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

Lewis B. Schiff*
Russell M. Cummings†
Reese L. Sorenson*
Yehia M. Rizk‡

NASA Ames Research Center
Moffett Field, CA 94035

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 $Re_\infty = 11.52 \times 10^6$) show good agreement with surface and off-surface visualizations obtained in flight.

* Research Scientist, Applied Computational Fluids Branch.
† National Research Council Research Associate. Associate Professor, on leave from California Polytechnic State University, Aeronautical Engineering Department.
‡ Member of the Professional Staff, Sterling Federal Systems, Inc., Palo Alto, CA.
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

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

- 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
TANGENT OGIVE–CYLINDER SINGLE–BLOCK GRID

59 x 63 x 50 POINTS

NASAS–AMES
HIGH ALPHA GROUP
COMPUTED SURFACE OIL FLOW

\[ M_\infty = 0.2, \alpha = 20^\circ \]

\[ \text{Re}_D = 5.0 \times 10^6 \] (TURBULENT)
HELCITY

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

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

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

\[ Re_c = 11,540,000 \text{ (TURBULENT)} \]
FLIGHT SURFACE FLOW VISUALIZATION QUARTER VIEW, $\alpha = 30^\circ$
HELICITY DENSITY

$M_\infty = 0.2, \alpha = 30^\circ$

$Re_C = 11,540,000$ (TURBULENT)
Wingtip Photograph of F-18
\( \alpha = 20.8^\circ \) 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