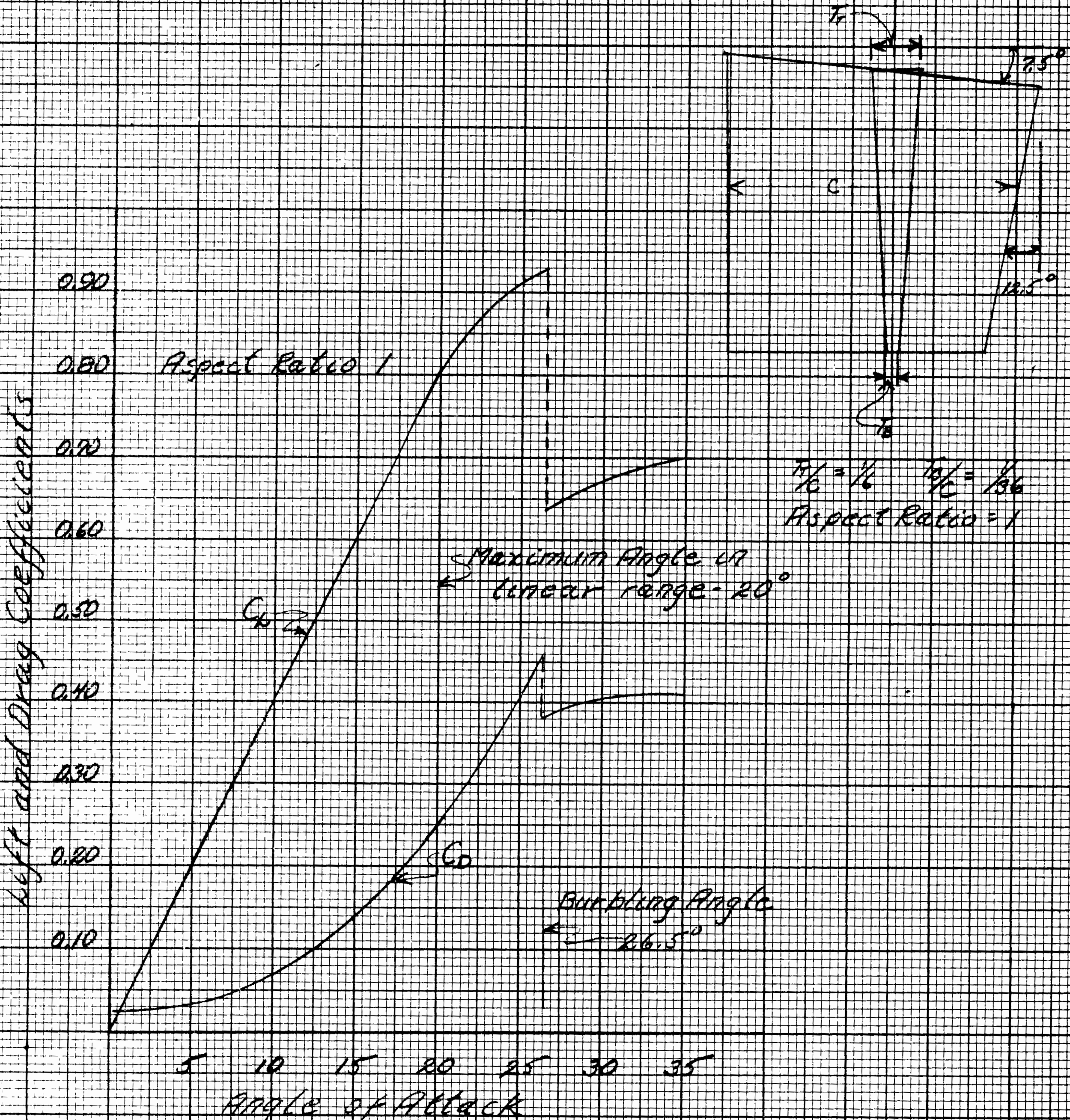


FIGURE 5

taken of the effect of the hull on the control surfaces.

The hydrodynamic characteristics of the control surfaces which were used in the calculations are given in Table 1.

