NUMERICAL SIMULATION OF ROTORCRAFT*

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The objective of this research is to develop and validate accurate, user-oriented viscous CFD codes (with inviscid options) for three-dimensional, unsteady aerodynamic flows about arbitrary rotorcraft configurations. This effort draws heavily from the supercomputer capabilities of the National Aerodynamic Simulation project, and it will provide significantly better design and analysis tools to the rotorcraft industry. Better vehicles can be designed at lower cost, with less expensive testing, and with less risk.

Unsteady, three-dimensional Euler and Navier-Stokes codes are being developed, adapted, and extended to rotor-body combinations. Flow solvers are being coupled with zonal grid topologies, including rotating and nonrotating blocks. Special grid clustering and wave-fitting techniques have been developed to capture low-level radiating acoustic waves.

Significant progress has been made in computing the propagation of acoustic waves due to the interaction of a concentrated vortex and a helicopter airfoil. In this study, the need for higher-order schemes was firmly established in relatively inexpensive two-dimensional calculations. In three dimensions, the number of grid points required to capture the low-level acoustic waves becomes *very* large, so that large supercomputer memory becomes essential.

Good agreement was obtained between the numerical results obtained with a thin-layer Navier-Stokes code and experimental data from a model rotor. In addition, several nonrotating configurations that are sometimes proposed to simulate rotor blade tips in conventional wind tunnels were examined, and the complex flow around the radical tip shape of the world's fastest helicopter is under investigation. These studies demonstrate the flexibility and power of CFD to gain physical insight, study novel ideas, and examine various possibilities that might be difficult or impossible to set up in physical experiments.

As a prelude to studies of rotor-body aerodynamic interactions, a preliminary grid topology and moving-interface strategy has been developed. A new Euler / Navier-Stokes code using these techniques computes the vortical wake directly, rather than modeling it, as in most previous rotorcraft studies. Several hover cases were run for conventional and advanced-geometry blades. Numerical schemes using multi-zones and/or adaptive grids appear to be necessary to simulate the complex vortical flows in rotor wakes.

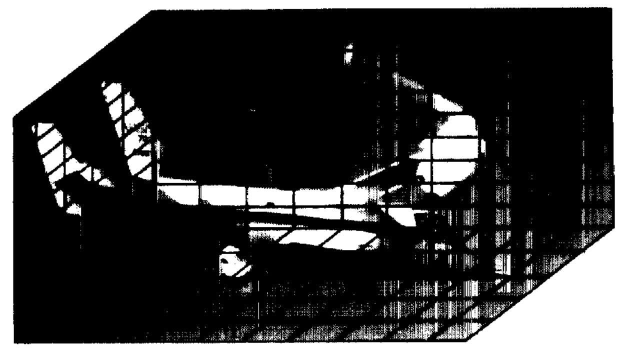
Although major improvements both in supercomputers and in codes will be required, the present trends and rate of progress indicate that practical computations of rotor-body combinations will be feasible in the mid-1990's.

*This research is performed by the Rotorcraft CFD Group, consisting of James Baeder, Ryan Border, Earl Duque, G.R. Srinivasan, and Sharon Stanaway, whose contributions are gratefully acknowledged.

NUMERICAL SIMULATION OF ROTORCRAFT

OBJECTIVE:

- DEVELOP AND VALIDATE CFD CODES FOR 3-D VISCOUS FLOWS ABOUT ARBITRARY ELASTIC ROTORCRAFT CONFIGURATIONS



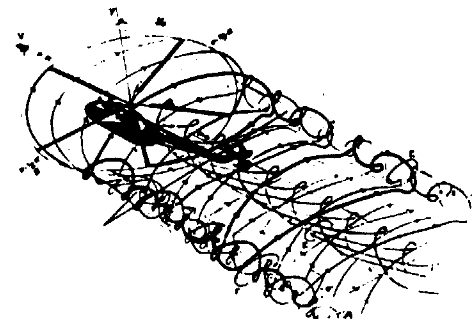
APPROACH:

- DEVELOP AND VALIDATE EULER AND NAVIER-STOKES CODES FOR FUTURE NAS SUPERCOMPUTERS

BACKGROUND:

- PRESENT DESIGN AND ANALYSIS TOOLS FOR ROTORCRAFT ARE INADEQUATE
- TRIAL-AND-ERROR TESTING IS EXPENSIVE AND TIME-CONSUMING
- FOREIGN COMPETITION IS GROWING RAPIDLY
- CFD TECHNOLOGY FOR ROTORCRAFT LAGS FIXED-WING DEVELOPMENTS BY YEARS, *BUT FUTURE SUPERCOMPUTERS WILL PERMIT REALISTIC ROTORCRAFT APPLICATIONS*

NUMERICAL SIMULATION OF ROTORCRAFT



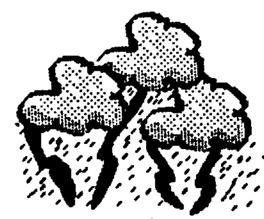
I. Very Difficult Problems

II. We're Doing Great Work

Specific Examples

III. We Have Great Plans

Complete Aeroelastic Rotor–Body Combinations, etc.



