

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 $Re_z = 11.52 \times 10^6$) 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

$$\frac{\partial \hat{Q}}{\partial \tau} + \frac{\partial \hat{F}}{\partial \xi} + \frac{\partial \hat{G}}{\partial \eta} + \frac{\partial \hat{H}}{\partial \zeta} + \frac{1}{Re} \frac{\partial \hat{S}}{\partial \zeta}$$

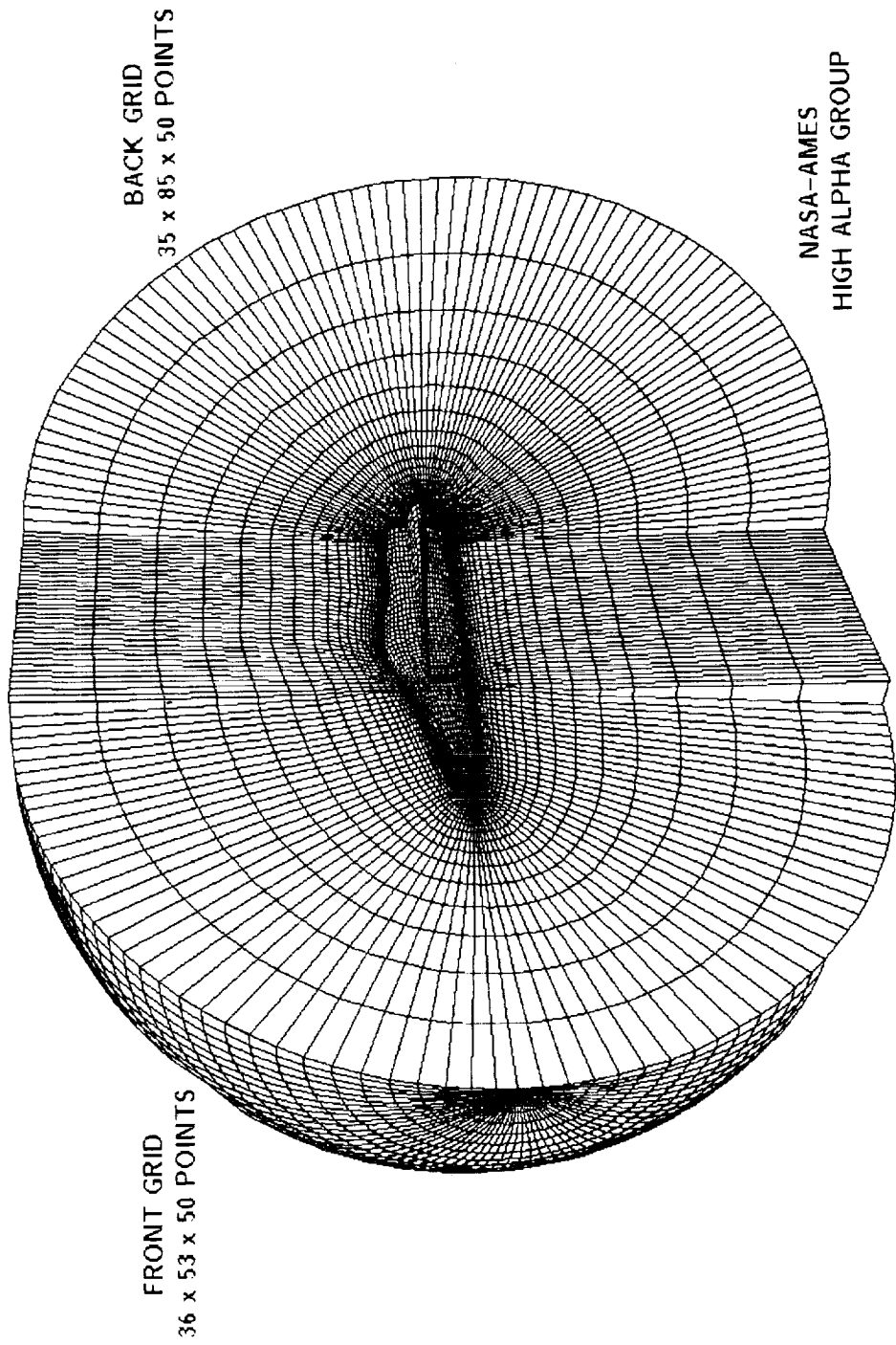
- THIN-LAYER NAVIER-STOKES EQUATIONS
- CURVILINEAR, BODY-CONFORMING COORDINATES
- HIGH REYNOLDS NUMBER FLOWS
- LAMINAR VISCOSITY FROM SUTHERLAND'S LAW
- ALGEBRAIC EDDY-VISCOSITY MODEL CORRECTED FOR CROSSFLOW SEPARATION

