JAN 30 1947

RB No. 3I27

Copy 1

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
September 1943 as
Restricted Bulletin 3I27

NOTES ON THE SKIPPING OF SEAPLANES

By John B. Parkinson

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

NOTES ON THE SKIPPING OF SEAPLANES

By John B. Parkinson

L-333

SUMMARY

Skipping is a form of hydrodynamic instability, present during water take-offs and landings, that tosses the seaplane into the air below flying speed. Several investigations of actual airplanes and dynamically similar models have shown that the primary cause of the instability is a large suction force on the afterbody generated by the flow behind a shallow step. The results of the investigations indicate that, for flying boats, catastrophic skipping may be avoided by the use of depths of step of from 7- to 12-percent beam. With depths of step of 5-percent beam, skipping may be alleviated by ventilation openings in the afterbody as close to the step and keel as possible. The total area of openings and ducts should be 2-percent of the square of the beam.

INTRODUCTION

Skipping is a form of instability encountered in water take-offs and landings, so-called because of the resemblance of the motions of the seaplane to those of a skipping stone. It occurs at high water speeds at which the gross weight of the seaplane is nearly air borne. The motions are rapid and not under control of the pilot, and the seaplane is often thrown clear of the water below flying speed.

The hazardous nature of skipping in the operation of large flying boats was first brought to the attention of the National Advisory Committee for Aeronautics by Captain Harold E. Gray, a member of the Subcommittee on Seaplanes. A large flying boat with violent skipping characteristics had to be landed at lower trims and higher speeds than would otherwise have been used, which added to operational hazards in close quarters and increased the tendency to "water loop." Captain Gray's experience indicated that the instability was mainly a function of trim and water speed and was relatively unaffected by gross weight and normal variations in the position of the center of gravity. It could occur in smooth water and at low sinking speeds and appeared to be caused by a large suction force acting aft of the center of gravity.

In another instance, a flying boat with unstable landing characteristics was also subject to "jump" take-offs in smooth water during which altitudes of 30 feet or more were attained before flying speed was reached. The flying boat then returned to the water in an uncontrollable attitude after which the cycle was repeated until flight was maintained.

The skipping of several seaplanes has been investigated both full-scale and by the use of dynamically similar models in NACA tank no. 1. The results of the tests of the models have, in general, been in satisfactory agreement with the results of experience with full-size flying boats. The purpose of this paper is to summarize the information obtained up to the present time as an aid in understanding the phenomenon of skipping and in avoiding catastrophic skipping tendencies in future seaplanes.

TEST PROCEDURES

Investigations of skipping have been mainly qualitative and the data have been based on the impressions of pilots or observers. This procedure has been generally adequate for the improvement of specific designs because of the large differences in behavior when the seaplane or model is skipping and when it is not skipping. Trim has been established as the most important independent variable in skipping tests.

Tests of full-size flying boats.- Take-offs and landings were made in relatively smooth water at various predetermined trims over the useful range of gross weight, flap deflection, airspeed, and sinking speed. Before take-off or contact, the trim was adjusted by the pilot with the aid of an NACA optical trim indicator or a gyroscopic trim indicator. In one case, the NACA recording phototheodolite was used to obtain time histories of the extremely rapid motions of the seaplane in trim and rise. The NACA take-off and landing events recorder has also been used to obtain time histories of trim, water speed, airspeed, elevator and rudder manipulation, and power applied during maneuvers.

Tests of models.— Take-off and landing maneuvers were simulated in NACA tank no. 1 by a dynamically similar model free to rise and pitch but restrained in roll and yaw. The towing carriage was accelerated until the model took off at the trim to be investigated and was then decelerated until the model landed. The trim during the take-off and landing was adjusted by a "stick" on the carriage connected with the elevators of the model. The behavior of the model was recorded by a motion-picture camera and, when time histories were required, by a mechanical trim and rise recorder. By this procedure, the effects of trim or of modifications of the model can readily be detected.

