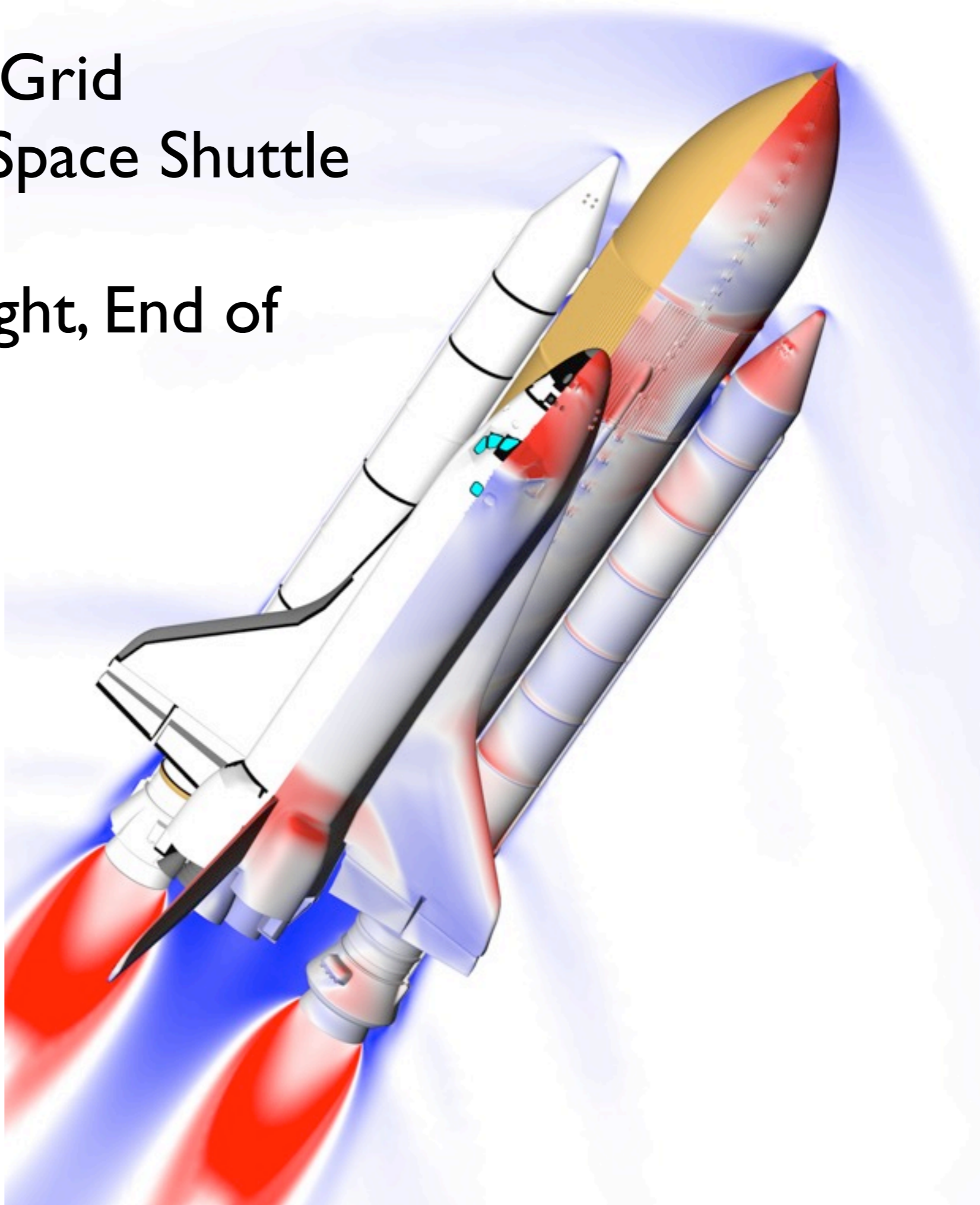
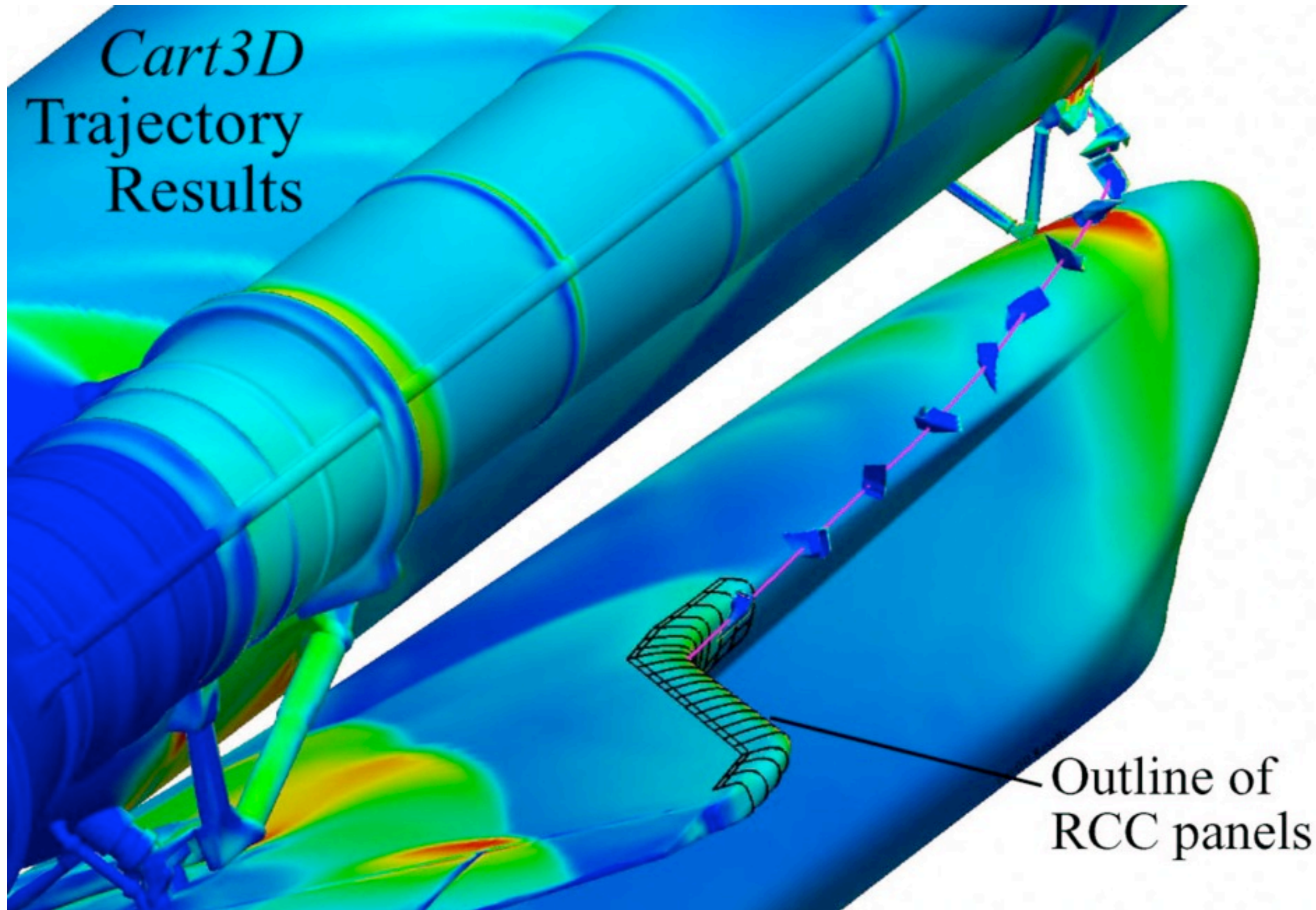


20+ Years of Chimera Grid Development for the Space Shuttle

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





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

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

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

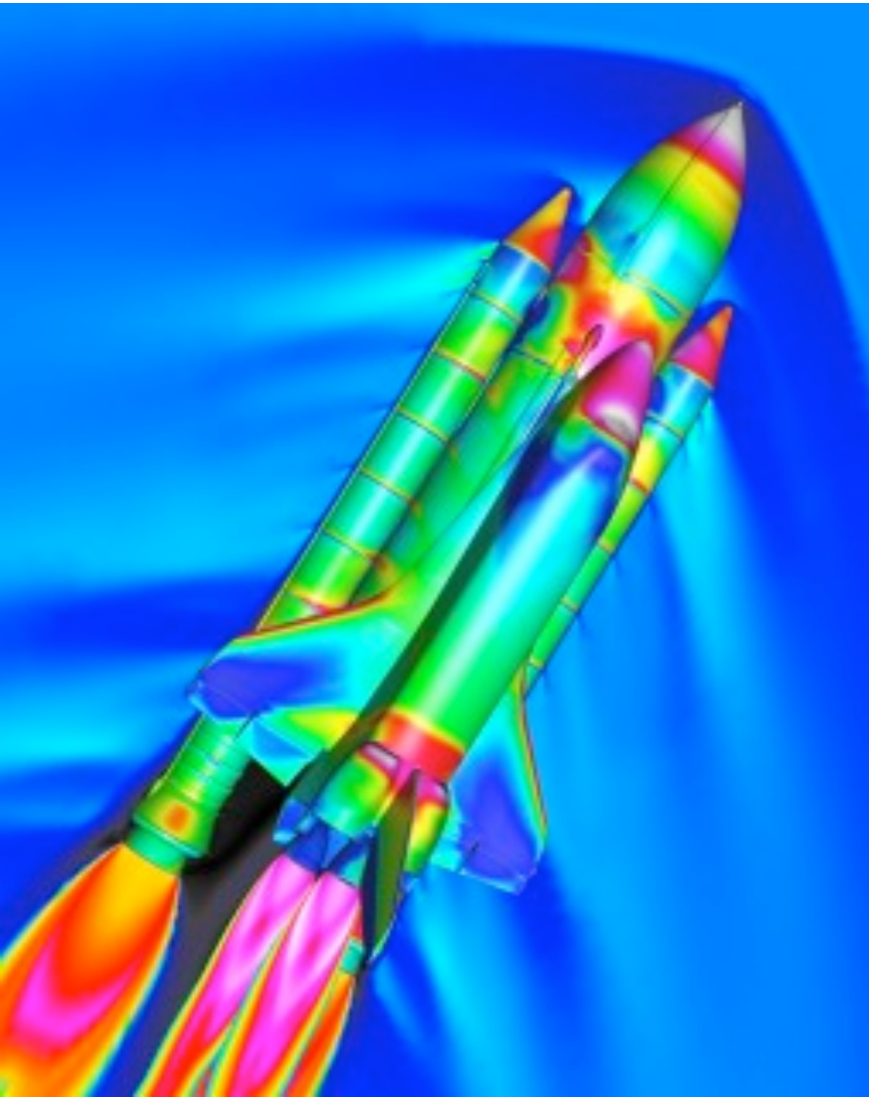
Bipod redesign assessments.

Greatly increased emphasis on verification & validation.

STS-114

▶ PAL ramp foam loss, additional redesign work.

