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 ($M_\infty = 0.2$, $\alpha = 30°$, and $Re_{\bar{c}} = 11.52 \times 10^6$) 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

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

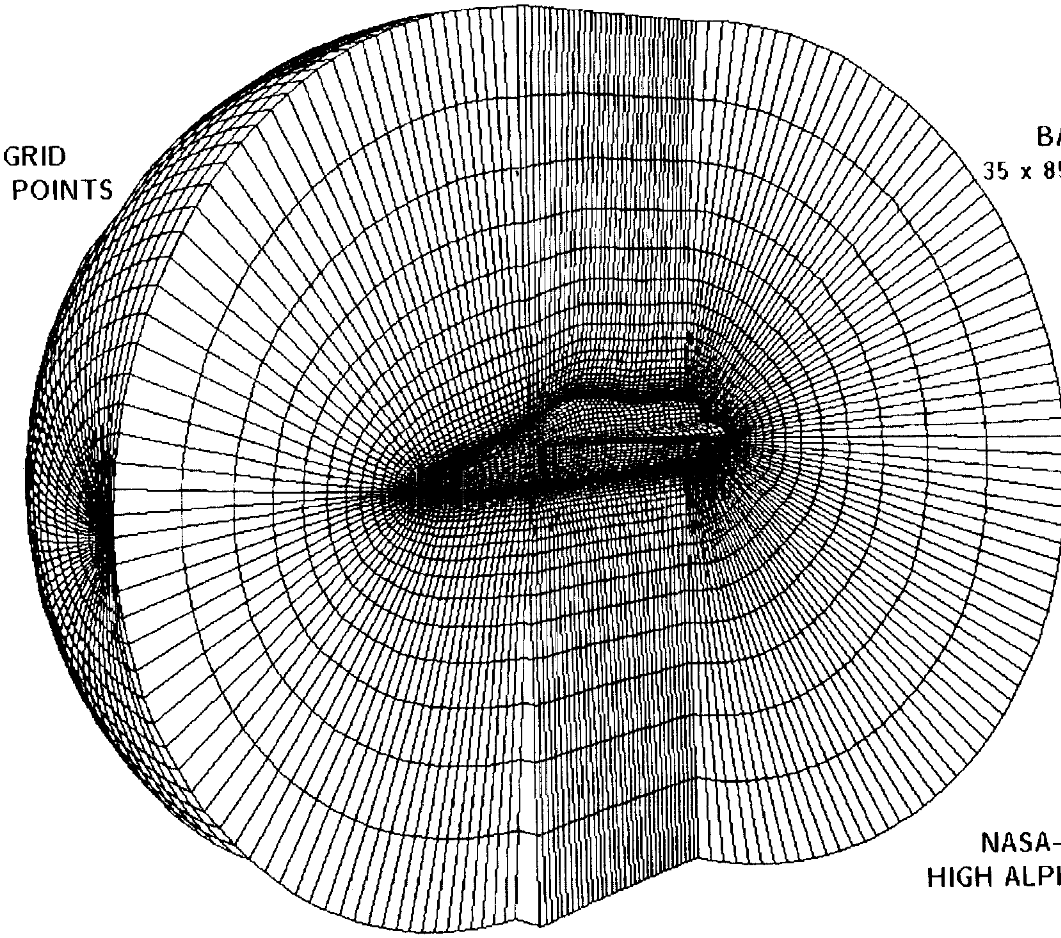
- THIN-LAYER NAVIER-STOKES EQUATIONS
- CURVILINEAR, BODY-CONFORMING COORDINATES
- HIGH REYNOLDS NUMBER FLOWS
- LAMINAR VISCOSITY FROM SUTHERLAND'S LAW
- ALGEBRAIC EDDY-VISCOSITY MODEL CORRECTED FOR CROSSFLOW SEPARATION

