Influence of Sideslip on Double Delta Wing Aerodynamics

Deborah S. Grismer*
Wright Laboratory,
Wright-Patterson Air Force Base, Ohio 45433
Robert C. Nelson†
University of Notre Dame,
Notre Dame, Indiana 46556
and
Wayne L. Ely‡
McDonnell Aircraft Company,
St. Louis, Missouri 63166

Introduction

DOUBLE delta wings are planforms that incorporate two distinct leading-edge sweep angles. The first part of the double delta wing, the strake, has a much higher sweep angle than its aft portion, the main wing. A double delta wing has been shown to have better aerodynamic performance than a simple delta wing of comparable area having the same sweep as the main wing of the double delta. The improved aerodynamic performance is due to the interaction of the vortices created by the strake and main wing.

Very few studies have examined the performance of double delta wings in sideslip.[1,2] In sideslip, each side of the wing experiences an effective change in sweep angle. The side leading into the flow, the windward side, will see an effective decrease in sweep angle, whereas the side trailing, the leeward side, will see an effective increase in sweep angle. On a double delta wing this can result in some very complex vortical interactions. This Note discusses the nonlinear behavior of a double delta wing examined in a low-speed wind tunnel at high angle of attack in sideslip. A significantly larger amount of data on the effects of sideslip for double delta wings is contained in previous references.[3-5]

Experimental Apparatus

Two geometrically similar sets of models were constructed from the same mold, one for pressure experiments and the other for flow visualization and force balance tests. The model was a 1.27-cm- (0.5-in.-) thick flat plate with no bevel on the trailing edge, but with sharp upper surface leading edges resulting from a 45-deg underside bevel. A planview drawing of this model, shown with the rows of upper surface pressure taps, is given in Fig. 1. Also shown in Fig. 1 is a side view of how the model was mounted to the tunnel floor through the use of a cylindrical vertical strut that was attached to the model's spanwise center.

The flow visualization tests were conducted at a Reynolds number, based on the model centerline chord, of 1×10^5, using the visualization technique described by Visser et al.[6] Side and planview flow visualization images were used together to obtain actual three-dimensional coordinates of both

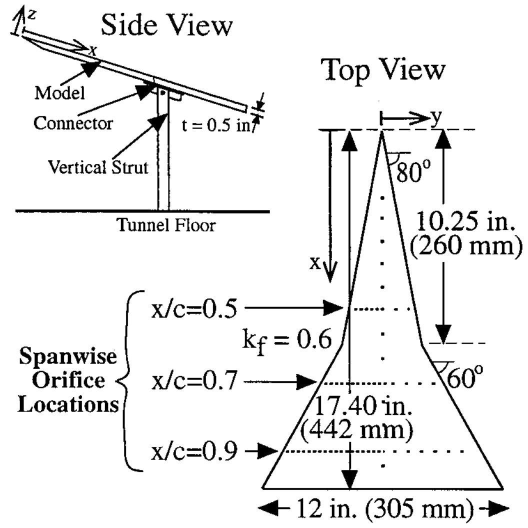

Fig. 1 80 deg/60 deg/0.6 double delta model with upper surface pressure taps and vertical mounting apparatus.

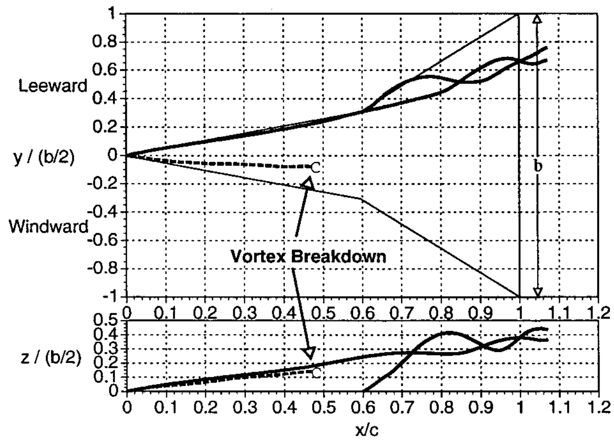

Fig. 2 Vortex trajectories at α = 30 deg and β = −12 deg.

the wing and strake vortex trajectories, as well as where breakdown occurred for each vortex. Both surface pressure, and five-component force and moment measurements were obtained at a Reynolds number of 7.25×10^5, based on the root chord of the model.

The wake blockage correction method of Pass[7] was employed in an attempt to quantify the effects of blockage due to the model size relative to the size of the test section. The model planform area was 13.0% of the tunnel cross-sectional area. A maximum normal force coefficient $C_{N_{max}}$ of just slightly greater than 1.6 occurred at $\alpha = 30$ deg. Application of the blockage correction lowered $C_{N_{max}}$ to 1.5. Because there was not a high degree of confidence in the application of the blockage technique under these particular test conditions, no blockage correction was made to the presented data. This, however, does not alter the observed aerodynamic trends that will be discussed here.