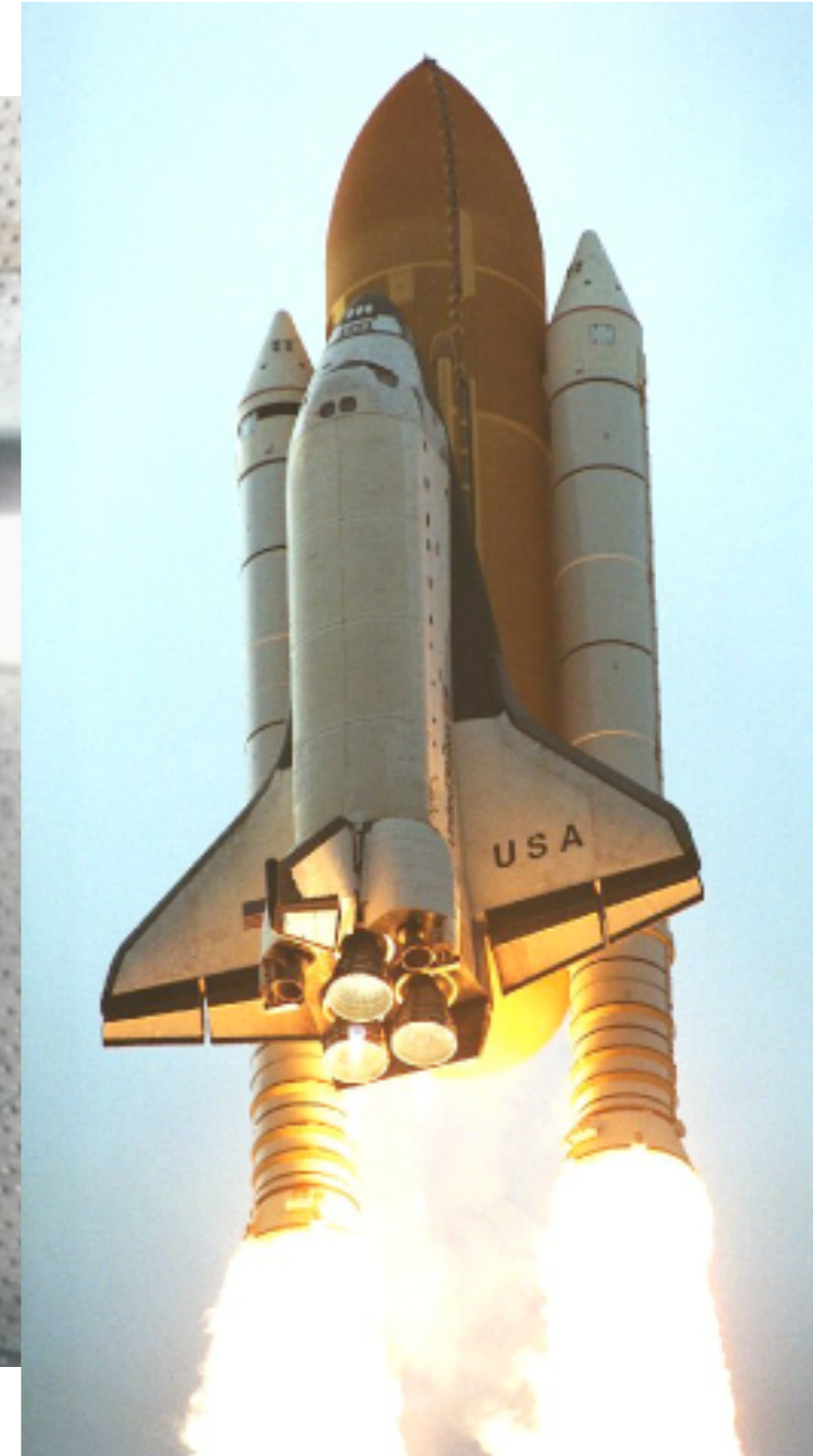
Space Shuttle Aerodynamic Tools



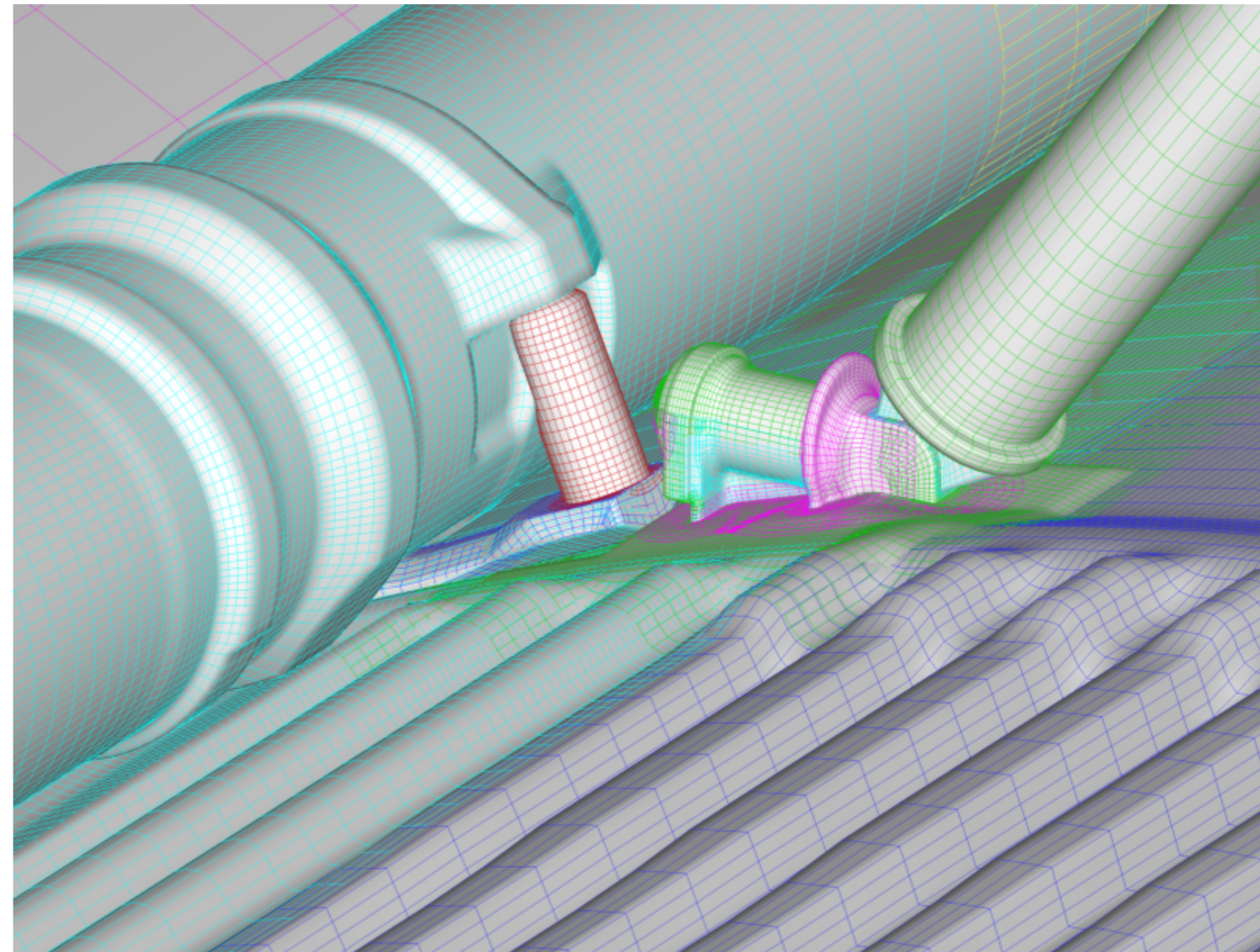
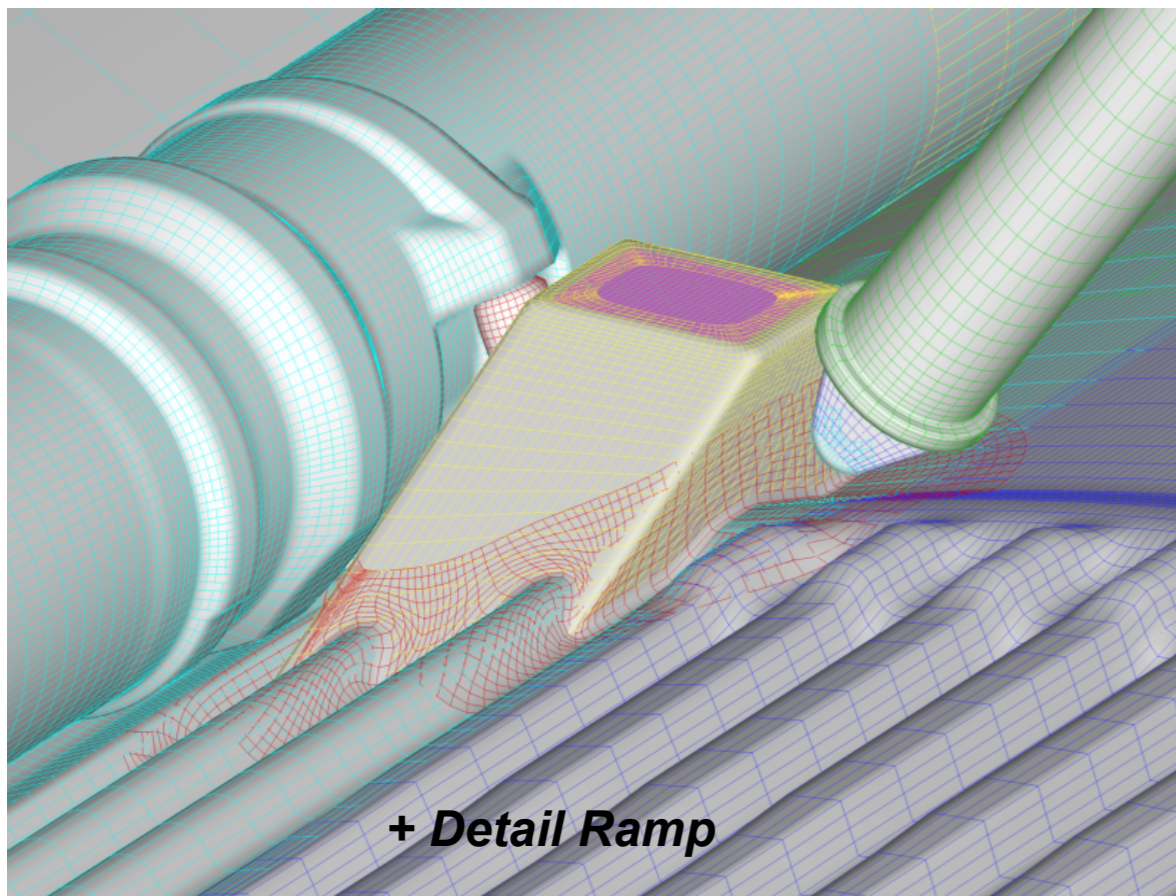
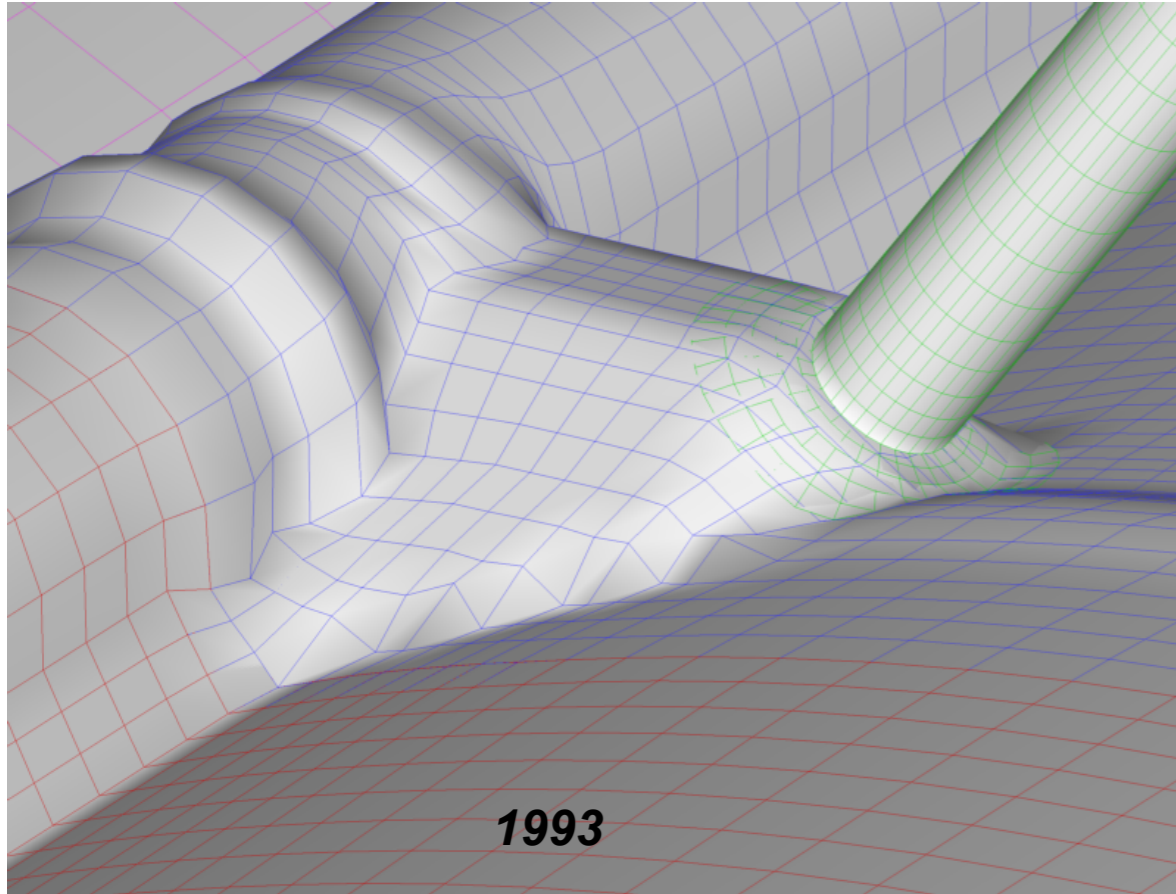
**Modeling &
Simulation**



