Copy 6
RM L53D29

NACA RM L53D29

NACA

RESEARCH MEMORANDUM

ESTIMATION OF WATER LANDING LOADS ON

HYDRO-SKI-EQUIPPED AIRCRAFT

By Emanuel Schnitzer

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

July 17, 1953

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

ESTIMATION OF WATER LANDING LOADS ON HYDRO-SKI-EQUIPPED AIRCRAFT

By Emanuel Schnitzer

SUMMARY

Available methods developed at the National Advisory Committee for Aeronautics for estimation of water landing loads on hydro-ski-equipped aircraft are summarized in order to provide a unified picture and bibliography of NACA work on this subject. Two approaches to the problem of calculating hydro-ski landing loads are covered. Both are based on the evaluation of downwash momentum; one makes use of a computed downwash momentum and applies to flat and V-bottom skis of rectangular plan-form, whereas the other makes use of planing data and applies to skis of varied cross section and plan form.

An adaptation of this theory for investigating the effect of shock strut mounting on hydro-ski landing loads is mentioned. An illustrative computation indicates that substantial load reductions may be achieved by means of such mountings. A procedure for estimating hydro-ski pressure distributions is reviewed which is applicable over a wide range of wetted aspect ratio, to flat and V-bottom skis of rectangular plan form. A rather extensive list of references is presented which contains the details of all of this material, with the exception of the calculations for the shock-mounted ski.

INTRODUCTION

Load investigations on hydro-skis have been going on for some time at the Langley Aeronautical Laboratory and it is the purpose of this paper to present the status of this research. Although hydro-ski-equipped aircraft may be operated from snow, ice, or sod in addition to water, this discussion will be restricted to water operations and, more specifically, to the loads encountered in these operations. The problem of hydrodynamic behavior pertinent to water operations is treated in references 1 to 6 and will not be considered here.

[redacted]

The problem considered in this paper may be stated as follows: For specified ranges of initial landing velocity, attitude, and ski geometry, what are the loads and their distributions during impact? The results of the work on this problem will be presented in the following order. First, theoretical methods for computing hydro-ski landing loads will be touched on and their results compared with experimental data. Then the effect of chine immersion in reducing hydro-ski impact loads will be reviewed. Next, the use of shock-strut mountings for further reduction of hydro-ski loads will be discussed, and, finally, hydro-ski pressure distributions calculated by a recently developed method will be compared with experimentally obtained pressures on flat and V-bottom rectangular skis.

DISCUSSION

Some of the nomenclature and the pertinent parameters used in the following discussion of the basic load theory are shown in figures 1 and 2. Figure 1 pictures a hydro-ski-equipped aircraft in the landing condition, while figure 2 illustrates some of the many shapes which actual ski configurations may assume. The plan forms shown in figure 2 include the rectangular, V-step, and triangular shapes. The cross sections shown, some of which have been enlarged for clarity, include flat and V-bottom skis of several dead-rise angles and having flared and vertical chines, and also curved bottom shapes.

Impact Load Theory for Rigidly Mounted Hydro-Skis

In order to begin the discussion of the basic load theory, consider the aircraft of figure 1, which is landing with the resultant velocity V_R. The component of this velocity normal to the ski bottom is designated V_N. Since viscous forces along the ski are usually very small during impact, the resultant hydrodynamic force is directed normal to the ski bottom and is designated F_N. For practical impacts of such narrow, heavily loaded bodies, it can be shown that, for a given ski, this normal force at any instant is a function principally of the wetted length l_w, the trim τ, and the normal velocity V_N. Consequently, the force on the impacting ski shown in figure 1 is the same as the force on this same ski in the planing condition, for identical values of wetted length, trim, and normal velocity. The problem is thus simplified in that it now becomes similar to that of a wing in steady flight for which the force at any instant is determined by the downwash momentum. Substitution of the relation between this force and the wetted length into the classical equation of motion results in a differential equation which can be integrated to yield impact load time histories.

Two methods have been developed at the NACA for estimating the downwash momentum for hydro-skis having negligible longitudinal bottom curvature. One, which is termed the deflected-mass theory, involves the computation of this downwash momentum, while the other, which is termed the planing-data theory, involves the determination of this momentum from planing data obtained with the ski model in question. The deflected-mass theory (ref. 7), which is simple to apply, is at present restricted to skis of rectangular plan form, whereas the planing-data theory (ref. 8), although involving additional work, is more general and may be extended to skis of varied plan form and cross section.