NUMERICAL METHOD

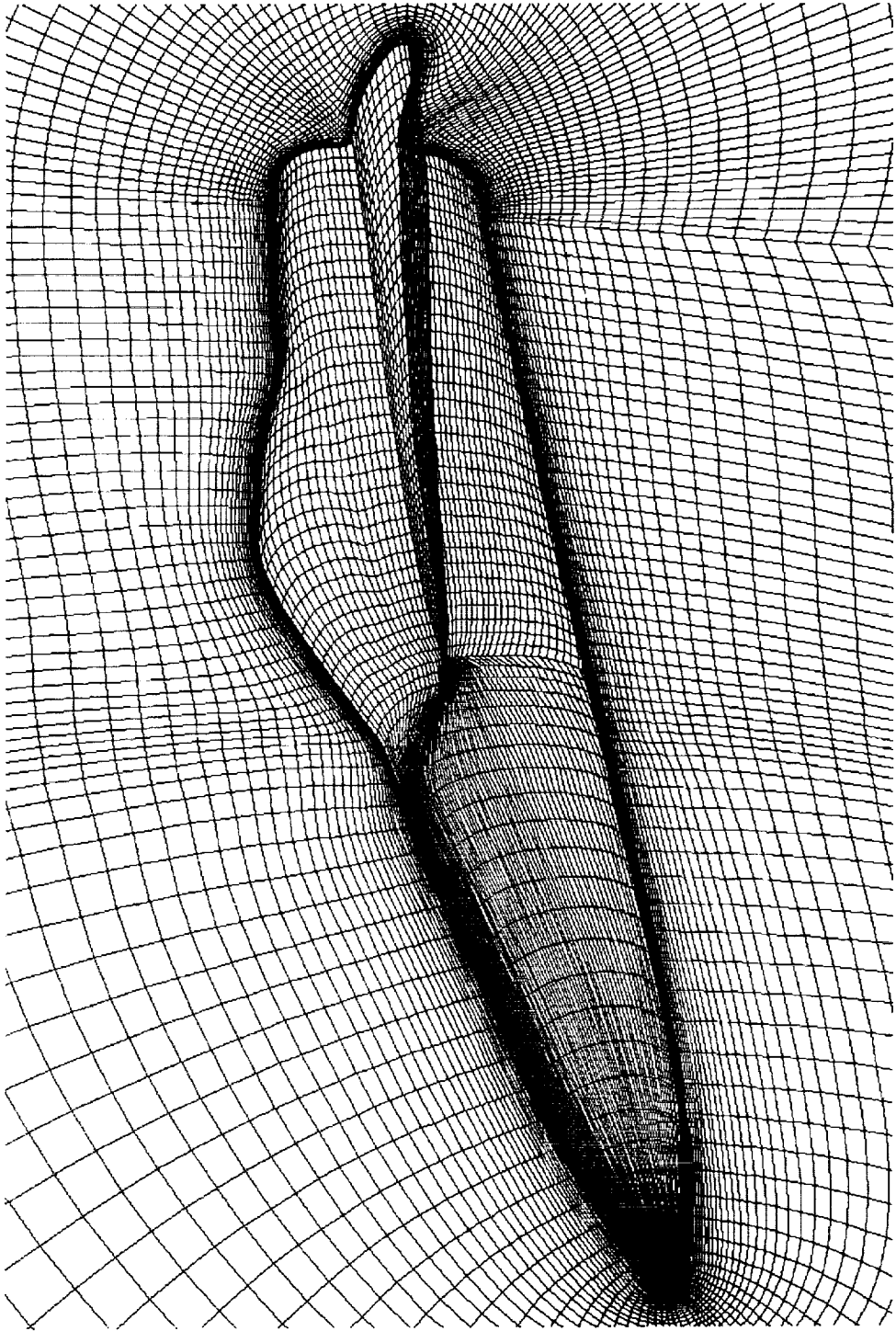
$$\left\{ I + h \left[\delta_{\xi}^b(\hat{A}^+) + \delta_{\zeta} \hat{C} - \frac{1}{Re} \bar{\delta}_{\zeta} \hat{M} \right] \right\} \left\{ I + h \left[\delta_{\xi}^f(\hat{A}^-) + \delta_{\eta} \hat{B} \right] \right\} \Delta \hat{Q}^n = R.H.S.$$

