NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2353

CHARTS AND TABLES FOR USE IN CALCULATIONS OF DOWNWASH OF WINGS OF ARBITRARY PLAN FORM

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Page 4: In the second line of equation (2), the quantity Δy_v^2 which appears in the numerator of the fraction under the radical in the first term within the brackets should be Δz_v^2.

Page 6: In equation (8), the minus sign inside the parentheses should be a plus sign.

Page 6: In equation (9), the minus sign inside the parentheses should be a plus sign.

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SUMMARY

Values of the downwash of a horseshoe vortex in incompressible flow are presented in the form of charts and tables. The use of the charts and tables in the calculations of the downwash of wings of arbitrary plan form is discussed. The results of a few calculations are compared with experimental results.

INTRODUCTION

A knowledge of the downwash behind the wing is required for the rational design of the horizontal tail surfaces as well as for the analysis of the longitudinal stability of an airplane. The design charts of reference 1, which are based on the experiments and analysis of reference 2, afford a convenient means of estimating the downwash behind unswept wings. These charts are basically inapplicable to swept wings and to wings of more complicated plan form because the assumed bound vortex is unswept and because the assumed spanwise lift distributions are those of unswept wings and differ from those of swept wings.

Inasmuch as sweep constitutes an additional geometric variable and because the use of more complicated plan forms introduces still further variables, the preparation of extensive charts that give directly the downwash field for any arbitrary plan form is not considered practical. When the spanwise lift distribution is known for any particular case the representation of the wing by a vortex pattern and calculation of the downwash field associated with that pattern in the tail region with certain simplifying assumptions, such as that of a plane vortex sheet, is a fairly straightforward, although somewhat time consuming problem.

This paper presents a method, together with the necessary charts and tables, for facilitating such calculations. As is described herein, the tables and charts give the downwash field of an elemental rectangular horseshoe vortex. The method consists basically of distributing these vortices along the wing span in such a way that they approximate the lifting action of the wing and of superimposing the downwash fields of the individual vortices.

The method is probably inapplicable (without modifications) in many cases of present interest where such characteristics as high angle of attack, low aspect ratio, large angle of sweep, high taper, or relatively large fuselage result in uncertain spanwise lift distributions, partly separated flow, and rolled-up vortices extending rearward off the upper surface of the wing. No effort has been made in this paper to study downwash for these cases or to define the limitations of the present method in a quantitative sense. A few comparisons have been made, however, between calculated and experimental results for cases in which the aspect ratio, leading-edge radius, and angle of attack are reasonably favorable for such comparisons. Although even for these cases certain discrepancies, probably related in some way to sweep, remain unexplained, the comparisons are rather satisfactory in general.

These charts and tables may also be used in Falkner's method of calculating lift distribution (reference 3) in which the wing is replaced by a system of horseshoe vortices. A short table of the required downwash function has previously been presented for this purpose in reference 4. The present charts and tables are more extensive, primarily in that they apply to planes above and below that of the wake, and more accurate, in that they require less interpolation.

SYMBOLS

A aspect ratio (b^2/S)

b wing span, feet

C_L wing lift coefficient

c chord (measured parallel to plane of symmetry), feet

$\bar{c}$ average chord, feet

c_l section lift coefficient

F downwash factor $\left(\frac{4\pi s}{\Gamma} w\right)$

M Mach number

S	wing area, square feet
s	semispan of main horseshoe vortices, feet
w	downwash velocity, feet per second
V	forward speed, feet per second
x	longitudinal coordinate along direction of relative wind rearward of quarter-chord point of chord in plane of symmetry, feet
x_v	dimensionless longitudinal coordinate (x/s)
y	lateral coordinate, feet
y_v	dimensionless lateral coordinate (y/s)
z	coordinate normal to wake, feet
z_v	dimensionless coordinate normal to wake (z/s)
Γ	circulation, feet^2 per second
ϵ	downwash angle, degrees
α	angle of attack, degrees
λ	taper ratio
Δx, Δy, Δz	differences in coordinates of a downwash point and those of a lift point, feet

DERIVATION OF DOWNWASH CHARTS AND TABLES

At a point $P(x+\Delta x, y+\Delta y, z+\Delta z)$ the downwash angle due to a horseshoe vortex of semispan s located at a point $Q(x,y,z)$ may, according to reference 5, be found from the relation

$$\frac{w}{V}(\Delta x, \Delta y, \Delta z) = \frac{\Gamma}{4\pi Vs} F(\Delta x_v, \Delta y_v, \Delta z_v) \qquad (1)$$

where

$$\Delta x_v = \frac{\Delta x}{s}$$

$$\Delta y_v = \frac{\Delta y}{s}$$

$$\Delta z_v = \frac{\Delta z}{s}$$

and

$$F = -\frac{2}{\Delta y_v^2 - 1} \frac{1 - \dfrac{\Delta z_v^2}{\Delta y_v^2 - 1}}{\left(1 - \dfrac{\Delta z_v^2}{\Delta y_v^2 - 1}\right)^2 + 4\dfrac{\Delta y_v^2 \Delta z_v^2}{\left(\Delta y_v^2 - 1\right)^2}} +$$

$$\frac{\Delta x_v}{\Delta x_v^2 + \Delta z_v^2}\left[\frac{1 + \dfrac{\Delta x_v^2 + \Delta z_v^2}{\Delta z_v^2 + (\Delta y_v + 1)^2}}{\sqrt{\dfrac{\Delta x_v^2 + \Delta y_v^2}{(\Delta y_v + 1)^2} + 1}} - \frac{1 + \dfrac{\Delta x_v^2 + \Delta z_v^2}{\Delta z_v^2 + (\Delta y_v - 1)^2}}{\sqrt{\dfrac{\Delta x_v^2 + \Delta z_v^2}{(\Delta y_v - 1)^2} + 1}}\right] \qquad (2)$$

For the special case when $\Delta z_v = 0$,

$$F = -\frac{2}{\Delta y_v^2 - 1} \mp \frac{1}{\Delta x_v}\left[\sqrt{1 + \left(\frac{\Delta x_v}{\Delta y_v - 1}\right)^2} - \sqrt{1 + \left(\frac{\Delta x_v}{\Delta y_v + 1}\right)^2}\right] \qquad (2a)$$

In equation (2a), the minus sign applies for positive values of Δy_v and the plus sign, for negative values.

The downwash function F is symmetrical with respect to the XY-plane and the XZ-plane so that

$$F(\Delta x_V,-\Delta y_V,\Delta z_V) = F(\Delta x_V,\Delta y_V,\Delta z_V) \tag{3}$$

and

$$F(\Delta x_V,\Delta y_V,-\Delta z_V) = F(\Delta x_V,\Delta y_V,\Delta z_V) \tag{3a}$$

and its values for negative Δx_V bear the following relationship to those for positive Δx_V:

$$F(-\Delta x_V,\Delta y_V,\Delta z_V) = -\frac{4}{\Delta y_V^2 - 1}\frac{1 - \dfrac{\Delta z_V^2}{\Delta y_V^2 - 1}}{\left(1 - \dfrac{\Delta z_V^2}{\Delta y_V^2 - 1}\right)^2 + 4\dfrac{\Delta y_V^2\Delta z_V^2}{\left(\Delta y_V^2 - 1\right)^2}} - F(\Delta x_V,\Delta y_V,\Delta z_V) \tag{4}$$

and, specifically,

$$F(-\Delta x_V,\Delta y_V,0) = -\frac{4}{\Delta y_V^2 - 1} - F(\Delta x_V,\Delta y_V,0) \tag{4a}$$

The values of F for certain special cases are

$$F(0,\Delta y_V,0) = -\frac{2}{\Delta y_V^2 - 1} \tag{5}$$

(provided $\Delta y_v \neq 0$) and

$$F(\Delta x_v, 0, 0) = 2\left(1 + \frac{1}{\Delta x_v}\sqrt{1 + \Delta x_v^2}\right) \tag{6}$$

For values of $\Delta z_v = 0$, the values of F may be approximated as follows:

For large negative values of Δx_v and small values of Δy_v,

$$F \approx -\frac{1}{\Delta x_v^2} \tag{7}$$

For large positive values of Δx_v and small values of Δy_v,

$$F \approx 4 + \frac{1}{\Delta x_v^2} \tag{7a}$$

For large values of Δy_v and small values of Δx_v,

$$F \approx -\frac{2}{\Delta y_v^2}\left(1 - \frac{\Delta x_v}{|\Delta y_v|}\right) \tag{8}$$

For large values of Δx_v and Δy_v,

$$F \approx -\frac{2}{\Delta y_v^2}\left(1 - \frac{\Delta x_v}{\sqrt{\Delta x_v^2 + \Delta y_v^2}}\right) \tag{9}$$

For the XY-plane ($\Delta z_v = 0$) the values of the function F are presented in table 1 and figure 1(a) for even values of Δy_v. For values of Δy_v of ±1.25, ±3.25, . . . ±37.25, the values of $4F(4\Delta x_v, 4\Delta y_v)$ are tabulated and plotted (in table 1 and fig. 1(b), respectively) because these values of Δy_v apply to the corrector vortices (defined in the succeeding section), which have a span one-fourth that of the other horseshoe vortices. (Full-size figs. 1(a) and 1(b) are enclosed in a flap at the back of this paper. They consist of two parts each. The two parts have to be joined along the indicated lines.) In the region of values of Δy_V between -2 and 2 and values of Δx_V between -4 and 4, the factor F varies very rapidly with Δx_V. In this region (which is indicated in table 1 by a heavy border line around the values), values of F are presented in table 2 for intervals of Δx_V smaller than those of table 1.

For planes above and below the wake by the amounts $\Delta z_V = \pm 2$, ± 4, ± 8, and ± 12, the values of the downwash function F are presented in tables 3 to 6 and in figures 2 to 5. (Full-size figs. 2 to 5 are enclosed in the flap at the back of this paper.) These tables and figures are not so extensive as table 1; they do not contain values for negative values of Δx_V, nor do they contain values at as close intervals for small values of Δx_V nor for as many values of Δy_v. The reason for this nonuniformity in coverage is that tables 1 and 2 (and fig. 1) are intended to aid in the application of Falkner's method, for which downwash values are required close to and ahead of the origin, as well as for the determination of downwash at the tail location; whereas tables 3 to 6 (and figs. 2 to 5) are intended only for the determination of downwash at the tail location.

The horseshoe vortex for which figures 1 to 5 are plotted has a semispan of 0.250 inch; the center of its lateral leg (the bound part of the vortex) is located at the origin, and its longitudinal legs (the trailing parts of the vortex) extend toward the bottom of the figures. The lateral and longitudinal distances (in inches) from the origin to any point divided by 0.250 yield the values of Δy_v and Δx_v, respectively. The regions surrounded by a long-dash-line circle are accurate to three decimal places only, the one surrounded by the short-dash-line circle in figure 1(a), to two places only; if greater accuracy is desired, the tables must be resorted to. Elsewhere the charts are accurate to four or more decimal places.

If the semispan of the vortices is taken as one-fortieth of the wing span, equation (1) becomes

$$\frac{w}{V} = \frac{10}{\pi} \frac{\Gamma}{Vb} F \tag{10}$$

and if the vortex under consideration is considered to be the only one in the chordwise direction so that it is responsible for the entire lift carried by the given section

$$\Gamma = \frac{c_l c V}{2} \tag{11}$$

and

$$\frac{w}{V} = \frac{10}{4\pi} \frac{c_l c}{b/2} F$$

$$= 0.7958 \frac{c_l c}{b/2} F \qquad (12)$$

or

$$\frac{w}{V} = \frac{10}{2\pi} \frac{1}{A} \frac{c_l c}{\bar{c}} F$$

$$= \frac{1.5915}{A} \frac{c_l c}{\bar{c}} F \qquad (13)$$

The downwash angles in degrees may therefore be obtained from equations (12) or (13), respectively, as

$$\epsilon = 45.60 \frac{c_l c}{b/2} F \qquad (14)$$

$$\frac{\epsilon}{C_L} = \frac{91.19}{A} \frac{c_l c}{\bar{c} C_L} F \qquad (14a)$$

APPLICATION OF CHARTS AND TABLES TO

CALCULATION OF DOWNWASH

Location of Vortices

In order to use the charts and tables of the function F for calculating downwash, the lifting action of the wing must be represented by a system of horseshoe vortices such as that indicated in figure 6(a). The centers of the lateral legs of the vortices, which will hereinafter be referred to as the "lift points," are located on the quarter-chord line at integer tenths of the semispan from 0 to 0.9. The semispan of these vortices is one-fortieth of the wing span. In addition to these main vortices two corrector vortices are located near the tip in such a way that the centers of their lateral legs are located at ±0.9625 of the semispan on the quarter-chord line. The semispan of these vortices is one-fourth that of the main vortices. The corrector vortices have been shown in reference 3 to increase the accuracy of loading calculations. Whether the corresponding improvement in the accuracy of downwash calculations behind the wing warrants the added complication is doubtful. No corrector-vortex charts have consequently been prepared for planes above the wake.

In the calculation of the downwash factor F, the vertical dimensionless distance Δz_V is assumed to be measured from the XY-plane, which contains the horseshoe vortex. In using this factor in calculations of the downwash angles behind the wing, the fact that the trailing vortices are not contained in the XY-plane but tend to follow the wing wake must be remembered. (See reference 1.) Consequently, for the purpose of such calculations, the ordinate Δz is assumed to be measured from the wake rather than from the XY-plane.

The charts and tables give values of the function F only at points located laterally and vertically at integral multiples of the span of the horseshoe vortex (at integral tenths of the semispan) from the lift point; consequently, when there is a choice, downwash points should be located at such points. In calculating downwash angles at other points interpolation between downwash angles calculated at adjacent points for which values of the function F are presented is generally preferable to the use of interpolated values of the function F, particularly for points near the plane $\Delta z = 0$.

If the downwash is to be calculated for a wing in a yawed attitude, the span may be defined as the distance between the wing tips (at the quarter-chord line) perpendicular to the relative wind. The lift points would then be located at 0.9625, 0.9, 0.8, and so forth, of the semispan from the midspan location, both the semispan and the midspan position being based on the foregoing definition of the span.

Use of Tables

The values of the downwash angle associated with a given horseshoe vortex may be calculated from equations (14) or (14a). For the vortex configuration indicated in figure 6(a), the downwash at a given point (hereinafter referred to as the "downwash point") may consequently be calculated by summing up the contribution of the individual horseshoe vortices so that

$$\epsilon = 45.60\sum_{i=1}^{21}\left(\frac{c_l c}{b/2}\right)_i F_i \tag{15}$$

$$\frac{\epsilon}{C_L} = \frac{91.19}{A}\sum_{i=1}^{21}\left(\frac{c_l c}{\bar{c}C_L}\right)_i F_i \tag{15a}$$

where F_i is the value of F which corresponds to the dimensionless distance of the downwash point from the ith lift point; that is,

$$(\Delta x_v)_i = (x_v)_{\text{downwash point}} - (x_v)_{\text{ith lift point}}$$

$$(\Delta y_v)_i = (y_v)_{\text{downwash point}} - (y_v)_{\text{ith lift point}}$$

$$(\Delta z_v)_i = (z_v)_{\text{downwash point}}$$

Because the corrector vortices have one-fourth the span of the main vortices, the values of Δx and Δy pertaining to them should be made dimensionless with a distance one-fourth that of the main vortices. Also, from equation (1) it follows that the value of F obtained for these vortices should be multiplied by four times the value used for the main vortices in equations (13), (14), and (14a). In order to avoid the necessity of treating these vortices as special cases, the function $F' = 4F(4\Delta x_v, 4\Delta y_v)$ has been tabulated in tables 1 and 2 instead of the function F for values of Δy_v pertinent to the corrector vortices. In all further calculations, the difference in the spans of the main and corrector vortices may therefore be disregarded.

