N91-10851

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# RECENT ADVANCES IN RUNGE-KUTTA SCHEMES FOR SOLVING 3-D NAVIER-STOKES EQUATIONS

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## Abstract

A thin-layer Navier-Stokes has been developed for solving high Reynolds number, turbulent flows past aircraft components under transonic flow conditions. The computer code has been validated through data comparisons for flow past isolated wings, wing-body configurations, prolate spheroids and wings mounted inside wind-tunnels. The basic code employs an explicit Runge-Kutta time-stepping scheme to obtain steady state solution to the unsteady governing equations. Significant gain in the efficiency of the code has been obtained by implementing a multigrid acceleration technique to achieve steady-state solutions. The improved efficiency of the code has made it feasible to conduct grid-refinement and turbulence model studies in reasonable amount of computer time. The non-equilibrium turbulence model of Johnson and King has been extended to three-dimensional flows and excellent agreement with pressure data has been obtained for transonic separated flow over a transport type of wing.

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# OBJECTIVES

- Develop an efficient Navier-Stokes code for high Reynolds number, transonic, separated flows
- Assess the effect of grid refinement
  - — on solution accuracy
  - — on convergence properties
- Improve turbulence model for separated flows by including non-equilibrium effects
- Validate the code via data comparisons

# GOVERNING EQUATIONS

- Reynolds-averaged Navier-Stokes equations
- Thin-layer approximation
- Equations are written in conservation law form
- Turbulence models

    Equilibrium model : Baldwin-Lomax model

    Non-equilibrium model : Johnson-King model

# BOUNDARY CONDITIONS

- Solid surface : viscous
  - no slip and zero injection
  - zero normal pressure gradient
  - specified temperature or adiabatic condition
- Solid surface : inviscid
  - zero flux across surface
  - extrapolate surface pressure
- Inflow/outflow : free-air
  - Riemann invariants for farfield
  - extrapolate all variables at downstream
- Inflow/outflow : in-tunnel simulations
  - Riemann invariants at inflow
  - specify initial profile for viscous sidewall
  - specify pressure and extrapolate other variables at downstream

