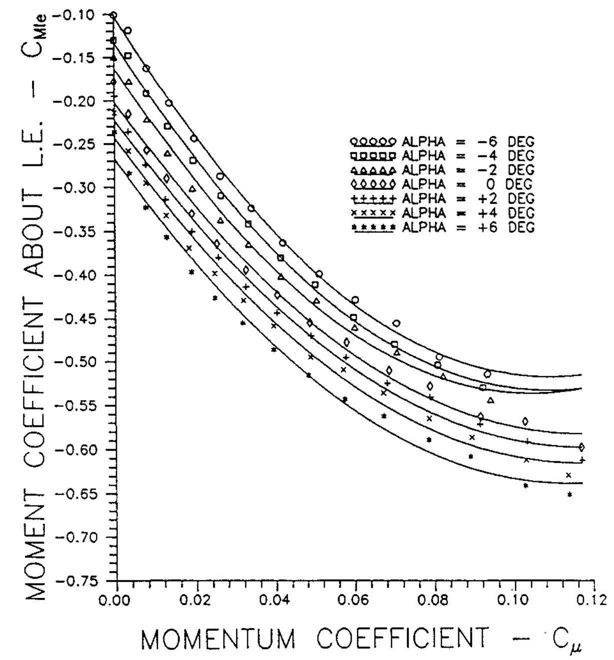

Fig. 6 Effect of blowing and angle of attack on pitching-moment coefficient.

moments are characteristic of circulation control wings and increase the trim requirements.

While this study was undertaken to show the effects of aspect ratio, the wing would require significant redesign for use in most applications. Englar[2-4] has provided design details and test results for a number of proposed applications.

Conclusions

Tests of a sting-mounted circulation control wing of aspect ratio 2.3 showed that the values of the wing lift coefficient were at least three times lower than those reported for similar two-dimensional configurations and blowing conditions. The lower values of wing lift coefficient obtained are reconciled on the basis of low aspect ratio, nonoptimized wing and slot design, partial span blowing, and sting mounting. Three-dimensional effects on circulation control wings of low aspect ratio can significantly reduce the benefits of circulation control, and practical methods to reduce these effects are needed.

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Simplified Tunnel Correction Method

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Introduction

IN wind-tunnel testings, large models relative to the test section size present challenging problems, known as wall effects. In this study, the classical method[1] was used to correct wind-tunnel data for downwash due to the walls, in conjunction with the classical method[1] of blockage correction to account for the increased velocity due to the presence of the model and wake in the test section. The classical method of blockage correction requires the obtaining of factors or constants from published documents that may or may not be available to users of this method. In some cases, this correction method cannot be applied on-line, depending on the test program.

This Note presents a simple and effective method of applying blockage corrections to the aerodynamic characteristics of airplane models tested in low-speed wind tunnels with closed test section. The method does not require reference to other documents, and the applicability of the method was experimentally investigated, using two complete airplane models; one with a rectangular wing and the other with a delta wing. The method is suitable for on-line processing. The validity of the correction methods used was examined by comparing the corrected data obtained in a typically large model-to-tunnel size ratio testing environment with those acquired in a near free air testing configuration. Experiments proved the results of this simplified method to be equivalent or superior to those of the classical method.

Experimental Facility and Models

The entire experimental study was conducted at the University of Washington Aeronautical Laboratory, 8- × 12-ft (2.438- × 3.658-m) low-speed wind tunnel. Features of the airplane models used are shown in Table 1.

The rectangular wing model was constructed so that it could be built up from the wing to the complete airplane during the test. Twenty percent chord zap flaps were available for this model. The delta wing model was not designed to be built up in the tunnel. Combinations of configurations shown in Table 1 were tested in the 8- × 12-ft (2.438- × 3.658-m) test section, which was considered to be near free air, and in a 2.5- × 3.75-ft (0.726- × 1.143-m) insert to simulate a more realistic wind-tunnel model to tunnel size ratio. Reference 2 describes

