NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1325

HYDRODYNAMIC IMPACT LOADS IN SMOOTH WATER FOR A PRISMATIC FLOAT HAVING AN ANGLE OF DEAD RISE OF 30°

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SUMMARY

As part of a series of impact tests made to investigate the effects of angle of dead rise on the hydrodynamic loads on floats and hulls, a prismatic-float forebody of 30° angle of dead rise was subjected to impacts in smooth water. The test runs were made at fixed trims of 6° and 15° and flight-path angles up to 20° under conditions where the effects of chine immersion and afterbody presence are small.

On a nondimensional basis, data from the tests of the float of 30° angle of dead rise and similar data from tests of a float of $22\frac{1}{2}°$ angle of dead rise were compared with each other and with values determined by application of theory. Curves are presented which show the variation of hydrodynamic impact loads with trim and flight-path angle, within the range of conditions specified. A function used by Wagner is shown to represent the variation of hydrodynamic impact load with dead-rise angle within about 6 percent for the range of dead-rise angle considered.

INTRODUCTION

In order to secure a compromise between the good planing characteristics of a flat bottom and the impact-reducing properties of a V-bottom, values of dead-rise angle from 18° to 25° are widely used in present-day floats and hulls. The uso of jet assistance for take-off and the trend toward decreased power loadings have reduced the importance of optimum planing performance as a criterion in float design. The problem of reduction of landing loads, however, is becoming increasingly critical because of the use of higher wing loadings (and hence higher sinking speeds) and because of expanding operations under adverse sea conditions.

One approach to the solution of this problem is an investigation of the variation of hydrodynamic impact loads with dead-rise angle.

Accordingly, a program has been undertaken at the Langley impact basin to determine the effects of dead-rise angle on the hydrodynamic impact loads to which floats or hulls are subjected during landings in smooth water. This program is being carried out by investigating a series of V-bottom prismatic-float forebodies at fixed trim for conditions at which the effects of the presence of an afterbody are small. The models differ from each other primarily in angle of dead rise. A dead-rise angle of $22\frac{1}{2}^\circ$ was the first to be investigated (reference 1).

The present paper gives impact-load data for a float forebody having a dead-rise angle of 30°. In addition, these data and similar data from tests of a float having a dead-rise angle of $22\frac{1}{2}^\circ$ are compared with each other and with values obtained by application of theory.

Since the theoretical curves presented are strictly applicable only for impacts where the float chines are not immersed, the experimental data represent impacts where the amount of chine immersion was so small as to have a negligible effect on the loads. Inasmuch as previous tests have indicated that the horizontal component of the impact load is relatively small for the investigated trims, only the vertical component of the load is presented.

The Froude number for most of the runs corresponded to landings at 70 miles per hour by full-scale flying boats of gross weights ranging beyond those of present flying boats. The results of the tests are, therefore, directly applicable to impacts of present-day full-scale seaplanes.

SYMBOLS

$C_{l_{max}}$	maximum load-factor coefficient
$n_{i_{w_{max}}}$	impact load factor (maximum hydrodynamic load normal to plane of water surface divided by W)
$\phi(A)$	aspect-ratio correction factor (ratio of hydrodynamic load for three-dimensional flow to load for two-dimensional flow)
$f(\beta)$	function representing variation of hydrodynamic load or virtual mass with angle of dead rise for two-dimensional flow
A	aspect ratio
g	acceleration of gravity, feet per second per second

V	resultant velocity of float, feet per second
V_p	component of float velocity parallel to keel (assumed constant during a given impact), feet per second
W	dropping weight, pounds
y	linear displacement of float measured normal to plane of water surface, feet
β	angle of dead rise, radians except where noted
γ	flight-path angle measured from plane of water surface, degrees
ρ	mass density of fluid, slugs per cubic foot
τ	trim (angle between plane of water surface and keel at step), degrees

Subscript:

o	at contact

APPARATUS

The Langley impact basin and the standard equipment used are described in reference 2.