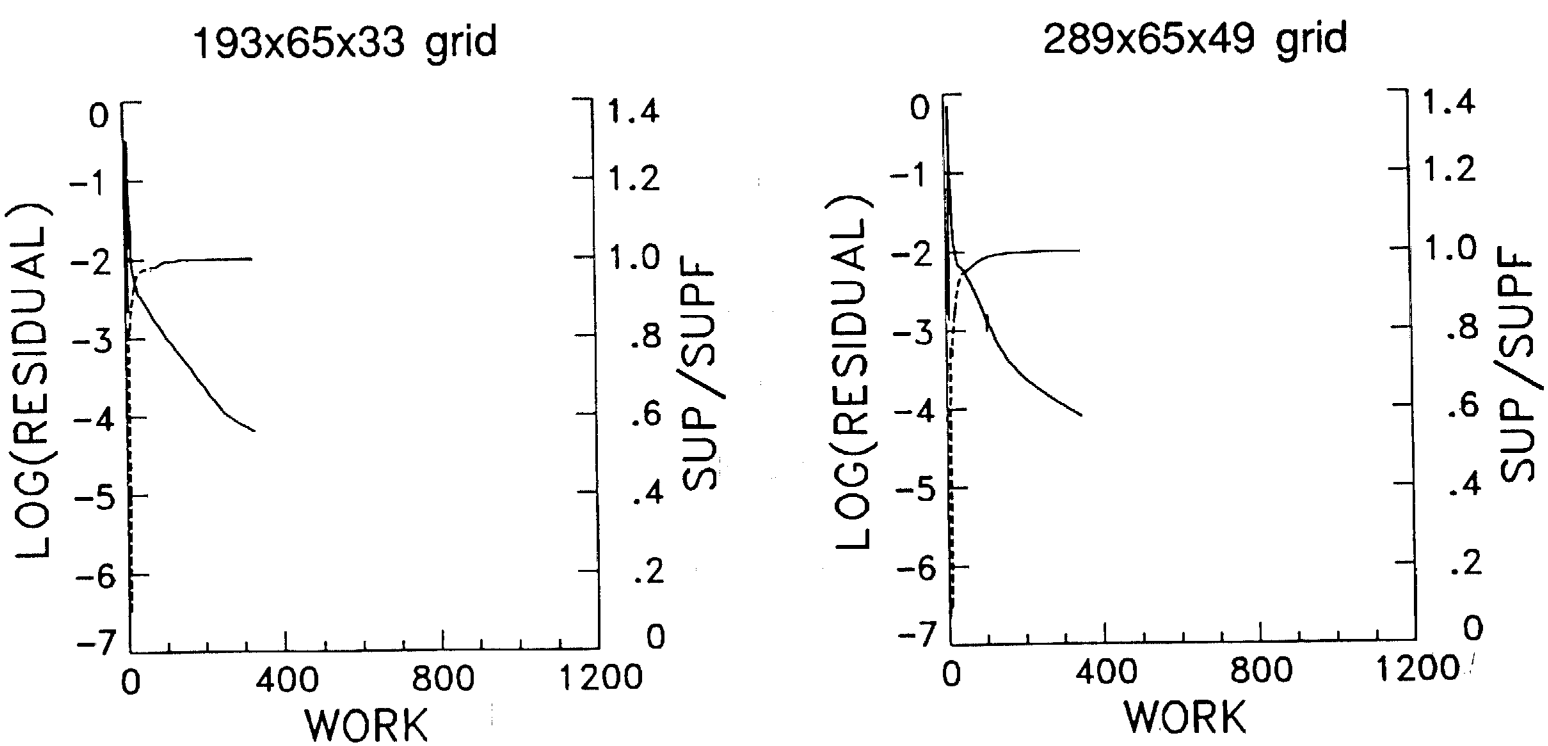
# NUMERICAL ALGORITHM

- Based on Runge-Kutta schemes of Jameson and co-workers : 5-stage scheme with 3 dissipation evaluations
- Finite volume, central-difference scheme
- Non-isotropic artificial dissipation added for stability
- Variable coefficient, grid aspect-ratio dependent, implicit residual smoothing for increasing stability bound
- Multigrid acceleration technique
  - Full multigrid ( FMG ) strategy
  - V-cycle ( saw-tooth )
  - Viscous fluxes evaluated only on fine mesh

# Effect of grid refinement on convergence history for ONERA M6 wing

( $M_\infty = 0.84$, $\alpha = 6.06^o$ )

