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NASA-AMES RESEARCH CENTER UNSTRUCTURED TECHNOLOGY DEVELOPMENT

WILLIAM R. VAN DALSEM
NASA AMES RESEARCH CENTER

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UNSTRUCTURED TECHNOLOGY DEVELOPMENT

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Aerophysics & Aeroflightdynamics Directorates
NASA-Ames Research Center

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AMES PROGRAM REVIEW

- Cartesian, Prismatic & Hybrid
    - Overview
    - Highlights
- Tetrahedra (including surface modeling/gridding)
    - Overview
    - Highlights
- Summary
- Future Directions

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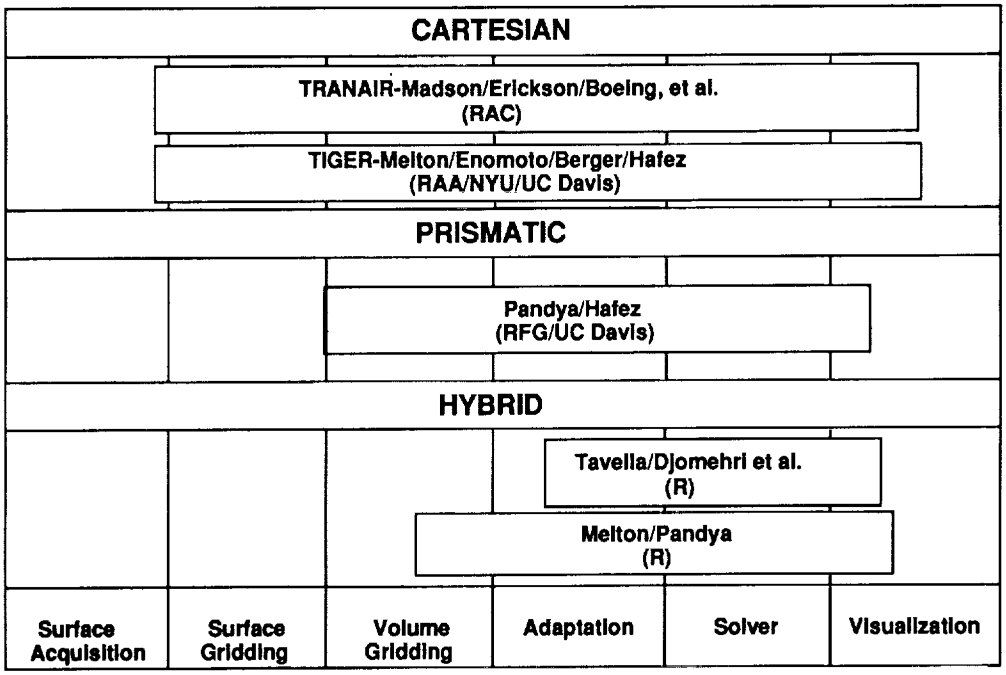
OVERVIEW OF CARTESIAN, PRISMATIC, & HYBRID ACTIVITIES



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TRANAIR
TRANSONIC ANALYSIS CODE FOR ARBITRARY CONFIGURATIONS

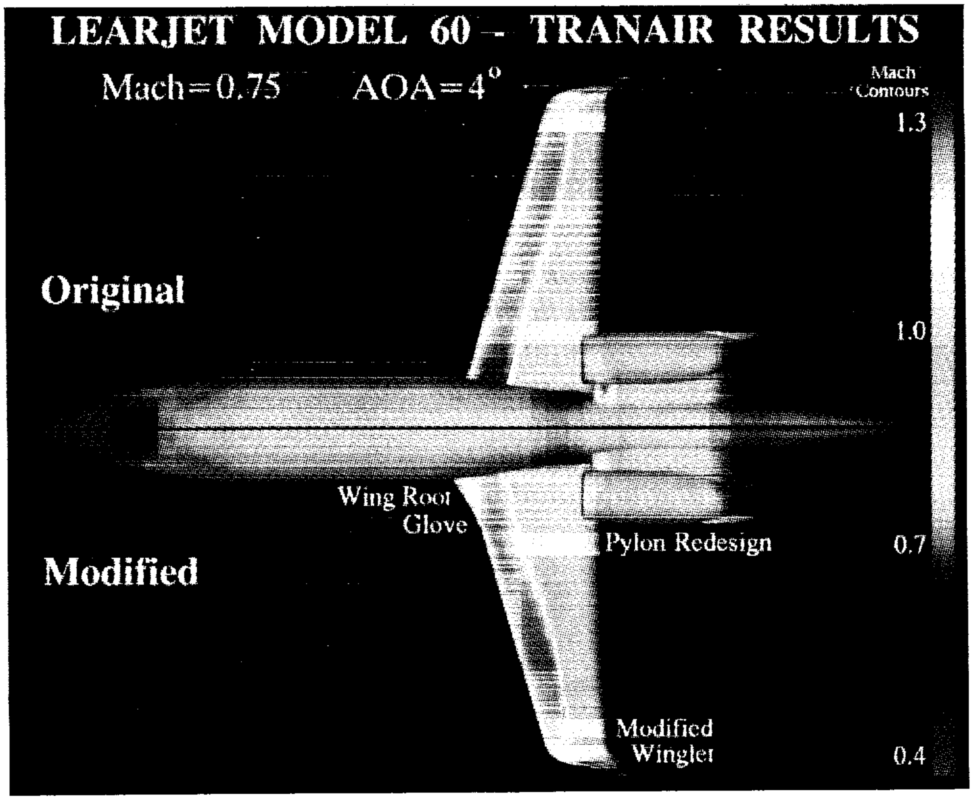
MADSON, ERICKSON, BOEING (JOHNSON), et al.

OBJECTIVE
- Develop and validate an aerodynamic analysis and design capability which eliminates the use of surface-conforming grids

TECHNICAL APPROACH
- Embed surface panel model in a uniform Cartesian gird
- Local grid refinement based on surface model, flow gradients, or user input
- Finite-element non-linear full-potential operators applied and solved iteratively
- Coupled three-dimensional finite-difference boundary-layer code

STATUS
- Extensive NASA and U.S. Aerospace Industry user base: Boeing, Grumman, Learjet, Beech, Gulfstream, etc...

FUTURE DIRECTIONS
- Complete validation of viscous capability



LEARJET MODEL 60 - TRANAIR RESULTS

Mach=0.75 AOA=4°

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TIGER
AUTOMATED 3D CARTESIAN GRID GENERATION AND EULER FLOW SOLUTIONS

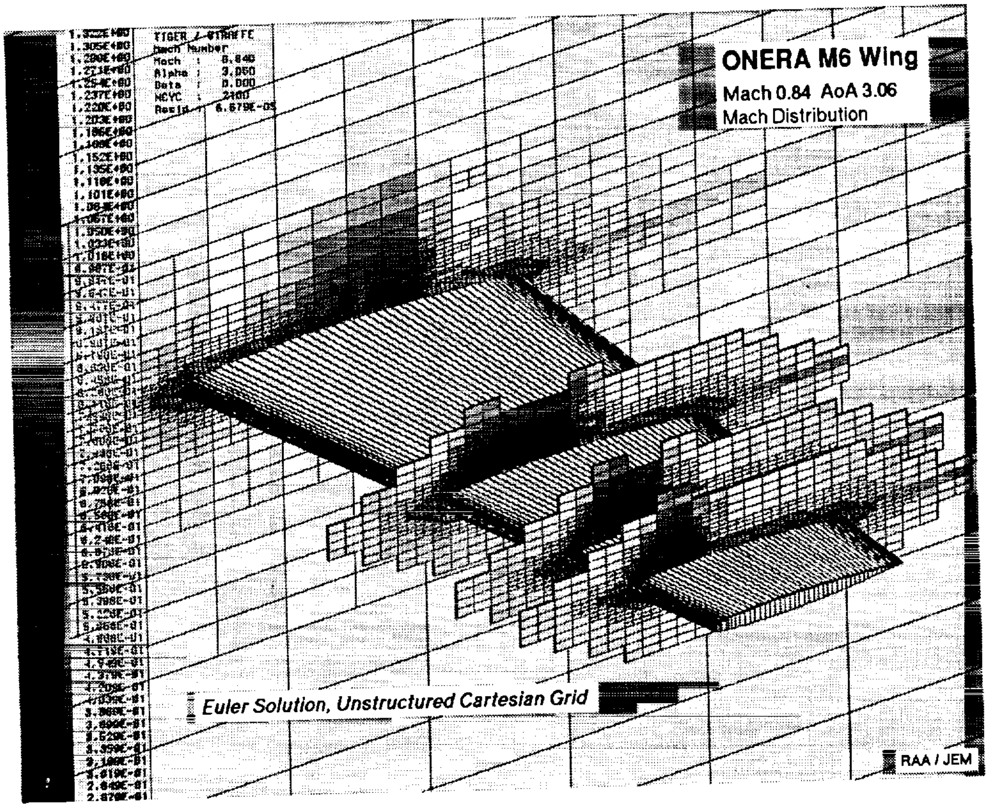
MELTON, ENOMOTO, BERGER, & HAFEZ

OBJECTIVE
- Complete automation of Cartesian Euler grid generation and flow simulation for arbitrary 3D NURBS geometries

