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RESEARCH MEMORANDUM

AN INVESTIGATION OF THE HYDRODYNAMIC CHARACTERISTICS OF A DYNAMIC MODEL OF A TRANSONIC SEAPLANE DESIGN HAVING A PLANING-TAIL HULL

By Archibald E. Morse, Jr., David R. Woodward, and Ulysse J. Blanchard

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation was made of the hydrodynamic characteristics of a 1/17-size dynamic model of a 160,000-pound transonic seaplane design having a planing-tail hull with the center of gravity located 2.1 beams aft of the step. Longitudinal stability during smooth-water take-off and landing was satisfactory, and the landing behavior in waves was good. These results were similar to that of a previously tested planing-tail-hull model having the center of gravity slightly aft of the step. The thrust from currently available engines was sufficient to accelerate to take-off in 20 seconds in a distance of 2,530 feet (full-size) with a gross load of 160,000 pounds, and in 34 seconds in a distance of 4,320 feet with a gross load of 200,000 pounds. Spray characteristics were very good in smooth water and in waves.

INTRODUCTION

As part of a study of transonic and supersonic configurations for water-based aircraft, a hydrodynamic investigation of a seaplane design with a gross load of 160,000 pounds and a planing-tail hull was made in Langley tank no. 1. This particular design was of interest because its center of gravity was located appreciably behind the step; thus, a bomb door aft of the hull impact areas was provided.

The design used for this investigation was a Bureau of Aeronautics, Department of the Navy seaplane design, which had a shape conforming to the transonic area rule. The wings were swept back and had integral wing-tip floats. The nacelles were located in the wing root and would accommodate four of the currently available engines rated to supply a thrust, with afterburning, of 88,000 pounds. In order to expedite this investigations an existing wing was substituted for the basic design wing.

The investigation included longitudinal stability during take-off and landing in smooth water, resistance in smooth water, landing behavior in waves, and spray characteristics in smooth water and while taxying and landing in waves.

SYMBOLS

b	maximum beam of hull at chine, ft
C_{Δ_o}	gross load coefficient, Δ_o/wb^3
$\bar{c}$	mean aerodynamic chord, ft
R	total resistance (water plus air), lb
V_h	total horizontal velocity (carriage speed plus speed along fore-and-aft gear), knots
V_v	vertical velocity, ft/min
w	specific weight of water (63.4 for tank water; usually taken as 64 for sea water), lb/cu ft
γ	flight path angle, deg
δ_f	flap deflection, deg
δ_s	stabilizer deflection, deg
Δ_o	gross load, lb
τ_L	landing trim (trim is angle between forebody keel at step and horizontal), deg

DESCRIPTION OF MODEL

Photographs of the model and lines of the hull are shown in figures 1 and 2, respectively. The general arrangement of the model is shown in figure 3. Offsets of the hull are given in table I and pertinent dimensions and characteristics of the hull and tail are given in table II.

The total cross-sectional-area curve, preliminary hull stations, and general arrangement of the design were supplied by the Bureau of Aeronautics, Department of the Navy. The area curve was developed for a Mach number of 1 and is presented in figure 4. The equivalent-body fineness ratio for this design is 12.2.

The hull stations were faired in detail and a 1/17-size dynamic model hull and tail were constructed at the Langley Aeronautical Laboratory. The hull was a high length-beam ratio planing-tail hull with a gross load coefficient C_{Δ_0} of 7.4. The center of gravity was located 2.1 beams aft of the step.

The horizontal and vertical tails were similar to those of the transonic seaplane models described in reference 1, but the area and span conformed to those of the proposed design.

In order to expedite model procurement an existing wing was adapted to fit the newly constructed hull. The wing loading resulting from using this wing, and the design gross load of 160,000 pounds was 86 pounds per square foot as compared to the basic design wing loading of 89 pounds per square foot. The wing incidence was set at 6° to give the desired take-off speed. The tip floats were installed so that their afterbody keels were parallel to and touching the water surface with the hull at the static-load water line. This wing did not have the same station areas as shown in figure 4 but was considered suitable for the hydrodynamic investigation. The test model was designated Langley tank Model 325.

APPARATUS

The investigation was made in the Langley tank no. 1. A general description of the tank and its wave-making equipment are described in references 2 and 3. A photograph of the model and the towing apparatus is shown in figure 5. The model was free to trim about its center of gravity (24-percent mean aerodynamic chord) and free to move vertically, but was restrained laterally and in roll and yaw. During landing and taxying in waves, approximately 5 feet of fore-and-aft freedom, with respect to the towing carriage, was available to permit the model to act as a longitudinally free body. While the model was taxying in waves, a long rubber band with a spring constant of 1.5 pounds per foot approximated the horizontal component of thrust as the model traveled along the fore-and-aft gear.

Smooth-water resistance was measured by using the optical dynamometer as described in reference 2. Slide-wire pickups (fig. 5) were used to measure trim, rise of the center of gravity, and position along the fore-and-aft gear. These measurements were recorded on a multichanneled oscillograph recorder.

During landing tests, an electrically operated trim brake was used to hold the model at the desired trim in the air. This brake was automatically released when either of the contacts located along the hull at the sternpost and step touched the water. Wetting of these contacts was also recorded, and the records showed which portions of the hull were submerged at any time during the investigation.

PROCEDURES

All data were obtained with the model unpowered and with the center of gravity located at 24 percent of the mean aerodynamic chord. The majority of the tests were made at a design gross load of 160,000 pounds but some tests were made at an overload condition of 200,000 pounds. A ratio of 2° of elevator for each degree of stabilizer was used during these tests until the full-down condition, when the elevator linkage would not permit sufficient deflection for this ratio to hold.

Trim limits of stability.- The trim limits of stability were determined at constant speeds by the use of methods described in reference 4. Visual observations and recorded data defining the trim limits were obtained.

Smooth-water take-offs.- The longitudinal stability during smooth-water take-offs for several stabilizer settings was determined by making accelerated runs up to take-off speed with a rate of acceleration of 4 ft/sec. If the model trim became less than approximately 2° at high speeds the run was discontinued.

Landing in smooth water and in waves.- In order to determine the landing characteristics of the model in smooth water and in waves, the model was fixed at the desired landing trim with the trim brake. The towing carriage was accelerated to a speed slightly above model flying speed and then decelerated at a uniform rate to allow the model to glide onto the water and simulate an actual landing. The aerodynamic control surfaces were preset to trim the model at the desired trim. Upon contact with the water surface the trim brake automatically released and the model was free to trim during the landing runout.

In smooth water the model was restrained from traveling along the fore-and-aft gear, and the rate of deceleration of the towing carriage was from 6.2 to 7.5 ft/sec^2. During landings in waves the model was free to move within the limits of the fore-and-aft gear, and the rate of deceleration was selected for each landing to maintain longitudinal freedom of the model. The rate of deceleration in waves varied from 5.6 to 8.5 ft/sec^2.

Resistance in smooth water.- The free-to-trim resistance of the complete model in smooth water was determined for a range of constant speeds. A sufficient number of stabilizer deflections was investigated to obtain the minimum resistance for stable trims at each speed.

Spray characteristics in smooth water and in waves.- Visual observations and photographs were used to study spray. The smooth-water spray characteristics were determined with the model free to trim at a series of constant speeds up to take-off. Spray characteristics in waves were determined during landings and during taxying runs. For the taxying runs the long-rubber-band arrangement was used to approximate the horizontal component of thrust and the towing-carriage was accelerated at the rate of 2 ft/sec^2.

RESULTS AND DISCUSSION

All model test results have been converted to values corresponding to the full-size seaplane.

Trim limits of stability.- The trim limits of stability are presented in figure 6. No lower trim limit was found with the available trimming moment. An upper trim limit of stability was found at speeds above approximately 106 knots, but the porpoising motions were not violent. Application of full-down stabilizer (bow-up pitching moment) often reduced the amplitude of the porpoising motions. Apparently the increase in wetted area with increase in trim provided the damping necessary for reducing the porpoising. This same behavior was noted for a previously tested planing-tail model with the center of gravity located slightly aft of the step. The trim at which a recovery from upper-limit porpoising was possible could not be determined. Apparently the water striking the afterbody created a suction force and a large bow-down pitching moment had to be applied to decrease the trim below the upper limit. Recovery was accompanied by a sharp decrease in trim.

Smooth-water take-off.- The variation of trim with speed during take-offs in smooth water is presented in figure 7(a) for a gross load of 160,000 pounds. No porpoising occurred with a stabilizer deflection of 0°, and only negligible porpoising occurred with a stabilizer deflection of -2.5°. However, because of the low trim at high speed with these deflections, it appeared that an increase to a stabilizer deflection of at least -5° at a speed of 115 knots would be necessary to permit take-off. The model took off at stabilizer deflections of -5°, -7.5°, and -10° but porpoising occurred with each deflection. The maximum amplitude of porpoising did not exceed 3° and occurred with a stabilizer deflection of -7.5°. A stable take-off was made with a stabilizer deflection of -15° (maximum bow-up pitching moment).

Figure 7(b) presents the variation of trim with speed at a gross load corresponding to 200,000 pounds. Only one stabilizer setting ($\delta_s = -4^\circ$) was investigated. The increase in load increased both the trim and speed at which upper-limit porpoising occurred, but the porpoising motions remained small.

Smooth-water landing.- Figure 8 presents typical oscillograph records showing trim, rise, and speed during landings in smooth water at a gross load of 160,000 pounds. With the center of gravity located aft of the step, landings at trims below the sternpost angle (7.25°) resulted in a sharp increase in trim subsequent to the initial contact. (See fig. 8(a).) Also, landings at trims above the sternpost angle resulted in a sharp decrease in trim subsequent to the initial contact. (See fig. 8(b).) Several oscillations in trim then occurred but these were quickly damped. The maximum variations in trim and rise are presented in figure 9. Trim at initial contact appeared to have no significant effect on the amplitude of the trim and rise cycles. One landing at 13° and a gross load of 200,000 pounds showed landing behavior similar to that at a gross load of 160,000 pounds.

Landing in waves.- Pertinent data for landings made in oncoming waves approximately 4 feet and 8 feet high and 255, 340, and 440 feet long are given in table III. The initial landing trim was generally about $9\frac{1}{2}^\circ$. In general, the landing behavior in waves was good. The landing motions encountered are shown in figure 10 by typical records of landings in waves 4 and 8 feet high, respectively, and 340 feet long.

