NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1752

JET-BOUNDARY-INDUCED-UPWASH VELOCITIES FOR SWEPT REFLECTION-PLANE MODELS MOUNTED VERTICALLY IN 7- BY 10-FOOT, CLOSED, RECTANGULAR WIND TUNNELS

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SUMMARY

Numerical values of the calculated boundary-induced-upwash velocities necessary for the determination of the jet-boundary corrections for swept reflection-plane models mounted vertically in 7- by 10-foot, closed, rectangular wind tunnels are presented in chart form. A few calculations made by using these values of upwash, indicated that for plan forms having taper ratios of about 1/2, sweep has essentially no effect on the correction. Except for extreme cases of inverse taper the effect of sweep appears to be less than 10 percent for sweep angles up to 60°.

INTRODUCTION

The general methods of calculating the various corrections necessitated by the influence of the jet boundaries upon the characteristics of semispan models mounted on reflection planes in rectangular wind tunnels have been developed in reference 1. Also presented in reference 1 are numerical values of the corrections for unswept wings mounted from the 7-foot wall in 7- by 10-foot, closed, rectangular wind tunnels.

The purpose of the present paper is to present values of the jet-boundary-induced-upwash velocities from which the corrections for swept wings mounted from the 10-foot wall in 7- by 10-foot, closed, rectangular wind tunnels can be calculated by the methods of reference 1.

SYMBOLS

w induced-upwash velocity

Γ circulation strength of vortex

s	vortex semispan
S	wing semi-area
b	wing span
C	tunnel cross-sectional area, 70 square feet
c	local wing chord
x	distance parallel to X-axis
y	distance from reflection wall
δ_{ll}	jet-boundary correction factor for induced angle at lifting line (total)
δ_{ll}'	jet-boundary correction factor at lifting line for untapered wing
K_λ	taper factor
λ	taper ratio (Tip chord/Root chord)
Λ_{ll}	sweep angle of lifting line, positive when swept back
h	tunnel height, 7 feet
a	tunnel width, 10 feet

RESULTS AND DISCUSSION

Boundary-Induced-Upwash Velocities

A complete discussion of the image method of satisfying the boundary condition and calculating the induced upwash velocity for closed rectangular tunnels is presented in reference 1. The boundary-induced-upwash velocity at the lifting line of an unswept wing may be determined from a two-dimensional image arrangement satisfying the boundary conditions for a single trailing vortex and its reflection. Values of this boundary-induced-upwash velocity for trailing vortices located at various distances s from the reflection wall are presented in figure 1.

The upwash velocity at the lifting line for swept wings may be determined by the use of horseshoe-type vortices with swept bound vortices. This method, however, is very tedious (see reference 2) and would entail calculations for wings of various spans and various sweep angles. A simpler method in which the swept lifting line, or bound vortex, is replaced by a stepped lifting line which is obtained by superimposing horseshoe-type vortices of various spans at various positions along the lifting line is illustrated in figure 2. Inasmuch as stepped vortex lines with relatively few steps have been used satisfactorily in wing theory, this method seems to be sufficiently accurate for determining the boundary-induced-upwash velocity. All the trailing vortices except the one at the tip have been canceled (fig. 2) and represent a wing with a rectangular-type loading which in most cases approximates the actual loading well enough for the determination of the boundary-induced-upwash velocity. Reference 3 has shown that the upwash velocity is mainly dependent upon the total lift and is relatively independent of the lift distribution. However, if a more accurate approximation of the actual load distribution is desired it may be obtained by breaking up the actual loading into steps, as in reference 1, and by assigning the strength of each step to the corresponding positive horseshoe-type vortex in figure 2. The strength of each negative horseshoe-type vortex is equal to the strength of the positive horseshoe-type vortex, the bound vortex of which coincides with that of the negative horseshoe-type vortex. For example, vortex C has the same strength as vortex B but is of opposite sign and leaves a trailing vortex between vortex A and vortex B of strength equal to the difference between vortex A and vortex B.

Figure 2 shows that when the upwash velocity along the lifting line due to each horseshoe-type vortex is being determined the upwash velocity ahead of and behind each horseshoe-type vortex must be known. Since figure 1 presents only the upwash velocity at the horseshoe-type vortex, additional calculations have been made and are presented in figure 3. This figure presents the additional upwash velocity at various distances y from the reflection wall and x behind the lifting line of various horseshoe-type vortices of semispan s. In determining the upwash velocity at a point behind the horseshoe-type vortex the value from figure 3 is added to that of figure 1. If, however, the point in question is ahead of the horseshoe-type vortex the value from figure 3 is subtracted from that of figure 1.

The boundary-induced-upwash velocity along various swept lifting lines has been determined by using figures 1 and 3 and is presented in figure 4. These values are based on a rectangular loading and a stepped lifting line where each step had a span of 1 foot. (See fig. 2.) In order to determine the upwash velocity along the span of a given wing, the sweep of the lifting line (usually the quarter-chord line) and the effective vortex semispan (usually about 90-percent wing semispan) must be determined. Once these two factors are known the upwash velocity at any point y along the lifting line can be obtained from figure 4.

Figure 4 can also be used to determine the boundary-induced-upwash velocity for any type loading by superposition of various rectangular loadings.

Correction Factors

Once the induced velocities have been determined the various correction factors may be obtained by the methods described in reference 1. In order to determine the order of magnitude of the sweep effect on the angle-of-attack correction, the correction factor at the lifting line δ_{ll} has been determined for various sweep angles and is presented in figure 5. This factor was calculated by the following formula which weights the effect of the boundary-induced-upwash velocity according to the local chord:

$$\delta_{ll} = \frac{C}{2sS} \int_{0}^{b/2} \frac{w}{\Gamma} c \, dy$$

Inasmuch as the taper effect is rather small, the actual variation of δ_{ll} with taper was replaced by a linear variation which resulted in the following expression:

$$\delta_{ll} = \delta_{ll}' + K_{\lambda} \left(1.0 - \lambda\right)$$

where δ_{ll}', the jet-boundary correction factor at the lifting line for untapered wing, and K_{λ}, the taper factor, are presented in figure 5. A rectangular span loading and a vortex semispan equal to 0.9 of the wing semispan were assumed for these calculations. The correction factor increases with sweepback for the untapered wings and decreases with sweepback for the highly tapered wing. However, for plan forms having taper ratios of about 1/2, sweep has essentially no effect on the correction. Except for extreme cases of inverse taper the effect of sweep appears to be less than 10 percent for sweep angles up to 60°.

