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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1290

APPRECIATION AND DETERMINATION OF THE HYDRODYNAMIC QUALITIES OF SEAPLANES

By John B. Parkinson

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

The hydrodynamic qualities of interest in the normal operation of a seaplane, established over a period of years by model testing and by some knowledge of full-size operation, are summarized and briefly discussed. The qualities provide a basis for the determination of consistent information for a number of seaplanes that can eventually be correlated with pilots' opinions to establish quantitative requirements for satisfactory handling on the water. They also provide means for comparative evaluations of different seaplanes and direct correlations between model tests and actual seaplane operation. A suggested tabulation of the information required for a comprehensive hydrodynamic evaluation of a seaplane is given in an appendix.

INTRODUCTION

In research on seaplanes conducted by the National Advisory Committee for Aeronautics it has become desirable to summarize briefly the hydrodynamic qualities that have been used in the Langley tanks to evaluate the relative merit of various seaplanes, the relative importance of various operational parameters, and the relative effectiveness of various modifications of seaplane designs. These qualities have been established over a period of years by a large amount of model testing as well as by a limited amount of experience with actual seaplane operation. The qualities are confined in the most part to recognizable characteristics during familiar maneuvers and to those characteristics susceptible of direct measurement during normal operation on the water.

This paper is intended to serve in a broad sense as a common basis for further seaplane flight testing, tank investigations, and design. It thus becomes an outline for a determination of consistent information regarding the qualities of a number of seaplanes that can eventually be correlated with pilots' opinions to establish quantitative requirements for satisfactory hydrodynamic qualities. Such research would be a logical extension to that carried out by the NACA on the requirements for satisfactory flying qualities of airplanes.

The qualities listed do not include reference to the final control forces and movements, which are of first importance from the pilots' point of view and are an essential part of the flying-qualities research. Moreover, the qualities cannot be considered complete at the present time but are subject to revisions and additions with new seaplane developments and more full-size testing.

A large part of the tank experience has been with large multiengine configurations having relatively high wing, power, and hull loadings. The relative importance of the qualities changes with the loadings; hence those described may not be equally applicable to all classes of seaplanes. The qualities are, however, representative of those receiving most attention at present.

HYDRODYNAMIC QUALITIES

The hydrodynamic qualities of interest in the normal operation of a seaplane may be grouped under four headings as follows:

1. Longitudinal stability and control
    (a) Trim limits of stability
    (b) Center-of-gravity limits of stability
    (c) Landing stability

2. Seaworthiness
    (a) Spray
    (b) Motions and accelerations in rough water

3. Performance
    (a) Take-off acceleration
    (b) Take-off time and distance

4. Lateral stability and control
    (a) Handling in close quarters
    (b) Taxying
    (c) Take-off and landing

These qualities are discussed briefly in the order named, and typical data from model investigations are presented, when available, to illustrate the types of plotting believed to be most useful. The discussion has been made independent of detailed references, but additional information and examples of the patterns to be expected may be found in various NACA papers on seaplanes.

LONGITUDINAL STABILITY AND CONTROL

Trim Limits of Stability

The trim limits of stability define the ranges of trim and speed in which porpoising occurs and provide the basis for investigating dynamic longitudinal stability on the water. Typical trim limits for various multiengine flying boats as determined by dynamic-model tests in the Langley tanks are shown in figure 1.

In general, seaplanes are dynamically stable in the displacement-speed range up to the hump speed. At planing speeds, there is a stable range of trim bounded by the upper and lower trim limit of stability. Both limits are a function of the load on the hull; hence, for configurations where slipstream has a large effect on wing lift, the limits are lowered by the application of power as shown.

<u>Lower trim limit</u>.- Porpoising below the lower limit primarily involves the forebody and is first found at a speed slightly above the hump where the afterbody comes clear and at a trim near the sternpost angle (angle between the forebody keel and a line joining the forebody keel at the main step with the sternpost or after end of the afterbody keel). The lower limit decreases rapidly with speed and, for conventional hulls, approaches a trim at high planing speeds between 1° and 2° referred to the forebody keel.

The lower limit is not always well-defined at speeds near the hump but is more definite at higher speeds. Very small external disturbances are sufficient to start the porpoising once the limit has been crossed.

The lower limit is sometimes affected at high speeds by afterbody wetting or other interference flows. Such an effect is shown in figure 1(c) in which the limit, power on, apparently jumps suddenly to the limit, power off, near a speed of 60 miles per hour.

<u>Upper trim limits</u>.- Porpoising above the upper limits involves both the forebody and afterbody. It may begin near the hump speed, but the limits are usually determined from a higher speed at which the trims can be attained with available up-elevator and after center-of-gravity positions to the take-off speed.

In general, the upper limits have two branches. The first branch is obtained in going from the stable to the unstable range. The second branch, lying below the first, corresponds to the trims at which the porpoising stops once it has been started. This hysteresis is the result of the afterbody running in the wake of the forebody.

The two branches almost coincide at the low-speed end but, when the porpoising is violent, diverge rapidly at higher speeds. (See fig. 1(b).) When the porpoising is relatively mild, as is the case with ample depth of step, the branches remain within approximately 1° of each other out to the take-off speed. (See fig. 1(a).) The upper limits are sometimes affected by interference effects such as shown in figure 1(c). In this figure, the lower branch without power is normal, but the lower branch with power has a more complex shape.

Test procedure.- In the Langley tanks, the limits of a model are determined by a succession of runs at constant speed and power during which the trim range is covered by varying the elevator deflection and center-of-gravity position. The effect of these moment parameters on the position of the limits has been established to be negligible.

The corresponding determination for the seaplane is more difficult because of the necessity for planing at constant speed as the trim is varied. Limits have been measured during accelerated runs when the accelerations have not been so great as to obscure the boundary between stable and unstable trims.

Center-of-Gravity Limits of Stability

The trim limits of stability, although of basic importance, are not in themselves a significant hydrodynamic quality because the actual instability encountered during take-offs depends on the relationship of the trim limits and the running trims. If the trim track (variation of trim with speed) lies wholly within the stable range of trims, the take-off will be stable. If, however, the trim track intersects a trim limit, porpoising will occur of an amplitude depending on the penetration into and the duration of operation in the unstable range.

Whether the trim tracks lie within the stable range of trims or not depends on the external longitudinal moments acting. Thus the important sources of these moments become in a practical sense significant parameters when dealing with porpoising. The longitudinal position of the center of gravity, as in the case of aerodynamic stability, is a convenient parameter to define the stable range of moments.

Definition of center-of-gravity position. - The longitudinal position of the center of gravity is usually defined in percent of the mean aerodynamic chord (M.A.C.) of the wing to be consistent with the method universally employed in aircraft operation. In the case of seaplanes, where the center of gravity is often at some distance from the M.A.C., the reference axes must be defined. For convenience, the position is usually referred to the horizontal projection of the M.A.C. parallel to the longitudinal reference line of the airplane as shown in figure 2.

The vertical position of the center of gravity is usually defined as its distance in feet or inches above the keel at the step perpendicular to the longitudinal reference line. The dimension should be recorded since the vertical position has an appreciable effect on the effective horizontal position at trims other than zero.

Variation of amplitude of porpoising with center-of-gravity position. - Typical plots of maximum amplitude of porpoising during accelerated take-offs against position of the center of gravity, determined from tank tests of dynamic models, are shown in figure 3. The amplitude is defined as the largest difference between the maximum and minimum trims during one porpoising cycle at any speed during the take-off. It usually varies approximately linearly with the center-of-gravity position in the unstable range. The slopes are generally the same for different elevator deflections but are not the same for the lower-limit and upper-limit porpoising and for different seaplanes.

