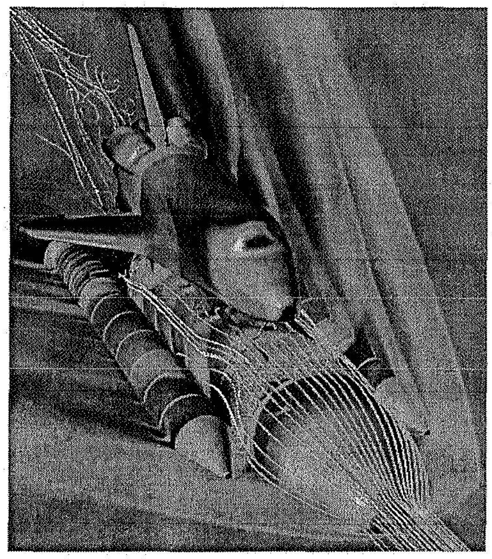
Aerodynamics at NASA JSC



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EG3 – Applied Aeroscience & CFD Branch
NASA Johnson Space Center
Houston, Texas

Presentation Outline

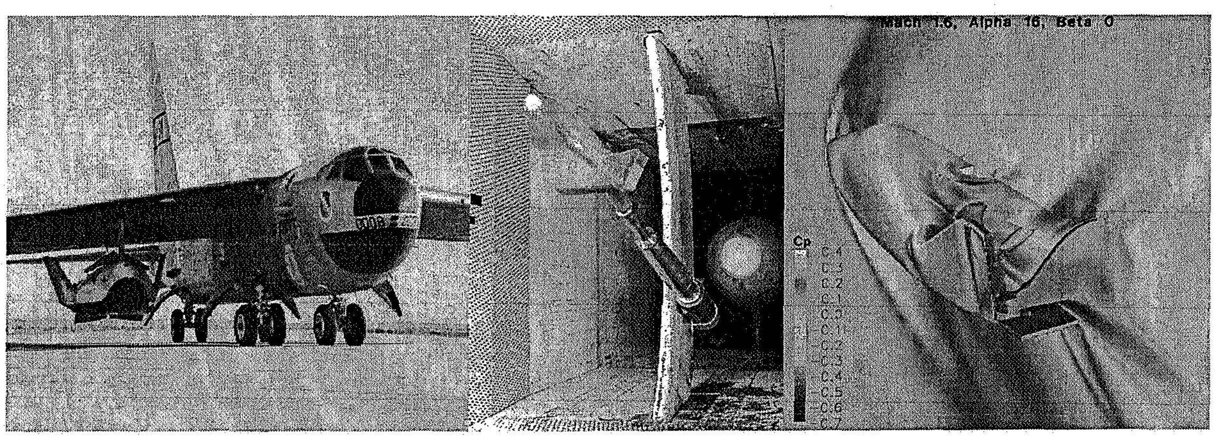
- Personal Background
- Aerodynamic Tools
- The Overset Computational Fluid Dynamics (CFD) Process
- Recent applications
  - X-38
    - V-131r Vehicle Scan
    - AEDC Wind Tunnel Test
  - Shuttle
    - STS-107 Investigation
    - Return to Flight

Personal Background

- Born and raised in Des Moines, IA
- *Aug 1997 – Aug 1999*, 4 co-op tours
  - EP4, Propulsion and Fluid Systems
  - EG3, Applied Aeroscience and CFD
  - EM, Manufacturing – "The Shops"
  - EG5, Advanced Mission Design
- *May 2000*, graduated from Iowa State University with a Bachelors degree, Aerospace Engineering
- ~~*August 2000*, hired by NASA/EG3~~
- *January 2001*, started Masters degree at Rice University

Aerodynamic Tools

X-38 Crew Return Vehicle

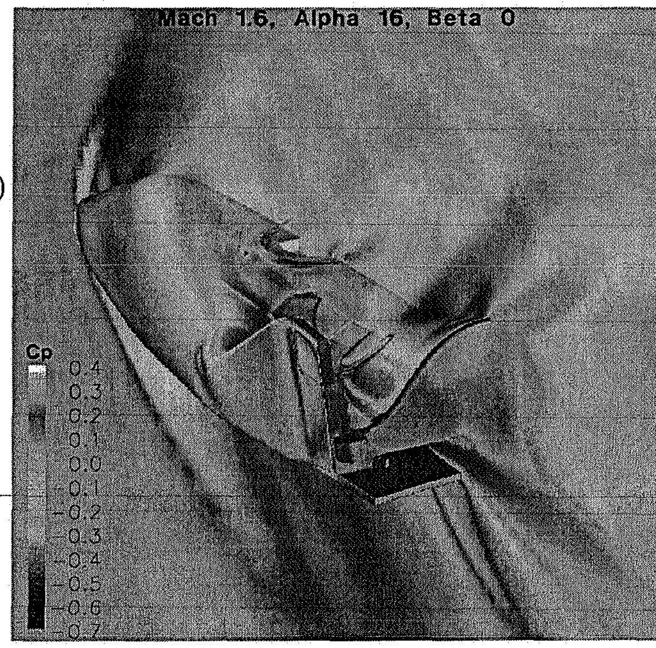


Flight Test **Wind Tunnel Test** **CFD**

The Overset CFD Process

What is CFD? – A “numerical wind tunnel”

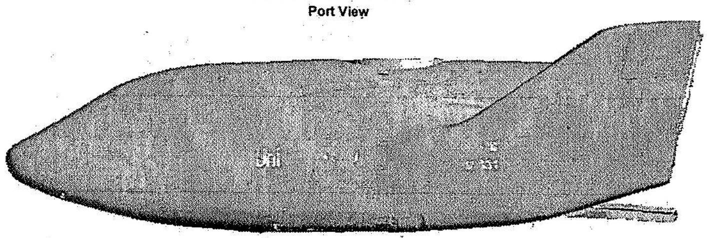
- Geometry Database (CAD)
  - Mathematical Surface (Continuous)
- Surface Grids
  - Computational surface (discrete)
  - May arbitrarily overlap
- Volume Grids
  - Computational domain
- Flow Solution
  - Define flight conditions
  - Apply boundary conditions
  - Solve Navier-Stokes eq’ns
- Data Extraction
  - Calculate and validate the desired results