The model tested was the forebody of a prismatic float having a dead-rise angle of 30°. Except for the angle of dead rise, the model was substantially the same as that used in the tests of reference 1. The principal lines and dimensions defining the shape and size of the model are shown in figure 1, and the offsets are given in table I.

The instruments used to measure horizontal displacement and velocity and vertical displacement and velocity were those described in reference 2. Accelerations in the vertical direction were measured by standard NACA accelerometers having natural frequencies of 21 and 26 cycles per second with approximately 0.67 critical damping and a range of 0g to 10g.

PRECISION

The apparatus used in the tests gives measurements that are believed accurate within the following limits:

Horizontal velocity, feet per second	±0.5
Vertical velocity, feet per second	±0.2
Weight, pounds	±2.0
Acceleration, g, percent of reading	0 to -10

TEST PROCEDURE

The test program was carried out in the Langley impact basin at fixed trims of 6° and 15° with the float model loaded to a weight of 1230 pounds. A series of impacts in smooth water was made for each of the two trim angles. The flight-path angle was varied from about 3° to approximately 20° to cover the practical range of flight-path angles for conventional seaplanes. Time histories of horizontal and vertical velocities and vertical acceleration were recorded for each run.

During all the runs after the model had acquired the proper vertical velocity under free fall, a force introduced by the lift (buoyancy) engine described in reference 2 counterbalanced the dropping weight. Thus, the impacts were made under conditions simulating landings in which the wing lift is sufficient to support the weight of the airplane. A detailed description of the procedure is given in reference 2.

RESULTS AND DISCUSSION

The data obtained in the tests are presented in the form of impact load factors in table II. Similar data obtained from tests of a float having an angle of dead rise of $22\frac{1}{2}°$ are given in table III.

The conditions of these tests were such that the results are not directly comparable. They may, however, be made comparable by applying hydrodynamic impact load theory which provides a means of converting from one set of conditions to another by an expression relating the maximum load factor to the variables of which the effect on the load is known and to a nondimensional load-factor coefficient which includes the effect of all other variables. The impact load factor may thus be written as

$$n_{i_{W_{max}}} = C_{l_{max}} V_o^2 \left[\frac{\rho\, \phi(A)\, f(\beta)}{g^2 W}\right]^{1/3} \qquad (1)$$

In reference 1 the impact load factor $n_{i_{W_{max}}}$ was explicitly related to the float velocity and weight, the density of the water, and the acceleration of gravity; and the effects of dead-rise angle, aspect ratio, trim, and flight-path angle were combined as the maximum load-factor coefficient $C_{l_{max}}$. Since further study has indicated how the load varies with functions of dead-rise angle and aspect ratio, these quantities may be included explicitly in the equation for the impact load factor; the maximum load-factor coefficient now includes only the effects of trim and flight-path angle.

In order to use equation (1) in the determination of the maximum loads on a float, the value of the maximum load-factor coefficient $C_{l_{max}}$ as a function of flight-path angle and trim must be known throughout the range required. This information may be obtained by the solution of the equations of motion of the float. These equations of motion are as follows:

$$-\ddot{y} = \frac{3Dy^2(\dot{y} + B)^2}{\frac{W}{g} + Dy^3} \tag{2}$$

$$C\left(\frac{W}{g} + Dy^3\right)(\dot{y} + B)e^{\frac{B}{\dot{y}+B}} = 1 \tag{3}$$

where

$$B = V_p \sin \tau$$

$$C = \frac{1}{\frac{W}{g}(\dot{y}_o + B)e^{\frac{B}{\dot{y}_o+B}}}$$

$$D = \frac{\rho\pi\,\phi(A)\,f(\beta)}{6 \sin\tau \cos^2\tau}$$

and

$\ddot{y}$ vertical acceleration of float at any instant.

$\dot{y}$ vertical velocity of float at any instant.

Equation (2) is derived in reference 3 (equation (22)) where it appears as a force equation instead of one of acceleration and is applicable only for impacts in which the amount of chine immersion is not enough to have an appreciable effect on the loads. Equation (3) is obtained by integrating equation (2) and substituting the initial values of the variables for the purpose of evaluating the constant of integration. These equations are slightly different from those of reference 1, as they are derived for somewhat different assumed conditions, but the method of solving them for specific conditions is similar to that employed in reference 1.