TESTS AND RESULTS

Case I.— An 86,000-pound commercial flying boat was violently unstable just after landing at high trims. A $\frac{9}{100}$-full-size dynamic model in the tank had similar characteristics, which were later identified as skipping. In both the full-size flying boat and the model, the presence of a large suction force under the afterbody was readily apparent. The stability of the model was definitely improved either by increasing the depth of the transverse step from the original depth of 3-percent beam to 6-percent beam or by moving the step aft, thereby increasing the depth because of the angle between forebody and afterbody. Moving the step aft was the more feasible modification for the existing airplanes and was tried full-size. A great improvement in landing stability at high trims resulted and all the airplanes of the type were modified accordingly.

Case II.— An investigation was made of an 8000-pound amphibian. Six amphibians of this type had been lost in smooth-water landings because of instability that developed after an apparently satisfactory contact had been made. The pilots reported that the amphibians would suddenly leap clear of the water after contact and return nose down in an uncontrollable attitude.

Typical time histories of the motions during landing of this amphibian in smooth water were obtained with an NACA phototheodolite and are shown in figure 1. Contact with the water was made at a speed of 71 miles per hour, a trim of 8.2°, and a sinking speed of 102 feet per minute. Within a fraction of a second, the trim increased to 10.7° at a rate of 6.5° per second and an upward velocity of 372 feet per minute (3.5 times the sinking speed) was induced. The trim dropped sharply after the amphibian left the water and the second contact was made at a trim of 5.5°. The motions then died out as the speed decreased. This landing was made at a safe landing speed but the type of motion shown was considered the cause of the several accidents that occurred at the higher landing speeds normally used in service.

A 1/5–full–size dynamic model of the amphibian exhibited similar skipping tendencies when tested in the tank. Measurements of the pressure behind the step during the unstable landings indicated that negative pressures of several inches of water were generated during the skipping motions. The instability of the model was eliminated by increasing the depth of step from 5–percent beam to 8.2–percent beam or by ventilating the original step, the ventilation being more extensive than had hitherto been tried.

The minimum size and arrangement of ventilation openings and ducts that gave satisfactory landing characteristics with the original depth of step are shown in figure 2. It should be noted that the duct openings are in the afterbody directly behind the step and the ducts extend to the interior of the model above the load water line. The total area of openings and ducts is given by

$$A = 0.0208b^2$$

where

A area, square feet

b beam, feet

Additional tests showed that the ventilation at the keel was relatively more effective than the same area of opening located farther outboard. These tests demonstrated that the source of the violent instability was the negative pressure behind the shallow step at the keel and could be eliminated by ventilation, either by deepening the step to afford natural ventilation from the chines or by using artificial ventilation of the critical area.

The modifications described were not applied full-size. Moving the step aft, thereby increasing its depth, was reported to have improved the landing characteristics appreciably, however.

Case III.– The skipping of a 66,000–pound Navy flying boat was considered to be a serious drawback in service and made night landings extremely hazardous. Because it would have been difficult to increase the depth of step of the experimental airplane, ventilation ducts based on the results described in Case II were tested full–size. Multiple ducts were installed in the afterbody behind the step in such a way that the minimum area of opening and the optimum location could be determined. The step had a 30° plan form and its depth at the keel was 5.5 percent of the beam. Skipping at all trims and sinking speeds was eliminated by a total duct–opening area of 1.4 percent of of the square of the beam, located as close to the step and the keel as possible. Ducts located in the vertical portion of the step were ineffective, however. These results were substantially in agreement with those obtained with a 1/8–full–size powered dynamic model in the tank.

Typical records of the motions of the dynamic model during landing (fig. 3(a)) illustrate the large effect of trim on the skipping characteristics. The model landed smoothly at 6° trim but skipped violently when landed at 7° trim. From analysis of the record for 7° trim, the magnitude of the corresponding full–size motions would be as follows:

Vertical speed, feet per minute

First contact	–141
First skip	243
Second skip	403

Angular velocity, degrees per second:

First contact	-1
First skip	20
Second skip	24.3

The large favorable effect of increasing the depth of step on the skipping at 7° trim is shown in figure 3(b).

