NUMERICAL SIMULATION OF F-18 FUSELAGE FOREBODY FLOWS AT HIGH ANGLES OF ATTACK

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Abstract

As part of the NASA High Alpha Technology Program, fine-grid Navier-Stokes solutions have been obtained for flow over the fuselage forebody and wing leading edge extension of the F/A-18 High Alpha Research Vehicle at large incidence. The resulting flows are complex, and exhibit crossflow separation from the sides of the forebody and from the leading edge extension. A well-defined vortex pattern is observed in the leeward-side flow. Results obtained for laminar flow show good agreement with flow visualizations obtained in ground-based experiments. Further, turbulent flows computed at high-Reynolds-number flight-test conditions ($M_\infty = 0.2$, $\alpha = 30^\circ$, and $Re_x = 11.52 \times 10^6$) show good agreement with surface and off-surface visualizations obtained in flight.

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OBJECTIVE

- DEVELOP FLIGHT-VALIDATED DESIGN METHODS THAT ACCURATELY PREDICT THE AERODYNAMICS OF AIRCRAFT MANEUVERING AT LARGE ANGLES OF ATTACK

APPROACH

- UTILIZE A THREE-DIMENSIONAL NAVIER-STOKES CODE, WITH SUITABLE GRIDS AND AN EDDY-VISCOSITY TURBULENCE MODEL, TO COMPUTE HIGH-ALPHA FLOWS OVER THE F-18 FUSELAGE FOREBODY AND LEX

- VALIDATE THE NUMERICAL RESULTS BY COMPARISON WITH FLIGHT-TEST DATA OBTAINED ON THE NASA F-18 HIGH ALPHA RESEARCH VEHICLE (HARV)
GOVERNING EQUATIONS

\[ \frac{\partial \dot{Q}}{\partial \tau} + \frac{\partial \dot{F}}{\partial \xi} + \frac{\partial \dot{G}}{\partial \eta} + \frac{\partial \dot{H}}{\partial \zeta} = \frac{1}{Re} \frac{\partial \dot{S}}{\partial \zeta} \]

- THIN-LAYER NAVIER-STOKES EQUATIONS
- CURVILINEAR, BODY-CONFORMING COORDINATES
- HIGH REYNOLDS NUMBER FLOWS
- LAMINAR VISCOSITY FROM SUTHERLAND’S LAW
- ALGEBRAIC EDDY-VISCOSITY MODEL CORRECTED FOR CROSSFLOW SEPARATION
NUMERICAL METHOD

\[
\left\{ I + h \left[ \delta^b_\zeta (\hat{A}^+) + \delta_\zeta \hat{C} - \frac{1}{Re} \delta_\zeta \hat{M} \right] \right\} \left\{ I + h \left[ \delta^f_\zeta (\hat{A}^-) + \delta_\eta \hat{B} \right] \right\} \Delta \hat{Q}^n = R.H.S.
\]

- TWO-FACTORED ALGORITHM (F3D)
- FIRST OR SECOND-ORDER ACCURACY IN TIME
- SECOND-ORDER SPATIAL ACCURACY
  - FLUX-VECTOR SPLITTING AND UPWIND DIFFERENCING IN \( \xi \) (STREAMWISE) DIRECTION
  - CENTRAL DIFFERENCING IN THE \( \eta \) (CIRCUMFERENTIAL) AND \( \zeta \) (RADIAL) DIRECTIONS
- COMBINATION OF SECOND AND FOURTH-ORDER SMOOTHING USED IN THE \( \eta \) AND \( \zeta \) DIRECTIONS
  - SMOOTHING TERMS SCALED BY \( q/q_\infty \)
- SINGLE-BLOCK AND TWO-BLOCK GRIDS USED
COMPUTED SURFACE OIL FLOW

$M_\infty = 0.2$, $\alpha = 20^\circ$

$Re_D = 5.0 \times 10^6$ (TURBULENT)
HELCITY

$M_\infty = 0.2, \alpha = 20^\circ$

$Re_D = 5.0 \times 10^6$ (TURBULENT)
SURFACE FLOW PATTERN

\[ M_{\infty} = 0.2, \alpha = 30^\circ \]

\[ Re_c = 11,540,000 \text{ (TURBULENT)} \]
FLIGHT SURFACE FLOW VISUALIZATION

QUARTER VIEW, $\alpha = 30^\circ$

- PRIMARY VORTEX SEPARATION LINE
- SECONDARY VORTEX SEPARATION LINE
- SURFACE STREAMLINE
HELCITY DENSITY

\[ M_\infty = 0.2, \alpha = 30^\circ \]
\[ Re_C = 11,540,000 \text{ (TURBULENT)} \]
Wingtip Photograph of F-18

\[ \alpha = 20.8^\circ \text{ and } \beta = +1.15^\circ \]

LEX vortices visualized using smoke
SUMMARY REMARKS

- NAVIER-STOKES COMPUTATIONS FOR HIGH-ALPHA SEPARATED TURBULENT FLOW ABOUT THE F-18 (HARV) FUSELAGE FOREBODY AND LEX SHOW GOOD AGREEMENT WITH FLIGHT-TEST DATA
  - ONLY MINOR DIFFERENCES BETWEEN SINGLE-BLOCK AND TWO-BLOCK RESULTS
  - EFFECTS OF INCREASING INCIDENCE CONSISTENT WITH EXPERIMENT
  - CFD RESULTS HAVE GIVEN NEW INSIGHT INTO HIGH-ALPHA FLOW STRUCTURE
- COMPUTATION-TO-FLIGHT PREDICTIONS OF FULL F-18 CONFIGURATIONS ARE NEXT STEP
- USE OF CFD AS A DESIGN TOOL FOR VORTEX CONTROL CONCEPTS IS AT HAND