Engineering Notes

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Aircraft Configurations with Outboard Horizontal Stabilizers

J. A. C. Kentfield*
University of Calgary, Calgary, Alberta, Canada

Nomenclature

A = aspect ratio
b = wing span
C_L = lift coefficient
C_m = pitching moment (positive nose-up)
C_1 = constant (positive)
D_{ratio} = ratio of total of drags of horizontal surfaces: drag (outboard)/drag (conventional)
Re = Reynolds number (based on chord)
U = flight velocity
w = downwash velocity (positive downward)
Y = $(2y)/b$
y = displacement from center of wing (Fig. 2)
α = incidence angle
ϵ = downwash angle (positive downward)

Subscripts
W = wing
T = tail

Introduction

A DESCRIPTION is given of an aircraft configuration that avoids, at the expense of increased structural complexity, the aerodynamic disadvantages associated with the traditional location of the horizontal stabilizer surface immersed in the wing downwash. The proposed configuration provides the advantage of allowing the horizontal stabilizer to contribute significantly to the lift of the aircraft. The major feature of the proposed arrangement is that each half of the horizontal stabilizer is located outboard of a wingtip and, hence, lies within the upwash created by the wing and sustained by the wing trailing vortices. A configuration of the proposed type is illustrated in Fig. 1, which shows, by way of example, a light transport.

It is found that the span of each half of the horizontal stabilizer is limited by the aerodynamic desirability of locating it within a zone of significant upwash velocity in order to benefit from the resultant forward inclination of the tail-surface lift vector as a means of offsetting drag. The maximum acceptable aspect ratio of the horizontal tail surface is dominated by the desirability of having a lift-curve slope lower than that of the mainplane so that stalling of the mainplane will always occur prior to stalling of the tail surfaces.

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*Professor, Department of Mechanical Engineering. Member AIAA.

Upwash Velocity Field

The potential flow in the wake of a lifting wing can be modeled, for a station far downstream of the wing, as two parallel, counter-rotating, infinite vortices. When the wing is loaded elliptically, it can be shown that the axes of the vortices are separated horizontally by a distance of $(\pi/4)b$. The two vortices represent the fully rolled-up form of the wing trailing vortex sheet. Figure 2 is a graphical presentation of the flowfield. The negative portion of the ordinate of Fig. 2, representing the upwash flow, is drawn above the abscissa so that the wake is shown as it appears physically. The vortices are normally considered to be fully rolled up at a distance proportional to A_W and inversely proportional to C_{LW}. This translates, by means of approximate formulations,[1] to a distance of about $4b$ downwind for $C_{LW} = 0.5$ with $A_W = 6$. At the wing itself Glauert[2] showed for an elliptically loaded wing, modeled as a flat plate moving downward at the wing uniform downwash velocity, that the upwash profile outboard of the wingtips was approximately the same as that presented in Fig. 2 for $Y \geq 1$. This suggests the suitability, at least as an approximation, of assuming that the upwash profile of Fig. 2 for $Y \geq 1$ is applicable at stations closer to the wing where vortex roll up is incomplete. The upwash profile of Fig. 2 indicates that, for example, with a horizontal-tail semispan of 40% of the wing semispan the tail spanwised-average upwash angle is 18.3 deg (C_{LW}/A_W).

Longitudinal Stability

An important concern relating to the aerodynamic practicality of the type of configuration illustrated in Fig. 1 is longitudinal stability. It has been shown for conventional configurations that, generally, stability is due solely to the action of the tailplane; this is particularly true when the center of grav-

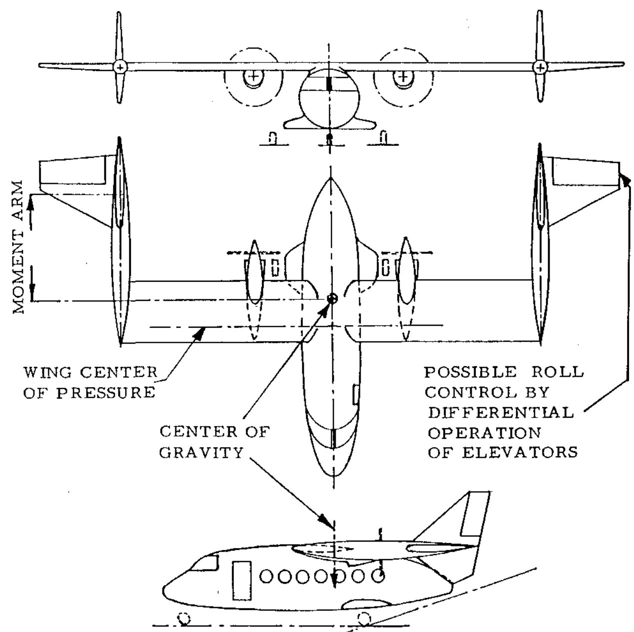

Fig. 1 Aircraft configuration with outboard stabilizers (diagrammatic).