As may be seen from figure 3, any degree of instability may be encountered with a conventional seaplane depending on the center-of-gravity position and elevator deflection. The practical center-of-gravity limit for one elevator and flap deflection is usually defined as the position for a maximum amplitude of porpoising of 2° as shown.

Lower-limit porpoising, defining the forward center-of-gravity limit, usually occurs at intermediate planing speeds where the trim track intersects the lower limit and then reenters the stable range after which the instability damps out. Upper-limit porpoising, defining the after center-of-gravity limit, usually occurs at speeds near take-off where the trim track crosses the upper limit, increasing trim, and continues above it until the hull is air-borne. In some cases with abnormal trim tracks or unstable "islands" in the trim limits of stability, the practical limits are more difficult to determine and must be further qualified.

Variation of center-of-gravity limits with elevator and flap deflection.- Typical variations of the center-of-gravity limits of stability with upward deflection of the elevator are shown in figure 4. Similar data showing variations with flap deflection for various elevator deflections are shown in figure 5. These plots vary widely among different designs and, consequently, offer a means of quantitative differentiation between satisfactory and unsatisfactory longitudinal stability and control.

Figure 4(b) presents data for a flying boat, the stability of which is critical with elevator deflection and which, with the center of gravity forward of 30 percent M.A.C., requires a large upward deflection to avoid lower-limit porpoising near the hump speed. These characteristics, however, are considered satisfactory in service. Data very similar to those shown have been obtained for the full-size seaplane by the Navy using a relatively simple technique.

For conservative practice, the center-of-gravity limits are defined for elevator deflections which leave a reserve for recovery in the event of porpoising induced by a large disturbance, such as the wake of a boat. Downward deflections of the elevator are not normally considered in defining the limits. For example, at the forward limit with neutral elevator, the full up-elevator travel is available for recovery from lower-limit porpoising, and, at the after limit with full-up elevator, the full down-elevator travel to neutral is available for recovery from upper-limit porpoising. This favorable pattern is illustrated in figure 5(a). Figure 5(b), on the other hand, shows no stable range between the forward limit with zero elevator deflection and the after limit with -20° elevator deflection, and stable take-offs with constant elevator can only be made with little deflection available for recovery. Such a characteristic is not necessarily unsatisfactory because service take-offs are not normally made with constant elevator deflection and the reserve deflection may not be considered essential by the pilot.

Plots of the type shown in figures 4 and 5, together with the aerodynamic-center-of-gravity limits, determine the range of positions of the center of gravity for practical operation and should be included in the operating instructions of the airplane.

Test procedure.- Measurement of water speed is not normally required to determine the center-of-gravity limits; hence, the instrumentation may be simplified to include only a visual trim indicator, an elevator-position indicator, and a flap-position indicator. The Navy procedure is to make a succession of take-offs with the copilot maintaining constant elevator deflection and understanding that the pilot may overpower his control if required. Elevator deflections at various center-of-gravity positions for amplitude of porpoising of approximately 2° are then plotted as in figure 4. For unusual patterns, the approximate water speed at which the instability is encountered should also be noted as an aid in interpreting the data.

A large number of take-offs at full power is detrimental to the engines; consequently, it may be necessary to explore completely the limits by means of model tests and to confine the full-size experiments to those required for correlation with the model data. The type of data shown in figures 4 and 5 in any case supply the necessary information for the operating instructions of the airplane.

Landing Stability

The hydrodynamic longitudinal stability of a seaplane applies to both take-offs and landings, but the maneuvers differ in detail and the landing stability is best treated as a separate hydrodynamic quality. The landing stability becomes of particular importance when the hull tends to leave the water in a succession of skips below flying speed and when the seaplane is not under complete control. Skipping is primarily a function of landing speed and trim but is also influenced by the approach technique and the vertical speed.

In practical operation, it is desirable to land stably at high trims to obtain slower landing speeds. Instability at contact trims, for which the afterbody touches first, is usually associated with the upper porpoising limits. Skipping of equal or greater violence may also occur at trims below the lower branch of the upper trim limit and above the lower trim limit.

Variation in amplitudes of skipping with contact trim.- Typical variations of skipping amplitudes with contact trim, obtained from landing tests in the Langley tanks, are shown in figure 6. Figure 6(a) illustrates the effect of afterbody ventilation varied by changing the depth of the step. Below the angle for which the afterbody keel is horizontal on contact, the amplitudes are negligible for either depth of step. Above this angle the amplitudes are dangerously high with the shallower step but are negligible at all trims with the deeper step.

Figure 6(b) illustrates a form of landing instability associated with the position of the center of gravity with respect to the step. In this case, landings with the center of gravity at 40 percent M.A.C. are also unstable below the afterbody-keel angle and become progressively worse until the afterbody is horizontal. Above this angle the amplitudes decrease suddenly and are approximately constant at higher trims as for a shallow step. Moving the center of gravity forward 10 percent M.A.C. eliminates the sharp increase in amplitude below the critical angle but makes little difference at other trims.

Landing instability from additional causes may be encountered, in which case the pattern may be more complex than those shown, and trims other than that corresponding to the afterbody-keel angle may become critical.

Test procedure.- Landing tests are made by making a succession of landings at various contact trims and recording the subsequent behavior. The violence of the resulting oscillations or skips in terms of vertical motion, trim change, or number of skips is then plotted against the contact trim for various landing-flap settings and positions of the center of gravity.

Landing tests are made by the Navy using a visual trim indicator and an airspeed indicator to guide the pilot during the approach and to determine the trim and airspeed at contact. The number of skips after contact is counted as a measure of the landing stability. Amplitude in trim, for the type of plot shown in figure 6, can be read directly from the trim indicator by an observer. Amplitude in vertical motion is difficult to measure for a full-size seaplane but is easily measured in the Langley tanks as a criterion for systematic investigation of various parameters.

SEAWORTHINESS

Spray

Spray is of importance in the operation of seaplanes when it obscures vision, inflicts physical damage to structural components, causes instability, or delays take-offs by reducing the power of the engines. The spray of heavily loaded multiengine configurations often results in one or more of these defects and, in any case, is a significant quality from considerations of research and design.

Spray characteristics are usually recorded qualitatively from pilot's observations or photographs. The value of the data is greatly enhanced if accompanied by tangible evidence of spray effects, such as corrosion of propeller blades, damage to flaps, or undue engine maintenance. For comparison and correlation purposes, it is of value to record the range of speed over which spray effects of interest occur and the effects of acceptable overloads. Any spray limitation on the maximum gross load is an important quality. The minimum loads for spray wetting the windshield, the propellers, the flaps, and the tail surfaces are additional items for quantitative comparisons between types and correlations with model data.

Typical smooth-water spray ranges.- Typical ranges of speed for spray in propellers and on flaps of multiengine types are shown as functions of the gross load in figure 7. These data were obtained with powered dynamic models in smooth water in the Langley tanks and can be obtained in a comparable form for full-size seaplanes with the aid of a water-speed indicator or a sensitive airspeed indicator. The data do not, of course, indicate the important characteristics of density and duration, which have a direct bearing on the spray effects.

Rough-water spray.- Spray in rough water is a more complex problem, and quantitative determinations of this quality are difficult to make. During wave encounters, bursts of spray strike components not normally wetted in smooth water, and the severity of the effects is increased. Spray under adverse sea conditions will always be an important consideration, however, and its evaluation will logically take the form of measurement of the spray loads on the components or other pertinent effects.

Motions and Accelerations in Rough Water

The most severe service conditions for a seaplane are the rough-water take-off and landing. A quantitative investigation of rough-water qualities for a full-size seaplane is not often feasible or even safe. Nevertheless, these qualities are of primary importance in the design of types requiring a high order of seaworthiness.