Ground Test

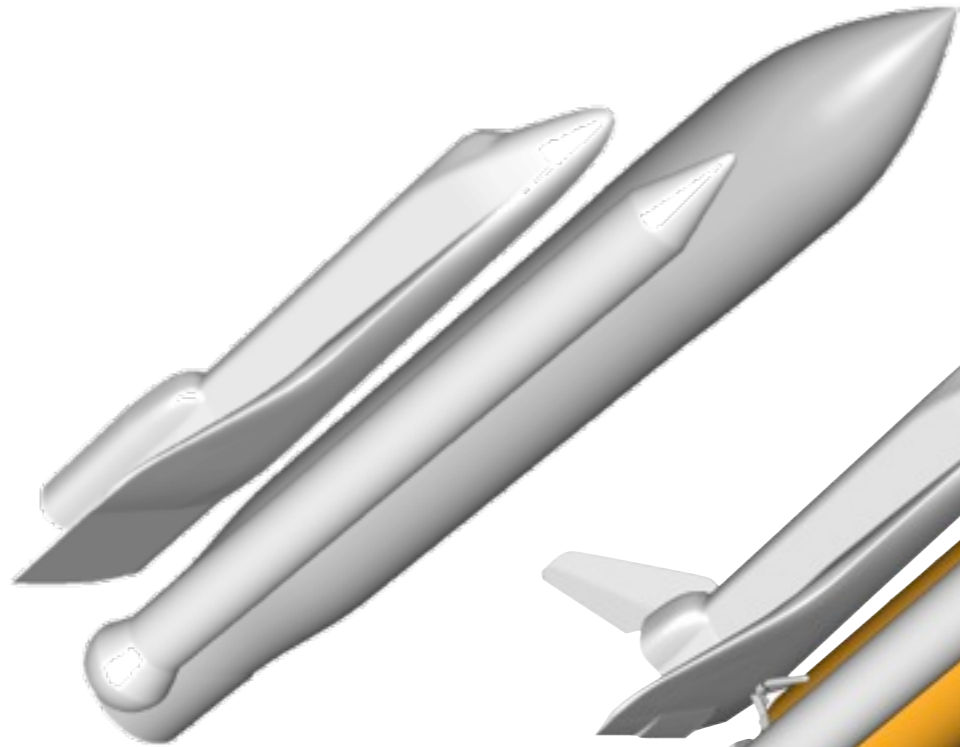


Bipod Ramp Redesign



Current Configuration

SSLV Grid System Evolution

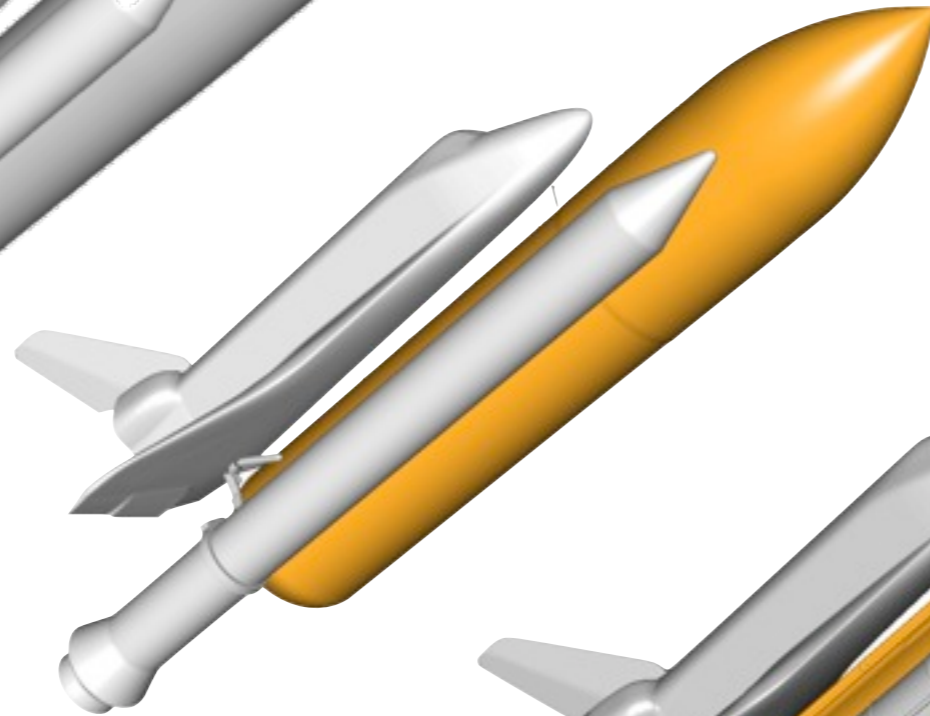


Early 80's grid system

3 Grids

10k surface points

0.3 million volume points

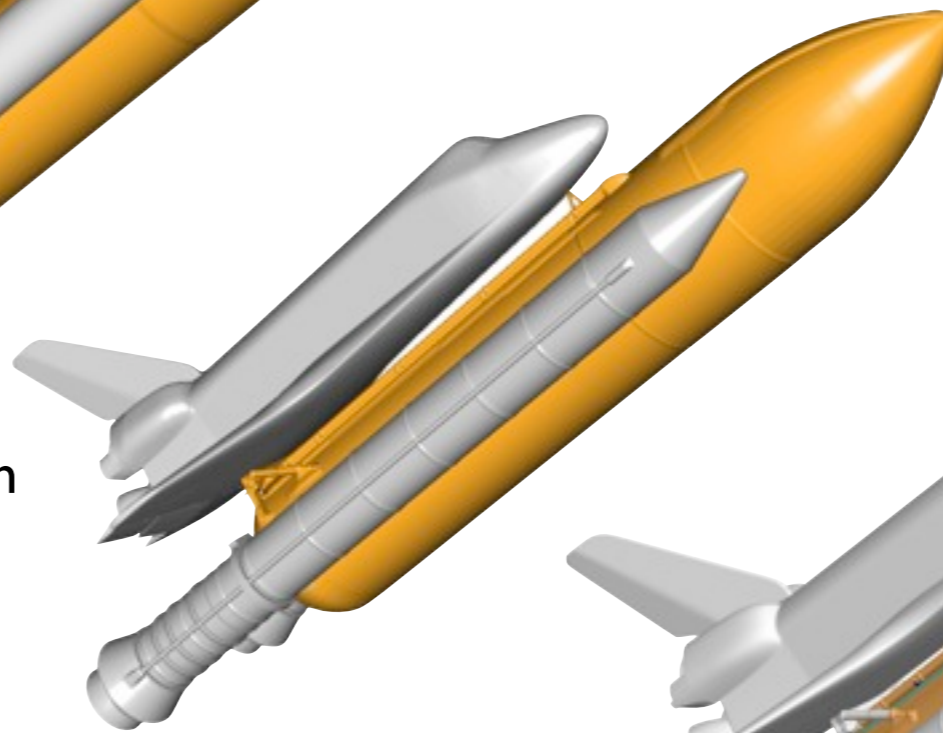


Late 80's grid system

14 Grids

35k surface points

1.6 million volume points

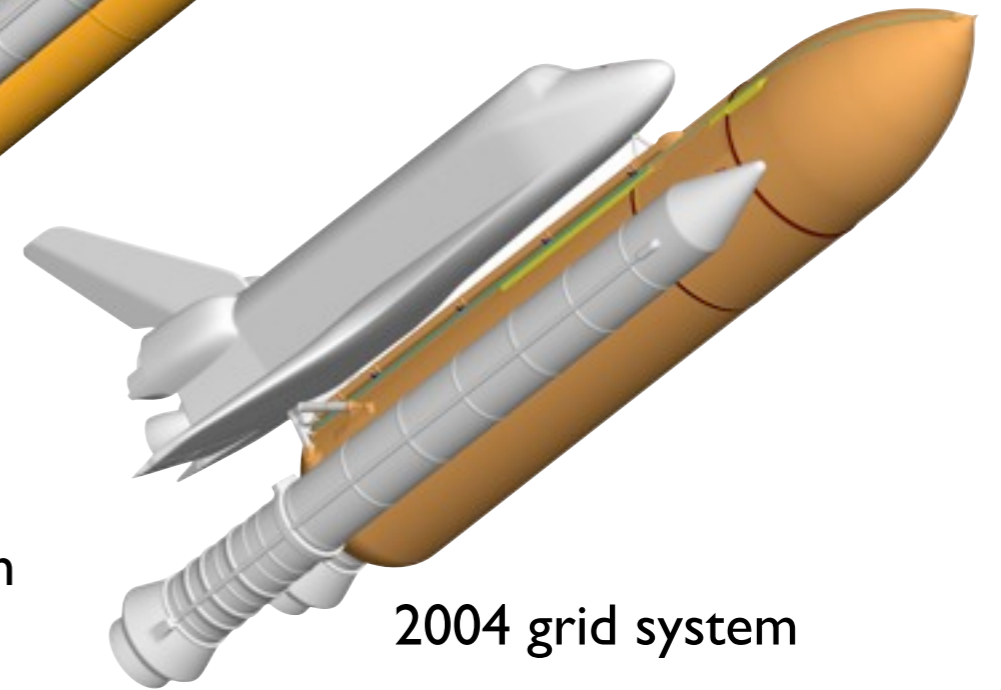


Early 90's grid system

113 Grids

268k surface points

16.4 million volume points



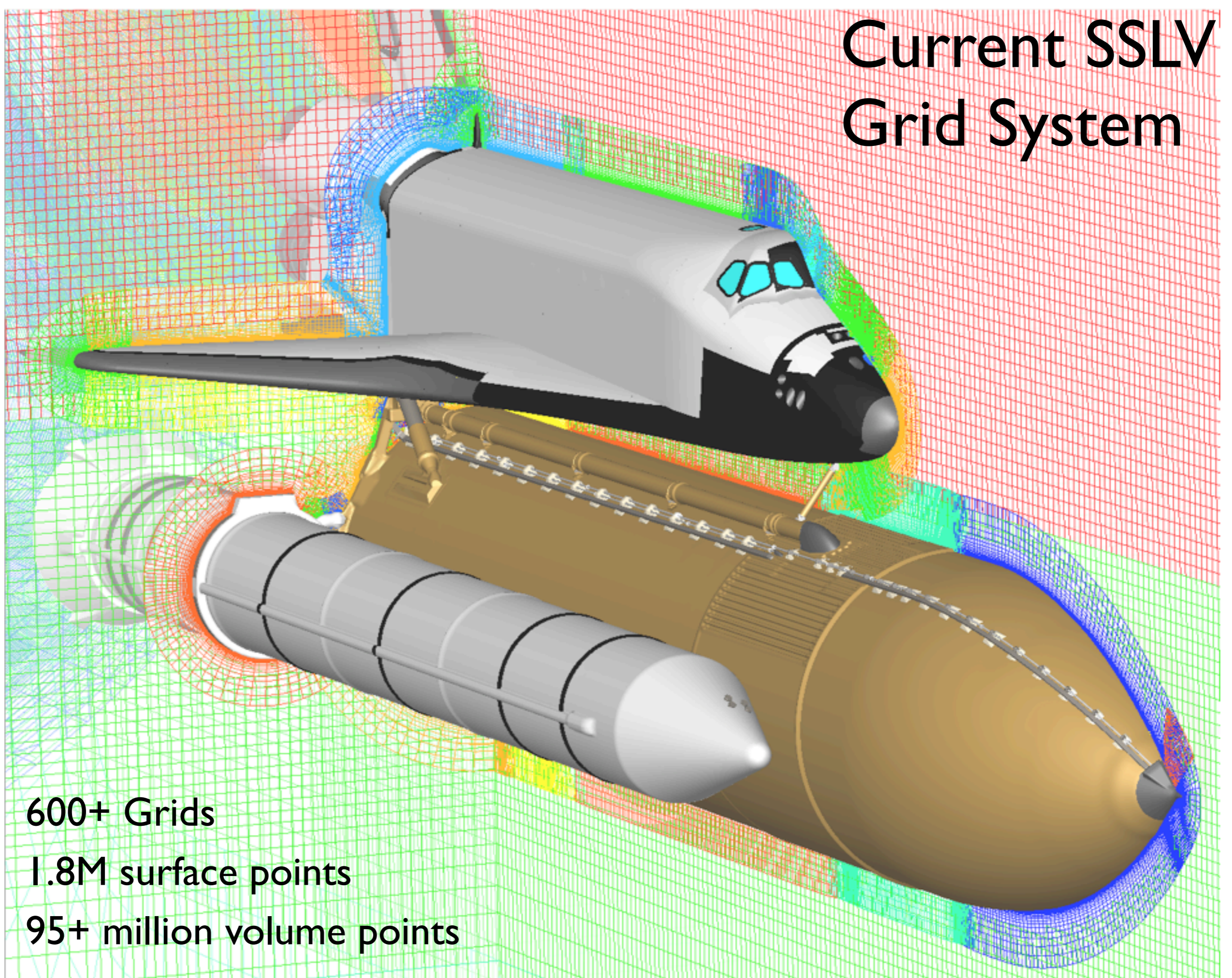
2004 grid system

267 Grids

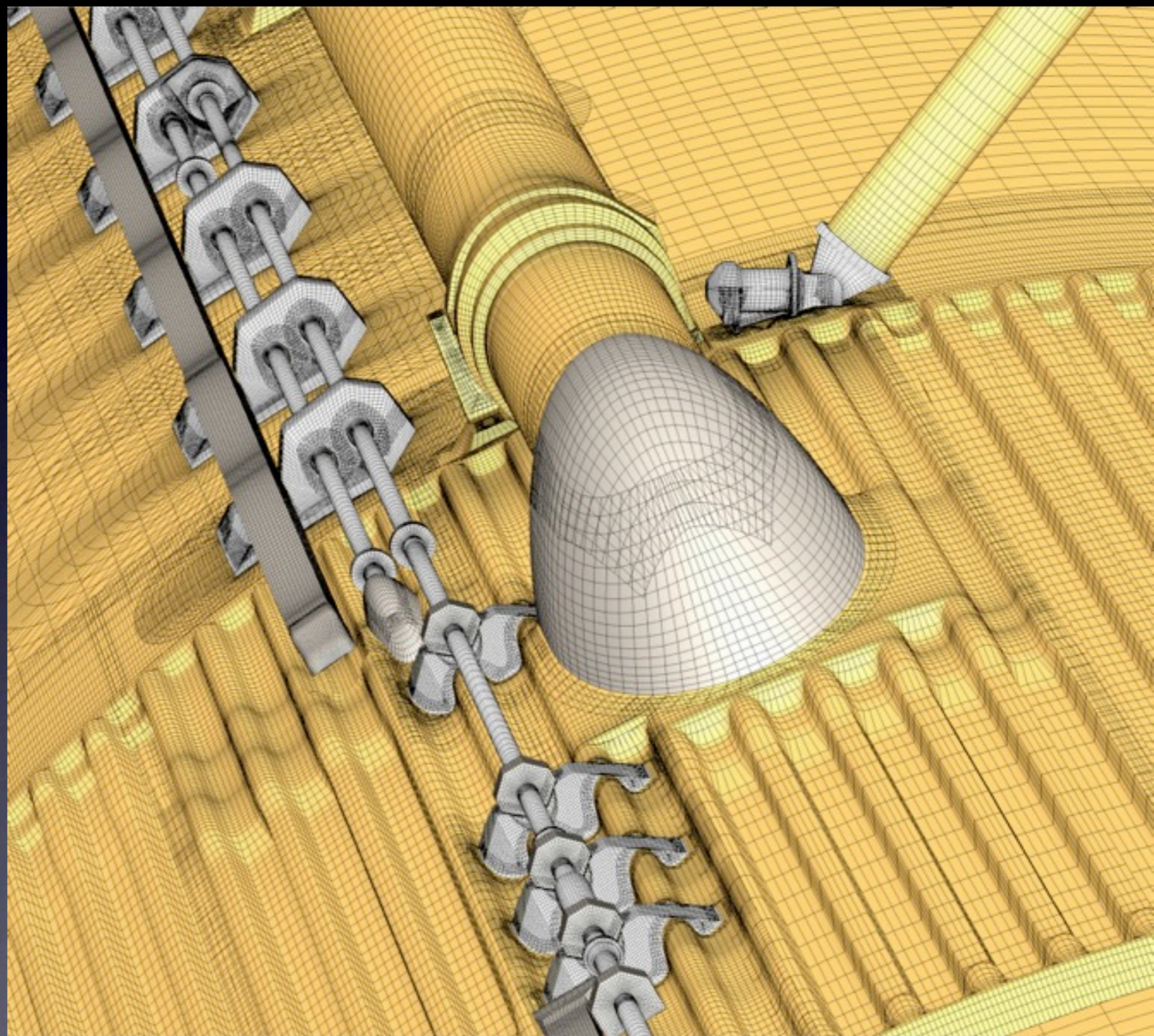
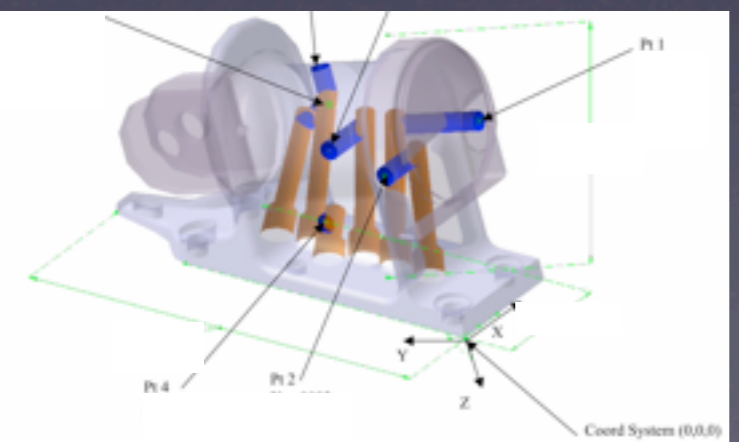
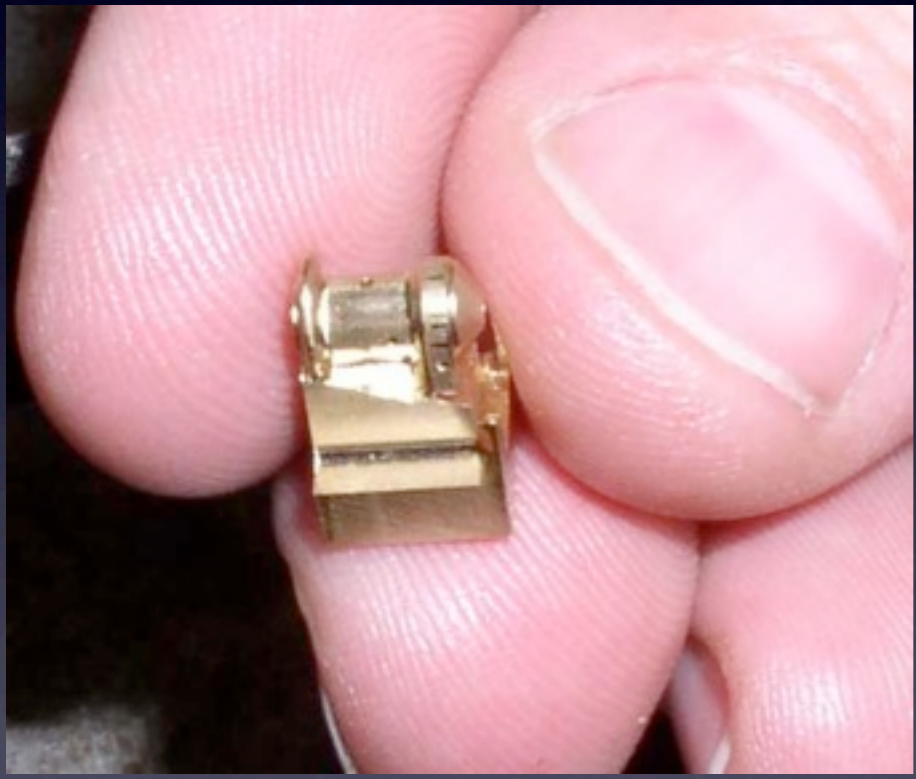
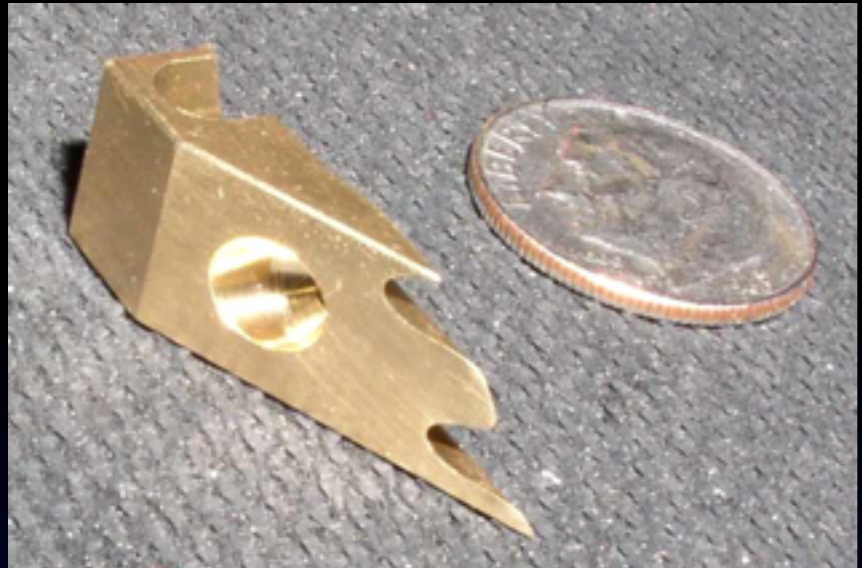
636k surface points

34.8 million volume points

Current SSLV Grid System



Wind tunnel validation & CFD extrapolation



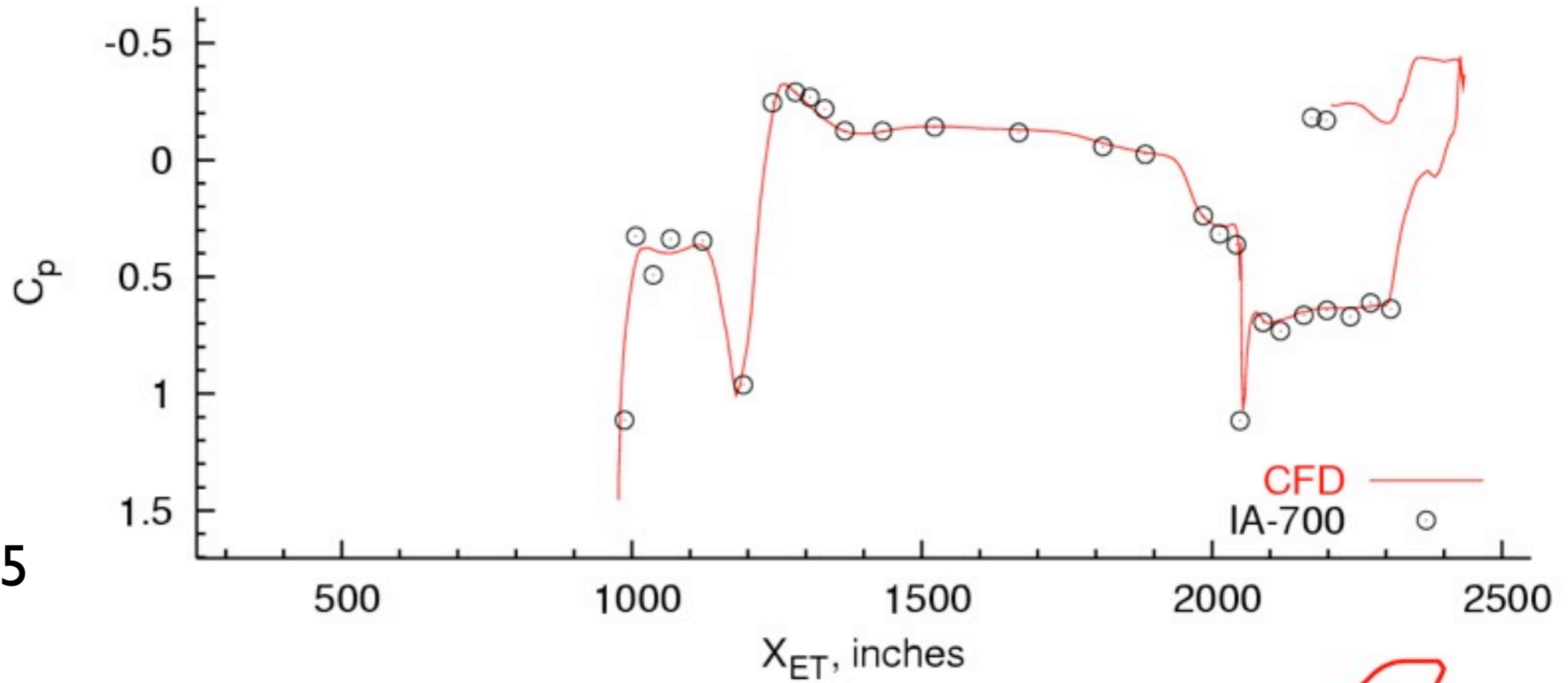
Wind Tunnel Test (IA-700) Comparisons - Orbiter - Phi = 180°

CFD conditions: $M_\infty = 1.550$, $\alpha = 0.00^\circ$, $\beta = 0.00^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00°