In figure 5 the span is presented in terms of the tunnel height. Therefore, these correction factors can be used in determining the correction for any tunnel having the same height-to-width ratio.

CONCLUDING REMARKS

The boundary-induced-upwash velocity behind and ahead of the lifting line has been calculated and the values are presented in chart form. From these charts the boundary-induced-upwash velocity for swept reflection-plane wings mounted vertically in 7- by 10-foot, closed, rectangular wind tunnels can be determined. The various correction factors can then be calculated by previously developed methods.

Calculations have shown that for plan forms having taper ratios of about 1/2, sweep has essentially no effect on the correction. Except for extreme cases of inverse taper the effect of sweep appears to be less than 10 percent for sweep angles up to 60°.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 13, 1948

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2. Swanson, Robert S.: Jet-Boundary Corrections to a Yawed Model in a Closed Rectangular Wind Tunnel. NACA ARR, Feb. 1943.

3. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA ARR No. L5G31, 1945.

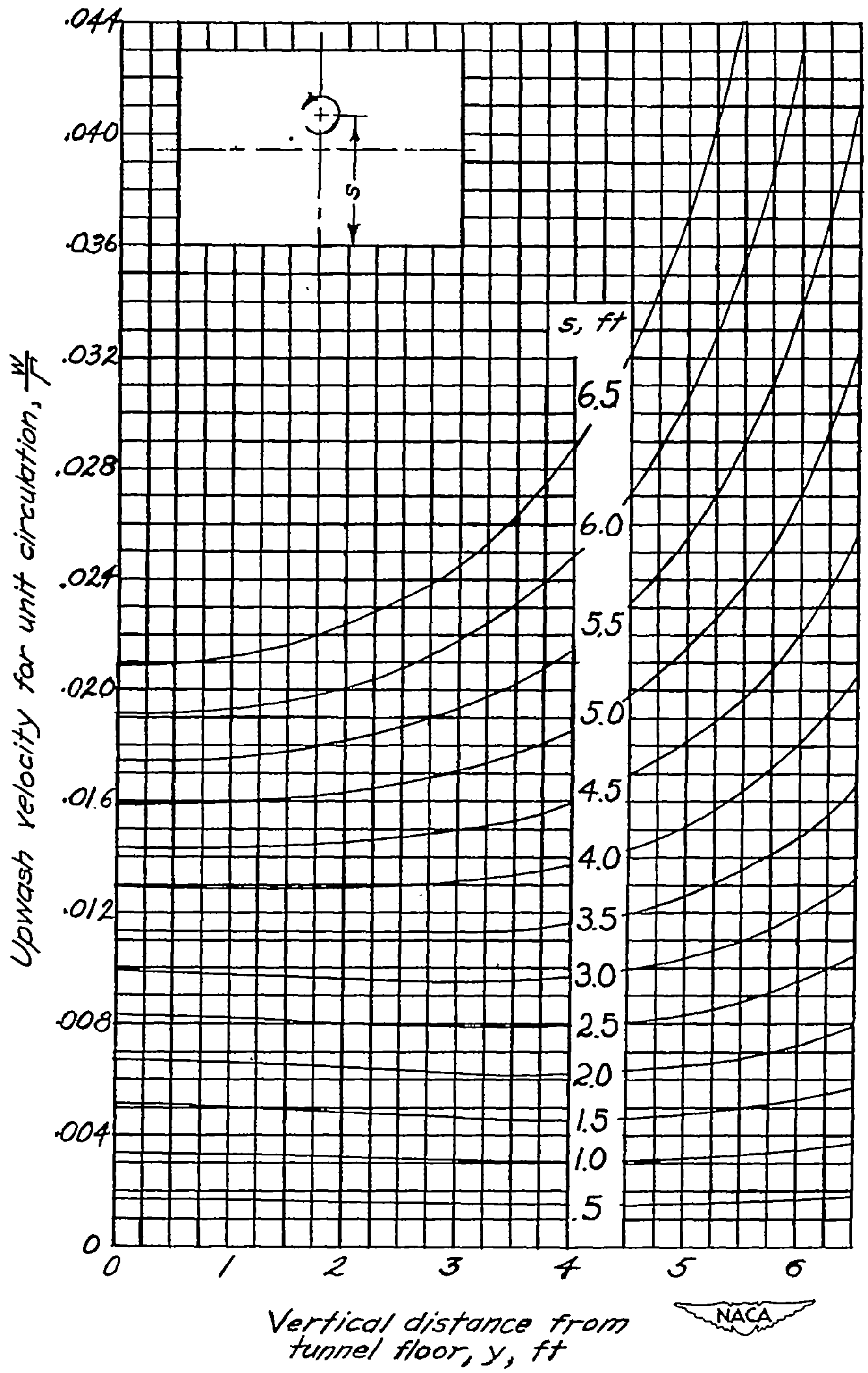


Figure 1.—Boundary-induced-upwash velocity at the lifting line due to a single trailing vortex located at various distances s from the floor of a 7-by 10-foot, closed, rectangular wind tunnel.