The calculations of the downwash may be carried out conveniently by means of a computing form such as the one shown in table 7. The coordinates of the downwash point or points are entered at the top of the table, the coordinates of the lift points at the left; all coordinates are made dimensionless by dividing by one-fortieth of the wing span. The differences in the lateral and longitudinal coordinates are obtained at any place in the table by subtracting algebraically the value of the left end of the table from the value at the top. The difference in the z-ordinate is the same as the z-ordinate of the downwash point (measured from the wake). The values of F are obtained from tables 1 to 6 (depending on the normal distance of the downwash point above the wake Δz_V) for the given values of Δx_V and Δy_V and are entered in the appropriate spaces. All values in tables 1 to 6 are negative unless specifically prefixed by a plus sign.

The values of the vortex strength $\left(\text{expressed as } \frac{cc_l}{\bar{c}C_L} \text{ or as } \frac{cc_l}{b/2}\right)$ are entered at the left of table 7. For the purpose of calculating downwash, these values may be estimated conveniently by means of reference 6 or 7. (The limitations in using such theoretical loadings as the basis for downwash computations have not, however, been established. In particular, both the charts of reference 7 and the empirical method of reference 6 may be too inaccurate for satisfactory results close to the wake.) If the wing is yawed, the appropriate values of $\frac{cc_l}{\bar{c}C_L}$ or $\frac{cc_l}{b/2}$ must be used.

Each value of F for a given downwash point is multiplied by the appropriate value of the vortex strength (at the left in the same row), and the 19 or 21 products (depending on whether the corrector vortices are used) are added and entered at the bottom of the table. The downwash (in degrees) may be obtained by multiplying these products by 45.60 or $91.19\frac{C_L}{A}$, depending on whether the vortex strengths are expressed as $\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}C_L}$, respectively.

Use of Charts

Much of the computing involved in filling out table 7 may be avoided if the charts (figs. 1 to 5) are used. In order to use the charts, the wing plan form has to be drawn on a transparent paper to such a scale as to reduce the span to 10 inches. On the quarter-chord line of this plan form, the lift points are marked as shown in figure 6(b). Similarly, downwash points are marked wherever the downwash may be of interest, except that the downwash points should preferably be located at integral tenths of the semispan from the midspan.

A grid drawn through the lift points as shown in figure 6(b) usually facilitates the alinement of the plan form with the downwash charts. If the wing is yawed, the lines of this grid have to be drawn parallel and perpendicular to the relative wind. The drawing of figure 6(b) is placed on the downwash chart for the Δz_V value of interest in such a manner that the first vortex (at -0.9 semispan) is located on the origin of the chart and the grid on the plan form is alined with the chart. The values of the downwash are then read at the downwash points and entered opposite the -0.9 semispan station in a table similar to table 8. The plan-form drawing is then moved so that the second lift point (at -0.8 semispan) is located at the origin of the chart; the grid on the plan form is alined again, and the values of the downwash are read at the downwash points and entered in the table opposite the -0.8 semispan station. This procedure is continued until all main lift points have been located at the origin and the corresponding values of the downwash entered in the table. For example, figure 7(a) shows the lift point at -0.3 semispan located at the origin of the chart for $\Delta z_V = 0$. All values of the downwash read from this chart are negative, except for those values immediately downstream of the origin.

Whenever a downwash point is so located relative to a lift point that it is not on the chart when that lift point is located at the origin, the transparent drawing is turned over about the longitudinal axis of the wing plan form. The given lift point is placed at the origin again and the drawing is alined with the chart; the downwash point is now on the chart so that the downwash at that point may be read from the chart. Figure 7(b) shows the lift point at 0.3 semispan located at the origin; the values of the downwash at points 1, 2, 6, and 7 cannot be read unless the drawing is turned over.

When all the downwash contributions due to the main vortices have been obtained in this manner and it is desired to use the corrector vortices, the downwash due to the corrector vortices may be obtained from figure 1(b) provided $\Delta z_V = 0$. The corrector lift point at -0.9625 semispan is located on the origin of figure 1(b) and the values of the downwash are read at the downwash points and entered in the table. The plan-form drawing is then turned over, the corrector lift point at 0.9625 semispan placed on the origin, and the values of the downwash read again. All values read from this chart are negative.

The values of the vortex strengths $\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}C_L}$ are entered in the second column of table 8. The total downwash at a given downwash point is obtained by multiplying the values entered in the table for that downwash point by the corresponding values of the vortex strengths and summing up the products. The value of the downwash is then either 45.60 or $91.19\frac{C_L}{A}$ times the sum of the products, depending on whether $\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}C_L}$ was used.

As stated previously, the values of $\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}C_L}$ are obtained from a curve of the spanwise lift distribution, which may be estimated by the method of reference 6 or 7.

Correction for Compressibility Effects

The representation of a wing by vortices in the manner indicated in the preceding sections is valid only in incompressible flow. The three-dimensional Glauert-Prandtl rule for linearized subsonic flow may be used, however, to apply a first-order correction for compressibility effects to the results obtained from incompressible-flow theory. This correction consists of multiplying all longitudinal dimensions and ordinates by the factor $\frac{1}{\sqrt{1 - M^2}}$. This correction affects the chord, the aspect ratio, the sweep angle, and the longitudinal location of the downwash points. The downwash angles calculated for this stretched plan form and for the downwash points with stretched longitudinal ordinates by use of the actual lift distribution are the downwash angles on the actual wing in compressible flow.

Results of Specific Calculations

As stated previously, the values of downwash angles calculated in the manner outlined in the preceding sections are idealized in that they involve certain approximations and are subject to certain limitations. As a practical example of results obtainable by the method of calculating downwash angles (outlined in the foregoing sections), and in order to permit a further comparison of experimental and theoretical results, downwash angles have been calculated for one of the models used in the tests described in reference 8 for a wing with 30° sweepback, aspect ratio 4.5, and taper ratio 1.0. The angle for which the calculations have been performed is 8.18°; the lift coefficient, 0.487.

Downwash angles have been calculated by the method of the preceding sections for points at 0.4, 1.0, and 1.6 semispan behind the intersection of the quarter-chord line and the plane of symmetry, in the plane of symmetry and 0.3 semispan from the plane of symmetry, and at several heights $\left(\frac{z}{b/2} = 0, 0.2, 0.4, \text{ and } 0.6\right)$ above the wake, the position of the wake being that obtained from the data of reference 8. These angles are shown in figure 8. Also shown, for comparison, are downwash angles obtained from the experimental data of reference 8 at the same points (except that the lateral ordinate of points 4 and 5 of figure 8 is one-third semispan for the experimental results and 0.3 semispan for the calculated results).

The agreement between the calculated and the experimental results is good for most points, as may be expected for a wing with reasonably high aspect ratio and at a reasonably low angle of attack except for points downstream of the wing tip and for points in the wake. The largest discrepancies are at point 1, which is too close to the trailing edge to permit calculation of the downwash on the basis of a single concentrated load vortex.

In order to show some of the trends in the effects of some wing parameters on downwash (if the wings and their lift coefficients are assumed to remain within the ranges for which the present method is applicable) some additional calculations have been made for two sets of wings of aspect ratio 6, with taper ratios of 0.5 and 1.0, respectively, and with various angles of sweep. Spanwise lift distributions given in reference 7 were used in the calculations. Values of the downwash ratio $d\epsilon/d\alpha$ were calculated and are shown in figure 9 for points located, longitudinally, at 0.4, 1.0, and 1.6 semispans behind the intersection of the quarter-chord line and the plane of symmetry, laterally, in the plane of symmetry, and, vertically, in the plane of the wake. These values of $d\epsilon/d\alpha$ do not actually correspond to the rate of change of downwash at a tail surface because the height of the tail surface relative to the wake changes with angle of attack.

In the plane of symmetry the downwash angle decreases as the wing is swept back as a result of the fact that with increasing sweep the wing as a whole and the region of the wing near the plane of symmetry, in particular, carry less lift and, consequently, produce less downwash. At 0.4 semispan outboard of the plane of symmetry, the downwash angle increases slightly as the angle of sweepback increases from negative values (sweptforward wing) to about 20° to 30° sweepback, and then the downwash angle gradually decreases as the angle of sweepback increases further. This trend is due to the fact that the decrease of lift with sweepback is less pronounced at 0.4 semispan away from the plane of symmetry than in the plane of symmetry and that the wing approaches the two downwash points (4 and 5) as it is swept back so that its bound vorticity produces more downwash at the downwash points.

If these results are to be interpreted correctly, some of the limitations of the theory underlying the calculations must be remembered. For example, the downwash angles calculated for the plane of the wake may be largely invalidated by the inflow into the wake and the reduced streamwise velocity component. Furthermore, if the wings have fairly sharp leading edges, the flow over the more highly swept members of this series may be very different from the assumed flow except at the very lowest angles of attack. In spite of these difficulties, the results are probably fairly representative at low angles of attack. The downwash angles in the plane of symmetry are likely to be less reliable than those at 0.4 semispan away from it, as shown by the comparisons of figure 8. The least reliable results are probably those for point 1 because of its proximity to the trailing edge.

DISCUSSION

Some of the limitations of the procedure of using the charts and tables of this paper in the calculation of downwash angles are inherent in linearized potential theory; whereas some others are consequences of the simplifications made to facilitate calculations based on this theory.

As a result of the fact that potential theory does not take viscous effects into account, any effect of the wake on the downwash angles in the wake or in the vicinity of the wake cannot be determined by potential theory, nor can downwash angles be predicted on the basis of such theory for the higher angles of attack because boundary-layer separation affects the lift carried by the wing and, hence, the downwash field associated with that lift. Linearized theory implies a wake which is plane and has the same spanwise distribution of trailing vorticity at every section through the wake downstream of the wing. Because the trailing vorticity actually rolls up into two tip vortices downstream of the wing tips, downwash angles downstream of the wing tips cannot be estimated directly by linearized theory nor can the downwash angles behind wings of low aspect ratio be predicted by linearized theory because for such wings the tip vorticity affects the downwash angles in the entire region where downwash angles are likely to be of interest.

The calculating procedures outlined in this paper are based on the assumption that the lifting action of the wing may be represented by a single concentrated vortex at the quarter-chord line. Within the framework of linearized potential theory this assumption is adequate for calculating the downwash angles at points which are not too close to the wing. The presence of a fuselage, vertical tail surface, or propeller slipstream cannot be taken into account, however, by the simple vortex representation described in this paper. (The effect of the fuselage on the downwash is particularly difficult to take into account because it is only partly a potential-flow phenomenon and partly the type of phenomenon associated with boundary-layer and wake effects.)

CONCLUDING REMARKS

Charts and tables have been presented for the downwash of a horseshoe vortex in incompressible flow. The use of these charts and tables in the calculations of the downwash angles behind the wings of arbitrary plan form has been described and discussed. A correction for compressibility effects has been outlined. The results of a few calculations of downwash angles for a rather favorable case (a moderately swept wing with no taper and a thick leading edge at a moderate angle of attack) have been found to agree satisfactorily with the experimental results except perhaps near the midspan region of the wake. The applicability of the present approach for less favorable conditions (such as large angle of sweep, low aspect ratio, thin leading edge, and high angle of attack) has not been determined, and such application, even when the true loading is known, is not at present recommended.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., January 30, 1951

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TABLE 1.- DOWNWASH FACTOR, F

[All values of the downwash factor are negative unless specifically prefixed by a plus sign.]