From an over-all standpoint, the qualities of most interest are the normal and angular accelerations and the maximum trims. The accelerations are measures of the load factors for structures supporting concentrated masses, and the maximum trims are indicative of the extent of dangerous operation above the stall angle, usually below flying speed and without lateral control. These qualities may be directly measured either for the full-size seaplane or for a dynamic model in the more controlled conditions of the towing tank.

The surface of the sea is usually a confused pattern of superimposed wave trains, and the waves vary widely in length and height. Moreover, the maneuvers are favored as much as possible by the pilot by a judicious choice of operating area and direction with respect to the prevailing swell. In the tank, however, more regular reproducible wave systems are used, and trends may be established with variations in the important parameters that serve as guides for limited open-water testing.

Variation of maximum acceleration and trim with wave size.- Typical variations of maximum acceleration and trim with wave length and height, as obtained from free landings of powered dynamic models in oncoming waves in the Langley tanks, are shown in figure 8. There is a pronounced effect of wave length on the normal acceleration at the center of gravity, and the highest maximum acceleration apparently occurs near a wave length of 2.5 hull lengths (measured from bow to sternpost). Increasing the wave height for a given length increases the acceleration as would be expected. The maximum trims obtained are not greatly affected by the wave parameters and, in general, are higher than the stall trim.

Test procedure.- The points shown from the model tests are the probable maximums obtained from a number of landing runs at each wave length and height and usually occur during an uncontrolled encounter with a wave front subsequent to the initial contact. Although obtaining similar consistent data for a full-size seaplane would be difficult, it can be attempted with standard flight accelerometers, a visual trim indicator, and some method of observing the size of the waves such as a hydrometer-type buoy.

PERFORMANCE

Take-off performance was originally of first importance as a hydrodynamic quality and remains so for the very high power loadings of long-range transports and some personal-owner types, as well as for the wing loadings resulting in a long planing run and high take-off speed. The performance is conveniently defined in terms of the take-off time and distance which are direct measures of engine-cooling, operating-area, and other problems.

Take-off acceleration.- The take-off time and distance are functions of the longitudinal accelerating force and, hence, of the longitudinal acceleration. A typical variation of the acceleration of a large long-range flying boat with speed for various elevator deflections, as determined from tests of a powered dynamic model in the Langley tanks, is shown in figure 9. In this figure, the acceleration varies widely with the elevator deflections. At the hump speed, low deflections are favorable which sometimes lead to lower-limit porpoising; whereas near take-off, intermediate deflections are favorable which sometimes lead to upper-limit porpoising. Some manipulation of the controls is required to obtain the best take-off performance.

Take-off time and distance. - The take-off performance is readily determined from the curve of acceleration against speed as shown in figure 9. Take-off time is the area under the curve of $1/a$ plotted against speed; take-off distance is the area under the curve of v/a plotted in the same way. For the seaplane considered and at a constant elevator deflection of -15°, the time for a given increment in speed is greatest near the hump speed. The distance for a given increment in speed, however, is also large near take-off, as is usually the case with high wing loadings.

Test procedure. - The data shown in figure 9 can be measured directly with a low-frequency accelerometer and a water-speed indicator during take-offs at various constant elevator deflections. For consistency, the measurements should be made from the time the engines develop full take-off rotational speed to the time the step leaves the water. If these times are definitely established, take-off time may be directly measured with a stop watch or timer record. Take-off distance is most conveniently calculated from the plot of v/a or from the area under a water speed-time curve if this curve is recorded.

LATERAL STABILITY AND CONTROL

Very little systematic research has been done on lateral stability and control in terms of full-size operating parameters similar to that described for the other hydrodynamic qualities. This section, therefore, merely summarizes the obvious lateral qualities as a means of pointing out observations that may be made in the course of flight tests and as a means of providing a basis for further research in model size.

Handling in close quarters. - The handling problem in close quarters is essentially the same as for surface vessels, and its evaluation is largely dependent on the seamanship of the pilot. Qualitative information of value include response to air controls or water rudder, sensitivity to differential power, and weathercocking tendency. More quantitative information includes such items as minimum speed with engines running, which may be negative with reversible propellers, and minimum turning circle.

Taxying. - The ability to taxy crosswind may be expressed in terms of ability to hold a straight course, ability to turn downwind, and tendency of the downwind tip float to bury. A numerical value of interest for comparison purposes is the maximum advisable crosswind or, more specifically, the crosswind at which a tip float submerges and its ability to emerge when the seaplane is turned into or out of the wind. The ability to taxy downwind may likewise be described by ability to hold course and tendency to weathercock in winds of various magnitudes.

Take-off and landing. - Lateral stability and control problems associated with take-offs and landings include the tendency to yaw at low speeds on take-off, to skid at high planing speeds, and to yaw or "water loop" on landing. The ability to hold course can be described roughly in terms of the control deflections or differential power required and characteristics exhibited in a crosswind. Notes on the adequacy of the tip floats underway and their effects on course-keeping qualities are useful supplementary information.

CONCLUDING REMARKS

The hydrodynamic qualities presented are generally expressed in terms appropriate to various sizes and types of seaplanes and to both the prototype and powered dynamic model. These qualities provide, therefore, means for comparative evaluations of different seaplanes and for direct correlations between tank operation and actual seaplane operation as well as for the establishment of quantitative requirements.

A suggested tabulation of the information required for a comprehensive hydrodynamic evaluation of a seaplane, either by full-size or model tests, is given in the appendix. All the items named have not yet been determined for any one design, and some of them are not of sufficient importance to justify complete investigation in all cases. They serve, however, to outline the possible scope of a flight or tank investigation of a specific design and of further hydrodynamic research on conventional seaplane problems.

The adequacy of the qualities for the purposes stated can best be established by their determination for as large a variety of seaplanes as possible. It is urged that agencies in a position to conduct hydrodynamic investigations along the lines proposed will continue the research as opportunity offers in order eventually to provide a broader basis for the over-all improvement of the operating characteristics of seaplanes.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., March 18, 1947

APPENDIX

INFORMATION REQUIRED FOR HYDRODYNAMIC EVALUATION OF A SEAPLANE

General:

Three-view drawing of general arrangement
Span, ft
Over-all length, ft
Height, ft
Normal operational gross load, lb
Maximum overload gross load, lb
Wing area, sq ft
Total take-off horsepower
Minimum flight speed, flaps in normal landing position, mph
Average landing speed, flaps in normal landing position, mph
Average take-off speed, flaps in normal take-off position, mph
Aerodynamic center-of-gravity limits, normal and overload, percent M.A.C.
Average vertical distance of center of gravity from keel at step, normal and overload, ft

Hull particulars:

Length, ft
Beam over chines, ft
Height at step, ft
Length of forebody, chines at bow to step, ft
Length of afterbody, ft
Static trim, normal and overload, deg
Static draft, normal and overload, ft
Static heel, normal and overload, deg
Angle of afterbody keel to forebody keel, deg
Sternpost angle to forebody keel, deg
Angle of dead rise forward of step including flare, deg
Angle of dead rise forward of step excluding flare, deg
Angle of dead rise at bow, deg
Angles of dead rise of afterbody, deg
Depth of step at keel, ft
Depth of step at chine, ft
Propeller diameter, ft
Static propeller clearance on low side, normal and overload, ft
Static flap clearance on low side, take-off and landing position, normal and overload, ft
Static tail-surface clearance on low side, elevator neutral, normal and overload, ft

Quantitative hydrodynamic qualities, normal and overload:

