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Summary

As a means to achieve a minimum interference correction wind tunnel, a partially actively controlled test section was experimentally examined. A jet flapped wing with 0.91 m (36 in) span and AR = 4.05 was used as a model to create moderately high lift coefficients. The partially controlled test section was simulated using an insert, a rectangular box 0.96 x 1.44 m (3.14 x 4.71 ft) open on both ends in the direction of the tunnel air flow, placed in the University of Washington Aeronautical Laboratories (UWAL) 2.44 x 3.66 m (8 x 12 ft) wind tunnel. A tail located three chords behind the wing was used to measure the downwash at the tail region.

The experimental data indicates that, within the range of momentum coefficient examined, it appears to be unneccessary to actively control all four sides of the test section walls in order to achieve the near interference free flow field environment in a small wind tunnel. The remaining wall interference can be satisfactorily corrected by the vortex lattice method.

Introduction

Wind tunnel testing of an aircraft with high lift coefficients involves nonlinearities of the flow field which require interference correction of large magnitude. Validity of the test data then becomes more dependent on the accuracy of the corrections used. The aerodynamicist's desire is to keep the tunnel interference on the model aerodynamic characteristics as small as possible. To this end, effort have been expended to retain a small model-to-tunnel size ratio, by either using small models or large wind tunnels. Neither one of these solutions to the unique testing problem of the vehicle with high lift coefficients has been completely satisfactory because: 1) it is costly to build small high lift models with a high degree of accuracy; 2) the Reynold's number obtainable with a small model is generally not considered adequate; and 3) large wind tunnels suitable for reasonably sized powered models are not readily available.

One possible solution to this conflicting problem is to build an average sized wind tunnel which can actively control the flow field around the model to nearly match that of free air, thereby reducing the tunnel interference to a minimum.

A theoretical study was made by Atkinson (Ref. 1) to examine a method to obtain a minimum interference wind tunnel in three dimension. This study showed that it was necessary to actively control only certain portions of the ceiling and floor to reduce the tunnel interference to such a low level that the remaining interference velocity components can be adequately accounted for by the vortex lattice methods of Joppa (Ref. 2). The goal of this experimental work was to test the theoretical work of Atkinson and to provide data that might be useful in further study of the interference problem.

The theoretical proposition states that, if the flow normal to the walls of the wind tunnel is controlled by suction or blowing such that it matches what it would be at that location in free air, then the lifting model in the tunnel will experience zero interference. Since most of the air that must go through the walls does so on the floor and ceiling inside the horseshoe vortex location, most of the interference can be removed by controlling only that area. The remaining interference is to be calculated using a vortex lattice method to represent the remaining solid walls.

Plan of Test Program

A proper test of this hypothesis would require measuring a set of characteristics of a high lift model under three conditions: in a test section large enough to present very small interference, in a test section of "normal" size that would cause "large" interference, and in a test section having actively controlled areas designed to minimize this interference. The first two requirements could be met easily, but the third was considered to be expensive, so an alternative method was proposed.

It was noted that the vortex lattice method of Ref. 2 represents the tunnel walls by a cylinder having the cross section of the wind tunnel, and that the infinite stream of air flows by outside of this cylinder as well as inside. The "large" tunnel and "small" tunnel tests could then be accomplished by using a small model for the first, and inserting a cylinder around the same model for the second test. The third test, to represent the controlled wall, could be approximated by simply cutting holes in the walls and allowing the free air condition to be met naturally. The experiment was designed according to this plan, to provide data for a later theoretical comparison of results under these three conditions described above.

Model Description

A jet flapped wing with a 0.91 m (3 ft) span, AR = 4.05 was designed and built for the purpose of this and other studies funded by NASA at this department, (Ref. 3). The wing was equipped with a tail, 0.3 m (1 ft) span, $\mathcal{R}$ = 4.0, located three chords behind the wing. Non-metrically mounted to the main balance fairing, the tail had a separate balance in order to avoid the possibility of losing the small tail lift force measurement in the shadow of the large lift generated by the wing. The tail was designed and constructed to rotate about its quarter chord to yield angles of attack from 10 to 25 degrees by five degree increments.

The UWAL 2.44 x 3.66 m (8 x 12 ft) low speed wind tunnel was used for this study to obtain the approximately free air aerodynamic characteristics of the jet flapped wing with the tail. A smaller test section was simulated using an insert, which is a rectangular box with the dimensions of 0.96 x 1.44 m (3.14 x 4.71 ft) by 3.5 m (11.5 ft) long open on both ends in the direction of tunnel air flow. Of the total length, 1.5 m (5 ft) was in the upstream of the wing quarter chord. The width to height ratio of the insert was 1.5, which was same as the tunnel in which the insert was placed.

One of the insert configurations examined was to simulate a test section that is closed on four sides. The other configuration had equal amount of opening in the ceiling and floor to simulate the actively controlled surfaces to achieve a minimum correction wind tunnel. The opening width (0.96 m (3.14 ft)) was nearly same as the wing span which was 0.91 m (3ft). The ratio of the opening width to the height of the insert was 1.00 latterally equally distributed from the tunnel centerline. The ratio of the opening length to the insert height was 1.91 of which 0.477 was upstream of the wing quarter chord. The amount and location of the opening was suggested by Atkinson in Ref. 1.

The insert assembly was supported and suspended by streamlined struts and cables in the middle of the 2.44 x 3.66 m (8 x 12 ft) test section. The number of support members was minimized in order to reduce the restriction for the flow in and out of the insert openings. They were placed symmetrically as close as possible to avoid the possibility of causing asymmetrical flow field around the model. Figure 1 shows the partially open insert in the UWAL wind tunnel.

A five-hole yaw head probe suitable for this project was designed and built. The probe diameter is 9.5 mm (3/8 in) and the portion of the tip, 11.1 mm (7/16 in) from the front, can be pulled out and rotated 180° to facilitate the probe angularity calibration.

The model required a supply of compressed air, 1.03×10^5 N/m^2 (15-psig), in the model pressure chamber at the rate of 167.8 gm/sec (0.37 lb/sec). The UWAL 1.03×10^7 N/m^2 (1500 psig) auxiliary air system was used to supply the compressed air.

The Experimental Program and Data Reduction

A series of static tests was conducted to determine the best jet slot opening to provide the momentum coefficient range between 0.2 and 6.0 using the available facility. During this static calibration, the pressure ratio between the model pressure chamber and the atmospheric was held at approximately two or more in order to obtain sonic velocity at the model jet throat. By assuming an isentropic expansion, the jet velocity was calculated using:

$$v_j = \sqrt{\frac{2\gamma}{\gamma-1} RTg \left[1 - \left(\frac{P_s}{P_t}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

Using the UWAL pressure system calibrated mass flow meter, the air mass flow, $\dot{\omega}$, through the jet slot was measured.

The model was tested in the UWAL 2.44 x 3.66 m(8 x 12 ft) test section at tunnel dynamic pressures, q, ranging from 47.88 N/m^2 (1.00 psf) to 1197 N/m^2 (25.00 psf). Then the momentum coefficient was calculated by

$$C_\mu = \frac{\dot{\omega} v_j}{gqS}$$

where S is the wing area, and g is the gravitational acceleration.

The UWAL main balance, to which the wing was mounted, measured six aerodynamic components while the model was pitched from -12° to 14° by 2° increments.

The downwash behind the wing was measured at three chords downstream of the wing using the tail. The tail was set at an angle of attack and its normal force was recorded while the wing angle of attack was varied. The process was repeated with the tail angle of attack at various values. The downwash angle behind the wing was calculated by finding the tail angle when the normal force was zero.