The deflected-mass theory has been substantiated in comparisons with experimental data from references 9 to 11 covering wide ranges of trim, dead-rise angle, flight-path angle, and ski loading. Examples of the agreement between this theory and experimental data are shown in figures 3 and 4. The variation of impact load factor with time after contact during a typical landing of a rectangular flat-plate hydro-ski is given in figure 3, whereas figure 4 gives the load-factor variation for a typical landing of a rectangular V-bottom hydro-ski. The loads on the two figures should not be compared since the landing speed is greater for figure 4 than for figure 3. The agreement shown between theory and experiment, however, indicates that the deflected-mass theory may be used with reasonable accuracy to predict loads on relatively straight-sided, rectangular hydro-skis and to determine trends with ski geometry and fuselage weight over the practical range of hydro-ski landing conditions. Although the loads predicted by the planing-data theory have been checked with only limited data, the results of the checks, in addition to theoretical considerations, indicate that this theory should give even better agreement over this range.

In order to test the applicability of the more general planing-data theory for plan forms other than rectangular, comparisons were made of load time histories calculated by this theory with impact data for a flat-bottom, V-step hydro-ski (ref. 12). A typical impact is illustrated in figure 5, in which the solid line is the theory for the V-step ski and the circles are the corresponding experimental data. The quality of the agreement shown indicates that the planing-data theory can also be used with reasonable accuracy to predict loads on skis of nonrectangular plan form. The dashed line is included as a matter of interest to show the difference between the theoretical force curves for a rectangular and a V-step ski, for identical landing conditions.

Since the planing-data theory shows promise for calculation of loads on hydro-skis of varied plan form, extensive high-speed experimental planing data collected in towing tanks have been made available in references 13 to 23 for use in practical hydro-ski landing calculations. The NACA planing data were collected with the series of hydro-ski models shown in figure 2 for wide ranges of wetted length and trim.

The effects of plan form and bottom cross-sectional shapes on impact characteristics may be determined by substituting these data into the planing-data theory for the desired cases.

Effect of Chine Immersion on Landing Loads

At this point, it might be of interest to discuss the load-reducing quality of the hydro-ski with the aid of figure 6. This figure shows the variation of maximum load with flight-path angle at water contact for V-bottom models having angles of dead rise of 30°. The circles represent data collected in high-trim experimental landings of a heavily loaded hydro-ski (ref. 10). The upper dashed line represents the wide-float seaplane theory of references 24 and 25, which are based on Wagner's expanding-plate solution (refs. 26 and 27) and assume no immersion of the float side or chines. The error which would be introduced through the use of this theory for computing loads on narrow hydro-skis is illustrated by the separation between the dashed line and the data points. The solid line, which was computed from the deflected-mass theory, follows the wide-float theory until the flight-path angle is reached above which chine immersion occurs (roughly 2° for this case). At this point the wetted width ceases to expand, which results in a slower build-up of downwash momentum, allowing deeper penetrations with consequent reduction of load. This line agrees fairly well with the experimental data. The beneficial effect of chine immersion on loads for narrow, heavily loaded hydro-skis is thus indicated for single impacts. This effect was also demonstrated in actual multiple-impact landing tests made at the towing tanks with free-flying models. In these tests, which are described in reference 5, the load reduction appeared to result from two separate causes. First, the narrow skis penetrated the water to considerable drafts, allowing a large vertical travel for absorption of sinking-speed energy and for knifing through waves, and, second, the hydro-ski-equipped aircraft exhibited improved hydrodynamic behavior inasmuch as vertical and pitching oscillations in rough water were reduced, with a consequent reduction in the amplitude and severity of successive bounces in a landing run.

Impact Load Theory for Shock-Mounted Hydro-Skis

A further means for reduction of water landing loads which has been considered is that of mounting hydro-skis on shock struts. The essential principle of operation of the shock-mounted hydro-ski is that the shock strut permits a greater vertical travel of the aircraft than the rigidly mounted ski does. This greater travel over which the vertical momentum can be dissipated results in a smaller hydrodynamic force. The shock strut has the additional desirable feature of reducing rebound velocity, thereby minimizing the tendency of the initial conditions of subsequent impacts to be more severe than the conditions of the first impact in a landing run.