TECHNICAL APPROACH
- Automated Cartesian 3D body-intersecting grid generation using NURBS CAD/CAM database and DTNURBS evaluation routines
- Modified Jameson finite-volume Euler flow solver

STATUS
- Developing complete NURBS/IGES input capability
- Improving flux/dissipation calculations
- Integrating "intelligent" feature-based and automated refinement grid generation capabilities

FUTURE DIRECTIONS
- Continued development towards a completely automated adaptive Euler flow simulation capability



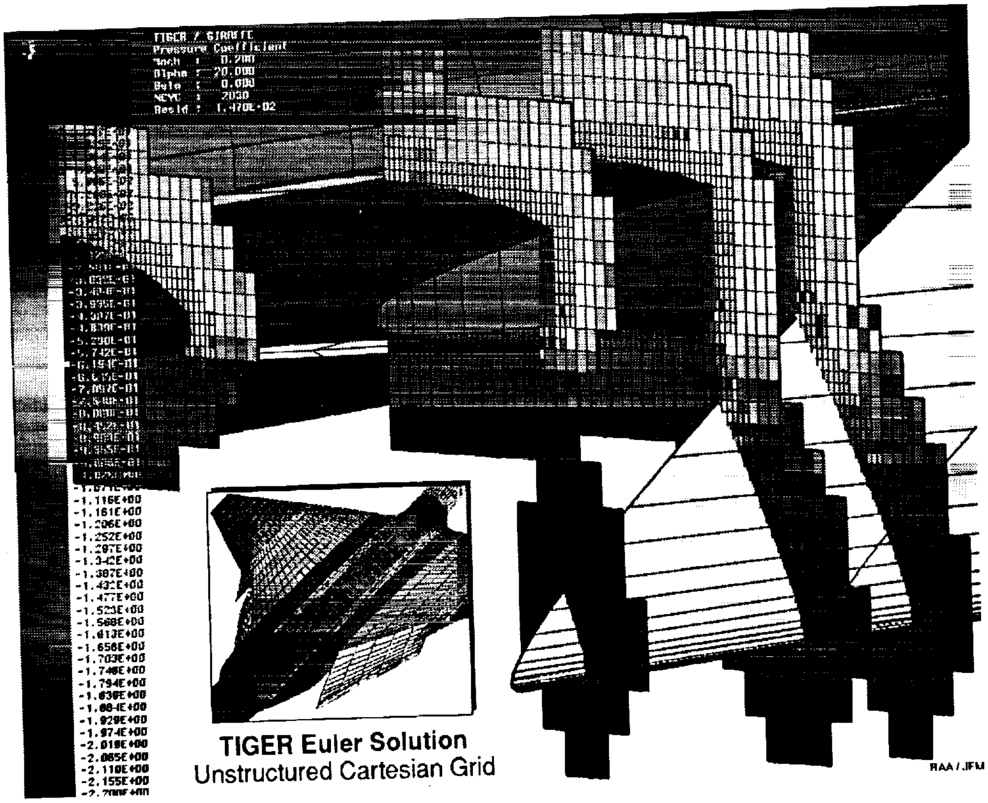
ONERA M6 Wing

Mach 0.84 AoA 3.06

Mach Distribution

Euler Solution, Unstructured Cartesian Grid

RAA / JEM



TIGER Euler Solution

Unstructured Cartesian Grid

RAA / JEM

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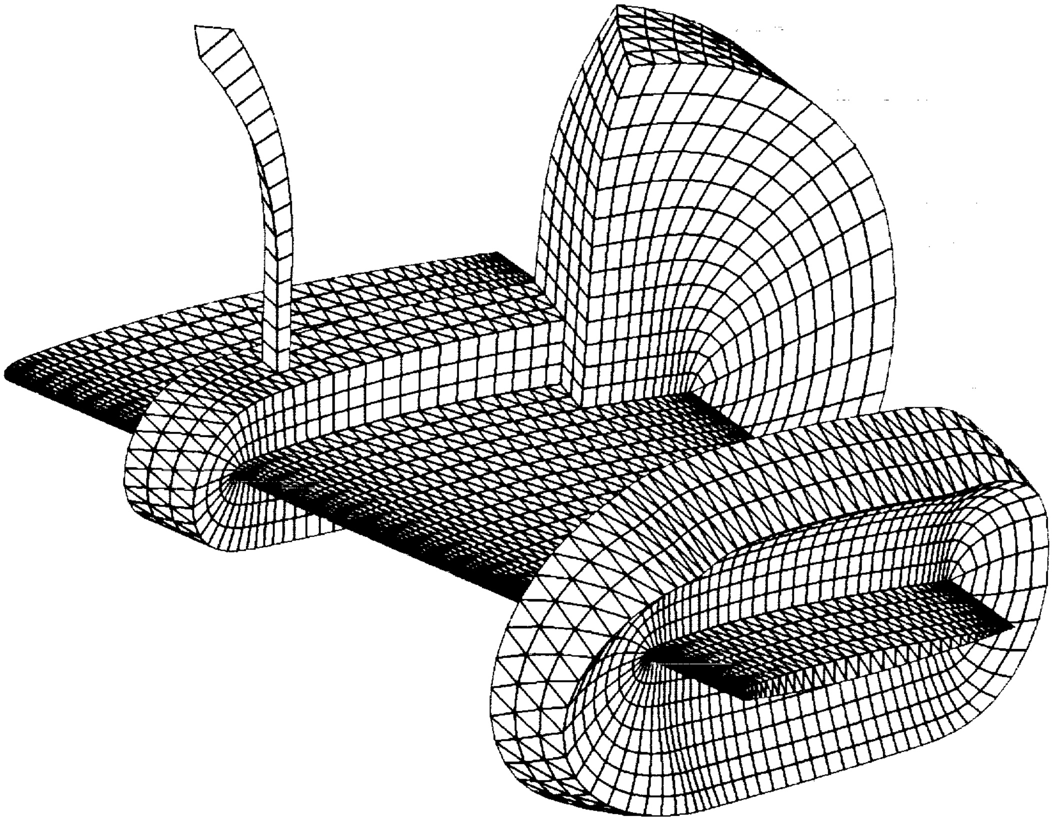
PRISMATIC GRID GENERATION/FLOW SOLVER
PANDYA & HAFEZ

OBJECTIVE
- Explore feasibility of prismatic grid/solver technology for use in hybrid schemes (combine with overset structured, tetrahedra, or Cartesian)

TECHNICAL APPROACH
- Use hyperbolic structured grid technology (Steger et al.) to "grow" volume grids from surface triangularization
- Developing semi-implicit solvers

STATUS
- Explicit hyperbolic volume grid generator complete
- Hybrid grid scheme (prismatic/Cartesian) prototyped
  - Simplified grid generation and low memory requirements
- Semi-implicit inviscid solver in development

FUTURE DIRECTIONS
- Develop implicit hyperbolic volume grid generator
- Develop semi-implicit viscous solver



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HYBRID PRISMATIC/CARTESIAN GRID GENERATION /SOLVER
MELTON, PANDYA & STEGER

OBJECTIVE
- Explore hybrid prismatic/Cartesian grid/solver technology

TECHNICAL APPROACH
- Combine prismatic near-body grid with outer Cartesian grid using a hybrid Chimera technique

