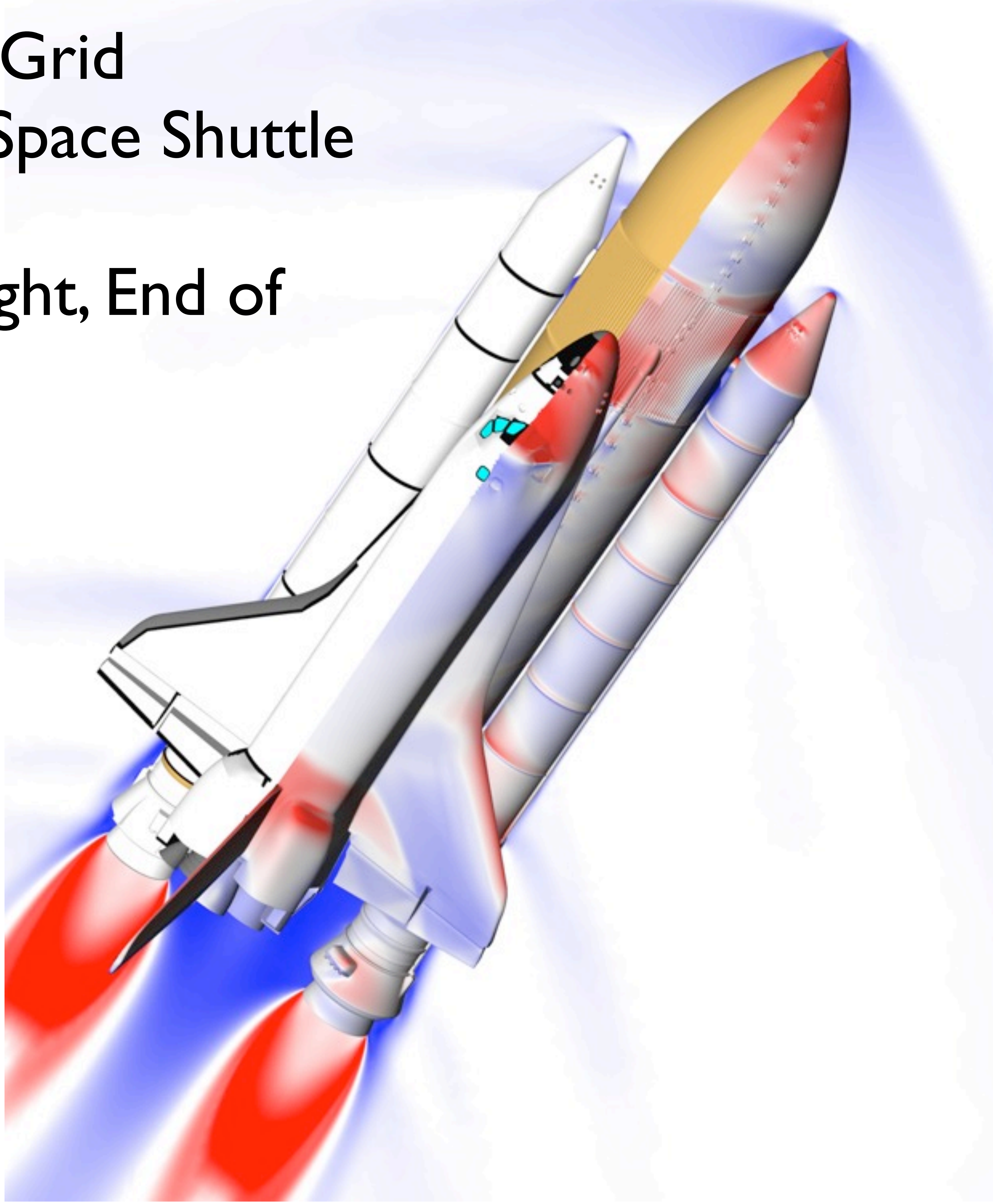
20+ Years of Chimera Grid Development for the Space Shuttle

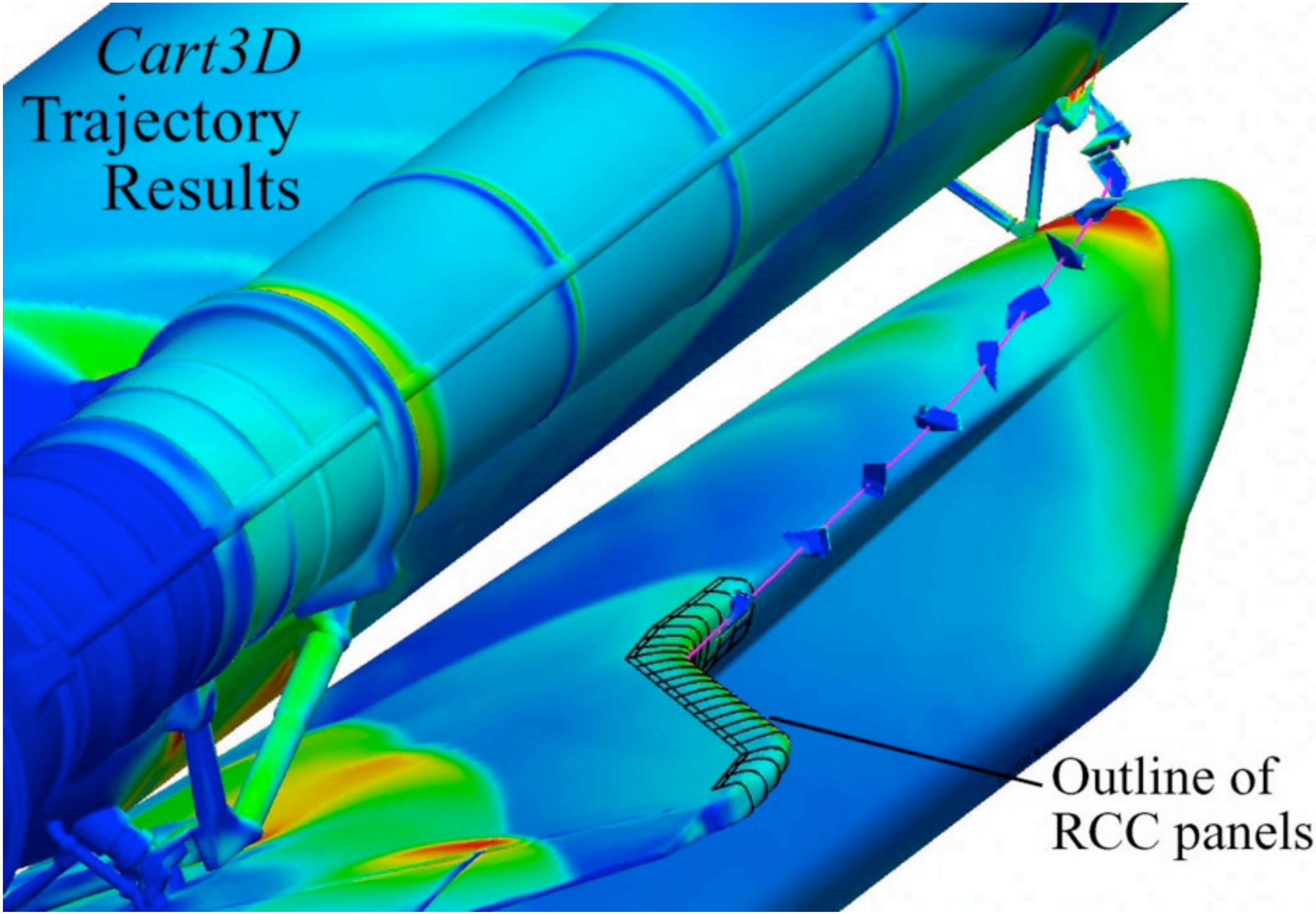
STS-107, Return To Flight, End of the Program



Reynaldo J. Gómez III
EG/Aeroscience & Flight Mechanics
NASA Johnson Space Center
Houston, Texas
September 2010

STS-107 Debris

AIAA 2005-1223



Reynaldo J. Gomez III NASA/JSC/EG3

The loss of STS-107 initiated an unprecedented detailed review of all external environments.

Ascent **airloads**, acoustics, **heating**

Debris liberation, **transport** and capability assessments.

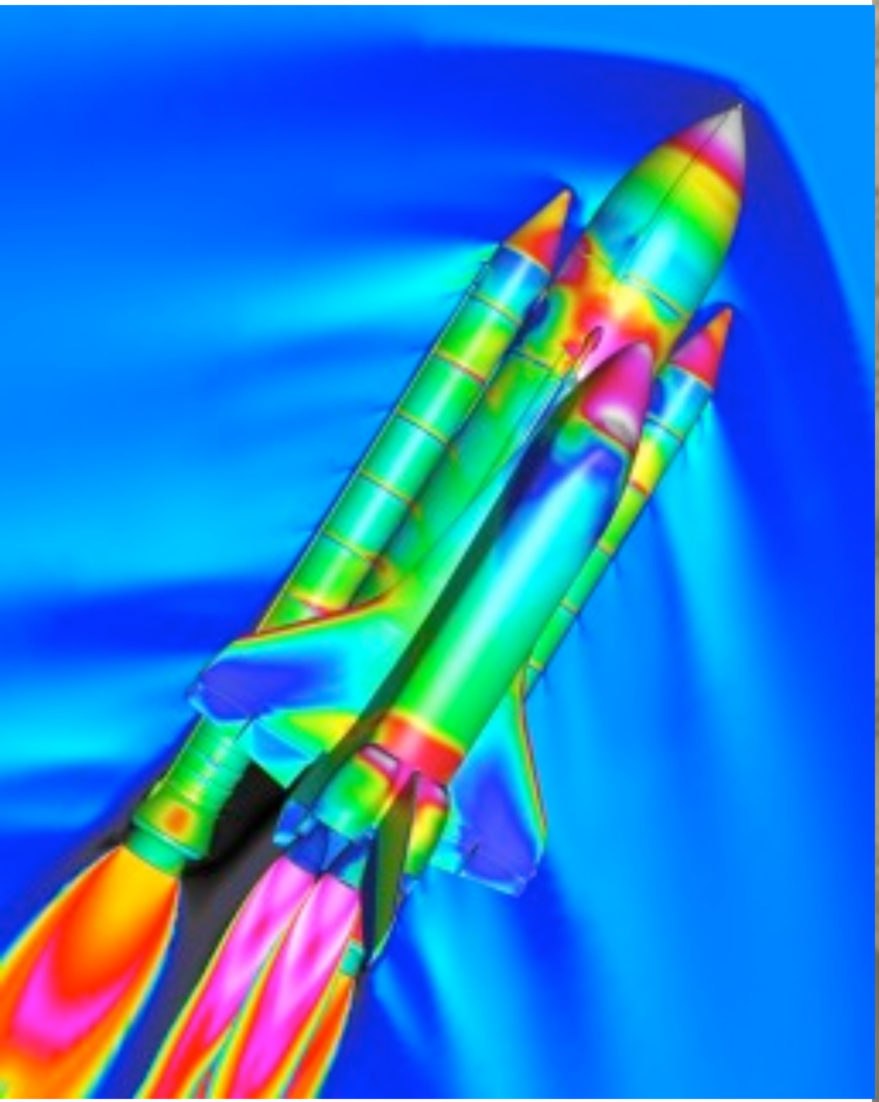
Bipod redesign assessments.

Greatly increased emphasis on verification & validation.

STS-114

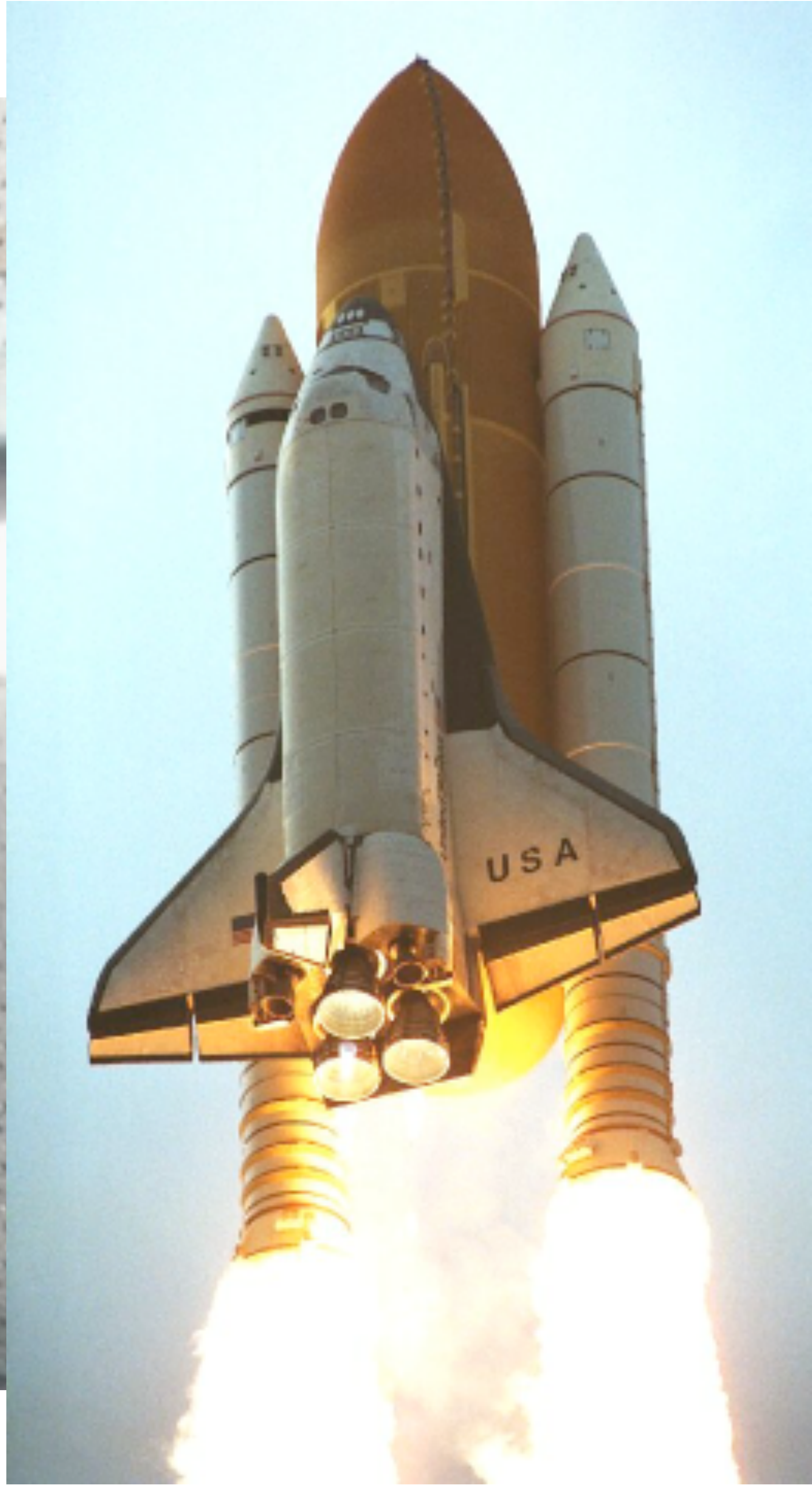
- PAL ramp foam loss, additional redesign work.

