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APPLICATION OF UNSTRUCTURED GRID METHODS TO STEADY AND UNSTEADY AERODYNAMIC PROBLEMS

John T. Batina
Unsteady Aerodynamics Branch
NASA Langley Research Center
Hampton, Virginia 23665-5225

Abstract

The presentation summarizes recent work in the Unsteady Aerodynamics Branch at NASA Langley Research Center on developing unstructured grid methods for application to steady and unsteady aerodynamic problems. The CAP-TSD transonic aeroelasticity code, which is based on the transonic small-disturbance (TSD) theory, is described first to provide background information to put the present work in context. The CAP-TSD code is the most fully-developed code for aeroelastic analysis of complete aircraft configurations at the TSD equation level and has been widely accepted throughout the U.S. aerospace industry. Currently, aeroelastic analysis capabilities are being developed at NASA Langley for the Euler and Navier-Stokes equations based on both structured and unstructured grids. The purpose of the presentation is to describe the development of unstructured grid methods which have several advantages when compared to methods which make use of structured grids. Unstructured grids, for example, easily allow the treatment of complex geometries, allow for general mesh movement for realistic motions and structural deformations of complete aircraft configurations which is important for aeroelastic analysis, and enable adaptive mesh refinement to more accurately resolve the physics of the flow. The presentation is therefore organized in three parts including: (1) steady Euler calculations for a supersonic fighter configuration to demonstrate the complex geometry capability; (2) unsteady Euler calculations for the supersonic fighter undergoing harmonic oscillations in a complete-vehicle bending mode to demonstrate the general mesh movement capability; and (3) vortex-dominated conical-flow calculations for highly-swept delta wings to demonstrate the adaptive mesh refinement capability. The basic solution algorithm is a multi-stage Runge-Kutta time-stepping scheme with a finite-volume spatial discretization based on an unstructured grid of triangles in 2D or tetrahedra in 3D. The moving mesh capability is a general procedure which models each edge of each triangle (2D) or tetrahedra (3D) with a spring. The resulting static equilibrium equations which result from a summation of forces are then used to move the mesh to allow it to continuously conform to the instantaneous position or shape of the aircraft. The adaptive mesh refinement procedure enriches the unstructured mesh locally to more accurately resolve the vortical flow features. These capabilities are described in detail along with representative results which demonstrate several advantages of unstructured grid methods. The presentation further discusses the applicability of the unstructured grid methodology to steady and unsteady aerodynamic problems and suggests directions for future work.

