NACA

RESEARCH MEMORANDUM

CONSIDERATIONS AFFECTING HYDRO-SKI AIRPLANE DESIGN

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NATIONAL ADVISORY COMMITTEE
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Several methods of basing and operating airplanes become possible when the airplanes are equipped with hydro-skis. This paper, however, is concerned only with the fully water-based hydro-ski airplane that starts at rest in the water and makes the complete take-off and landing run on the water. An airplane of this type is shown in figure 1. Before discussing the hydrodynamic performance of this type of airplane, it may be well to consider how the application of hydro-skis affects supersonic configurations. Such details as the location of the wing, tail, air intakes, and jet exhaust must be examined with reference to the peculiarities of water operation.

The airplane shown in figure 1 was derived from the Douglas D-558-II research airplane. The location of the air intakes of the D-558-II on the under side of the fuselage is an example of how water operation influences the aerodynamic configuration. This location is obviously not suitable for the water-based hydro-ski airplane since the intakes would be submerged when the airplane is at rest and at low speeds. The air intakes were, therefore, moved to the upper portion of the fuselage. Also, the jet and rocket exhausts were inverted to keep the jet exhaust as high as possible. Tests have shown that air intakes in this position can be kept clear of water by the use of small strips placed along the fuselage center line below the intakes and extending forward to the nose.

For airplanes of this type, portions of the aerodynamic surfaces may be wetted or even be under water at rest and at low speeds and be subjected to hydrodynamic loads. The dynamic pressure of the water at these low speeds, however, is of the same order as the dynamic pressure of the air at supersonic speeds. For example, the dynamic pressure of the water at 45 fps is comparable to that encountered in the air at sea level at a Mach number of 1.2. Hydro-skis normally raise most of the airplane clear of the water before a speed of 45 fps is reached; therefore, airplanes that operate at supersonic airspeeds will, because of aerodynamic requirements, normally be designed to a strength of the order of that necessary for the water loads encountered by aerodynamic surfaces.

In considering the take-off performance of the hydro-ski airplane, water resistance is generally one of the first problems to arise. A typical water-resistance curve for a hydro-ski airplane is presented in figure 2. As the water speed is increased, the resistance rises rapidly to a peak value or "hump." This rapid rise occurs when the fuselage is carrying most of the load. The hump occurs in the speed range where

the skis are emerging from the submerged to the planing condition. As the speed increases further, the hydrodynamic load is transferred entirely to the skis and the resistance decreases because of inherent decreases in load and angle of attack. Also included in this figure are curves showing the resistance of the fuselage alone and of the planing skis alone when the fuselage and the skis are operating under the same load conditions. These two components are the primary sources of the hydrodynamic resistance. However, for a hydro-ski airplane when the load is divided between the fuselage and the skis, other factors, such as the hydrodynamic resistance of the supporting struts and wetted portions of the wing, spray, and interference effects, influence the total hydrodynamic resistance. These factors result in the over-all resistance differing from the dashed-line curves shown for the two principal components.

The resistance of the fuselage rises rapidly and indefinitely with speed while the planing resistance of the skis decreases as the speed is increased and becomes zero, of course, when the skis leave the water at take-off. If the fuselage were not lifted clear of the water, the resistance would continue to rise and the airplane would not take off. It is necessary, therefore, for the skis to raise the fuselage clear of the water before the take-off resistance of the airplane exceeds the available thrust. The characteristics of the skis selected must be such that the intersection of the separate resistance curves for the fuselage and the skis occurs at an acceptable value of resistance.

The remainder of this paper summarizes hydrodynamic investigations by the National Advisory Committee for Aeronautics of fuselages, hydro-skis, and struts and how the results of these investigations may be used to assist in the design of hydro-ski airplanes. Investigations on complete configurations are reported in references 1 to 7. The scope of the available NACA information is shown in figures 3 and 4. Data have been obtained for three streamline bodies of revolution having fineness ratios of 6, 9, and 12, for a body having a fineness ratio of 9 but modified to increase the longitudinal curvature, and for a fuselage having a fineness ratio of 9 with the aft end modified to accomodate a jet exhaust (refs. 8 to 11).

