Engineering Notes

Lift and Drag Characteristics of a Biannular Wing Airplane

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Nomenclature

C = wing chord
C_D = drag coefficient
C_L = lift coefficient
C_{L0015} = lift coefficient of an NACA 0015 airfoil corrected for aspect ratio of 3.8
D_i = induced drag
L = lift
q = dynamic pressure = $\frac{1}{2}\rho V^2$
R = wing radius
V = freestream velocity
α = angle of attack
ρ = air density

Ribner[1] has derived a theoretical expression for lift on isolated annular airfoils at subsonic velocities. His formula was verified experimentally by Fletcher[2] when he measured lift and drag on five annular airfoils that had the same projected area, but aspect ratios of $\frac{1}{3}$, $\frac{2}{3}$, 1.5, and 3.0. In order to determine the effect of fuselage interference on annular airfoils, the authors of this note measured the lift and drag of a model airplane equipped with an annular wing for each semispan and with an annular wing for the empennage (Figs. 1 and 2).

The model was built of balsa wood around an aluminum frame. The wings and empennage are ring airfoils with an NACA 0015 cross section. The diameter of each wing is 14 in. and that of the tail is 6 in.; the wing chord is 5 in., and the tail chord 4 in. The fuselage is a parabolloid of revolution 28 in. long and 5 in. at its maximum diameter. For more details of the model, see Ref. 3.

The tests were performed at the subsonic wind tunnel of the University of Oklahoma, which is a return-flow, closed-throat, atmospheric pressure unit with a nearly elliptic test section of 4 × 6 ft and capable of producing an air speed of 200 mph. The results of the tests, performed with air speeds ranging from 175 to 237 fps, are shown in Fig. 3.

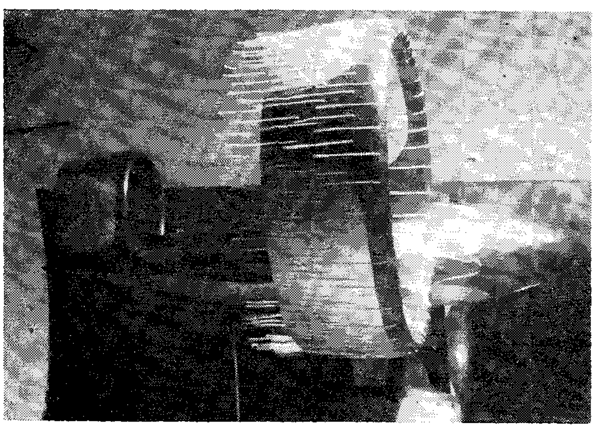

Fig. 1 Model at 0° angle of attack.

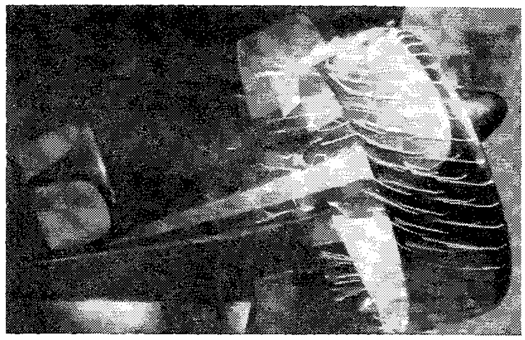

Fig. 2 Model at 20° angle of attack.

In an attempt to find theoretical expressions to correlate the experimental results, Ribner's[1] formula for lift on a ring airfoil,

$$L = (4R)(\rho V^2 \pi^2 R C \alpha)/(\pi C + 4R) \tag{1}$$

was used, and an expression for induced drag, based on Ribner's equation for induced angle of attack, was developed for a ring airfoil:

$$D_i = (L^2)/(4R^2 \pi^2 q) \tag{2}$$

It was found that the experimental lift and induced drag were somewhat larger than those predicted by these equations when applied to the two wings and the empennage. The dif-

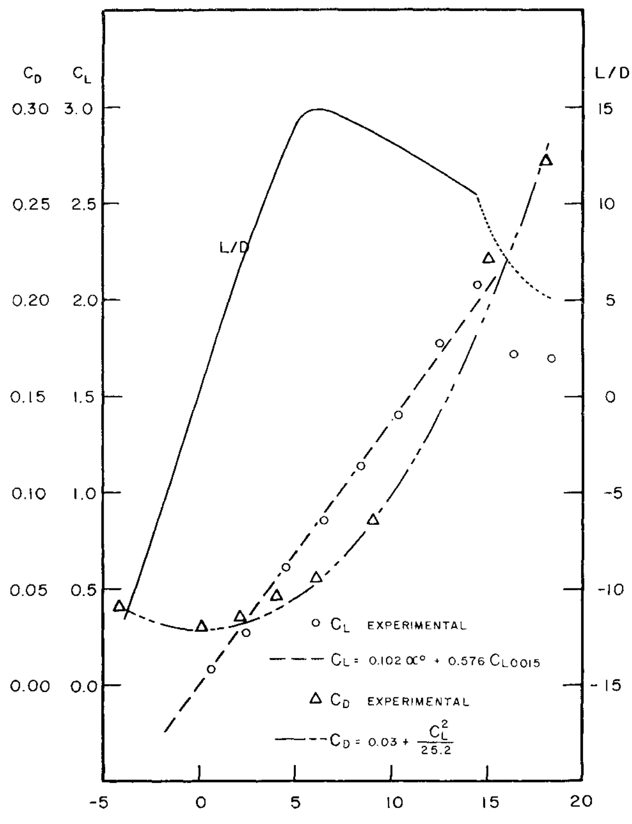

Fig. 3 Lift and drag characteristics.

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ference was attributed to the ring airfoil-fuselage interference.