Table 1 Features of models tested

	Rectangular wing	Delta wing
Wing area S, ft^2 (m^2)	1.50 (0.139)	1.86 (0.173)
Wing span b, in. (m)	36.0 (0.914)	22.66 (0.576)
MAC, in. (m)	6.0 (0.152)	16.49 (0.419)
Aspect ratio, AR	6.0	1.92
Flaps, 100% b and 40% b, deg	30, 45, 60	Fixed
Leading-edge sweep-back angle, deg	0	68.48

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Table 2 Model to test section size ratios

	Rectangular wing		Delta wing	
Test section—height × width, ft^2 (m^2)	S/C	b/B	S/C	b/B
2.5 × 3.75 (0.762 × 1.143)	0.160	0.800	0.199	0.504
8 × 12 (2.438 × 3.658)	0.016	0.250	0.019	0.157

the method of using an insert to experimentally study jet boundary effects. Table 2 shows the model-to-tunnel size ratios examined in this study.

In Table 2, C and B are the test section area and width, respectively. The insert dynamic pressure and upflow characteristics were calibrated. The entire test was conducted at 35 psf (1675.5 Pa) dynamic pressure.

Data Reduction—Classical Method

The classical blockage correction factors[1,3] were calculated in terms of solid ε_{sb}, and wake ε_{wb}, blockages:

$$\varepsilon_{sb} = (K_1 \tau V_W)/(C^{3/2}) + (K_2 \tau V_B)/(C^{3/2}) \tag{1}$$

$$\varepsilon_{wb} = (S/4C)(C_{D0}) + (5S/4C)(C_D - C_{D0} - C_{Di}) \tag{2}$$

where V_W and V_B are wing and fuselage volumes, respectively. C_D, C_{D0}, and C_{Di} are total, profile, and induced drag coefficients, respectively. Values for tunnel-shape factor τ, airfoil shape constant K_1, and fuselage slenderness ratio constant K_2, must be obtained from Ref. 3. In applying Eqs. (1) and (2), the following definitions of C_{Di} and C_{D0} were used as described in Ref. 1:

$$\begin{aligned} C_{Di} &= A_1 C_L^2 + A_2 C_L^{2\prime} \\ C_{D0} &= C_D' - (A_1 + A_2) C_L^{2\prime} \end{aligned} \tag{3}$$

where A_1 is $1/\pi AR$, and A_2 is $K/\pi AR$, with K being the flap coefficient obtained from Ref. 4. Coefficients with ′ marks are the values recorded when the model angles of attack and yaw are zero. Correction to the dynamic pressure due to the total blockage is

$$q_c = q[1 + (\varepsilon_{sb} + \varepsilon_{wb})]^2 \tag{4}$$

Aerodynamic coefficients were recomputed to reflect the blockage effects of Eq. (4).

Downwash corrections by the classical method were applied using the method described in Ref. 1. The angle of attack, drag coefficient, and pitching moment coefficient were corrected using the following equations:

$$\begin{aligned} \alpha &= \alpha_u + \delta_w \left(\frac{S}{C}\right) C_{LC} \\ C_D &= C_{DC} + \delta_w \left(\frac{S}{C}\right) C_{LC}^2 \\ C_m &= C_{mC} + \delta_{AS} \left(\frac{S}{C}\right) \left(\frac{\partial C_m}{\partial \delta_s}\right) C_{LC} \end{aligned} \tag{5}$$

Values of downwash correction constants δ_w and δ_{AS}, were obtained from Refs. 5 and 6. The tail effectiveness factor, $\partial C_m/\partial \delta_s$, was acquired during the test. Subscripts c and u denote blockage corrected coefficients and the downwash uncorrected term, respectively.