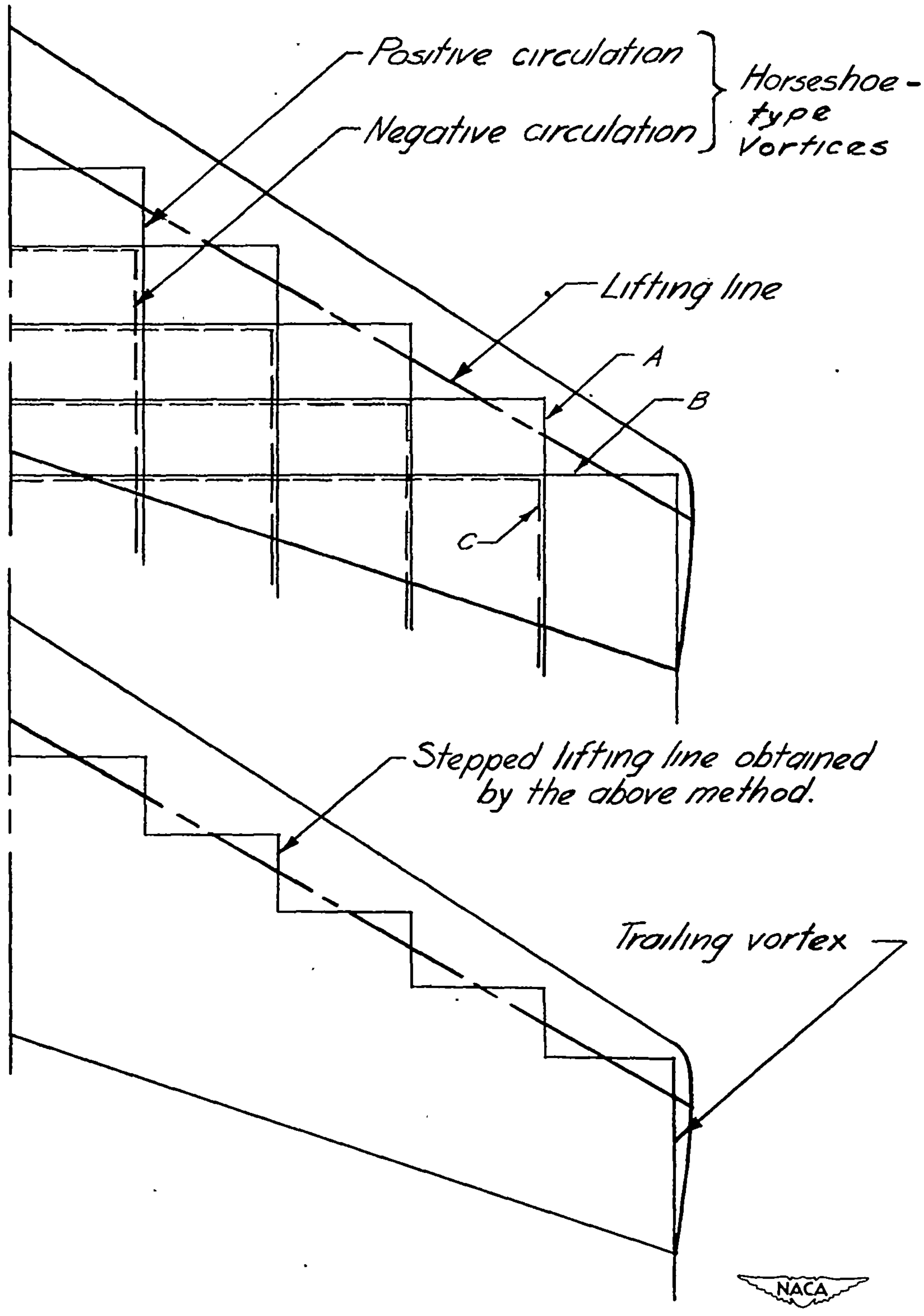


Figure 2.- Method by which the swept lifting line is replaced with a stepped line for the determining of the boundary-induced-upwash velocity.