Resistance in smooth water.- Free-to-trim total resistance and trim in smooth water are plotted against speed in figure 11(a). Minimum resistance and trim for minimum resistance are represented by the solid lines. The resistance increased rapidly up to approximately 45 knots. At 35 knots the afterbody sides and the deck were heavily wetted. At speeds above 45 knots, when the flow broke away from the afterbody, it did so unsymmetrically and caused a mild yawing tendency. When the flow was completely detached, there was an immediate decrease in resistance and trim and the yawing tendency disappeared.

At speeds subsequent to the clearing of the afterbody there was no pronounced hump in the resistance curve. At high speeds the model tended to porpoise at trims above the sternpost angle.

At approximately 115 knots with small stabilizer setting, the model trimmed down rapidly to approximately 7° and there was a corresponding decrease in resistance. This change in trim and resistance was accompanied by a sudden clearing of the forebody spray from the afterbody bottom.

The total load-resistance ratio at hump speed at a gross load of 160,000 pounds was 4.7. Take-off time was calculated from the total-resistance curve to be 20 seconds in a distance of 2,530 feet.

Data obtained during an abbreviated smooth-water resistance test at a gross load of 200,000 pounds are presented in figure 11(b). In general, the shapes of these curves are similar to those obtained at the lighter load. The total load-resistance ratio was 4 and the take-off time was calculated to be 34 seconds in a distance of 4,320 feet.

Spray characteristics in smooth water and in waves.- Photographs of the model at various speeds throughout the take-off range, which show spray on the forebody and afterbody, are presented in figure 12. Speeds, trim, and stabilizer settings are the same as for the resistance points shown in figure 11(a). The jet inlets were clear of spray at all speeds. The afterbody deck was wetted at a speed of from 35 to 40 knots. The horizontal tail received only light spray during all the smooth-water tests.

During landings and taxying in waves the jet inlets were free of spray except during landings in the 8 foot high and 255 foot long waves. This short, high wave caused the model to nose under, and light spray entered the inlets. The tail was clear of heavy spray at all times.

CONCLUDING REMARKS

Tank tests of a 1/17-size dynamic model of a transonic seaplane design having a planing-tail hull with the center of gravity located 2.1 beams aft of the step indicate that the longitudinal stability during smooth-water take-off and landing was satisfactory. Trim oscillations were evident during all smooth-water landings but were quickly damped. Landing trim had little effect on the amplitude of the trim and rise cycles. Landing behavior in waves was good.

Longitudinal stability and rough-water behavior compared favorably with that of a previously tested planing-tail-hull model having the center of gravity only slightly aft of the step.

The gross load-resistance ratio at hump speed was 4.7. Take-off time was calculated to be 20 seconds in a distance of 2,530 feet for a gross load of 160,000 pounds, and 34 seconds in a distance of 4,320 feet for a gross load of 200,000 pounds.

The spray characteristics were very good. The jet inlets were clear of spray at all times except during the landing runout in the 8 foot high and 255 foot long waves. The tail was clear of heavy spray during all tests.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 23, 1956.

REFERENCES

1. Olson, Roland E., and Bielat, Ralph P.: An Aerodynamic and Hydrodynamic Investigation of Two Multijet Water-Based Aircraft Having Low Transonic Drag Rise. NACA RM L55A11a, 1955.

2. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM 918, 1939.

3. Parkinson, John B.: NACA Model Investigations of Seaplanes in Waves. NACA TN 3419, 1955.

4. Olson, Roland E., and Land, Norman S.: Methods Used in the NACA Tank for the Investigation of the Longitudinal-Stability Characteristics of Models of Flying Boats. NACA Rep. 753, 1943. (Supersedes NACA WR L-409.)

TABLE I.- HULL OFFSETS FOR LANGLEY TANK MODEL 325

[All dimensions are in inches. Distance between all buttock and all water lines, 0.882 inch]

Station	Distance to FP	Height above baseline										
		Keel	Chine	Cove	Hull at Cl	Buttock 1		Buttock 2		Buttock 3		
						Upper	Lower	Upper	Lower	Upper	Lower	
FP	0	4.78			4.78							
1	3.53	3.88			5.41							
2	7.06	2.95			6.04	3.90	5.33					
3	10.59	2.03	3.58		6.66	3.04	6.18					
4	14.12	1.20	3.18		7.26	2.19	6.86	3.11	5.28			
5	17.65	.54	2.81		8.75	1.50	7.46	2.47	6.35			
6	21.18	.31	2.44		9.55	1.04	8.08	1.94	7.27			
7	24.71	0	2.10		9.75	.77	8.74	1.54	8.17	3.85	6.42	
8	28.24		1.84	3.92	9.69	.67	9.37	1.32	8.93	3.95	7.75	
9	31.76		1.57	3.51	9.82	.67	9.66	1.32	9.26	3.88	8.33	
10	35.29		1.20	3.16	10.04	.67	9.90	1.18	9.45	4.02	8.51	
11	38.82		.72	2.97	10.61	.64	10.40	3.21	9.79	4.29	8.61	
12	47.35		0	2.86	11.10	2.98	10.85	3.44	10.13	4.57	8.68	
13	45.88	3.10			10.96	3.19	10.68	3.65	9.96	4.80	8.68	
14	49.41	3.34			10.61	3.45	10.36	3.91	9.72	5.01	8.59	
15	52.94	3.58			10.23	3.71	10.08	4.16	9.60	5.19	8.65	
16	56.47	3.82			10.06	4.01	9.97	4.48	9.64	5.36	8.77	
17	60.00	4.06	5.20		10.13	4.32	10.02	4.78	9.72	5.53	8.96	
18	63.53	4.30	5.34		10.24	4.64	10.13	5.10	9.83	5.70	9.07	
19	67.06	4.54	5.47		10.62	4.94	10.46	5.34	10.01	5.93	9.19	
20	70.59	4.78	5.61		11.38	5.21	11.21	5.53	10.68	6.37	9.37	
21	74.12	5.02	5.74		12.07	5.44	11.84	5.71	11.08	7.54	9.11	
22	77.65	5.26	5.87		12.48	5.63	12.10	5.86	11.06			
23	81.18	5.50	6.01		12.62	5.83	12.14	6.01	10.50			
24	84.71	5.74	6.14		12.40	6.04	11.81					
25	88.24	5.98	6.28		12.04	6.76	10.85					
AP	91.76	6.22	6.42		11.65							
27	95.29	10.11			11.19							

Station	Half-breadths														
	Chine	WL 1	WL 2	WL 3	WL 4	WL 5	WL 6	WL 7	WL 8	WL 9	WL 10	WL 11	WL 12	WL 13	WL 14
FP															
1						0.83	0.35								
2					0.49	1.24	.92								
3	1.55			0.53	1.45	1.58	1.34	0.90							
4	1.98		0.51	1.29	1.98	1.92	1.76	1.38	0.65						
5	2.26	0.32	1.11	1.94	2.29	2.28	2.14	1.84	1.29						
6	2.49	.72	1.57	2.51	2.56	2.57	2.51	2.29	1.91	1.13					
7	2.63	1.02	2.01	2.63	2.63	2.74	2.79	2.70	2.46	1.98	0.60				
8	2.63	1.16	2.35	2.63	2.63	2.81	2.98	3.02	2.89	2.54	1.89				
9	2.47	1.16	2.47	2.49	2.50	2.84	3.09	3.17	3.10	2.84	2.26	0.79			
10	2.03	1.16	2.03	2.03	2.34	2.82	3.07	3.19	3.14	2.93	2.45	1.38			
11	1.22	1.22	1.21	1.22	2.14	2.71	3.00	3.12	3.09	2.89	2.54	1.85	0.30		
12	0				1.88	2.58	2.89	3.04	3.03	2.88	2.59	2.10	1.31		
13					1.59	2.44	2.82	3.00	3.04	2.93	2.58	2.01	1.02		
14					1.11	2.28	2.77	3.01	3.07	2.95	2.51	1.78	.21		
15						2.06	2.70	3.02	3.11	2.96	2.53	1.64			
16						1.69	2.61	3.02	3.15	3.00	2.63	1.66			
17	2.40					1.11	2.51	2.98	3.15	3.09	2.74	1.82			
18	2.40					.37	2.17	2.91	3.19	3.18	2.84	1.99			
19	2.38						1.62	2.79	3.07	3.14	2.89	2.19	.35		
20	2.33						1.06	2.59	2.86	2.96	2.84	2.52	1.86		
21	2.24						.55	2.37	2.58	2.70	2.69	2.52	2.12	1.42	
22	2.09						.04	2.15	2.28	2.36	2.40	2.33	2.06	1.47	0.51
23	1.90							1.91	1.96	2.00	2.03	1.98	1.74	1.32	.69
24	1.59							1.57	1.61	1.60	1.59	1.51	1.36	1.07	.28
25	1.08							.48	1.09	1.09	1.08	1.02	.94	.73	
AP	.11								.29	.42	.49	.51	.50	.34	
27													.07		

TABLE II.- PERTINENT DIMENSIONS AND CHARACTERISTICS OF HULL AND TAIL OF LANGLEY TANK MODEL 325

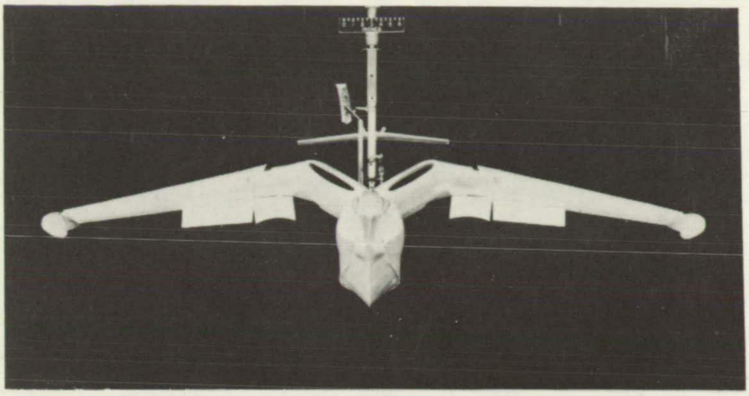
Hull:	
Maximum beam, ft	0.44
Length:	
Forebody (bow to step), ft	3.53
Afterbody (step to station 26), ft	4.12
Forebody length-beam ratio	8.6
Afterbody length-beam ratio	10
Step:	
Type	Pointed
Depth at keel, ft	0.28
Depth at keel, percent beam	58
Afterbody keel angle, deg	3.75
Sternpost angle, deg	7.25
Center of gravity ($0.24\bar{c}$) above baseline, ft	0.72
Horizontal tail:	
Span, ft	1.95
Airfoil section	NACA 65A006
Area, sq ft	1.28
Sweepback ($0.25\bar{c}$), deg	45
Dihedral, deg	0
Height above baseline, ft	1.84
Vertical tail:	
Airfoil section	NACA 65A008
Area, sq ft	0.87
Sweepback ($0.25\bar{c}$), deg	48
Bullet fairing	NACA 64A012