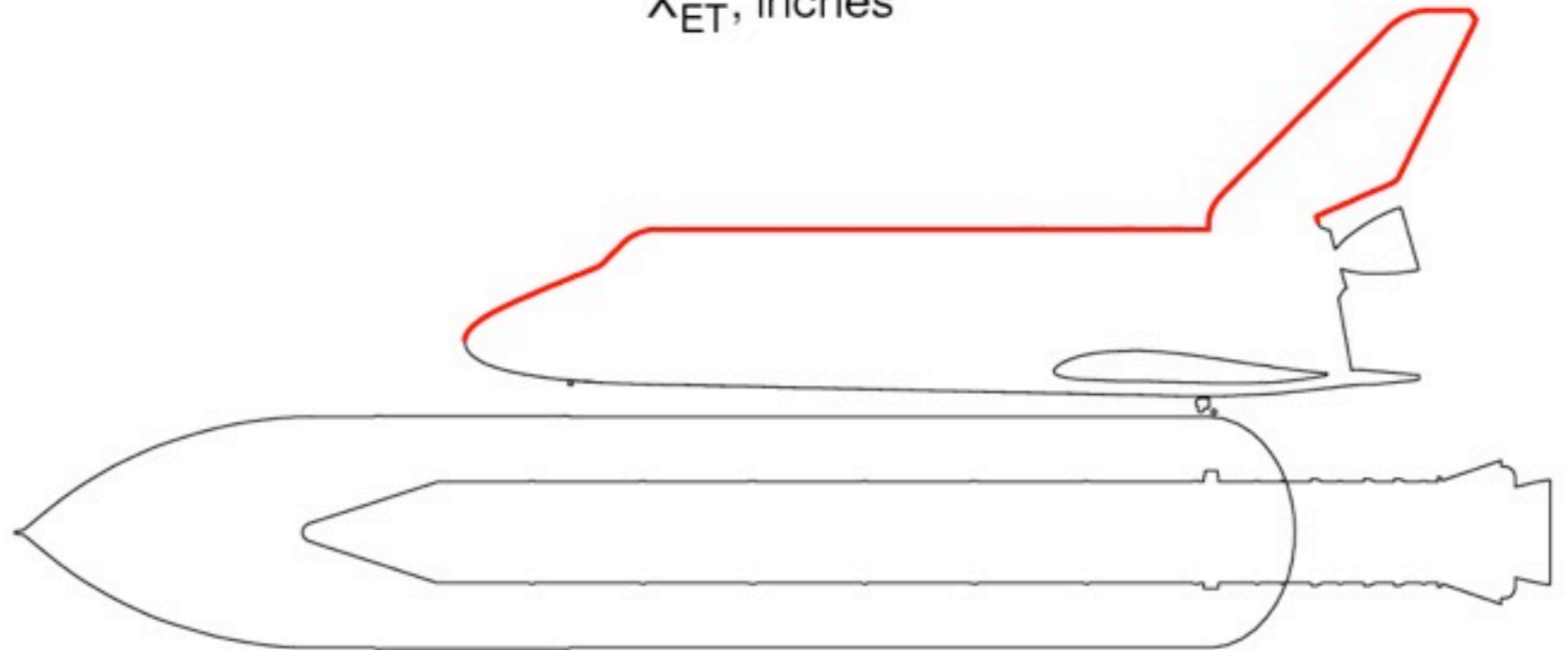
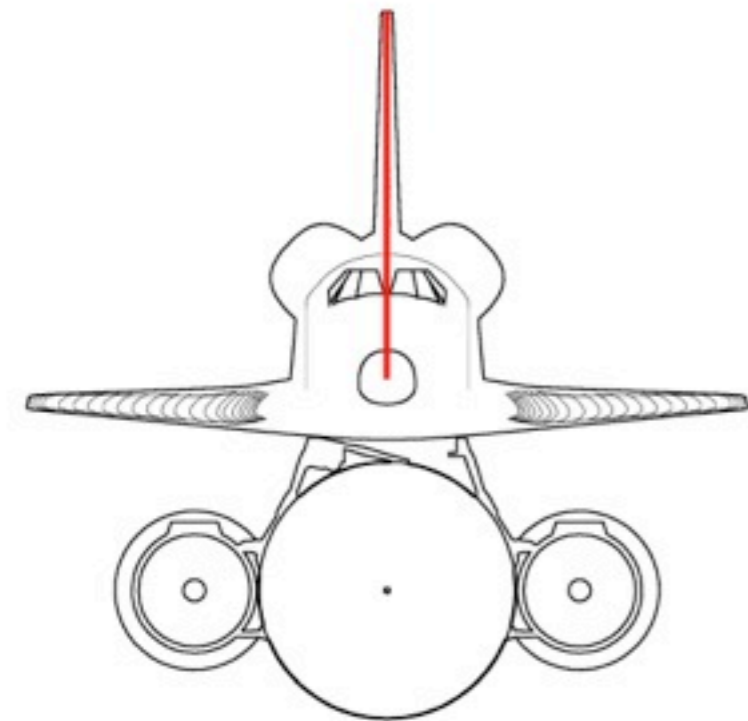
WTT conditions: $M_\infty = 1.550$, $\alpha = -0.12^\circ$, $\beta = 0.06^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 212, Point = 4, LOX Roll = 0°

WTT conditions: $M_\infty = 1.551$, $\alpha = -0.10^\circ$, $\beta = 0.06^\circ$, Reynolds # = $2.52 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 308, Point = 4, LOX Roll = 15°

WTT conditions: $M_\infty = 1.551$, $\alpha = -0.08^\circ$, $\beta = 0.02^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 315, Point = 4, LOX Roll = -15°



JSC 2005-62925



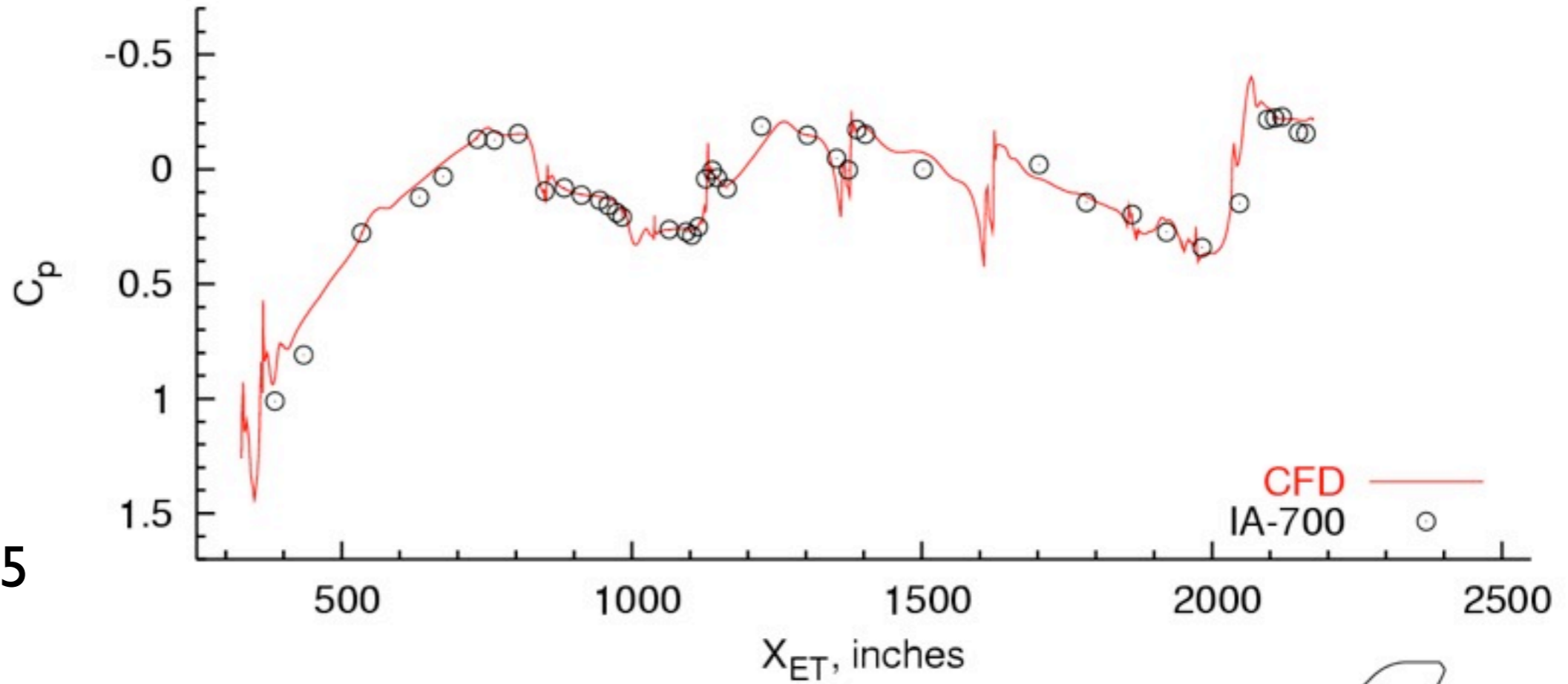
Wind Tunnel Test (IA-700) Comparisons - External Tank - Phi = 203.75°

CFD conditions: $M_\infty = 1.550$, $\alpha = 0.00^\circ$, $\beta = 0.00^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00°

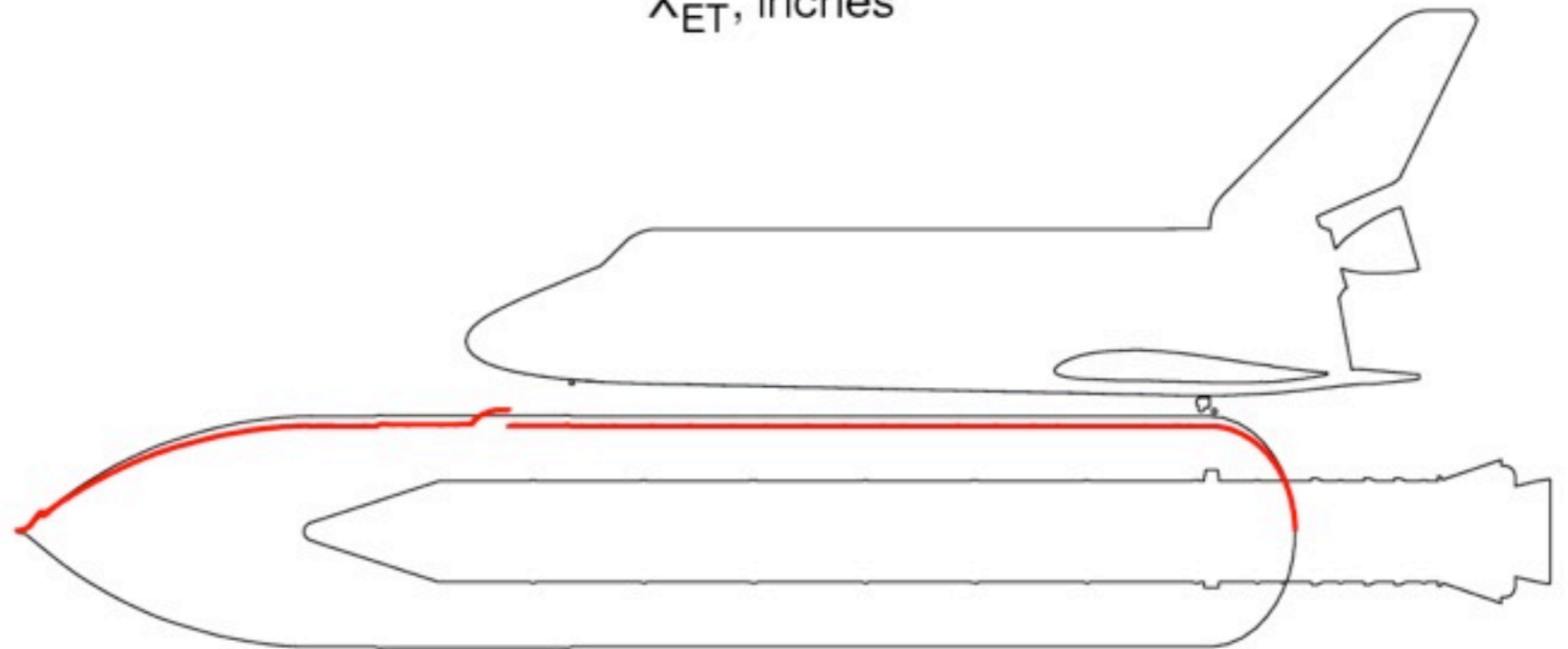
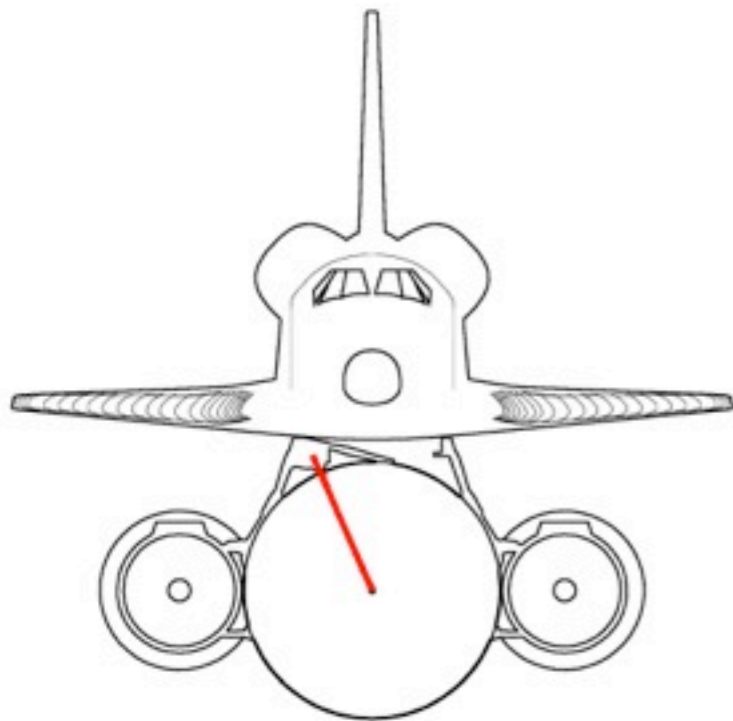
WTT conditions: $M_\infty = 1.550$, $\alpha = -0.12^\circ$, $\beta = 0.06^\circ$, Reynolds # = $2.52 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 212, Point = 4, LOX Roll = 0°

WTT conditions: $M_\infty = 1.551$, $\alpha = -0.10^\circ$, $\beta = 0.06^\circ$, Reynolds # = $2.54 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 308, Point = 4, LOX Roll = 15°

WTT conditions: $M_\infty = 1.551$, $\alpha = -0.08^\circ$, $\beta = 0.02^\circ$, Reynolds # = $2.52 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = -2.00° , Run = 315, Point = 4, LOX Roll = -15°



JSC 2005-62925

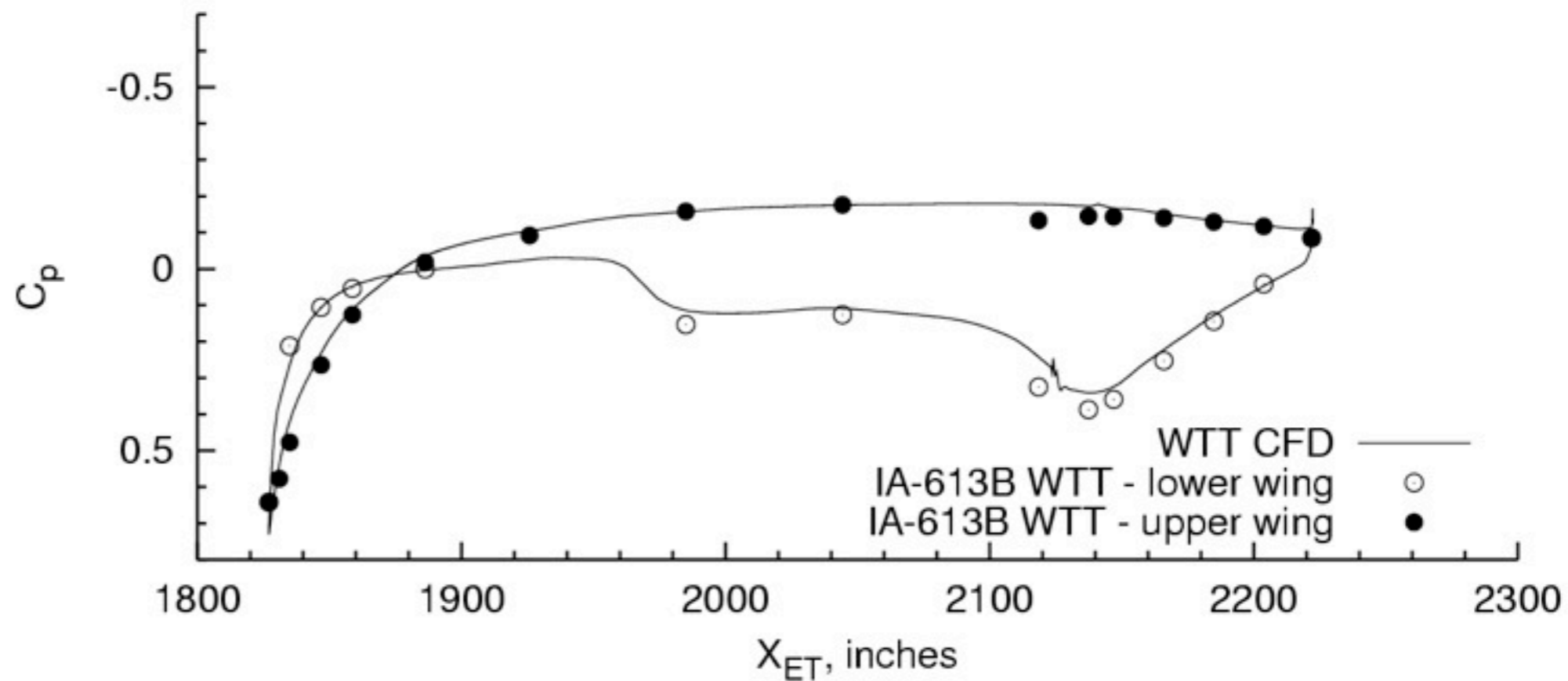
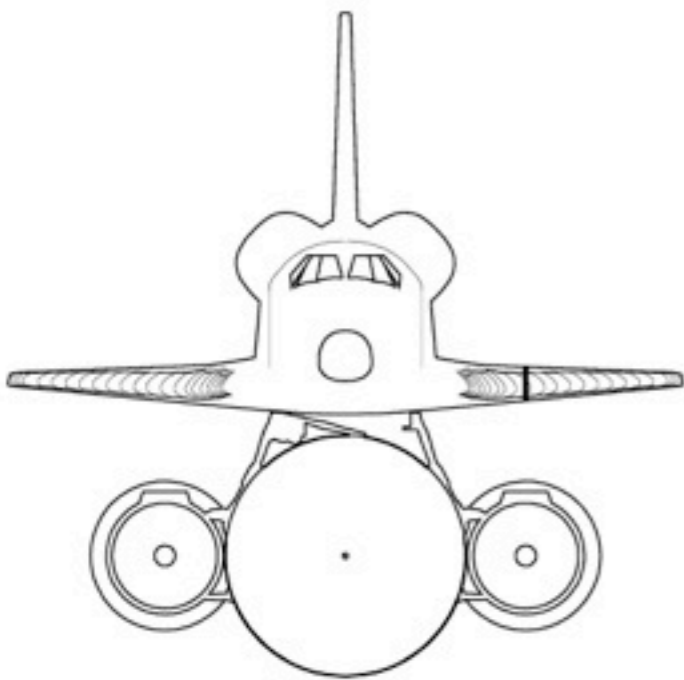