Discussion of Results

Figure 2 shows the vortex trajectories, in the nondimensional xy and xz planes, for the model at $\alpha = 30$ deg and $\beta = -12$ deg. As the angle of sideslip was varied from $\beta = 0$ deg through $\beta = -12$ deg, the windward strake vortex breakdown location moved nearer to the model apex. On the leeward side vortex breakdown moved off the wing and two coiling vortices were seen. Figure 2 also shows that at a fixed chordwise location on the strake, the leeward strake vortex was located farther from the model surface than the windward strake vortex.

Received Feb. 15, 1993; revision received July 12, 1994; accepted for publication July 20, 1994.

*Captain, United States Air Force, Control Dynamics Branch, WL/FIGC, Building 146, Room 305, 2210 8th St. Ste. 21. Student Member AIAA.

†Professor, Department of Aerospace and Mechanical Engineering, Building 66, Room 106, Hessert Center for Aerospace Research. Associate Fellow AIAA.

‡Group Manager, Department 341, Mail Code 1064126, P.O. Box 516. Senior Member AIAA.

Figure 3 shows the surface pressures and vortex core locations at fixed chordwise stations for $\alpha = 30$ deg. On the strake, at $x/c = 0.5$, finely spaced data points are shown for both sides of the model. Finely spaced pressure ports were only located on the port side of the model, and so, to get finely spaced data for the starboard side, surface pressures were obtained on the port side for the same sideslip angle magnitude, but in the opposite direction, and the data was flipped to the starboard side. Aft of the strake/wing juncture, where the data flipped to the starboard side did not agree with the widely spaced real starboard data, the surface pressures shown for the starboard side were from the widely spaced pressure ports.

Figure 3 shows, at $x/c = 0.5$, the suction peaks and the vortex core locations were seen to shift in the leeward direction as the magnitude of the sideslip angle was increased. With this increase, the leeward strake vortex also moved an appreciable amount away from the model surface and suction on the leeward side was decreased. These trends were also observed at the other angles of attack tested. At $x/c = 0.7$ an asymmetric spanwise surface pressure distribution was seen at $\beta = 0$ deg, with the higher suction peak occurring on the port side. The asymmetry in breakdown shown from the flow visualization would seem to favor a surface pressure distribution where the maximum suction peak occurred on the starboard side. The extreme sensitivity for this combination of angle of attack and sweep angle, which always led to a small asymmetry both in the location of breakdown and in

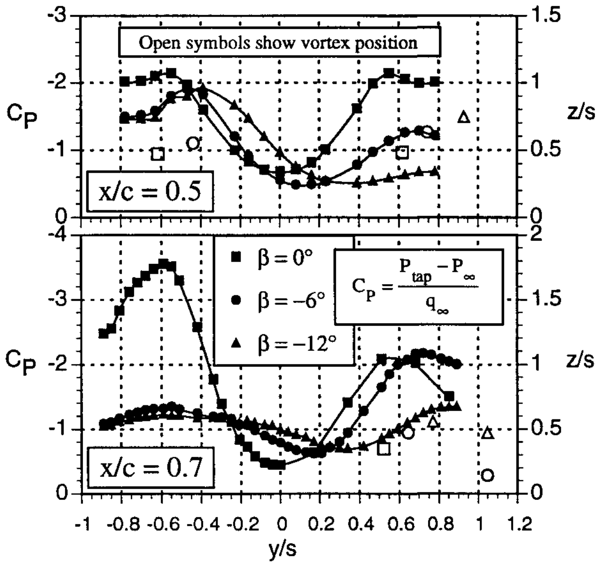

Fig. 3 Spanwise surface pressure distribution and vortex position at $\alpha = 30$ deg for three sideslip angles at two constant-chord stations.

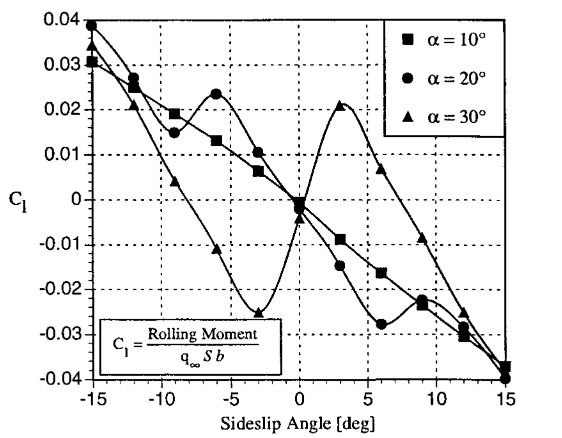

Fig. 4 Rolling moment variation with sideslip angle for three angles of attack.

