were obtained even for the case of partial span flaps. The theoretical estimate of the vortex core location compared reasonably well with the spanwise position measurement. The vertical position measurement may be significantly influenced by the wind tunnel walls.

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Correlation for Estimating Vortex Rotational Velocity Downstream Dependence

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Nomenclature

AR	= aspect ratio
b	= wing span
C_L	= lift coefficient
$f(\Gamma_0/\nu)$	= Reynolds number parameter
R_{e_b}	= Reynolds number based on wing span
U_∞	= freestream velocity (towing speed for water tank)
V_1	= vortex maximum rotational velocity
X	= downstream distance, aft from trailing edge of wingtip
α	= angle of attack
Γ_0	= circulation shed from one side of wing
Γ_0/ν	= vortex Reynolds number

Subscripts

B	= downstream distance where plateau region ends
P	= plateau region

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Introduction

LIFT-GENERATED wake vortices trailing behind present-day heavy aircraft are currently of great concern to the aviation community. In order to minimize the upset potential which these vortices present to following aircraft, it is necessary to have an understanding of the wake characteristics in the far field, where such encounters are likely to occur.

Available wind-tunnel data of wake vortex velocity profiles are limited by the physical lengths of tunnel test sections. Downstream distances of up to 30-span lengths have been obtained in the NASA Ames 40- by 80-ft Wind Tunnel.[1] However, these distances are not great enough to obtain the characteristics of vortex decay. Recent measurements[2,3] made in the wake of wings being towed under water have identified two characteristic flow regions for the dependence of vortex maximum tangential velocity on downstream distance. The first, a "plateau" region, with little, if any, change in maximum tangential velocity, extends from wake rollup to downstream distances as great as 100-span lengths, depending on span loading and angle of attack. This is followed by a decay region in which the maximum tangential velocity decreases with downstream distance at a rate nominally proportional to the inverse one-half power. This note describes a correlation of these water-tank results that relates the magnitude of vortex maximum tangential velocity in the plateau region to the downstream extent of this region. With this knowledge, near field wake velocity measurements in the plateau region (i.e., wind-tunnel results) can be used to estimate the far field vortex characteristics.

Plateau Region Correlation

A correlation function based on the self-similar turbulent decay of a line vortex has been developed[4] and utilized to substantiate the validity of using ground-based scale model data to predict high Reynolds number flight results. It was found that if the downstream dependence of vortex maximum rotational velocity is presented as a vortex velocity scaling parameter, $V_1 b/\Gamma_0 AR$, vs a distance scaling parameter, $(X/b)(\Gamma_0/U_{\infty b})(AR)^2 f(\Gamma_0/\nu)$, the scale model and flight data collapse to a single curve. Presented in Fig. 1 are the results of employing these scaling parameters to plot vortex maximum rotational velocity in the plateau region versus a corresponding downstream duration of this region obtained from the experimental data of Refs. 2 and 3. The line faired through the experimental points has a slope of -1. This implies the following in-

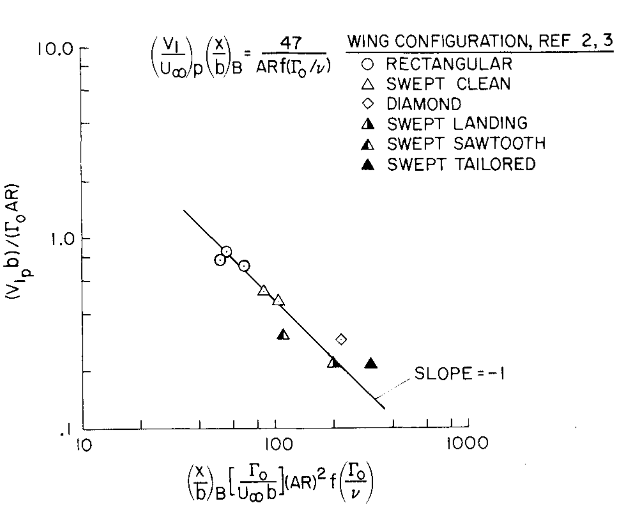

Fig. 1 Correlation of vortex maximum rotational velocity in plateau region to downstream duration of this region.

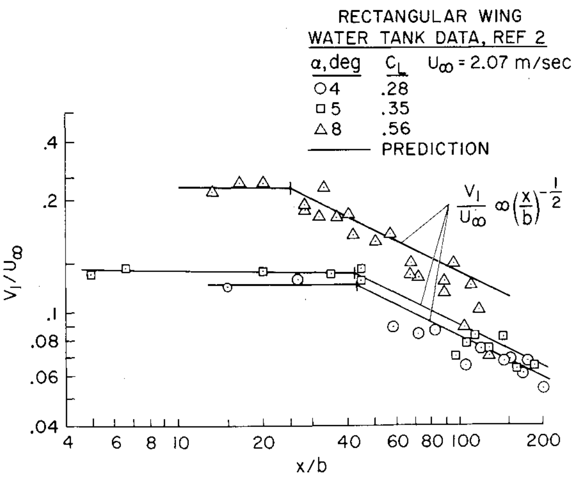

Fig. 2 Comparison of measured and predicted maximum tangential velocity downstream dependence.

