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TANK TESTS OF A 1/5 FULL-SIZE DYNAMICALLY SIMILAR MODEL OF THE ARMY OA-9 AMPHIBIAN WITH MOTOR-DRIVEN PROPELLERS - NACA MODEL 117

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SUMMARY

The influence of running propellers on the hydrodynamic characteristics of a model of a seaplane were investigated in the NACA tank to evaluate the importance of power in tests of dynamically similar models. Various increments of power, including that sufficient for self-propulsion, were applied; and a gear allowing fore-and-aft freedom of the model with respect to the towing carriage when self-propelled was provided.

It was found that, as in wind-tunnel work, the powered propellers have a large effect on the aerodynamic characteristics of the model and consequently on the hydrodynamic stability, which depends to a certain extent on those characteristics. Furthermore, the interference of the propellers and the slipstream with the wave system around the hull at taxying speeds is the most significant factor in the problems of spray control and limitation in load imposed by the spray. Hence the use of powered models is desirable in tank tests of new designs for a more precise prediction of stability and spray while taking off and landing.

In general, the magnitude of the effects of a given increment of power in such tests decreases as the power is increased. The use of powers and revolution speeds that are less than the scale values would be preferable to neglecting entirely the effects of the running propellers. Fore-and-aft freedom of the model has a negligible effect on the trims at which porpoising begins but changes the character of the motion somewhat.

INTRODUCTION

The influence of running propellers on the aerodynamic characteristics of highly powered and heavily loaded airplanes has become of fundamental importance in design. The general effects of the slipstream are to increase lift, to increase the effectiveness of the controls, and to decrease stability. The phenomena involved are of a complex nature, which precludes at the present time either an exact theoretical treatment or empirical research extensive enough to cover all cases. Consequently, powered models are being widely used in wind-tunnel tests of new designs for a more precise determination of stability, control, and flying qualities (reference 1).

In the case of the seaplane during take-offs and landings, the effects of the powered propellers should be basically the same except as modified by the proximity of the surface of the water. These effects are therefore factors in the determination of hydrodynamic characteristics, such as hydrodynamic stability and resistance, which are functions of the aerodynamic forces and moments particularly in investigations of the porpoising characteristics of multiengine long-range flying boats for which the percentage of wing area affected by the slipstream is very large.

Of equal importance with the aerodynamic effects of the slipstream is the profound influence of the rotating propellers on the spray characteristics, which in contemporary seaplanes constitute a limitation on maximum take-off load. The objectionable spray is greatest at slow speeds and full power when it is picked up by the propeller tips and the slipstream and blown back over the engines, wing, and tail. The influence of the propellers is therefore a factor in the determination of limitations in load imposed by spray and in studies of methods of controlling the spray.

The foregoing considerations point to the desirability of the use of powered models in tank tests of models of seaplanes as well as in the wind-tunnel tests since the effects of the propellers on the aerodynamic characteristics or on the spray cannot be adequately taken into account by other means. In addition, the use of power-driven propellers permits tests in which the model is self-propelled instead of pulled by the towing carriage so that its behavior as a free body can be investigated. Furthermore, the increase in lift and in elevator effectiveness with power enables dynamic maneuvers, such as take-offs and landings, to be reproduced at water speeds and trims corresponding more closely with full-size values.

The present investigation was made in the NACA tank to determine the magnitude of the effects of powered propellers on the hydrodynamic stability and the spray characteristics of a dynamic model. For this purpose, the 1/5 full-size model of the Army OA-9 amphibian was fitted with model airplane propellers driven by direct-current motors that had sufficient power for self-propulsion and low enough weight to retain dynamic similarity with the full-size craft. The provision of scale power and propeller speed, as in the more precise wind-tunnel tests, was not considered essential for the investigation and would have involved additional delay and cost.

The means for investigating the effect of the longitudinal restraint imposed by the usual towing procedure were provided by a modification of the gear that permitted fore-and-aft movement of the model with respect to the towing carriage. For convenience, the usual restraint in roll and yaw was retained in the gear.

DESCRIPTION OF MODEL

The model with the motor-driven propellers installed is shown in figure 1. General data regarding the OA-9 amphibian and the corresponding model data are given in table I.

The power was supplied by two 110-volt high-speed series-wound direct-current motors mounted in the existing nacelles. These motors were connected in series across the 240-volt direct-current supply on the towing carriage, their speed being controlled by a series rheostat. They drove the propellers through special planetary-type reduction gears (fig. 2) so designed that the propellers would have a speed to absorb the rated power when the motors turned at their rated speed.

The propellers were two-blade standard wooden model airplane propellers having a diameter of 20 inches and a pitch of 12 inches. The diameter was chosen to correspond approximately to that of the full-size propellers and the pitch was selected for best efficiency in the take-off range of the model.

During runs at low speeds, aluminum "spray disks" (figs. 1 and 2) were used to keep salt water out of the motors, which were necessarily exposed for proper cooling.

Spray striking the rotating disks was deflected outward by centrifugal force. Although the disks had no apparent effect on the static thrust of the propellers, they apparently reduced the thrust slightly at planing speeds and were therefore omitted in the stability tests.

The characteristics of the power installation as compared with those corresponding to the full-size are given in table II. Actually, the rated power of the motors was exceeded somewhat at full voltage, which was 120 volts per motor. The rated revolution speed of the motors was not obtained in the static tests, but tests with propellers at lower blade-angle settings indicate that they turned faster with the model under way; hence, the gear reduction used was approximately correct.

Because of inherent differences in the characteristics of the motors, the starboard propeller ran about 250 rpm faster than the port propeller. The difference in thrust was negligible, however, and a closer balance of the motors was not necessary. The speed and power regulation given by the series rheostat was more than adequate for the purpose of the tests.

The model with power installed was approximately in balance about the design center of gravity and required only a small amount of lead ballast to obtain scale dynamic properties. The pitching moment of inertia of the complete model was determined by swinging as a compound pendulum and was found to be 3.23 slug-feet^2 at the start of the tests.

APPARATUS AND PROCEDURE

The model was tested at the 6-foot water level under the "pusher carriage" where the airspeed near the water is approximately 90 percent of the carriage speed.

The gear providing fore-and-aft freedom for the model is shown in figure 3. It consisted of a light carriage having eight ball-bearing flanged wheels that ran on four machined rails located at the bottom of a special towing pylon (fig. 1). On this carriage were mounted the usual ball-bearing rollers that permit freedom in rise of the towing staff while restraining the model in roll and yaw. Long-stroke pneumatic shock absorbers were fitted at each end of the carriage travel to safeguard the model during possible sudden changes in its speed with respect to the towing carriage.

With this arrangement the model was free to pivot about the center of gravity, to rise, and to move fore and aft. It was thus a free body in a fore-and-aft vertical plane except for the friction of the rollers and the inertia force of the moving carriage. The weight of the complete carriage was 12.5 pounds or about one-fifth the gross weight of the model.

The elevators and the trim brake were operated from the carriage through flexible Bowden cables as in the previous tests. Power was supplied to the motors through a flexible rubber-covered cable having a safety disconnect plug as seen in figure 3. The small moments of the connections were taken into account in balancing the model about the center of gravity.

The effects of power on the aerodynamic lift and pitching moment were determined at a speed of 45 feet per second by supporting the model on the gear just clear of the water and measuring the change of tension in vertical wires supporting the towing staff and the tail. Tests were made with the propellers stopped in a vertical position and with various fractions of the full-input power, as indicated by a voltmeter and an ammeter in the circuit.

The effects of power on stability and control were investigated by determining the usual trim limits of stability with predetermined increments of input power. In these tests, the model was free to rise and to pivot about the center of gravity, the fore-and-aft carriage being locked in a convenient position.

The influence of the propellers on the spray at low speeds was recorded for various amounts of power by motion pictures and photographs. The lighting for the pictures was arbitrarily reduced below that normally used because of the load of the motors on the limited auxiliary power supply.

In preliminary runs with fore-and-aft freedom, the model with flaps down 30° was found to have sufficient power to overcome the hump resistance and to fly. It could not, however, propel itself at high planing speeds near take-off, even at best trim, or at lower planing speeds near the trim limits of stability, which generally represent wide departures from best trim. With the flaps up, however, the power was sufficient to obtain limits of stability when self-propelled because of the reduced aerodynamic drag. The effect of longitudinal freedom on the trim limits of stability was therefore obtained for the flaps-up condition only.

