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A BRIEF INVESTIGATION OF A HYDRO-SKI STABILIZED HYDROFOIL SYSTEM ON A MODEL OF A TWIN-ENGINE AMPHIBIAN

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SUMMARY

Results are presented from a tank investigation of a supercavitating hydrofoil system mounted on an existing 1/8-size powered dynamic model of a twin-engine amphibian. The system consisted of a hydrofoil as the main lifting element and twin hydro-skis located forward of the hydrofoil for stability. The hydrofoil was supported at the tips by twin ventilating struts and had a thin cambered section with sharp leading edge developed for good operation in supercavitating flow. The stabilizing planing surfaces (hydro-skis) had pointed bows to alleviate emergence spray and tapered trailing edges to decrease trim disturbances. This configuration was briefly investigated to determine some of its resistance characteristics during take-off and stability characteristics during take-off and landing.

The results indicate this configuration is capable of stable take-offs with available thrust and control. The hydrofoil ventilated, to effectively give supercavitating flow, at speeds above 15 knots. The water resistance of the hydrofoil system for stable take-off runs was greater than that of the model without the hydrofoil system. Landing behavior with 10° model trim was stable in calm water and in waves 2 feet high and 80 feet long (full scale) for yaw angles of 0° and 5° and in waves 3 feet high and 120 feet long for 0° yaw.

INTRODUCTION

Recent developments in the field of supercavitating hydrofoils (ref. 1) have aroused interest in the application of hydrofoil landing gears to high-speed aircraft. Such a landing gear has been proposed using a twin-engine amphibian as a test vehicle. The landing gear consisted of a supercavitating hydrofoil located slightly aft of the center of gravity as the main supporting element and twin hydro-skis located well forward of the foil as stabilizing elements. The basic hydrodynamic characteristics of this type of system for waterborne aircraft have been investigated (ref. 2) and the system is relatively stable and efficient. A brief investigation of the proposed landing gear was conducted in the Langley towing tanks using an existing 1/8-size model of a twin-engine amphibian. The aim of the investigation was to determine the feasibility of a supercavitating hydrofoil system designed to operate on high-speed aircraft. No attempt was made to systematically vary parameters to produce an optimum configuration; however, the original configuration was changed several times, principally to aid ventilation, before a suitable system was found. For example, lower hump resistance values were obtained with small angles of hydrofoil incidence, but were not reported since only angles at which supercavitating flow occurred were being considered. The advantages of a supercavitating hydrofoil over a conventional hydrofoil are discussed in the introduction of reference 1. Only the results for the final configuration are presented herein. The effects of varying element spacing and attitudes for such a system are discussed in reference 2.

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DESCRIPTION OF MODEL

The model used for testing the hydrofoil system was an existing 1/8-size powered dynamic model of the amphibian used in the investigations reported in reference 3. The general arrangement of the configuration is shown in figure 1. Photographs of the model are shown as figure 2. The model had scale diameter two-bladed propellers driven by variable frequency motors. Elevators of scale dimensions were the only movable (±30°) control surfaces. Slats were added to the leading edge of the wing to obtain the full-scale stall angle.

The aircraft center of gravity was located at 0.226 of the wing mean aerodynamic chord, and 0.988 of the horizontal distance from the hydro-ski trailing edge to the hydrofoil 50-percent-chord line. The incidence of the hydrofoil reference line with respect to the hull reference line was 4°. Details of the hydrofoil configuration are shown in figure 3. The foil had a projected area of 1012.50 square inches (full size) and dihedral of 25°. Details of the hydrofoil section are given in figure 4. The main features of the foil section are the sharp leading edge, developed for good operation in supercavitating flow, and the highly cambered bottom shape which is a Tulin-Burkart section. The hydrofoil was supported at the tips by twin ventilating-type struts that were designed with a notch along the inner strut face and a blunt trailing edge (fig. 5) to supply air to the hydrofoil down the cavities caused by the flow around the notched side and blunt trailing edge of the strut.

Details of the hydro-skis which comprised the stabilizing planing surfaces are shown in figure 6. They were designed with a pointed bow, as suggested in reference 4, to alleviate the emergence spray and with tapered trailing edges to decrease trim disturbances. The skis were set at 15° incidence to the hull reference line and were supported by struts of parabolic section with blunt trailing edges.

APPARATUS AND PROCEDURE

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Take-Off Tests

General.- The test setup on the Langley tank no. 1 towing carriage with the model floating at the test gross weight (9,000 pounds full size) is shown in figure 7. The model was approximately 18 percent overweight, and the overload was relieved through the use of a long rubber spring which maintained an almost constant vertical force over the rise range encountered during the tests. The model was free to trim about the center of gravity ($0.226\bar{c}$) and free to rise but was restrained in both roll and yaw. Three elevator settings were used (-10°, -20°, and -30°). A flap deflection of 30° was maintained throughout the investigation.

Stability.- Accelerated take-off runs at an acceleration of approximately 0.5 ft/sec^2 were made to determine whether stable take-off runs could be made with constant elevator settings. The speed, rise of the center of gravity, and trim were recorded on an oscillograph. Rise was considered zero with the model floating at approximately 3° trim (power on). Trim was measured as the angle between the horizontal and the hull reference line.

Resistance.- Resistance data were obtained from constant speed runs and from accelerated runs at approximately 0.5 ft/sec^2. For both constant speed and accelerated runs, the model was tested with full power corresponding to a static thrust of 3,375 pounds (full size). The resistance data were recorded on a strip chart recorder using a strain-gage load cell pickup. Resistance as determined in these tests is defined by the equation

$$R = T_e - T_X$$

where

R total model resistance, lb

T_e effective thrust of model installation, lb

T_X resultant horizontal force developed by model with power on in water, lb

The effective thrust T_e is defined by the equation

$$T_e = D + F_X$$

where

D aerodynamic drag of model with propellers fixed, lb

F_X resultant horizontal aerodynamic force with power on, lb

L320

Values of D and F_X were determined at various speeds with the model just clear of the water at a trim of 0° with the elevators set at 0°. The resultant horizontal force T_X was determined from both constant speed and accelerated speed runs. For the accelerated runs the force due to acceleration was subtracted to enable comparison with the constant speed runs.