IV. BUT . . .

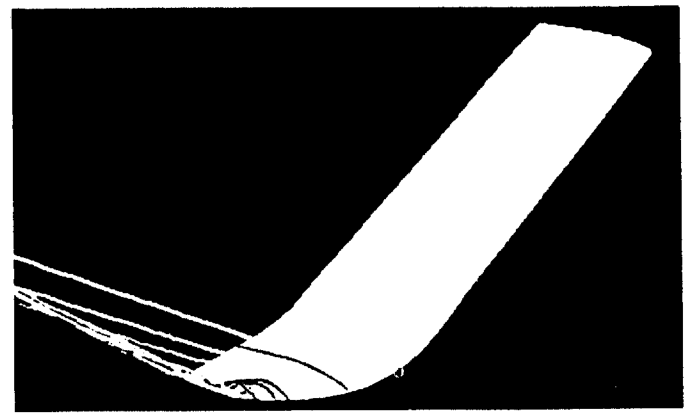
Hardware
Software
Algorithms
Grids
Turbulence Model

V. Summary and Conclusions

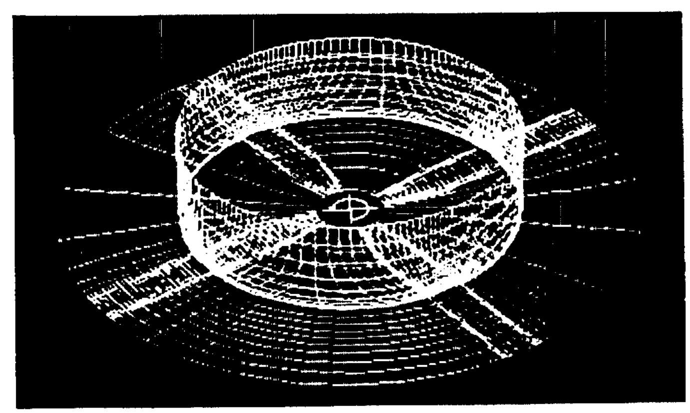
Supercode R C 2 2 2

ARMY/NASA ROTORCRAFT CFD PROGRAMS

- **INDIVIDUAL COMPONENTS**
  1. TRANSONIC AIRFOIL CHARACTERISTICS
  2. BLADE-VORTEX INTERACTIONS
  3. ROTOR TIP-VORTEX FORMATION
  4. 3-D ACOUSTIC PROPAGATION