RESULTS AND DISCUSSION

The results of the aerodynamic tests are plotted in figure 4. The general effects of the running propellers near the water were the same as found in wind-tunnel tests (reference 1) except that the shape of the pitching-moment curve was not changed so radically. With the maximum power available, the lift coefficient was increased approximately 43 percent, with a small increase in the slope of the lift curve, and the positive increment in pitching-moment coefficient was about 0.11.

The increase in lift is roughly proportional to the applied power at low power but falls off at higher powers. Apparently, at lower power the slipstream acts to correct the general blanketing of the wing by the large nacelles. Once the proper flow is well established, further increments of power have only a slight effect on the lift by increasing the slipstream velocity over a relatively small percentage of the wing. The same trends appear in the pitching-moment curves, the effects in this case being associated with the blanketing of the tail surfaces by the nacelles and flaps.

Aerodynamic tests at various elevator settings were not included in the present program but the effect of power on the effectiveness of the elevators near the surface of the water may be judged from figure 5. These curves show the minimum trim attained with full-down elevator and various amounts of power near the hump speed, where changes in trim correspond to large changes in hydrodynamic trimming moment. Here again, the effect of a given increment of power is greater at low powers, indicating a marked improvement in the flow over the tail surfaces given by a small amount of slipstream.

The effect of power on the trims at which porpoising starts (limits of stability) is shown in figure 6 to be quite large. The trends with increase in power are similar to those obtained from tests of other models with changes in load except for the upper limit, increasing trim, which was definitely not affected by the application of power. The character of the porpoising beyond the limits was not essentially changed by the slipstream. More care was required in passing through the limits because of the greater range of available trims beyond them. The effect of various increments of power was generally similar to that obtained on lift in the aerodynamic tests. The influence of power on the limits of stability is therefore attributed mainly to the changes in the lift and hence in the load on the water, with power.

Longitudinal freedom of the center of gravity (fig. 7) has a negligible effect on the limits of stability. This result confirms the similar conclusion from a theoretical study by Perring and Glauert (reference 2). It was interesting to note, however, that during porpoising the center of gravity moved appreciably fore and aft with respect to the towing carriage and that this movement was greater for the upper limit type of porpoising. The actual travel was of the order of 1 or 2 inches and was, of course, reduced somewhat by the inertia of the fore-and-aft carriage. It was also interesting to note that considerably more power was required for self-propulsion during porpoising than for steady running at the same trim and speed.

The effect of the propellers on the spray at various speeds and powers is shown in figures 8 to 13. All these photographs were taken with neutral elevator so that the effect of reduction in trim due to thrust moment was included. The change in trim with the application of full power was negligible at 14 feet per second, about 3° at 17 feet per second, and about 4° at 20 feet per second.

The greatest interference with the bow spray was found to occur between 8 and 14 feet per second and two different effects were noticed. At first the bow wave, normally clear of the propeller disks, was sucked up ahead of and into the propellers as high as their centers where it was broken up by impact with the blades and blown backward over the wings and the tail. This effect, seen in figures 8 and 9, would cause maximum damage to the propellers and wetting of the engines and carburetor intakes. At a slightly higher speed, (fig. 10) the spray ahead of the propeller disks was unaffected and the propeller tips were clear but the spray literally jumped up into the slipstream just aft of the tips, where it was blown back onto the under surface of the wing and the flaps. At this stage, the maximum damage to the aerodynamic structure would be likely to take place.

At 17 feet per second (fig. 11) the bow spray had moved aft of the propeller disks and the under side of the wing was clear, the combined effect of the slipstream and thrust moment being to lower the height of the bow blister with respect to the flaps.

At speeds above the hump (figs. 12 and 13) the effect of power was to reduce the height and the amount of spray striking the horizontal tail surfaces. Throughout the speed range, the effects of the running propellers on the spray characteristics were almost as great with 1/4 power as with full power, but more damage was sustained by the model at full power because of the higher speed of the propeller tips and slipstream.

The most important result of the spray tests was the establishment of the narrow speed range below the hump speed over which the maximum spray and spray damage occurred. Unfortunately, this range is probably greatly broadened in practice by the presence of wind and waves.

SUMMARY OF RESULTS

A. Aerodynamic effects of powered propellers:

1. The lift of the model was increased 18 percent at 1/4 power, 30 percent at 1/2 power, and 43 percent at full power. The slope of the lift curve and the angle of maximum lift were slightly increased.

2. The pitching moment was increased in a positive direction. The slope of the pitching-moment curve was affected only slightly.

B. Hydrodynamic effects of powered propellers:

1. Elevator effectiveness was greatly increased.

2. The lower limit of stability was lowered 3° at 1/4 power and 5° at full power at 25 feet per second; 0.3° at 1/4 power and 0.6° at full power at 50 feet per second.

3. The upper limit of stability, increasing trim, was not affected.

4. The upper limit of stability, decreasing trim, was lowered generally; at 35 feet per second the reduction was 1° at 1/4 power and 2.5° at full power.

5. Self-propulsion with fore-and-aft freedom of the center of gravity had a negligible effect on the limits of stability. More power was required for propulsion at constant speed when porpoising than for steady conditions.

6. The rotating propeller blades and the slipstream greatly increased the height and the volume of undesirable spray entering the propeller disks. The slipstream reduced the height and amount of water striking the tail surfaces at high speeds. The change in spray pattern in going from 0 to 1/4 power was greater than in going from 1/4 to full power.

CONCLUSIONS

1. The use of powered propellers in tank tests of dynamically similar seaplane models is desirable for the adequate investigation of stability and spray characteristics.

2. The magnitude of the effects of power in such tests decreases, in general, with additional increments of power. Under-powering to save weight and inertia, or cost, would be preferable to neglecting entirely the effects of the running propellers.

3. For more precise investigations of stability, control, and dynamic properties while on the water or determination of the limits in take-off weight imposed by spray characteristics for new seaplane designs, the provision of scale power and revolution speed would probably be advisable.

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REFERENCES

1. Millikan, Clark B.: The Influence of Running Propellers on Airplane Characteristics. Jour. Aero. Sci., vol. 7, no. 3, Jan. 1940, pp. 85-106.

2. Perring, W. G. A., and Glauert, H.: The Stability on the Water of a Seaplane in the Planing Condition. R. & M. No. 1493, British A.R.C., 1933.

TABLE I

Army OA-9 Amphibian - NACA Model 117

GENERAL DATA

	Full size	Model
Hull:		
Length of forebody, in.	175.00	35.00
Length of afterbody, in.	148.25	29.65
Length over-all, in.	460.00	92.00
Beam, in.	59.50	11.90
Depth of main step, station 16, in.	3.00	.60
Depth of second step, station 29, in.	4.38	.87
Dead-rise angle at main step, excluding flare, deg	25	25
Angle between keel lines at main step, deg	7.5	7.5
Angle between forebody keel and base line, deg	-2.1	-2.1
Angle between afterbody keel and base line, deg	9.6	9.6
Wing:		
Area, sq ft	375	15.0
Span, in.	588.0	117.60
Root chord, in. (NACA 23015 section)	120.0	24.00
Tip chord, in. (NACA 23009 section)	60.0	12.00
Angle of wing setting to base line, deg	3.0	3.0

TABLE I (continued)

	Full size	Model
Mean aerodynamic chord (M.A.C.)		
Length, in.	97.40	19.48
Angle to base line, deg	3	3
L.E. aft of bow, in.	136.05	27.21
L.E. forward of main step, in.	38.95	7.79
Propellers:		
Angle of thrust line to base line, deg	3	3
Height of thrust line above keel at step, in.	94.38	18.87
Propeller center line forward L.E. M.A.C., in.	57.92	11.58
Gross load, normal, lb	7925	63.4
Center-of-gravity location:		
Horizontal, percent M.A.C.	22.6	22.6
Forward of step, percent length of M.A.C.	18.2	T8.2
Vertical, above keel at step, percent length of M.A.C.	79.2	79.2
Maximum forward position, percent M.A.C.	16.2	16.2
Maximum rearward position, percent M.A.C.	29.1	29.1
Pitching moment of inertia about normal c.g., slug-ft^2	10,636	3.41

TABLE II

Engine and Propeller Characteristics

OA-9 airplane power plant - Two Pratt & Whitney radial air-cooled engines, Model R-985-17