Δx_v \ Δy_v	0	±1.25	±2	±3.25	±4	±5.25	±6	±7.25	±8	±9.25	±10	±11.25
-∞	0	0	0	0	0	0	0	0	0	0	0	0
-100	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-90	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-80	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000
-70	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0000
-60	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001
-50	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001
-45	.0005	.0001	.0005	.0001	.0005	.0001	.0005	.0001	.0005	.0001	.0005	.0001
-40	.0006	.0002	.0006	.0002	.0006	.0002	.0006	.0002	.0006	.0001	.0006	.0001
-35	.0008	.0002	.0008	.0002	.0008	.0002	.0008	.0002	.0008	.0002	.0008	.0002
-30	.0011	.0003	.0011	.0003	.0011	.0003	.0011	.0003	.0011	.0003	.0010	.0003
-25	.0016	.0004	.0016	.0004	.0016	.0004	.0015	.0004	.0015	.0004	.0014	.0003
-20	.0025	.0006	.0025	.0006	.0024	.0006	.0023	.0006	.0022	.0005	.0021	.0005
-18	.0031	.0008	.0031	.0008	.0030	.0007	.0029	.0007	.0027	.0006	.0025	.0006
-16	.0039	.0010	.0039	.0009	.0037	.0009	.0035	.0008	.0033	.0008	.0030	.0007
-14	.0050	.0013	.0050	.0012	.0048	.0012	.0045	.0011	.0041	.0010	.0037	.0009
-12	.0069	.0017	.0068	.0016	.0064	.0015	.0059	.0014	.0053	.0012	.0046	.0011
-10	.0100	.0025	.0097	.0023	.0089	.0021	.0079	.0018	.0069	.0016	.0059	.0013
-9	.0123	.0030	.0119	.0028	.0108	.0025	.0093	.0021	.0079	.0018	.0066	.0015
-8	.0156	.0038	.0149	.0035	.0132	.0030	.0111	.0025	.0092	.0020	.0075	.0017
-7	.0203	.0050	.0192	.0044	.0165	.0036	.0134	.0029	.0107	.0023	.0086	.0019
-6	.0276	.0067	.0256	.0057	.0210	.0045	.0163	.0034	.0125	.0027	.0097	.0021
-5	.0396	.0095	.0356	.0076	.0274	.0056	.0201	.0041	.0148	.0031	.0111	.0023
-4.5	.0488	.0117	.0429	.0090	.0317	.0063	.0224	.0045	.0160	.0033	.0119	.0025
-4.0	.0616	.0146	.0526	.0106	.0368	.0071	.0249	.0049	.0174	.0035	.0126	.0026
-3.5	.0800	.0186	.0657	.0127	.0431	.0081	.0278	.0054	.0189	.0038	.0135	.0028
-3.0	.1082	.0246	.0840	.0152	.0507	.0091	.0311	.0059	.0205	.0040	.0143	.0029
-2.5	.1541	.0338	.1103	.0185	.0599	.0104	.0347	.0064	.0222	.0043	.0153	.0031
-2.0	.2361	.0486	.1496	.0226	.0709	.0117	.0386	.0070	.0239	.0046	.0162	.0033
-1.8	.2879	.0572	.1706	.0245	.0759	.0123	.0403	.0076	.0247	.0047	.0166	.0033
-1.6	.3585	.0679	.1958	.0265	.0812	.0129	.0420	.0075	.0254	.0049	.0170	.0034
-1.4	.4578	.0815	.2260	.0287	.0869	.0136	.0438	.0077	.0262	.0050	.0174	.0035
-1.2	.6034	.0988	.2625	.0310	.0928	.0142	.0456	.0080	.0270	.0051	.0178	.0035
-1.0	.8284	.1210	.3066	.0335	.0990	.0148	.0475	.0082	.0278	.0052	.0182	.0036
-.8	1.2016	.1490	.3596	.0362	.1056	.0154	.0494	.0085	.0285	.0053	.0186	.0037
-.6	1.8873	.1847	.4227	.0389	.1123	.0161	.0513	.0087	.0293	.0055	.0190	.0037
-.5	2.4721	.2054	.4582	.0403	.1156	.0165	.0523	.0089	.0298	.0055	.0192	.0038
-.4	3.3852	.2281	.4962	.0418	.1192	.0168	.0532	.0090	.0302	.0056	.0194	.0038
-.3	4.9602	.2526	.5365	.0432	.1227	.0171	.0542	.0091	.0305	.0057	.0196	.0038
-.25	6.2462	.2654	.5574	.0438	.1245	.0173	.0547	.0092	.0308	.0057	.0197	.0039
-.20	8.1980	.2786	.5787	.0447	.1262	.0175	.0552	.0093	.0310	.0057	.0198	.0039
-.15	11.4825	.2920	.6004	.0454	.1280	.0177	.0557	.0093	.0312	.0058	.0199	.0039
-.10	18.0998	.3057	.6223	.0461	.1298	.0178	.0561	.0094	.0314	.0058	.0200	.0039
-.05	38.0500	.3195	.6445	.0469	.1315	.0180	.0565	.0095	.0316	.0058	.0201	.0039
0	∞	.3333	.6667	.0476	.1333	.0182	.0571	.0095	.0318	.0058	.0202	.0040
+.05	+42.0500	.3472	.6889	.0484	.1351	.0184	.0577	.0096	.0320	.0059	.0203	.0040
+.10	+22.0998	.3610	.7110	.0491	.1368	.0185	.0581	.0097	.0322	.0059	.0204	.0040
+.15	+15.4825	.3747	.7329	.0498	.1387	.0187	.0586	.0097	.0324	.0059	.0205	.0040
+.20	+12.1980	.3881	.7546	.0506	.1404	.0189	.0591	.0098	.0326	.0060	.0206	.0040
+.25	+10.2462	.4013	.7759	.0513	.1422	.0190	.0596	.0099	.0328	.0060	.0207	.0040
+.3	+8.9602	.4141	.7968	.0520	.1440	.0192	.0601	.0099	.0330	.0060	.0208	.0041
+.4	+7.3852	.4386	.8371	.0535	.1475	.0196	.0610	.0100	.0334	.0061	.0210	.0041
+.5	+6.4721	.4612	.8752	.0549	.1510	.0199	.0620	.0102	.0338	.0062	.0212	.0041
+.6	+5.8873	.4819	.9107	.0563	.1544	.0202	.0630	.0103	.0342	.0062	.0214	.0042
+.8	+5.2016	.5177	.9738	.0591	.1611	.0209	.0649	.0106	.0350	.0064	.0218	.0042
+1.0	+4.8284	.5457	1.0268	.0617	.1676	.0216	.0668	.0108	.0357	.0065	.0222	.0043
+1.2	+4.6034	.5679	1.0709	.0642	.1739	.0222	.0687	.0111	.0365	.0066	.0226	.0044
+1.4	+4.4578	.5852	1.1073	.0665	.1798	.0228	.0705	.0113	.0373	.0067	.0230	.0044
+1.6	+4.3585	.5988	1.1376	.0687	.1854	.0235	.0722	.0115	.0381	.0068	.0234	.0045
+1.8	+4.2879	.6095	1.1628	.0708	.1908	.0241	.0740	.0118	.0388	.0070	.0238	.0046
+2.0	+4.2361	.6180	1.1838	.0727	.1957	.0247	.0757	.0121	.0396	.0071	.0242	.0046
+2.5	+4.1541	.6329	1.2230	.0767	.2068	.0260	.0796	.0126	.0414	.0074	.0251	.0048
+3.0	+4.1082	.6421	1.2494	.0800	.2160	.0272	.0832	.0132	.0430	.0077	.0261	.0050
+3.5	+4.0800	.6480	1.2677	.0826	.2236	.0283	.0865	.0137	.0446	.0079	.0269	.0051
+4.0	+4.0616	.6521	1.2808	.0846	.2298	.0292	.0894	.0141	.0461	.0081	.0278	.0053
+4.5	+4.0488	.6550	1.2905	.0863	.2350	.0300	.0919	.0146	.0475	.0084	.0286	.0054
+5	+4.0396	.6571	1.2977	.0876	.2392	.0307	.0942	.0149	.0487	.0086	.0293	.0056
+6	+4.0276	.6599	1.3078	.0895	.2457	.0319	.0980	.0156	.0510	.0090	.0307	.0058
+7	+4.0203	.6617	1.3142	.0908	.2502	.0327	.1009	.0161	.0528	.0094	.0319	.0060
+8	+4.0156	.6628	1.3185	.0918	.2535	.0334	.1032	.0166	.0543	.0097	.0329	.0062
+9	+4.0123	.6636	1.3215	.0924	.2559	.0339	.1050	.0169	.0556	.0099	.0338	.0064
+10	+4.0100	.6642	1.3237	.0929	.2577	.0343	.1064	.0172	.0566	.0101	.0345	.0066
+12	+4.0069	.6649	1.3265	.0936	.2603	.0348	.1084	.0177	.0583	.0105	.0358	.0068
+14	+4.0050	.6654	1.3283	.0940	.2619	.0352	.1098	.0180	.0594	.0107	.0367	.0070
+16	+4.0039	.6657	1.3295	.0943	.2629	.0355	.1108	.0182	.0602	.0109	.0374	.0072
+18	+4.0031	.6659	1.3303	.0945	.2637	.0356	.1114	.0184	.0608	.0110	.0379	.0073
+20	+4.0025	.6660	1.3309	.0946	.2642	.0358	.1119	.0185	.0613	.0112	.0383	.0074
+25	+4.0016	.6663	1.3318	.0948	.2651	.0360	.1128	.0187	.0620	.0113	.0390	.0076
+30	+4.0011	.6664	1.3322	.0950	.2656	.0361	.1132	.0188	.0624	.0114	.0394	.0077
+35	+4.0008	.6665	1.3325	.0950	.2659	.0362	.1135	.0189	.0627	.0115	.0396	.0077
+40	+4.0006	.6665	1.3327	.0951	.2660	.0362	.1137	.0189	.0629	.0116	.0398	.0078
+45	+4.0005	.6665	1.3328	.0951	.2662	.0362	.1138	.0189	.0630	.0116	.0399	.0078
+50	+4.0004	.6666	1.3329	.0951	.2663	.0363	.1139	.0189	.0631	.0116	.0400	.0078
+60	+4.0003	.6666	1.3331	.0952	.2664	.0363	.1140	.0190	.0632	.0116	.0401	.0078
+70	+4.0002	.6666	1.3331	.0952	.2665	.0363	.1141	.0190	.0633	.0116	.0402	.0079
+80	+4.0002	.6666	1.3332	.0952	.2665	.0363	.1141	.0190	.0633	.0117	.0402	.0079
+90	+4.0001	.6666	1.3332	.0952	.2665	.0363	.1142	.0190	.0634	.0117	.0403	.0079
+100	+4.0001	.6666	1.3332	.0952	.2666	.0363	.1142	.0190	.0634	.0117	.0403	.0079
+∞	+4.0000	.6667	1.3333	.0952	.2667	.0364	.1143	.0190	.0635	.0117	.0404	.0079

NACA

TABLE 1- DOWNWASH FACTOR, F - Continued

[All values of the downwash factor are negative.]

Δx_v \ Δy_v	±12	±13.25	±14	±15.25	±16	±17.25	±18	±19.25	±20	±21.25	±22	±23.25
-∞	0	0	0	0	0	0	0	0	0	0	0	0
-100	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-90	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-80	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0001	.0000
-70	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000
-60	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001
-50	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001
-45	.0005	.0001	.0005	.0001	.0005	.0001	.0004	.0001	.0004	.0001	.0004	.0001
-40	.0006	.0001	.0006	.0001	.0006	.0001	.0005	.0001	.0005	.0001	.0005	.0001
-35	.0008	.0002	.0007	.0002	.0007	.0002	.0007	.0002	.0007	.0002	.0006	.0002
-30	.0010	.0002	.0010	.0002	.0009	.0002	.0009	.0002	.0008	.0002	.0008	.0002
-25	.0014	.0003	.0013	.0003	.0012	.0003	.0012	.0003	.0011	.0003	.0010	.0002
-20	.0020	.0005	.0019	.0004	.0017	.0004	.0016	.0004	.0015	.0003	.0013	.0003
-18	.0023	.0006	.0022	.0005	.0020	.0005	.0018	.0004	.0017	.0004	.0015	.0004
-16	.0028	.0007	.0025	.0006	.0023	.0005	.0021	.0005	.0019	.0004	.0017	.0004
-14	.0034	.0008	.0030	.0007	.0027	.0006	.0024	.0006	.0021	.0005	.0019	.0004
-12	.0041	.0009	.0036	.0008	.0031	.0007	.0028	.0006	.0024	.0006	.0022	.0005
-10	.0050	.0011	.0043	.0010	.0037	.0008	.0032	.0007	.0028	.0006	.0024	.0006
-9	.0056	.0012	.0047	.0011	.0040	.0009	.0034	.0008	.0030	.0007	.0026	.0006
-8	.0062	.0014	.0052	.0012	.0043	.0010	.0037	.0008	.0031	.0007	.0027	.0006
-7	.0069	.0015	.0057	.0013	.0047	.0010	.0039	.0009	.0034	.0008	.0029	.0007
-6	.0077	.0017	.0062	.0014	.0051	.0011	.0042	.0009	.0036	.0008	.0031	.0007
-5	.0086	.0018	.0068	.0015	.0055	.0012	.0045	.0010	.0038	.0009	.0032	.0007
-4.5	.0091	.0019	.0071	.0015	.0057	.0013	.0047	.0010	.0039	.0009	.0033	.0007
-4.0	.0095	.0020	.0074	.0016	.0059	.0013	.0048	.0011	.0040	.0009	.0034	.0008
-3.5	.0101	.0021	.0078	.0017	.0062	.0014	.0050	.0011	.0041	.0009	.0035	.0008
-3.0	.0106	.0022	.0081	.0017	.0064	.0014	.0052	.0011	.0043	.0010	.0036	.0008
-2.5	.0111	.0023	.0085	.0018	.0066	.0014	.0053	.0012	.0044	.0010	.0037	.0008
-2.0	.0117	.0024	.0088	.0019	.0069	.0015	.0055	.0012	.0045	.0010	.0038	.0008
-1.8	.0119	.0025	.0089	.0019	.0070	.0015	.0056	.0012	.0046	.0010	.0038	.0009
-1.6	.0121	.0025	.0091	.0019	.0071	.0015	.0056	.0012	.0046	.0010	.0038	.0009
-1.4	.0124	.0025	.0092	.0020	.0072	.0015	.0057	.0013	.0047	.0010	.0039	.0009
-1.2	.0126	.0026	.0094	.0020	.0073	.0016	.0058	.0013	.0047	.0010	.0039	.0009
-1.0	.0128	.0026	.0095	.0020	.0074	.0016	.0058	.0013	.0048	.0011	.0040	.0009
-.8	.0131	.0027	.0097	.0020	.0075	.0016	.0059	.0013	.0048	.0011	.0040	.0009
-.6	.0133	.0027	.0098	.0021	.0075	.0016	.0060	.0013	.0049	.0011	.0040	.0009
-.5	.0134	.0027	.0099	.0021	.0076	.0016	.0060	.0013	.0049	.0011	.0040	.0009
-.4	.0135	.0028	.0100	.0021	.0076	.0016	.0061	.0013	.0049	.0011	.0041	.0009
-.3	.0136	.0028	.0100	.0021	.0077	.0016	.0061	.0013	.0049	.0011	.0041	.0009
-.25	.0137	.0028	.0101	.0021	.0077	.0017	.0061	.0013	.0050	.0011	.0041	.0009
-.20	.0137	.0028	.0101	.0021	.0077	.0017	.0061	.0013	.0050	.0011	.0041	.0009
-.15	.0138	.0028	.0102	.0021	.0078	.0017	.0061	.0013	.0050	.0011	.0041	.0009
-.10	.0139	.0028	.0102	.0021	.0078	.0017	.0062	.0013	.0050	.0011	.0041	.0009
-.05	.0140	.0028	.0102	.0021	.0078	.0017	.0062	.0013	.0050	.0011	.0041	.0009
0	.0140	.0028	.0103	.0022	.0078	.0017	.0062	.0013	.0050	.0011	.0041	.0009
+.05	.0140	.0029	.0103	.0022	.0079	.0017	.0062	.0014	.0050	.0011	.0042	.0009
+.10	.0141	.0029	.0103	.0022	.0079	.0017	.0062	.0014	.0050	.0011	.0042	.0009
+.15	.0142	.0029	.0104	.0022	.0079	.0017	.0062	.0014	.0050	.0011	.0042	.0009
+.20	.0142	.0029	.0104	.0022	.0079	.0017	.0063	.0014	.0051	.0011	.0042	.0009
+.25	.0143	.0029	.0104	.0022	.0080	.0017	.0063	.0014	.0051	.0011	.0042	.0009
+.3	.0144	.0029	.0105	.0022	.0080	.0017	.0063	.0014	.0051	.0011	.0042	.0009
+.4	.0145	.0029	.0105	.0022	.0080	.0017	.0063	.0014	.0051	.0011	.0042	.0009
+.5	.0146	.0030	.0106	.0022	.0081	.0017	.0064	.0014	.0051	.0011	.0042	.0009
+.6	.0147	.0030	.0107	.0022	.0081	.0017	.0064	.0014	.0052	.0011	.0043	.0009
+.8	.0149	.0030	.0109	.0023	.0082	.0018	.0065	.0014	.0052	.0011	.0043	.0010
+1.0	.0152	.0031	.0110	.0023	.0083	.0018	.0065	.0014	.0053	.0012	.0043	.0010
+1.2	.0154	.0031	.0111	.0023	.0084	.0018	.0066	.0014	.0053	.0012	.0044	.0010
+1.4	.0156	.0031	.0113	.0023	.0085	.0018	.0067	.0014	.0054	.0012	.0044	.0010
+1.6	.0159	.0032	.0114	.0024	.0086	.0018	.0067	.0015	.0054	.0012	.0044	.0010
+1.8	.0161	.0032	.0116	.0024	.0087	.0019	.0068	.0015	.0055	.0012	.0045	.0010
+2.0	.0163	.0033	.0117	.0024	.0088	.0019	.0069	.0015	.0055	.0012	.0045	.0010
+2.5	.0169	.0034	.0121	.0025	.0091	.0019	.0070	.0015	.0056	.0012	.0046	.0010
+3.0	.0174	.0035	.0124	.0026	.0093	.0020	.0072	.0016	.0058	.0013	.0047	.0010
+3.5	.0179	.0036	.0128	.0026	.0095	.0020	.0074	.0016	.0059	.0013	.0048	.0011
+4.0	.0184	.0037	.0131	.0027	.0098	.0021	.0075	.0016	.0060	.0013	.0049	.0011
+4.5	.0189	.0038	.0134	.0028	.0100	.0021	.0077	.0017	.0061	.0013	.0050	.0011
+5	.0194	.0039	.0137	.0028	.0102	.0021	.0079	.0017	.0062	.0014	.0051	.0011
+6	.0203	.0040	.0143	.0029	.0106	.0022	.0082	.0017	.0065	.0014	.0052	.0012
+7	.0211	.0042	.0149	.0030	.0110	.0023	.0084	.0018	.0067	.0015	.0054	.0012
+8	.0218	.0043	.0154	.0031	.0114	.0024	.0087	.0019	.0069	.0015	.0056	.0012
+9	.0224	.0044	.0158	.0032	.0117	.0025	.0090	.0019	.0071	.0015	.0057	.0013
+10	.0230	.0046	.0162	.0033	.0120	.0025	.0092	.0020	.0073	.0016	.0059	.0013
+12	.0239	.0048	.0170	.0035	.0126	.0026	.0096	.0021	.0076	.0017	.0061	.0013
+14	.0246	.0049	.0175	.0036	.0130	.0027	.0100	.0021	.0079	.0017	.0064	.0014
+16	.0252	.0050	.0180	.0037	.0134	.0028	.0103	.0022	.0081	.0018	.0066	.0014
+18	.0256	.0051	.0184	.0038	.0137	.0029	.0106	.0023	.0084	.0018	.0068	.0015
+20	.0260	.0052	.0187	.0039	.0140	.0030	.0108	.0023	.0086	.0019	.0069	.0015
+25	.0266	.0054	.0192	.0040	.0145	.0031	.0112	.0024	.0089	.0020	.0073	.0016
+30	.0270	.0055	.0196	.0041	.0148	.0031	.0115	.0025	.0092	.0020	.0075	.0017
+35	.0272	.0055	.0198	.0041	.0150	.0032	.0117	.0025	.0094	.0021	.0076	.0017
+40	.0274	.0056	.0199	.0042	.0151	.0032	.0118	.0026	.0095	.0021	.0078	.0017
+45	.0275	.0056	.0201	.0042	.0152	.0032	.0119	.0026	.0096	.0021	.0079	.0017
+50	.0276	.0056	.0201	.0042	.0153	.0033	.0120	.0026	.0097	.0021	.0079	.0018
+60	.0277	.0056	.0202	.0042	.0154	.0033	.0121	.0026	.0098	.0022	.0080	.0018
+70	.0278	.0056	.0203	.0043	.0155	.0033	.0122	.0027	.0098	.0022	.0081	.0018
+80	.0278	.0057	.0204	.0043	.0155	.0033	.0122	.0027	.0099	.0022	.0081	.0018
+90	.0278	.0057	.0204	.0043	.0156	.0033	.0123	.0027	.0099	.0022	.0082	.0018
+100	.0279	.0057	.0204	.0043	.0156	.0033	.0123	.0027	.0099	.0022	.0082	.0018
+∞	.0280	.0057	.0205	.0043	.0157	.0034	.0124	.0027	.0100	.0022	.0083	.0019

NACA

TABLE 1.- DOWNWASH FACTOR, F - Concluded

[All values of the downwash factor are negative.]

