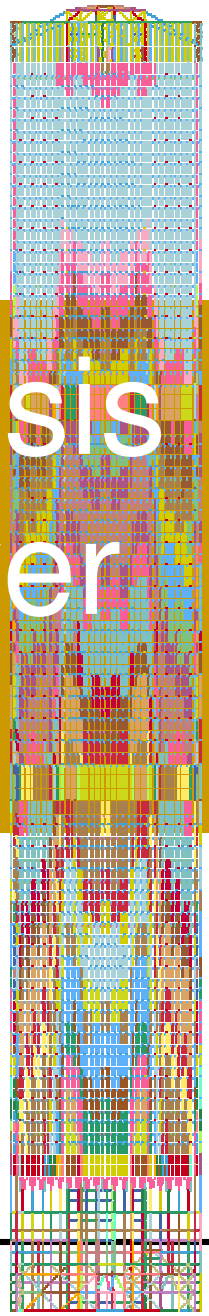
Finite Element Analysis The WTC North Tower



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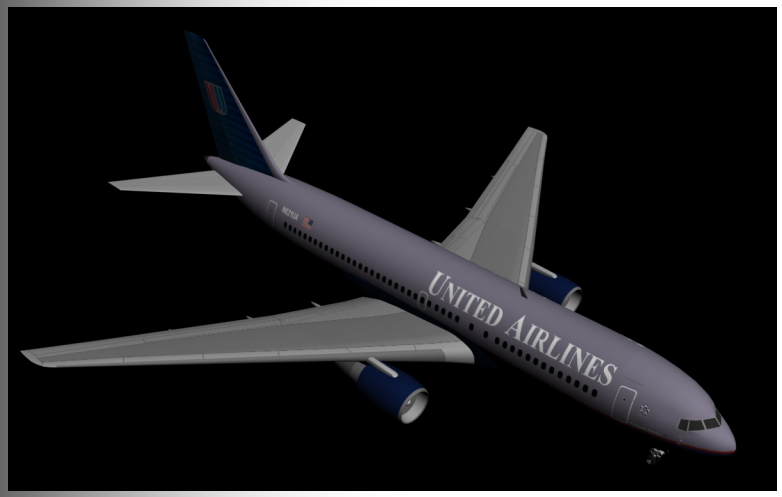
Overview

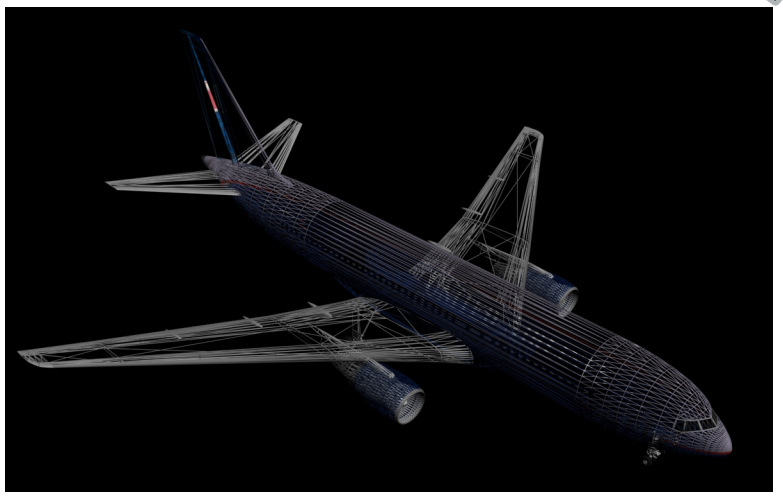
- What is FEA?
  - Computational method to analyze problems of displacements, stresses, and interactions between objects
- What does this mean to us?
  - Physics engine that is physically “accurate”
- Who uses this stuff?
  - Auto Industry
  - Aviation Industry
  - Semiconductor industry
  - …

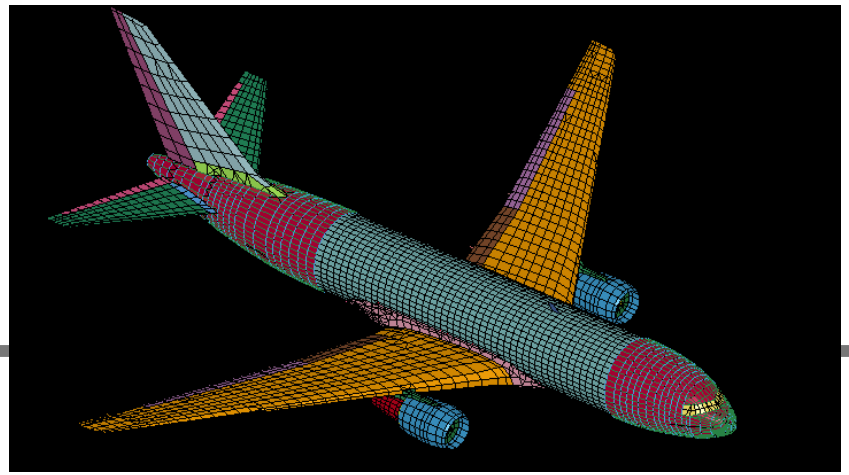
Finite Element Model

- Nodes
- Elements
  - Shells
  - Beams
  - Solids
  - Fluid (SPH or ALE)
- Materials
- Contacts

Converting From Graphics to Finite Elements







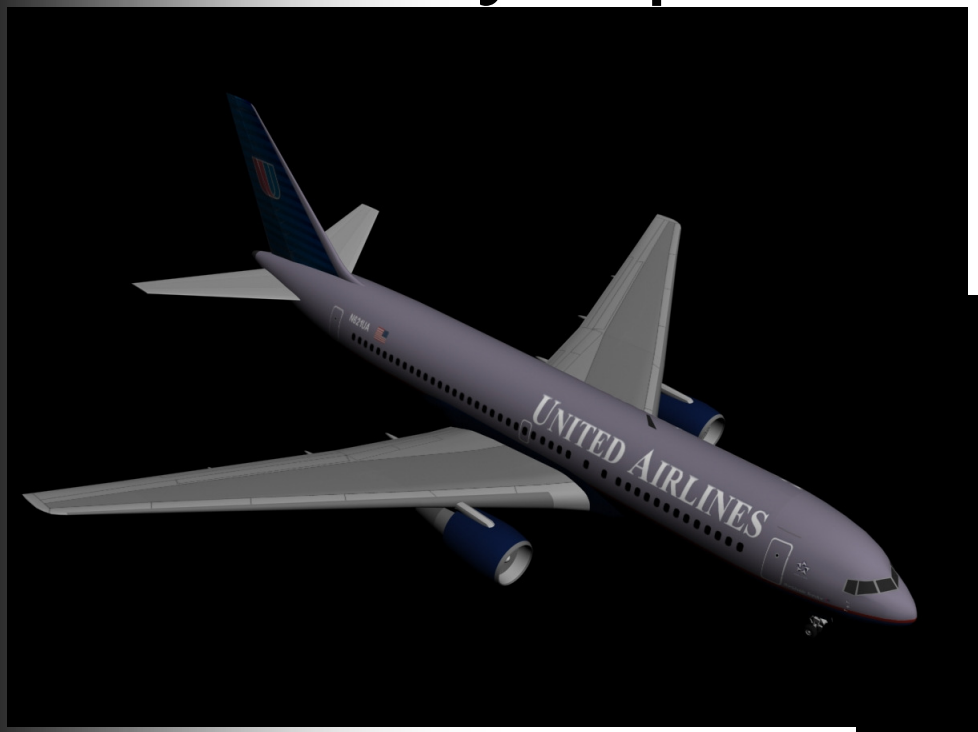
The Task

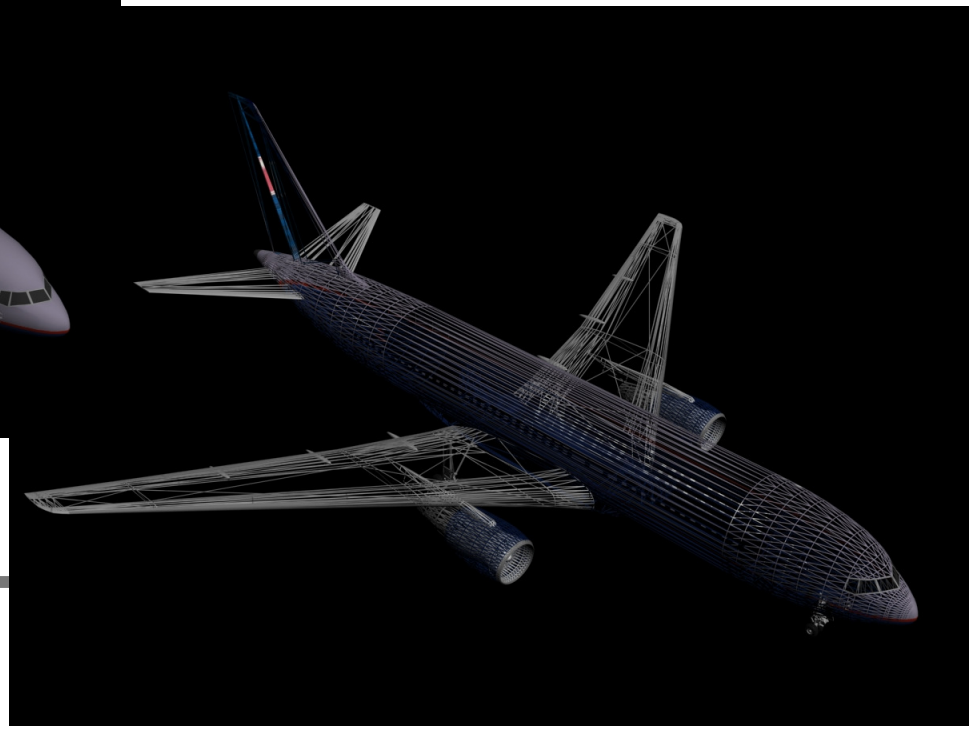
- Graphics models need no connection between parts, they only look good.
- So, we need to:
  - Remesh the skins and connect them
  - Add structural elements
  - Add floors, tanks, etc.