- TWO-FACTORED ALGORITHM (F3D)
- FIRST OR SECOND-ORDER ACCURACY IN TIME
- SECOND-ORDER SPATIAL ACCURACY
 - FLUX-VECTOR SPLITTING AND UPWIND DIFFERENCING IN ξ (STREAMWISE) DIRECTION
 - CENTRAL DIFFERENCING IN THE η (CIRCUMFERENTIAL) AND ζ (RADIAL) DIRECTIONS
- COMBINATION OF SECOND AND FOURTH-ORDER SMOOTHING USED IN THE η AND ζ DIRECTIONS
 - SMOOTHING TERMS SCALED BY q/q_{∞}
- SINGLE-BLOCK AND TWO-BLOCK GRIDS USED

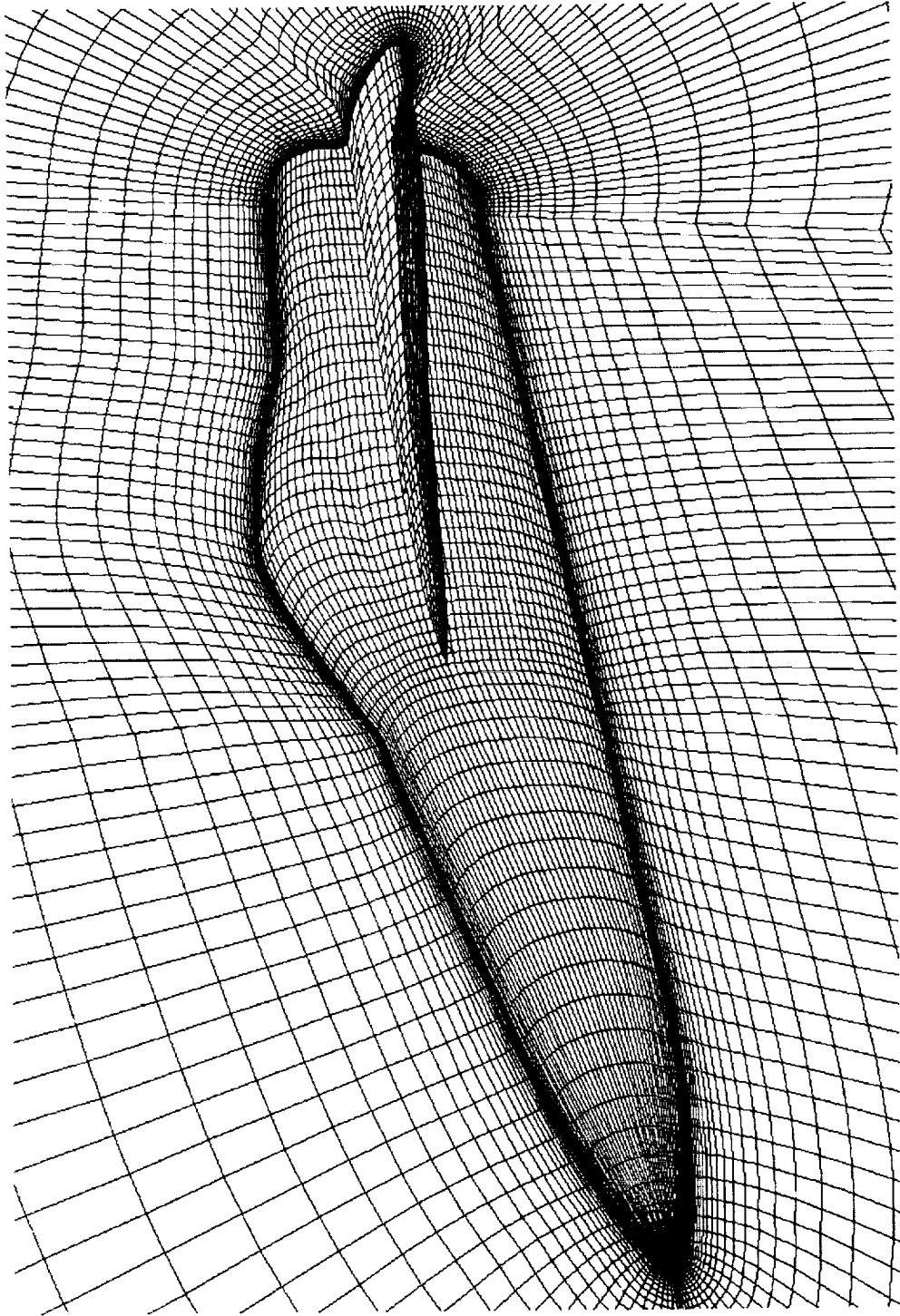
F-18 FOREBODY TWO-BLOCK GRID



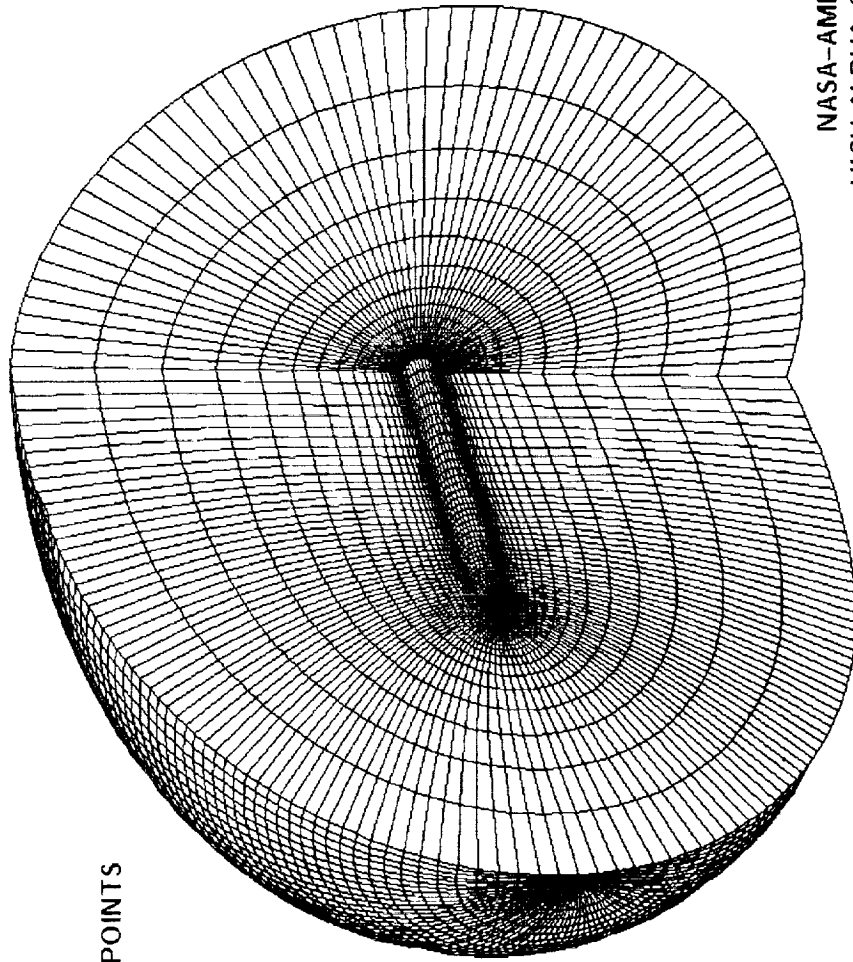