The variation $C_{l_{max}} = f(\tau,\gamma)$, as determined by solutions of equations (2) and (3) for particular conditions, may be presented in the form of a series of curves of maximum load-factor coefficient against flight-path angle, where each curve represents a different trim. Point solutions were made for $C_{l_{max}}$ by the method of reference 1 and were used to plot the curves shown in figure 2 for several trims and for flight-path angles from 0° to 20°. With curves of this type and pertinent flight data, equation (1) may be used to determine the impact loads encountered by a float if the proper values of the aspect-ratio and dead-rise factors are known.

The aspect-ratio correction factor $\phi(A)$ represents the ratio of the forces in three-dimensional flow to those which would exist in two-dimensional flow. As an empirical approximation for aspect-ratio losses, Pabst in reference 4 determined the factor $1 - \frac{1}{2A}$ from vibration tests of submerged plates. For a prismatic float at positive trim, with trianguler immersed area, the aspect ratio A may be taken as $\frac{\tan\beta}{\tan\tau}$ and the correction factor becomes $1 - \frac{\tan\tau}{2\tan\beta}$. This factor is valid where the aspect ratio has a value of the order of 2 or more. The geometric parameter τ which appears in the factor is merely a part of the aspect-ratio correction and must not be considered to furnish the total variation of load with trim.

The other factor $f(\beta)$ represents the variation of virtual mass with dead-rise angle for which Wagner in reference 5 uses the expression $\left(\frac{\pi}{2\beta} - 1\right)^2$. In order to determine experimental values of the dead-rise function, equation (1) was solved for $\left[f(\beta)\right]^{1/3}$ since $n_{i_{w_{max}}}$ is proportional to the cube root of the function. The aspect-ratio factor $\phi(A)$, together with successive sets of data from tables II and III and with the theoretical values of $C_{l_{max}}$ corresponding to each set of test conditions, was substituted into the resulting equation, and values of $\left[f(\beta)\right]^{1/3}$ were computed. The average of all these values for each dead-rise angle, with equal weight given to each trim condition, was taken to be the experimental value of the function for that particular angle of dead rise.

The quantity $\left[\left(\frac{\pi}{2\beta} - 1\right)^2\right]^{1/3}$ agrees with Wagner's iterative calculations for an 18° dead-rise angle and is compared in figure 3 with experimental values of $\left[f(\beta)\right]^{1/3}$ for $22\frac{1}{2}^{\circ}$ and 30° angles of dead rise. The quantity agrees with the experimental values within about 6 percent and should have a similar degree of agreement for slight extensions of this range of dead-rise angle. The extent of the range of dead-rise angle through which this function is applicable cannot be determined until experimental data have been obtained for additional values of dead-rise angle. However, it can be seen from figure 3 that, as expected, an increase in the dead-rise angle results in a considerable decrease in the hydrodynamic load encountered.

In the comparison of the experimental and theoretical data a study was made of the values of maximum load-factor coefficient in which average values of $f(\beta)$ were used. Figure 4 shows a comparison of the two sets of experimental data with each other and with the theoretical values for comparable conditions. Since the scatter which does exist may be attributed to experimental error, it appears that the maximum load-factor coefficient computed with average values of $f(\beta)$ for any particular angle of dead rise is applicable within the investigated range of trim and flight-path angle.

CONCLUSIONS

An analysis was made of experimental data for fixed trim impacts in smooth water of a prismatic-float forebody having an angle of dead rise of 30° at 6° and 15° trim and of a similar float of $22\frac{1}{2}^{\circ}$ angle of dead rise at 6° trim. These data were compared with each other and with the theoretical variation of the maximum load-factor coefficient and with a theoretical dead-rise function. This analysis and comparison have resulted in the following conclusions for fixed trim impacts of prismatic V-bottom floats in which the effects of chine immersion and afterbody are small:

1. The loads encountered during impacts under the foregoing conditions can be predicted within the limits of experimental accuracy by the curves and equations presented.