TABLE III.- DATA OBTAINED DURING LANDINGS IN WAVES

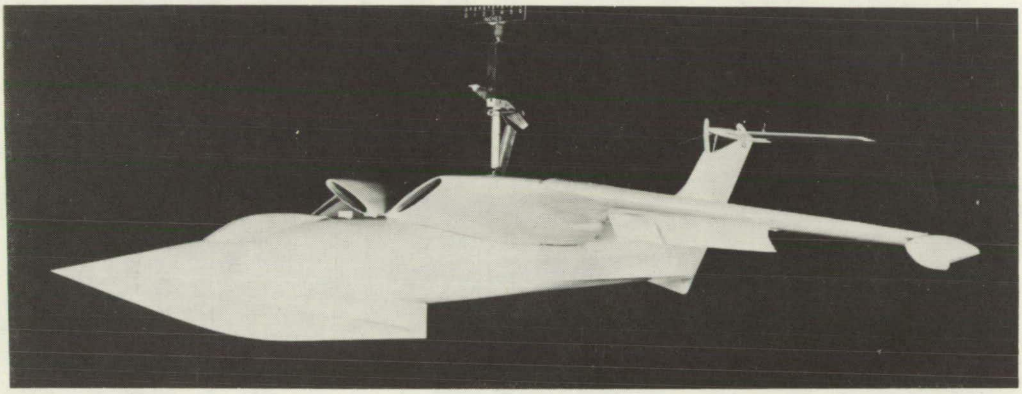
FOR LANGLEY TANK MODEL 325

[All values are full-size]

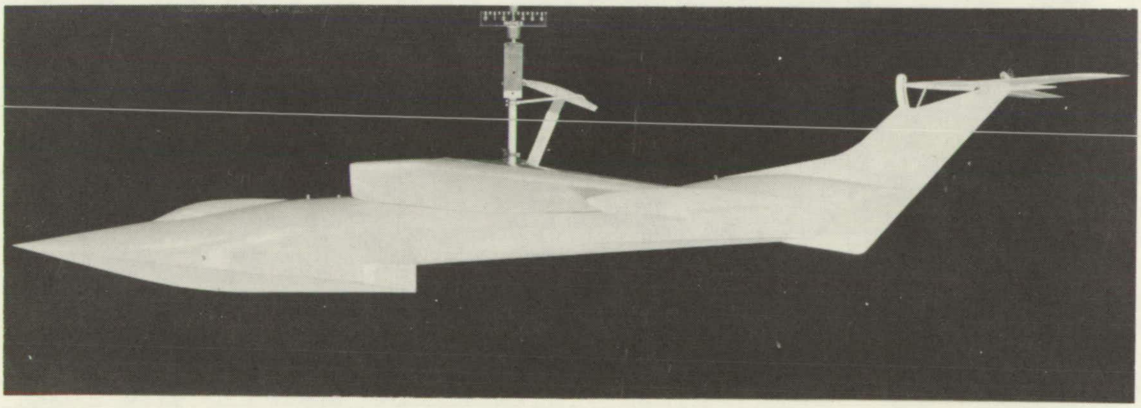
Landing	Wave height, ft	Wave length, ft	At initial impact				Maximum trim	Minimum trim	Maximum rise	Minimum rise
			τ_L, deg	V_v, ft/min	V_h, knots	γ, deg				
1	4	250	9.4	349	121.2	1.62	15.8	4.4	6.6	-7.1
2	↓	↓	7.4	326	126.4	1.45	16.3	5.4	9.2	-6.8
3	↓	↓	9.4	428	119.3	2.02	15.4	3.9	9.5	-6.4
4	↓	340	9.4	371	123.2	1.70	13.0	2.5	-2.4	-7.2
5	↓	↓	9.4	344	123.0	1.57	14.8	2.4	3.0	-6.4
6	↓	↓	9.4	354	123.7	1.64	14.4	2.3	6.8	-5.8
7	↓	440	9.5	462	120.8	2.15	13.6	1.1	5.4	-7.7
8	↓	↓	9.5	433	122.5	2.00	13.3	3.5	1.6	-6.4
9	↓	↓	9.4	396	121.8	1.83	13.3	2.9	3.0	-6.2
10	8	250	9.4	383	123.9	1.74	13.4	2.7	1.6	-7.6
11	↓	↓	9.4	368	122.0	1.70	15.4	.3	6.8	-7.1
12	↓	↓	9.4	368	122.5	1.70	14.9	-.1	12.6	-5.1
13	↓	340	9.4	284	121.2	1.32	17.1	2.4	20.8	-9.2
14	↓	↓	9.4	393	119.1	1.87	14.9	2.2	7.9	-10.6
15	↓	↓	9.4	386	125.1	1.74	15.9	.5	11.9	-10.2
16	↓	440	7.5	319	126.6	1.43	15.3	3.8	17.7	-3.3
17	↓	↓	9.4	386	111.3	1.95	15.4	.4	17.1	-8.1
18	↓	↓	9.4	458	119.6	1.15	15.8	1.1	10.5	-10.1



(a) Front view.



(b) Three-quarter front view.



(c) Side view. L-92452

Figure 1.- Langley tank model 325.

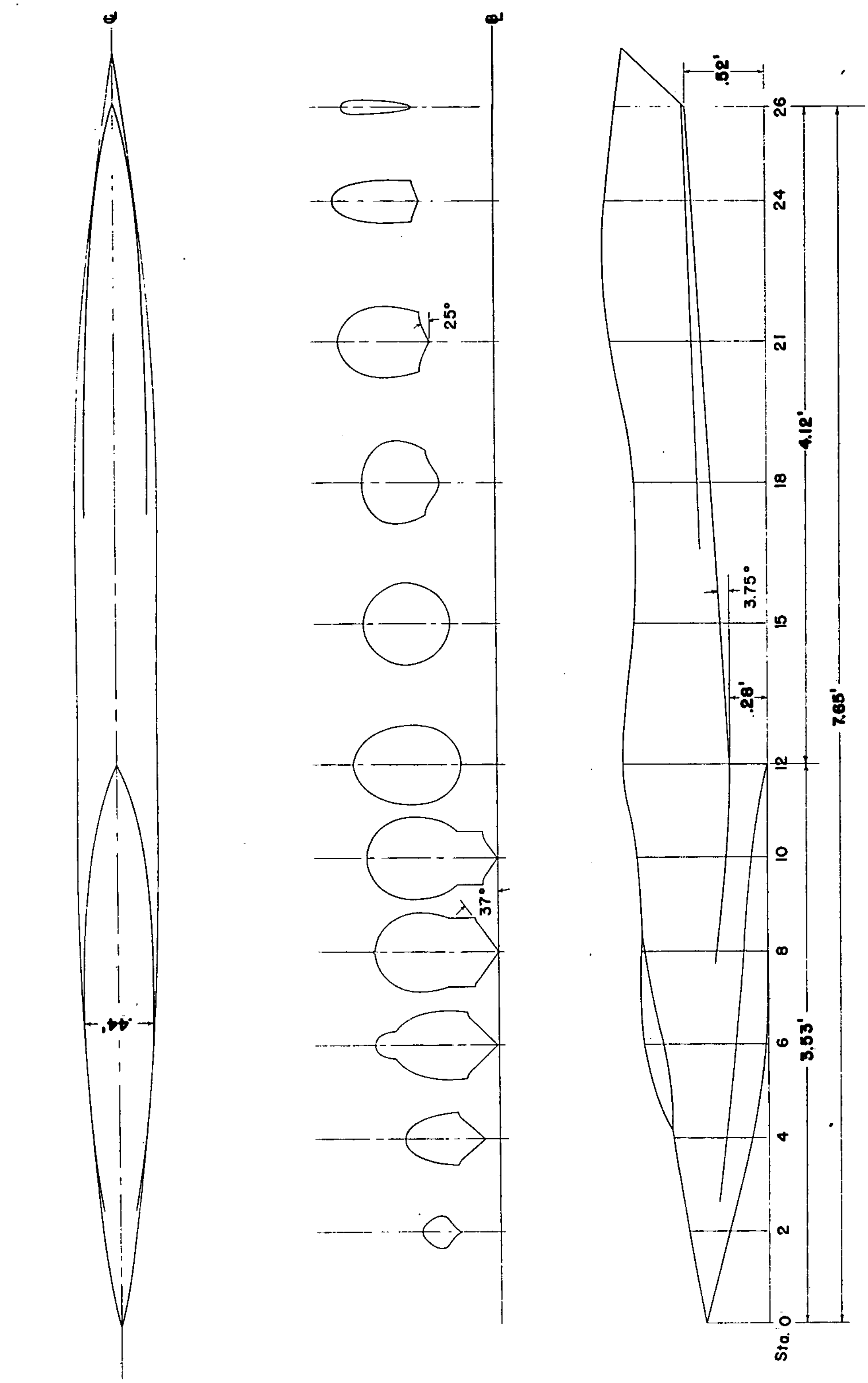


Figure 2.- Hull lines for Langley tank model 325.