The flow angularites around the model in 2.44 x 3.66 m (8 x 12 ft) text section were measured using the yaw head probe described earlier. The probe was placed in the vertical and horizontal planes where the insert ceiling, floor and two walls would be. Four longitudinal locations were selected, X/H = 0.32, 0.69, 0.95, and 1.27, to coincide with the control points which were used by Atkinson in his preliminary study. The yaw head probe data were recorded on punched cards using pressure transducers and a data scanner system.

When the insert was placed around the model in the 2.44 x 3.66 m (8 x 12 ft) test section, it was necessary to calibrate the insert dynamic pressure system and upflow because of the possible unknown interference of the insert structure on the tunnel dynamic pressure system. A pitot-static yaw head probe was used to measure the dynamic pressure in the region where the model wing would be located.

Due to its length in the stream wise direction, 3.5 m (11.5 ft), it was necessary to compensate for the boundary layer growth on the inside surface of the insert. This was accomplished by adjusting the insert side walls outward to give a larger exit area than the inlet to produce a zero static pressure gradient.

The jet flapped wing with the tail was tested in the closed insert and open insert in a similar manner as was tested in 2.44 x 3.66 m (8 x 12 ft) test section. With the open insert, the yaw head probe was once again used to measure the flow angularities in the planes of the ceiling and floor openings.

From the yaw head probe data, it is possible to find the component of flow normal to the horizontal plane by using

$$\sin \theta = \frac{v_N}{v_L}$$

where: θ = local flow angle in vertical plane

v_N = velocity component normal to the horizontal plane

v_L = local velocity

Data Analysis

The tunnel boundaries produce restrictions on the downwash. The aerodynamic data acquired in a wind tunnel where this restriction is significant, in other words, with a large model to tunnel size ratio configuration, a larger magnitude of lift curve slope is exhibited than those obtained in a less restricted environment and in the minimum correction wind tunnel. This trend is clearly shown in Figures 2-a through 2-e. The lift coefficient of the jet flapped model in two different size test sections at constant momentum coefficients, C_μ, 0.6, 1.02, 2.43, 3.44, and 6.01 are shown in these figures. The tunnel boundary influence is almost insignificant at relatively low momentum coefficients as in Figure 2-a. When the monentum coefficient reaches 1.0 and higher, the wall induced change in the lift coefficient slope becomes significant, Figures 2-b through 2-e. The present model in 2.44 x 3.66 m (8 x 12 ft) test section may be considered to be adequately small so that the configuration is nearly representative of free air. Although the Glauert's correction for this configuration is small, the data obtained in this test section are corrected using the classical method. Similarly, the same correction method has been applied to the data obtained in 0.96 x 1.44 m (3.14 x 4.71 ft) insert. The amount of Glauert's correction appeared to be insufficient to convert the lift coefficient data obtained in a conventional wind tunnel to those of free air. The same model in the partially open 0.96 x 1.44 m (3.14 x 4.71 ft) insert displayed lift coefficient characteristic similar to free air case even at higher momentum coefficients, except at C_μ = 6.01 when the tunnel dynamic pressure was extremely low, q = 45.97 N/m^2 (0.96 psf).

The correction to the pitching moment is examined by studying the downwash angle variation with respect to the momentum coefficient. The tail described earlier was used to measure the downwash at three wing chords downstream of the wing quarter chord. The downwash at the tail varies with the momentum coefficient in various test section configurations as shown in Figure 3. In a typical closed wind tunnel, the downwash at the tail increases as the momentum coefficient is increased. In the present study, the maximum downwash angle in the closed 0.96 x 1.44 m (3.14 x 4.71 ft) insert was reached at a momentum coefficient of approximately 3. In the 2.44 x 3.66 m (8 x 12 ft) and the partially open 0.96 x 1.44 m (3.14 x 4.71 ft) insert, the downwash angle continued to increase without reaching a maximum value within the range of momentum coefficient examined. Note, in Figure 3, the close agreement of the 2.44 x 3.66 m (8 x 12 ft) data with those of the 0.96 x 1.44 m (3.14 x 4.71 ft) partially open insert.

The V/STOL low speed test limit, flow breakdown phenomenon, was predicted as shown in the figure using Reference 4 data. This limitation did not appear to apply to the partially open insert configuration simulation of an actively controlled wind tunnel.

Although the ultimate performance of the minimum correction wind tunnel should be determined using the model aerodynamic characteristics, the amount and distribution of flow in and out of the insert ceiling and floor openings, when compared with those of the free air configuration, should show the degree of success in simulating the actively controlled wind tunnel. This flow survey would yield the distribution of velocity component normal to the control surface. Generally, the velocity component normal to the ceiling control surface is inward. On the floor, the flow is outward. Flow field surveys were conducted to measure the velocity component normal to the control surface in the planes that the

0.96 x 1.44 m (3.14 x 4.71 ft) insert would occupy in the 2.44 x 3.66 m (8 x 12 ft) test section. Then similar surveys were carried out in the planes of control surfaces (open portion) of the 0.96 x 1.44 m (3.14 x 4.71 ft) insert. Representative results of the flow field surveys are shown in Figures 4-a through 4-d in the form of lateral distribution of the normal velocity to free stream velocity ratio at longitudinal stations X/H = 0.32, 0.69, 0.95, and 1.27. Data from the partially open insert and the near free air test section show good agreement at nearly all longitudinal stations studied, except at X/H = 0.69 where the probe was believed to be in the trailing vortices of the jet flapped wing. The longitudinal distribution of the flow normal to the control surface at lateral station Z/H = 0.125 is shown in Figure 5.

Concluding Remarks

The theoretical study made in Reference 1 showed that the entire test section surfaces need not be controlled to achieve adequate performance of a minimum correction wind tunnel. The experimental study to determine the feasibility of the minimum correction wind tunnel by the use of partially actively controlled test section was examined using a partially open ceiling and floor of a closed test section insert placed in the 2.44 x 3.66 m (8 x 12 ft) UWAL wind tunnel. Flow surveys showed that the open insert represented well what would be acheived with active controlled walls.

The jet flap model used in this study showed a close agreement of lift coefficient characteristics between the near free air configuration and the partially open insert simulating the actively controlled wind tunnel. The comparison of downwash angles at the tail, which contributes to the pitching moment, exhibited a close agreement between the free air and the simulated controlled test section. The velocity component normal to the control surfaces agree quite well with that measured in the near free air environment. The actively controlled tunnel successfully extended the low speed test limit of V/STOL aircraft imposed by the flow breakdown phenomenon.

Generally speaking, the actively controlled test section appears to be able to provide a testing environment similar to the free air, or at least adequately close so that the remaining corrections required are not excessively large. They can be controlled to the level of magnitude which can be handled by the vortex lattice method.

References

1. Atkinson, Alan James, "Three-Dimensional Low Speed Minimum Interference Wind Tunnel Simmulation Based on Potential Modeling," M.S. Thesis, Department of Aeronautics and Astronautics, University of Washington, May, 1978.

2. Joppa, R. G., "Wind Tunnel Interference Factors for High-Lift Wings in Closed Wind Tunnels," NASA CR-2191, February, 1973.

3. Titera, C. G., "Design of a High Lift Wing for the Investigation of Wind Tunnel Wall Correction and Test Limits,", M.S. Thesis, Department of Aeronautics and Astronautics, University of Washington, 1974.

4. Rae, W. H., Jr., "Limits on Minimum-Speed V/STOL Wind Tunnel Tests," Journal of Aircraft, Vol. 4, May-June, 1967, pp. 249-254.

