NUMERICAL AERODYNAMIC SIMULATION OF THE SPACE SHUTTLE ASCENT ENVIRONMENT

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ABSTRACT

After the STS 51-L accident, an extensive review of the Space Shuttle Orbiter's ascent aerodynamic loads uncovered several questionable areas that required further analysis. The insight gained by comparing the Shuttle ascent CFD numerical simulations, obtained by the NASA Ames Space Shuttle Flow Simulation Group led by Dr. J.L. Steger, to the current IVBC-3 aerodynamic loads database was instrumental in resolving uncertainties on the Orbiter payload bay doors and fuselage. Initial confidence in the numerical simulations was gained by comparing them with the limited flight data that had been obtained during the Orbiter Flight Test (OFT) program. Current CFD results exist for Mach numbers 0.6, 0.9, 1.05, 1.55, 2.0, and 2.5. Since the pre STS-1 wind tunnel test program (IA-105) often yields considerable differences when compared to STS-5 flight data, the M_∞=1.05 transonic case is the most investigated. The IA308 mated-vehicle hot gas plume wind tunnel test, recently completed at AEDC 16T (transonic) and Lewis (hypersonic), is also used to compare with the computation where applicable.

Objective

- *Joint* effort between the ARC team led by J.L. Steger and P.G. Buning and a JSC team led by F.W. Martin, Jr.

- ARC Team : Develop the technology to numerically simulate the complex launch vehicle (SSLV) geometry in a time accurate manner to
  - compute SSLV flowfield data
  - support Fast Separation Abort study
  - assist JSC with Orbiter problematic issues:
    - Crew Escape flowfield
    - STS-27 Debris Study flowfields

- JSC Team : Apply the CFD technology to gain insight into the ascent aerodynamic loads environment
  - SSLV payload bay pressure distribution
  - Orbiter Wing Loads

Scope

- ARC Team
  - Model the Orbiter ascent configuration with the *Chimera* composite grid discretization approach.
  - Overset body-conforming grids for each major component (CALSPAN *Pegasus* code).
  - Apply *F3D*, an implicit approximately factored finite-difference procedure, to solve the three-dimensional thin-layer Navier-Stokes equations.
  - Employ the NAS Cray 2 and Cray Y-MP.

- JSC Team
  - Provide technical guidance and evaluate ARC results with respect to existing databases:
    - ▷ IA-105 WTT, high resolution model.
    - ▷ IA-308 WTT, hot gas plume simulation.
    - ▷ *Limited* flight data from STS-1 through STS-5.
    - ▷ IVBC-3 operational database.

