NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 870

TANK INVESTIGATION OF A POWERED DYNAMIC MODEL OF A LARGE LONG-RANGE FLYING BOAT

By JOHN B. PARKINSON, ROLAND E. OLSON, and MARVIN I. HAAR

1947

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - - - - - - - - - Price 20 cents

AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft (or mi)
Time	t	second	s	second (or hour)	sec (or hr)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb
Power	P	horsepower (metric)		horsepower	hp
Speed	V	kilometers per hour	kph	miles per hour	mph
		meters per second	mps	feet per second	fps

2. GENERAL SYMBOLS

W Weight $=mg$

g Standard acceleration of gravity $=9.80665$ m/s^2 or 32.1740 ft/sec^2

m Mass $=\frac{W}{g}$

I Moment of inertia $=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ Coefficient of viscosity

ν Kinematic viscosity

ρ Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C and 760 mm; or 0.002378 lb-ft^{-4} sec^2

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb/cu ft

3. AERODYNAMIC SYMBOLS

S Area

S_w Area of wing

G Gap

b Span

c Chord

A Aspect ratio, $\frac{b^2}{S}$

V True air speed

q Dynamic pressure, $\frac{1}{2}\rho V^2$

L Lift, absolute coefficient $C_L=\frac{L}{qS}$

D Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_0 Profile drag, absolute coefficient $C_{D_0}=\frac{D_0}{qS}$

D_i Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

i_w Angle of setting of wings (relative to thrust line)

i_t Angle of stabilizer setting (relative to thrust line)

Q Resultant moment

Ω Resultant angular velocity

R Reynolds number, $\rho\frac{Vl}{\mu}$ where l is a linear dimension (e.g., for an airfoil of 1.0 ft chord, 100 mph, standard pressure at 15° C, the corresponding Reynolds number is 935,400; or for an airfoil of 1.0 m chord, 100 mps, the corresponding Reynolds number is 6,865,000)

α Angle of attack

ϵ Angle of downwash

α_0 Angle of attack, infinite aspect ratio

α_i Angle of attack, induced

α_a Angle of attack, absolute (measured from zero-lift position)

γ Flight-path angle

REPORT No. 870

TANK INVESTIGATION OF A POWERED DYNAMIC MODEL OF A LARGE LONG-RANGE FLYING BOAT

By JOHN B. PARKINSON, ROLAND E. OLSON, and MARVIN I. HAAR

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW, Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 49, sec. 241). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT CONSTRUCTION
OPERATING PROBLEMS
SELF-PROPELLED GUIDED MISSILES
INDUSTRY CONSULTING

Coordination of Research Needs of Military and Civil Aviation
Preparation of Research Programs
Allocation of Problems
Prevention of Duplication
Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
Langley Field, Va.

AMES AERONAUTICAL LABORATORY,
Moffett Field, Calif.

FLIGHT PROPULSION RESEARCH LABORATORY,
Cleveland Airport, Cleveland, Ohio

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

---

OFFICE OF AERONAUTICAL INTELLIGENCE,
Washington, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

REPORT No. 870

TANK INVESTIGATION OF A POWERED DYNAMIC MODEL OF A LARGE LONG-RANGE FLYING BOAT

By John B. Parkinson, Roland E. Olson, and Marvin I. Harr

SUMMARY

Principles for designing the optimum hull for a large long-range flying boat to meet the requirements of seaworthiness, minimum drag, and ability to take off and land at all operational gross loads were incorporated in a 1/12-size powered dynamic model of a four-engine transport flying boat having a design gross load of 165,000 pounds. These design principles included the selection of a moderate beam loading, ample forebody length, sufficient depth of step, and close adherence to the form of a streamline body.

The aerodynamic and hydrodynamic characteristics of the model were investigated in Langley tank no. 1. Tests were made to determine the minimum allowable depth of step for adequate landing stability, the suitability of the fore-and-aft location of the step, the take-off performance, the spray characteristics, and the effects of simple spray-control devices. The test results indicated that: Landing stability was satisfactory with a depth of step of 9 percent beam at the centroid; the hydrodynamic center-of-gravity range for stable take-offs was satisfactory as to extent and position with respect to the stable flight range desired; the take-off performance was satisfactory for the power loading assumed; the relation of the proportions to the design loading of the hull was correct for satisfactory spray characteristics; and large overloads were possible with relatively simple spray-control devices. The application of the design criterions used and test results should be useful in the preliminary design of similar large flying boats.

INTRODUCTION

In reference 1, principles for designing the optimum hull for a large long-range flying boat were proposed to meet the requirements of seaworthiness, minimum drag, and ability to take off and land at all operational gross loads. These principles included the selection of a moderate beam loading, ample forebody length, sufficient depth of step, and close adherence to the form of a streamline body.

Figure 5 of reference 1 shows the lines of an experimental hull form illustrating the application of the proposed principles. This form has since been incorporated in a powered dynamic model of a four-engine transport flying boat, Langley tank model 180, and has been tested in Langley tank no. 1. The investigation included the determination of the aerodynamic lift and pitching moment, take-off and landing stability, spray chracteristics, and excess thrust of the powered model.

The present paper summarizes the results of the tests for use in the application of the hull lines to the design of similar airplanes. This paper also further illustrates the procedure for the design of flying-boat hulls outlined in reference 1 and redefines the hydrodynamic criterions used in the Langley tanks for evaluating depth or ventilation of the step, fore-and-aft location of the step, and effectiveness of devices for control of spray. The modifications investigated are typical of small changes in hull lines that offer the possibility of large improvements in the hydrodynamic characteristics if their effects are judged in the terms of the pertinent full-size performance criterions.

SYMBOLS

C_Δ	load coefficient (Δ/wb^3)
C_{Δ_0}	gross-load coefficient (Δ_0/wb^3)
C_V	speed coefficient ($V/\sqrt{gb}$)
k	forebody-spray coefficient $\left(\frac{C_{\Delta_0}}{(L_f/b)^2}\right)$
C_L	aerodynamic lift coefficient $\left(\frac{\text{Lift}}{\frac{1}{2}\rho SV^2}\right)$
C_m	aerodynamic pitching-moment coefficient $\left(\frac{M}{\frac{1}{2}\rho SV^2\bar{c}}\right)$
T_e	effective thrust, pounds ($T-\Delta D=D_c+R$)
b	maximum beam over chines, feet
$\bar{c}$	mean aerodynamic chord (M.A.C.), feet
D_c	drag of model without propellers, pounds
ΔD	increase in drag due to slipstream, pounds
Δ	load on water, pounds
Δ_0	gross load, pounds
g	acceleration of gravity, feet per second per second
L_f	length of forebody from bow to step centroid, feet
M	aerodynamic pitching moment, foot-pounds
R	measured resultant horizontal force with power on, pounds
ρ	density of air, slugs per cubic foot
S	area of wing, square feet
T	propeller thrust, pounds
V	carriage speed, feet per second (approx. 95 percent of airspeed)
w	specific weight of water, pounds per cubic foot (63.2 for these tests; usually taken as 64 for sea water)
δ_e	elevator deflection, degrees
δ_f	flap deflection, degrees
τ	trim (angle between base line of hull and water plane), degrees

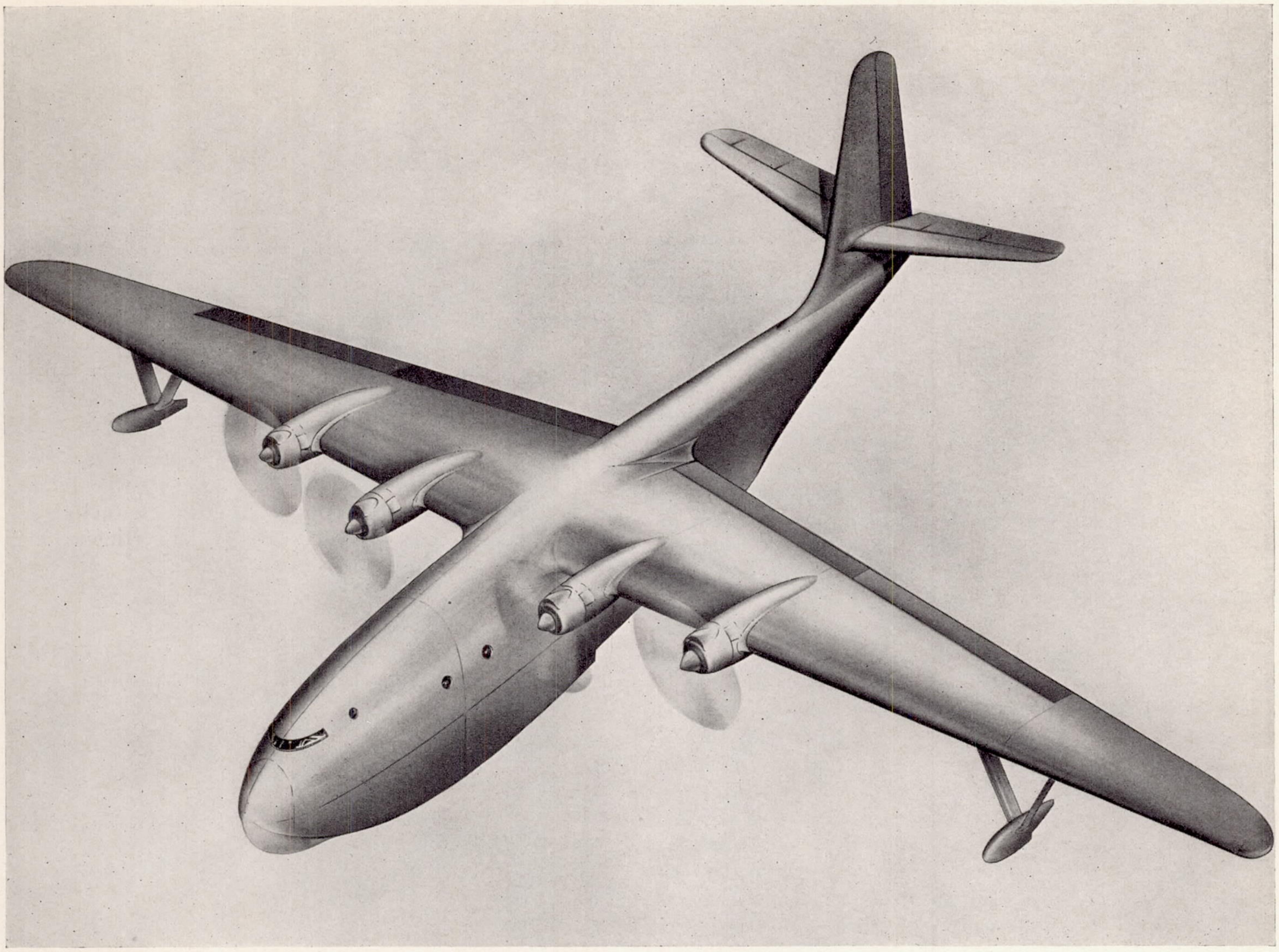


FIGURE 1.—Perspective drawing of proposed airplane.

DESCRIPTION OF MODEL

OVER-ALL DESIGN

Langley tank model 180 represents a long-range transport seaplane powered by four 3000-horsepower engines and having a design gross load of 165,000 pounds. Such a seaplane should be seaworthy in sheltered waters and moderate open-sea conditions, should have a considerable range of hydrodynamic as well as aerodynamic stable positions of the center of gravity to accommodate a variety of loading conditions, and should be capable of overloading for economy on long over-ocean flights. The hydrodynamic design generally should be conservative to allow for the variety of operating conditions encountered in long-range commercial service without undue impairment of the primary functions of the airplane.

A perspective drawing of the type of airplane represented by model 180 is shown in figure 1; the aerodynamic and propulsive characteristics and hull dimensions for its design are given in table I. The general arrangement of the model, which is 1/12 full size, is shown in figure 2.

HULL DESIGN

The hull was designed according to the procedure of reference 1 after the general specifications and over-all design had been determined.

Beam.—The beam was selected to give a satisfactory functional width of fuselage for the type of airplane and to give a value of the gross-load coefficient (beam loading) near the upper limit recommended in reference 1 for conventional length-beam ratios. From the expression for gross-load coefficient

$$C_{\Delta_0}=\frac{\Delta_0}{wb^3}$$

the beam of 15 feet and the design gross load of 165,000 pounds correspond to a C_{Δ_0} of 0.76.

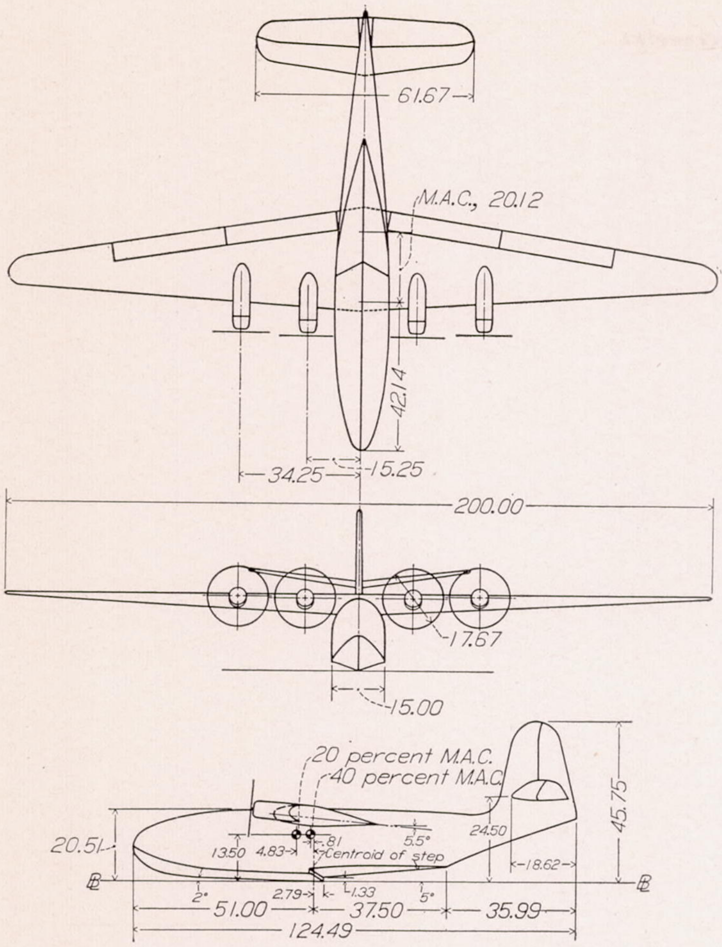


FIGURE 2.—General arrangement of Langley tank model 180. (All dimensions are in inches.)

In considering the design wing and power loadings, some overloading should be anticipated in the airplane design in order to make operation possible under extreme loading conditions. If an overload gross load of 185,000 pounds is assumed, the gross-load coefficient becomes 0.86, which is still within the range of those currently used for conventional hulls. The actual hydrodynamic limit in load depends on the spray characteristics and stability of the specific configuration, as well as the power loading, and is a subject for additional investigation both in the tank and after the airplane is placed in operation.