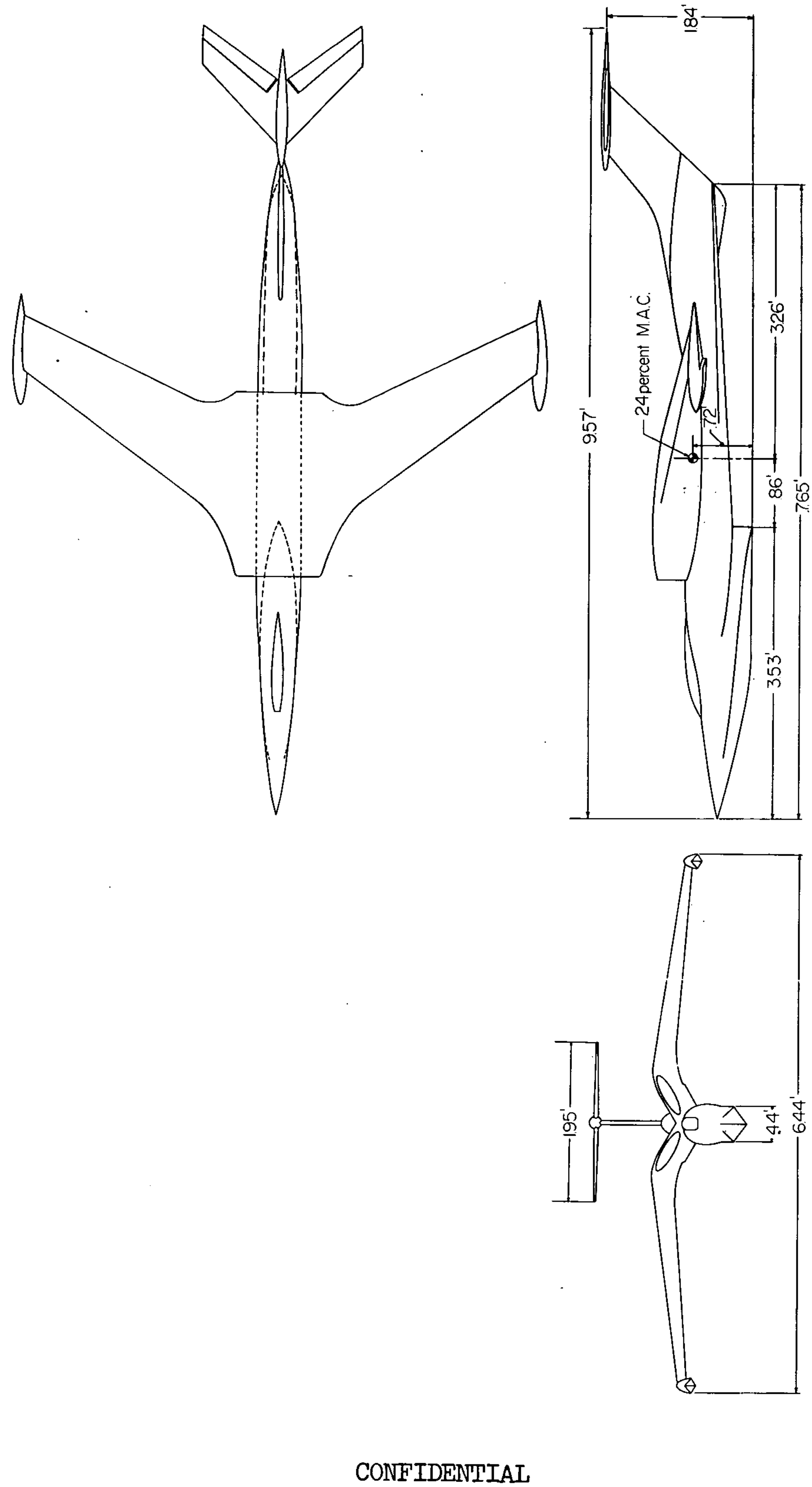


Figure 3.- General arrangement of Langley tank model 325.

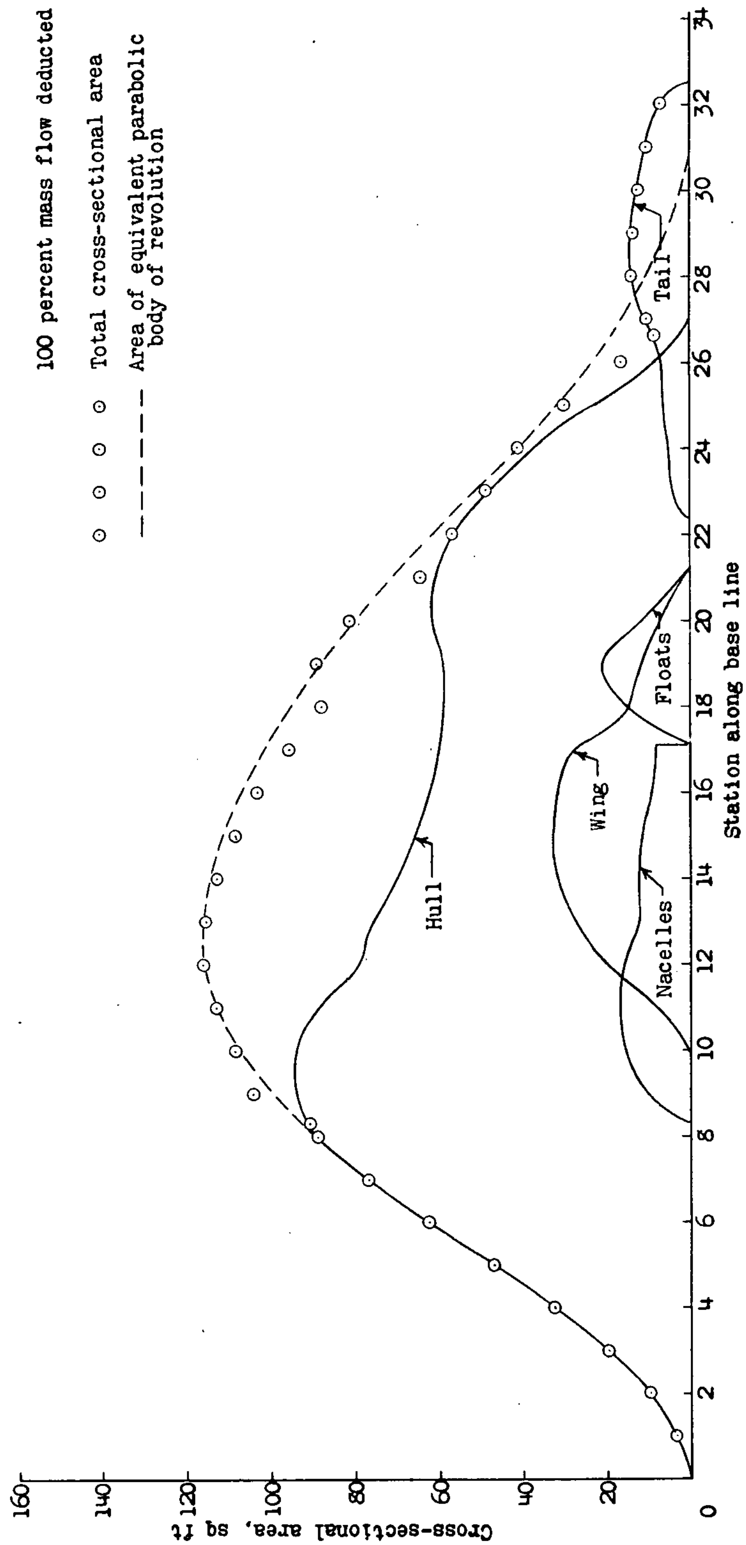


Figure 4.- Cross-sectional-area curve for basic design.