Geometric Considerations

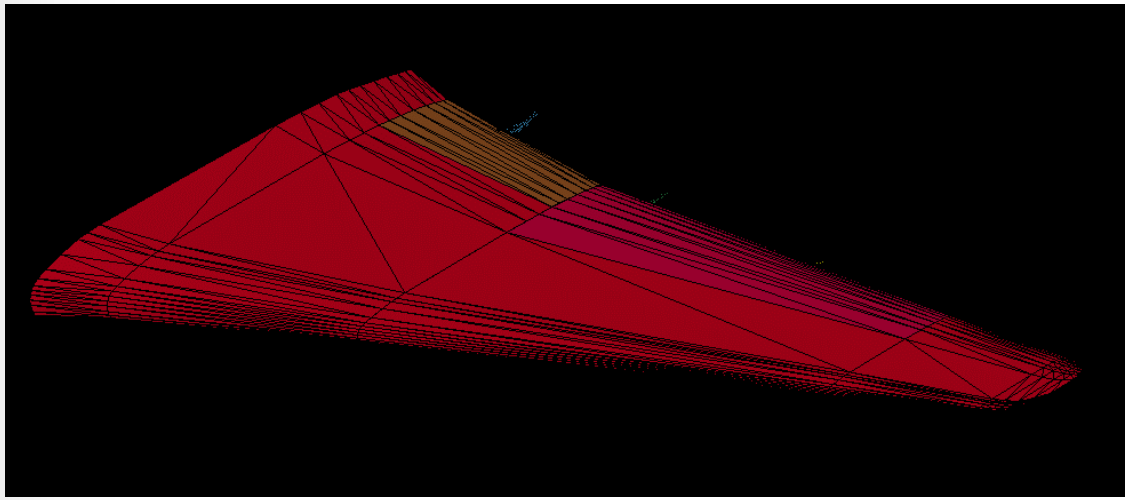
- Element shape
  - Quadrilateral vs. Triangular Elements
  - Regular Sized Elements
- Features to Avoid
  - Long and Thin Elements
  - Small Internal Angles
  - T-Junctions