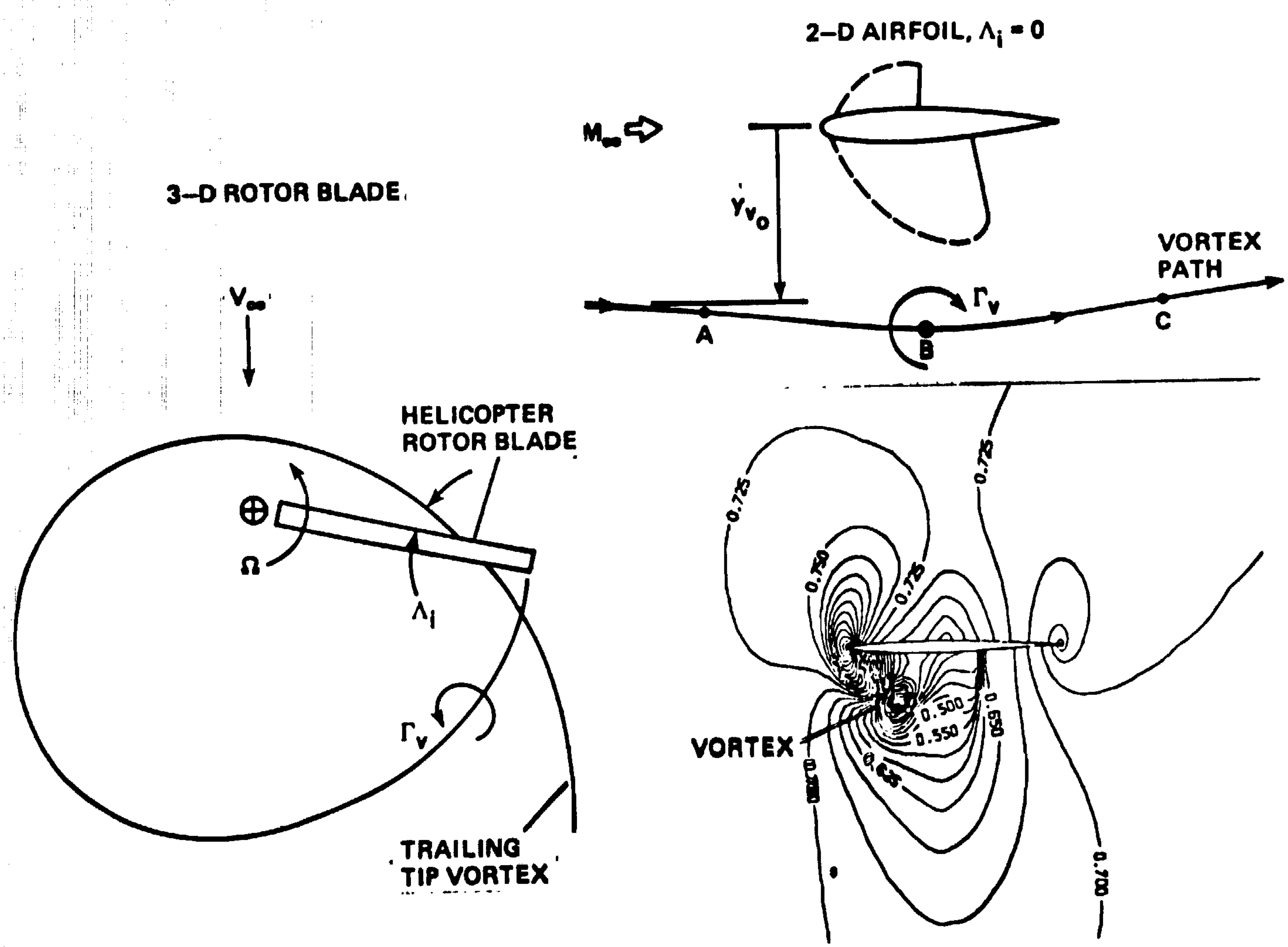
- **COUPLED FINITE-DIFFERENCE CODES AND WAKE MODELS**



- **ISOLATED ROTOR** *(NAVIER STOKES)*

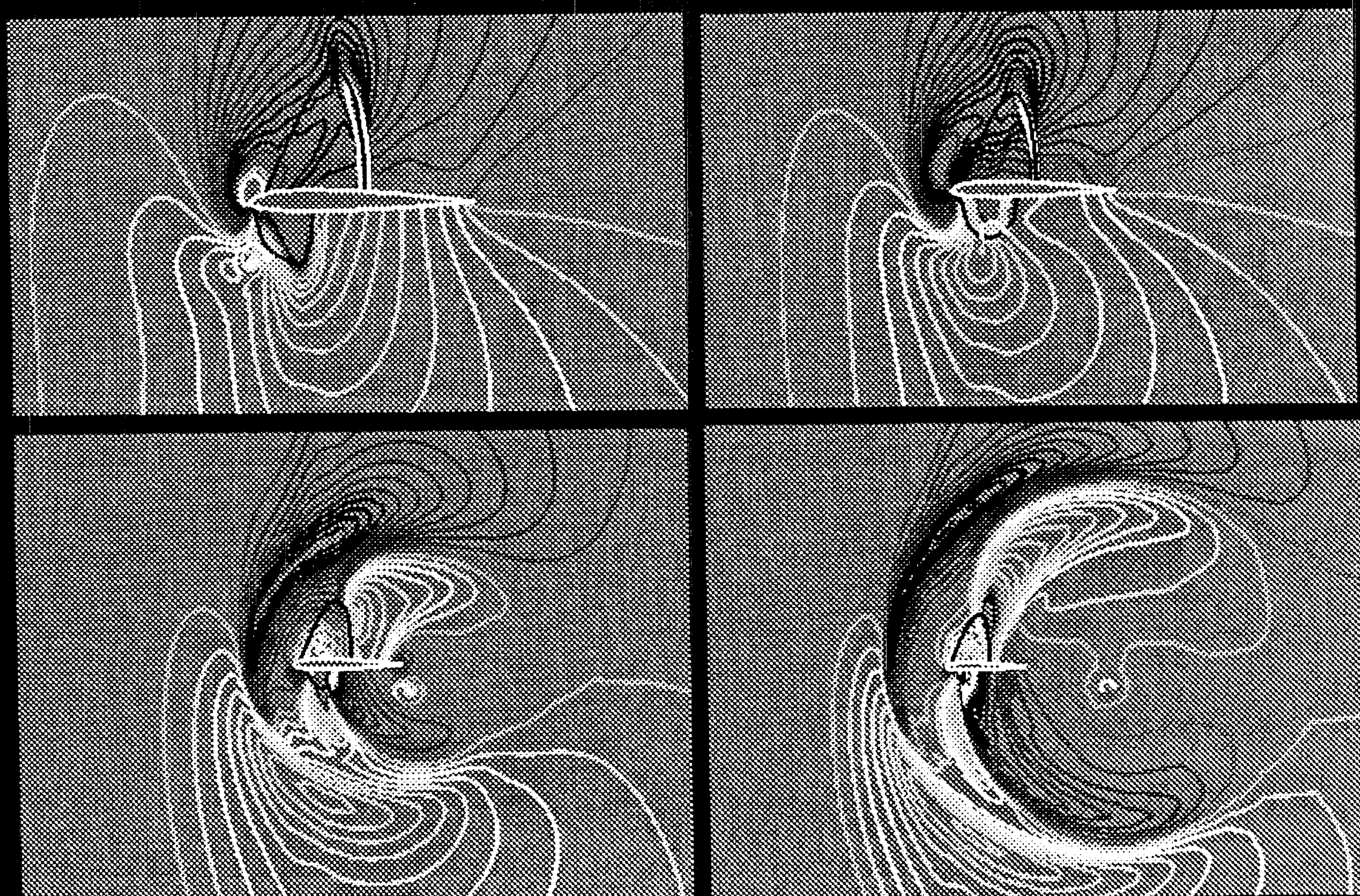
- **ROTOR-BODY COMBINATIONS**

UNSTEADY VORTEX INTERACTIONS



Transonic Airfoil-Vortex Interaction