In the case of the lift, a semiempirical relation has been found which seems to account for the difference; the extra lift due to interference was assumed to be produced by a straight wing that is the horizontal projection of the inner half of the ring wings plus the connecting portion of the fuselage. This "auxiliary wing" is thus assumed to have an NACA 0015 airfoil with a span of 19 in. and a chord of 5 in. (aspect ratio of 3.8).

With this correction and the use of Eq. (1), the expression for C_L becomes

$$C_L = 0.102\alpha^0 + 0.576C_{L0015} \tag{3}$$

In the case of the drag coefficient, the experimental data can be curve-fitted by the following equation:

$$C_D = 0.03 + (C_L^2/25.2) \tag{4}$$

The second term in Eq. (4) corresponds to an airplane efficiency factor of 1.212 based on an aspect ratio (over-all wing span/chord) of 6.6. Equations (3) and (4) are based upon a reference area equal to the horizontal projected area of both wings plus the connecting portion of the fuselage.

References

[1] Ribner, H. S., "The ring airfoil in nonaxial flow," J. Aeronaut. Sci. **14**, 529–530 (1947).

[2] Fletcher, H. S., "Experimental investigation of lift, drag and pitching moment of five annular airfoils," NACA TN 4117 (October 1957).

[3] Milla, J. H., "Experimental determination of aerodynamic characteristics of a model airplane with annular airfoils," Masters Thesis, School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, Okla. (1966).

Thrust Performance of Suppressor Nozzles

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Nomenclature

c_v = velocity coefficient
c_{vs} = velocity coefficient of standard nozzle at critical pressure ratio
c_{vp} = maximum velocity coefficient of suppressor nozzle configuration
D = diameter of standard nozzle
D_e = diameter of equal area circle for suppressor configuration
D_h = hydraulic diameter = 4 area/perimeter
D_{he} = equivalent hydraulic diameter = D_h/D_e = $(4\pi\text{area})^{1/2}/$perimeter
θ = momentum boundary-layer thickness
ρ^* = local fluid density at nozzle throat
V^* = sonic velocity at nozzle throat
g = standard gravity
C_f = local skin-friction coefficient
St = Stanton number
Nu = Nusselt number
Re = Reynolds number based on hydraulic diameter
Pr = Prandtl number

THE suitability of a suppression device as a propulsion nozzle depends upon the level of the thrust performance required for the airplane mission. The thrust performance is presented as a semiempirical correlation of velocity coefficient with a function of the hydraulic diameter at the nozzle throat (Fig. 1). The suppressor applications considered are the reduction of soundpower level generated in the exhaust jet wake and the reduction of ground surface deterioration from VTOL lift jets.[1]

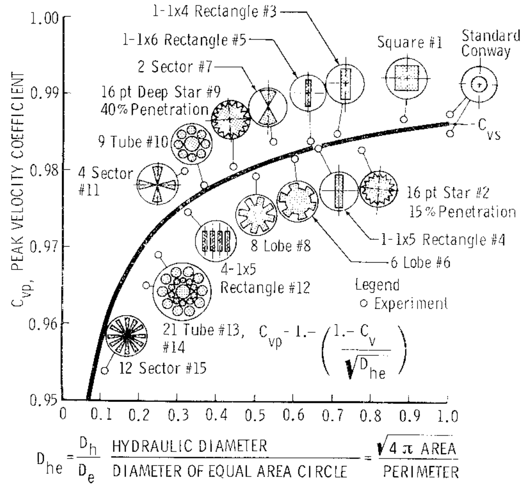

Fig. 1 Convergent nozzle performance maximum velocity coefficient for noise suppressor and jet mixing configurations.

The nozzle performance is shown in terms of the maximum value that the velocity coefficient can achieve for a convergent nozzle on a static test stand. The velocity coefficient is defined as the ratio of the measured thrust divided by the thrust of a fully expanded isentropic flow process at the measured nozzle pressure ratio and flow rate. The maximum value of the velocity coefficient occurs at a pressure ratio such that the convergent nozzle is choked but does not exhibit any underexpansion loss. Ideally, the condition occurs at the critical pressure ratio for sonic flow. The correlation was obtained by separating the measured thrust term into an ideal thrust and the aerodynamic drag at the critical pressure ratio.

Consider this aerodynamic drag as consisting of three parts: the internal flow losses caused by eddies in wakes of internal struts and irregular contours in the flow passage, a negative pressure drag on the external surface caused by unventilated base areas, and the skin-friction losses in the boundary layer.

In developing suppressor nozzles, an attempt is made to keep the internal losses to a minimum by providing smooth, continuous, streamlined contours. The pressure drag is kept to a minimum by eliminating blunt base areas and by providing smoothly converging exterior passageways for the induced secondary or ventilation air flow.

The peak velocity coefficient can be reduced to a simple equation if the convergent nozzle losses can be assumed to be represented in terms of a boundary-layer momentum thickness.

Velocity coefficient is calculated with the measured flow as

$$c_v = \frac{F_{\text{measured}}}{F_{\text{ideal}}} = \frac{F_{\text{ideal}} - \text{drag}}{F_{\text{ideal}}} = 1 - \frac{\text{drag}}{F_{\text{ideal}}} \tag{1}$$

Peak velocity coefficient for a standard round convergent nozzle[2] is

$$c_{vp} = 1 - \frac{\pi D\theta(\rho^* V^{*2}/g)}{(\pi D^2/4)(\rho^* V^{*2}/g)} = 1 - \frac{4\theta}{D} \tag{2}$$

The hydraulic diameter D_h is introduced to account for nozzles of different cross-sectional geometry. In order to compare all configurations on the basis of equal size, the hydraulic diameter is divided by the diameter D_e of a circular nozzle of equal area. This equivalent hydraulic diameter

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