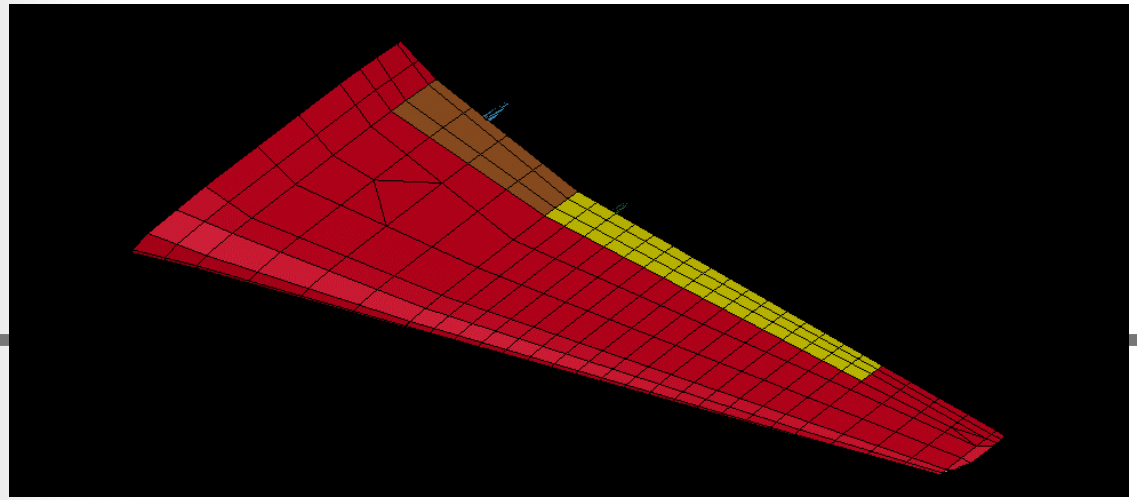
Boeing 767-200 Geometry Input



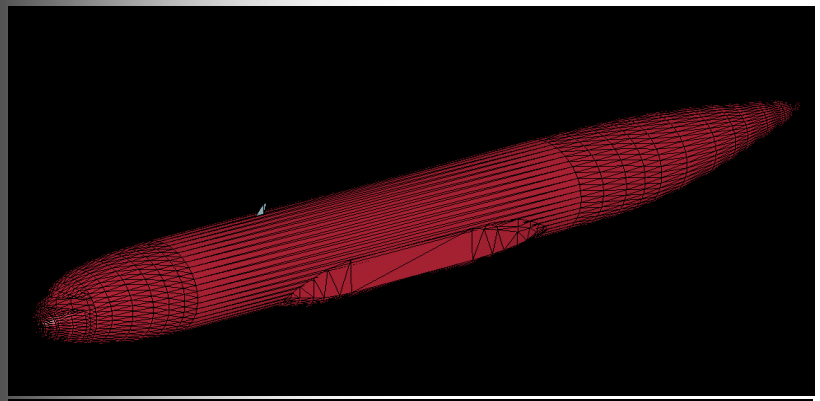


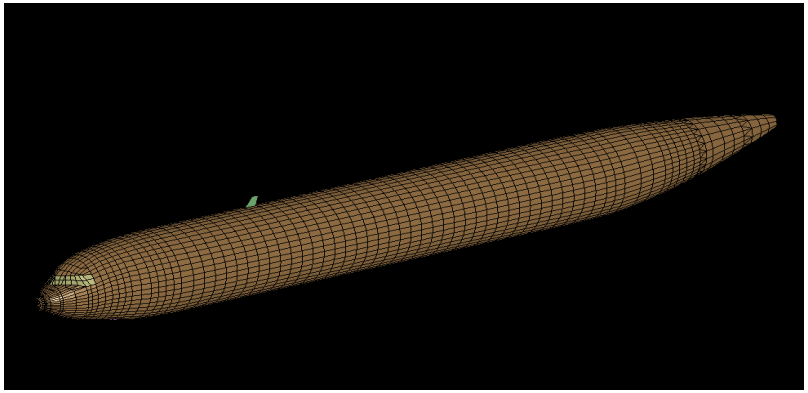
Boeing 767-200 Wing Skin

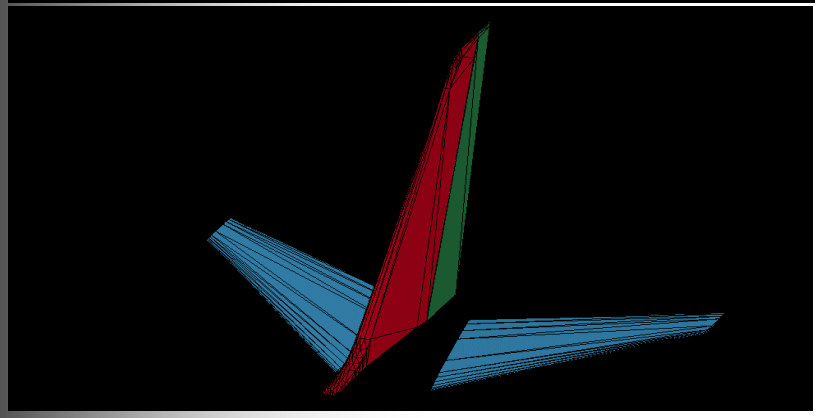


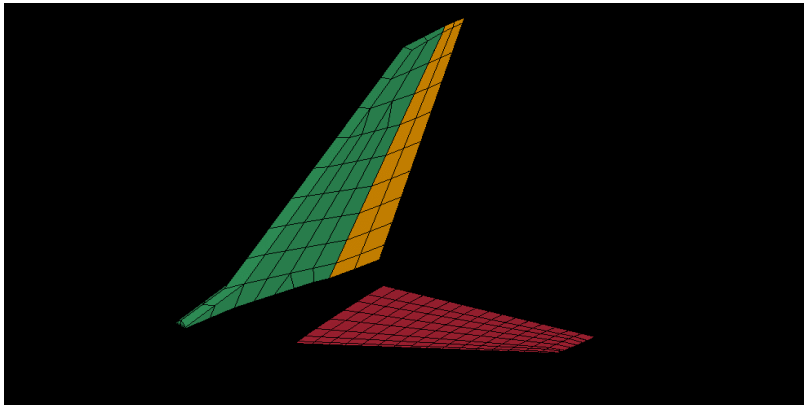


Boeing 767-200
Fuselage & Empennage

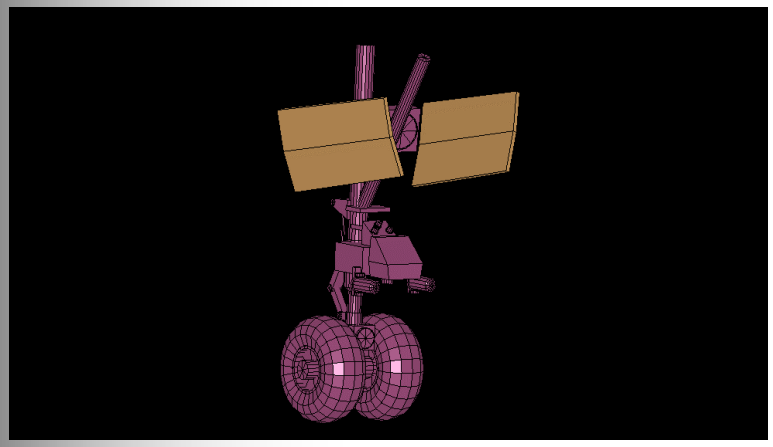


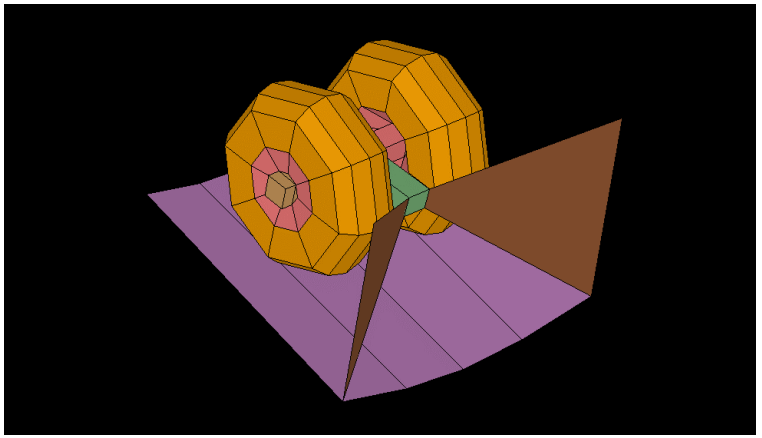


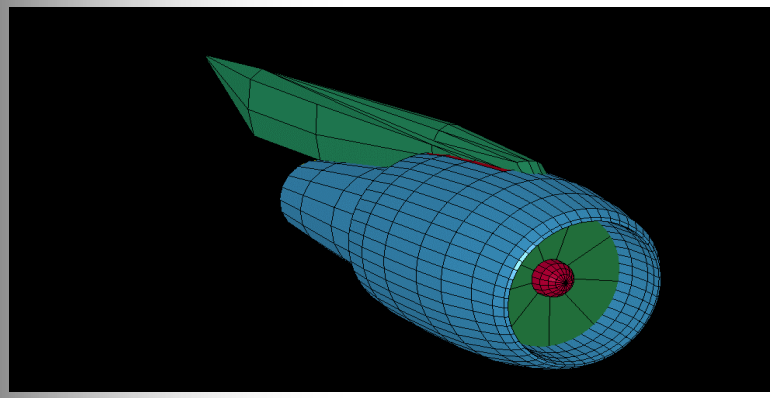


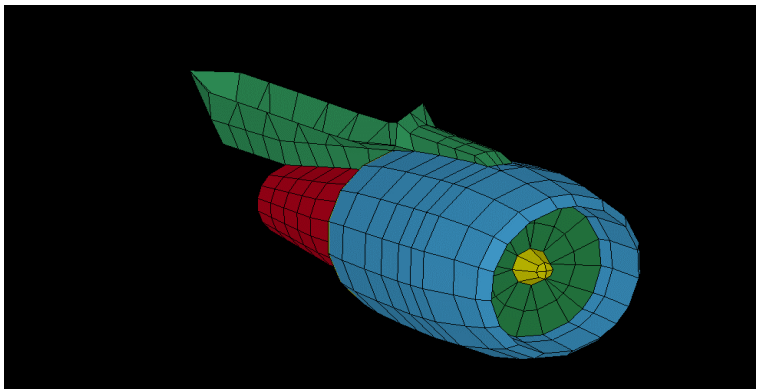


Boeing 767-200
Landing Gear & Engine