ONE-BLOCK GRID: F-18 FOREBODY CLOSE-UP



TWO-BLOCK GRID: F-18 FOREBODY CLOSE-UP



TANGENT OGIVE-CYLINDER SINGLE-BLOCK GRID



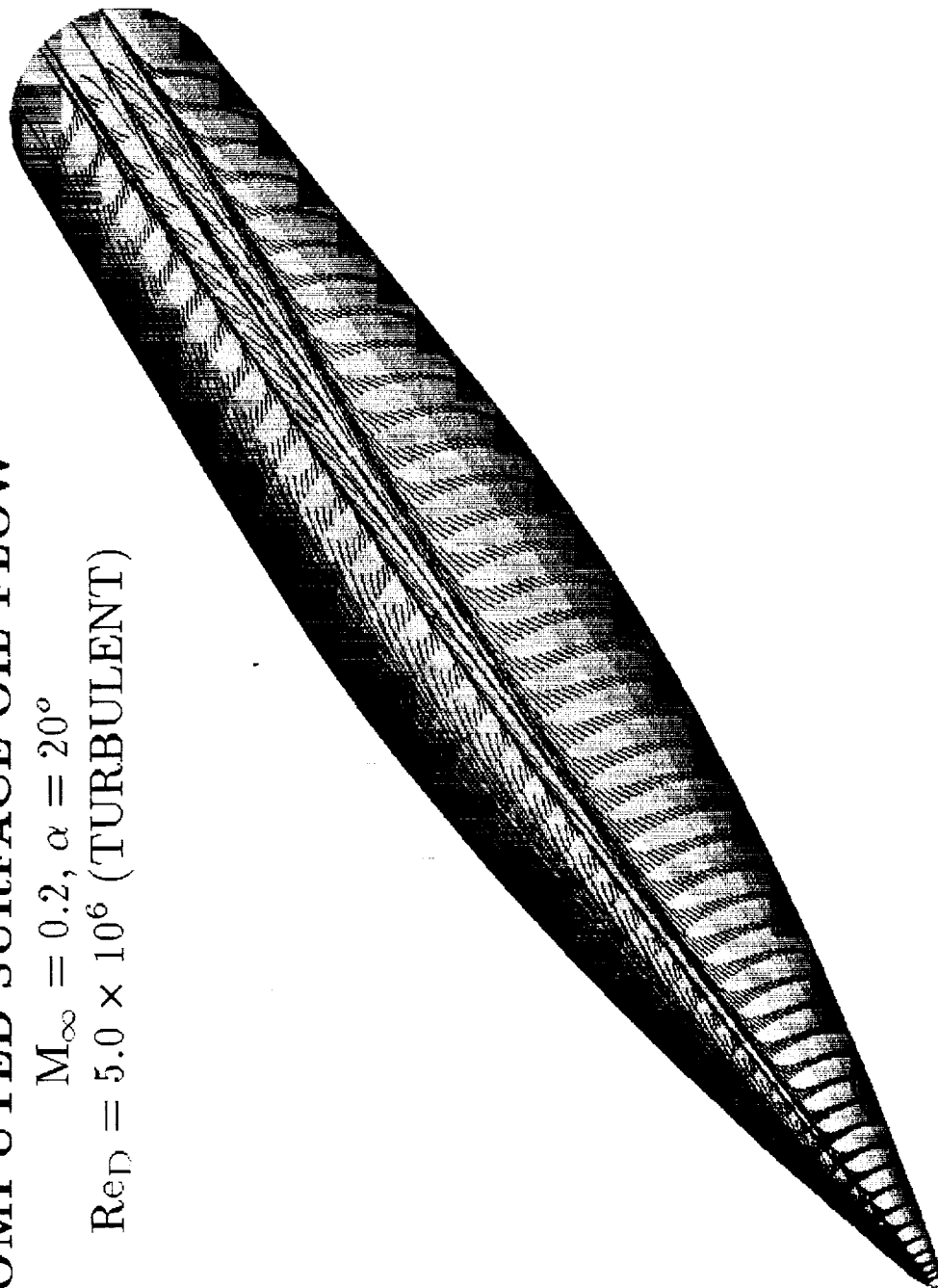
59 x 63 x 50 POINTS

NASA-AMES
HIGH ALPHA GROUP

COMPUTED SURFACE OIL FLOW

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