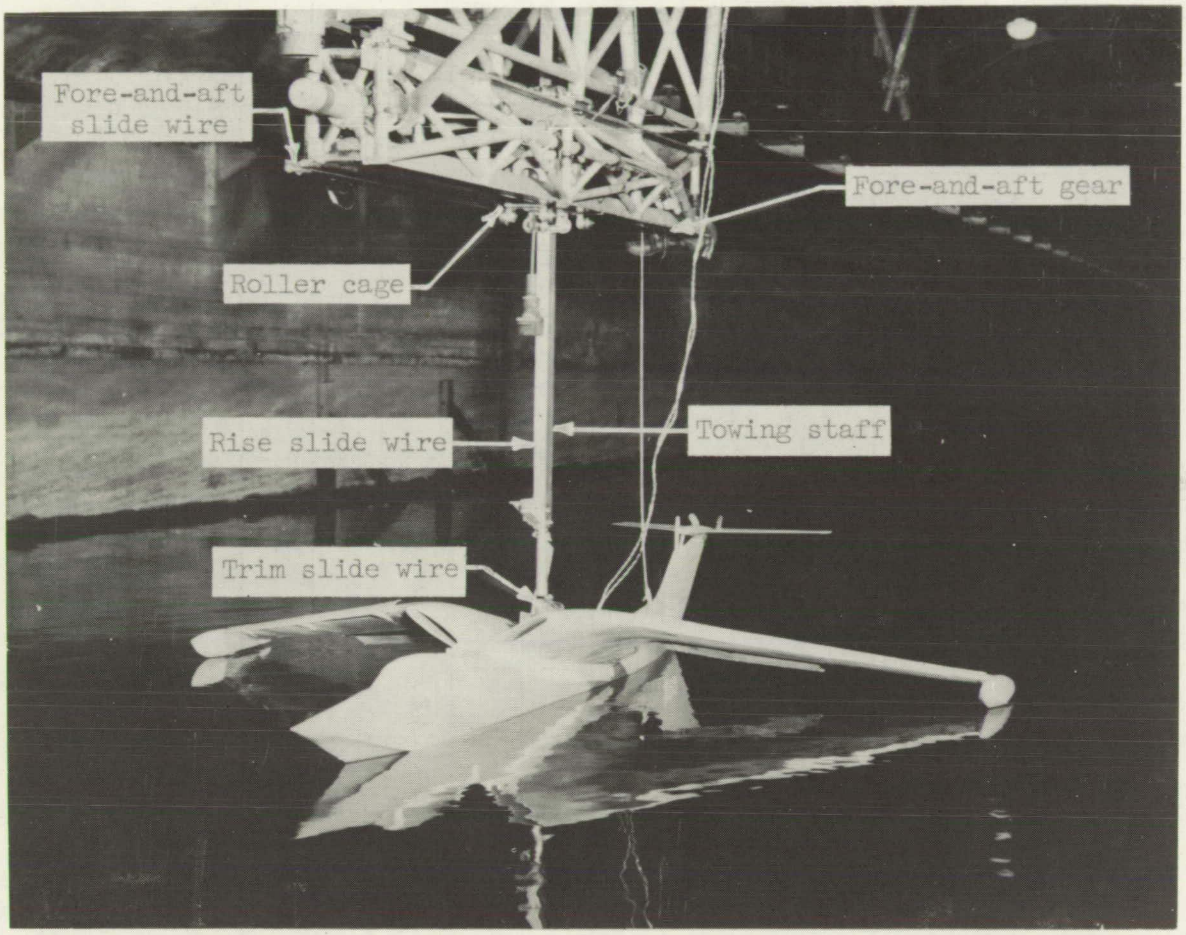


Figure 5.- Photograph of model on towing apparatus. L-92453

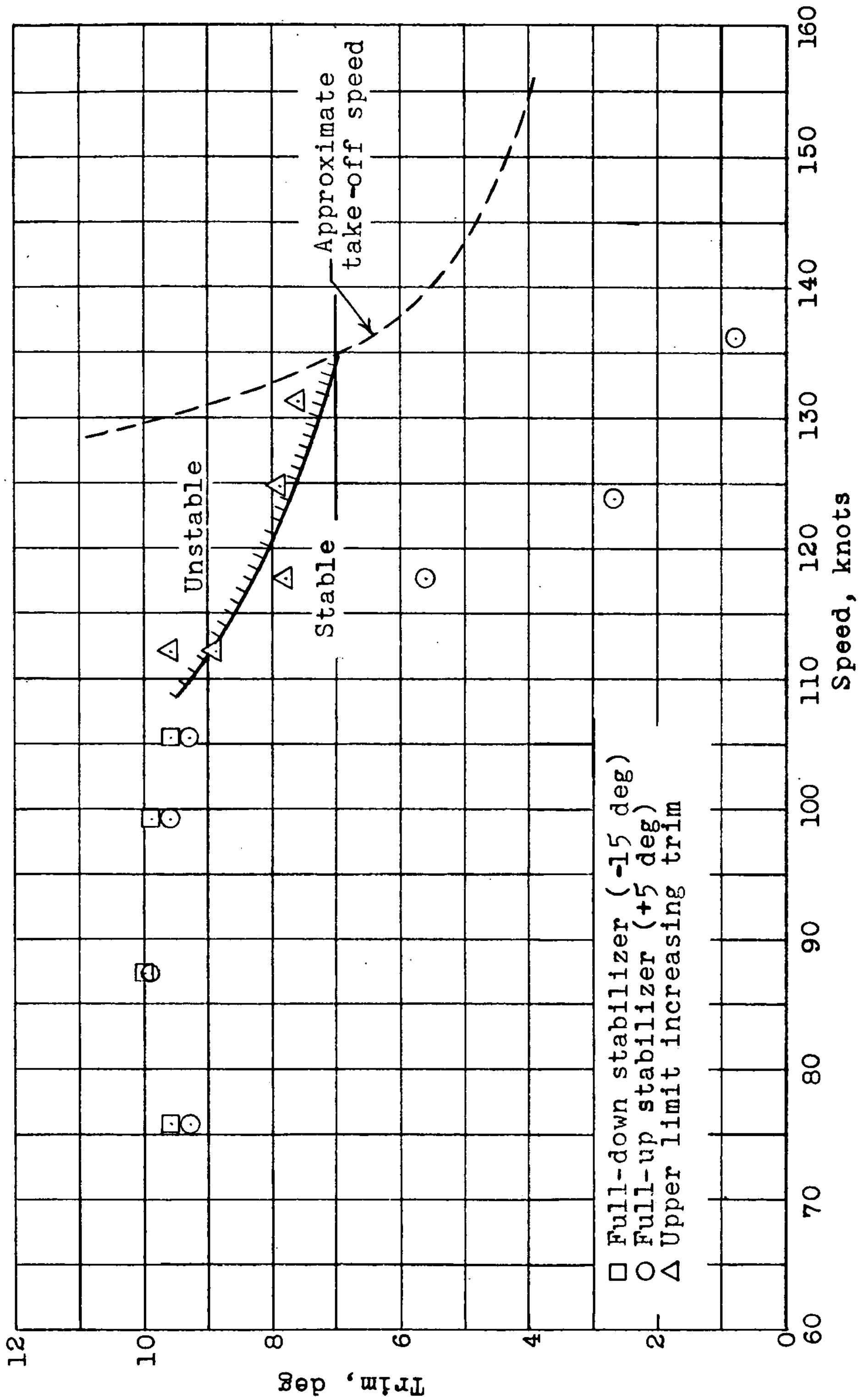
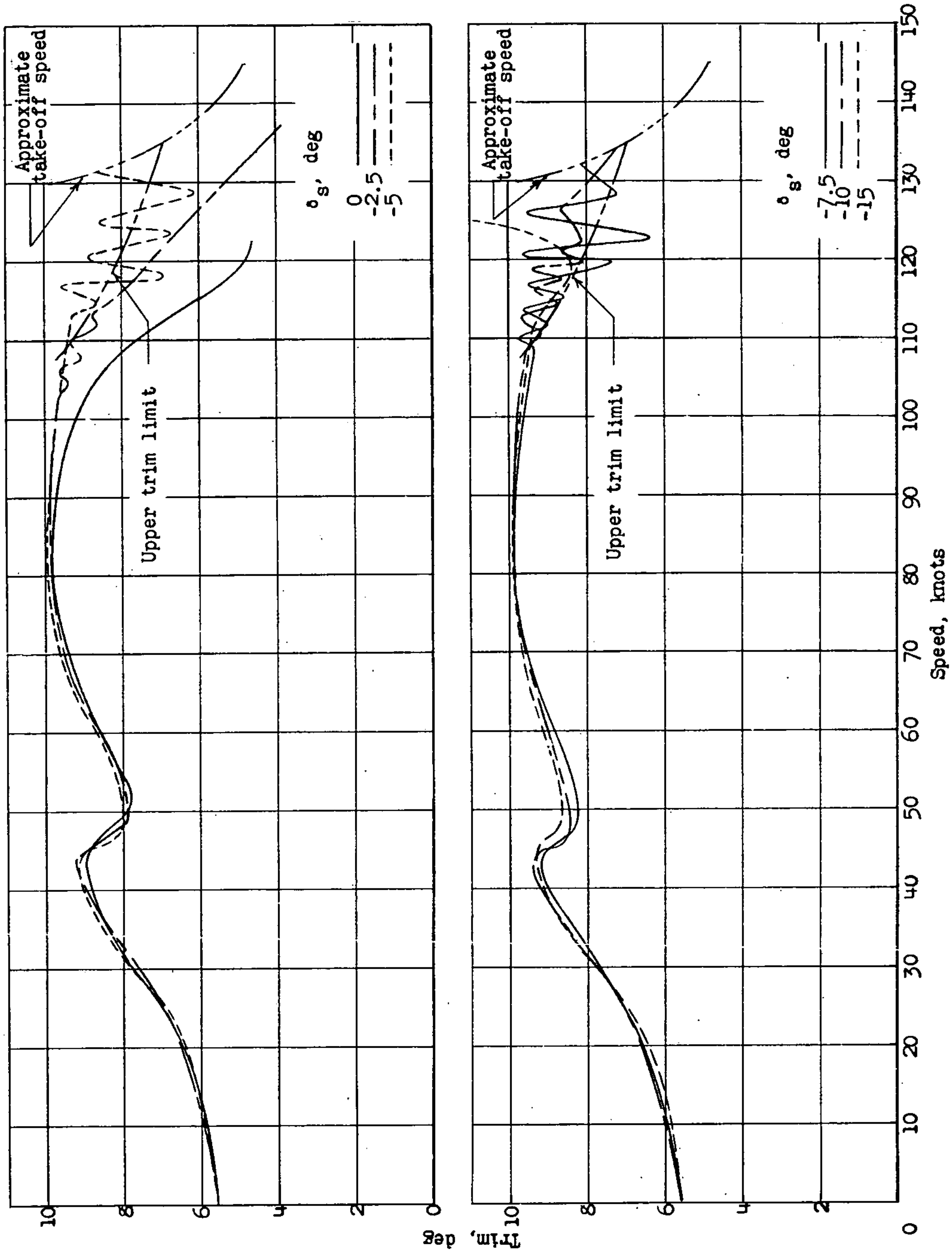
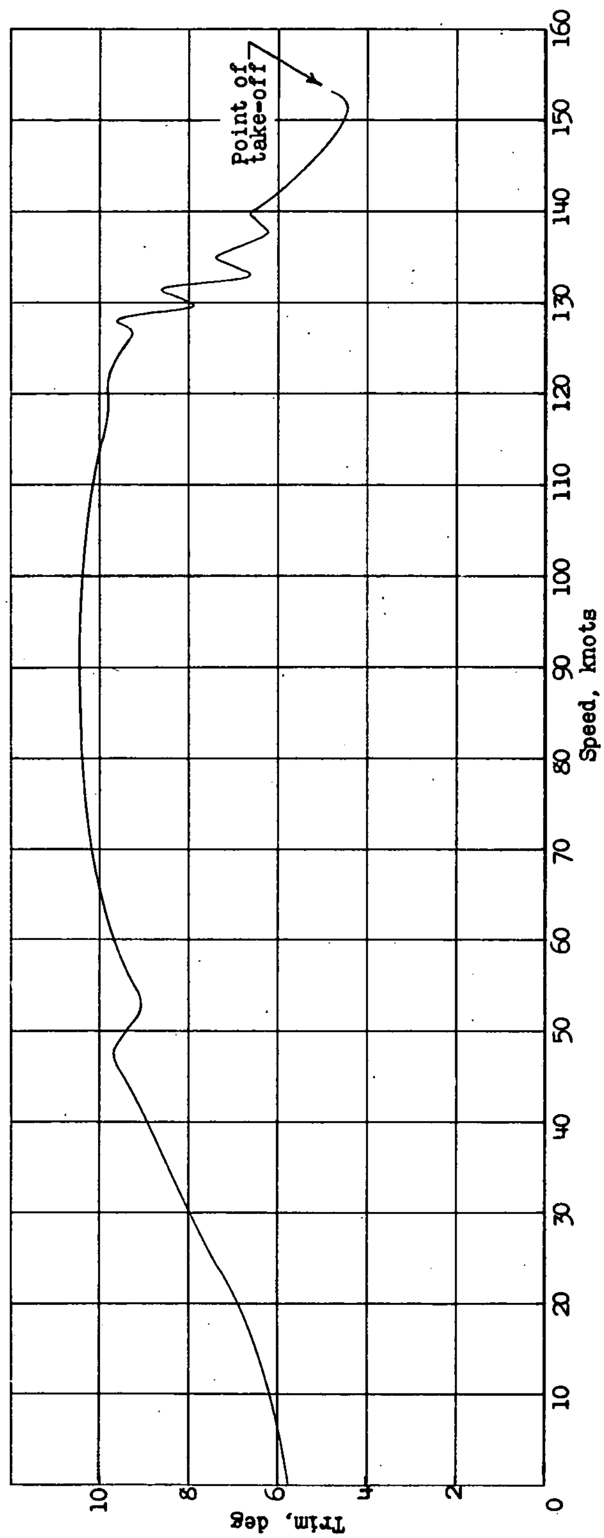


Figure 6.- Trim limits of stability. Δ_0 = 160,000 pounds; $\delta_f = 20^{\circ}$.