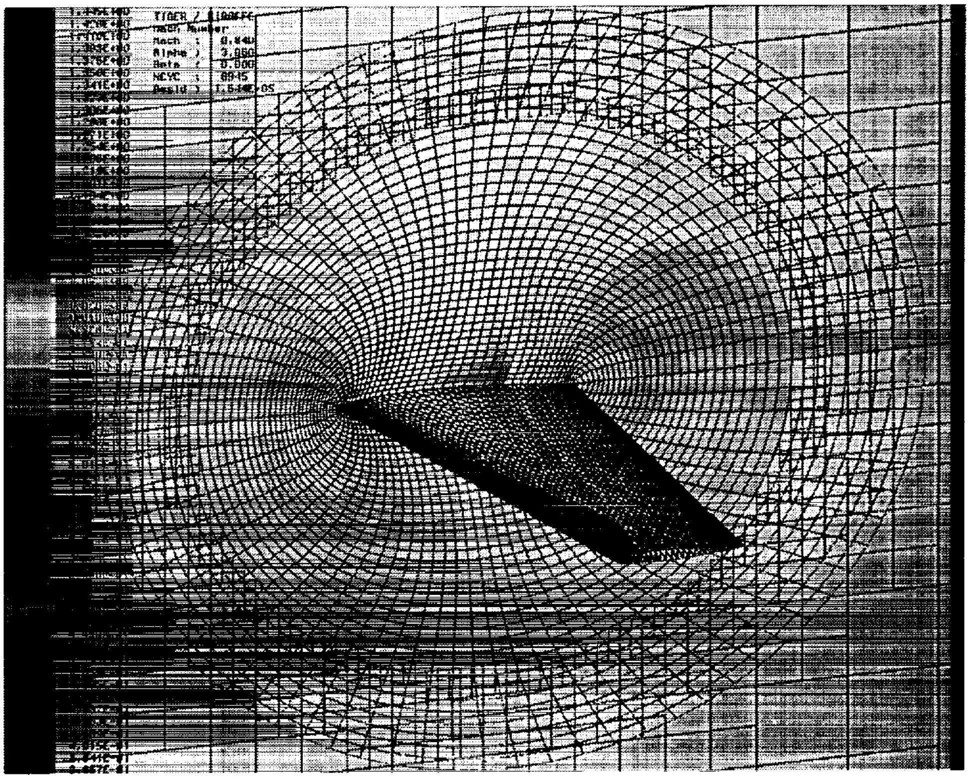
- Solve Euler equations via modified Jameson finite-volume solver

STATUS
- Demonstrated Euler solutions about ellipsoid and ONERA M6 wing

FUTURE DIRECTIONS
- Continued development of prismatic and Cartesian grid generation/solver technology before further hybrid work pursued

    - Semi-implicit prismatic Navier-Stokes solver

    - Improved Cartesian grid adaptation



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HYBRID STRUCTURED/UNSTRUCTURED NAVIER-STOKES

TAVELLA, DJOMEHRI, KISLITZIN, BLAKE, & ERICKSON

OBJECTIVE

- Explore hybrid structured/unstructured grid/solver technology

TECHNICAL APPROACH

- Combine structured near-body grid/solver with outer unstructured grid/solver
- Couple highly-developed structured/unstructured solvers with minimum modification using sockets programming
- Each solver execute separately as a UNIX process

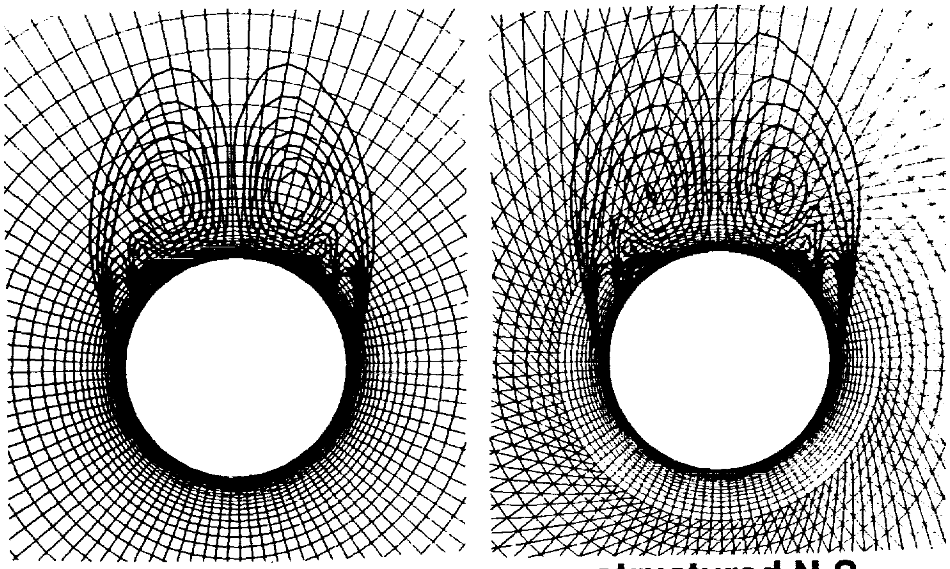
STATUS

- Demonstrated hybrid Euler-unstructured/Navier-Stokes-structured simulation of high-angle-of-attack flow

FUTURE DIRECTIONS

- Upgrade solvers
- Explore heterogeneous environments

VORTICITY DENSITY
MISSILE AT 30 DEGREES, MACH 0.2



structured N-S

structured N-S
+
unstructured Euler

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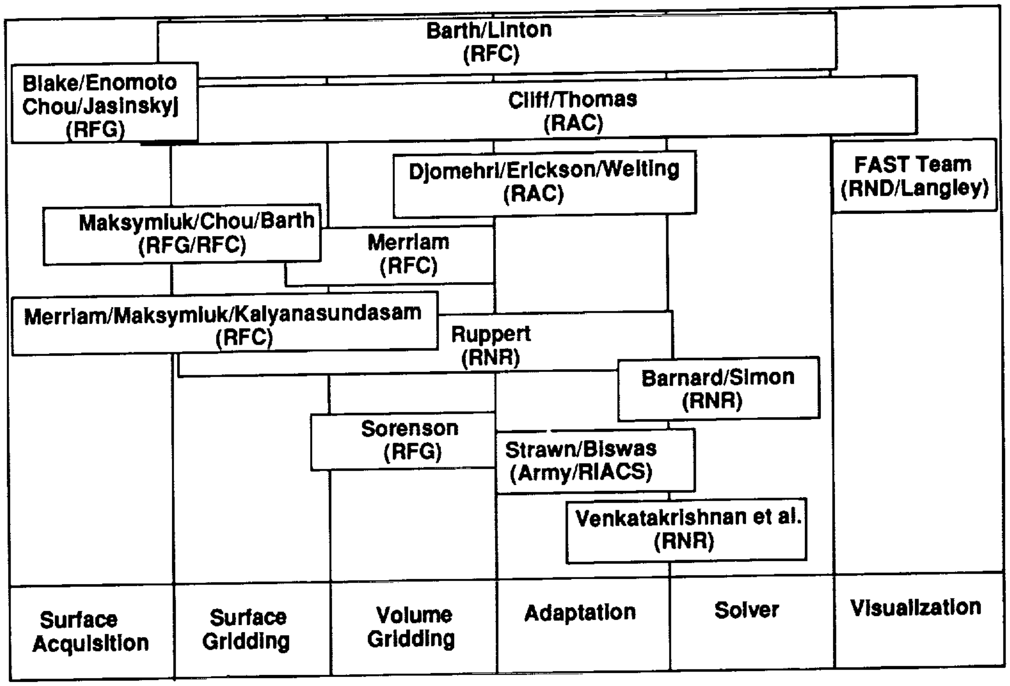
OVERVIEW OF TETRAHEDRA ACTIVITIES



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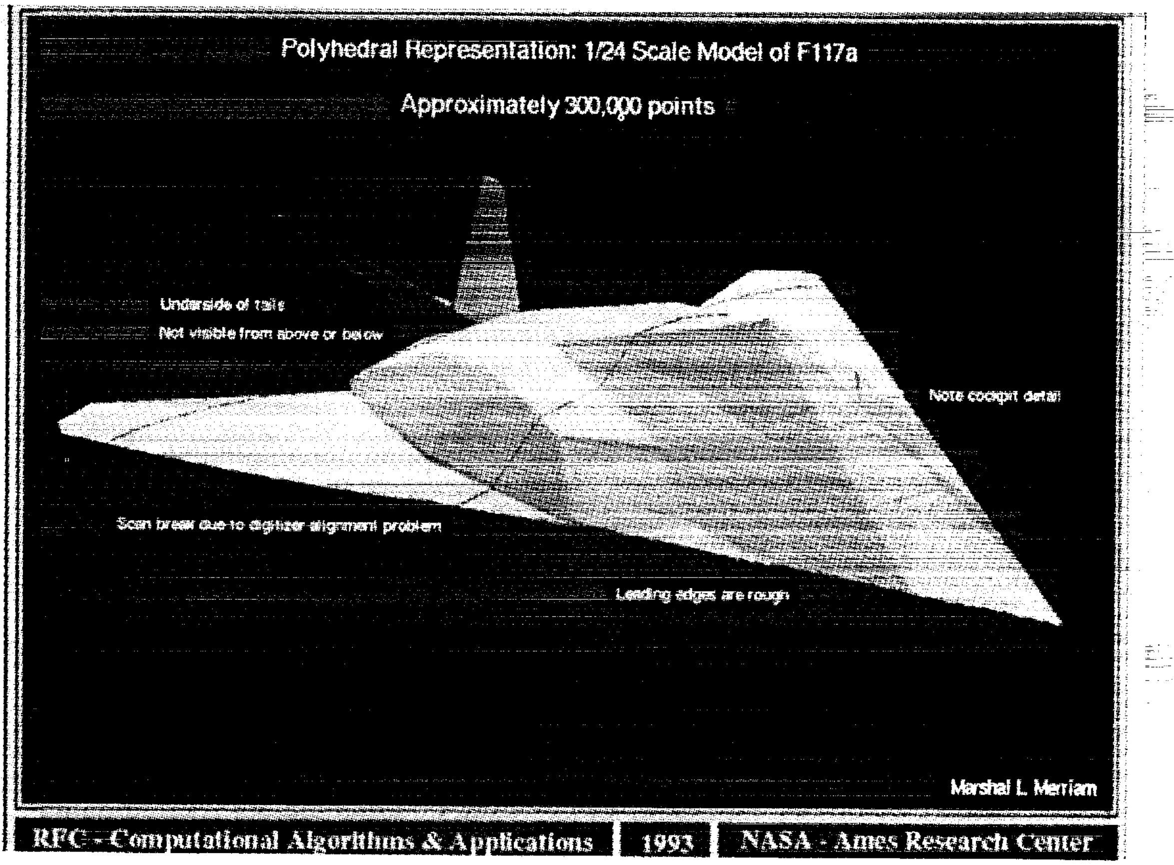
SURFACE DEFINITION THROUGH VIRTUAL MILLING
MERRIAM, MAKSYMIUK, & KALYANASUNDARAM