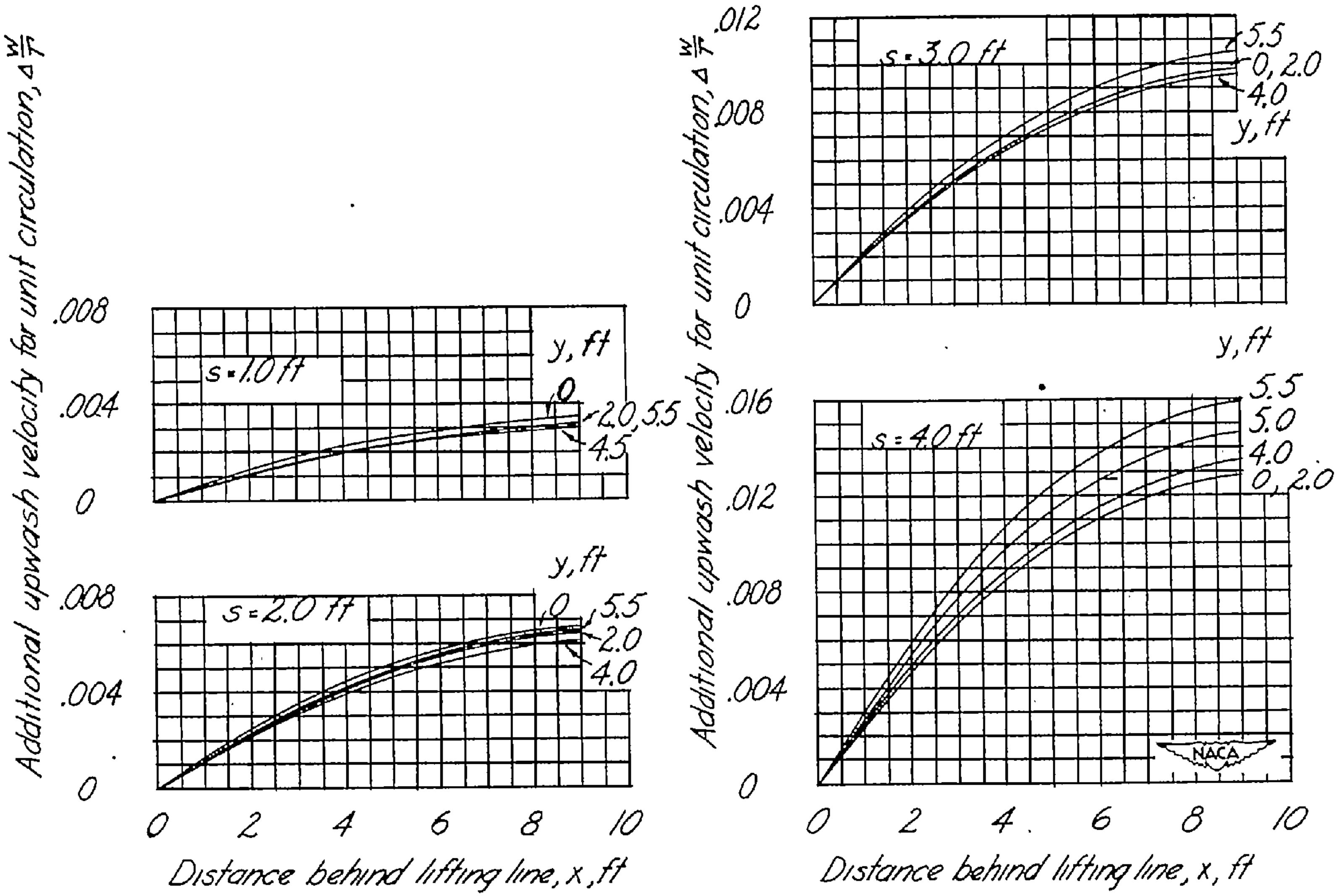


Figure 3.- Additional boundary-induced-upwash velocity for reflection-plane models mounted vertically in 7-by 10-foot, closed, rectangular wind tunnels.