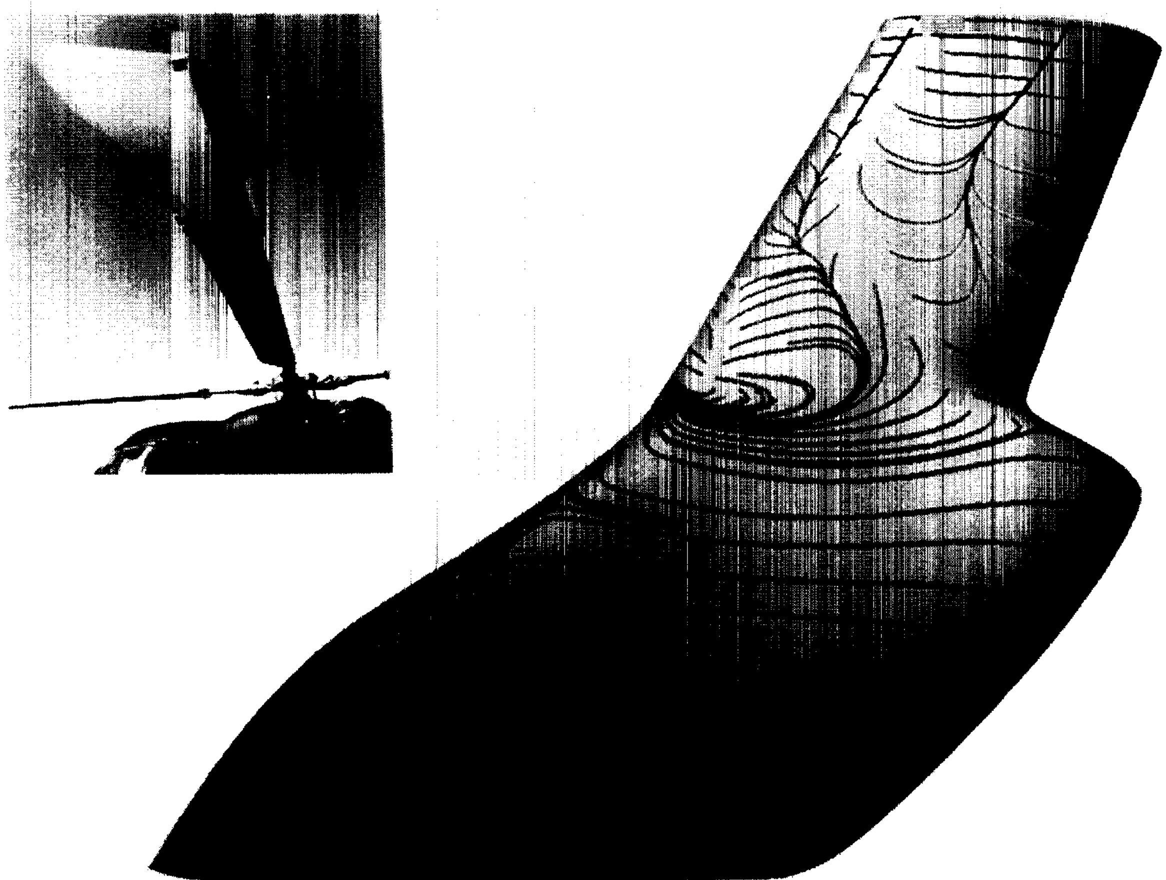
Formation of Acoustic Wave - SC1095



Computations & Graphics : James D. Baeder, Army AFDD / NASA Ames

BERP ROTOR

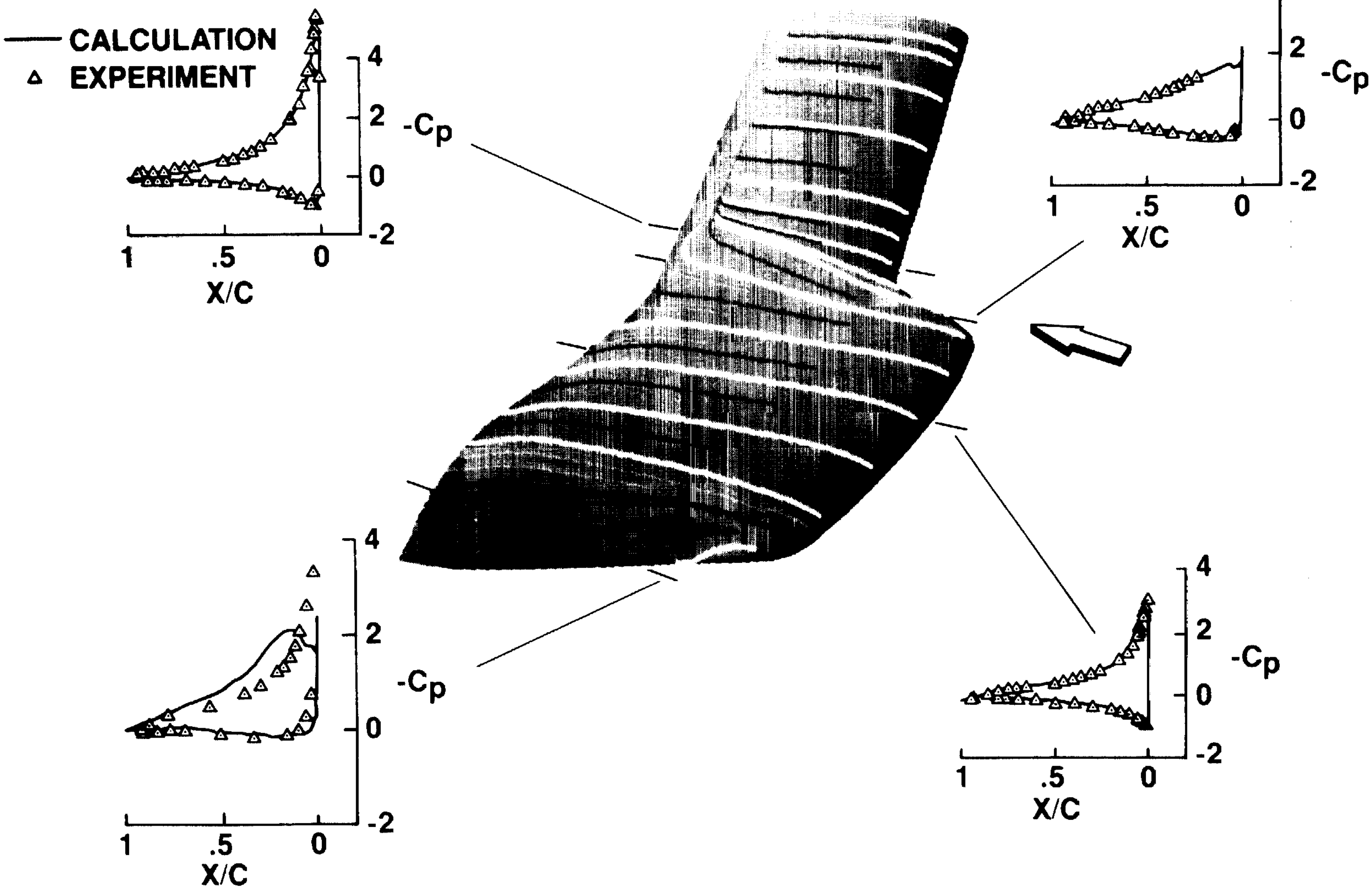
$\alpha = 20^{\circ}$, $Re = 1.5 \times 10^{6}$, $M = 0.2$