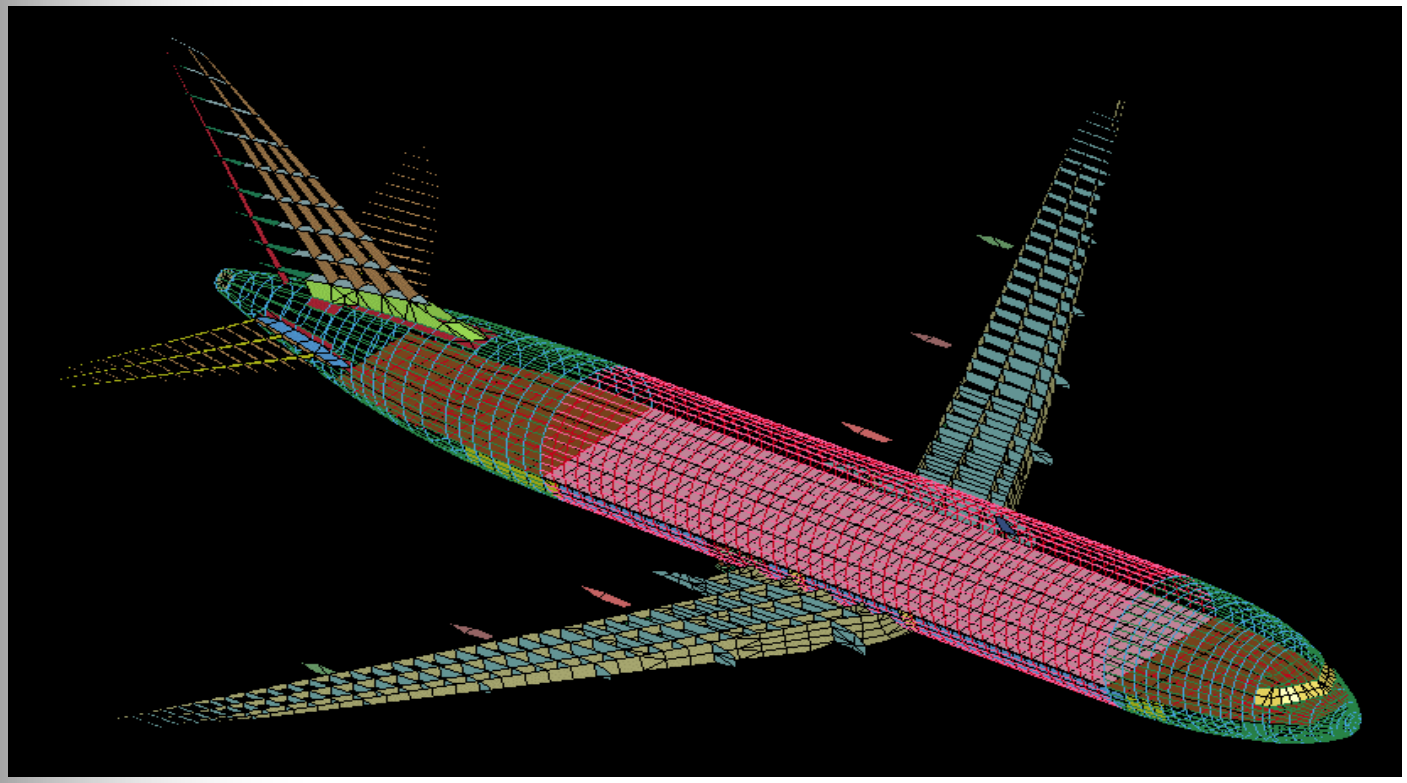




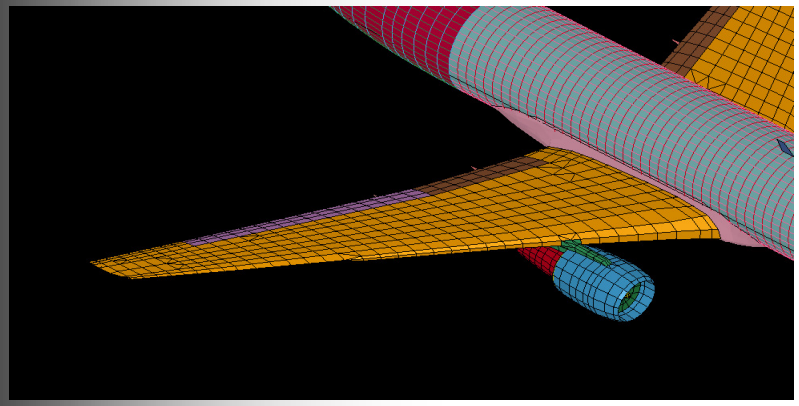


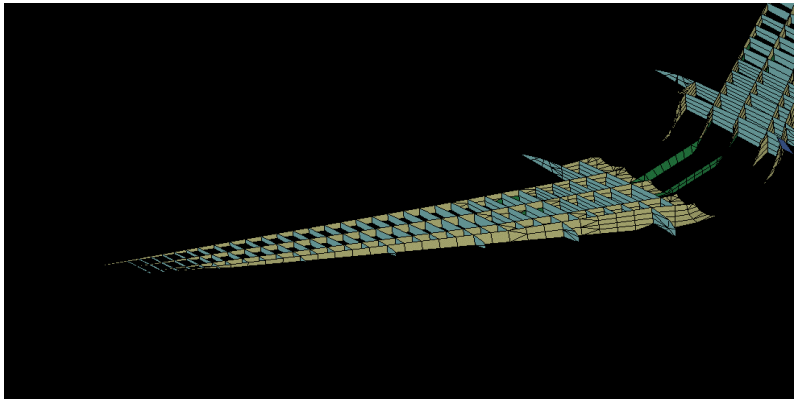


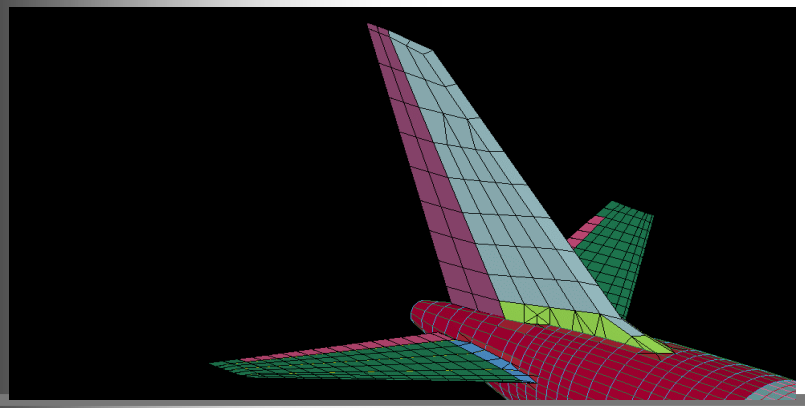
Boeing 767-200 Internal Structure

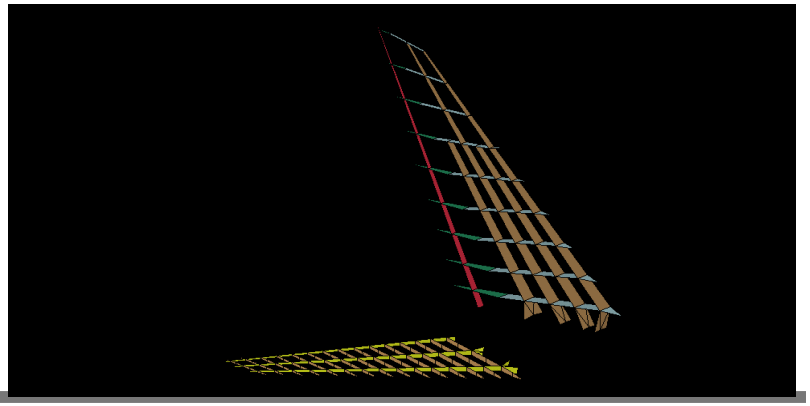


Boeing 767-200
Wings and Empennage

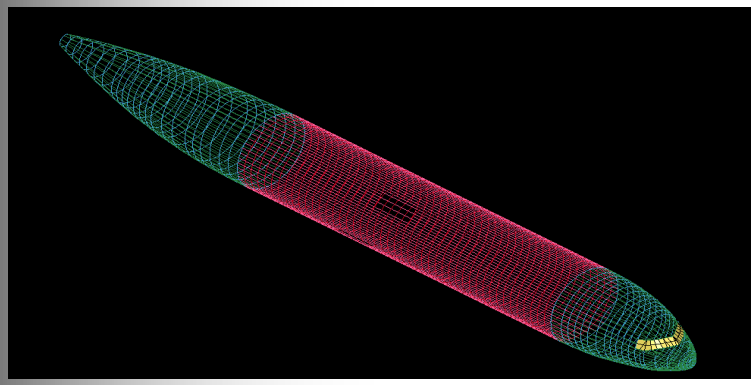


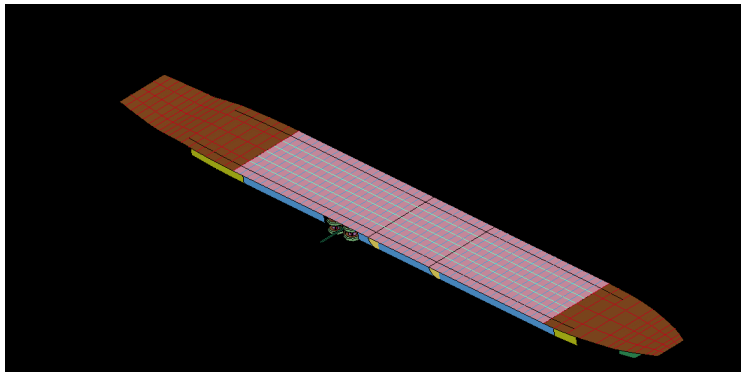


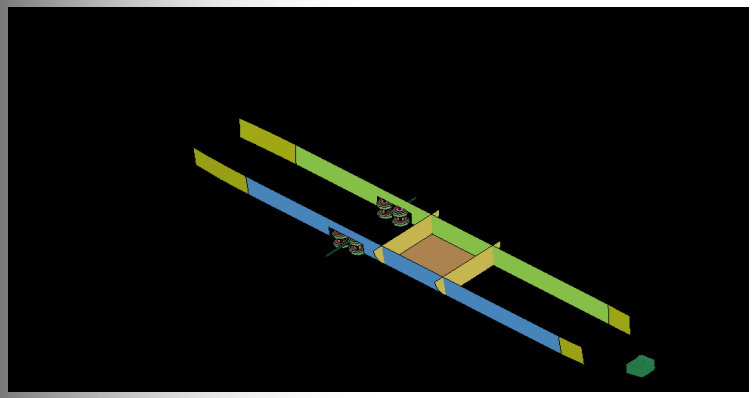


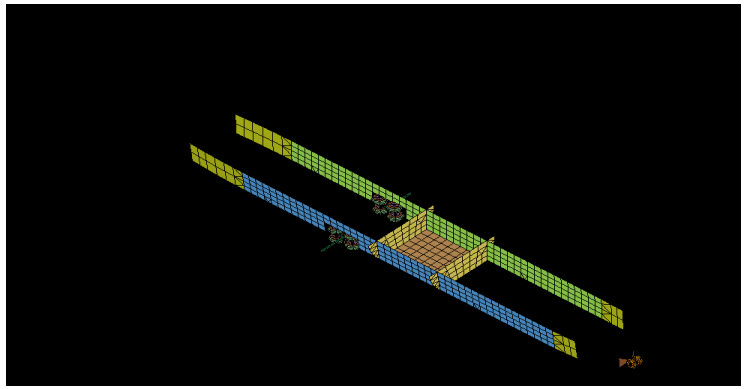


Boeing 767-200 Fuselage

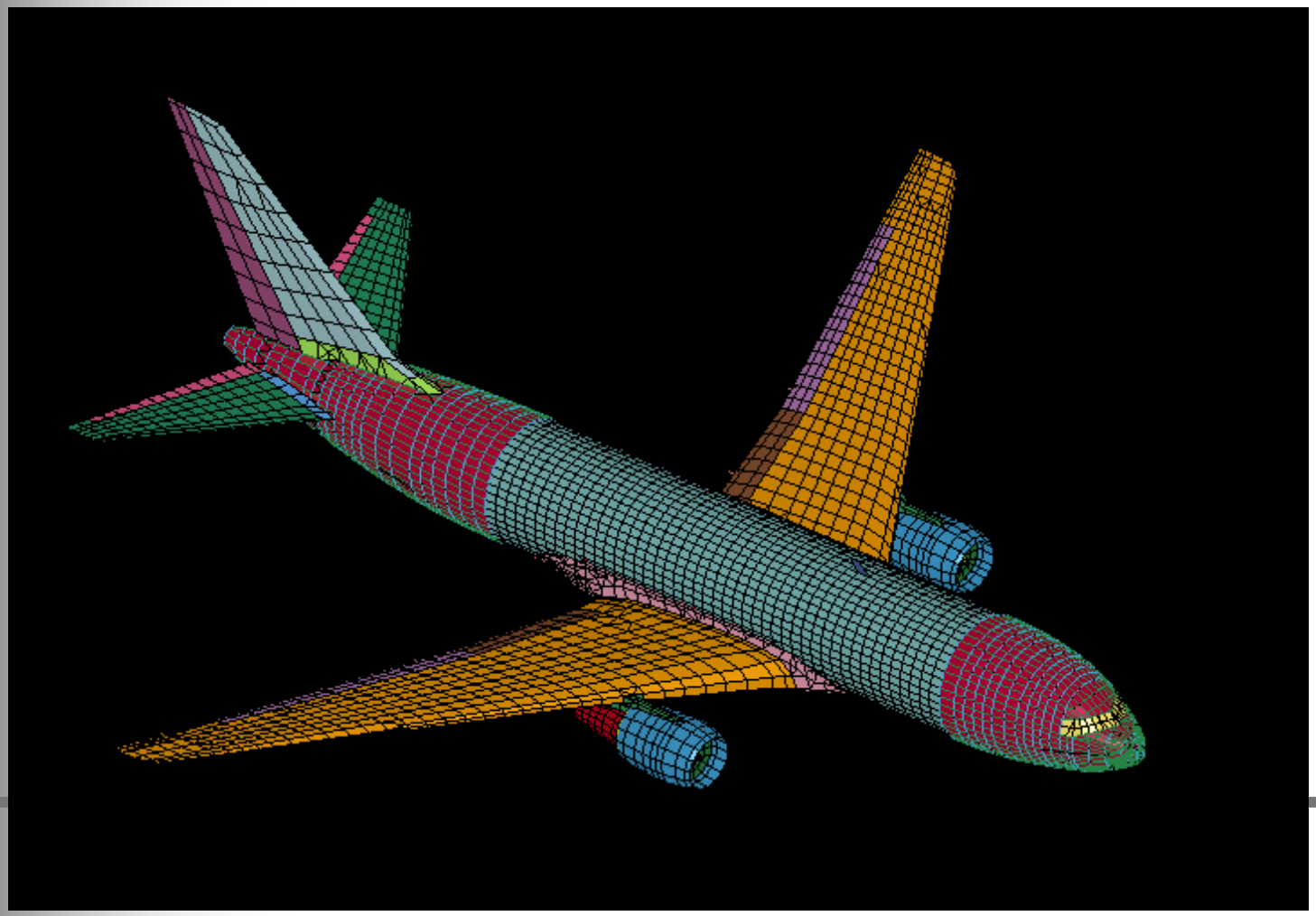








Boeing 767-200