Length.—The length of the forebody was selected to provide a satisfactory functional length of fuselage ahead of the center of gravity, and a conservative length-beam ratio for the gross-load coefficient was chosen to insure adequate spray control and seaworthiness at low speeds. From the following relation from reference 2

$$C_{\Delta_0}=k\left(\frac{L_f}{b}\right)^2$$

the forebody length-beam ratio of 3.4 gives a value of k of 0.066 for the design gross load, which, from experience with similar configurations, insures sufficient length of forebody. The overload gross load corresponds to a value of k of 0.074, which was within the accepted range in reference 2 for an overload condition, although not the value recommended for the design condition.

The afterbody length-beam ratio of 2.5 was selected arbitrarily from previous experience. This value was checked by a preliminary load water-line calculation to insure sufficient buoyancy aft of the center of gravity and to insure longitudinal stability for the static condition. The length-beam ratio of forebody plus afterbody therefore is 5.9, which is representative of design practice for the assumed gross-load coefficient.

Depth.—The depth of the hull was chosen from experience with a similar model to correspond to a height of the buried wing root that gives satisfactory clearance from spray for the propellers and flaps. The depth of the hull is also suitable for the layout of two full decks, which would be desirable for a transport fuselage of the size represented.

Step.—As stated in reference 1, a 30° V-step was selected in preference to a transverse step on the basis that less mean depth would be required for adequate landing stability. The forebody and afterbody lengths are then referred to the center of gravity of the step plan form (centroid). A tentative depth of step of 6.5 percent beam at the centroid was selected with the assumption that the final depth would be based on the landing stability of the model. The relative fore-and-aft location of the step and wing was selected so that a line from the step centroid to the mean design location of the center of gravity (30 percent M.A.C.) makes an angle of 12° with the vertical. This angle is the same as the estimated angle of trim for a full-stall landing as proposed in reference 1, with the assumption that the final location of the step would be based on the take-off stability of the model, particularly the location of the forward limit of stable positions of the center of gravity.

Angle between forebody and afterbody keels.—The angle between the keels has a marked effect on the trim and spray at taxying speeds. The value of 7° used is a good compromise for most flying-boat hulls to give satisfactory trims up to the hump speed and acceptable resistance at speeds approaching take-off.

Shape.—The lines of the hull are shown in figure 3 and detailed offsets of the form are given in table II. Since the height of hull at the wing root is greater than the maximum beam, the basic form of the hull for minimum drag was taken as a streamline body with elliptical cross sections to which the forebody and afterbody planing surfaces were added and blended as harmoniously as possible by means of drawing-board layouts. The plan form of the hull and the variation of the minor axes of the ellipses are the same as the thickness variation of the NACA 00 series of airfoils (fig. 1 of reference 3). The ratio of the major to the minor axis of the cross section has a constant value of 1.35. The mean line of the elliptical body (loci of the centers of the ellipses) is curved upward aft of the maximum section to give the desired deck line aft of the wing and the desired vertical location of the tail root.

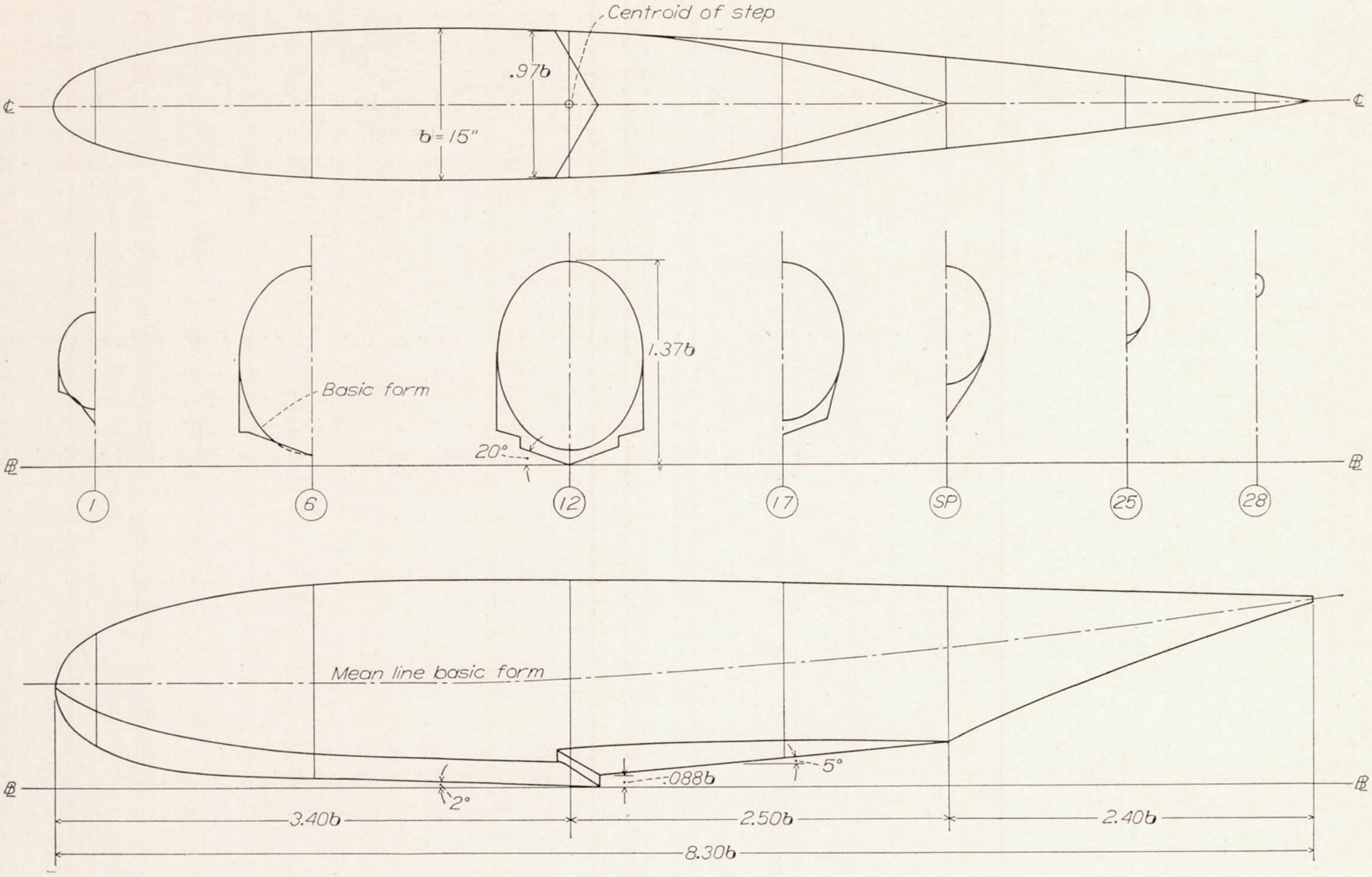


FIGURE 3.—Lines of hull. Model 180.

The forebody planing bottom at the maximum beam, station 9, has an angle of dead rise of 20° at the keel excluding chine flare and an angle of dead rise of approximately 17.5° including the chine flare. The buttocks in this area are straight and parallel for approximately 1.5 beams forward of the step centroid. Forward of the planing bottom the angle of dead rise increases to about 50° at the forward perpendicular, and the bottom sections are faired to give straight or slightly concave water lines near the bow.

The afterbody bottom has straight-line-bottom sections with 20° dead rise. The tail extension above and aft of the sternpost is faired to give easy water lines and to blend into the basic elliptical body at the tail root.

The use of the streamline plan form and ellipitical topsides results in over-all form which presumably has a relatively low aerodynamic drag for the dimensions and proportions derived. Modifications for adaptation to the final design such as the addition of the pilot's canopy, fairing of the wing root, and widening of the plan form aft for structural rigidity of the tail extension are outside the scope of the preliminary design and would not have a large effect on the results presented in this paper.

THE POWERED DYNAMIC MODEL

Photographs of model 180 are shown in figure 4. The model was constructed of balsa and plywood and was powered with four variable-frequency alternating-current motors installed in the nacelles and driving four-blade wooden propellers.

The model was fitted with leading-edge slats to obtain an angle of stall equal to that estimated for the full-size wing and with movable elevators controlled from the observer's seat on the towing carriage. The flaps were of the simple split type extending over 51.6 percent of the wing span and having a chord 21.5 percent of the mean aerodynamic chord.

The hull had a horizontal parting line and a removable step section to facilitate changes in the hull bottom during the tests. The hull was equipped with racks for lead ballast and fittings for various locations of the towing pivot from 20 to 42 percent of the mean aerodynamic chord.

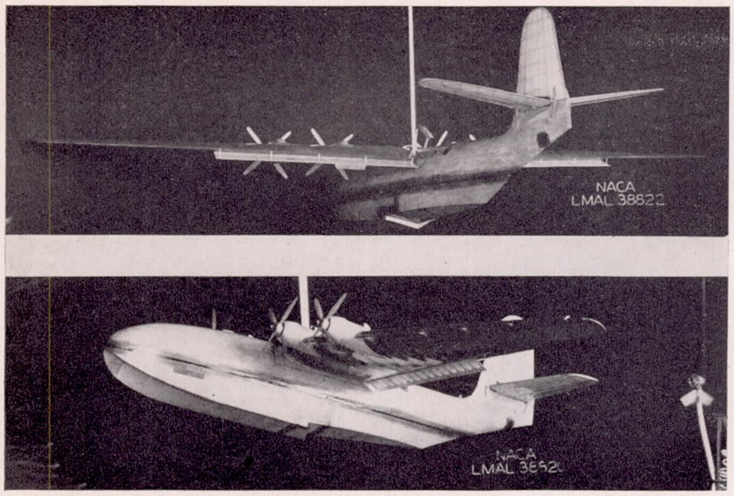


FIGURE 4.—Model 180.

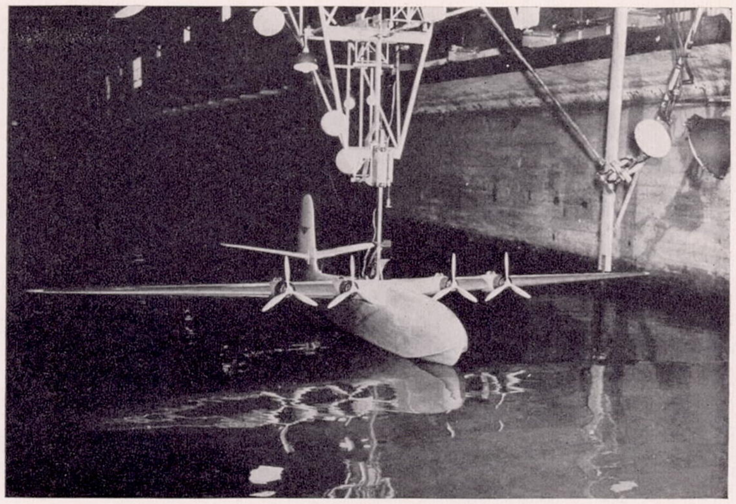


FIGURE 5.—Model 180 and towing apparatus.

The pitching moments of inertia of the ballasted model were:

Pivot position (percent M.A.C.)	Moment of inertia (slug-ft²)
20	8.7
40	10.3

The total weight of the ballasted model and towing staff was somewhat greater than the scale design gross load; therefore, tests requiring complete dynamic similarity were made at the scale overload gross load without the use of counterweights.

GENERAL APPARATUS AND PROCEDURE

The tests of Langley tank model 180 were made in Langley tank no. 1, which is described in reference 4. The apparatus and procedures used for the towing of powered dynamic models are described in references 5 and 6. In general, the model was run at the 6-foot water level under the center of the towing carriage where the air flow is parallel to the water surface and the airspeed is approximately 5 percent higher than the carriage speed. The model was free to trim about the pivot, which is located at its ballasted center-of-gravity position, and was free to move vertically but was restrained in roll and yaw. The towing gear was connected to the resistance dynamometer which measures the net horizontal force applied to the model by the gear. A view of the model setup on the towing apparatus is shown in figure 5.

AERODYNAMIC CHARACTERISTICS

EFFECTIVE THRUST

The effective thrust, defined as the propeller thrust minus the increase in drag due to slipstream, was determined at various speeds throughout the take-off range with the model supported in the air so that its center of gravity was 1.3 beams above the water. This thrust was calculated from the relation

$$T_e = T - \Delta D = D_c + R$$

The effective thrust thus determined for the model at the full-power condition is plotted against speed in figure 6 and is shown together with the estimated scale thrust for the assumed full-size engines and propellers.

LIFT AND PITCHING MOMENT

Values of the lift and pitching moment were determined at various speeds and trims with the model in the air in the same position as for the determination of the thrust. The moments were taken about a pivot point located at 24 percent of the mean aerodynamic chord. The data from the tests with full power are plotted against speed in figure 7.

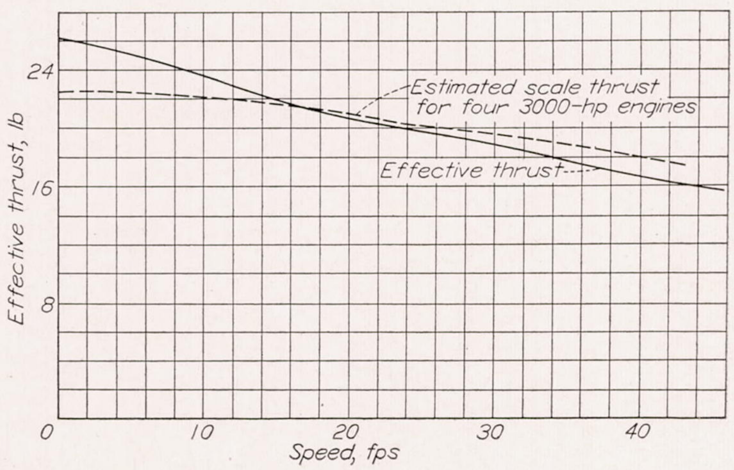
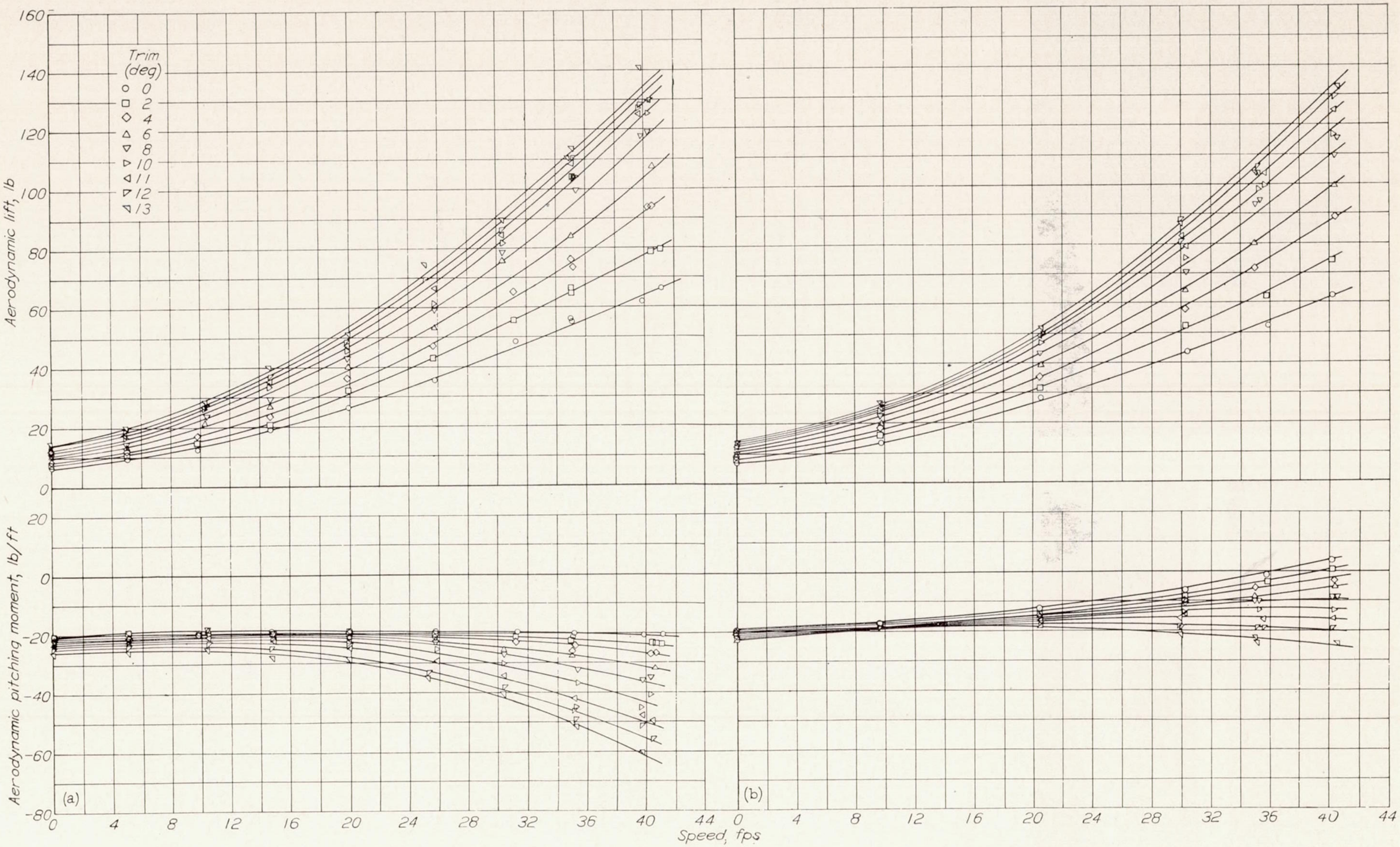


FIGURE 6.—Variation of effective thrust with speed. Model 180; trim, 0°; $\delta_f=30°$; $\delta_e=0°$.