V-131R Analysis

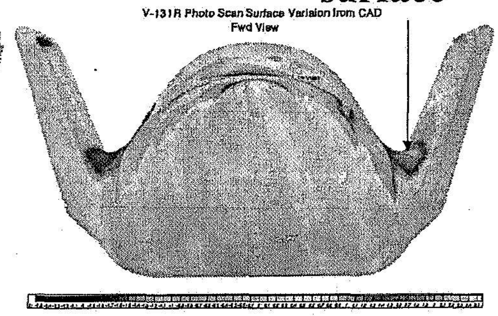
- Background
  - “Unplanned maneuver” occurred during the first drop test of V131R
  - Post-flight analysis revealed an unmodeled aerodynamic force as the primary cause
  - A bent airframe was the prime suspected
- CFD used to characterize the bent airframe aero
- Photogrammetric scan of the vehicle was performed to obtain surface geometry
  - 1.6 million points total in scan – average $\Delta s = 0.4$” (lower in high curvature areas)
  - IGES surfaces created from point cloud
- CFD grids were created on the “as-built” IGES surfaces

V-131 R Photo Scan Surface
Port View



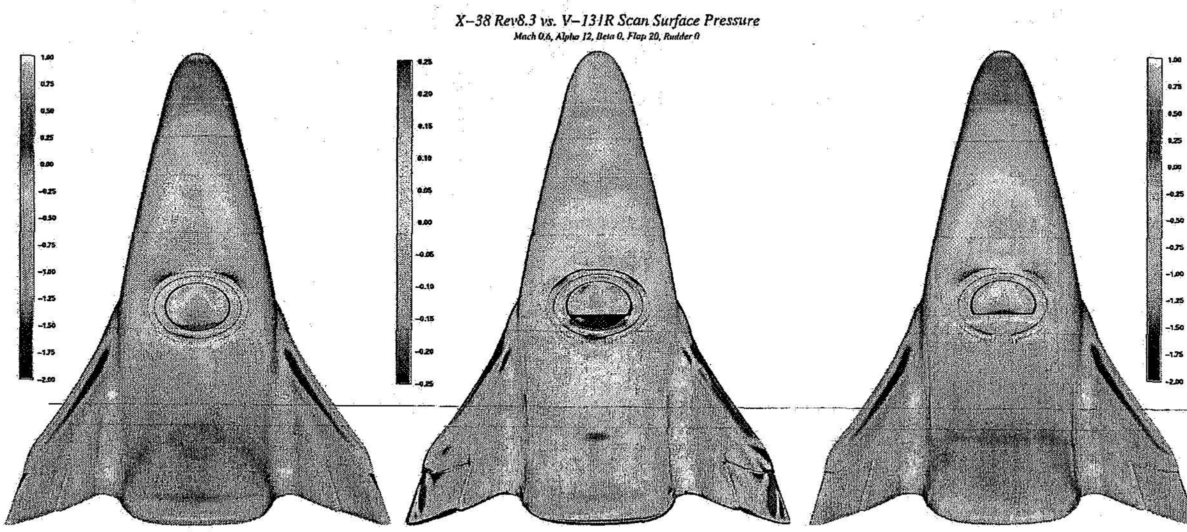
2” above CAD surface

V-131R Photo Scan Surface Variation from CAD
Fwd View



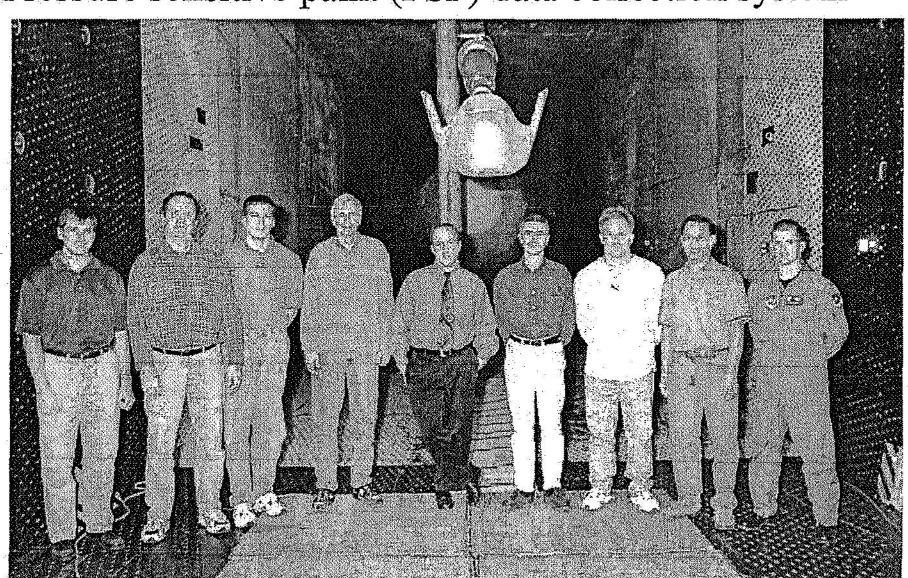
V-131R Analysis

- Solutions obtained using OVERFLOW with the “as-built” grids
- Surface C_p delta between CAD and “as-built”