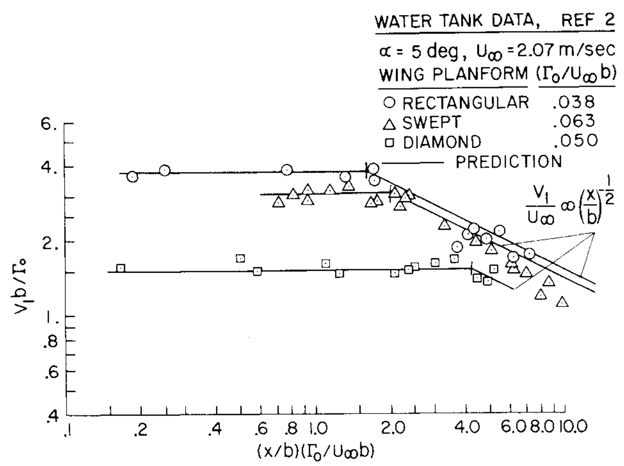

Fig. 3 Comparison of measured and predicted maximum tangential velocity downstream dependence.

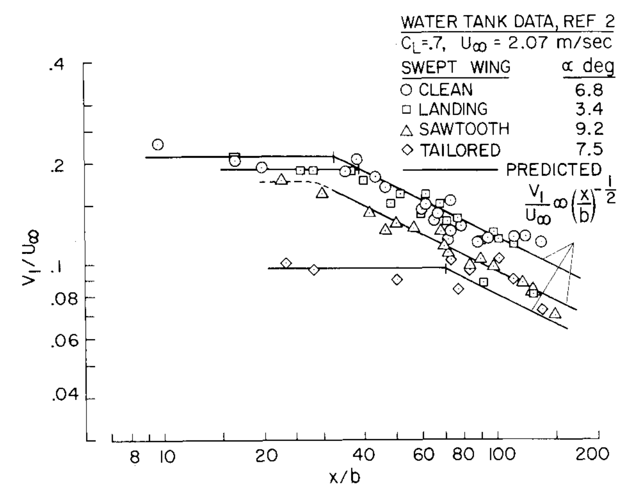

Fig. 4 Comparison of measured and predicted maximum tangential velocity downstream dependence.

verse proportionality between the plateau velocity and extent of the plateau region:

$$\left(\frac{V_1}{U_\infty}\right)_p \left(\frac{X}{b}\right)_B = \frac{47}{ARf(\Gamma_0/\nu)} \quad (1)$$

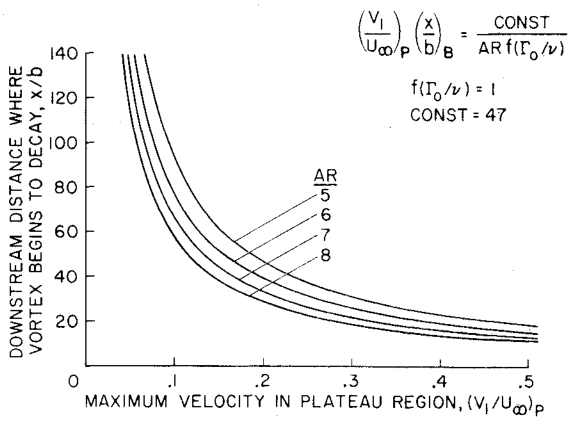

Fig. 5 Predicted downstream distance behind an aircraft in flight where its trailing vortex will begin to decay. Calm day.

The Reynolds number parameter, $f(\Gamma_0/\nu)$, was developed in Ref. 4 and is a function of vortex Reynolds number, $\Gamma_0/\nu = (\Gamma_0/U_{\infty b})R_{e(b)}$. For $\Gamma_0/\nu \geq 3 \times 10^5$, $f(\Gamma_0/\nu) = 1$, Hence, for all flight conditions, $f(\Gamma_0/\nu) = 1$, and for most ground based tests (including the water-tank tests of Refs. 2 and 3) $f(\Gamma_0/\nu)$ is of order 1.

Application of Correlation

Use of Eq. (1) and a $-1/2$ decay region downstream dependence of vortex maximum rotational velocity,[2,3] allows near field wake velocity measurements in the plateau region to be used to estimate subsequent far field vortex characteristics. Figures 2–4 show a comparison of the measured downstream variation of vortex maximum rotational velocity with faired curves which predict the downstream variation using the above ideas. The vertical bars indicate the predicted end of the plateau region. The data of Fig. 2 show the effect of angle of attack of a rectangular wing on the downstream variation of vortex maximum rotational velocity. Figures 3 and 4 illustrate the effect of wing span loading. The span loading variation shown in Fig. 3 was achieved by using three different wing planforms (rectangular, swept, diamond), at an angle of attack of 5°. This data has been normalized by nondimensional circulation to eliminate effects due to differences in lift coefficient and aspect ratio of the wings. Figure 4 shows the effect of span load variations obtained with different flap deflections on a swept wing at a constant lift coefficient of 0.7. The predictions and measurements are seen to be in good agreement. A complete description of the wing geometries is given in Ref. 2.

Figure 5 presents the estimated downstream distance behind an aircraft in flight where its trailing vortex will begin to decay as a function of vortex maximum rotational velocity in the plateau region and aspect ratio. It should be realized that in the presence of atmospheric disturbances, these estimates would be conservative.

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