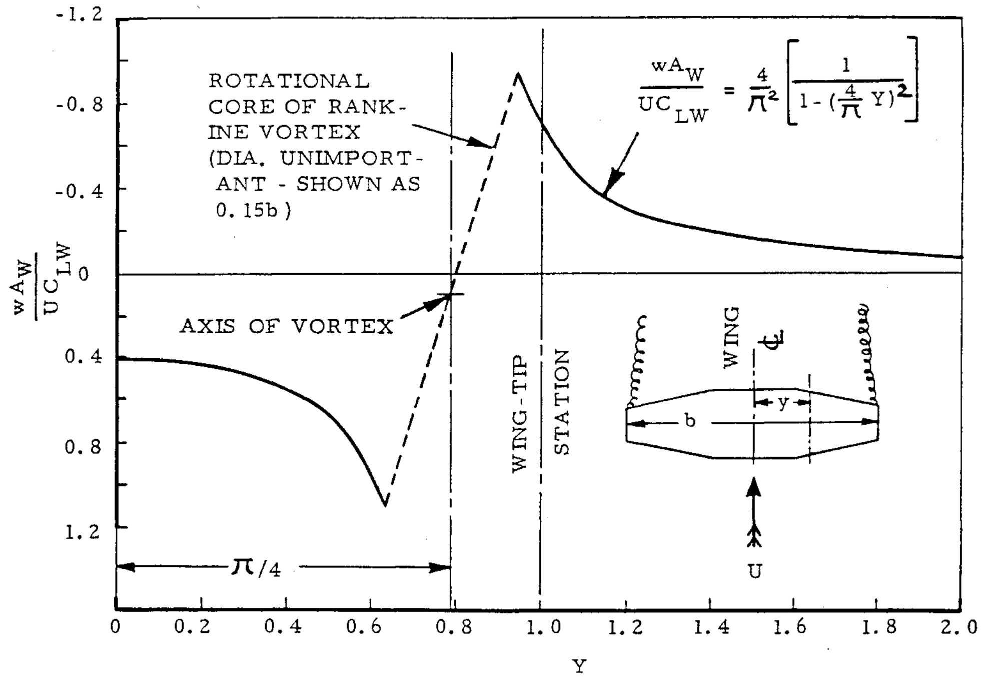

Fig. 2 Wing-wake flowfield far downstream of an elliptically loaded airfoil.

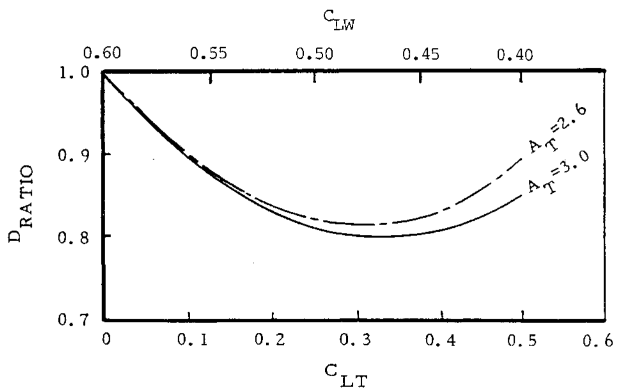

Fig. 3 Variation of ratio of total drags of horizontal surfaces, D_{ratio}, with change of lift coefficient of the outboard tail (A_W = 6).

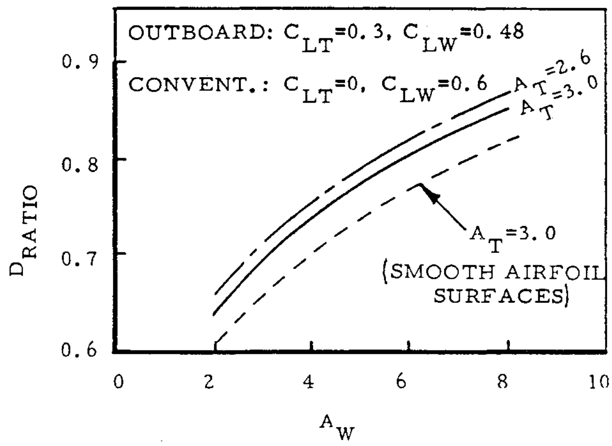

Fig. 4 Response of ratio of drags of horizontal surfaces, D_{ratio}, to variation of A_W.