NUMERICAL METHOD

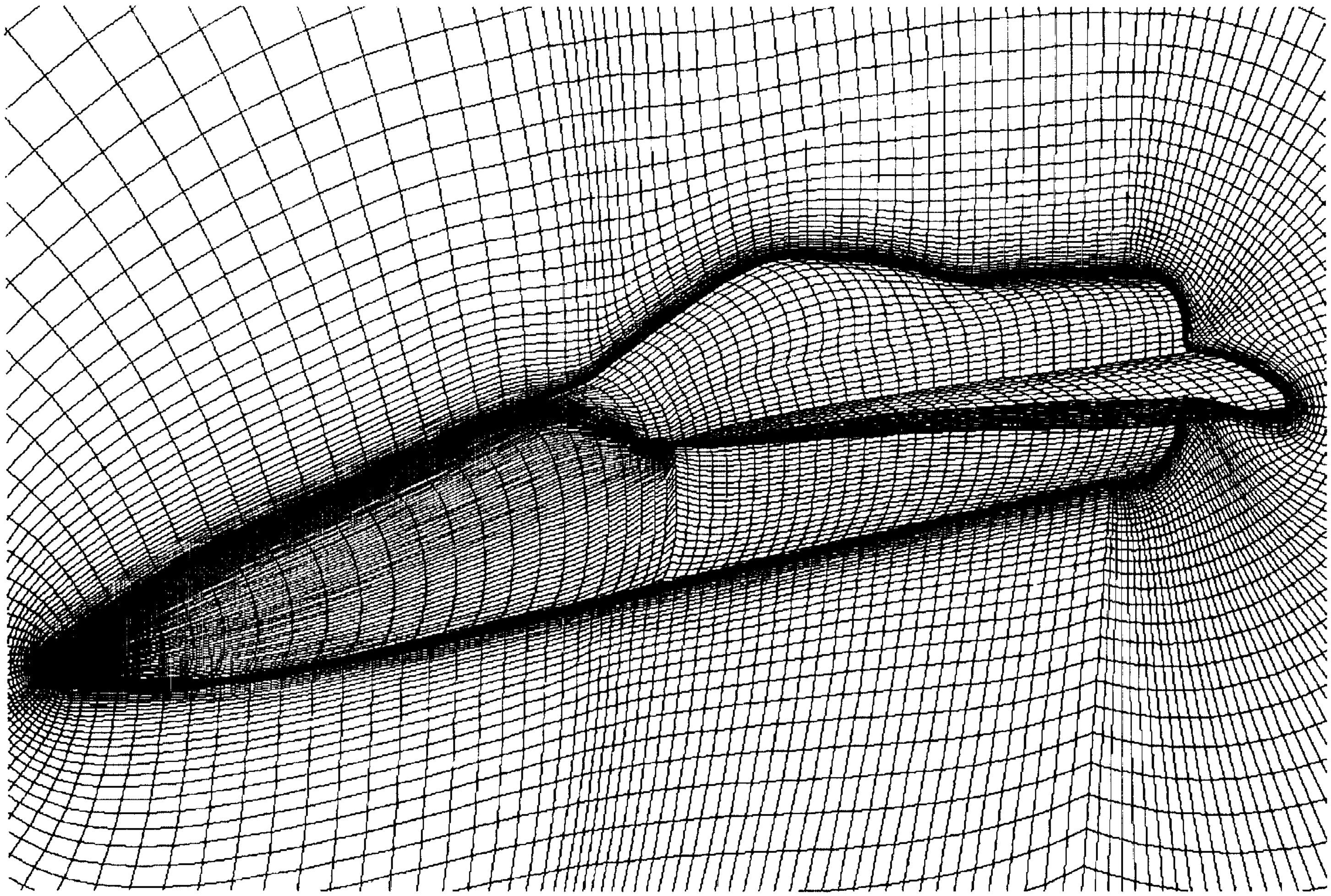
$$\left\{I + h\left[\delta_\xi^b(\hat{A}^+) + \delta_\zeta\hat{C} - \frac{1}{Re}\overline{\delta}_\zeta\hat{M}\right]\right\}\left\{I + h\left[\delta_\xi^f(\hat{A}^-) + \delta_\eta\hat{B}\right]\right\}\Delta\hat{Q}^n = R.H.S.$$