CFD vs. IA-613B Wing Pressures

Mach 2.50, $\gamma = -250''$

CFD run with as measured elevons

CFD conditions: $M_\infty = 2.50$, $\alpha = 2.03^\circ$, $\beta = 0.00^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 4.07° , OB elevon = -4.39°
WTT conditions: $M_\infty = 2.50$, $\alpha = 2.03^\circ$, $\beta = 0.00^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 4.07° , OB elevon = -4.39°



AIAA 2004-2226

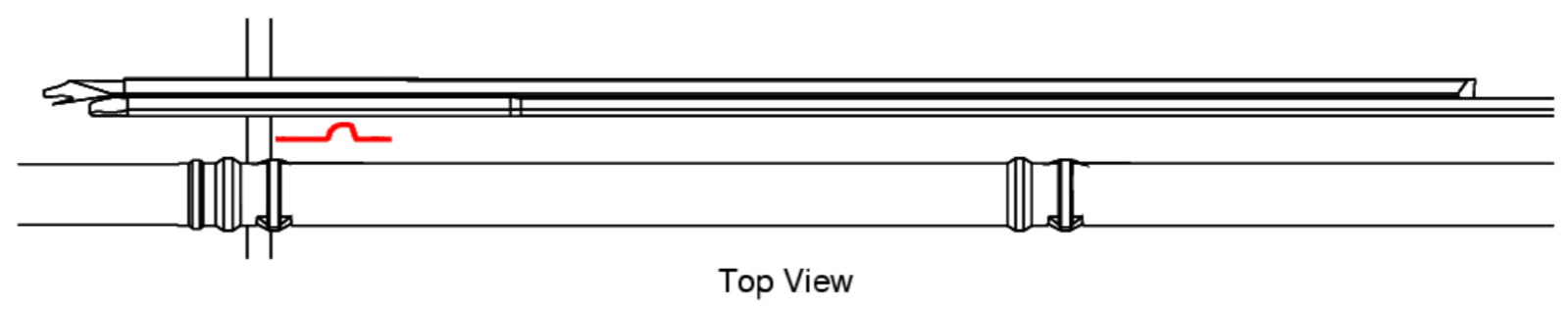
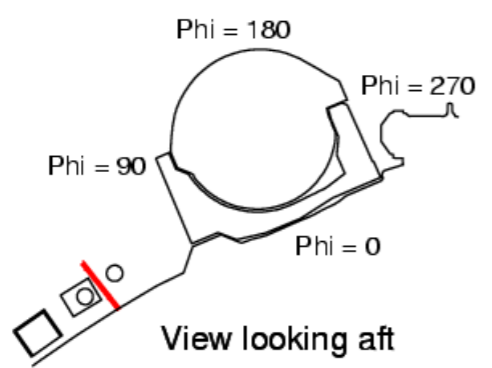
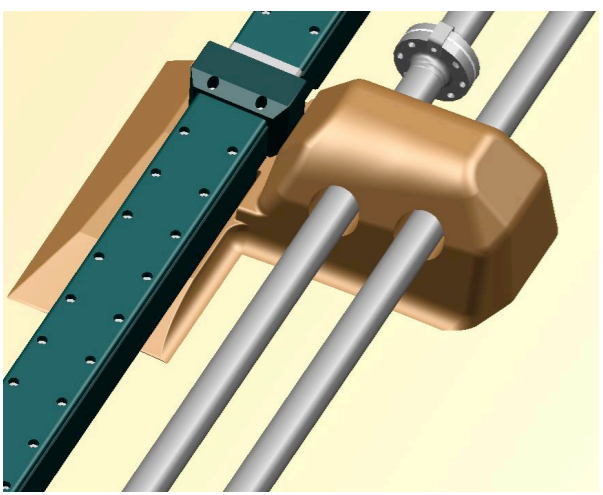
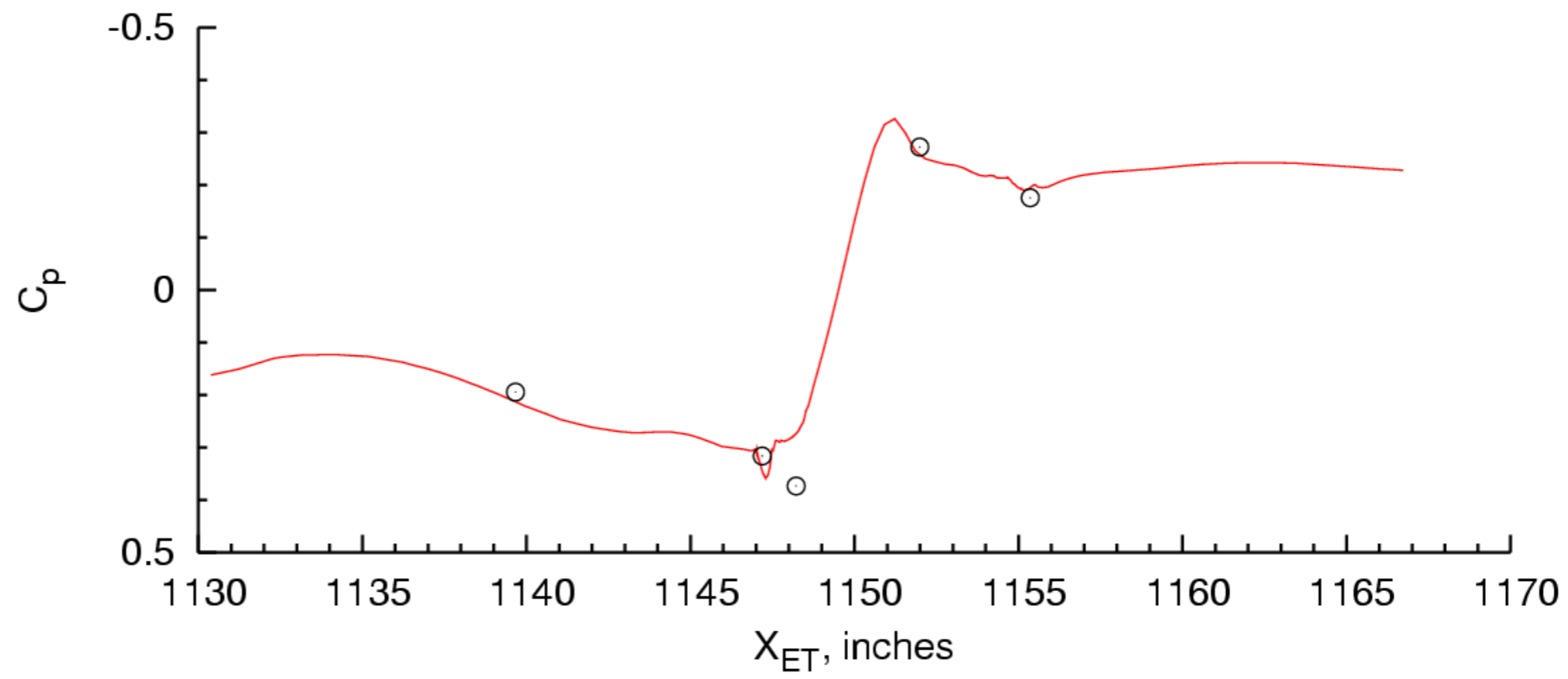


Proposed ice/frost ramp configuration, tested but not flown.

Wind Tunnel Test Comparisons - Ice/Frost Ramp Station 1151.8

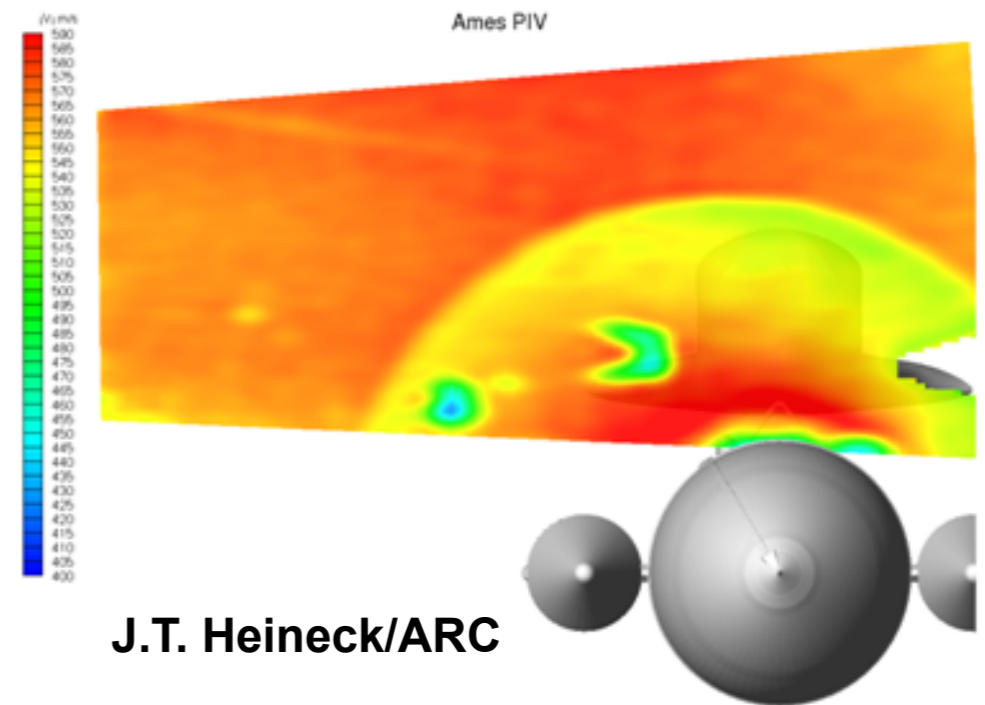
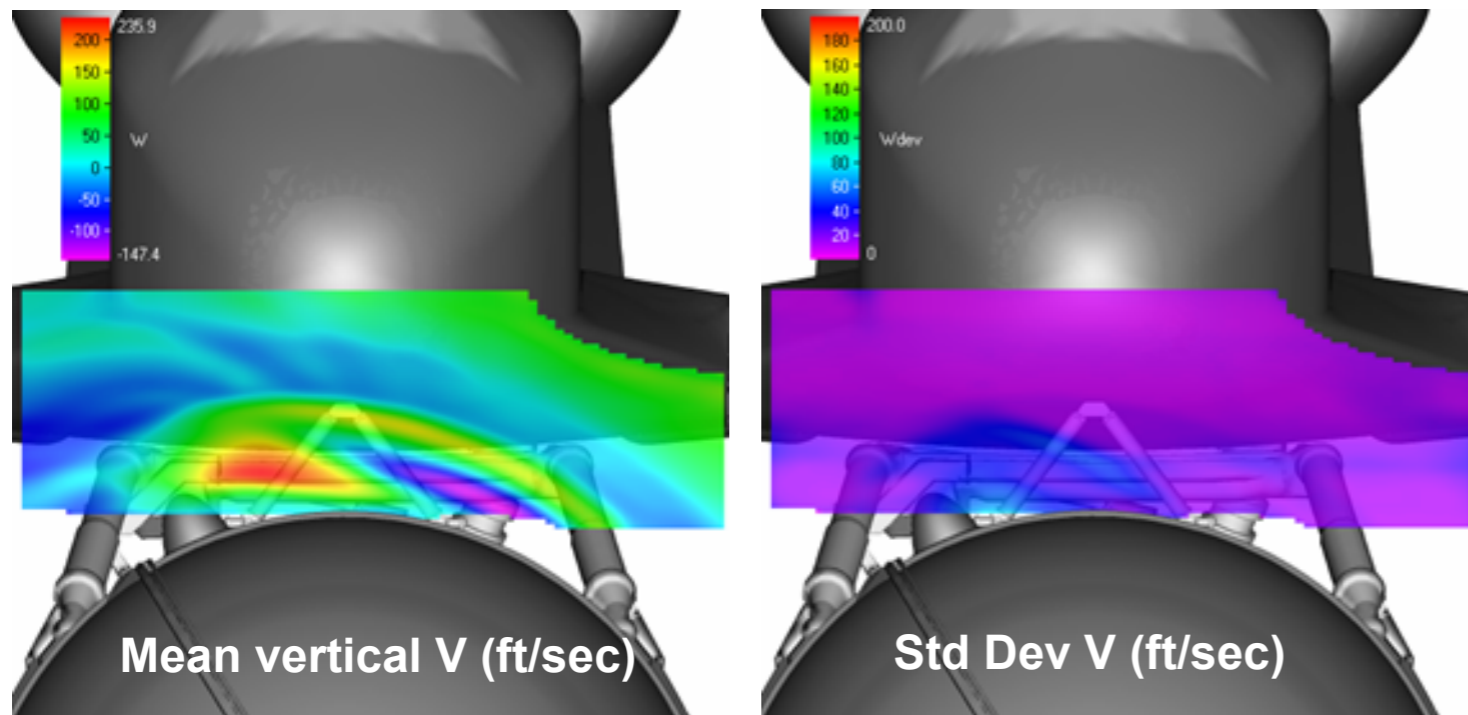
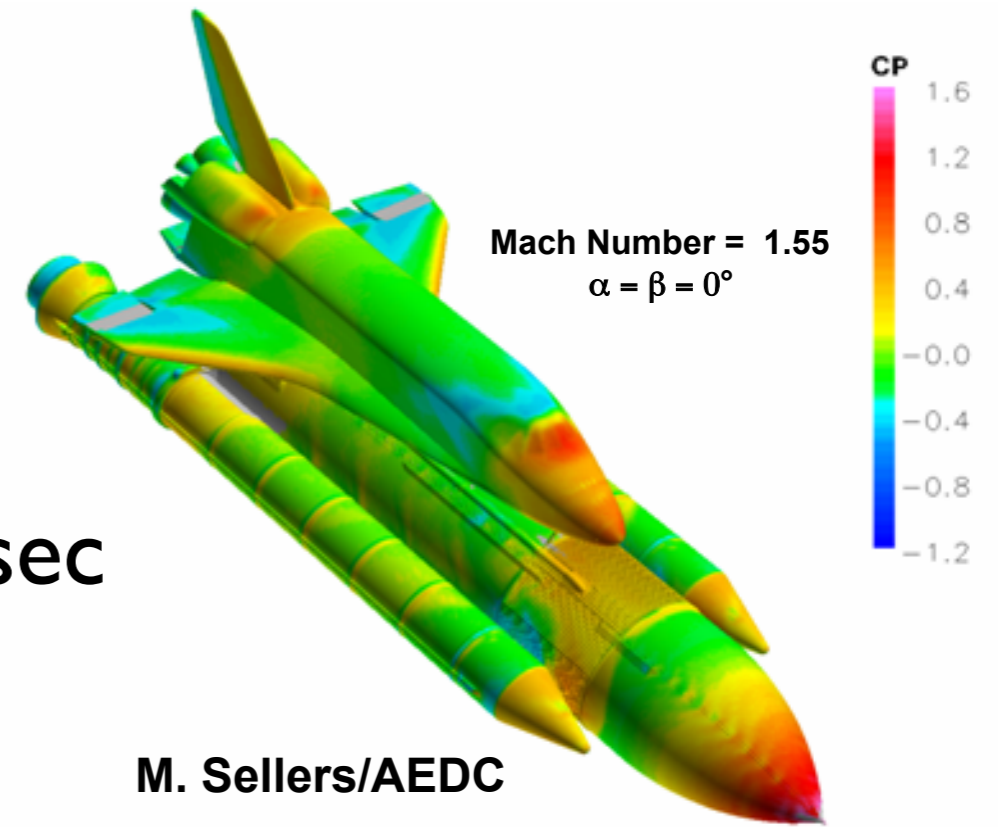
CFD conditions: $M_\infty = 1.250$, $\alpha = -4.00^\circ$, $\beta = 0.00^\circ$, Reynolds # = $2.50 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = 9.00°
 IS-21A conditions: $M_\infty = 1.252$, $\alpha = -4.03^\circ$, $\beta = 0.05^\circ$, Reynolds # = $2.51 \times 10^6/\text{ft}$, IB elevon = 10.00° , OB elevon = 9.00° , Run = 709, Point = 4, pal = 0

CFD —
 IS-21A ○



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

- Pressure sensors vs. CFD ≈ 0.01 Cp
- Integrated Loads vs. CFD $\approx 5\%$ of flt
- Pressure Sensitive Paint
- Particle Imaging Velocimetry ± 20 ft/sec