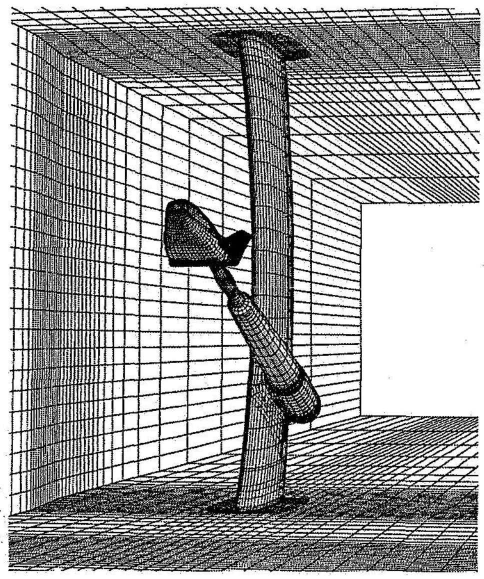


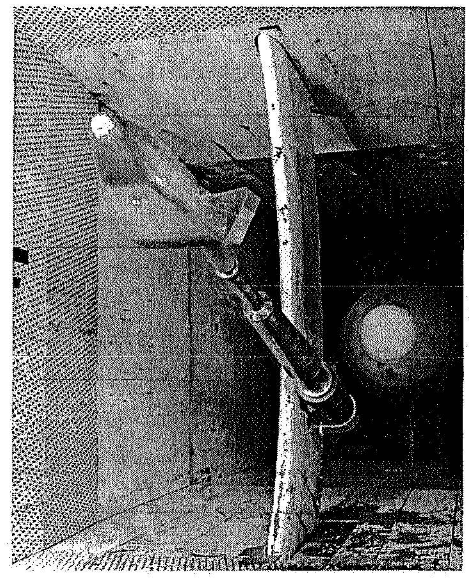
X-38 Model G Wind Tunnel Test

- Arnold Engineering and Development Center 16’ transonic tunnel (AEDC 16T) in Tullahoma, TN
  - Pressure sensitive paint (PSP) data collection system



Wind Tunnel Grids





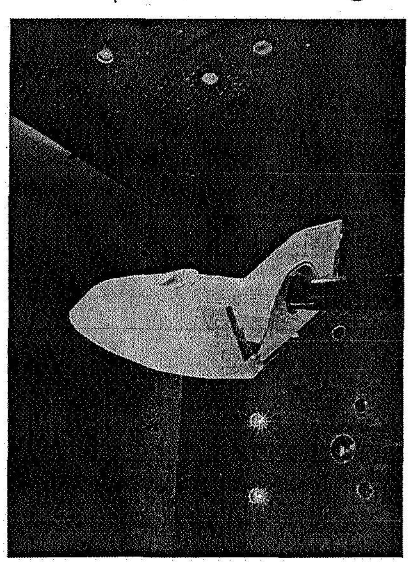
Note: every 4th point shown on X-38, every 2nd point shown on tunnel and support structure

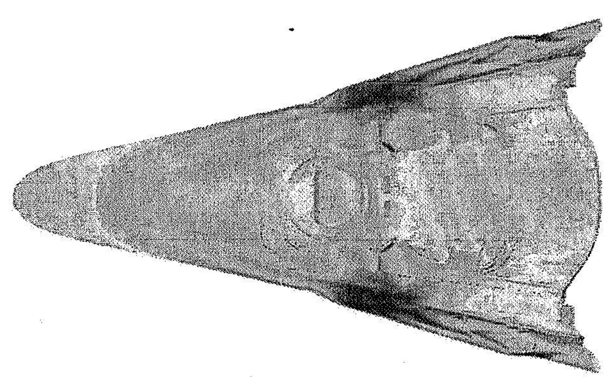
<u>Tunnel/Model G Grid System</u>

76 zones, 8.5 million points

Pressure Sensitive Paint

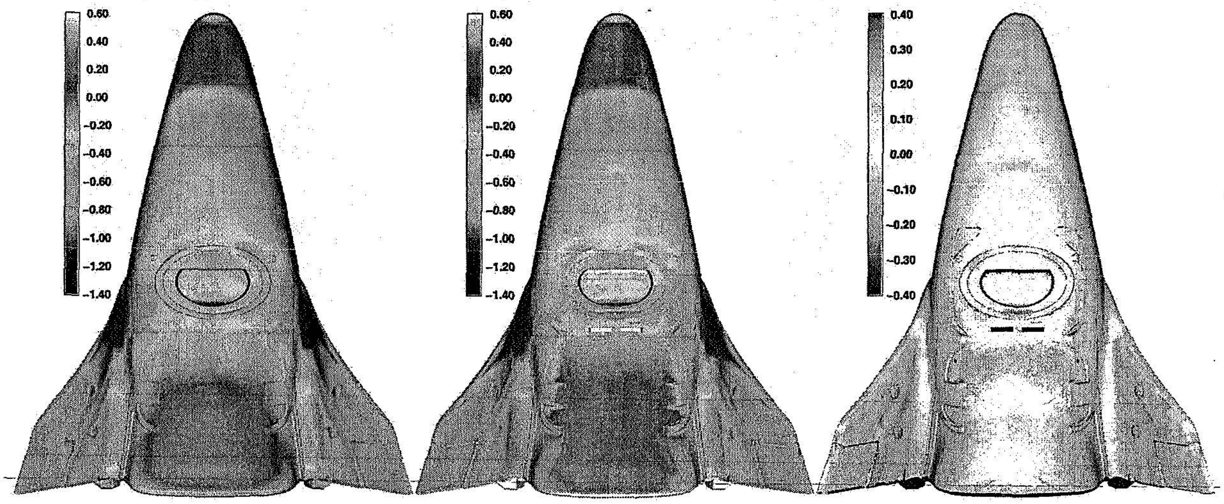
- Intensity based PSP system
  - Paint is excited by xenon lights
  - Light intensity emitted is dependant on the pressure
- Allows collection of high-resolution pressure distributions in WT





PSP vs. CFD

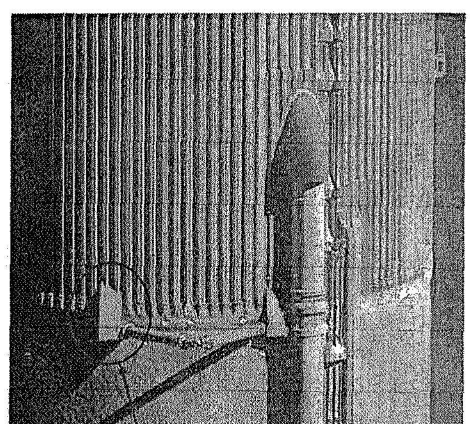
Mach 0.95, Alpha 16°, Beta 0°, Flap 20°, Rudder 0°