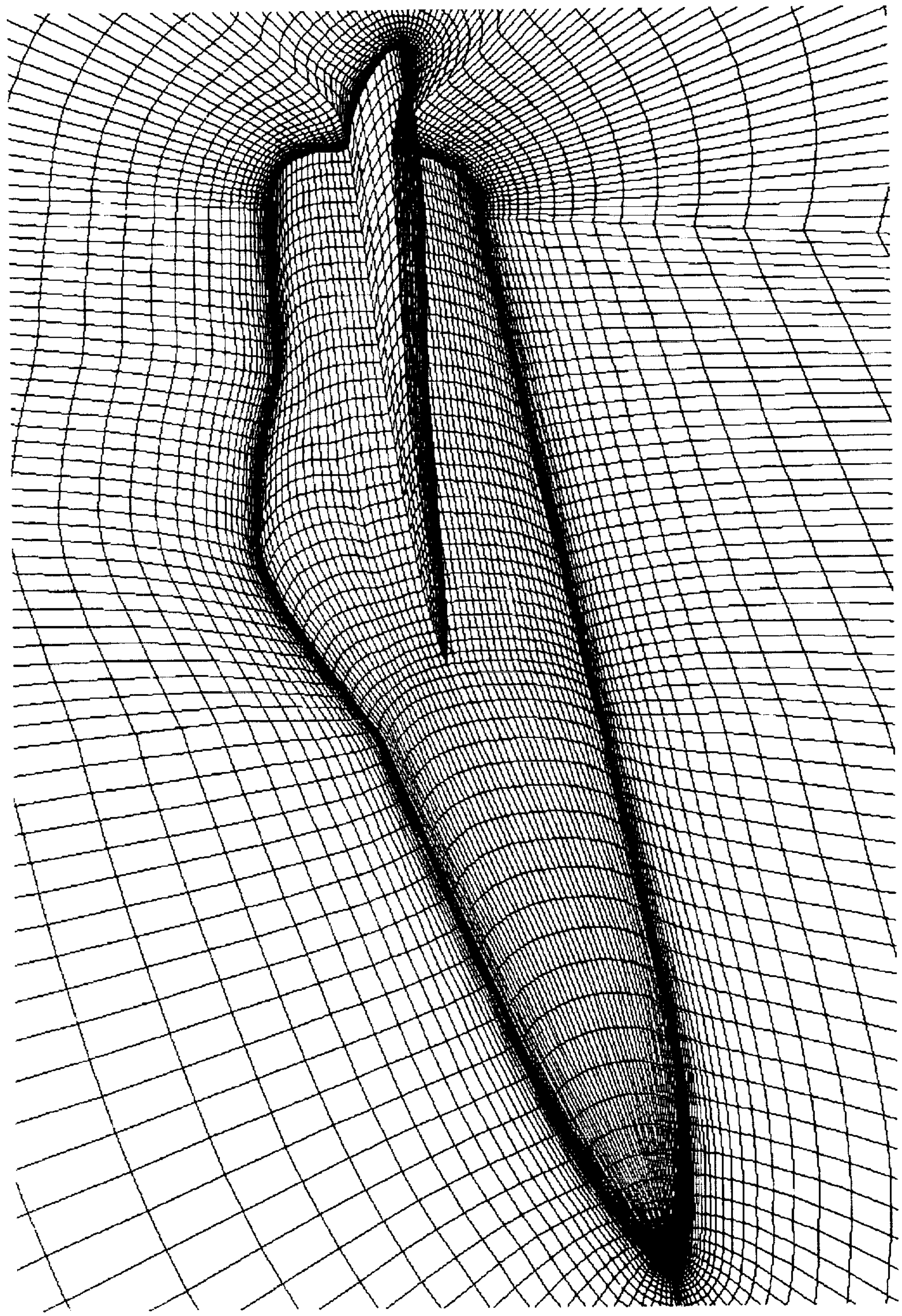
- TWO-FACTORED ALGORITHM (F3D)
- FIRST OR SECOND-ORDER ACCURACY IN TIME
- SECOND-ORDER SPATIAL ACCURACY
  - FLUX-VECTOR SPLITTING AND UPWIND DIFFERENCING IN ξ (STREAMWISE) DIRECTION
  - CENTRAL DIFFERENCING IN THE η (CIRCUMFERENTIAL) AND ζ (RADIAL) DIRECTIONS
- COMBINATION OF SECOND AND FOURTH-ORDER 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