OBJECTIVE
- Develop an automated 3-D laser digitizer capability to obtain an accurate surface representation of an aircraft model for use in CFD simulations

TECHNICAL APPROACH
- A 3-D laser digitizer system is used to acquire a rich (~300,000 pts.) and accurate definition of the model surface
- Surface measurements are converted to a polyhedral representation of the model using a virtual milling algorithm
- Unstructured surface grid is generated from acquired polyhedral surface model

STATUS
- An arbitrary number of scans can be combined to produce a polyhedral surface model

FUTURE DIRECTIONS
- Developing a geometry adaptive algorithm for development of optimal surface model and grid
- Integrate with volume gridding/solver technology (Barth, et al.)



Polyhedral Representation: 1/24 Scale Model of F117a

Approximately 300,000 points

Marshal L. Merriam

RFC - Computational Algorithms & Applications | 1993 | NASA - Ames Research Center

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SUPERPATCH
BLAKE, ENOMOTO, CHOU, & JASINSKYJ

OBJECTIVE

- Allow acquisition of surface models from diverse sources and:
  - Modest repair and editing of surfaces
  - Addition of patch-topology information (automated and interactive)
- Output B-Rep/SUPERPATCH solid model which contains all surface information for automated surface gridding

TECHNICAL APPROACH

- Define NASA-IGES and SUPERPATCH (IGES B-Rep) standards
- Develop automated software library for:
  - I/O and interrogation of all NASA-IGES entities
  - Convert all NASA-IGES entities to NURBS
  - Add patch-topology information (with interactive back-up)

STATUS:

- NASA-IGES/SUPERPATCH standards proposed (NASA-wide activity)
- NASA-IGES I/O and interrogation library near completion

FUTURE DIRECTIONS:

- Develop automated patch-topology definition techniques

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AUTOMATED SURFACE GRIDDING FROM CAD MODEL

MAKSYMIUK, CHOU, & BARTH

OBJECTIVE

- Develop automated unstructured surface grid generation technology:
  - Surface/solution adaptive clustering
  - NASA-IGES and SUPERPATCH I/O

TECHNICAL APPROACH

- Combine:
  - NIGES/SUPERPATCH I/O and interrogation functions
  - Barth's surface grid generation (incremental insertion with local optimization, geometric error minimization, and quality repair)

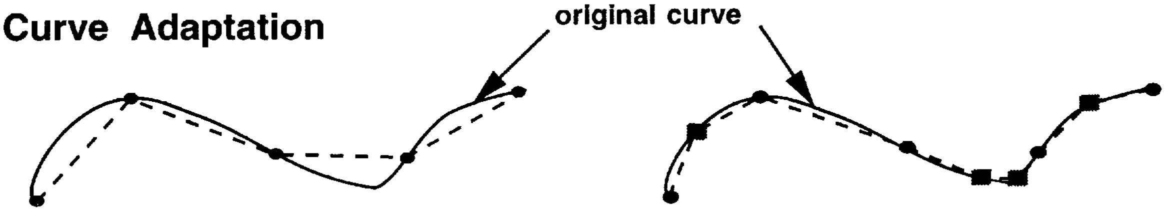
STATUS

- SUPERPATCH integrated with surface grid generator
- Surface gridding with geometric/quality adaptation off IGES B-Rep models accomplished, awaiting additional B-Rep models

FUTURE DIRECTIONS

- Integrate NIGES to allow gridding off NASA-IGES data
- Add solution adaptation capabilities
- Develop completely patch-independent gridding

Curve Adaptation



initial distibution

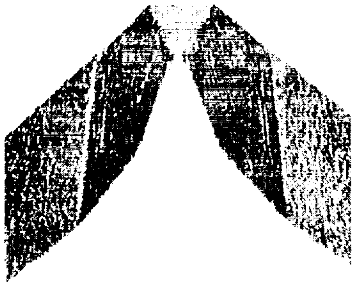
equal arc–length spacing

final distribution

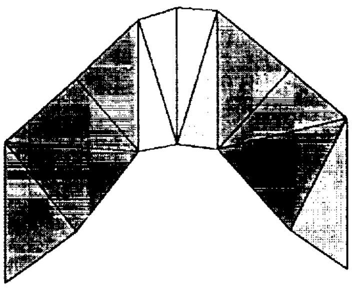
■ marks points added to reduce deviation below tolerance

Surface Adaptation

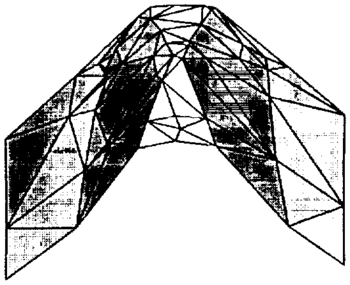
original surface



initial grid, obtained from triangulation of edges



final grid, after adding points until max. deviation is less than tolerance



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UNSTRUCT2D & UNSTRUCT3D
EFFICIENT CONSTRAINED DELAUNAY TRIANGULATION
MERRIAM

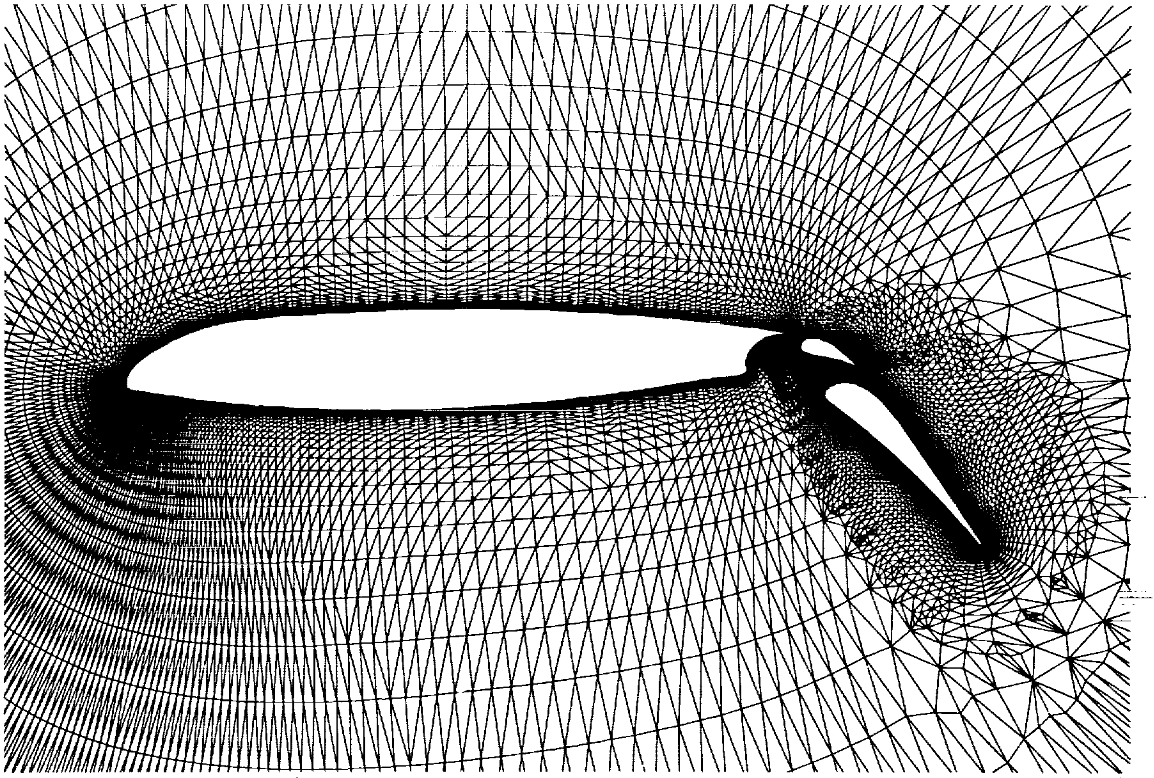
OBJECTIVE
- Develop automated Delaunay triangulation that respects boundary data