ity lies aft of the wing center of pressure. The contribution of the tail to the pitching moment must be negative and, for a prescribed flight speed, aircraft geometry, and tail efficiency, it has been shown that[3]

$$\frac{dC_m}{d\alpha} = -C_1\left\{1 - \frac{d\epsilon}{d\alpha}\right\} \tag{1}$$

For a conventional configuration, the term $d\epsilon/d\alpha$ is positive and typically has values, even with a raised horizontal stabilizer, in the range of $0.2 \leq (d\epsilon/d\alpha) \leq 0.3$. With an outboard tail arrangement $d\epsilon/d\alpha$ is negative. For a tail semispan equal to 40% of the wing semispan, $d\epsilon/d\alpha$ has a numerical value of about half that applicable to a conventional aft tail. Thus, re-evaluation of Eq. (1) shows that the modulus of $dC_m/d\alpha$ is typically increased by 50%, and, hence, the tail of a configuration of the type shown in Fig. 1 is much more effective than an otherwise comparable conventionally located horizontal stabilizer.

Drag Reduction

Comparative evaluations of drag were made for conventional and outboard configurations having equal lift and equal total planform areas. In each case, the tail planform area was assumed to be 40% of the wing planform area. For each of the outboard configurations, the semispan of the stabilizer was taken to be approximately 40% of the wing semi-span. Two aspect ratios A_T were considered for the sum of the two halves of the horizontal stabilizer of the outboard configuration, namely, 2.6 and 3.0. The aspect ratio of the sum of the two halves of the stabilizer was regarded as relevant since a large vertical stabilizer effectively terminates the inboard end of each half of the horizontal stabilizer in the manner indicated in Fig. 1. Such an assumption was also considered justifiable due to the beneficial influence of the mainplane tip vortices in reinforcing the action of the end plates. The modeling, which took no account of fuselage or vertical stabilizer drags, was based on NACA 0012 airfoil surfaces of standard roughness[4] for which $Re = 6 \times 10^6$.

The results of the analysis are presented in Figs. 3 and 4. Figure 3 shows, for an $A_W = 6$ mainplane, the effect of varying the lift coefficient of the horizontal stabilizer of the outboard configuration. The corresponding conventional arrangement also employed an $A_W = 6$ mainplane, for which $C_{LW} = 0.6$, in conjunction with a (nominally) nonlifting horizontal stabilizer. It can be seen from Fig. 3 that the optimum value of C_{LT} is approximately 0.3, which is close to that for the maximum efficiency of the $A_T = 3.0$ lifting surface. Figure 4 shows the influence of mainplane aspect ratio A_W on drag reduction. It should be pointed out, however, that the assumed constancy of C_{LW} over a wide range of A_W departs, particularly at low aspect ratios, from the conditions for maximum wing efficiency. Nevertheless, the indication from Fig. 4 is that the relative usefulness, as a means of reducing drag, of the outboard configuration declines as A_W increases.

The preliminary analysis resulting in Figs. 3 and 4 showed that significant lift-related drag reductions appear to be possible using an outboard configuration.

Design Example

The configuration shown in Fig. 1 was the result of a simple exercise aimed at establishing a feasible layout for a light, 26 place, 17-m (56-ft) span-mainplane commuter aircraft employing an outboard configuration and, hence, making it possible to compare the predicted drag with that of a comparable conventionally arranged version incoprorating the same mainplane. The lifting surface designs were based on those giving rise to the lowest point on the lowest curve of Fig. 3, i.e., $A_W = 6$ with, for the conventional configuration, $C_{LW} = 0.6$ and $C_{LT} = 0$ and for the outboard version $C_{LW} = 0.48$, $C_{LT} = 0.3$, thereby giving equal lifts. It was found that for equal gross takeoff weights the total drag of the outboard version was about 14% less than that of the conventional aircraft. Naturally, this saving would have been less impressive had the comparison been based on less well-faired designs, for example, with box-like fuselages and nonretracting gear. Also, the assumption of standard roughness airfoils emphasized the relative significance of wing and tail drag as a fraction of the total drag. It appears that the vertical stabilizers of the outboard design can be arranged to benefit from the skewed flowfield in which they are immersed, much in the manner of a conventional winglet, and, hence, offer a lower drag than the profile drag corresponding to an aligned flow. A preliminary study of the wing major structural loads showed that, provided the aircraft design parameters are chosen correctly, the wing bending and torsional loadings are fairly comparable with those of a corresponding conventional aircraft.[5]

References

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