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BIBLIOGRAPHY AND REVIEW OF INFORMATION RELATING

TO THE HYDRODYNAMICS OF SEAPLANES

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SUMMARY

A bibliography and a review of information relating
to the hydrodynamics of seaplanes have been presented.
Data and conclusions obtained from the references in the
bibliography have been correlated to present in quali-
tative form a summary of the status of knowledge
pertaining to the hydrodynamics of seaplanes and to
point out the need for further research. Characteristics
of conventional hulls and floats are discussed to show
the effects upon performance of changes in design
parameters such as dead rise, depth of step, and angle
of afterbody keel. A separate section has been devoted
to special problems relating to floats for seaplanes.
Other topics discussed include lateral stabilizers,
aerodynamic and propulsive considerations, unconventional
configurations, hydrofoils, and piloting and handling.

The arrangement of the bibliography in general is
similar to that of the text. References on flying-boat
hulls, planing surfaces, and seaplane floats, however,
have been listed separately in the bibliography. Refer-
ence material pertaining to impact loads has been
included in the bibliography although the subject has
not been reviewed. Information on experimental pro-
cedures used to obtain the results discussed in the text
may be found in the references in the concluding section
of the bibliography.

INTRODUCTION

An increasing demand for information relating to
the hydrodynamics of seaplanes has indicated the need
for a compilation of existing scattered data. The
present report, which has been prepared in an attempt

to fill this need, is in the form of a bibliography and
a brief review of the subject. Wherever possible the
present status of the various phases of hydrodynamic
research is indicated and the need for further research
is pointed out although an extensive treatment of the
subject has not been attempted. Complete data and the
detailed development of the important conclusions may,
in general, be found in the reports listed in the
bibliography. In some instances, however, previously
unpublished data and data from sources not suitable for
reference purposes have been included. Reports that
are not generally available for distribution, either for
security or proprietary reasons, are marked with an
asterisk in the bibliography.

The material presented herein has been organized
in a way that isolates insofar as practical the effects
of design parameters such as dead rise, depth of step,
and angle of afterbody keel in preference to more general
subjects such as resistance, stability, and air drag.
A list of references pertaining to impact loads has been
included in the bibliography although the subject has
not been discussed in the text. Properties of both hulls
and floats are discussed under the heading "Conventional
Hulls and Floats" and special problems relating to floats
are taken up under the heading "Floats for Seaplanes."

Acknowledgment is made to Boeing Aircraft Company,
Consolidated Vultee Aircraft Corporation, Edo Aircraft
Corporation, and The Glenn L. Martin Company for
furnishing copies of engineering reports pertaining to
flight tests of seaplanes and the application of the
results of model tests to design practice. The following
members of the staff of the Langley Hydrodynamics
Division gave material assistance in correlating the large
amount of data: Joe W. Bell, John R. Dawson,
John W. Ebert, Jr., Leo F. Fehlner, Douglas A. King,
Norman S. Land, Roland E. Olson, John B. Parkinson,
and Henry B. Suydam.

CONVENTIONAL HULLS AND FLOATS

Over-All Proportions and Shape of Flying-Boat Hulls

The hull of a flying boat performs the functions
of fuselage, flotation gear, and landing gear. The

over-all proportions and shape of a hull result from a
harmonious combination of the proportions and shapes of
the various components designed for each function or
combination of functions. The over-all form is important
in itself mainly in connection with the fuselage and
flotation functions rather than with the detailed hydro-
dynamic characteristics during motion on the water. A
hull is best designed by taking into consideration its
requirements - that is, space for accommodation, sea-
worthiness, tail length, etc. - rather than by trying
to fit the requirements into a preconceived over-all
form.

Maximum beam.- The maximum beam of a flying-boat
hull is determined somewhat by the buoyancy required and
in transport airplanes by the width required for accom-
modation of the pay load. The beam loading is properly
regarded as a very important criterion and must be
selected to suit the intended service.

Over-all length.- The over-all length of the hull
is approximately made up of the length of the forebody
required for accommodation ahead of the center of gravity
and for adequate seaworthiness underway plus the pre-
determined distance from the center of gravity to the tail
surfaces. In contemporary hulls, the over-all length is
usually greater than the sum of forebody and afterbody
lengths. The additional length is the tail extension.

Over-all length-beam ratio.- The over-all length-
beam ratio is fairly well determined by the type and
configuration of the airplane. It is possible, however,
to vary the ratio for the same design and still maintain
the same degree of seaworthiness by varying the beam
loading, the forebody length-beam ratio, and the size
of the tail surfaces. The effect of such a variation on
the aerodynamic drag is included with the hydrodynamic
effects under "Hull Loading and Length-Beam Ratio."

Height and height-beam ratio.- The height of the
hull is usually greater than that required for accom-
modation and aerodynamic configuration in order to
provide sufficient spray clearance for the propellers
and aerodynamic surfaces. It is possible, however, to
use different heights for different beam loadings and
still maintain the same degree of seaworthiness. Most
present-day multiengine flying boats are characterized
by high beam loadings combined with high height-beam

ratios, and some authorities conclude that this combina-
tion is preferable from all standpoints (reference 18).
The PBY-5 (Catalina), however, is one example in which
low beam loading is combined with low height-beam ratio
of the hull, the wing being carried on a pylon, yet is
considered exceptionally seaworthy. Hydrodynamic tests
of a related family of powered dynamic models having
systematic variations in height-beam ratio combined with
appropriate values of length-beam ratio are required to
determine whether there is an optimum height-beam ratio
for a given class of airplane.

        Tests in the Langley propeller-research tunnel of
two models of flying-boat hulls have shown that the drag
coefficient based on frontal area decreases with an
increase in the height of the hull for a given beam and
length although the drag actually increases (reference 43).
Coombes and Clark (reference 18) have concluded from
these data that high values of height-beam ratio are
preferable. The data are shown in figure 1(a) as curves
of drag coefficient based on frontal area plotted against
height-beam ratio, along with similar data from tests of
a streamline body in the Langley 8-foot high-speed tunnel
which show a similar trend (reference 70). The same data
presented in figure 1(b) as curves of drag coefficient
based on the two-thirds power of the hull volume plotted
against height-beam ratio, however, indicate a different
conclusion. The drag coefficient based on volume for
model 35 is at a minimum near a height-beam ratio of 1.2
while the trend for the streamline body is reversed.
In general, it would be reasonable to expect that the
minimum drag for a given volume would occur near a height-
beam ratio of 1.0.

        Shape.- When the over-all proportions and dimensions
of the hull have been determined, the drag becomes a
function of the detailed shape. Below the chines the
shape must have suitable hydrodynamic characteristics
but otherwise should be smooth and fair in three
dimensions for the minimum of interference to the flow
of water or air and for ease of construction.
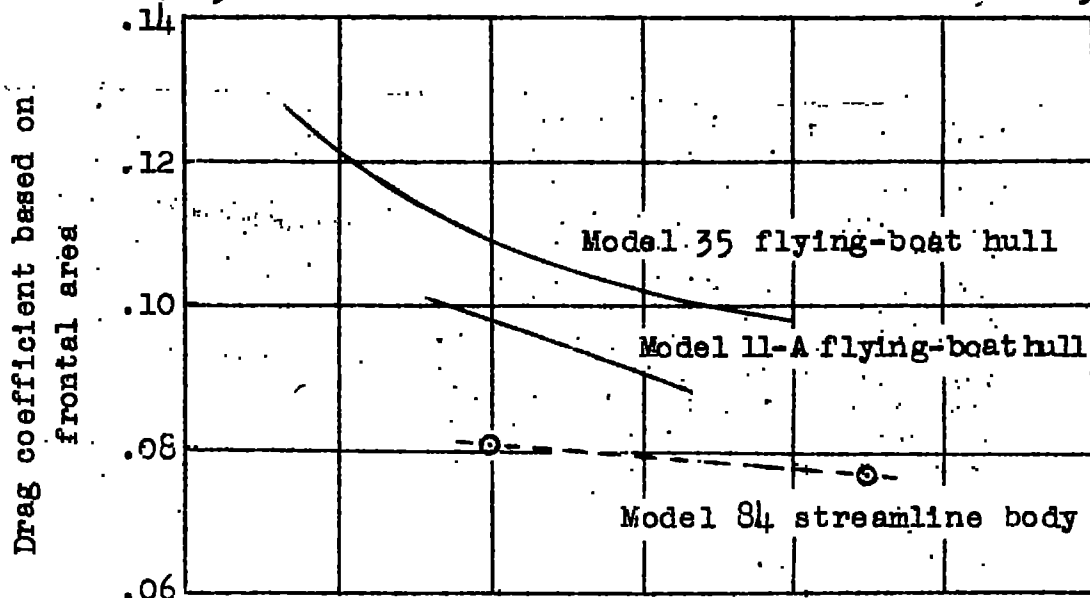
(a) Drag coefficient based on frontal area.
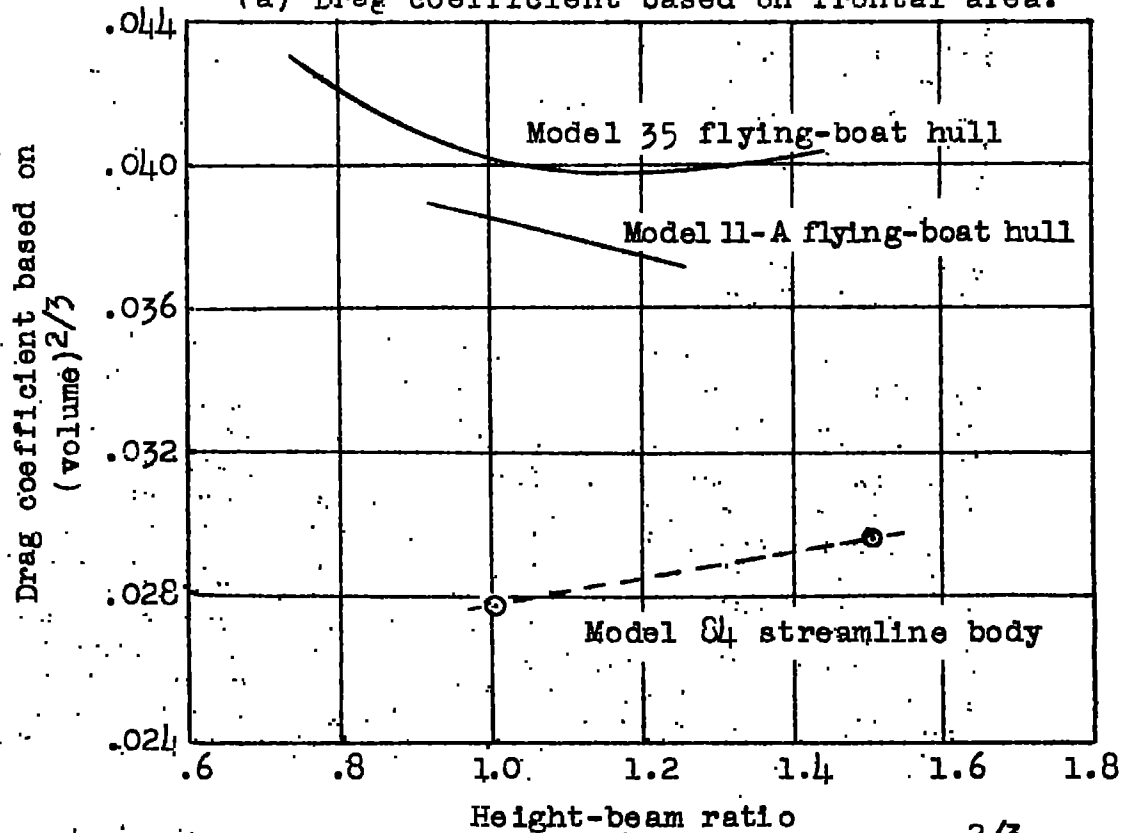
Height-beam ratio

(b) Drag coefficient based on (volume)$^{2/3}$.