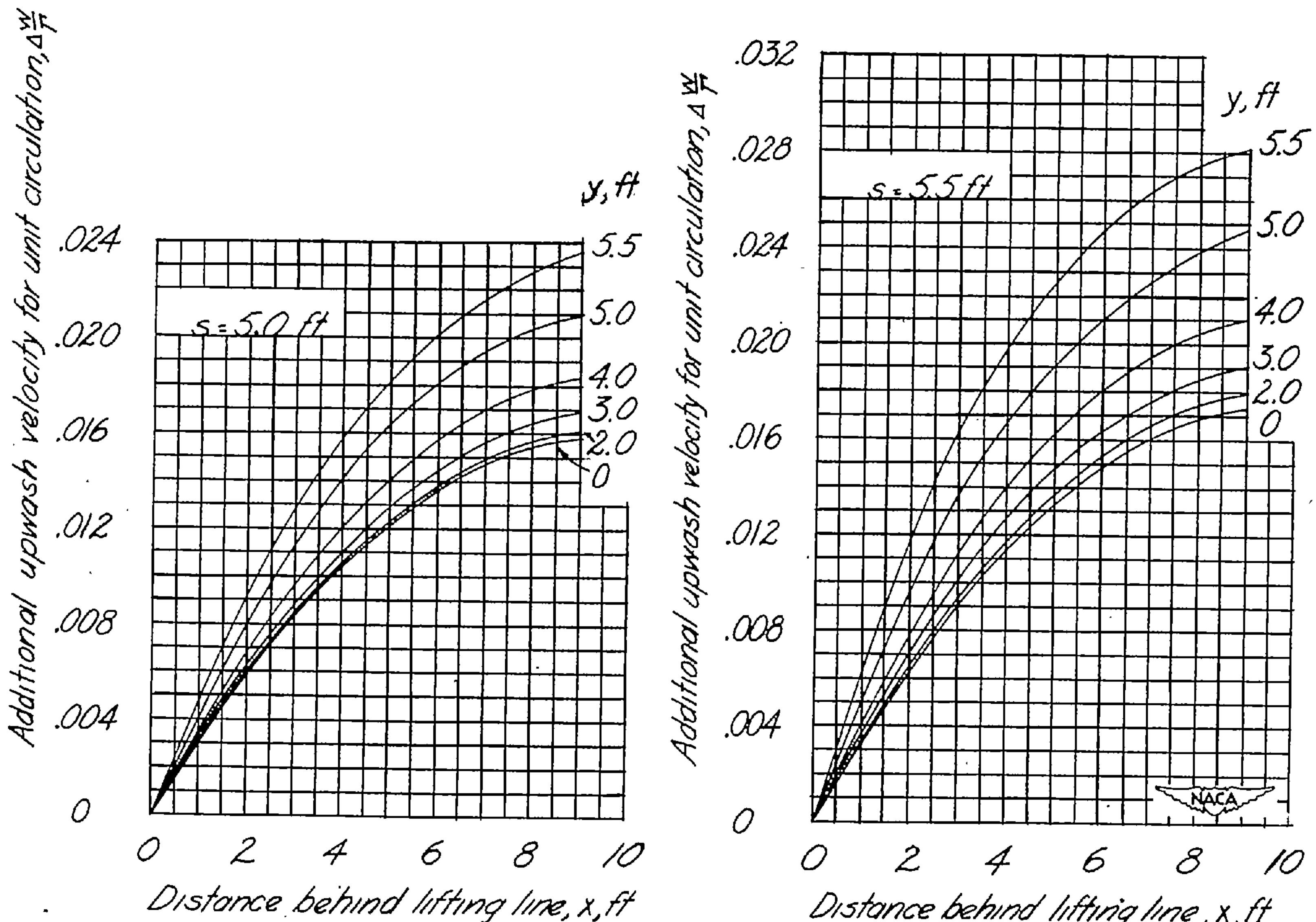
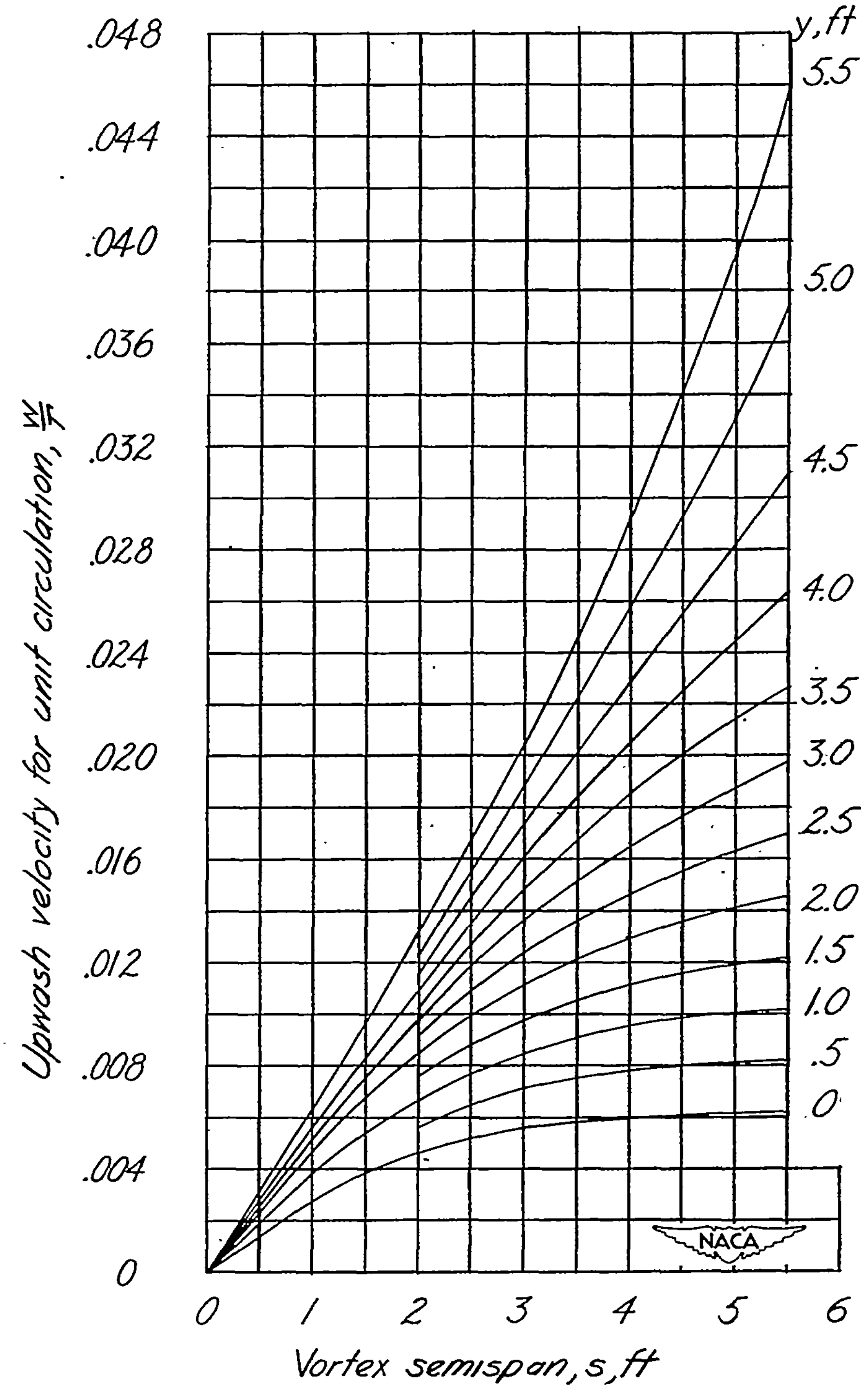
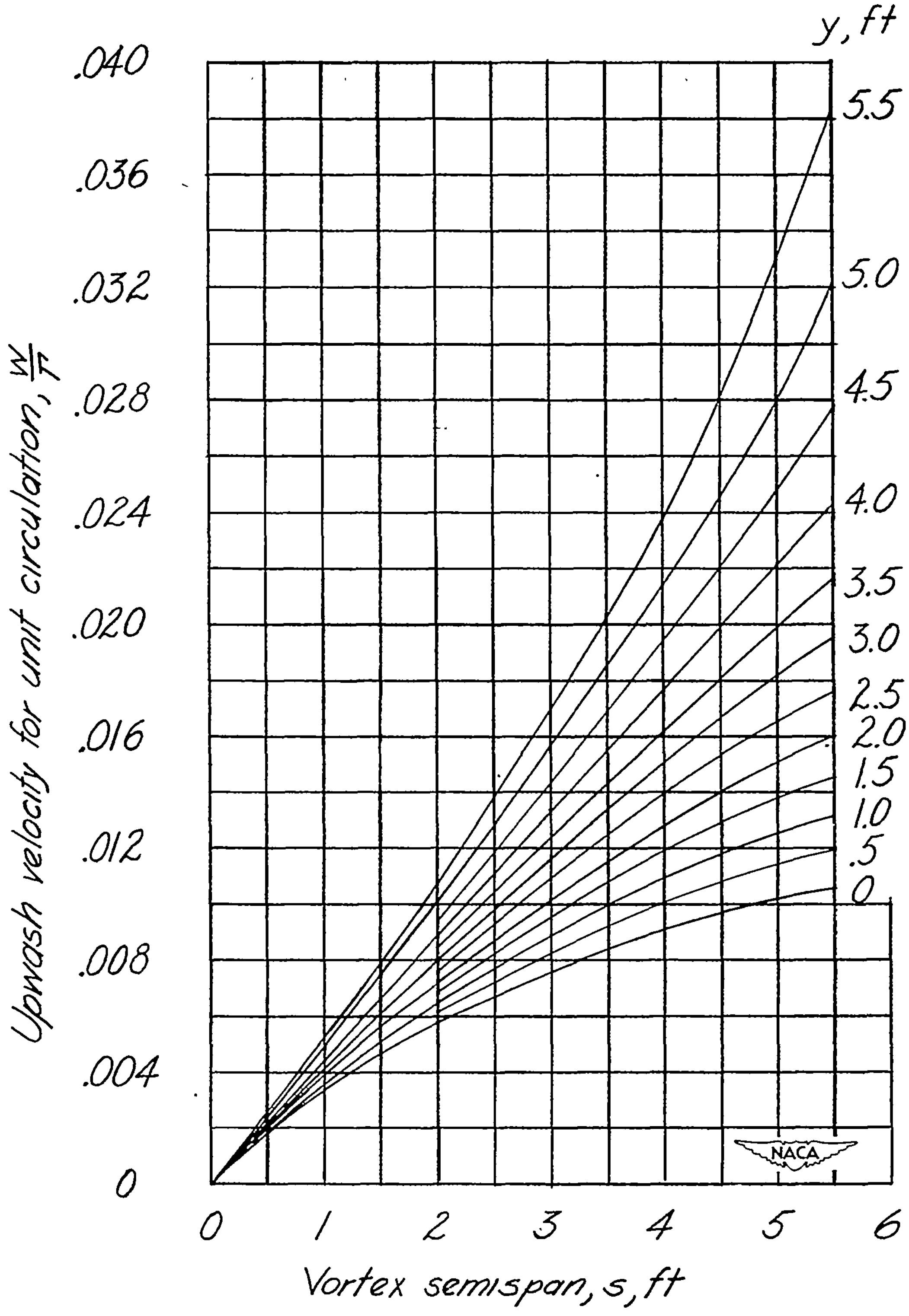