Space Shuttle Aerodynamic Tools

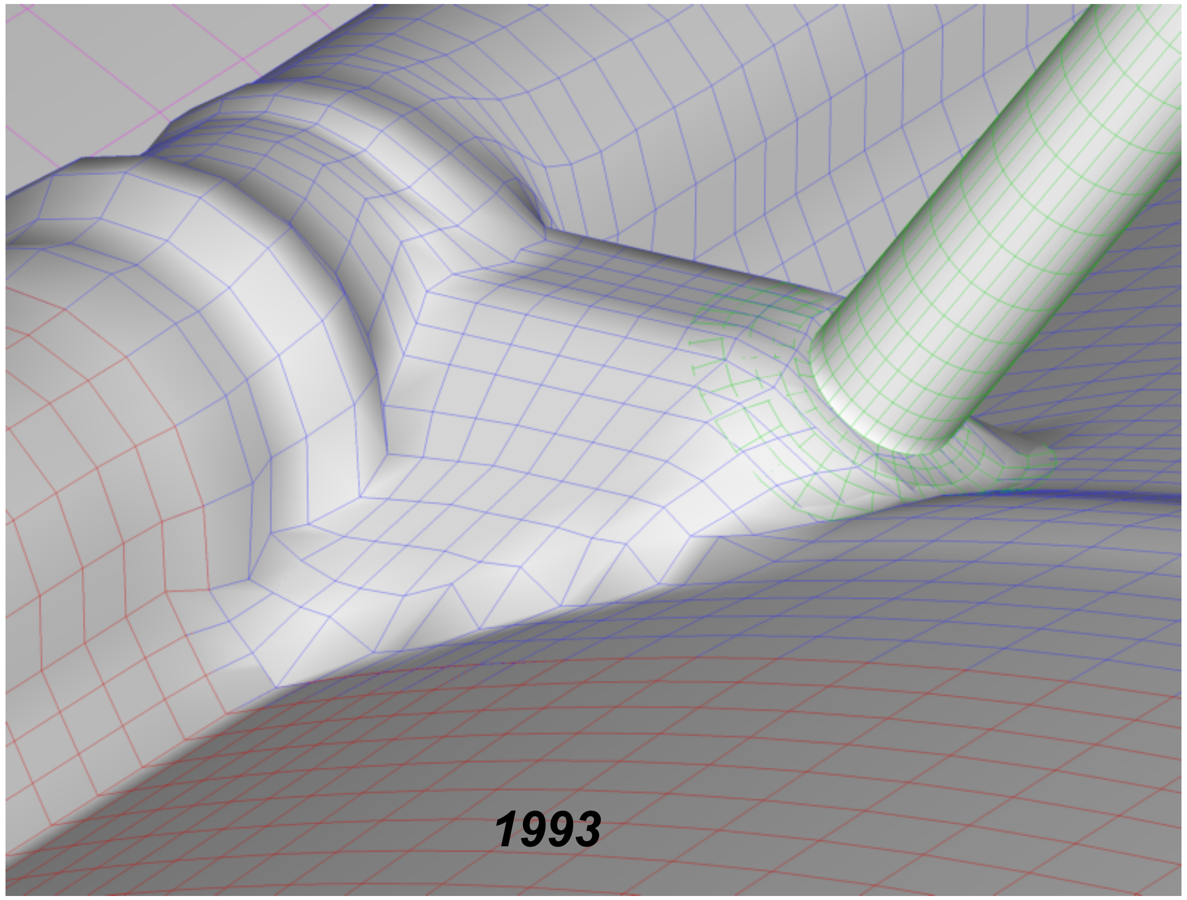


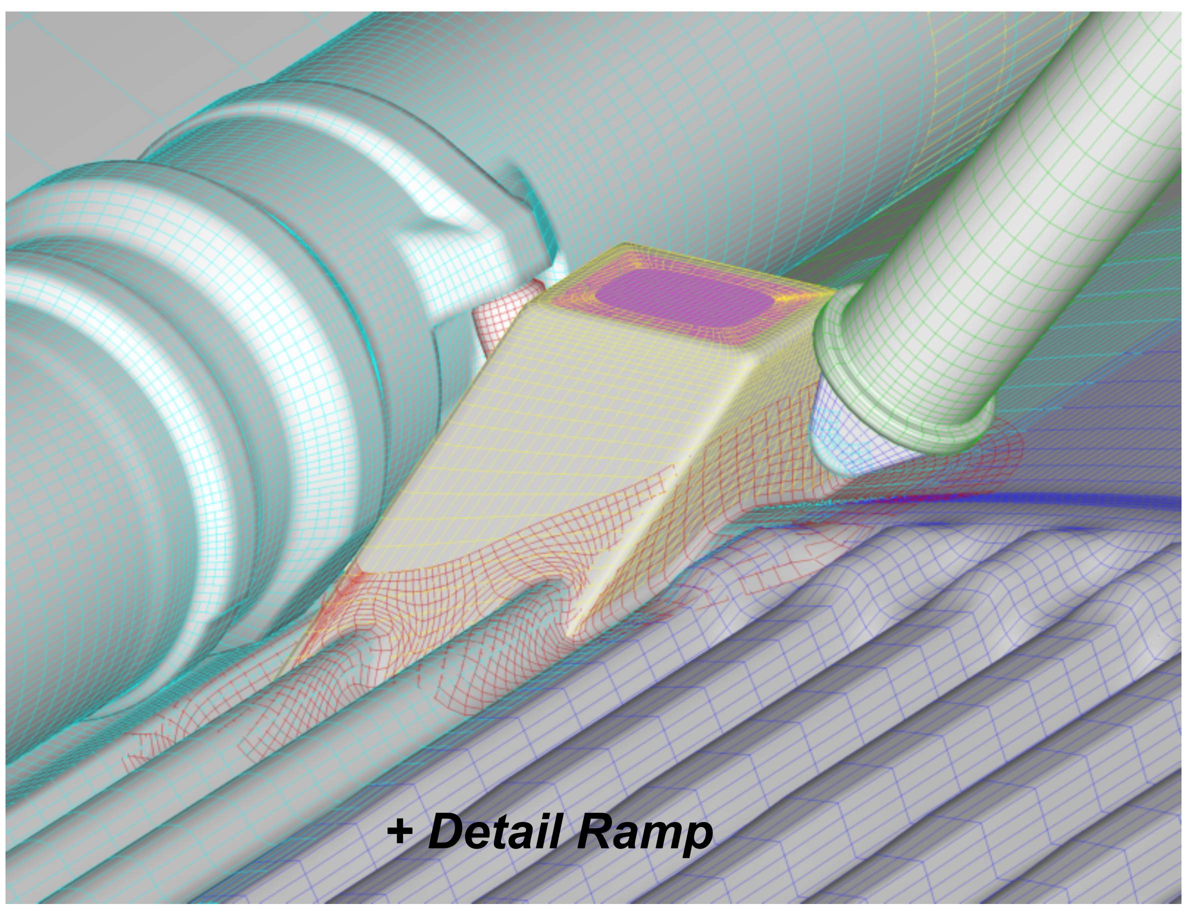
Modeling & Simulation

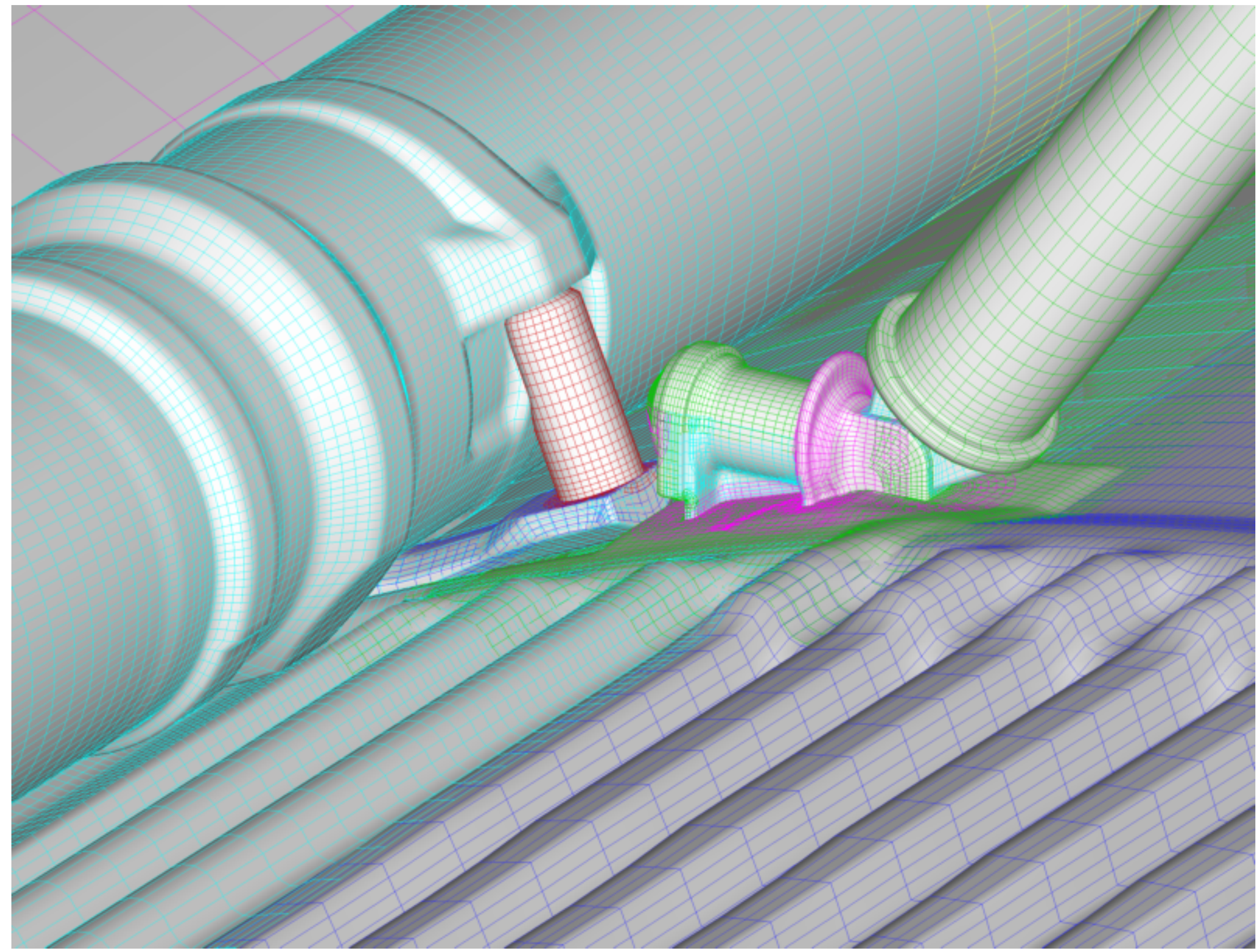
Ground Test



Bipod Ramp Redesign

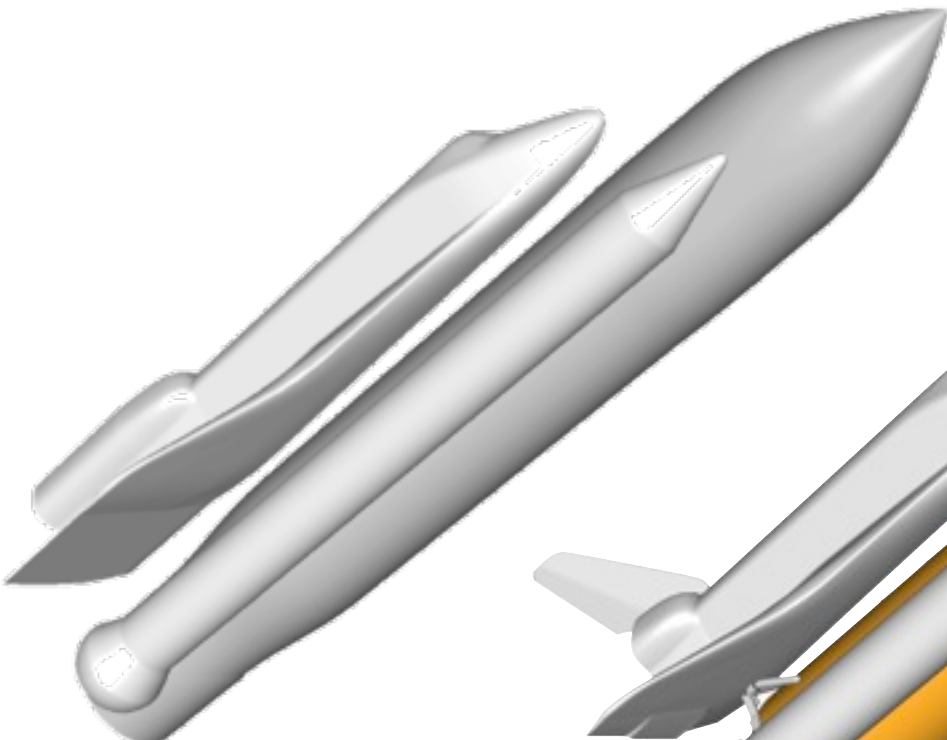




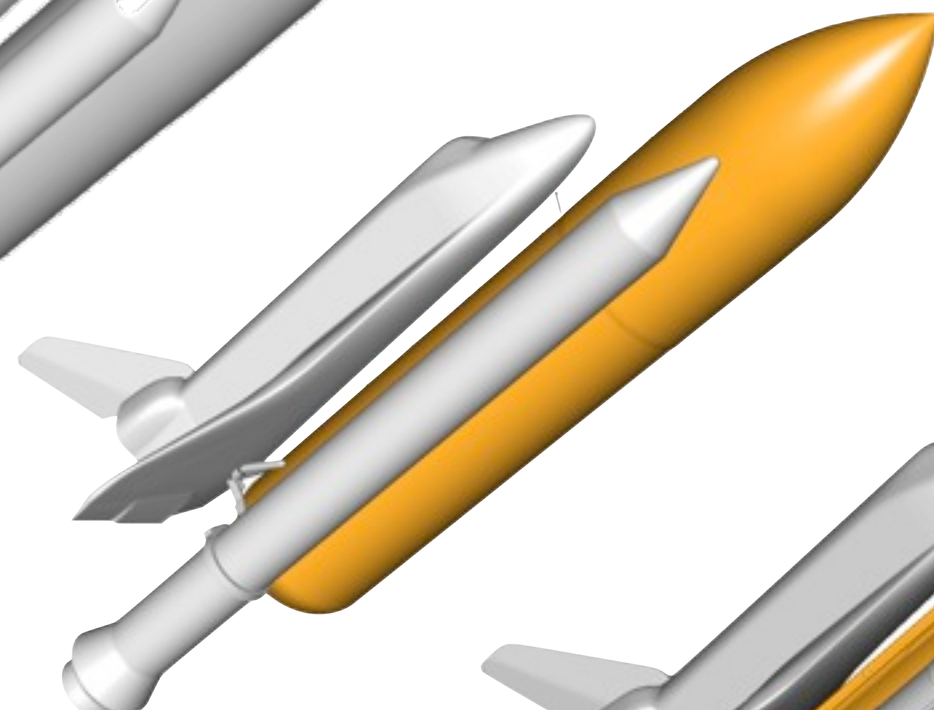


Current Configuration

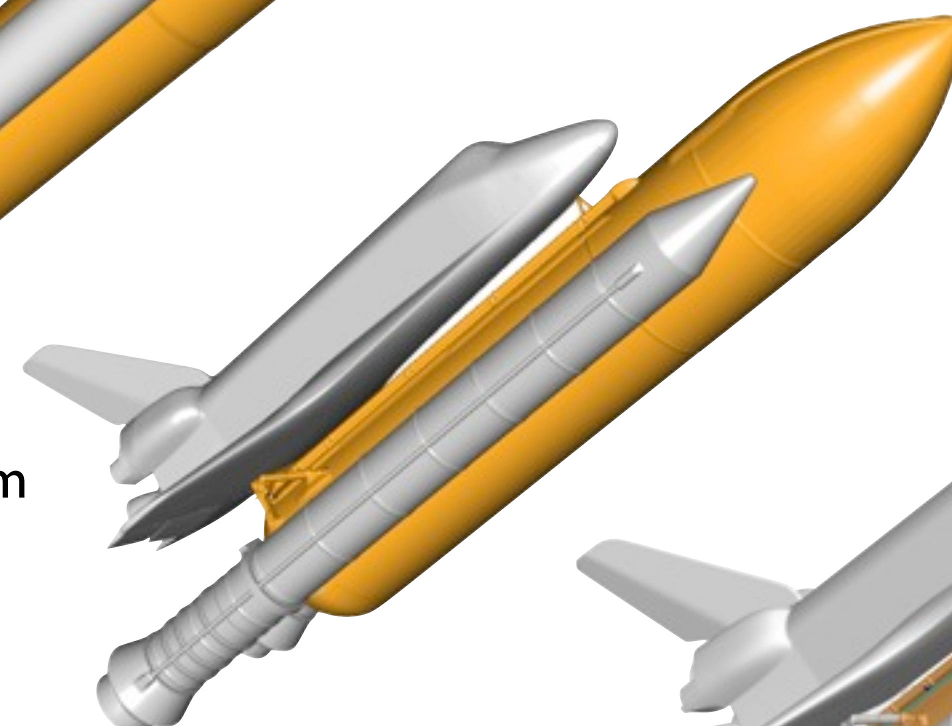
SSLV Grid System Evolution



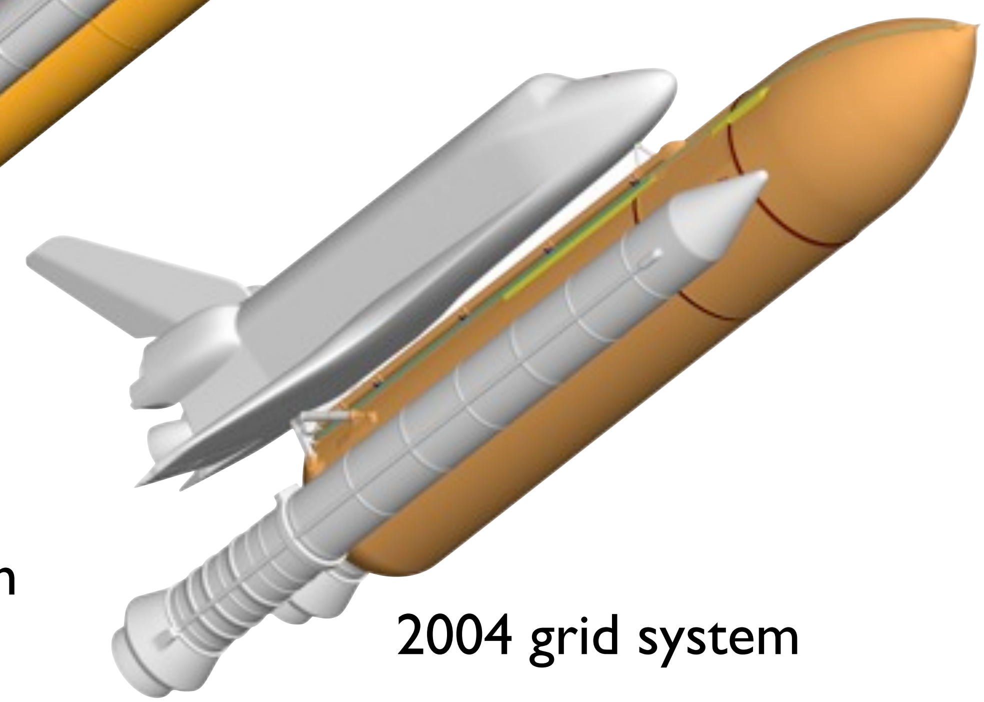
Early 80's grid system
3 Grids
10k surface points
0.3 million volume points