There are three basic methods for mounting hydro-skis on shock struts, examples of which are illustrated in figure 7. One method, shown at the upper left, consists of mounting the hydro-ski so that its trim relative to the aircraft is constant, with the shock strut acting as in a conventional landing-gear arrangement. A second method, shown at the upper right, consists of mounting the hydro-ski so that it may trim relative to the aircraft, with the shock strut resisting the trimming motion. The latter type of shock-mounted hydro-ski has been employed in a current design. A third method, shown at the bottom, consists of using variable-dead-rise skis with hinged sides and employing shock struts that resist upward flapping of these sides.

The method developed for computing loads and motions during hydro-ski impacts has been adapted to impact calculations for the fixed-trim type of shock-mounted hydro-ski. The result of a sample computation is illustrated in figure 8, which provides an estimate of the amount of load reduction that might be provided by the fixed-trim type of shock mounting. This example represents a typical high-speed landing of a 16,000-pound aircraft equipped with twin flat-bottomed rectangular hydro-skis, 2 feet wide. The upper line in the plot represents the rigid case and the lower line represents the shock-mounted case, both for the same ski. The load reduction achieved by the shock strut for this case was 35 percent, whereas the vertical rebound velocity, not shown here, was reduced by 50 percent. Some experimental checks of this analytical approach are contemplated upon completion of landing tests now being conducted at the towing tanks with free-flying scale models.

The decrease in landing loads achieved by means of shock struts can also be realized through the use of narrower skis. Such skis would, however, exhibit increased drag during the take-off run. The designer may therefore sacrifice part of the inherent landing-load-reducing quality of the narrower ski for an increase of take-off lift-drag ratio by using a wider ski mounted on a shock strut.

Estimation of Water Pressure Distribution on Impacting Hydro-Skis

The water-pressure distribution on an impacting hydro-ski, which is of interest for ski design and for obtaining the variation of pitching moment on an aircraft during landing, will now be considered. A method has been advanced for estimating the instantaneous pressure distribution on straight-sided rectangular hydro-skis during water impact (ref. 28). This method is based on the observation that the pressure distribution along the longitudinal center line of a rectangular flat-bottomed ski depends only on the normal-force coefficient. On this basis, the longitudinal-center-line pressure distribution for an immersing ski at a given trim may be obtained from the classical two-dimensional pressure distribution (ref. 29) for an infinitely wide planing plate at the trim for which the normal-force coefficient is the same as that of the ski.

To illustrate the accuracy of this procedure, figure 9 presents comparisons of the pressure estimation procedure with experimental data for flat and V-bottom rectangular hydro-skis (refs. 9 and 30), respectively. The computed longitudinal-center-line distributions were obtained by the method mentioned, whereas the computed transverse distributions were obtained from modifications of classical two-dimensional wide- and narrow-body theories (refs. 31 and 32). These comparisons demonstrate that the pressure-estimation procedure may be used with reasonable accuracy to evaluate the effects of aspect ratio on hydro-ski pressure distributions during impact. The effects of a wheel well and a pulled-up bow on hydro-ski pressure distribution are shown in reference 33.

CONCLUDING REMARKS

Methods developed at the NACA for calculating loads and pressure distributions during water landings of hydro-ski-equipped aircraft have been summarized for both the rigid and shock mounted skis. Samples of comparison with experiment indicated that these methods should be reasonably applicable over the practical ranges for simple configurations. For more complex configurations additional problems may exist. Some of these problems include determination of the effects of trimming shock mounts on ski loads, the effects of longitudinal ski twist and of extreme longitudinal curvature, ski upwash loads on fuselages, and impact loads on skis following submergence of the leading edge below the water surface.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 21, 1953.

REFERENCES

1. Dawson, John R., and Wadlin, Kenneth L.: Preliminary Tank Tests of NACA Hydro-Skis for High-Speed Airplanes. NACA RM L7I04, 1947.

2. Wadlin, Kenneth L., and Ramsen, John A.: Tank Spray Tests of a Jet-Powered Model Fitted With NACA Hydro-Skis. NACA RM L8B18, 1948.

3. Ramsen, John A.: The Effect of Rear Chine Strips on the Take-Off Characteristics of a High-Speed Airplane Fitted With NACA Hydro-Skis. NACA RM L9B10a, 1949.

