3D EULER SOLUTIONS USING AUTOMATED CARTESIAN GRID GENERATION

JOHN E. MELTON
NASA AMES RESEARCH CENTER

FRANCIS Y. ENOMOTO
NASA AMES RESEARCH CENTER

MARSHA J. BERGER
NEW YORK UNIVERSITY
Agenda

- History
- Cartesian Overview
- Technique Comparisons
- 3D Cartesian Grid Generation Strategy
- Survey of simple test cases
- Current research and future plans
- Summary

History

- Lessons from ATP grid generation
- AIAA 91-0637 with Thomas and Cappuccio
  - Unstructured, refined, hexahedral body-fitted grid
  - Euler FV RK4 Jameson flow solver algorithm (FLO57)
- TIGER = Topologically Independent, Euler Refinement
- GIRAFFE = Grid Interactive Refinement and Flow Field Examination
CFD and the Design Cycle

Compute *better* solutions *faster* and *cheaper*

**Analysis Issues**
- Resolution adequate for detailed design
- Refinement appropriate for each Mach, $\alpha$, $\beta$

**Flexibility**
- Multi-block
- Unstructured

**Geometry Issues**
- Turnaround inside the design cycle
- Use of CAD/CAM and automated geometry handling wherever possible
Three Important Questions

Are CFDers doomed to eternal grid generation?
Why shouldn't CFD be like structural FEA?

How can we automate the geometry manipulation and grid generation processes?

Cartesian Grid Strategy

- South, Clarke, Salas, Hassan, Berger, LeVeque, Powell, Epstein, Morinishi, TRANAIR

  - Make the computer do the work
    - Interactivity ≠ Automation
      - Divorce surface grid from field grid
      - Use computational geometry algorithms to extract surface/cell intersection information
      - Use NURBs (Non-Uniform Rational B-Splines) to maintain a single, accurate, database

  - Use grid refinement for "efficient" resolution
    - Unstructured grid (block or cell)
    - Flowfield and geometry-based refinement
### Technique Comparisons

<table>
<thead>
<tr>
<th>Task</th>
<th>Structured Body-fitted</th>
<th>Cartesian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid generation</td>
<td>tedious and boring</td>
<td>automated</td>
</tr>
<tr>
<td></td>
<td>time-consuming</td>
<td>NURB accuracy</td>
</tr>
<tr>
<td></td>
<td>requires surface grid</td>
<td>no surface grid</td>
</tr>
<tr>
<td></td>
<td>good tools are available</td>
<td>research software</td>
</tr>
<tr>
<td>Flux and BCs</td>
<td>&quot;simple&quot; and familiar</td>
<td>&quot;complicated&quot;</td>
</tr>
<tr>
<td>Connectivity overhead</td>
<td>minimal</td>
<td>~60 words/cell</td>
</tr>
<tr>
<td>Grid refinement/adaptation</td>
<td>not automated</td>
<td>automated for both</td>
</tr>
<tr>
<td></td>
<td>difficult</td>
<td>geometry and flowfield</td>
</tr>
<tr>
<td>Flow solver</td>
<td>highly vectorizable</td>
<td>vectorizable</td>
</tr>
</tbody>
</table>

### TIGER Surface Geometry

<table>
<thead>
<tr>
<th>Entity</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangles</td>
<td><em>Simple</em> intersections</td>
<td>Poor refinement accuracy</td>
</tr>
<tr>
<td></td>
<td>LaWGS / FEM / PANAIR</td>
<td>Creation</td>
</tr>
<tr>
<td></td>
<td>Compute - inexpensive</td>
<td>Loss of surface information</td>
</tr>
<tr>
<td>NURBS</td>
<td>Direct from CAD</td>
<td><em>Nonlinear</em> intersections</td>
</tr>
<tr>
<td></td>
<td>Complete accuracy</td>
<td>- tolerance specifications</td>
</tr>
<tr>
<td></td>
<td>Complete information</td>
<td>- polynomial root-finding</td>
</tr>
<tr>
<td></td>
<td>NASA/IGES standard</td>
<td>Topology determination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfamiliarity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compute - expensive</td>
</tr>
</tbody>
</table>
2-Step Cartesian Grid Generation Algorithm

1 - Create initial equi-spaced Cartesian grid

   Flag cells that intersect with surface
   Refine along with a number of neighbors
   Repeat to create desired resolution

2 - Compute cell geometric information

   • face areas
   • body surface normals
   • cell volumes
   • face and volume centroids

Current TIGER Connectivity Data Structure

<table>
<thead>
<tr>
<th>Item</th>
<th>Words per cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pointer to connecting cells</td>
<td>6 faces x 4 connections per face</td>
</tr>
<tr>
<td>Face BC flags</td>
<td>6 faces x 2 flags per face</td>
</tr>
<tr>
<td>Face area vectors</td>
<td>7 faces x 3 components per face</td>
</tr>
<tr>
<td>Cell Refinement Level</td>
<td>1</td>
</tr>
<tr>
<td>Cell BC flag</td>
<td>1</td>
</tr>
<tr>
<td>Cell volumes</td>
<td>1</td>
</tr>
</tbody>
</table>

Unstructured Cartesian Overhead ~ 60+ words per cell
Survey of Test Cases

- Prolate Spheroid - NURB input

- ONERA M6 wing - Triangle input

- HSCT with LE flap - Triangle input
ONERA M6 Mach=0.84 AoA 3.06
Mach Distribution

Euler Solution, Unstructured Cartesian Grid.
HSCT Grid Generation Command Files

**Step 1**
1: use tiger.net data  2: use tiger.tri
1: flip y-z  0: don't flip
1: make new base grid  2: restart
-1 4000  : x-range
-1300 1700  : y-range
 0 1201    : z-range
 17 15  9   : dims
1: split surface cells  0: stop
6  : number of splitting passes
2  : number of buffer layers
1  : reset symmetry plane cells  0: skip
1  : compress the files  0: skip

**Step 2**
1: read from tiger.net  2: tiger.tri
1: flip y-z  0: don't flip
1: reset symmetry plane cells  0: skip
1  : compress files  0: skip
Current Research and Future Plans

• Improved flux and dissipation modeling
• Improved boundary conditions
• "Intelligent" grid generation
• Flowfield refinements
• Validations

Summary

• Use of a single NURB geometry database for design and analysis has many advantages
  - allows for geometry manipulation with commercial CAD/CAM tools
  - provides analyst with complete and accurate surface information
  - provides consistent method for data transfer

• A mature unstructured Cartesian approach will have additional advantages
  - eliminate surface and volume gridding tasks via automation
  - provide local resolution appropriate for each flow condition
  - shrink CFD turnaround from months to hours
  - allow designers to concentrate on aerodynamic performance instead of computational geometry and numerical analysis

• Interactive techniques should be viewed as short term solutions, and not as long term CFD goals