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Simplified Method for Testing Finite Wings in Wind Tunnels with Two Adaptive Walls

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Introduction

THE use of test chambers with two adaptive walls for testing three-dimensional models appears to be attractive in view of the complexities and shortcomings of three-dimensional adaptive walls' wind tunnels both in mechanical design (sealing) and operational aspects (many time-consuming measurements of the boundary conditions), apart from the difficulties in calculating residual corrections in complex test section shapes.[1]

Obviously, in the case of only two adaptive walls the concept of streamlining the walls cannot be applied. The idea is to minimize walls' interferences on the model only along a selected streamwise line (target line: T.L.). The aim of adaptation is therefore to reduce blockage velocity and upwash and their chordwise gradients. Spanwise gradients cannot be eliminated because in two-dimensional adaptation the deflections of the walls are constant across the wind-tunnel width.

The walls' interferences along the target line can be calculated by a measured boundary condition (MBC) method as the one by Ashill and Weeks,[2] based on the application of the Green formula. Applying this formula a complete survey of the pressure on the whole boundary, the two horizontal flexible walls, and the two vertical rigid walls, requires at least eight rows of pressure orifices (three on each flexible wall and one on the middle of each rigid wall) that, together with the pressure orifices needed to monitor the pressure distribution on the model, results in hundreds of wires or tubes, depending on the available scanning system, and a time-consuming adaptation procedure; both features would be scarcely desirable in high-productivity testing (industrial wind tunnels).

Therefore, to alleviate the complexity of pressure readings and reduce computational time, a simpler method has been proposed and tested in the present work. The fundamental idea consists of calculating the wall displacements by a three-dimensional strategy[3] and in calculating walls interference on the selected target line on the model considering the effects of the pressure data measured on one row of pressure orifices on each flexible wall lying in the same plane of the target line (Cauchy formula). Within this approach the choice of the target line most effective in reading global walls interference on the wing planform is of fundamental importance; this optimization has been possible because of the existing five rows of pressure orifices on each flexible wall of the AWWT.

Experimental Setup

The AWWT in Naples is an open-return, indraft wind tunnel with a 0.2 m × 0.2 m × 1 m closed test chamber. Maximum Mach number M in the empty wind tunnel is 0.55. The maximum unit Reynolds number is 10^7 m^{-1}. Stepless variation of speed from zero to the maximum value is achieved through an inlet vane control that changes the angle at which the airstream approaches the impeller.

Adaptation is obtained by modifying the shape of the flexible horizontal walls of the test chamber made with 0.6-mm-thick steel plates. On each plate 16 control stations, less spaced in the model zone, are equipped with a jack, a wall displacement indicator, and five pressure orifices. Therefore on each flexible wall 5 rows of 16 orifices are provided (Fig. 1). Two 48-port Scanivalves are used to measure pressures that are transmitted, through an A/D converter, to a control computer.

Measurements have been performed at $M = 0.4$ in the range of angle-of-attack $0 \leq \alpha \leq 10$ deg on a rectangular half-wing based on a NACA 0012 airfoil. The geometrical parameters are chord $c = 0.2$ m, semispan $b/2 = 0.21$ m, aspect ratio = 1.05, geometrical blockage = 6% at $\alpha = 0$ deg. The model is mounted on one sidewall of the test chamber. To monitor the pressure distribution on the model, four rows of 41 pressure

Fig. 1 Layout of the rows of pressure orifices on the model and on the flexible walls.

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orifices (1 on the leading edge, 20 on each surface), less spaced in the leading-edge zone where pressure gradients are stronger, are provided. The rows on the model are in the same planes of the first four rows of orifices on the flexible walls.

Results

The aim of the present work is to find the target line giving the strongest reduction of wall interference in terms of blockage (ΔM) and of induced upwash on the model. Choosing the target line at the centerline of the test chamber gives no adaptation because the interference effects are too small. Going from the tip to the root of the wing it has been found that for each angle of attack the more efficient target line is the one closest to the wing root ($2y/b = 0.1$). In fact, typically at α = 8 deg, the average chordwise variations of $\Delta\alpha$ and ΔM on the wing planform are reduced from 0.59 deg (for flat walls) to 0.075 deg and from 0.01 to 0.002, respectively. The average spanwise variations of $\Delta\alpha$ and ΔM are reduced from 0.10 deg (for flat walls) to 0.05 deg and from 0.003 to 0.002, respectively.

By using the method from Ref. 4, based on the Green formula, the choice of the target line was far less influential on the adaptation process. Nevertheless it was found that the best target line was the one located at mid-semispan of the wing. In the present method the choice of the target line (or the row of pressure orifices) to efficiently reduce walls' interference on the wing planform is, conversely, very critical.

The comparison of the results by the two methods, in terms of residual Mach number increment and upwash, shows that the present simplified method is only slightly less efficient than the more rigorous method of Ref. 4, requiring about two hundred wall pressure readings. As a result of the small differences in the residual interference obtained by the two methods, the global effects on the performance of the wing are quite similar, as shown in Fig. 2, where the distribution of the pressure coefficient C_p on the wing at $2y/b = 0.5$ is reported.