4. Fisher, Lloyd J.: Model Ditching Investigations of Three Airplanes Equipped With Hydro-Skis. NACA RM L9K23, 1950.

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

6. Ramsen, John A., and Gray, George R.: Tank Investigation of the Grumman JRF-5 Airplane With a Single Hydro-Ski and an Extended Afterbody. NACA RM L51E21, 1951.

7. Schnitzer, Emanuel: Theory and Procedure for Determining Loads and Motions in Chine-Immersed Hydrodynamic Impacts of Prismatic Bodies. NACA TN 2813, 1952.

8. Smiley, Robert F.: The Application of Planing Characteristics to the Calculation of the Water-Landing Loads and Motions of Seaplanes of Arbitrary Constant Cross Section. NACA TN 2814, 1952.

9. Smiley, Robert F.: An Experimental Study of Water-Pressure Distributions During Landings and Planing of a Heavily Loaded Rectangular Flat-Plate Model. NACA TN 2453, 1951.

10. Batterson, Sidney A., and McArver, A. Ethelda: Water Landing Investigation of a Model Having a Heavy Beam Loading and a 30° Angle of Dead Rise. NACA TN 2015, 1950.

11. McArver, A. Ethelda: Water-Landing Investigation of a Model Having Heavy Beam Loadings and 0° Angle of Dead Rise. NACA TN 2330, 1951.

12. Miller, Robert W.: Water-Landing Investigation of a Flat-Bottom V-Step Model and Comparison With a Theory Incorporating Planing Data. NACA TN 2932, 1953.

13. Wadlin, Kenneth L., and McGehee, John R.: Planing Characteristics of Three Surfaces Representative of Hydro-Ski Forms. NACA RM L9C03, 1949.

14. Wadlin, Kenneth L., and McGehee, John R.: Planing Characteristics of Six Surfaces Representative of Hydro-Ski Forms. NACA RM L9L20, 1950.

15. Land, Norman S., and Fontana, Rudolph E.: Preliminary Tank Tests of Some Hydro-Ski—Wheel Combinations in the Planing Condition. NACA RM L52H15, 1952.

16. Land, Norman S., and Pelz, Charles A.: Force Characteristics in the Submerged and Planing Condition of a $\frac{1}{5.78}$-Scale Model of a Hydro-Ski-Wheel Combination for the Grumman JRF-5 Airplane. NACA RM L52B28, 1952.

17. Kapryan, Walter J., and Weinstein, Irving: The Planing Characteristics of a Surface Having a Basic Angle of Dead Rise of 20° and Horizontal Chine Flare. NACA TN 2804, 1952.

18. Blanchard, Ulysse J.: The Planing Characteristics of a Surface Having a Basic Angle of Dead Rise of 40° and Horizontal Chine Flare. NACA TN 2842, 1952.

19. Chambliss, Derrill B., and Boyd, George M., Jr.: The Planing Characteristics of Two V-Shaped Prismatic Surfaces Having Angles of Dead Rise of 20° and 40°. NACA TN 2876, 1953.

20. Weinstein, Irving, and Kapryan, Walter J.: The High-Speed Planing Characteristics of a Rectangular Flat Plate Over a Wide Range of Trim and Wetted Length. NACA TN 2981, 1953.

21. Locke, F. W. S., Jr.: Tests of a Flat Bottom Planing Surface To Determine the Inception of Planing. NAVAER DR Rep. 1096, Bur. Aero., Dec. 1948.

22. Korvin-Kroukovsky, B. V., Savitsky, Daniel, and Lehman, William F.: Wetted Area and Center of Pressure of Planing Surfaces. Preprint No. 244, S.M.F. Fund Paper, Inst. Aero. Sci. (Rep. No. 360, Project No. NR062-012, Office Naval Res., Exp. Towing Tank, Stevens Inst. Tech., Aug. 1949.)

23. Savitsky, Daniel: Wetted Length and Center of Pressure of Vee-Step Planing Surfaces. S.M.F. Fund Paper No. FF-6, Inst. Aero. Sci. (Rep. No. 378, Project No. NR062-012, Office Naval Res., Exp. Towing Tank, Stevens Inst. Tech.), Sept. 1951.

24. Mayo, Wilbur L.: Analysis and Modification of Theory for Impact of Seaplanes on Water. NACA Rep. 810, 1945. (Supersedes NACA TN 1008.)