Figure 1.- Variation of drag coefficient with height-beam ratio for flying-boat hulls and streamline body.

As an indication of the relative "cleanness" of
flying-boat hulls, Hartman (reference 43) compared their
drag coefficients with the drag coefficient of an airship
hull at the same Reynolds number. The best hull with a
tail extension had a minimum frontal-area drag coeffi-
cient of 0.092 as compared with the airship drag coef-
ficient of 0.052; hence, if all practical considerations
are neglected, it would be possible to reduce the drag
of this hull about 47 percent. The minimum frontal-
area drag coefficient of a very clean hull (fig. 2) as
measured in the Langley two-dimensional low-turbulence
pressure tunnel (reference 70) was found to be 0.080
as compared with a skin-friction drag coefficient
of 0.056 at the same Reynolds number; the increment
not chargeable to skin friction was therefore 42 percent
of the total.

A closer estimate of increment chargeable to the
function of the hull as a landing gear is given in
reference 79, in which the minimum drag coefficient of
a streamline hull was shown from tests in the Langley
8-foot high-speed tunnel to be about 20 percent greater
than that of either the straight or the warped stream-
line body from which it was derived. A similar com-
parison was made in reference 18 which indicated that,
for the hull considered, the minimum drag coefficient
was 22 percent greater than that of the warped stream-
line body from which it was derived.

In references 18, 70, and 79 the general premise
is advanced that the best over-all shape for a hull is
one for which the departures from a streamline body of
revolution are kept at a minimum consistent with hydro-
dynamic requirements. Increasing the height of a well-
faired bow has only a small adverse effect on the drag;
increasing the height of the stern by warping the basic
form but holding the afterbody position fixed has a
larger adverse effect (reference 79). Warping a stream-
line body at the stern is shown in reference 79 to have
no adverse effect on the minimum drag but increases the
angle of minimum drag as would be expected. In refer-
ence 18, however, warping the tail of the streamline
body is said to increase the drag 13 percent, presumably
at the same angle of attack.

In reference 43 the beneficial effect of a rounded
deck for the same frontal area is estimated to be a
reduction in minimum drag of 21, 23, and 26 percent,
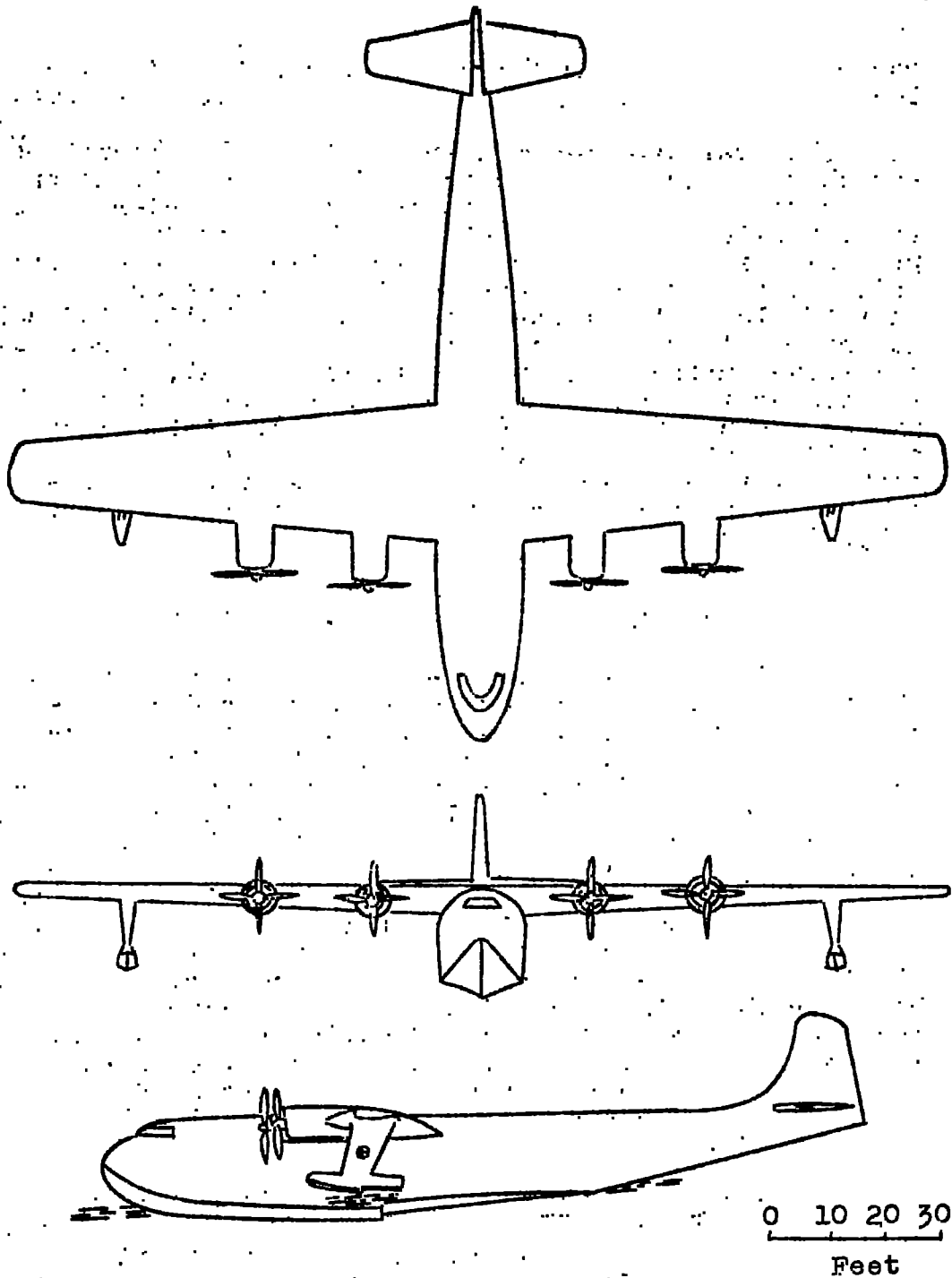
Figure 2.- Conventional flying boat for transport
    service with hull designed for low air drag
    (reference 70).

respectively, for the three models considered. The
increase in drag attributed to the windshield is small.

The available data on the effects of proportions
and shape indicate that careful design and attention
to the shape of the hull are essential in order to keep
the parasite drag at a minimum. The added drag of
properly arranged chines and steps becomes of the same
order of magnitude as that due to roughness and
unavoidable protuberances on the actual hull. Radical
departures from the form for minimum drag or forms having
excessive surface area will not, in general, be desirable
for high-performance airplanes regardless of their
hydrodynamic advantages (reference 70). (Fig. 2 shows
a flying boat of conventional arrangement for transport
service with a low-drag hull having suitable hydro-
dynamic characteristics for a gross weight of about
120,000 lb.).

Hull Loading and Length-Beam Ratio

The loading of a flying-boat hull or a seaplane
float is usually expressed in terms of load coeffi-
cient C_Δ, which is based upon beam as the charac-
teristic dimension. Load coefficient provides a good
scale for the load on hulls having comparable length-
beam ratios and for any hull in the planing condition,
in which wetted length is a dependent variable. At
low speeds, however, when the bow of the hull is wetted,
load coefficient loses most of its significance in the
comparison of hulls of different length-beam ratios.
Because of the close relationship between load coeffi-
cient and length-beam ratio, it is necessary to consider
both variables in discussion of the load-carrying
capacity or the performance of hulls at low speeds. The
length and beam of the forebody are considered the most
important dimensions because the dimensions of the after-
body must be made approximately in proportion to those of
the forebody.

Effects of load with hull proportions held constant.-
The effects of load have been investigated in numerous
general tests of flying-boat hulls and in overload tests
of most specific designs. Data from these sources show

the effects of load on the performance of flying-boat hulls of conventional shape and proportions. Increasing the load coefficient

(a) reduces load-resistance ratio Δ/R at hump speed

(b) increases Δ/R at speeds near get-away

(c) raises both the upper and lower trim limits of stability

(d) usually decreases the range of stable locations of the center of gravity

(e) increases difficulty of directional control at low speeds (Several cases are known in which the load of a flying boat has been limited by directional instability.)

(f) increases the height and intensity of spray

Length-beam ratio.- A criterion relating the gross-load coefficient C_{Δ_0} of a flying-boat hull to the length-beam ratio of the forebody has been established by analysis of the spray characteristics of existing flying boats (reference 69). This analysis shows that the load capacity of a hull of conventional proportions varies with the first power of the beam and the second power of the length of forebody. The maximum gross-load coefficient for the hull of a multiengine flying boat may be determined by the following expression:

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

where L_f is the length of forebody, b is the beam, and k is a nondimensional criterion ranging from 0.0525 for hulls with light spray to 0.0975 for hulls with excessive spray.

In references 17 and 18 it was assumed that uniform seaworthiness may be maintained by varying loading so

that the draft of the main step at rest remains a con-
stant proportion of the length of the forebody of the
hull. From data in these reports for over-all length-
beam ratios from 5.5 to 10.0, the following expression
may be obtained:

$$C_{\Delta_0} \propto \left(\frac{L}{b}\right)^{2.5}$$

The approximate relationship

$$C_{\Delta_0} \propto \left(\frac{L}{b}\right)^{2}$$

has also been supported by Davidson and Locke (refer-
ence 20) on the basis of conclusions reached in general
tests. Tests made in Langley tank no. 1 (reference 8)
have shown that holding C_{Δ_0} proportional to L/b gives
very conservative loading at high values of L/b.

Resistance data from systematic investigations of
length-beam ratio are available in references 8, 17,
18, 20, 91, and 143. The effects of length-beam ratio
on the trim limits of stability are included in refer-
ence 20. These references include data on spray with-
out power, or notes on observations of spray, but no
systematic spray investigations have been made with
powered models of different length-beam ratios.

When the load of a hull is held constant and the
length-beam ratio is varied by changing length or beam,
the effects of length-beam ratio are usually obscured
by the effects of changing the size of the hull. In
variations of this type, the effects of increasing
length or beam are in the same direction as those of
reducing load without changing dimensions. The effects
of increasing the length of a powered dynamic model
have been reported in reference 49.

Analysis of data from references 8, 20, and 143
indicates that when C_{Δ_0} is proportional to $(L/b)^{2}$

the spray and resistance characteristics are not
impaired if length-beam ratios are increased from 5.5
to 10.5. From the same analysis the length-beam ratio
for optimum resistance characteristics depends upon the
lines of the hulls considered. There is some indication
that the ratio of over-all length to beam beyond which
no further gain is obtained in hydrodynamic characteristics
is between 9 and 10 (references 17 and 18). The best
trim at the hump decreases as length-beam ratio is
increased. It has been shown that the stable range of
trim is reduced with increasing length-beam ratio (refer-
ence 20). Recent tests of a family of models derived
from the proportions of the XPBB-1 airplane indicated
that the stable range of center-of-gravity locations was
about the same for a length-beam ratio of 9 as for the
basic value of 6.3. The principal advantage of high
length-beam ratio appears to be that of reducing length-
beam product and thereby reducing the size of the hull.

Dead Rise

For most present-day flying boats of American design,
the angles of dead rise measured adjacent to the fore-
body keel near the step lie between 20° and 25°. Some
recent British designs employ an angle of dead rise of
as much as 30° (reference 35). Angles within the range
of 20° to 30° probably represent the best compromise for
over-all performance.