PRESENTATION OVERVIEW

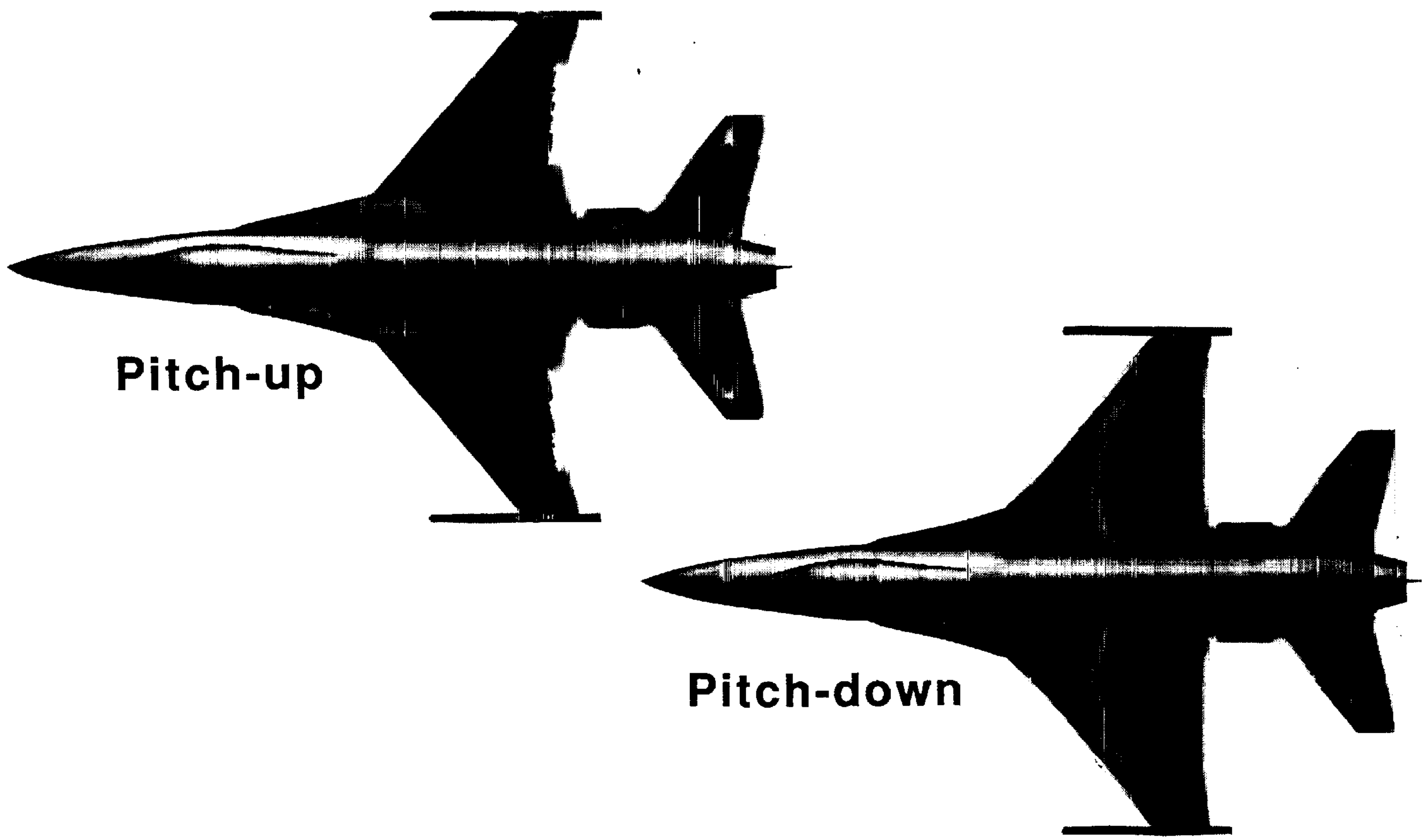
- Background on CAP-TSD transonic aeroelasticity code
- Unstructured grid methods
    - steady and unsteady Euler calculations for a supersonic fighter configuration
    - vortex-dominated conical-flow calculations including adaptive mesh refinement
- Concluding remarks

CAP-TSD: COMPUTATIONAL AEROELASTICITY PROGRAM - TRANSONIC SMALL DISTURBANCE

- Based on time-accurate approximate factorization algorithm
- Complete aircraft modeling involving arbitrary combinations of lifting surfaces and bodies
- Static and dynamic aeroelastic analysis
- Aircraft trim capability
- Longitudinal short-period response
- Entropy and vorticity effects included to treat cases with strong shock waves