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 InitialWallSpacing 1.6e-4
```

Configuration

Intra- Configuration Options

Control Surface Deflections

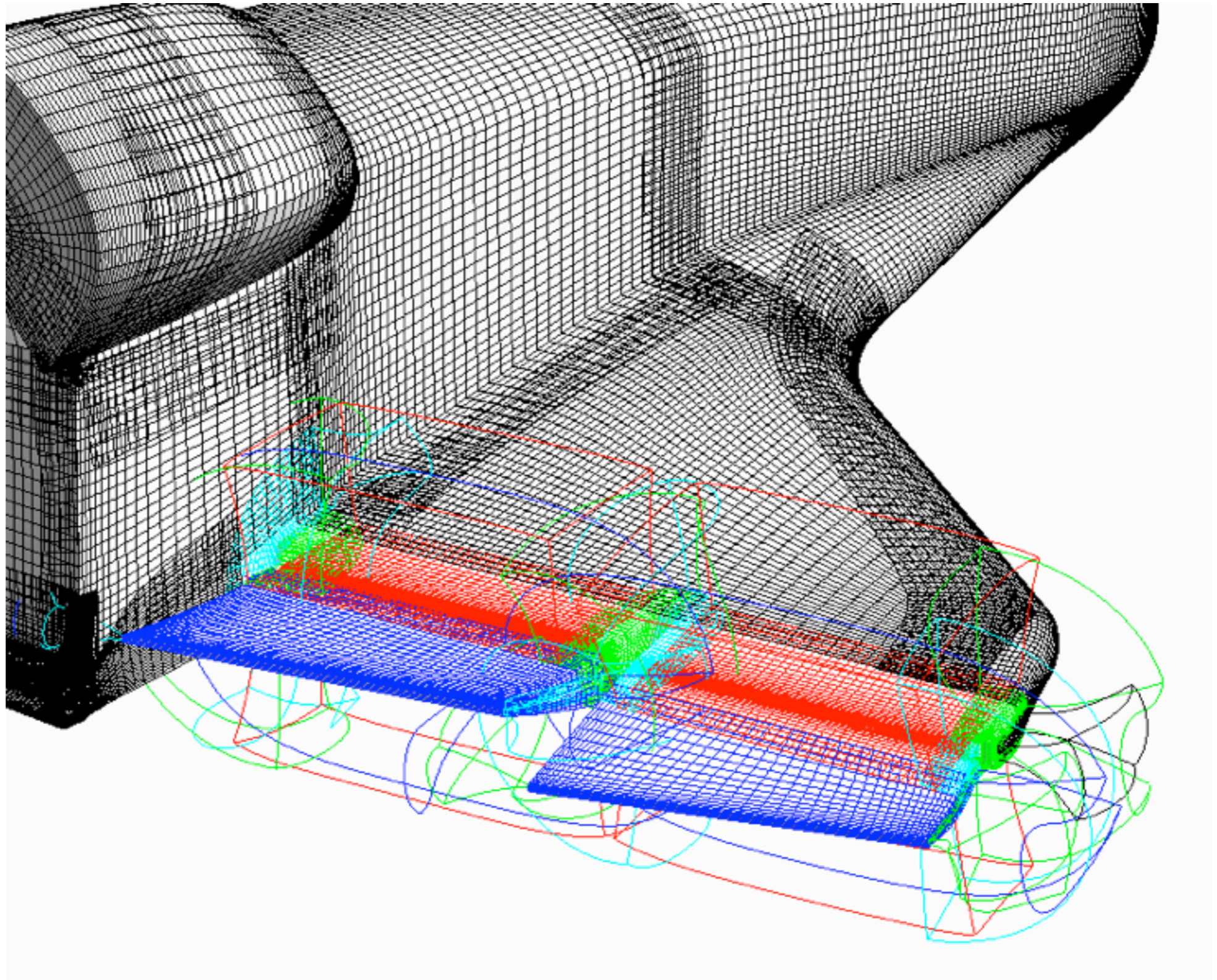
Engine Gimbals

Tunnel Controls Viscous Spacing

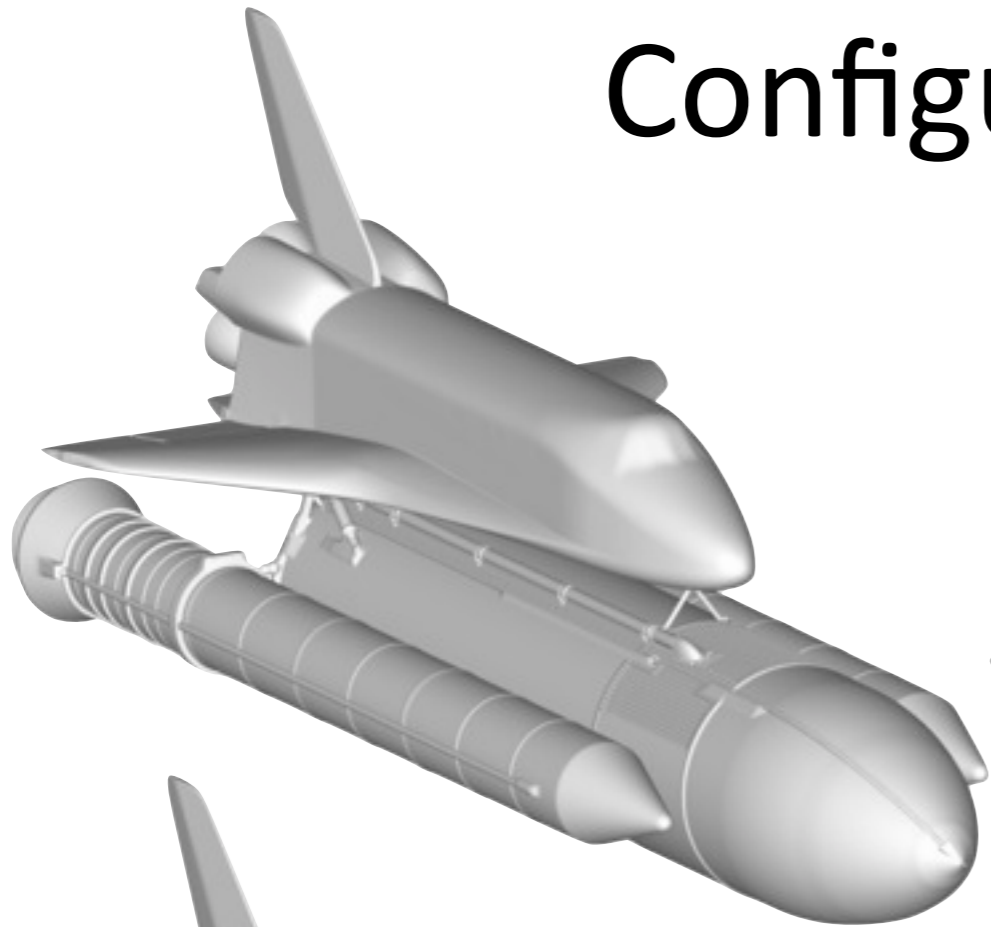
To build a grid system:

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

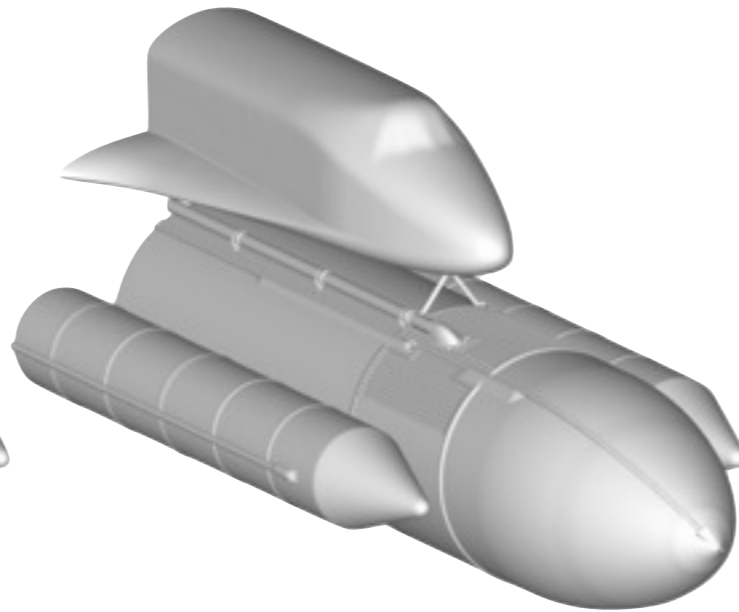
Scripted control surface motion is key to automation.



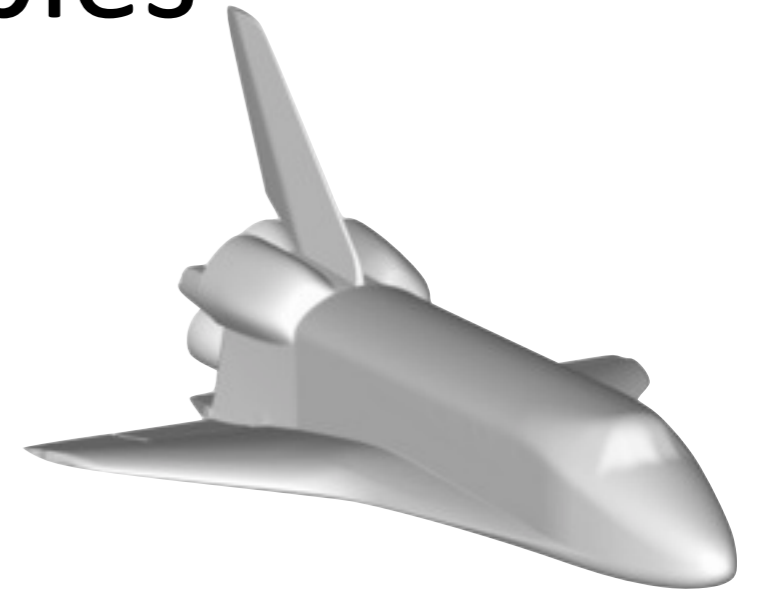
Configuration Examples



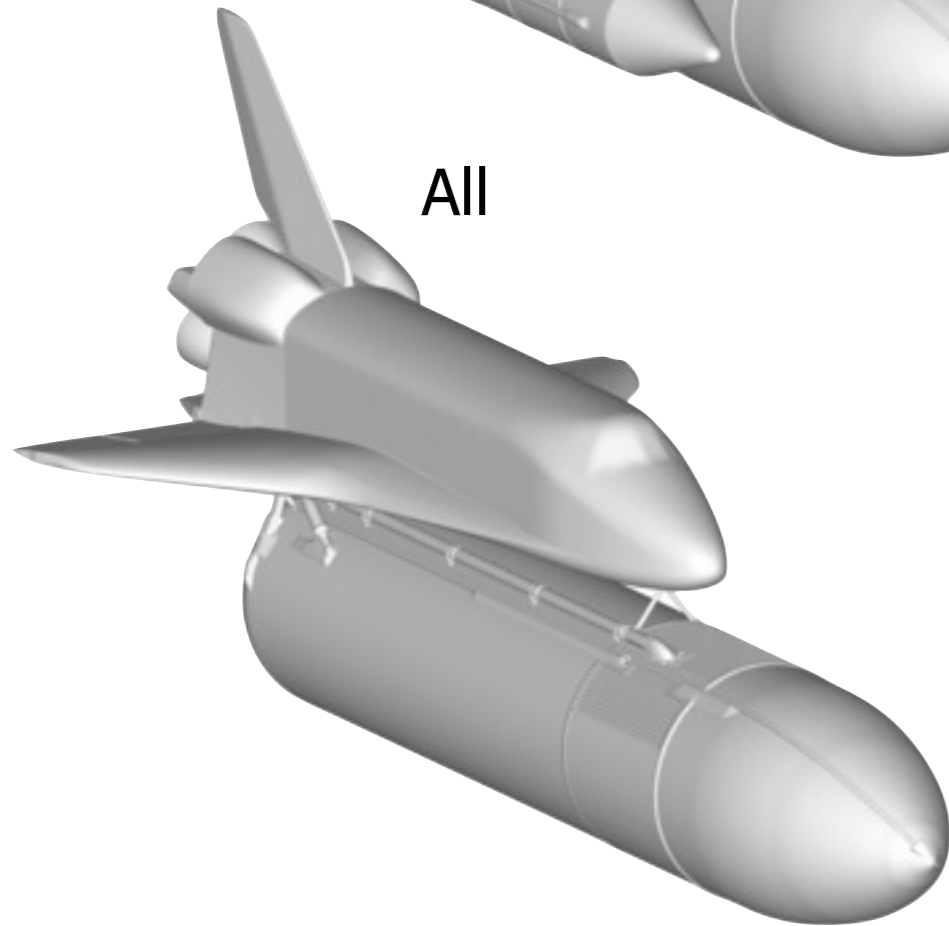
All



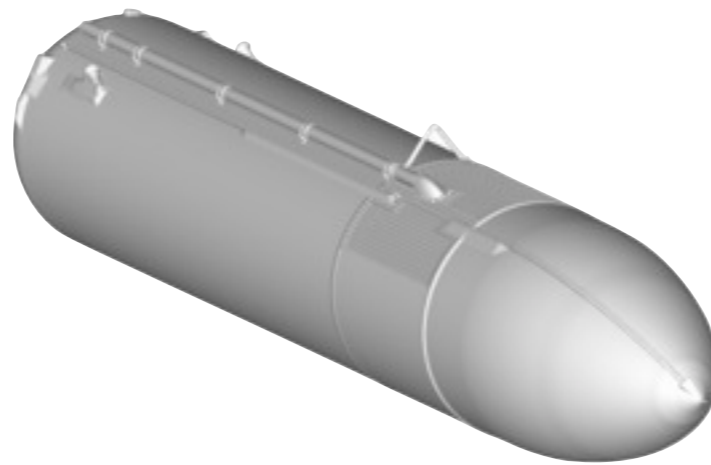
AllShort



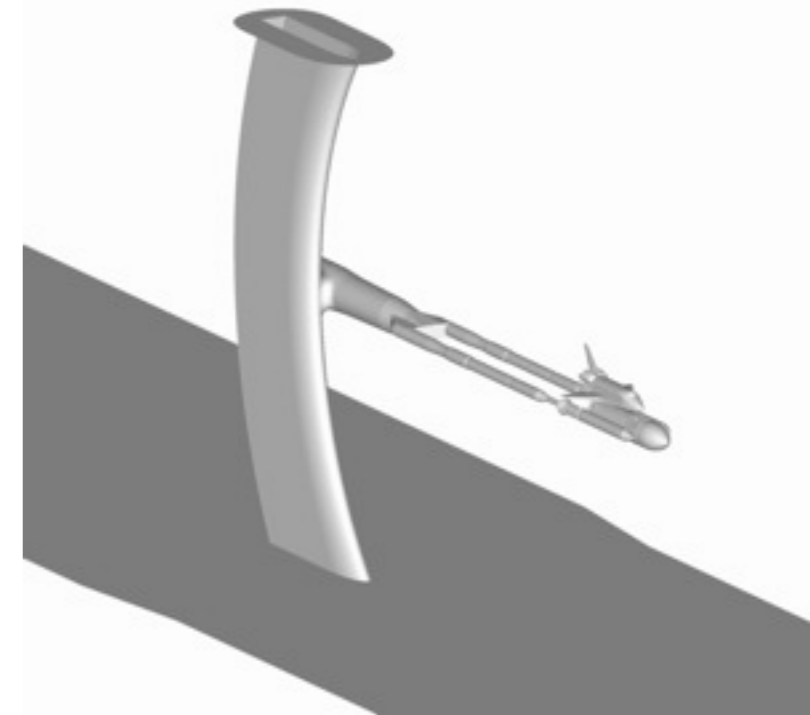
Orbiter



OrbiterET

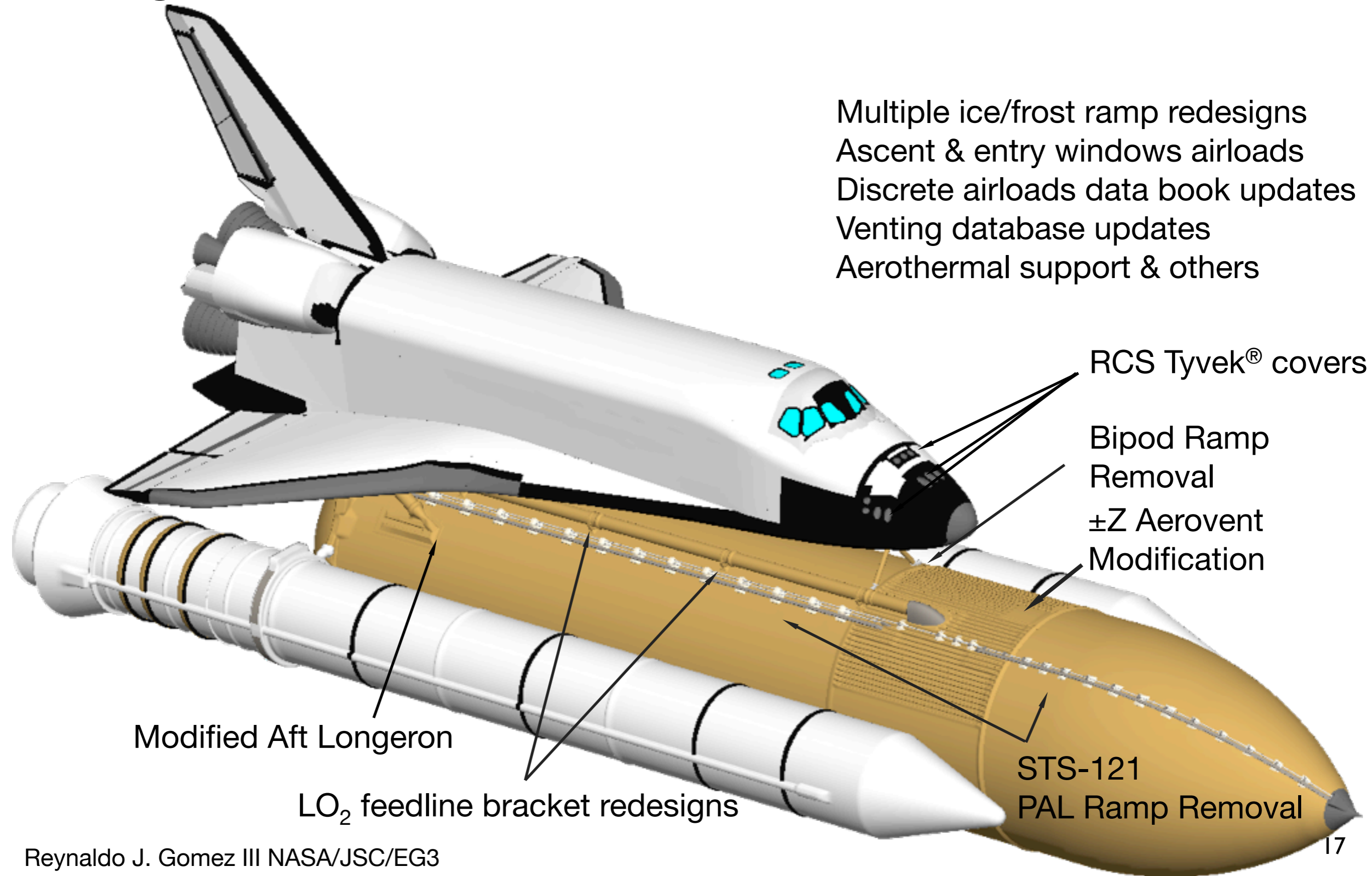


External Tank



