ON THE EFFECT OF AREA RULING ON TRANSONIC ABRUPT WING STALL

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Abstract

Reynolds-averaged Navier-Stokes simulations of the transonic flow over a generic fighter aircraft wing/LEX/body configuration are presented. Data in the pre and post-stall regime are presented, and it is shown that small changes in the cross-sectional area distribution in the aft body has a significant effect on the onset of wing stall, but more systematic computations are needed before the effectiveness of area-ruling can be firmly established.

1. Introduction

The phenomenon of abrupt wing stall (AWS), also known as wing drop or transonic lateral anomaly, was recorded on many fighter aircraft in the past during their development phase (e.g. F-4, F-5, F-8, F-15, F-86, F-104, F-111, YF-16, YF-17, G-91, T-38, Gnat, Hawk and Harrier). More recently, the U. S. Navy encountered AWS during the development of the F-18 E/F aircraft.

Due to the very complex wing stall mechanisms typically encountered on these aircraft, reliable prediction methods are still unavailable. Abrupt wing stall is usually only discovered during flight testing, and remedies are typically only found using cut and try efforts which generally require many additional hours of expensive flight testing. On the

F/A-18 E/F aircraft AWS was eliminated by installing a porous surface area near the leading-edge snag.

The unsatisfactory state-of-the-art of the prediction methodology for AWS led to a national program to develop a comprehensive understanding of the phenomena. Initiated in 1998, the program was intended to develop analytical and experimental tools to help avoid AWS in future aircraft designs.

As part of this program the authors performed computational studies of transonic flow past an F/A-18E/F aircraft and a more generalized wing/LEX/body configuration using the three-dimensional RANS-solver HiMAP. It is the objective of this paper to summarize certain results which were obtained as part of this investigation. Readers interested in related computational fluid dynamics studies of AWS on the F/A-18 E/F aircraft, already reported in the open literature, are referred to Stookesbury, 2001 and Grove et al., 2002.

2. Basic Approach

The importance of the transonic area rule (or equivalence rule) found experimentally by Whitcomb, 1952 and theoretically by Oswatitsch, 1952 is well recognized for the design of transonic aircraft. The question posed here is whether area ruling can have a significant effect on the occurrence/avoidance of AWS. We regard it as instructive that the earlier F/A-18 C/D aircraft experienced no AWS while the E/F model, although geometrically quite similar, experienced severe AWS. A comparison of the equivalent cross-sectional area distributions immediately reveals the fact that the maximum cross-sectional area of the E/F model is about 35% larger than on the C/D model, although the distributions themselves are quite similar. Clearly, the adverse pressure gradient to achieve recompression of the flow to free-stream condition is much more severe on the E/F than on the C/D model. This fact suggested that the flow may be quite sensitive to area ruling. Therefore, a simplified geometry was developed which preserved the primary AWS characteristics, but which enabled rapid CFD computations, and a series of simulations was undertaken where the aft-body of the simplified geometry was slightly bloated to alter the aft-body adverse pressure gradient. The surface topology and cross-sectional area distributions are shown in Fig. 1. Significant features include a LEX, a leading-edge flap deflected at 10 degrees, with a *snag* at about 60% span, a trailing-edge flap deflected at 10 degrees, and an aileron deflected at 5 degrees.

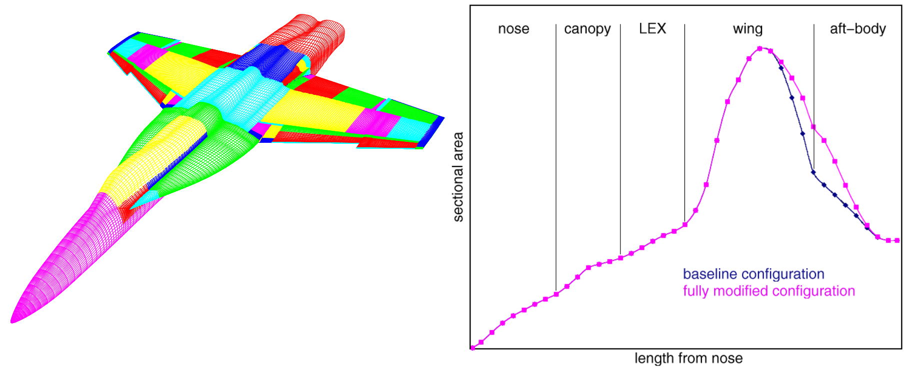

Figure 1. Surface geometry of the 5-million point, 56-block grid and the area distributions of the baseline and modified configurations.