CAP-TSD INSTANTANEOUS PRESSURES ON F-16C AIRCRAFT DUE TO RIGID PITCHING MOTION

- $M_\infty = 0.9$, $\alpha_o = 2.38°$, $k = 0.1$



ADVANTAGES OF UNSTRUCTURED GRID METHODOLOGY

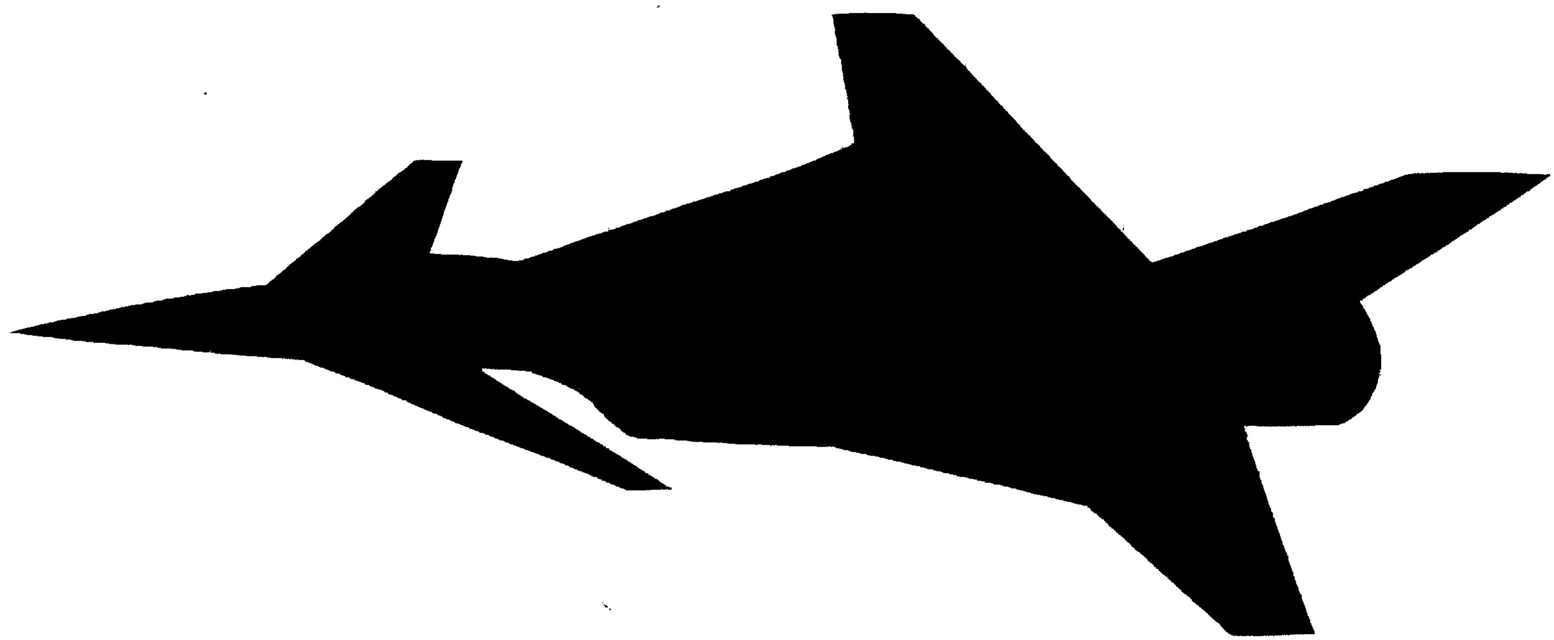
- Allows the treatment of complex geometries
- Allows general mesh movement for realistic motions and structural deformations of complete aircraft
- Enables adaptive mesh refinement to more accurately resolve the physics of the flow

DESCRIPTION OF EULER SOLUTION ALGORITHMS

- Four-stage Runge-Kutta time-stepping scheme
- Finite-volume spatial discretization on unstructured grids of triangles in 2D or tetrahedra in 3D
- Adaptive blend of harmonic and biharmonic operators for artificial dissipation
- Enthalpy damping, local time-stepping, and implicit residual smoothing to accelerate convergence to steady state
- Dynamic mesh algorithm employed for unsteady applications