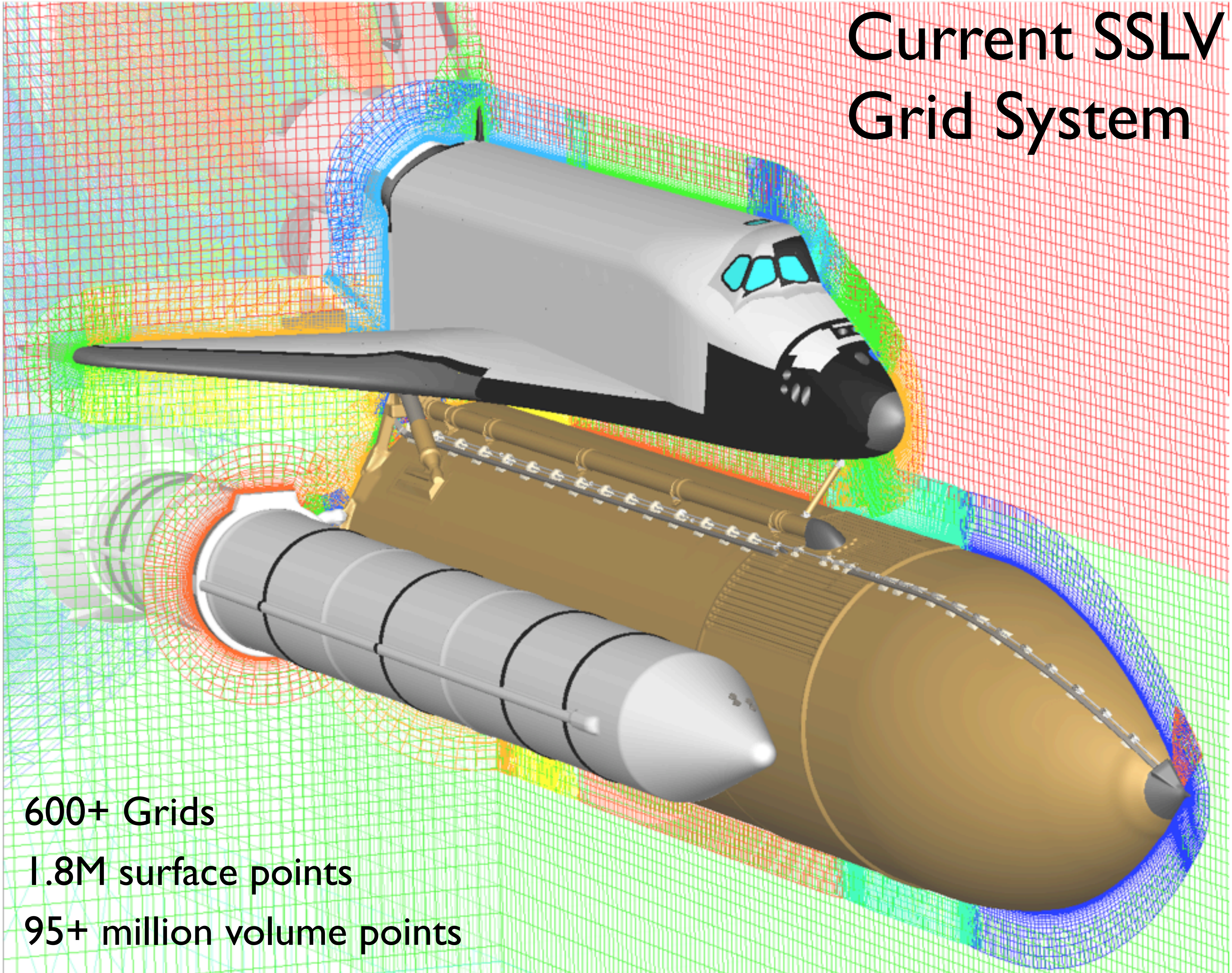
Late 80's grid system
14 Grids
35k surface points
1.6 million volume points



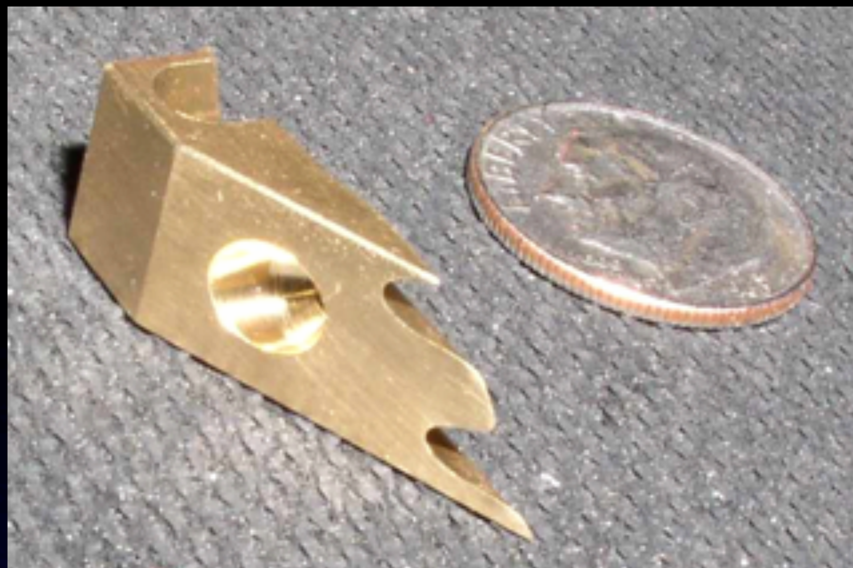
Early 90's grid system
113 Grids
268k surface points
16.4 million volume points

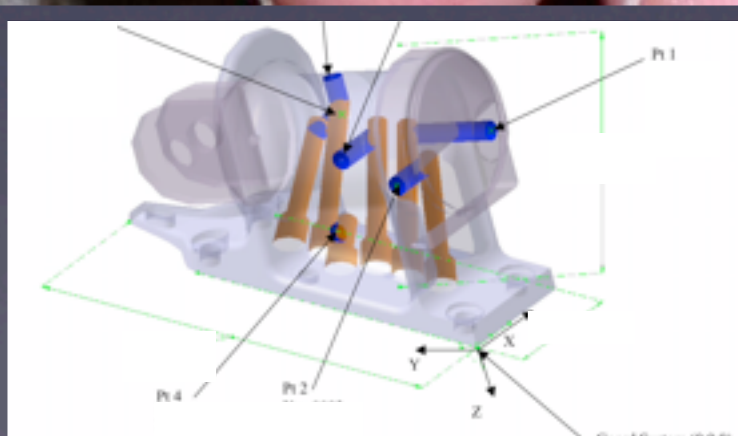


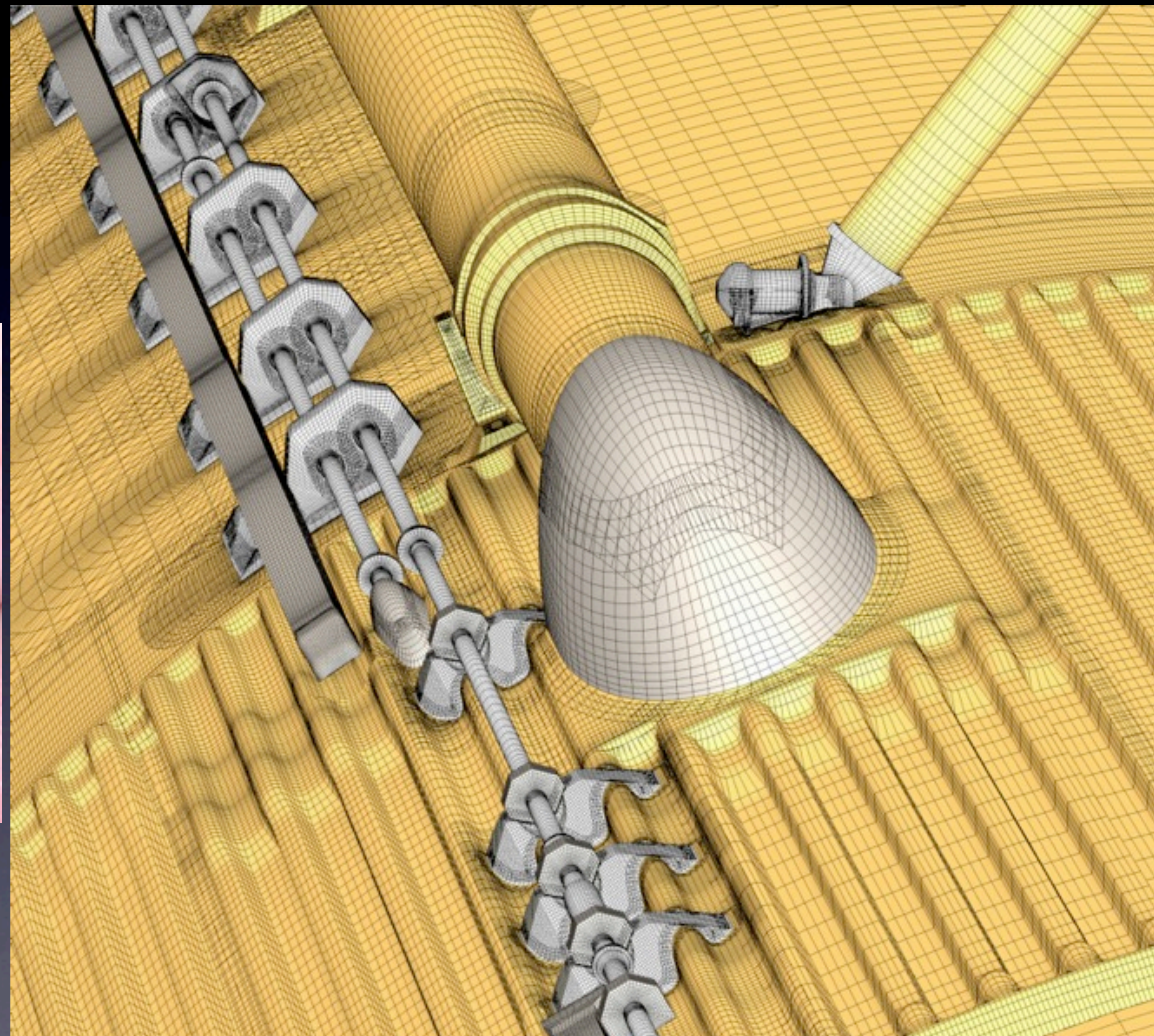
2004 grid system
267 Grids
636k surface points
34.8 million volume points


Current SSLV
Grid System
600+ Grids
1.8M surface points
95+ million volume points

Wind tunnel validation & CFD extrapolation







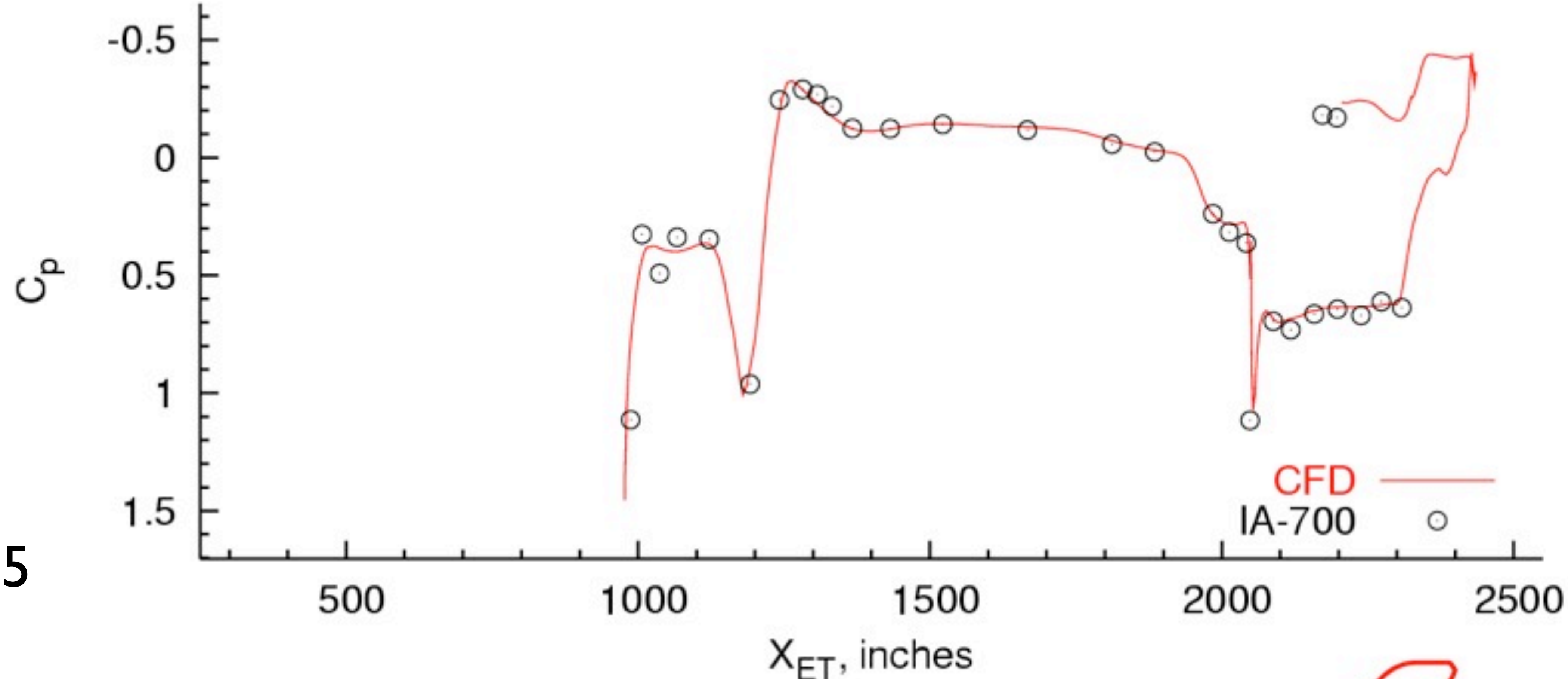
Wind Tunnel Test (IA-700) Comparisons - Orbiter - Phi = 180°

CFD conditions: M_∞ = 1.550, α = 0.00°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°

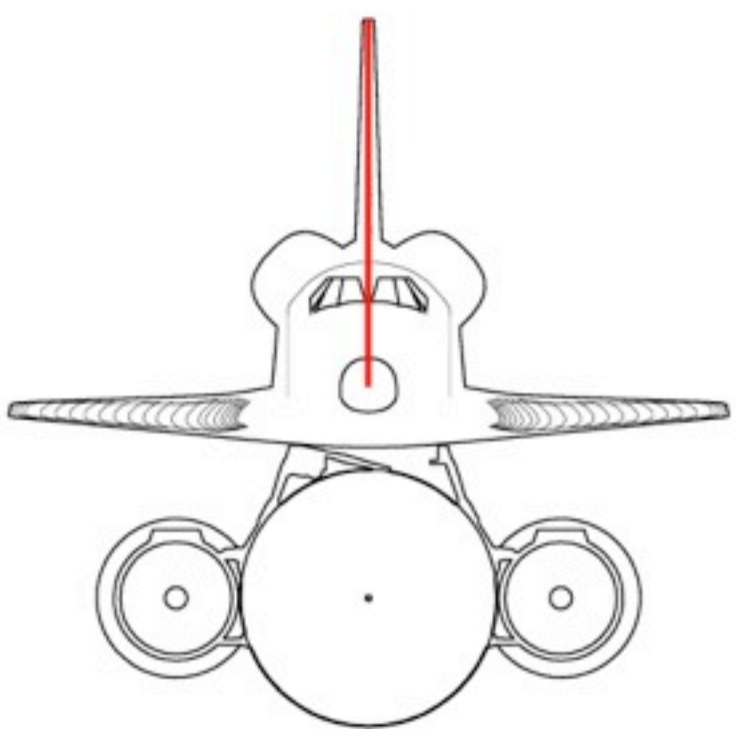
WTT conditions: M_∞ = 1.550, α = -0.12°, β = 0.06°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 212, Point = 4, LOX Roll = 0°