(a) $\delta_e=0°$.

(b) $\delta_e=-15°$.

FIGURE 7.—Variation of aerodynamic lift and pitching moments with trim. Mode 180; $\delta_f=30°$; center of gravity, 24 percent mean aerodynamic chord; full power.

Data with and without power plotted in coefficient form against trim for a speed of 35 feet per second are shown in figure 8. These results are typical for multiengine configurations in the take-off range and illustrate the large effect of power on the coefficients. The results also include the ground effect due to the proximity of the water which decreases the downwash and constricts the slipstream flow under the model.

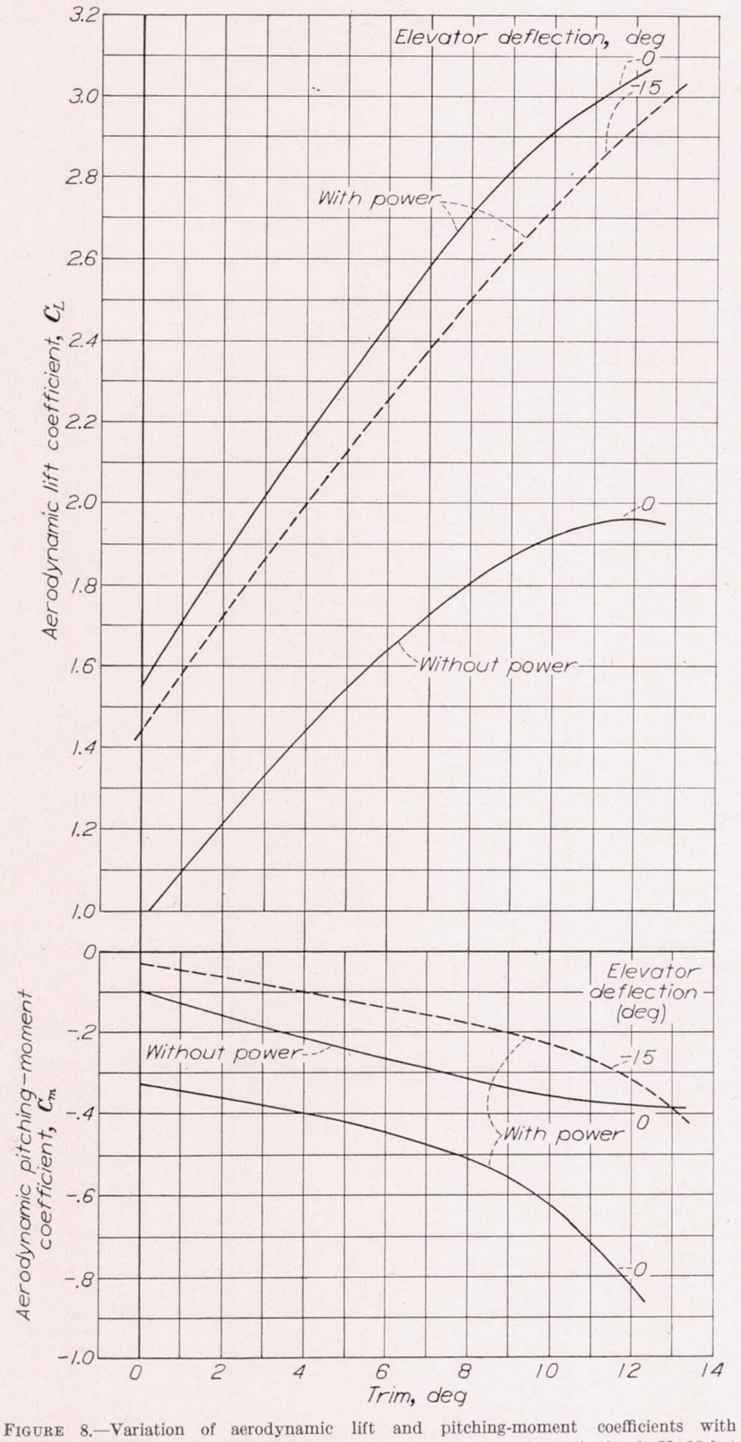


FIGURE 8.—Variation of aerodynamic lift and pitching-moment coefficients with trim. Model 180; $\delta_f=30°$; center of gravity, 24 percent mean aerodynamic chord; $V=35$ feet per second.

HYDRODYNAMIC LONGITUDINAL STABILITY

LANDING STABILITY

The landing stability was investigated at various landing trims by flying the model at the desired trim and then uniformly decelerating the towing carriage to simulate the landing maneuver. The resulting variations in trim and rise were recorded on wax paper by a stylus attached to the model, and the records obtained were used as an indication of the landing stability.

Landings of the original configuration, Langley tank model 180, with the center of gravity at 30 and 40 percent of the mean aerodynamic chord, were made at a rate of deceleration of 2.5 feet per second per second with the flaps in the landing position and with the propellers windmilling. The results are shown in figure 9. The model was unstable during landings at trims above 5° (afterbody keel parallel to the water surface), indicating that the depth of step was inadequate for complete ventilation. The depth of step was therefore increased from 6.5 to 9.0 percent beam at the centroid by lowering the forebody.

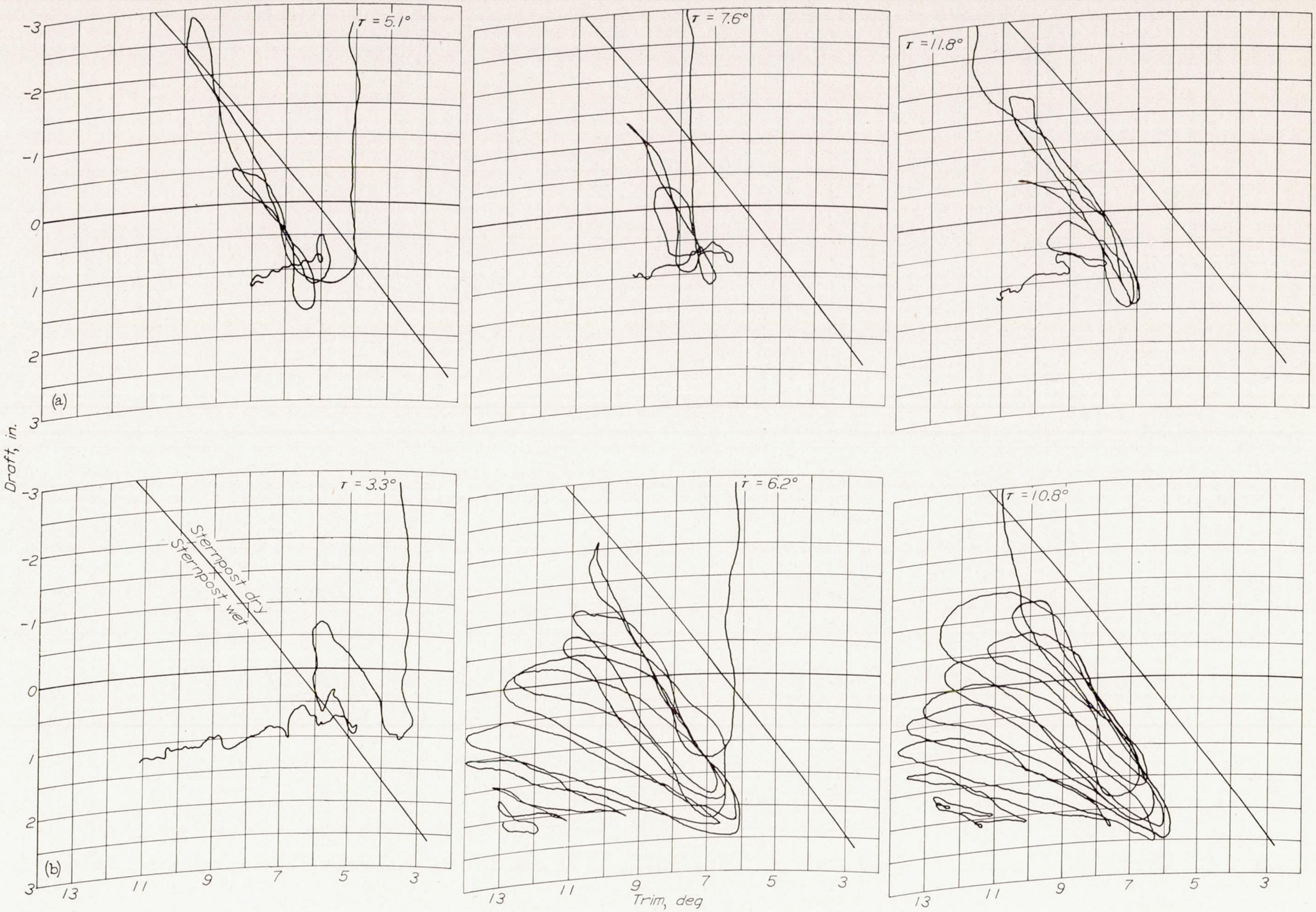
Tests of the model with the deeper step, Langley tank model 180–1, were made under the same conditions except that the deceleration was reduced to 1.0 foot per second per second, and the results are shown in figure 10. The effect of the modification was to eliminate most of the instability shown in figure 9.

The landing stability of model 180–1 with the center of gravity at 40 percent mean aerodynamic chord and at the overload gross load is shown in figure 11. The records in figures 10 and 11 indicate that with adequate depth of step the position of the center of gravity and the gross load have little effect on the landing characteristics.

TRIM LIMITS OF STABILITY

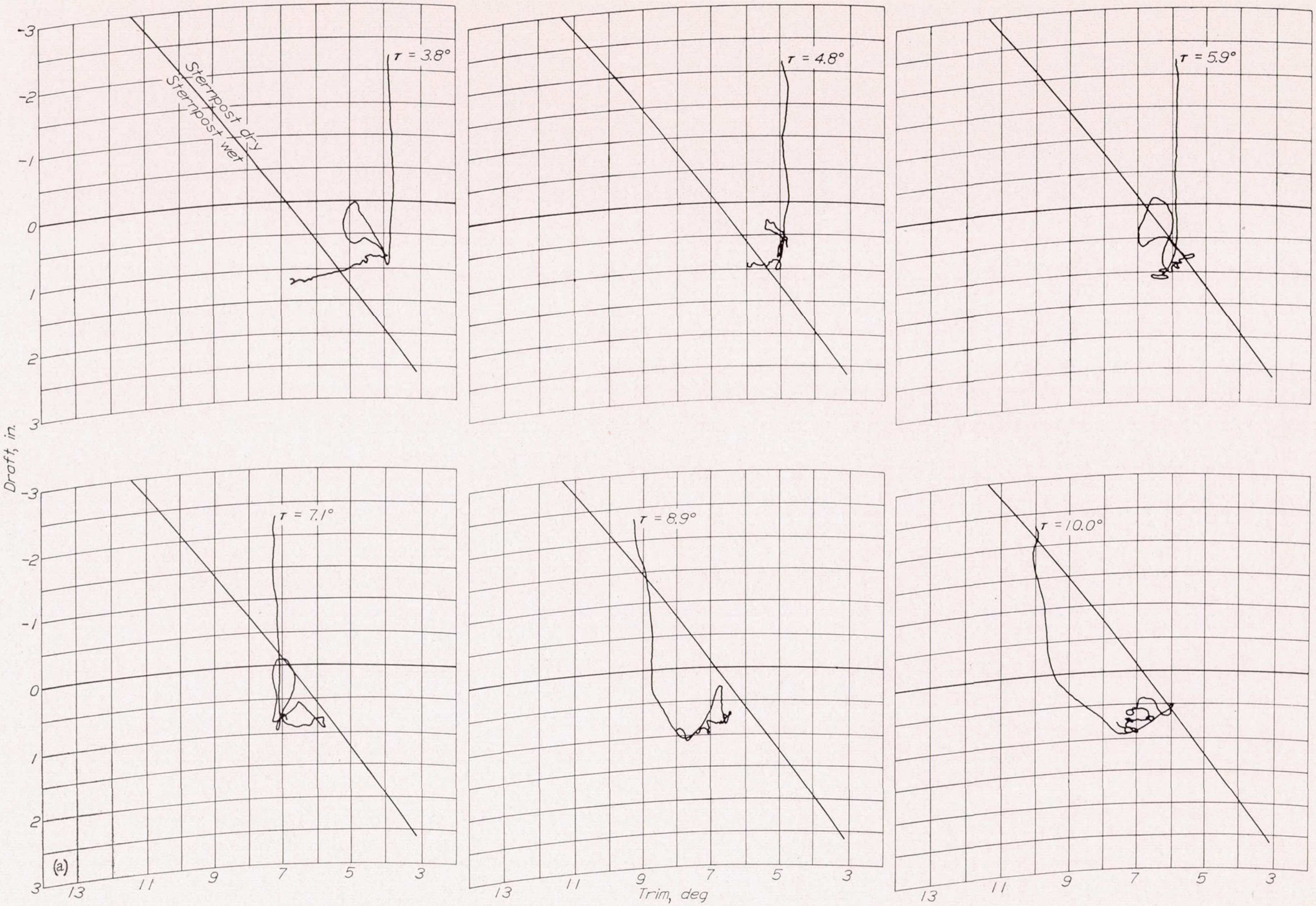
Since longitudinal stability characteristics are commonly evaluated in terms of the trim limits of stability, these limits without power were determined at the design gross load for both models 180 and 180–1 and are shown in figure 12. Increasing the depth of step to insure adequate landing stability raised both branches of the upper limit and reduced the spread between the two branches, at speeds just before get-away, from 4.5° to 1.5°. At high speeds, the stable range of trim between the lower limit and upper limit, decreasing trim, for model 180–1 was about 7°.