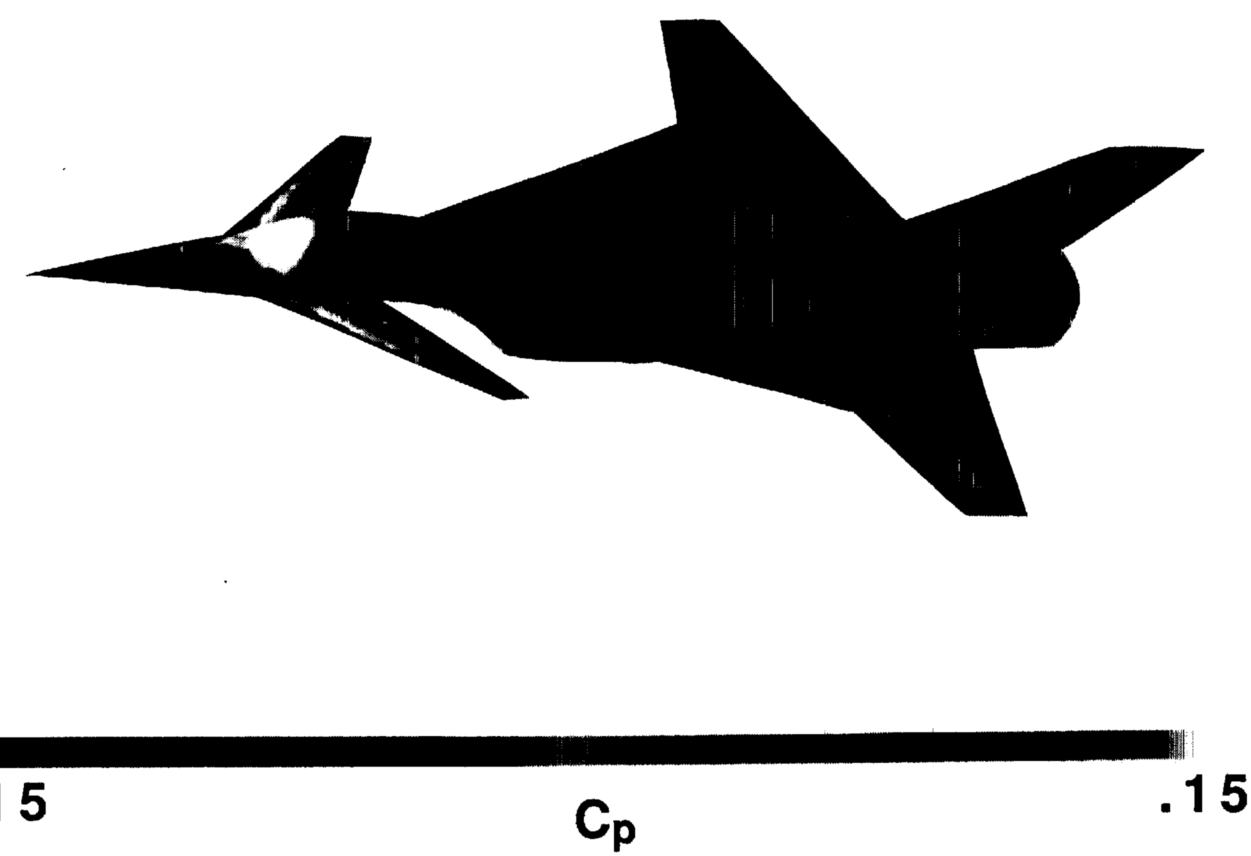
SURFACE TRIANGULATION FOR LANGLEY FIGHTER

- Total grid has 13,832 nodes and 70,125 tetrahedra



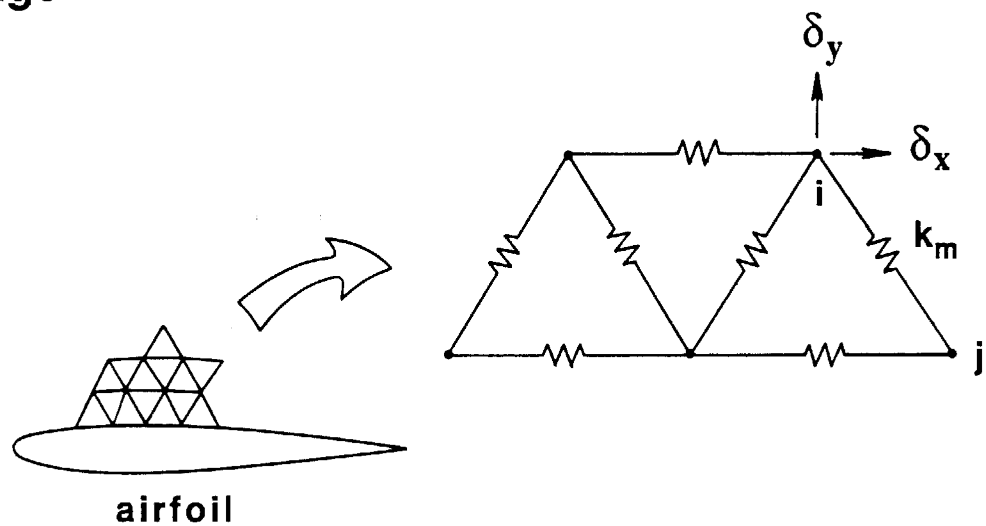
STEADY PRESSURE CONTOURS ON LANGLEY FIGHTER