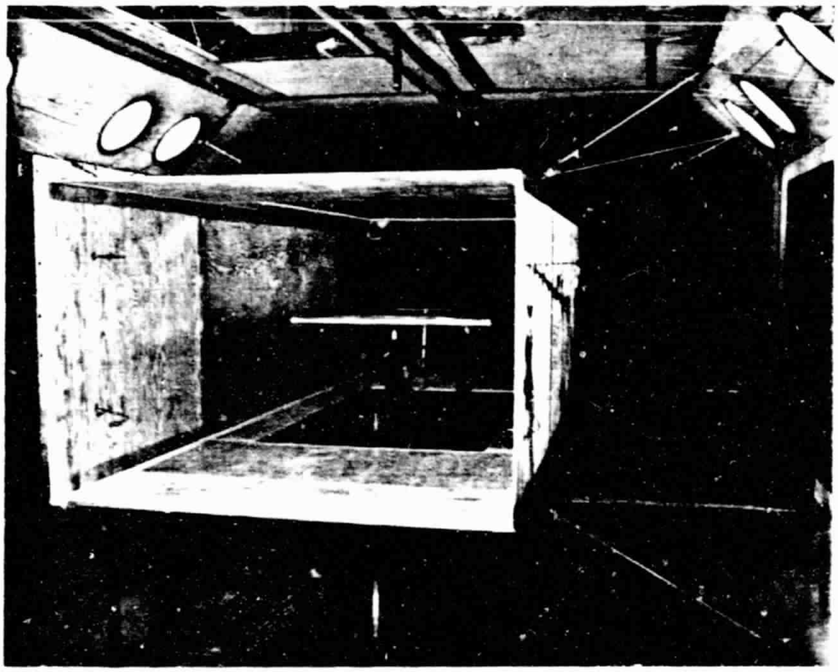
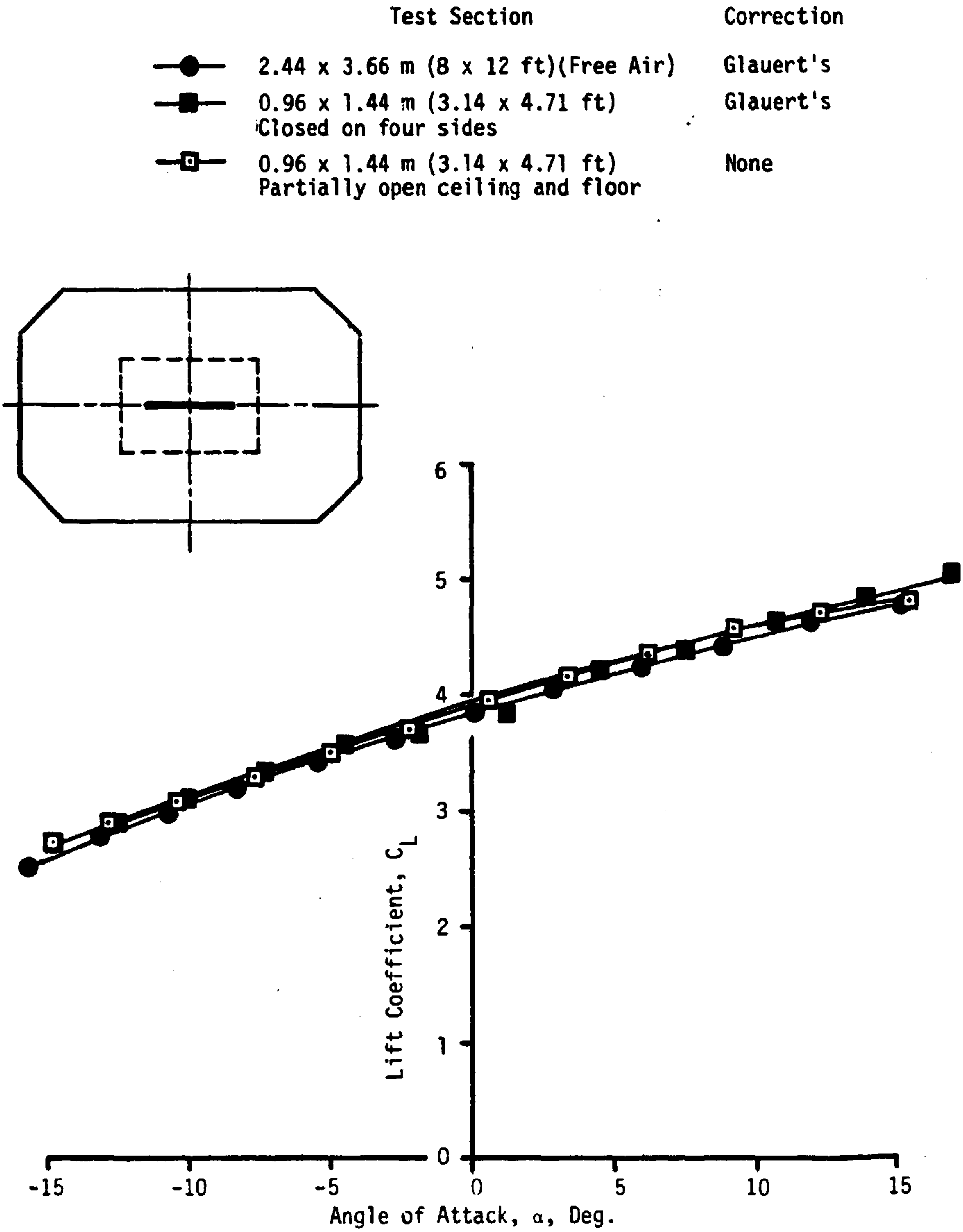
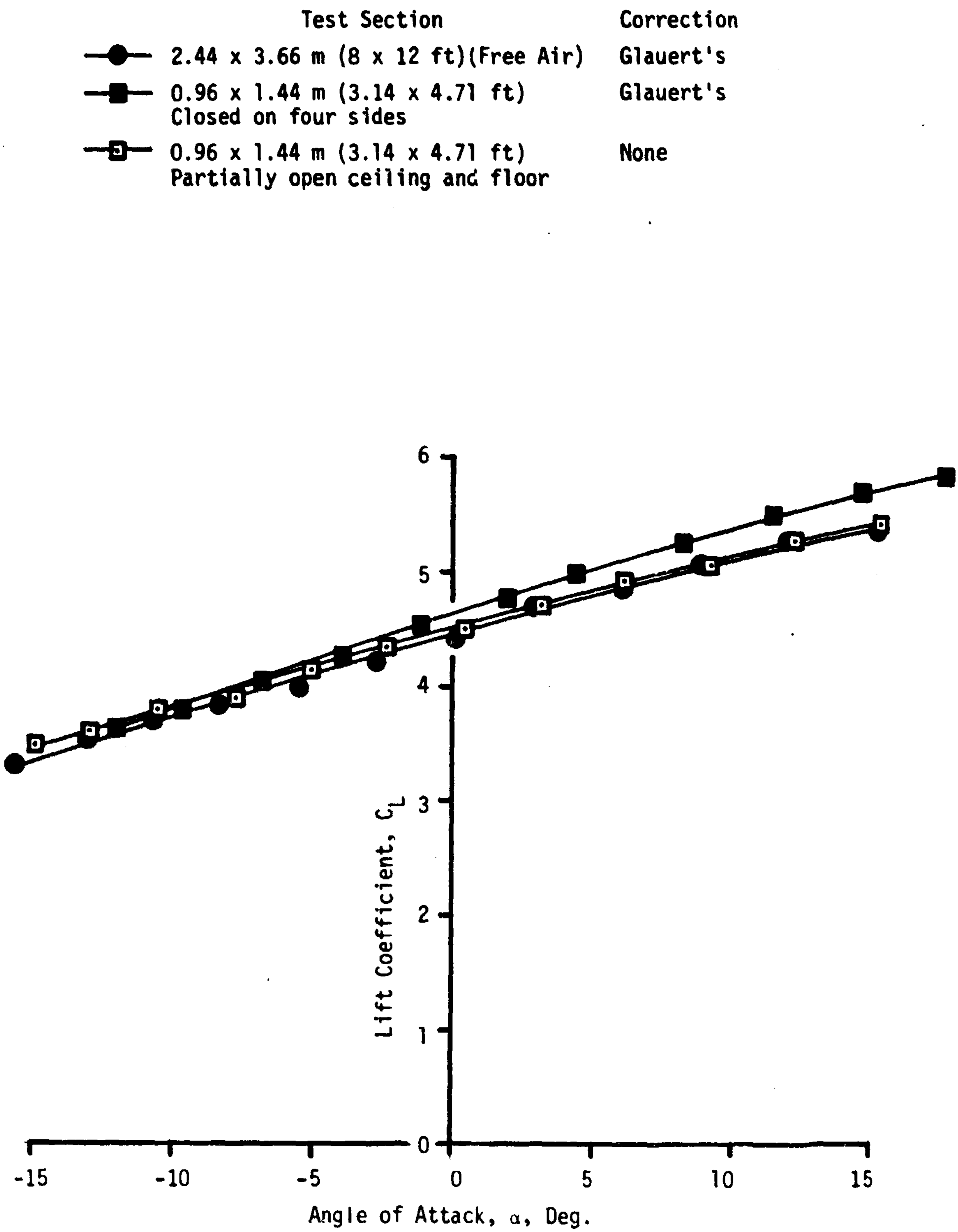