The trim limits of stability for model 180–1 with power and at the overload corresponding to 185,000 pounds are shown in figure 13. The spread between the two branches of the upper limit and between the upper and lower trim limits is approximately the same as for the trim limits without power at the design gross load. The trim limits of model 180–1 with and without power are plotted nondimensionally in figure 14.



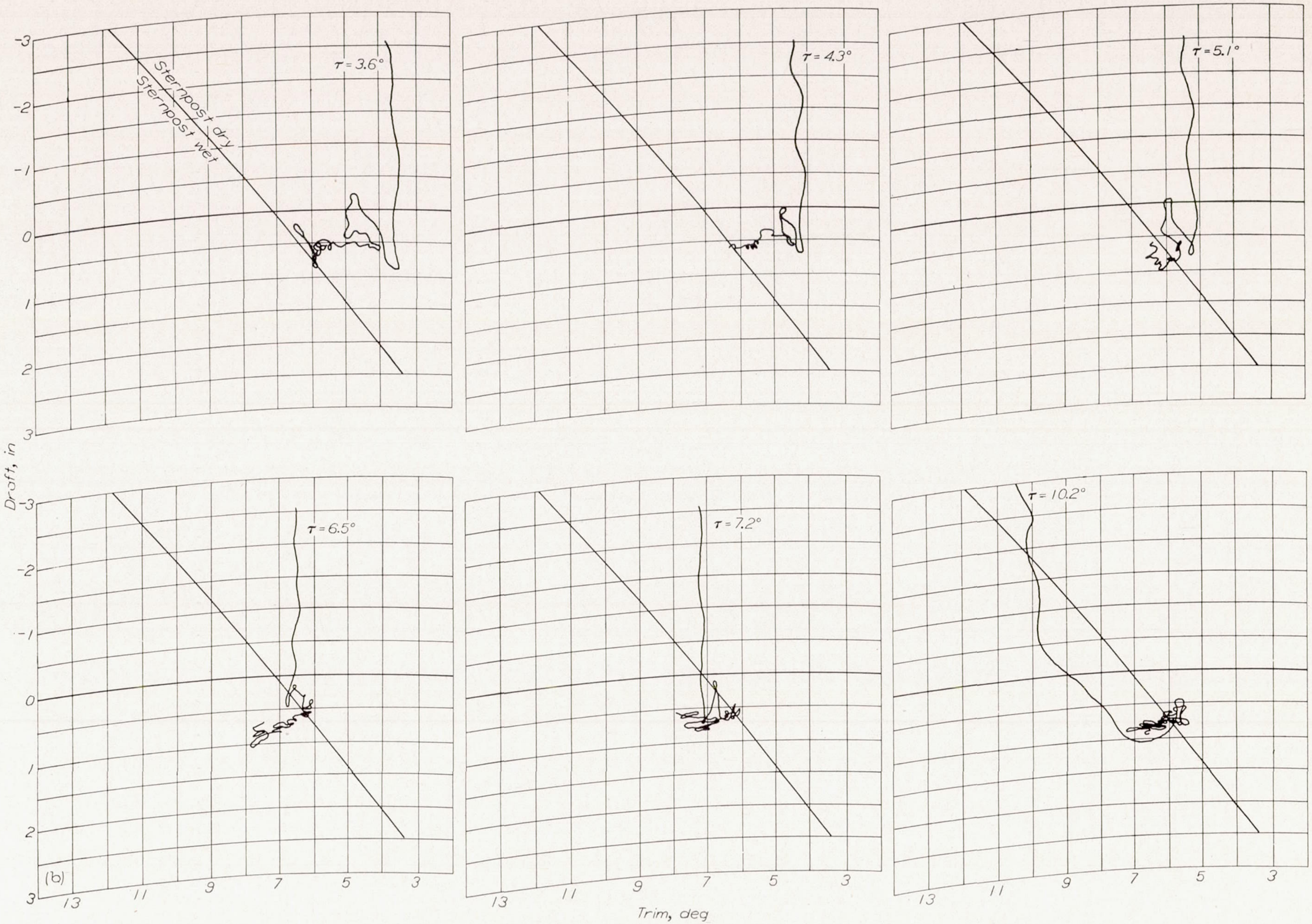
(a) Center of gravity, 30 percent mean aerodynamic chord.
(b) Center of gravity, 40 percent mean aerodynamic chord.

FIGURE 9.—Variation of trim and draft during landing. Model 180; gross load, 94.3 pounds (165,000 lb, full size); without power; $\delta_f = 55°$.



(a) Center of gravity, 30 percent mean aerodynamic chord.

FIGURE 10.—Variation of trim and draft during landing. Model 180–1; gross load 94.3 pounds (165,000 lb, full size); without power; $\delta_f=55°$.



(b) Center of gravity, 40 percent mean aerodynamic chord.

FIGURE 10.—Concluded.

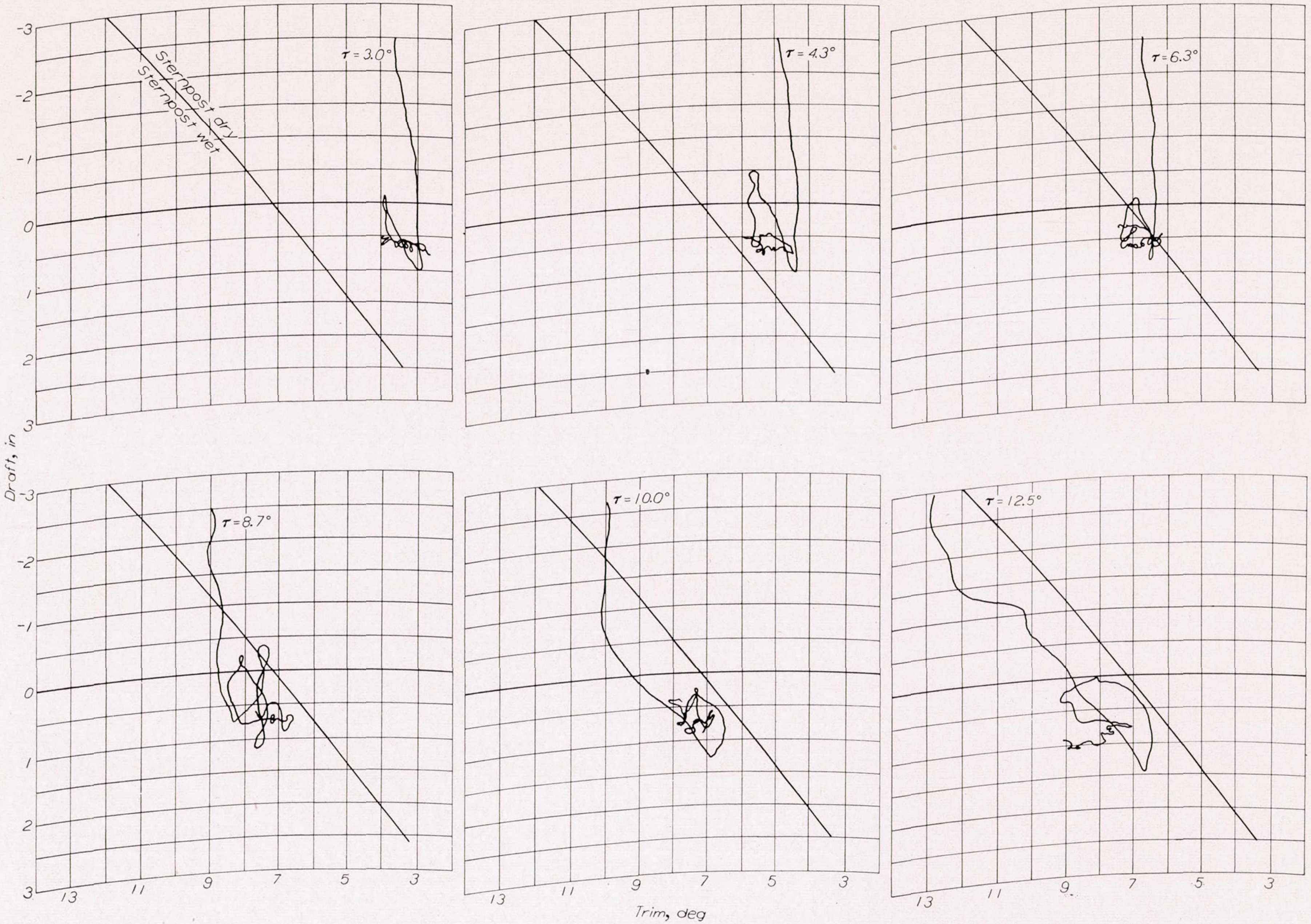


FIGURE 11.—Variation of trim and draft during landing. Model 180-1; gross load, 105.7 pounds (185,000 lb, full size); center of gravity, 40 percent mean aerodynamic chord; without power; $\delta_f = 55°$.

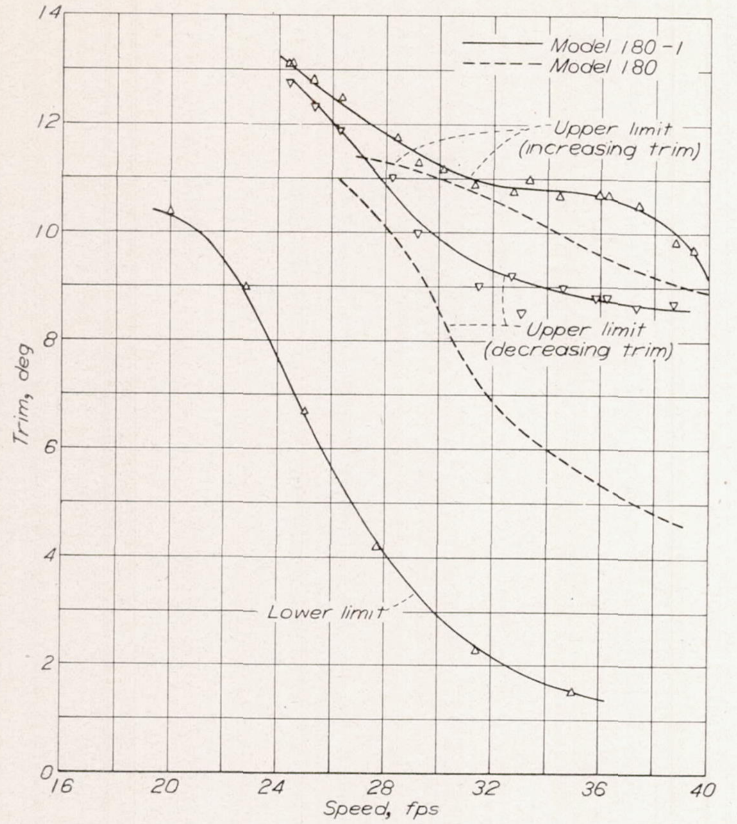


FIGURE 12.—Trim limits of stability without power. Models 180 and 180-1; gross load, 94.3 pounds (165,000 lb, full size); $\delta_f=55°$.

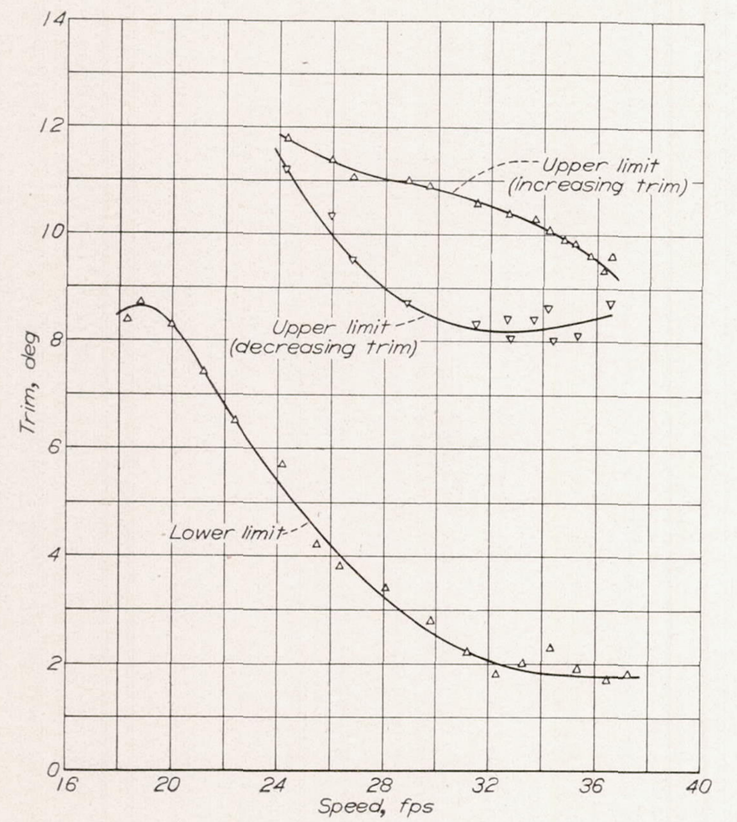


FIGURE 13.—Trim limits of stability with power. Model 180-1; gross load, 105.7 pounds (185,000 lb, full size); $\delta_f=30°$.