Data Reduction—A Simplified Method

Reference 7 had developed a blockage correction factor ε for three-dimensional wakes, using doubly infinite point sources and sinks:

$$\varepsilon = (\tfrac{1}{4})(S/C)C_D \tag{6}$$

Induced drag is subtracted from the blockage uncorrected drag coefficient C_D, and the factor $\frac{1}{4}$ is deleted from Eq. (6), and a new simplified total blockage correction factor has been empirically derived:

$$\varepsilon = (S/C)[C_D - C_L^2(1/\pi AR)_{EFF}] \tag{7}$$

A new definition of induced drag based on the effective aspect ratio has been developed for the purpose of blockage corrections in wind-tunnel testings. Using the blockage uncorrected lift coefficient C_L, the increment to the angle of attack due to the wall effect is

$$\Delta\alpha/C_L = \delta_w(S/C) \tag{8}$$

The term $\Delta\alpha/C_L$ is the difference in lift curve slopes between the wind-tunnel data and the unknown free air data, and it can be expressed in terms of free air geometric and wind-tunnel effective aspect ratios AR_{GEO} and AR_{EFF}, respectively:

$$\Delta\alpha/C_L = (1/\pi AR)_{GEO} - (1/\pi AR)_{EFF} \tag{9}$$

Combining Eqs. (8) and (9), and inserting into Eq. (7)

$$\varepsilon = (S/C)\{C_D - C_L^2[(1/\pi AR)_{GEO} - \delta_w(S/C)]\} \tag{10}$$

is obtained. Equation (10) is the newly developed total blockage correction factor, and the correction to the dynamic pressure is

$$q_c = q(1 + \varepsilon)^2 \tag{11}$$

Aerodynamic coefficients have been corrected for blockage effects using Eq. (11), and results are compared with those obtained by Eq. (4). The same classical downwash corrections, using Eq. (5), were applied in combination with the simplified blockage corrections described above.

Results and Conclusions

Uncorrected and corrected data in the 2.5- × 3.75-ft (0.762- × 1.143-m) insert, and corrected data in the 8- × 12-ft (2.438- × 3.658-m) test section are shown in data presented in this Note. Since the model to the test section area ratio in the 8- × 12-ft (2.438- × 3.658-m) test section is considered to be near free air condition, the degree of coalescence of the cor-

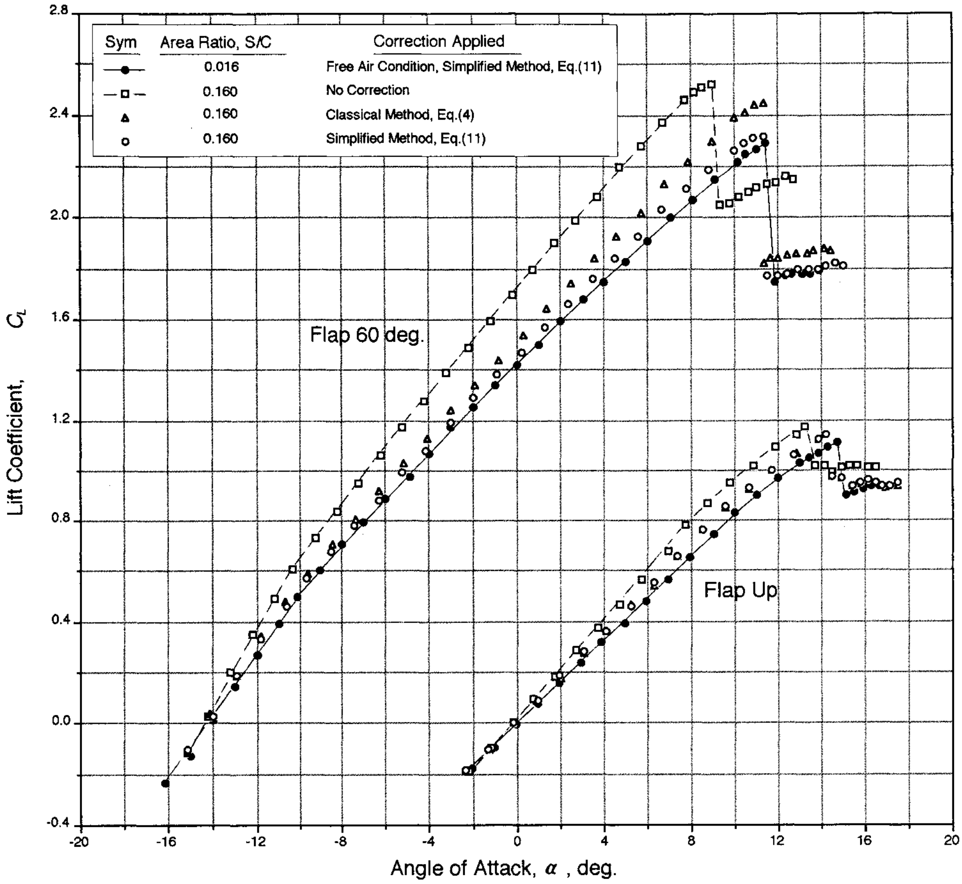

Fig. 1 Lift characteristics—rectangular wing airplane model.