Propellers - Two-blade Hamilton Standard constant speed

	Full size	Model Scale value	Model Actual value
Rated horsepower, take-off	900	3.2	1.8
Rated speed, take-off, rpm	2300	5150	15,000
Gear ratio	1:1	1:1	3.286:1
Propeller speed, rpm	2300	5150	4560
Propeller diameter, in.	102	20.4	20
Propeller blade-angle setting at 0.823R, deg	12 to 23	12 to 23	13

Model characteristics from static test

Power	1/4	1/2	3/4	Full
Input to motors, hp	0.77	1.54	2.31	3.08
Propeller speed, rpm	2500	3300	3800	[a]4150
Static thrust, lb	5.8	11.0	15.0	[a]18.0

[a]Estimated

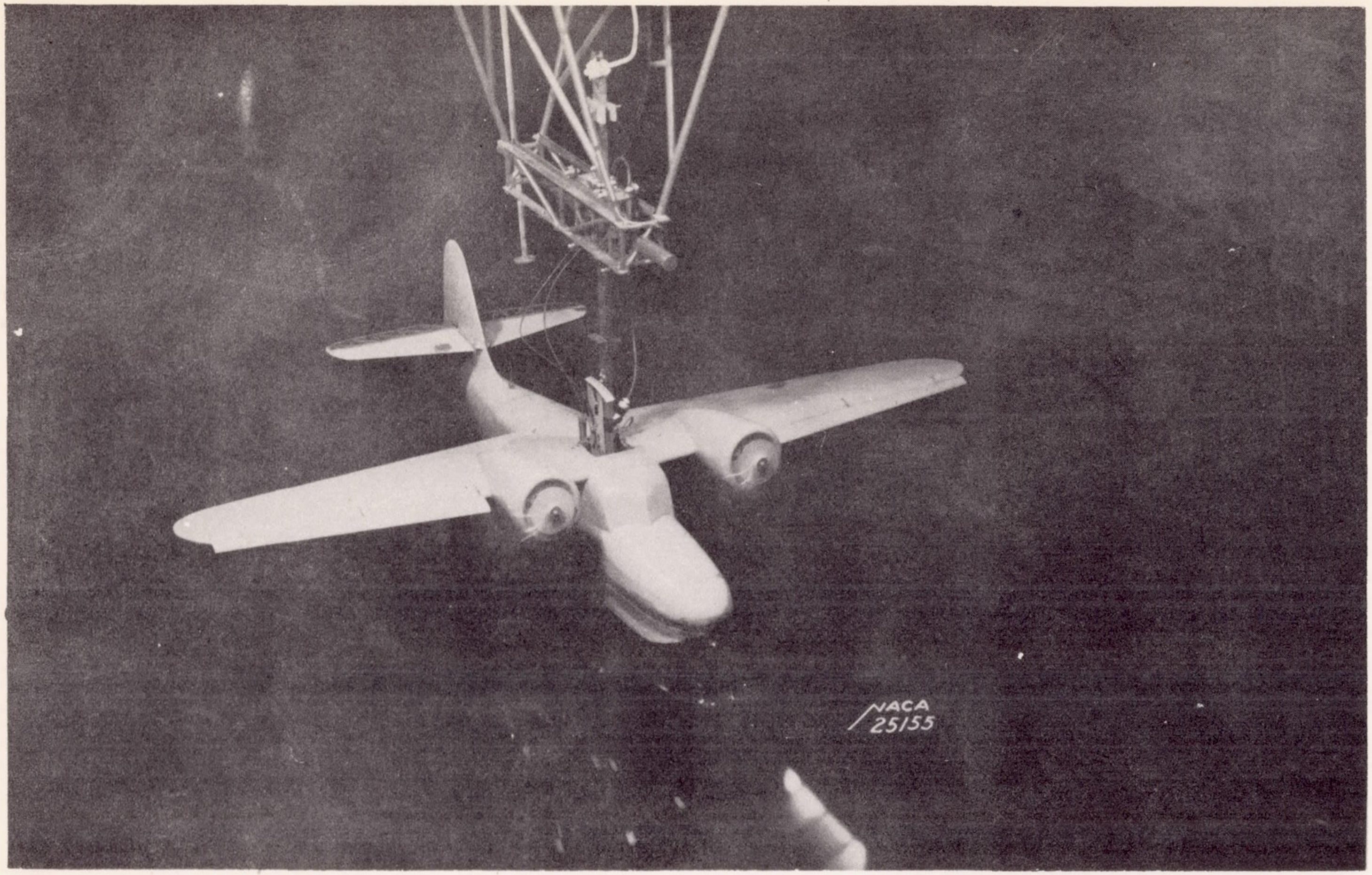

Figure 1.- Set-up for NACA model 117 with motor-driven propellers.

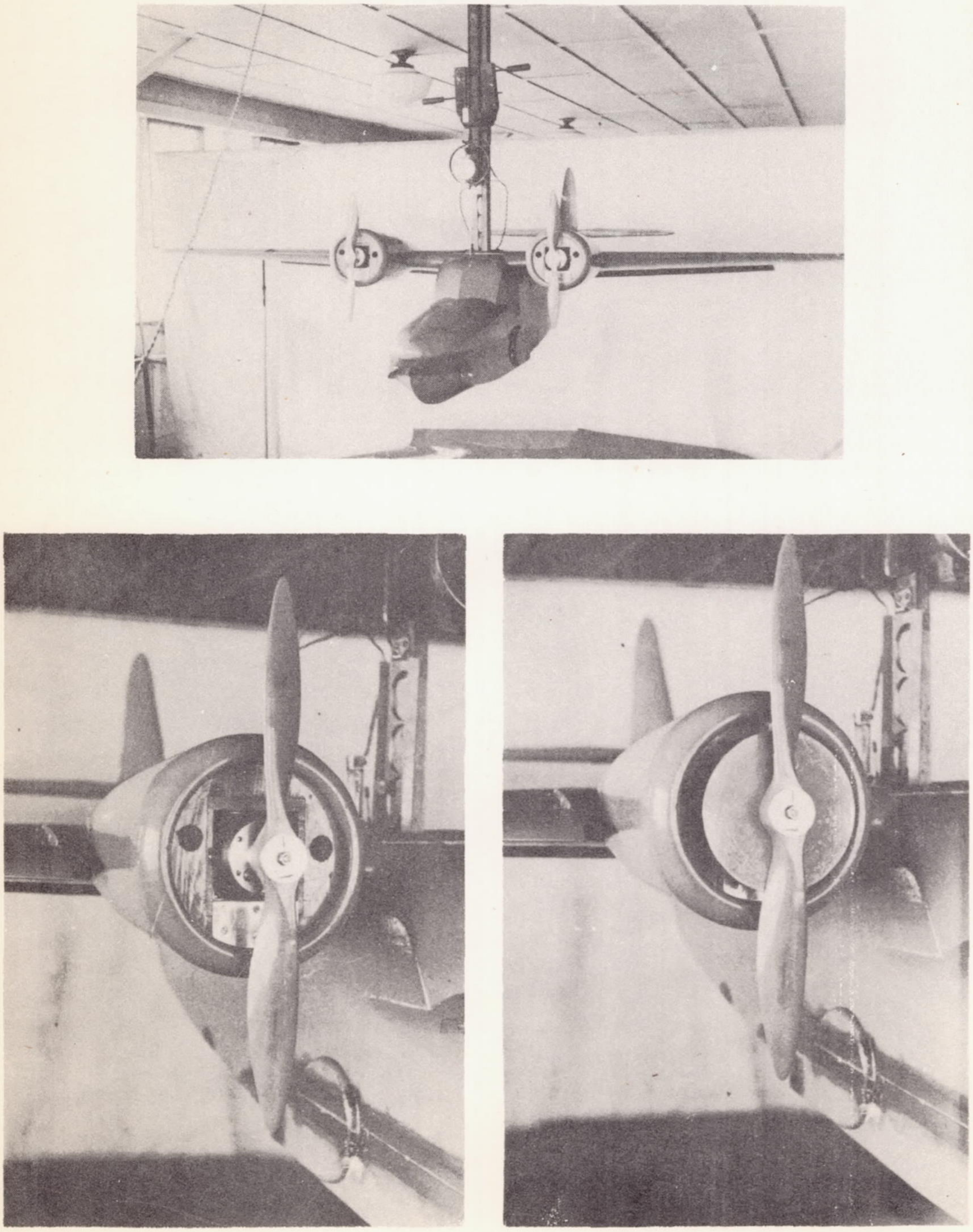

Fig. 2. Model 117. Installation of motors in nacelles, showing reduction gear and spray disc.