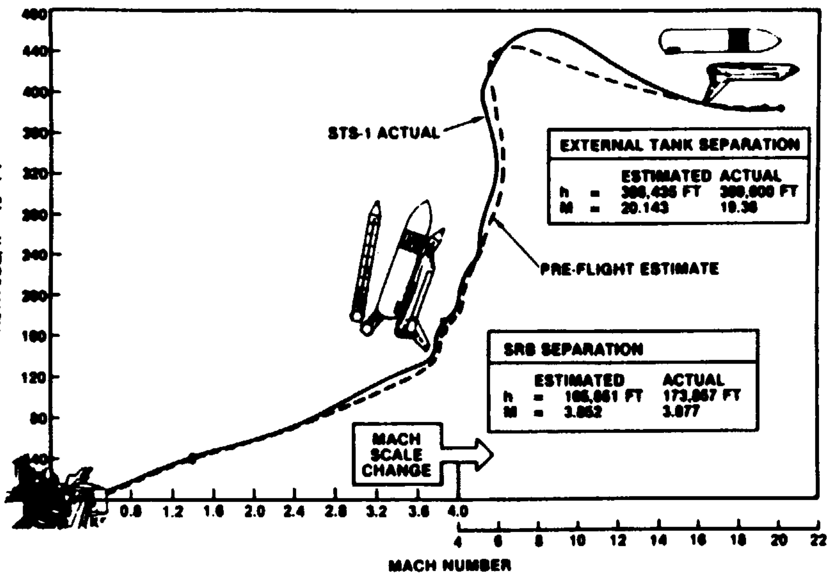
Justification

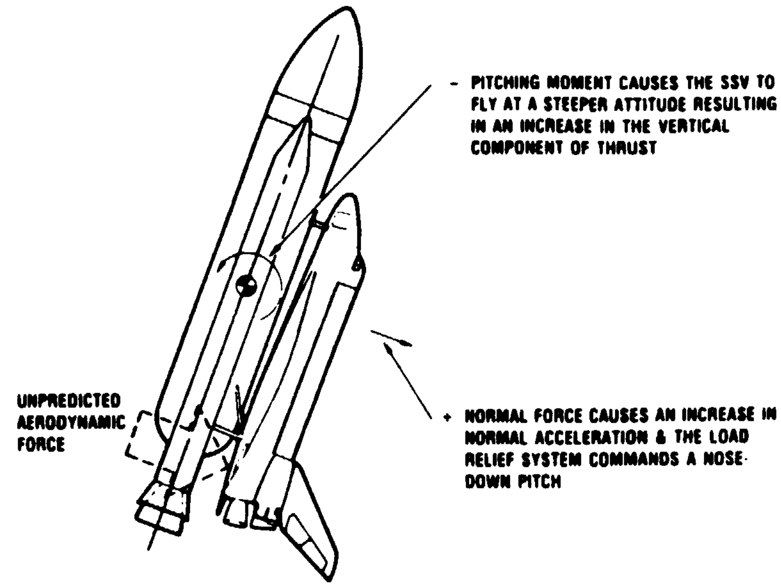
The Orbiter's modest structural capability, coupled with a complex launch vehicle configuration and severe ascent environment, places unprecendented demands on the aerodynamacist.

- Orbiter structure was designed to civil transport specifications.
  - Consistent with entry flight envelope.
  - $\bar{q} \approx 350$ psf, g_z=2.5 (g_z=2.25 as weight increases).
- Ascent environment is considerably more severe, $\bar{q}$=750-819 psf, with the simultaneous occurance of:
  - maximum $\bar{q}$
  - jet stream penetration (perturbates α, β and $\bar{q}$)
  - transonic flow field
  - maximum differential pressure, inside-outside, as the vehicle vents
  - plume/flow field interactions
  - High R_e ($\sim$ 100 million) at maximum load condition

Historical Perspective

- Discrepancies exist between aerodynamic predictions and flight experience.





- Force and moment data was easily corrected with flight derived aerodynamic increments.
- Aerodynamic loads (pressure distribution) cannot be readily corrected because of *limited* flight pressure measurements.

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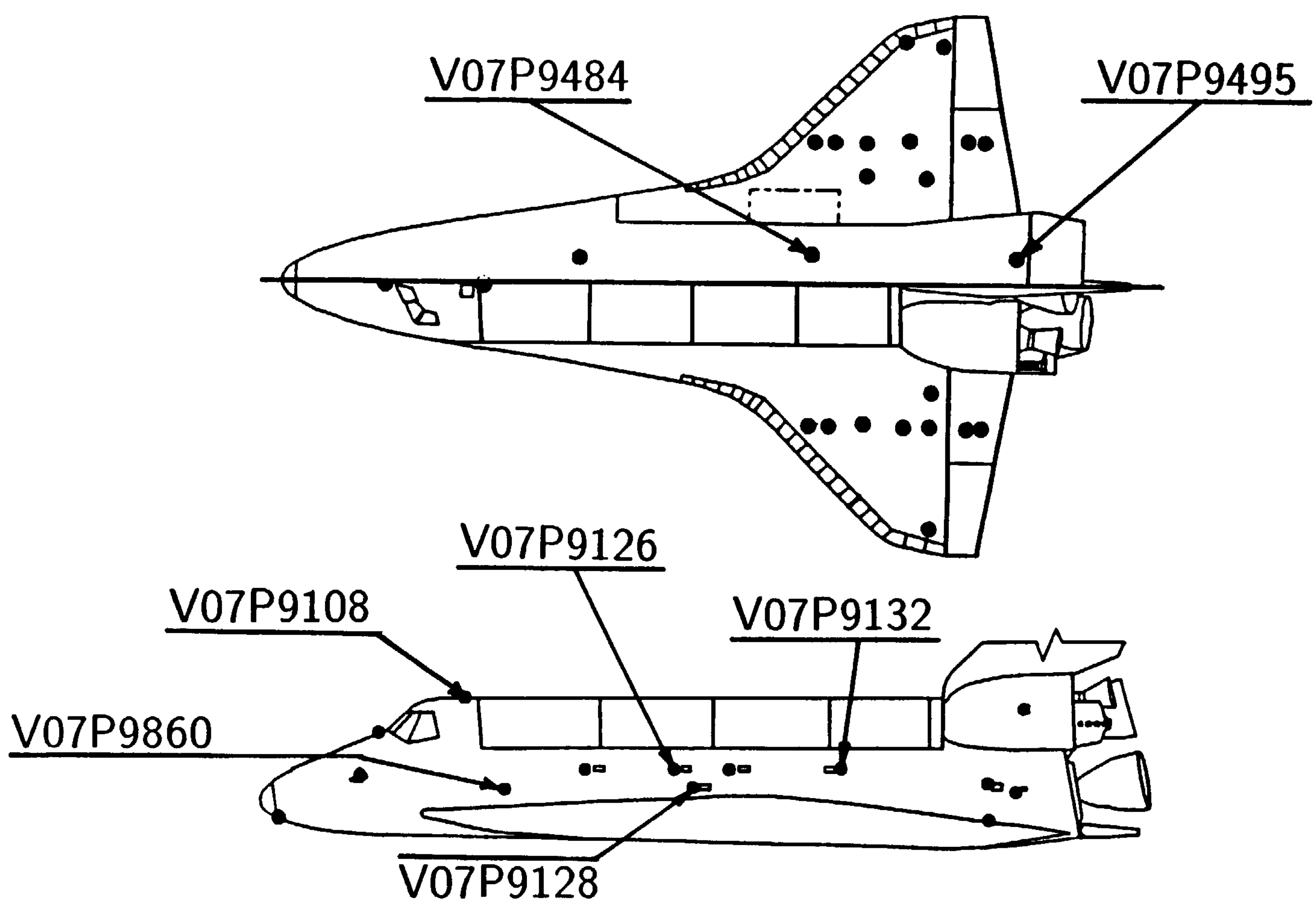
Current Database