25. Milwitzky, Benjamin: A Generalized Theoretical and Experimental Investigation of the Motions and Hydrodynamic Loads Experienced by V-Bottom Seaplanes During Step-Landing Impacts. NACA TN 1516, 1948.

26. Wagner, Herbert: Über Stoss- und Gleitvorgänge an der Oberfläche von Flüssigkeiten. Z.a.M.M., Bd. 12, Heft 4, Aug. 1932, pp. 193-215.

27. Wagner, Herbert: Landing of Seaplanes. NACA TM 622, 1931.

28. Smiley, Robert F.: A Semiempirical Procedure for Computing the Water-Pressure Distribution on Flat and V-Bottom Prismatic Surfaces During Impact or Planing. NACA TN 2583, 1951.

29. Pierson, John D., and Leshnover, Samuel: An Analysis of the Fluid Flow in the Spray Root and Wake Regions of Flat Planing Surfaces. Preprint No. 166, S.M.F. Fund Paper, Inst. Aero. Sci. (Rep. No. 335, Project No. NR 062-012, Office of Naval Res., Exp. Towing Tank, Stevens Inst. Tech.), Oct. 1948.

30. Smiley, Robert F.: A Study of Water Pressure Distributions During Landings With Special Reference to a Prismatic Model Having a Heavy Beam Loading and a 30° Angle of Dead Rise. NACA TN 2111, 1950.

31. Pierson, John D., and Leshnover, Samuel: A Study of the Flow, Pressures, and Loads Pertaining to Prismatic Vee-Planing Surfaces. S.M.F. Fund Paper No. FF-2, Inst. Aero. Sci. (Rep. No. 382, Project No. NR 062-012, Office of Naval Res., Exp. Towing Tank, Stevens Inst. Tech.), May 1950.

32. Korvin-Kroukovsky, B. V., and Chabrow, Faye R.: The Discontinuous Fluid Flow Past an Immersed Wedge. Preprint No. 169, S.M.F. Fund Paper, Inst. Aero. Sci. (Rep. No. 334, Project No. NR 062-012, Office of Naval Res., Exp. Towing Tank, Stevens Inst. Tech.), Oct. 1948.

33. Batterson, Sidney A.: Water Landing Investigation of a Hydro-Ski Model at Beam Loadings of 18.9 and 4.4. NACA RM L51F27, 1951.

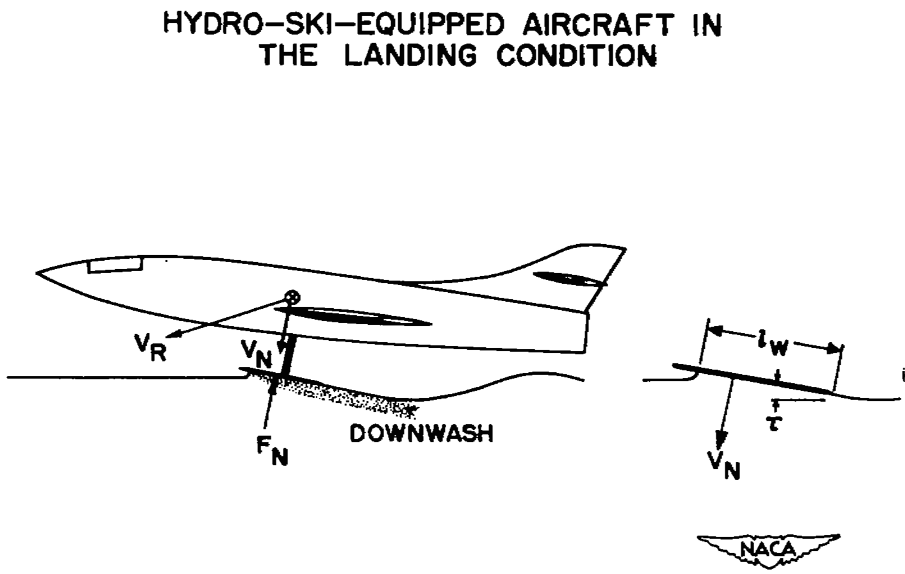

Figure 1.