Δx_v \ Δy_v	±24	±25.25	±26	±27.25	±28	±29.25	±30	±31.25	±32	±33.25	±34	±35.25	±36	±37.25
-∞	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-100	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-90	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-80	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001	.0000
-70	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000	.0002	.0000
-60	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001	.0002	.0001
-50	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001	.0003	.0001
-45	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0003	.0001
-40	.0005	.0001	.0005	.0001	.0005	.0001	.0004	.0001	.0004	.0001	.0004	.0001	.0004	.0001
-35	.0006	.0001	.0006	.0001	.0006	.0001	.0005	.0001	.0005	.0001	.0005	.0001	.0005	.0001
-30	.0008	.0002	.0007	.0002	.0007	.0002	.0007	.0002	.0006	.0002	.0006	.0001	.0006	.0001
-25	.0010	.0002	.0009	.0002	.0009	.0002	.0008	.0002	.0007	.0002	.0007	.0002	.0007	.0002
-20	.0012	.0003	.0012	.0003	.0011	.0003	.0010	.0002	.0009	.0002	.0009	.0002	.0008	.0002
-18	.0014	.0003	.0013	.0003	.0012	.0003	.0011	.0003	.0010	.0002	.0009	.0002	.0009	.0002
-16	.0015	.0004	.0014	.0003	.0013	.0003	.0012	.0003	.0011	.0003	.0010	.0002	.0009	.0002
-14	.0017	.0004	.0016	.0004	.0014	.0003	.0013	.0003	.0012	.0003	.0011	.0003	.0010	.0002
-12	.0019	.0004	.0017	.0004	.0015	.0004	.0014	.0003	.0013	.0003	.0012	.0003	.0011	.0002
-10	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0004	.0014	.0003	.0012	.0003	.0011	.0003
-9	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004	.0014	.0003	.0013	.0003	.0012	.0003
-8	.0024	.0005	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0003	.0013	.0003	.0012	.0003
-7	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004	.0014	.0003	.0012	.0003
-6	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004	.0014	.0003	.0013	.0003
-5	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0003	.0013	.0003
-4.5	.0028	.0006	.0025	.0006	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0004	.0014	.0003
-4.0	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004	.0014	.0003
-3.5	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0016	.0004	.0014	.0003
-3.0	.0030	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004	.0014	.0003
-2.5	.0031	.0007	.0027	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004	.0014	.0003
-2.0	.0032	.0007	.0027	.0006	.0024	.0005	.0021	.0005	.0018	.0004	.0016	.0004	.0015	.0003
-1.8	.0032	.0007	.0028	.0006	.0024	.0005	.0021	.0005	.0018	.0004	.0016	.0004	.0015	.0003
-1.6	.0032	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0003
-1.4	.0033	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0003
-1.2	.0033	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004	.0015	.0003
-1.0	.0033	.0008	.0028	.0006	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0003
-.8	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.6	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.5	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.4	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.3	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.25	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.20	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004	.0015	.0004
-.15	.0035	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0005	.0017	.0004	.0015	.0004
-.10	.0035	.0008	.0030	.0007	.0025	.0006	.0022	.0005	.0019	.0005	.0017	.0004	.0015	.0004
-.05	.0035	.0008	.0030	.0007	.0025	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0015	.0004
0	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0015	.0004
+.05	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0015	.0004
+.10	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0015	.0004
+.15	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0016	.0004
+.20	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0016	.0004
+.25	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0016	.0004
+.3	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004	.0016	.0004
+.4	.0035	.0008	.0030	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+.5	.0036	.0008	.0030	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+.6	.0036	.0008	.0030	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+.8	.0036	.0008	.0031	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+1.0	.0036	.0008	.0031	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+1.2	.0037	.0008	.0031	.0007	.0027	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+1.4	.0037	.0008	.0031	.0007	.0027	.0006	.0023	.0005	.0020	.0005	.0018	.0004	.0016	.0004
+1.6	.0037	.0008	.0031	.0007	.0027	.0006	.0023	.0005	.0021	.0005	.0018	.0004	.0016	.0004
+1.8	.0037	.0008	.0032	.0007	.0027	.0006	.0024	.0005	.0021	.0005	.0018	.0004	.0016	.0004
+2.0	.0038	.0008	.0032	.0007	.0027	.0006	.0024	.0005	.0021	.0005	.0018	.0004	.0016	.0004
+2.5	.0038	.0009	.0032	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004
+3.0	.0039	.0009	.0033	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004	.0017	.0004
+3.5	.0040	.0009	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004
+4.0	.0041	.0009	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004	.0017	.0004
+4.5	.0041	.0009	.0035	.0008	.0030	.0007	.0026	.0006	.0022	.0005	.0020	.0005	.0017	.0004
+5	.0042	.0009	.0035	.0008	.0030	.0007	.0026	.0006	.0023	.0005	.0020	.0005	.0018	.0004
+6	.0043	.0010	.0036	.0008	.0031	.0007	.0027	.0006	.0023	.0005	.0020	.0005	.0018	.0004
+7	.0045	.0010	.0037	.0008	.0032	.0007	.0027	.0006	.0024	.0005	.0021	.0005	.0018	.0004
+8	.0046	.0010	.0038	.0009	.0033	.0007	.0028	.0006	.0024	.0006	.0021	.0005	.0019	.0004
+9	.0047	.0010	.0039	.0009	.0033	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0019	.0004
+10	.0048	.0011	.0040	.0009	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005	.0020	.0005
+12	.0050	.0011	.0042	.0009	.0036	.0008	.0031	.0007	.0026	.0006	.0023	.0005	.0020	.0005
+14	.0052	.0012	.0044	.0010	.0037	.0008	.0032	.0007	.0027	.0006	.0024	.0006	.0021	.0005
+16	.0054	.0012	.0045	.0010	.0038	.0009	.0033	.0007	.0028	.0006	.0025	.0006	.0022	.0005
+18	.0056	.0012	.0047	.0010	.0039	.0009	.0034	.0008	.0029	.0007	.0025	.0006	.0022	.0005
+20	.0057	.0013	.0048	.0011	.0040	.0009	.0035	.0008	.0030	.0007	.0026	.0006	.0023	.0005
+25	.0060	.0013	.0050	.0011	.0043	.0010	.0037	.0008	.0032	.0007	.0028	.0006	.0024	.0006
+30	.0062	.0014	.0052	.0012	.0044	.0010	.0038	.0009	.0033	.0008	.0029	.0007	.0025	.0006
+35	.0063	.0014	.0053	.0012	.0045	.0010	.0039	.0009	.0034	.0008	.0030	.0007	.0026	.0006
+40	.0065	.0015	.0054	.0012	.0046	.0011	.0040	.0009	.0035	.0008	.0031	.0007	.0027	.0006
+45	.0065	.0015	.0055	.0012	.0047	.0011	.0041	.0009	.0036	.0008	.0031	.0007	.0028	.0006
+50	.0066	.0015	.0056	.0013	.0048	.0011	.0041	.0009	.0036	.0008	.0032	.0007	.0028	.0006
+60	.0067	.0015	.0057	.0013	.0049	.0011	.0042	.0010	.0037	.0008	.0032	.0007	.0029	.0007
+70	.0068	.0015	.0057	.0013	.0049	.0011	.0043	.0010	.0037	.0009	.0033	.0008	.0029	.0007
+80	.0068	.0015	.0058	.0013	.0050	.0011	.0043	.0010	.0038	.0009	.0033	.0008	.0030	.0007
+90	.0068	.0015	.0058	.0013	.0050	.0011	.0043	.0010	.0038	.0009	.0034	.0008	.0030	.0007
+100	.0069	.0015	.0058	.0013	.0050	.0011	.0044	.0010	.0038	.0009	.0034	.0008	.0030	.0007
+∞	.0070	.0016	.0059	.0013	.0051	.0012	.0044	.0010	.0039	.0009	.0035	.0008	.0031	.0007

NACA

TABLE 2.- DOWNWASH FACTOR F FOR $\Delta y_v = 0$, ± 1.25, AND ± 2

$\Delta y_v = 0$								
Δx_v	$F(-\Delta x_v)$	$F(\Delta x_v)$	Δx_v	$F(-\Delta x_v)$	$F(\Delta x_v)$	Δx_v	$F(-\Delta x_v)$	$F(\Delta x_v)$
0.20	-8.1980	12.1980	0.64	-1.7102	5.7102	1.16	-0.6401	4.6401
.21	-7.7315	11.7315	.65	-1.6698	5.6698	1.18	-.6212	4.6212
.22	-7.3083	11.3083	.66	-1.6308	5.6308	1.20	-.6034	4.6034
.23	-6.9227	10.9227	.67	-1.5931	5.5931	1.22	-.5858	4.5858
.24	-6.5700	10.5700	.68	-1.5568	5.5568	1.24	-.5690	4.5690
.25	-6.2462	10.2462	.69	-1.5216	5.5216	1.26	-.5530	4.5530
.26	-5.9481	9.9481	.70	-1.4876	5.4876	1.28	-.5378	4.5378
.27	-5.6727	9.6727	.71	-1.4547	5.4547	1.30	-.5233	4.5233
.28	-5.4181	9.4181	.72	-1.4229	5.4229	1.32	-.5090	4.5090
.29	-5.1807	9.1807	.73	-1.3921	5.3921	1.34	-.4953	4.4953
.30	-4.9602	8.9602	.74	-1.3622	5.3622	1.36	-.4822	4.4822
.31	-4.7545	8.7545	.75	-1.3333	5.3333	1.38	-.4697	4.4697
.32	-4.5622	8.5622	.76	-1.3053	5.3053	1.40	-.4578	4.4578
.33	-4.3821	8.3821	.77	-1.2782	5.2782	1.42	-.4461	4.4461
.34	-4.2155	8.2155	.78	-1.2519	5.2519	1.44	-.4348	4.4348
.35	-4.0542	8.0542	.79	-1.2263	5.2263	1.46	-.4240	4.4240
.36	-3.9046	7.9046	.80	-1.2016	5.2016	1.48	-.4136	4.4136
.37	-3.7635	7.7635	.81	-1.1775	5.1775	1.50	-.4037	4.4037
.38	-3.6303	7.6303	.82	-1.1542	5.1542	1.55	-.3800	4.3800
.39	-3.5044	7.5044	.83	-1.1315	5.1315	1.60	-.3585	4.3585
.40	-3.3852	7.3852	.84	-1.1095	5.1095	1.65	-.3386	4.3386
.41	-3.2721	7.2721	.85	-1.0881	5.0881	1.70	-.3204	4.3204
.42	-3.1649	7.1649	.86	-1.0673	5.0673	1.75	-.3035	4.3035
.43	-3.0629	7.0629	.87	-1.0471	5.0471	1.80	-.2879	4.2879
.44	-2.9660	6.9660	.88	-1.0274	5.0274	1.85	-.2734	4.2734
.45	-2.8737	6.8737	.89	-1.0083	5.0083	1.90	-.2601	4.2601
.46	-2.7858	6.7858	.90	-0.9897	4.9897	1.95	-.2476	4.2476
.47	-2.7019	6.7019	.91	-.9716	4.9716	2.0	-.2361	4.2361
.48	-2.6218	6.6218	.92	-.9540	4.9540	2.1	-.2149	4.2149
.49	-2.5453	6.5453	.93	-.9368	4.9368	2.2	-.1969	4.1969
.50	-2.4721	6.4721	.94	-.9201	4.9201	2.3	-.1807	4.1807
.51	-2.4021	6.4021	.95	-.9038	4.9038	2.4	-.1667	4.1667
.52	-2.3351	6.3351	.96	-.8880	4.8880	2.5	-.1541	4.1541
.53	-2.2708	6.2708	.97	-.8725	4.8725	2.6	-.1428	4.1428
.54	-2.2092	6.2092	.98	-.8574	4.8574	2.7	-.1327	4.1327
.55	-2.1501	6.1501	.99	-.8427	4.8427	2.8	-.1237	4.1237
.56	-2.0933	6.0933	1.00	-.8284	4.8284	2.9	-.1155	4.1155
.57	-2.0387	6.0387	1.02	-.8004	4.8004	3.0	-.1082	4.1082
.58	-1.9863	5.9863	1.04	-.7739	4.7739	3.2	-.0924	4.0924
.59	-1.9359	5.9359	1.06	-.7488	4.7488	3.4	-.0798	4.0798
.60	-1.8873	5.8873	1.08	-.7251	4.7251	3.6	-.0705	4.0705
.61	-1.8405	5.8405	1.10	-.7029	4.7029	3.8	-.0644	4.0644
.62	-1.7955	5.7955	1.12	-.6809	4.6809	4.0	-.0616	4.0616
.63	-1.7521	5.7521	1.14	-.6600	4.6600			