Data on the effect of dead rise are available from
tests of hulls and floats (references 11, 18, 22, 23,
26, 140, 143, and 254) and from tests of planing surfaces
(references 108, 109, 116, and 119). These data are in
general agreement on most of the effects of dead rise.
Increasing the angle of dead rise

    (a) has little effect on hump resistance in the
        range from 15° to 30°

    (b) increases resistance at speeds above hump speed

    (c) increases positive trimming moment at planing
        speeds

    (d) raises the lower trim limit of stability

    (e) reduces the impact loads

It is believed that increasing the angle of dead rise
raises the upper trim limit of stability, as indicated
in references 23 and 108, but reference 22 shows a
slight lowering of the upper limit with an increase
from 20° to 30° in angle of dead rise.

Increasing the angle of dead rise within the
range of 15° to 30° generally reduces the spray but
tests with planing surfaces (reference 119) indicated
an increase in spray with increasing angle of dead rise.
Model tests of a flying-boat hull with slightly arched
cross sections (negative angle of dead rise) showed
excellent spray characteristics and low resistance
(reference 3).

The available information on the effect of angle
of dead rise on air drag is limited and is not in
agreement. Langley wind-tunnel tests of three sea-
plane floats having angles of dead rise of 20°, 25°,
and 30° (reference 140) show increasing air drag with
increasing angle of dead rise, while a British com-
pilation of data (reference 18) indicates that air
drag decreases with increasing angle of dead rise.

Tests of powered dynamic models of a flying boat
(reference 23) indicate that the landing stability is
improved by increasing the angle of dead rise from 20°
to 25°.

Forebody

Bow.- Compromises in the shape of the bow are
frequently made to accommodate bombardiers' windows
or armament in military designs and may be made to
favor seaworthiness, air drag, or simplicity of con-
struction. In general, however, certain principles
should be followed in order to provide seaworthiness
and resistance characteristics consistent with opera-
tional requirements, with a minimum of departure from
the best aerodynamic form. For a hull that is devel-
oped about a streamline body of revolution, the air
drag will be at a minimum if the chines are located in
planes passing through the axis of the basic body of
revolution (reference 79). (See fig. 3.)

Axis of warped
streamline body

Axis of streamline
body of revolution

Basic
form

Plane of
chines
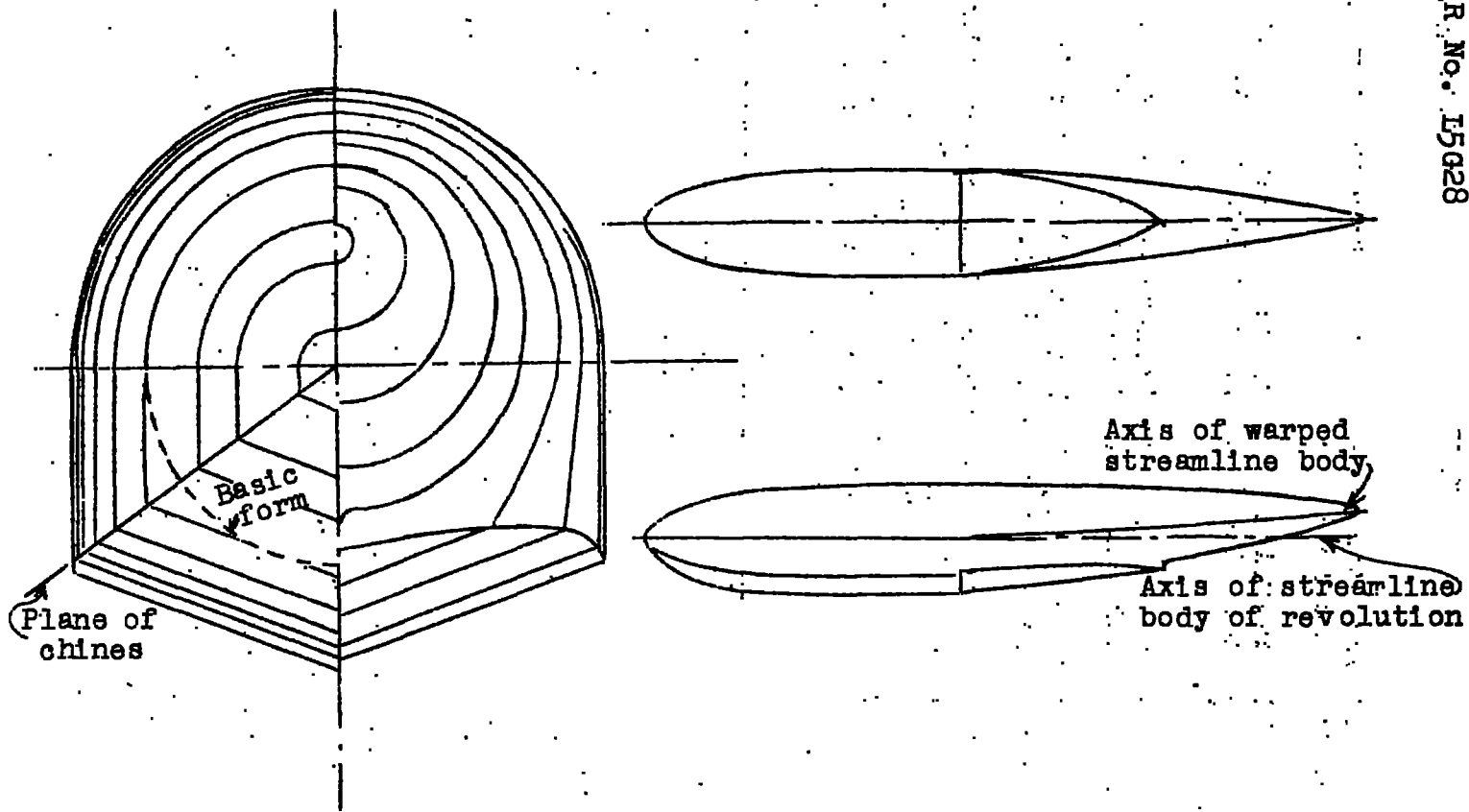
Figure 3.- Full developed about a streamline body of revolution.
(From reference 79.)

Effects of changes in the shape of the bow are summarized as follows:

(1) Insufficient buoyancy forward results in low trim and excessive bow spray at low speeds (reference 79).

(2) Increasing the "fineness" of the bow below the chine reduces bow spray (references 55 and 79).

(3) Increasing the height of the bow increases the air drag (references 79 and 139).

(4) Rounding the chines (in cross section) at the bow will severely increase the bow spray and will reduce the air drag at large or low angles of attack (reference 79). At angles near those for the minimum drag of a suitably designed hull, rounding the chines has no significant effect on the air drag (references 58 and 79).

Longitudinal curvature of planing bottom.- It is generally considered desirable that the forebody bottom have no longitudinal curvature for some distance forward of the main step. A rough rule often quoted is that the buttocks should be straight and parallel for about 1.5 beams forward of the step in order to obtain satisfactory spray, resistance, and stability characteristics (reference 70).

The more significant effects of longitudinal curvature of the planing bottom near the step are:

(1) Convex curvature of the buttocks causes negative pressures at planing speeds that may significantly reduce dynamic lift and impair the efficiency of the hull (references 68, 90, and 91).

(2) Longitudinally concave buttocks have little effect on hump resistance but reduce the resistance and volume of the spray at high speeds (references 67 and 119).

(3) Concavity that is localized near the step in a length of the order of one-half the beam or less may cause extremely severe instability (references 12 and 61).

Warping of bottom surfaces of forebody.- Systematic investigations of warped planing bottoms having straight buttocks have been reported in references 22 and 55.

Warping the forebody bottom (dead rise increasing toward
the bow) lowers the lower trim limit of stability but
the change at speeds just beyond the hump is relatively
small. This lowering of the lower trim limit is
accompanied by a lowering of the trim track, which may
result in a change in the stable range of center-of-
gravity positions. The upper trim limit is lowered
slightly but not as much as the lower limit. Increasing
the warping increases the resistance at the hump and at
high speeds. The bow spray is improved somewhat by
increased warping, but it is also shown in references 55
and 79 that by confining the warping to the forward
portions satisfactory bow spray characteristics may be
obtained without compromising the planing characteristics.

Chine flare.- Tests of a large number of variations
of chine flare (reference 9) have shown that good spray
characteristics may be obtained with flare on the planing
bottom confined to a width of about 8 percent of the beam
and ending with a horizontal or slightly downward direc-
tion at the chine. Wide variations in the width, radius,
or final downward angle of the flare, however, cause
relatively small differences in the spray or resistance
characteristics. Chine flare reduces the height of the
forward part of the spray where the spray leaves the model
above the water level but has little effect on the spray
where the chine of the model is below the water level.
Chine flare has little effect on resistance at the hump
and at speeds near get-away; but the addition of chine
flare, by reducing the height of the chines above the
keel, causes a slight reduction in resistance at speeds
just beyond the hump. Chine flare has little effect on
the air drag of a hull if the chines are located approxi-
mately along the natural lines of air flow (reference 79).

External chine strips.- Chine strips may take the
form of relatively thin projections extending outward or
downward from the chines (references 23, 43, 76, 98,
140, and 256) or of sponsons, as shown in figure 4, that
increase the beam and have a depth approximately equal
to the width (references 49 and 60). Strips are some-
times incorporated instead of chine flare to improve
the spray characteristics without involving complicated
construction. In most cases, however, external chine
strips of either type are added to improve the hydro-
dynamic performance of overloaded hulls or hulls with
insufficient chine flare.

Strips having a width of about 3 percent beam and downward angles of 10° to 45° improve the spray characteristics and cause some reduction in resistance (references 45, 98, and 256). Wind-tunnel tests have shown, however, that such strips increase the air drag of hulls by 8 to 20 percent (references 43, 140, and 256).

Sponsons on the bow and the forward portion of the forebody have been used to control the spray of heavily loaded hulls (references 49 and 60). Model and full-size
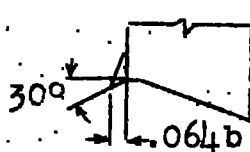
Figure 4.- Sponsons extending
outward and downward.

tests have indicated that sponsons greatly increase the overload capacity of flying boats by reducing the bow spray at heavy loads. Like the thinner chine strips, the sponsons significantly increase the air drag and are suggested for use only when it is necessary to increase the load-carrying capacity of an existing hull. Recent tests (reference 45) have shown that vertical spray strips projecting about 3 percent of the beam downward from the chine (fig. 5) are about as effective as sponsons in
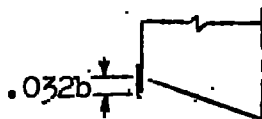
Figure 5.- Spray strips extending vertically
downward from chine.

controlling spray. Information regarding the air drag
of vertical strips is not available and the value of
retracting this type of spray strip is questionable.

    Longitudinal steps.- Longitudinal steps combined
with flat surfaces having little or no dead rise were
used on the forebodies of a number of flying boats some
years ago. This type of bottom, in contrast with a
conventional V-bottom, increases the resistance at low
speeds and decreases the resistance at speeds near get-
away (reference 4). Apparently no data are available
regarding the effect of an arrangement of this type on
dynamic stability.

