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# Engineering Notes

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## Multifaceted Influence of Fuselage Geometry on Delta-Wing Aerodynamics

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### Introduction

THE complicated, multifaceted influence of fuselage geometry on delta-wing aerodynamics remains a poorly understood and, therefore, often ignored flow phenomenon. As more and more experimental results become available, the problem becomes harder to ignore. In the present Note the existing database is analyzed to provide the background information needed to include a realistic consideration of delta-wing-body aerodynamics in future vehicle design.

The fact that a fuselage or centerbody can have a large effect on delta-wing aerodynamics was first recognized through the extensive tests perfomed on a 65-deg delta-wing-body configuration.[1] When the measured breakdown location was compared with that observed on a pure 65-deg delta wing,[2] the presence of the centerbody was found to delay significantly the occurrence of vortex breakdown (Fig. 1a). This was in sharp contrast to the experimental results for a 69.33-deg delta-wing-body configuration, on which the pointed, ogival centerbody was located differently on the delta wing[3] (Fig. 1b). It was suggested[4] and later demonstrated[5] that in that case the body-induced upwash along the leading edge would generate a negative wing-camber effect, which has been shown to promote vortex breakdown.[6] In the case of the 65-deg delta-wing-body (Fig. 1a), the pointed ogival portion of the body is not located forward of the wing apex, as in Fig. 1b, but slightly aft of the wing apex, generating a positive wing camber effect,[5] which delays vortex breakdown.[6]

### Discussion

If the body in Fig. 1a is moved forward so that wing and body apexes coincide,[7] the body-induced upwash will no longer generate a positive but rather a negative camber effect.[8] When this body-induced camber effect is combined with the pitch-rate-induced camber effect,[9] the pitching-moment loops become asymmetrically displaced relative to the static $C_m(\alpha)$ characteristics.[7] The body-induced negative camber effect reinforces the pitch-rate-induced negative camber effect[9] during the downstroke, but opposes the positive rate-induced camber during the upstroke, generating asymmetrically displaced $C_m(\alpha)$ loops relative to the static characteristics.[7]

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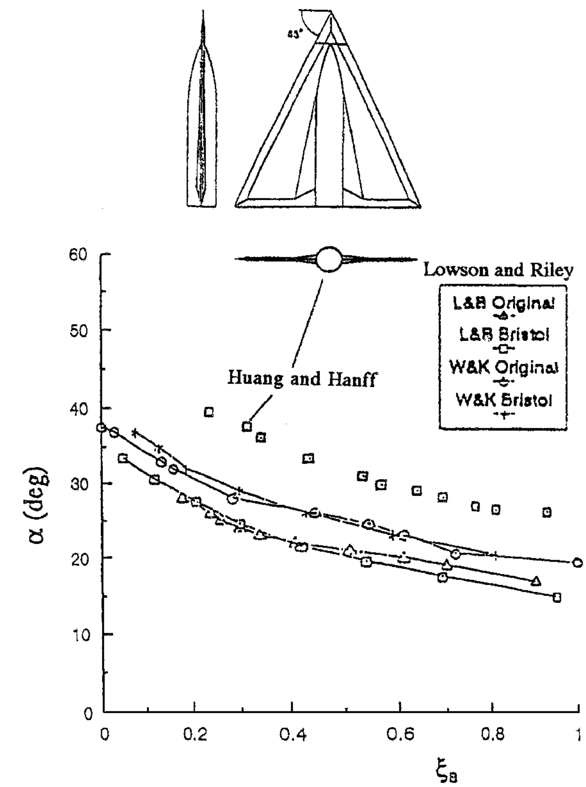
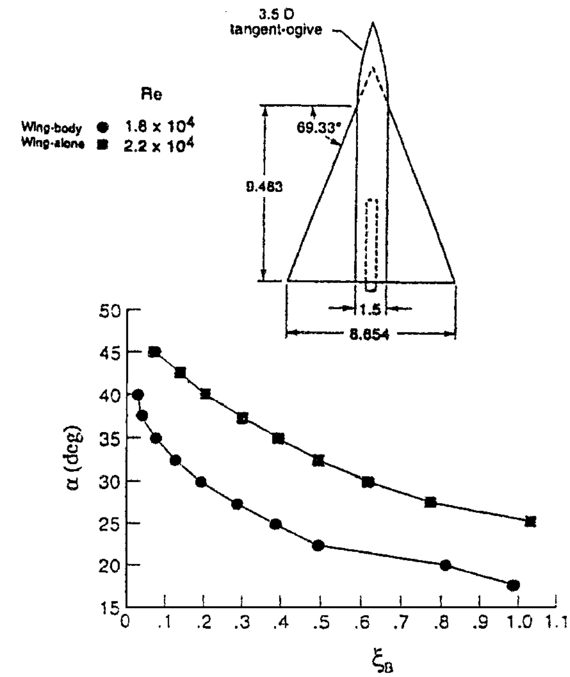
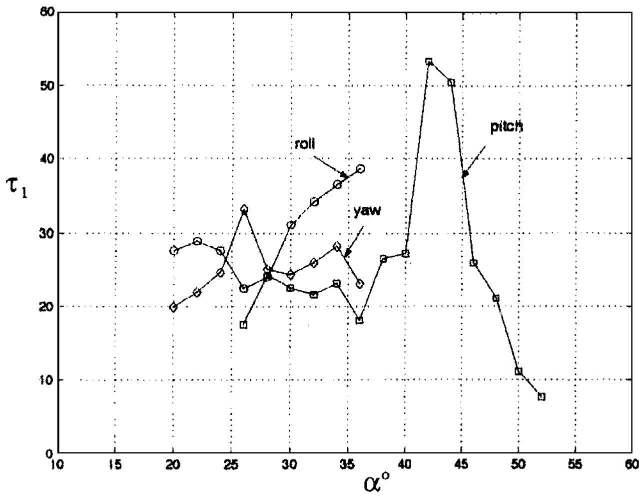