$\Delta y_v = \pm 1.25$		
Δx_v	$F(-\Delta x_v)$	$F(\Delta x_v)$
0.00	-0.3333	-0.3333
.05	-.3195	-.3472
.10	-.3057	-.3610
.15	-.2920	-.3747
.20	-.2786	-.3881
.25	-.2654	-.4013
.30	-.2526	-.4141
.35	-.2401	-.4265
.40	-.2281	-.4386
.45	-.2165	-.4501
.50	-.2054	-.4612
.55	-.1948	-.4698
.60	-.1847	-.4819
.65	-.1751	-.4915
.70	-.1660	-.5007
.75	-.1574	-.5093
.80	-.1490	-.5177
.85	-.1415	-.5251
.90	-.1343	-.5324
.95	-.1274	-.5393
1.0	-.1210	-.5457
1.1	-.1092	-.5575
1.2	-.0988	-.5679
1.3	-.0896	-.5770
1.4	-.0815	-.5852
1.5	-.0791	-.5876
1.6	-.0679	-.5988
1.7	-.0522	-.6044
1.8	-.0572	-.6095
1.9	-.0527	-.6140
2.0	-.0486	-.6180
2.2	-.0418	-.6249
2.4	-.0362	-.6305
2.6	-.0316	-.6351
2.8	-.0278	-.6389
3.0	-.0246	-.6421
3.2	-.0219	-.6447
3.4	-.0196	-.6470
3.6	-.0177	-.6490
3.8	-.0160	-.6507
4.0	-.0146	-.6521

$\Delta y_v = \pm 2$		
Δx_v	$F(-\Delta x_v)$	$F(\Delta x_v)$
0.00	-0.6667	-0.6667
.05	-.6445	-.6889
.10	-.6223	-.7110
.15	-.6004	-.7329
.20	-.5787	-.7546
.25	-.5574	-.7759
.30	-.5365	-.7968
.35	-.5161	-.8172
.40	-.4962	-.8371
.45	-.4769	-.8564
.50	-.4582	-.8752
.55	-.4401	-.8933
.60	-.4227	-.9107
.65	-.4060	-.9275
.70	-.3899	-.9436
.75	-.3744	-.9590
.80	-.3596	-.9738
.85	-.3454	-.9880
.90	-.3318	-1.0016
.95	-.3189	-1.0145
1.0	-.3066	-1.0268
1.1	-.2834	-1.0500
1.2	-.2625	-1.0709
1.3	-.2433	-1.0901
1.4	-.2260	-1.1073
1.5	-.2101	-1.1232
1.6	-.1958	-1.1376
1.7	-.1826	-1.1508
1.8	-.1706	-1.1628
1.9	-.1596	-1.1738
2.0	-.1496	-1.1838
2.2	-.1292	-1.2042
2.4	-.1124	-1.2210
2.6	-.0993	-1.2341
2.8	-.0890	-1.2436
3.0	-.0840	-1.2494
3.2	-.0750	-1.2584
3.4	-.0673	-1.2661
3.6	-.0611	-1.2723
3.8	-.0561	-1.2773
4.0	-.0526	-1.2808

NACA

TABLE 3.- DOWNWASH FACTOR FOR $\Delta z_v = \pm 2$

[All values of the downwash factor are negative except those specifically marked with a plus sign.]

Δx_v \ Δy_v	0	±2	±4	±6	±8	±10	±12	±14	±16	±18	±20	±22	±24	±26	±28	±30
0	+0.4000	+0.0308	0.0584	0.0403	0.0262	0.0179	0.0129	0.0096	0.0075	0.0060	0.0049	0.0040	0.0034	0.0029	0.0025	0.0022
.2	+.4979	+.0448	.0599	.0415	.0268	.0182	.0131	.0098	.0076	.0060	.0049	.0041	.0034	.0029	.0025	.0022
.4	+.5551	+.0582	.0615	.0426	.0274	.0186	.0133	.0099	.0077	.0061	.0050	.0041	.0035	.0030	.0026	.0022
.6	+.6225	+.0703	.0631	.0437	.0280	.0189	.0135	.0100	.0078	.0062	.0050	.0041	.0035	.0030	.0026	.0022
.8	+.6799	+.0808	.0647	.0448	.0286	.0192	.0137	.0102	.0078	.0062	.0051	.0042	.0035	.0030	.0026	.0023
1.0	+.7266	+.0895	.0663	.0459	.0292	.0196	.0139	.0103	.0079	.0063	.0051	.0042	.0035	.0030	.0026	.0023
1.4	+.7903	+.1013	.0696	.0481	.0303	.0202	.0143	.0106	.0081	.0064	.0052	.0043	.0036	.0031	.0026	.0023
2	+.8333	+.1079	.0746	.0512	.0320	.0212	.0149	.0110	.0084	.0066	.0053	.0044	.0037	.0031	.0027	.0023
3	+.8441	+.1039	.0825	.0559	.0347	.0228	.0159	.0116	.0088	.0069	.0056	.0046	.0038	.0032	.0028	.0024
4	+.8364	+.0954	.0893	.0601	.0371	.0242	.0168	.0122	.0093	.0072	.0058	.0048	.0040	.0034	.0029	.0025
5	+.8281	+.0878	.0948	.0635	.0392	.0255	.0176	.0128	.0097	.0075	.0060	.0049	.0041	.0035	.0030	.0026
6	+.8217	+.0820	.0991	.0664	.0410	.0267	.0184	.0134	.0101	.0078	.0062	.0051	.0042	.0036	.0030	.0026
8	+.8136	+.0746	.1049	.0705	.0439	.0287	.0198	.0143	.0108	.0084	.0067	.0054	.0045	.0038	.0032	.0028
10	+.8091	+.0704	.1084	.0733	.0459	.0302	.0209	.0151	.0114	.0088	.0070	.0057	.0047	.0039	.0034	.0029
12	+.8065	+.0679	.1107	.0751	.0474	.0313	.0218	.0158	.0119	.0092	.0073	.0060	.0049	.0041	.0035	.0030
14	+.8049	+.0663	.1121	.0764	.0484	.0322	.0225	.0164	.0124	.0096	.0076	.0062	.0051	.0043	.0036	.0031
16	+.8038	+.0653	.1131	.0772	.0492	.0328	.0230	.0168	.0127	.0099	.0079	.0064	.0053	.0044	.0038	.0032
18	+.8030	+.0645	.1138	.0779	.0498	.0333	.0234	.0172	.0130	.0101	.0081	.0066	.0054	.0046	.0039	.0033
20	+.8024	+.0640	.1143	.0784	.0502	.0337	.0238	.0175	.0133	.0104	.0083	.0067	.0056	.0047	.0040	.0034
25	+.8016	+.0631	.1152	.0792	.0509	.0344	.0244	.0180	.0137	.0108	.0086	.0071	.0059	.0049	.0042	.0036
30	+.8011	+.0626	.1156	.0796	.0513	.0347	.0247	.0183	.0141	.0111	.0089	.0073	.0061	.0051	.0043	.0037
35	+.8008	+.0623	.1159	.0799	.0516	.0350	.0250	.0186	.0143	.0113	.0091	.0074	.0062	.0052	.0045	.0039
40	+.8006	+.0622	.1161	.0801	.0518	.0352	.0251	.0187	.0144	.0114	.0092	.0076	.0063	.0053	.0046	.0039
45	+.8005	+.0620	.1162	.0802	.0519	.0353	.0252	.0188	.0145	.0115	.0093	.0077	.0064	.0054	.0046	.0040
50	+.8004	+.0619	.1163	.0803	.0520	.0354	.0253	.0189	.0146	.0116	.0094	.0077	.0065	.0055	.0047	.0041

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TABLE 4.- DOWNWASH FACTOR FOR $\Delta z_v = \pm 4$

[All values of the downwash factor are negative except those specifically marked with a plus sign.]

Δx_v \ Δy_v	0	±2	±4	±6	±8	±10	±12	±14	±16	±18	±20	±22	±24	±26	±28	±30
0	+0.1176	+0.0612	+0.0020	0.0143	0.0149	0.0125	0.0100	0.0080	0.0065	0.0053	0.0044	0.0038	0.0032	0.0028	0.0024	0.0021
.2	+.1294	+.0676	+.0032	.0143	.0151	.0127	.0102	.0081	.0066	.0054	.0045	.0038	.0032	.0028	.0024	.0021
.4	+.1410	+.0739	+.0045	.0144	.0153	.0129	.0103	.0082	.0067	.0054	.0045	.0038	.0033	.0028	.0024	.0021
.6	+.1522	+.0800	+.0057	.0144	.0156	.0131	.0104	.0083	.0067	.0055	.0046	.0038	.0033	.0028	.0025	.0022
.8	+.1629	+.0860	+.0069	.0145	.0158	.0132	.0106	.0084	.0068	.0056	.0046	.0039	.0033	.0028	.0025	.0022
1.0	+.1731	+.0916	+.0080	.0145	.0160	.0134	.0107	.0085	.0069	.0056	.0047	.0039	.0033	.0029	.0025	.0022
1.4	+.1913	+.1018	+.0101	.0147	.0164	.0138	.0110	.0087	.0070	.0057	.0047	.0040	.0034	.0029	.0025	.0022
2.0	+.2126	+.1140	+.0126	.0150	.0171	.0143	.0114	.0090	.0072	.0059	.0049	.0041	.0035	.0030	.0026	.0022
3.0	+.2339	+.1265	+.0151	.0156	.0182	.0152	.0121	.0095	.0076	.0062	.0051	.0042	.0036	.0031	.0027	.0023
4.0	+.2431	+.1320	+.0158	.0166	.0192	.0161	.0127	.0100	.0079	.0064	.0053	.0044	.0037	.0032	.0027	.0024
5.0	+.2460	+.1336	+.0155	.0176	.0203	.0169	.0133	.0104	.0083	.0067	.0055	.0045	.0038	.0033	.0028	.0024
6.0	+.2463	+.1334	+.0146	.0187	.0213	.0177	.0139	.0109	.0086	.0069	.0057	.0047	.0039	.0034	.0029	.0025
8.0	+.2444	+.1313	+.0124	.0208	.0230	.0190	.0150	.0116	.0092	.0074	.0060	.0050	.0042	.0035	.0030	.0026
10.0	+.2424	+.1293	+.0105	.0224	.0243	.0201	.0158	.0123	.0097	.0078	.0063	.0052	.0044	.0037	.0032	.0028
12.0	+.2407	+.1277	+.0090	.0237	.0254	.0210	.0165	.0129	.0102	.0081	.0066	.0055	.0046	.0039	.0033	.0029
14.0	+.2396	+.1266	+.0080	.0247	.0262	.0217	.0170	.0133	.0106	.0085	.0069	.0057	.0048	.0040	.0035	.0030
16.0	+.2387	+.1257	+.0072	.0254	.0269	.0222	.0175	.0137	.0109	.0087	.0071	.0059	.0049	.0042	.0036	.0031
18.0	+.2381	+.1251	+.0066	.0259	.0274	.0227	.0179	.0141	.0112	.0090	.0073	.0061	.0051	.0043	.0037	.0032
20.0	+.2376	+.1246	+.0061	.0264	.0278	.0230	.0182	.0143	.0114	.0092	.0075	.0062	.0052	.0044	.0038	.0033
25.0	+.2368	+.1239	+.0054	.0271	.0284	.0236	.0187	.0148	.0118	.0096	.0078	.0065	.0055	.0046	.0040	.0034
30.0	+.2364	+.1234	+.0050	.0275	.0288	.0240	.0191	.0151	.0121	.0098	.0081	.0067	.0057	.0048	.0041	.0036
35.0	+.2361	+.1231	+.0047	.0277	.0291	.0242	.0193	.0153	.0123	.0100	.0082	.0069	.0058	.0049	.0043	.0037
40.0	+.2359	+.1230	+.0045	.0279	.0292	.0244	.0195	.0155	.0125	.0101	.0084	.0070	.0059	.0050	.0044	.0038
45.0	+.2358	+.1228	+.0044	.0280	.0293	.0245	.0196	.0156	.0126	.0102	.0085	.0071	.0060	.0051	.0044	.0038
50.0	+.2357	+.1227	+.0043	.0281	.0294	.0246	.0197	.0157	.0126	.0103	.0085	.0072	.0061	.0052	.0045	.0039

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TABLE 5.- DOWNWASH FACTOR FOR $\Delta z_v = \pm 8$

[All values of the downwash factor are negative except those specifically marked with a plus sign.]

Δx_v \ Δy_v	0	±2	±4	±6	±8	±10	±12	±14	±16	±18	±20	±22	±24	±26	±28	±30
0	+0.0308	+0.0257	+0.0151	+0.0058	+0.0001	0.0026	0.0037	0.0039	0.0037	0.0035	0.0031	0.0028	0.0025	0.0022	0.0020	0.0018
.2	+.0323	+.0270	+.0159	+.0061	+.0003	.0026	.0037	.0039	.0038	.0035	.0031	.0028	.0025	.0023	.0020	.0018
.4	+.0338	+.0283	+.0167	+.0065	+.0004	.0025	.0037	.0039	.0038	.0035	.0032	.0028	.0025	.0023	.0020	.0018
.6	+.0354	+.0296	+.0174	+.0069	+.0005	.0025	.0037	.0040	.0038	.0035	.0032	.0029	.0026	.0023	.0020	.0018
.8	+.0369	+.0308	+.0182	+.0073	+.0007	.0025	.0037	.0040	.0039	.0036	.0032	.0029	.0026	.0023	.0021	.0018
1.0	+.0383	+.0321	+.0190	+.0076	+.0008	.0024	.0037	.0040	.0039	.0036	.0032	.0029	.0026	.0023	.0021	.0019
1.4	+.0412	+.0345	+.0205	+.0083	+.0011	.0024	.0037	.0041	.0039	.0036	.0033	.0029	.0026	.0023	.0021	.0019
2.0	+.0453	+.0379	+.0226	+.0094	+.0015	.0023	.0038	.0041	.0040	.0037	.0034	.0030	.0027	.0024	.0021	.0019
3.0	+.0511	+.0428	+.0256	+.0109	+.0021	.0022	.0038	.0043	.0042	.0038	.0035	.0031	.0028	.0025	.0022	.0020
4.0	+.0556	+.0466	+.0281	+.0121	+.0025	.0021	.0039	.0044	.0043	.0040	.0036	.0032	.0028	.0025	.0023	.0020
5.0	+.0588	+.0495	+.0299	+.0130	+.0029	.0020	.0040	.0045	.0044	.0041	.0037	.0033	.0029	.0026	.0023	.0021
6.0	+.0611	+.0514	+.0312	+.0136	+.0031	.0020	.0041	.0047	.0046	.0042	.0038	.0034	.0030	.0027	.0024	.0021
8.0	+.0634	+.0535	+.0326	+.0143	+.0032	.0022	.0043	.0049	.0048	.0045	.0040	.0036	.0032	.0028	.0025	.0022
10	+.0642	+.0541	+.0330	+.0144	+.0031	.0024	.0046	.0052	.0051	.0047	.0042	.0038	.0033	.0029	.0026	.0023
12	+.0643	+.0542	+.0329	+.0143	+.0029	.0026	.0049	.0055	.0053	.0049	.0044	.0039	.0035	.0031	.0027	.0024
14	+.0641	+.0540	+.0327	+.0140	+.0026	.0029	.0051	.0057	.0056	.0051	.0046	.0041	.0036	.0032	.0028	.0025
16	+.0638	+.0537	+.0324	+.0137	+.0024	.0032	.0054	.0060	.0058	.0053	.0048	.0042	.0037	.0033	.0029	.0026
18	+.0636	+.0534	+.0321	+.0135	+.0021	.0034	.0056	.0062	.0060	.0055	.0049	.0043	.0038	.0034	.0030	.0027
20	+.0633	+.0532	+.0319	+.0132	+.0019	.0036	.0058	.0063	.0061	.0056	.0050	.0045	.0039	.0035	.0031	.0027
25	+.0628	+.0527	+.0314	+.0128	+.0015	.0040	.0062	.0067	.0064	.0059	.0053	.0047	.0041	.0037	.0032	.0029
30	+.0625	+.0524	+.0311	+.0125	+.0012	.0043	.0065	.0069	.0067	.0061	.0055	.0049	.0043	.0038	.0034	.0030
35	+.0623	+.0521	+.0309	+.0122	+.0009	.0045	.0067	.0071	.0068	.0063	.0056	.0050	.0044	.0039	.0035	.0031
40	+.0621	+.0520	+.0307	+.0121	+.0008	.0047	.0068	.0073	.0070	.0064	.0058	.0051	.0045	.0040	.0036	.0032
45	+.0620	+.0519	+.0306	+.0120	+.0007	.0048	.0069	.0074	.0071	.0065	.0058	.0052	.0046	.0041	.0036	.0032
50	+.0619	+.0518	+.0305	+.0119	+.0006	.0049	.0070	.0074	.0071	.0066	.0059	.0053	.0047	.0042	.0037	.0033

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TABLE 6.- DOWNWASH FACTOR FOR $\Delta z_v = \pm 12$

[All values of the downwash factor are negative except those specifically marked with a plus sign.]