- The *I*ntegrated *V*ehicle *B*aseline *C*onfiguration (IVBC) - 3 aero loads database is a composite of
  - IA-105 WTT data
  - Flight pressure measurements
  - Flight strain measurements
  - Engineering judgement
- This resulting database contains relatively large uncertainties which have led to structural analysis predictions that were inconsistent with flight experience, especially in the payload bay door area.

Selected STS-5 Tap Points



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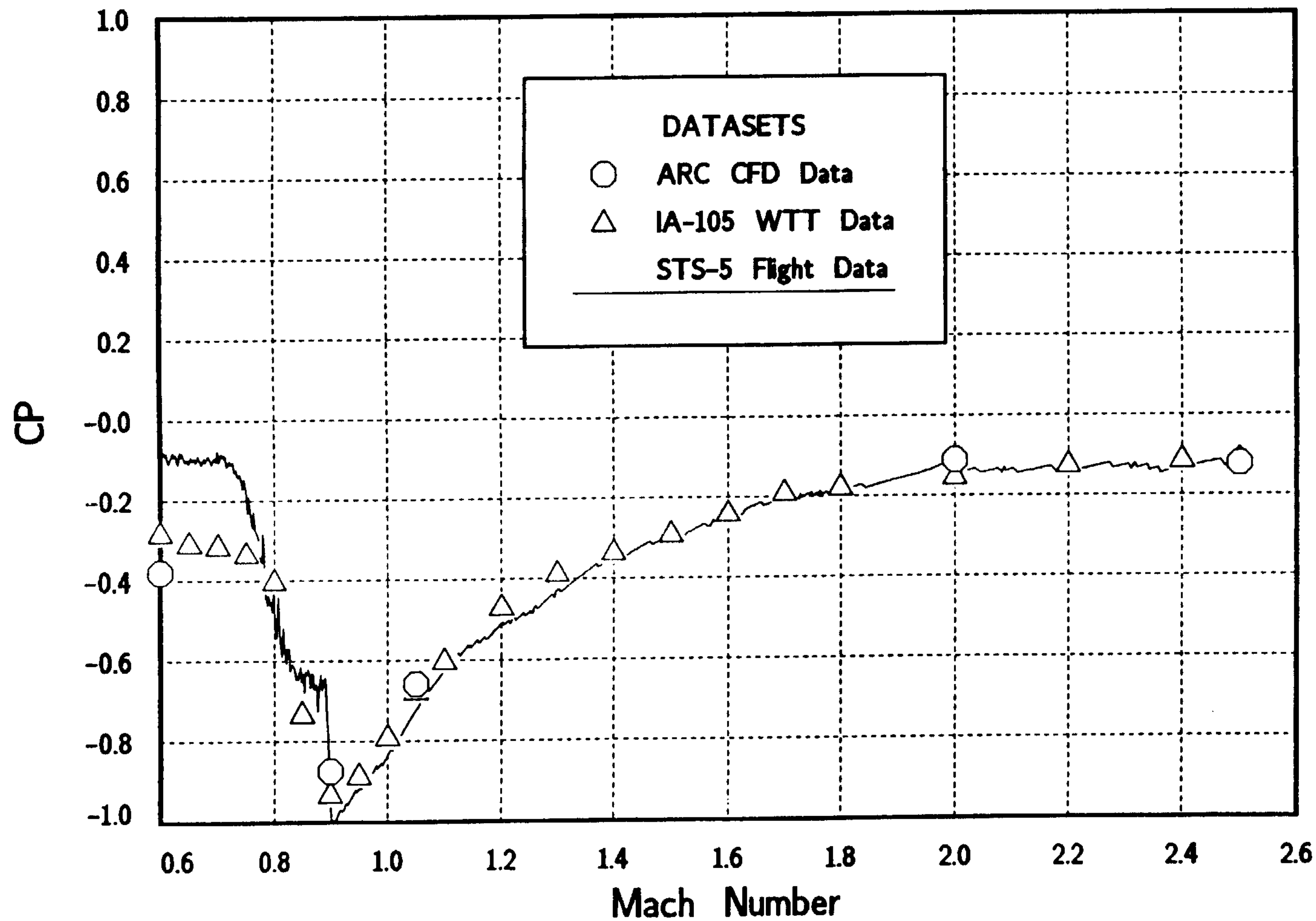
AERO DATABASE COMPARISONS