A summary of the amplitudes in trim and rise for landings at trims from 5° to full stall is given in figure 4. This figure shows that with a normal depth of step, 5.5-percent beam, the model landed smoothly at trims less than the trim at which the afterbody was horizontal and skipped violently at trims greater than the trim at which the afterbody was horizontal. The range of trims at which skipping occurred was entirely above this angle and the amplitudes in the skipping range were practically independent of the trim. Increasing the depth of step at the keel to 7.2-percent beam eliminated the skipping at all trims at which it formerly occurred.

Case IV.- A powered dynamic model of a 46,000-pound Navy flying boat skipped violently on landing at trims greater than that at which the afterbody keel was horizontal. The model had a 30° V-plan-form step with a depth at the keel of 6.25-percent beam. The instability was eliminated when the depth of step at the keel was increased to 12-percent beam. It was also eliminated with ventilation openings behind the original step at the keel having an area 2.4 percent of the square of the beam.

Case V.- On the basis of tank tests of a 1/10-full-size dynamically similar model, a 62,000-pound Navy flying boat was built with a transverse step having a depth of 8.8-percent beam. This airplane had excellent hydrodynamic stability characteristics and no tendency to skip at any trim with overloads up to 82,000 pounds.

DISCUSSION

The suction force on the afterbody is obviously generated by the flow from the main step. The afterbody is usually a V-bottom planing surface without longitudinal convexity and the flow at high water speeds is approximately parallel to its surface. It is inconceivable, therefore, that the afterbody can produce negative dynamic lift of any magnitude by imparting upward momentum to the water leaving it.

The work on skipping to date has been based on the hypothesis that the suction force is the result of a negative air pressure acting on the afterbody bottom, the source of which is mechanical entrainment of the air by the high-speed jets of water coming off the step. This hypothesis has been amply supported both by tests of full-size flying boats and by tests of models, in which ventilation of the area behind the step either by the natural ventilation from the chines afforded by a deep step or by artificial ventilation of a shallow step by air ducts has eliminated the suction forces and the skipping tendency. The tests have shown further that the area directly behind the step and near the keel is the only area that requires ventilation, a result that satisfactorily localizes the source of the instability.

Slow-motion pictures made during high-angle porpoising and skipping of models with shallow steps have shown that, under the influence of the negative pressure induced by entrainment of the air behind the step and by the downward velocity of the step as it enters the water, the flow from the forebody bends upward just aft of the step and effectively closes off the area near the keel from natural ventilation from the chines. Pressure measurements have indicated that the suctions generated during porpoising and skipping cycles are greater than the suctions obtained at constant trim and draft. The flow mechanism is therefore unstable and the forces generated are out of all proportion to the initial disturbance.

It appears then that at high speeds and light loads the step of a seaplane acts as the throat of a jet air pump able to produce a high vacuum in a very short time unless more air can be supplied than is drawn aft by the entrainment action of the jets. The suction force generated is increased during successive cycles by the motions induced in the seaplane. In order to avoid violent or catastrophic skipping, the step must be adequately ventilated either by sufficient depth or by auxiliary ducts.

The skipping of a given seaplane has been found both in practice and by use of models to be mainly a function

The skipping of a given seaplane has been found both in practice and by use of models to be mainly a function of trim and water speed and to be relatively uninfluenced by other variables such as sinking speed, gross weight (except for its influence on water speed), pitching moment of inertia, and position of the center of gravity with respect to the step. This evidence supports the hypothesis regarding the source of skipping and indicates an essential difference between skipping and the classic upper-limit porpoising of two planing surfaces in tandem.

It can be proposed with reasonable assurance that at a given trim the higher the water speed at take-off and contact, the more violent the skipping becomes. This statement is borne out by experience with full-size flying boats and can be explained by the greater mechanical entrainment obtained with higher jet speeds.