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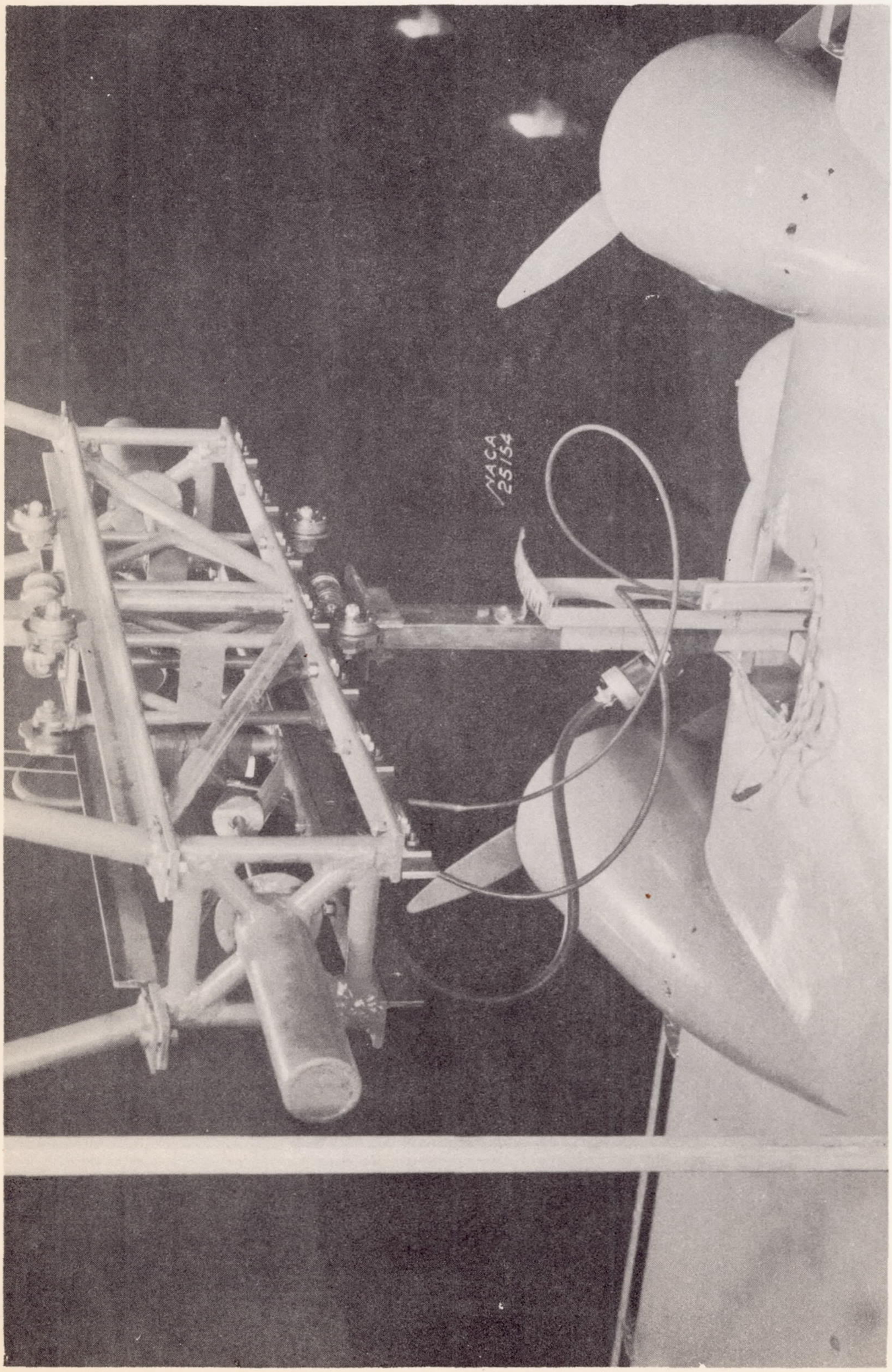

Figure 3.- Towing gear for providing fore-and-aft freedom.

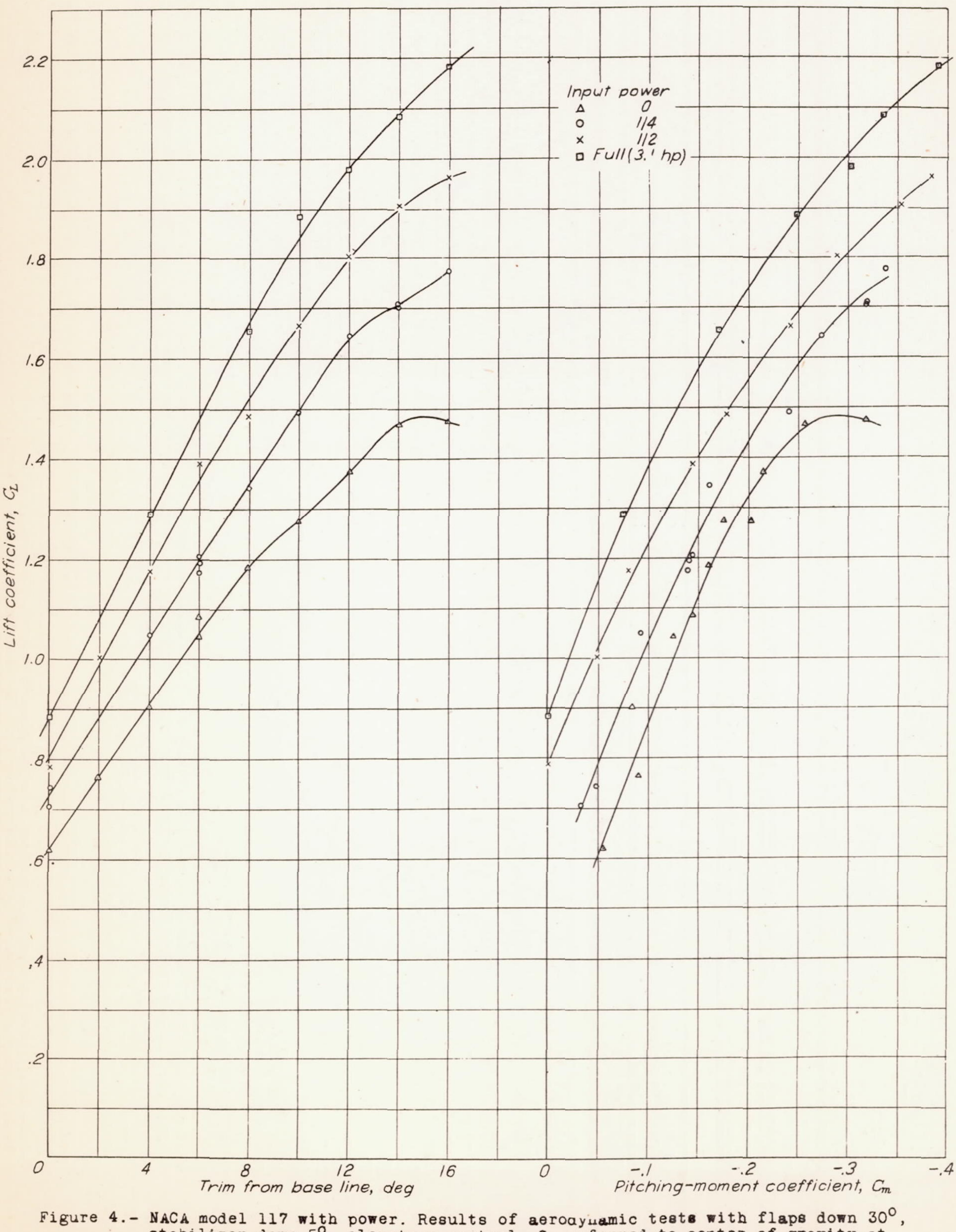

Figure 4.- NACA model 117 with power. Results of aerodynamic tests with flaps down 30°, stabilizer down 5°, elevators neutral. C_m referred to center of gravity at 22.6 percent M.A.C. Height of center of gravity was such that afterbody was just clear of water at 16° trim.