- $M_\infty = 2.0$ and $\alpha_o = 0°$



OVERVIEW OF DYNAMIC MESH ALGORITHM

- Each edge of each triangle is modeled using a spring
- Spring stiffness is inversely proportional to the length of the edge



- Points on outer boundary of grid are fixed
- Locations of points on inner boundary of grid are specified

OVERVIEW OF DYNAMIC MESH ALGORITHM

- Displacement of interior nodes determined by solving the static equilibrium equations

- Equations solved using predictor-corrector procedure

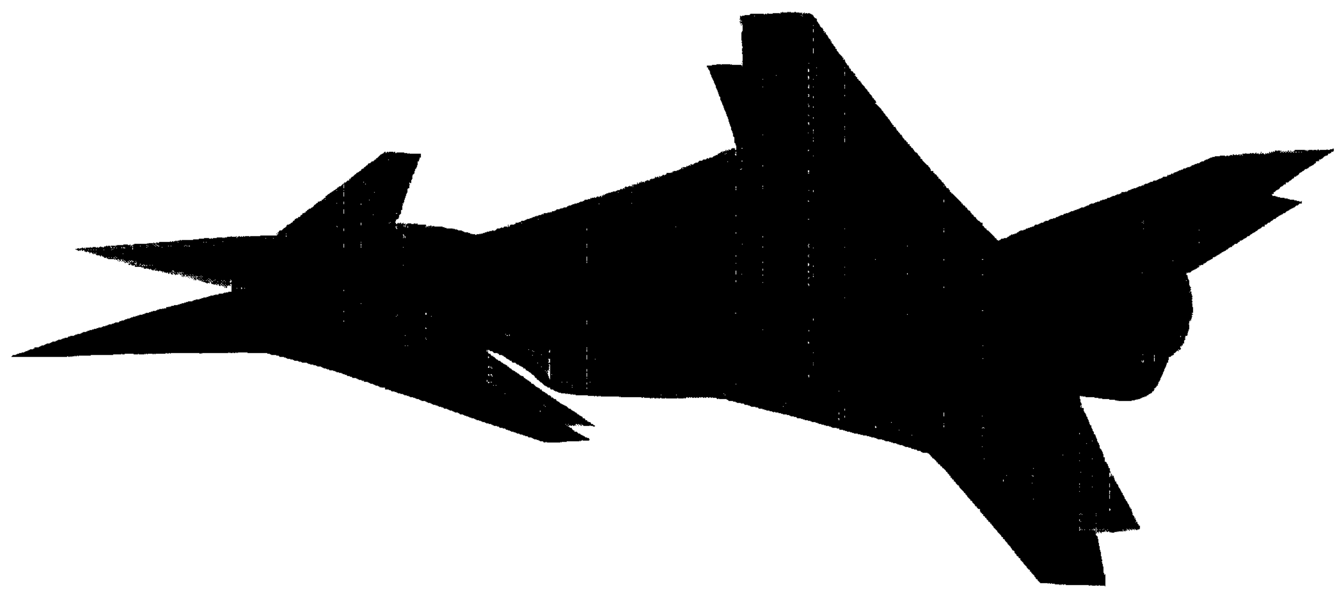
  - new locations of nodes predicted by extrapolation

$$\tilde{\delta}_{x_i} = 2\,\delta_{x_i}^{n} - \delta_{x_i}^{n-1} \qquad \tilde{\delta}_{y_i} = 2\,\delta_{y_i}^{n} - \delta_{y_i}^{n-1} \qquad \tilde{\delta}_{z_i} = 2\,\delta_{z_i}^{n} - \delta_{z_i}^{n-1}$$