Figure 1. Open Insert in UWAL Wind Tunnel.



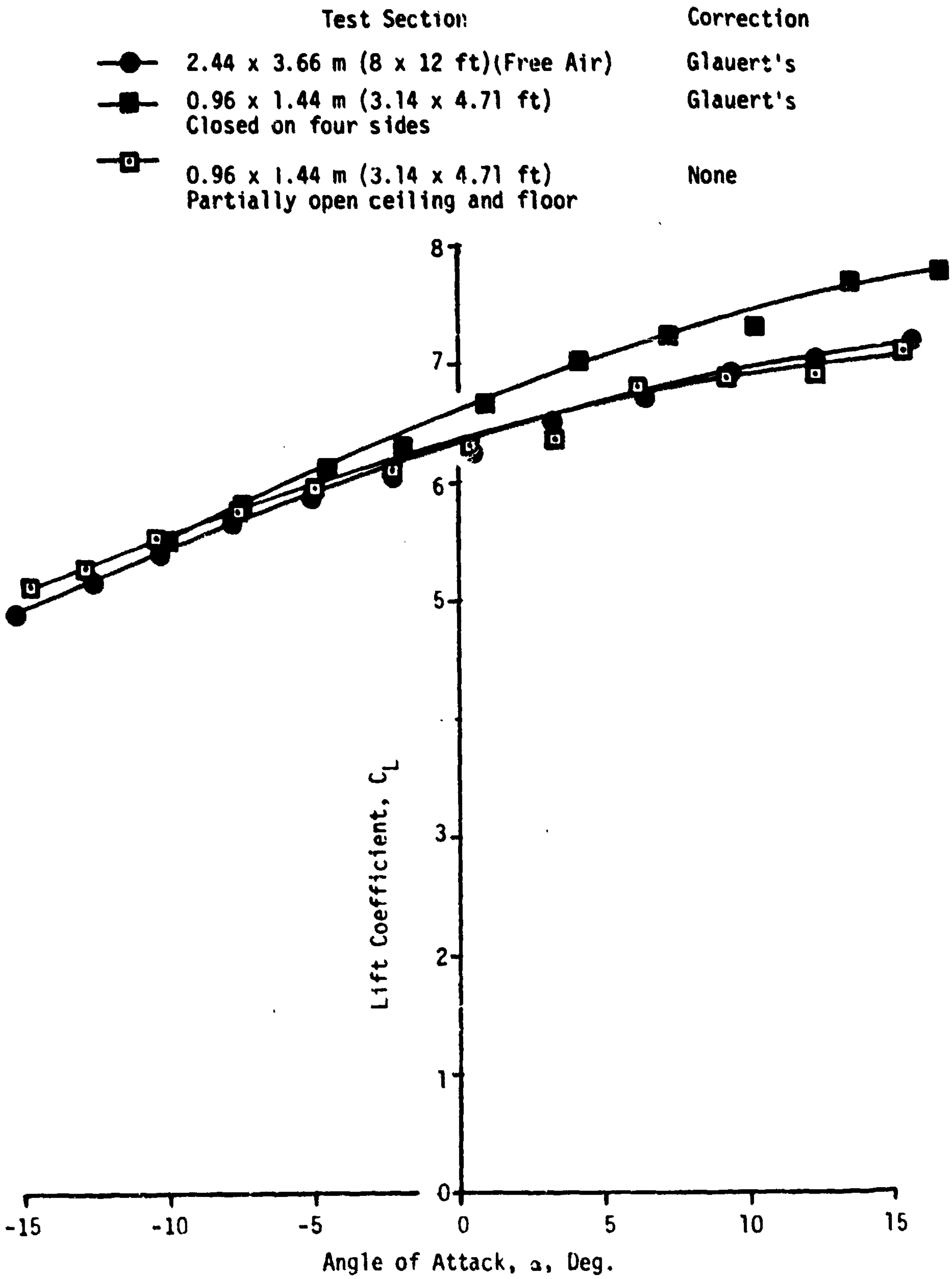
(a) $C_\mu = 0.6$

Figure 2. Lift Coefficient of Wing With Jet Flap



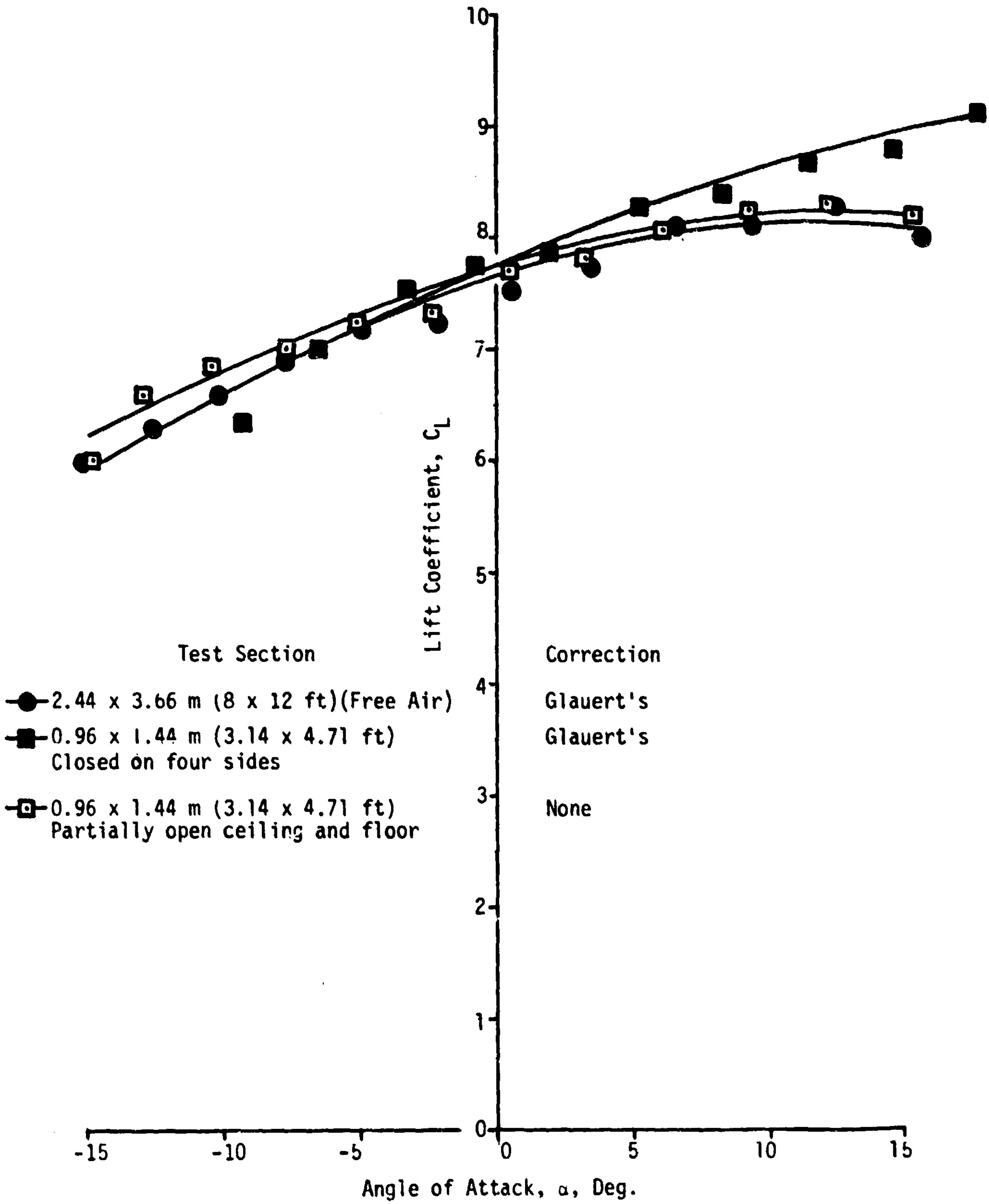
(b) $C_\mu = 1.02$

Figure 2. Continued.