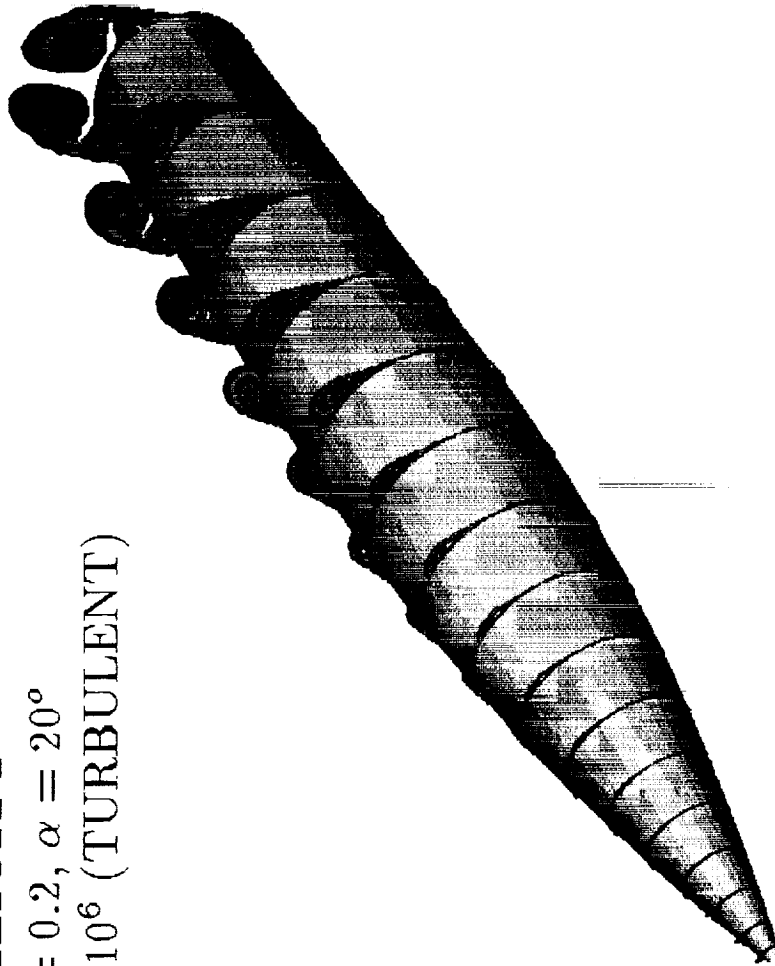
$$Re_D = 5.0 \times 10^6 \text{ (TURBULENT)}$$



HELICITY

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

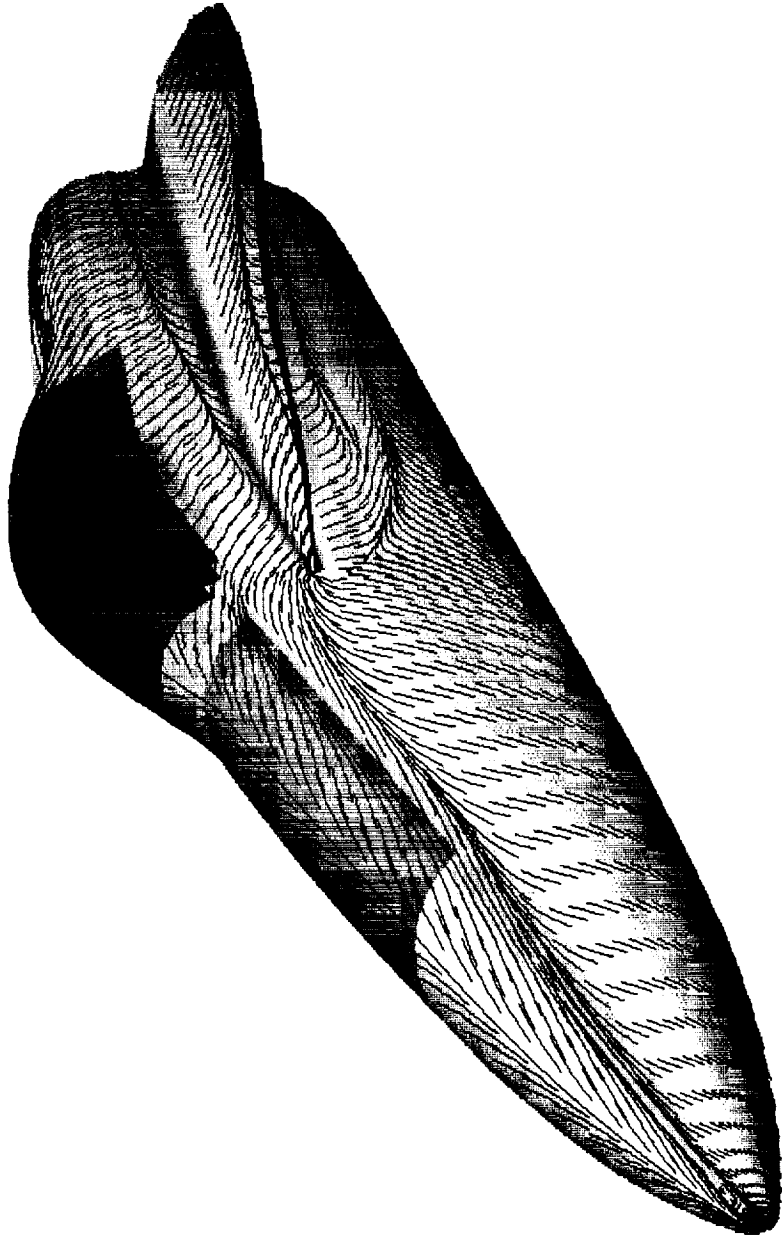
$$Re_D = 5.0 \times 10^6 \text{ (TURBULENT)}$$