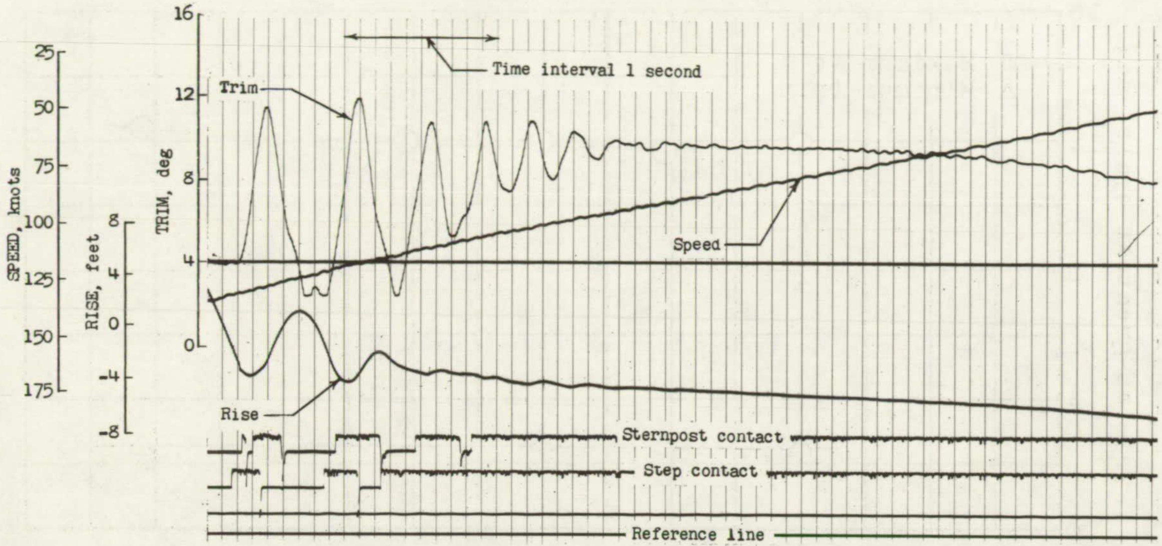
(a) Δ_o = 160,000 pounds; δ_f = 20°.

Figure 7.- Variation of trim with speed during take-offs.

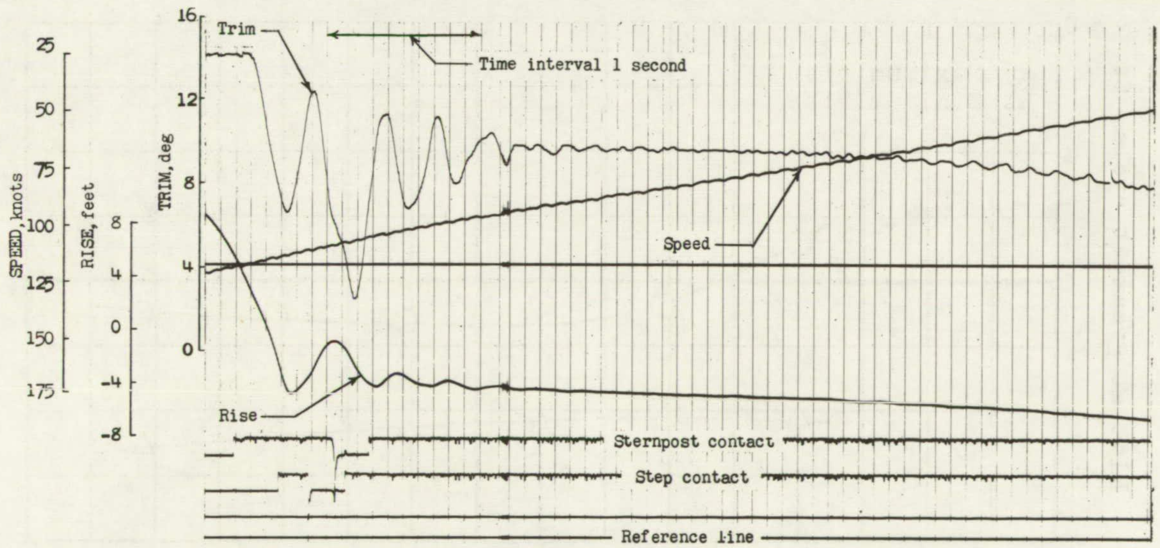


(b) Δ_o = 200,000 pounds; $\delta_f = 50^\circ$; $\delta_s = -4^\circ$.

Figure 7.- Concluded.



(a) Landing trim, 4°.



(b) Landing trim, 14°.

Figure 8.- Typical oscillograph records of landings in smooth water. Δ_o = 160,000 pounds; δ_f = 50°.

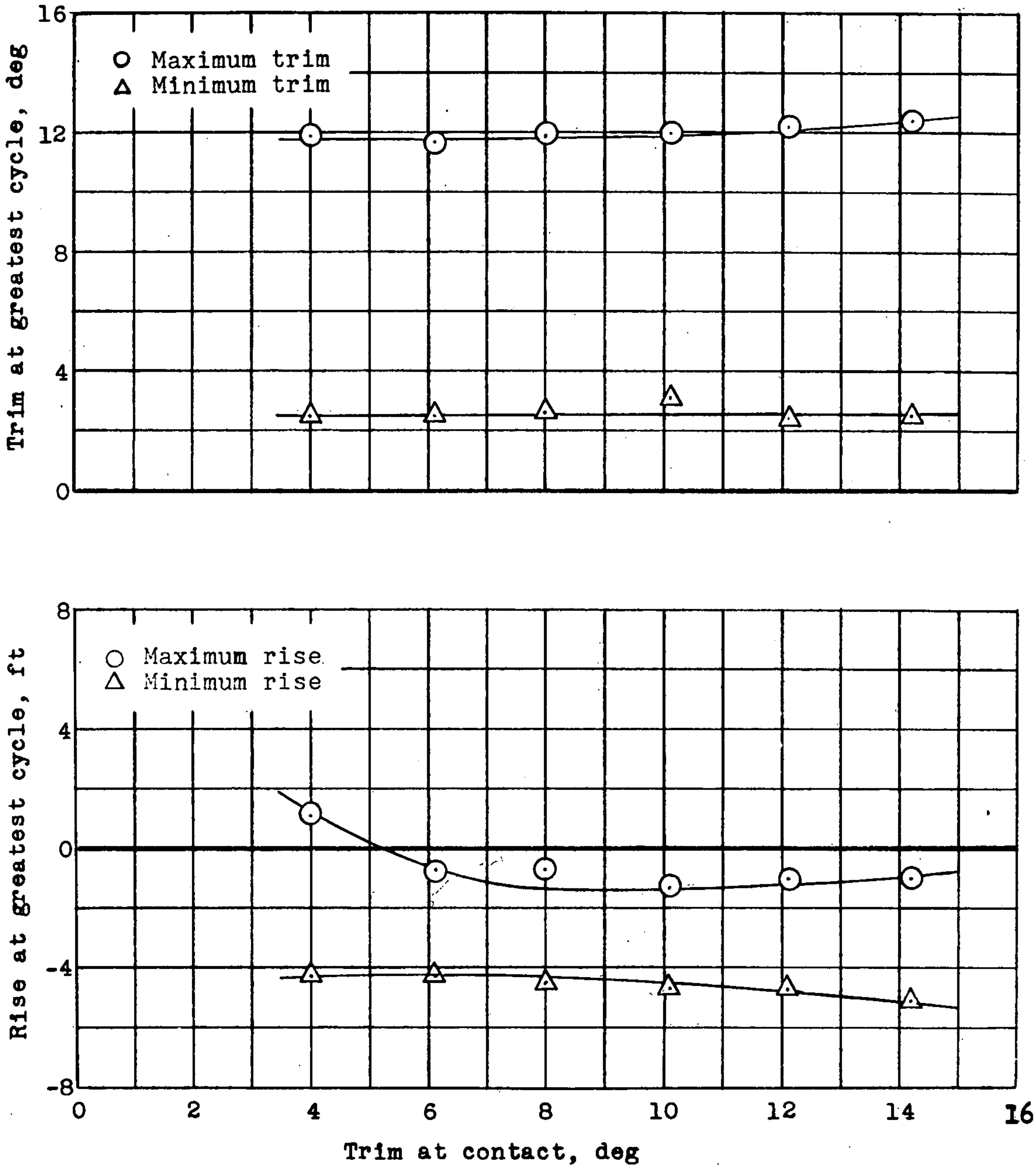
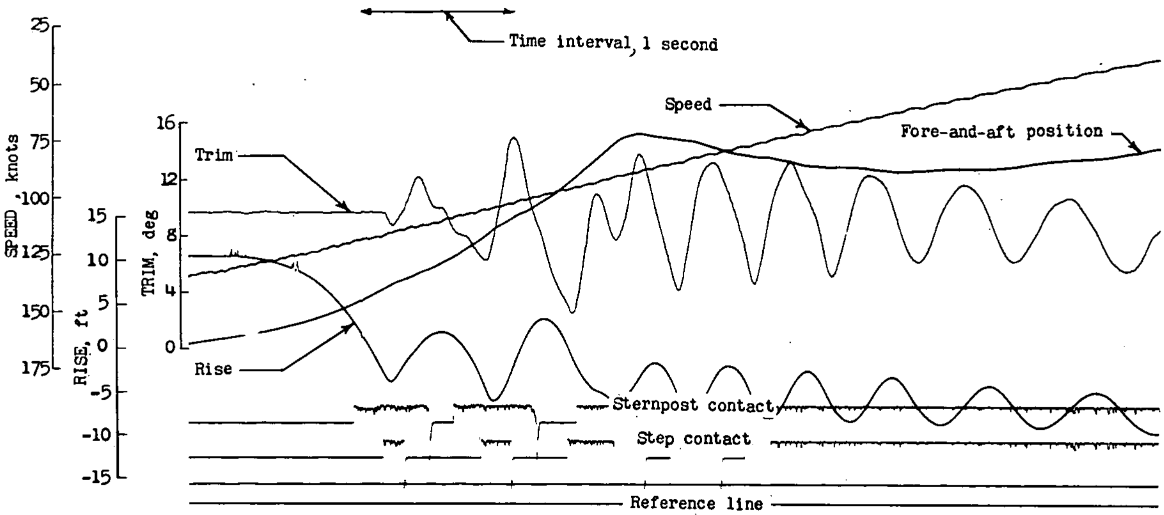
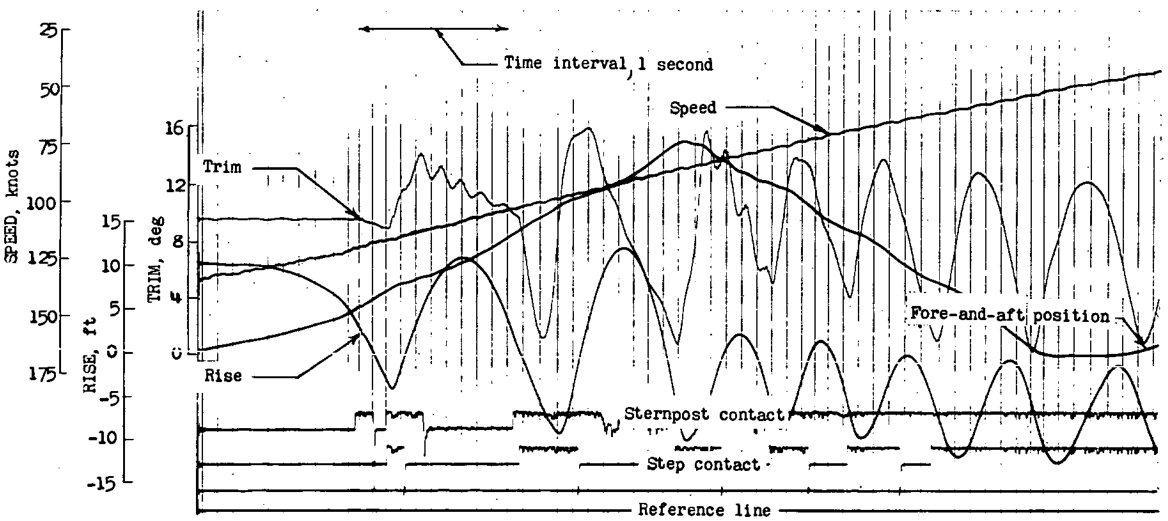