In Fig. 3 the lift distribution along the semispan is reported. The curves obtained with the adapted walls show some degree of compensation that can give comparable global results. This behavior is confirmed by Fig. 4, where the wing lift curves, obtained with flat walls and with walls adapted by the present method using target lines at different stations across the span, and the curve obtained by correcting the straight walls data with classical correction formulas, are reported. By using as a reference the curve obtained by adapting the walls with the method of Ref. 4, it is established that adaptation is more effective when the target line is moved from the tip to the root of the wing, where wall interference is strongest. Results obtained with the present method, by using as a reference the plane in proximity of the root of the wing, are quite similar to the results obtained with the more complicated method of Ref. 4.

Fig. 2 Distribution of pressure coefficient along the chord at α = 8 deg and M = 0.4.

Fig. 3 Distribution of lift coefficient along the wingspan at α = 8 deg and M = 0.4.

Fig. 4 Lift curves at M = 0.4.

The data obtained with straight walls overestimate lift by more than 50%. Applying the classical correction formulas reduces the error to an unacceptable 13.6%. This shows that wall adaptation, although limited to only two walls, and with the present simplified method, can drastically alleviate walls interference also with high blockage ratios.

Acknowledgment

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Lift-Enhancing Tabs on Swept, Three-Dimensional High-Lift Systems

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Introduction

HIGH-LIFT aerodynamicists continue to look for simple ways to achieve greater lift from multielement airfoil sections. One such possibility is the lift-enhancing tab (LET) introduced by Ross et al.[1] A lift-enhancing tab is a small mechanical tab placed at or near the trailing edge of an airfoil element, similar to a Gurney flap. Two-dimensional studies[2,3] have shown that LETs can dramatically improve high-lift system performance. The present study computationally investigates LETs on a simple, three-dimensional high-lift system, including the effects of wing sweep. Only a brief description of the computational and experimental approaches is given here. A more thorough discussion can be found in Refs. 4–7.

Geometry and Flow Conditions

The geometry consists of a NACA 63_2-215 Mod. B airfoil section[8] that spans the wind-tunnel test section. Over one-half of the span, a 30% chord Fowler flap has been installed with a gap of 3.6% chord, an overlap of 1.5% chord, and a deflection of 40 deg. All of the results were obtained at an angle of attack of 10 deg, an angle representative of the landing attitude for a commercial aircraft. In the cases where LETs are used, a 0.5% chord tab is placed just upstream of the trailing edge of the flapped portion of the main wing. Three leading-edge sweep angles are presented, 0, 15, and 30 deg, but experimental data only exist for the 0-deg case. The wing was swept such that the flapped portion of the wing was forward of the unflapped section.

The experimental investigation was conducted in the NASA Ames Research Center's 7- by 10-Foot Wind Tunnel.[9] The data were obtained at a freestream Mach number of 0.22, low enough to justify the use of an incompressible flow solver. The resulting Reynolds number, based on the unflapped airfoil chord, was 3.7×10^5. A thorough discussion of the experiment can be found in Ref. 7.

Numerical simulation of the flow was performed using the INS3D-UP code.[9] A six-zone, structured mesh containing 1.8 million points was used,[4] requiring 450 iterations to converge. Approximately 20 CPU hours were used on a supercomputer for each case. The one-equation Baldwin–Barth turbulence model was used to model the eddy viscosity in this study.[10]

Results and Discussion

The lift-enhancing tab is most effective when applied to high-lift systems experiencing flow separation on the flap, as shown in Fig. 1. In this figure, a large recirculation region is seen above the surface of the flap. The system is still generating a fair amount of lift ($C_L = 2.28$) because the main wing is largely unseparated. This does not restrict the use of LETs to poorly designed sections, as flap separation can limit the maximum efficient deflection angle of any section. Lift-enhancing tabs may increase the lift of a well-designed section by allowing the flap to be deflected farther before the onset of separation.

With the addition of the tab the flow remains attached as shown in Fig. 2. Fluid shed from the main element is turned downward by the tab, reducing the effective angle of attack seen by the flap. Attached flow on the flap not only increases the lift carried by the flap, but also increases the lift carried by the main element. The net effect is to increase the lift of the entire system by much more than just the additional flap lift.

Figure 3 shows the total lift coefficient plotted vs sweep angle for all of the presented cases. As expected, the baseline lift, i.e., without LET, decreases as the wing sweep increases. The magnitude of the lift decrease is quite dramatic between 0 and 15 deg, reducing the total amount by nearly one-half. This change is so large because of the low aspect ratio of the flap. With such a low aspect ratio, the change in the flow at the flap tip because of sweep can be felt over the entire span. The change in C_L between 15 and 30 deg is much less. The corresponding values with tabs are also shown. The lift–sweep trends are the same, but the tab reduces the amount of lift loss caused by sweep.

Perhaps a better comparison can be made if the percentage increases in total lift are compared. Figure 3 showed that the baseline lift decreases with sweep angle, and the change in lift because of the tabs gets larger with increasing sweep. This suggests that the relative effectiveness of the tabs strongly increases with sweep, as shown in Fig. 4. A 5% increase in C_L is seen for the unswept wing (both experimental and computed), whereas the increase jumps to 27% for the moderately swept wing (15 deg). The tab is even more effective for the highly swept case, increasing the lift by 36%.

Fig. 1 Particle traces over the flap element at the wind-tunnel wall, unswept case, no tab.

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