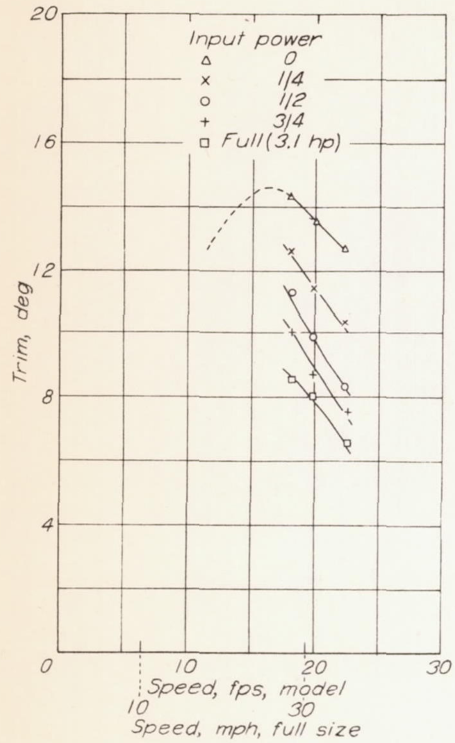

Figure 5.- NACA model 117. Effect of power on minimum trim available at speeds just beyond hump speed. Elevators full down, flaps down 30°.

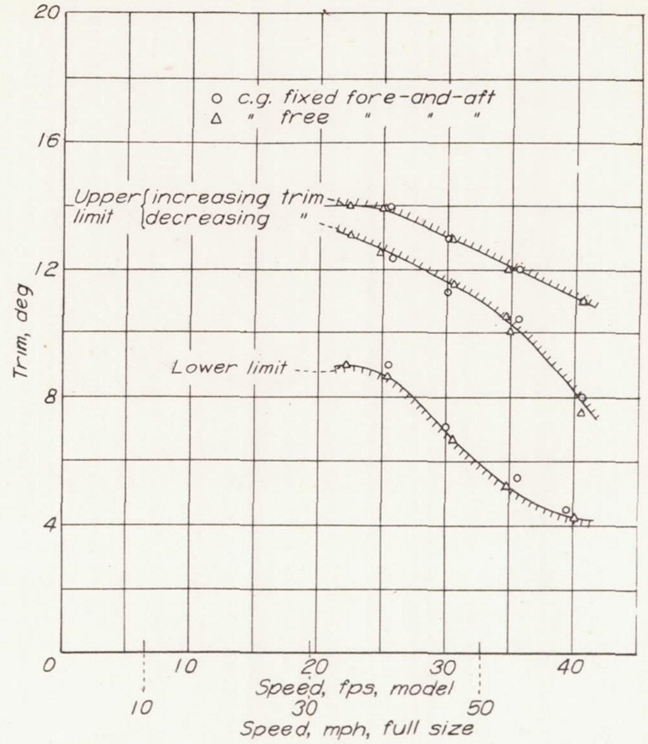

Figure 7.- NACA model 117. Effect of fore-and-aft freedom of the center of gravity on limits of stability. Flaps up. Power applied at each speed and trim was that required for self-propulsion at constant speed.

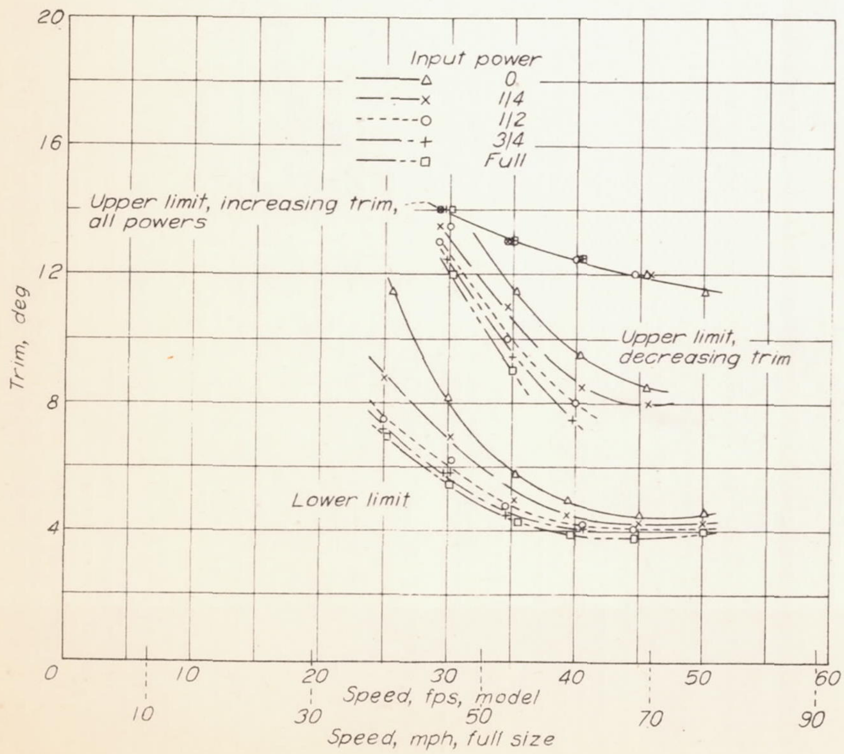

Figure 6.- NACA model 117. Effect of power on limits of stability. Flaps down 30°

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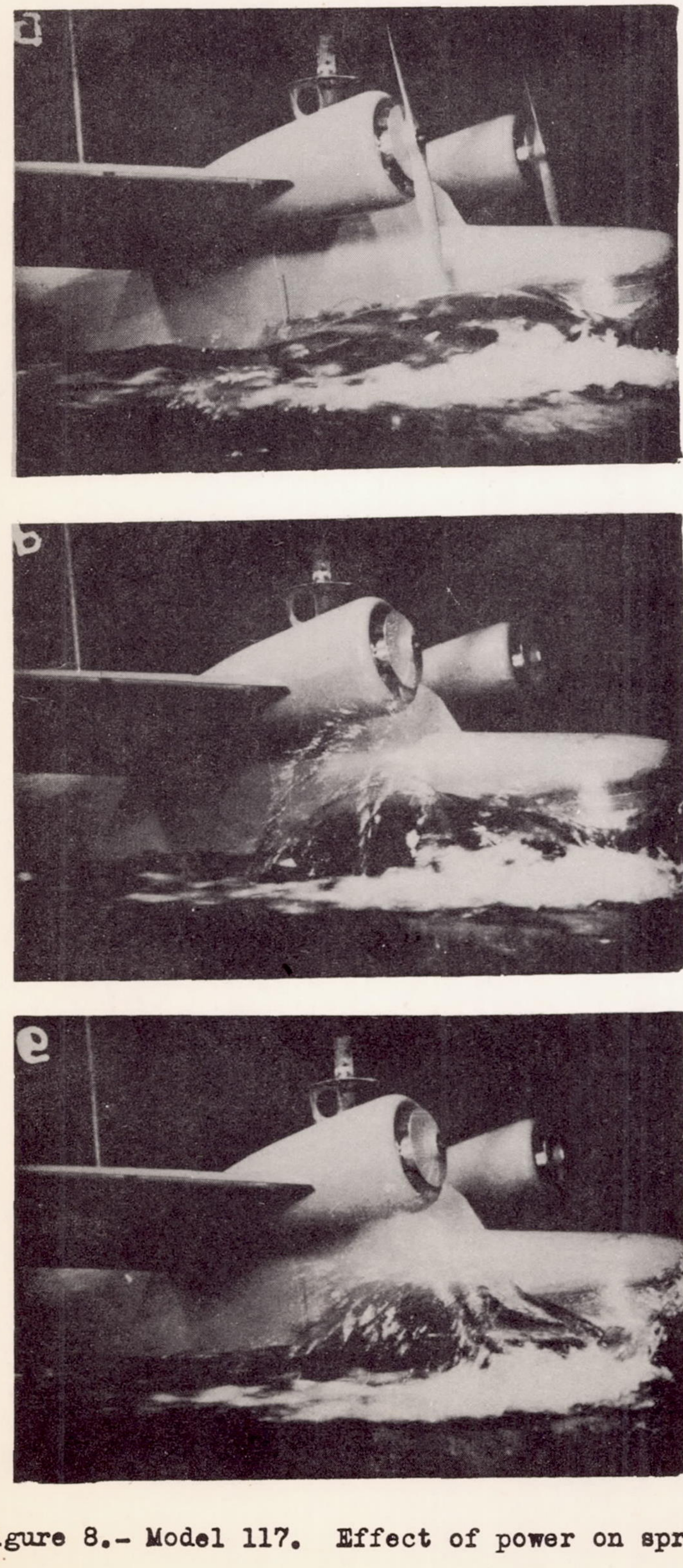

0 power

1/4 power

Full power

Figure 8.- Model 117. Effect of power on spray at 8 f.p.s.