Δx_v \ Δy_v	0	±2	±4	±6	±8	±10	±12	±14	±16	±18	±20	±22	±24	±26	±28	±30
0	+0.0138	+0.0127	+0.0100	+0.0067	+0.0037	+0.0015	+0.0000	0.0009	0.0014	0.0016	0.0017	0.0017	0.0017	0.0016	0.0015	0.0014
.2	+.0143	+.0131	+.0103	+.0069	+.0039	+.0016	+.0001	.0009	.0014	.0016	.0017	.0017	.0017	.0016	.0015	.0014
.4	+.0147	+.0136	+.0106	+.0071	+.0040	+.0017	+.0001	.0008	.0014	.0016	.0017	.0017	.0017	.0016	.0015	.0014
.6	+.0152	+.0140	+.0110	+.0074	+.0042	+.0018	+.0001	.0008	.0014	.0016	.0017	.0017	.0017	.0016	.0015	.0014
.8	+.0156	+.0144	+.0113	+.0076	+.0043	+.0018	+.0002	.0008	.0014	.0016	.0018	.0018	.0017	.0016	.0015	.0014
1.0	+.0161	+.0148	+.0116	+.0078	+.0045	+.0019	+.0002	.0008	.0014	.0017	.0018	.0018	.0017	.0016	.0015	.0014
1.4	+.0170	+.0156	+.0123	+.0083	+.0047	+.0021	+.0003	.0008	.0014	.0017	.0018	.0018	.0017	.0016	.0015	.0014
2.0	+.0183	+.0168	+.0132	+.0090	+.0051	+.0023	+.0004	.0007	.0014	.0017	.0018	.0018	.0017	.0017	.0016	.0015
3.0	+.0203	+.0187	+.0147	+.0100	+.0058	+.0027	+.0006	.0006	.0013	.0017	.0018	.0018	.0018	.0017	.0016	.0015
4.0	+.0221	+.0204	+.0161	+.0109	+.0064	+.0030	+.0008	.0006	.0013	.0017	.0019	.0019	.0018	.0017	.0016	.0015
5.0	+.0236	+.0218	+.0172	+.0118	+.0069	+.0033	+.0009	.0005	.0013	.0017	.0019	.0019	.0019	.0018	.0017	.0016
6.0	+.0249	+.0230	+.0182	+.0124	+.0074	+.0036	+.0011	.0005	.0013	.0017	.0019	.0020	.0019	.0018	.0017	.0016
8.0	+.0267	+.0247	+.0196	+.0135	+.0080	+.0040	+.0013	.0004	.0014	.0018	.0020	.0020	.0020	.0019	.0018	.0017
10	+.0278	+.0257	+.0205	+.0141	+.0084	+.0042	+.0014	.0004	.0014	.0019	.0021	.0021	.0021	.0020	.0019	.0017
12	+.0284	+.0263	+.0209	+.0144	+.0086	+.0043	+.0014	.0004	.0014	.0019	.0022	.0022	.0022	.0021	.0019	.0018
14	+.0287	+.0266	+.0211	+.0146	+.0087	+.0043	+.0014	.0005	.0015	.0020	.0022	.0023	.0022	.0021	.0020	.0019
16	+.0288	+.0266	+.0212	+.0146	+.0087	+.0043	+.0013	.0005	.0016	.0021	.0023	.0024	.0023	.0022	.0021	.0019
18	+.0288	+.0266	+.0212	+.0146	+.0087	+.0042	+.0012	.0006	.0017	.0022	.0024	.0024	.0024	.0023	.0021	.0020
20	+.0288	+.0266	+.0211	+.0145	+.0086	+.0041	+.0012	.0007	.0017	.0023	.0025	.0025	.0024	.0023	.0022	.0020
25	+.0286	+.0264	+.0209	+.0143	+.0084	+.0039	+.0010	.0009	.0019	.0024	.0027	.0027	.0026	.0025	.0023	.0021
30	+.0284	+.0262	+.0207	+.0143	+.0082	+.0038	+.0008	.0011	.0021	.0026	.0028	.0028	.0027	.0026	.0024	.0022
35	+.0282	+.0261	+.0206	+.0140	+.0081	+.0036	+.0006	.0012	.0022	.0027	.0029	.0029	.0028	.0027	.0025	.0023
40	+.0281	+.0259	+.0205	+.0139	+.0080	+.0035	+.0005	.0013	.0023	.0028	.0030	.0030	.0029	.0028	.0026	.0024
45	+.0280	+.0258	+.0203	+.0138	+.0079	+.0034	+.0005	.0014	.0024	.0029	.0031	.0031	.0030	.0028	.0026	.0024
50	+.0280	+.0258	+.0203	+.0137	+.0078	+.0034	+.0004	.0014	.0024	.0029	.0031	.0031	.0030	.0029	.0027	.0025

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TABLE 7.- TABLE FOR CALCULATION OF DOWNWASH BY MEANS OF DOWNWASH TABLES

	Downwash points				
	1	2	3	4	5
x					
y					
z					
x_v					
y_v					
z_v					

Lift points

$\frac{y}{b/2}$	Values of $\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}C_L}$ ↓	x	x_v	y_v	Δy_v (1)	Δx_v (1)	F (1)	Δy_v (2)	Δx_v (2)	F (2)	Δy_v (3)	Δx_v (3)	F (3)	Δy_v (4)	Δx_v (4)	F (4)	Δy_v (5)	Δx_v (5)	F (5)
-0.9625				-19.25															
-.9				-18															
-.8				-16															
-.7				-14															
-.6				-12															
-.5				-10															
-.4				-8															
-.3				-6															
-.2				-4															
-.1				-2															
0				0															
.1				2															
.2				4															
.3				6															
.4				8															
.5				10															
.6				12															
.7				14															
.8				16															
.9				18															
.9625				19.25															
Sum of products																			

TABLE 8.- TABLE FOR CALCULATION OF DOWNWASH

BY MEANS OF CHARTS

Station/(b/2)	$\frac{cc_l}{b/2}$ or $\frac{cc_l}{\bar{c}}$	Downwash points				
		1	2	3	4	5
-0.9625						
-.9						
-.8						
-.7						
-.6						
-.5						
-.4						
-.3						
-.2						
-.1						
0						
.1						
.2						
.3						
.4						
.5						
.6						
.7						
.8						
.9						
.9625						
Sum of products						

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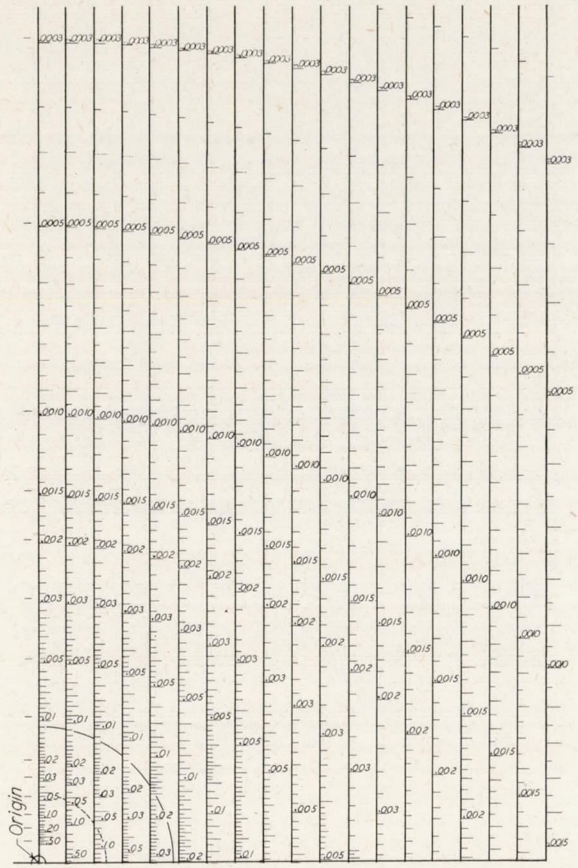
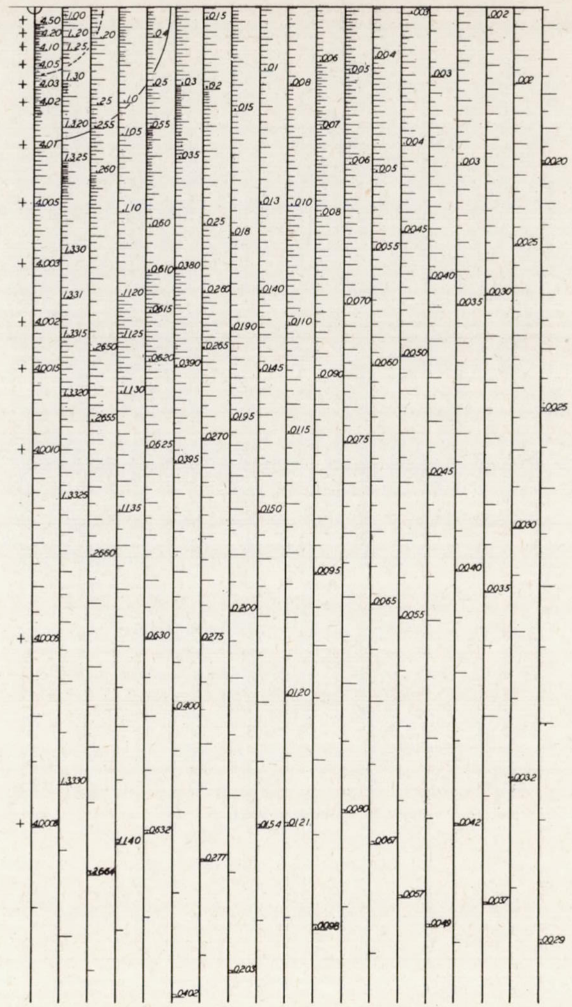
Join here.

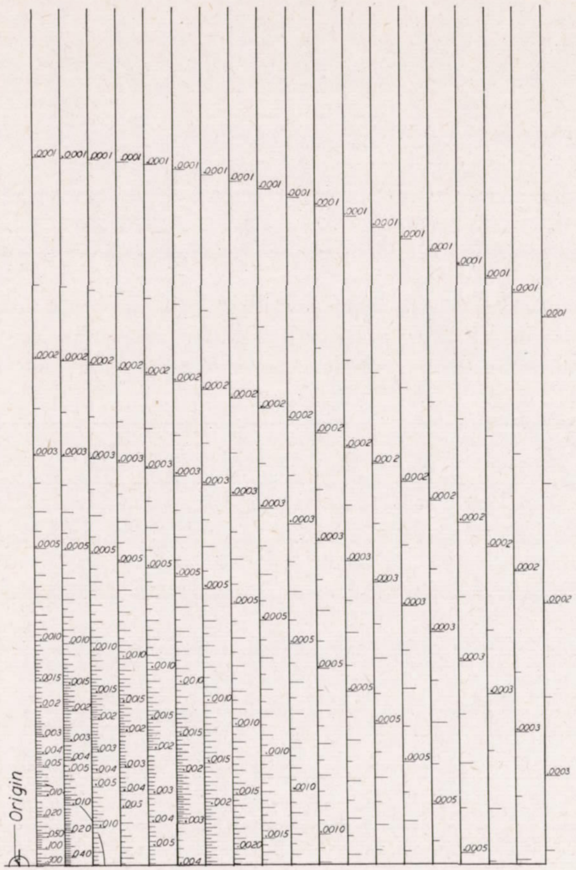




Join here.
Top part of figure 1(a).

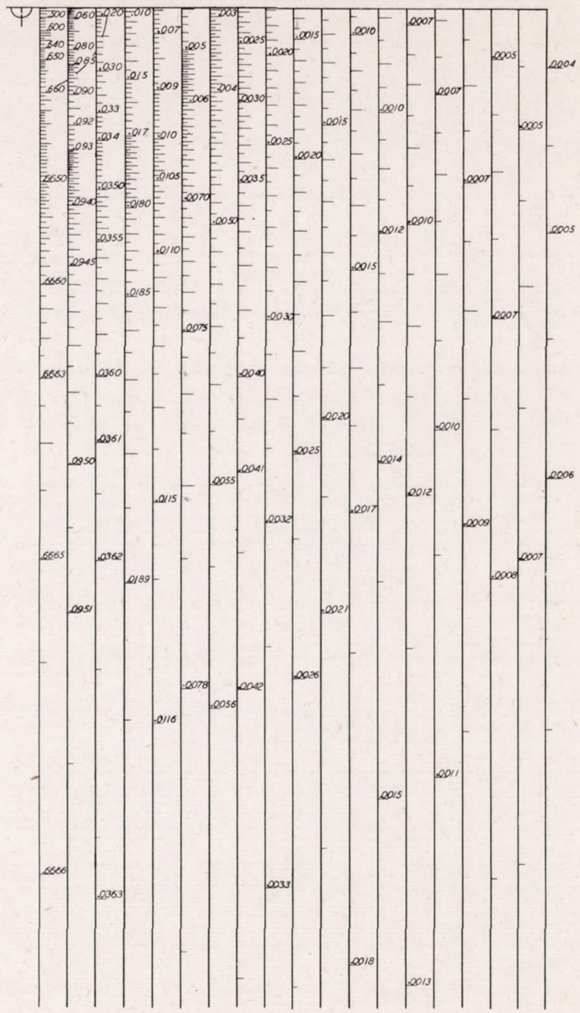
(a) Main vortices. (All values are negative except those specifically marked with a plus sign.)

Figure 1.- Downwash charts for plane of wake. (Full-size figure will be found in the flap at the back of this paper.)



Join here.
Top part of figure 1(b).

Join here.



(b) Corrector vortices. (All values are negative.)

Figure 1.- Concluded.