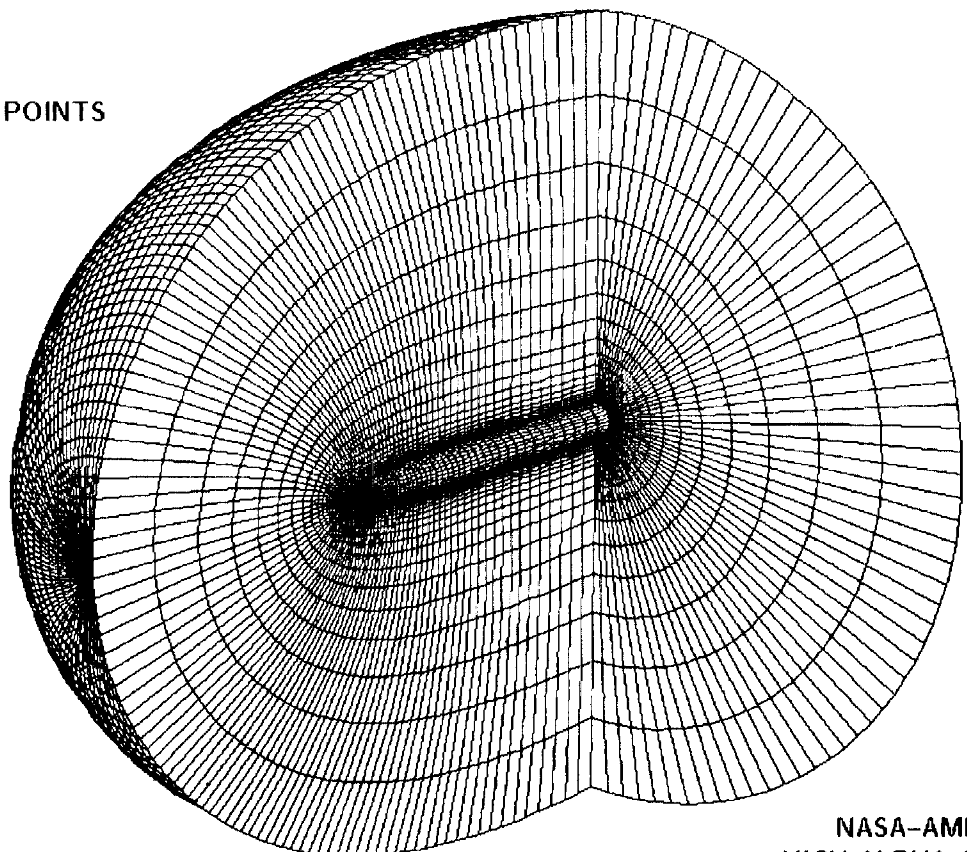




TWO-BLOCK GRID: F-18 FOREBODY CLOSE-UP

TANGENT OGIVE–CYLINDER SINGLE–BLOCK GRID

59 x 63 x 50 POINTS

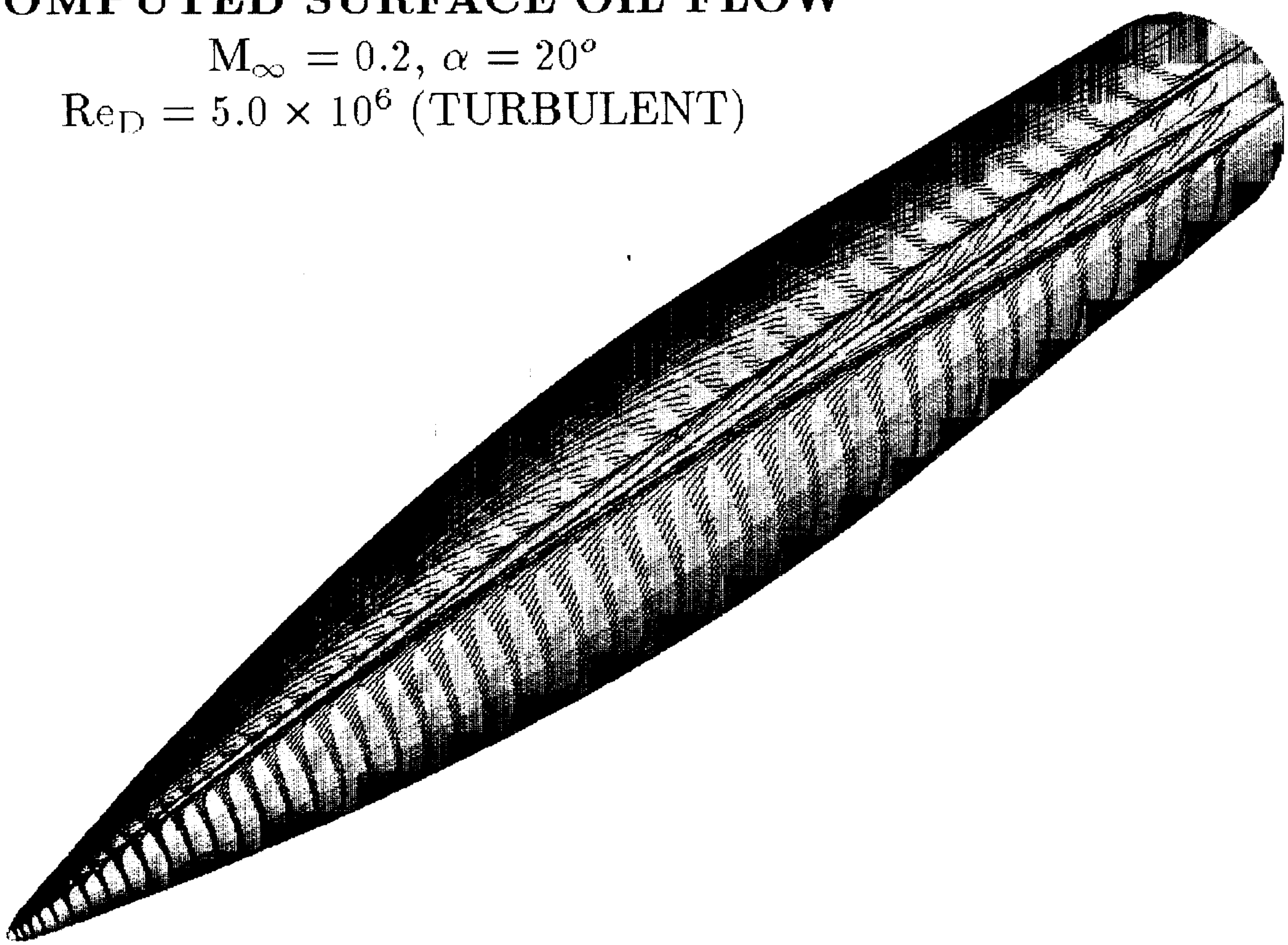