E.P.N. DUQUE, U.S. ARMY AEROFLIGHTDYNAMICS DIRECTORATE, AVSCOM

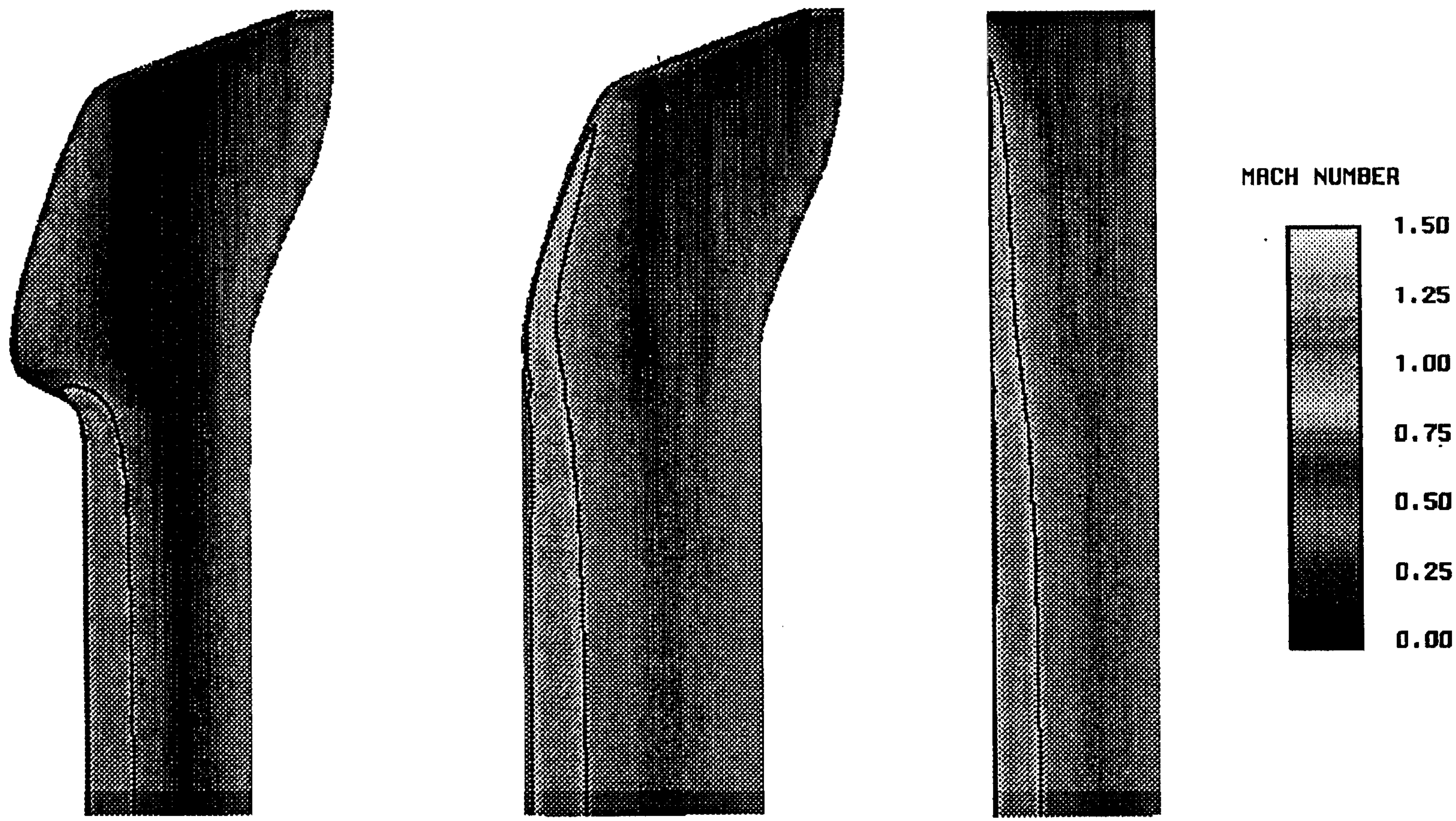
THE BRITISH EXPERIMENTAL ROTOR PROGRAM BLADE