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

RCS Tyvek® covers

Bipod Ramp
Removal
±Z Aerovent
Modification

Modified Aft Longeron

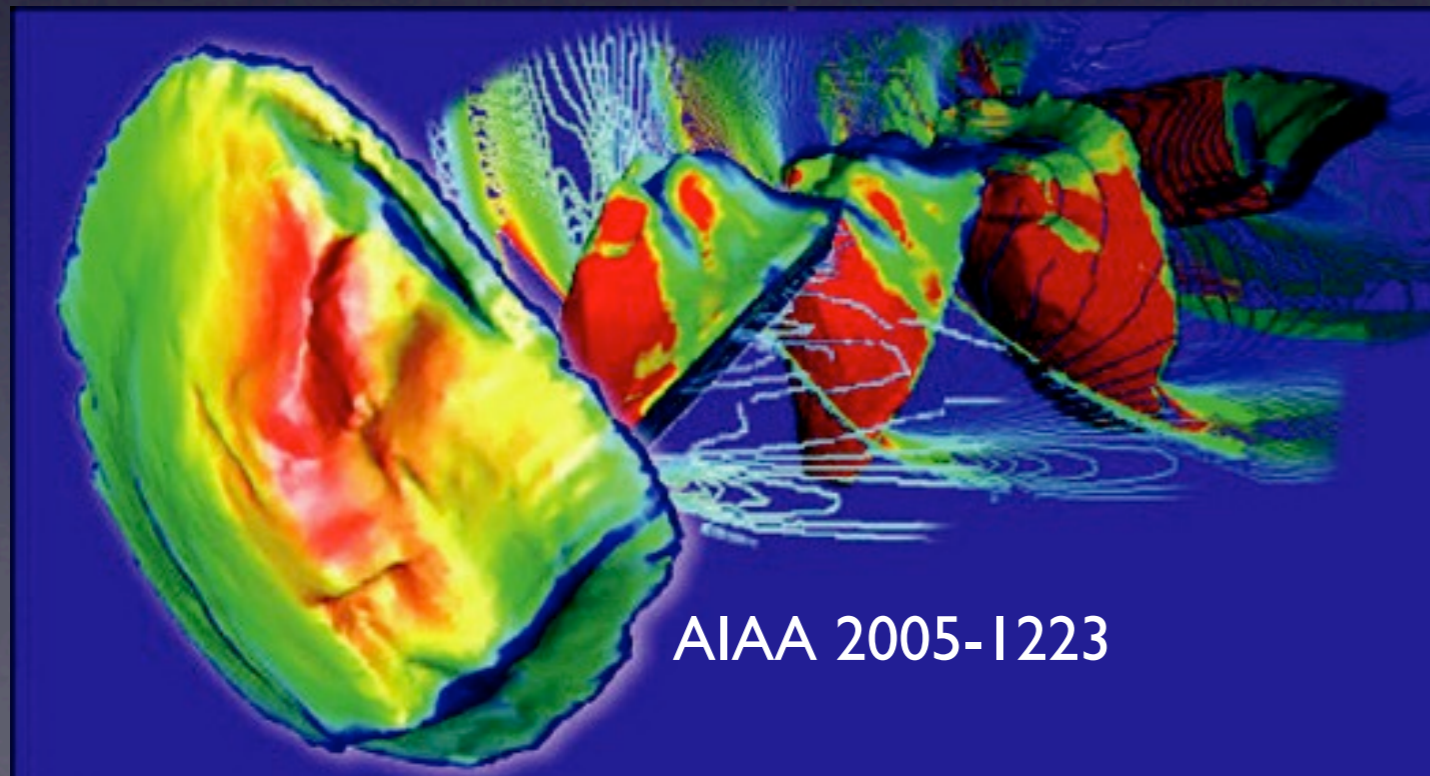
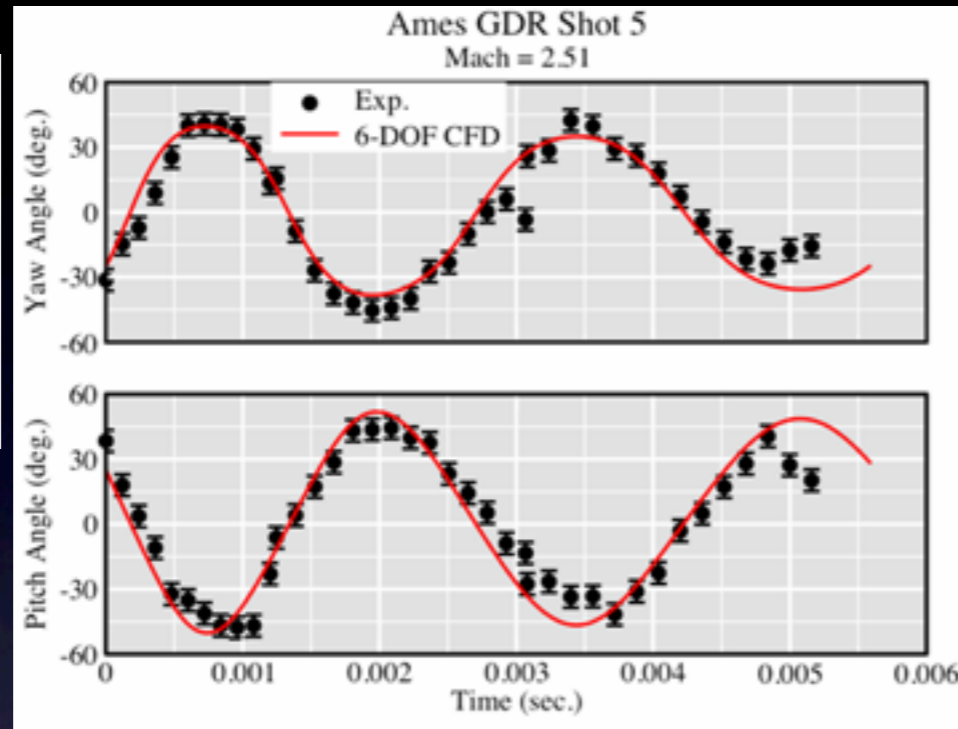
LO₂ feedline bracket redesigns

STS-121
PAL Ramp Removal

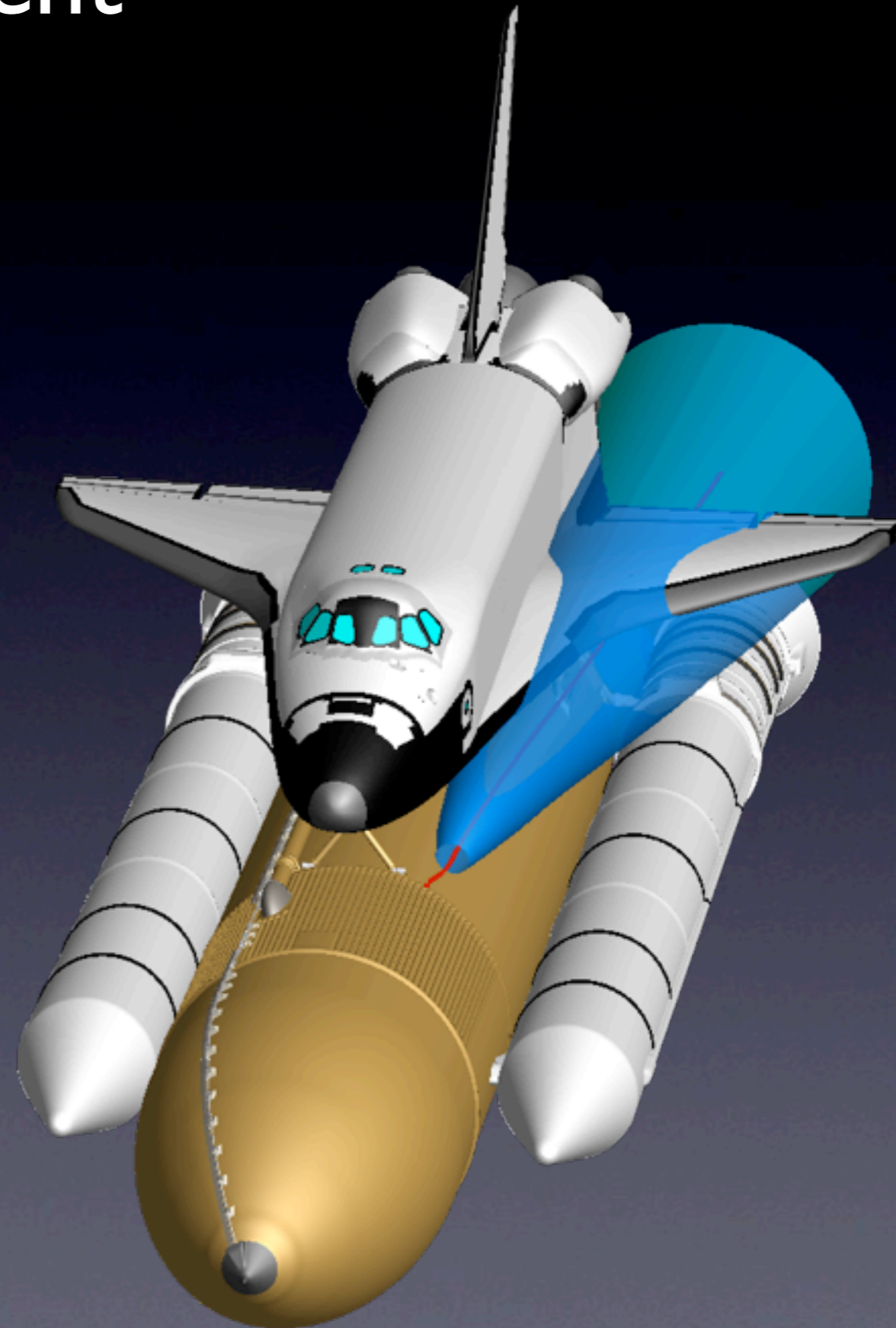
Debris transport aerodynamic models & prediction tools development



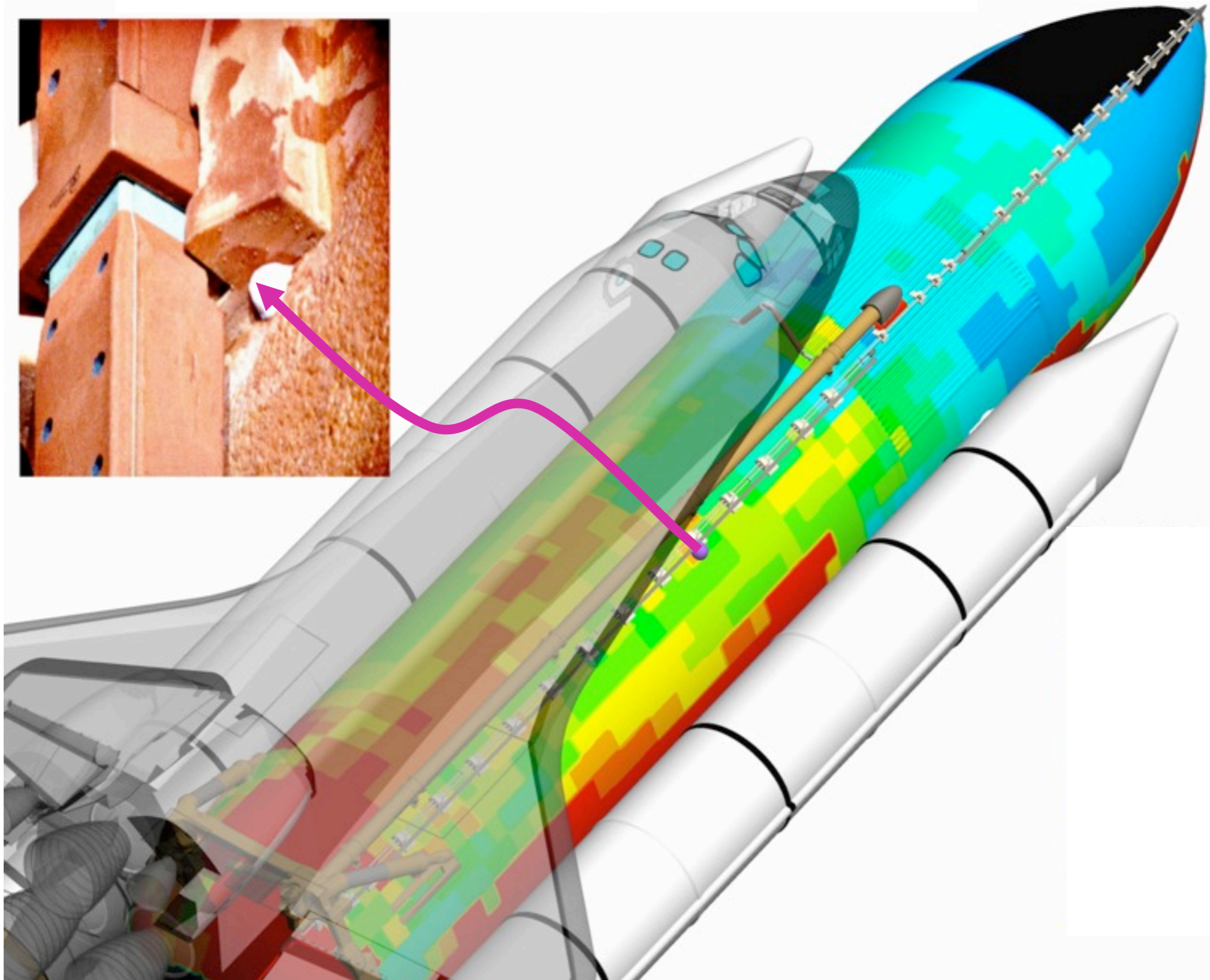
AIAA-2006-0662



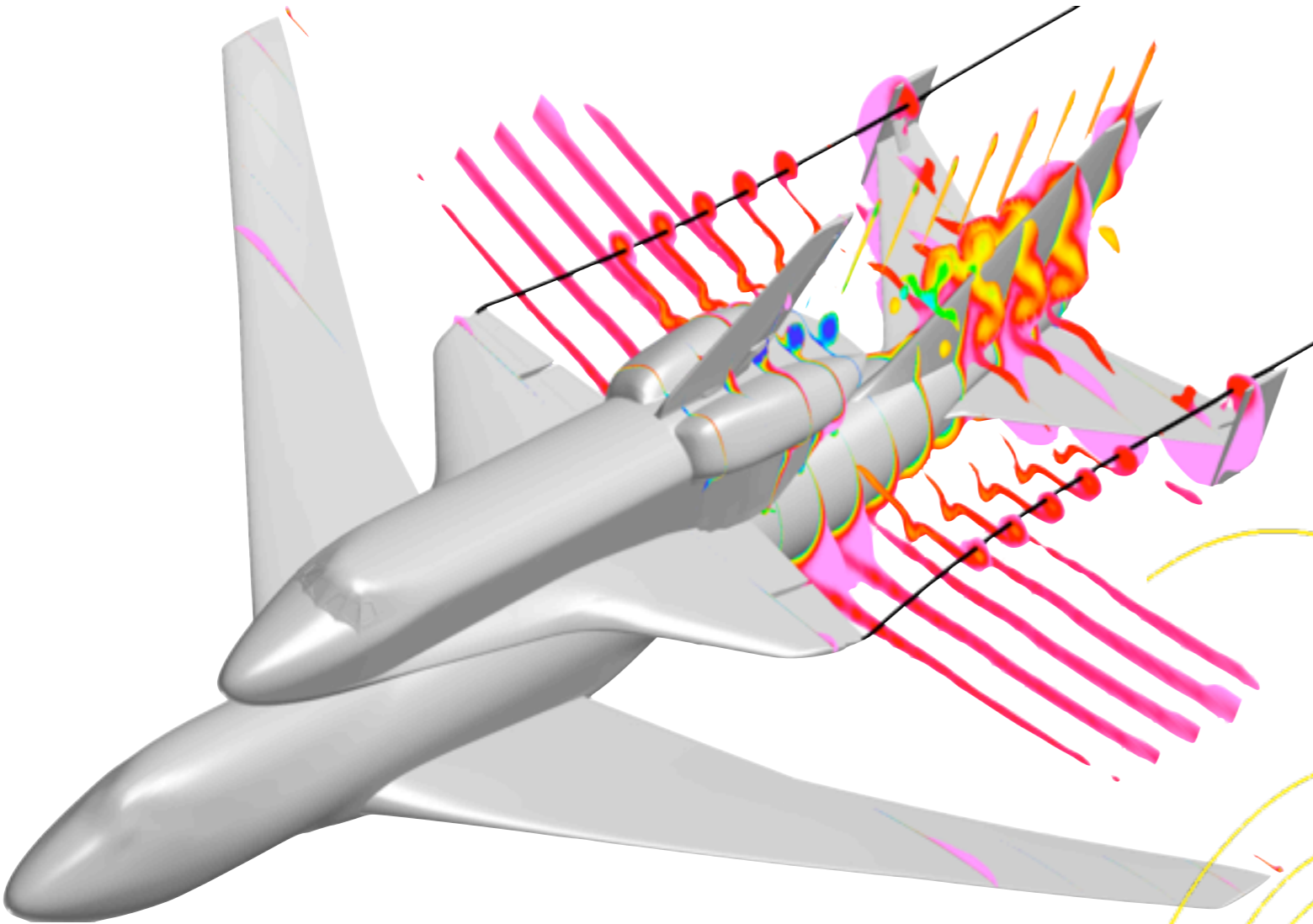
AIAA 2005-1223



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

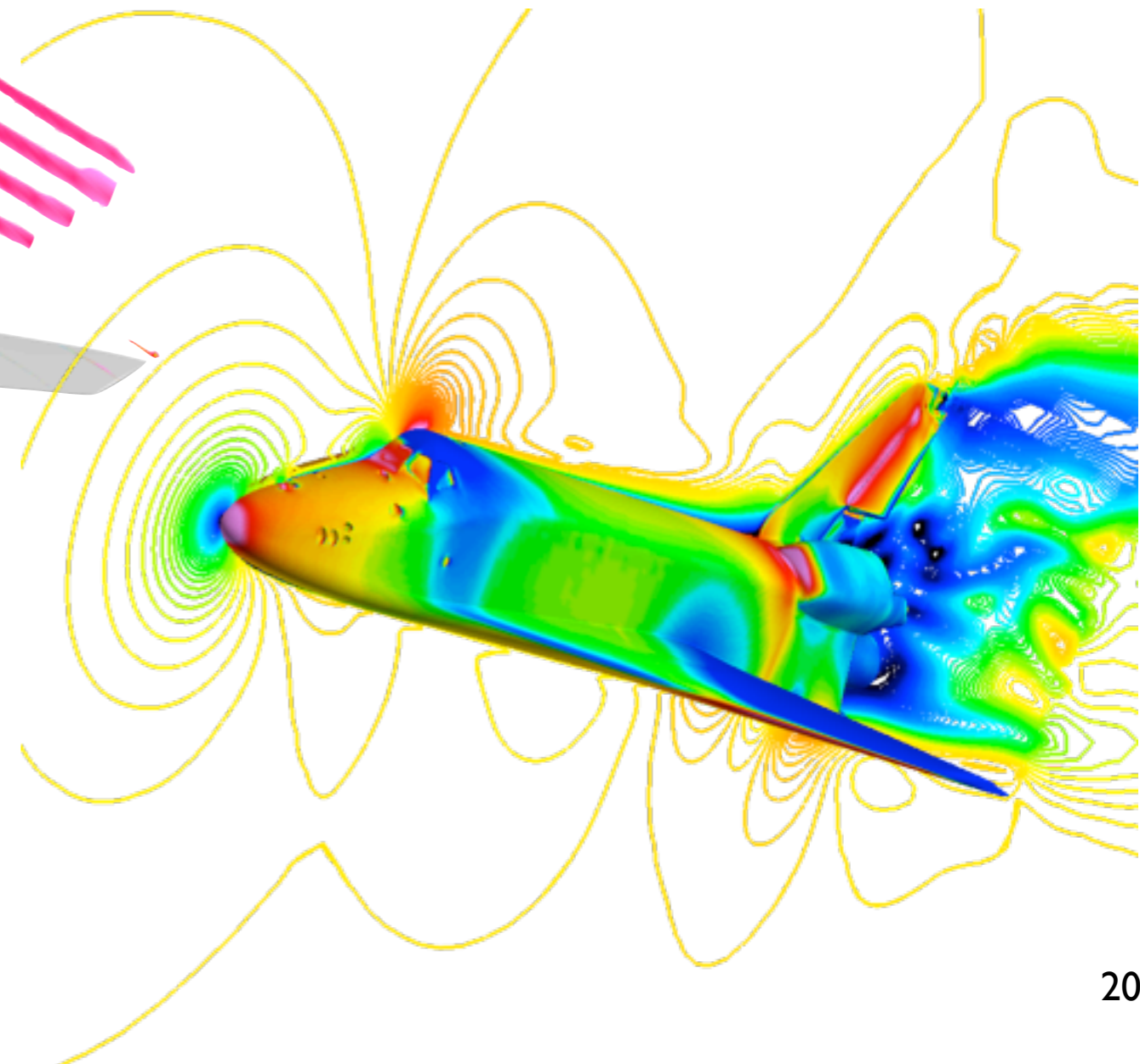


Other applications

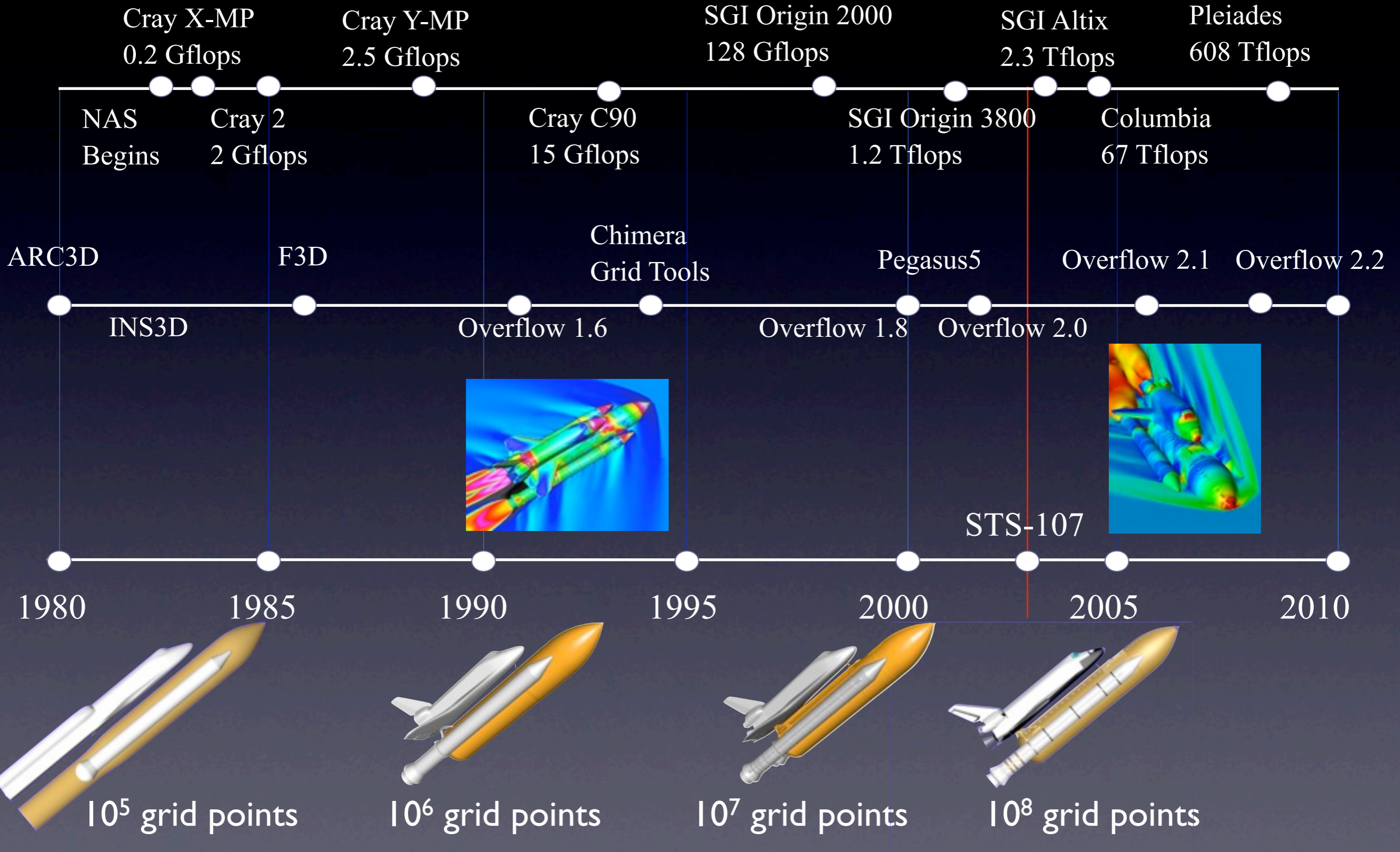


Shuttle Carrier Aircraft
Mach = 0.3, $\alpha = 3^\circ$
G. Schauerhammer

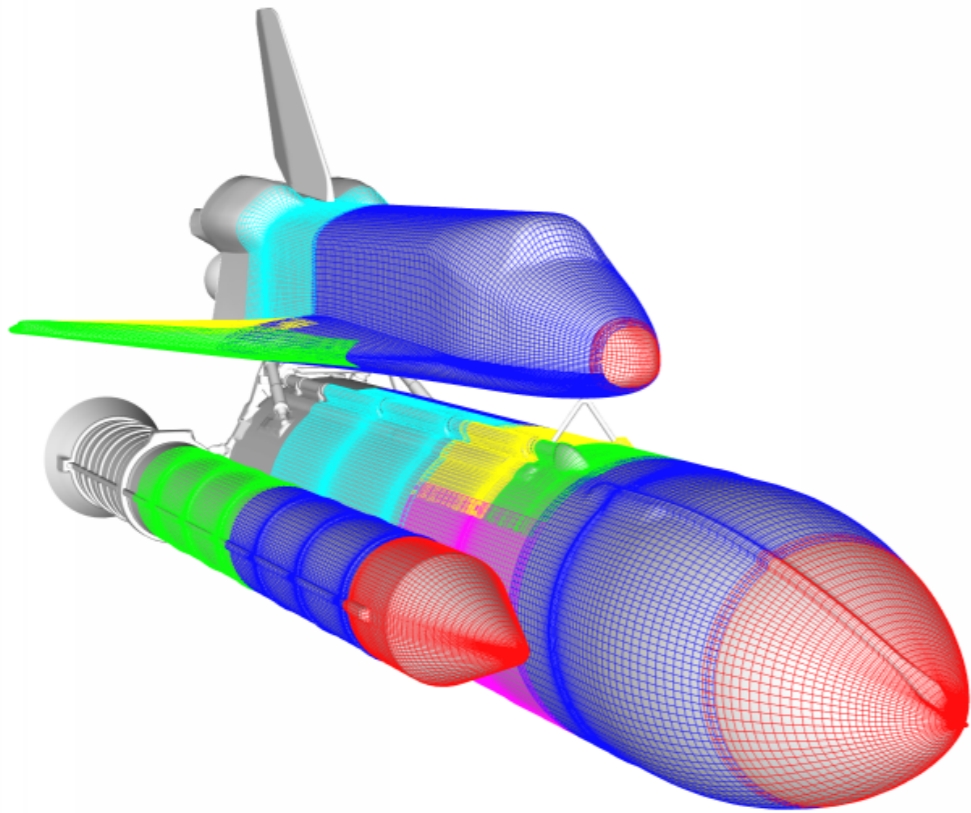
Entry Calculations