  - locations corrected by several Jacobi iterations

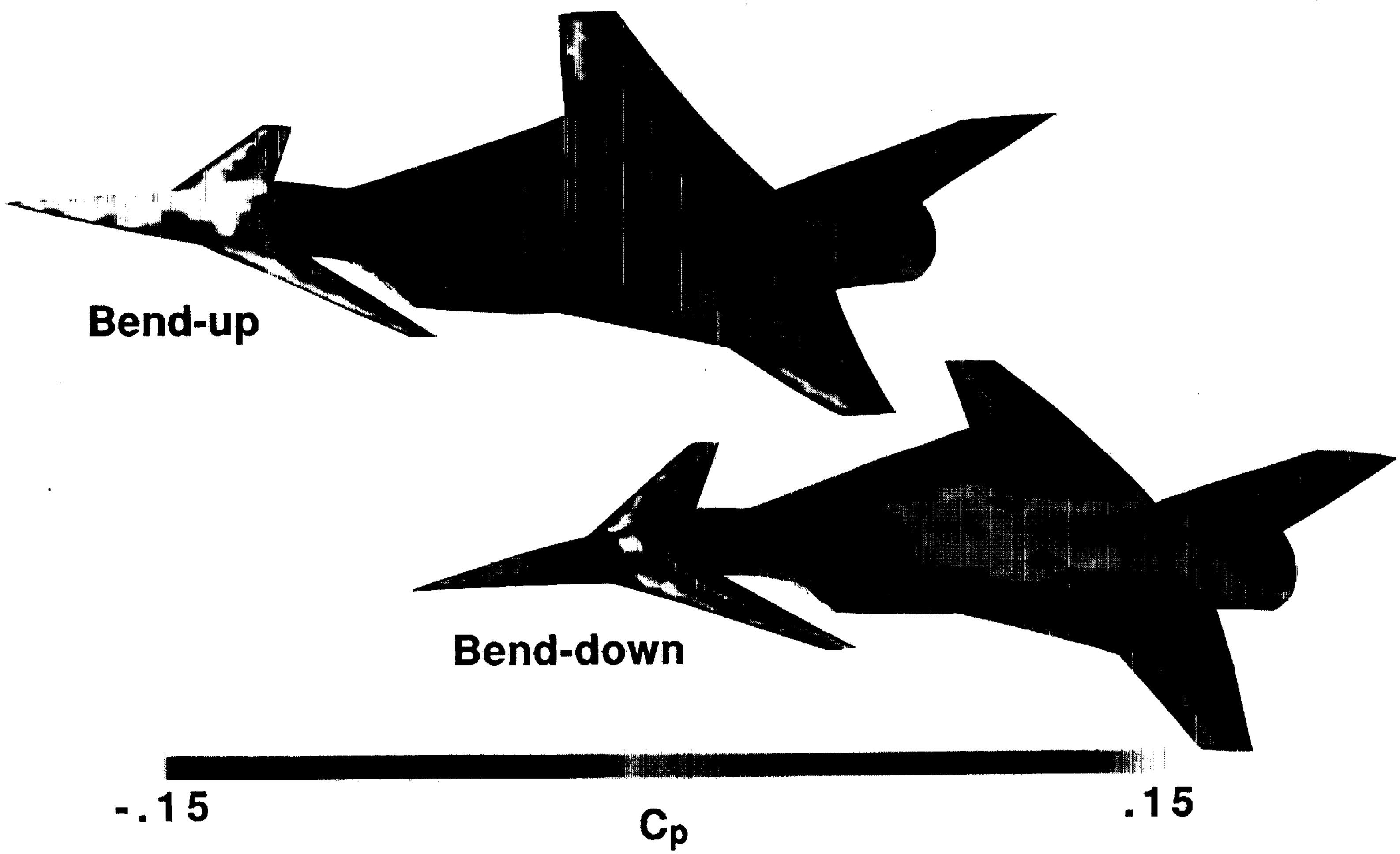
$$\delta_{x_i}^{n+1} = \frac{\sum k_m \tilde{\delta}_{x_m}}{\sum k_m} \qquad \delta_{y_i}^{n+1} = \frac{\sum k_m \tilde{\delta}_{y_m}}{\sum k_m} \qquad \delta_{z_i}^{n+1} = \frac{\sum k_m \tilde{\delta}_{z_m}}{\sum k_m}$$