a) 65-deg delta-wing body[1]

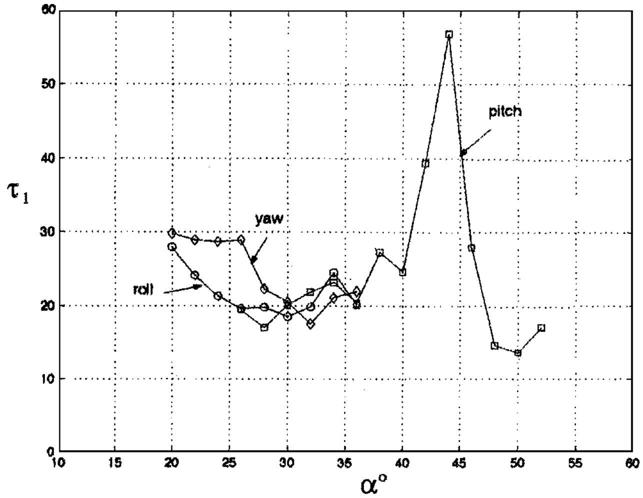



b) 69.33-deg delta-wing-body[3]

Fig. 1 Measured breakdown on delta-wing-body configurations.




**a) With centerbody**




**b) Without regular centerbody**

**Fig. 2 Characteristic time constant $\tau_1$ for 65-deg delta wing with and without centerbody.[10]**

Recent tests[10] of the 65-deg delta-wing-body configuration (Fig. 1a) gave the results shown in Fig. 2. It can be seen that the characteristictime constant $\tau_1$ varied with angle of attack in a similar fashion for oscillations in pitch for body-on (Fig. 2a) and body-off (Fig. 2b), whereas the centerbody had a dramatic effect on $\tau_1$ for the roll oscillations and a somewhat smaller smaller effect for the yaw oscillations. The results in Fig. 2 pose the following question: Why does the body have no significant effect on $\tau_1$ for pitch oscillations in Fig. 2, although it has been shown to have a large effect on the $C_m(\alpha)$ loops[7]? The likely reason is that the time constant $\tau_1$ in Fig. 2 was obtained for the $C_N(\alpha)$ loops.[9] The experimental results[7] showed that although the body presence had a large effect on the $C_m(\alpha)$ loops the body did not generate any significant asymmetry on the $C_N(\alpha)$ loops. This is not surprising considering the relative insensitivity of $C_N$ to the longitudinal lift distribution compared to $C_m$. One question remaining to be answered is why $\tau_1(\alpha)$ is so sensitive to the body presence for the roll oscillations. Analogous to the pitch-rate-induced camber,[9] there is also a roll-rate-induced camber effect,[11] verified for the 65-deg wing body by measurements[12] on a "dynamically equivalent steady" configuration.[11] Combining the roll-rate-induced camber effect[11] with the body-induced camber effect[1] (Fig. 1a), one finds that the body-induced camber acts to increase the crossflow angle of attack generated by the roll-rate-induced camber on the downstroking wing half but acts opposite to it on the upstroking wing half.

Thus, the interaction between body-induced and rate-induced camber effects is very similar for upstroking and downstroking wing halves in rolling or pitching motions. The difference is that the rolling delta-wing configuration has upstroking and downstroking wing halves acting simultaneously to generate the wing loading producing the meaured rolling moment,[10] not at different times as in the case of the measured pitching moment. As a consequence, the body-induced camber effect can only distort the time history for the rolling motion, not for the pitching motion, where the body-induced camber only can generate a bias effect. For yaw oscillations the two wing halves also contribute simultaneously to the measured yawing moment. The likely reason for the lesser body effect in this case than for the rolling oscillations is that the yaw-induced change of the effective wing sweep has a more modest effect on vortex breakdown and the associated aerodynamic loads than the roll-rate-induced camber effect.

So far only the part of the fuselage geometry located on the windward, bottom side of the delta wing has been considered. Experiments with the 65-deg delta-wing-body configuration[13] (Fig. 1a) have shown that the part of the fuselage located on the leeward, top side of the wing also can have a significant influence on the vortex breakdown, a body misalignment to the left or right promoting