- Longitudinal stability and control
  - Variation of center-of-gravity limits with upward elevator angle, take-off flap deflection
  - Variation of center-of-gravity limits with flap deflection, lowest practicable upward elevator deflection for forward limit and highest practicable upward elevator deflection for after limit
  - Variation of number of skips and amplitude in trim with contact trim, landing flap deflection, and position of center of gravity
- Seaworthiness
  - Water speeds at which windshields, inboard and outboard propellers, flaps, and tail surfaces are subject to spray
  - Maximum normal accelerations and trims in rough water
- Performance
  - Variation of longitudinal acceleration with speed and upward elevator deflection, full-power take-offs, take-off flap deflection
  - Take-off time
  - Take-off distance
- Lateral stability and control
  - Minimum speed, engines running, mph
  - Minimum turning circle, ft
  - Maximum advisable crosswind for taxying or crosswind at which tip float submerges, mph
  - Maximum advisable crosswind for landing
  - Control deflections required to hold course on take-off and landing, fractions of full deflection

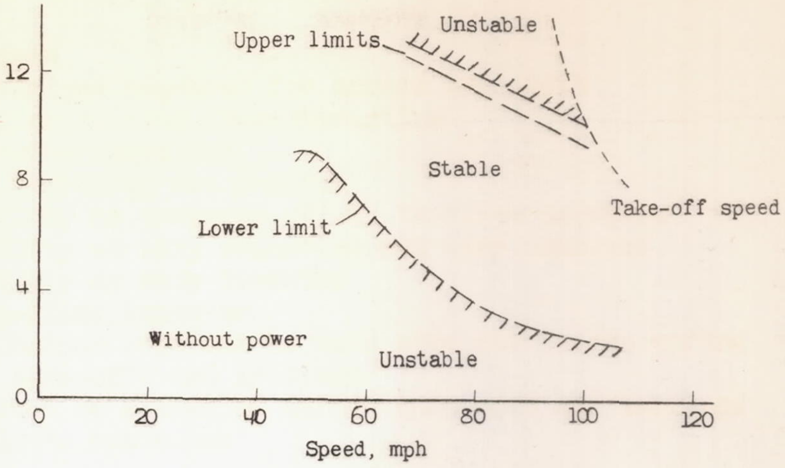
Qualitative observations, normal and overload:

- Longitudinal stability and control
  - Technique required during take-off to avoid porpoising
  - Technique required for approach, contact and remainder of landing run to avoid instability
  - Pilot's reactions
- Seaworthiness
  - Technique required to alleviate spray damage
  - Photographs or observations of critical spray conditions
  - Spray damage and maintenance required
  - Rough water behavior
  - Pilot's reactions

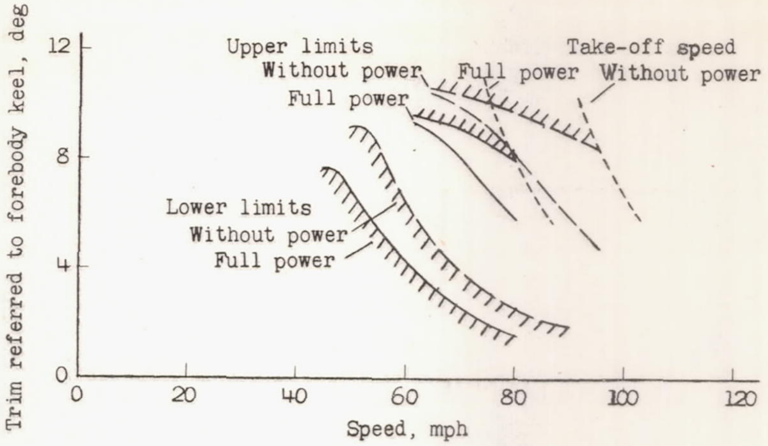
- Performance
    - Technique required for normal take-offs
    - Engine cooling characteristics
    - Pilot's reactions
- Lateral stability and control
    - Ability to maneuver safely in close quarters
    - Ability to taxy crosswind and turn downwind
    - Ability to taxy downwind
    - Tip-float behavior
    - Technique required to hold straight course during take-offs and landings
    - Effect of crosswind during take-offs and landings
    - Pilot's reactions

Pilot's over-all evaluations, normal and overload:

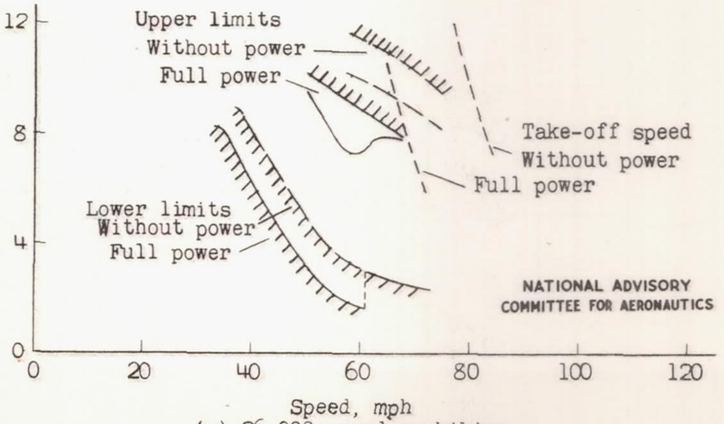
Pilot's over-all evaluation of water handling, take-off, and landing qualities as compared with similar types and with other classes of seaplanes



(a) 400,000-pound cargo flying boat.
Flap deflection, 20°.



(b) 145,000-pound cargo flying boat.
Flap deflection, 30°.



(c) 26,000-pound amphibian.
Flap deflection, 20°.

Figure 1.- Typical trim limits of stability.