2. For each trim a single curve may be used to represent the maximum loads for a wide range of impact conditions.

3. The variation of hydrodynamic impact load with dead-rise angle β may be represented for the range of dead-rise angle considered by the function $\left[\left(\frac{\pi}{2\beta} - 1\right)^2\right]^{1/3}$, which agrees with the experimental data within about 6 percent. An increase in dead-rise angle, therefore, results in a considerable decrease in the loads encountered.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., April 2, 1947

REFERENCES

1. Mayo, Wilbur L.: Theoretical and Experimental Dynamic Loads for a Prismatic Float Having an Angle of Dead Rise of $22\frac{1}{2}^{\circ}$. NACA RB No. L5F15, 1945.

2. Batterson, Sidney A.: The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. NACA ACR No. L4H15, 1944.

3. Mayo, Wilbur L.: Analysis and Modification of Theory for Impact of Seaplanes on Water. NACA TN No. 1008, 1945, p. 24.

4. Pabst, Wilhelm: Theory of the Landing Impact of Seaplanes. NACA TM No. 580, 1930.

5 Wagner, Herbert: Über Stoss- und Gleitvorgänge an der Oberfläche von Flüssigkeiten. Z.f.a.M.M., Bd.12, Heft 4, Aug. 1932. p. 214.

TABLE I.- OFFSETS OF LANGLEY IMPACT BASIN FLOAT MODEL M-2 (SEE FIG. 1)

[All dimensions are in inches]

Station	Half-breadth		Height above datum line			
	Upper and lower chine	Deck	Keel	Upper chine	Lower chine	Deck
0	0	0.33	23.05	25.26	23.05	32.28
2	2.15	1.45	16.25	25.71	21.04	32.85
5	4.25	3.05	12.52	26.53	22.70	33.49
9	7.80	4.58	9.52	26.32	23.41	34.19
14	10.31	5.93	6.94	24.47	22.18	34.77
21	12.81	7.23	4.47	21.62	19.44	35.20
29	15.09	8.15	2.60	19.36	16.55	35.27
38	16.86	8.71	1.24	16.41	13.64	35.27
47	18.04	8.94	.40	14.54	11.62	35.27
58	18.87	9.00	0	12.90	10.70	35.27
72	19.33	9.00	0	11.58	10.96	35.27
87.25	19.40	9.00	0	11.18	10.99	35.27
106.625	19.40	9.00	0	11.18	10.99	35.27
120.75	19.40	9.00	0	11.18	10.99	35.27

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TABLE II.- TEST DATA FOR LANGLEY

IMPACT BASIN FLOAT MODEL M-2

[W = 1230 pounds; $\beta = 30^{\circ}$]

Run	Test conditions			$n_{i_{w_{max}}}$ (g)
	τ (deg)	γ (deg)	V (fps)	
1	6	3.0	89.0	1.6
2	6	8.2	58.2	2.9
3	6	14.4	37.2	2.6
4	6	17.4	30.5	2.4
5	15	2.9	92.6	2.0
6	15	7.9	62.6	3.7
7	15	15.5	35.2	2.7
8	15	16.1	35.3	2.7
9	15	16.3	33.6	2.5
10	15	17.5	30.9	2.5

TABLE III.- TEST DATA FOR LANGLEY

IMPACT BASIN FLOAT MODEL M-1

[W = 1040 pounds; $\beta = 22.5^{\circ}$]

Run	Test conditions			$n_{i_{w_{max}}}$ (g)
	τ (deg)	γ (deg)	V (fps)	
1	6	1.3	100.0	0.8
2	6	1.9	94.9	115
3	6	2.8	104.4	2.6
4	6	3.6	41.8	0.6
5	6	5.2	41.4	1.0
6	6	5.4	42.8	1.3
7	6	6.9	42.2	1.9
8	6	10.2	43.5	3.0
9	6	13.5	45.6	4.7
10	6	13.5	42.9	4.4