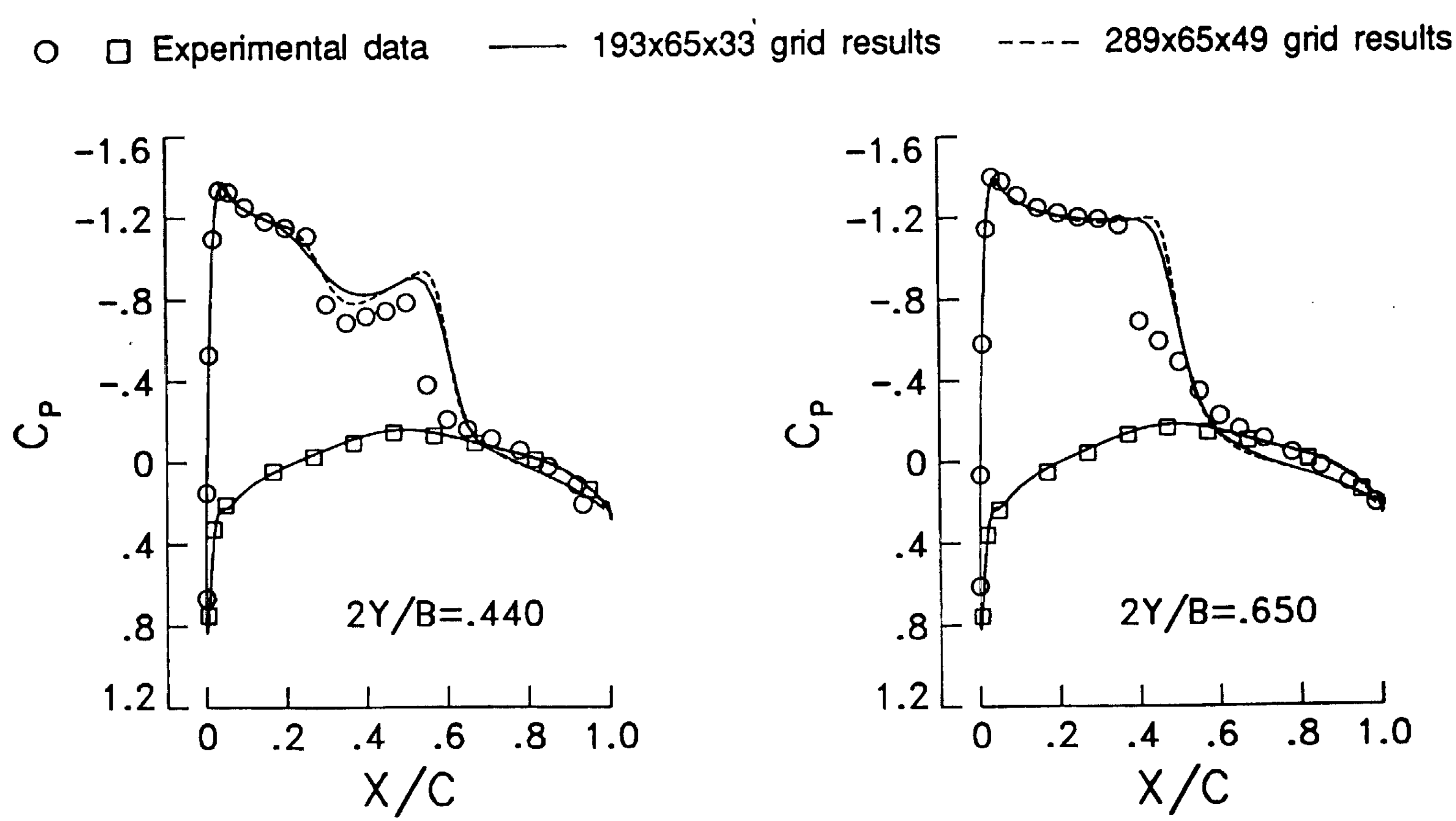
Baldwin-Lomax Turbulence Model



# Effect of grid refinement on pressure distributions for ONERA M6 wing

( $M_\infty = 0.84$, $\alpha = 6.06^{\circ}$ )

Baldwin-Lomax Turbulence Model



# Effect of grid refinement on pressure distributions for ONERA M6 wing

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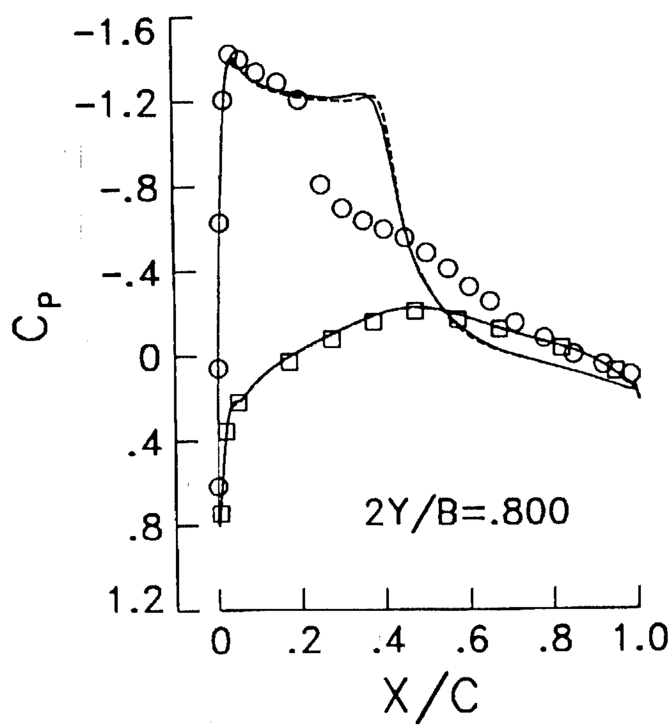
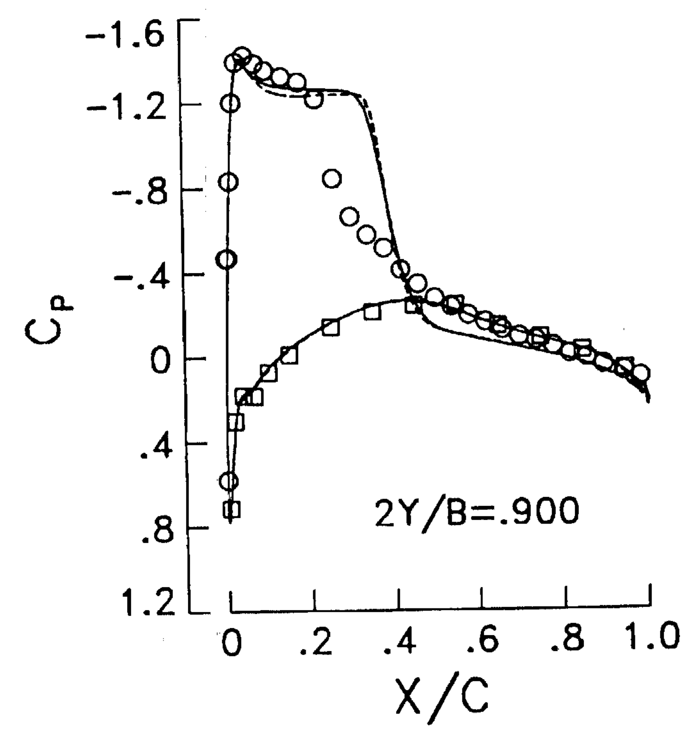
Baldwin-Lomax Turbulence Model