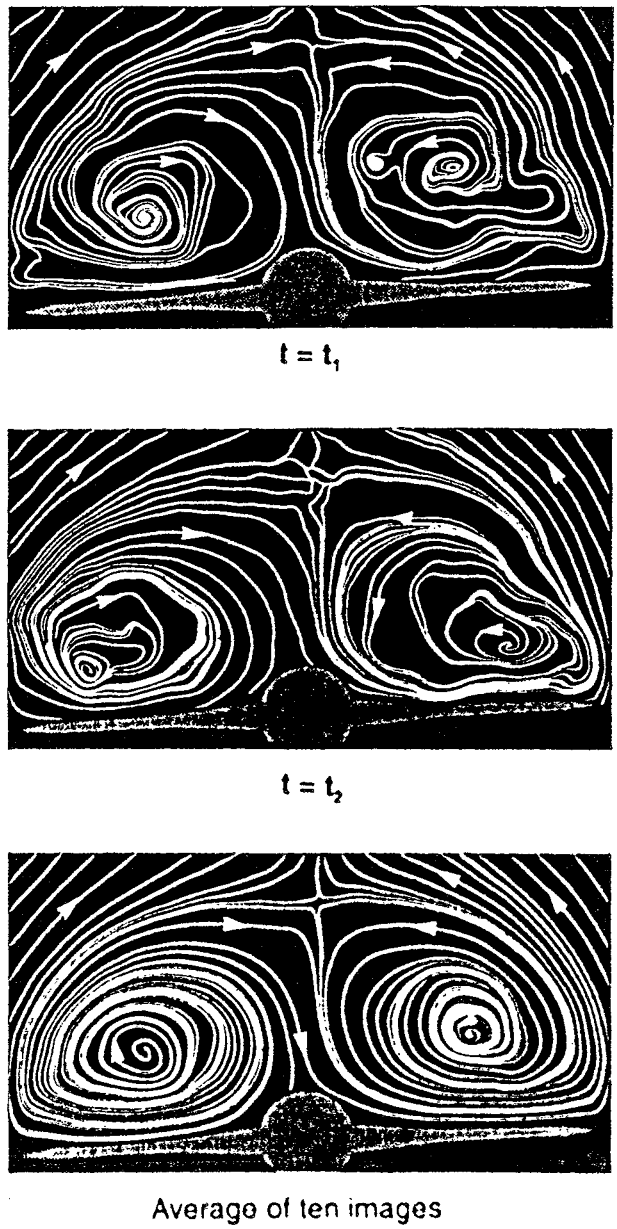



**Fig. 3 Instantaneous streamline patterns in the vortex breakdown region of a stationary 65-deg delta-wing-body configuration at $\alpha$ = 30 deg for zero sideslip and roll.[15]**

breakdown on that side compared to the opposite side. Based on the measured effect of a shallow centerline spline on the vortex formation above a thick delta wing with triangular cross section,[14] the asymmetry observed on the 65-deg delta-wing-body configuration (inset in Fig. 1a) in tests at $\alpha = 30$ deg by Cipolla and Rockwell[15] at $Re = 0.0324 \times 10^6$ (Fig. 3) could be expected.[16,17] In spite of the symmetric flow conditions at $\alpha = 30$ deg and $\phi = 0$, the helical flow structure downstream of the spiral vortex breakdown was found to be asymmetric.[18] Of course, when the top-side centerbody is off center,[13] it should be expected to cause the observed static vortex asymmetry.

## Conclusions

The significant effects on delta-wing aerodynamics of subtle changes in the centerbody geometry need to be fully understood when designing future unmanned combat air vehicles and low-observable configurations, having wings with sharp leading edges that generate vortices likely to be influenced to a unanticipated degree by the presence of an apparently insignificant fuselage.

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# Trajectory Analyses of External Store Separation by Using the Euler Equations

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## Introduction

THE prediction of the separation behavior for an external store released from a military aircraft is most concerned about the flight safety. The individual aerodynamic loads that acted on the store, however, possibly can cause the released stores to impact the aircraft. Thus, accurate predictions for the trajectory of external store such as bombs, tanks, and missiles released from the aircraft is one of the important missions for the design engineer. In general, there are three kinds of methods commonly used in determining the store separation characteristics. They are captive-trajectory system (CTS), free flight test, and numerical analysis. The CTS test can provide some useful data for regarding store carriage, but it is severely limited by the scaling