Figure 3.- Concluded.



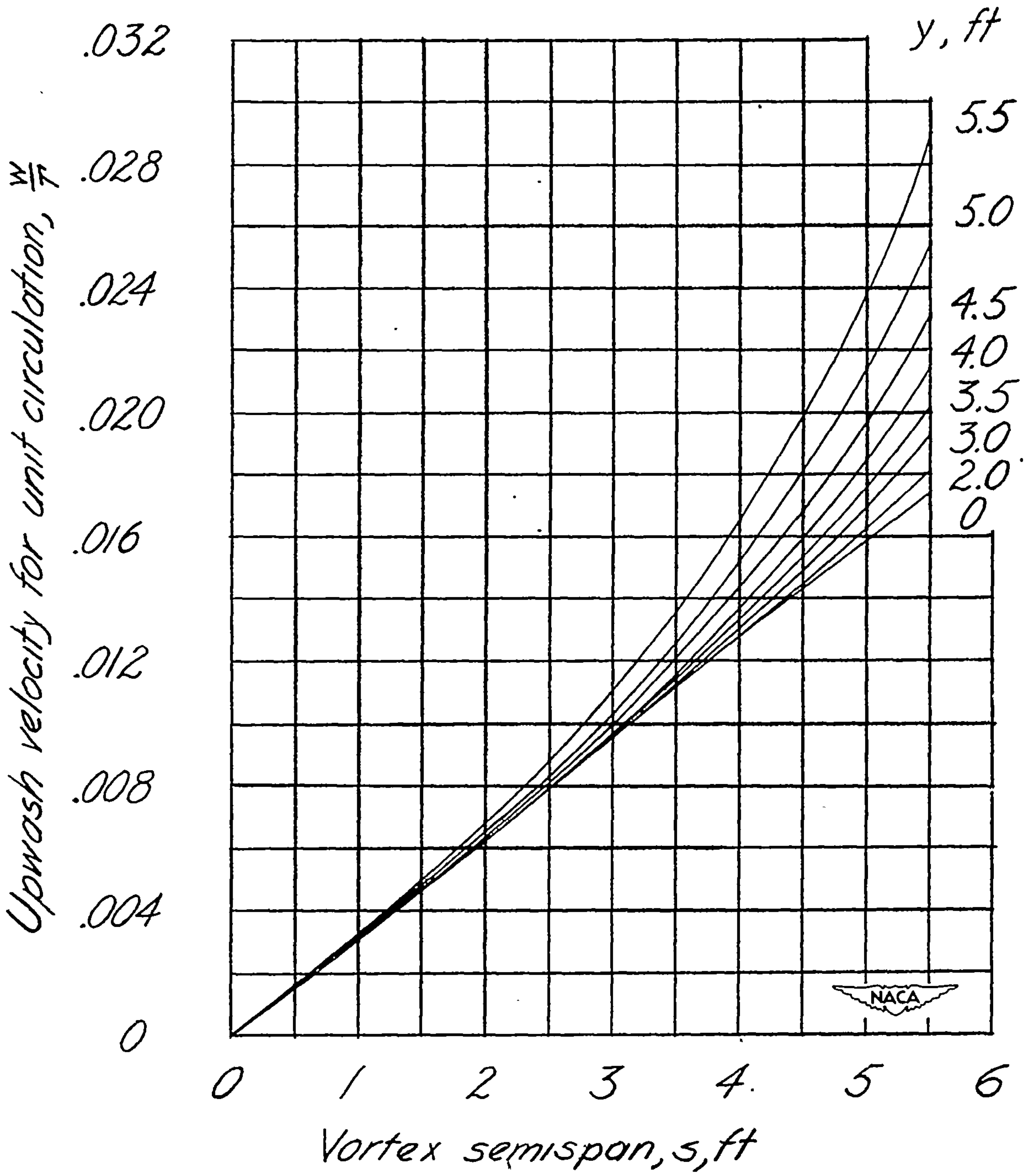
(a) Lifting line swept back 60°.

Figure 4.- Boundary-induced-upwash velocity along the lifting line for reflection-plane models mounted vertically in 7- by 10-foot, closed, rectangular wind tunnels.