CONCLUDING REMARKS

With present-day take-off and landing speeds, conventional depths of step (up to 5-percent beam) are insufficient to prevent dangerous skipping tendencies. Depths of transverse or V-plan-form steps should be from 7- to 12-percent beam for stable take-offs and landings at high trims.

The minimum amount of ventilation for a shallow step required to eliminate the skipping hazard depends on the depth of the step and the water speeds involved. As a first approximation for depths of step of around 5 percent of the beam and landing speeds of 70 to 90 miles per hour, the total area of openings and ducts should be 2 percent of the square of the beam. The openings should be located as close to the step and the keel as possible. Care should be taken to avoid large reductions in the area of the openings by structural members, particularly at the keel, and to avoid any reduction in the cross-sectional area of the ducts themselves below that of the area of the openings.

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

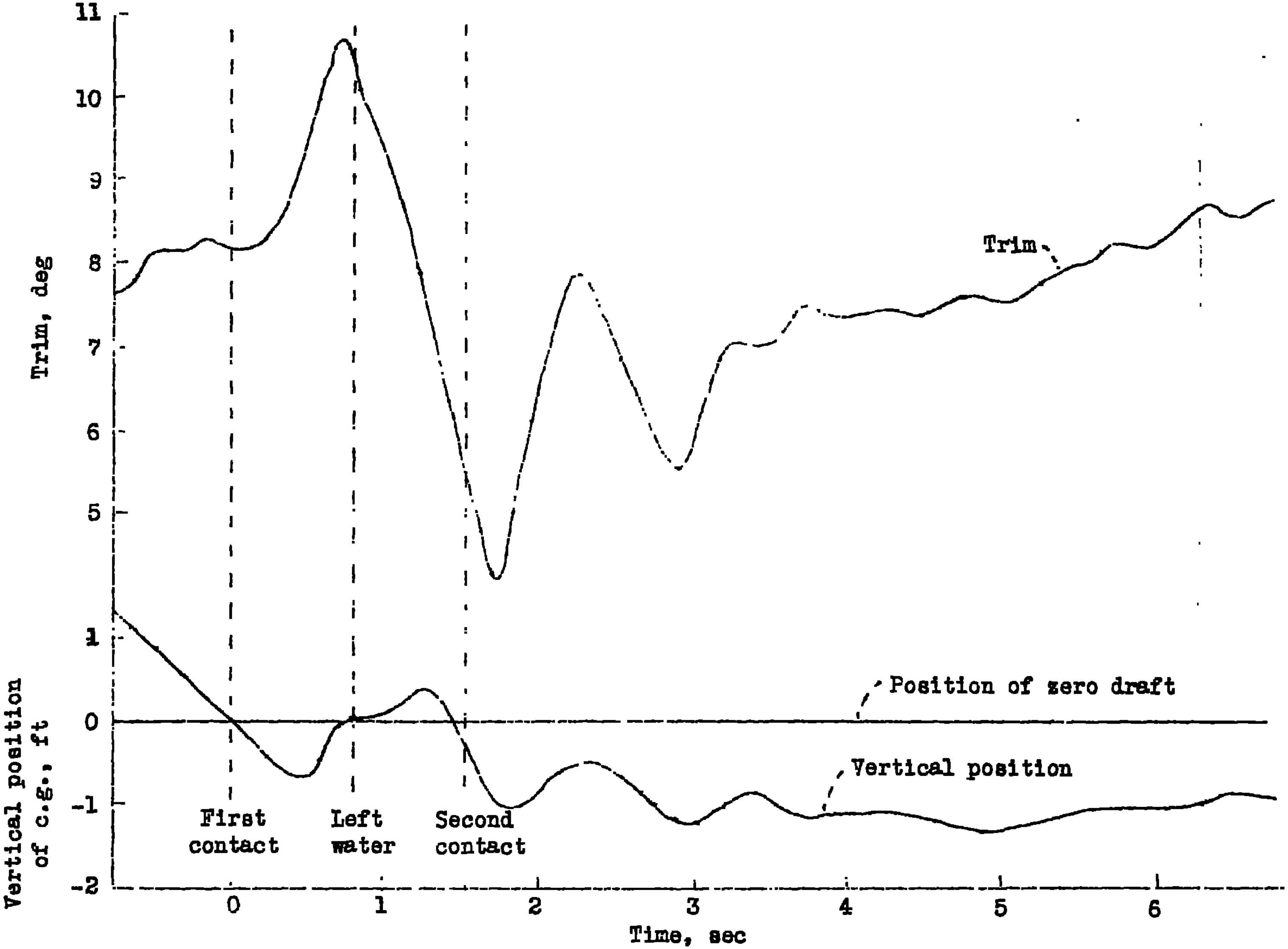


Figure 1.- Time histories of the motions during landing of an 8000-pound amphibian as obtained with the NACA recording phototheodolite (case II).