TAP V07P9108A CP HISTORY



AERO DATABASE COMPARISONS

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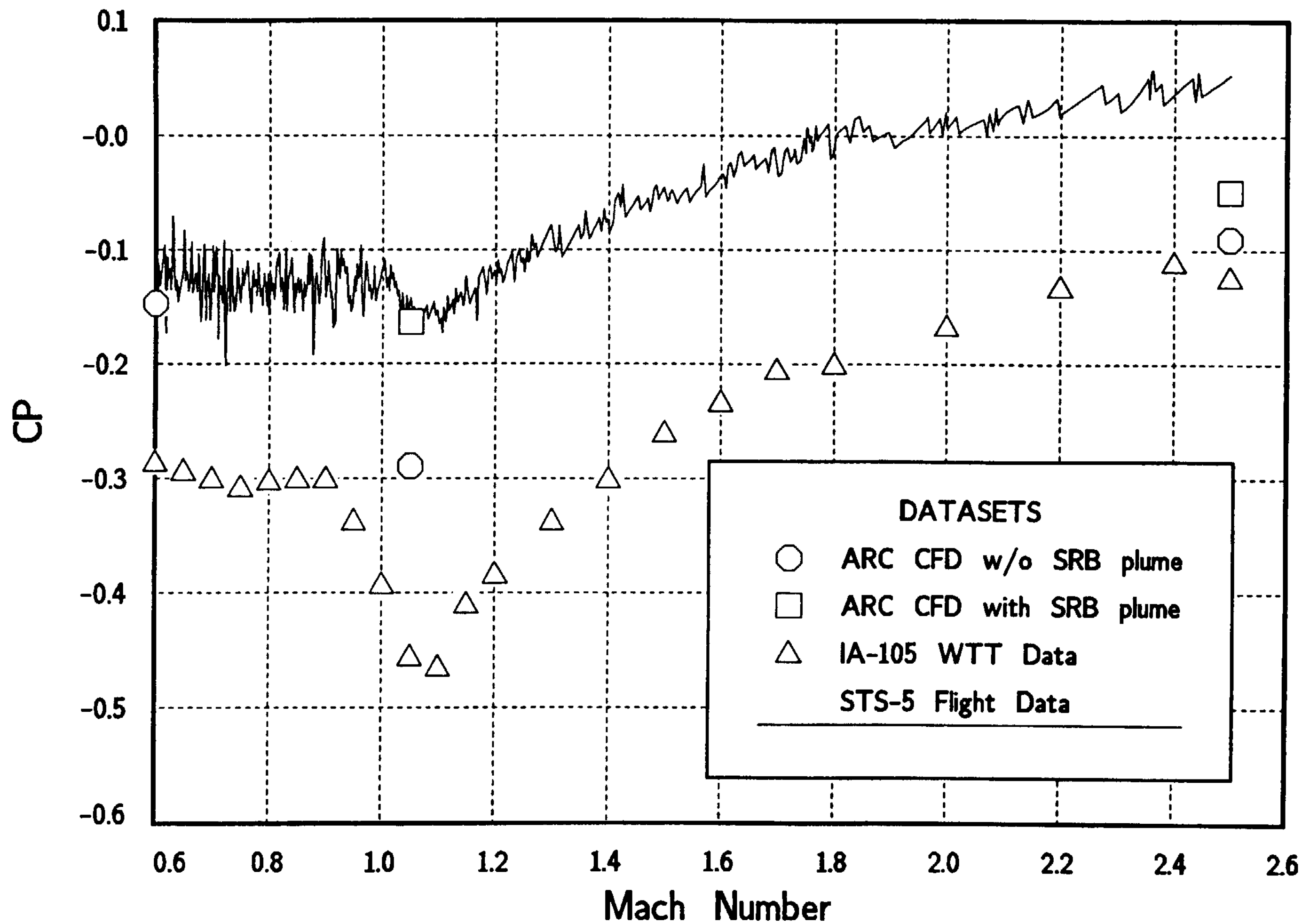
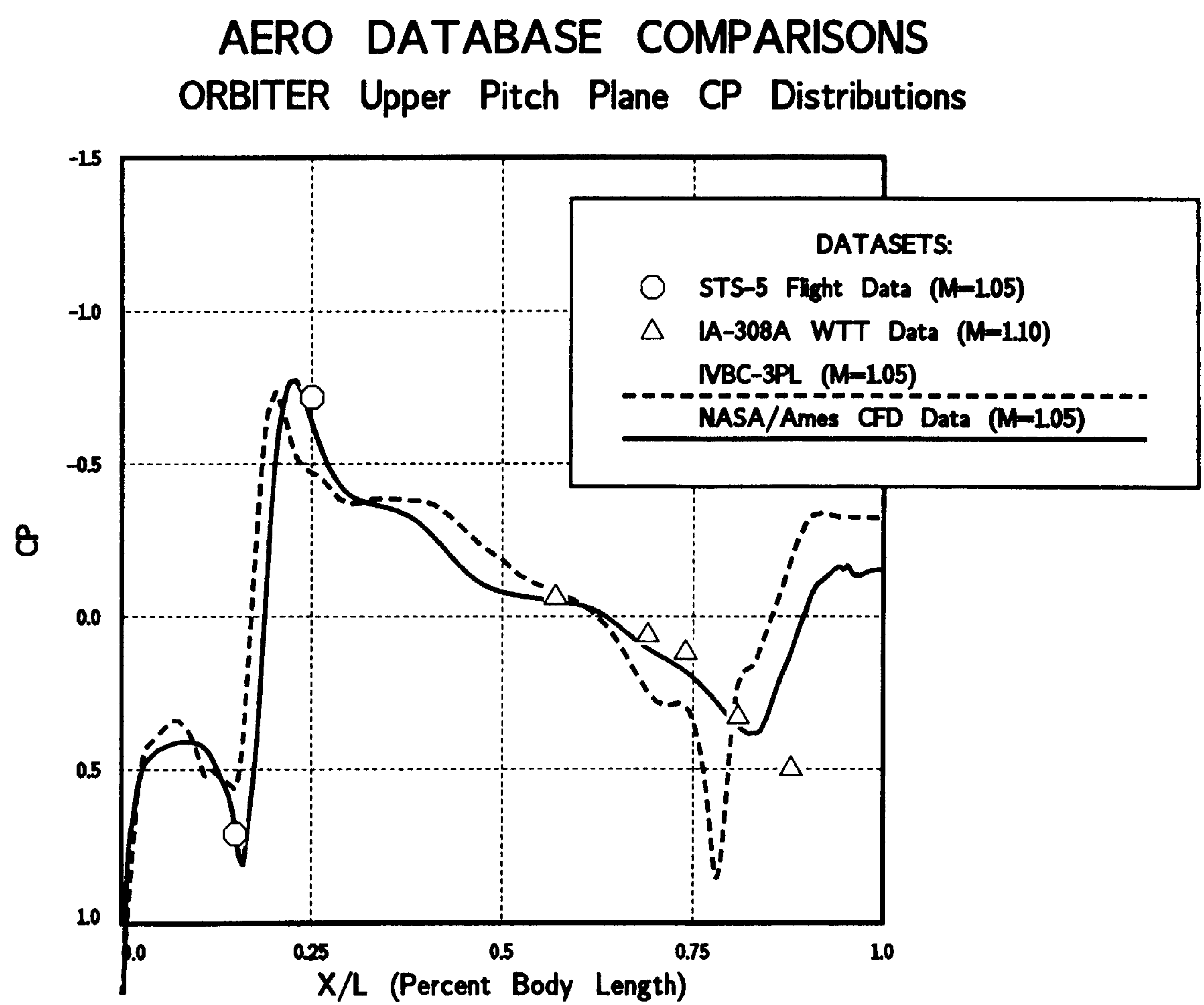