CFD Cp – PSP Cp = ΔCp

STS-107 Investigation

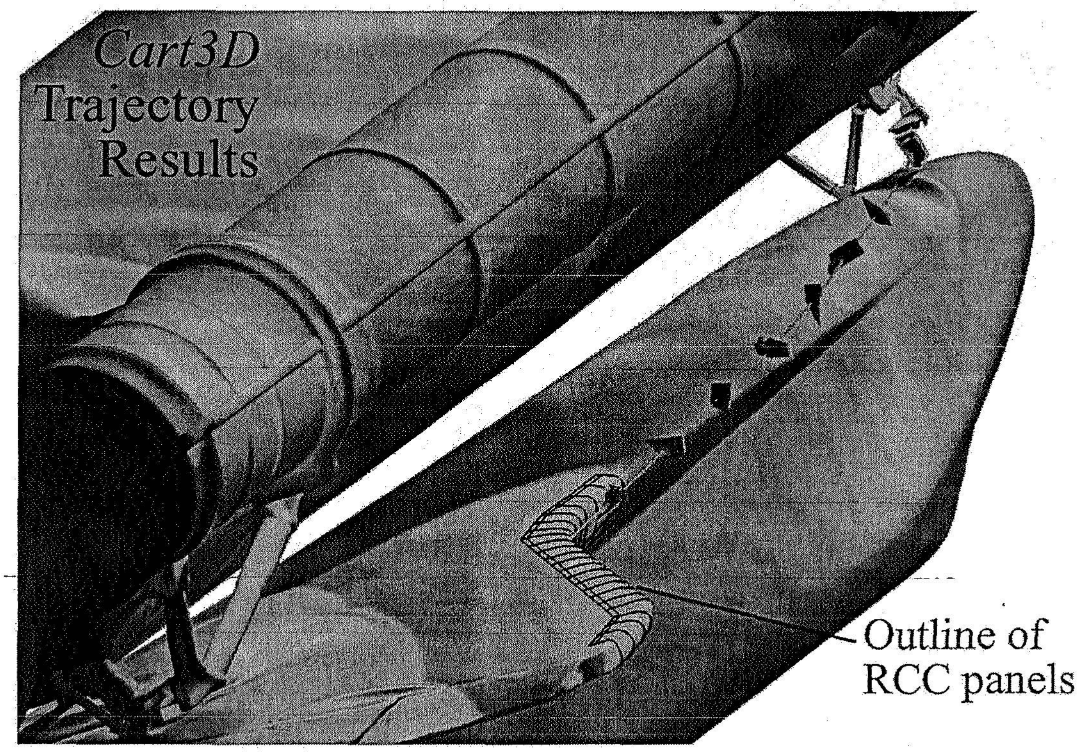
- Known:
  - Flight conditions at debris shedding
  - Debris came from left bipod ramp
  - Foam density approx 2.4 lbs/cu ft
- Unknown:
  - Debris shape, size, mass
  - Initial conditions
- Desire:
  - Possible impact locations
  - Impact velocity
  - Impact angle



Left bi-pod ramp

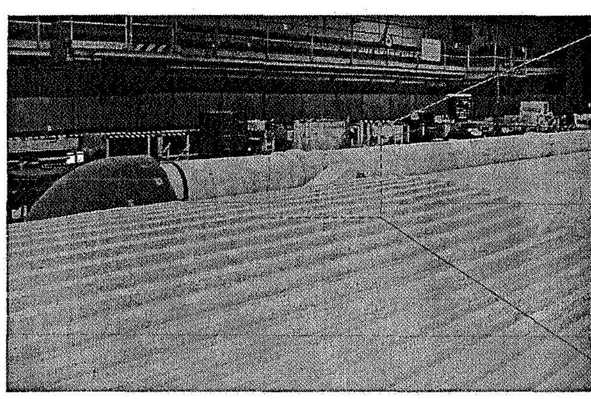
- Note: video evidence suggests impact velocities from 669 – 853 ft/sec: ambiguity due to distortions, lack of high-resolution / high-speed cameras