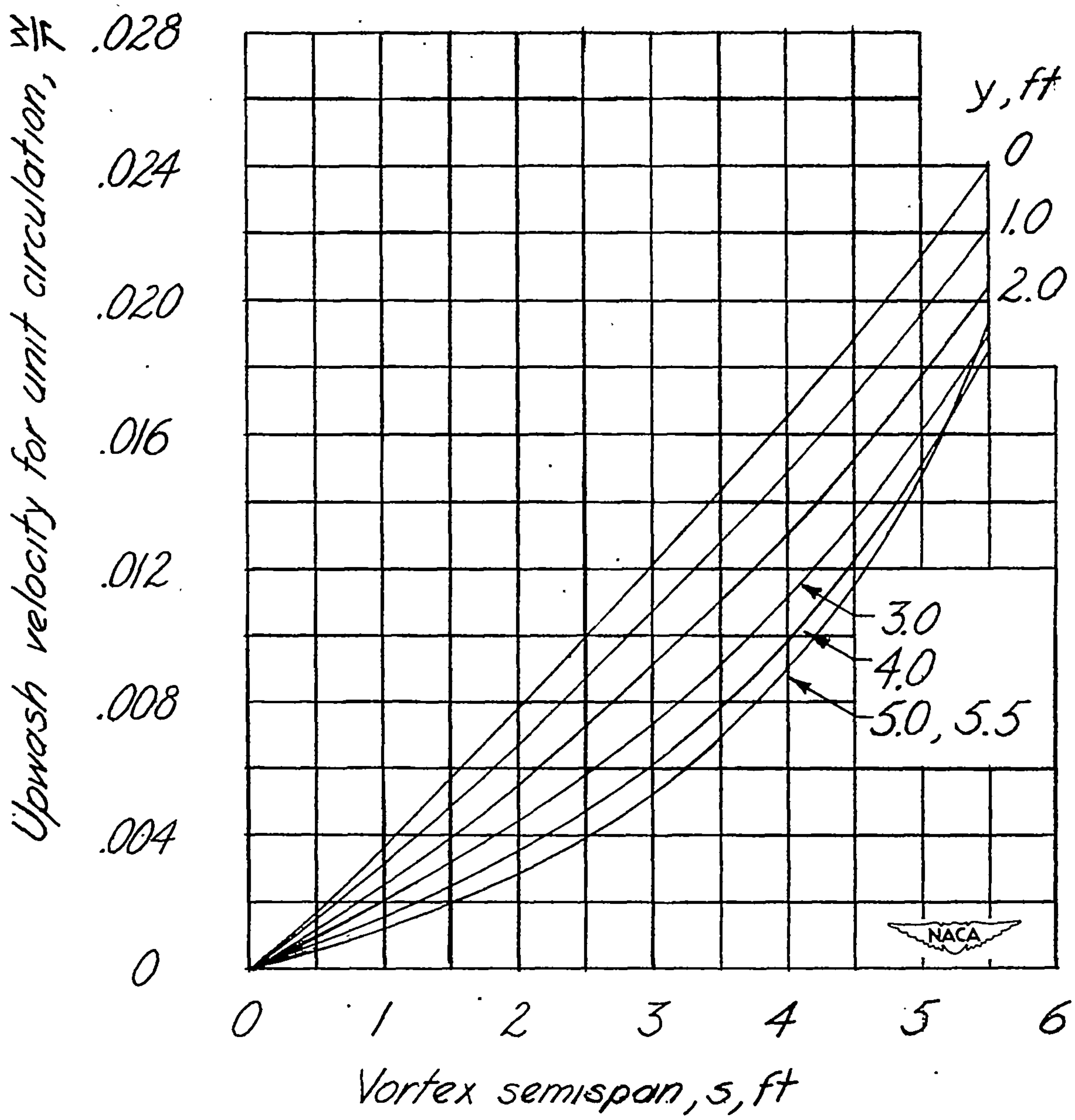
(b) Lifting line swept back 40°.

Figure 4.- Continued.



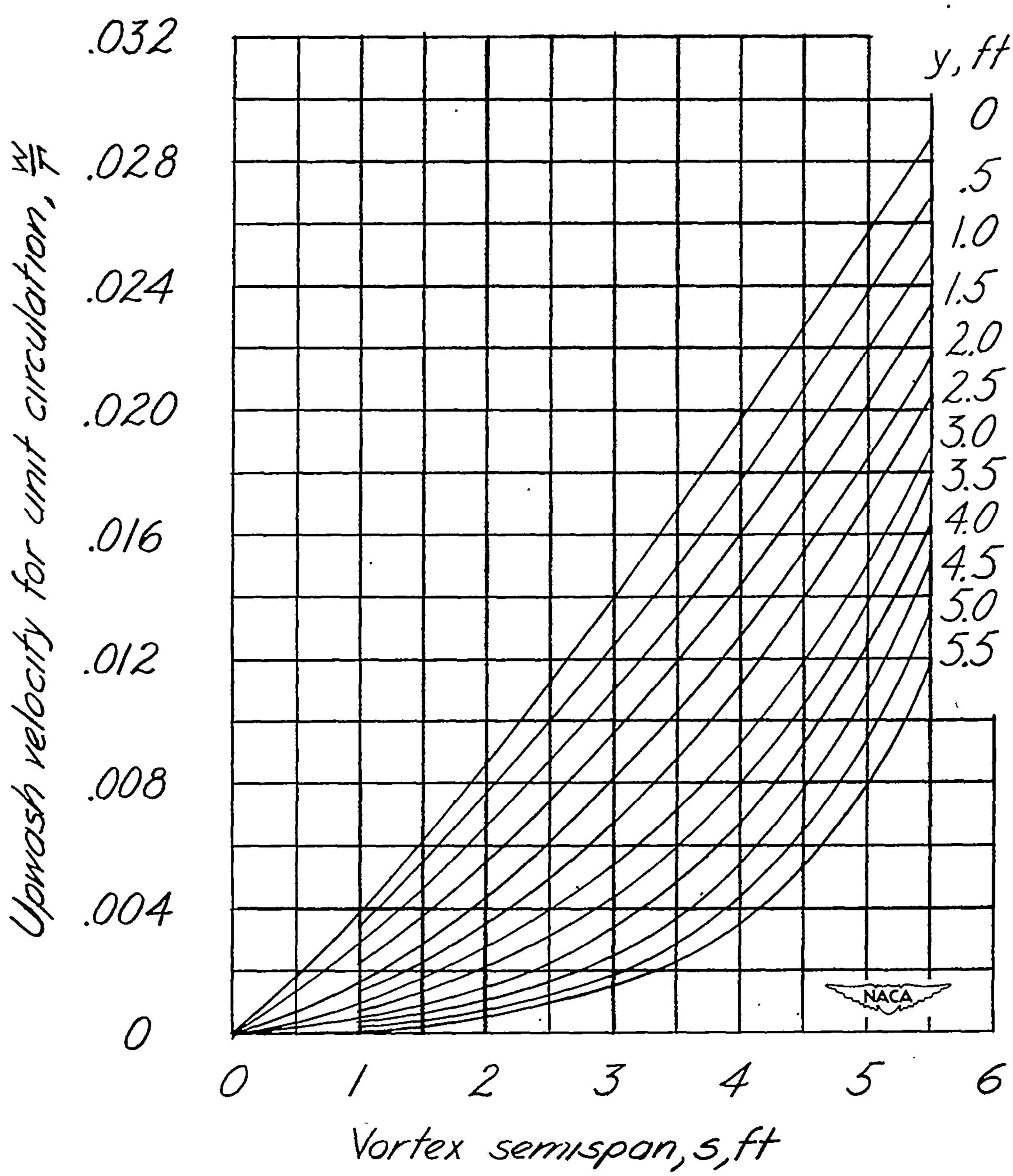
(c) Lifting line unswept.

