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# Effect of Wing Tip Vortices on a Trailing Aircraft

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## Abstract

THE effect of trailing vortices from a large leading wing on a trailing aircraft is studied experimentally. The aerodynamic response of the trailing aircraft is examined through measurements of lift, drag, and pitching moment for various angles of attack of the two models and different separation distances between them. The results show that trailing vortices cause a remarkable loss of lift on the trailing aircraft. This phenomenon becomes more significant as the angle of attack of the leading object is increased. Results demonstrate that in order to maintain the same lift, drag would increase as the leading wing angle of attack is increased.

## Nomenclature

$C$ = chord length of the trailing aircraft
$C_D$ = drag coefficient of the trailing aircraft
$C_L$ = lift coefficient of the trailing aircraft
$C_M$ = pitching moment coefficient of the trailing aircraft
$X$ = separating distance between the two models in the horizontal plane
$Y$ = separating distance between the two models in the vertical plane
$\alpha$ = trailing aircraft angle of attack
$\beta$ = leading wing angle of attack

## Contents

The effect of wing tip vortices on trailing aircraft has been an aviation safety problem since the introduction of large airliners in the early 1970s up to now. Hallock and Eberle[1] presented a review of the efforts made to understand the nature of trailing vortices. Vortex measurements were taken at several major airports to form the Vortex Advisory System that helped in reducing the vortex imposed separation distance.[2] The Federal Aviation Administration obtained measurements of the swirling velocities in the vortices of full-scale aircraft.[3] On the other hand, there have been many efforts to reduce the hazard of trailing vortices.[4-6] In this paper, the effect of trailing vortices from a wing on the lift, drag, and pitching moment of a trailing aircraft is investigated.

A low-speed, nonreturn type of wind tunnel with a test section of $0.5 \times 0.7 \times 2.0$ m$^3$ and a maximum speed of 45 m/s was utilized. The forces and moment were measured by an external three-component balance. The leading wing was a NACA 0015 of rectangular planform with a wing span of 0.498 m, a chord length of 0.275 m, and an area of 0.137 m$^2$. The wing of the trailing aircraft was a straight-tapered untwisted wing of airfoil section RAE 101 and 10% thickness with a wing span of 0.44 m, a mean aerodynamic chord of 0.079 m, and an area of 0.03476 m$^2$.

The two models were installed symmetrically at the center of the test section. The distance between the two models was varied both horizontally (four locations) and vertically (three locations) as illustrated in Fig. 1. In all cases, the symmetry between the two models was maintained as pointed out earlier. The leading wing was equipped with 15-deg flaps.

Several parameters were employed in the investigation. Each set of results is presented for $\beta = 0$, 4, and 8 deg. All measurements were conducted at a velocity of 30 m/s, corresponding to $Re = 1.5 \times 10^5$ based on the trailing wing chord length. The trailing wing planform area, 0.02614 m$^2$, was used as the reference area in the pitching-moment coefficient.

The complete results of the forces of lift and drag and the pitching moment, which were obtained at the six locations of the leading wing shown in Fig. 1, are available in the full paper (see Ref. 7). The results presented here are for the central location of the leading wing ($X/C = 13.92C$ and $Y/C = 0$).

Figure 2 shows that increasing the angle of attack of the leading wing precipitates, in general, a remarkable reduction in the lifting force. It is conceivable that this decline can reverse the lift to become a downward force at low angles of $\beta$. The figure further shows that $\beta$ has no effect on the slope of the linear part of the $C_L - \alpha$ curve, while it increases the zero-lift angle of attack and decreases the maximum lift coefficient.

Results of the drag polar, presented in Fig. 3, indicate that the maximum ratio of lift to drag decreases with increasing $\beta$. Also the maximum lift relative to the associated drag decreases as $\alpha$ increases. It may be further shown that increasing $\alpha$ reduces both $C_L$ and $C_D$ for the same $\beta$. It follows that, to maintain the same lifting force, the drag will increase with increasing $\beta$. In other words, it is imperative to increase the angle of attack of the trailing aircraft to offset the wake effect, thus increasing the drag. The same figure also depicts a constant $C_D$ of 0.1 at zero lifting force for all values of $\beta$.