Figure 9.- Maximum variation in trim and rise during smooth water-landings. Δ_0 = 160,000 pounds; δ_f = 50°.

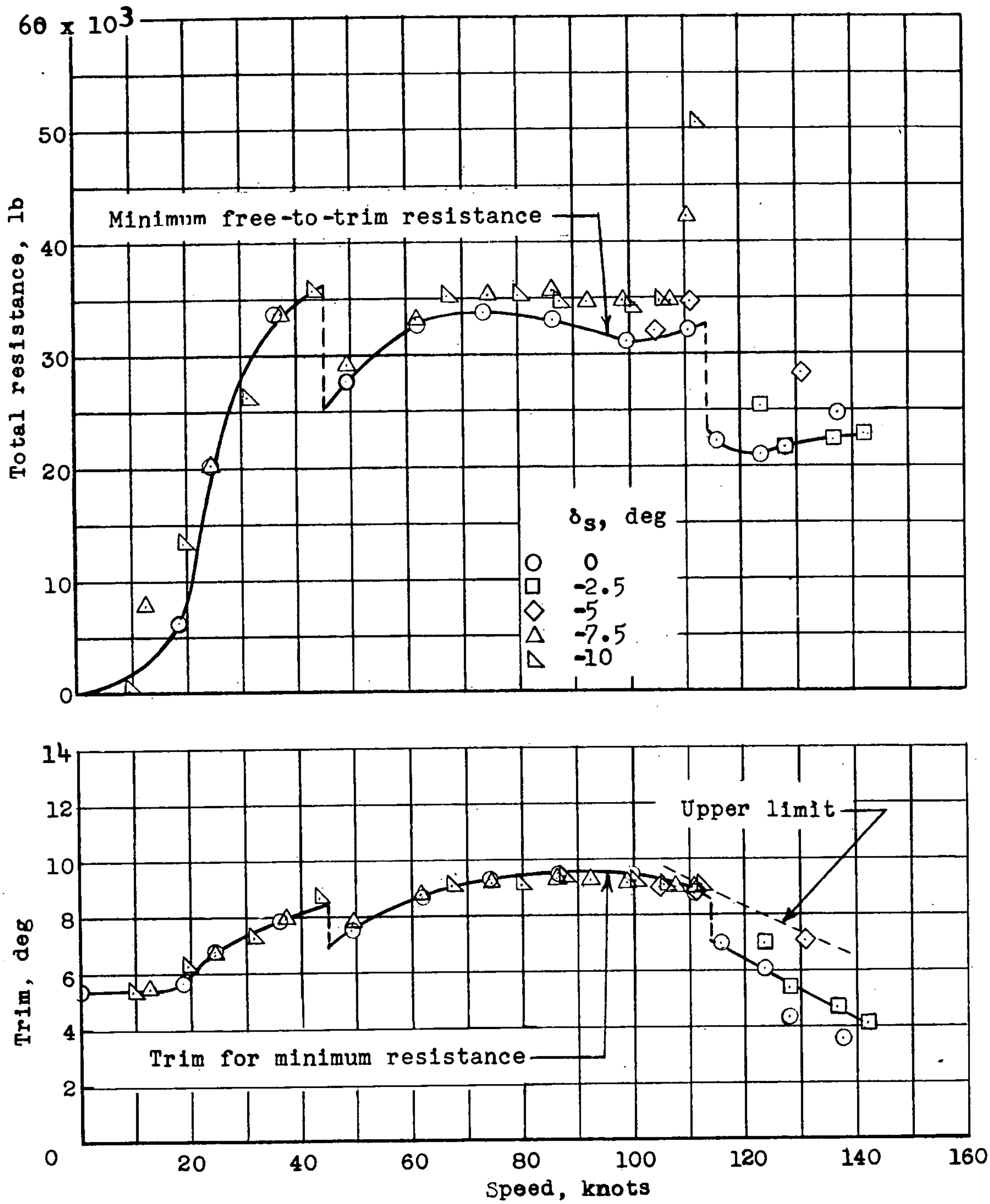


(a) Wave height, 4 feet; wave length, 340 feet. Deceleration, 7 ft/sec^2.



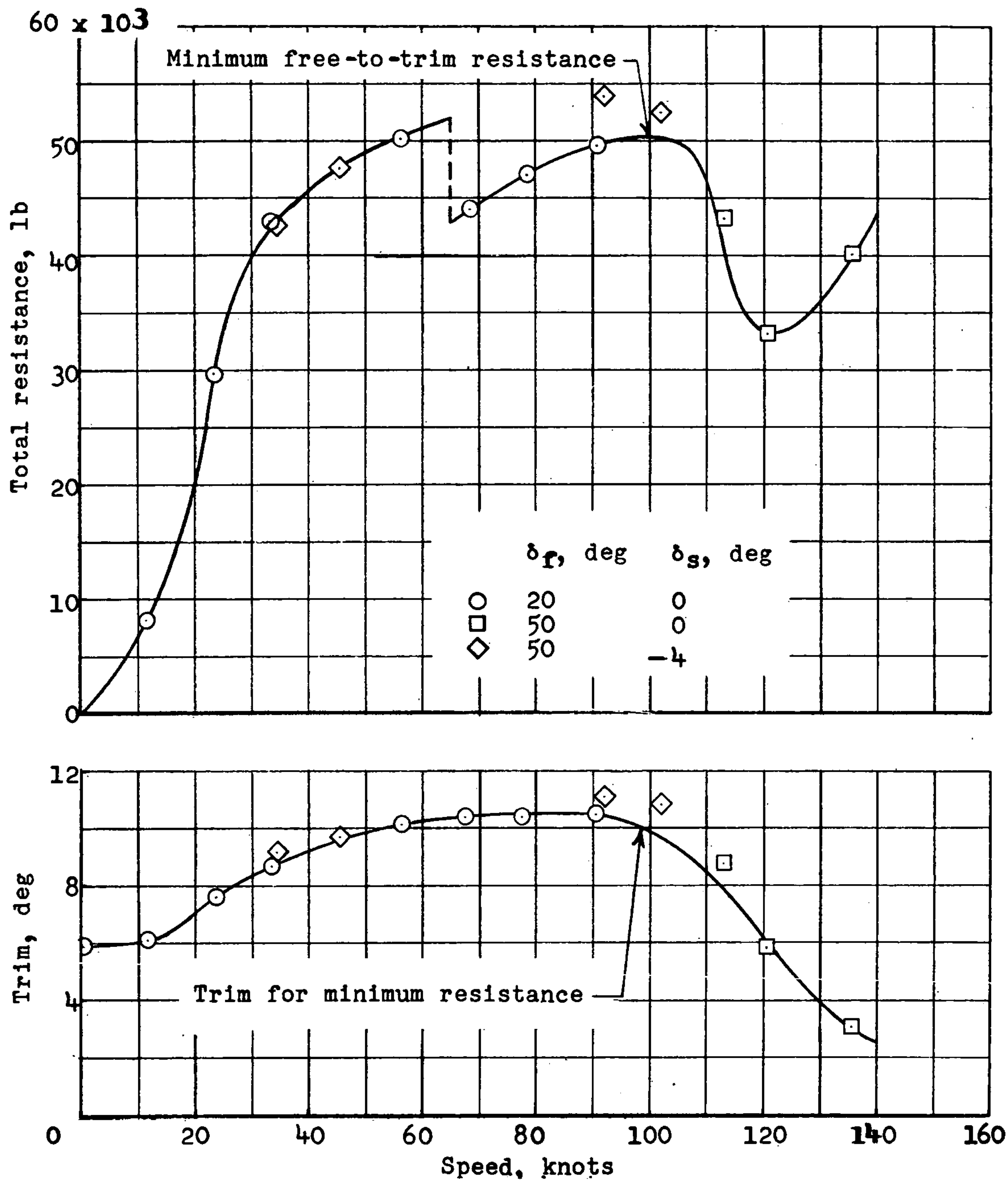
(b) Wave height, 8 feet; wave length, 340 feet. Deceleration, 6.6 ft/sec^2.

Figure 10.- Typical records of landings in waves. Δ_o = 160,000 pounds; $\delta_f = 50^o$.



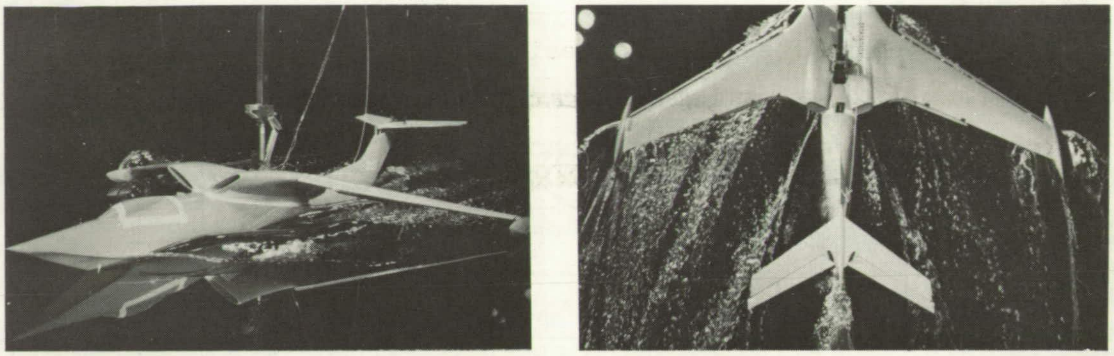
(a) Δ_o = 160,000 pounds; δ_f = 20°.