Cart3D 6-DOF Results, Mach = 2.46

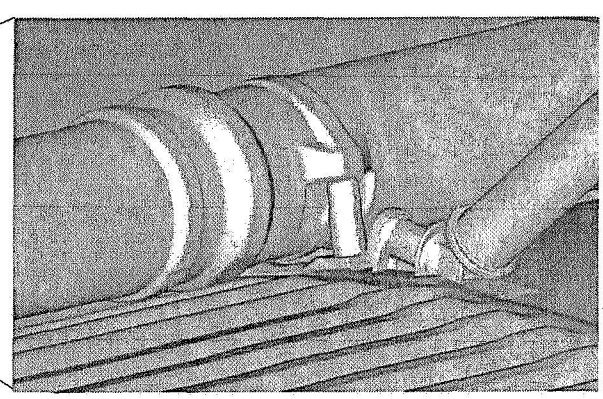


Return-to-Flight

- Bipod ramps have been removed
- Shape change → Change in aerodynamics

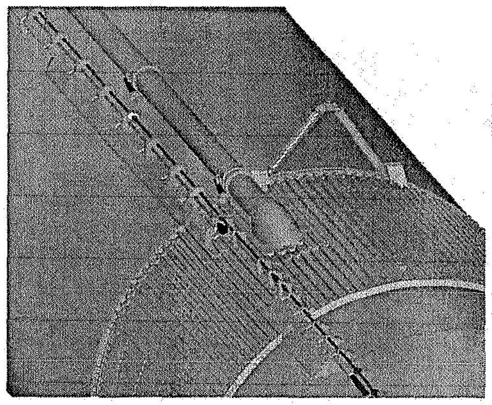


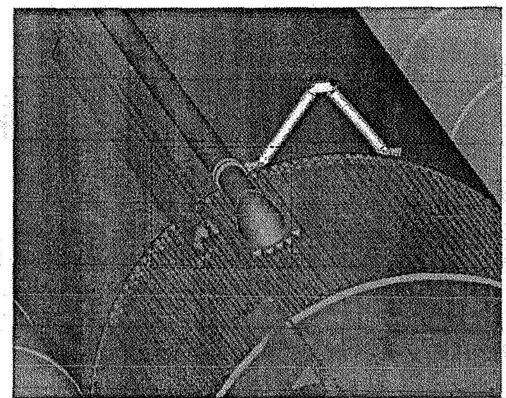
Old Configuration:
Bipod Ramps



New Configuration:
Bare Spindle

Improvement of ET CFD Grid

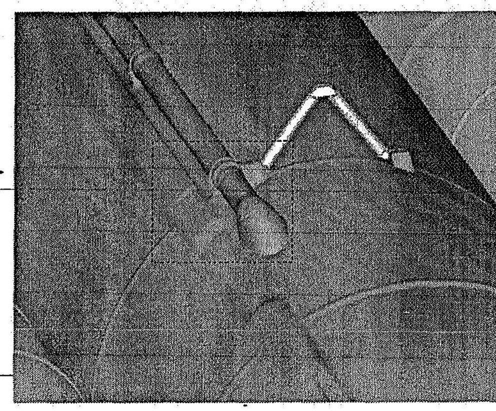




MAF CAD