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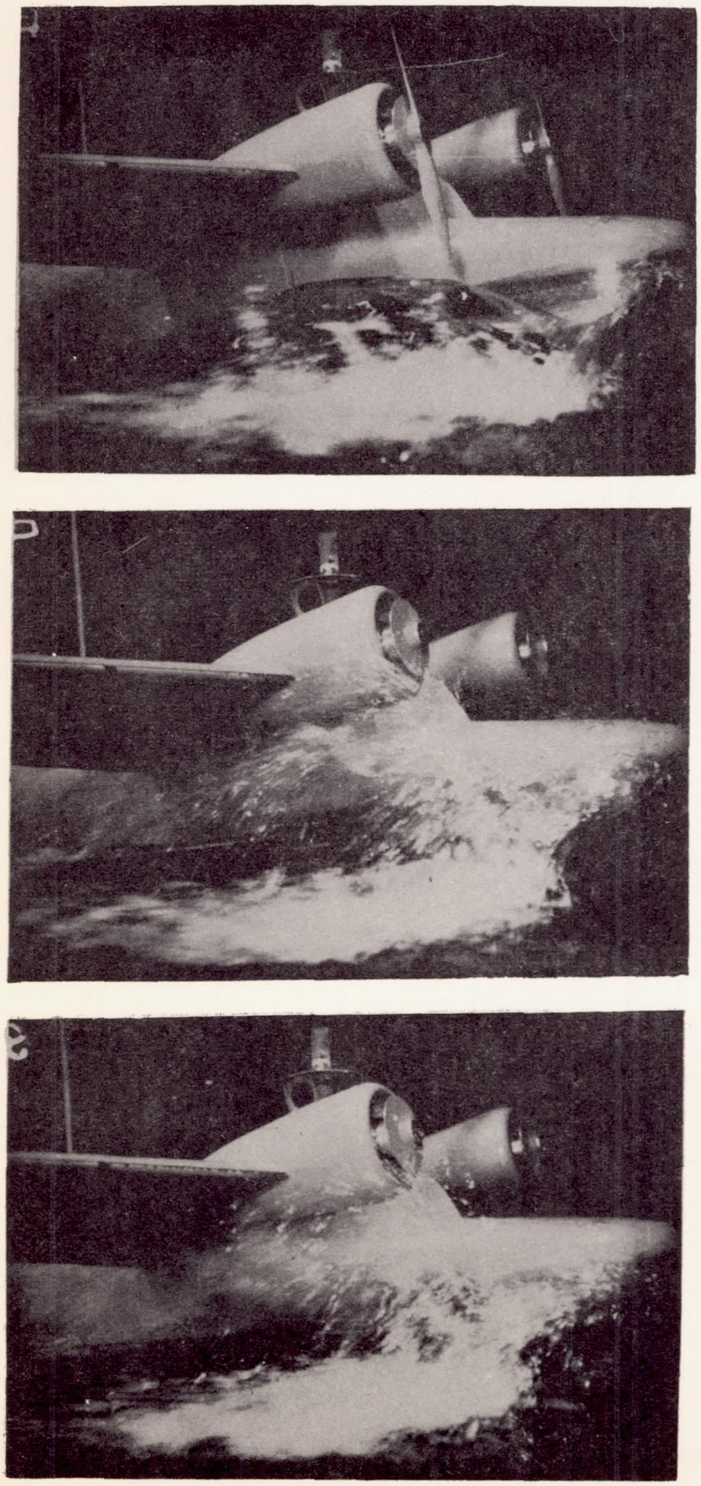

0 power

1/4 power

Full power

Figure 9a.- Model 117. Effect of power on spray at 11 f. p. s.

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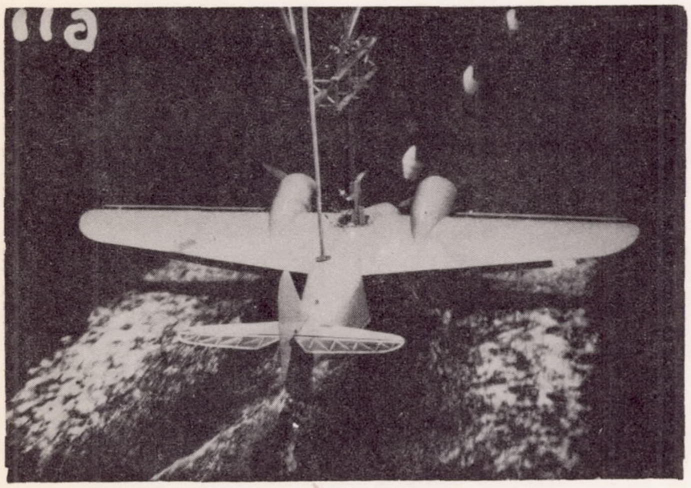

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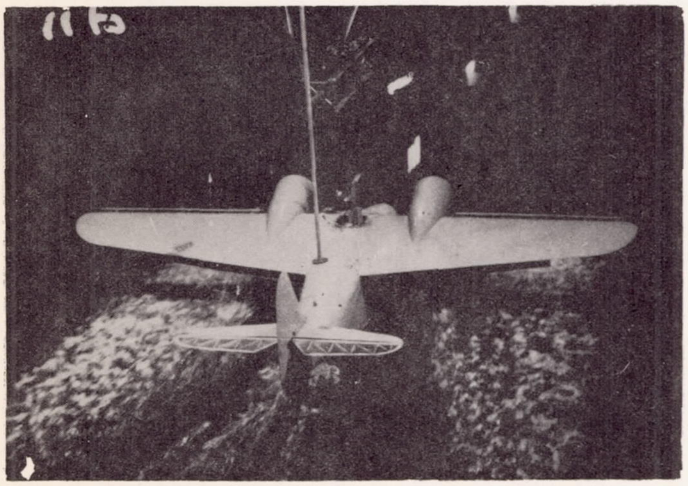
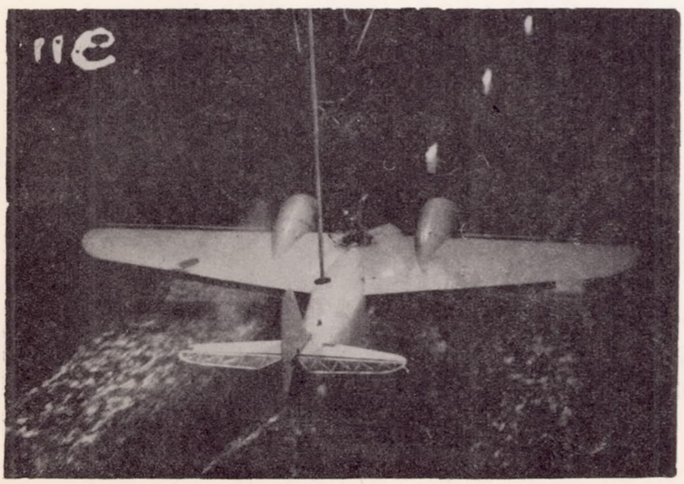


1/4 power



Full power

Figure 9b.- Model 117. Effect of power on spray at 11 f.p.s.