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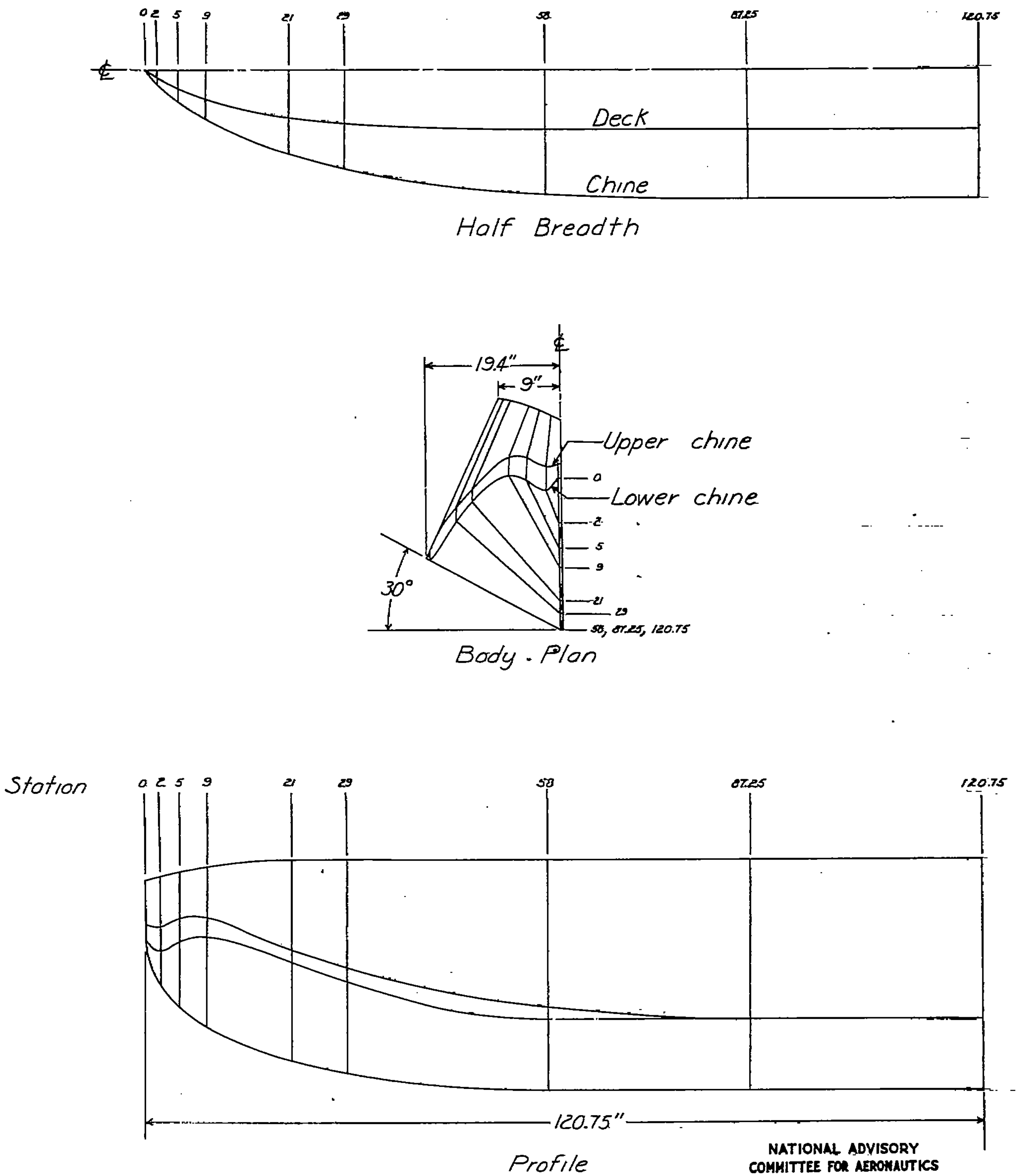

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Figure 1.- Lines of Langley impact basin float model M-2.