NASA–AMES
HIGH ALPHA GROUP

COMPUTED SURFACE OIL FLOW

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

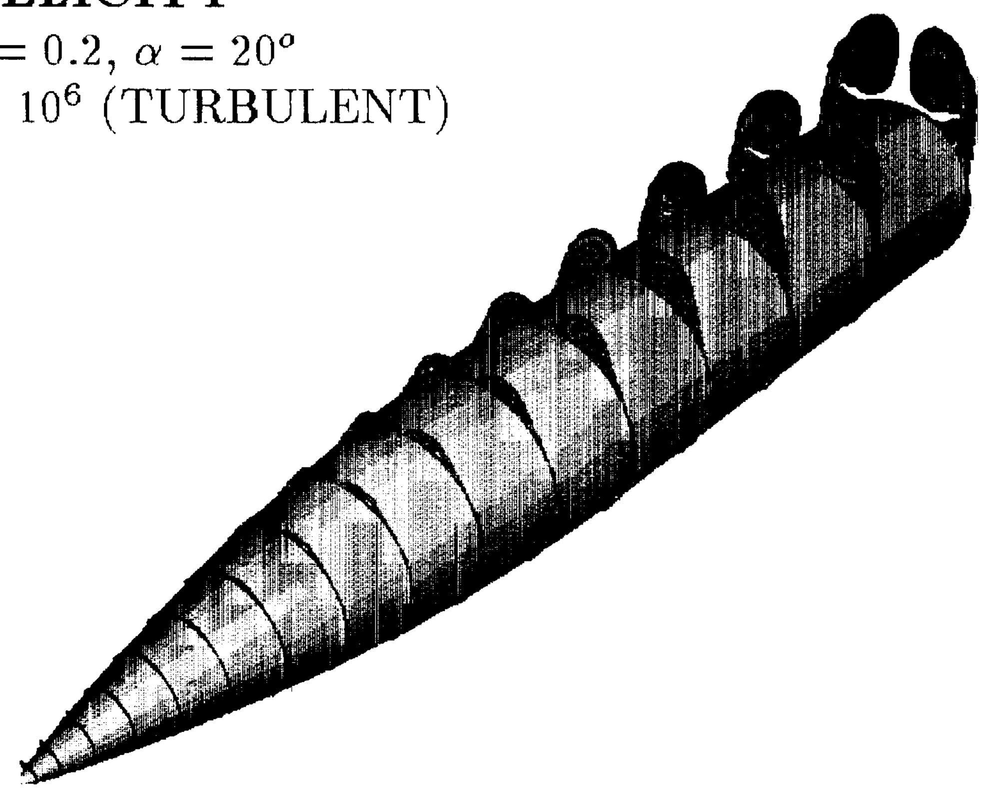