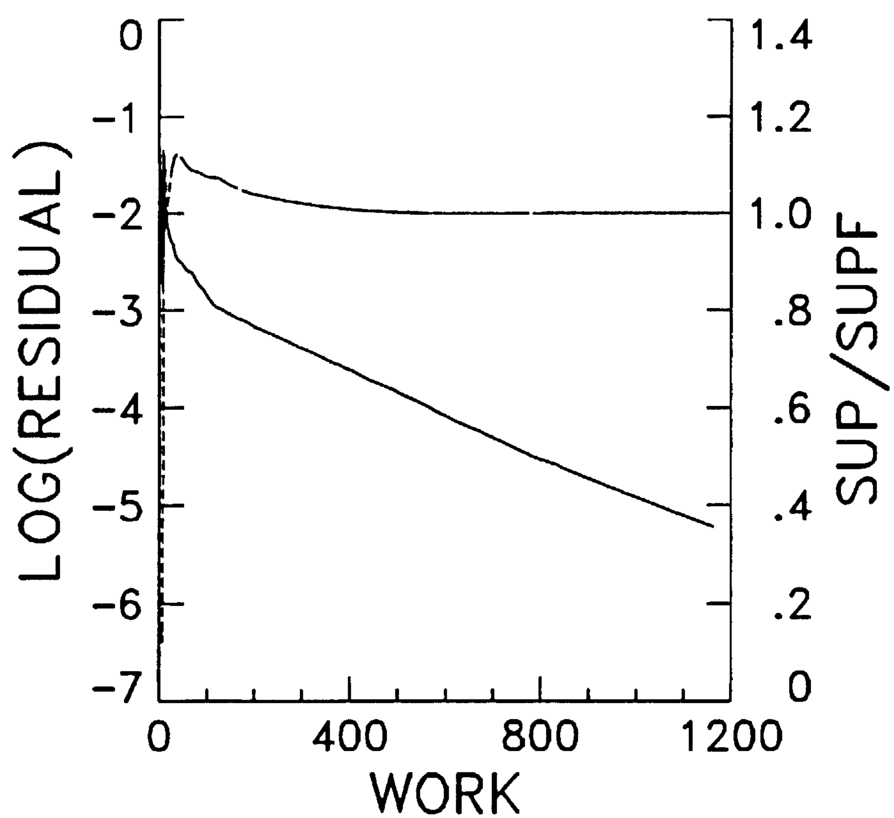
○ □ Experimental data —— 193x65x33 grid results ---- 289x65x49 grid results



## Convergence history for ONERA M6 wing with Johnson-King model, 289x65x49 grid

( $M_\infty = 0.84$, $\alpha = 6.06^\circ$ )