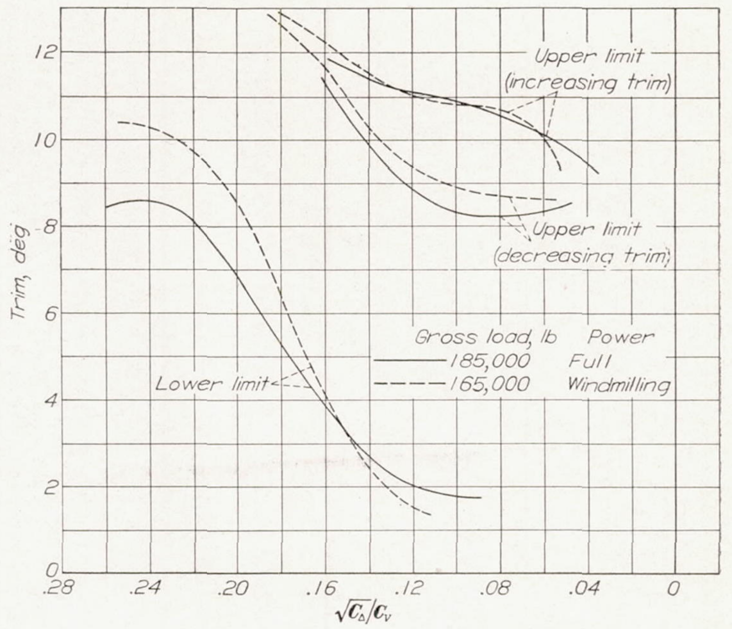


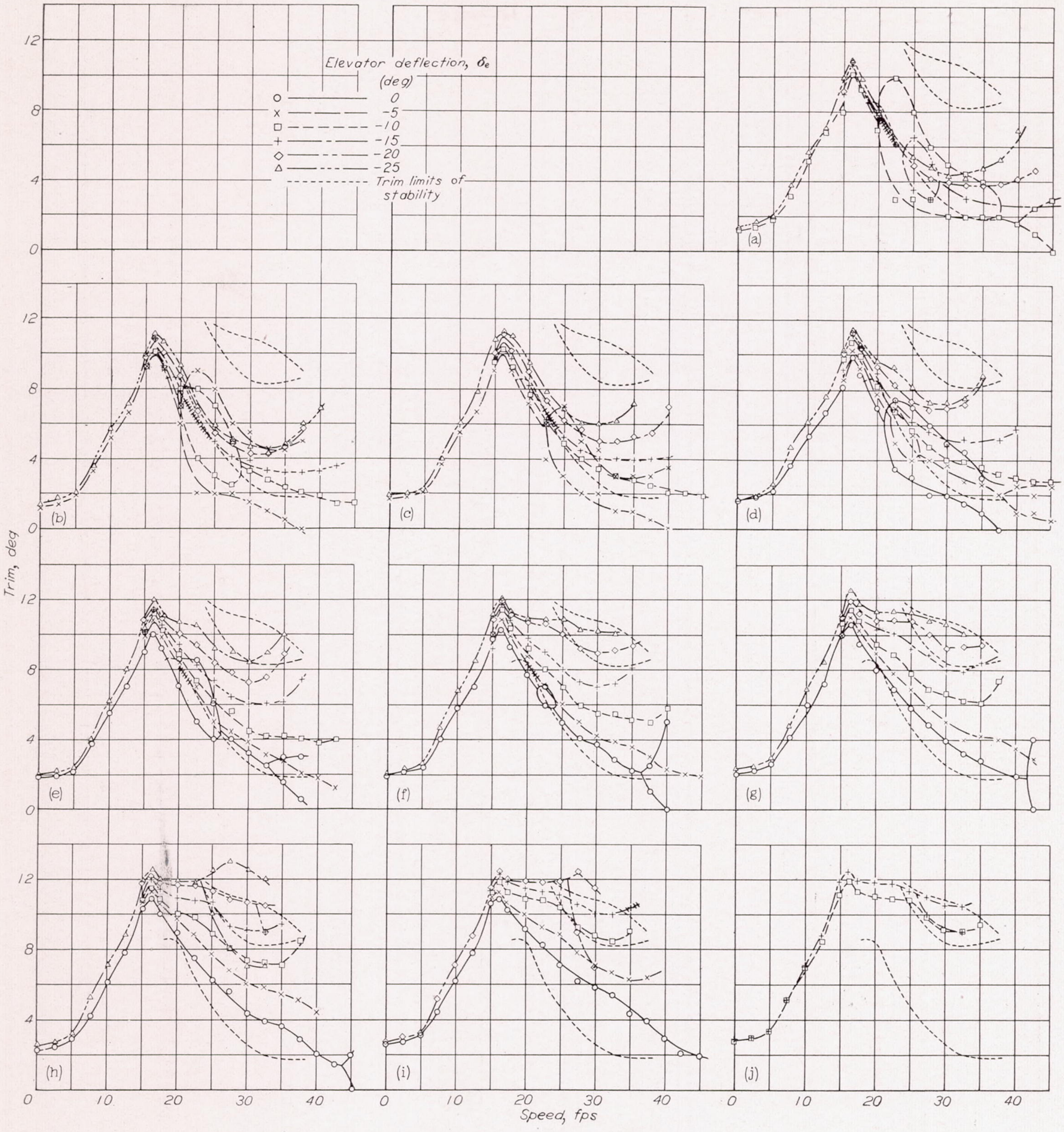
FIGURE 14.—Nondimensional trim limits of stability. Model 180-1.

TAKE-OFF STABILITY

The range of stable position of the center of gravity of model 180–1 was determined by making take-offs with power at various positions of the center of gravity and several elevator deflections. In these tests a uniform rate of acceleration of 1.0 foot per second per second was used. Representative trim tracks and their relation to the trim limits of stability are presented in figure 15 for various positions of the center of gravity over the anticipated take-off range. The results are summarized in figure 16 as a plot of maximum amplitude of porpoising against position of the center of gravity. This figure indicates that stable take-offs could be made with a fixed elevator deflection of −20° at positions of the center of gravity from 24 to 37 percent mean aerodynamic chord. A cross plot of elevator deflection required for stable take-off against position of the center of gravity is shown in figure 17. Stable take-offs with fixed elevator deflections were possible at all practicable positions of the center of gravity, and elevator control was also available for recovery in the event that porpoising occurred. The stable range of position of the center of gravity for take-off of model 180–1 was larger than for most models tested in the Langley tanks. The location of the stable range of the model for take-off with respect to the stable range for flight was satisfactory; therefore, no fore-and-aft movement of the step was required.

HYDRODYNAMIC TAKE-OFF PERFORMANCE

The resistance characteristics of the model at trims and loadings corresponding to take-off power were investigated by measuring the excess thrust available for acceleration with the propellers developing the scale effective thrust shown in figure 6. This thrust was made equal to the estimated value at each speed by adjusting the revolutions per minute. The model was tested at the design gross load with the flaps in take-off position and with several deflections of the elevators in order to include trim for maximum excess thrust.



(a) Center of gravity, 24 percent mean aerodynamic chord.
(b) Center of gravity, 26 percent mean aerodynamic chord.
(c) Center of gravity, 28 percent mean aerodynamic chord.
(d) Center of gravity, 30 percent mean aerodynamic chord.
(e) Center of gravity, 32 percent mean aerodynamic chord.
(f) Center of gravity, 34 percent mean aerodynamic chord.
(g) Center of gravity, 36 percent mean aerodynamic chord.
(h) Center of gravity, 38 percent mean aerodynamic chord.
(i) Center of gravity, 40 percent mean aerodynamic chord.
(j) Center of gravity, 42 percent mean aerodynamic chord.

FIGURE 15.—Variation of trim with speed. Model 180–1; gross load, 105.7 pounds (185,000 lb, full size); $\delta_f=30°$; full power.

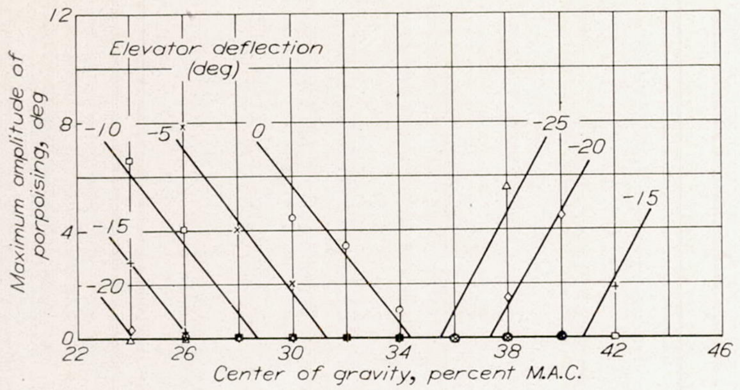


FIGURE 16.—Maximum amplitude of porpoising at different positions of the center of gravity with power. Model 180-1; gross load, 105.7 pounds (185,000 lb, full size); $\delta_f=30°$.

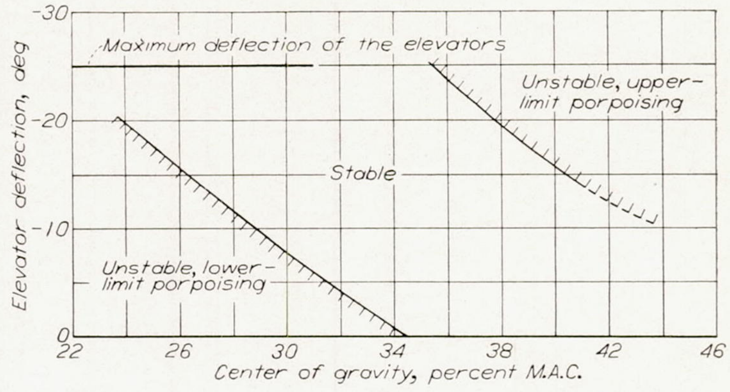


FIGURE 17.—Range of position of the center of gravity for stable take-off with power. Model 180-1; gross load, 105.7 pounds (185,000 lb, full size); $\delta_f=30°$.

The excess thrust and trim of Langley tank models 180 and 180-1 are presented in figures 18 and 19, respectively. These curves have been plotted so that they have the same general shape as the resistance curves used for take-off computations. A comparison of similar curves for both models indicates that the increase in depth of step raised the hump trim approximately 1° and slightly increased the hump resistance. When maximum excess thrust is used, model 180 requires a take-off time of 53 seconds and a take-off distance of 4100 feet; whereas the take-off time of Langley tank model 180-1 is 54 seconds and the take-off distance is 4300 feet (full size).

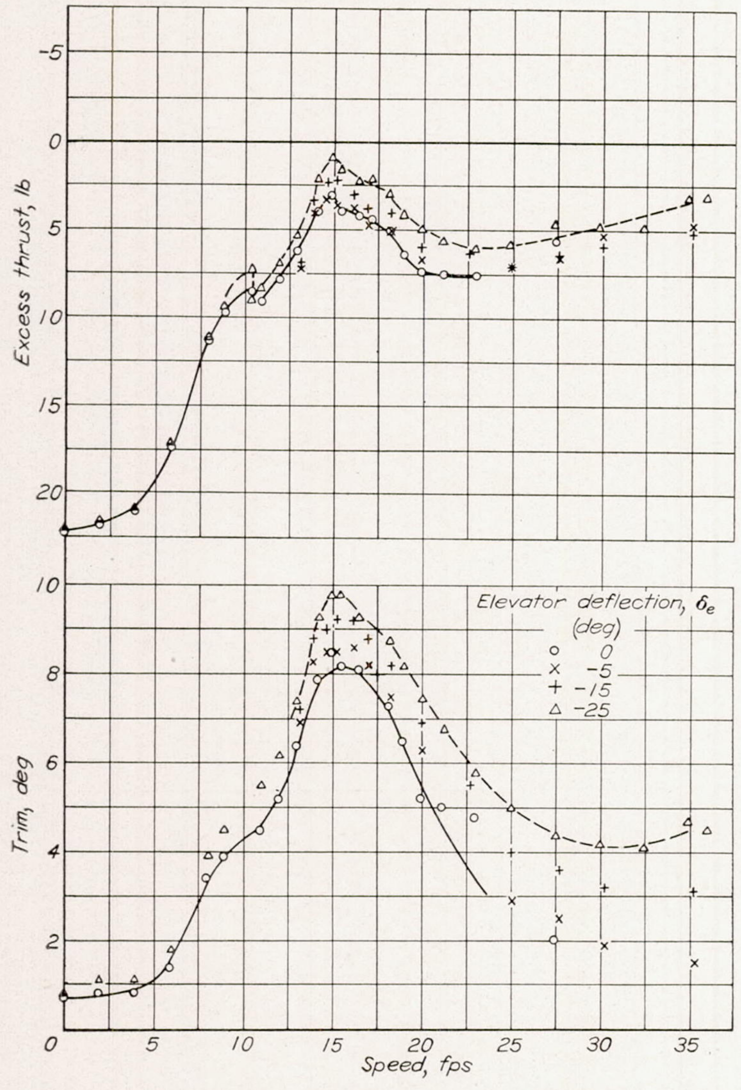


FIGURE 18.—Variation of excess thrust and trim with speed. Model 180; gross load, 94.3 pounds (165,000 lb, full size); $\delta_f=30°$; center of gravity, 28 percent mean aerodynamic chord.

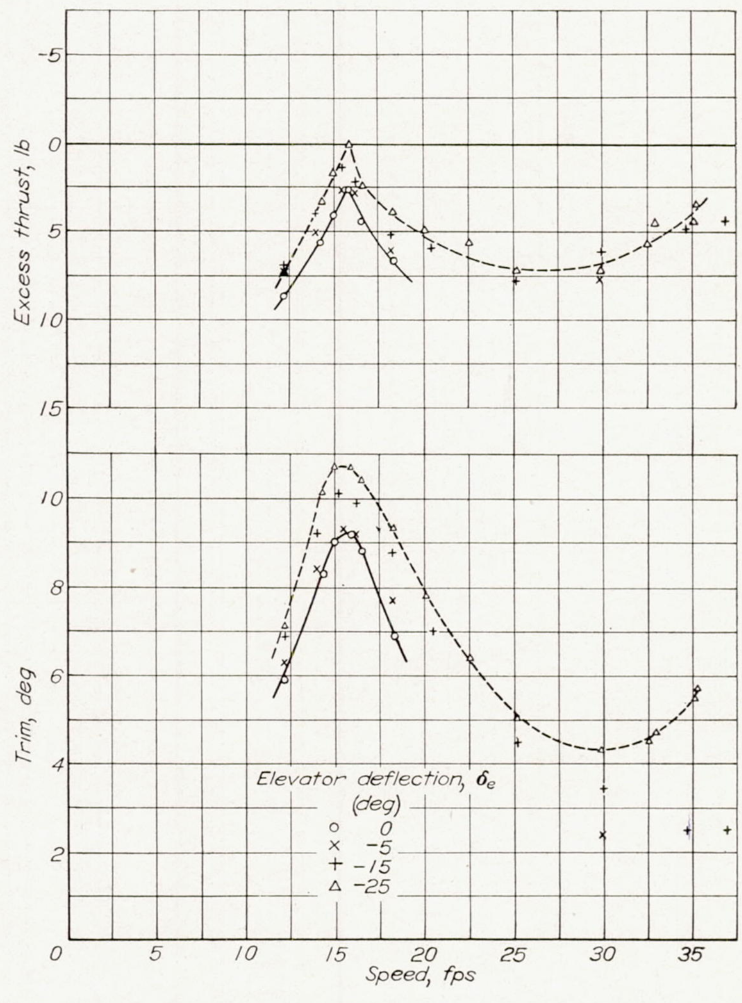


FIGURE 19.—Variation of excess thrust and trim with speed. Model 180-1; gross load, 94.3 pounds (165,000 lb, full size); $\delta_f=30°$; center of gravity, 28 percent mean aerodynamic chord.

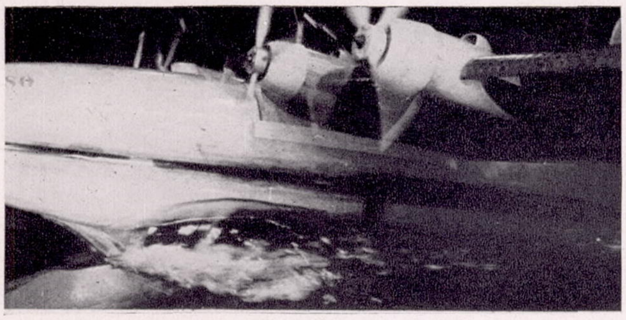
SPRAY CHARACTERISTICS

BASIC CONFIGURATION

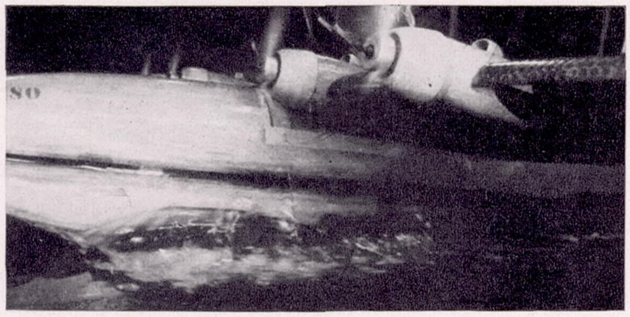
The spray characteristics were investigated by making constant speed and accelerated runs with full power and with the propellers windmilling in order to observe the effect of power. Photographs were taken of the spray in the propellers and of the flow of water around the afterbody and tail extension during the constant-speed runs, and motion pictures were taken during the accelerated runs for additional study. For the power-on tests, the propellers were driven at a constant value of 4000 rpm, which was a mean value for development of scale thrust throughout the speed range.