Model Summary

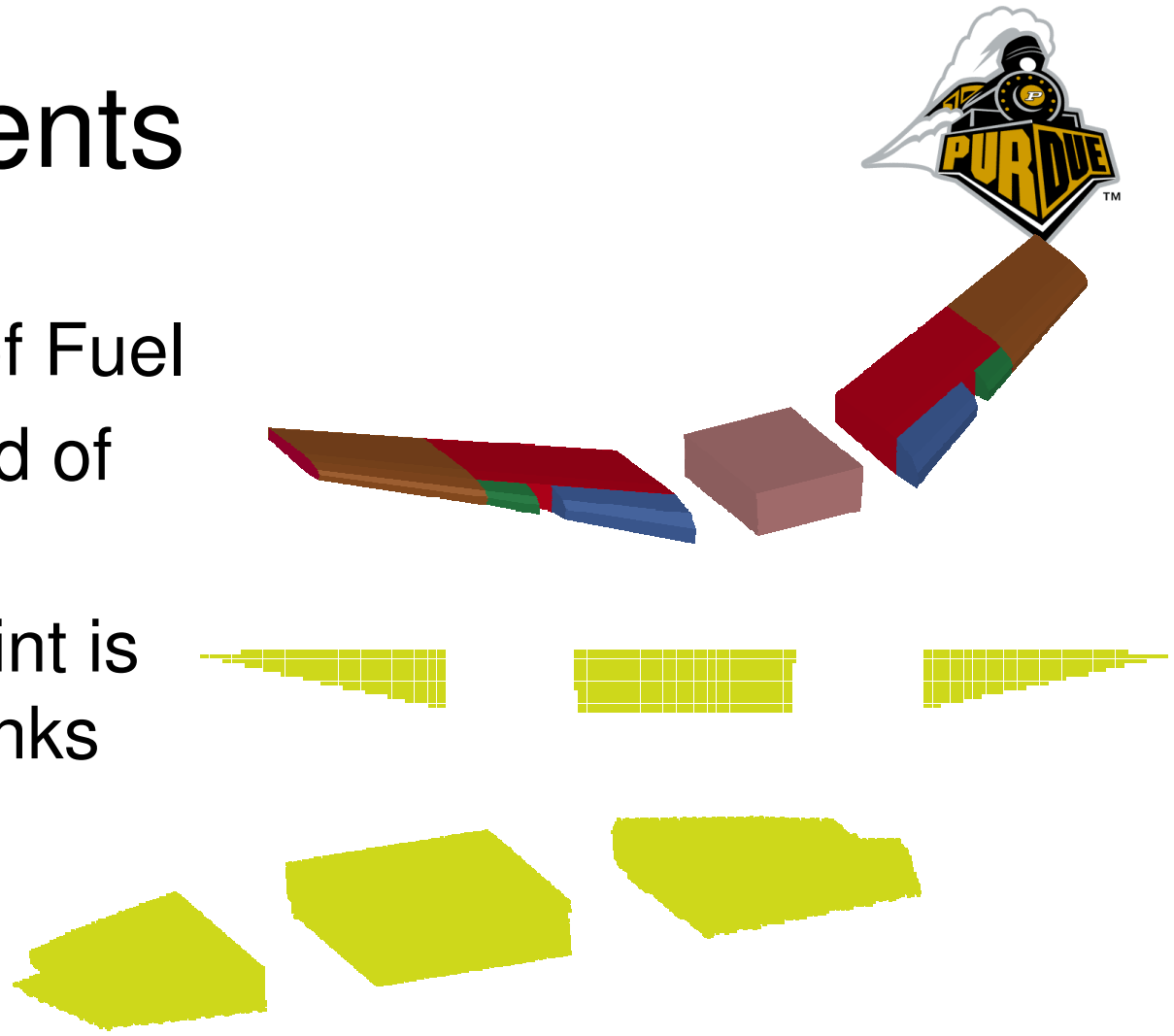
- Statistics:
  - 14341 nodes
  - 11244 shell elements
  - 9001 beam elements
  - 674 solid elements
- Many parts of the process can automated
- Many issues require human interaction
  - No good tools exist for this process

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

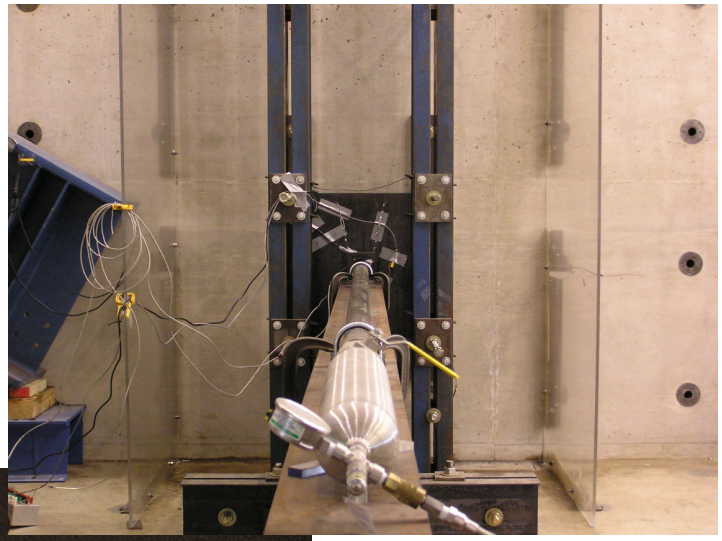
SPH Elements

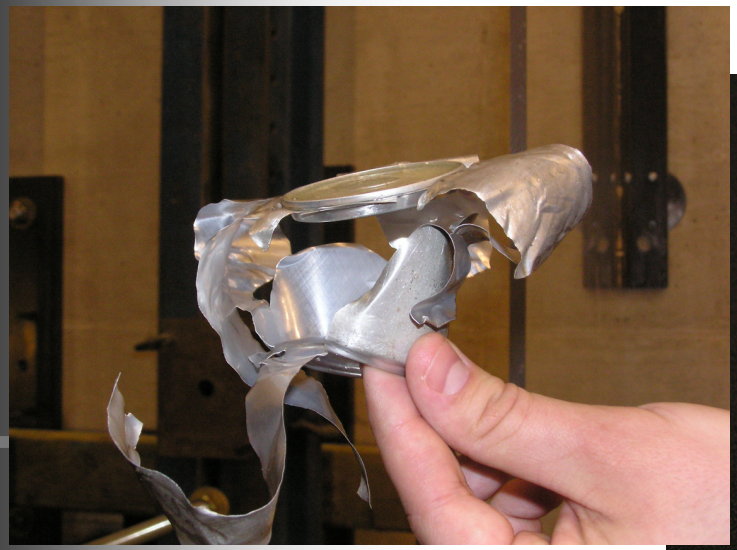
- 9118 Gallons of Fuel
- Use regular gird of points
- Test if each point is inside of the tanks