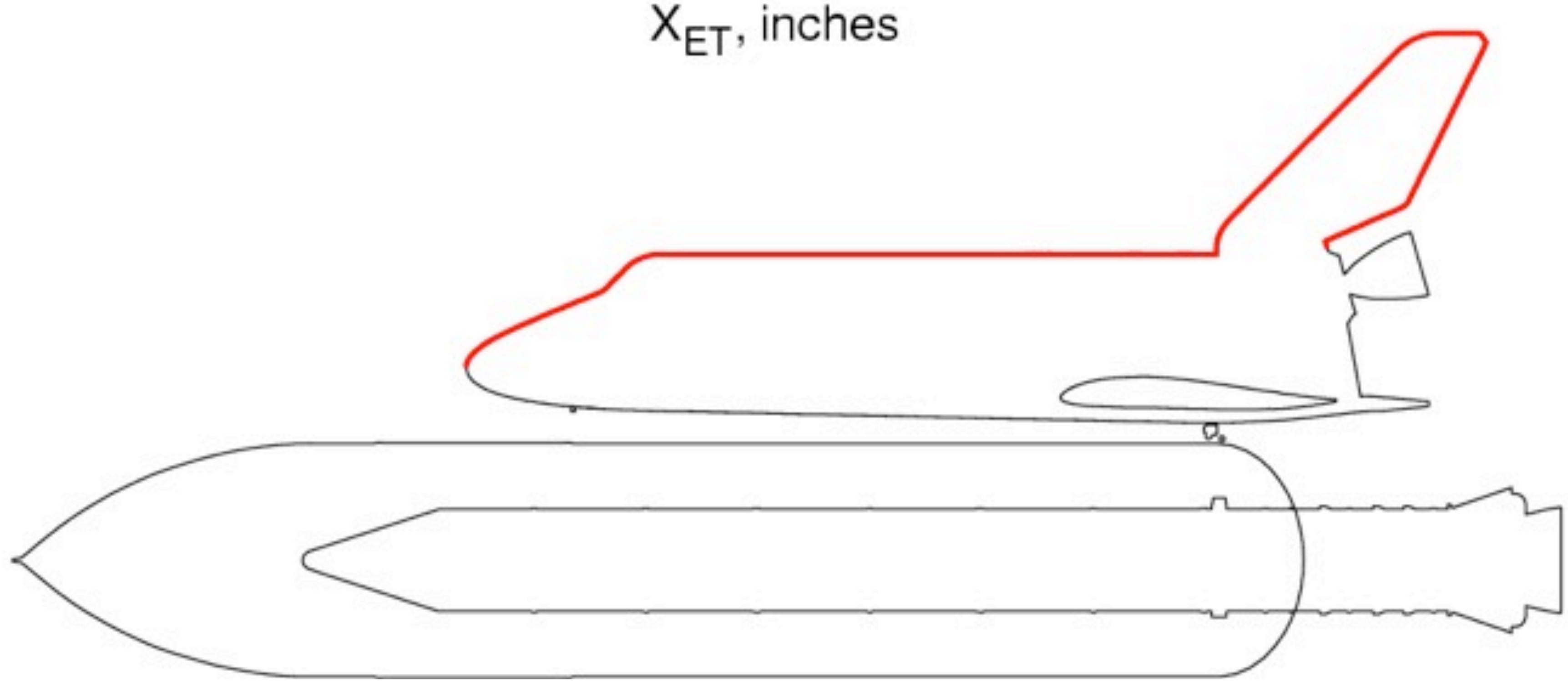
WTT conditions: M_∞ = 1.551, α = -0.10°, β = 0.06°, Reynolds # = 2.52 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 308, Point = 4, LOX Roll = 15°

WTT conditions: M_∞ = 1.551, α = -0.08°, β = 0.02°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 315, Point = 4, LOX Roll = -15°



JSC 2005-62925





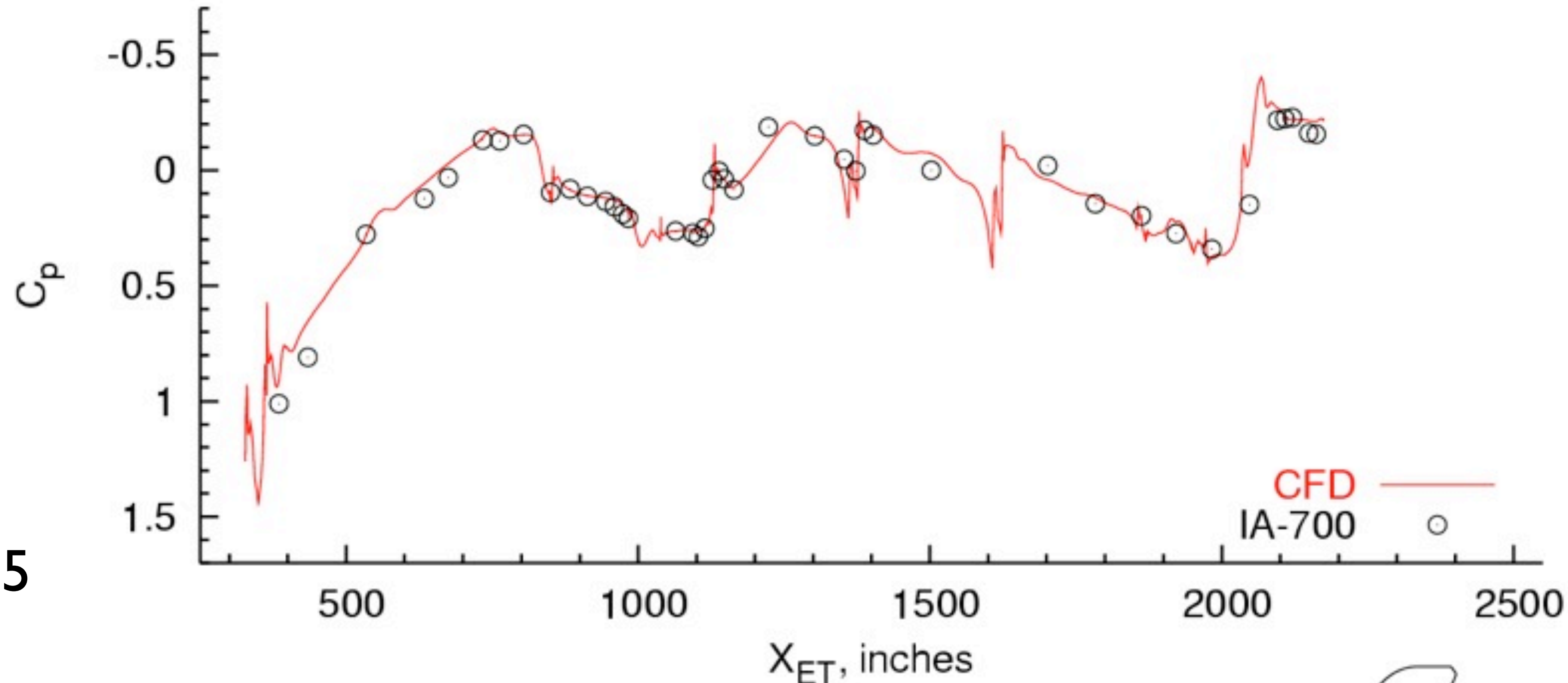
Wind Tunnel Test (IA-700) Comparisons - External Tank - Phi = 203.75°

CFD conditions: M_∞ = 1.550, α = 0.00°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°

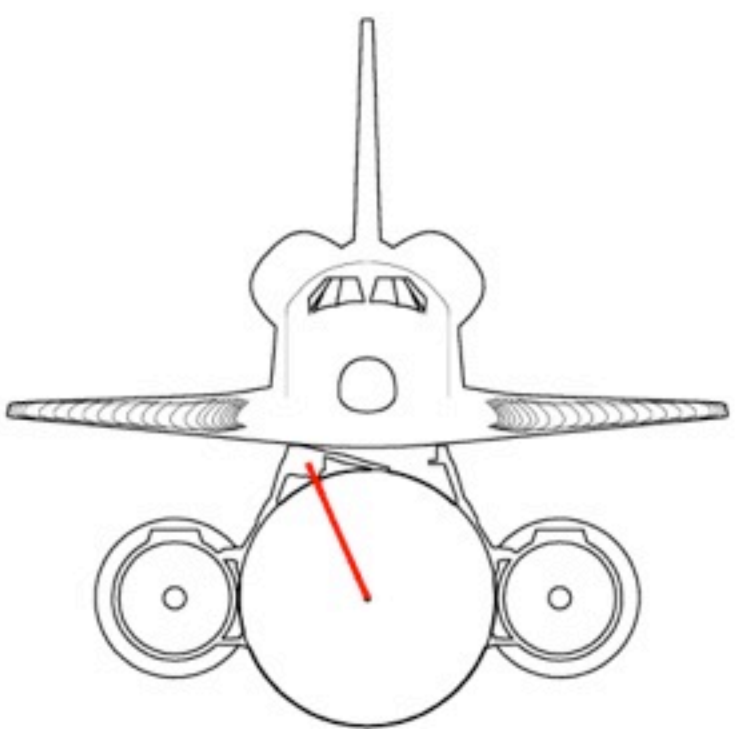
WTT conditions: M_∞ = 1.550, α = -0.12°, β = 0.06°, Reynolds # = 2.52 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 212, Point = 4, LOX Roll = 0°

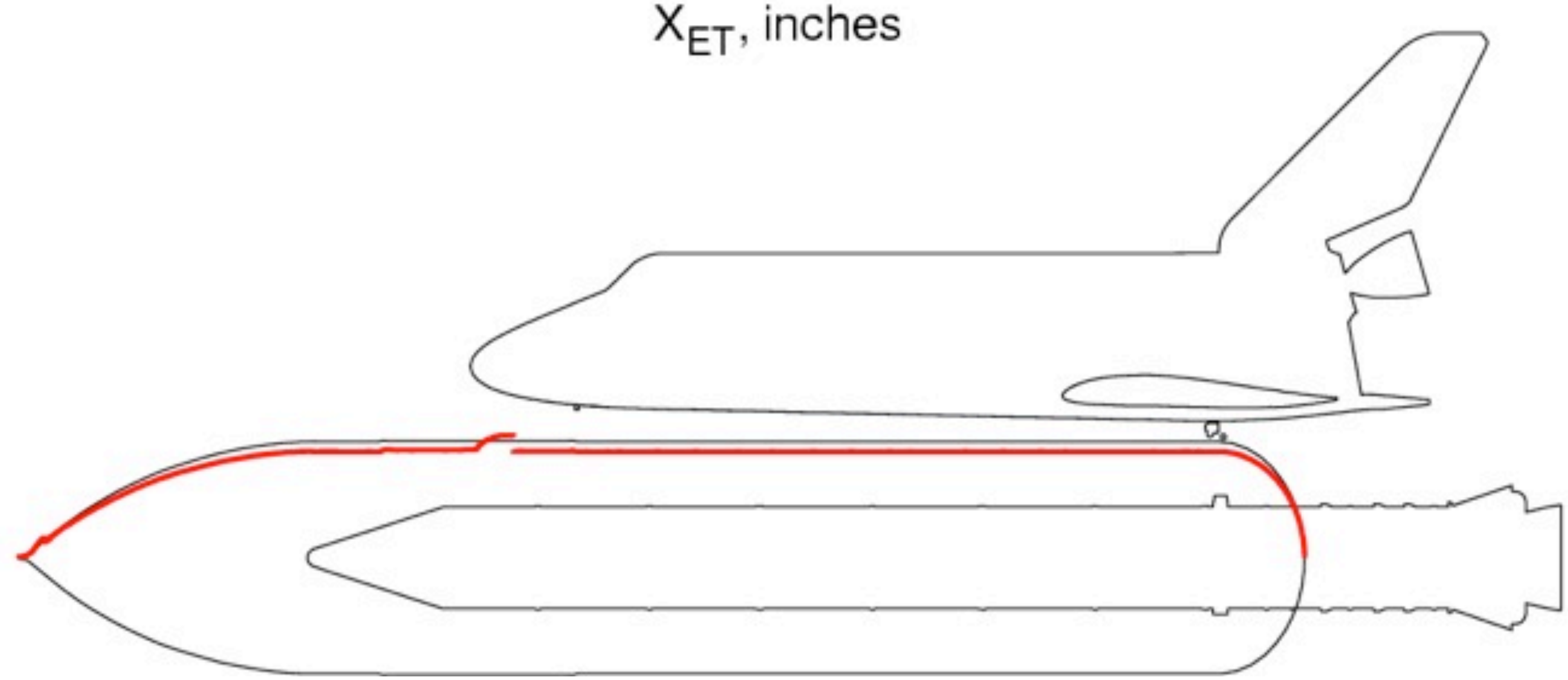
WTT conditions: M_∞ = 1.551, α = -0.10°, β = 0.06°, Reynolds # = 2.54 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 308, Point = 4, LOX Roll = 15°

WTT conditions: M_∞ = 1.551, α = -0.08°, β = 0.02°, Reynolds # = 2.52 x10^6/ft, IB elevon = 10.00°, OB elevon = -2.00°, Run = 315, Point = 4, LOX Roll = -15°



JSC 2005-62925





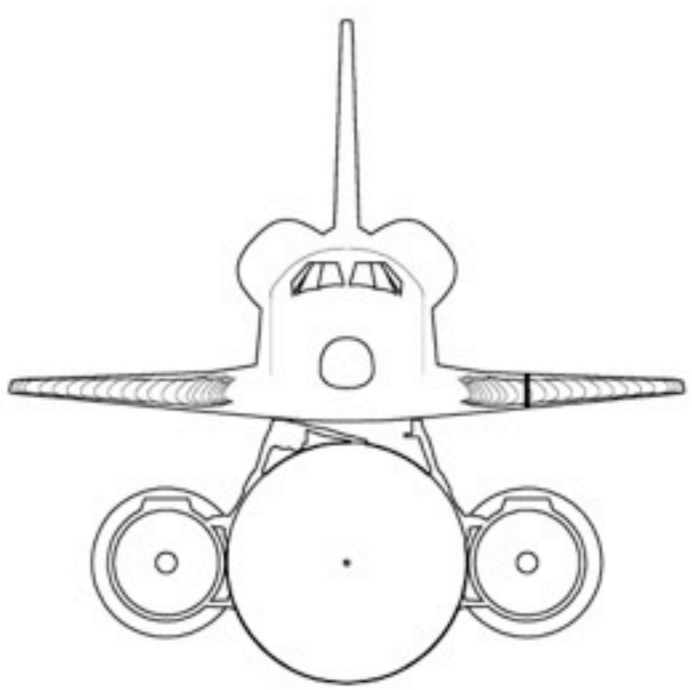
CFD vs. IA-613B Wing Pressures

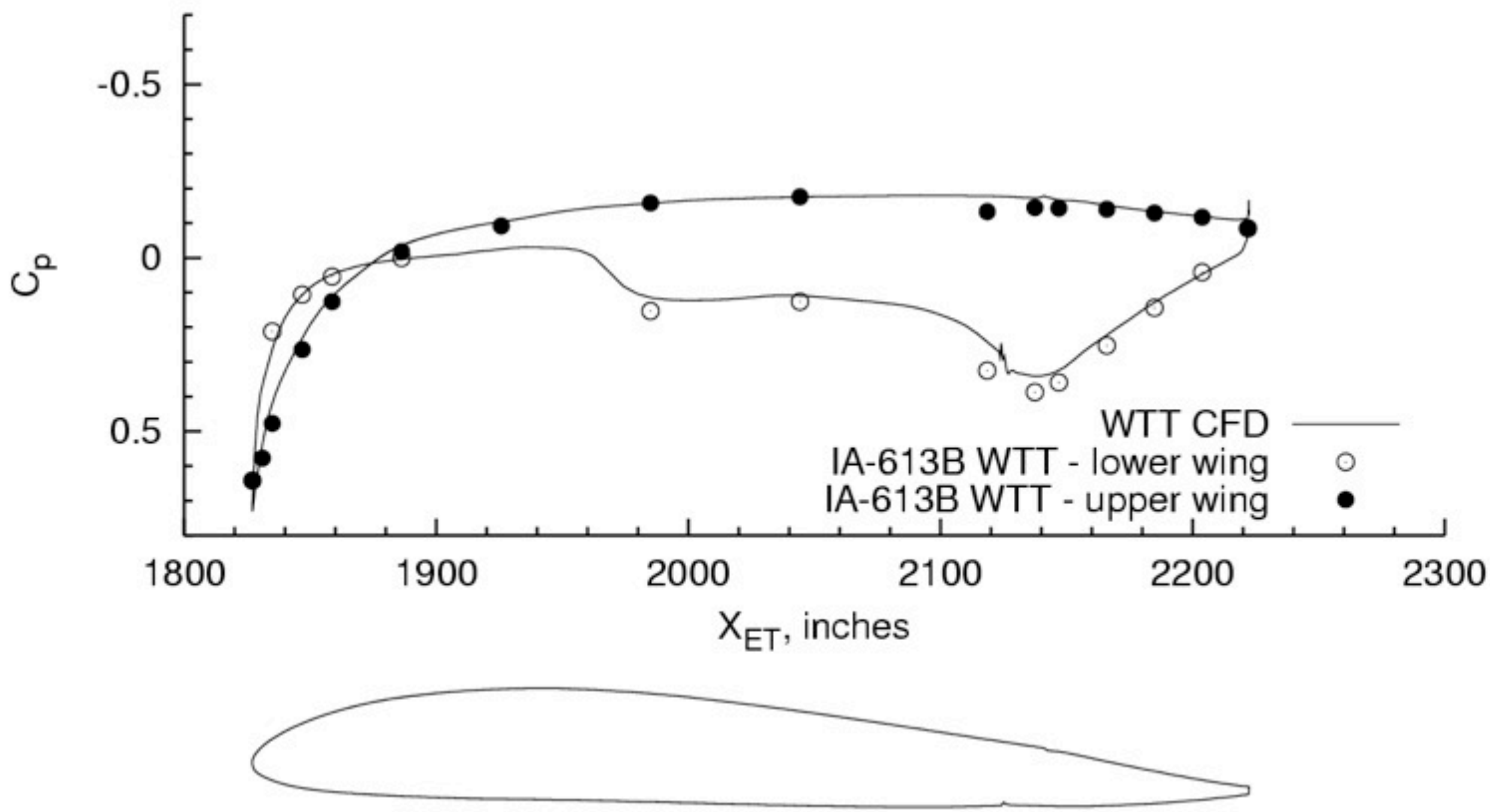
Mach 2.50, Y = -250”

CFD run with as measured elevons

CFD conditions: M_∞ = 2.50, α = 2.03°, β = 0.00°, Reynolds # = 2.50 $\times 10^6$/ft, IB elevon = 4.07°, OB elevon = -4.39°