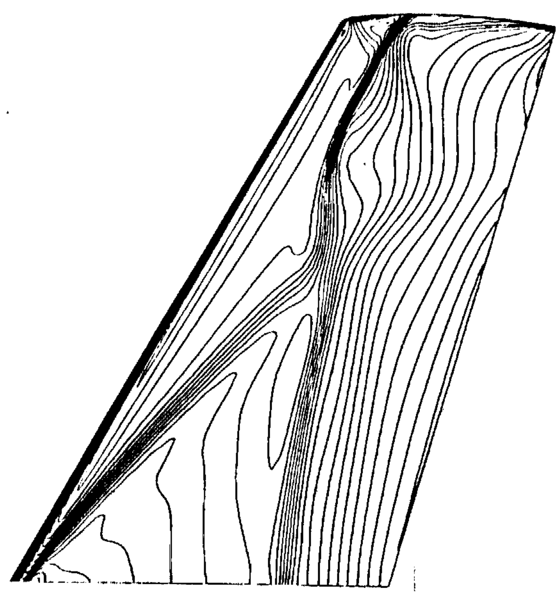


# Effect of turbulence model on pressure contours for ONERA M6 wing

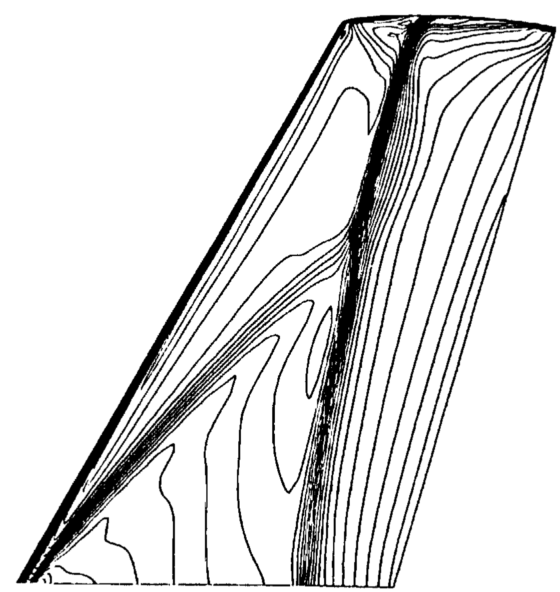
( $M_\infty = 0.84$, $\alpha = 6.06^o$ )