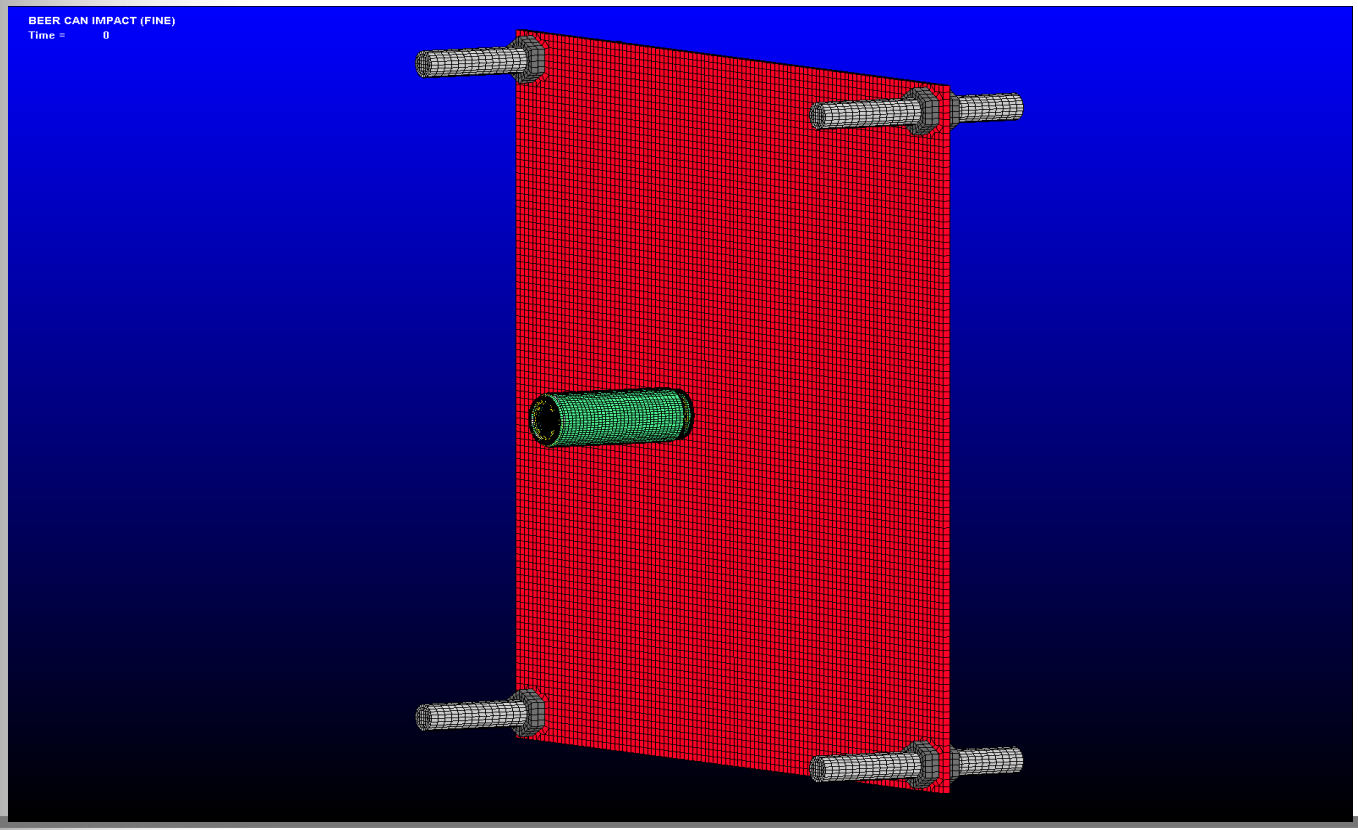
Fluid Structure Interaction SPH Test

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





SPH Test



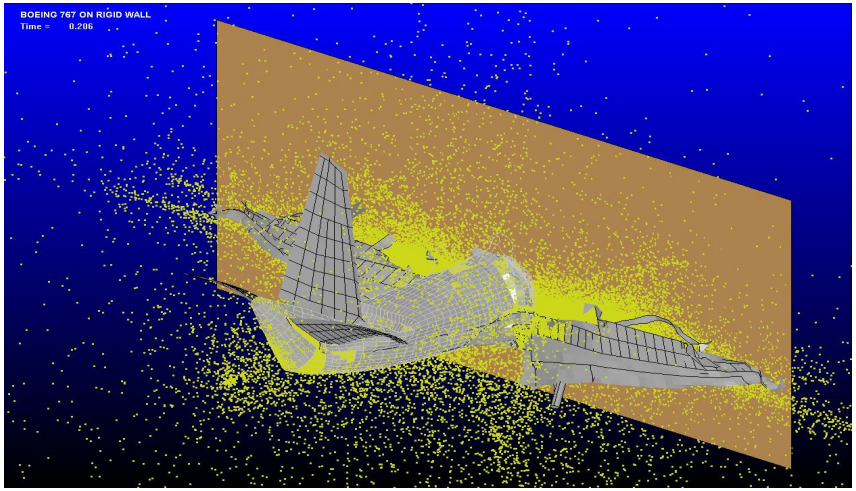
Riera Calibration

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

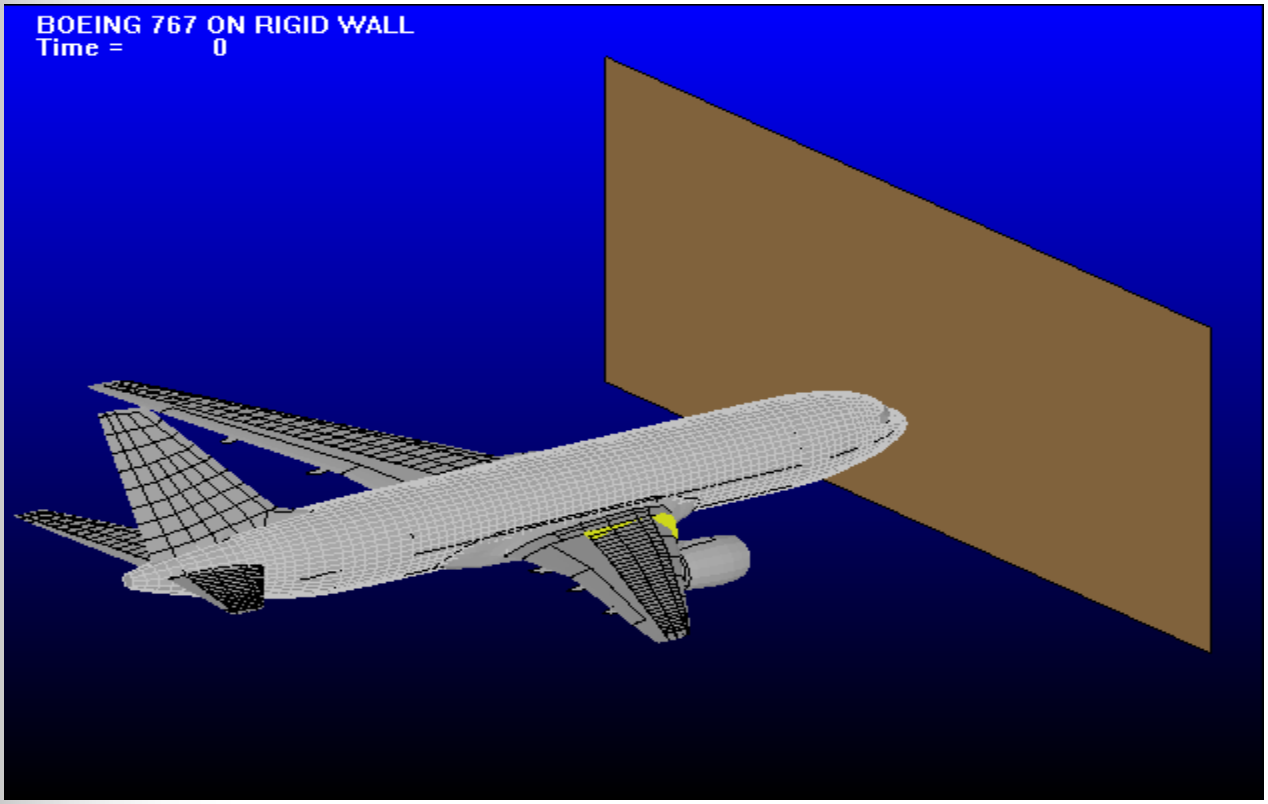
Riera Calibration

Riera Calibration

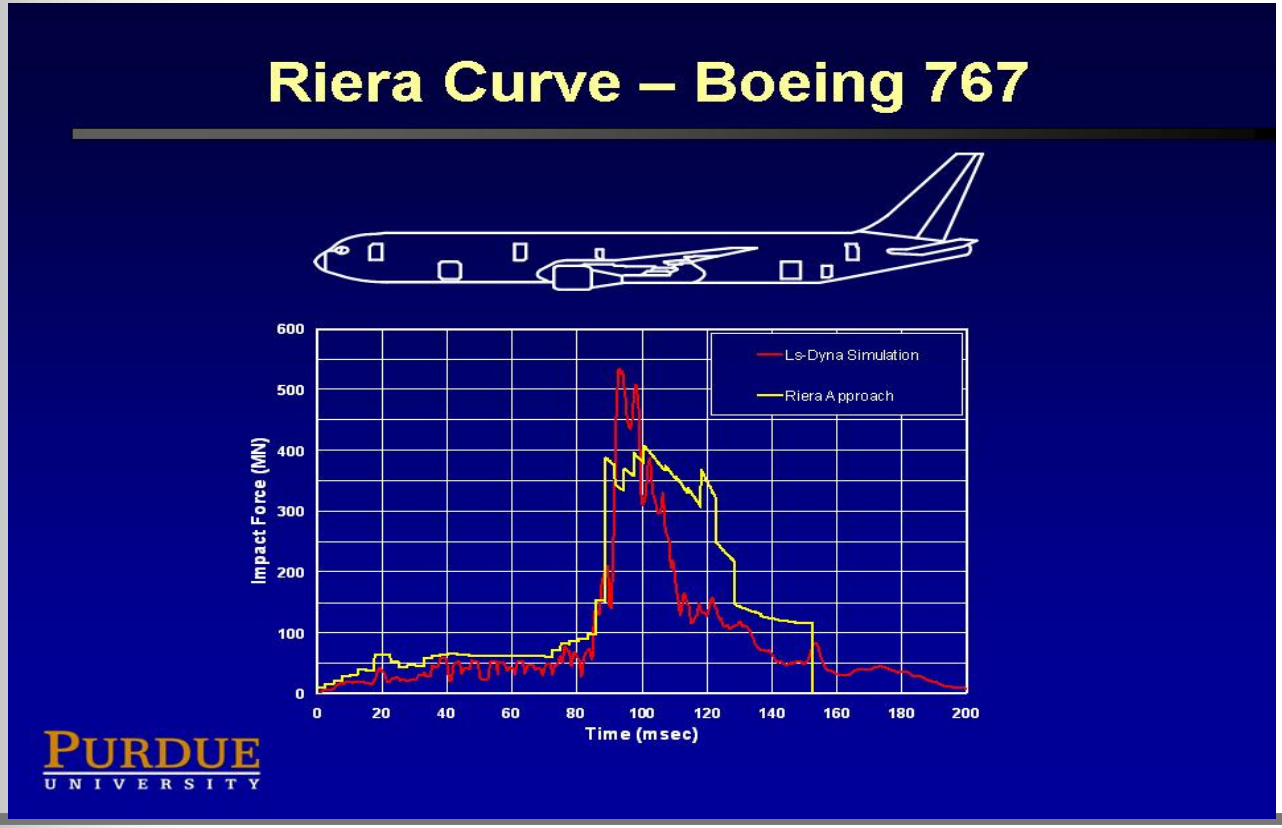
- Riera's calculation requires velocity and mass of individual slices of the aircraft
- Slicing the aircraft is simple geometry problem