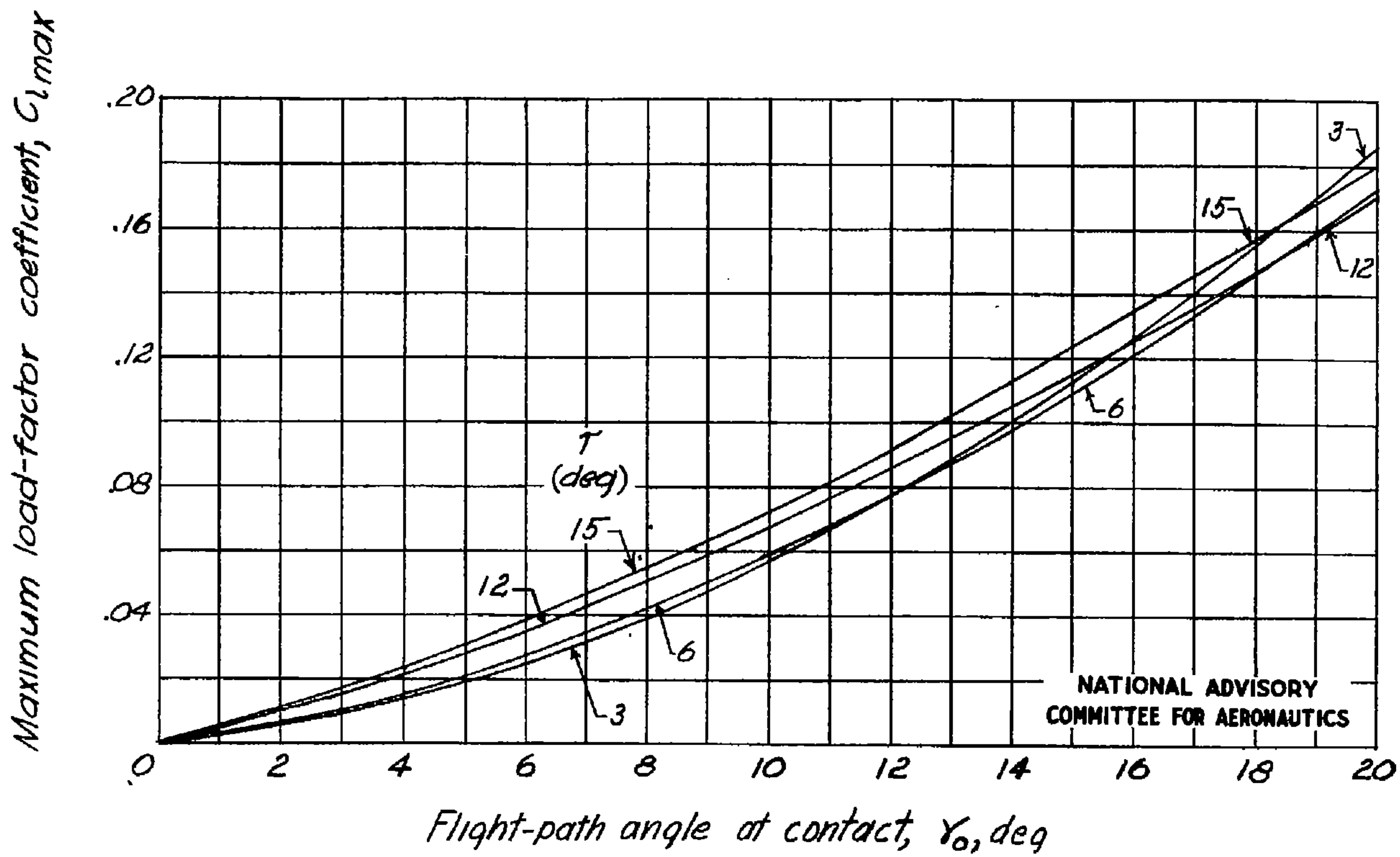

Figure 2.—Theoretical variation of load-factor coefficient with flight-path angle at contact.