L-3.3

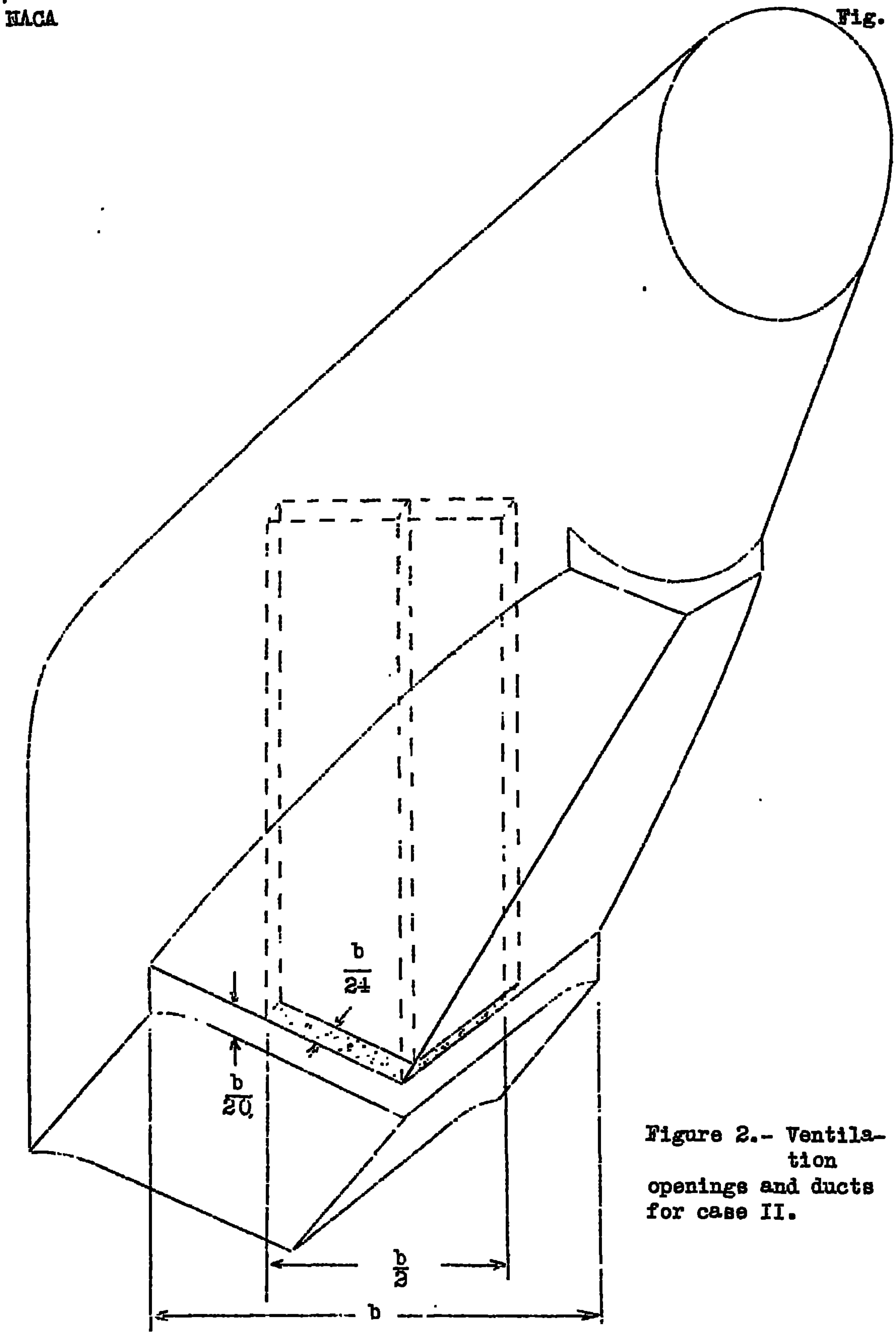
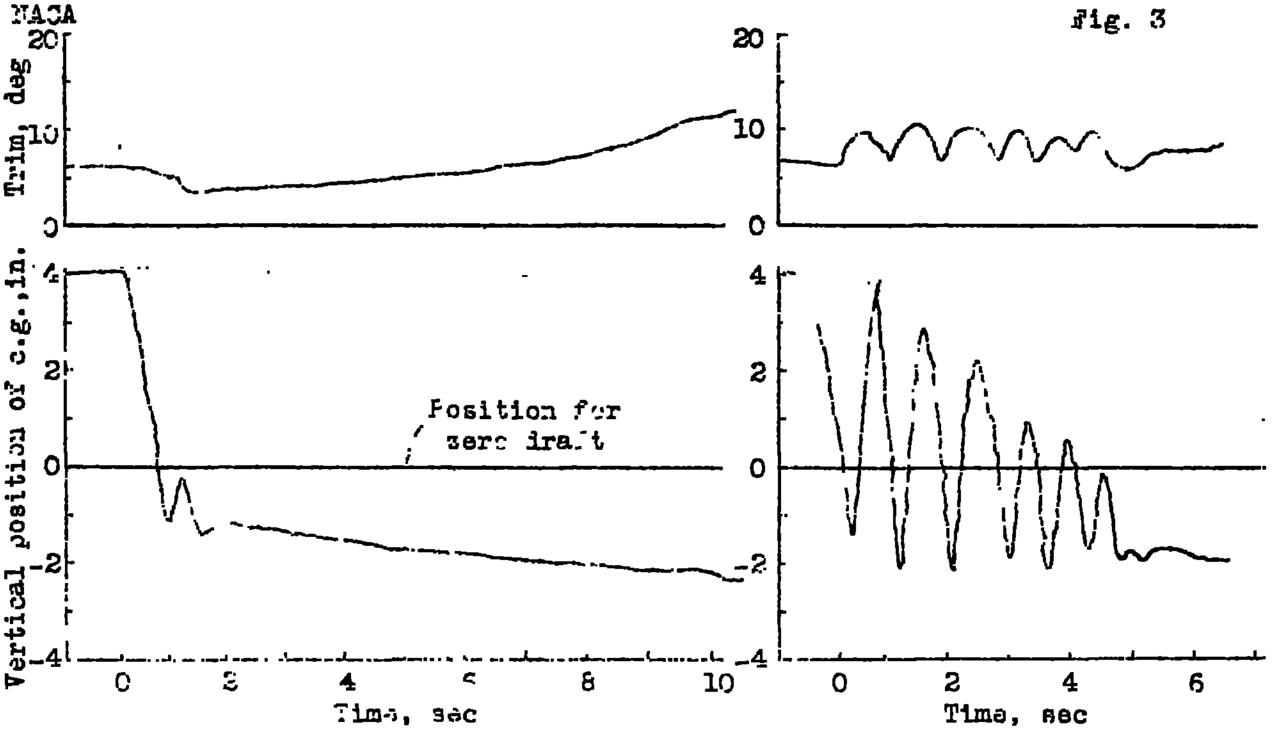


Figure 2.- Ventilation openings and ducts for case II.