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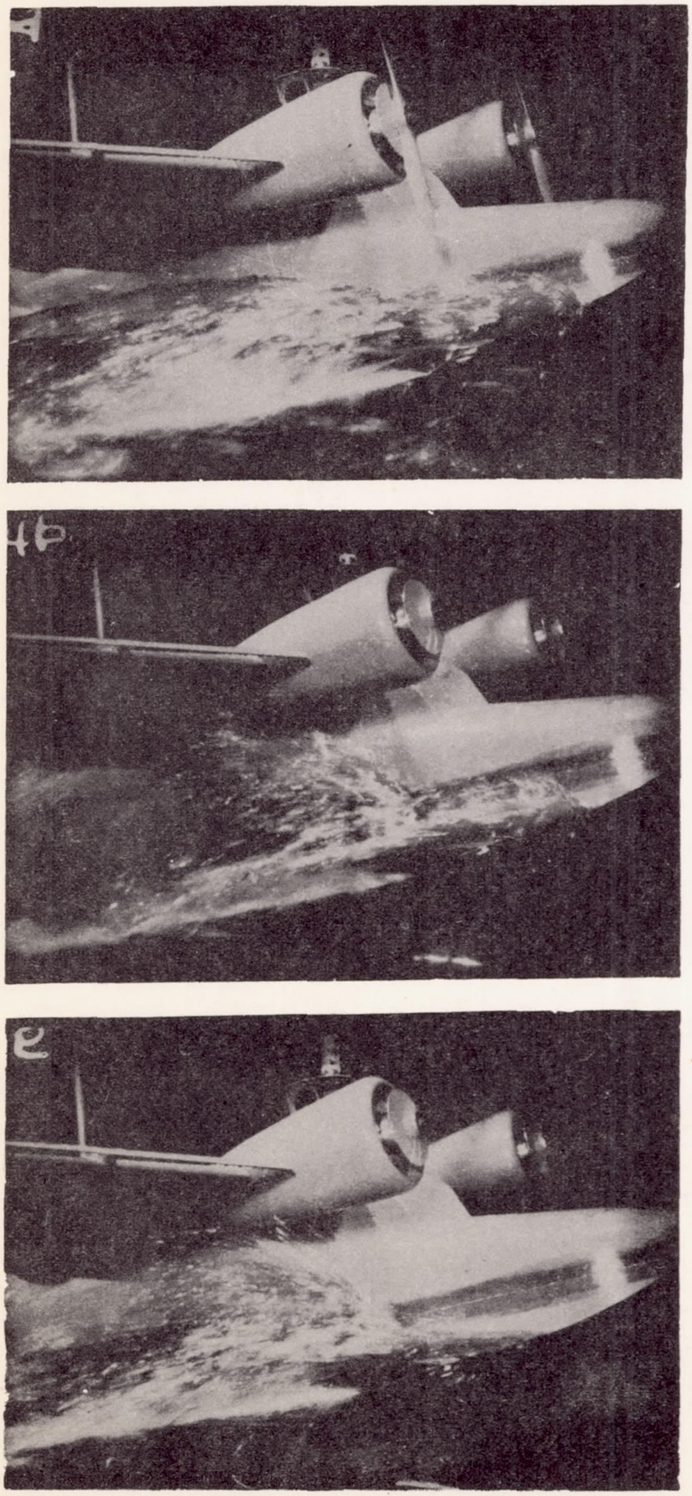
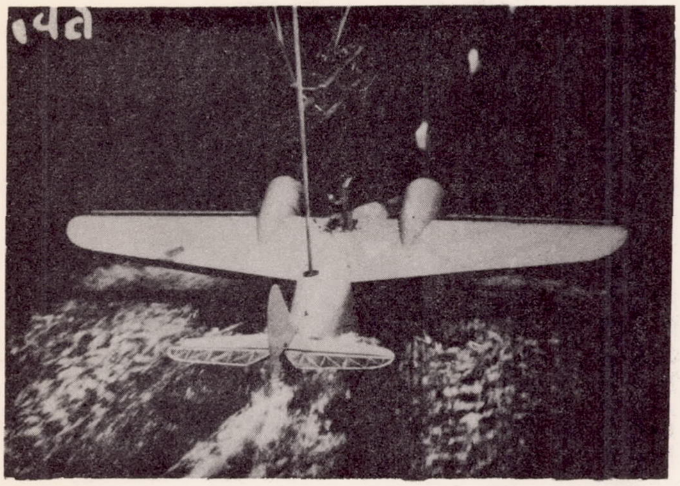


0 power

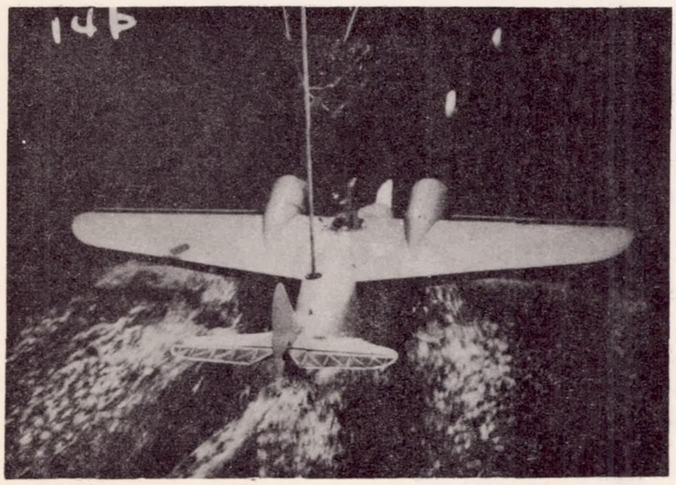
1/4 power

Full power

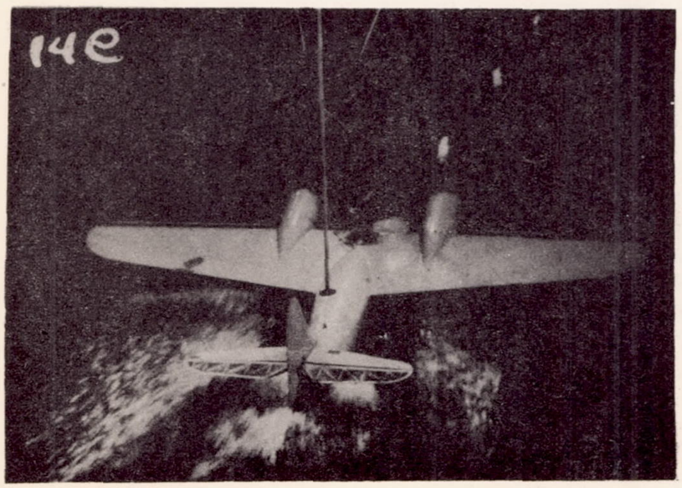
Figure 10a.- Model 117. Effect of power on spray at 14 f.p.s.