the spanwise surface pressure distribution aft of the strake/wing juncture, could easily have yielded the opposite asymmetry. The lower speed used for the flow visualization experiments could also affect the asymmetric breakdown at $\alpha = 30$ deg, since this model was found to be so extremely sensitive to the initial conditions.[3]

Figure 4 illustrates the variation in rolling moment with sideslip angle for each of the three angles of attack. At $\alpha =$ 10 and 20 deg the model exhibits static roll stability. Hummel[1] did experimentation on a thin flat plate 80 deg/60 deg/0.5 double delta wing for variations in sideslip. For the angles of attack he tested, $\alpha = 11.8$ and 23.7 deg, he found that his double delta wing also possessed static roll stability. However, at the stall angle, $\alpha = 30$ deg, this model is statically unstable for $-3 \text{ deg} \leq \beta \leq 3$ deg, but for $\beta < -3$ deg and $\beta > 3$ deg the model exhibits static roll stability. Manor and Wentz[2] studied an 80 deg/65 deg/0.55 double delta wing, and they found abrupt changes in the rolling moment with α at the stall angle even at zero sideslip. They attributed this to asymmetric vortex bursting.

Conclusions

A coordination of flow visualization, surface pressure, and force and moment experiments yielded the following observations about the aerodynamic effects of sideslip on an 80 deg/60 deg/0.6 double delta wing.

1) As the sideslip angle was increased, breakdown was seen to move toward the apex on the windward side and toward the trailing edge on the leeward side. Coiling was observed between the strake and wing vortex on the leeward side. For most cases, except near the trailing edge, the leeward strake vortex moved away from the model surface, and both the leeward and windward strake vortices moved laterally in the leeward direction as the sideslip angle was increased.

2) In the absence of breakdown, as the sideslip angle was increased, consistent with the vortex movement, a decrease in suction was seen on the leeward side and an increase in suction was seen on the windward side of the strake.

3) At $\alpha = 10$ and 20 deg, the model was statically stable in roll for variations in the sideslip angle. At the stall angle $\alpha = 30$ deg, the model possessed static roll stability for large sideslip angles, but for smaller sideslip angles the double delta wing was statically unstable in roll. This was due to the nonlinear, extremely sensitive behavior of this model at high angle of attack to nearzero sideslip conditions. With zero sideslip the breakdown location of the strake vortices was found to be asymmetric, which was evident in the surface pressure distributions.

Acknowledgments

The research presented was made possible by the support of the McDonnell Aircraft Company and the University of Notre Dame. The authors wish to acknowledge the support of Michael Swadener, Joel Preston, and Matthew Grismer of the Department of Aerospace and Mechanical Engineering at the University of Notre Dame. Mention is also given to McDonnell Aircraft Company for supplying the balance and providing technical support.

References

[1]Hummel, D., "Aerodynamic Investigations on Double-Delta-Wings in Unsymmetrical Flow," 87-2, BMVg-FBWT, Forschungsbericht aus der Wehrtechnik, Dec. 1986 (in German).

[2]Manor, D., and Wentz, W. H., Jr., "Flow over Double-Delta Wing and Wing Body at High α," *Journal of Aircraft*, Vol. 22, No. 1, 1985, pp. 78–82.

[3]Grismer, D. S., Nelson, R. C., and Ely, W. L., "An Experimental Study of Double Delta Wings in Sideslip," AIAA Paper 91-3308, Sept. 1991.

[4]Grismer, D. S., Nelson, R. C., and Ely, W. L., "The Aerodynamic Effects of Sideslip on Double Delta Wings," AIAA Paper 93-

0053, Jan. 1993.

[5]Grismer, D. S., "An Experimental Study of the Steady and Unsteady Aerodynamics of Double Delta Wings for Zero and Non-Zero Sideslip," Ph.D. Dissertation, Univ. of Notre Dame, Notre Dame, IN, Nov. 1994.

[6]Visser, K. D., Nelson, R. C., and Ng, T. T., "Method of Cold Smoke Generation for Vortex Core Tagging," *Journal of Aircraft*, Vol. 25, No. 11, 1988, pp. 1069–1071.

[7]Pass, C. Q., "A Wake Blockage Correction Method for Small Subsonic Wind Tunnels," AIAA Paper 87-0294, Jan. 1987.

Directional Stability of a Large Receiver Aircraft in Air-to-Air Refueling

A. W. Bloy* and K. A. Leat†
University of Manchester,
Manchester M13 9PL, England, United Kingdom

Introduction

THE "directional wandering" of large receiver aircraft in air-to-air refueling is a problem discussed by Bradley.[1] During flight tests, receiver aircraft such as the Hercules were found to experience a loss of directional stability, quantified by the gradient of the rudder angle vs sideslip. The loss of stability increased as the tanker lift coefficient increased, and is partly due to the effect of the sidewash from the tanker wing on the receiver's fin. At low speed and high tanker weight the handling of the Hercules was judged to be unacceptable.