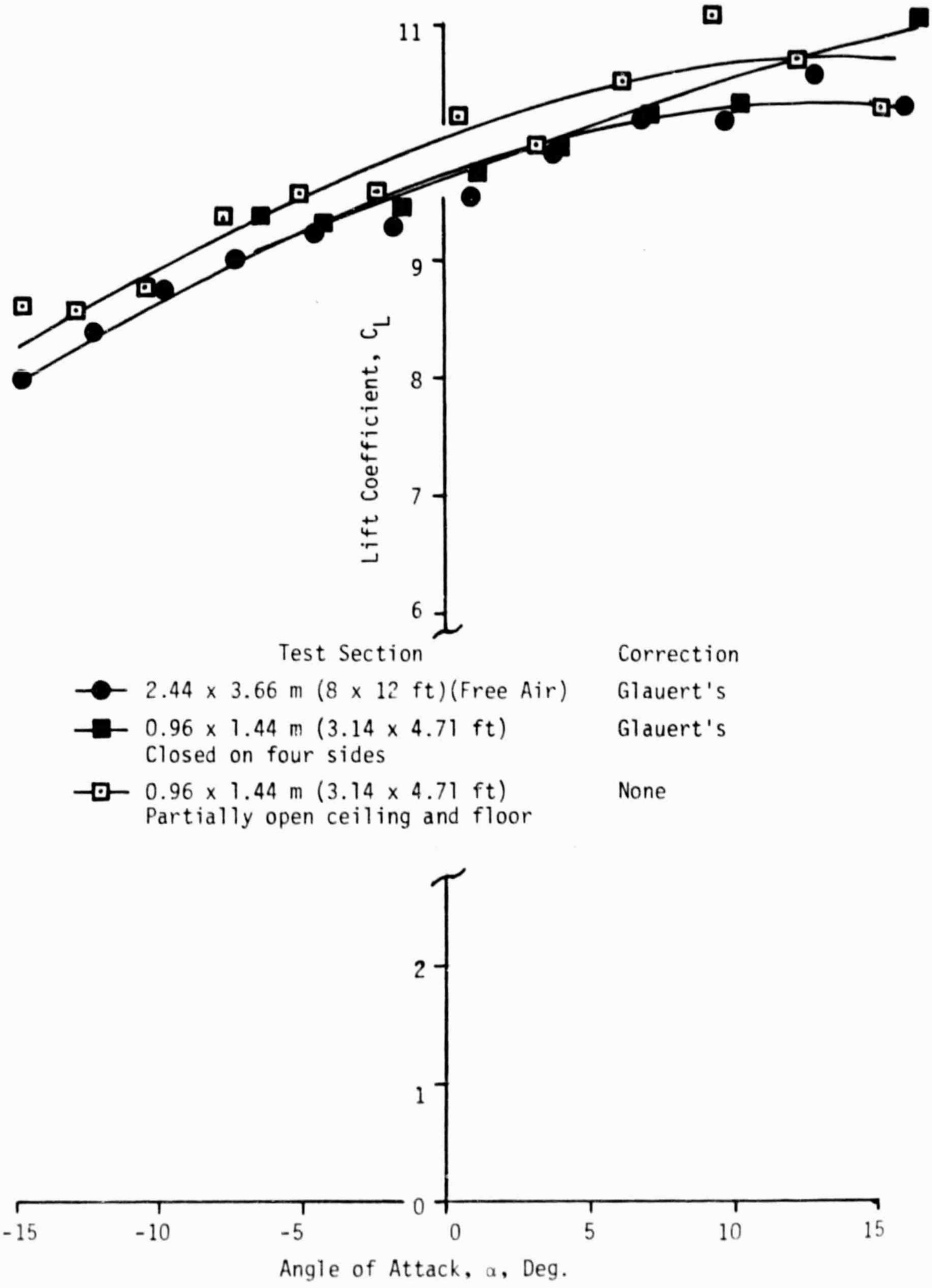
(c) $C_\mu = 2.43$

Figure 2. Continued



(d) $C_\mu = 3.44$

Figure 2. Continued



(e) $C_\mu = 6.01$

Figure 2. Concluded

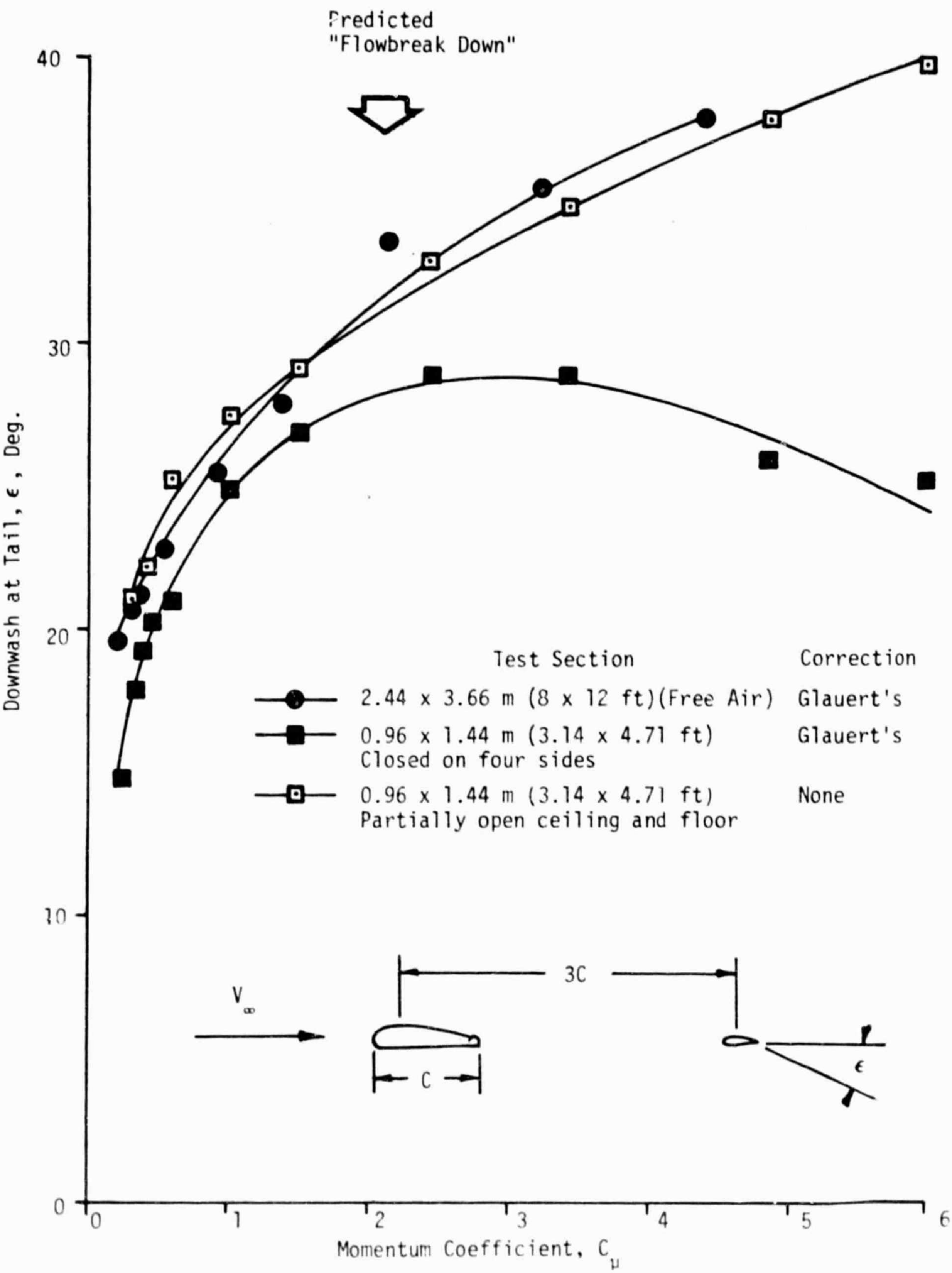
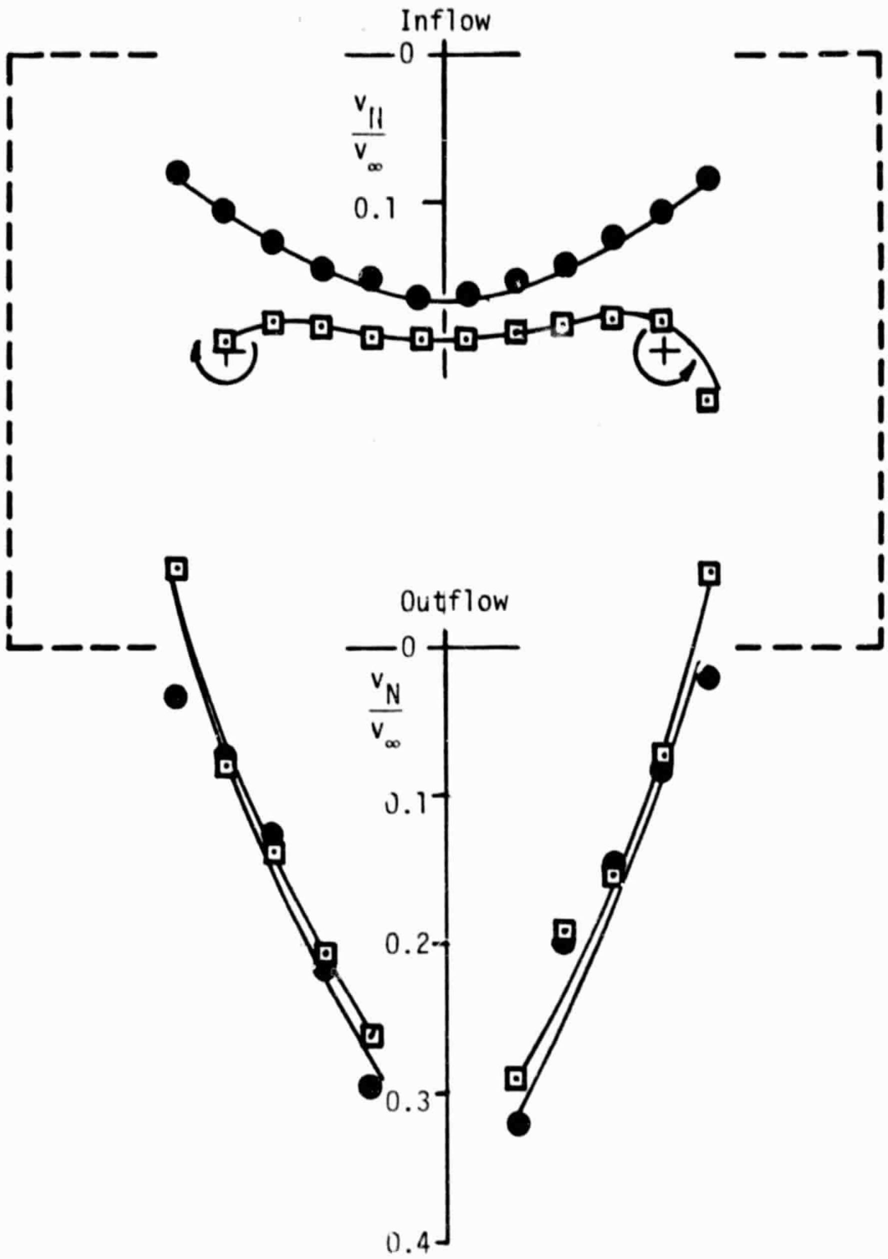