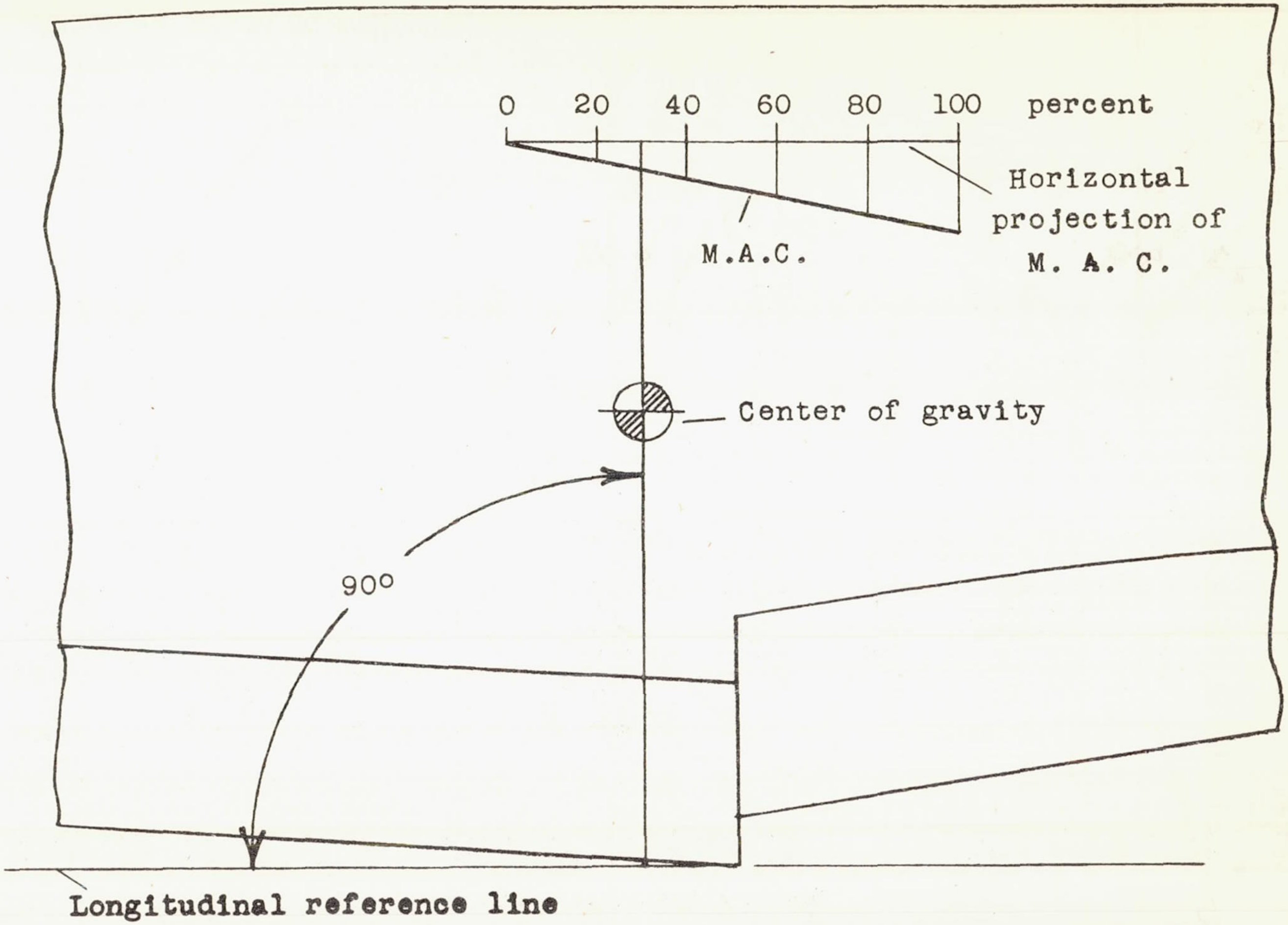


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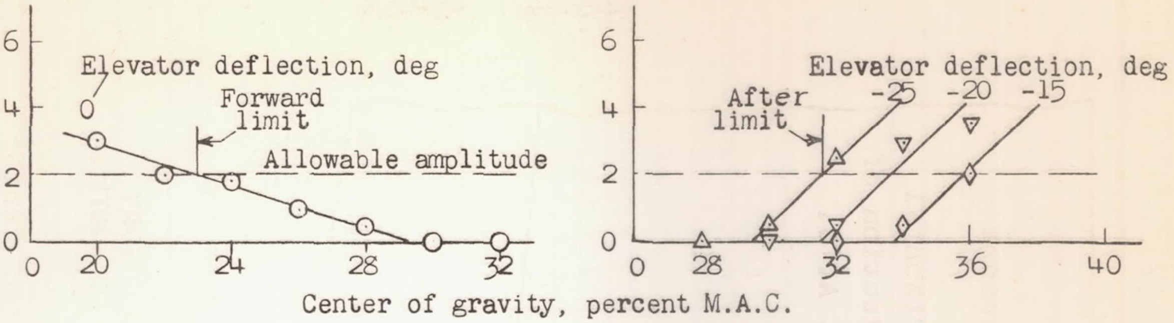
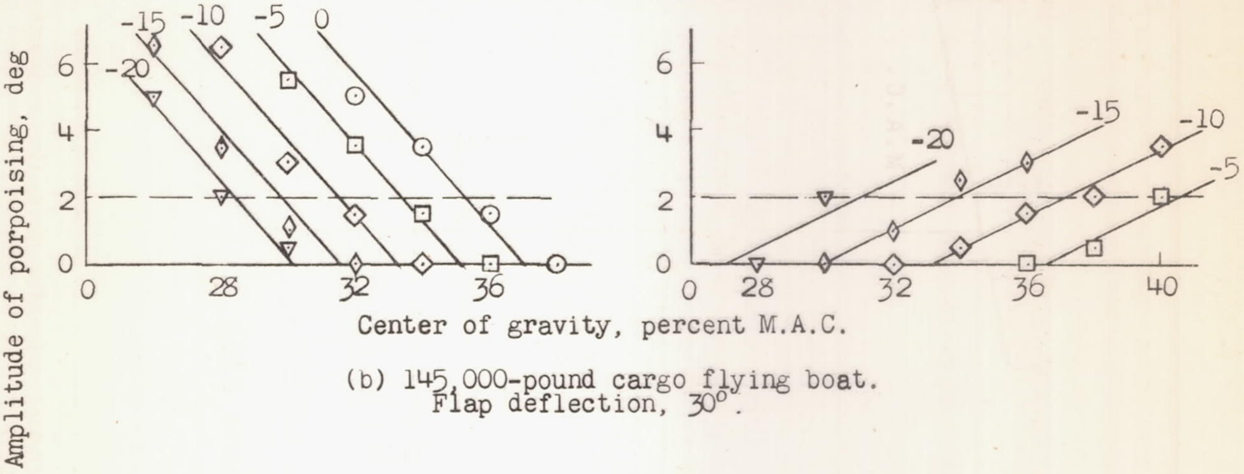
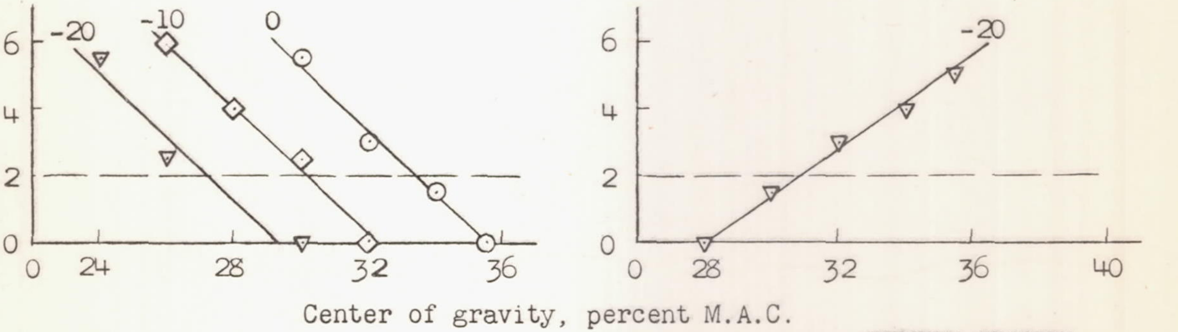
Figure 2.- Standard definition of longitudinal position of center of gravity in percent of the M.A.C. Center of gravity shown is 30 percent M.A.C.



(a) 400,000-pound cargo flying boat. Flap deflection, 20°.



(b) 145,000-pound cargo flying boat. Flap deflection, 30°.