0 power



1/4 power



Full power

Figure 10b.- Model 117. Effect of power on spray at 14 f p s

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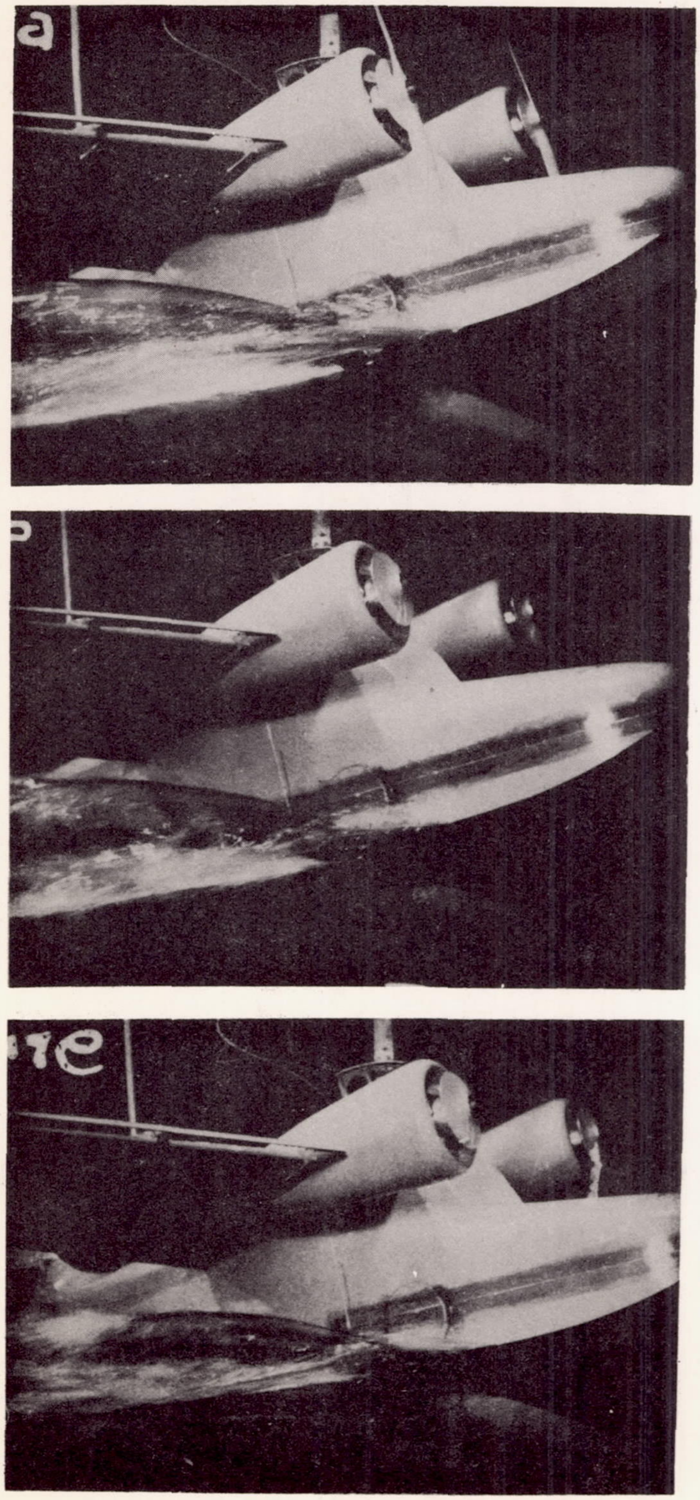
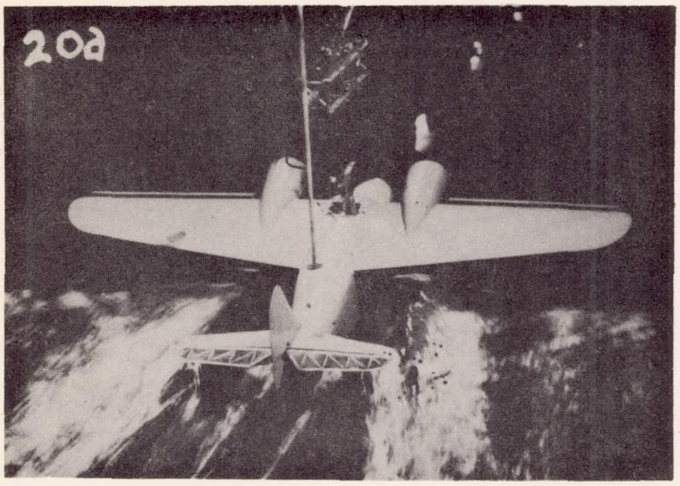


0 power

1/4 power

Full power

Figure 11.- Model 117. Effect of power on spray at 17 f.p.s.



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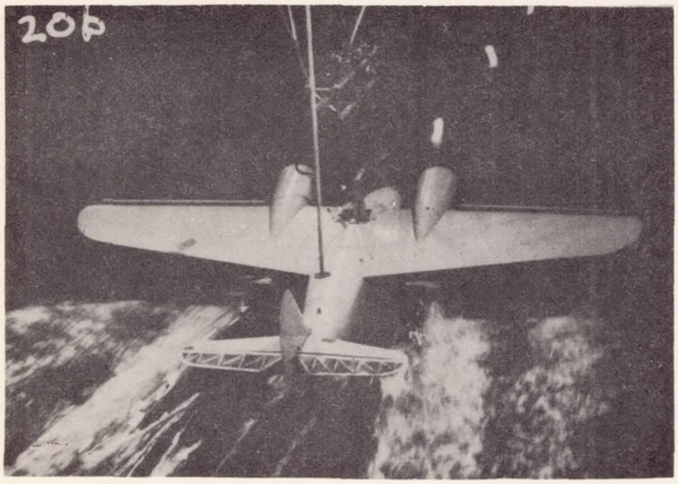
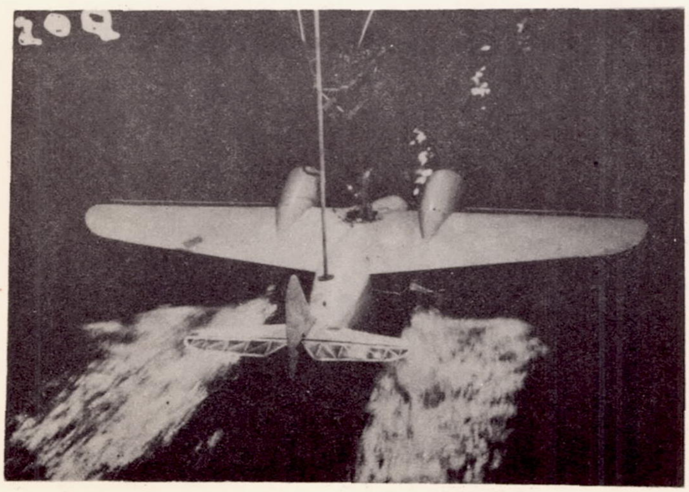
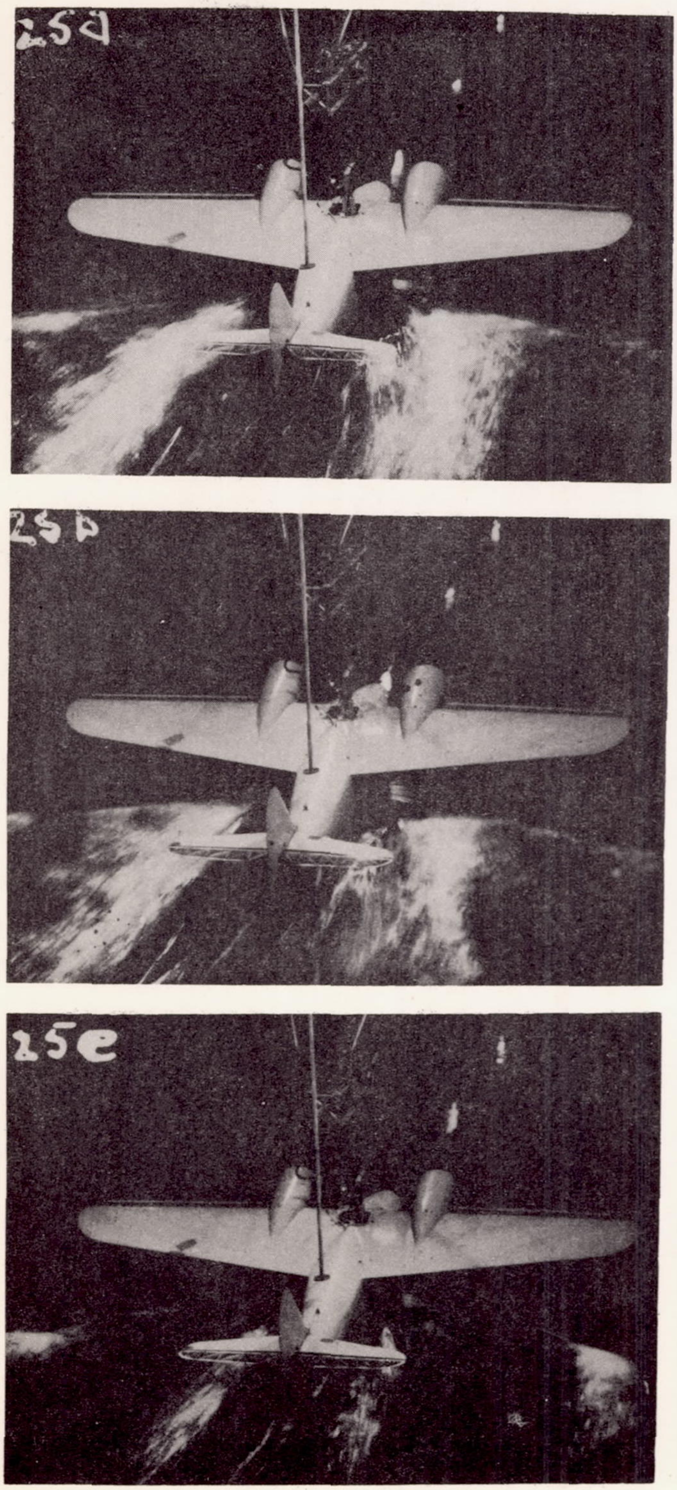


1/4 power



Full power

Figure 12.- Model 117. Effect of power on spray at 20 f p s.



0 power

1/4 power

Full power

Figure 13.- Model 117. Effect of power on spray at 25 f.p.s