At speeds where the skis are submerged, the struts supporting the skis contribute to the total resistance. The resistance of the struts at preemergence speeds, which are generally below the inception of cavitation, is estimated to be less than 5 percent of the total hydrodynamic resistance. Surface-piercing struts at zero yaw have been investigated at speeds up to 80 fps at several depths of immersion, with zero rake and raked 30° forward and aft. NACA 66-series airfoil sections of 12- and 21-percent thickness were used.

The range of ski shapes covered is shown in figure 4. The plan forms for which planing data have been obtained include rectangular and

triangular forms and rectangular forms with triangular aft ends. The
triangular aft ends have been found to be of interest because of their
improved stability and lower landing loads as compared with rectangular
aft ends. The cross sections include curved, flat, and V-bottom shapes
with several dead-rise angles and flared and vertical chines (refs. 12
to 17). Planing data have been obtained for a flat ski with taxying
wheels of several sizes and cross sections located at a variety of posi-
tions with respect to the ski (refs. 18 and 19). In addition, data have
been obtained in the submerged condition for flat plates having length-
beam ratios of 8, 4, and 1.

From fuselage data (refs. 8 to 11), it is possible to determine
the maximum speed which a fuselage can attain before exceeding a speci-
fied value of resistance. Figure 5 presents such data as a plot of the
lift-resistance ratio of several fuselages against the Froude number.
The Froude number is the speed divided by the square root of the product
of the gravitational constant and the wetted length. It is usually the
governing parameter when, as in the case of the fuselage, wave-making
resistance is predominant. When plotted in this manner, the data for
each fuselage at various speeds and loads fall along a single curve.
From these curves the speed at which the fuselage must clear the water
to attain a given lift-resistance ratio can be estimated.

Since in the low-speed range the hydrodynamic lift supports nearly
all the weight of the airplane and since the resistance cannot exceed
the thrust available for take-off, the minimum allowable lift-resistance
ratio is determined by the ratio of weight to thrust of the airplane.
The thrust of recent high-speed airplanes has been such that the required
lift-resistance ratio falls between 2.5 and 4. In this range of lift-
resistance ratios, fuselages, in general, would have to be lifted clear
of the water at a Froude number of approximately 1.3, which corresponds
to a speed of 45 fps if the fuselage is 40 feet long, or 65 fps if
80 feet long. A hydro-ski that will lift the fuselage from the water
at this speed can be selected by using data similar to that given in
figures 6 and 7.

Figure 6 presents the variation of hydrodynamic lift coefficient
with angle of attack (where the lift coefficient is based on the wetted
area) for a flat ski, a curved-bottom ski suitable for flush retraction
into a streamline fuselage, and for a curved ski with vertical chine
strips equal to 10 percent of the beam. The data shown are for a wetted
length-beam ratio of 4. These lift curves are nonlinear as for low-
aspect-ratio airfoils. The convex ski has lower lift at all angles of
attack than the flat-bottom ski. The addition of vertical chines to
the curved-bottom ski, however, increases the lift to values larger than
for the flat ski.

Figure 7 presents the variation of lift-resistance ratio with lift coefficient for the same three skis. The flat-bottom ski and the convex-bottom ski have approximately the same maximum lift-resistance ratio, whereas the convex-bottom ski with the vertical chines has a lower maximum. These maximum lift-resistance ratios occur at low lift coefficients. For ease of retraction and for limiting landing loads, hydro-skis are preferably small and must, therefore, operate at high lift coefficients in the critical region of ski emergence. At the higher lift coefficients, the lift-resistance ratio of the curved-bottom ski is considerably lower than that for the flat-bottom ski. The addition of the vertical chine strips, however, increases the lift-resistance ratio to a value higher than that of the flat-bottom ski. In the higher range of lift coefficients, the lift-resistance ratio is primarily determined by the resistance due to lift, and the ski with the greatest lift for a given angle of attack will generally also have the highest lift-resistance ratio as shown in figures 6 and 7.