Landing Tests

Landing tests were made without power and with the model balanced about the center of gravity ($0.226\bar{c}$) at a gross weight of 9,000 pounds (full size). The test setup with the model mounted on the Langley tank catapult for free-body landings is shown in figure 8. Elevator deflection was set to hold 10° trim until initial contact with the water. The model was launched by the catapult at speeds of 58 to 62 knots (full size). Still photographs and motion pictures were taken and the model behavior was observed. In order to provide stability in roll, small skis were added to the tip floats during the landing tests (fig. 8). These skis are merely a test feature and would presumably be unnecessary on the full-scale airplane since the required roll control would be provided by the pilot. Landings were made with 0° and 5° yaw in calm water and directly into oncoming waves 2 feet by 80 feet (full size). Landings were also made in waves 3 feet by 120 feet with 0° yaw. The waves were generated by the Langley tank wave maker.

RESULTS AND DISCUSSION

Take-Off Tests

The resistance, trim, and rise obtained during accelerated and constant speed take-off runs for elevator settings of -10°, -20°, and -30°

are shown in figure 9. Included in these plots are estimates of thrust available and of the minimum resistance without the hydrofoil system obtained from reference 3. The resistance curve from reference 3 was extrapolated to 9,000 pounds gross weight on the basis of a constant load-resistance ratio.

As a take-off run began, the model trimmed up, rotating about a point aft of the step, wetting the afterbody, and changing rise slightly until the hydro-skis emerged. After hydro-ski emergence, the model continued to rise but rotated about the hydro-skis, thus trimming down.
L The hull was supported by the hydrofoil system at approximately 28 knots.
3 For the -30° and -20° elevator settings, the model then trimmed up
2 against the trim stop accompanied by a sharp increase in rise. For the
0 -10° elevator setting, the model ran at a low trim with only a small portion of the hydrofoil and hydro-skis wetted until sufficient speed was obtained for take-off.

During the entire take-off run, there were no extreme motions, and emergence of both the hydro-skis and the hydrofoil was smooth and developed little spray. The hydrofoil appeared to ventilate at about 15 knots for all three elevator settings; however, for the -10° setting the cavity had a tendency to collapse through the low-trim high-speed range prior to take-off. The resistance of the hydrofoil system in the hump region is considerably higher than that of the hull. For accelerated runs, the lowest resistance for the hydrofoil system in the hump region was obtained by using a -20° or -30° elevator setting. For the -10° elevator setting, the resistance above 40 knots falls slightly below the resistance for the hull. Results obtained from accelerated runs (fig. 9(a)) agree closely with those obtained from constant speed runs (fig. 9(b)). The results indicate that this hydrofoil configuration is capable of stable take-offs with available thrust and control.

Landing Tests

Landings in calm water.- Stable calm-water landings at a trim of 10° were made for yaw angles of 0° and 5°. The hydrofoil ventilated upon entering the water and maintained the cavity throughout most of the landing run. There was little difference in landing behavior with or without yaw except for a slightly longer run-out without yaw (table I). (At the landing trim used, the hydrofoil was the first portion of the model to contact the water (fig. 10).) After initial contact, the model trimmed down until the hydro-skis were wetted and forces developed sufficient to cause the model to begin trimming up. The model trimmed up until it attained a flying attitude and then flew a short distance to a second contact. Following the trimming down after the second contact, the model remained upon the water oscillating slightly in trim until it slowed down and was supported by the hull.

Landings in waves.- Stable landings at 10° trim were made in waves up to 3 feet high and 120 feet long for 0° yaw and in waves 2 feet high and 80 feet long for 0° and 5° yaw. The model behavior was more violent in waves (figs. 11 and 12) than in calm water. Table I indicates that the length of run decreased as the wave size was increased. There was a tendency of the feet to dig into the crests of the waves tested, but there was no indication of upset being imminent. Behavior of the model on landing appeared to depend mainly on how the model made initial contact. In general the model gave two different behaviors, depending on the location of the hydrofoil relative to the wave on first impact. If the hydrofoil made initial contact on or near the crest of a wave there was little trim change and subsequent changes in trim and rise were of low magnitude. If, however, the hydrofoil made initial contact on the leading flank of a wave, the model would pitch down and enter the next wave at a negative trim. The model then trimmed up rapidly, skipped off the water, and fell into the succeeding wave. Figure 11 illustrates the motion of the model in waves 2 by 80 feet, and figure 12 illustrates motions in waves 3 by 120 feet.

CONCLUSIONS

Results of tests of a model of a typical twin-engine amphibian equipped with hydro-ski stabilized hydrofoil system led to the following conclusions:

1. The system is capable of stable take-offs with the available thrust and control.

2. The minimum water resistance of the hydrofoil system is greater than that of the hull at low speeds.

3. Landings with a model trim of 10° were stable in calm water and waves 2 feet high by 80 feet long (full scale) for yaw angles of 0° and 5°, and in waves 3 feet high by 120 feet long for 0° yaw.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 17, 1959.

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1. Johnson, Virgil E., Jr.: Theoretical and Experimental Investigation of Arbitrary Aspect Ratio, Supercavitating Hydrofoils Operating Near the Free Water Surface. NACA RM L57I16, 1957.

2. Land, Norman S., Chambliss, Derrill B., and Petynia, William W.: A Preliminary Investigation of the Static and Dynamic Longitudinal Stability of a Grunberg Hydrofoil System. NACA RM L52D15, 1952.

3. Wadlin, Kenneth L., and Ramsen, John A.: Tank Investigation of the Grumman JRF-5 Airplane Fitted With Hydro-Skis Suitable for Operation on Water, Snow, and Ice. NACA RM L9K29, 1950.

4. McGehee, John R.: Effects of Nose Shape and Spray Control Strips on Emergence and Planing Spray of Hydro-Ski Models. NACA TN 4294, 1958.