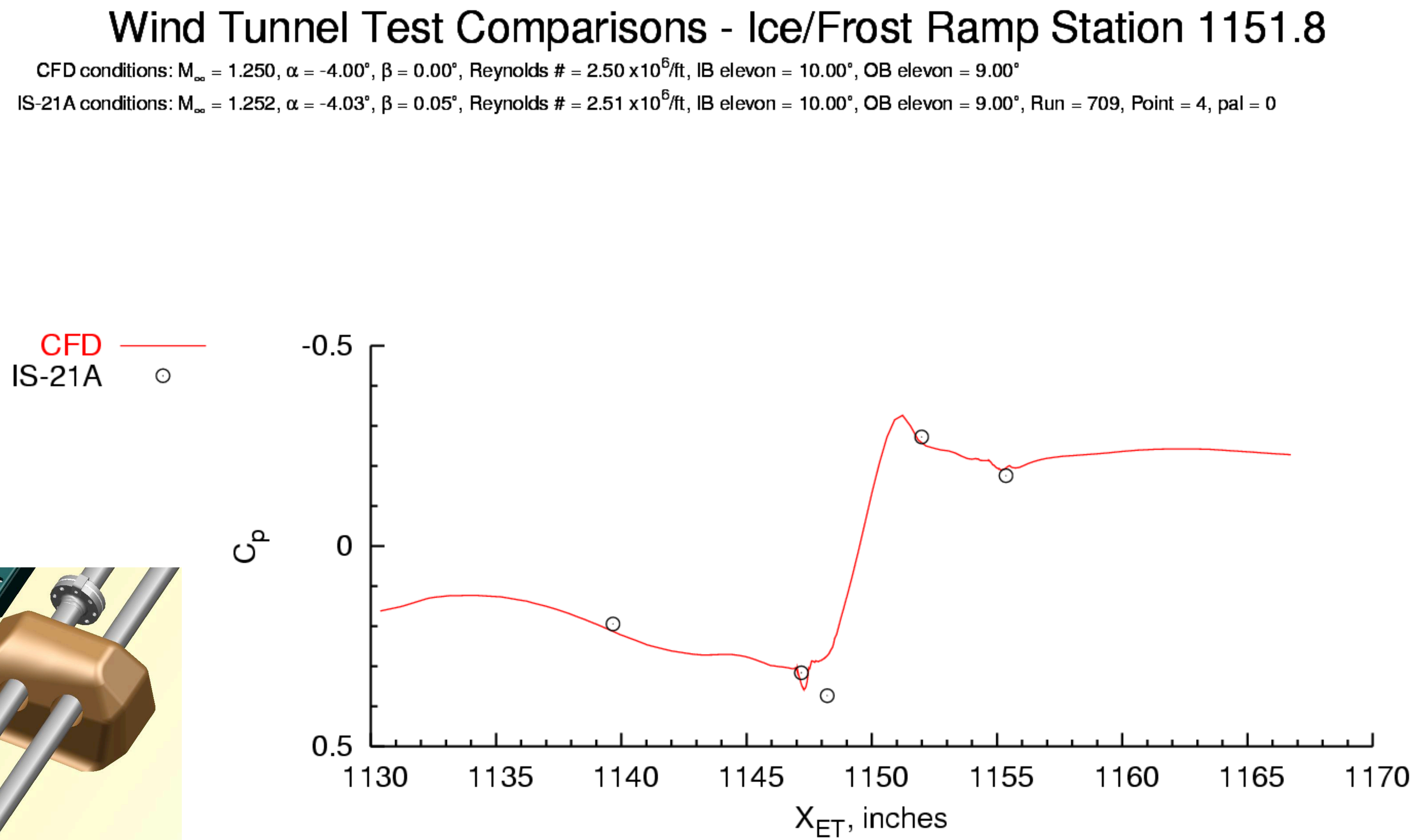
WTT conditions: M_∞ = 2.50, α = 2.03°, β = 0.00°, Reynolds # = 2.50 $\times 10^6$/ft, IB elevon = 4.07°, OB elevon = -4.39°

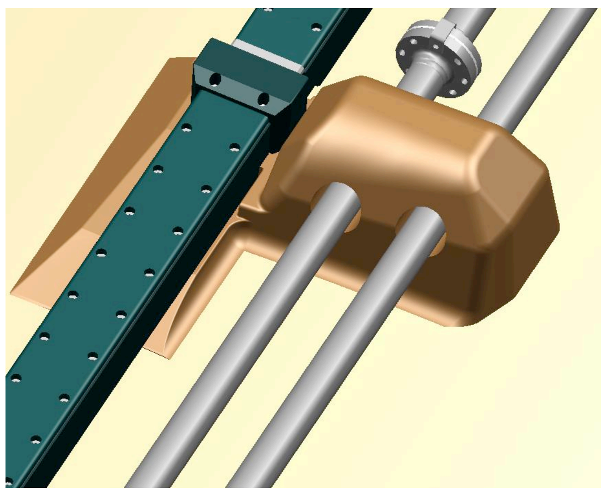


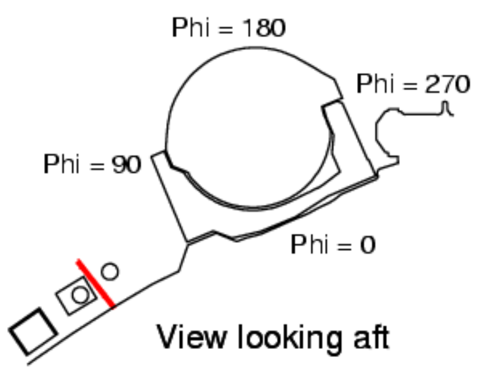


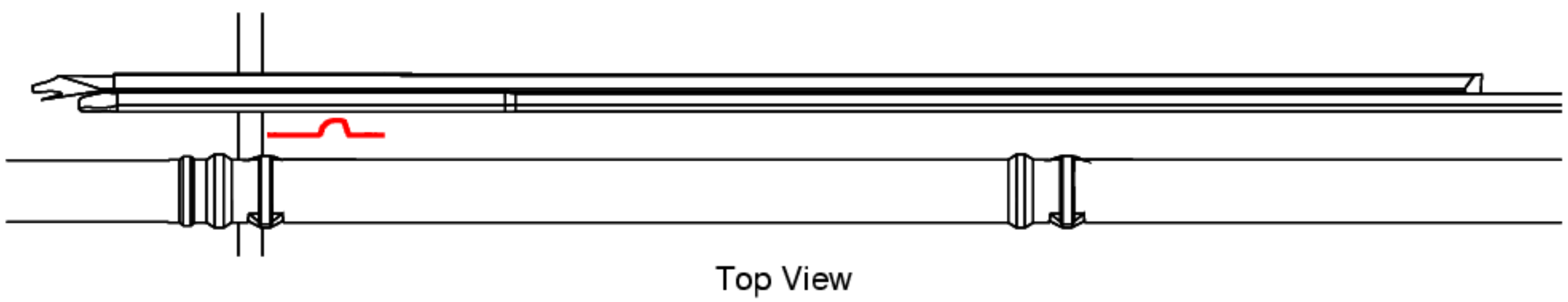
AIAA 2004-2226

Proposed ice/frost ramp configuration, tested but not flown.









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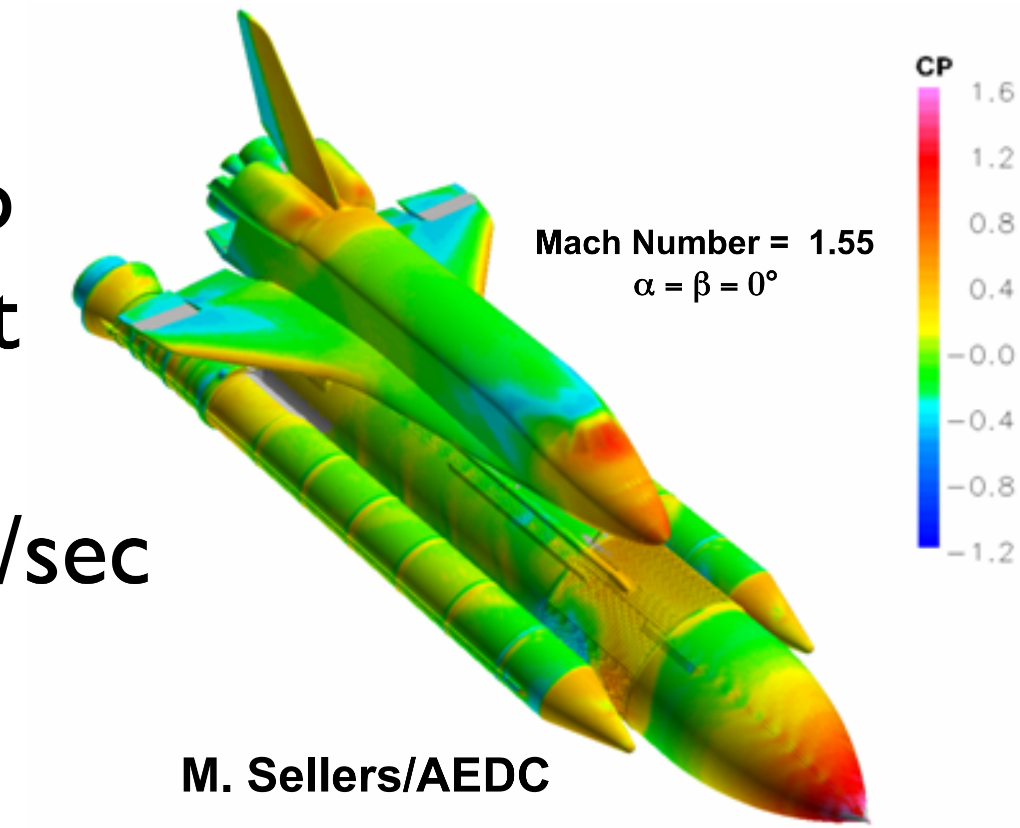
Offbody and integrated validation was required to support debris transport tools.

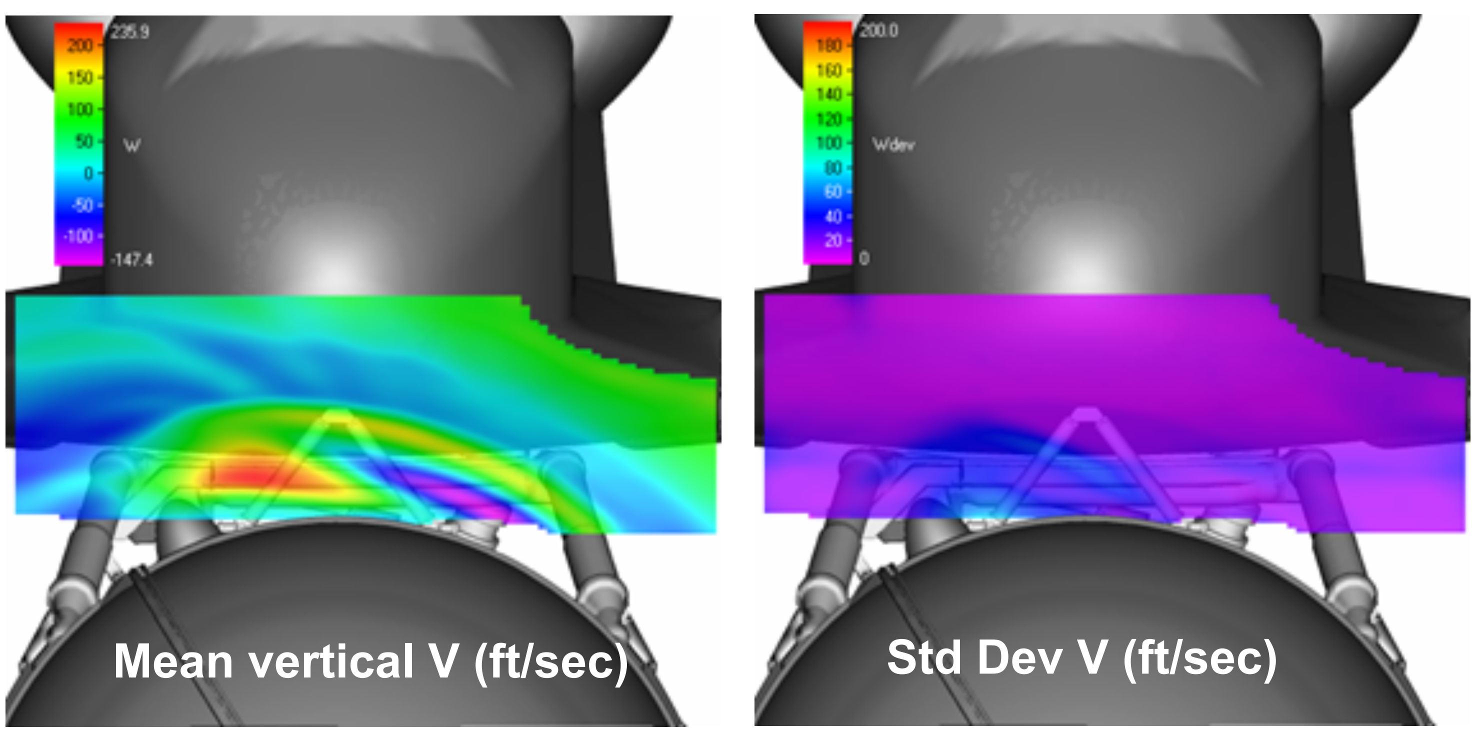
Pressure sensors vs. CFD ≈ 0.01 Cp

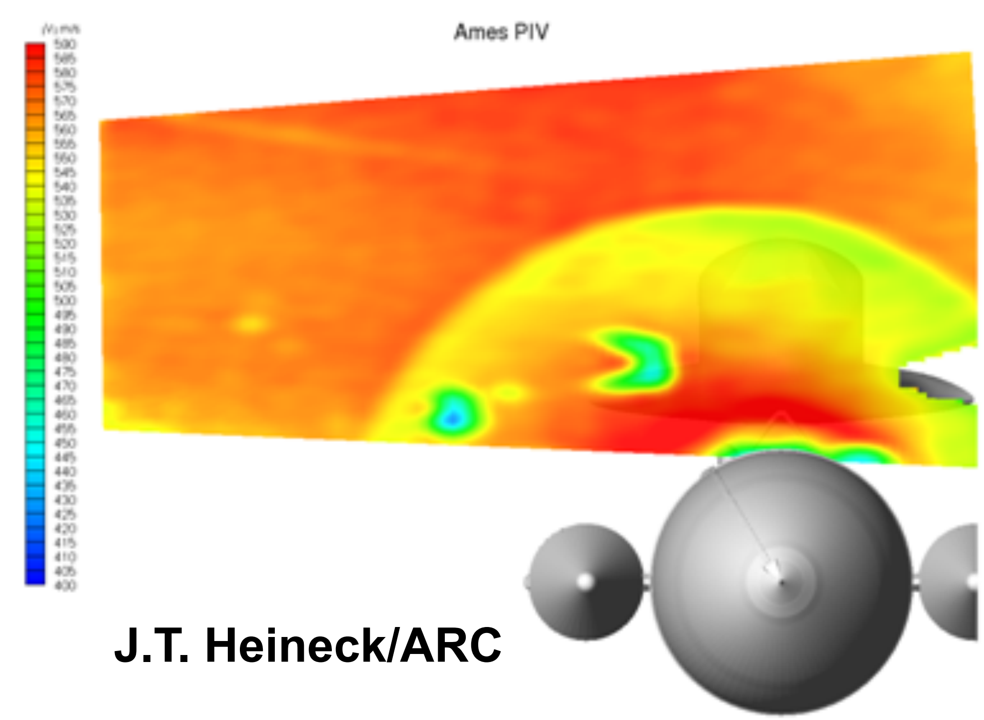
Integrated Loads vs. CFD ≈ 5% of flt

Pressure Sensitive Paint

Particle Imaging Velocimetry ± 20 ft/sec







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Grid Generation Automation

GlobalDefs.tcl

```
set Configuration OrbiterET

set ShockGrid     0
set PlumeGrid     0
set ETGrid        1
set BprGrid       1
set YokeGrid      1
set FwdIFRamps    0
set AftIFRamps    0

set BflapDeflection       0.000
set ObLeftElevonDefl      0.000
set IbLeftElevonDefl      0.000
set IbRightElevonDefl     0.000
set ObRightElevonDefl     0.000
set Gimbal(pitch,ssmet) 16.000
set Gimbal(pitch,ssmel) 10.000
set Gimbal(pitch,ssmer) 10.000
set Gimbal(pitch,lsrb)    0.000
set Gimbal(pitch,rsrb)    0.000
set Gimbal(yaw,ssmet)     0.000
set Gimbal(yaw,ssmel)     3.500
set Gimbal(yaw,ssmer)    -3.500
set Gimbal(yaw,lsrb)      0.000
set Gimbal(yaw,rsrb)      0.000

set TunnelRoll        -31.185
set TunnelPitch       -11.646

set InitialWallSpaceing 1.6e-4
```