The planing data were obtained at relatively low speeds in the towing tanks and the question of their validity at the high speeds involved in the take-off and landing of present high-speed airplanes is an obvious one. In view of this condition, the NACA has been investigating methods of obtaining data at higher speeds. A small blow-down water jet has been employed for an exploratory investigation. Tests of small planing surfaces at speeds up to 200 fps have been made in this jet. Figure 8 shows a schematic diagram of the apparatus. A high-pressure air supply is used to force water from a tank through a nozzle. The nozzle has an elliptical profile and produces a rectangular stream 3 inches wide and 3/4 inch deep. The model is supported in the stream by a strain-gage balance that measures lift, resistance, and trimming moment which are recorded on an oscillograph simultaneously with the pressure at the nozzle. A limited quantity of high-pressure air is admitted to the water tank. As water is forced out of the tank, the speed of the jet stream decreases because of the decreasing pressure of the expanding air. In this way data are obtained at speeds from 200 fps down to about 70 fps in a single run.

Figure 9 presents some of the lift data obtained with this apparatus and corresponding data obtained at lower speeds in Langley tank no. 1. The data in both cases are for a rectangular flat plate having a wetted length-beam ratio of 4. An experimentally determined boundary-correction factor has been applied to the data obtained in the jet, no correction being required for the towing-tank data. The data shown by the untagged points were obtained in the jet; the tagged points are towing-tank data. The upsweep at low speeds is due to buoyancy effects which decrease rapidly with speed and are not a consideration at the speeds in question. Except for a slight upsweep at the highest speeds, which is believed to be at least in part due to the boundary conditions imposed by the method of testing, there is no appreciable variation in lift coefficient with speed. The data that have been obtained up to the present time are

somewhat limited and have not as yet been completely analyzed; however, indications are that there is no significant effect of speed on the lift of prismatic planing surfaces, and the trends indicated by data obtained at towing-tank speeds can be expected to hold at the higher speeds encountered during landing and take-off of full-scale airplanes. For complex surfaces, however, where negative pressures may be present, this is not necessarily the case.

The considerations so far have been concerned with meeting the take-off requirements; however, the required ski size is also influenced by the landing load requirements. The beam of the ski and the flight-path angle at a given landing speed are the primary factors influencing the landing load on the ski. Figure 10 shows the theoretical variation of landing load factor with ski beam for a 20,000 pound airplane equipped with twin flat-bottom rectangular skis (ref. 20). The variation for flight-path angles of 3° and 6° are presented. It can be seen that for a given flight-path angle the load factor increases with increasing beam; therefore, in order to meet a specified load factor, the beam of the ski is limited. The trend of decreasing load factor with decreasing beam points out the structural advantage of the hydro-ski with its relatively narrow beam as compared with that of a typical flying-boat hull. Although figure 10 is limited to rectangular skis, similar theoretical information for skis with triangular aft ends is also available in references 21 and 22. Since triangular skis present smaller wetted beams during the initial phases of a landing, they will have correspondingly lower loads as indicated in figure 10.

If the size of ski required for take-off is not compatible with the landing load requirements, other load-alleviating features such as variable area or variable dead rise may be used. Shock absorbers may also be used to reduce the load factor and thereby allow more freedom in the selection of ski proportions that will meet both take-off and landing requirements.

The forces on the submerged hydro-ski or on its supporting struts do not generally have a major effect on the selection of the ski size. Force data on struts and submerged skis are, however, useful in determining design loads when the ski is submerged. They are also useful in calculations to assess the relative hydrodynamic performance of different configurations. Submerged-ski data indicate a basic stability problem encountered in the transition from the submerged to the planing condition. This condition is illustrated in figure 11 where the lift of a flat rectangular ski is plotted against the distance of the leading edge of the ski from the water surface measured in ski length, that is, z/l where l is the ski length and z is the distance of the leading edge from the water surface. For the submerged condition, z is taken as positive and indicates the draft of the ski leading edge; for the planing condition, z is negative and indicates the vertical distance that the ski protrudes above the water.