    One model has been investigated to determine the
effect of reversed lap strakes, similar to the clinker-
built arrangement of ship planking (fig. 6), added to a
planing bottom of the forebody of conventional form and
proportions (unpublished data). Resistance tests were
made of the model complete with a conventional afterbody.
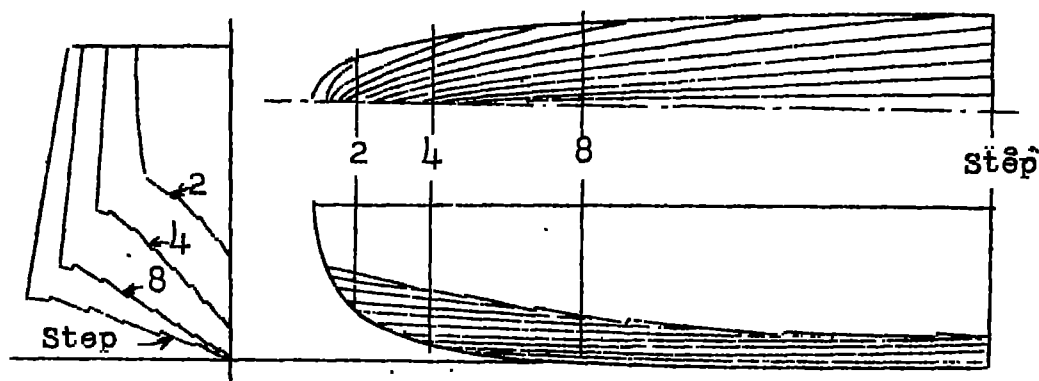
Figure 6.- Arrangement of longitudinal steps for
    NACA model 204. Depth of longitudinal steps,
    1 percent of beam.

These strakes had negligible effect on the resistance
at the hump but caused some reduction in resistance at
higher speeds. The spray from the model with lap strakes
was more finely broken up than that from the parent model
but had about the same volume and height. The effect on
dynamic stability has not been investigated.

Another variation of longitudinal steps has been
tested on a powered dynamic model (reference 61). This
modification consisted of a triangular strip on either
side of the planing bottom forward of the step, as shown
in figure 7. A depth of step of 11.5 percent of the beam
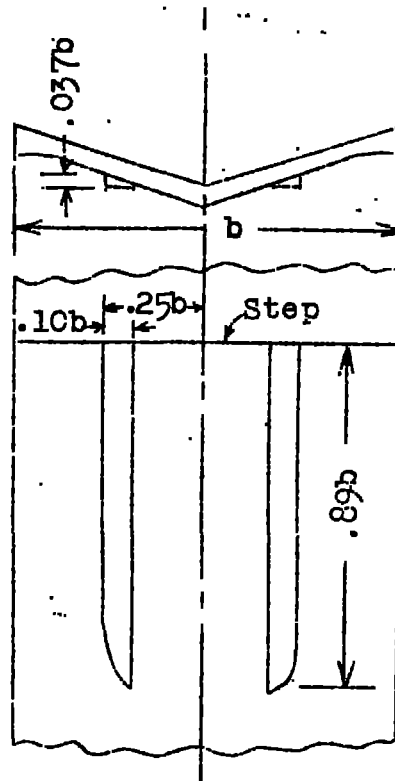
Figure 7.- Triangular strip added to
        planing bottom.

was required for adequate landing stability without the
longitudinal steps. Longitudinal steps of the dimensions
shown provided adequate landing stability when used in
conjunction with a depth of step of 5 percent of the beam.
It was also found that longitudinal steps of the same
type but of larger size provided adequate landing stability
with a depth of step of as little as 2 percent of the beam.
With this configuration the strips had a cross-sectional
area equivalent to an increase in depth of step of less
than 1 percent of the beam so that the combined cross-
sectional area of step and strips was less than half

the area normally required for sufficient ventilation
during take-offs and landings.

Fluted bottoms.- Model tests (references 25 and 264)
have indicated that the substitution of a fluted bottom
(fig. 8) for a conventional V-bottom causes some reduc-
tion in spray and a reduction in resistance at high speeds
but causes little change in resistance at low speeds and
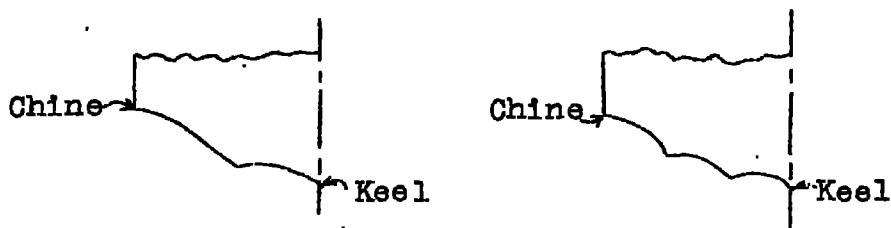
Figure 8.- Examples of fluted bottoms.

at the hump. The effects of flutes on dynamic stability
have not been investigated but no adverse effect has
been observed on full-size application. The principal
advantage of flutes appears to be that of improving the
structural efficiency.

Bottom roughness.- The increase in friction coef-
ficient of a planing surface with rivet heads is directly
proportional to the height of the rivet head above the
surface. The order of merit of commonly used rivet heads
in relation to low water resistance is: flush countersunk,
oval countersunk, brazier, and round (reference 101).
With a $\frac{1}{3.5}$-full-size seaplane model, the increase in
total water resistance caused by round-head rivets varied
from 5 to 20 percent at hump speed and from 15 to 40 per-
cent at high speed. The use of round-head rivets
increases the total air-plus-water resistance of a single-
float seaplane less than 5 percent at hump speed but as
much as 25 percent at high speed. If the total resistance
is calculated by Froude's law, it is found to be 2 percent
higher at hump speed and 8 percent higher at planing speeds
than that calculated by taking into account the effect of
scale on frictional resistance (reference 138). Con-
siderable difficulty has been experienced by service

organizations in maintaining watertightness with flush
rivets of the type currently in use.

Afterbody

A primary function of the afterbody is to provide
buoyancy and planing area aft of the center of gravity
so that trims at rest and at low speeds are acceptable
for practical operation. At speeds just before the
hump and at hump speeds, the dynamic lift developed by
the afterbody planing surface is one of the principal
forces that controls the trim and, therefore, the water
resistance. At planing speeds, the spray that strikes
the afterbody increases the water resistance and changes
the trimming moments. Take-off and landing instabilities
that occur at high speeds and trims are associated with
the position and form of the afterbody.

In general, changes in the afterbody that increase
the afterbody clearance increase the static trim, increase
the hump trim and resistance, decrease the high-speed
resistance, shift the peak of the lower trim limit to
lower speeds and higher trims, and also raise the upper
trim limits. The trim tracks (variation of trim with
speed) are shifted in the same direction that the trim
limits are changed. In tests at the Langley tanks, no
combination of conventional forebody and afterbody
planing surfaces has been found that eliminates either
the lower or the upper trim limits of stability or that
suppresses the upper trim limit at high speeds.

Afterbody length.- An increase in afterbody length
lowers the lower trim limits of stability at hump speed
and lowers the upper trim limits (references 21, 22, 23,
48, 61, and 100). For a given depth of step and angle of
afterbody keel, landings are more stable with a short
afterbody than with a long afterbody (references 48 and 61).
The depth of step required for the landing stability of
a model with an angle of afterbody keel of 6.2° was
approximately 8 percent beam for an afterbody length-
beam ratio of 1.7 and approximately 13 percent beam for
an afterbody length-beam ratio of 3.2 (unpublished data).

An increase in afterbody length without any change
in forebody length decreases the hump trim and resistance
(references 21 and 22) and may sometimes increase the
spray in the propellers. Experience has shown that .

decreasing the trim reduces spray in the region of the
flaps (reference 23). The tests described in reference 23
indicated that an increase in the length of the after-
body decreased but did not remove the directional insta-
bility at low speeds.

Angle of afterbody keel.- An increase in the angle
of afterbody keel raises the lower trim limits at low
speeds and raises the upper trim limits (references 21,
22, 48, 93, and 100). For a given depth of step and
length of afterbody, landings are more stable with a low
angle of afterbody keel than with a high angle of after-
body keel (reference 48). The depth of step required for
landing stability of a model with an afterbody length-
beam ratio of 2.7 was approximately 9 percent beam for an
angle of afterbody keel of 4.8° and approximately 14 per-
cent beam for an angle of afterbody keel of 9.3° (unpub-
lished data). For some comparisons involving changes in
both depth of step and angle of afterbody keel, the angle
between the forebody keel and a line joining the step and
sternpost, called the sternpost angle, is a useful
parameter (reference 22).

In tests of three series of models (references 1,
11, and 79) an increase in angle of afterbody keel
from 4° to 9° increased the free-to-trim hump resistance
approximately 25 percent and the best-trim hump resistance
approximately 15 percent.

Low angles of afterbody keel decrease the static
trim, increase the tendency for spray to come over the
bow at very low speeds (reference 55), and decrease
the hump resistance at low speeds (reference 11).

Aerodynamic drag measurements (reference 43) indi-
cate that differences in drag are practically negligible
for angles of afterbody keel of 6° or less. At larger
angles the aerodynamic drag increases appreciably.

Afterbody warping.- Effects of systematic changes
in warping have not been extensively investigated. From
the more or less isolated investigations that have been
made the following results are of interest:

(1) Warping in a manner that decreased the angle of
dead rise at the sternpost reduced the hump trim and
resistance (reference 79).

(2) Warping in a manner that increased the angle of
dead rise at the sternpost from 0° to 30°, with straight

buttock lines, raised the lower trim limit at hump speeds
and raised the upper trim limits (references 21 and 22).
Increasing the angle of dead rise at the sternpost of a
dynamic model from 20° to 30° raised the lower trim limit
at low speeds, did not affect the upper trim limits
except at low speeds, and slightly reduced the yawing
instability at speeds below the hump (unpublished data
from Langley tank no. 1).

(3) Increasing the angle of dead rise to a maximum
near the midlength of the afterbody has not significantly
affected the landing stability of models (references 23
and 61). It should be noted that tests of a full-size
flying boat (PBM-3) with an afterbody having this type
of warping showed satisfactory landing stability with a
depth of step of 5 percent of the beam and a load coef-
ficient of 0.8 (reference 34). Whether the warping con-
tributes to the satisfactory characteristics is not yet
established.

Afterbody plan form.- The plan form of the after-
body appears to be of secondary significance in resistance
and porpoising characteristics compared with the length
of afterbody, angle of afterbody keel, and angle of dead
rise. Changing from a pointed plan form to one with a
transverse second step had no significant effect on the
hump resistance (reference 9), reduced directional
instability at speeds below the hump (references 23
and 73), and increased the air drag (reference 18).
Modifying a pointed afterbody to form a cusped plan
form reduced the unstable yawing moments at speeds below
the hump (reference 10).

Afterbody chine flare.- Afterbody chine flare
increases the dynamic lift of the afterbody and reduces
both the hump trim and hump resistance (references 21, 22,
and 79). If the spray does not break clear at the after-
body chines, suction forces may develop that increase
both the hump and high-speed resistance (reference 70).
Under these circumstances, the use of chine flare is
advantageous and will reduce the landing instabilities
(unpublished data).

Position of Center of Gravity and Location

of Main Step

Preliminary design.- It has been suggested (refer-
ence 28) that the center of gravity be located on a line

passing through the step and inclined between 15° and 25°
forward of a line normal to the forebody keel. Tests of
powered models of current design indicate that a range
from 10° to 20° may be preferable. If the plan form of
the step is other than transverse, the centroid of this
plan form may be used as an equivalent location (refer-
ence 100). Reference 70 suggests that with the airplane
approximately in a stalled attitude the center of gravity
should be directly above the step. For airplanes with
abnormally high angles of stall, the maximum trim expected
in landing may be more applicable than the trim at stall.

Effects upon dynamic stability.- Variation in the
position of the center of gravity has negligible effect
upon the trim limits of stability (references 100
and 106) but has a large effect upon the trim tracks and
consequently upon the probability that porpoising will
be encountered. A forward movement of the center of
gravity lowers the trim track, and lower-limit porpoising
(low angles) may be expected at speeds just above the
hump. An after movement of the center of gravity raises
the trim tracks, and upper-limit porpoising (high angles)
may be expected near get-away. Instabilities while on
the water may therefore limit the range of positions of
the center of gravity that can be used for take-off.