L320

TABLE I.- LENGTH OF LANDING RUNS OF 1/8-SIZE MODEL OF A TWIN-ENGINE AMPHIBIAN WITH HYDRO-SKI STABILIZED HYDROFOIL SYSTEM UNDER VARIOUS CONDITIONS

[All dimensions are full size]

Water condition	Length of run, ft	Average length of run, ft
	Angle of yaw, 0°	
Smooth	656 808 688 664 760	715
Waves 2 ft by 80 ft	576	576
Waves 3 ft by 120 ft	560 544 592 496 512 512	536
	Angle of yaw, 5°	
Smooth	528 664 680 688 688	650
Waves 2 ft by 80 ft	512 528 448 488 528	501
Waves 3 ft by 120 ft	496 496	496

L-320

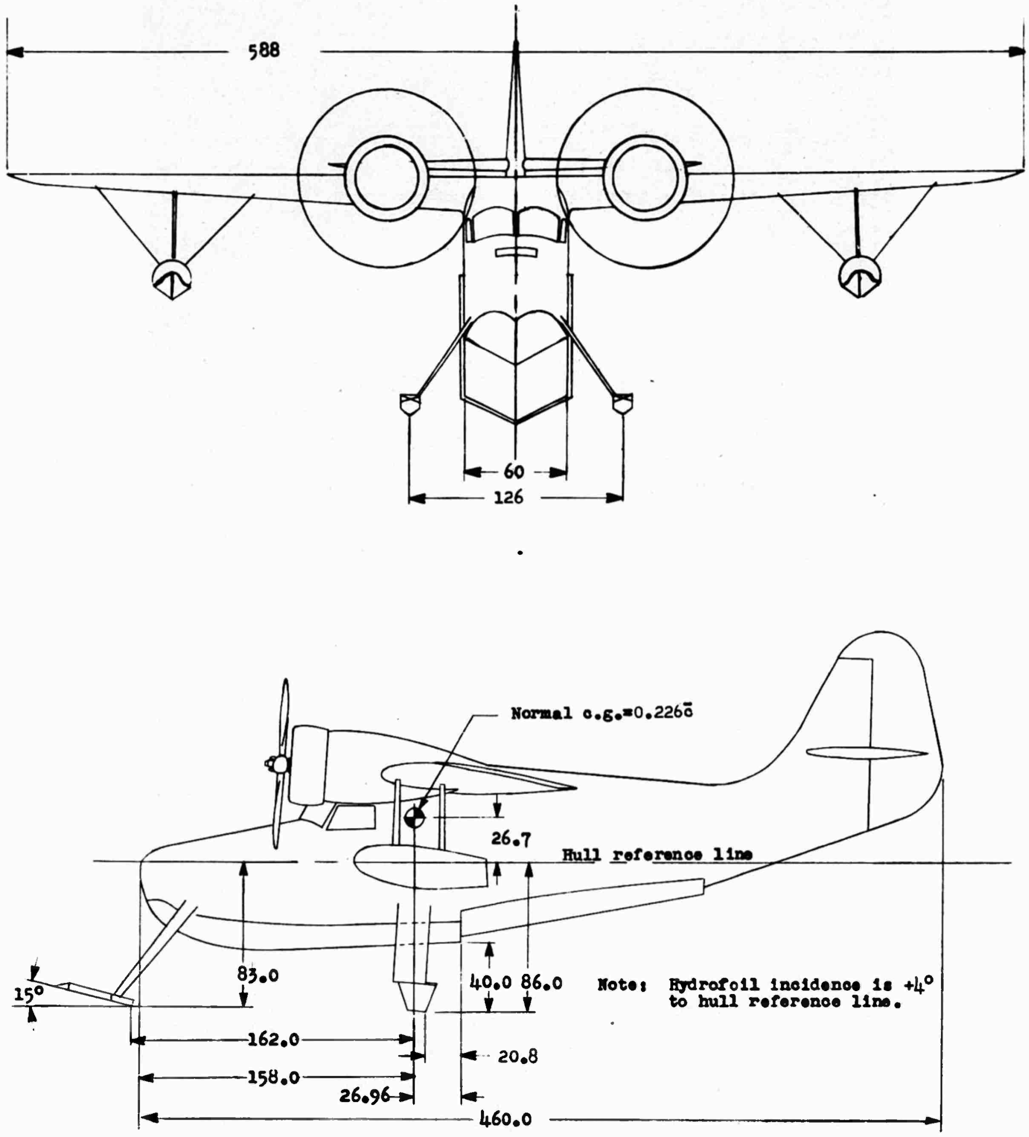
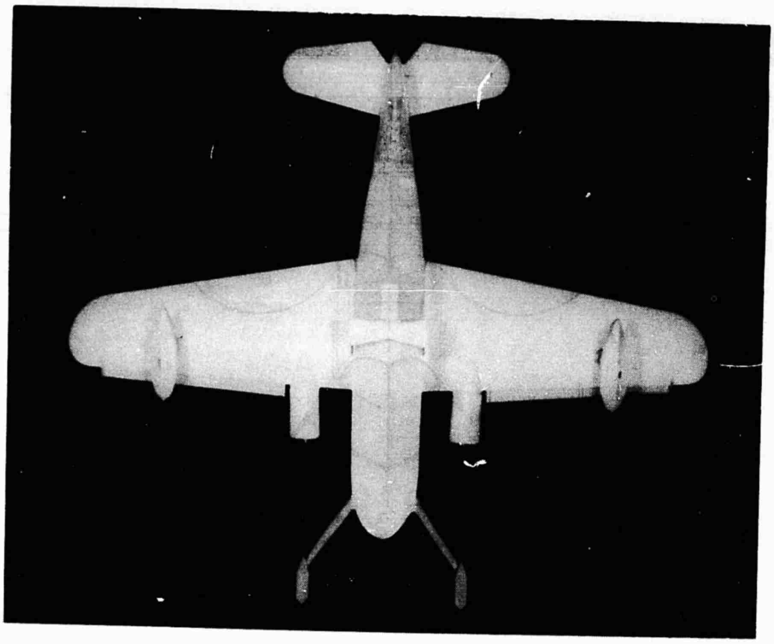
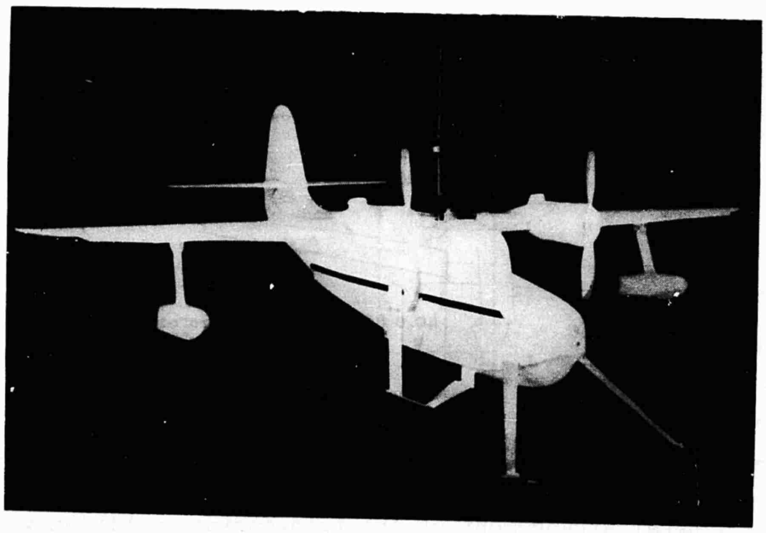


Figure 1.- General arrangement of the twin-engine amphibian with hydro-ski stabilized hydrofoil system. All dimensions are in inches, full size.