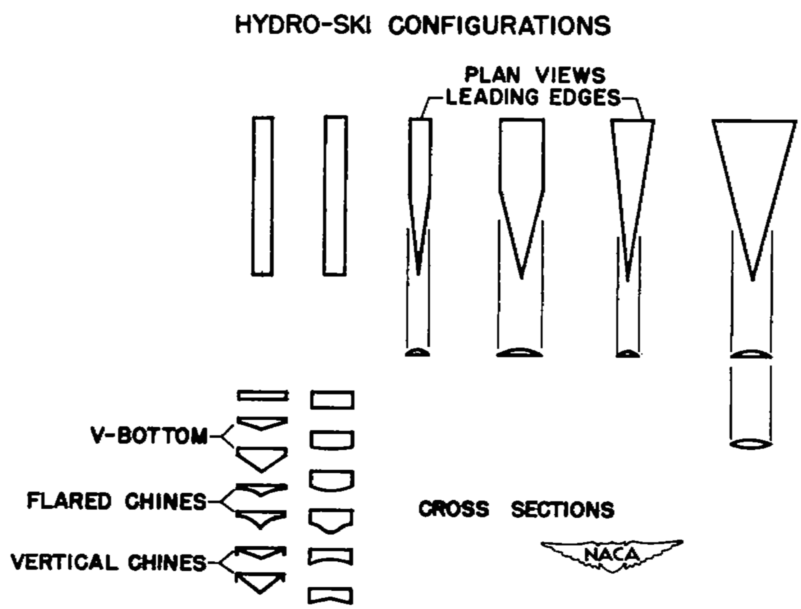

Figure 2.

IMPACT LOAD ON A FLAT RECTANGULAR HYDRO-SKI

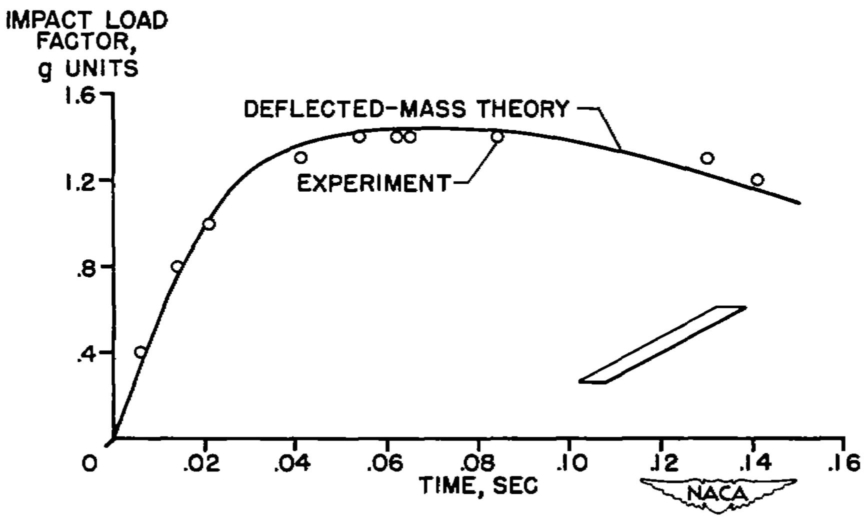

Figure 3.

IMPACT LOAD ON A V-BOTTOM RECTANGULAR HYDRO-SKI

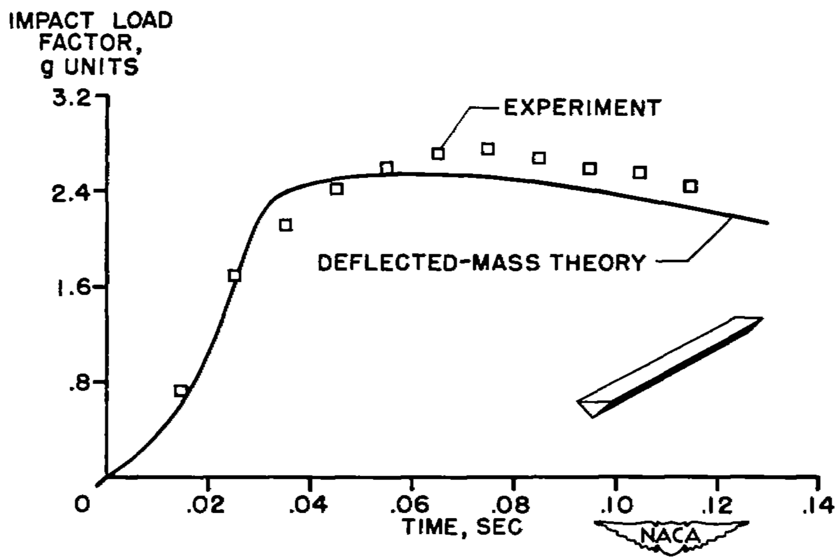

Figure 4.