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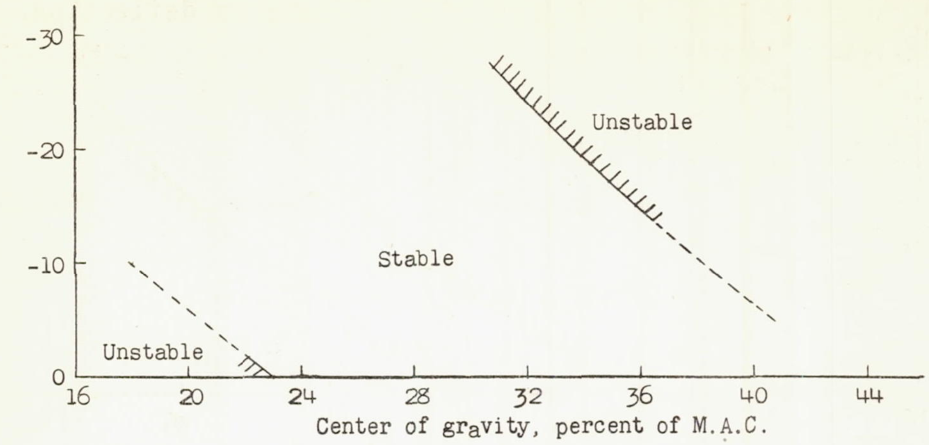
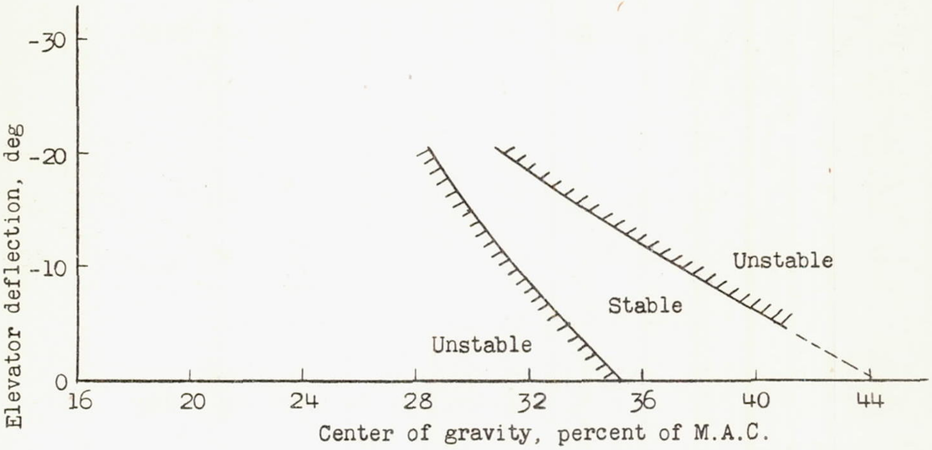
(c) 20,000-pound amphibian. Flap deflection, 20°.

Lower-limit porpoising Upper-limit porpoising

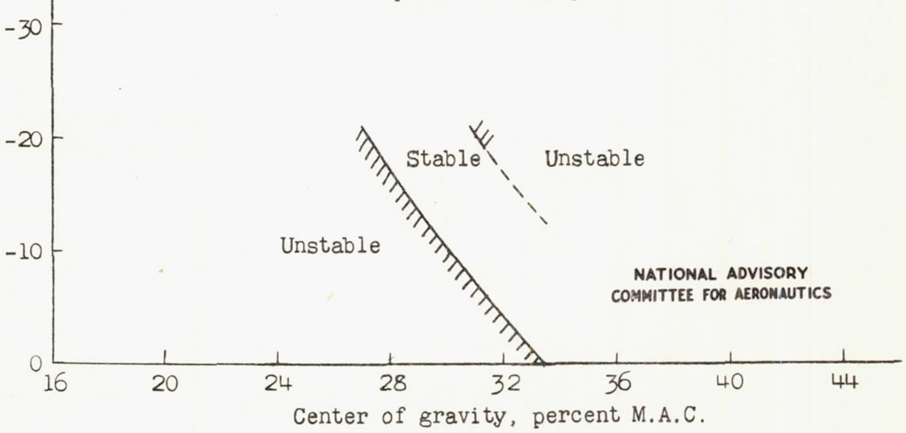
Figure 3.- Typical variations of amplitude of porpoising during take-off with position of the center of gravity and elevator deflection.



(a) 400,000-pound cargo flying boat.
Flap deflection, 20°.



(b) 145,000-pound cargo flying boat.
Flap deflection, 30°.



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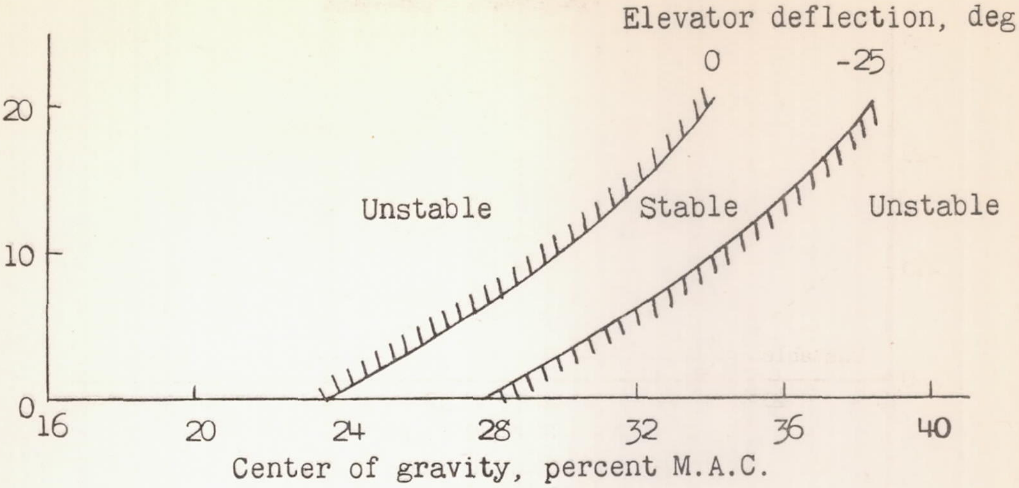
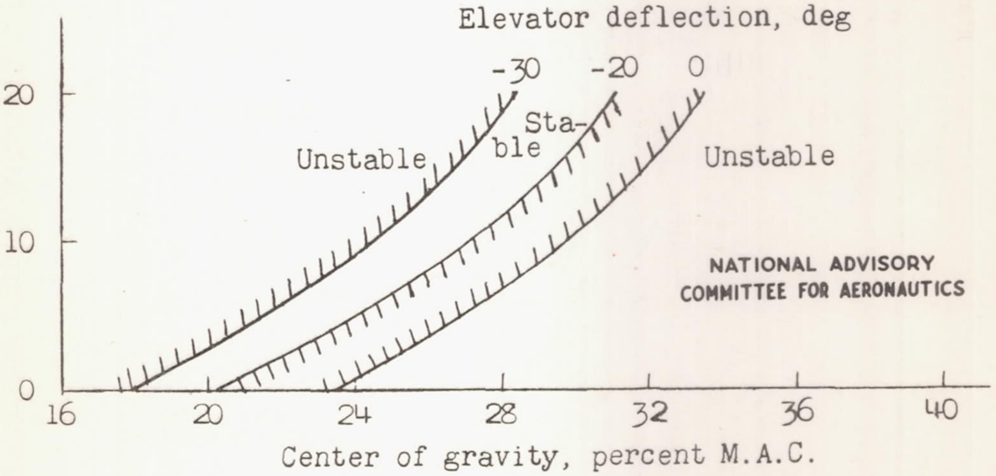
(c) 26,000-pound amphibian.
Flap deflection, 20°.

Figure 4.- Typical variations of center-of-gravity limits of stability for 2° amplitude of porpoising with elevator deflection.