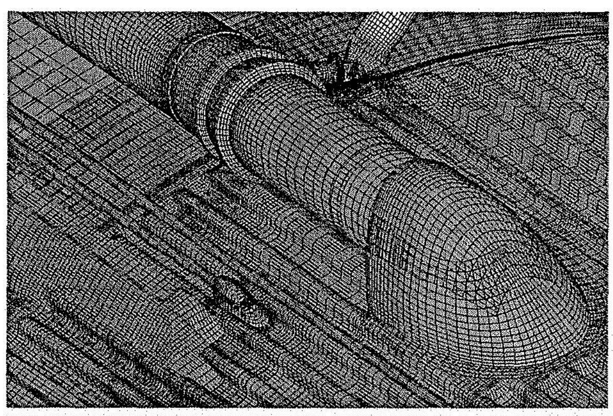
New CFD geometry

Old CFD geometry

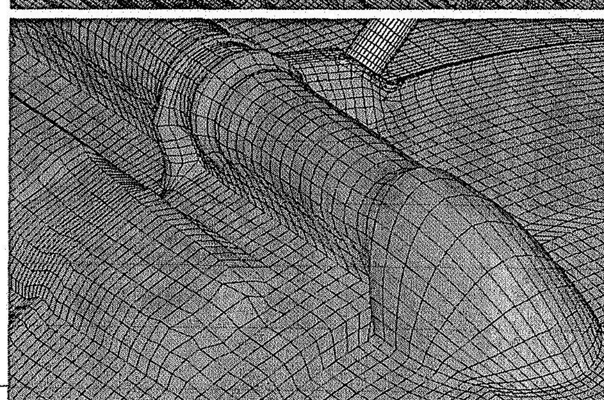


Grid details of boxed region on next page

Grid Comparison Detail

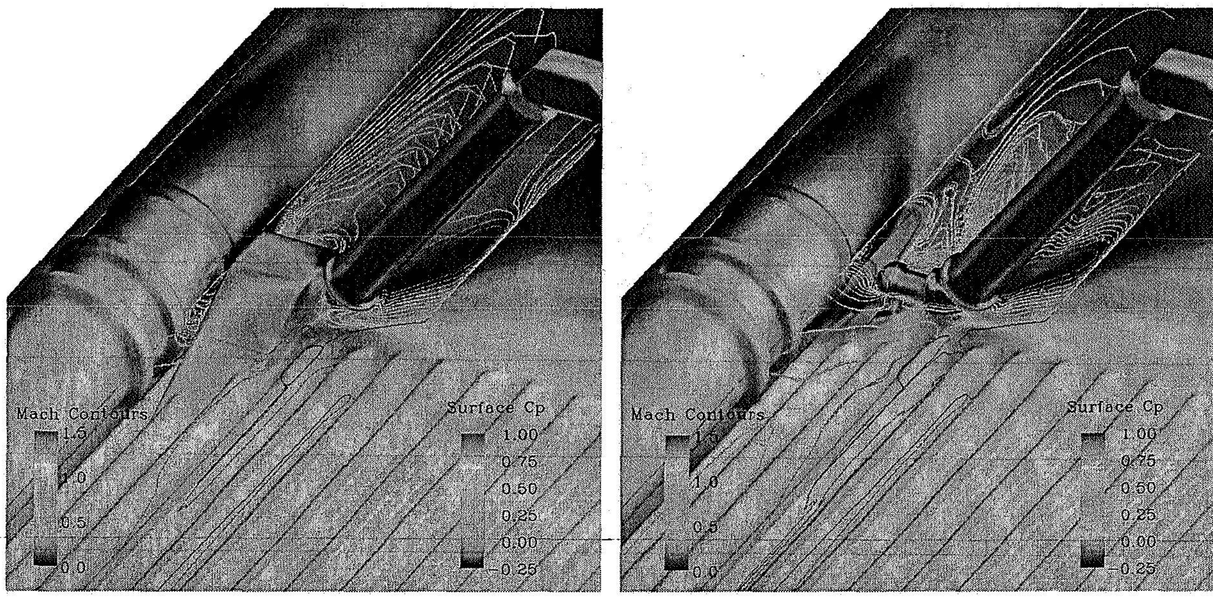


New CFD grids



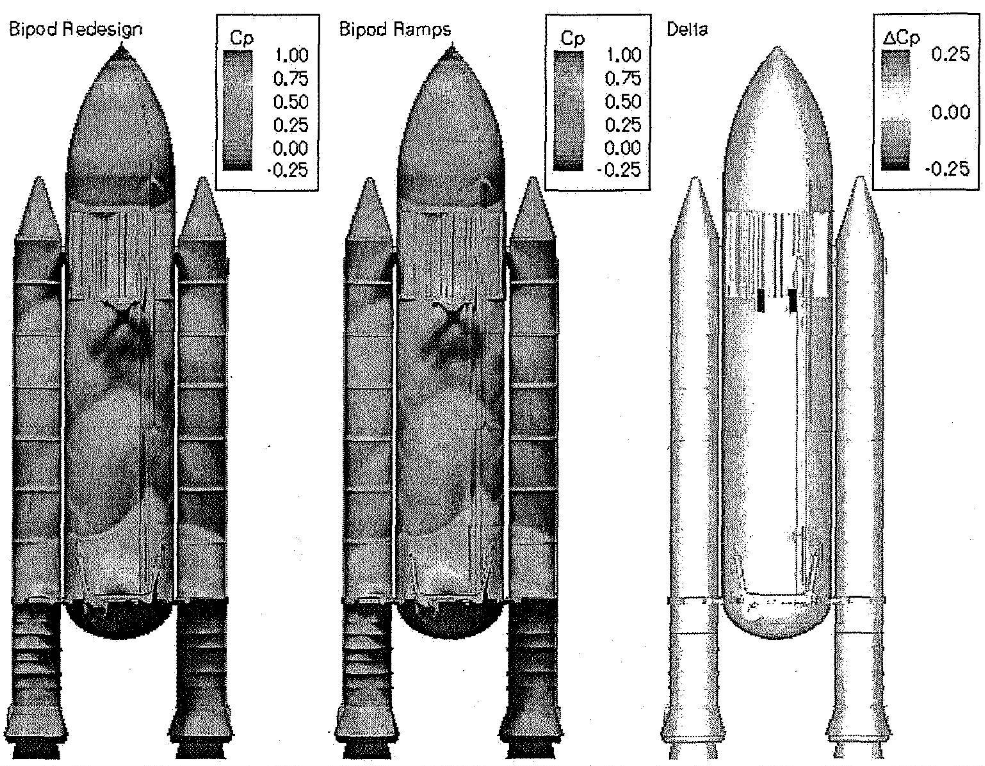
Old CFD Grids

Flow Visualization – Mach 1.55

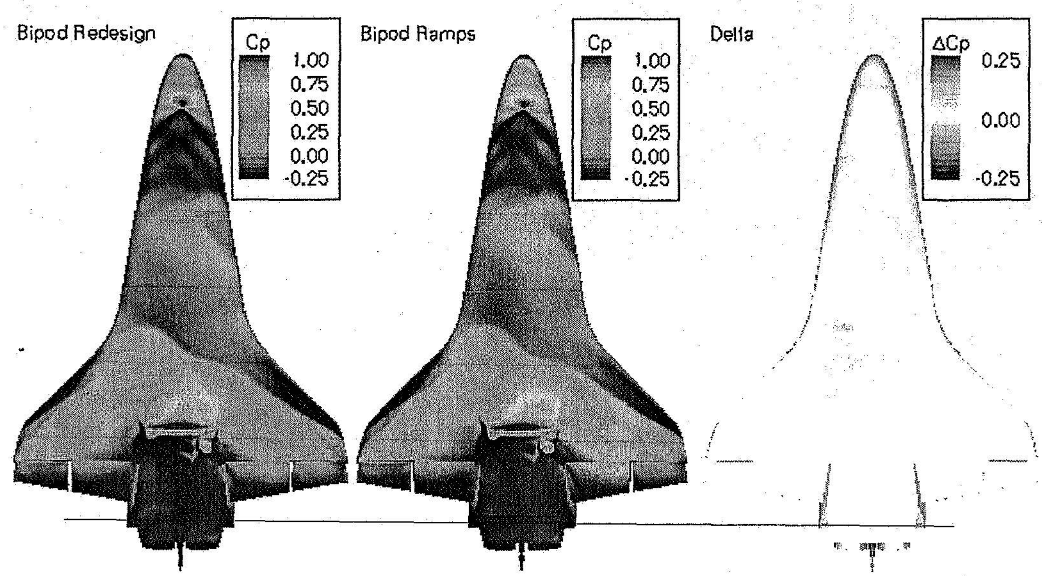


Mach contours in Z = 564 inch cutting plane

