Wind-Tunnel Wall Effects on Delta Wings

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Abstract

A COMPUTATIONAL study was performed to assess the effects of wind-tunnel wall interference on the flowfield around delta wings. The free vortex sheet theory was applied to three sizes of a 65-deg delta wing surrounded by representative wind-tunnel walls to determine the extent to which the walls displace the leading-edge vortex core and alter its circulation distribution, hence, altering detailed flowfield properties. A wing size is determined such that these details can be corrected through a simple global adjustment to the angle of attack.

Contents

A wind-tunnel experiment is under consideration for measuring Reynolds number effects on the subcritical flow around a 65-deg delta wing in the NASA Langley Research Center Low-Turbulence Pressure Tunnel (LTPT) using a three-component laser velocimetry (LV) system. The primary factors affecting the determination of model size are the contrasting requirements for 1) a large model for adequate LV resolution of flow details, with 2) a small wing to minimize wall interference effects. This issue is of particular importance here because the LTPT, primarily an airfoil test facility, has a narrow test section with solid walls, which limits the allowable model span. This study focused on determination of a model size that best meets the test requirements by using an available computational tool to estimate the wall effects on the flowfield.

The presence of the walls around a lifting wing induces variations in the magnitude and direction of the flow that are not present around the wing in free air. These effects increase substantially as model size increases. Induced curvature in the flow is manifested in the wing as artificial camber and twist. Because the proposed wing will primarily experience vortex flow, the induced camber and twist will alter the flow nonlinearly. With such effects present, details in the flow are difficult to correct because the principles of superposition are no longer valid. From a practical standpoint, it is desirable to determine the largest wing for which flow curvature effects are sufficiently small so that flow details in the confined flow can be directly related to a free-air flow through a simple adjustment to the global angle of attack.

The vortex flowfield was computed for several sizes of the 65-deg delta planform confined within simulated solid test-section walls using the free vortex sheet (FVS) theory of Ref. 1. The FVS code utilizes a potential-flow panel formulation to model steady subsonic, inviscid flow about wings or wing-body configurations with separation-induced leading- and/or side-edge vortex flow where the separation line is known a priori. The vortex position and strength, which are determined as a part of the nonlinear solution, define the dominant features of the flowfield and provide a sensitive measure for assessing changes in the flow. Applications of the FVS method have been documented in the open literature[2] for a broad class of generic wing shapes with generally good results.

Figure 1 depicts a FVS doublet panel formulation for a 65-deg delta wing with vortex flow at $\alpha = 15$ deg surrounded by the wall panels. Solutions were computed for model-span to tunnel-span ratios (R_b) of 0.44, 0.5, and 0.67, at angles of attack of 15 and 30 deg. (Attached-flow solutions were also computed with the same code but are not presented herein.) The ratios of wing-reference area to tunnel cross-sectional area (S/C) are 0.04, 0.05, and 0.10, respectively, for the three wing sizes. Present in the formulation, but not shown in Fig. 1, are trailing wakes attached to the wall panels and a higher-order near wake attached to the wing trailing edge and partially turned into the freestream, followed by a trailing wake extending well downstream parallel to the wall wakes. The tunnel inflow plane was located approximately 1.6 to 3.9 wing-root chord lengths ahead of the wing midchord station,

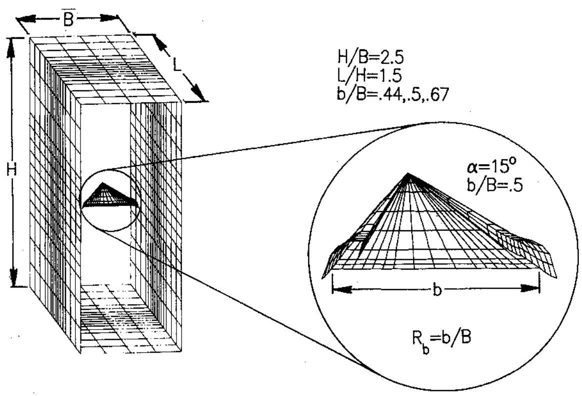

Fig. 1 FVS solution geometry for 65-deg delta wing in LTPT; vortex-flow model.

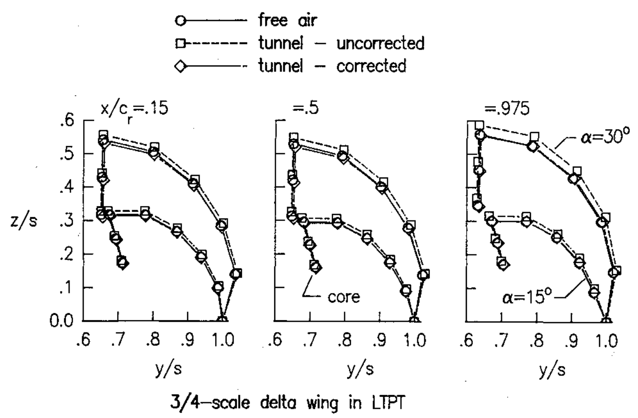

Fig. 2 Effect of upflow correction on vortex sheet geometry for 65-deg delta wing in LTPT; $R_b = 0.5$, $M_\infty = 0.22$.