TECHNICAL APPROACH
- Efficient implementation of Tanemura's algorithm
  - Add constrained triangulation to respect boundaries
  - Add fast search techniques (Bentley)
  - Parallelize

STATUS
- Implemented in 2-D and 3-D (UNSTRUCT2D and UNSTRUCT3D)
- Rapid grid generation
  - 1000 points/second on SGI 320/VGX (2-D)
  - 100 points/second on SGI 320/VGX (3-D)
  - 4000 points/second on IPSC/860 (3-D)

FUTURE DIRECTIONS
- Integrate faster searches
- Further improve parallel architecture implementation
- Improve robustness of 3-D code (e.g., add Steiner points)

One View Of The Completed Triangulation



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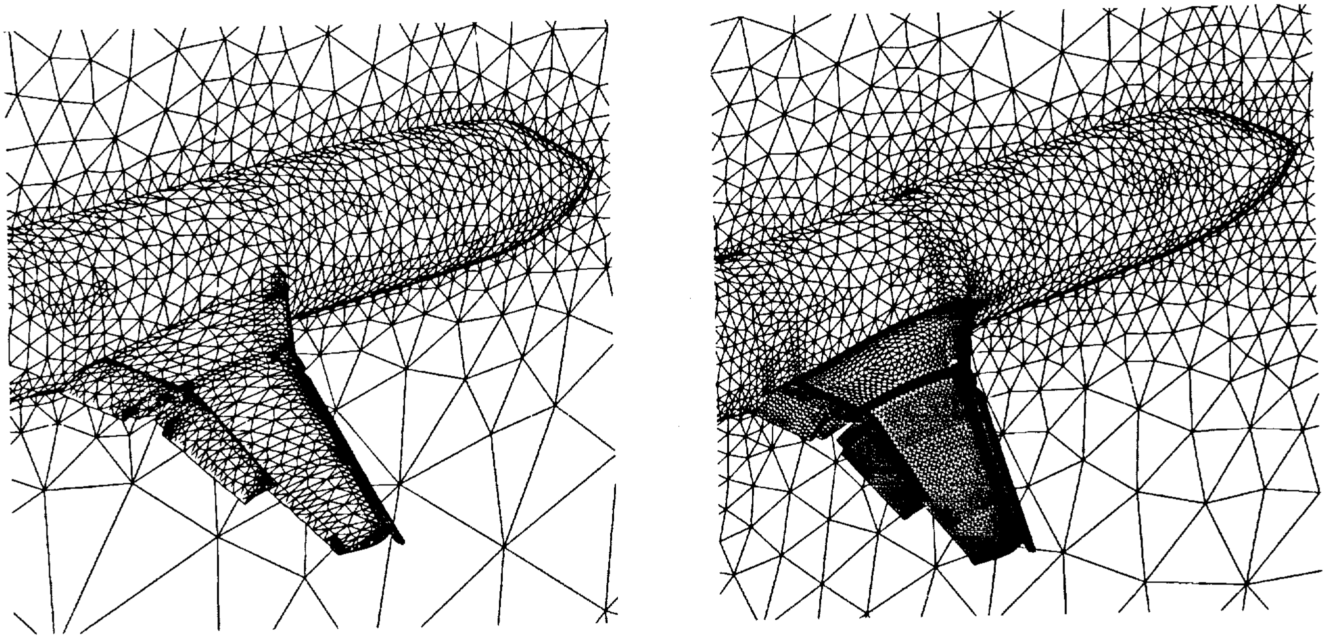
VISCOUS SURFACE & VOLUME MESHING
BARTH & LINTON

OBJECTIVE
- Develop an unstructured mesh generation capability suitable for high Reynold's number viscous computations

TECHNICAL APPROACH
- Incremental point insertion and local optimization
  - Local optimization allows the generation of high-quality stretched meshes
  - Amenable to solution adaptation
- Surface mesh capability on spline tensor product patches
  - Geometric error minimization
  - Quality repair
- Volume mesh capability includes the construction of conformed and constrained triangulations

STATUS
- Software complete and under evaluation for 3-D high-lift applications

FUTURE DIRECTIONS
- Complete development in cooperation with RFG



Sample surface triangulations contrasting isotropic and stretched capability

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DYNAMIC MESH ADAPTION
STRAWN & BISWAS

OBJECTIVE

- Develop a fast anisotropic mesh adaptation scheme for large 3-D problems

TECHNICAL APPROACH

- Anisotropic adaptation based on directional error indicators
- Parent element storage allows rapid and scalable grid coarsening
- Edge-based data structure with linked-lists
- Implemented in "C" with dynamic memory allocation

STATUS

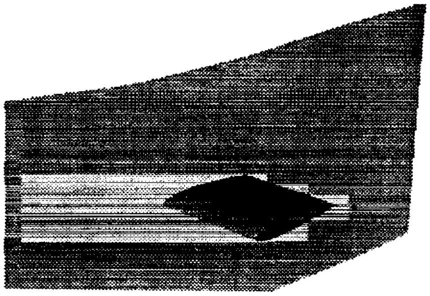
- Refinement/coarsening schemes have been implemented and applied in 2-D and 3-D

FUTURE DIRECTIONS

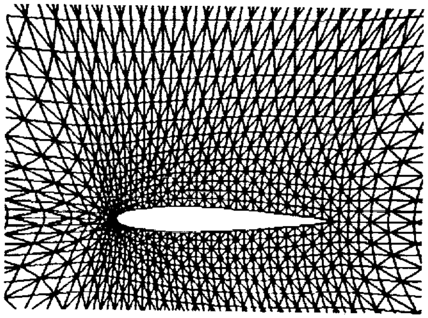
- Integration of mesh adaptation and flow solver (Barth et al.)
- Arbitrary levels of adaptation with assurance of high mesh quality
- Implement on CM-5

EXAMPLE: 3–D ADAPTIVE GRID REFINEMENT AND COARSENING

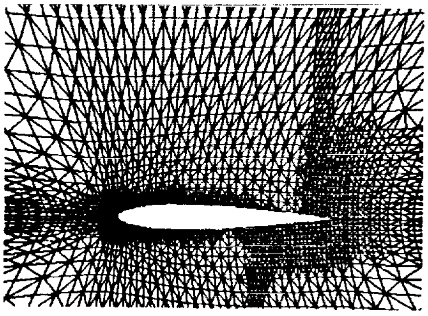
FSMACH = 0.85, ALPHA = 1.0 DEG



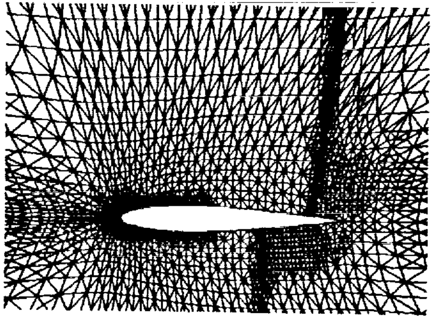
NACA 0012 WING – INVISCID SIDE WALLS



INITIAL MESH: 46,592 EDGES



FIRST REFINEMENT: 75,656 EDGES



3 REFINEMENT LEVELS, 2 COARSENING LEVELS
85,869 EDGES

Rupak Biswas – RIACS
Roger Strawn – US Army AFDD

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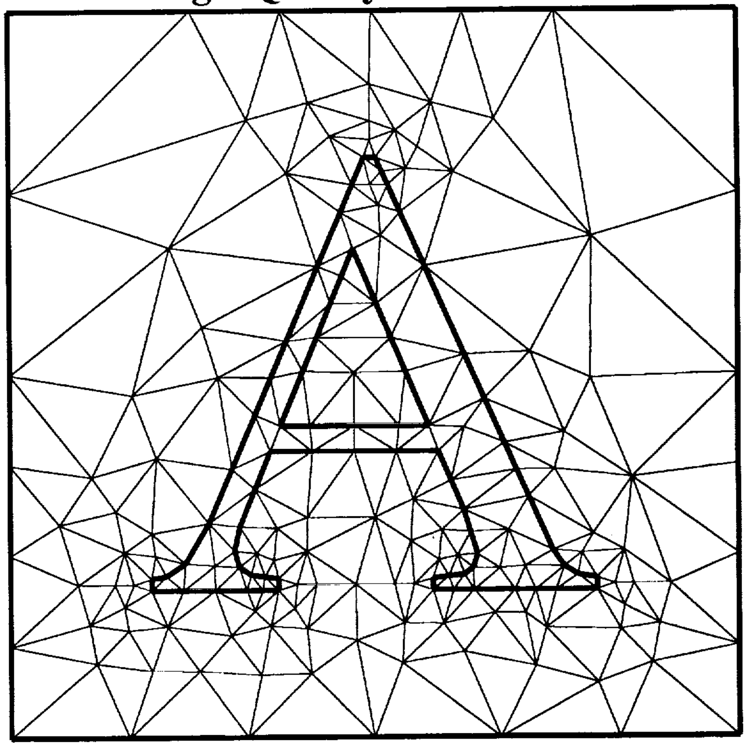
PARALLEL UNSTRUCTURED GRID GENERATION
RUPPERT