Figure 4.- Continued.



(d) Lifting line swept forward 40°

Figure 4.- Continued.



(e) Lifting line swept forward 60°.

Figure 4.- Concluded.

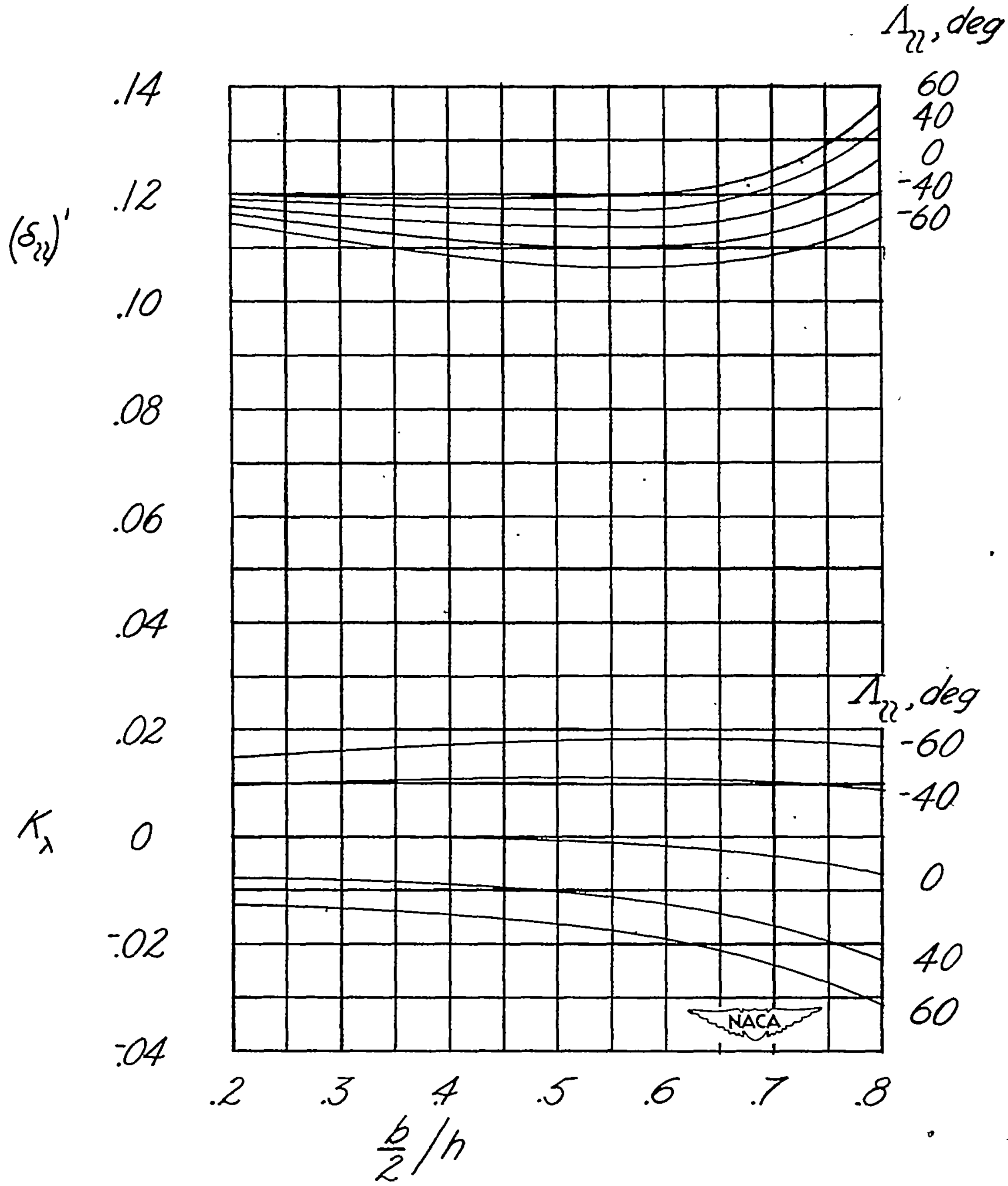


Figure 5.- Values of δ_{ll}' and K_λ for use in the equation for the jet-boundary correction factor at the lifting line: $\delta_{ll} = \delta_{ll}' + K_\lambda(1.0 - \lambda)$; $\frac{h}{d} = 0.7$.