The most forward position of the center of gravity
at which a flying boat can operate is generally limited
by aerodynamic requirements for control and hydrodynamic
requirements for stability. The main step is best
located so that the hydrodynamic requirements for stability
are met at the most forward position of the center of
gravity at which the flying boat will operate. The main
step must be located so that, with the center of gravity
of the flying boat at its most forward position, lower-
limit porpoising can be avoided during take-off. In the
event that porpoising does occur, positive trimming moment
(up elevators) should be available for increasing the trim
to angles above the lower trim limit. This procedure has
been used for locating the position of the step during
tests in the Langley tanks (references 10, 47, 60, 61,
63, and 100).

Relocation of step to improve stability of model or
full-size airplane.- If model or flight tests indicate
that the most forward position of the center of gravity
which is stable for take-off does not coincide with the
position required from aerodynamic considerations, the

location of the step or of the wing may have to be
changed. If relocation of the wing is impractical, the
step should be moved approximately 1.3 times the distance
the position of the center of gravity for take-off must
be shifted. The factor 1.3 is the ratio of the gross
load of the airplane to the approximate load on the water
at speeds and trims at which lower-limit porpoising occurs.

Because of the angle between the forebody and the
afterbody, a forward movement of the step results in a
reduction in the depth of step that may impair the landing
stability. A vertical displacement of either the forebody
or the afterbody planing surface is then required in order
to maintain adequate depth of step. An after movement of
the step results in an increase in the depth of step
which may cause a slight increase in the hump trim and
resistance but which also tends to increase the landing
stability. A forward movement of the step therefore is
likely to be more costly and difficult than an after
movement of the step. In preliminary design, it is
desirable to favor a forward position of the step if
further modifications are anticipated.

Depth and Form of Main Step

Depth of step.- An increase in depth of step raises
the lower trim limit at low speeds, raises the upper trim
limits, and reduces the violence of upper-limit porpoising
(references 21, 22, 62, 71, 100, and 108). High negative
pressures occur on the afterbody just aft of a shallow
step during landing and high-angle porpoising (refer-
ence 78). An increase in depth of step increases the
landing stability by relieving these suction forces
(references 47, 49, 71, 78, 93, and 100). Landing
instabilities of models of two airplanes were investi-
gated in the Langley tanks and in both instances increases
in depth of step resulted in satisfactory landing char-
acteristics. A similar increase in depth of step of the
full-size airplane was accomplished by an after movement
of the step, and satisfactory landing characteristics
were obtained for both airplanes (reference 71).

Increase in depth of step increases the hump trim
and resistance and decreases high-speed resistance
(references 7, 21, and 22). The aerodynamic drag of
the hull is increased 10 to 15 percent by the presence
of the step (references 18, 23, and 43) and the drag

of a transverse step is approximately proportional to the area of the rise of the step (reference 43).

Exceptionally stable landings of a model have been obtained with the depth of step reduced to zero (reference 13).

Ventilation of the step.- In the absence of adequate depth of step for landing stability, the use of ventilation ducts just aft of the step and as near the keel as possible has been successful on models (references 47, 49, 71, 78, 93, 100, and 243) and on full-size airplanes (reference 243). Ventilation does not affect the lower trim limit of stability but raises the upper trim limits slightly (references 47, 49, 78, and 100). When a shallow step is used, ventilation is also effective in reducing a resistance peak that occurs just before hump speed (reference 27). Ventilation apparently has no effect on directional stability (reference 10).

Step fairings.- In an effort to reduce the aerodynamic drag attributed to the presence of a step, fairings have been used aft of the step. Results of tests in reference 18 indicated that the step drag was practically eliminated by a fairing extending back six times the depth of the step. Fairings leaving half the depth of step were less effective while concave fairings, extending back five times the depth of step, saved only one-sixth of the step drag. Tests reported in references 37 and 58 showed similar reductions in air drag by use of step fairings. The addition of a step fairing to one of the Short Brothers flying boats (reference 260) increased the top speed by approximately 5 miles per hour.

The most notable use of step fairings has been on the Short Sunderland flying boat, which has a step that is V-shape in plan form. The hydrodynamic stability in take-off and landing is in general affected adversely by the addition of a fairing to a conventional hull although the characteristics of the Sunderland in this respect appear to be satisfactory (references 14, 18, and 35). Tests of a powered model in Langley tank no. 1 (reference 14) indicated that when a fairing is added to a conventional transverse step the use of ventilation is advisable in order to obtain satisfactory stability. More recent tests (unpublished) of a model with a faired V-shape step indicated that satisfactory stability may be obtained without ventilation and that further investigation of the effects of plan form of the step and camber of the fairing would be desirable.

Plan form of step.- A transverse step is the simplest
form of step and has been used on most flying boats and
seaplanes. Other plan forms of step, however, have been
used on full-size airplanes or tested on models. Some
of these forms are shown in figure 9. The effect of

Forebody

V   Swallow tail   Notched
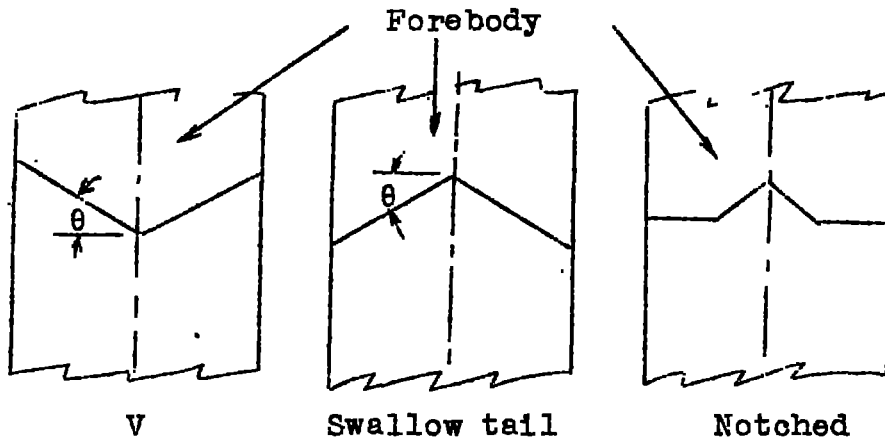
Figure 9.- Plan forms of step (θ,   angle of V
               or swallow tail).

change in the plan form of the step on the landing
stability cannot be isolated because the landing stability
is so closely associated with the depth of step. Tests
described in reference 77 indicate that, with the same
depth of step at the keel, the landing stability of a
model with a transverse step and with a 30° V-step are
comparable.

The lower trim limit is not greatly affected by
changes in plan form of the step (reference 100) but in
all probability the upper limits will be shifted in the
direction expected from the change in the depth of step.

Side Steps and Skegs

When operating at overloads, several present-
day flying boats are directionally unstable at low
taxying speeds. Unstable yawing moments are increased
by the flow of water over the sides of the afterbody and
tail extension. The directional control available by
throttling engines on one side lowers the reserve thrust
and increases the time of operating in the yawing region.

One means of reducing the directional instability by breaking the undesirable flow is by use of vertical steps on the sides of the afterbody. Such steps reduced unstable yawing moments on a model and were successfully used on the full-size airplane (reference 82). The directional instability of a model was reduced more effectively by multiple side steps than by a single side step (unpublished data).

The addition of skegs to the afterbody and tail extension reduced unstable yawing moments. As the speed increased, the effectiveness of the skegs decreased as they came out of the water (reference 74). Several arrangements of skegs on the full-size airplane were tried, and the results obtained were similar to those observed for the model. It should be emphasized that skegs, steps, and spoilers may substantially reduce the unstable hydrodynamic moments but may not be completely effective in stabilizing an airplane in which rotation of the slipstream contributes an additional yawing moment.

Tail Extension

Although the function of the tail extension of a flying boat is similar to that of the tail extension of a comparable landplane, the additional problems introduced by the flow of water over the tail extension and the necessity for spray clearance complicate the design. The flow of water over the tail extension may increase the violence of upper-limit porpoising, may introduce landing instability at high trims, may increase the hump trim and resistance, and may contribute to directional instability.

The addition of a planing surface or spray strips on the tail extension may be necessary to prevent excessive wetting of the horizontal tail surface or tail turret (references 74 and 79). The planing action of the tail extension may decrease the hump trim and resistance by developing dynamic lift (references 39 and 79).

Although the flow of water over the tail extension may contribute to the directional instability at low speed, the removal of the tail extension does not eliminate hydrodynamic directional instability (references 23 and 56). An increase in vertical clearance of the tail extension, a negative-dihedral hydrofoil on the tail extension, and

an inverted-V cross section on the tail extension were
tested on a model and found to be only partially effective
in counteracting yawing tendencies (unpublished data).
A planing surface on the tail extension of a model caused
no reduction in unstable yawing moments and increased the
range of speeds over which they occurred (reference 74).

FLOATS FOR SEAPLANES

Much of the preceding discussion relative to hulls
is also applicable to seaplane floats. In particular,
the planing areas of hulls and floats are generally
similar. The discussions of the geometric parameters
of hulls relating primarily to stable planing motions
will therefore not be repeated in the sections on floats.
In the design of floats special considerations arise from
the lower reserve buoyancy, the relatively greater distance
from the center of gravity to the keel, and the absence
of a tail extension. For twin-float designs an additional
consideration is that the distance between the floats must
be chosen to insure transverse static stability.

Over-all proportions and shape.- Adherence to the
requirements for longitudinal static stability usually
results in length-beam ratios for floats that are larger
than those customarily used for flying-boat hulls -
averaging about 7.35 for float seaplanes as compared
with 5.27 for hulls (from tabulations in reference 57).
The average length-beam ratio currently used for twin
floats appears to be somewhat greater than that for single
floats.

The shape of the bow of a float should be generally
similar to that of the hull, but the low height-beam
ratio restricts the possible variations in the shape of
the bow of a float. Lines of representative floats are
included in references 123, 139, 140, and 143, together
with data regarding the aerodynamic and hydrodynamic
characteristics of a wide range of changes in shape of
the bow.

Dead rise.- The effects of changes in dead rise are
generally the same for both hulls and floats. Aerodynamic
and hydrodynamic data are presented in reference 140 for
floats having angles of dead rise of 20°, 25°, and 30°. In
American practice the average dead rise for floats appears
to be higher than the dead rise for hulls (reference 57).

Statics.- It has been the practice in float design
to fix the volume of the floats so that the buoyancy is
some predetermined percentage of the gross load, varying
between 180 and 200 percent (references 120 and 121).
In any case there should be enough excess buoyancy to
prevent the bow from submerging at low taxying speeds.
A large excess buoyancy allows a lower and more stream-
line form of bow to be used. The high engine torque
inherent in racing seaplanes created such an eccentricity
of loading in the case of the S.5 (reference 256) that it
was found necessary to make one float larger than the
other for satisfactory spray characteristics.

The length of floats must be sufficient to assure
static longitudinal stability. According to refer-
ence 154, the longitudinal metacentric height GM for
either single or twin floats is given with sufficient
accuracy by the empirical equation

$$GM = \frac{K_2 n B L^3}{\Delta}$$

where

n   number of floats (that is, one or two)

B   beam of each float, feet

L   over-all length, feet

Δ gross weight of seaplane, pounds

K_2 a constant normally varying between 1.90 and 2.40
            with an average value of 2.10

The Canadian requirements (reference 120) for twin-float
seaplanes specify that the longitudinal metacentric height
shall not be less than

$$6\sqrt[3]{D}$$

where D is the total displacement of the seaplane in
cubic feet. As the reserve buoyancy is determined from
other considerations, the requirements for static longi-
tudinal stability indicate that the length-beam ratios of
twin-float arrangements will be larger than those of
single-float arrangements. Single-float seaplanes have

length-beam ratios varying from 5 to 7 while twin-float
seaplanes have length-beam ratios varying from 7 to $8\frac{1}{2}$
(reference 57).