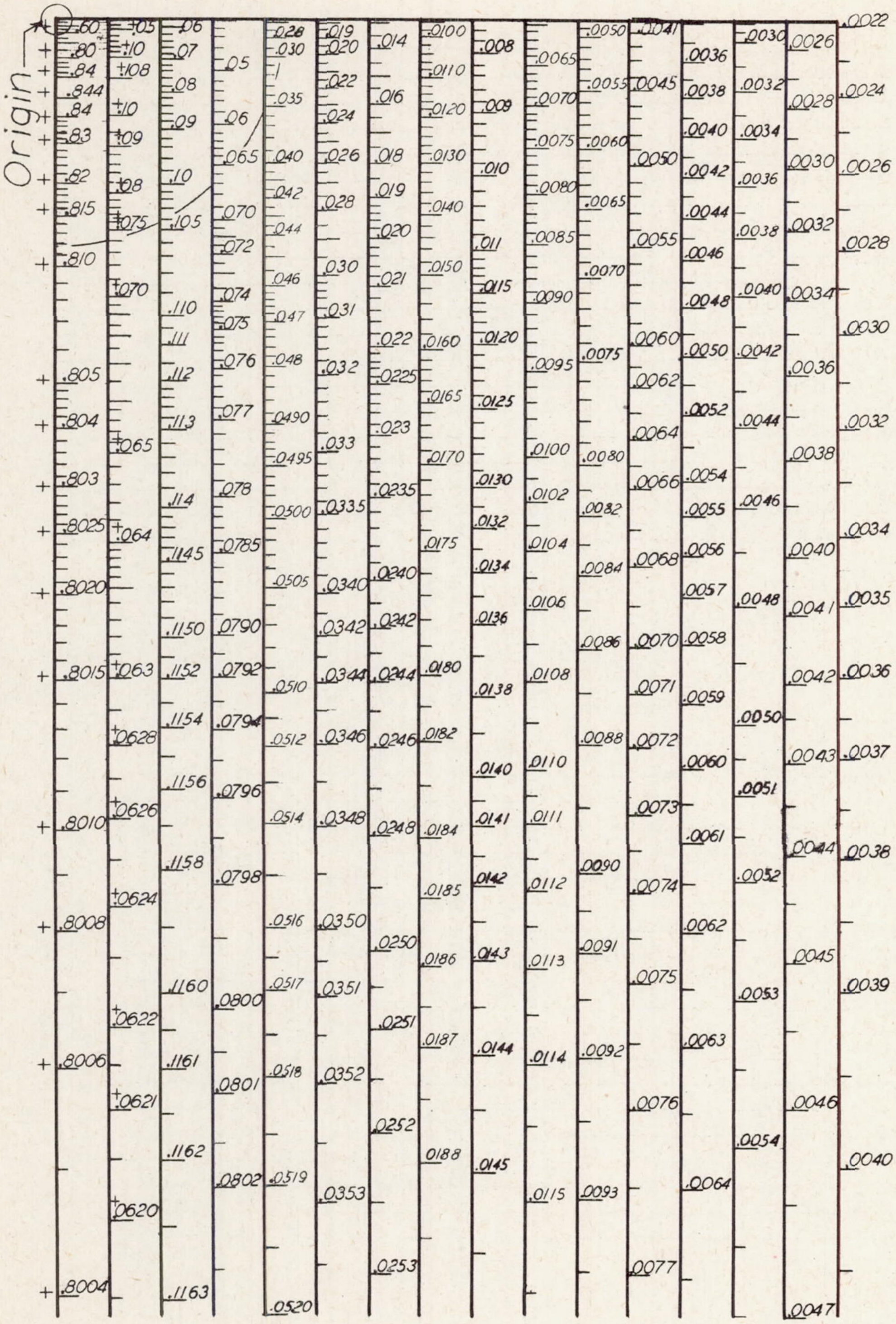


Figure 2.- Downwash chart for points 0.1 semispan above plane of wake. (All values are negative except those specifically marked with a plus sign.) (Full-size figure will be found in the flap at the back of this paper.)

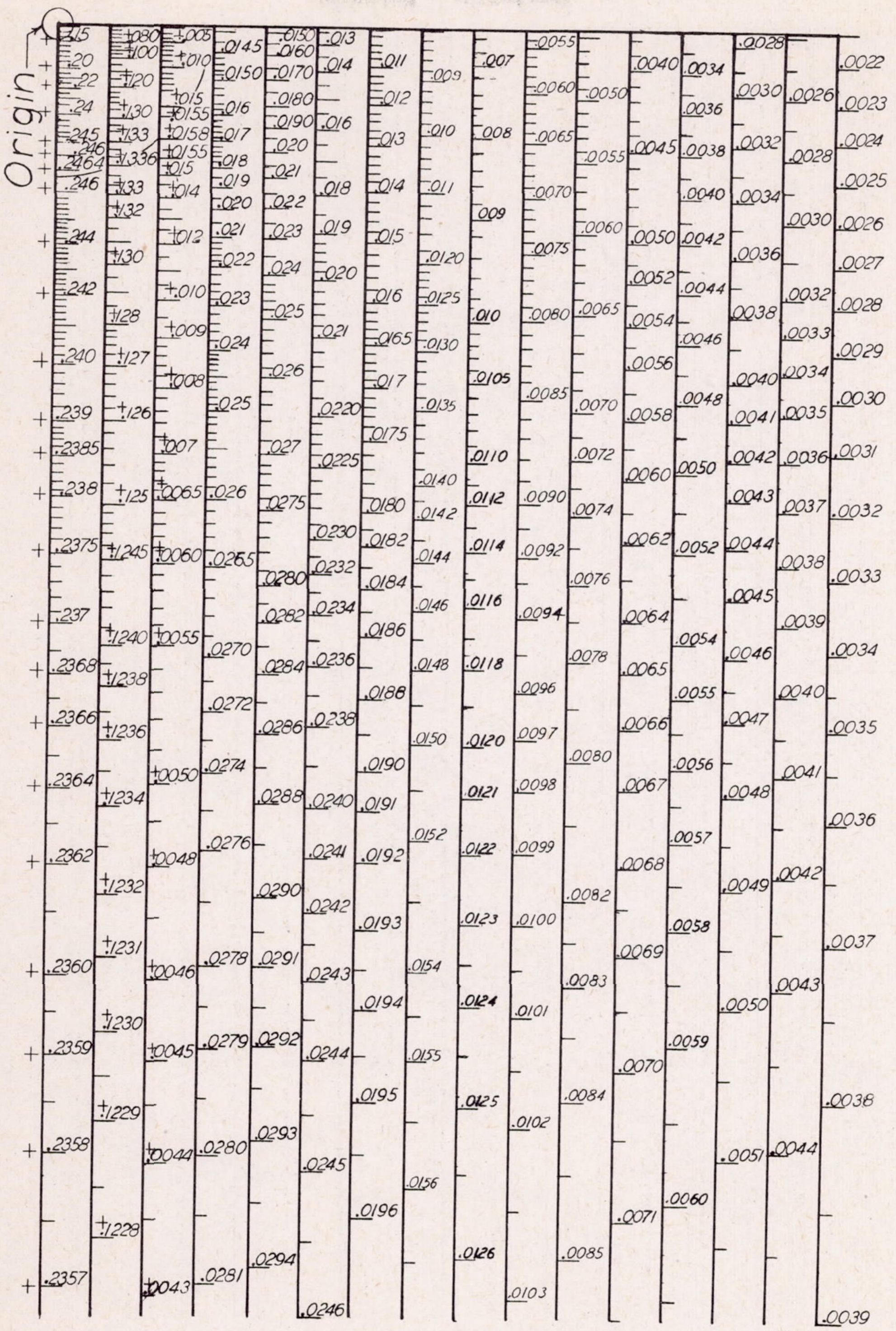


Figure 3.- Downwash chart for points 0.2 semispan above plane of wake. (All values are negative except those specifically marked with a plus sign.) (Full-size figure will be found in the flap at the back of this paper.)

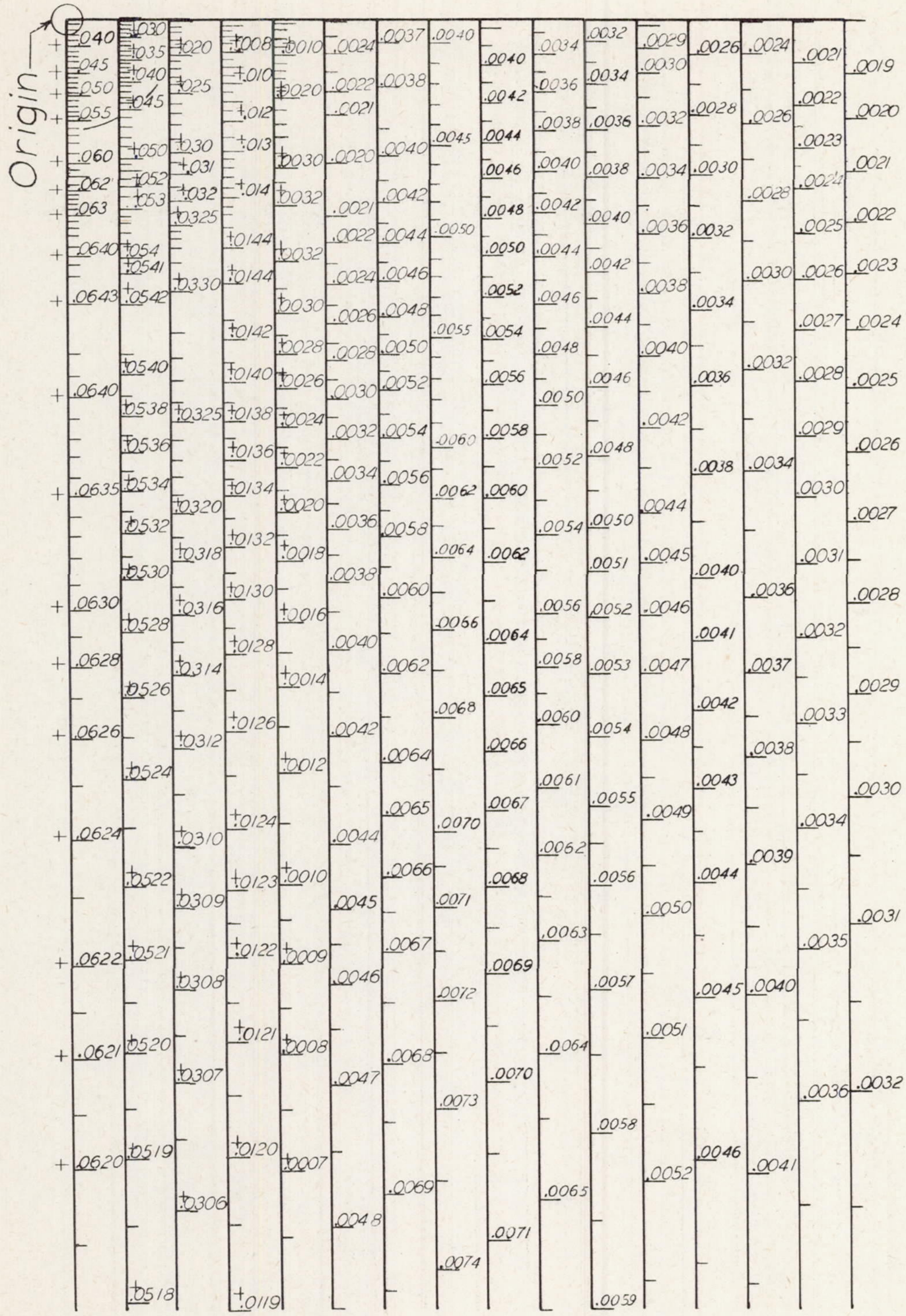


Figure 4.- Downwash chart for points 0.4 semispan above plane of wake. (All values are negative except those specifically marked with a plus sign.) (Full-size figure will be found in the flap at the back of this paper.)

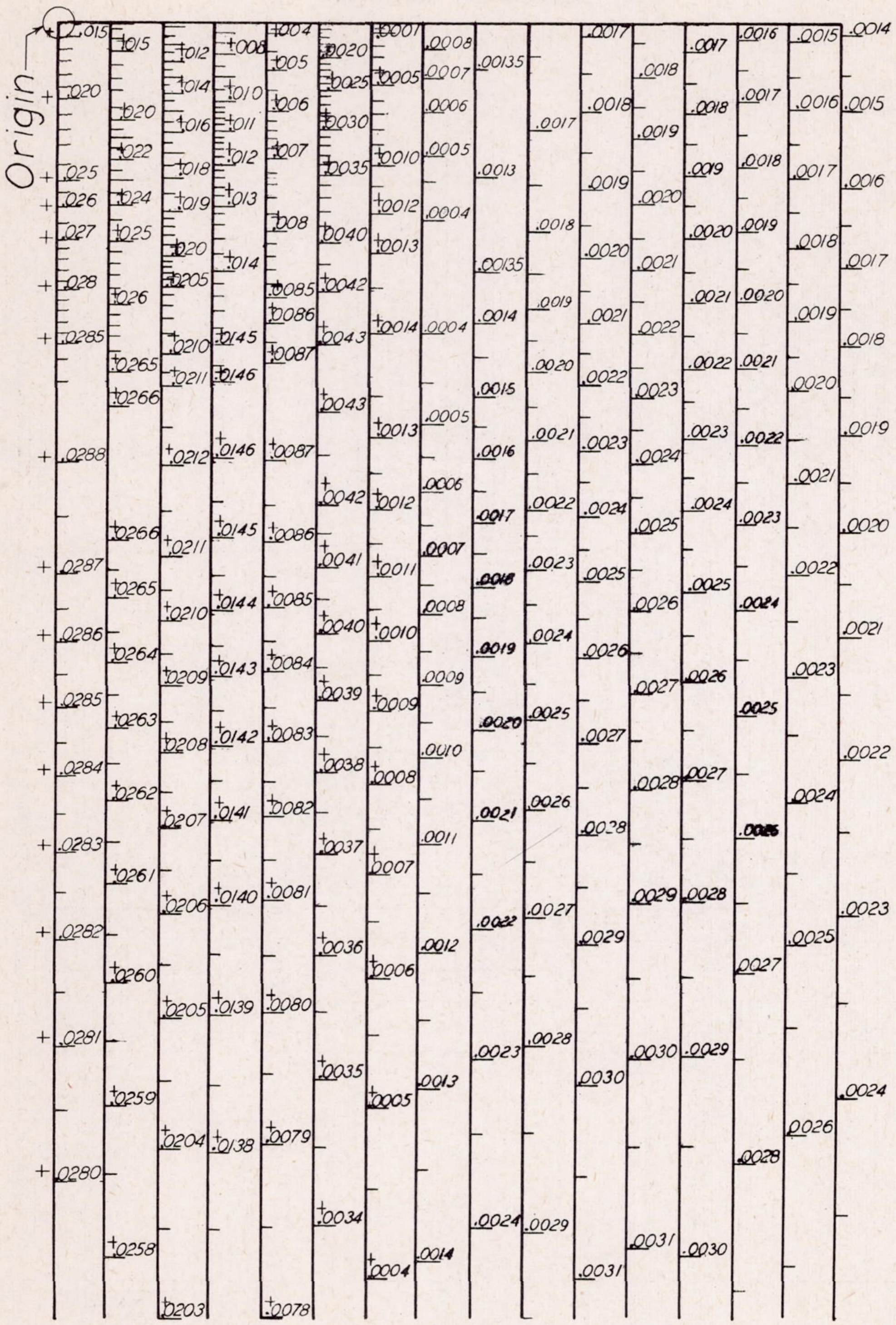
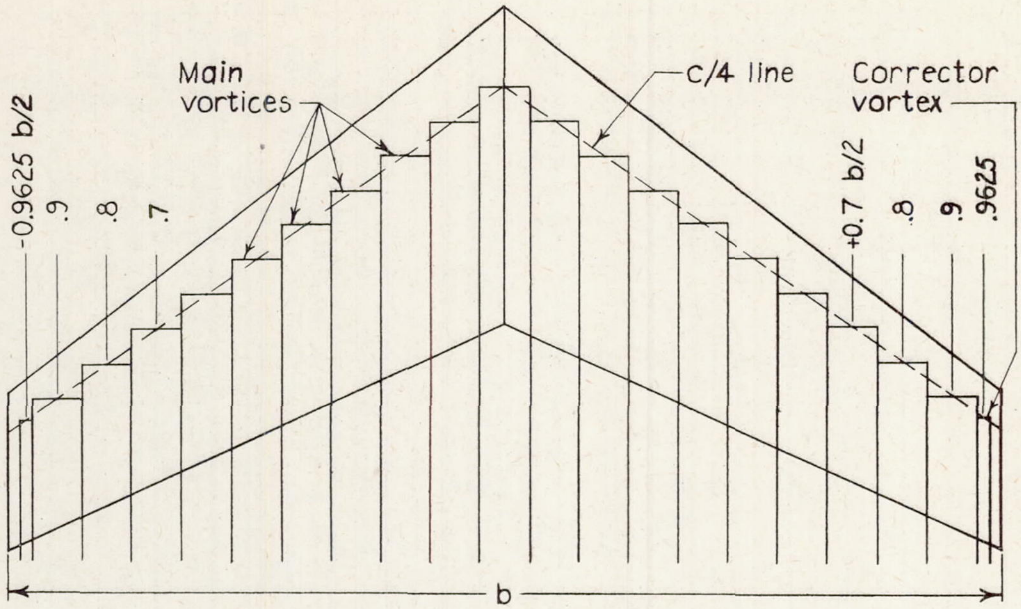
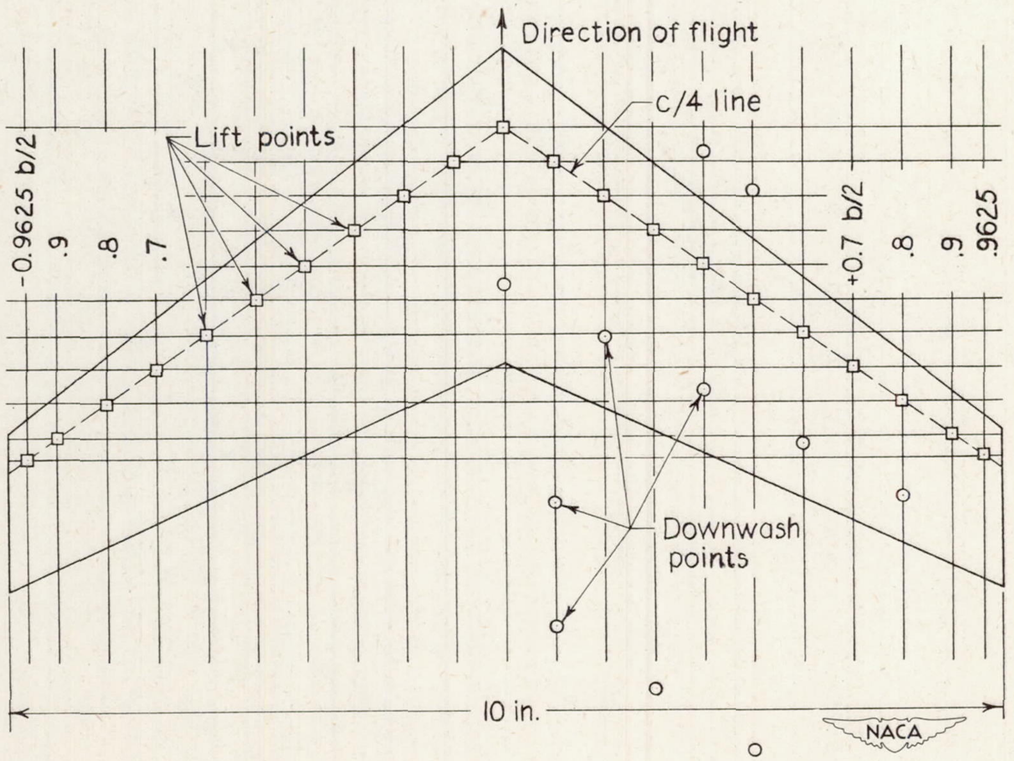