Riera Calibration

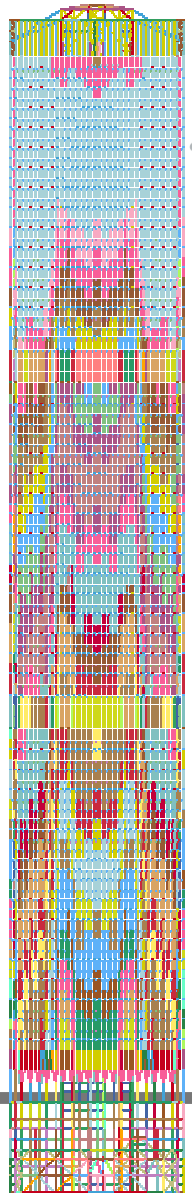


Riera Calibration



WTC North Tower

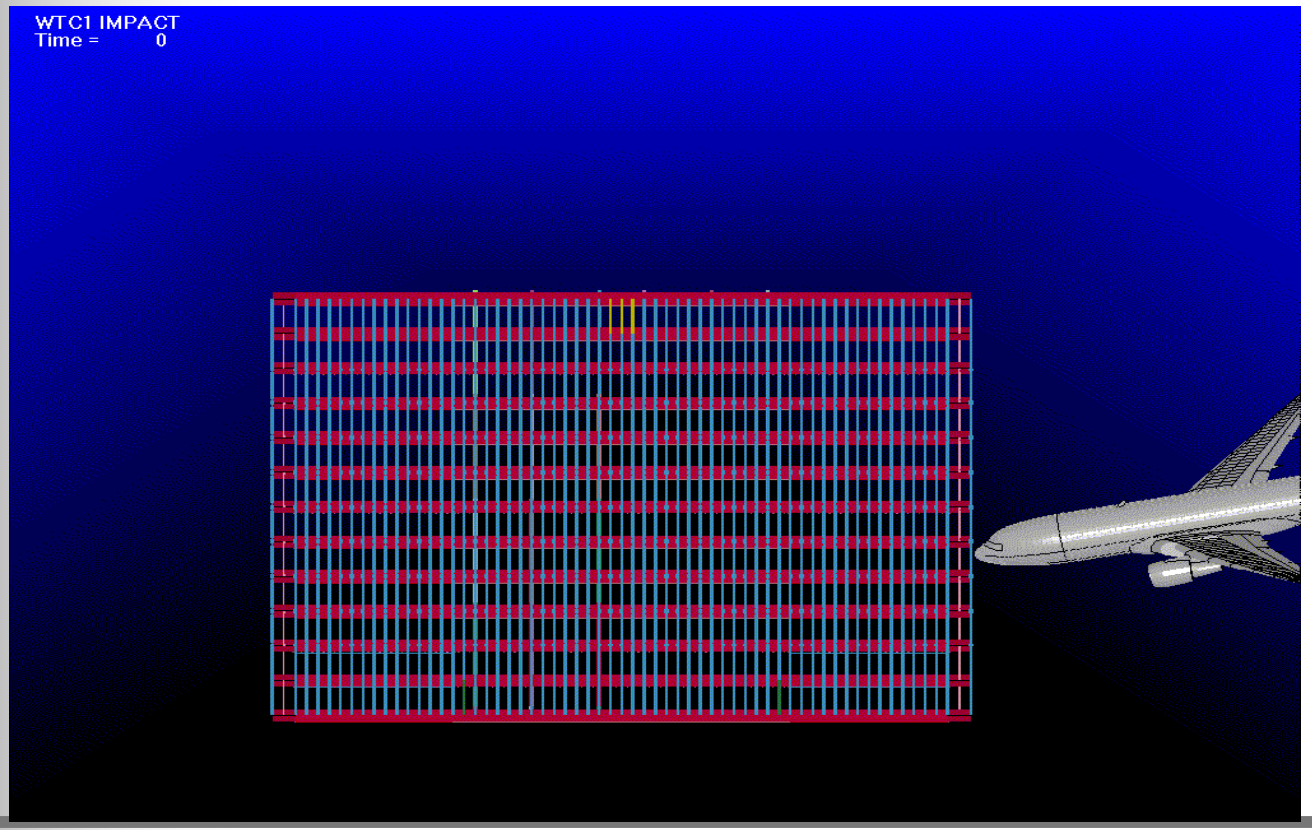
- Model by members of CE in application called SAP2000
- Conversion into LS-Dyna format
  - Both text based formats
  - Conversion of structural elements trivial
    - One exception: Orientation of beam elements
  - Part and material definitions more difficult