Effect of spacing between floats.- Tests of a model
of the S.5 twin-float seaplane (reference 256) show
increases in resistance with float spacing up to 20 per-
cent, apparently caused by heavy spray wetting the tail
plane and other parts of the structure. Unpublished
data from Langley tests for spacings ranging from 2 to
5 beam lengths, keel to keel, showed small differences
in resistance that were almost within the accuracy of
measurement.

Air drag of floats.- Results of wind-tunnel tests
of seaplane floats show that the form of the bow strongly
affects the minimum drag and the variation of drag with
angle of pitch. The angle of afterbody keel affects the
angle of minimum drag and is of practical significance in
the choice of a configuration for which the minimum drag
will occur within the desired range of flying speeds
(reference 139).

Tests of a full-size float seaplane in the Langley
full-scale tunnel (reference 145) indicated that the
maximum speed would oe increased from 307 to 336 miles
per hour by removing the main float (77 percent excess
buoyancy). The seaplane had a power loading of 5.9 pounds
per horsepower and a wing loading of 27.2 pounds per
square foot. Tests of four full-size floats in the
Langley propeller-research tunnel (reference 127) indi-
cated that a radical change in the design of the floats
was required to obtain significant reductions in the air
drag. Reducing the depth of step to zero decreased the
minimum drag about 16 percent. Adding a faired tail
extension to a float with a blunt stern reduced the
drag 8 percent. The flow of air over the floats was
shown to be so turbulent that minor refinements such as
flush rivets and recessed fittings would not appreciably
reduce the drag.

Dynamic stability of float seaplanes.- Porpoising
and skipping have appeared to be of much less practical
significance in operating float seaplanes than in operating
flying boats. Although differences have not been carefully
analyzed, two differences between the types are noteworthy
in comparing the stability characteristics: the pitching

radius of gyration of a float seaplane is generally
larger than that of a comparable flying boat; and recent
practice has been to provide relatively deeper steps on
floats than on hulls. Another consideration is that for
military use a number of the different types of float
seaplane have had considerably lower power loadings than
the patrol and cargo types of flying boat.

LATERAL STABILIZERS

Types of lateral stabilizer.- Three types of lateral
stabilizer have been used in the past: inboard floats,
stub wings, and wing-tip floats. Neither inboard floats
nor stub wings have been used, however, in recent designs.
Inboard floats are located inboard of about one-third the
semispan of the wing and therefore must be larger than
wing-tip floats in order to develop the same righting
moment. Inboard floats usually have a shallow draft at
rest whereas wing-tip floats are generally located to
clear the water at high speed and, because of their
location, only one wing-tip float contacts the water at
rest. Stub wings (reference 156) extend outward from
the chine near the main step in the form of aerodynamic
wings of low aspect ratio. The evidence seems to be in
favor of wing-tip floats for lateral stabilizers because
they are relatively small, their maximum restoring moment
is developed at small angles of heel, and they are not
influenced by the flow of water produced by other parts
of the seaplane.

Hydrodynamic data concerning wing-tip floats.- The
usual consideration in the choice of the shape for a tip
float has been that any lines suitable for a main float
are adaptable for a tip float (reference 147). The
contour of the bottom of a tip float is generally made
to resemble that of a V-bottom hull and the required
volume is then disposed in a manner either to obtain
minimum aerodynamic drag or to comply with other require-
ments (for example, retraction) of the specific instal-
lation.

The performance characteristics during operation at
low speed have been determined for a number of typical
designs of wing-tip floats. The data have been obtained
from tests in towing tanks in the speed range at which
wing-tip floats are necessary. Some of these data are

reported in references 74, 152, 153, 160, and 164. A
significant result of the tests has been the placing of
emphasis upon the importance of designing the lines
above the chines to avoid losing lift at large drafts
and thereby to prevent "digging in" of the float. Wing-
tip floats have been built with steps to incorporate a
satisfactory planing surface on a form that will have
low air drag in flight. Later tests, however, have shown
that low air drag and satisfactory performance at low
speed can also be realized without a step (reference 164).

Captain H. C. Richardson has emphasized in letters
to the NACA that the behavior of a tip float in drifting
astern is of special importance in the event of a forced
landing. His experience in "sailing" a disabled flying
boat, the NC-3, for a distance of about 200 miles in the
Atlantic Ocean (reference 211) led to the conclusion that
satisfactory seaworthiness requires the tip float to be
free of any tendency to "dig in" when making sternway.
Specific test data are not available for tip floats
moving astern but it has appeared that a float with a
step is advantageous because the "afterbody" may be
sloped upward to develop lift.

Hydrodynamic characteristics of stub wings.- Inter-
ference between the water flow around the hull and the
stubs affects the resistance, the trimming moment, the
dynamic stability, and the transverse static stability
of the flying boat. Tests of a limited number of con-
figurations indicate that stub wings reduce the hump
speed without significantly affecting the magnitude of
the hump resistance, reduce the trim at zero applied
moment (reference 146), reduce markedly the region of
speeds and trims in which low-angle porpoising occurs,
and adversely affect the upper trim limit of stability
(reference 163). Data regarding the effects of vari-
ations in the position of stub wings are given in refer-
ences 146, 149, and 151. At rest, stub wings develop
their maximum righting moment at very large angles of
heel; hence, the righting moment may be insufficient when
the hull is lightly loaded. Underway, the stub wing is
subject to the influence of the bow wave that leaves it
free of "solid" water through a small range of speeds.
If the flying boat with stub wings is not accelerated
rapidly through this speed range, it may heel sufficiently
to submerge a wing tip.

Air drag.- The air drag of tip floats amounts to
$3\frac{1}{2}$ to 8 percent of the total drag for a number of flying
boats that have wing-tip floats currently considered

well streamlined. Reference 150 presents data showing
the air drag of wing-tip floats to be of the same order
of magnitude as the air drag of well-faired unretracted
landing gear on comparable landplanes. Reference 18
contains a comparison of the air drag of six configurations
of flying-boat hulls differing only in the arrangement of
the lateral stabilizers. (See fig. 10.) Results of tests
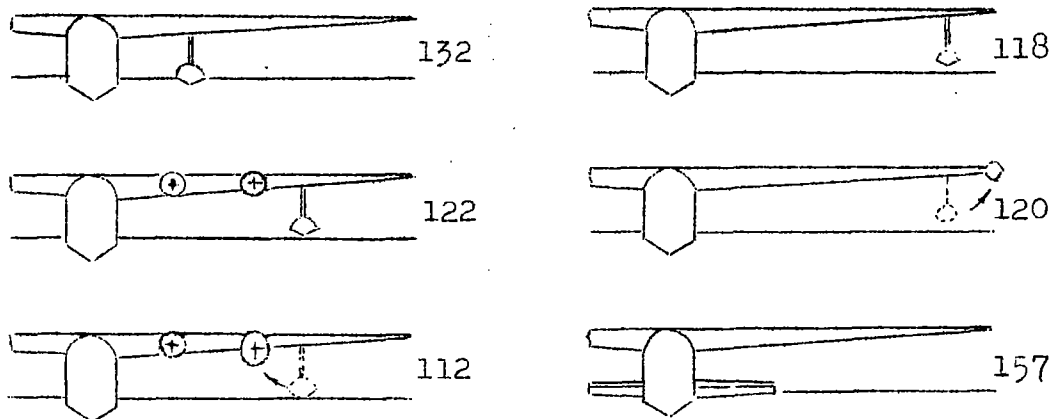
Figure 10.- Comparative diagrams of air drag of hull and
     lateral stabilizers. Numbers give drag relation to
     basic hull, taken as 100 (from reference 18).

of four different types of conventional wing-tip float
(reference 153) led to the significant conclusion that
the chines of an unretracted wing-tip float should be
alined with the air flow in cruising flight to avoid
excessive air drag. The air drag of partially retracted
tip floats may be estimated from data concerning pro-
tuberances on the lower surface of the wing (refer-
ences 157 and 158).

     Present status of design criterions.- Several dif-
ferent specifications and criterions have been used in
the past for lateral stabilizers (references 51, 59,
and 251). Current American practice conforms in general
to the specifications given in references 6 and 147.
The specifications present formulas for computing the
size of conventional lateral stabilizers for obtaining
an arbitrary minimum lateral stability at rest. Current
practice is to provide the righting moments needed to

counteract the upsetting moments due to gravity and
cross wind and to provide an additional reserve buoyancy
determined on the basis of past experience. For the
larger sizes of flying boat the reserve buoyancy is very
much larger than either of the other two allowances
(reference 162) and a more detailed examination of the
design requirements than heretofore employed is considered
necessary if the structural and aerodynamic efficiency
are not to be unduly impaired by the tip floats. In
reference 155, the numerous upsetting moments including
propeller torque, unsymmetrical slipstream, and wave
slope are listed in outlining a procedure for defining
in detail the necessary buoyant and dynamic character-
istics of tip floats. There is some indication that,
if the tip floats can be designed to have suitable
dynamic reaction when submerged, smaller tip floats than
those currently used on large flying boats may be
adequate.

Unconventional forms of stabilizers.- A large reduc-
tion in drag of a fixed tip float might be realized by
using a streamline spindle fitted with a hydrofoil instead
of a conventional shape. Stabilizers of this kind are
shown in reference 166 and test results are presented in
references 159 and 161. A comparison of the drag of the
streamline shape with that of a conventional wing-tip
float is made in reference 145. A streamline float of
rectangular cross section with a hydrofoil was used on
the ND-1 float seaplane out test results do not appear
to be available. Until adequate data are available for
predicting the hydrodynamic lift and drag of hydrofoils,
this type of configuration cannot be designed with
assurance that the high-speed characteristics will be
satisfactory.

Broad, shallow floats having the form of a some-
what distorted spherical segment have been suggested
(reference 150). Unpublished data from tank tests indi-
cate that, although retraction would be facilitated, this
shape would give rise to very large dynamic lift that
would necessitate a type of oleo strut for operation in
rough water. Rapid retraction and extension would permit
the wing-tip floats to be located out of danger at high
speed.

A very interesting possibility for obtaining lateral
stabilization, especially for high-performance single-
engine seaplanes, is by use of the dynamic and buoyant

properties of the wing located in the low-wing position,
as described in the section entitled "Unconventional
Configurations."

Emergency devices.- When it is necessary for a sea-
plane to remain at rest under abnormally severe condi-
tions, emergency stabilizing devices can be provided in
the form of sea anchors (trimming buckets, canvas bags
filled with water and hung in the water from an outboard
position on the wing, as shown in reference 32) or
inflatable devices.

AERODYNAMIC AND PROPULSIVE CONSIDERATIONS

The aerodynamic and propulsive arrangements for
flying boats are primarily determined by their flight
performance specifications, which are beyond the scope
of this report. Hydrodynamic considerations that may
modify these configurations are discussed in this section.

Wing.- The area of the wing is determined by the
service conditions for which the flying boat is designed.
The main effect of high wing loadings on the take-off
performance of a flying boat appears in the higher get-
away speeds. As the get-away speed becomes higher, the
resistance at high speeds becomes more significant.
Computations show that take-off performance is improved
by increasing the aspect ratio (reference 167). The
angle of incidence of the wing is of significance in
relation to the hump trim and the trim of the hull in
flight. When the high-speed resistance is critical,
the setting that gives best take-off characteristics
may be taken as approximately that which gives minimum
total resistance at 65 percent of the stalling speed
(references 90 and 167).