$Re_D = 5.0 \times 10^6$ (TURBULENT)



HELICITY

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

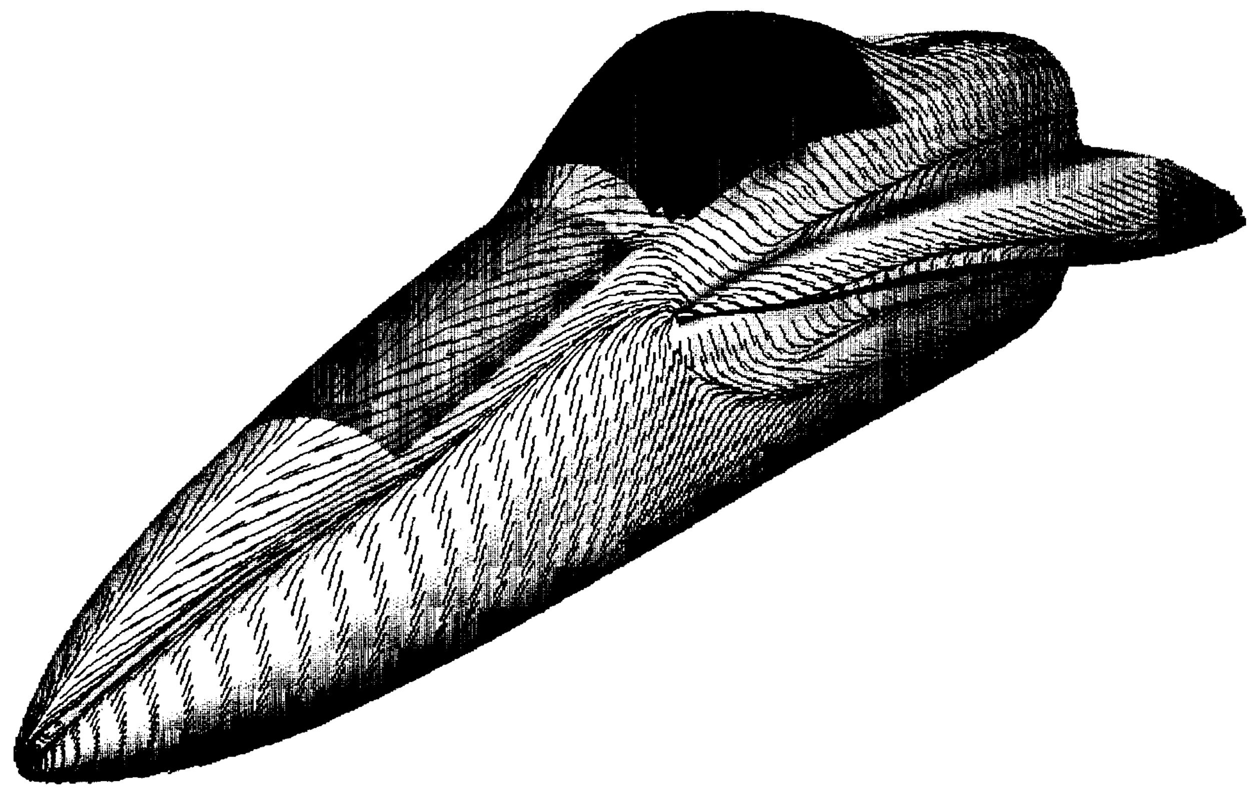
$Re_D = 5.0 \times 10^6$ (TURBULENT)