Configuration

Intra-Configuration Options

Control Surface Deflections

Engine Gimbals

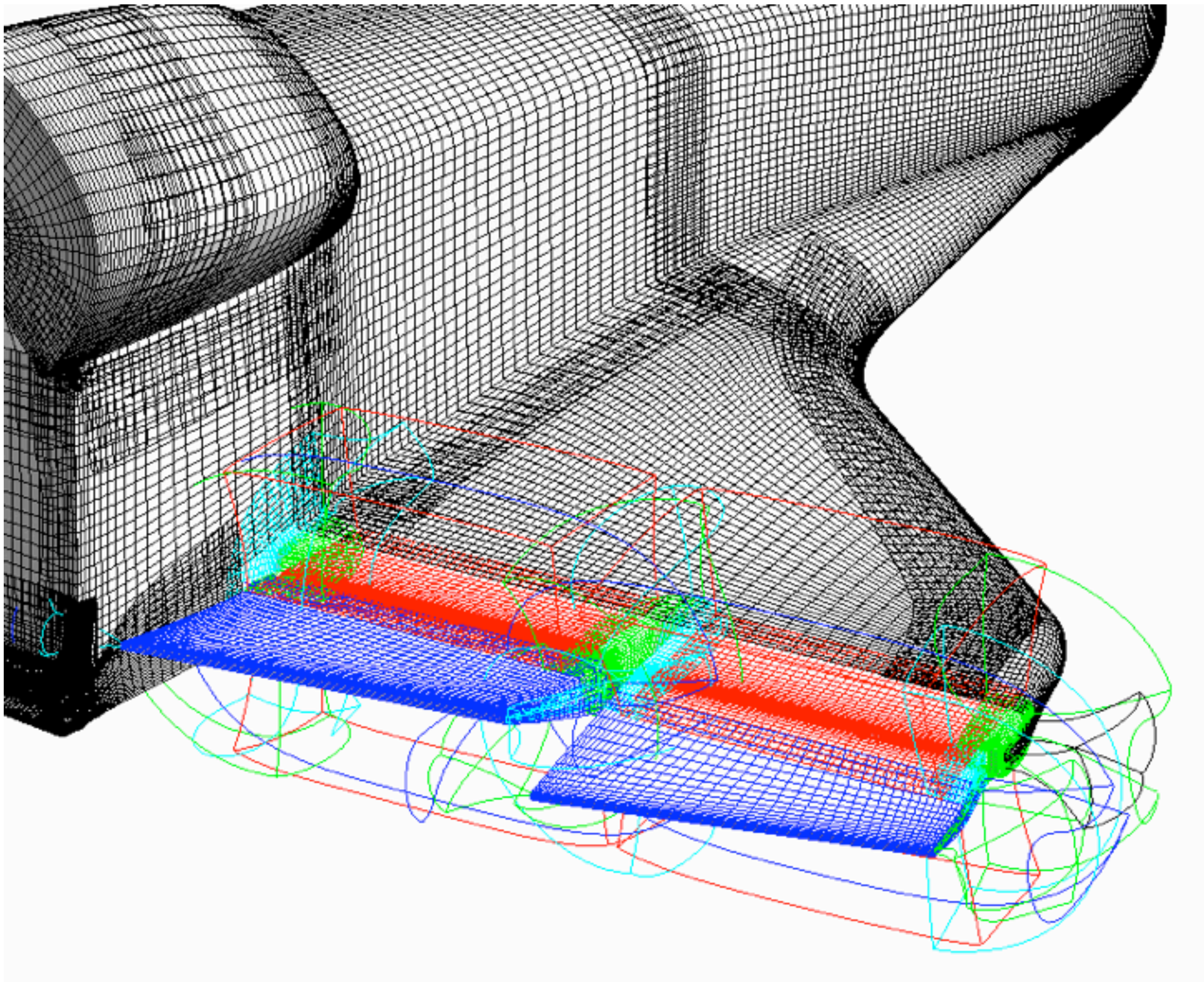
Tunnel Controls

Viscous Spacing

To build a grid system:

```
% BuildControlSurf
% BuildGimbNoz
% BuildVol
% BuildPeg5i
% addmanual.pl
% pegasus5 < peg.i.mod
% BuildMixsuri
% BuildOveri
% mkplumes
```

Scripted control surface motion is key to automation.



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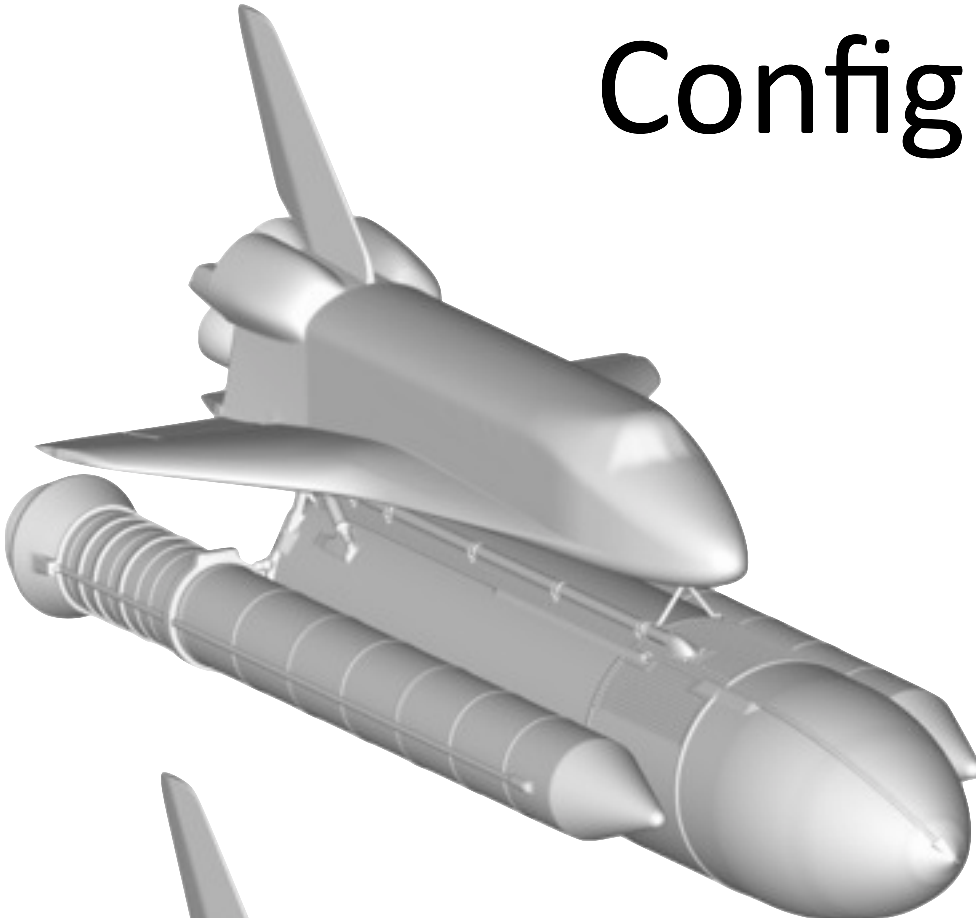
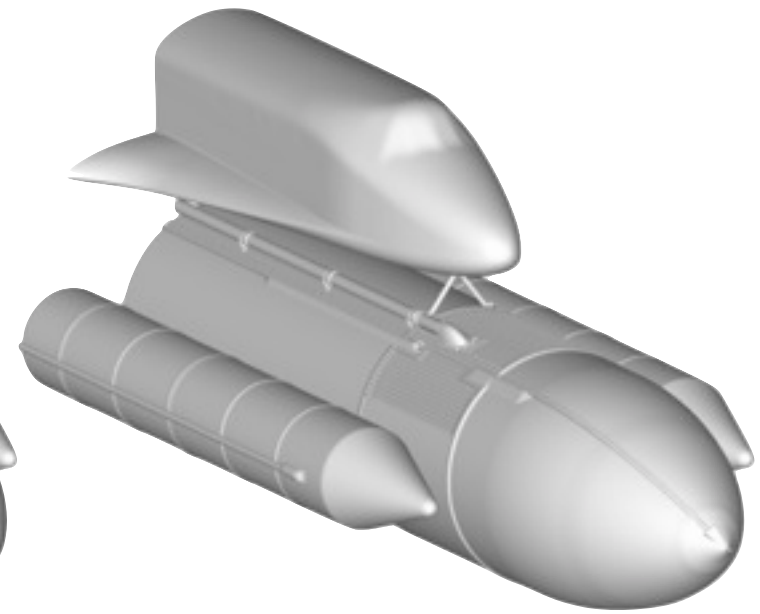
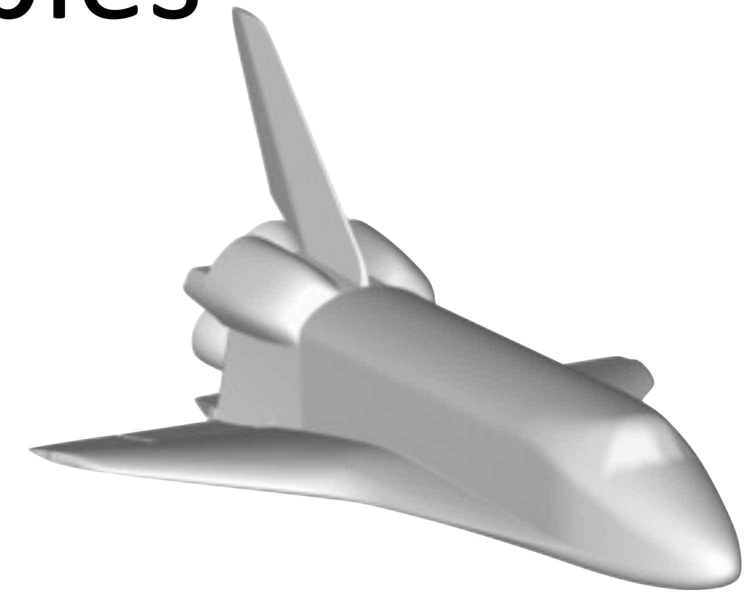
Configuration Examples



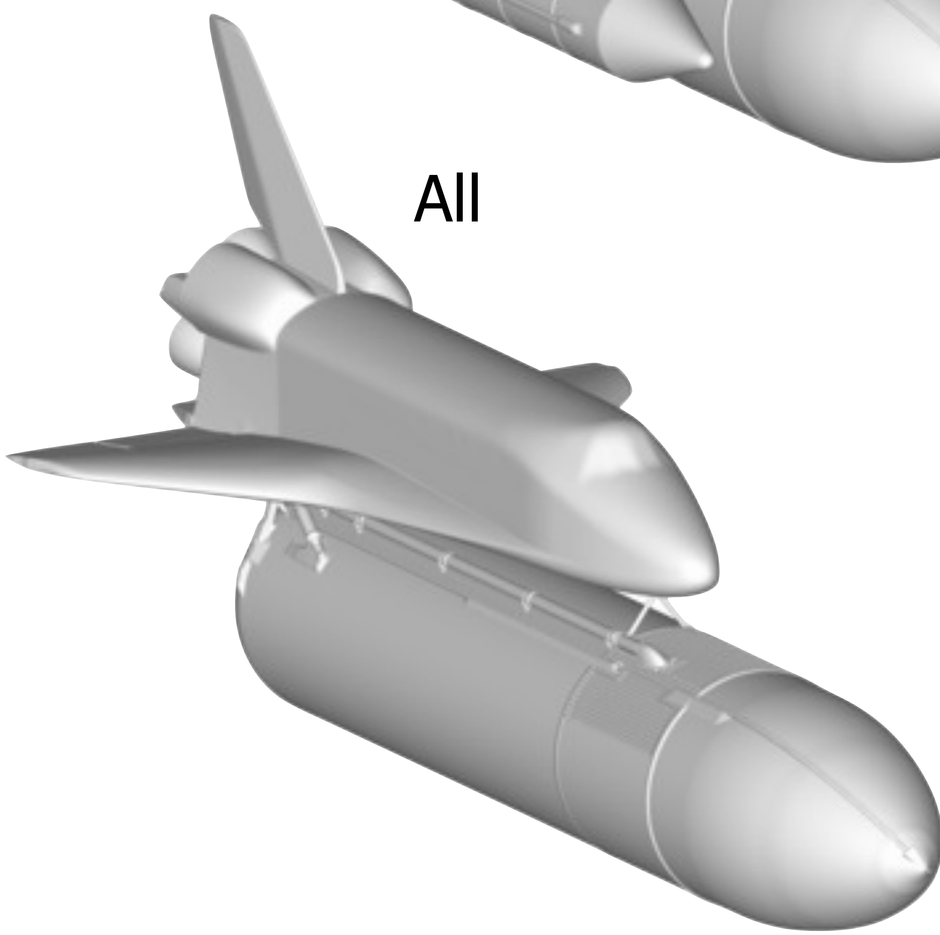
All



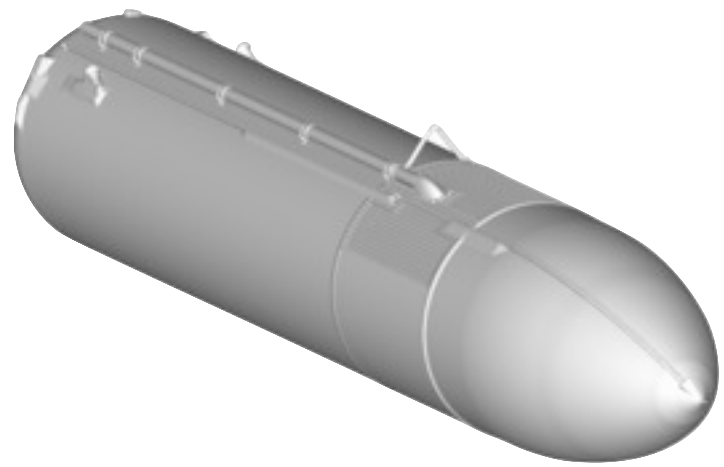
AllShort



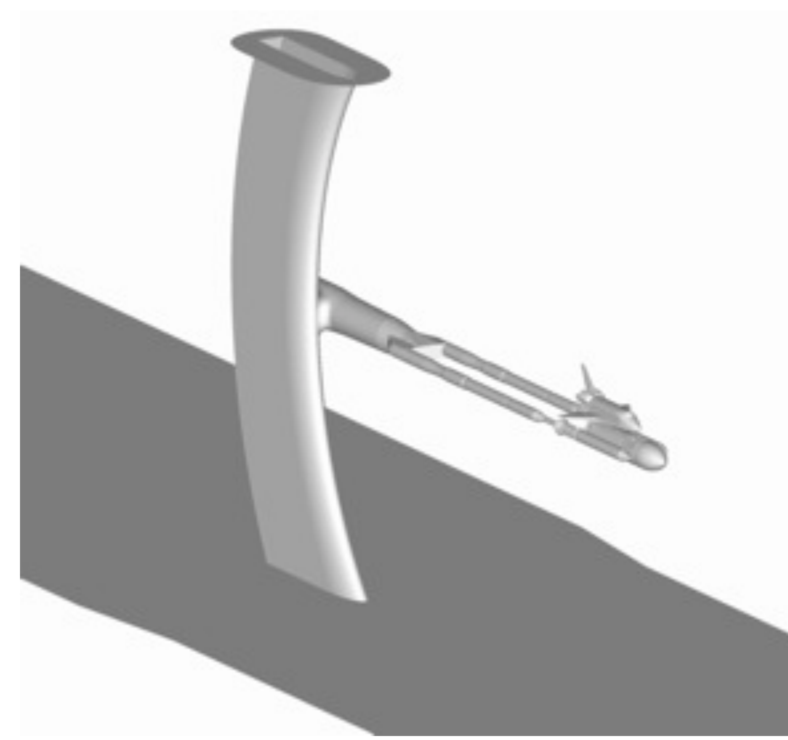
Orbiter



OrbiterET



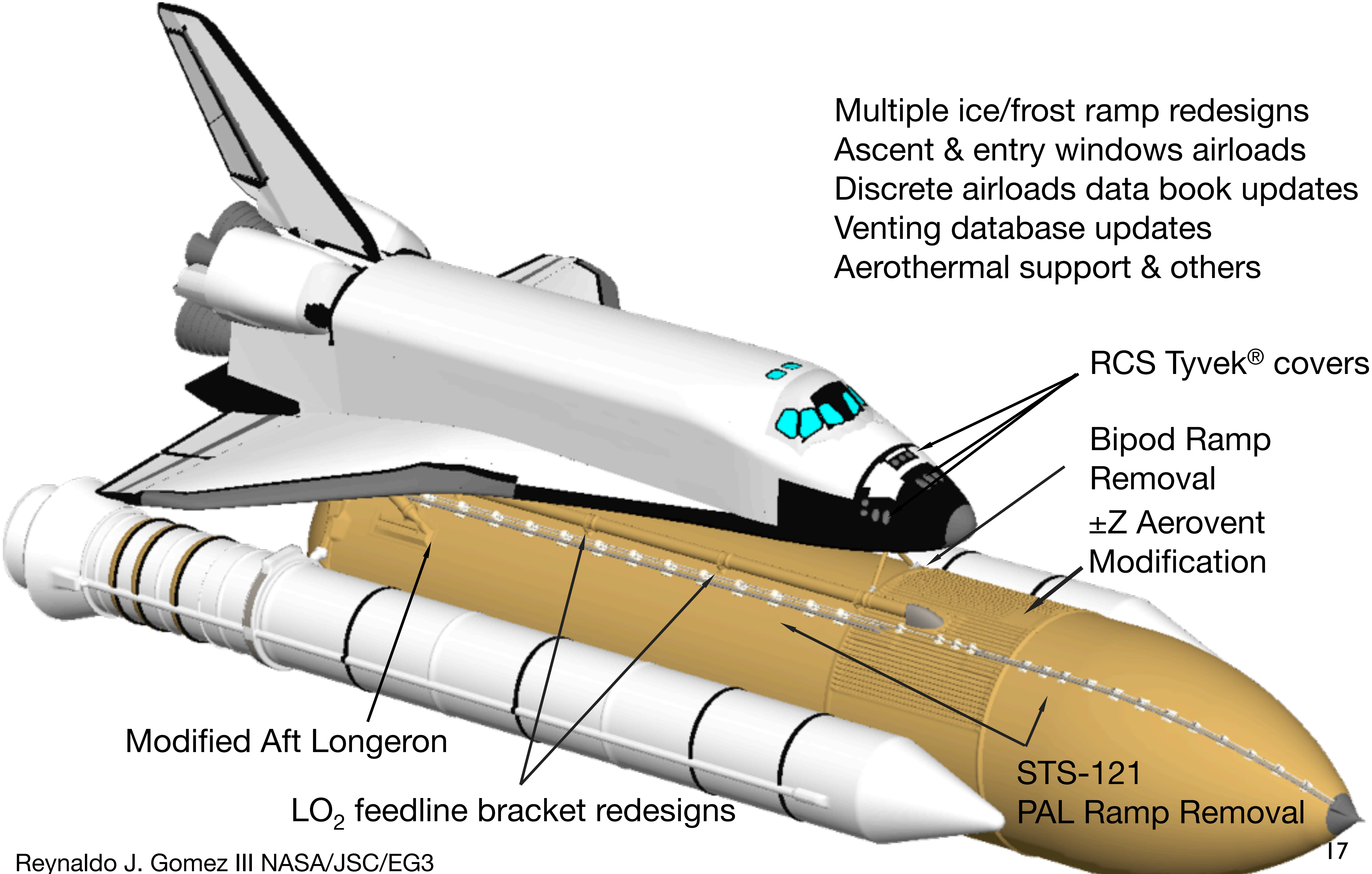
External Tank



IA700A

Overset CFD was a key input to many External Tank redesign assessments.