OBJECTIVE
- Develop efficient adaptive parallel-computer unstructured surface and volume grid generation capability

TECHNICAL APPROACH
- Begin with advanced sequential grid generators:
  - Delaunay Refinement algorithm
    Triangles guaranteed to have specified range of aspect ratios
    Number of triangles within a constant factor of optimal
- Research grid quality criteria
- Interface with solver
- Generalize for moving objects
- Parallelize on CM-5

STATUS
- Delaunay Refinement algorithm developed



High-Quality 2D Grid

188 points, 96 segments, min angle=25.2 degrees

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FAST PARTITIONING & LOAD BALANCING FOR UNSTRUCTURED SOLVERS

BARNARD & SIMON

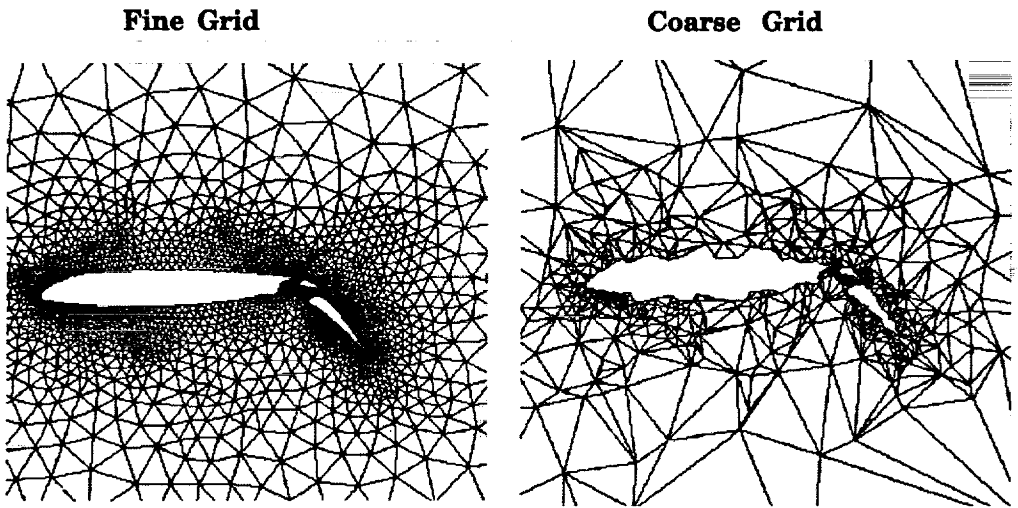
OBJECTIVE
- Develop partitioning and load balancing technology which allows optimal use of a parallel computer

TECHNICAL APPROACH
- Recursive spectral bisection (RSB) has proven effective, but costly
- A multilevel implementation of RSB which retains favorable features of RSB partitions and reduced cost was developed

STATUS
- Implemented on workstations, savings up to a factor of 20 verified

FUTURE DIRECTIONS
- Extension to dynamic partitioning of an adapting grid
- Implement in heterogeneous computer network

A Fast Multilevel Implementation of RSB for Partitioning Unstructured Problems



Images by S. Barnard and H. Simon
NASA Ames Research Center

- The coarse grid gives qualitatively the same partitioning.
- Multilevel is an order of magnitude faster than single level for large grids.

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DYNAMIC LOAD BALANCING FOR UNSTRUCTURED SOLVERS
VENKATAKRISHNAN, VIDWANS, & KALLINDERIS

OBJECTIVE

- Develop dynamic load balancing technology which allows optimal use of a parallel computer with dynamic unstructured grid adaptation

TECHNICAL APPROACH

- Divide-and-Conquer strategy used to balance load between each processor
- Local Migration strategy used to actually move points between processors

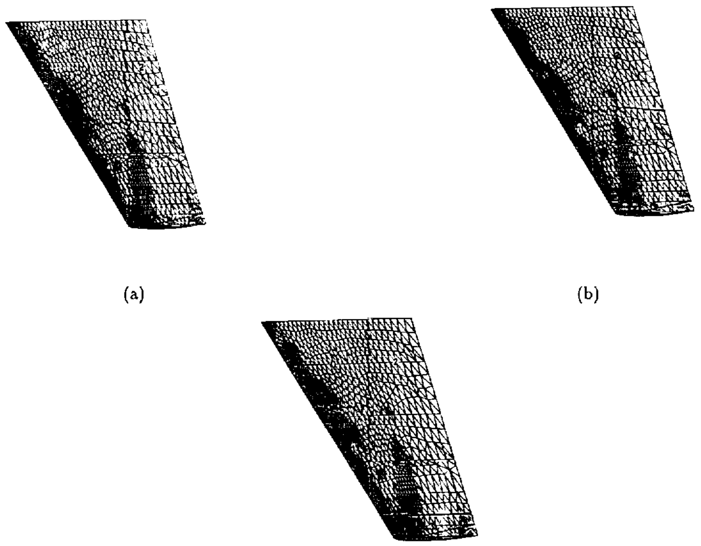
STATUS

- Implemented on iPSC/860 with application to a variety of grid systems
- Efficient dynamic load-balancing achieved, confirming advantage of using load balancing approaches (e.g., Divide-and-Conquer) with inherent parallel structure

FUTURE DIRECTIONS

- Integrate load balancing technology with complete adaptive unstructured grid generation/flow solver technology, to allow effective use of parallel computer systems in large scale applications

LOAD BALANCING STEPS FOR AN ADAPTED M6 WING



(a) (b)

(c)

Surface plots for an adapted M6 wing. The thick lines denote partition boundaries. (a) Initial grid. (b) After the first step of load balancing. Processor groups 0,1 and 2,3 are balanced. (c) At the completion of the load balancing. All the processors now have the same load.

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FELISA

(Finite Element, Langley, Imperial Swansea, Ames)

DJOMEHRI, ERICKSON, WEITING, & IMPERIAL COLLEGE

OBJECTIVE

- Develop a robust solution-adaptive, unstructured Euler grid-generation/solver tool for complex configurations

TECHNICAL APPROACH

- Splined surface definition
- Advancing front grid generation
- Runge-Kutta and Taylor-Galerkin solvers
- Remeshing based on solution gradients

STATUS

- Code evaluation (usability and capabilities)

