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

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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

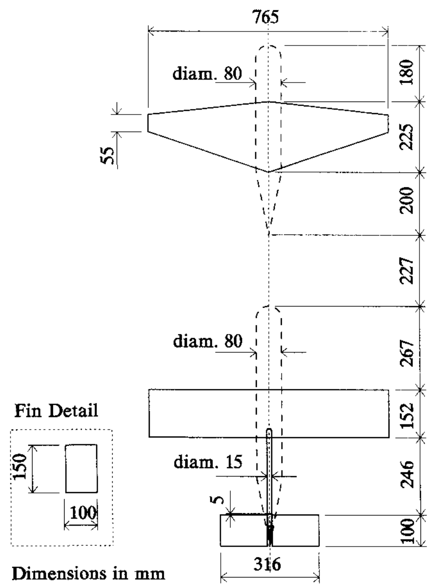

Fig. 1 Dimensions of tanker/receiver aircraft model.

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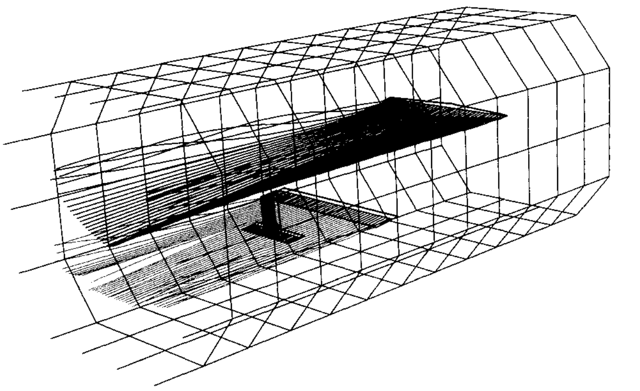

Fig. 2 Roll-up of tanker and receiver wing wakes in wind tunnel.

tanker wing used in the present work have been given previously by Bloy and West.[3] In the present work sufficient accuracy is achieved using 40 trailing line vortices across both the tanker and receiver wings, with 20 line vortices across the receiver tailplane and 30 along the receiver fin. The wake roll-up is performed by stepping downstream from the trailing edge aligning the trailing vortex lines with the local stream direction. A step length of one-quarter of the tanker wing mean chord is taken with the vortex lines initially equally spaced. The roll-up calculations are continued to a distance one wing span downstream of the receiver tail, at which point the wake is extended to infinity in the freestream direction. For these conditions it was found unnecessary to incorporate Krasny's smoothing factor used in the previous work by Bloy and West[3] to prevent chaotic motion.

The present method differs from that used previously in that the loads on the tanker wing and receiver aircraft are determined simultaneously. This allows for the small upstream influence effect of the receiver on the tanker. Initially, the wake from each surface is taken as flat. The wake roll-up calculations are then performed simultaneously and the nonlinear effect of the wake roll-up on the surface loadings is determined. The vortex lattice model applied to the receiver wing and tailplane in sideslip is that proposed by Weissinger[5] and described by Queijo.[6]

A further improvement in the model is made by the incorporation of the wind-tunnel wall effect. In the case of the sideslip tests, the effect, which is relatively small, is essentially on the vertical position of the wing wakes. The method described by Joppa[4] has been extended to cover the asymmetric case with the tunnel walls divided into 14 × 12 panels as shown in Fig. 2. Each panel has a vortex ring placed on it, and the no through-flow condition is satisfied at the center of each panel. Two sets of panels are placed upstream of the tanker with the others covering the region in which the wake roll-up is performed. The final downstream set of panels is extended to infinity in the streamwise direction. Figure 2 shows typical tanker and receiver wing wake roll-ups with the receiver tailplane and fin wake roll-ups eliminated for clarity.

When the receiver is yawed behind the tanker, the main component of the sidewash is that due to the tanker wing, although there is a significant component due to the receiver's main wing. This is associated with the modified lift distribution on the receiver wing in the presence of the tanker. The flowfield below the tanker wake has a destabilizing effect on the fin, which decreases as the tip of the fin moves upwards above the wake. The sidewash effect on the receiver fuselage is not included in the theoretical model. Figure 3 shows the sidewash due to sideslip $\partial\sigma/\partial\beta$ along the quarterchord line of the receiver fin due to the rolled-up tanker and receiver wing wakes. The curves are given at various values of z/b, where z is the vertical separation measured between the quarterchord lines of the tanker and receiver, and b is the wingspan. The test conditions are tanker and receiver lift coefficients of 0.5 and

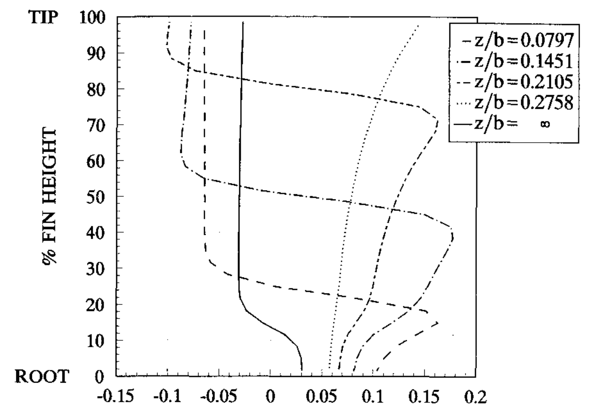

Fig. 3 Sidewash factor $\partial\sigma/\partial\beta$ along quarterchord line of receiver fin.