ASSUMED BENDING MODE FOR LANGLEY FIGHTER



INSTANTANEOUS PRESSURE CONTOURS ON LANGLEY FIGHTER

- $M_\infty = 2.0$, $\alpha_o = 0°$, and $k = 0.1$

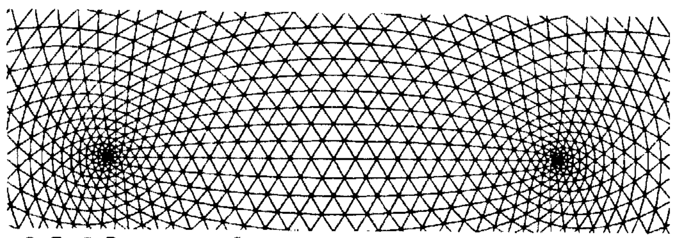


DESCRIPTION OF CONICAL EULER/NAVIER-STOKES ALGORITHM

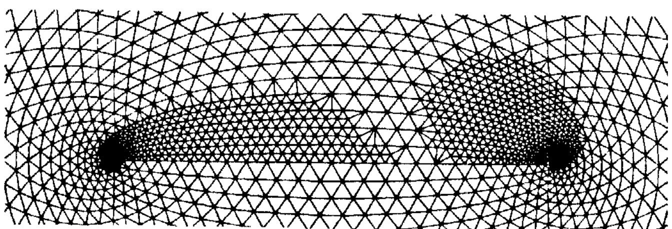
- Solves the conical Euler/Navier-Stokes equations
- Multi-stage Runge-Kutta time-stepping with finite-volume spatial discretization on unstructured grid of triangles
- Scheme is a zonal method
- Mesh enrichment capability enables automatic refinement in regions of high flow gradients
- Presently limited to laminar flow

EFFECTS OF MESH ENRICHMENT ON CONICAL EULER VORTICAL FLOW SOLUTION

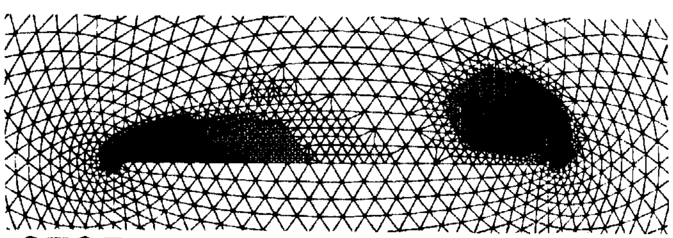
- 75° swept flat plate delta wing at $M_\infty = 1.7$, $\alpha = 12°$, $\beta = 8°$
- Meshes