M = 0.2, α = 13°, Re = 1.5×10^6, NONROTATING



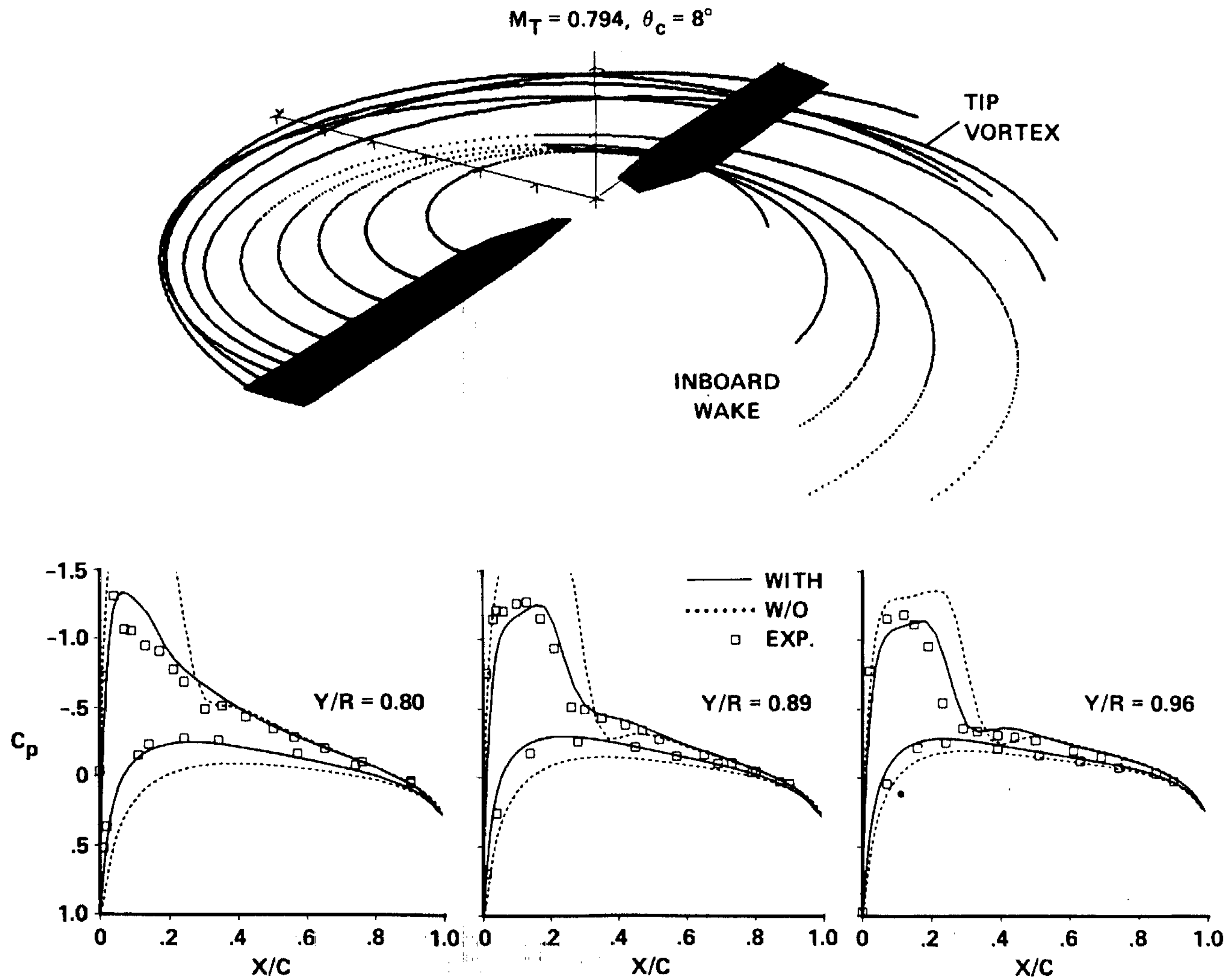
TIP SHAPE COMPARISON

M=0.6, alpha=6 degrees, Inviscid

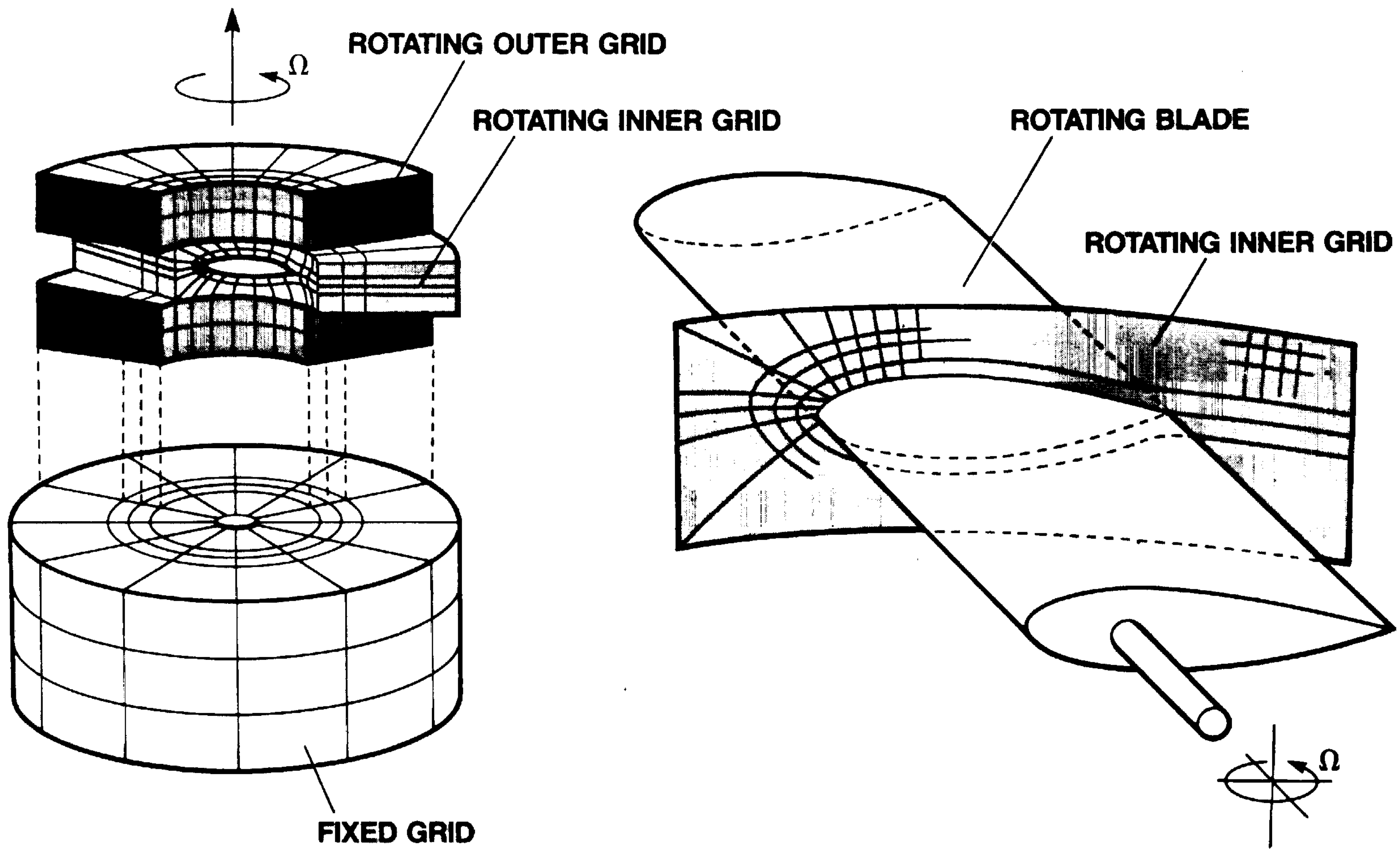


EULER HOVERING ROTOR CALCULATIONS