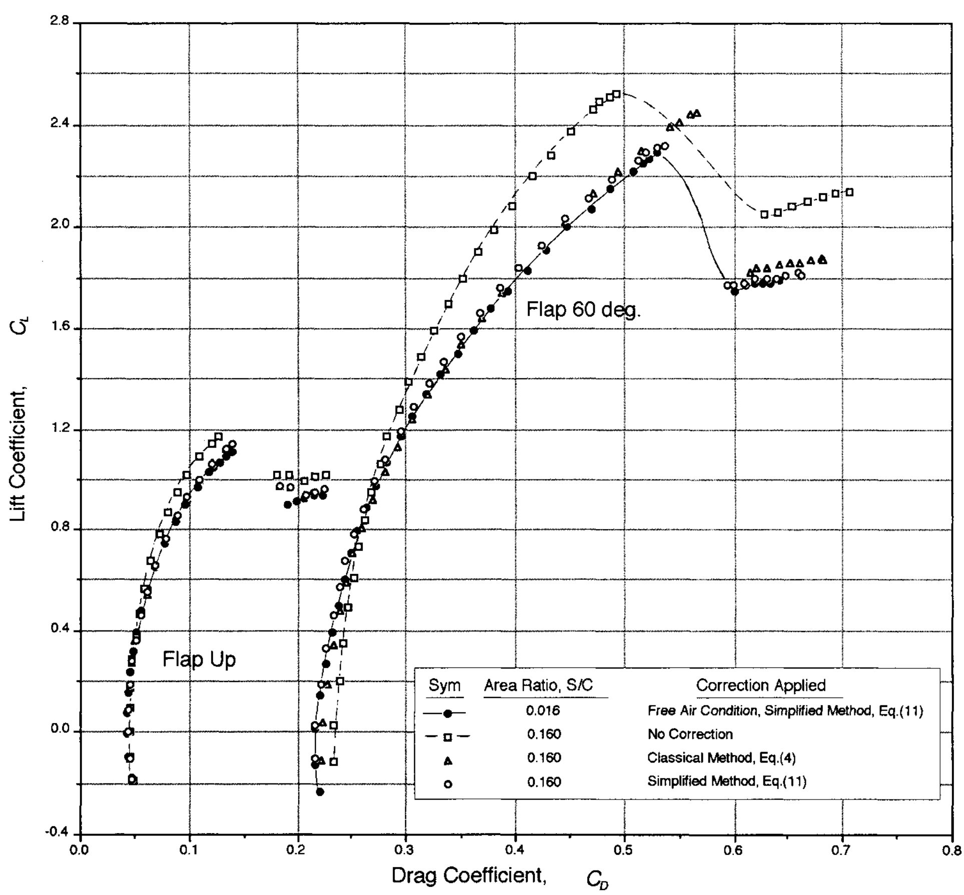

Fig. 2 Drag characteristics—rectangular wing airplane model.