3. Computational Approach

Flow solutions are produced using the HiMAP solver. HiMAP is a multi-disciplinary analysis software suite for fluid/structural/control interaction studies that includes the ENSAERO module (Guruswamy, 1994). It is documented by Guruswamy et al., 1999, and is therefore not described here in more detail. HiMAP couples the three-dimensional Reynolds-averaged Navier-Stokes code GO3D, developed at NASA Ames (Obayashi et al., 1991), with the structural analysis code NASTRAN in such a way that a portable, super-modular, multi-level parallel, multi-disciplinary process for large-scale analysis is achieved.

Parallelization is performed using a multi-zonal approach, where the fluid domain is partitioned into many sub-domains (zones), where each zone is solved on a separate processor, and boundary data are shared at the end of each time step. Communication between processors is handled using the MPI standard, and parallel execution is handled using the MPIRUN library developed by the NAS Parallel Systems Group and NASA Ames Research Center. All computations were run on the NAS Origin 2000 cluster using the GO3D module in HiMAP. The GO3D NS solver with the Spalart-Allmaras turbulence model runs at about 80MFLOPS on a single processor of the Origin 2000. It requires 30 micro-seconds of CPU time per step per grid point. Typical steady solutions on the 5-million point grid required about 10,000 steps to converge. The wall clock time is about 15 hours on 32 nodes ($\approx$ 480 node-hours) per solution.

Several sample results are presented demonstrating the sensitivity to area ruling. As shown in Fig. 1, the aft-body was slightly bloated to increase the centerline volume, thereby altering the adverse pressure gradient in the region of flow separation. The lines in Fig. 1 indicate the baseline configuration and the fully modified configuration. Additionally, 3 intermediate configurations with roughly 25%, 50% and 75% distortion were generated.

In Fig. 2 the pressure distributions on the upper surface of the wing for the undistorted and fully distorted geometry are shown at a pre-AWS angle of attack. The tight grouping of pressure isolines indicates the shock positions. In both cases, flow over the main wing is attached, but flow over most of the flap and aileron is detached, with a slight improvement shown for the deformed case.

In Fig. 3 the pressure distributions are shown for the baseline and 25% distorted configurations at a post-AWS angle of attack. Here flow is detached over the center portion of the main wing, and over most of the flap and aileron, but with just 25% deformation, we see partial reattachment at the inboard edge of the flap, as shown in Fig. 4.

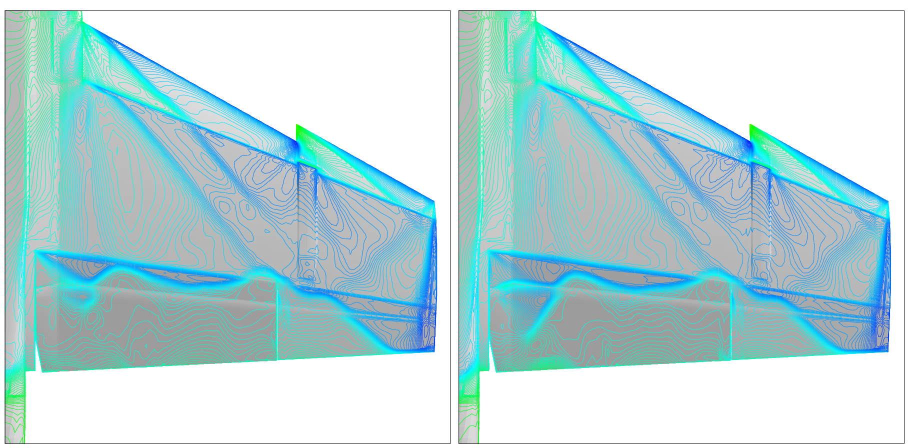

Figure 2. Upper surface pressure distribution on the wing for the baseline (left) and fully deformed (right) configurations at pre-AWS angle of attack.