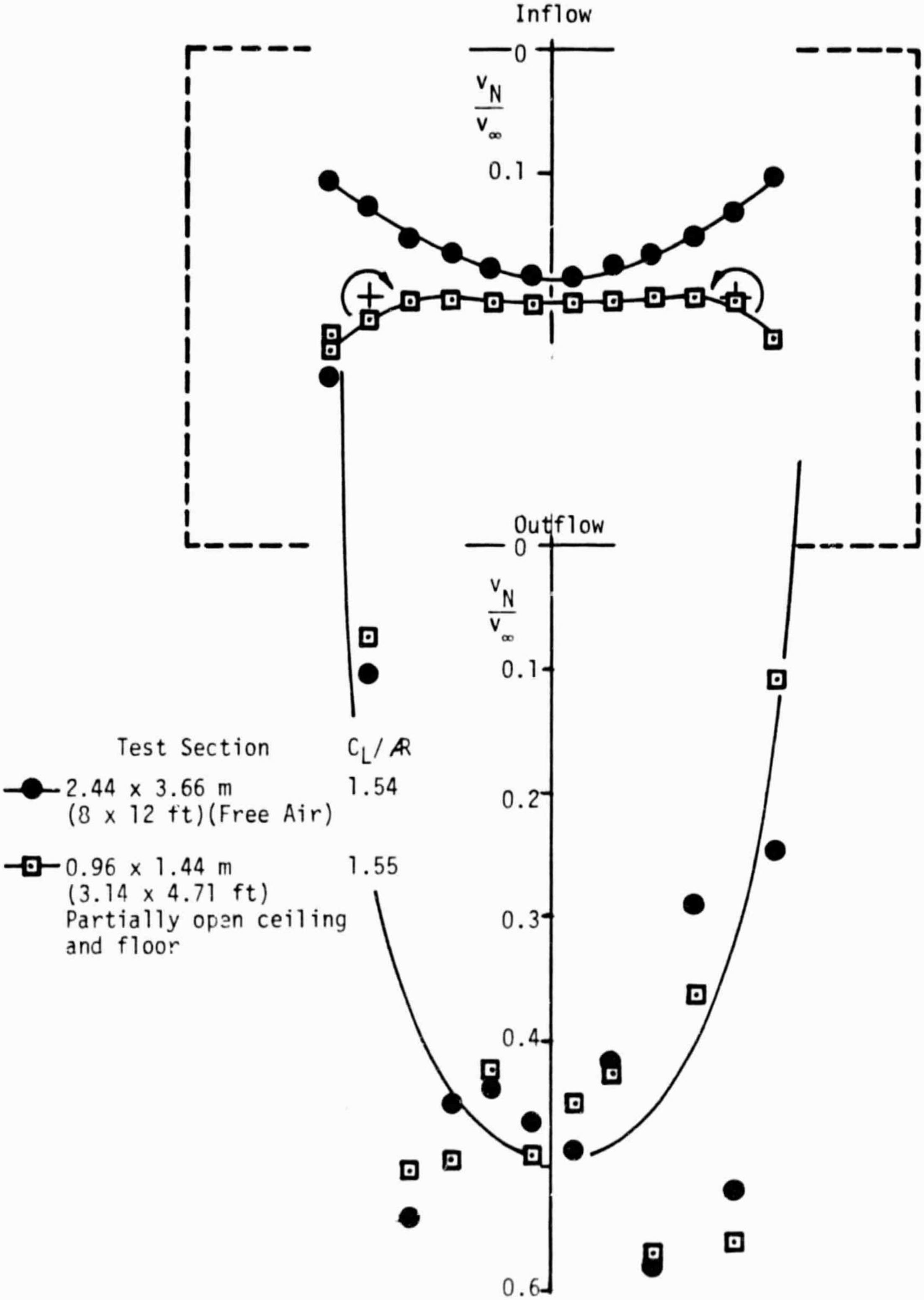
Figure 3. Effect of Momentum Coefficient on Downwash at Tail



Test Section	$C_L/A\!\!R$
● 2.44 x 3.66 m (8 x 12 ft)(Free Air)	1.54
⊡ 0.96 x 1.44 m (3.14 x 4.71 ft) Partially open ceiling and floor	1.55