Figure 11 shows that, for a fixed angle of attack, as the ski
approaches the water surface, the lift drops rapidly to a planing lift
that is only about one-half the lift obtained in the deeply submerged
condition. This decrease in lift will cause the ski to resubmerge when
it breaks the water surface and rise again when the flow is reestablished.
The ski will oscillate between planing and deep submergence. One obvi-
ous way to avoid such an oscillation is to increase the angle of attack
sufficiently to obtain planing lift equal to the submerged lift. Fortu-
nately, ski-airplane configurations that have been considered have usually
provided an inherent increase in ski angle of attack because of rotation
of the airplane about the aft end of the fuselage as the ski lifts itself
toward the water surface. Configurations that do not provide an inherent
increase in angle of attack with ski emergence may still merit considera-
tion if means for manual control of angle of attack by the pilot can be
provided.

In summarizing, it may be stated that, although the many interrelated
variables involved preclude the complete design of a hydro-ski airplane
without tank tests of models of complete configurations, sufficient data
are available to make some first approximations that will assist in pre-
liminary design and to establish trends that minimize the number of tests
required to arrive at a final design.

Langley Aeronautical Laboratory,
   National Advisory Committee for Aeronautics,
         Langley Field, Va., September 10, 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. Fisher, Lloyd J., and Hoffman, Edward L.: A Brief Investigation of a Navy Seaplane Design Equipped With a Hydro-Ski. NACA RM L53F04, 1953.

8. Weinflash, Bernard: The Effect of Air Jets Simulating Chines or Multiple Steps on the Hydrodynamic Characteristics of a Streamline Fuselage. NACA RM L8J21, 1949.

9. Weinflash, Bernard, Christopher, Kenneth W., and Shuford, Charles L., Jr.: The Effect of Air-Jet and Strip Modifications on the Hydrodynamic Characteristics of the Streamline Fuselage of a Transonic Airplane. NACA RM L9D20, 1949.

10. Weinflash, Bernard, Shuford, Charles L., Jr., and Christopher, Kenneth W.: Hydrodynamic Force Characteristics of a Streamline Fuselage Modified by Either Breaker Strips or Rows of Air Jets Simulating Chines. NACA RM L9L21a, 1950.

11. Weinflash, Bernard, and Shuford, Charles L., Jr.: Investigation of the Hydrodynamic Stability and Resistance of Two Streamline Fuselages. NACA RM L52B11, 1952.

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

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

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

15. 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.

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

17. 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.

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

19. 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.

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

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

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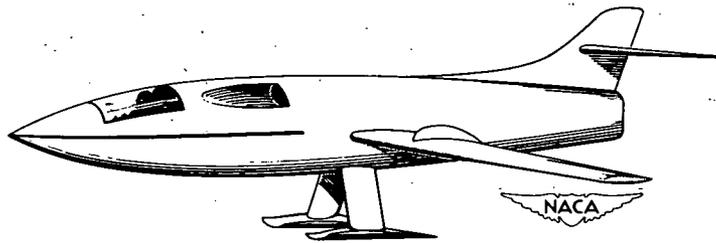   Data. NACA TN 2932, 1953.