The effect of $\beta$ on the $C_M - C_L$ curves is displayed in Fig. 4. These curves indicate that all configurations of the aircraft model under all effects exhibit stable longitudinal behavior. The figure further portrays that $\beta$ has a slight effect on the stability margin.

A summary of the effect of the leading wing position on the maximum lift-to-drag ratio of the trailing aircraft, $(C_L/C_D)_{max}$, obtained for all leading wing angles of attack and at all leading wing positions covered in the investigation, is presented in Table 1. It is apparent that as $\beta$ is increased more lift is generated and, henceforth, the trailing aircraft suffers from stronger trailing vortices. As the distance between the two models decreases, the effect of trailing vortices gets more profound. The results show that a downward displacement of the leading wing increases $(C_L/C_D)_{max}$. The maximum amount of lift-to-drag ratio is obtained when the leading wing is positioned lower than the leading wing and the former is at zero angle of attack.

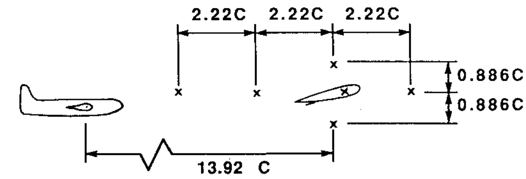


**Fig. 1 Schematic of the leading wing location with respect to the trailing aircraft. Dimensions are given in terms of the trailing aircraft wing mean aerodynamic chord *C*.**

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**Table 1 Maximum (lift/drag) ratio for all leading wing positions and angles of attack**

| Leading wing position | $(C_L/C_D)_{max}$ | | |
|---|---|---|---|
| | Leading wing angle | | |
| $(X/C, Y/C)$ | 0 | 4 | 8 |
| (9.49, 0) | 0.869 | 0.727 | 0.625 |
| (11.71, 0) | 1.072 | 0.966 | 0.700 |
| (13.92, 0) | 1.036 | 0.839 | 0.675 |
| (16.14, 0) | 1.036 | 0.869 | 0.727 |
| (13.92, 0.886) | 1.000 | 0.900 | 0.781 |
| (13.92, − 0.886) | 1.150 | 0.933 | 0.754 |

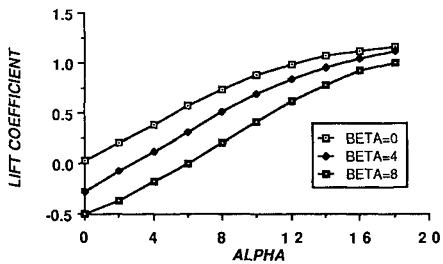


Fig. 2 Effect of $\beta$ on the $C_L - \alpha$ curves.

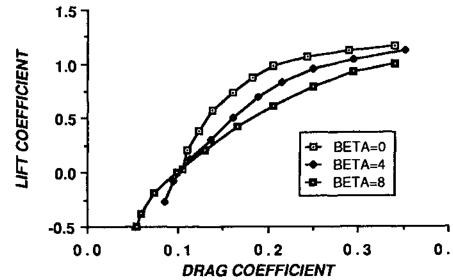


Fig. 3 Effect of $\beta$ on the drag polar curves.

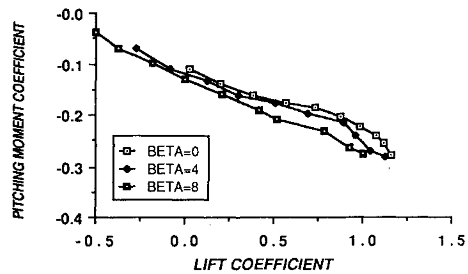


Fig. 4 Effect of $\beta$ on the $C_M - C_L$ curves.

## Acknowledgment

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