Multiple ice/frost ramp redesigns
Ascent & entry windows airloads
Discrete airloads data book updates
Venting database updates
Aerothermal support & others



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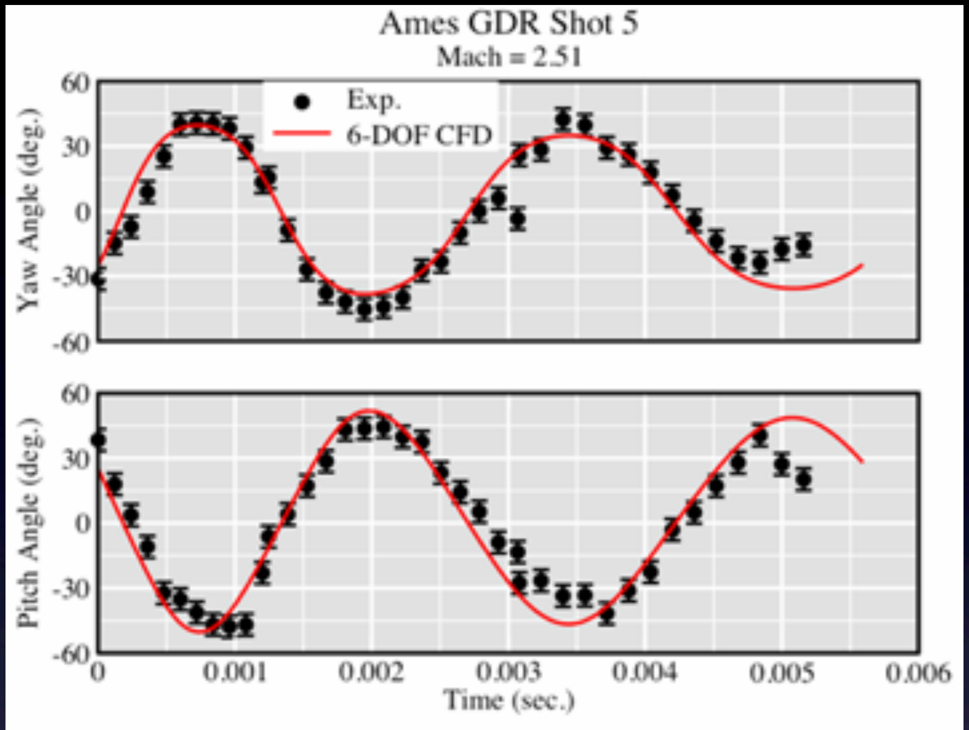
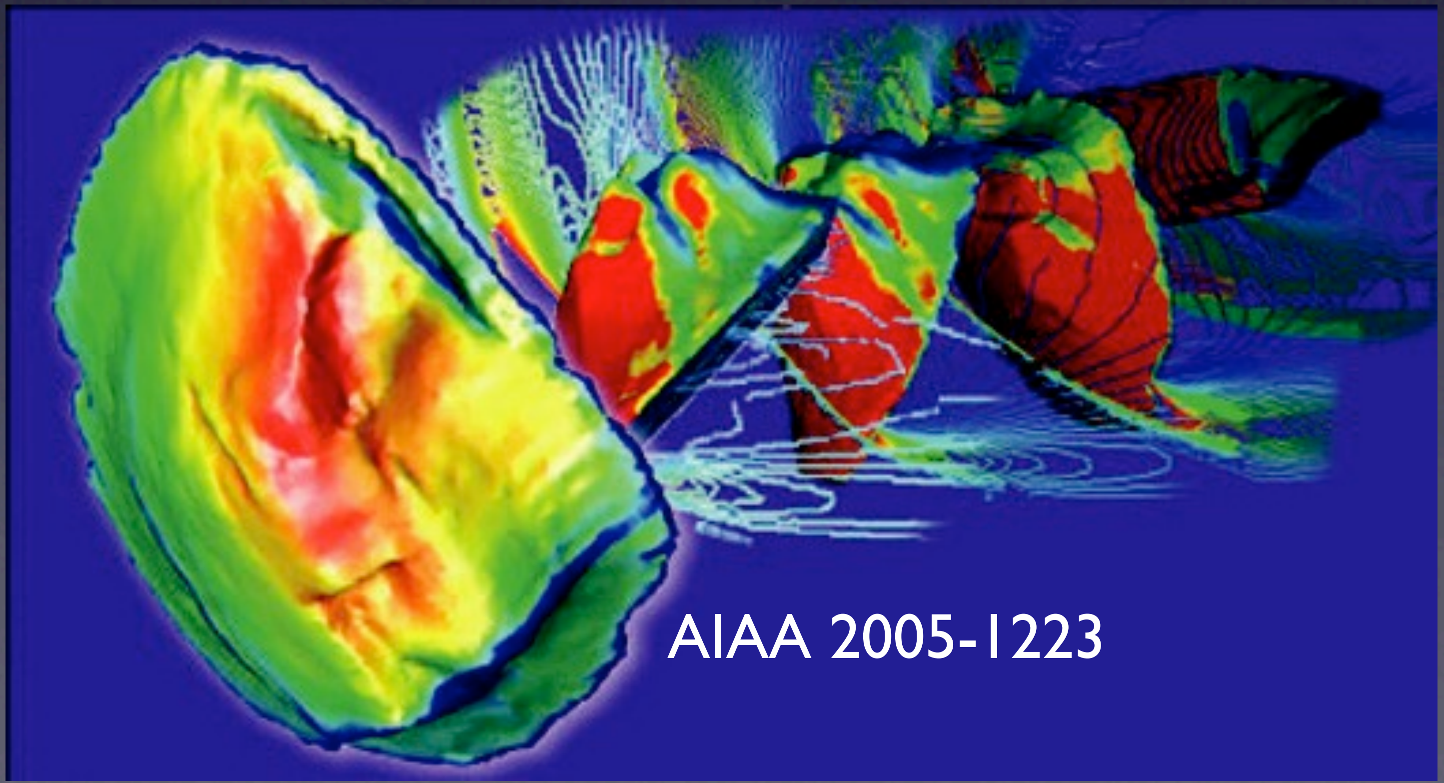
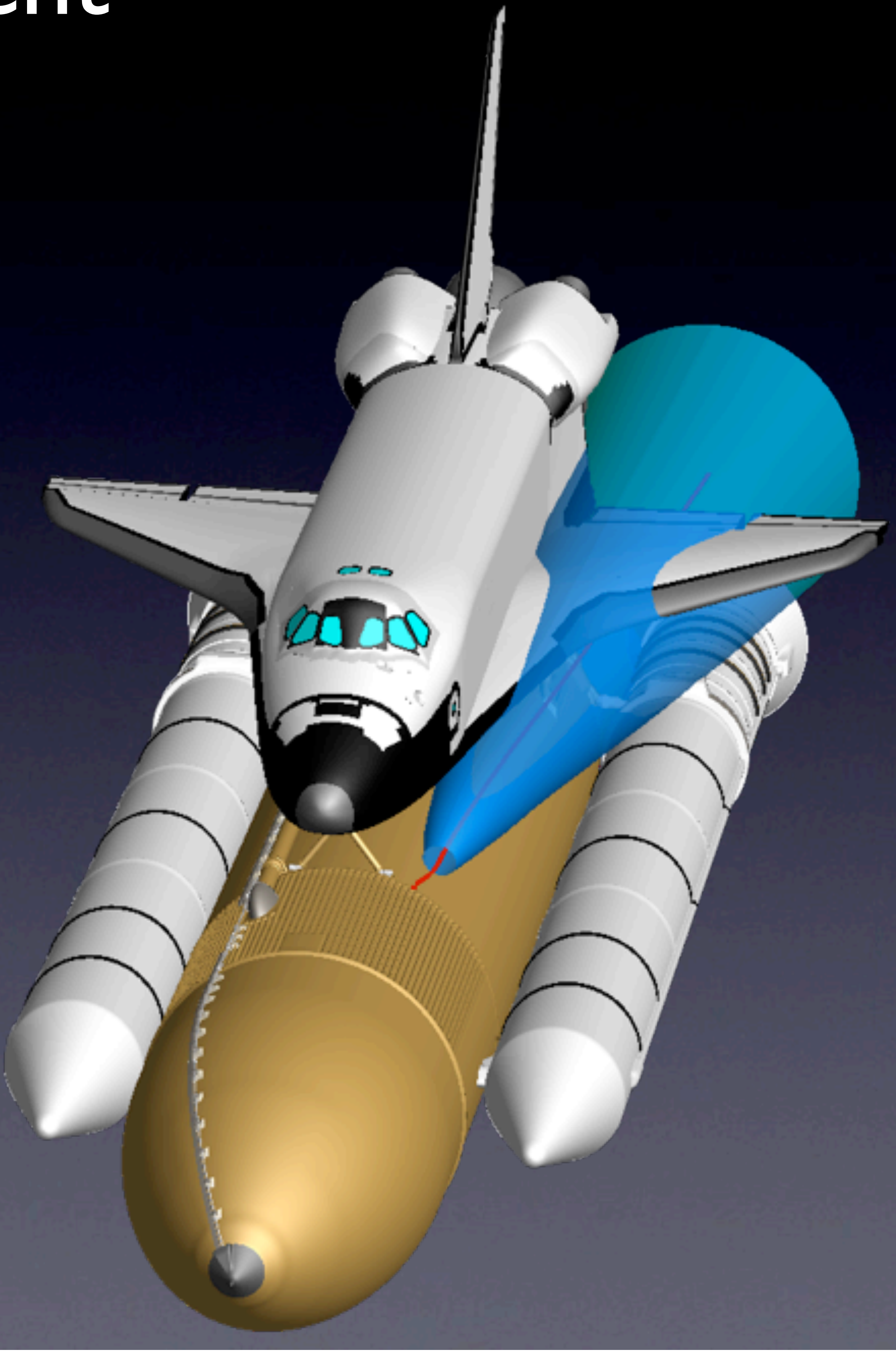
Debris transport aerodynamic models & prediction tools development

AIAA-2006-0662

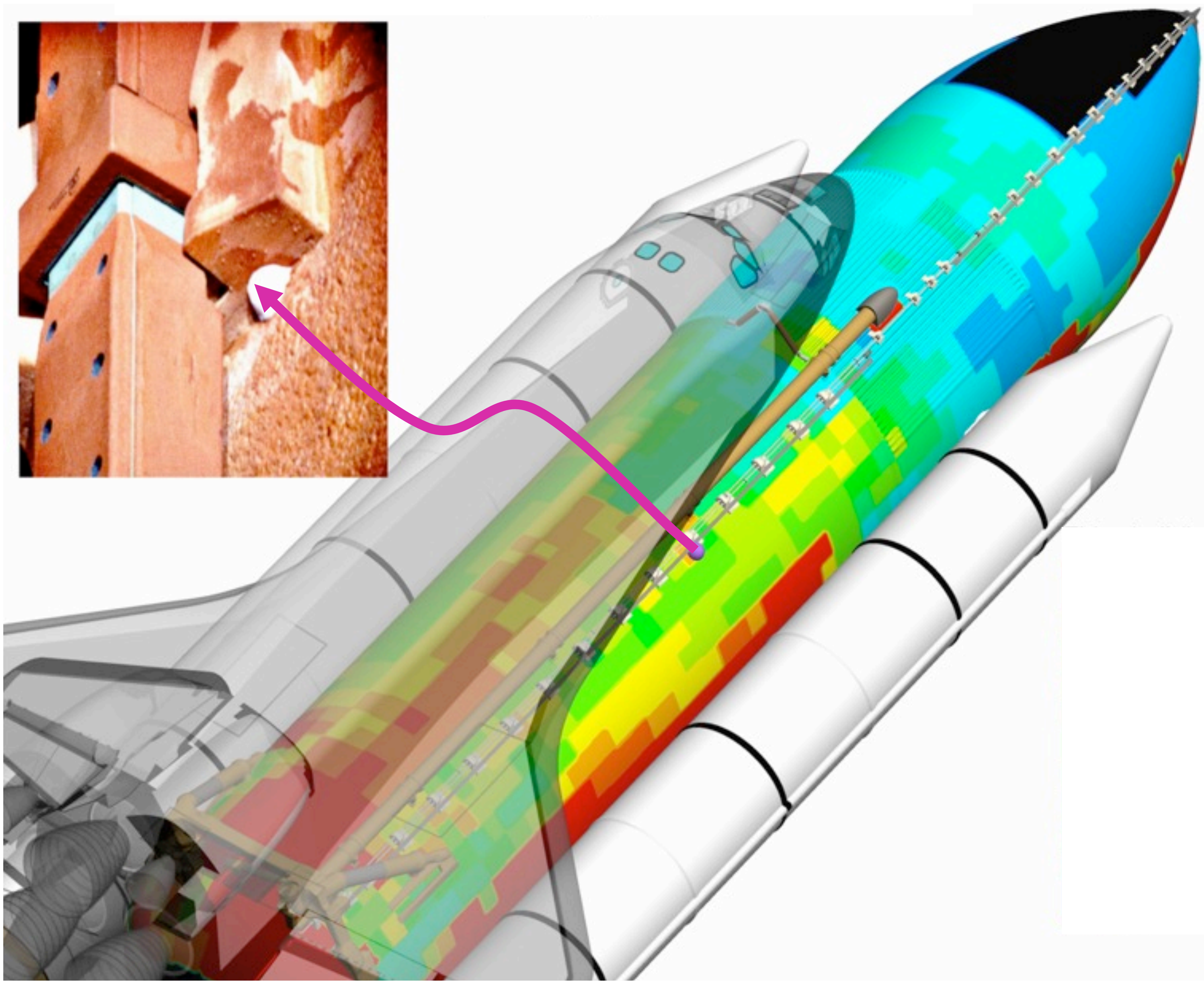




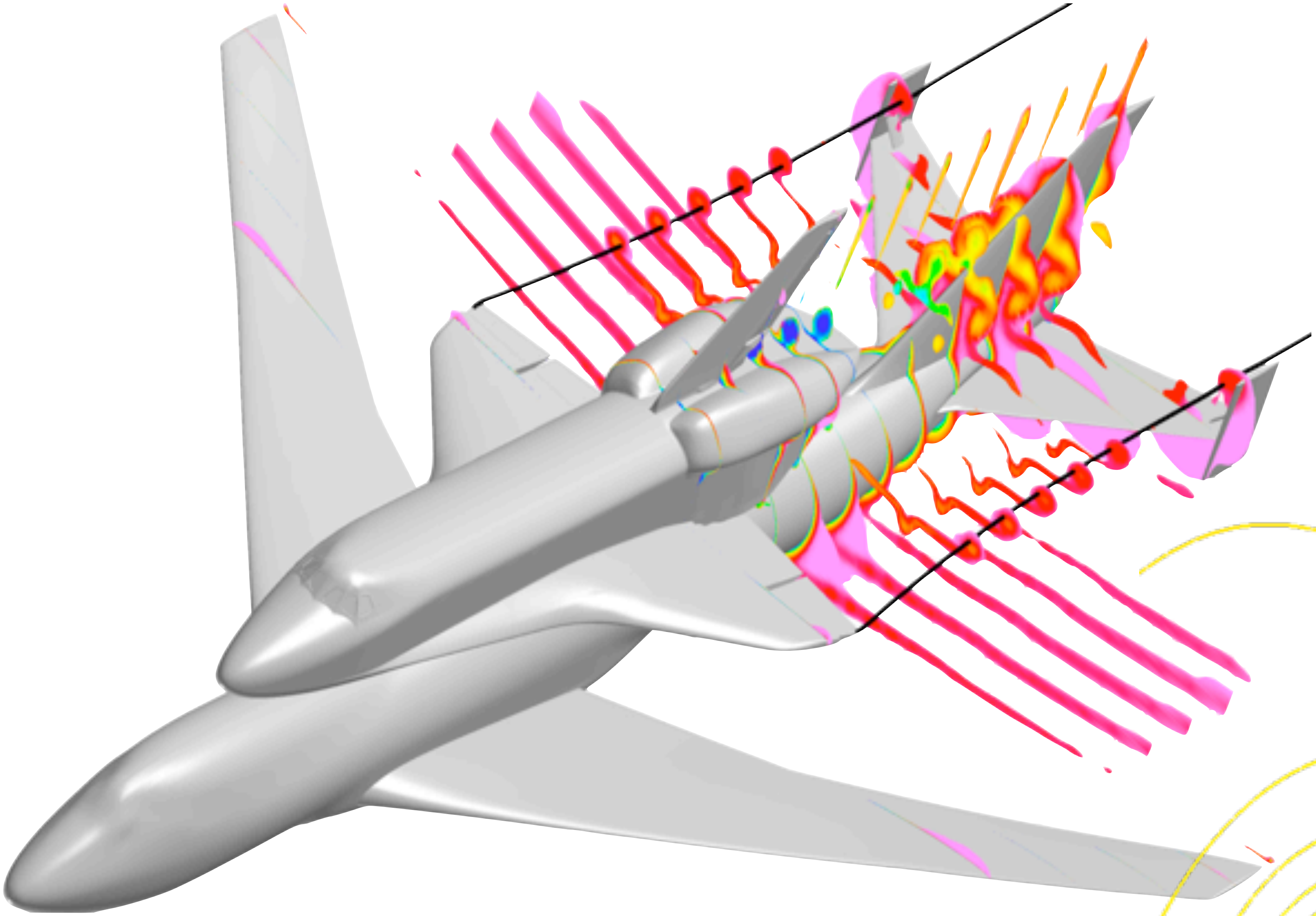
AIAA 2005-1223



NSTS 08303 day of launch ice ball launch commit tool developed by Stuart Rogers/ARC NAS-07-004