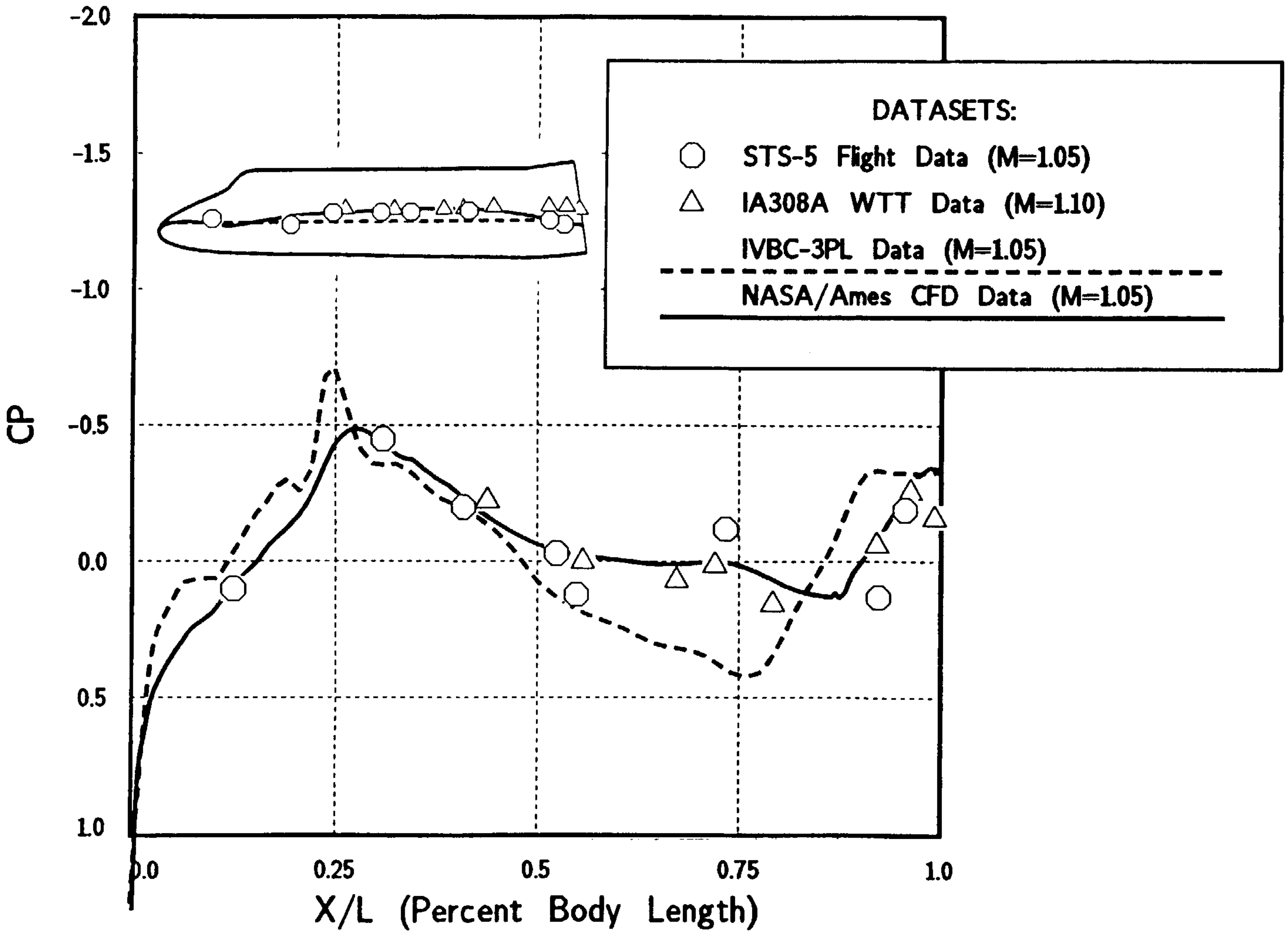
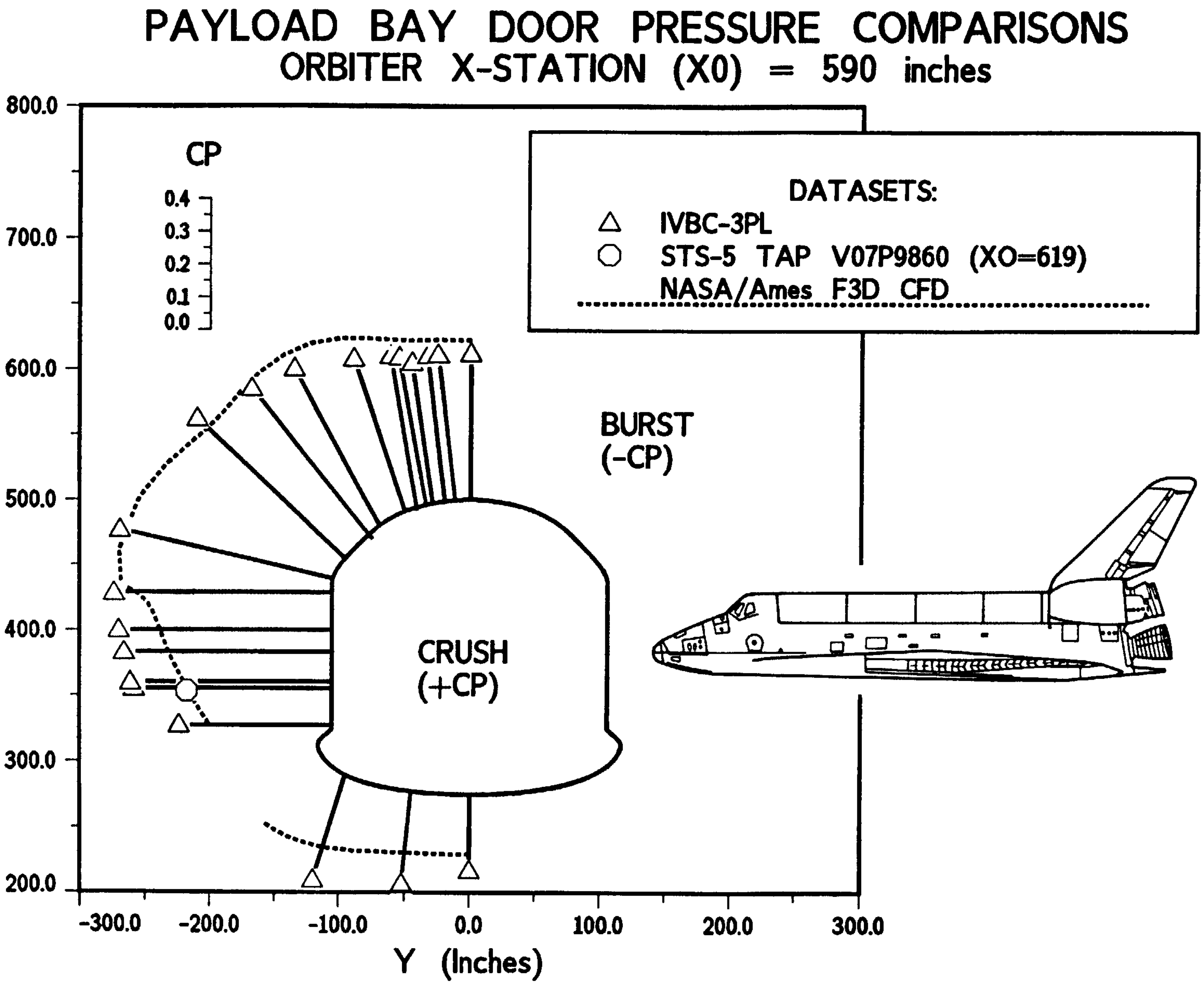