SURFACE FLOW PATTERN

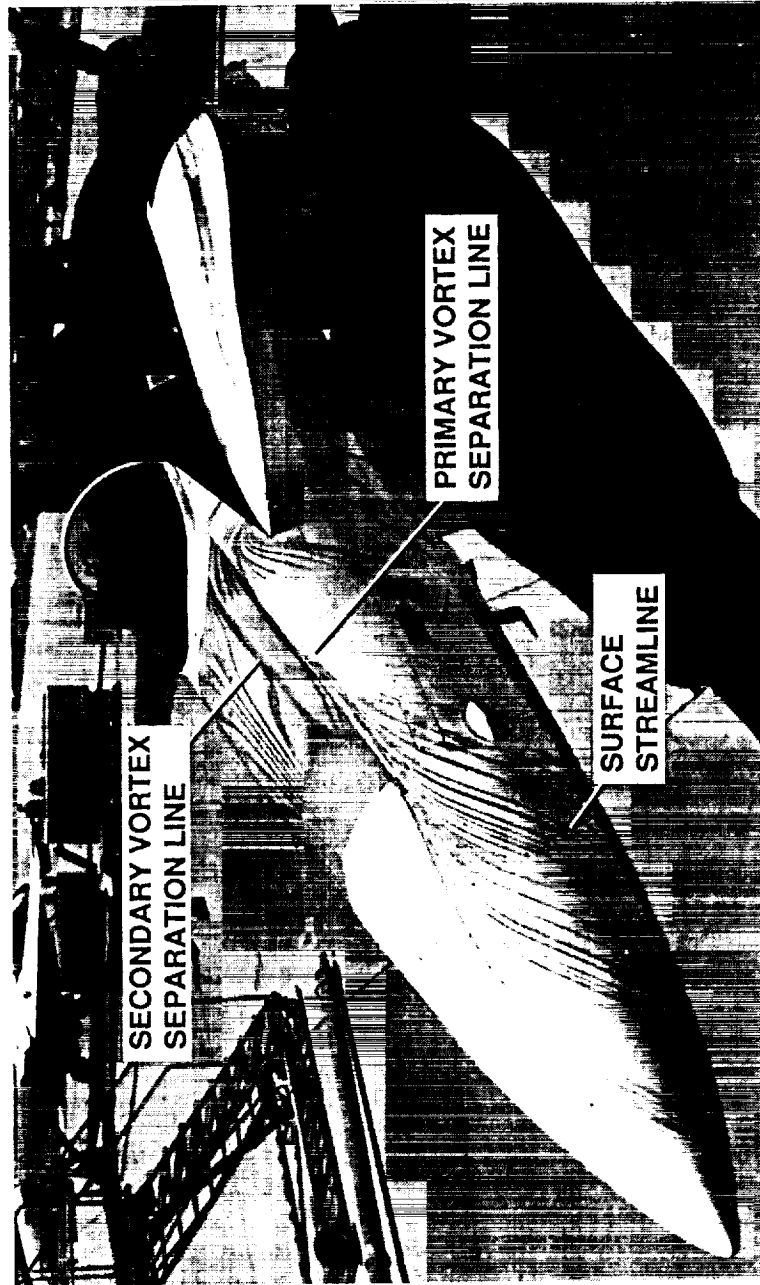
$M_\infty = 0.2, \alpha = 30^\circ$

$Re_c = 11,540,000$ (TURBULENT)



FLIGHT SURFACE FLOW VISUALIZATION

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



HELICITY DENSITY

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

$$Re_c = 11,540,000 \text{ (TURBULENT)}$$



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**