Figure 5.- Downwash chart for points 0.6 semispan above plane of wake. (All values are negative except those specifically marked with a plus sign.) (Full-size figure will be found in the flap at the back of this paper.)

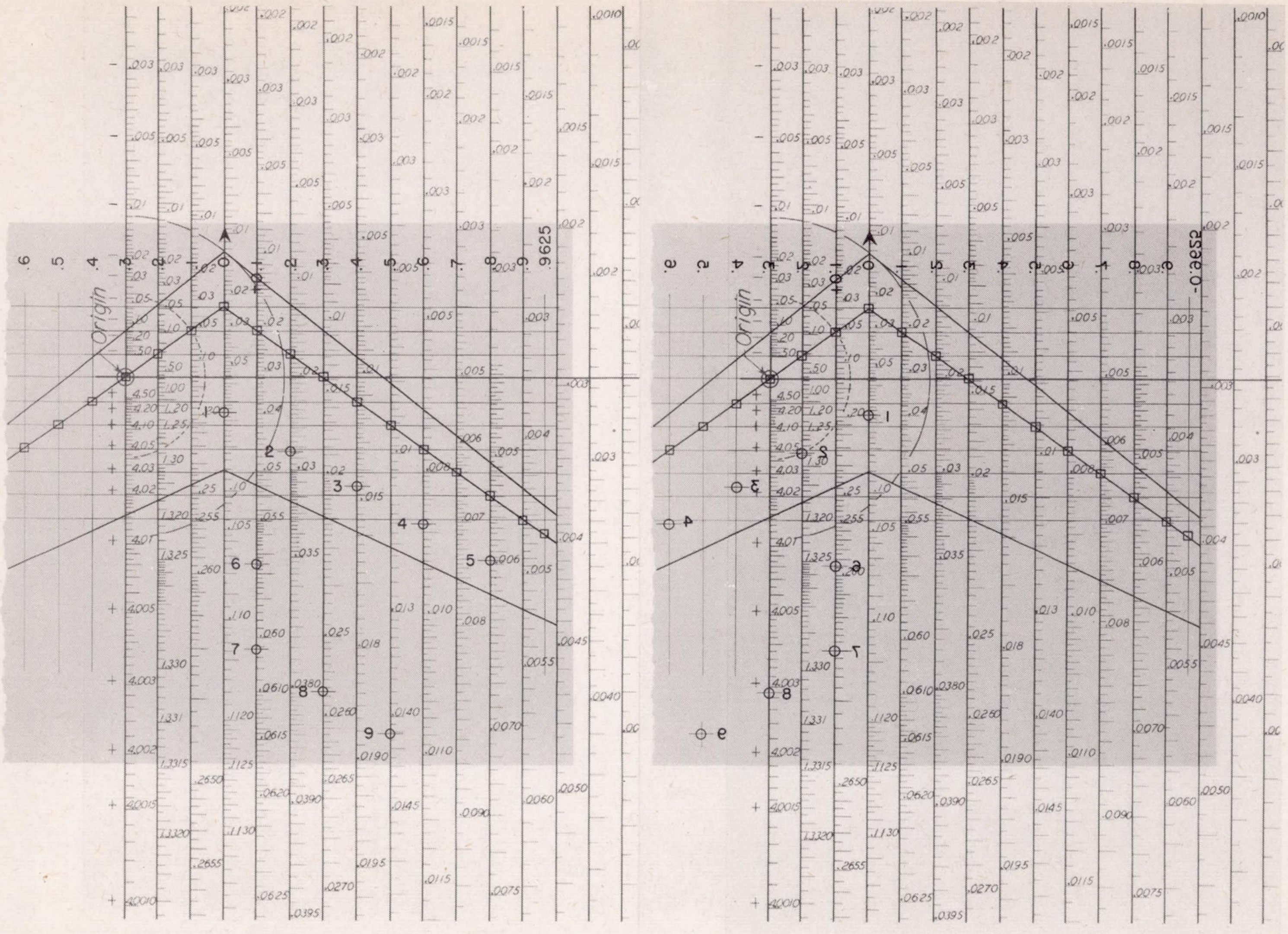


(a) Location of horseshoe vortices.



(b) Location of lift and downwash points.

Figure 6.- Definitions of geometrical terms.



(a) Plan form in normal position.

(b) Plan form in inverted position.

Figure 7.- Use of charts.

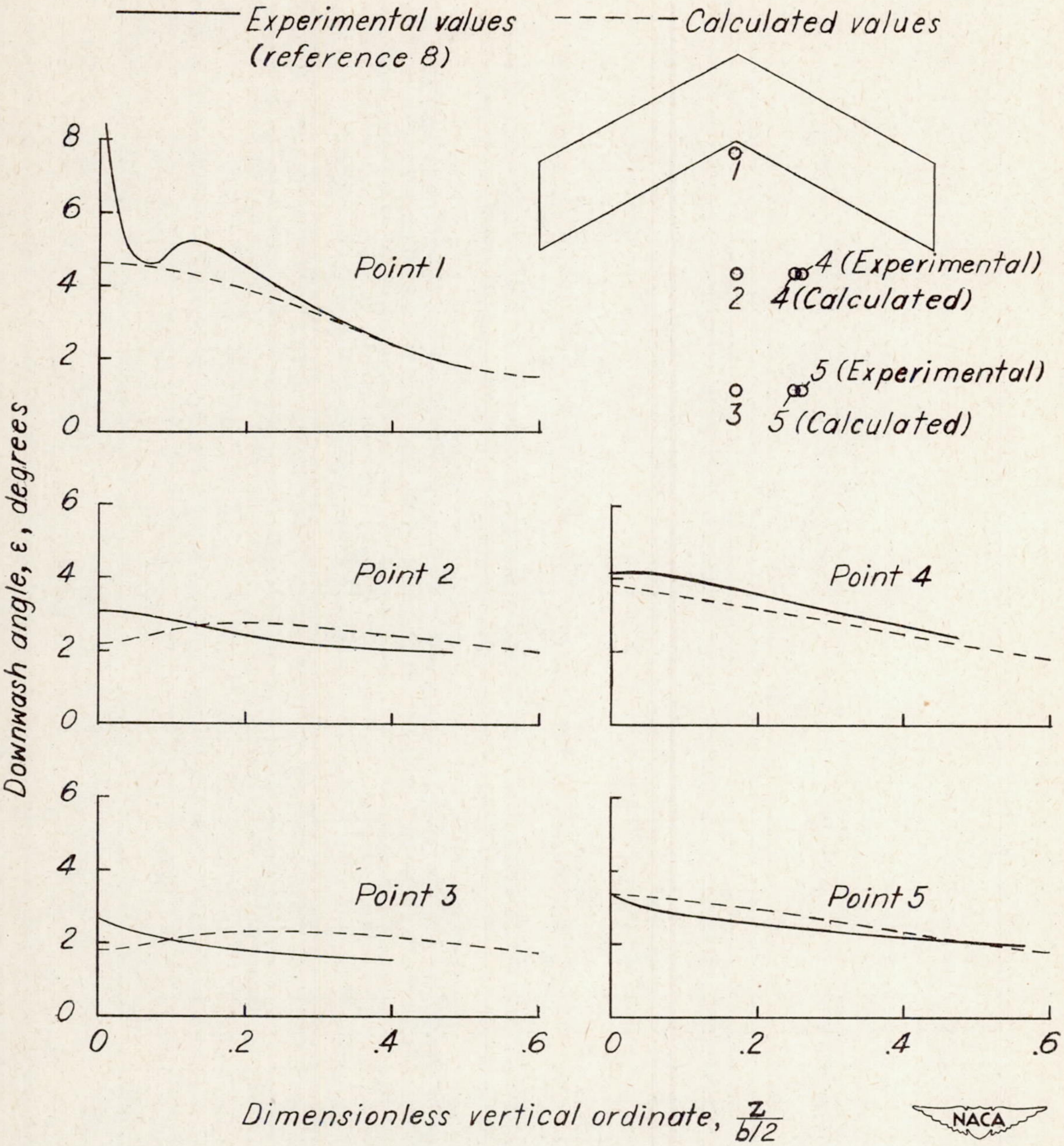


Figure 8.- Downwash angles behind 30° sweptback wing. $A = 4.5$; $\lambda = 1$; $\alpha = 8.18^{\circ}$.

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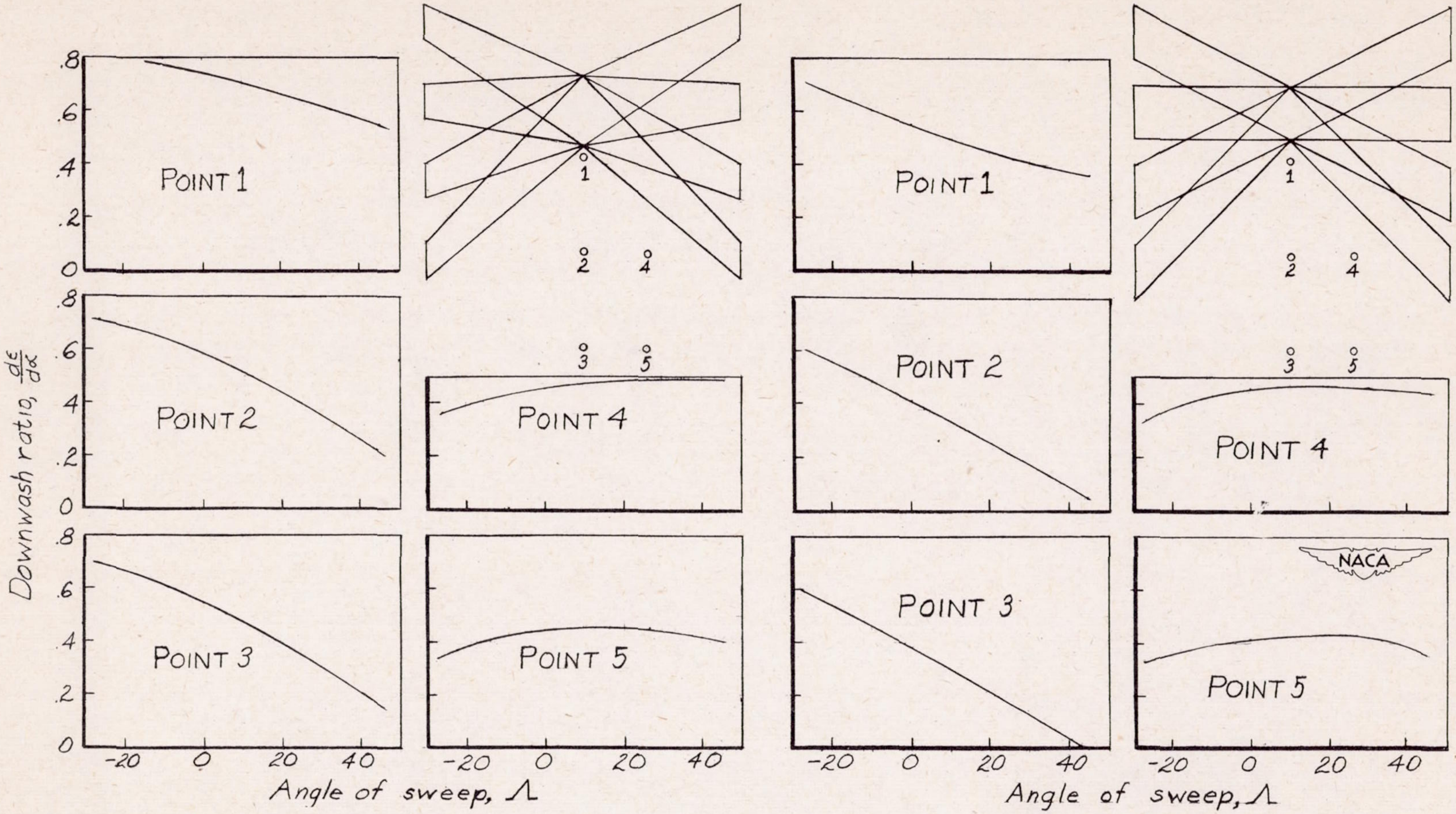

(a) Taper ratio = 0.5.

(b) Taper ratio = 1.0.

Figure 9.- Theoretical (linearized potential flow) downwash ratio $d\epsilon/d\alpha$ in plane of wake (A = 6).