2048 nodes



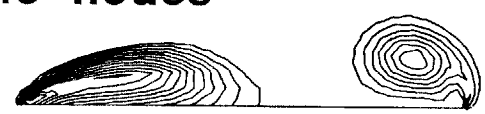
2555 nodes



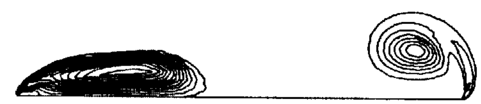
3735 nodes

- Total pressure loss contours

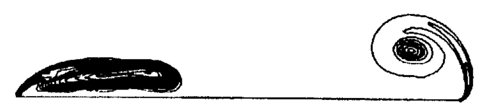
2048 nodes



2555 nodes

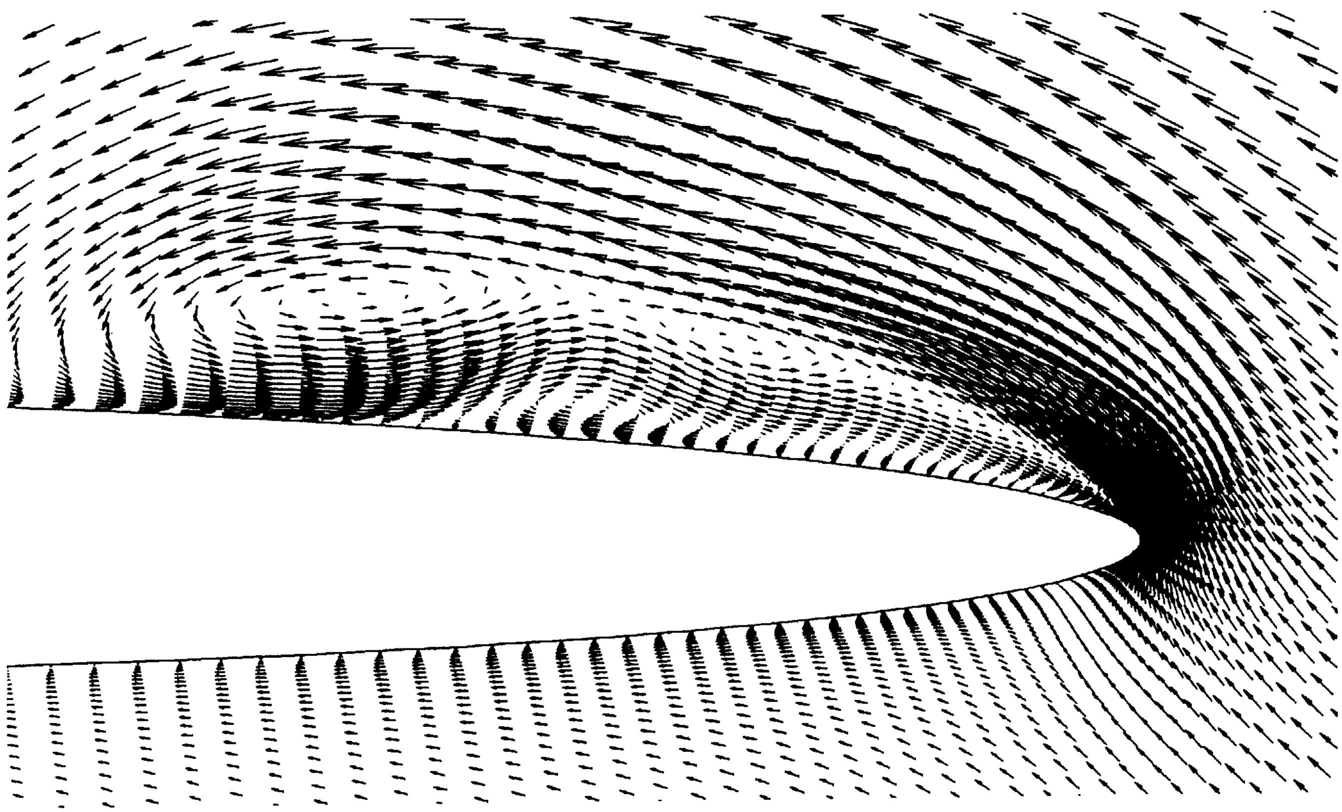


3735 nodes



CROSS FLOW VELOCITY VECTORS FROM CONICAL NAVIER-STOKES SOLUTION

- 70° swept elliptic cone delta wing; thickness ratio 14:1
- $M_\infty = 2.0$, $\alpha = 10°$, and $Re = 5 \times 10^5$



CONCLUDING REMARKS

- CAP-TSD code developed for transonic aeroelastic analysis at the transonic small-disturbance equation level

- Unstructured grid methods for the Euler and Navier-Stokes equations under development for steady and unsteady aerodynamic applications

  - Steady Euler calculations for a supersonic fighter demonstrated ability to treat complex geometries

  - Unsteady Euler calculations for a supersonic fighter demonstrated general dynamic mesh capability

  - Vortex-dominated conical-flow calculations demonstrated adaptive mesh refinement capability

SESSION V

FIGHTER AIRCRAFT

Chairman:
Terry L. Holst
Chief, Applied Computational Fluids Branch
NASA Ames Research Center