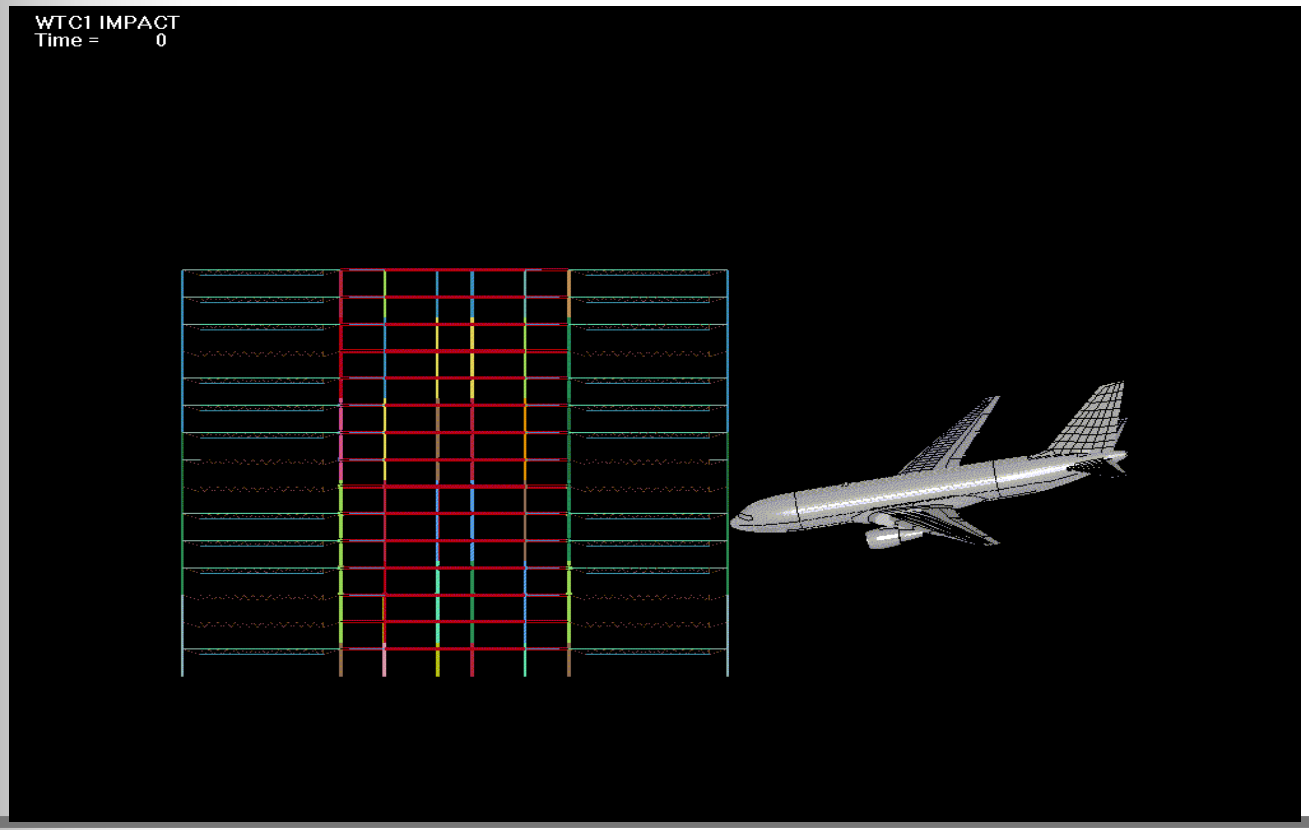
Bringing It All Together

- 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

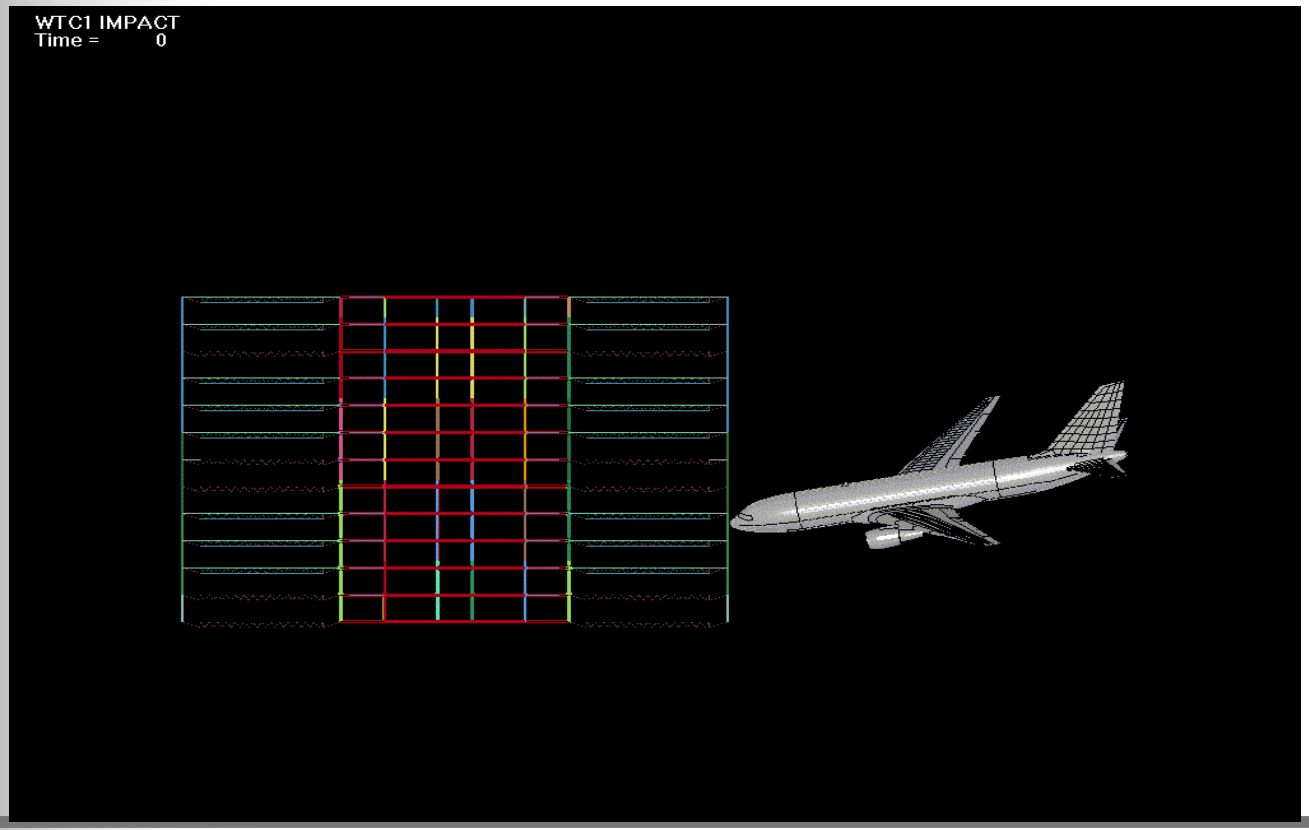
Latest Results – Side View



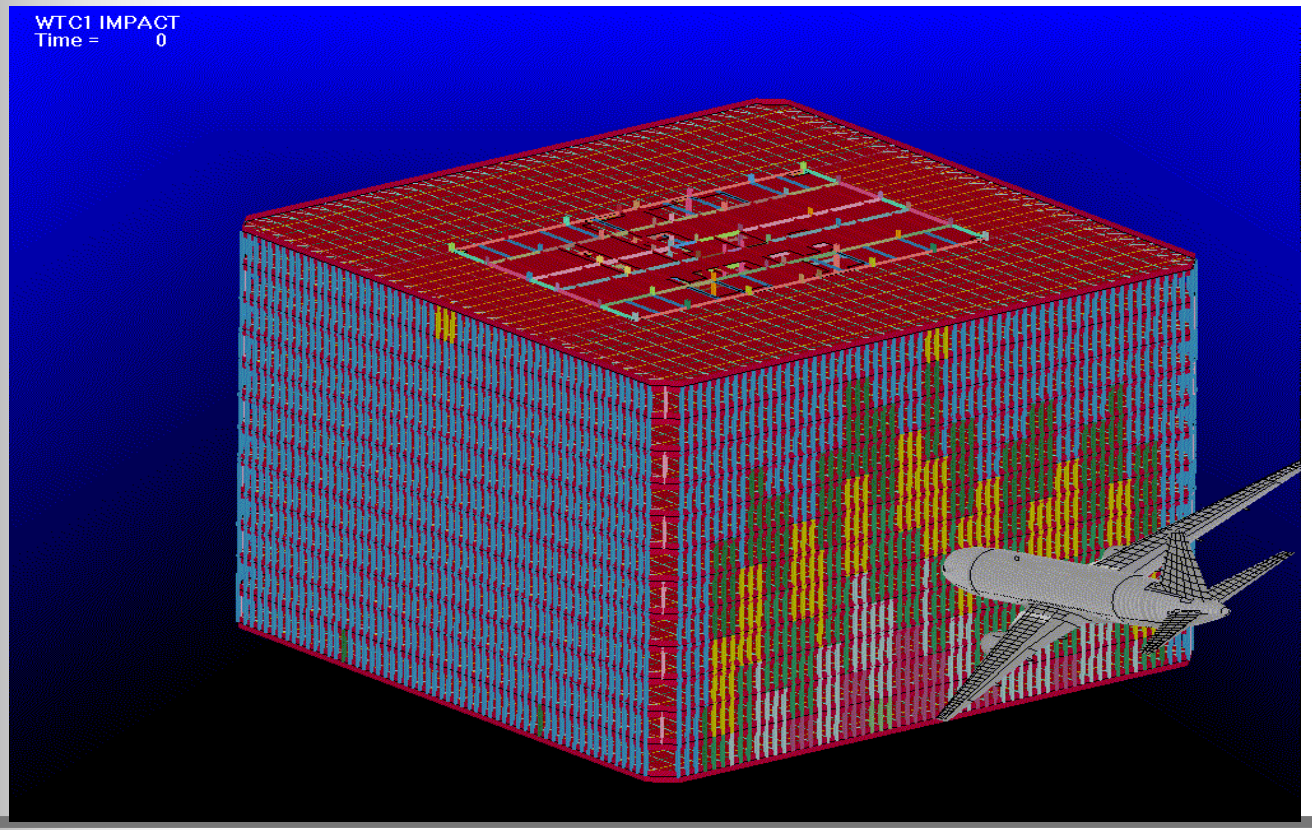
Latest Results – Core Only



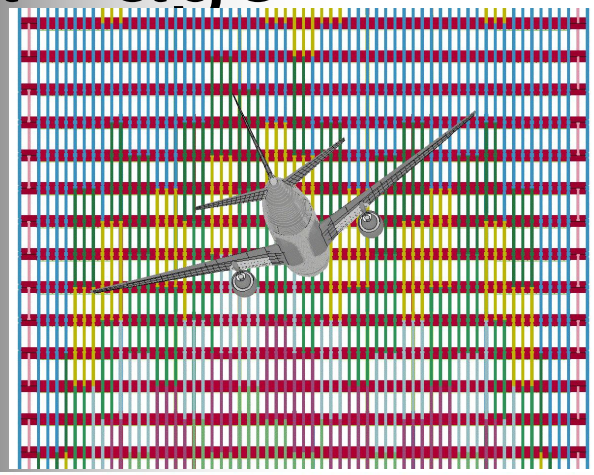
Latest Results – Core, No Fuel



Latest Results – Oblique View



Latest Results – Facade Damage



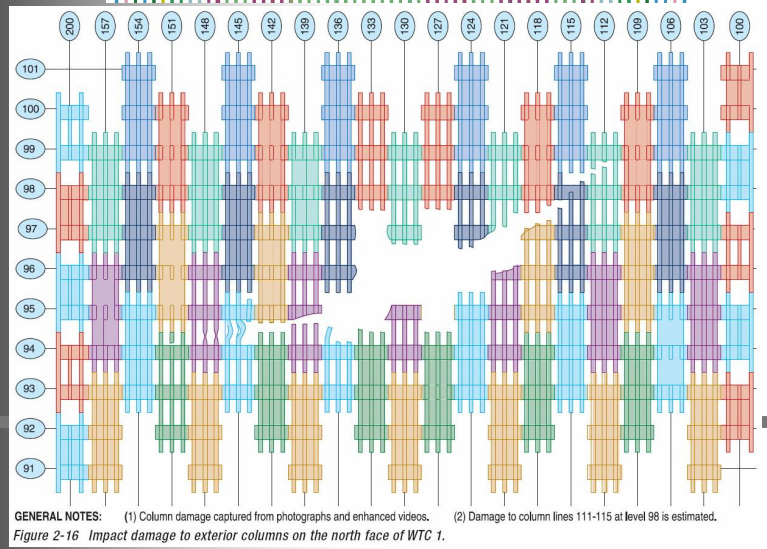


Figure 2-16 Impact damage to exterior columns on the north face of WTC 1.

Damage Diagram (FEMA Report)

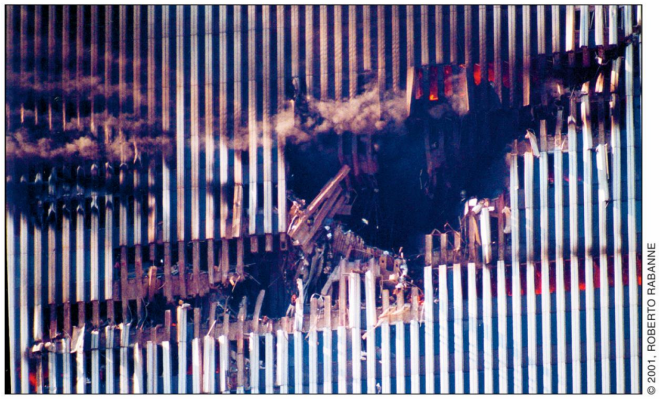


Figure 2-15 Impact damage to the north face of WTC 1.

Computational Results

Simulation	Time Required
SPH “Beer Can” Simulation	0.011 real time 99 hours dual opteron
Riera Calculation	0.2 sec. real time 99 hours dual opteron
WTC Run 11	0.5 sec. real time 100 hours nano regatta (8 cpus)
WTC Run 12	0.37 sec. real time 30 hours nano regatta (16 cpus)

Larger List of Contributors

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- Paul Rosen, Computer Science
- Santiago Pujol, Civil Engineering
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Questions?