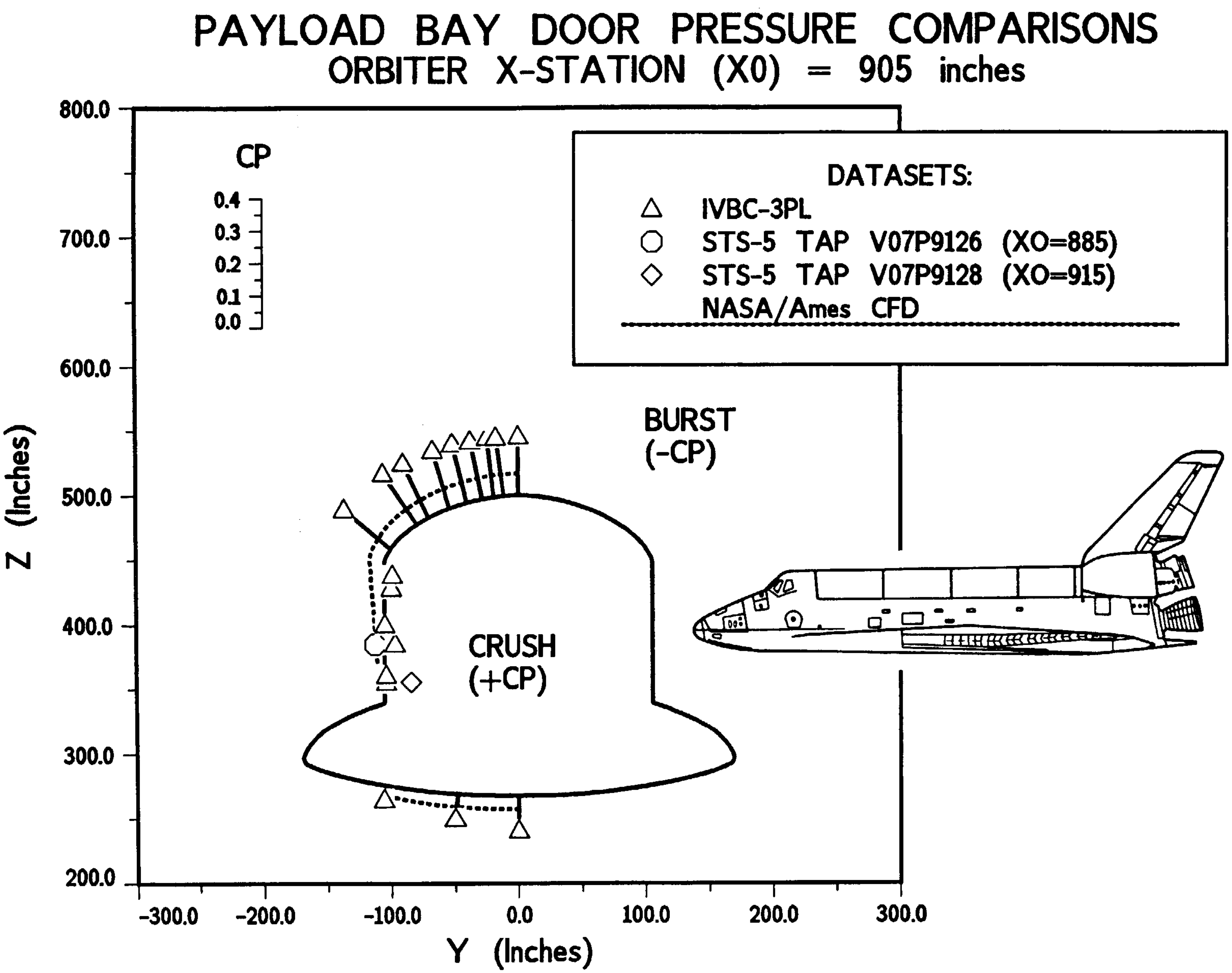

AERO DATABASE COMPARISONS
ORBITER Upper Pitch Plane CP Distributions
DATASETS:
STS-5 Flight Data (M=1.05)
IA-308A WTT Data (M=1.10)
IVBC-3PL (M=1.05)
NASA/Ames CFD Data (M=1.05)
-1.5
-1.0
-0.5
0.0
0.5
1.0
CP
0.0
0.25
0.5
0.75
1.0
X/L (Percent Body Length)