APPLICATIONS

- Generic sonic boom configurations

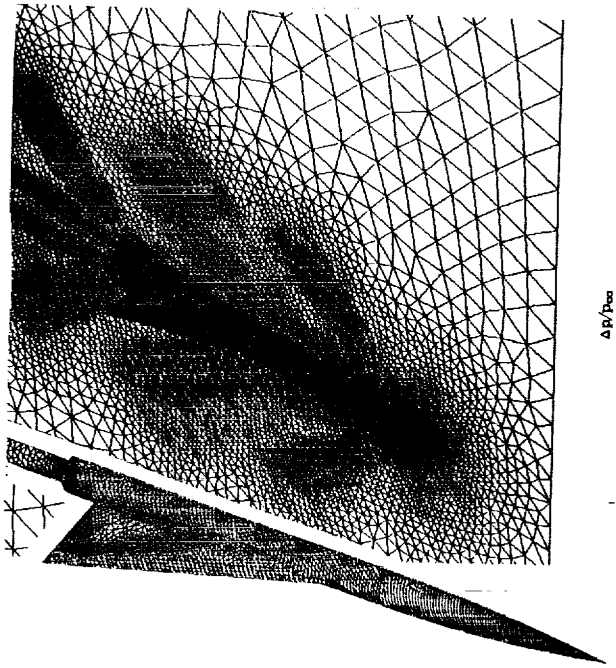
FUTURE DIRECTIONS

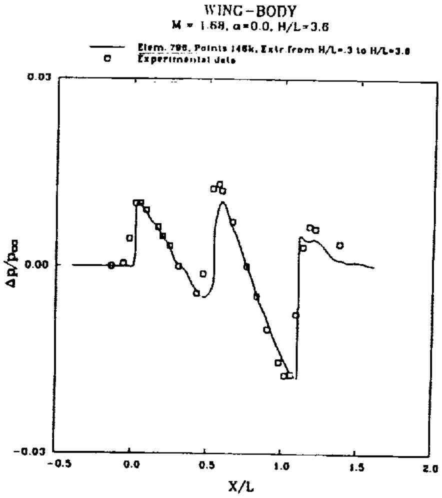
- Learjet applications

- Allow user-specification of surface grid

Wing-Body

Adaptive-Grid Solution





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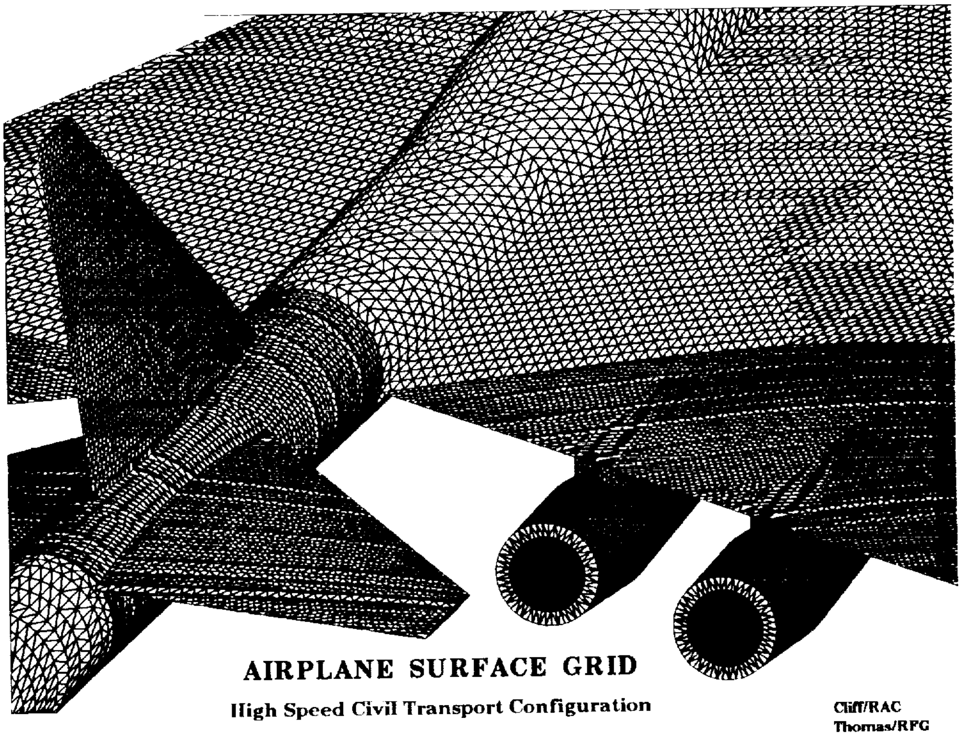
AIRPLANE CODE APPLIED TO HSCT CONFIGURATIONS
CLIFF & THOMAS

OBJECTIVE
- Evaluate sonic-boom pressure signatures and aerodynamic performance of High Speed Civil Transport (HSCT) configurations using the AIRPLANE unstructured tetrahedra grid generation/solver package

APPROACH
- Compute near-field off-body pressure signatures and aerodynamic quantities for complete HSCT configurations
- Integrate analysis capability into optimization process

STATUS
- Accurate prediction of sonic-boom signatures and aerodynamic quantities
- Useful tool for evaluation of complete configurations during the design process

FUTURE DIRECTIONS
- Surface gridding from triangulated surface definition and SUPERPATCH
- Solution adaptation



AIRPLANE SURFACE GRID

High Speed Civil Transport Configuration

Cliff/RAC
Thomas/RFG

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PARALLEL UNSTRUCTURED MESH FLOW SOLVERS
BARTH & LINTON

OBJECTIVE

- Develop a *fully-implicit* solver for the Euler & Navier-Stokes equations on tetrahedral meshes

TECHNICAL APPROACH

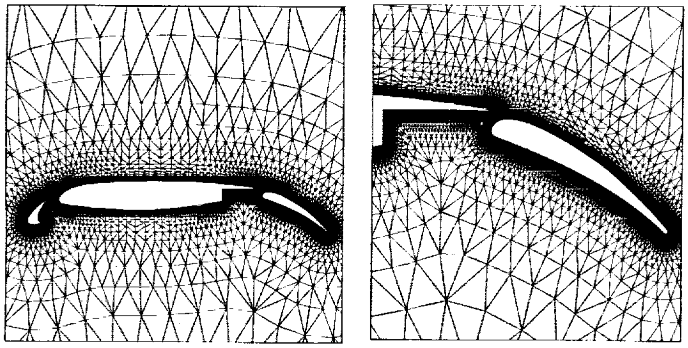
- Upwind finite-volume scheme with second-order spatial accuracy
- Fully implicit solver:
  - Utilizes a preconditioned minimum residual solver
  - Domain decomposed preconditioning using modified incomplete LU decomposition
  - Optimized for parallel computer (e.g., CM-5, Intel Paragon)
- One-equation turbulence transport model
- On-line mesh adaptation

STATUS

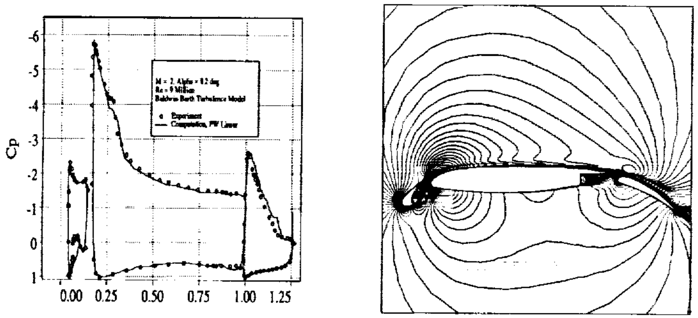
- Implicit 2-D Navier-Stokes solver capability
- Implicit Euler solver is currently in testing on CM-5

FUTURE DIRECTIONS

- Investigate alternative preconditioners and higher-order spatial discretizations
- Complete implicit 3-D Navier-Stokes solver



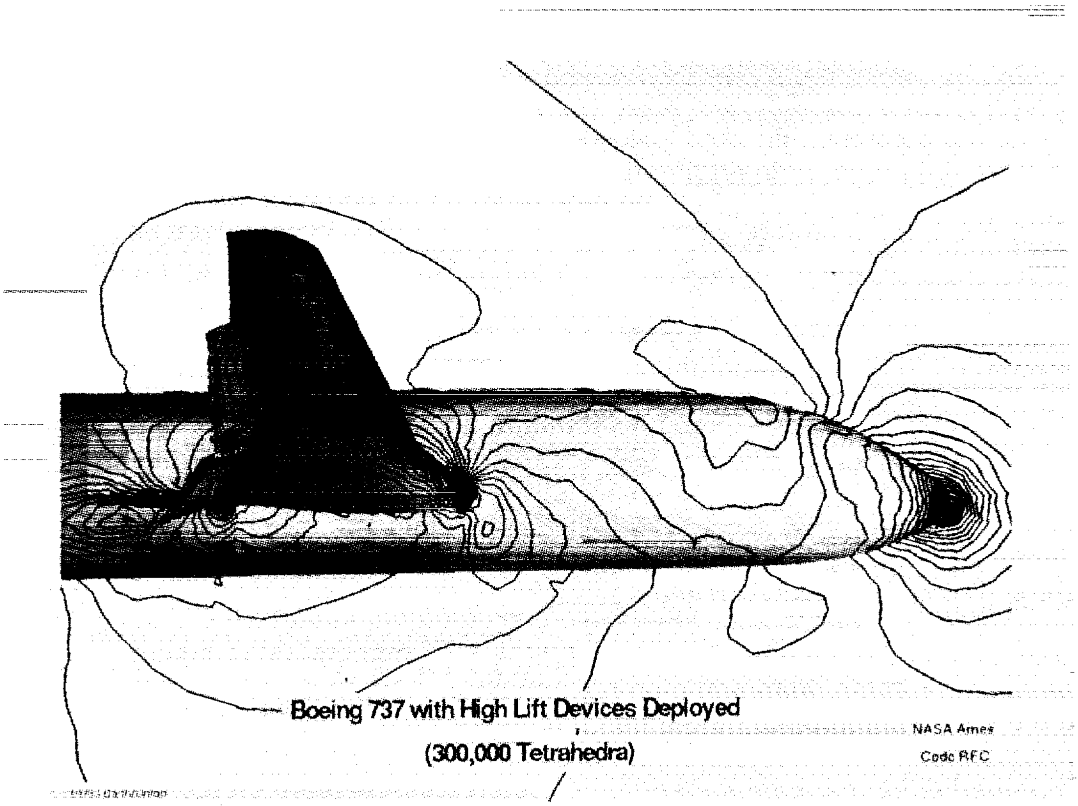
Optimized Triangulation   Closeup In TE Region