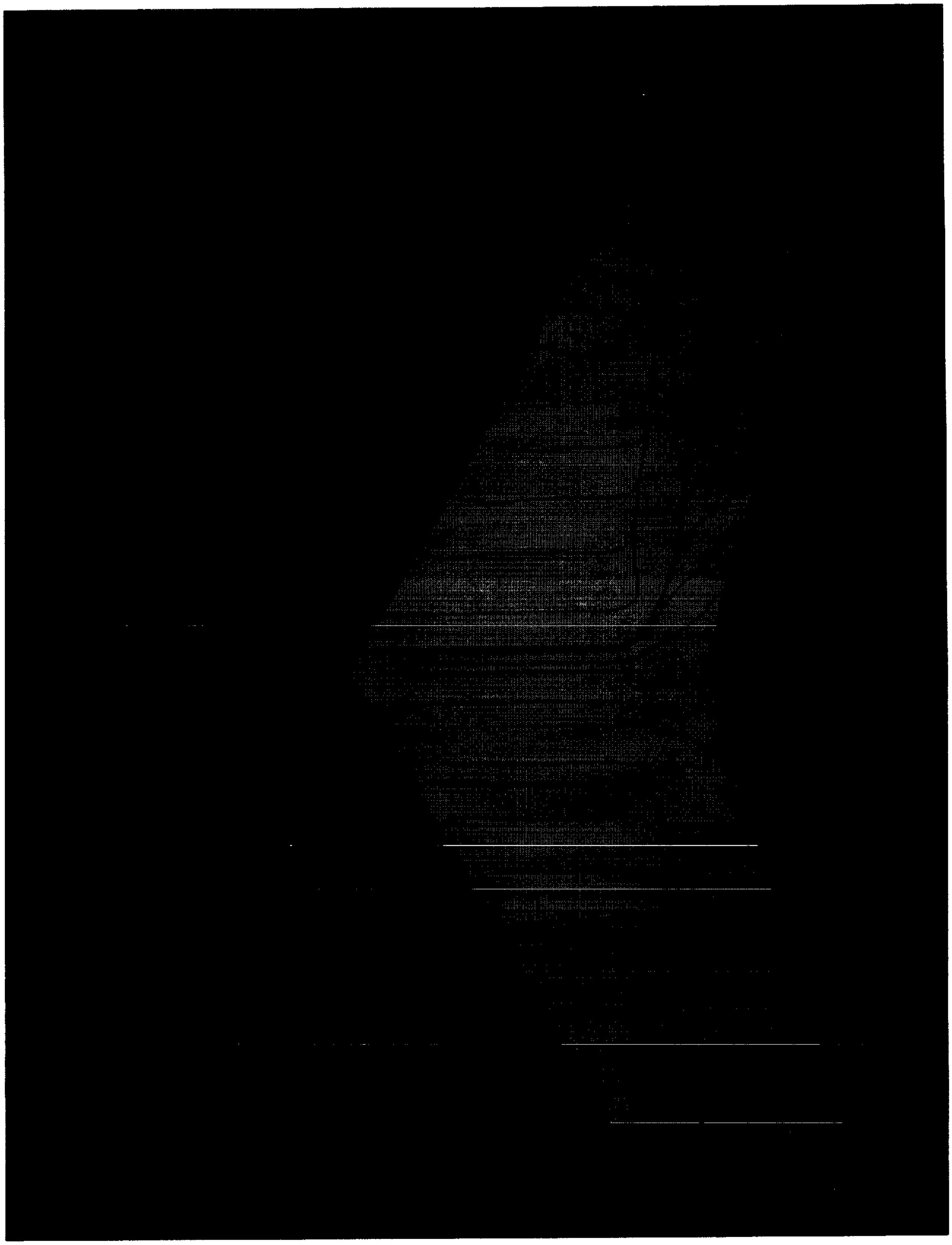
Upper surface, 289x65x49 grid

Johnson-King



Baldwin-Lomax





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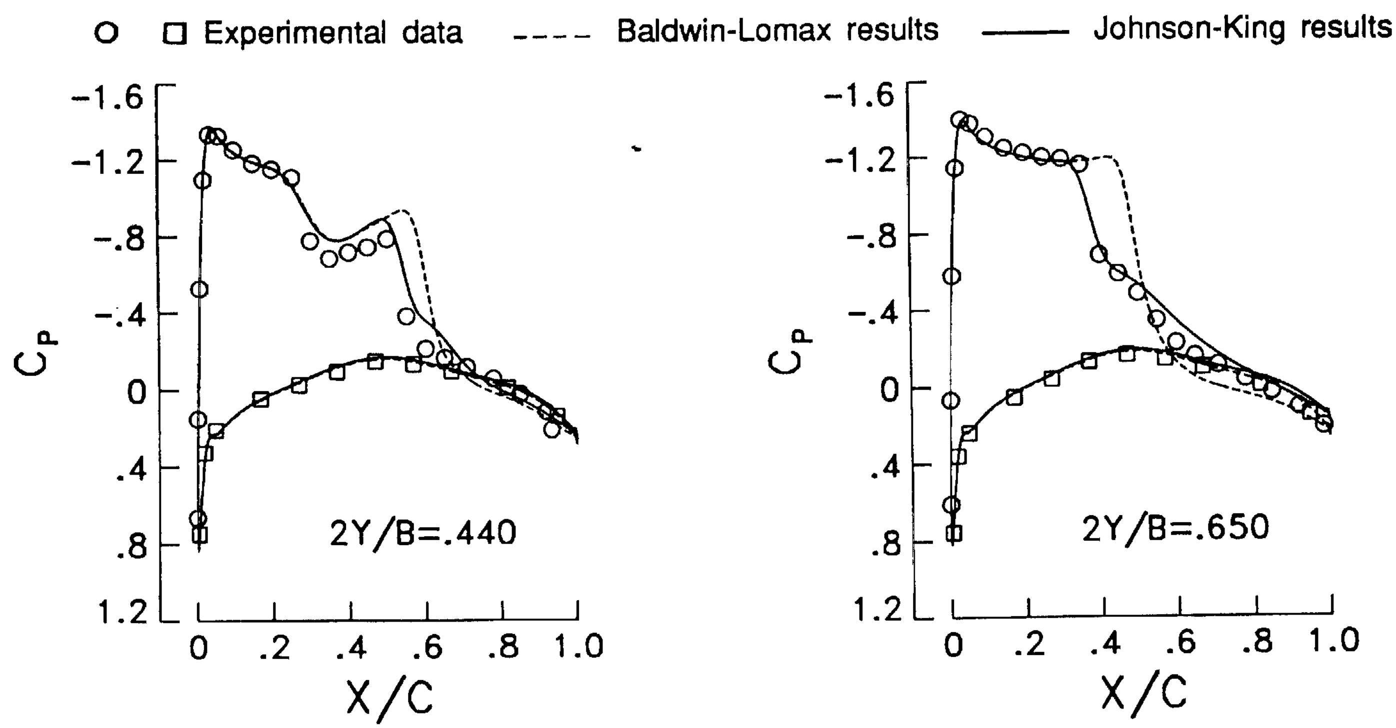
# Effect of turbulence model on pressure distributions for ONERA M6 wing