effects and practical design considerations. The free flight test is an option, but without extensively analytical or experimental results for evaluating flight possibility in advance the test can cause unpredictable danger during the flight mission. In recent years the availability of modern computer systems has made the analytical methods become more efficient for the store separation prediction.[1–3] Thus, the numerical approach for the store separation prediction is employed in the present study.

To treat complex configuration, composite grid techniques commonly use two or more meshes to discretize the space domains. Although the disadvantage of composite meshes is that the flow solver must be modified, the bookkeeping that tracks relationships among the meshes will be more complicated. It is well known that the use of a multiple grid approach can yield a better grid resolution, simplify the application of boundary conditions, and alleviate the task of grid generation. In 1986, Steger and Benek developed an overset grid technique for solving unsteady body motion problems.[4] In their technique one component grid can move with respect to the rest of the components. The bookkeeping technique in their packages is fully capable of tracking the overset relationship about the moving mesh with the fixed grids. Successful calculations for the three-dimensional calculation have been presented in the Ref. 5. In this Note the use of the multiblock overset grid method combined with an iterative time-accurate Euler solver is presented for the trajectory prediction about a centerline fuel tank separation. The analytical flows include subsonic, transonic, and supersonic regimes.

## Numerical Approach

### Iteration of Euler Solver and Multiblock Overset Grid Scheme

The three-dimensional Euler equations and an implicit approximate factorization scheme for inviscid calculation are used in the present numerical approach. Details about the expression of three-dimensional Euler equations and formulation of the implicit factorization finite difference forms are shown in the Ref. 6. As mentioned in the Introduction, the original Euler solver must be modified to track the bookkeeping of multiple meshes and the "hole" points that

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