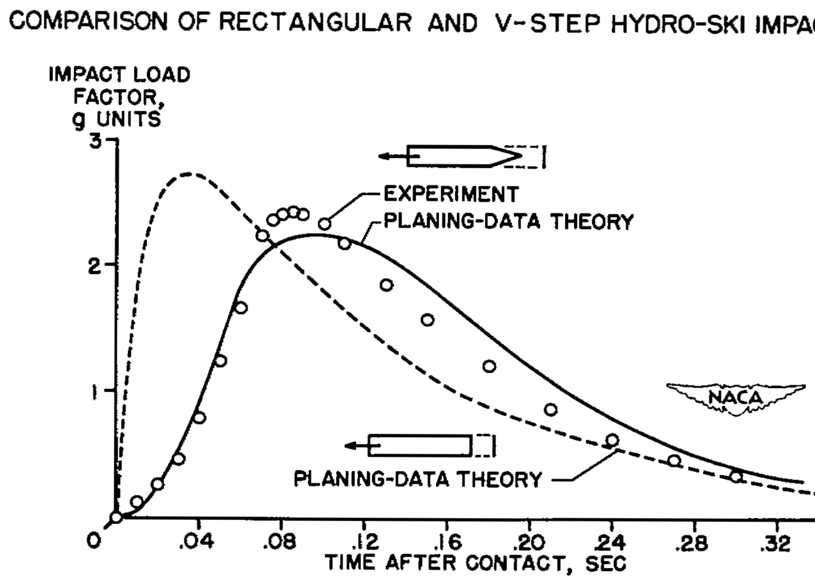

Figure 5.

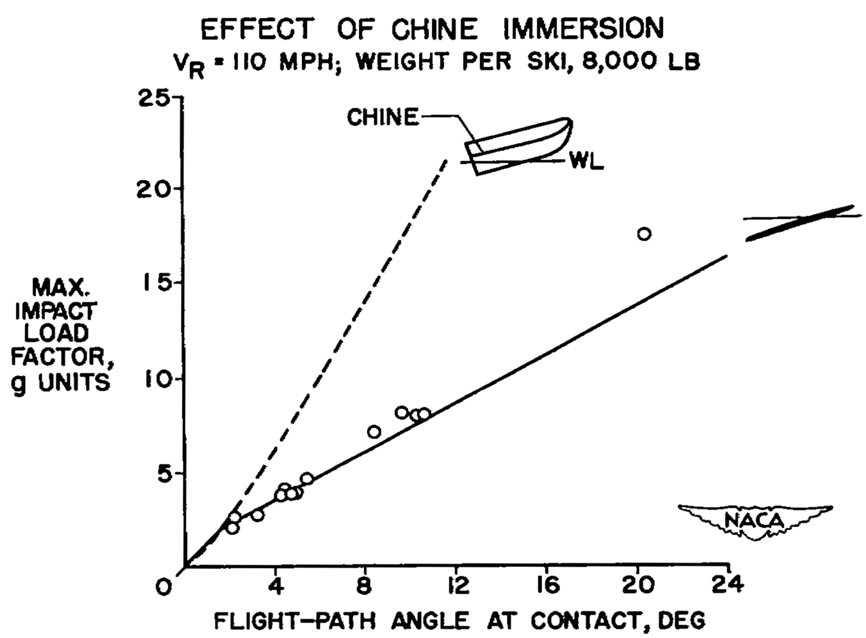

Figure 6.