(a) Bottom view. L-57-2544.1



(b) Three-quarter front view. L-57-2542

Figure 2.- The 1/8-size powered dynamic model with hydro-ski stabilized hydrofoil system.

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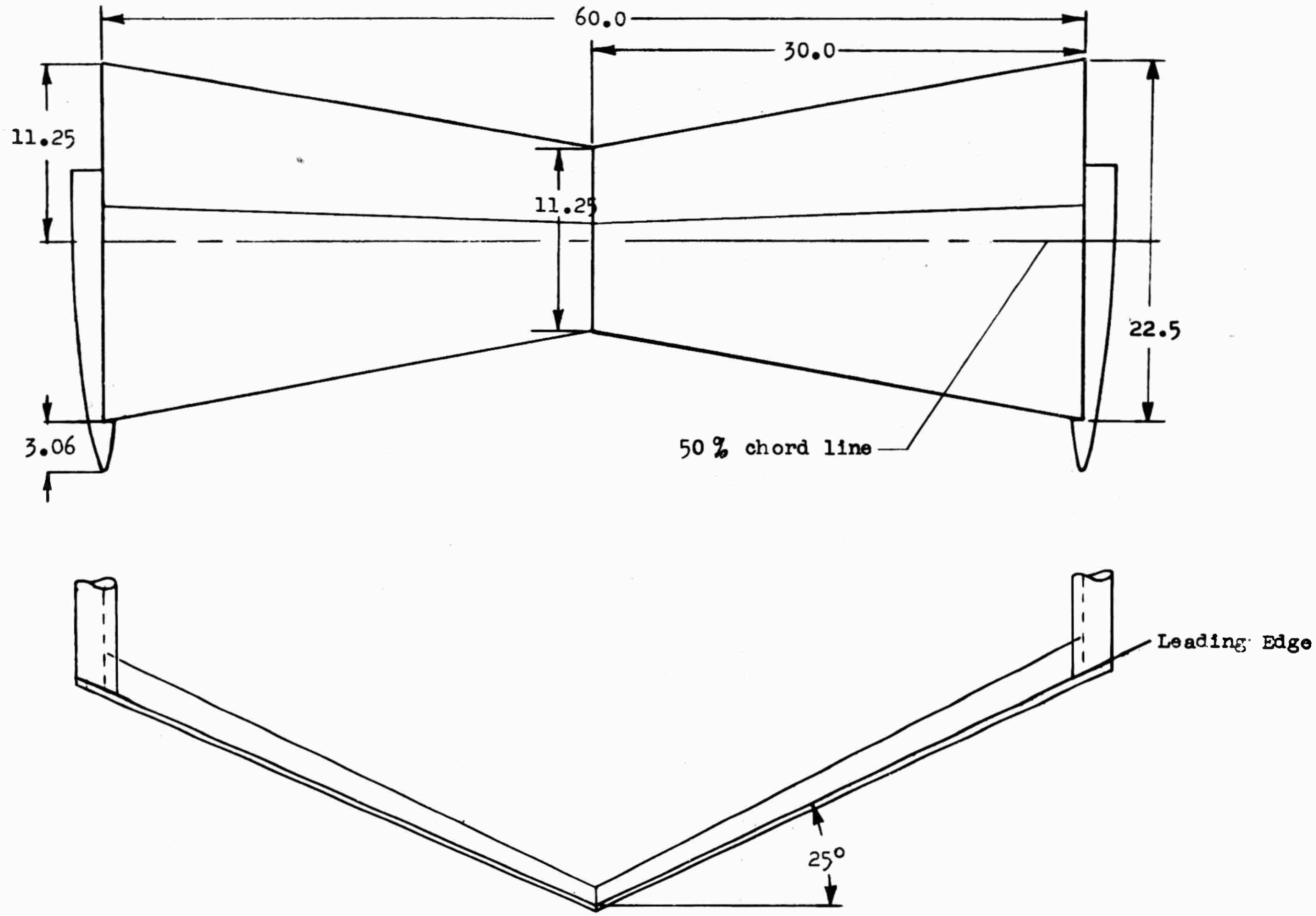

Figure 3.- Hydrofoil details. All dimensions are in inches, full size.

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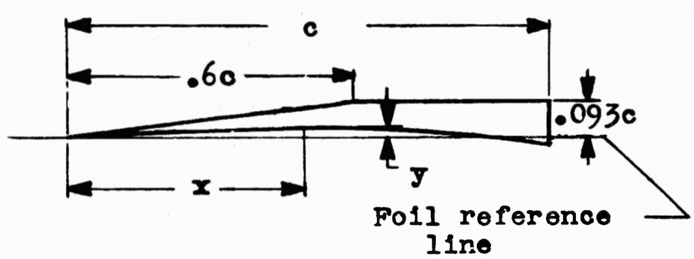
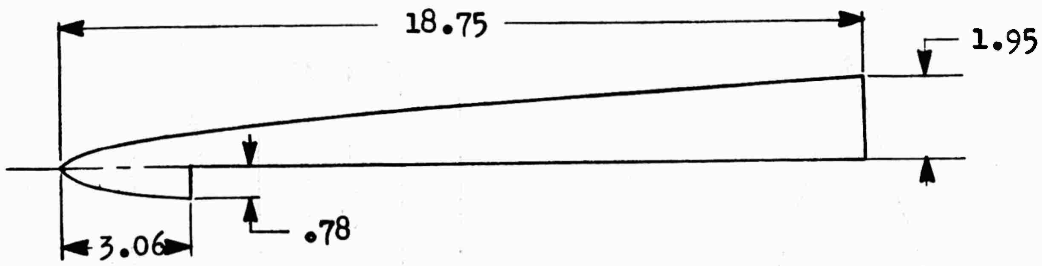


x/c	y/c
0.0	0.0000
.1	.0073
.2	.0142
.3	.0192
.4	.0222
.5	.0226
.6	.0204
.7	.0154
.8	.0076
.9	- .0037
1.0	-0.0170

NOTE: Included angle at the hydrofoil leading edge is 4°.