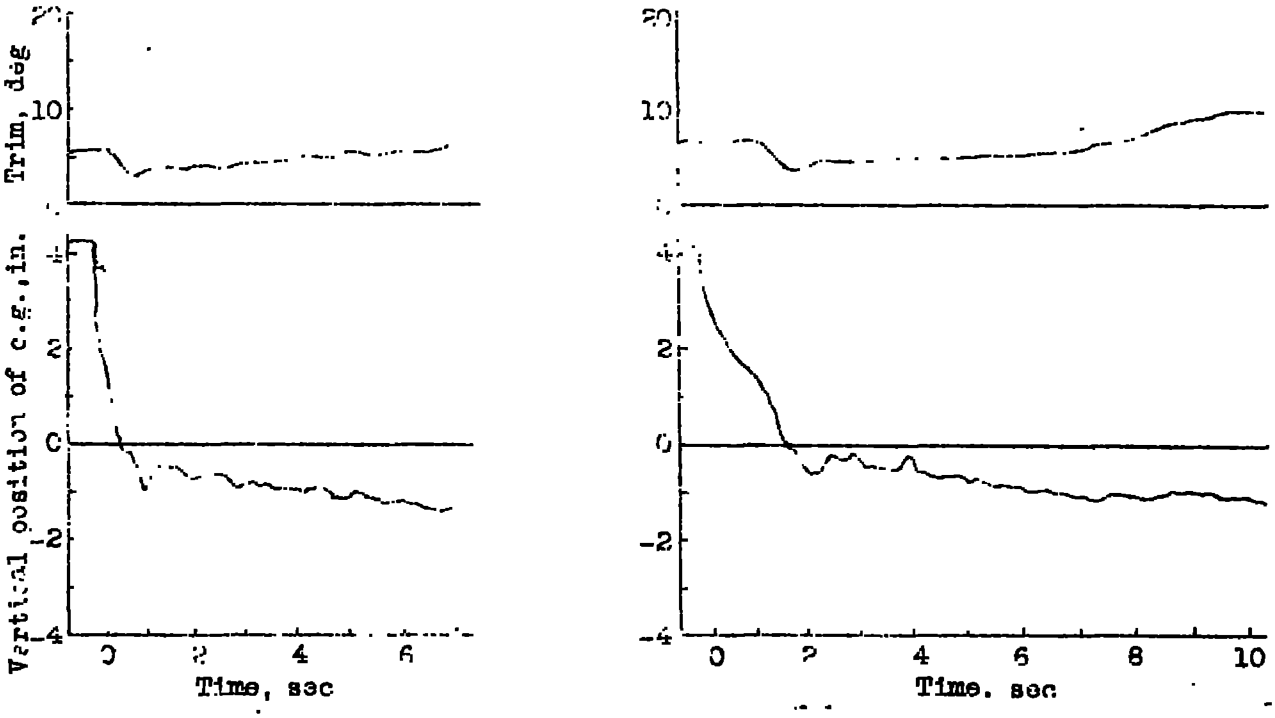
L-538



Trim at contact, 6°

Trim at contact, 7°

(a) Depth of step at keel 5.5-percent beam.