METHODS OF SHOCK-MOUNTING HYDRO-SKIS

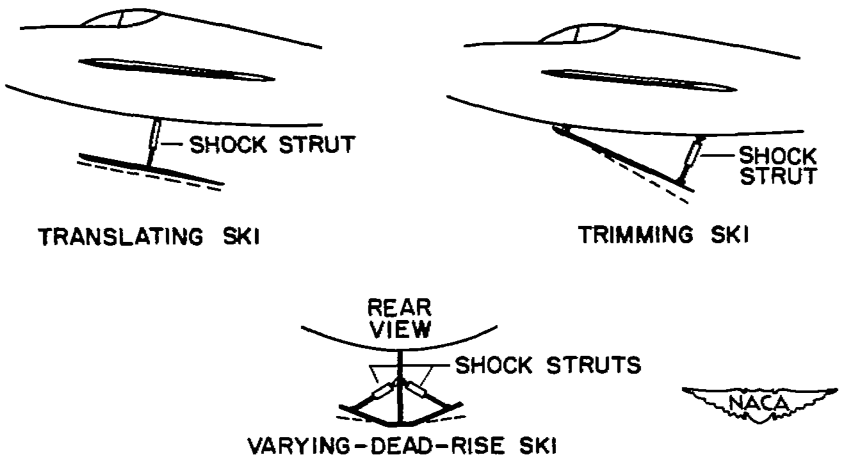

Figure 7.

COMPARISON OF HYDRO-SKI LANDINGS WITH AND WITHOUT SHOCK STRUTS

V_R = 110 MPH; V_V = 17 FPS

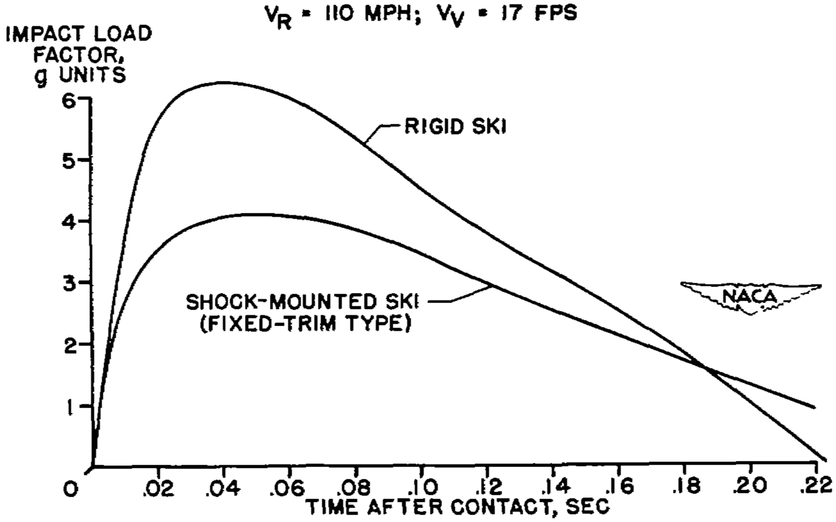

Figure 8.

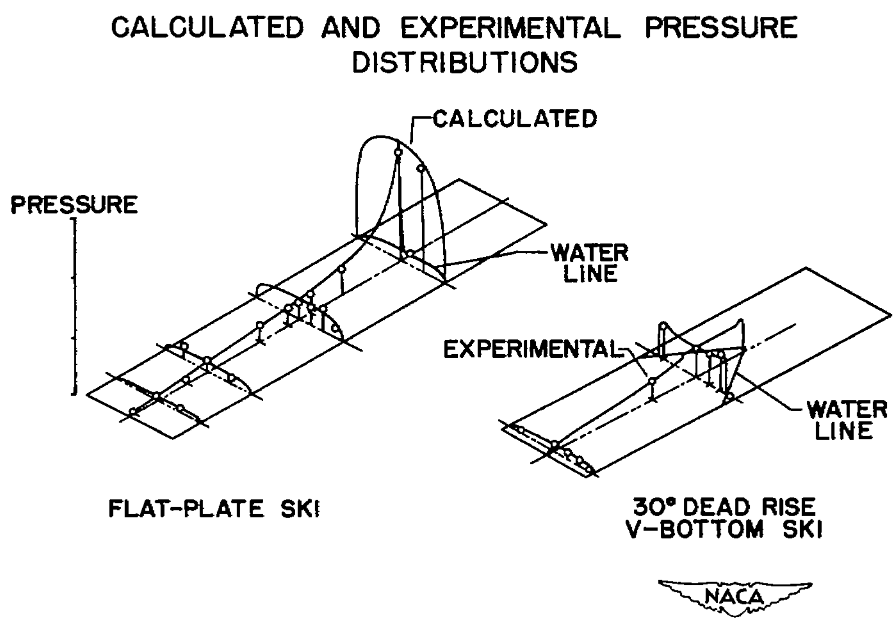

Figure 9.

[redacted]

SECURITY INFORMATION

[redacted]