Figure 4.- Hydrofoil-section details.



L-320

Ordinates of strut

Station	Upper Ordinate	Lower Ordinate
0	0	0
.47	.30	-.30
.94	.43	-.43
1.41	.53	-.53
1.87	.62	-.62
2.34	.70	-.70
2.82	.75	-.75
3.06	.78	-.78
3.75	.86	0
5.62	1.07	↓
7.50	1.24	↓
9.38	1.39	↓
11.25	1.52	↓
13.13	1.63	↓
15.01	1.74	↓
16.88	1.86	↓
18.75	1.95	0

Figure 5.- Ventilating strut section. All dimensions are in inches, full size.

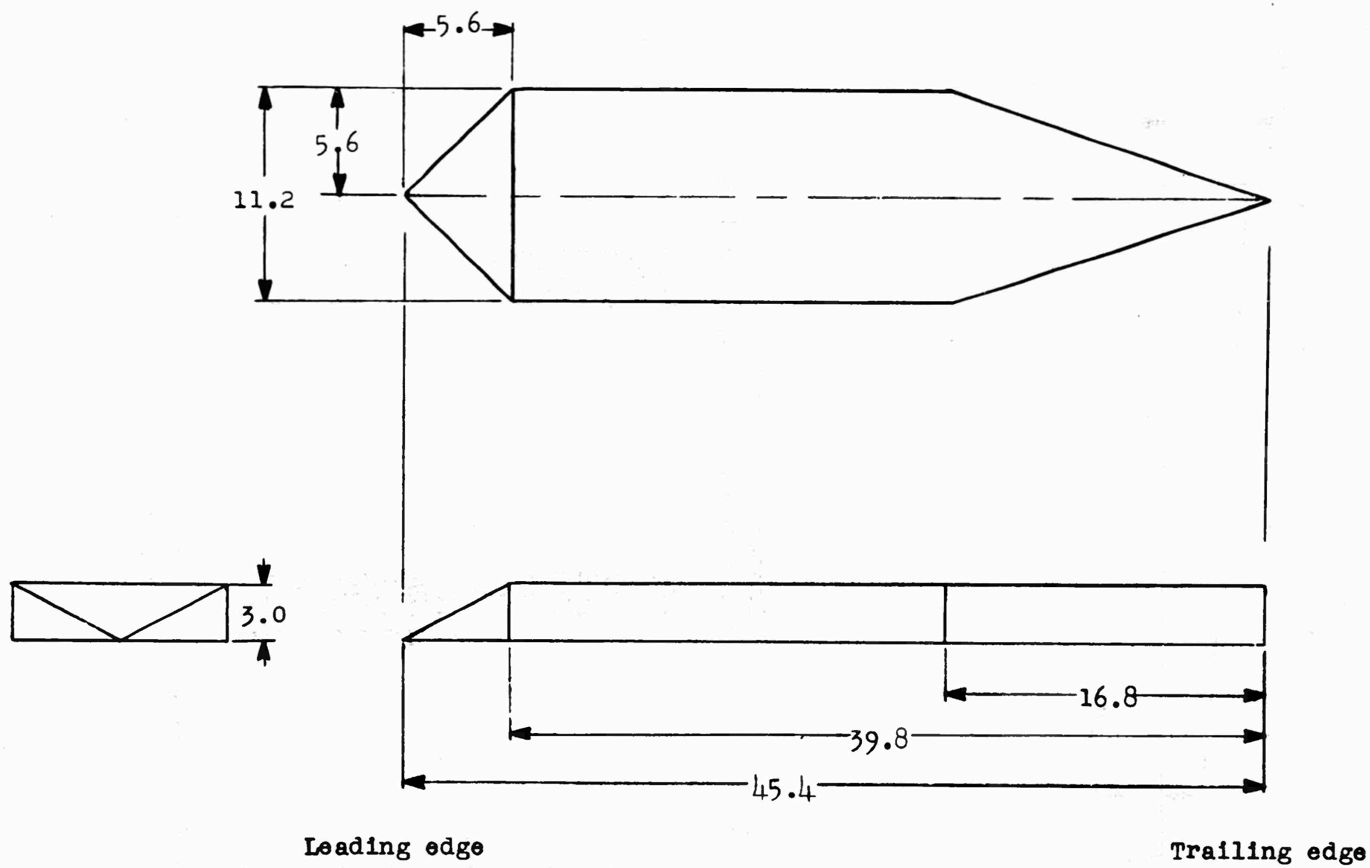


Figure 6.- Hydro-ski details. All dimensions are in inches, full size.