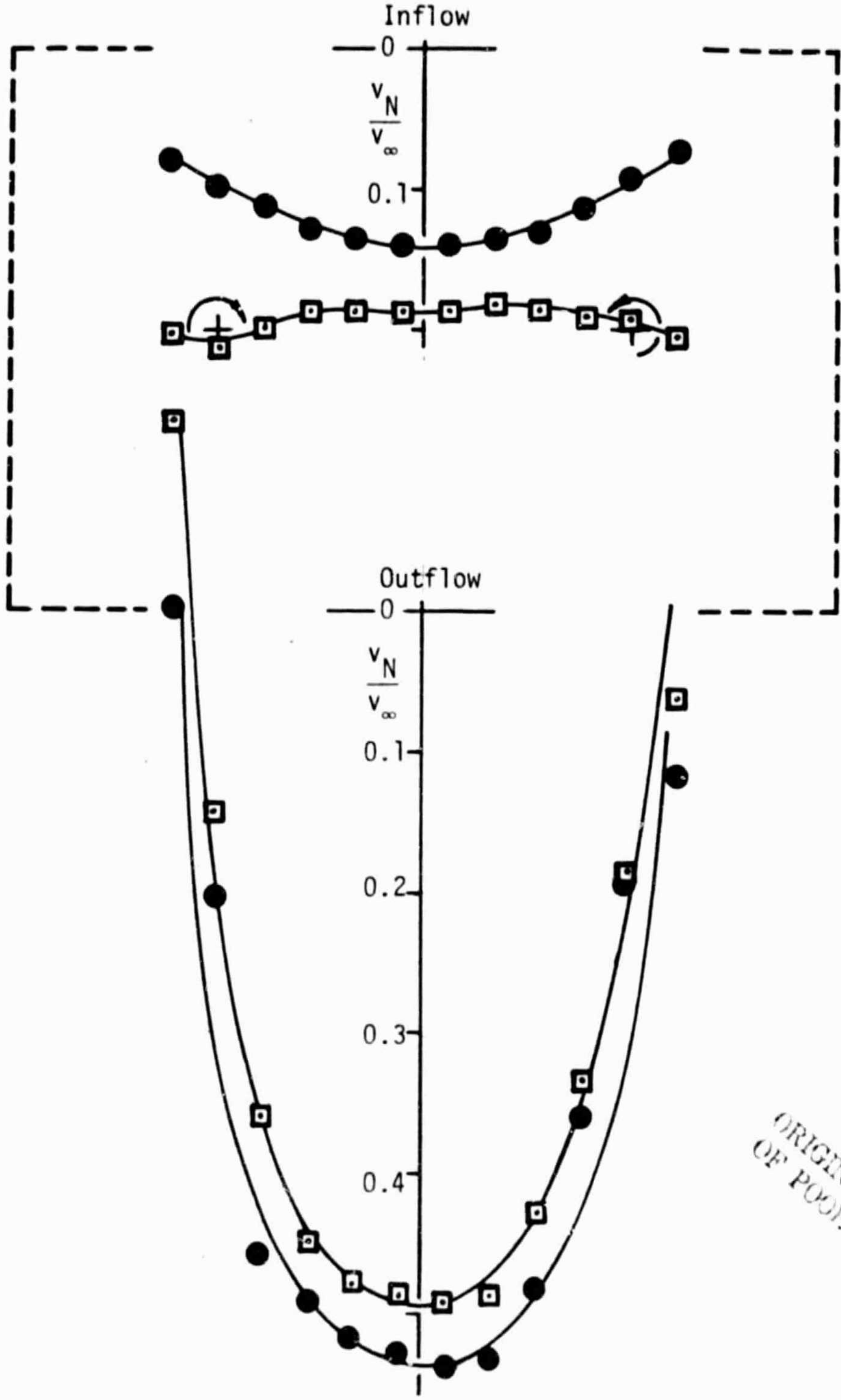
(a) X/H = 0.32

Figure 4. Distribution of Flow Normal to Control Surface



(b) X/H = 0.69

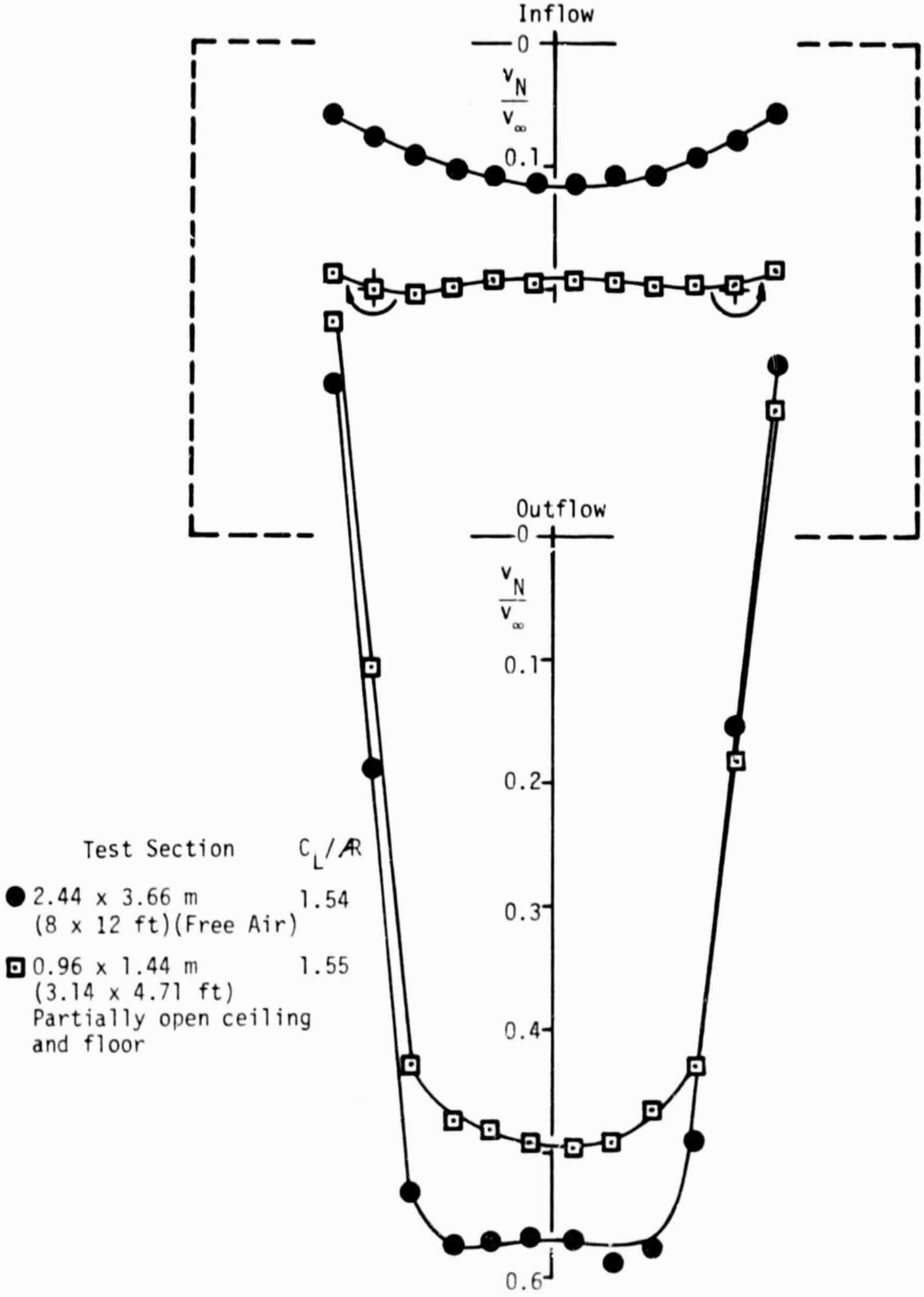
Figure 4. Continued.



Test Section	$C_L/Æ$
● 2.44 x 3.66 m (8 x 12 ft)(Free Air)	1.54