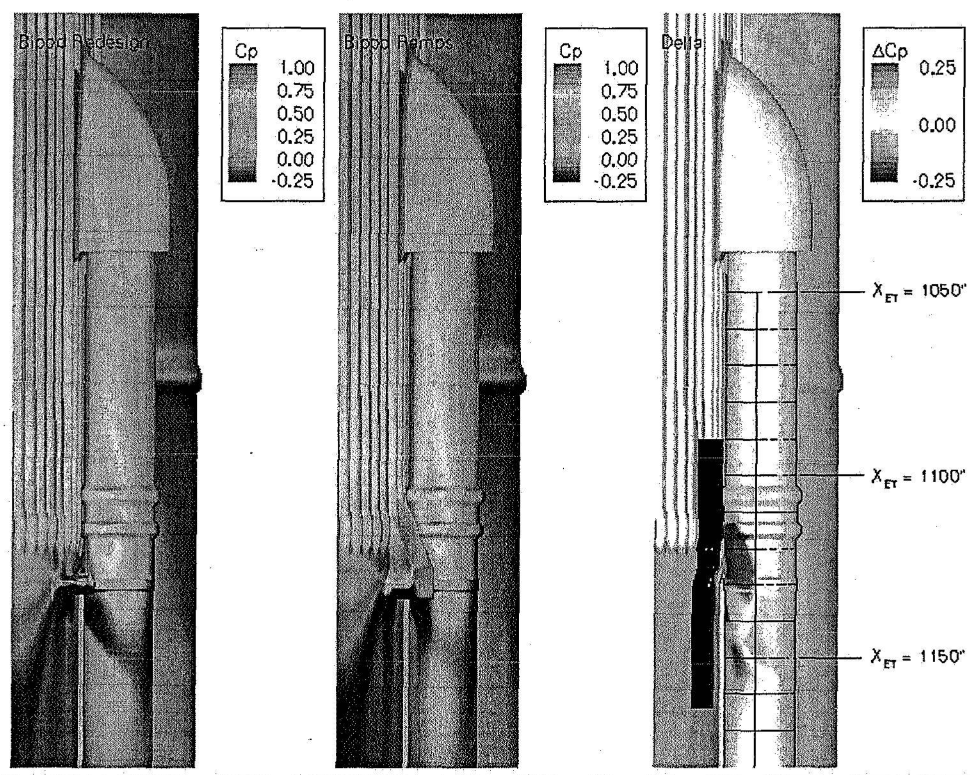
ET/SRB ΔCp – Mach 1.55



Orbiter ΔCp – Mach 1. 55



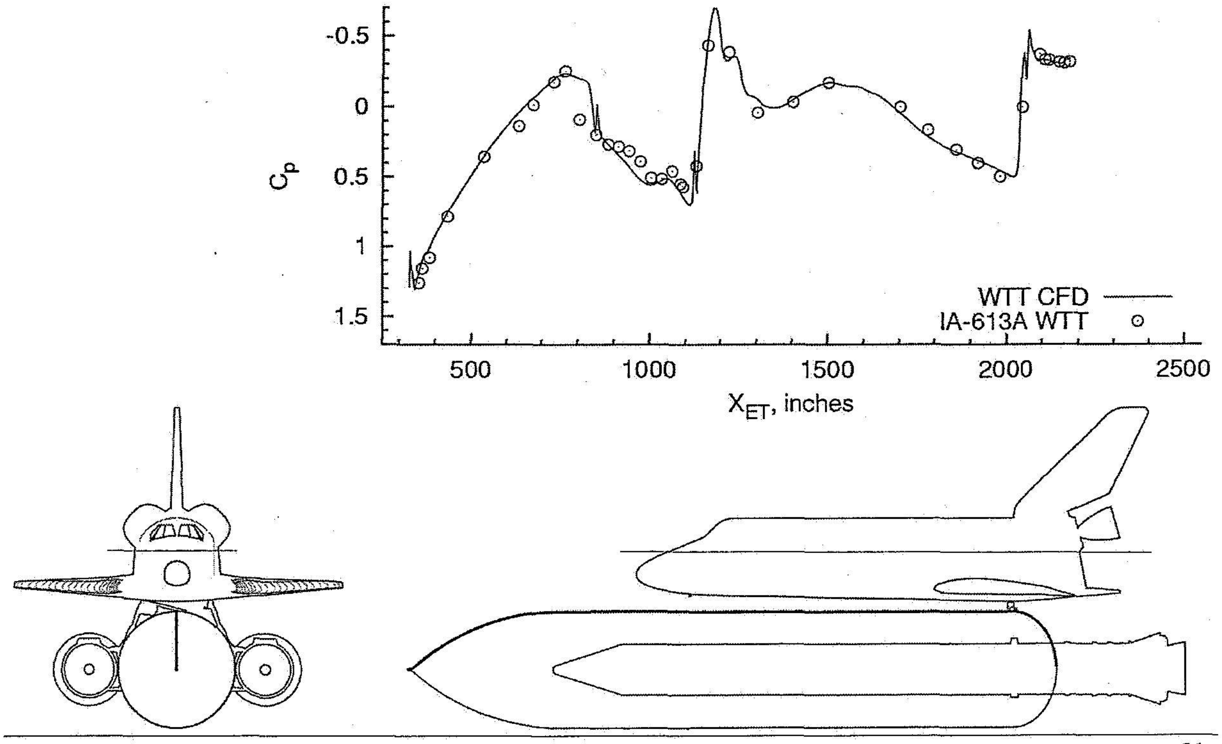
Inboard LO_2 Line ΔCp – Mach 1. 55



Wind Tunnel Test (IA-613) Comparisons - External Tank - Phi = 180°

CFD conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = 5.00°

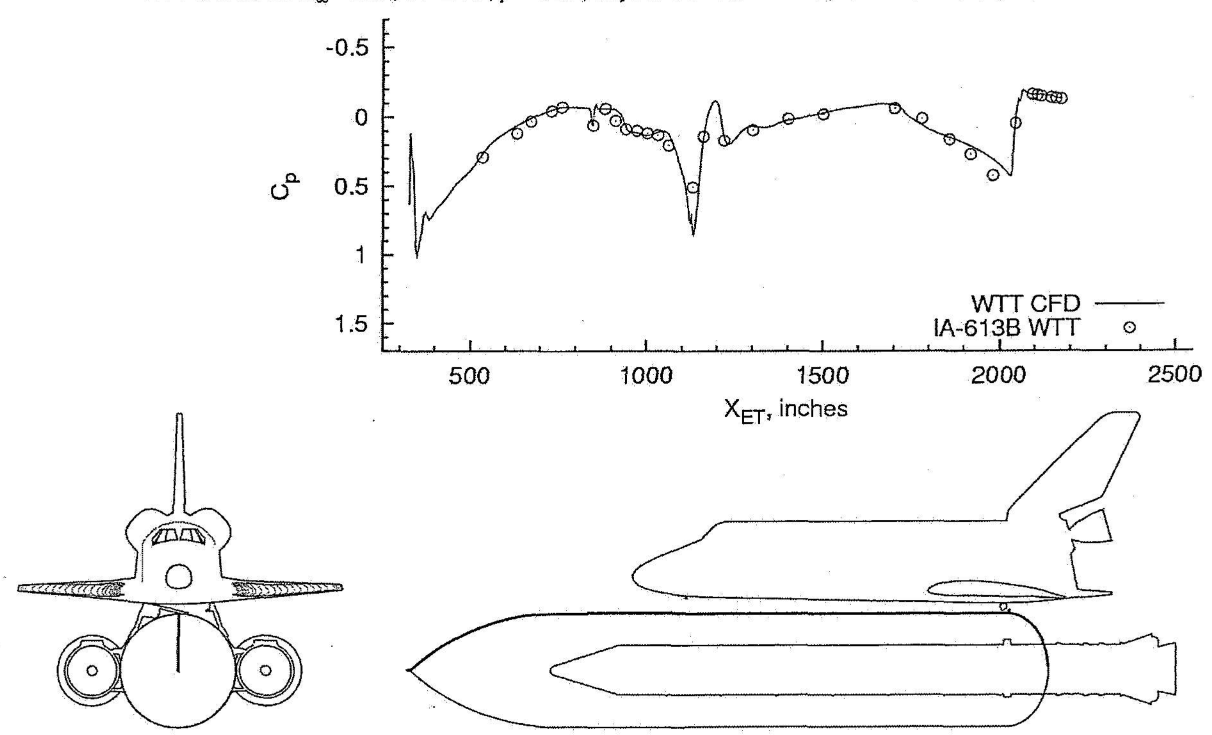
WTT conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = 5.00°