WITH AND WITHOUT COMPUTED VORTEX WAKE

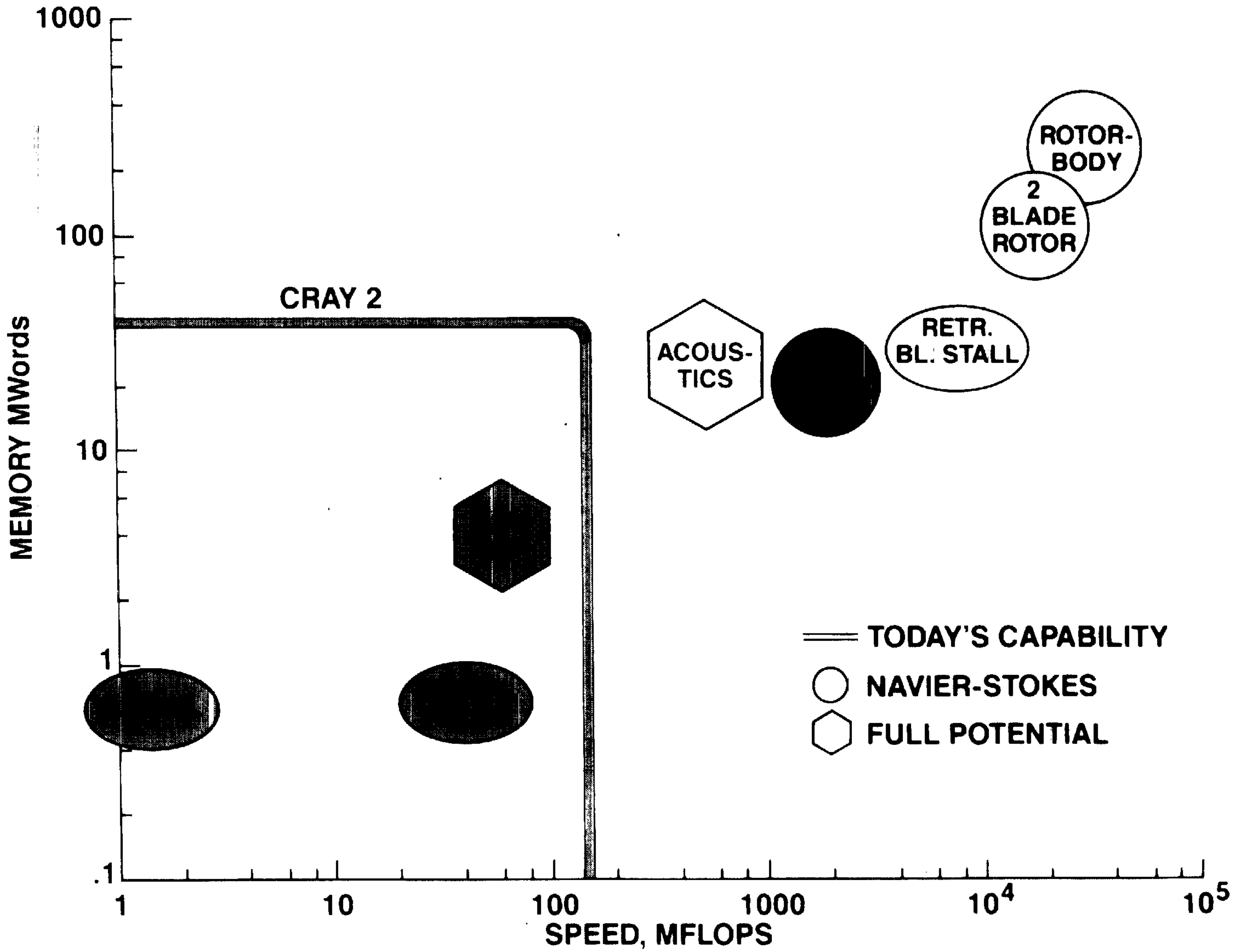


COMPUTATIONAL GRIDS FOR ROTORCRAFT



COMPUTER SPEED AND MEMORY REQUIREMENTS

FOR 1 HOUR RUNS



What Can We Do ?