TABLE 1

HYDRODYNAMIC CHARACTERISTICS of CONTROL SURFACES

	Speed 13.7 knots 17" x 34" planes	Speed 15.6 knots 17" x 34" planes	Speed 13.7 knots 20" x 40" planes
Aspect Ratio	½	½	½
Burbling Angle	38.7°	38.7°	38.7°
Maximum Angle In Linear Range	29.2°	29.2°	29.2°
$\frac{\Delta C_L}{\Delta \alpha}$	.0276	.0276	.0276
$\frac{\Delta C_D}{\Delta \alpha^2}$	$.0556 \times 10^{-2}$	$.0556 \times 10^{-2}$	$.0556 \times 10^{-2}$
Area of 2 planes (ft^2)	8.03	8.03	11.15
v ft/sec	23.2	26.3	23.2
$\rho/2\ Av^2$	4190	5410	5820
$\frac{\Delta L_b}{\Delta \alpha}$	115.4	149.3	160.3
$\frac{\Delta D_b}{\Delta \alpha^2}$	2.33	3.06	3.24

For other quantities in the equations the following assumptions were made:

a. That the center of gravity of the hull is located on the chord 14.3 feet aft of the bow.

b. That the distance, x_b, of the axes of the bow planes from the center of gravity is zero.

c. That the distance, x_s, of the axes of the stern planes from the center of gravity is - 14 feet.

d. That the distance, z_{cb}, of the center of buoyancy from the center of gravity is -1.

e. That the bow plane angle, δ_b, in all cases is -30°.

Having these quantities several solutions of the equations were made to determine the attitudes of the hull and of the stern planes for eqilibrium. In these different solutions the combinations of size of control surface and speed indicated in Table 1 were used together with assumed values of the buoyant force (B-W) of 15,000 and 12,500 pounds. These values for the buoyant force were arrived at by considering that since the craft is to carry a 10,000 pound cargo, if it is to be capable of submerging when not carrying cargo and to have positive buoyancy when loaded, then the buoyant force when light, must be in excess of 10,000 pounds.

RESULTS AND CONCLUSIONS

The results of the computations are summarized in Table 2. It appears that a buoyancy of 15,000 pounds is about the maximum that can be kept submerged by control surfaces of reasonable chord meeting the requirement of not protruding beyond the side of the hull more than 17 inches. At 13.7 knots, 17 x 34 inch planes will keep 15,000 pounds submerged, but only with the stern planes at nearly their maximum angle leaving little margin for control. By reducing the buoyancy to 12,500 pounds the margin for control is somewhat improved. The EHP estimates, however, indicate that a submerged speed in excess of the desired 13.7 knots can be reached with the available 750 horsepower. By making use of some of this additional speed, for instance by using a submerged speed of 15.6 knots, the 17 x 34 inch planes can be made to restrain a 15,000 pound buoyancy with a satisfactory control margin.

As previously pointed out the required size of the control surfaces to make the craft dive from the surface will be the largest. How much larger than the 17 x 34 inch planes they will have to be, cannot be predicted, but it can be conjectured that as much as twice the area may be needed. To double the area of the control surfaces while retaining the tentatively specified 17 inch span would require reducing the aspect ratio of the planes to exceedingly inefficient values. It is considered that the lower limit of the aspect ratio should be 1/3, but that planes of this low an aspect ratio should be avoided if possible. If the distance the planes can protrude beyond the hull is increased from 17 to 20 inches, the area of the planes could be doubled over that for the 17 x 34 inch ones without going below an aspect ratio of 1/3. Using a 20 inch span and the same aspect ratio of $\frac{1}{2}$, (20 x 40 inch planes), an increase in area of 38 per cent is obtained. The results of solving the equations of equilibrium using these 20 x 40 inch planes are also tabulated in Table 2.

Table 2

ESTIMATES OF SUBMERGED ATTITUDE OF HULL AND CONTROL SURFACES FOR SUBMERGED AMPHIBIOUS VEHICLE

Speed (Knots)	Span of Control Surfaces (inches)	Chord of Control Surfaces (inches)	Buoyancy (Pounds)	Hull Angle of attack ( ) (Deg)	Bow Plane Angle ( ) (Deg)	Stern Plane Angle ( ) (Deg)	Control Surface Burbling Angle (Deg)	EHP	Available SHP
13.7	17	34	15,000	-3.1	-30	-31.4	38.7	<330	750
13.7	17	34	12,500	-2.4	↓	-21.4	↓	<330	↓
15.6	17	34	15,000	-2.1		-15.6		330	
13.7	20	40	15,000	-2.7		-18.2		270	

RECOMMENDATION

It is therefore suggested that 20 x 40 inch planes be selected as a first approximation to the proper plane size and as a basis for further experimentation.

REFERENCES

(1) Hagen, Grant R. "Rudder Design Data for Hunter Killer Ship (CLK 1) Obtained from Lists on Five Model Rudders" TMB RESTRICTED report C-125 dated June 1948.

(2) Rossell, H. E., Chapman L. B. "Principles of Naval Architecture", Vol. II, page 206, Society of Naval Architects and Marine Engineers, 1939.

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