L-320

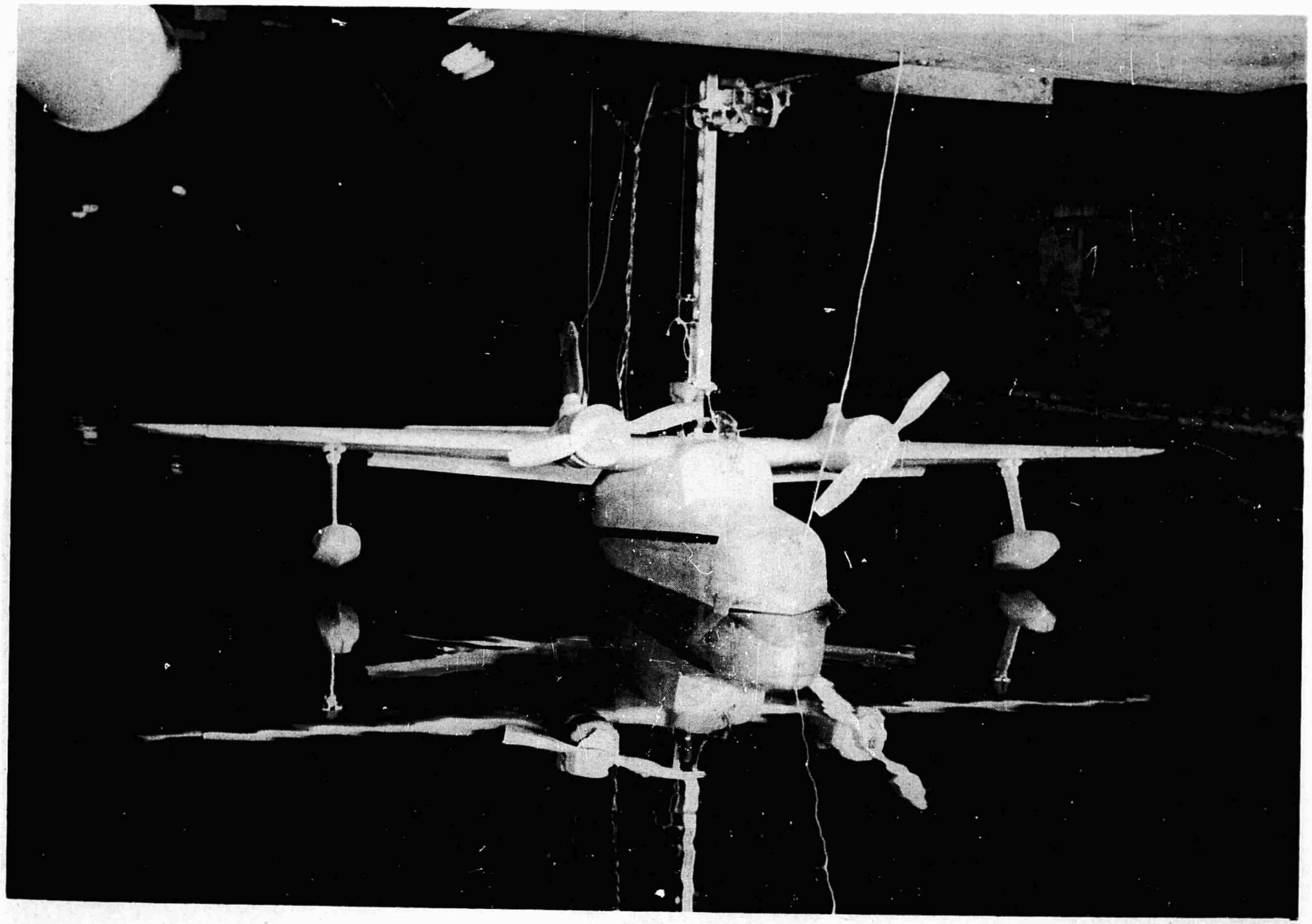


Figure 7.- Test setup showing model floating at normal gross weight. L-59-3062

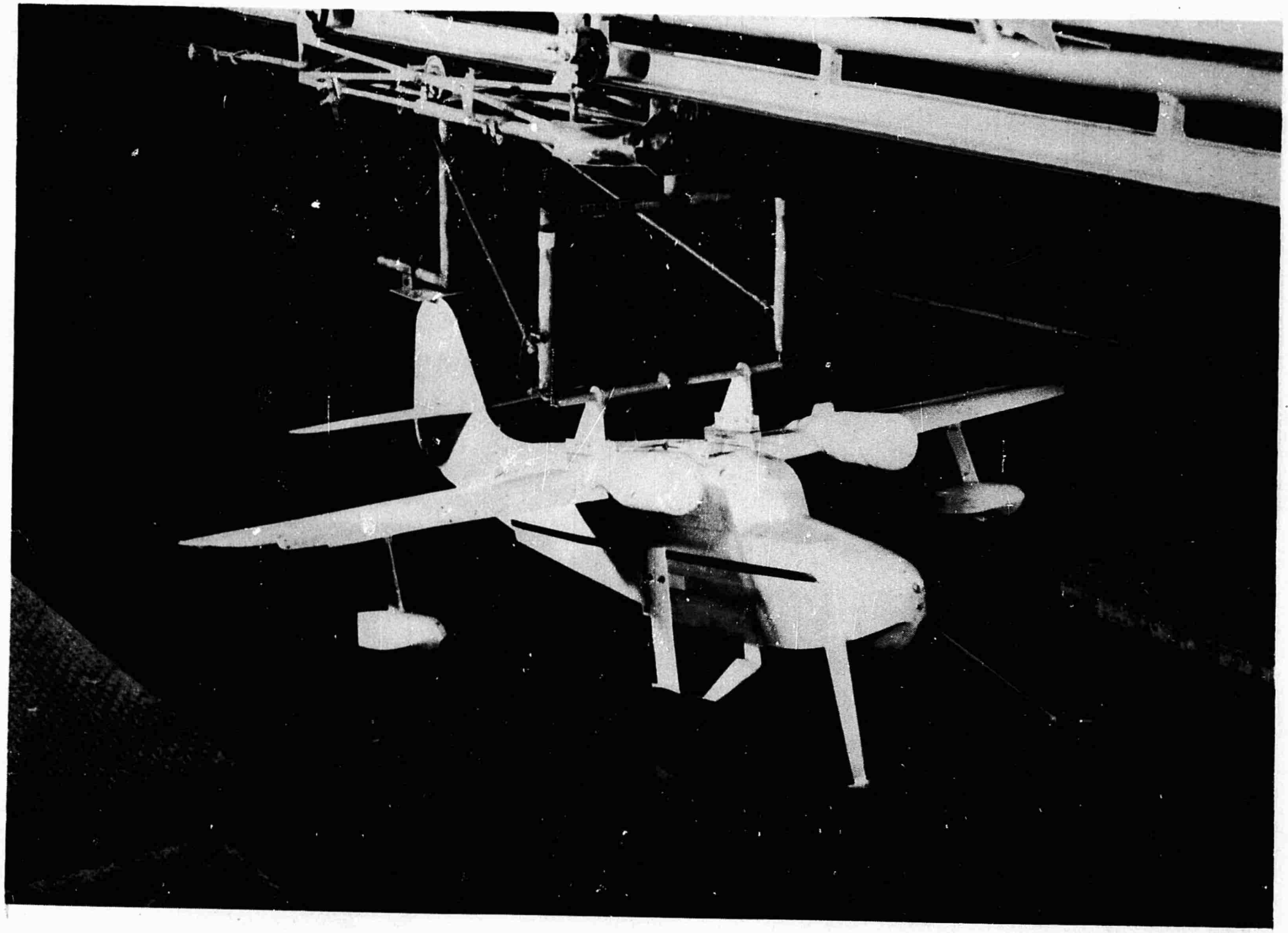
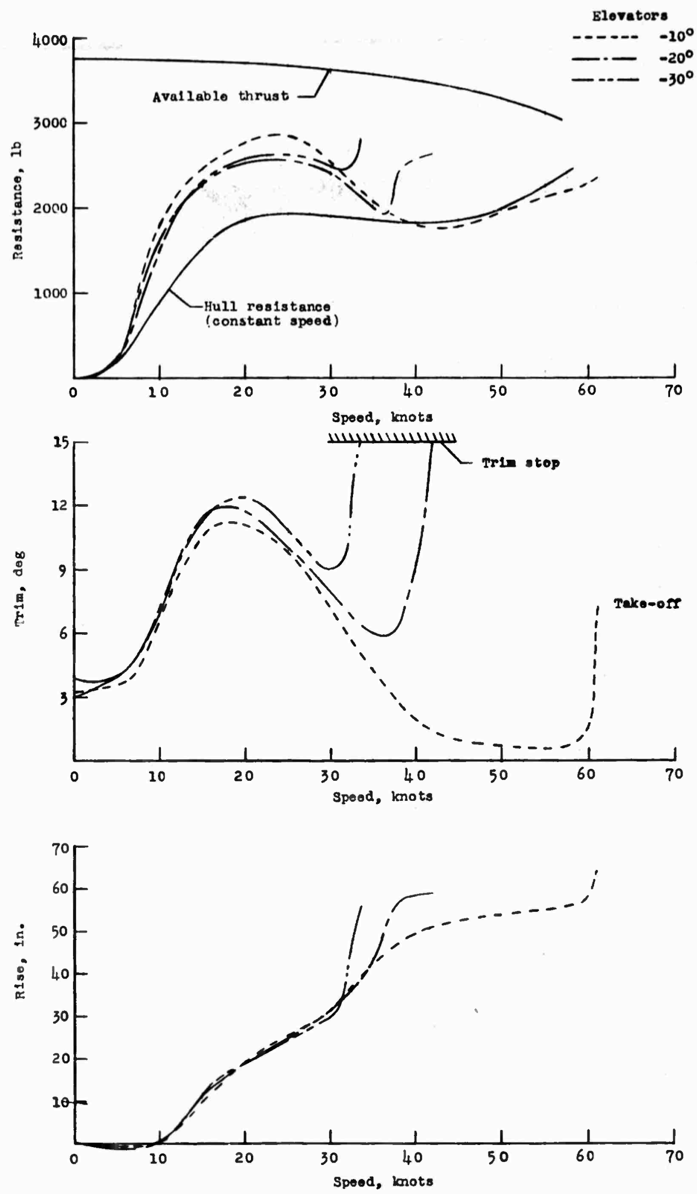
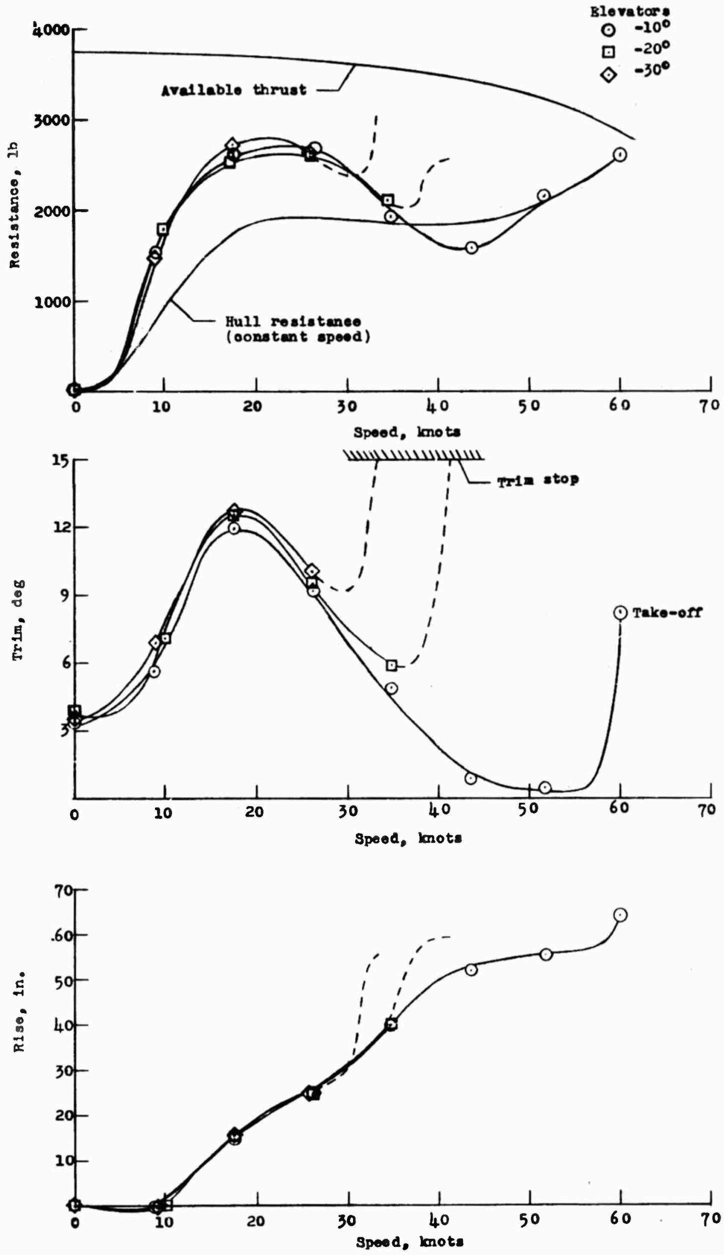


Figure 8.- Test setup showing model on catapult for free-body landing tests. L-57-2541



(a) Accelerated runs.

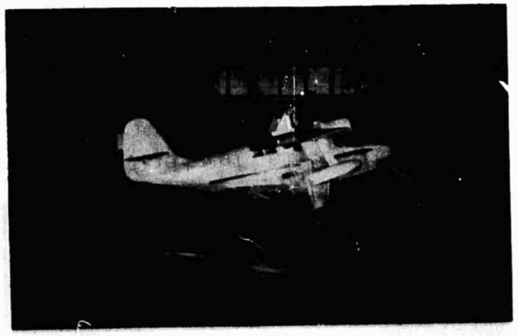
Figure 9.- Model resistance, trim, and rise. Flaps, 30°; values are full size.



(b) Constant-speed runs.