The general practice in airplane design is to mount
the engine nacelles on the wing with the thrust line
approximating the chord of the wing. Current practice
shows that if the propellers have adequate clearance
wings and flaps are adequately clear. (See section
entitled "Propellers.")

Flaps.- The effect of flaps on the take-off is
especially pronounced on airplanes having high wing and
power loadings. Although flap deflection increases the

total resistance, it generally improves the take-off
performance by lowering the stalling speed. The
optimum take-off can be made by taxying to high speed
with the flaps up and deflecting them part way for take-
off (reference 170). Deflecting the flaps reduces the
load on the water and causes a bow-down moment (refer-
ence 47). By reduction of the load on the water the
trim limits are generally lowered slightly, particularly
at high speeds. The bow-down moment requires up-elevator
deflections to counteract it and shifts the stable range
of center-of-gravity positions aft (reference 166).

The lift on the wings of a flying boat moored on
the water may be reduced by flap-type spoilers mounted
on the upper surface of the wing between 5 and 20 per-
cent of the chord with no gap between them and the wing
surface (reference 171). This device should be useful
if an airplane having a low wing loading is to be
moored in a high wind.

Tail surfaces.- The horizontal tail is usually
mounted rather high to clear the spray. At low speeds,
the roach may wet the tail heavily. At higher speeds,
the spray is higher at the tips of the tail than at the
root so that the use of considerable dihedral angle may
be advantageous; in fact, this dihedral angle may be
carried to the extreme of employing a V-tail (refer-
ence 169). Approximately the same total area is required
but there is a possibility of reducing the air drag by
eliminating one intersection with the fuselage. The
control system presents a complicated design problem.

The aerodynamic stability derivatives have some
effect on hydrodynamic stability (references 46 and 106).
It is pointed out in reference 46 that for the cases
considered therein it was quite impossible to neglect the
aerodynamic factors although the hydrodynamic effects
appeared to be much more important than the aerodynamic
factors.

Variations from the usual size of the horizontal
tail have a small effect on the lower trim limit of
stability. Reference 22 shows that increasing the
damping in pitch due to the horizontal tail M_q decreases
the lower limit of stability. The decrease is small at
low speeds and is appreciable at high speeds. At a
given high speed, the effect of increasing tail area

becomes less marked as the tail damping increases and
is not very significant at the normal values of tail
damping. These trends are also indicated in refer-
ences 53 and 106. The tail damping has a negligible
effect on the upper branch of the upper trim limit of
stability.

No data have been published on the amount of yawing
moment required of the vertical tail (or of water rudders)
to maintain control throughout the taxi and take-off run.
Unpublished data indicate that a model of a flying boat
with a gross-load coefficient of 1.05 at a speed coeffi-
cient of 2.6 required a yawing-moment coefficient C_n
of 0.12 to maintain a straight course. The yawing moment
coefficient

$$C_n = \frac{\text{Yawing moment}}{wb^4}$$

where w is specific weight of water and b is the beam.

Propellers.- On some heavily loaded flying boats,
spray from the forebody enters the propellers during a
short range of speeds just prior to hump speed. For any
given conventional flying boat, both the intensity of
the spray and the width of the speed range when the
spray is in the propellers increase with increasing gross
load (reference 61).

The inflow of air to powered propellers picks up
spray that would not hit the windmilling propellers
(reference 70). Some spray profiles for unpowered models
are given in references 20 and 254.

The right-hand rotation of propellers tends to make
the flying boat yaw to the left. During take-off, the
hull is directionally unstable just below the hump. A
heavily loaded flying boat with right-hand propellers
often makes uncontrollable turns to the left at this
speed. With opposite rotation of the propellers, the
yawing characteristics are symmetrical about zero yaw.
Propellers turning inboard at the top provide slightly
better rudder control than those turning outboard.

Reference 78 shows that the effect of power on trim
limits and center-of-gravity limits of a model is large.
The effect of the slipstream and thrust is to change
the load on water and the trimming moment and to influence

the water flow around the hull. Decreasing the power
loading of a flying boat increases the acceleration
during take-off but reference 50 shows that there is a
relatively small change in the stable center-of-gravity
range with change in acceleration.

Jet propulsion.- Jet assistance has enabled flying
boats to take off more quickly in rough water, to take
off in a shorter distance, or to take off with loads
greater than those possible with normal engine power.
The assisting jets are either of the powder type, which
may be dropped after take-off, or of the type in which
liquids are forced into a combustion chamber. The
liquid-type jet generally operates for longer periods
of time but requires that more equipment be carried in
the airplane throughout the flight. An advantage of
this type of jet is that it may be turned on and off as
desired.

The location of the assisting jets is not particularly
critical. They should be so arranged that the line of
thrust passes through, or slightly below, the center of
gravity of the airplane so that when the thrust ceases
no great change in the balance of the airplane will
result. One liquid-type jet has operated successfully
under water (reference 165) but no information is
available as to the behavior of the powder-type jet
when submerged.

Jet engines could be mounted closer to the water
than engine-driven propellers, provided a suitable loca-
tion for the air inlet can be found. There is no
information as to the extent that the inflow of air will
pick up spray or to the extent that spray will damage the
interior of the jet motors if it is allowed to enter with
the air. Jet engines designed to produce a given thrust
at flight speeds may be at a disadvantage during take-off
when compared with normal propellers because of differences
in the manner in which thrust varies with speed. The jet
engines for use on high-speed airplanes would probably
have sufficient thrust for take-off.

UNCONVENTIONAL CONFIGURATIONS

Tunnel bottoms.- Hull forms with a tunnel bottom
(an inverted V) have been proposed occasionally because

the amount of spray thrown out laterally is exceptionally
small (references 3, 172, and 177). Configurations of
the types that have been tested present a difficult
problem in avoiding excessive air drag. If the spray is
confined to the tunnel, the afterbody may be wet
excessively unless large clearance is provided. A model
with a forebody having an inverted-V cross section at
the bow with a transition to normal V-bottom about half-
way along the forebody was tested at the Short Brothers
Tank (reference 260). This unusual form had very good
spray characteristics and would presumably have acceptable
resistance and stability characteristics. Wind-tunnel
tests and structural studies showed, however, that the
air drag and the weight would be excessive.

        Asymmetrical floats.- The spray between the floats
of a twin-float single-engine seaplane resulting from
the meeting of the two bow blisters sometimes enters
the propeller in excessive amounts. A pair of floats
was designed (reference 124) having the planing bottoms
arranged on the outer sides of the floats (fig. 11).

Figure 11.- Asymmetrical float
for twin-float seaplane,
section at step.

It was found that these floats were clean running and
compared satisfactorily with conventional floats with
regard to porpoising, water resistance, and directional
stability. Modifications intended to reduce the air drag
of the asymmetrical floats introduced directional
instability.

        Planing tail.- A form of hull that inherently has
some desirable characteristics is being developed by

tests of models in Langley tank no. 2. Figure 12 shows
a typical configuration with a very deep step that is
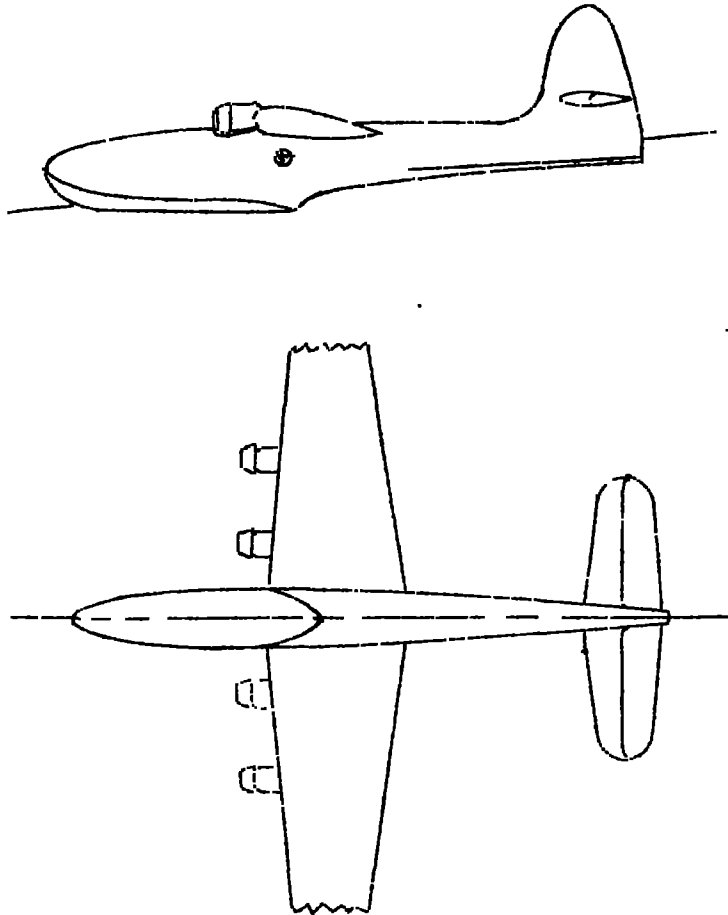
Figure 12.- Planing-tail configuration.

pointed in plan form combined with a long afterbody.
Preliminary tests (reference 176) and further tests of
modifications similar to those in figure 12 showed that
the hump resistance was lower than that of a conventional
hull $\left(\dfrac{\Delta}{R} = 6.5 \text{ compared with } \dfrac{\Delta}{R} = 5\right)$. Tests of a dynamic

model indicated that satisfactory stability character-
istics may be expected (unpublished data). Limitations
on the usable space aft of the center of gravity may be
undesirable for some types of service.

    Planing flaps.- Retractable planing flaps have been
suggested for use on the afterbody in a manner that would
allow an unusually high angle of afterbody keel (fig. 13(a)).
The flap would perform the normal function of the after-
body at speeds through the hump speed. At planing speeds
the flaps would be retracted to prevent high-angle
porpoising from occurring in the usual range of trim.
Tank tests were made at Stevens Institute of Technology
to determine several configurations that would have
suitable hydrodynamic characteristics (reference 178).
The structural weight, the aerodynamic effect of a high
angle of afterbody keel, and the necessity for adjusting
the flap during take-off present problems that introduce
some doubt as to the practical possibilities of this
type of flap. Reference 178 includes results obtained
from tests of a hull with a conventional afterbody to
which was added a planing flap near the sternpost
(fig. 13(b)). The results of the tests showing that
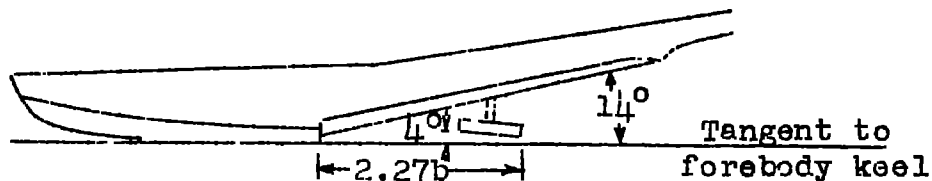
(a) High afterbody.
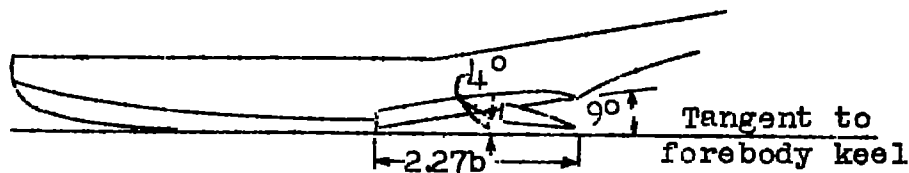
(b) Conventional afterbody.