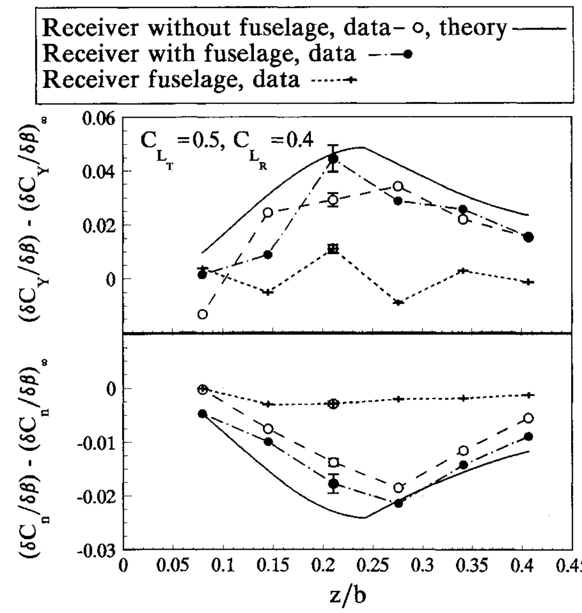

Fig. 4 Variation of receiver yawing moment and side force due to sideslip derivatives $(\partial C_n/\partial\beta)_R$ and $(\partial C_Y/\partial\beta)_R$, with vertical separation.

0.4, respectively. Figure 3 shows the change in direction of the sidewash, which in the "air-to-air refueling" case is due to the intersection of the tanker wing wake with the fin, and in the free-air case is due to the intersection of the receiver wing wake with the fin.

Experimental and Theoretical Results

Wind-tunnel tests were carried out with and without the fuselages shown in Fig. 1 attached to the models, and at tanker and receiver lift coefficients of 0.5 and 0.4, respectively. The tests involved yawing the receiver with and without the tanker in position.

Since the measured side force and yawing moment vary essentially linearly with sideslip over the test range of sideslip angle from −5 to + 5 deg, the data are presented in derivative form. For the receiver tested in free air the directional stability derivative $\partial C_n/\partial\beta$ was measured as 0.19 without the fuselage attached, and 0.13 with the fuselage attached. As in previous work, the effect of the tanker wake on the receiver yawing moment and side force derivatives is shown by presenting the results in the form of the difference between the tanker/receiver combination and the receiver only. This difference is relatively small compared with the measured derivatives, and is therefore sensitive to any measurement error. Consistent errors tend to cancel out when the difference in the derivatives is taken. To reduce experimental scatter, which is considered to be due mainly to the fluctuations in the balance readings, numerous samples of the data were taken at each yaw position. Estimated standard deviations are shown by the error bars in Fig. 4. The results, given in Fig. 4 for the case of the tanker without fuselage, indicate a loss in directional stability that is due mainly to the effect of the fin and is only slightly affected by the receiver fuselage. This is confirmed by the results of the tests made using the receiver fuselage only, which are also shown in Fig. 4. Addition of a fuselage to the tanker wing produced similar results with a measured 18% peak loss of directional stability of the receiver model with fuselage. This occurs at the vertical separation at which the tip of the fin intersects the tanker wing wake.

Side force data shown in Fig. 4 are similar in form to the yawing moment, and also indicate the relatively small effect of the receiver fuselage. The main contribution is due to the fin and, since the fin moment arm is equal to half the wingspan, the side force coefficient is, in theory, twice the yawing moment coefficient. This roughly agrees with the measured data. Similar results were obtained in the case of the tanker wing with fuselage.

The theoretical results given in Fig. 4 for the tanker/receiver combination without fuselage effects compare favorably with the experimental data.

Conclusions

Wind-tunnel data have been obtained from a receiver aircraft model tested in yaw behind a tanker aircraft model. Due to the effect of the sidewash acting on the fin below the tanker wake, the receiver aircraft experienced a significant loss of directional stability. The effect of the sidewash on the receiver fuselage was found to be relatively small. Tests with and without a fuselage on the tanker differed slightly. Similar results were obtained for the side force derivative.

The theoretical results obtained using a roll-up model of the tanker wing wake and excluding fuselage effects compare favorably with the experimental data.

Acknowledgment

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