Pressure Coefficient Comparison   Velocity Magnitude Contours

Viscous Flow Past Multi-Element Airfoil NASA Ames
Code RFC

11/15/92 Barth



Boeing 737 with High Lift Devices Deployed

(300,000 Tetrahedra)

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FAST DEVELOPMENT
MERRITT, McCABE, SANDSTROM, WEST, BARONIA, SCHMITZ, CASTAGNERA, NEELY & GUMBERT

OBJECTIVE
- A consistent environment for CFD visualization

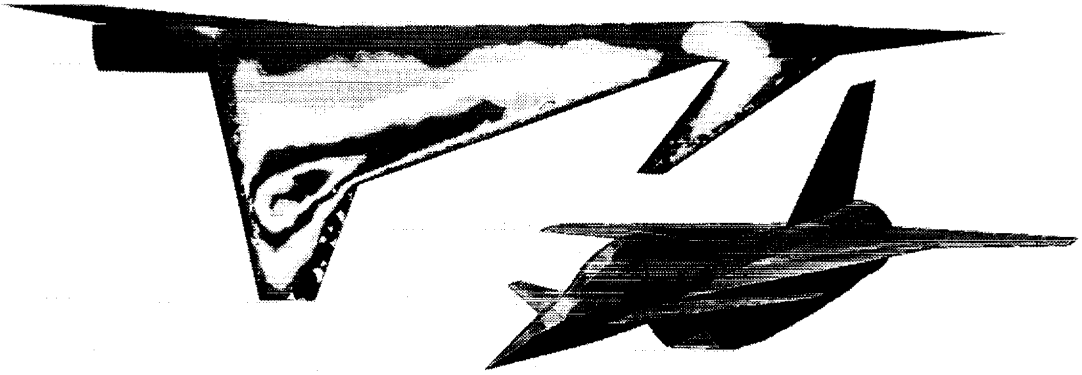
APPROACH
- In cooperation with NASA-Langley (Neely and Gumbert), integrate unstructured visualization modules into the FAST environment

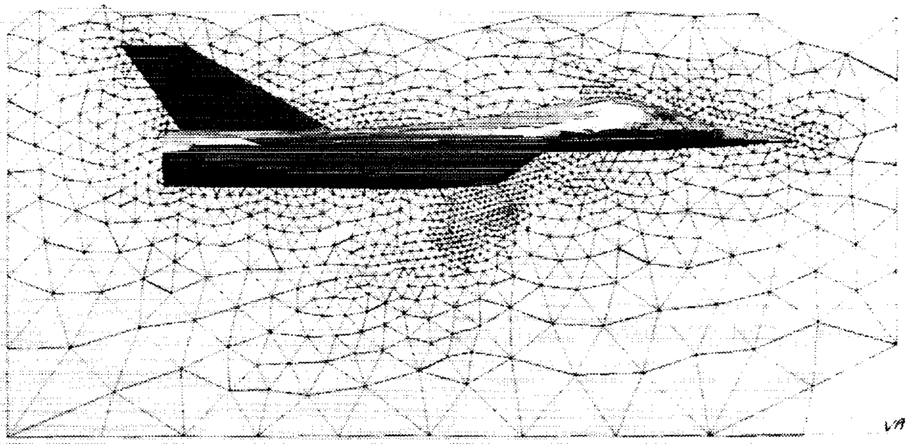
STATUS
- Following modules have been developed, integrated, and tested:

- SURFERU	renders surfaces
- ISOLEVU	displays isosurfaces, cutting planes, etc...
- SHOTET	analyze tetrahedral cells

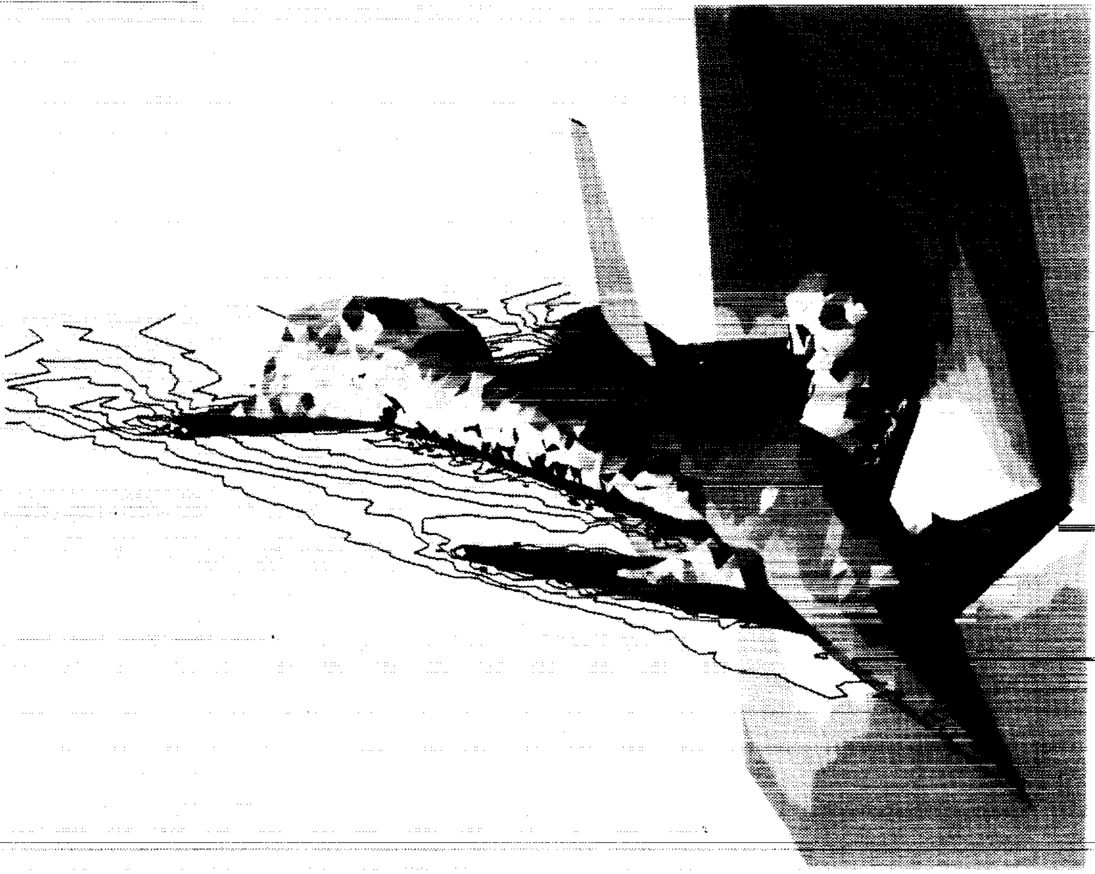
FUTURE DIRECTIONS
- Integrate TRACERU which is used to compute and display particle paths

- Allow visualization of hybrid grid results





VAN DALSEM41 60



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NASA-AMES UNSTRUCTURED TECHNOLOGY SUMMARY

DEVELOPING A BROAD SPECTRUM OF TECHNOLOGY:

CARTESIAN
- TRANAIR/TIGER capabilities for fully automated inviscid analysis of complex configurations

HYBRID
Two approaches to achieve viscous analysis capabilities:
- Tetrahedra/Structured (low risk)
- Cartesian/Prismatic (medium risk)

TETRAHEDRA
- Extensive experience with the present state of the art (AIRPLANE/FELISA)
- Developing all key technologies required for efficient and accurate viscous capabilities:
    - Direct CAD link via SUPERPATCH
    - Surface/volume grid generation designed for viscous computations
    - Implicit solvers
    - Turbulence models
    - Grid partitioning and solver technology for parallel architectures

AMES RESEARCH CENTER

NASA-AMES UNSTRUCTURED TECHNOLOGY FUTURE DIRECTIONS

CARTESIAN - INVISCID
- Pursue fully-automated inviscid analysis from CAD solids model

HYBRID - VISCOUS
- Pursue development of prismatic grid/solver technology
- Integrate prismatic technology with Cartesian, Overset, or Tetrahedra technology

TETRAHEDRA - VISCOUS
- Automated surface acquisition from laser digitizer
- Complete automated integration with CAD solids model
- Viscous surface/volume gridding
- Adaptation based on non ad-hoc criteria
- Turbulence models based on field equations
- Implicit solvers which run efficiently on:
    - vector computers
    - parallel computers
    - heterogeneous computer networks
- Resolve all parallel architecture implementation issues

Implement technology in modules and complete software for transfer to industry