Photographs of the bow spray of Langley tank model 180–1, over a speed range in which the bow spray enters the propellers, are presented in figure 20 for gross loads corresponding to 165,000 and 185,000 pounds. The spray characteristics of model 180–1 and model 180, which had 0.37 inch less clearance between the propeller disks and the water because of the shallower step, were approximately the same. At the gross load corresponding to 165,000 pounds, only light spray entered the propellers with full power over a speed range from 11.0 to 14.5 feet per second. At the overload condition corresponding to 185,000 pounds, the amount of spray in the propellers increased, but the spray characteristics were still acceptable (fig. 20). The amount of spray striking the flaps at the design gross load was light, both with full power and with propellers windmilling.

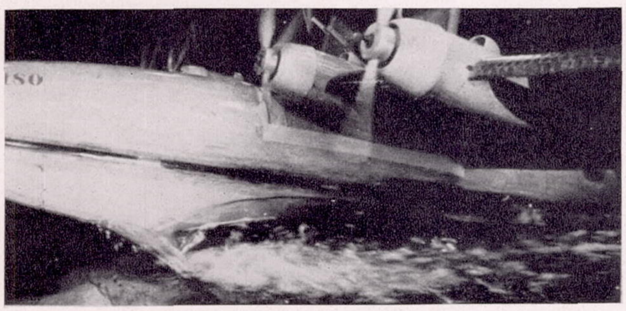
On both models 180 and 180–1, water from the afterbody flowed up the sides of the tail extension and wetted the under surface of the horizontal tail at approximately hump speed (fig. 21). This condition was slightly worse with the propellers windmilling than with full power.



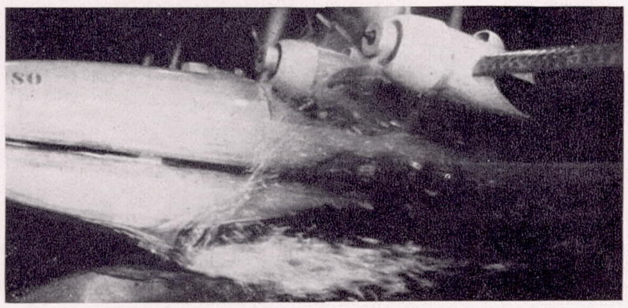
V=10.1 fps; τ=7.3°



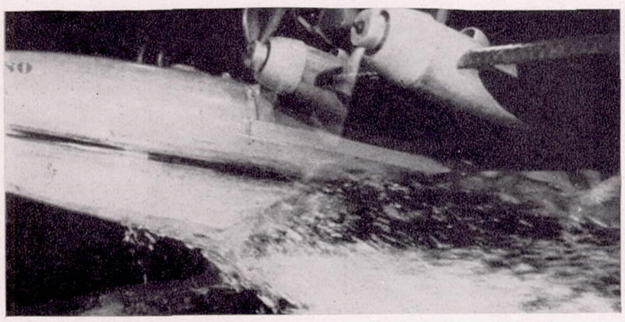
V=10.3 fps; τ=5.2°



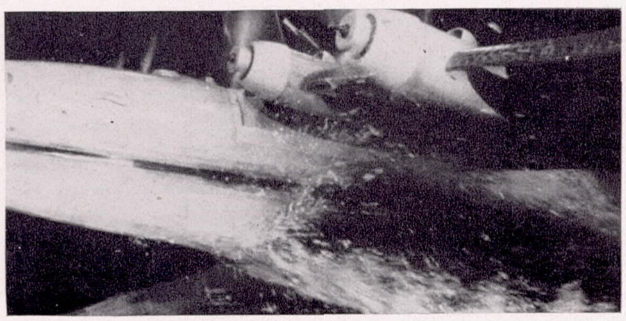
V=12.3 fps; τ=8.2°



V=12.3 fps; τ=6.3°



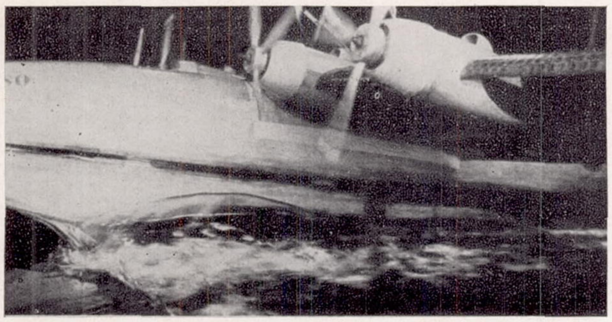
V=14.2 fps; τ=9.8°
Propellers windmilling



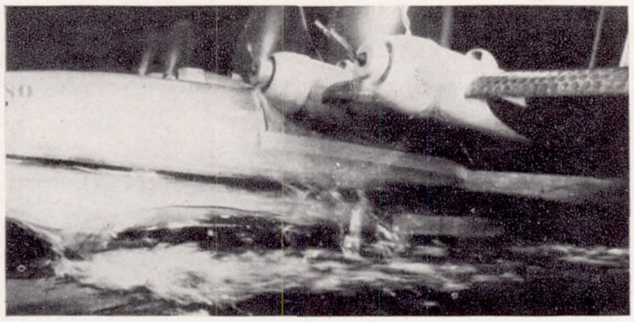
V=14.3 fps; τ=8.7°
Full power

(a) Gross load, 94.3 pounds (165,000 lb, full size).

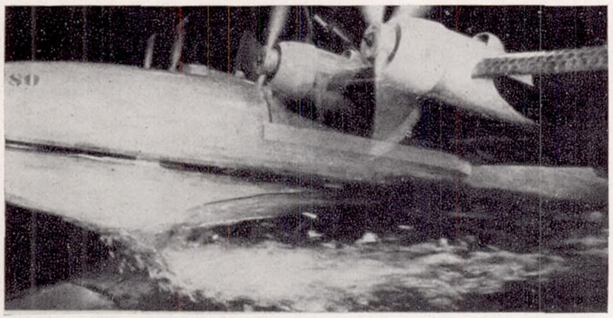
FIGURE 20.—Bow spray. Model 180–1; δ_s=0°; δ_f=30°; center of gravity, 28 percent mean aerodynamic chord.



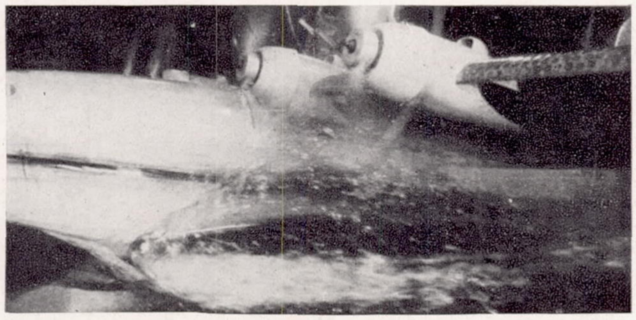
V=10.0 fps; τ=7.3°



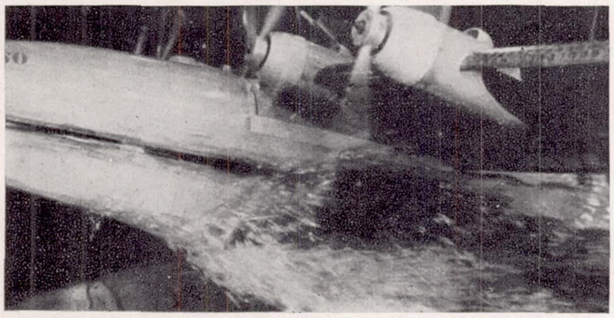
V=10.1 fps; τ=5.2°



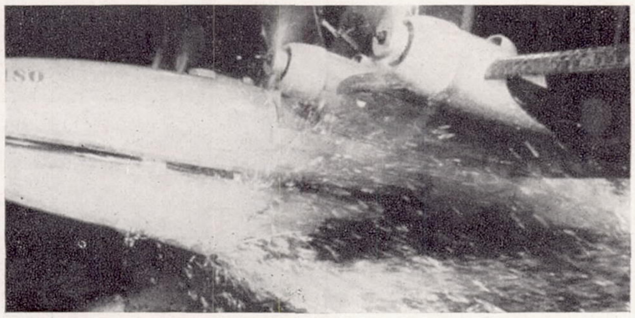
V=12.2 fps; τ=8.1°



V=12.2 fps; τ=6.3°



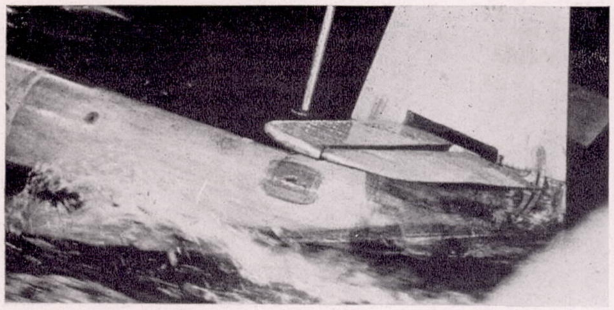
V=14.2 fps; τ=9.8°
Propellers windmilling



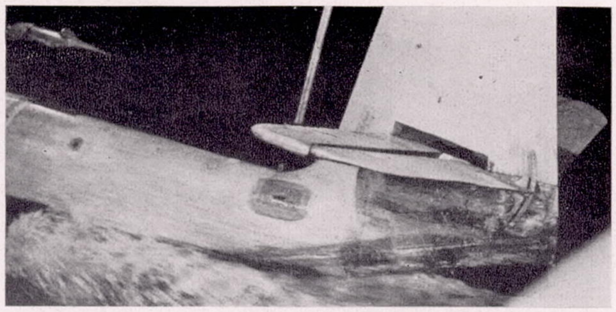
V=14.2 fps; τ=8.8°
Full power

(b) Gross load, 105.7 pounds (185,000 lb, full size).

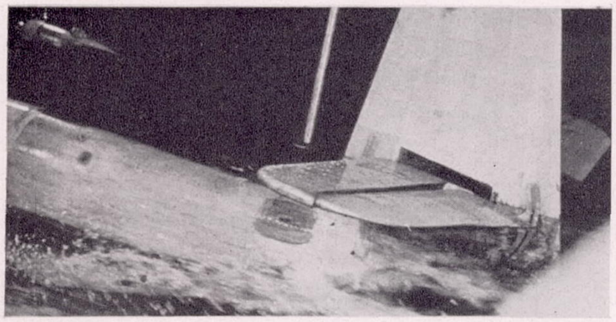
FIGURE 20.—Concluded.



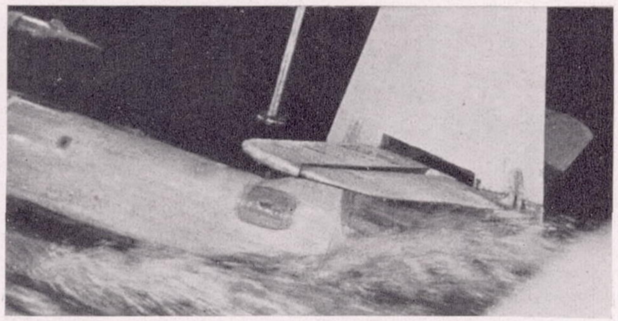
V=13.1 fps; τ=8.6°



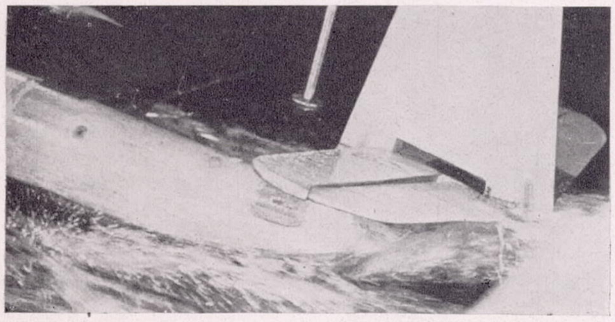
V=13.0 fps; τ=7.0°



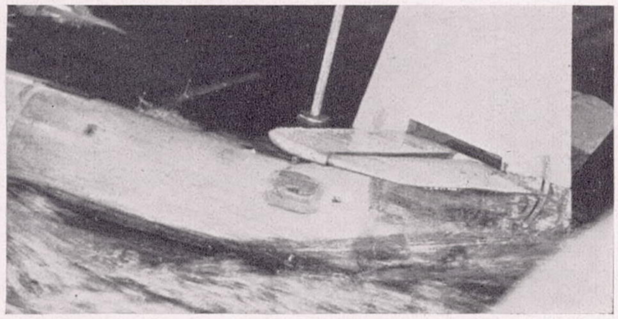
V=14.2 fps; τ=9.9°



V=14.2 fps; τ=8.7°

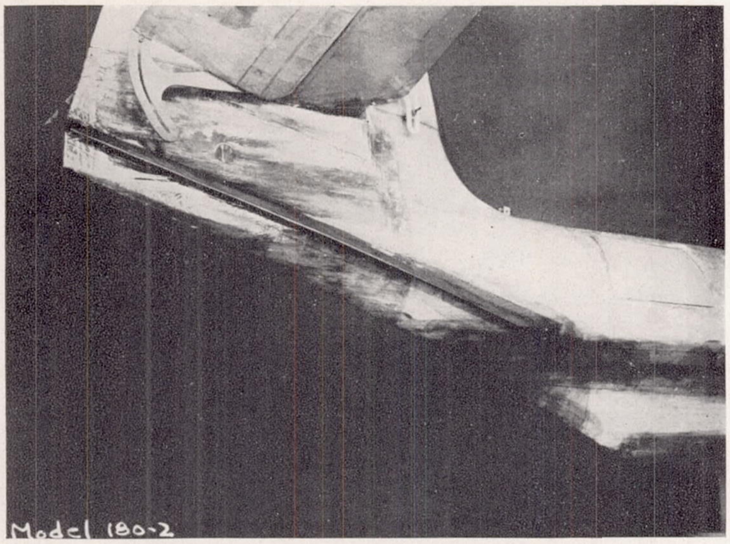


V=15.2 fps; τ=11.2°
Propellers windmilling

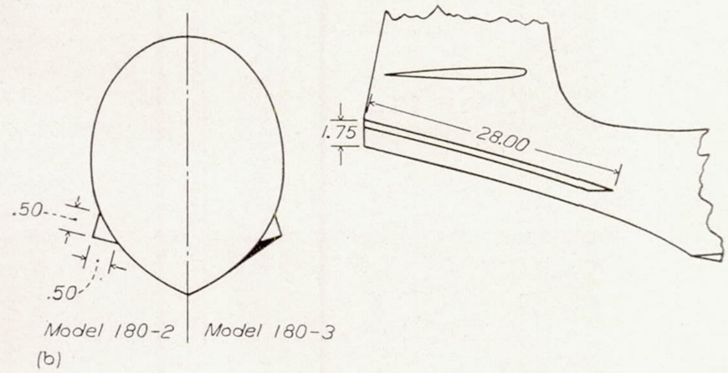


V=15.2 fps; τ=9.0°
Full power

FIGURE 21.—Flow of water around afterbody and tail extension. Model 180-1; gross load, 94.3 pounds (165,000 lb, full size); δ_e=0°; δ_f=30°; center of gravity, 28 percent mean aerodynamic chord.