In previous work Bloy et al.[2] presented wind-tunnel data obtained from a tanker/receiver aircraft model tested at varying vertical separation and at a horizontal separation less than one wing span. The tanker was modeled in the experiments by an unswept, tapered wing, and the receiver aircraft model consisted of a rectangular wing with a rectangular fin and tailplane. The tanker and receiver were identical in span with main wing aspect ratios of 5.5 and 5.0, respectively. The lateral aerodynamic interference between the tanker and receiver was determined experimentally by banking the tanker wing and displacing it sideways and by yawing the receiver aircraft model. Aerodynamic forces acting on the receiver aircraft model were measured and the data presented in derivative form.

When displaced in yaw it was found that the receiver aircraft experienced approximately 14% reduction in the directional stability derivative $\partial C_n/\partial \beta$, although the overall reduction in aircraft stability would be increased by the addition of a fuselage to the receiver aircraft model. The purpose of the present work is to present wind-tunnel data that includes fuselage effects on both the tanker and receiver and to compare the data with theoretical predictions.

The theoretical model used incorporates a three-dimensional roll-up model of the tanker wing wake to determine the induced velocities on the receiver aircraft with the resulting aerodynamic forces and moments determined by the vortex lattice method as described by Bloy et al.[2] The roll-up model represents the wake by line vortices and has been applied previously[3] to the untwisted tapered wing used in the present work. Wind-tunnel corrections are applied by extending the vortex lattice method of Joppa[4] to the asymmetric case.

Experimental Setup

As in previous tests,[2] the experiments were performed in a low-speed wind tunnel with a 0.87- × 1.13-m closed test section. The tanker aircraft model, shown in Fig. 1, used an unswept, straight tapered main wing of taper ratio 0.244. This wing was tested with and without the circular fuselage shown in Fig. 1. When attached to the fuselage the main wing was set low on the fuselage at a root incidence of 4 deg. For the interference tests the tanker aircraft model was supported at each wingtip by a tapered horizontal bar fixed to a traverse that allowed bank, pitch, spanwise, and vertical displacements of the wing while the receiver aircraft model was able to pitch and yaw on the wind-tunnel balance. The receiver aircraft model is that used in previous experiments, and consists of a main rectangular wing with a rectangular tailplane and fin attached to a center boom from the wing. For some tests this model was attached to a circular fuselage with the main wing located at a high position on the fuselage and set at an incidence of 4 deg. As in previous work the tailplane was set at the same incidence as the wing. For the receiver aircraft model all airfoil sections are NACA 0015 section. The tanker wing used the NACA 0018 section.

Tests were performed at a horizontal separation, measured between the quarterchord points of the tanker and receiver wings of 0.902 m, or 1.18 times the wingspan, which is similar to that used in contact between the tanker and receiver aircraft during air-to-air refueling. The receiver aircraft model was mounted inverted on a six-component balance and positioned 0.16 m above the centerline of the wind tunnel. The tanker aircraft model was traversed vertically varying the vertical separation between tanker and receiver from 0.06 to 0.31 m. The tunnel airspeed for all of the tests was 50 m/s, giving a Reynolds number based on the receiver wing chord of 0.52×10^6.

Theoretical Model

The theoretical model of the tanker/receiver interference, excluding fuselage effects, is a development of previous work.[2,3] This involves using the vortex lattice method to determine the loads on the tanker and receiver with the wake roll-up from each lifting surface modeled using a three-dimensional line vortex method. Results for the wake roll-up from the

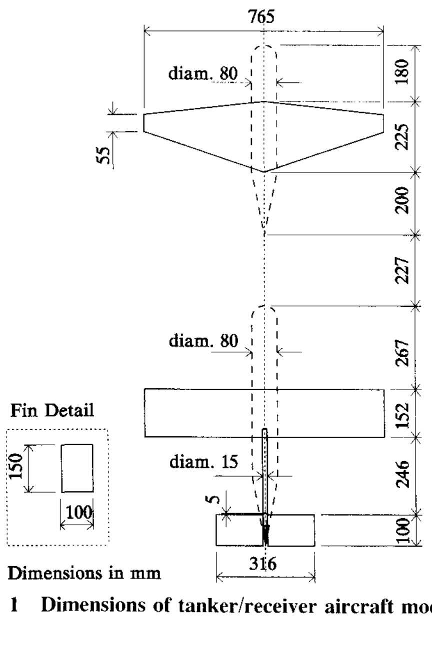

Fig. 1 Dimensions of tanker/receiver aircraft model.

Received March 1, 1994; revision received May 23, 1994; accepted for publication June 17, 1994.

*Lecturer, Department of Engineering.
†Research Student, Department of Engineering.