Finite Element Analysis
The WTC North Tower

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Overview

- What is FEA?
  - Computational method to analyze problems of displacements, stresses, and interactions between objects
- What does this mean to us?
  - Physics engine that is physically “accurate”
- Who uses this stuff?
  - Auto Industry
  - Aviation Industry
  - Semiconductor industry
  - ...

Finite Element Model

- Nodes
- Elements
  - Shells
  - Beams
  - Solids
  - Fluid (SPH or ALE)
- Materials
- Contacts
Converting From Graphics to Finite Elements
The Task

- Graphics models need no connection between parts, they only look good.
- So, we need to:
  - Remesh the skins and connect them
  - Add structural elements
  - Add floors, tanks, etc.
Geometric Considerations

- **Element shape**
  - Quadrilateral vs. Triangular Elements
  - Regular Sized Elements

- **Features to Avoid**
  - Long and Thin Elements
  - Small Internal Angles
  - T-Junctions
Boeing 767-200
Geometry Input
Boeing 767-200
Wing Skin
Boeing 767-200
Fuselage & Empennage
Boeing 767-200
Landing Gear & Engine
Boeing 767-200
Internal Structure
Boeing 767-200
Wings and Empennage
Boeing 767-200 Fuselage
Boeing 767-200
Model Summary

- Statistics:
  - 14341 nodes
  - 11244 shell elements
  - 9001 beam elements
  - 674 solid elements

- Many parts of the process can be automated
- Many issues require human interaction
  - No good tools exist for this process
Modeling Jet Fuel

- 2 systems for modeling fluid
  - ALE (Arbitrary Lagrange Eulerian)
    - Regular grid
    - Fluid is represented as percentage of volume filled
  - SPH (Smoothed Particle Hydrodynamics)
    - Discrete set of particles
    - Each one has a mass associate with it
SPH Elements

- 9118 Gallons of Fuel
- Use regular grid of points
- Test if each point is inside of the tanks
Fluid Structure Interaction
SPH Test

- Test to verify physical accuracy of SPH elements
- Can shot at 80m/s toward target
SPH Test
Riera Calibration

- Force vs. Time Measurement
- Used to calibrate the entire aircraft model
- F4 Phantom on rocket sled
Riera Calibration
Riera Calibration

- Riera’s calculation requires velocity and mass of individual slices of the aircraft
- Slicing the aircraft is simple geometry problem
Riera Calibration
Riera Calibration
WTC North Tower

- Model by members of CE in application called SAP2000
- Conversion into LS-Dyna format
  - Both text based formats
  - Conversion of structural elements trivial
    - One exception: Orientation of beam elements
  - Part and material definitions more difficult
Bringing It All Together

- Airplane model built by us
  - Units in millimeters…
- Tower built by members of CE
  - Units in feet…
- Estimation of fuel from NIST 9/11 Report
  - Units in gallons…
- All of these discrepancies must be addressed
Latest Results – Side View
Latest Results – Core Only
Latest Results – Core, No Fuel
Latest Results – Oblique View
## Computational Results

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Time Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPH “Beer Can” Simulation</td>
<td>0.011 real time 99 hours dual opteron</td>
</tr>
<tr>
<td>Riera Calculation</td>
<td>0.2 sec. real time 99 hours dual opteron</td>
</tr>
<tr>
<td>WTC Run 11</td>
<td>0.5 sec. real time 100 hours nano regatta (8 cpus)</td>
</tr>
<tr>
<td>WTC Run 12</td>
<td>0.37 sec. real time 30 hours nano regatta (16 cpus)</td>
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Questions?