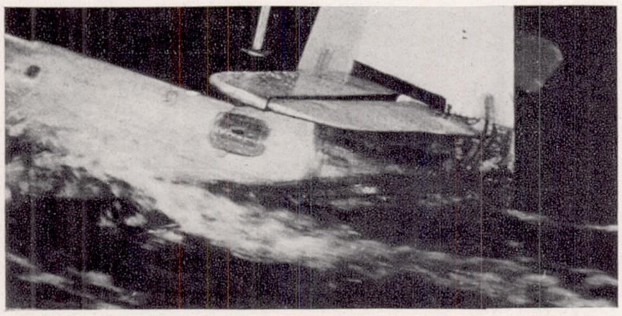


(a) Breaker strip on tail extension. Langley tank model 180–2.

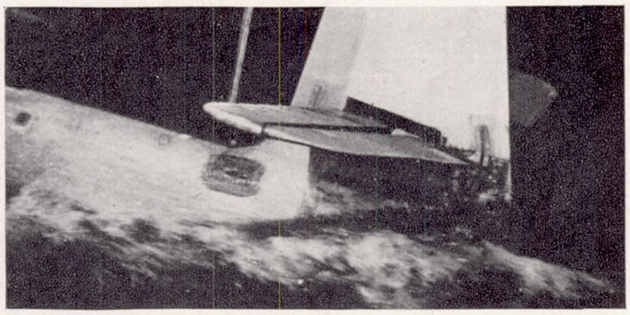


(b) Sketch of breaker strip. Langley tank models 180–2 and 180–3. (All dimensions are in inches.)

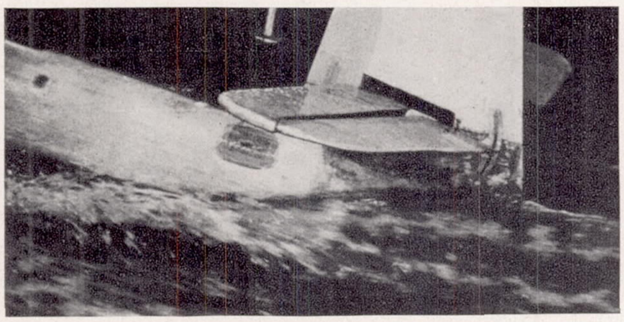
FIGURE 22.—Modifications on tail extension for spray control.



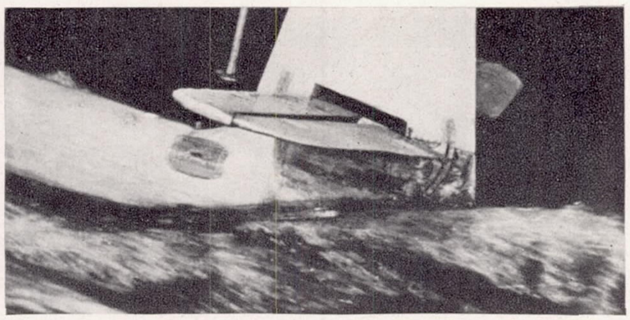
V=13.1 fps; τ=8.6°



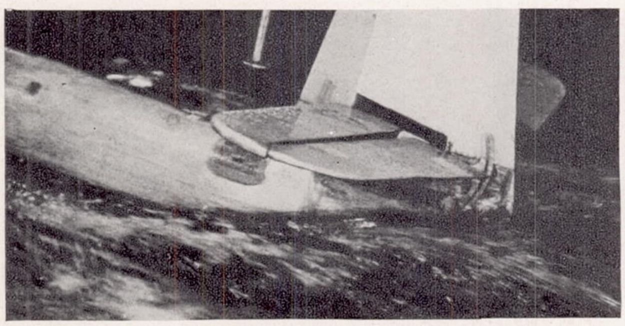
V=13.0 fps; τ=7.1°



V=14.0 fps; τ=9.8°

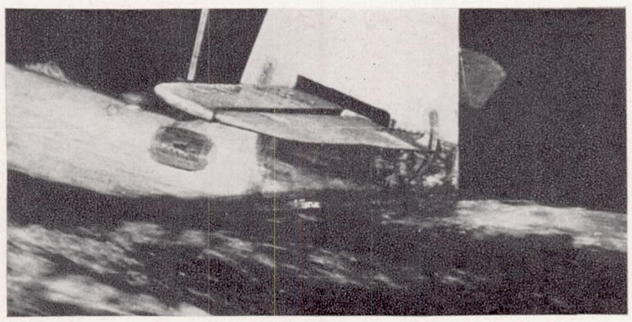


V=14.1 fps; τ=8.4°



V=15.0 fps; τ=11.2°

Propellers windmilling



V=14.9 fps; τ=8.8°

Full power

FIGURE 23.—Flow of water around afterbody and tail extension. Model 180–2; gross load, 94.3 pounds (165,000 lb, full size); δ_e=0°; δ_f=30°; center of gravity, 28 percent mean aerodynamic chord.

MODIFICATIONS FOR SPRAY CONTROL

Tail-extension breaker strips.—The addition of breaker strips, shown in figure 22, to the tail extension (Langley tank model 180–2) was effective in preventing the water from wetting the sides of the tail extension or the horizontal tail. Photographs showing the flow of water around the tail extension for model 180–2 are presented in figure 23 and may be compared with similar photographs shown in figure 21 for model 180–1. The formation of a planing surface on the tail extension (Langley tank model 180–3), shown in figure 22 (b), was almost as effective in deflecting the water as were the breaker strips.

Forebody spray strips.—Although the bow spray characteristics of models 180 and 180–1 were considered satisfactory at the design gross load, inboard spray strips were added to the forebody (Langley tank model 180–4) to observe their effectiveness in reducing the propeller and flap spray at overloads. The spray strips, shown in figure 24, were added without increasing the beam of the model. With the strips on the model, no spray entered the propellers up to a load corresponding to 200,000 pounds (fig. 25). No water struck the flaps with full power at the load corresponding to 185,000 pounds and only light spray struck the flaps at the load corresponding to 200,000 pounds. The addition of plasteline fairing, shown in figure 24, to the spray strips (Langley tank model 180–5) did not appear to reduce their effectiveness in preventing the spray from entering the propellers or striking the flaps.

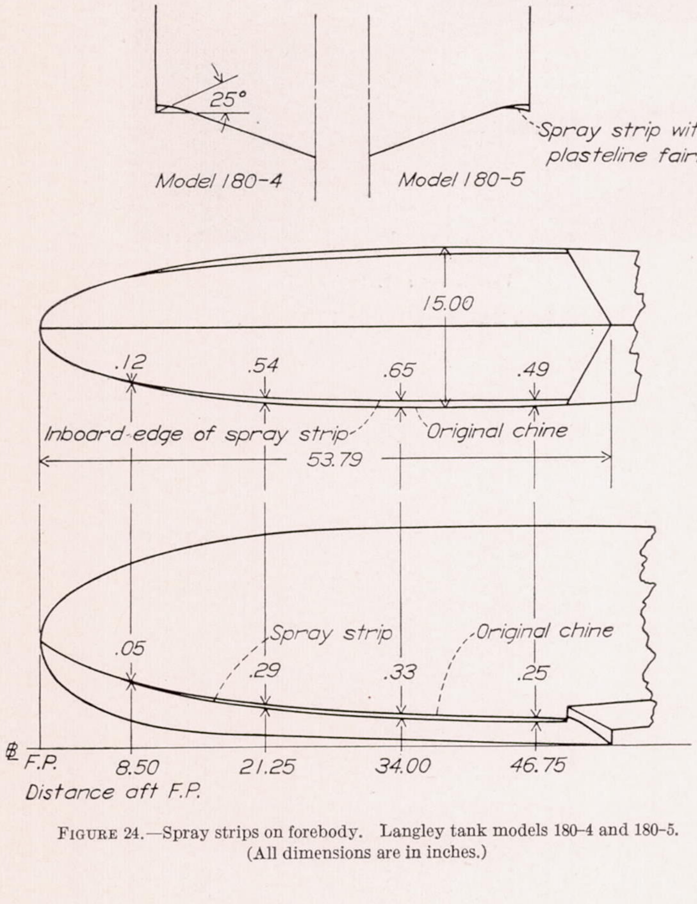


FIGURE 24.—Spray strips on forebody. Langley tank models 180–4 and 180–5. (All dimensions are in inches.)

Effect of spray-control devices on stability and take-off performance.—Breaker strips on the tail extension had no appreciable effect on either the take-off performance or the stability characteristics.

The addition of inboard forebody spray strips increased the range of stable trim by lowering the lower limit approximately ½°. A similar trend in the lower limit has been observed when the chine flare of another model was increased. Within the accuracy of the tests, the forebody spray strips had no appreciable effect on the upper trim limits, on the range of stable position of the center of gravity for take-off, on the landing stability, or on the resistance.

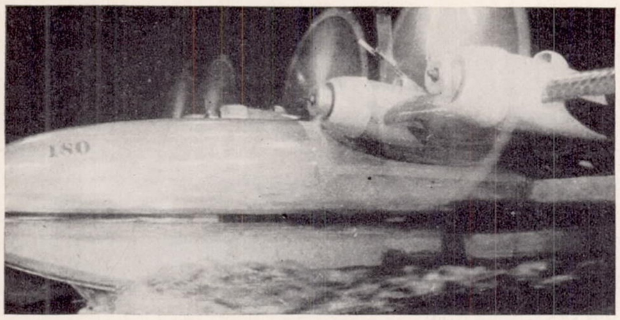
CONCLUSIONS

The results of the tank investigation of Langley tank model 180 indicate further the validity of the hydrodynamic design principles used and illustrate the hydrodynamic performance criterions employed at the Langley tanks for evaluating the merit of the proposed hull form. The significant conclusions regarding the design of the long-range transport flying boat investigated may be summarized as follows:

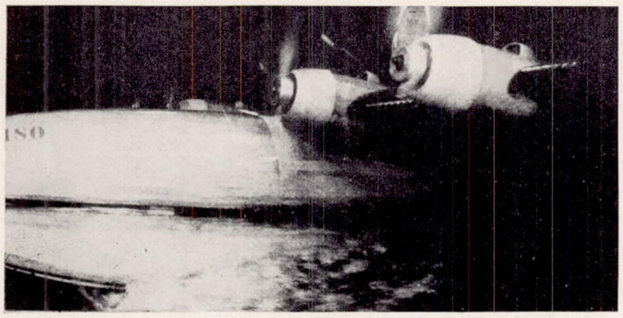
1. A depth of step of 9 percent beam at the centroid was required for satisfactory landing stability and recovery from upper-limit porpoising.
2. The hydrodynamic center-of-gravity range for stable take-offs was satisfactory as to extent and location with respect to the stable flight range desired. With fixed elevators, stable take-offs were possible over a range of position of the center of gravity of approximately 13 percent mean aerodynamic chord.
3. The take-off performance was satisfactory for the power loading assumed. The take-off time was approximately 54 seconds and the take-off distance was approximately 4300 feet at a gross load corresponding to 165,000 pounds.
4. The relation of the proportions to the design loading of the hull was correct for satisfactory spray characteristics. Overloads up to a gross load corresponding to 200,000 pounds were possible with relatively simple spray-control devices.
5. Favorable hydrodynamic characteristics were obtained without departing widely from the desirable aerodynamic form of hull compatible with an efficient over-all design.

These conclusions are believed to make the hull lines and the associated tank data of general interest and should be useful in the preliminary design of large flying boats of the model 180 type.

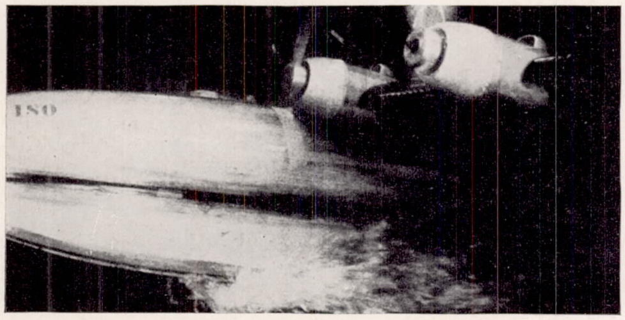
Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *November 29, 1946.*



V=10.1 fps; τ=5.2°

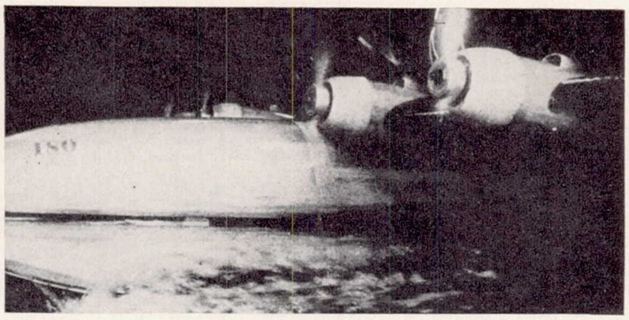


V=12.1 fps; τ=6.4°

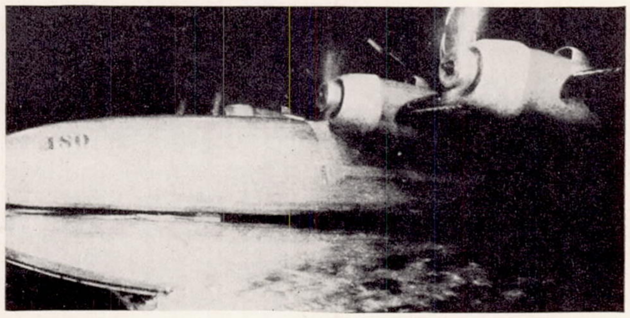


V=14.1 fps; τ=8.8°

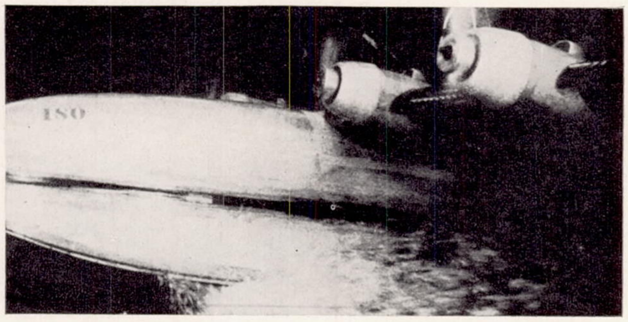
(a) Gross load, 105.7 pounds (185,000 lb, full size).



V=10.1 fps; τ=5.6°



V=12.2 fps; τ=7.0°



V=14.2 fps; τ=9.2°

(b) Gross load, 114.0 pounds (200,000 lb, full size).