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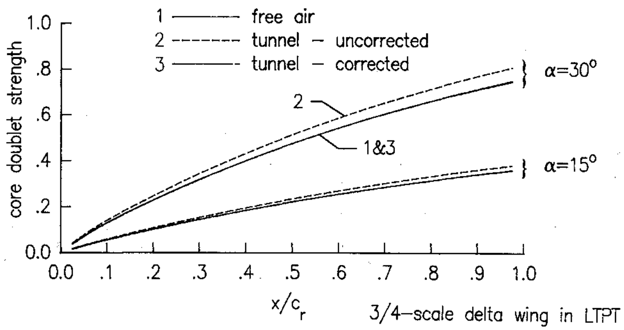

Fig. 3 Effect of upflow correction on core doublet strength for 65-deg delta wing in LTPT; $R_b = 0.5$, $M_\infty = 0.22$.

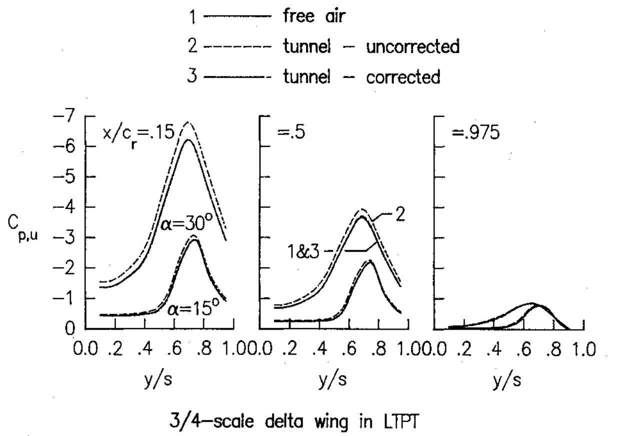

Fig. 4 Effect of upflow correction on vortex flow upper-surface pressures for 65-deg delta wing in LTPT; $R_b = 0.5$, $M_\infty = 0.22$.

where the velocity perturbations were determined to be small. Blockage effects due to wing thickness are assumed to be small, whereas those effects due to frontal area of the wing at angle of attack are accounted for within the three-dimensional formulation.

To determine the wall induced variations to the flow, the doublet singularities for the walls were extracted from the full solutions and used to compute the wall-induced velocity field. Consistent with classical correction procedures, incremental correction angles $\Delta\alpha$ were derived from the computed upflow at the 0.25 mean aerodynamic chord centerline point. For the range of cases studied (including the attached-flow cases not presented), the computed angles collapse with the expression

$$\Delta\alpha = C_L \frac{S}{C} \delta' \cos^{-p} \alpha \tag{1}$$

where $p = 1.75$ and $\delta' = 0.316$.[3] For $p = 0$, Eq. (1) reduces to the classical upflow parameter that is based on lifting line theory. The $\cos^{-p}\alpha$ term accounts for the nonplanar singularities, varying trailing-edge positions, and curved wakes.[3] It has been demonstrated in Ref. 3 that, for the fixed values for p and δ', Eq. (1) provides an accurate estimate for $\Delta\alpha$ vs C_L for the range of parameters investigated. It is also shown in Ref. 3 that Eq. (1) depends on the aggregate lift and not on details in the vortex- or attached-flow loadings; it should therefore also apply when more complicated flow features, such as vortex breakdown, are present. Equation (1) is used for estimating the global $\Delta\alpha$ corrections applied in the following results, where the goal is to achieve good correlation between the free-air and confined-flow details.

Figure 2 presents results for leading-edge vortex sheet and core positions on the midsized wing, $R_b = 0.5$, at chord stations near the apex, midchord, and trailing edge for $\alpha = 15$ and 30 deg. When comparing the free-air solution with the tunnel-uncorrected solution, note the general expansion in size of the vortex sheet and vertical displacement of the core. By recomputing the confined-flow cases with the appropriate $\Delta\alpha$ corrections, the new tunnel-corrected vortex geometries agree very well with those of the free-air cases at each chord station for both angles of attack. These results demonstrate that the effects of flow curvature on the vortex structure are small for this wing.

The core doublet strength is a relative measure of core circulation. Distributions of this parameter are shown in Fig. 3 for the $R_b = 0.5$ wing and are well corrected at both angles of attack. It can be concluded from these and the geometrical results that the vortex flowfield has been reasonably well corrected for the midsized wing at both angles of attack. As might be expected, the corresponding inviscid upper surface pressure distributions presented in Fig. 4 are also in good agreement along the entire chord after $\Delta\alpha$ corrections are applied. Similar results presented in Ref. 3 for the larger wing, $R_b = 0.67$, showed good averaged corrections to the flow parameters but exhibited noticeable effects of flow curvature at $\alpha = 30$ deg. Based on the results as a whole, it is concluded that the test requirements can be adequately met with the $R_b = 0.5$ wing.

References

[1]Johnson, F. T., Lu, P., Tinoco, E. N., and Epton, M. A., "An Improved Panel Method for the Solution of Three-Dimensional Leading-Edge Vortex Flows. Volume I – Theory Document," NASA CR-3273, July 1980.

[2]Luckring, J. M., Hoffler, K. D., and Grantz, A. C., "Recent Extensions to the Free-Vortex-Sheet Theory for Expanded Convergence Capability," NASA CP-2416, Oct. 1985.

[3]Frink, N. T., "Computational Study of Wind-Tunnel Wall Effects on Flow Field Around Delta Wings," *Proceedings of the AIAA 5th Applied Aerodynamics Conference*, AIAA, New York, 1987.