Figure 13.- Planing flaps.

high-angle porpoising was suppressed were not confirmed
in tests (unpublished data) of a'similar configuration
on a powered model in Langley tank no. 1.

Float-wing designs.- Tests have been made of models
(references 174 and 175) and of a full-size glider having
a conventional hull combined with a wing placed suffi-
ciently low to provide suitable transverse stability on
the water (fig. 14). Hydrodynamic characteristics of
the full-size glider were reported to be satisfactory

Figure 14.- Float-wing glider.

provided the flaps were not deflected while in contact
with the water. A preliminary design of a float-wing
seaplane that would employ a pusher propeller in a
transverse plane near the trailing edge of the wing is
known to have been made. If a suitable structure were
provided for the power unit and for those portions of
the wing and flaps subjected to water loads, it appears
that a high-performance seaplane with parasite drag
practically equal to that of an equivalent landplane
could be developed.

Hull-less designs.- In reference 173 several designs
are proposed, including a flying wing, in which the hydro-
dynamic and flotation requirements would be incorporated
as primary components of the wing. Preliminary results
of tank tests and of structural studies are cited to
support the belief that large seaplanes can be built in
one of the proposed forms with considerable reduction in
weight and in parasite drag compared with conventional
flying boats and landplanes. Two of the proposed con-
figurations are shown in figure 15.

HYDROFOILS

The application of hydrofoils to serve as a type of
landing gear on seaplanes or as auxiliary lifting devices
on wing-tip floats has long been an interesting possibility
with reference to the reduction of air drag and the
simplification of structural problems. It has appeared
that hydrofoils when compared with planing hulls offer
some possibility of reducing the structural weight and
the hazards associated with impacts in rough water.
Although hydrofoils have been successfully employed on
numerous seaplanes with a relatively low stalling speed
(reference 186), an evaluation of their potential use on
seaplanes that must operate on the water at speeds above
60 miles per hour is hindered by inadequate information
regarding the influence of cavitation.

Hydrofoils having cambered sections selected to
delay cavitation as much as appeared practicable were
towed in Langley tank no. 1 at depths up to 5 chord
lengths and at speeds up to 60 miles per hour. As the
speed was increased from 40 to 60 miles per hour, the
results showed that:

(1) The angle of zero lift increased about 3°

(2) The maximum lift-drag ratio decreased steadily
from about 16 at 40 miles per hour to 8 at 60 miles per
hour (references 181, 189, and 201)

(3) Cavitation caused vibration that became more
severe with increased speed
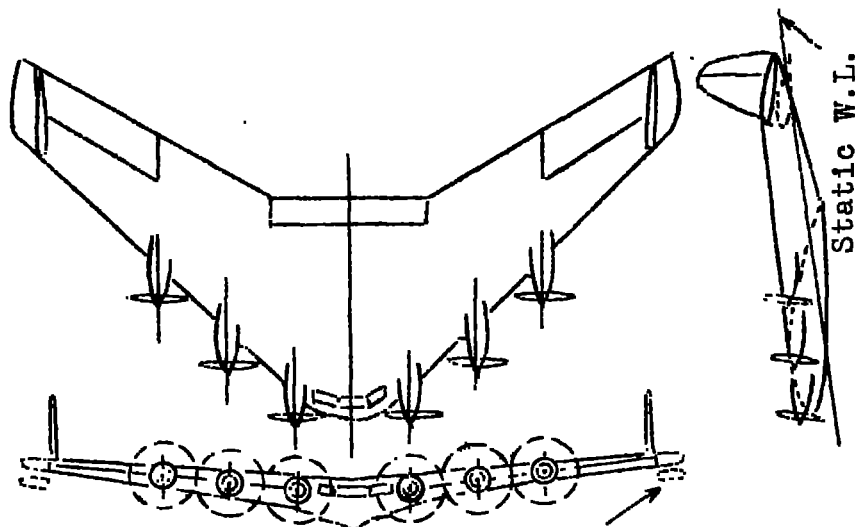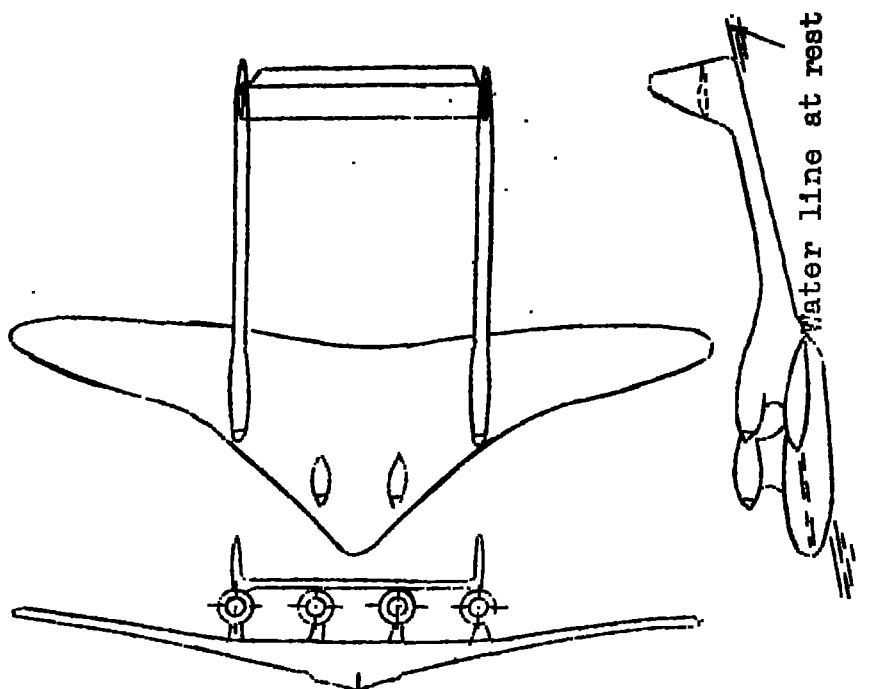
Floats for longitudinal
static stability are retracted
to form wing tips

Figure 15.- Hull-less design from reference 173.

Similar trends were obtained in water-tunnel tests of
planoconvex circular-arc sections in which extensive
cavitation was obtained (reference 200). The theo-
retical results in reference 183 are in partial agree-
ment with the trends given but there is still con-
siderable doubt as to the magnitude of the influence
of cavitation. There is some indication that a hydro-
foil in cavitating flow will have more favorable lift-
drag ratios if the lower surface is flat rather than
convex. Tests in a water tunnel (reference 194) indi-
cated that slots in a hydrofoil were ineffective in
preventing cavitation.

Ladderlike arrangements of hydrofoils with dihedral
of about 20° that have been used on seaplanes and on
surface boats apparently offer satisfactory stability,
but the associated struts and interference effects are
significant sources of drag and spray (references 180,
185, 186, and 192). Monoplane hydrofoils are likely to
suffer abrupt and large changes in lift and drag when
close to the free water surface (references 180, 181,
and 190). The severity of this type of instability is
less for the higher angles of dihedral because of the
more gradual reefing action as the hydrofoil passes into
or out of the water. Systems of monoplanes designed to
overcome this difficulty of operating near the water
surface have been proposed and tested at low speeds
by Tietjens (reference 198) and by Grunberg (refer-
ences 185 and 191). Further investigation under condi-
tions in which full-scale cavitation is reoresented are
required, however, before a practical design of a mono-
plane configuration for a seaplane may be carried out
with full assurance that stability and efficient lift-
drag ratios will be achieved (reference 196).

PILOTING AND HANDLING

A few clearly established principles can be outlined
that will assist the pilot of a seaplane of conventional
design to take off in the least time and distance possible
and at the same time to avoid much of the danger asso-
ciated with porpoising, yawing, and skipping. The
required technique for operation in smooth water can be
simply stated; but for operation in rough water the
importance of porpoising, yawing, and skipping as com-
pared with the importance of the waves to be encountered

in any particular instance must be evaluated on the
basis of the personal observation and experience of the
pilot. The principles for operation in smooth water
have been sufficiently well established by tests of
models and full-size aircraft to justify a revision of
some of the practices that appear to be currently
accepted.

Glassy water.- References 205, 206, and 211 point
out the difficulty of accurately observing the height
above the surface of the water as a seaplane approaches
a landing on glassy water, especially if there is a low-
hanging mist. No satisfactory technique or instrumenta-
tion appears to be available that will enable the pilot
to judge with confidence the point of contacting the
water surface. Terrain clearance indicators might be
of considerable value if they could be made to indicate
accurately at very low altitudes. Possibly absolute
altimeters will come into sufficiently wide use to
justify their development to a stage at which they can
be used for glassy-water landings.

Take-offs from glassy water have frequently been
reported to be more difficult than those from choppy
water. Definite data regarding these observations are
not sufficient to justify very definite conclusions.
Differences of opinion regarding these observations are
sufficiently great to justify a brief series of tank
tests or flight tests in which the influence of wind
(which generally accompanies rough water) and the
influence of trim may be isolated from the effects of
small waves on the resistance during take-off.

Stability.- Instructions to pilots regarding por-
poising should clearly distinguish between the low-
angle type and the high-angle type. The usual instruc-
tions to apply up elevators whenever porpoising occurs
(references 205, 206, and 211) are applicable only to
the low-angle type. Recovery from the high-angle type
of porpoising calls for down elevators.

Uncontrollable yawing of some flying boats may occur
in either of two speed ranges. The yawing at speeds
approaching the hump is associated with an unstable
type of flow over the bottom and sides of the afterbody
and may be aggravated by unsymmetrical slipstream over
the tail. A disastrous type of yawing may occur at speeds
near get-away if the hull is allowed to trim too low
(reference 40).

Rough water.- A PBM-3C flying boat has recently been tested by the U. S. Coast Guard to investigate the merits of different piloting techniques in rough water and to evaluate the hazards that are involved (reference 203). It is understood that wave heights ranged from 8 or 10 inches up to about 15 feet during the course of the tests. The tests were limited to the one airplane and to the sea conditions prevailing off the coast of southern California, but the results provide a note-worthy basis for setting up general principles for piloting in rough water. Results of the tests indicated that before making a landing in the open sea the pilot should fly at different altitudes to observe the different wave systems that may be present and in general to select the direction of run and the area that will result in the least number of severe wave impacts. For winds of less than 20 knots the most favorable direction was found to be parallel to the crests of the swells. Down-swell landings were considered feasible but more severe than along-swell landings. If the wind is greater than 20 knots, the recommended direction for the run is into the wind. Drift in a cross-wind landing was found to be of little practical consequence. Previously held fears of danger from dragging a wing-tip float in a swell on the beam or from sideslipping down the slope of a wave were not substantiated. With a complicated sea, the pilot should choose a direction for landing or take-off that will avoid heading directly into any wave system and will at the same time keep the wind as nearly ahead as possible.

Jets of the solid fuel type were used in some of the take-offs and found to be a very useful adjunct in rough-water operation. In several instances the use of jets at dangerous moments was believed to have saved the airplane from severe damage.

Reversible propellers.- Maneuvering to a buoy or other mooring device has been greatly facilitated by the use of reversible propellers that permit braking and maneuvering in close quarters. Reference 209 describes the maneuverability of a PB2Y-3 with reversible-pitch propellers and states that those propellers reverse in from 10 to 15 seconds, which is considered slower than desirable. Two of the four propellers are therefore continuously in reverse and the maneuvering in any desired direction is accomplished by manipulation of the throttles.

Depth of water.- Tests of models have indicated that
the water resistance is practically unaffected by vari-
ations in depth for depths greater than about 1 beam
length. At lesser depths the hump resistance may be
considerably more than that for deep water (references 210
and 244).

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