SURFACE FLOW PATTERN

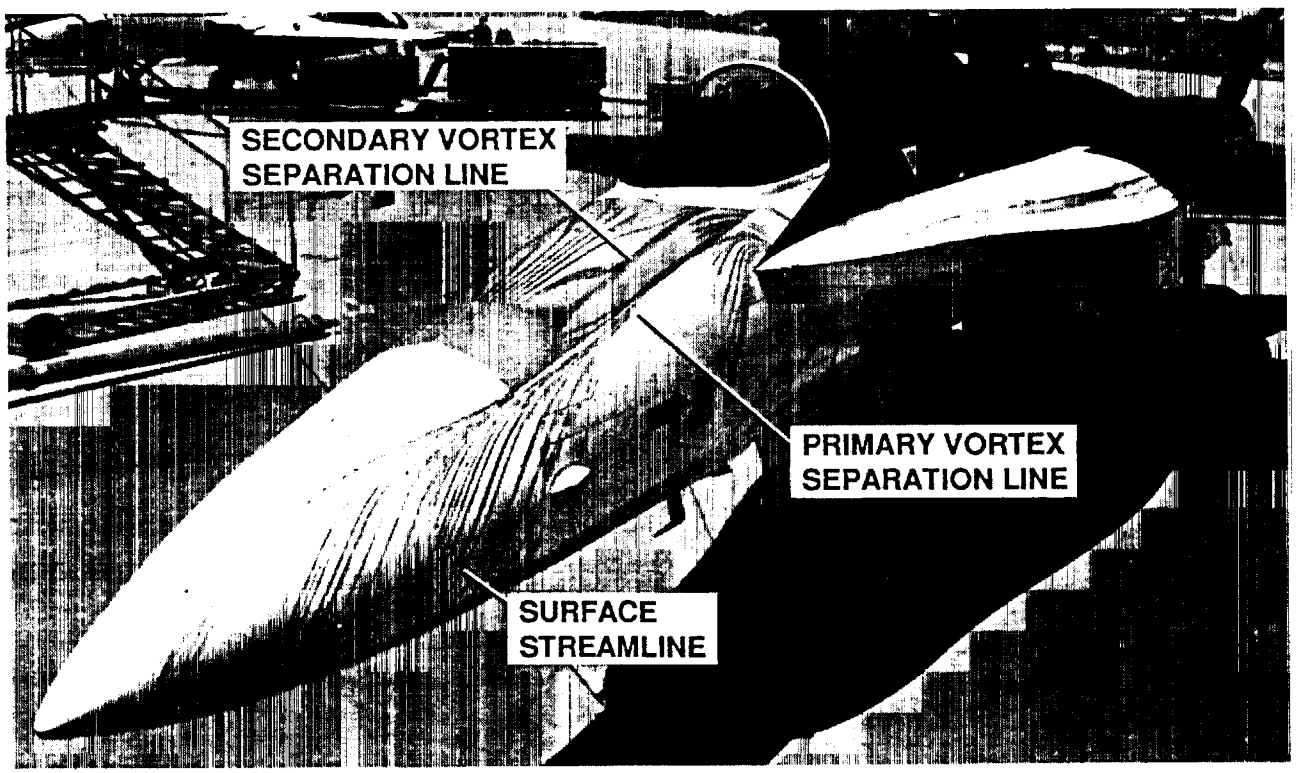
$M_\infty = 0.2,\ \alpha = 30°$

$Re_{\bar{c}} = 11{,}540{,}000$ (TURBULENT)