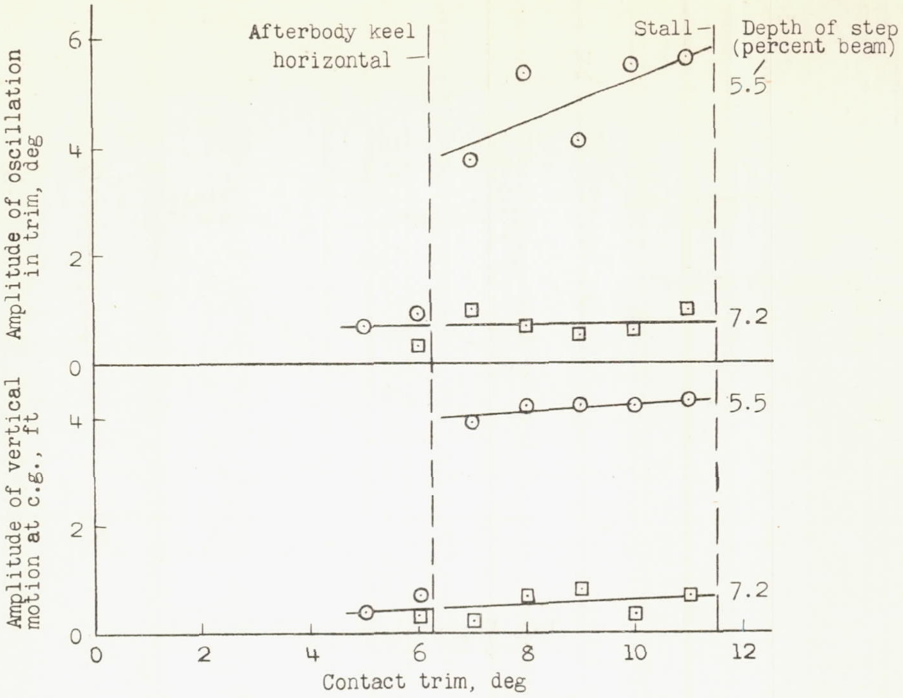


(a) 75,000-pound patrol-bomber flying boat.

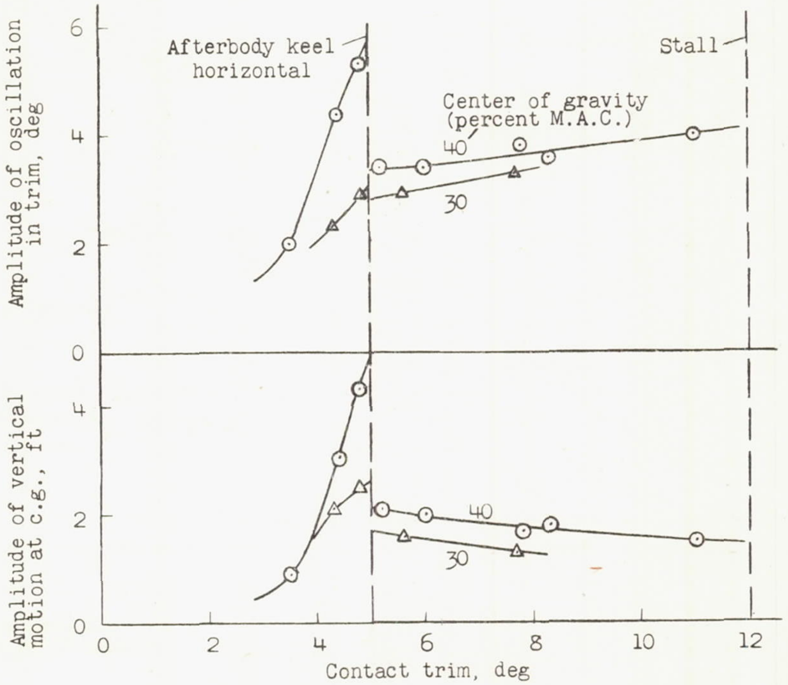


(b) 26,000-pound amphibian.

Figure 5.- Typical variations of center-of-gravity limits of stability for 2° amplitude of porpoising with flap deflection.



(a) 66,000-pound patrol-bomber flying boat.



(b) 145,000-pound cargo flying boat.

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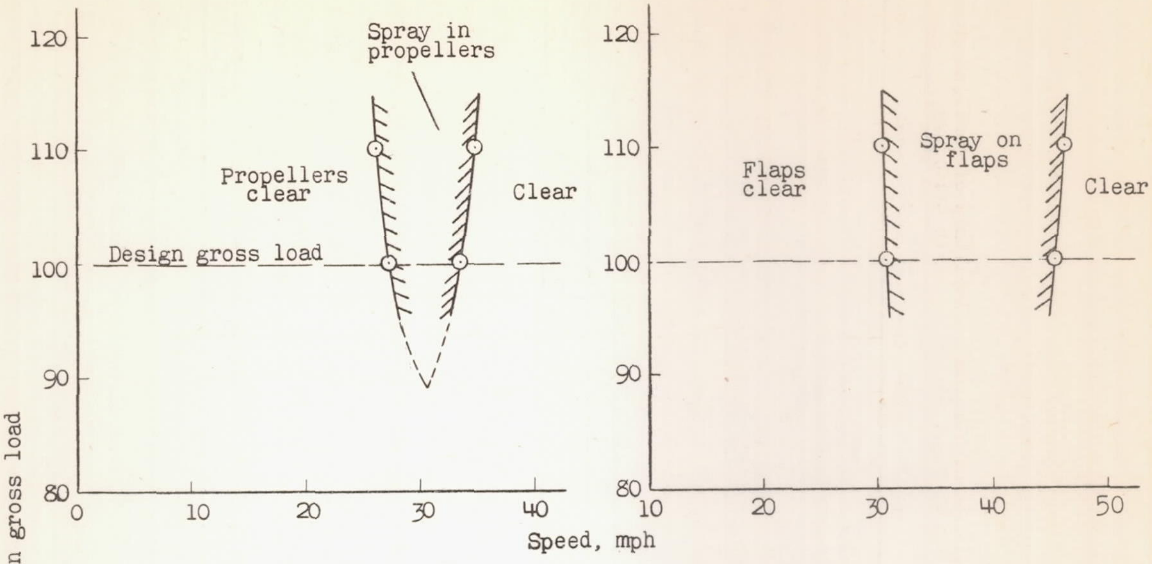
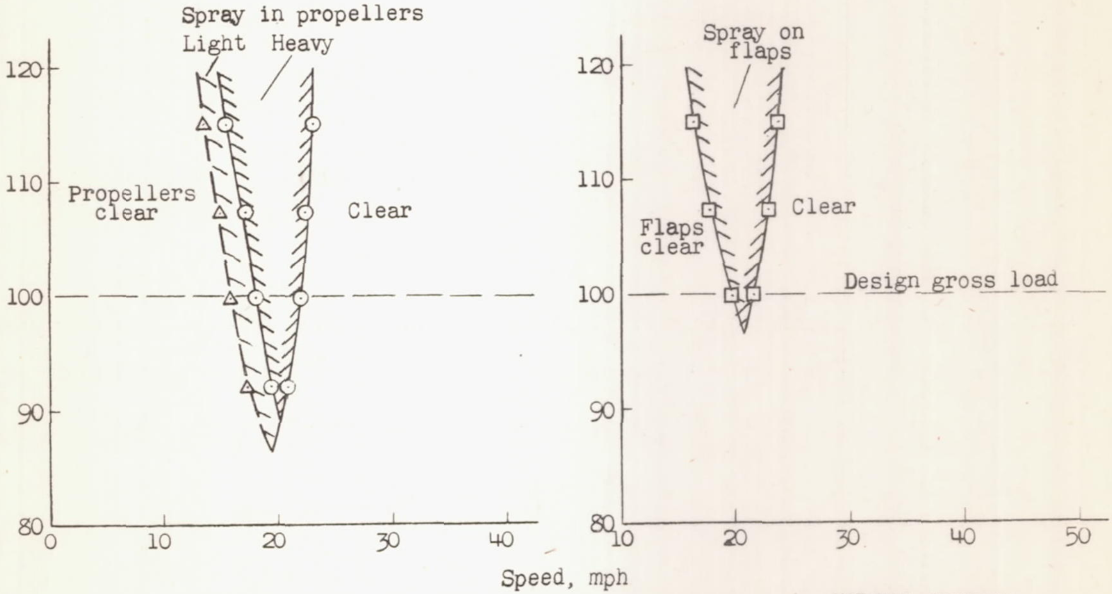
Figure 6.- Typical variations of skipping amplitudes with contact trim, depth of step, and position of the center of gravity.