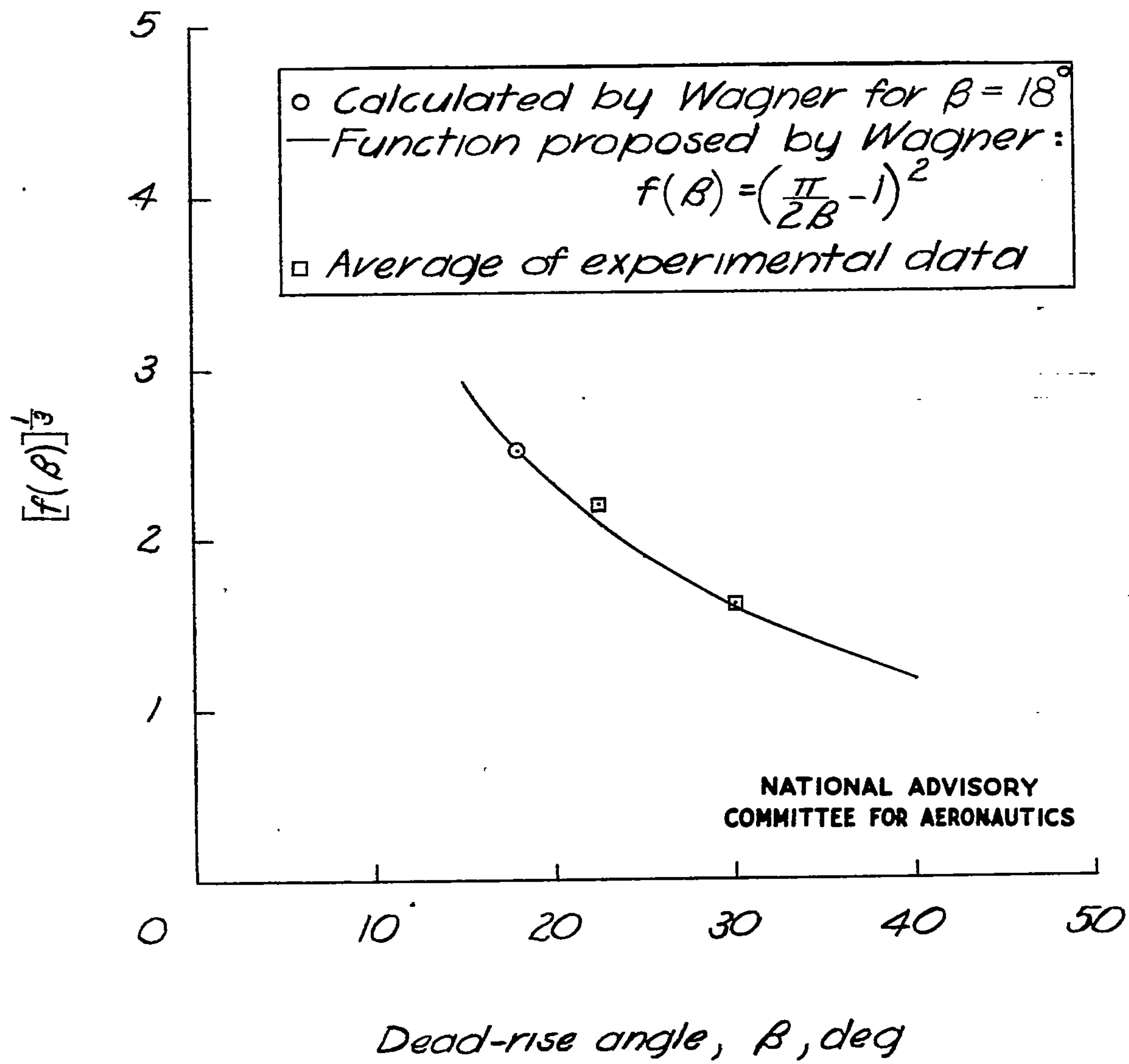

Figure 3. – Calculated and experimental values of dead-rise function.