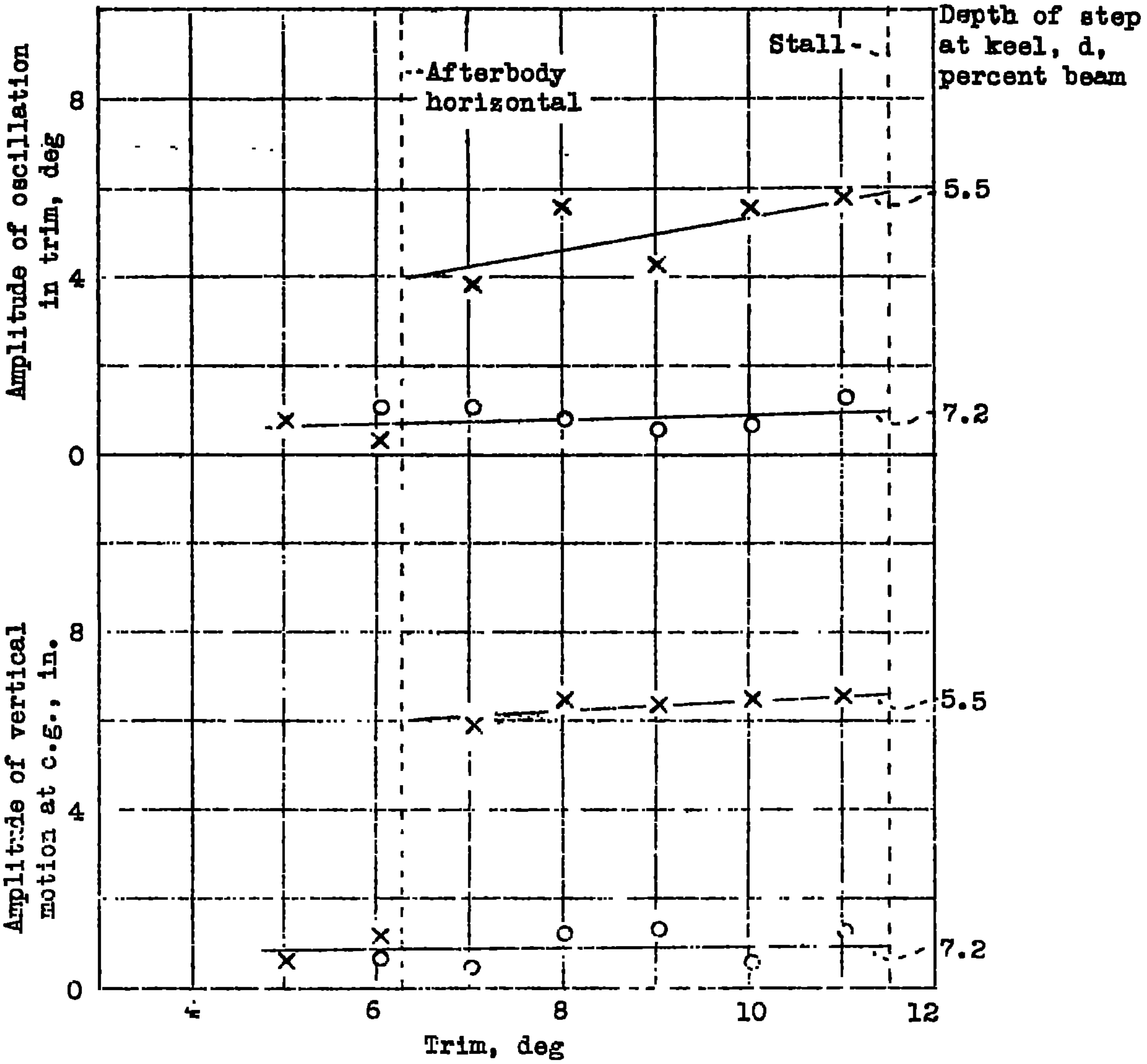


Trim at contact, 6°

Trim at contact, 7°

(b) Depth of step at keel 7.2-percent beam.

Figure 3.- Typical records of the motions during landing of a dynamic model of a large long-range flying boat.



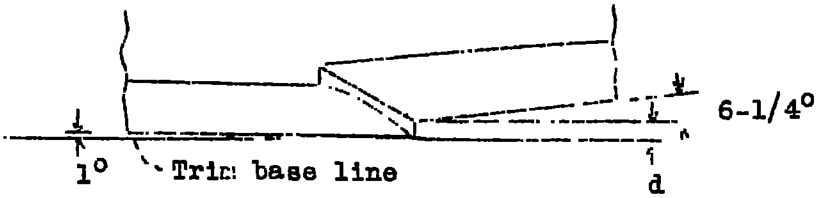


Figure 4.- Effect of depth of step on the amplitude of skipping during landing of a dynamic model of a large long-range flying boat.