HYDRO-SKI AIRPLANE CONFIGURATION

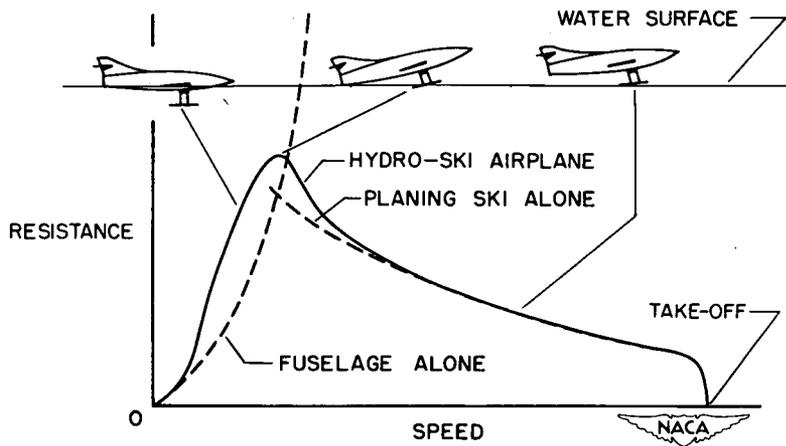Figure 1

HYDRODYNAMIC RESISTANCE OF HYDRO-SKI AIRPLANE

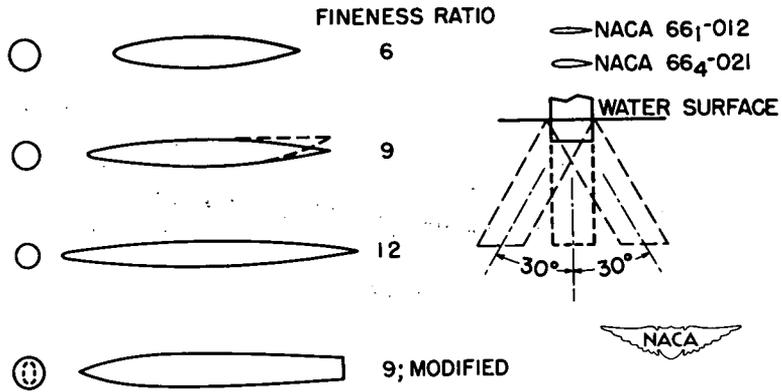Figure 2

SCOPE OF INVESTIGATION — FUSELAGES AND STRUTS

FINENESS RATIO

6

9

12

9; MODIFIED

NACA 66$_1$-012

NACA 66$_4$-021

WATER SURFACE

30° 30°

NACA

Figure 3

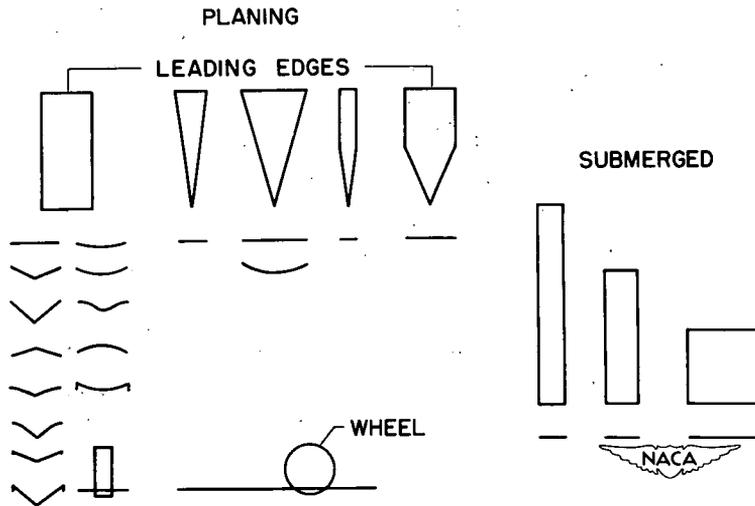SCOPE OF INVESTIGATION — SKIS

PLANING

LEADING EDGES

SUBMERGED

WHEEL

NACA

Figure 4

HYDRODYNAMIC LIFT-RESISTANCE RATIO OF FUSELAGES
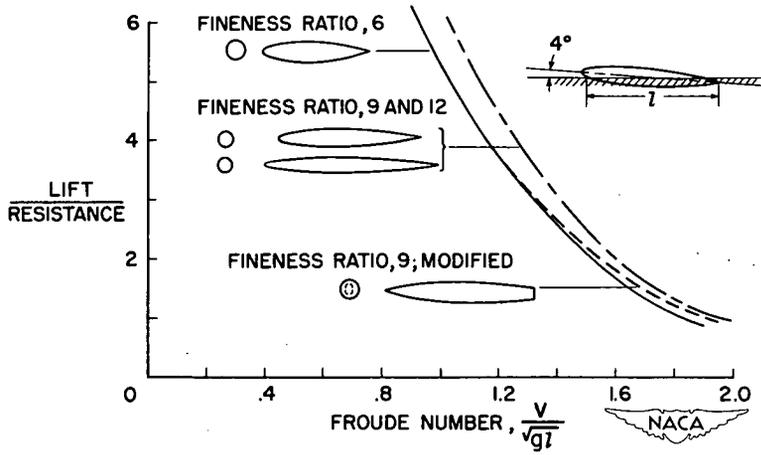
Figure 5