( $M_\infty = 0.84$, $\alpha = 6.06^o$ )

289x65x49 grid computations



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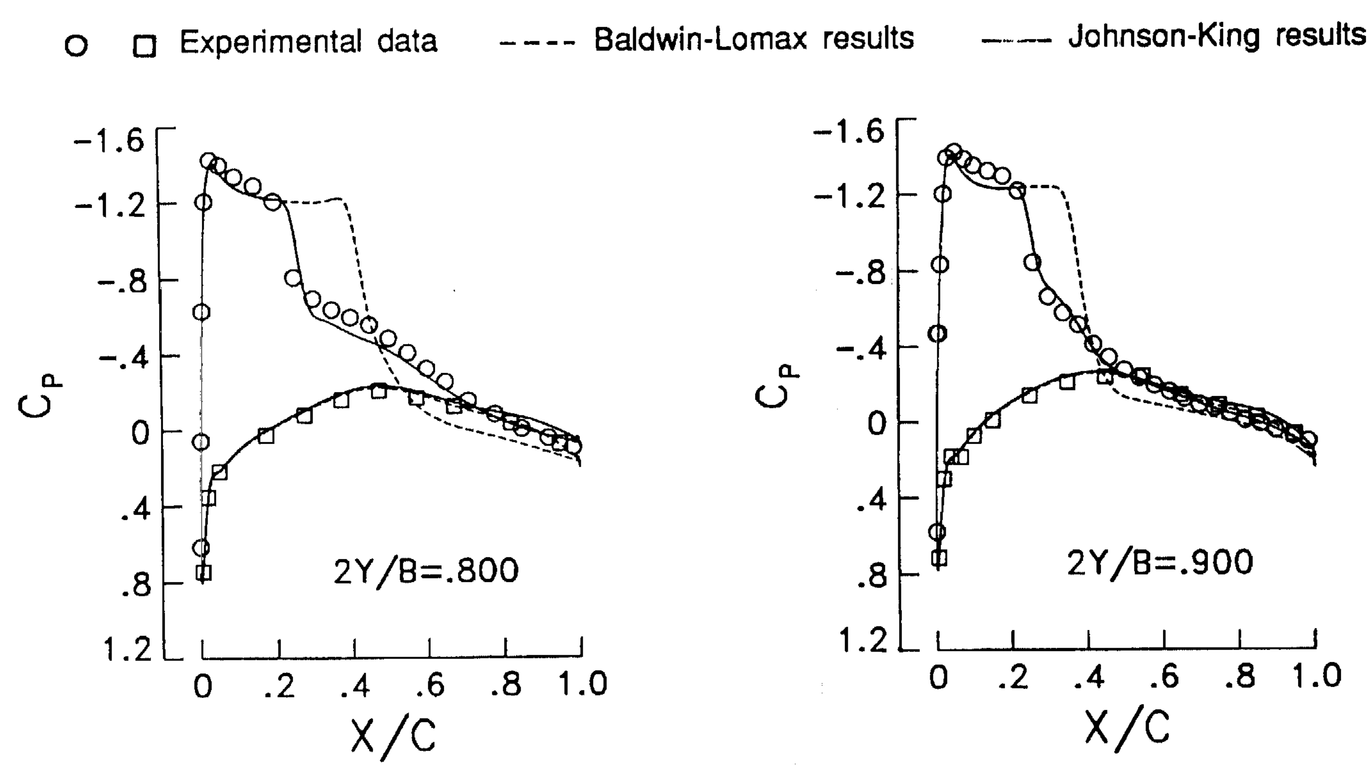

# CONCLUDING REMARKS

- Significant gains in efficiency are achieved through multigrid acceleration technique
- Grid-convergence studies feasible due to improved efficiency
- Baldwin-Lomax model gives good solutions for attached flows, but is found inadequate for separated flows
- Johnson-King model results in improved comparison with data for separated flows
- Block-structured grids must be employed for more efficient use of mesh points and for computing more complex configurations