Wind Tunnel Test (IA-613) Comparisons - External Tank - Phi = 180°

CFD conditions: M_∞ = 2.50, α = 2.03°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.07°, OB elevon = -4.39°

WTT conditions: M_∞ = 2.50, α = 2.03°, β = 0.00°, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.07°, OB elevon = -4.39°

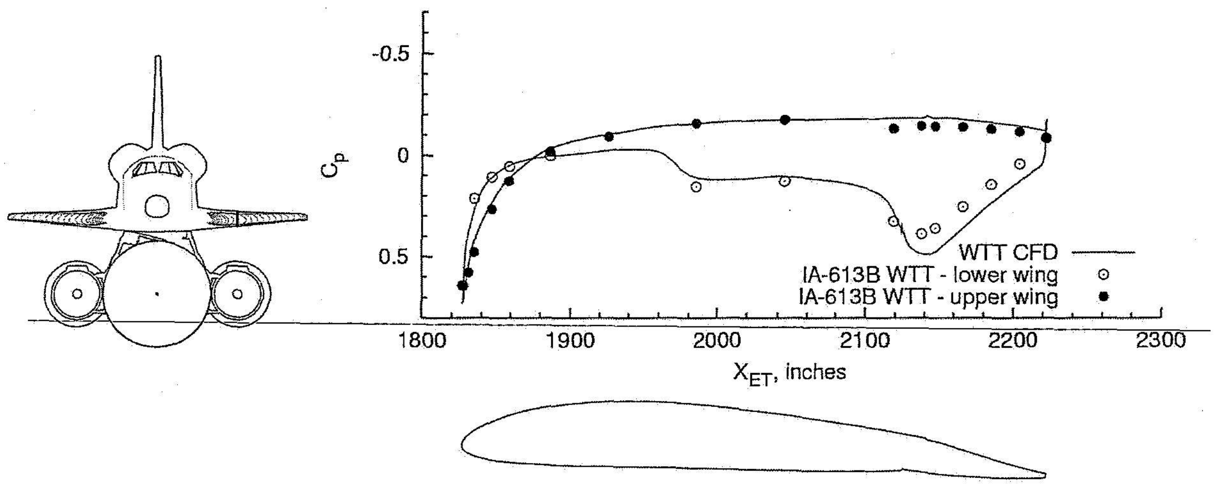


CFD vs. IA-613B Wing Pressures

Mach 2.50, Y = -250”

From WTT report: as measured elevons are:
Left IB = 4.07°±0.09 , Left OB = -4.39°±0.11

CFD conditions: $M_\infty = 2.50$, $\alpha = 2.03°$, $\beta = 0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.00°, OB elevon = -5.00°
WTT conditions: $M_\infty = 2.50$, $\alpha = 2.03°$, $\beta = 0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.00°, OB elevon = -5.00°

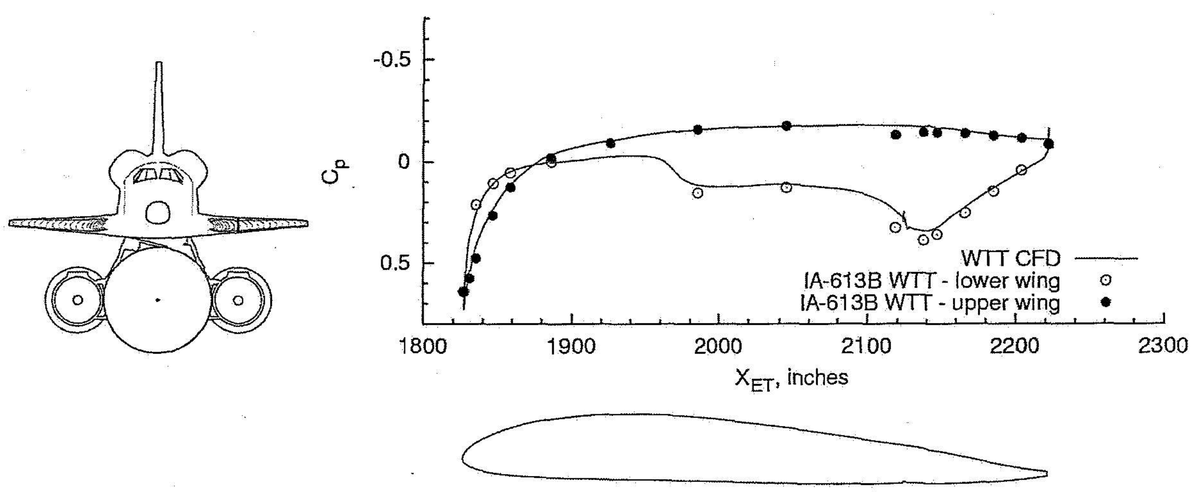


CFD vs. IA-613B Wing Pressures

Mach 2.50, Y = -250”

CFD run with as measured elevons

CFD conditions: $M_\infty = 2.50$, $\alpha = 2.03°$, $\beta = 0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.07°, OB elevon = -4.39°
WTT conditions: $M_\infty = 2.50$, $\alpha = 2.03°$, $\beta = 0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 4.07°, OB elevon = -4.39°



CFD vs. IA-613B Left SRB Pressures

Mach 1.25, $\Phi = 180°$

CFD conditions: $M_\infty = 1.25$, $\alpha = -3.95°$, $\beta = 0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = 5.00°

WTT conditions: $M_\infty = 1.25$, $\alpha = -3.95°$, $\beta = -0.00°$, Reynolds # = 2.50 x10^6/ft, IB elevon = 10.00°, OB elevon = 5.00°