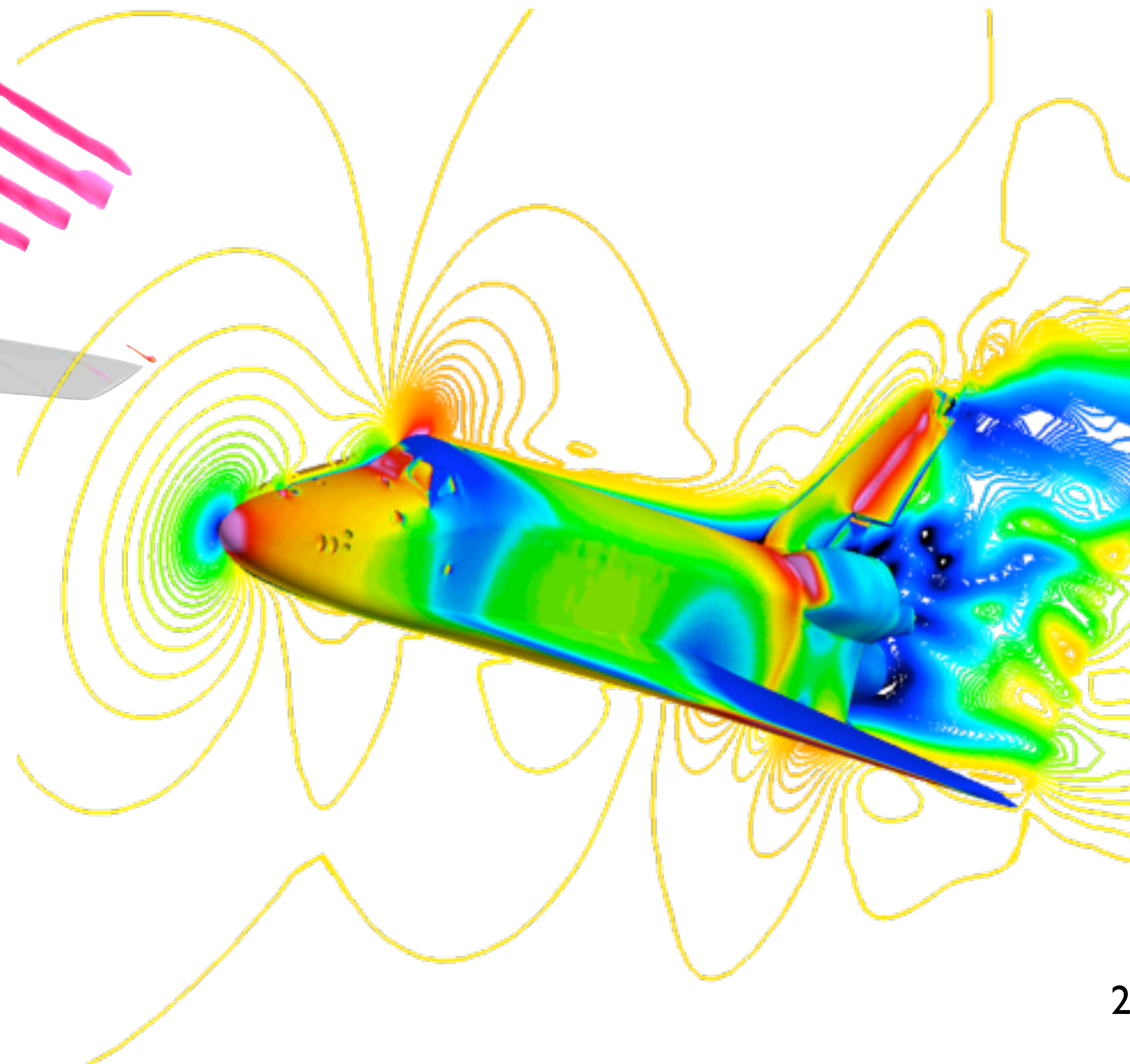


Other applications



Shuttle Carrier Aircraft
Mach = 0.3, α = 3°
G. Schauerhammer

Entry Calculations
Mach = 0.8, α = 17°
L. Marek/JSC



Timeline of Computing & Overset Space Shuttle Applications

Cray X-MP
0.2 Gflops

Cray Y-MP
2.5 Gflops

SGI Origin 2000
128 Gflops

SGI Altix
2.3 Tflops

Pleiades
608 Tflops

NAS
Begins

Cray 2
2 Gflops

Cray C90
15 Gflops

SGI Origin 3800
1.2 Tflops

Columbia
67 Tflops

ARC3D

F3D

Chimera
Grid Tools

Pegasus5

Overflow 2.1

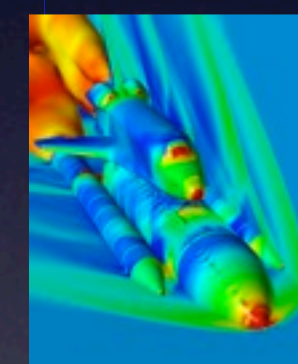
Overflow 2.2

INS3D

Overflow 1.6

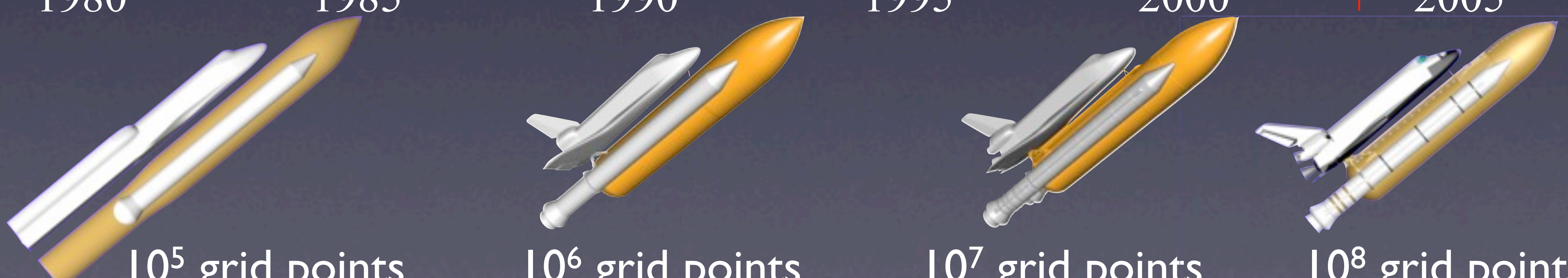
Overflow 1.8

Overflow 2.0



STS-107

1980 1985 1990 1995 2000 2005 2010



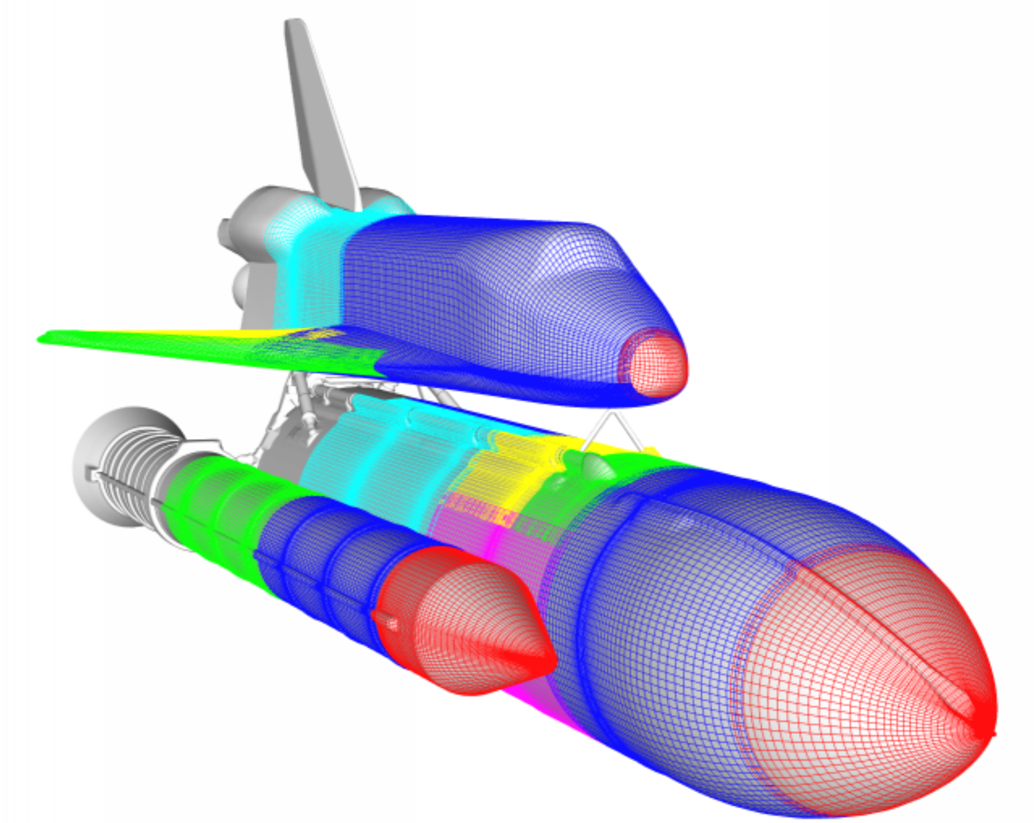
10^5 grid points

10^6 grid points

10^7 grid points

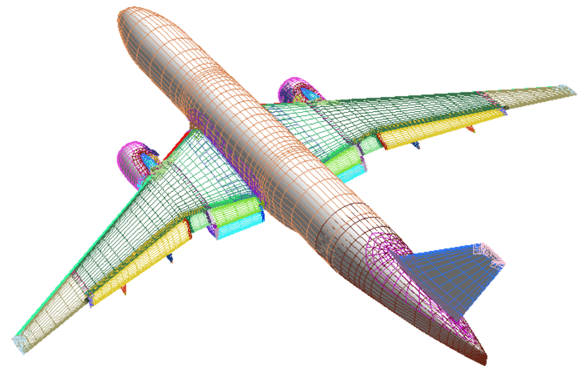
10^8 grid points

Overset Legacy



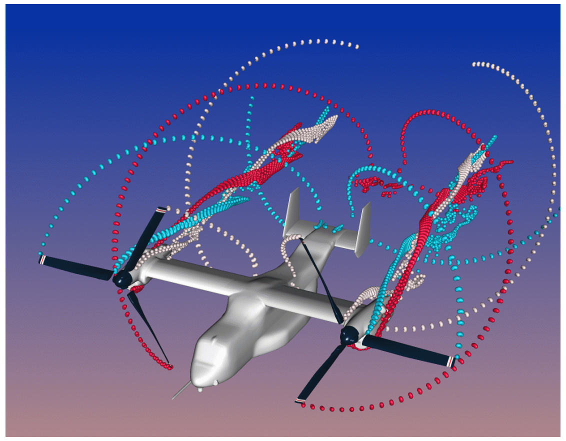
SSLV 1987-1993

Initial OVERFLOW development, collar grids, complex geometry issues, plumes



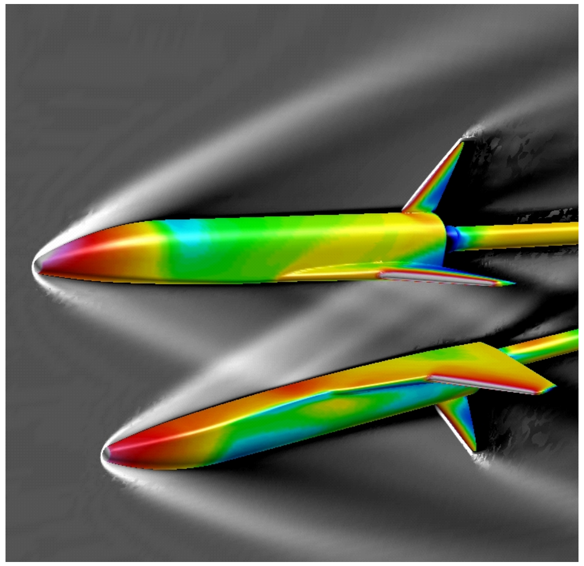
Advanced Subsonic Transport 1987-1993

Chimera Grid Tools, tcl scripting, turbulence modeling, PEGASUS 5



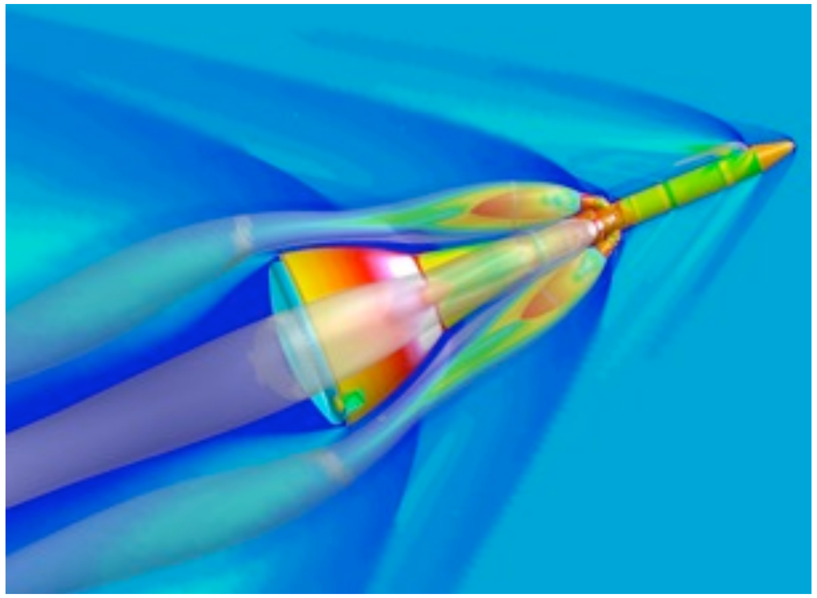
DoD High Performance Computer Modernization Project 1992-present

OVERGRID, OVERFLOW-D, rotorcraft applications.



Space Launch Initiative 2000-2002

OVERFLOW 2.0, moving body tools



Constellation 2004-2010

OVERFLOW 2.1, robustness improvements for high gradient plume driven unsteady flows.

After 20+ years was overset the right choice?

Weaknesses

- Relatively steep learning curve for new users.
- Double valued surface issues.

Strengths

- Accuracy
- Efficiency- Structured grids, grid scripts
- Flexibility - Nearly ideal for Shuttle redesign work.

Overall a pragmatic choice for our application.

But there is still more work to be done...

STS-133, STS-134, STS-135?

Some STS-1 flight anomalies are still beyond current CFD tool capabilities, e.g.

- Acoustics and heating on complex configurations with strong shock wave-boundary layer interactions
- Physical models (turbulence, chemistry, multiphase flows,...) are key limitations that need to be improved.

Future programs will need 10s to 100s of millions of CPU-hours to characterize external environments

- There is evidence that we need 10x more resolution and 10x more solutions than we can currently produce to generate grid converged solutions and populate databases.

Acknowledgments

Many contributors

NASA ARC

Joseph Steger
William Chan
Ing-Tsau Chiu
Robert Meakin
Shigeru Obayashi
Stuart Rogers
Edward Tejnil
Scott Murman

Wind tunnel model design, manufacturing and testing.

NAS facility

NASA JSC

Fred Martin
Steve Labbe
Darby Vicker
Jim Greathouse
Phil Stuart
Steve Parks
Jeff Slotnick
Dan Pearce
Scott Stanley
Edward Ma
Thomas Wey
Lindsay Marek
Alex Dobrinsky

Other organizations

Norm Suhs
Bill Dietz