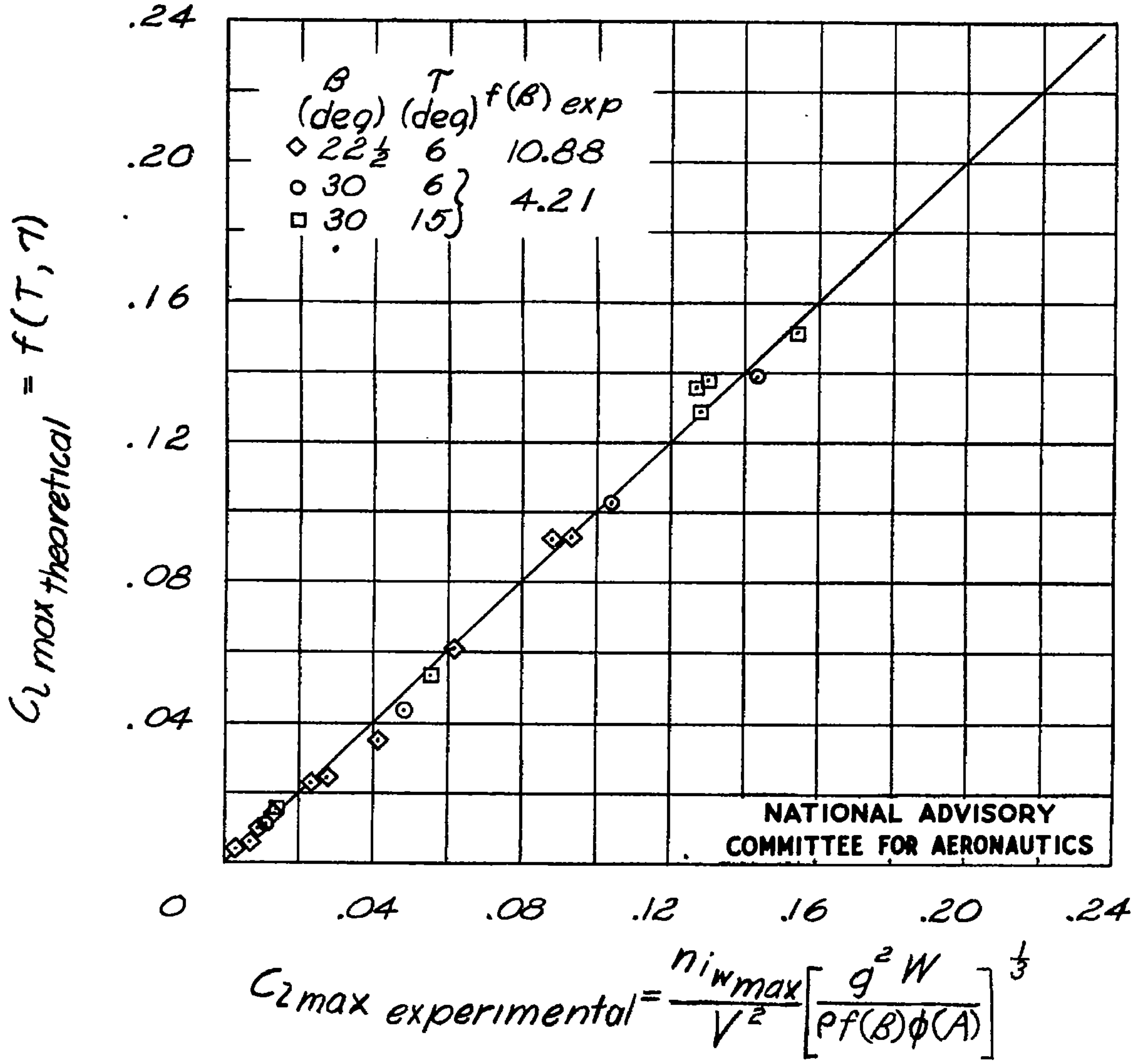

Figure 4.— Comparison of theoretical and experimental load-factor coefficients for prismatic floats of 22½° and 30° dead-rise angle.