(a) 145,000-pound cargo flying boat. Flap deflection, 30°.



(b) 26,000-pound amphibian. Flap deflection, 0°.

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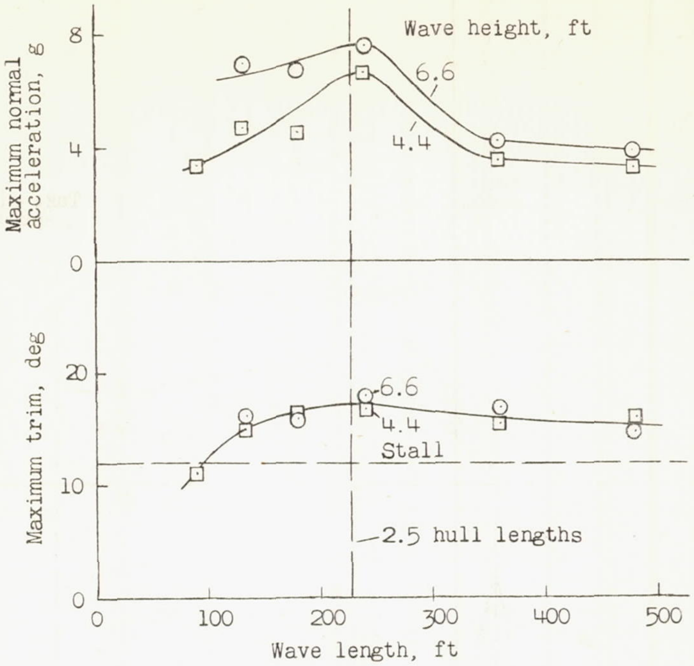
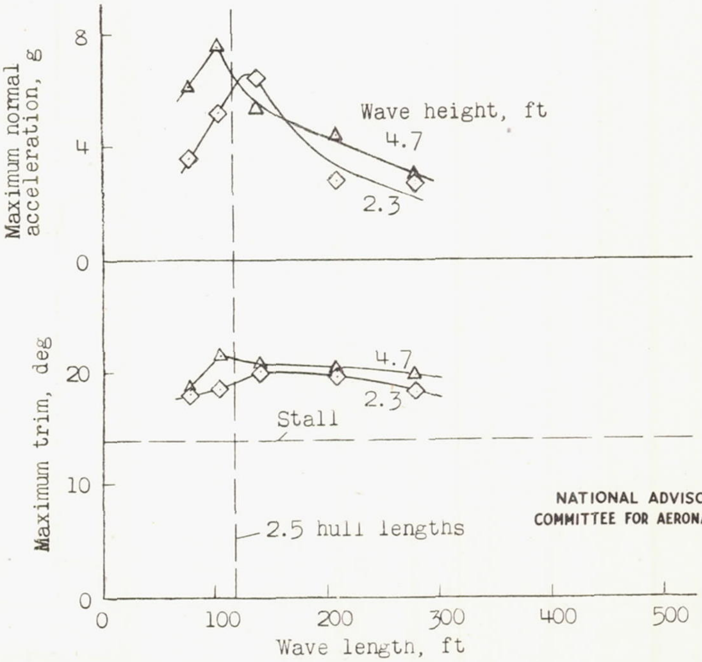
Propellers

Flaps

Figure 7. - Typical variations of range of speed for spray in propellers and on flaps with gross load.



(a) 145,000-pound cargo flying boat.



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(b) 26,000-pound amphibian.

Figure 8.- Typical variations of maximum vertical acceleration and trim during landing with wave length and height.

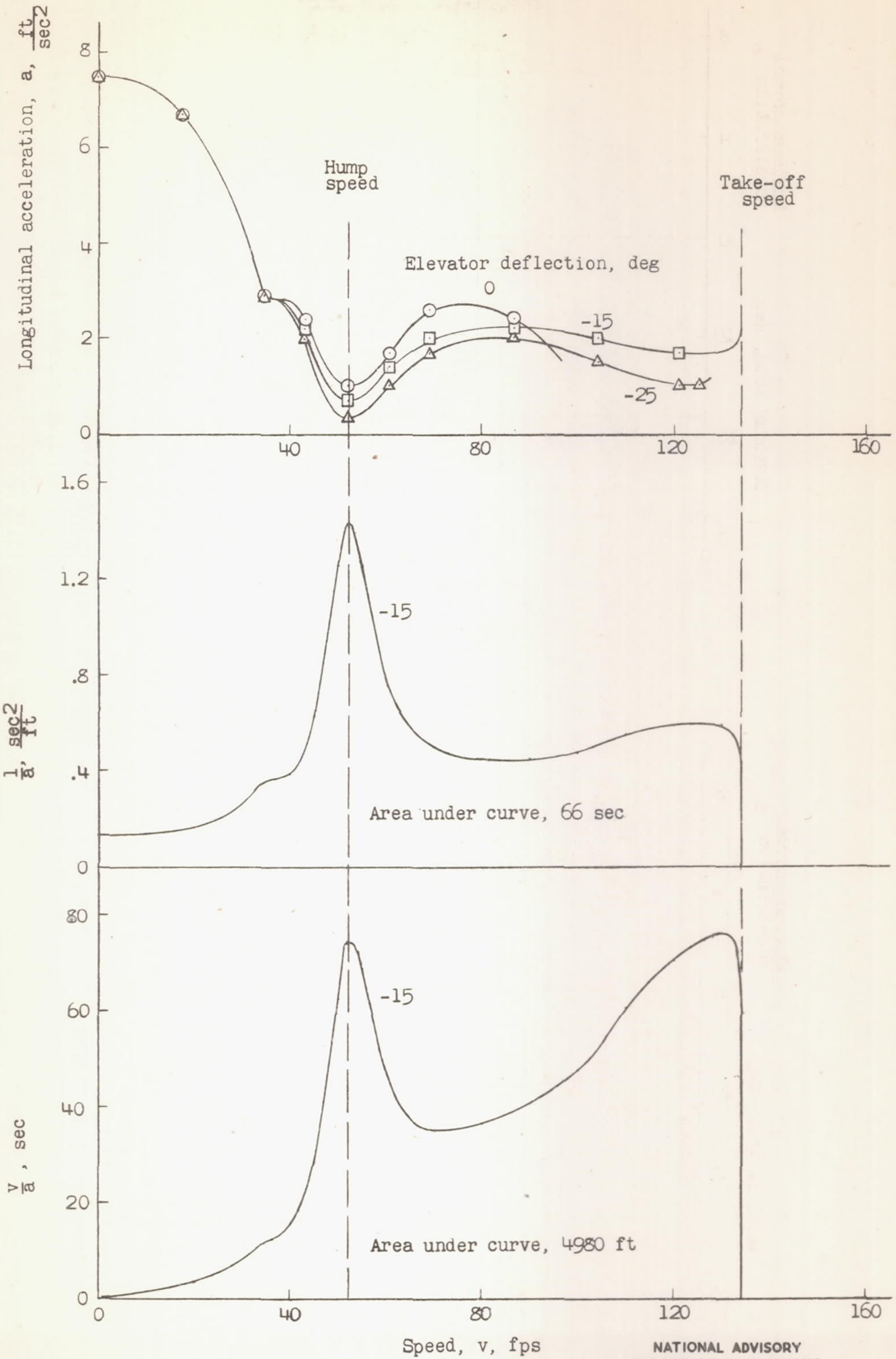

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Figure 9.- Typical variation of longitudinal acceleration a, 1/a, and v/a with speed during take-off. 165,000-pound cargo flying boat; wing loading, 45 pounds per square foot; power loading, 14 pounds per horsepower.