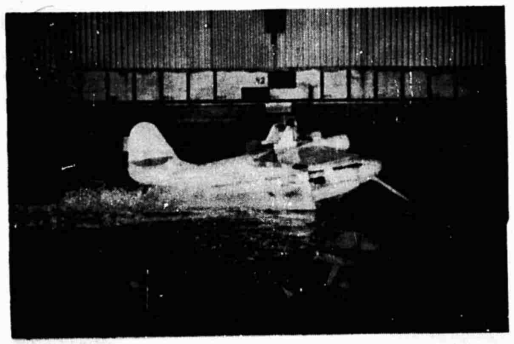
Figure 9.- Concluded.

L-320



First contact

80 feet after contact



272 feet after contact

376 feet after contact

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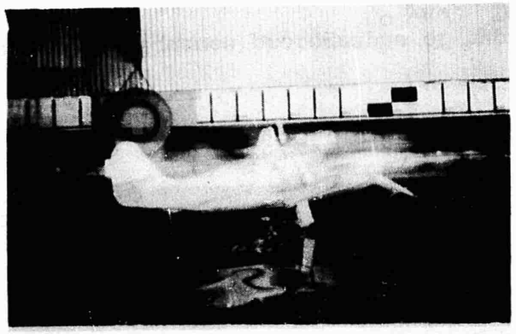
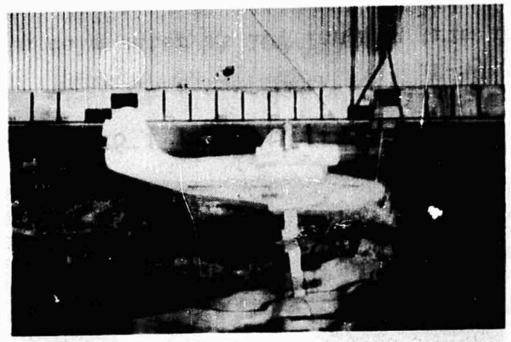
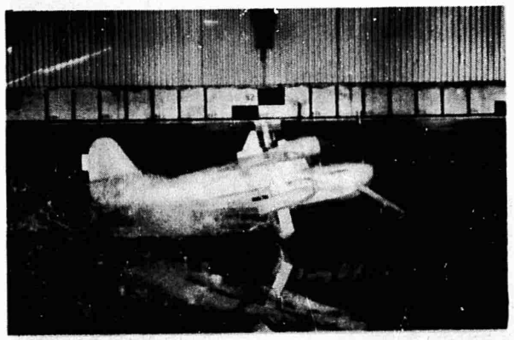
Figure 10.- Sequence photographs of typical landings in calm water at 10° landing trim for 5° yaw. Distances are full size.



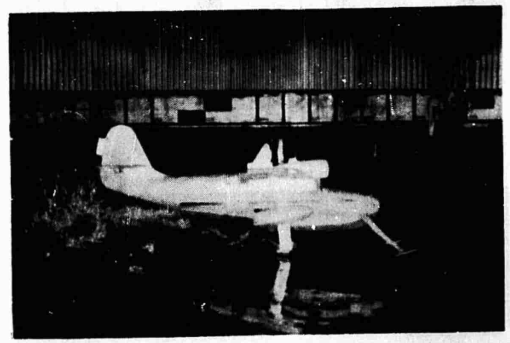
First contact



80 feet after contact



272 feet after contact



376 feet after contact

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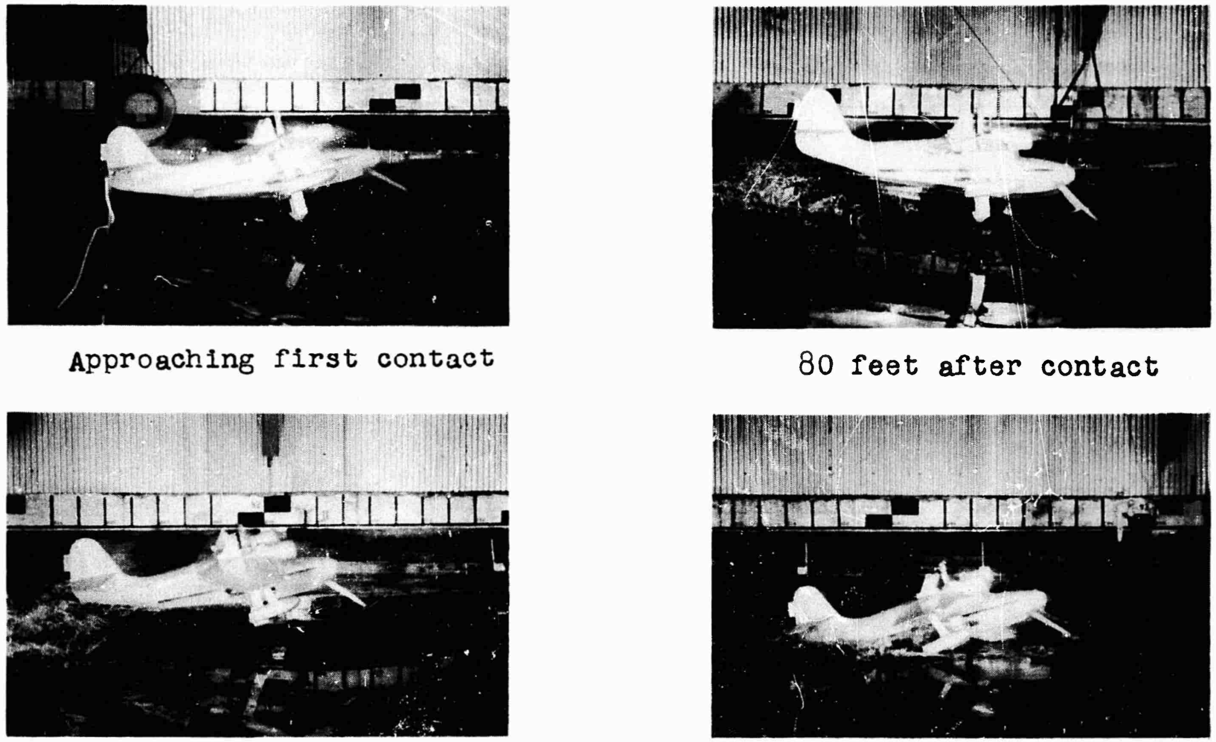
Figure 11.- Sequence photographs of typical landings in waves 2 feet high and 80 feet long at 10° landing trim for 0° yaw. Distances are full size.



Approaching first contact

80 feet after contact

272 feet after contact

376 feet after contact

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Figure 12.- Sequence photographs of typical landings in waves 3 feet high and 120 feet long at 10° landing trim for 0° yaw. Distances are full size.

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