FIGURE 25.—Model 180-4. Bow spray, full power. δ_e=0°; δ_f=30°; center of gravity, 28 percent mean aerodynamic chord.

REFERENCES

1. Parkinson, John B.: The Design of the Optimum Hull for a Large Long-Range Flying Boat. NACA ARR No. L4I12, 1944.
2. Parkinson, John B.: Design Criterions for the Dimensions of the Forebody of a Long-Range Flying Boat. NACA ARR No. 3K08, 1943.
3. Jacobs, Eastman N., Ward, Kenneth E., and Pinkerton, Robert M.: The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel. NACA Rep. No. 460, 1933.
4. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM No. 918, 1939.
5. 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. No. 753, 1943.
6. Truscott, Starr, and Olson, Roland E.: The Longitudinal Stability of Flying Boats as Determined by Tests of Models in the NACA Tank. II—Effect of Variations in Form of Hull on Longitudinal Stability. NACA ARR, Nov. 1942.

TABLE I.—AERODYNAMIC AND PROPULSIVE CHARACTERISTICS AND HULL DIMENSIONS OF LANGLEY TANK MODEL 180

	Full size	Model 180, 1/12 full size
General:		
Design gross load, lb	165,000	94.3
Wing area, sq ft	3,683	25.58
Take-off horsepower	12,000	2.01
Wing loading, lb/sq ft	44.9	3.69
Power loading, lb/hp	13.7	46.9
Wing:		
Span, ft	200	16.7
Root chord, ft (NACA 23020 section)	27.96	2.33
Tip chord, ft (NACA 23012 section)	9.36	0.78
Angle of wing setting to base line, deg	5.5	5.5
Mean aerodynamic chord (M.A.C.), ft	20.12	1.68
Leading edge, M.A.C.		
Aft of bow, ft	42.14	3.51
Above base line, ft	18.88	1.57
Flaps, split		
Semispan, ft	51.6	4.30
Chord, ft	4.33	0.36
Take-off deflection, deg	30	30
Landing deflection, deg	55	55
Horizontal tail surfaces:		
Span, ft	61.67	5.14
Leading edge at root:		
Aft of bow, ft	105.9	8.83
Above base line, ft	24.5	2.04
Area of stabilizer, sq ft	438.4	3.04
Area of elevator, sq ft	384.6	2.67
Total area, sq ft	823.0	5.71
Angle of stabilizer to base line, deg	3.0	3.0
Dihedral, deg	8.0	8.0
Propellers:		
Number	4	4
Blades	4	4
Diameter, ft	17.67	1.47
Blade angle, (3/4 rad), deg	---------	16
Full power, rpm	---------	4,000
Angle of thrust line to base line, deg	5.5	5.5
Center line of inboard propellers above base line, in.	254.5	21.2
Hull:		
Maximum beam, ft	15.0	1.25
Length of forebody, ft	51.0	4.25
Length of afterbody, ft	37.5	3.12
Length of tail extension, ft	35.99	3.0
Over-all length, ft	124.49	10.38
Angle of main step (V-type), deg	30	30
Depth of step at keel, in	15.96	1.33
Depth of step at centroid, in	11.76	0.98
Angle of forebody keel, deg	2.0	2.0
Angle of afterbody keel, deg	5.0	5.0
Angle between keels, deg	7.0	7.0
Angle of dead rise at step, deg		
Excluding chine flare	20.0	20.0
Including chine flare	17.5	17.5

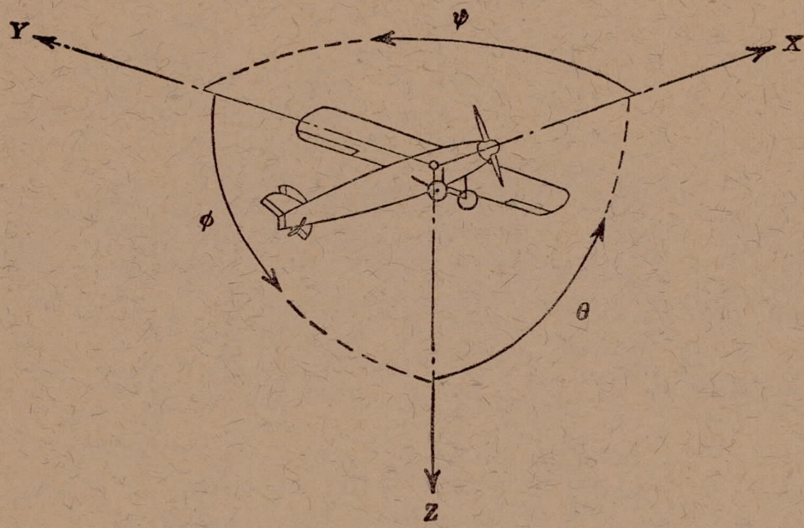
TABLE II.—HULL OFFSETS OF LANGLEY TANK MODEL 180

Station	Distance aft of F. P.	Half-beam at chine	Half max. beam (min. axis)	Major axis	Half-breadths																						
					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	WL 15	WL 16	WL 17	WL 18	WL 19	WL 20	WL 21	WL 22	WL 23
F. P.	0	0	0	0																							
½	2.12	2.74	2.74	3.71						0.19	0.78	1.61	2.74	2.74	2.70	2.46	1.92	0.52									
1	4.25	3.77	3.77	5.10					0.63	1.34	2.42	3.77	3.77	3.77	3.74	3.57	3.22	2.64	1.57								
2	8.50	5.03	5.03	6.81			0.62	1.59	2.59	4.42	5.03	5.03	5.03	5.03	5.01	4.88	4.64	4.24	3.68	2.81	1.12						
3	12.75	5.91	5.91	8.00		0.55	1.90	3.22	5.91	5.91	5.91	5.91	5.91	5.91	5.88	5.78	5.57	5.26	4.81	4.18	3.30	1.75					
4	17.00	6.50	6.50	8.80		1.40	3.28	5.22	6.50	6.50	6.50	6.50	6.50	6.50	6.48	6.39	6.21	5.92	5.53	4.99	4.27	3.23	1.23				
5	21.25	6.92	6.92	9.36		2.22	4.61	6.92	6.92	6.92	6.92	6.92	6.92	6.92	6.90	6.81	6.64	6.37	6.00	5.52	4.88	3.99	2.66				
6	25.50	7.21	7.21	9.76	0.26	2.92	5.68	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.20	7.11	6.95	6.70	6.35	5.89	5.28	4.49	3.36	1.13			
7	29.75	7.38	7.38	9.98	.71	3.44	6.60	7.38	7.38	7.38	7.38	7.38	7.38	7.38	7.36	7.28	7.11	6.87	6.54	6.08	5.51	4.75	3.70	1.91			
8	34.00	7.48	7.48	10.12	1.13	3.86	7.48	7.48	7.48	7.48	7.48	7.48	7.48	7.48	7.46	7.38	7.22	6.98	6.64	6.21	5.65	4.90	3.90	2.28			
9	38.25	7.50	7.50	10.15	1.53	4.29	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.48	7.40	7.24	7.00	6.67	6.24	5.68	4.94	3.94	2.34			
10	42.50	7.45	7.45	10.08	1.92	4.64	7.45	7.45	7.45	7.45	7.45	7.45	7.45	7.45	7.43	7.36	7.21	6.97	6.64	6.21	5.65	4.92	3.92	2.34			
11	46.75	7.34	7.34	9.94	2.32	5.05	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.33	7.26	7.11	6.88	6.56	6.14	5.59	4.86	3.87	2.29			
12	51.00	7.20	7.20	9.74	2.75		7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.13	7.00	6.78	6.47	6.05	5.50	4.78	3.79	2.19			
13	55.25	6.97	7.01	9.48				6.97	6.98	6.99	7.00	7.00	7.00	7.00	7.01	6.96	6.84	6.64	6.33	5.93	5.39	4.69	3.70	2.08			
14	59.50	6.61	6.79	9.19					6.65	6.68	6.70	6.71	6.74	6.77	6.78	6.76	6.66	6.46	6.18	5.79	5.27	4.56	3.59	1.96			
15	63.75	6.10	6.53	8.84					6.13	6.20	6.26	6.31	6.39	6.46	6.52	6.52	6.43	6.27	5.99	5.62	5.16	4.43	3.46	1.80			
16	68.00	5.35	6.23	8.44					5.41	5.55	5.69	5.81	5.94	6.08	6.20	6.23	6.17	6.01	5.77	5.42	4.93	4.25	3.30	1.57			
17	72.25	4.46	5.93	8.02					4.58	4.79	5.01	5.24	5.49	5.71	5.86	5.91	5.89	5.77	5.55	5.21	4.74	4.07	3.12	1.32			
18	76.50	3.46	5.57	7.54					3.61	3.94	4.27	4.59	4.91	5.24	5.45	5.56	5.56	5.46	5.27	4.96	4.50	3.86	2.91	.95			
19	80.75	2.35	5.20	7.04					2.59	3.00	3.45	3.86	4.30	4.70	5.00	5.15	5.20	5.14	4.99	4.70	4.27	3.65	2.70	.39			
20	85.00	1.14	4.80	6.50					1.46	1.96	2.49	3.01	3.58	4.10	4.46	4.69	4.79	4.77	4.65	4.40	3.99	3.39	2.45				
Stern-post	88.50	0	4.46	6.03					.45	1.03	1.63	2.21	2.86	3.48	3.95	4.24	4.42	4.45	4.37	4.15	3.78	3.20	2.26				
22	93.50		3.94	5.34							.24	.90	1.61	2.36	3.02	3.53	3.82	3.94	3.91	3.75	3.43	2.88	1.93				
23	97.75		3.49	4.72									.36	1.17	2.04	2.79	3.21	3.44	3.49	3.38	3.09	2.58	1.65				
24	102.00		3.00	4.06											.68	1.66	2.45	2.82	2.99	2.96	2.74	2.28	1.41	.91	0.68	0.48	
25	106.25		2.51	3.40												.11	1.35	2.10	2.43	2.50	2.37	1.97	1.45	1.17	1.02	.95	0.90
26	110.50		2.01	2.72														.90	1.71	1.99	1.97	1.69	1.40	1.17	1.03	.99	.96
27	114.75		1.47	2.00															.20	1.27	1.47	1.30	1.07	.94	.86	.84	.81
28	119.00		.93	1.26																	.82	.90	.71	.65	.60	.55	.52
A. P.	124.49		0	0																							

TABLE II.—HULL OFFSETS OF LANGLEY TANK MODEL 180—Concluded

Station	Distance aft of F. P.	Height of keel	Height of chine	Height of maximum beam	Height of hull at center line	Height below maximum beam from base line							Height above maximum beam from base line							
						Buttock							Buttock							
						1	2	3	4	5	6	7	½	1	2	3	4	5	6	7
F. P.	0	10.00	10.00																	
1/2	2.12	5.60	8.41	10.36	14.07	7.33	8.26							13.81	12.89					
1	4.25	4.03	7.42	10.36	15.46	5.55	6.70	7.30						15.27	14.68	13.44				
2	8.50	2.38	6.06	10.36	17.17	3.40	4.41	5.33	5.88	6.06				17.04	16.62	15.83	14.49	11.10		
3	12.75	1.58	5.00	10.36	18.36	2.33	3.09	3.84	4.48	4.88				18.24	17.87	17.24	16.24	14.63		
4	17.00	1.22	4.23	10.36	19.16	1.78	2.32	2.88	3.41	3.91	4.21			19.05	18.73	18.16	17.29	15.98	13.75	
5	21.25	1.04	3.67	10.36	19.72	1.47	1.90	2.33	2.76	3.19	3.57			19.63	19.32	18.80	18.00	16.83	15.03	
6	25.50	.89	3.30	10.36	20.12	1.27	1.66	2.03	2.40	2.77	3.11	3.29		20.03	19.74	19.23	18.47	17.39	15.76	12.70
7	29.75	.74	3.07	10.36	20.34	1.10	1.48	1.84	2.20	2.57	2.90	3.06		20.24	19.97	19.49	18.74	17.70	16.17	13.51
8	34.00	.59	2.92	10.36	20.48	.96	1.32	1.69	2.05	2.40	2.75	2.92		20.39	20.10	19.64	18.91	17.90	16.41	13.93
9	38.25	.44	2.78	10.36	20.51	.80	1.17	1.54	1.90	2.26	2.60	2.78		20.41	20.14	19.66	18.94	17.92	16.45	14.00
10	42.50	.30	2.63	10.43	20.51	.66	1.03	1.40	1.76	2.12	2.47	2.64		20.42	20.14	19.66	18.93	17.90	16.41	13.88
11	46.75	.15	2.49	10.56	20.50	.51	.89	1.25	1.61	1.98	2.32	2.50		20.40	20.12	19.62	18.89	17.83	16.28	13.55
12	51.00	0	3.59	10.72	20.46	.36	.73	1.09	1.45					20.37	20.07	19.57	18.81	17.73	16.09	12.99
13	55.25	1.35	3.89	10.95	20.43									20.33	20.04	19.51	18.72	17.59	15.84	11.45
14	59.50	1.72	4.13	11.20	20.39									20.29	19.98	19.44	18.63	17.41	15.50	
15	63.75	2.10	4.33	11.50	20.34									20.23	19.91	19.35	18.49	17.19	14.99	
16	68.00	2.47	4.42	11.84	20.28						9.38			20.17	19.83	19.24	18.32	16.88	14.12	
17	72.25	2.84	4.47	12.18	20.20					6.95				20.10	19.73	19.10	18.10	16.49		
18	76.50	3.21	4.47	12.57	20.11				6.20	9.23				19.99	19.61	18.92	17.81	15.89		
19	80.75	3.78	4.43	12.98	20.02			5.99	8.30	11.06				19.89	19.48	18.72	17.48	14.92		
20	85.00	3.95	4.37	13.41	19.91		6.10	7.96	9.80					19.76	19.31	18.47	17.00			
Stern-post	88.50	4.26	4.26	13.80	19.83	5.94	7.65	9.22	11.11					19.68	19.19	18.26	16.46			
22	93.50	6.64		14.35	19.69	8.14	9.56	10.96						19.51	18.94	17.81				
23	97.75	8.52		14.83	19.90	9.80	10.99	12.42					19.70	19.35	18.70	17.24				
24	102.00	10.29		15.36	22.82	11.33	12.37						21.95	19.71	18.39					
25	106.25	11.92		15.89		12.70	13.82							21.19	17.95					
26	110.50	13.45		16.42		14.09								21.80	16.69					
27	114.75	14.91		17.00		15.55								19.55						
28	119.00	16.34		17.60																
A. P.	124.49	18.11																		

U. S. GOVERNMENT PRINTING OFFICE: 1949



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D	Diameter
p	Geometric pitch
p/D	Pitch ratio
V'	Inflow velocity
V_s	Slipstream velocity
T	Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q	Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P	Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$
C_s	Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$
η	Efficiency
n	Revolutions per second, rps
Φ	Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp=76.04 kg-m/s=550 ft-lb/sec

1 metric horsepower=0.9863 hp

1 mph=0.4470 mps

1 mps=2.2369 mph

1 lb=0.4536 kg

1 kg=2.2046 lb

1 mi=1,609.35 m=5,280 ft

1 m=3.2808 ft