⊡ 0.96 x 1.44 m (3.14 x 4.71 ft) Partially open ceiling and floor	1.55

(c) X/H = 0.95

Figure 4. Continued.



(d) X/H = 1.27

Figure 4. Concluded.

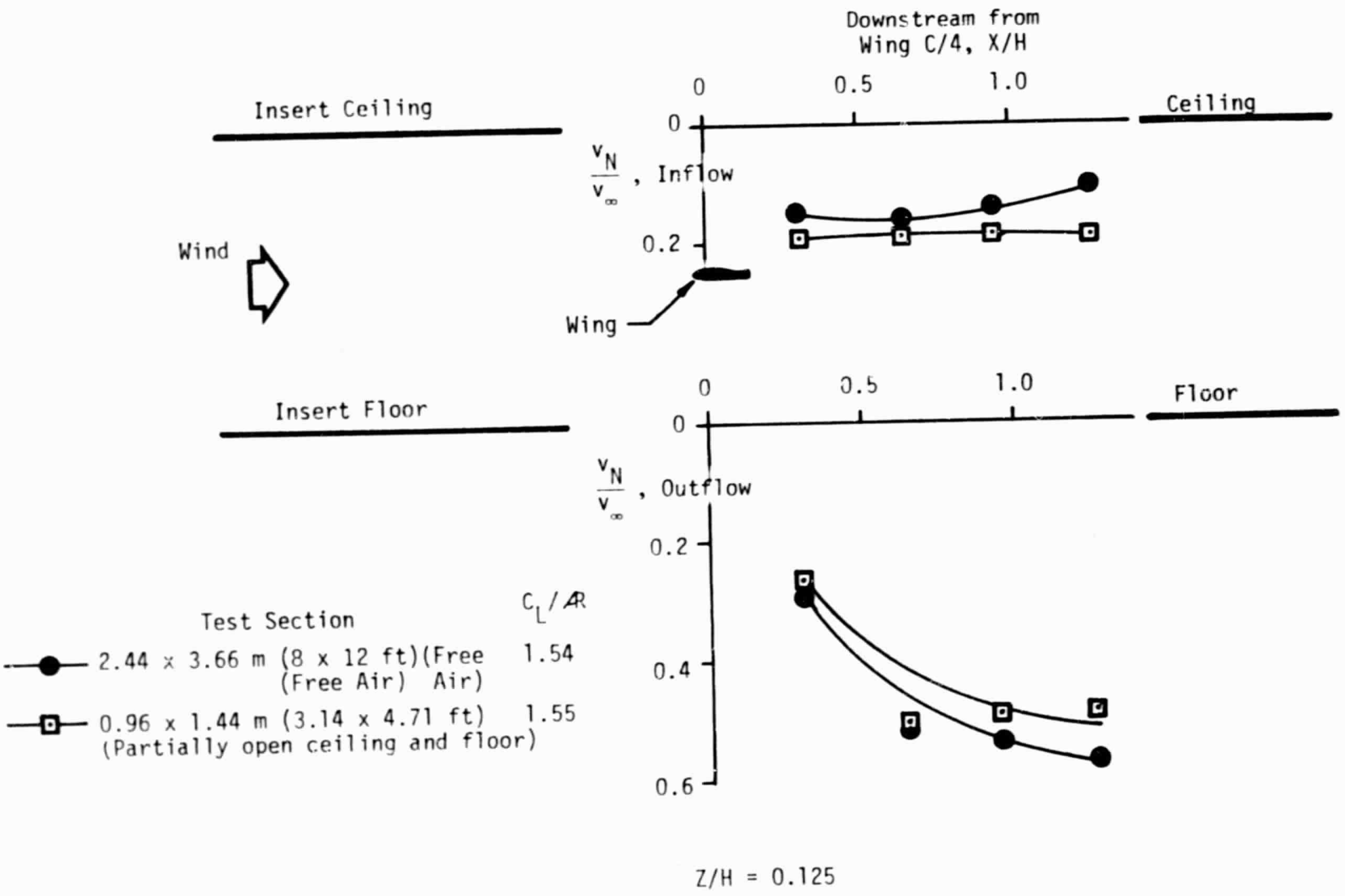


Figure 5. Longitudinal Distribution of Flow Normal to Control Surface