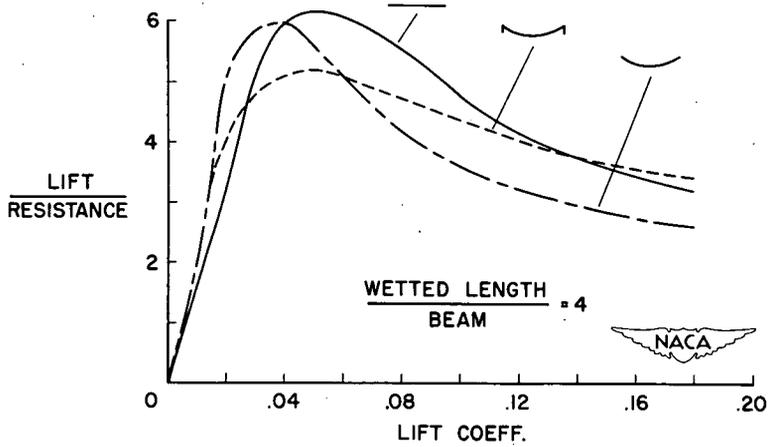HYDRODYNAMIC LIFT OF SKI SHAPES
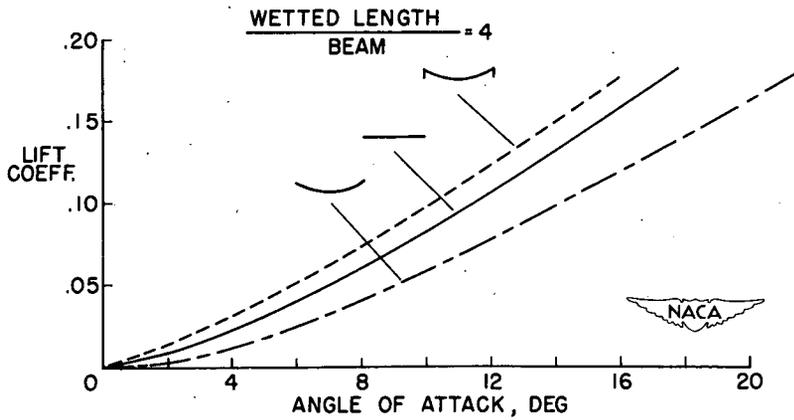
Figure 6