Mach = 0.8, $\alpha = 17^\circ$
L. Marek/JSC



Timeline of Computing & Overset Space Shuttle Applications

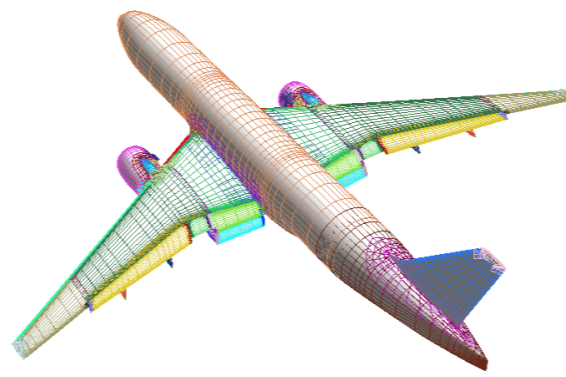


Overset Legacy

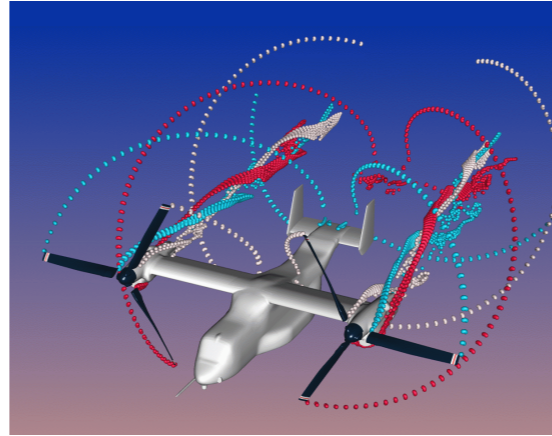


SSLV 1987-1993

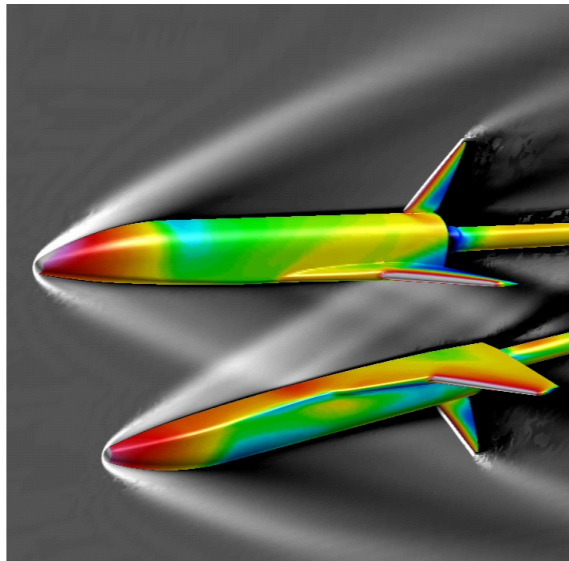
Initial OVERFLOW development, collar grids, complex geometry issues, plumes



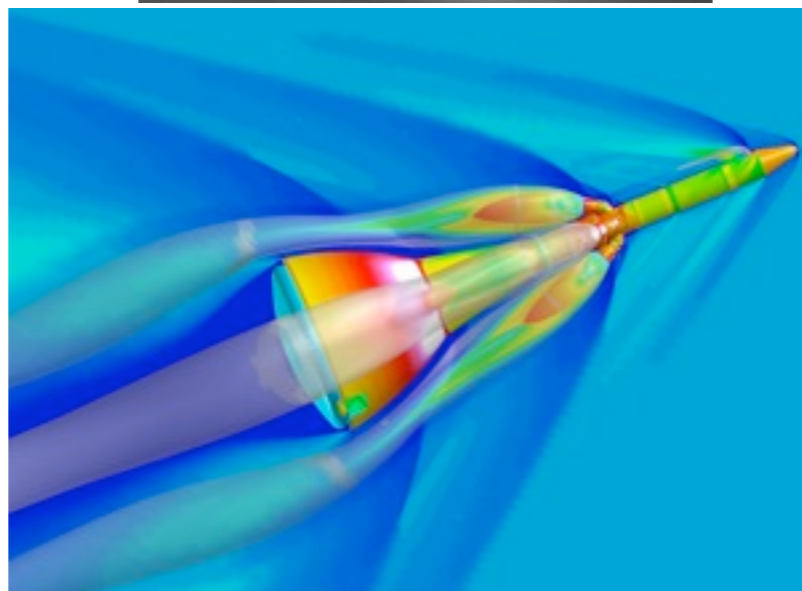
Advanced Subsonic Transport 1987-1993
Chimera Grid Tools, tcl scripting, turbulence modeling, PEGASUS 5



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 oversight 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-I 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

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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