FLIGHT SURFACE FLOW VISUALIZATION

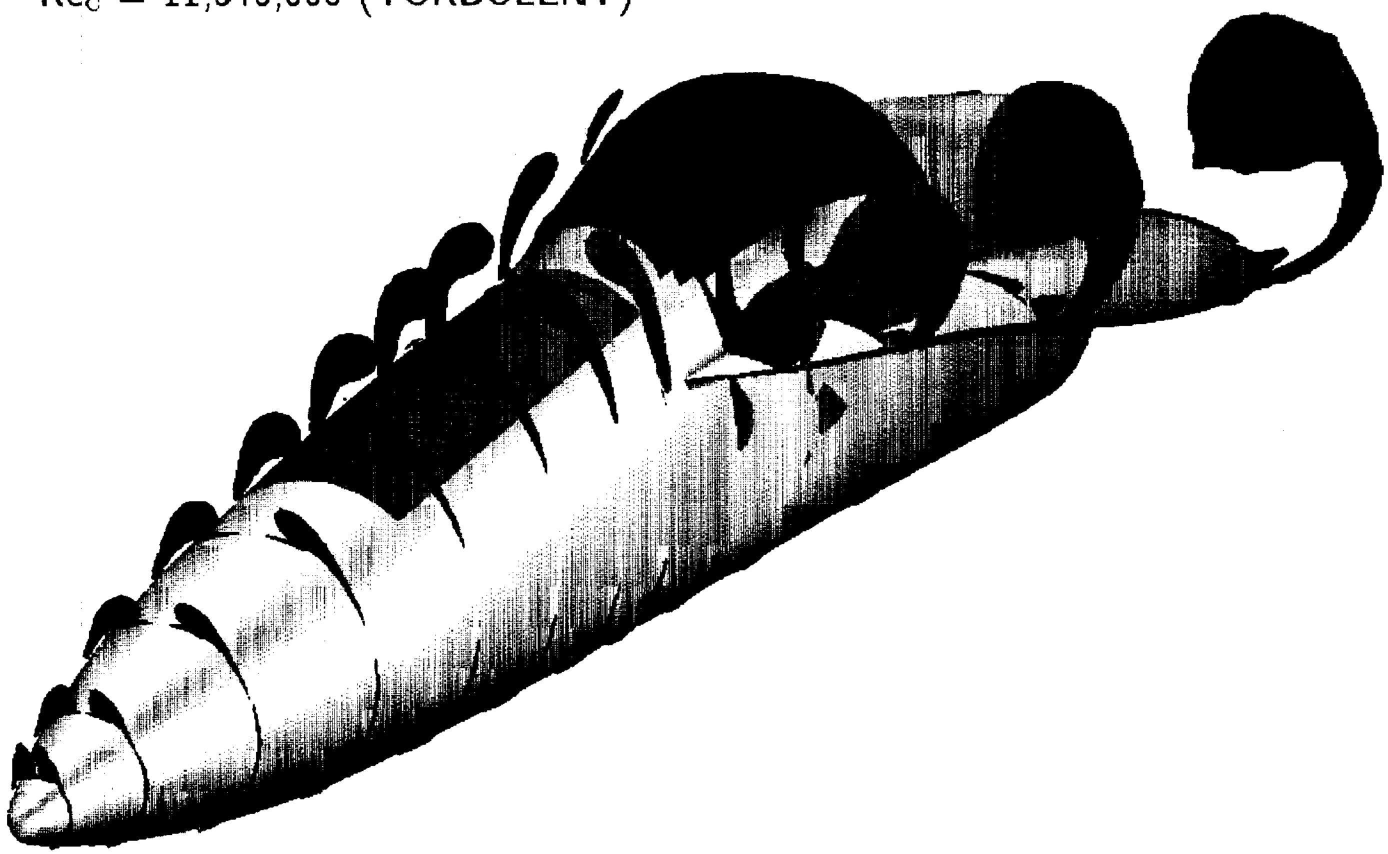
QUARTER VIEW, $\alpha = 30°$



HELICITY DENSITY

$M_\infty = 0.2$, $\alpha = 30°$

$Re_C = 11{,}540{,}000$ (TURBULENT)



Wingtip Photograph of F-18

$\alpha = 20.8°$ and $\beta = +1.15°$

- 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