4. Discussion

As shown by Grove et al., 2002, comparisons of their computations with the NASA Langley wind tunnel measurements on a tail-less F-18 E/F model showed that their Reynolds-averaged Navier-Stokes code, WIND, was able to reproduce the major measured flow features. Our computations using the HiMAP code support this conclusion. However, it is beyond the scope of this paper to present detailed comparisons between the two codes and the measurements and to assess the validity and limitations of the Reynolds-averaged Navier-Stokes computations

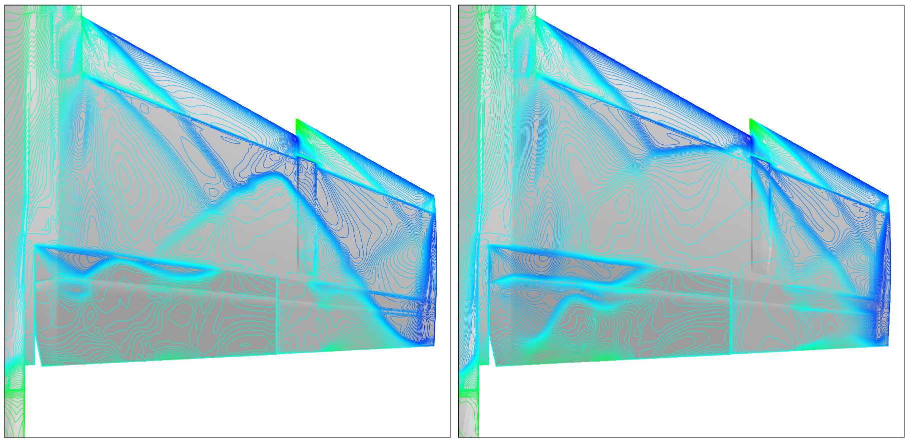

Figure 3. Upper surface pressure distribution on the wing for the baseline (left) and 25% deformed (right) configurations at post-AWS angle of attack.

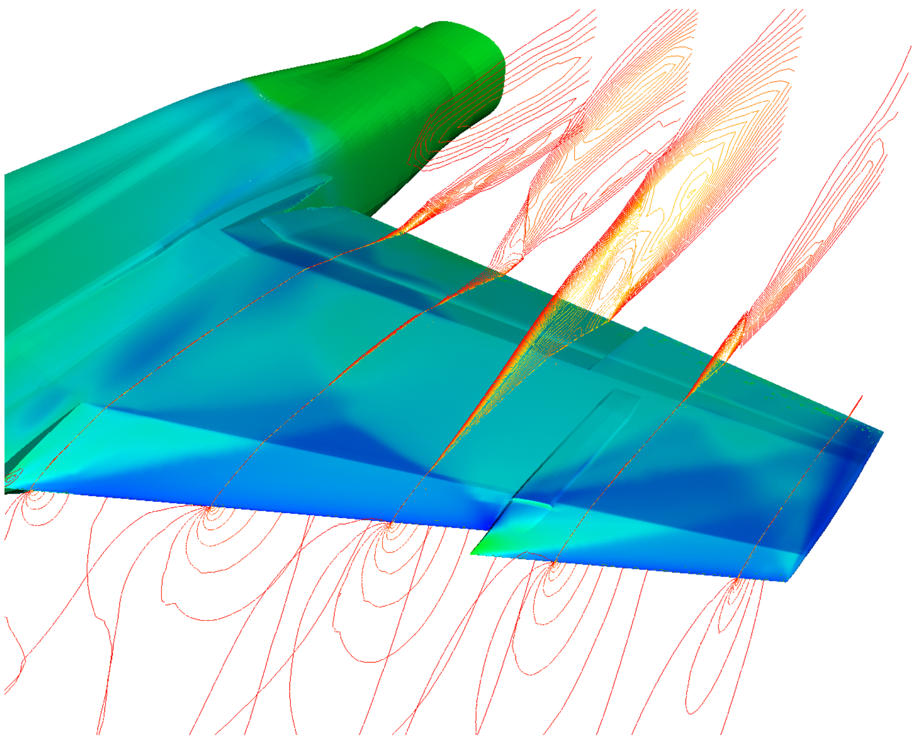

Figure 4. Mach isolines at several spanwise stations for the 25% distorted configuration at post-AWS angle of attack.

for the prediction of the very complex shock interactions and separated flows which occur prior and after the onset of transonic wing stall. In particular, we do not address the question of turbulence and transition modeling. Instead, we assume that the HiMAP code is suitable to predict the flowfield *changes* due to relatively small geometry changes, so that the influence of area ruling can be studied independently from the influences of turbulence and transition modeling.

5. Summary

The HiMAP computations presented in this paper show that area ruling has a significant effect on the transonic flow over a simplified F-18-like aircraft configuration. However, more systematic studies of the effect of incidence and geometry changes are needed before the effectiveness of area ruling can be established as a means of preventing or delaying transonic abrupt wing stall.

Acknowledgments

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