1. Accept Longer Run Times
2. Speed Up the Hardware
3. Change the Hardware and Software
   - Different Architectures,
   - Different Operating Systems,
   - Different Languages,
   - New / Improved Coding
4. Improve the Algorithms
   - Increase Stability → *increase* Δt
   - Reduce Numerical Dissipation
5. Use Dynamic, Solution – Adaptive Grids
6. Simplify the Turbulence Model

SUPERCODE RC222

- Two Blades + Body :

  10^6 grid pts/blade + 0.5×10^6 for body

  200 *Mwords*, 2 *Gflops* (4 μsec/grid pt/time step)

- <u>Major</u> Improvements Are Required

  20 Times Faster than Today's Unsteady Navier–Stokes Codes

  → Δt 10 *times larger* (1° azimuth per time step)

  → *Flow solver* 2 *times faster*

  Rotating and Nonrotating Grid Zones

  Solution – Adaptive Grids, <u>*Minimum*</u> Artificial Dissipation

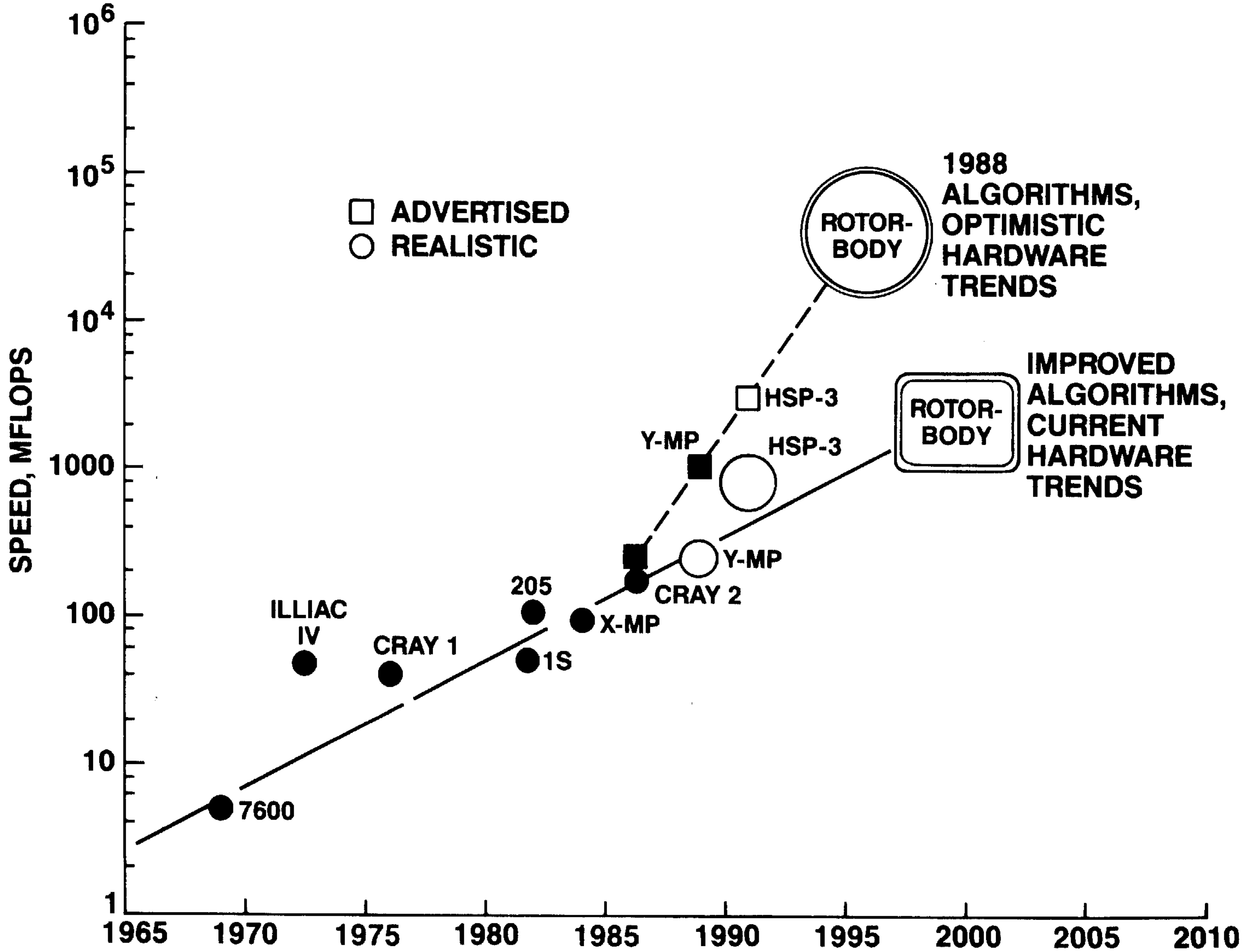
  Near – Wake Vortex Capturing, Far – Wake Modeling

  Improved Transition Modeling and <u>*Separation*</u> <u>*Prediction*</u>

- Flow Solver Coupled with Finite – Element Structural Model

ROTORCRAFT CFD PROJECTIONS

FOR 1 HOUR RUNS



SUMMARY AND CONCLUSIONS

- CFD IS VIABLE AND USEFUL FOR ROTORCRAFT

- FUTURE DIRECTIONS
  - Detailed Study of BERP and Other Advanced Tips
  - Rotor – Body Interactions
  - Improved Wake Computations
  - Increased Collaboration with Industry
  - New Tilt – Rotor Initiatives

- CONCERNS AND LIMITATIONS
  - Manpower – *Trained in Both CFD and Rotorcraft*
  - Far – Field Aeroacoustics and Structural Coupling
  - Wake Capturing vs. Wake Modeling
  - Turbulence Models
  - Grids for Complex Bodies in Relative Motion
  - Code Validation, Accuracy, and Reliability
  - Computer Power –– CPU and Clock Time
  - Mass Storage, Post – Processing, and Graphical Display of 3 – D Time – Dependent Results

- PRACTICAL ROTOR – BODY COMBINATIONS BY MID – 1990's