HYDRODYNAMIC LIFT-RESISTANCE RATIO OF SKI SHAPES

Figure 7

HIGH-SPEED JET
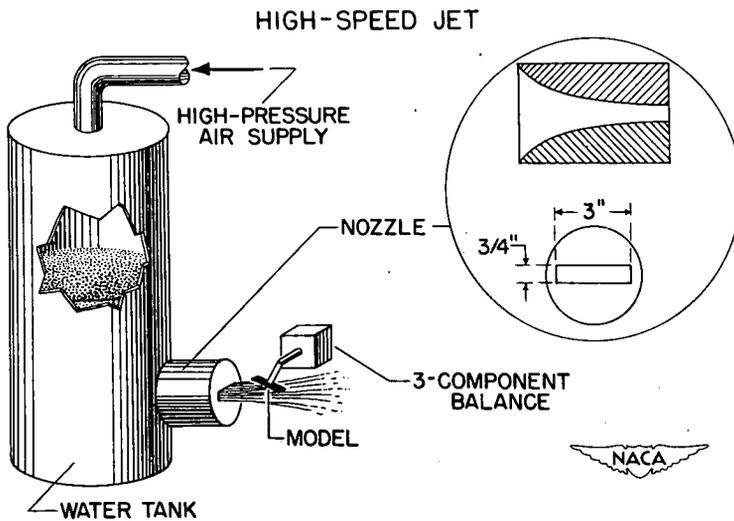
Figure 8

EFFECT OF SPEED ON HYDRODYNAMIC LIFT COEFFICIENT
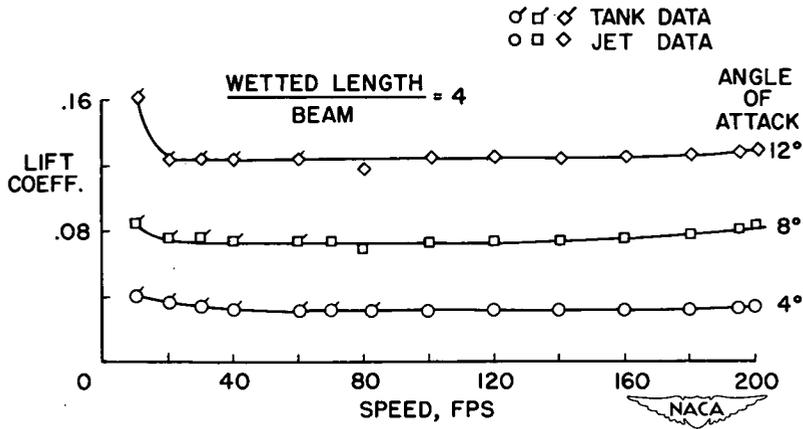

Figure 9

EFFECT OF SKI BEAM ON LANDING LOAD FACTOR

Figure 10

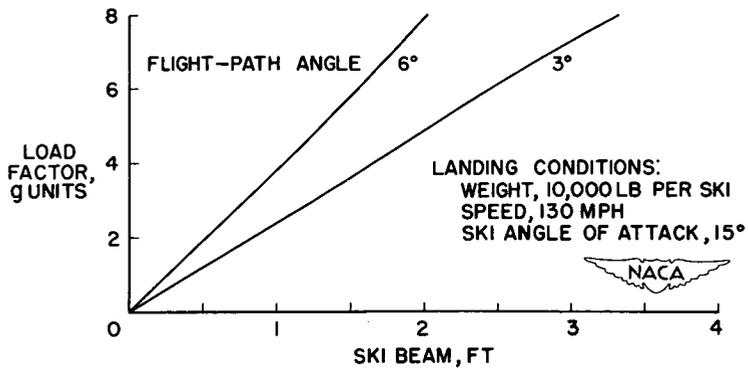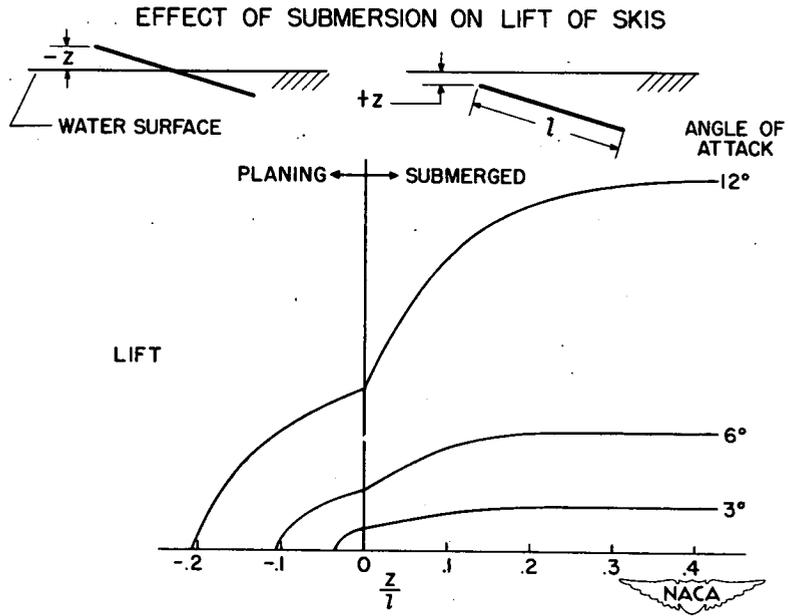EFFECT OF SUBMERSION ON LIFT OF SKIS

Figure 11