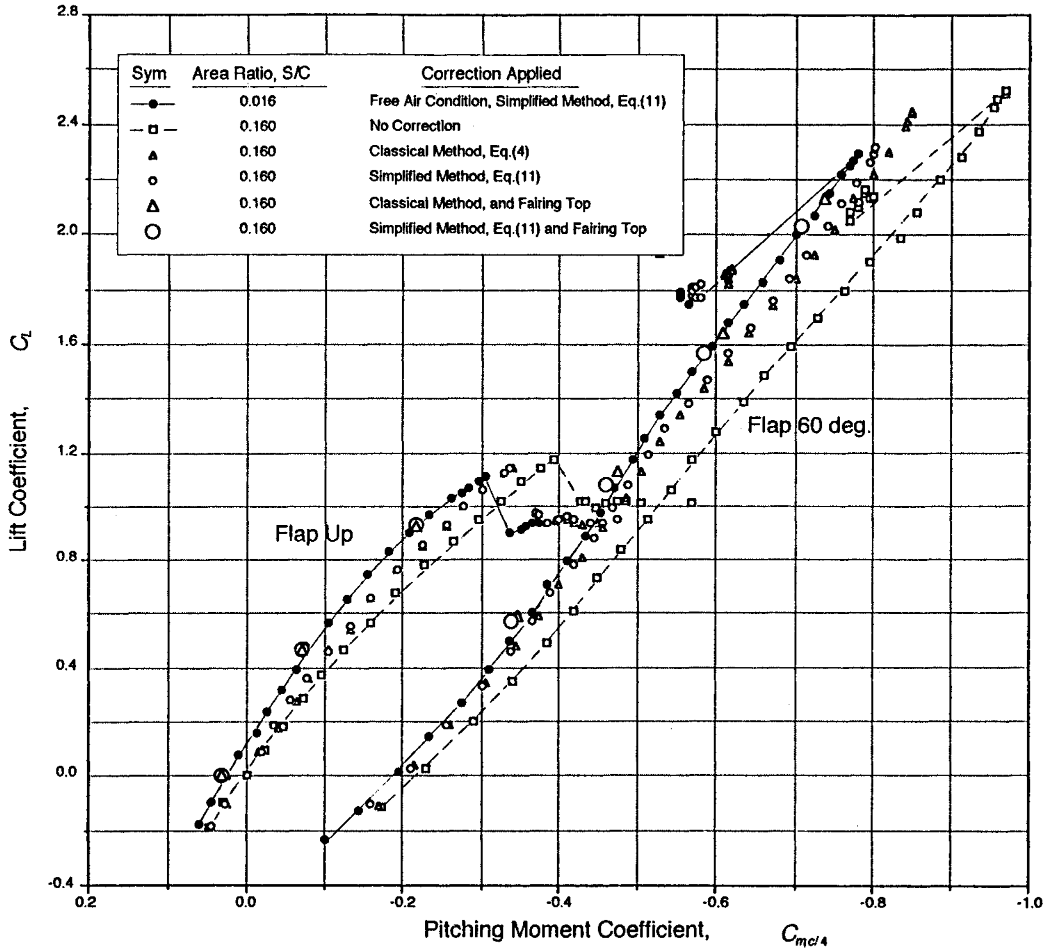

Fig. 3 Pitching moment characteristics—rectangular wing airplance model.

rected insert data with the corrected free air data determined the validity of the correction method used. The complete model of the rectangular wing with flaps up was selected as the basic model configuration, and its data are presented in Figs. 1–3. The same model with the 60-deg, full-span flap was also selected, as it was considered to be a case requiring one of the most severe corrections for blockages among the configurations tested, and its data are also included in the same figures.

The degree of coalescence in lift curve slopes and $C_{L\max}$ values between the insert data corrected by the simplified method and those of near free air is considerably better than the degree of coalescence between the data corrected by the classical method as shown in Fig. 1. Streamline curvature correction[8] was not applied in the classical data reduction method presented in Ref. 1. Accordingly, it was not applied in the present method to be consistent for the purpose of comparison. The application of such correction to the results of the present simplified correction method would yield near complete coalescence of the insert data with those of the free air configuration.

Drag characteristics shown in Fig. 2 resulted in approximately the same degree of coalescence. The $C_{D\min}$ corrected by the present simple data reduction method shows a significantly better agreement with the free air $C_{D\min}$ than that of the classical method. Although there are only a limited number of test points of pitching moment data corrected for the effect of the balance fairing, Fig. 3 shows that the results of the present simple correction method are as effective as those of the classical method.

Data from the delta wing model were examined in the same fashion, and found that the present simplified data reduction method appears to yield results similar to those obtained by the classical method.

Acknowledgments

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