Figure 11.- Variation of free-to-trim total resistance and trim with speed.

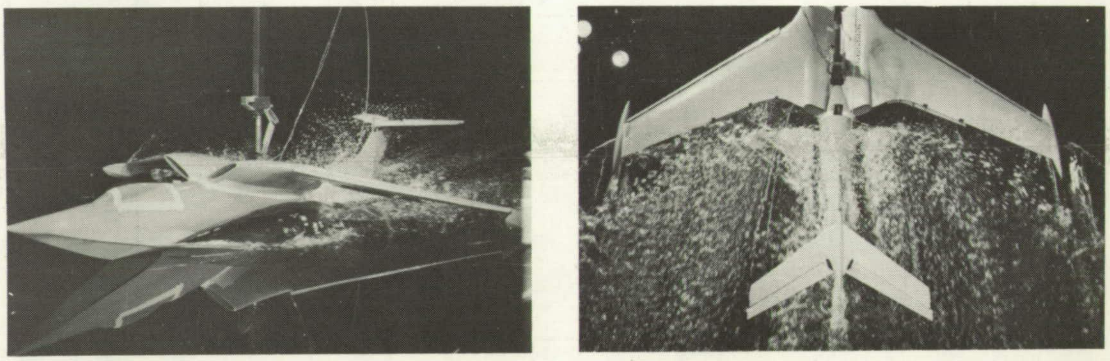


(b) Δ_o = 200,000 pounds.

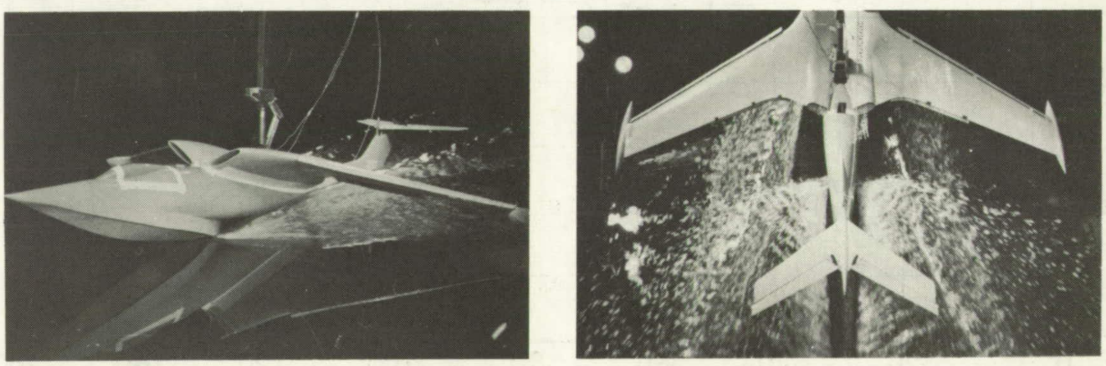
Figure 11.- Concluded.



(a) $V = 24.6$ knots; $\tau = 6.7^{\circ}$; $\delta_s = -7.5^{\circ}$.



(b) $V = 37.3$ knots; $\tau = 8.0^{\circ}$; $\delta_s = -7.5^{\circ}$.



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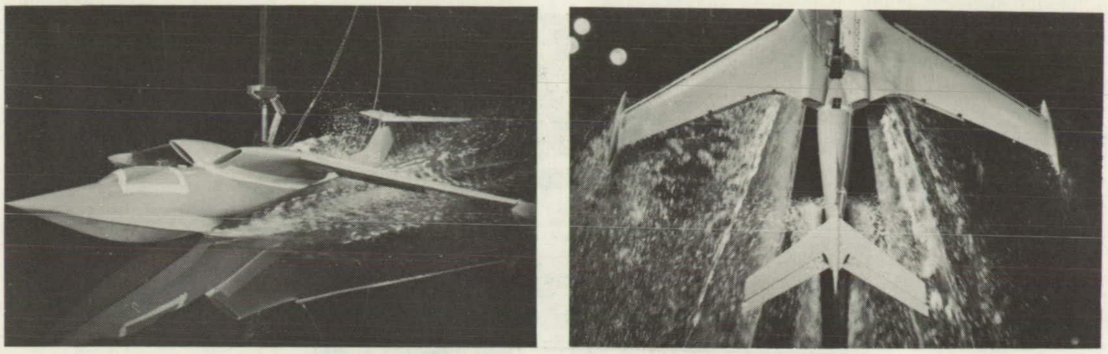
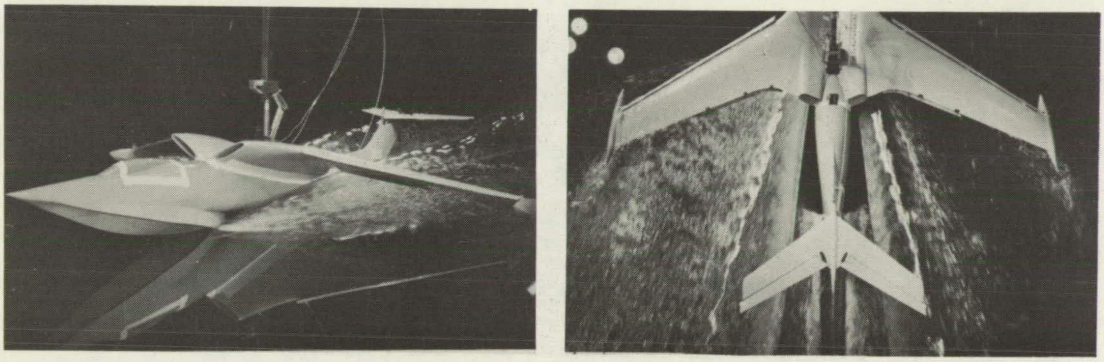
(c) $V = 49.3$ knots; $\tau = 7.8^{\circ}$; $\delta_s = -7.5^{\circ}$.

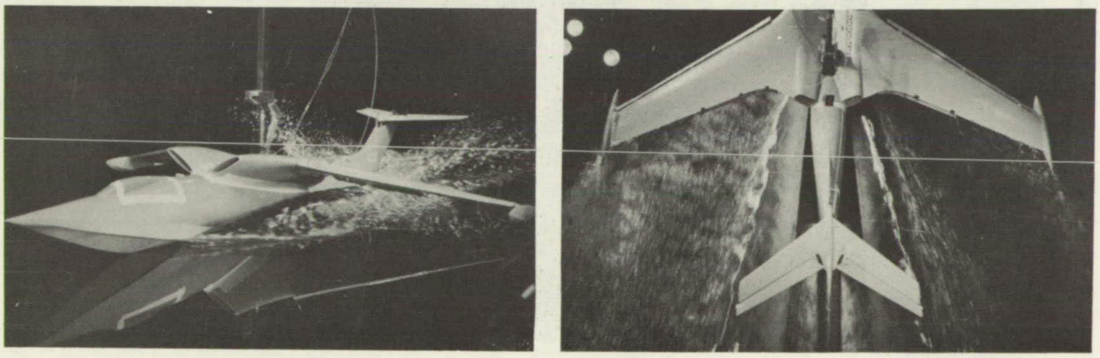
Figure 12.- Spray photographs. $\Delta_o = 160{,}000$ pounds; $\delta_f = 20^{\circ}$.



(d) V = 61.7 knots; $\tau = 8.8^{\circ}$; $\delta_s = -7.5^{\circ}$.



(e) V = 74.9 knots; $\tau = 9.2^{\circ}$; $\delta_s = -7.5^{\circ}$.



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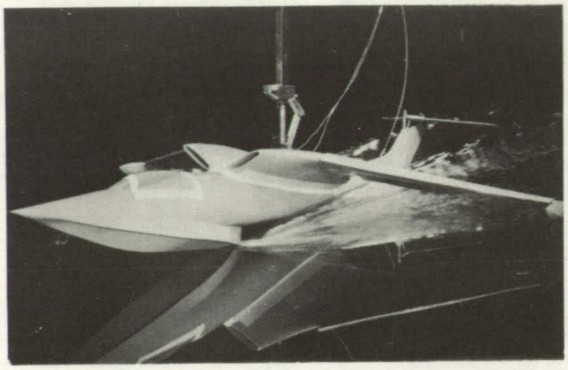
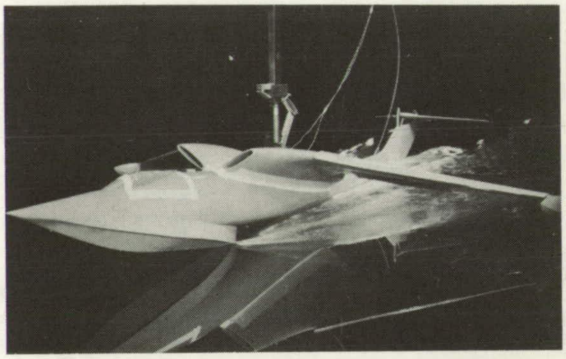
(f) V = 86.1 knots; $\tau = 9.3^{\circ}$; $\delta_s = -7.5^{\circ}$.

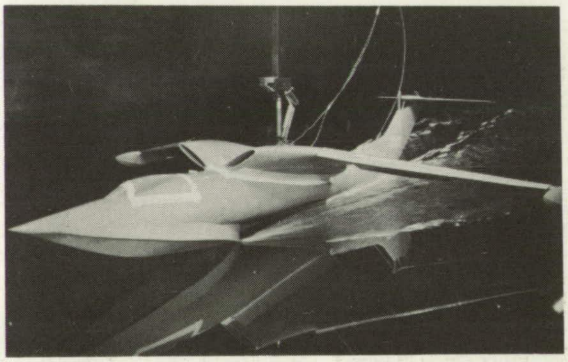
Figure 12.- Continued.



(g) V = 99.8 knots; $\tau = 9.1^{\circ}$; $\delta_s = 0^{\circ}$.



(h) V = 110.8 knots; $\tau = 8.8^{\circ}$; $\delta_s = 0^{\circ}$.



(i) V = 123.7 knots; $\tau = 6.1^{\circ}$; $\delta_s = 0^{\circ}$.

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Figure 12.- Concluded.

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