AERO DATABASE COMPARISONS

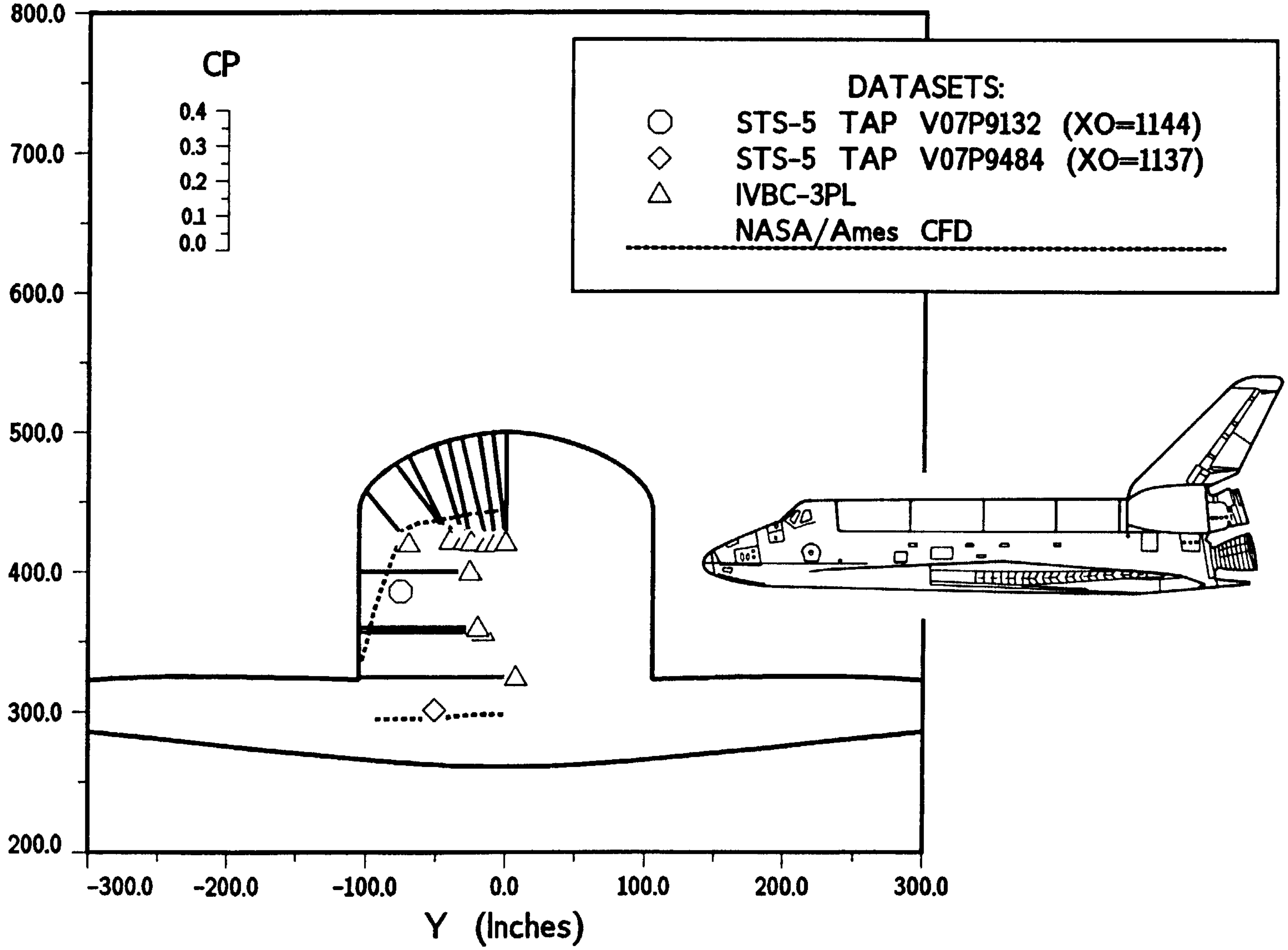
ORBITER Mid-Fuselage Region CP Distributions




PAYLOAD BAY DOOR PRESSURE COMPARISONS
ORBITER X-STATION (X0) = 590 inches
CP
0.4
0.3
0.2
0.1
0.0
DATASETS:
IVBC-3PL
STS-5 TAP V07P9860 (XO=619)
NASA/Ames F3D CFD
BURST
(-CP)
CRUSH
(+CP)
800.0
700.0
600.0
500.0
400.0
300.0
200.0
Z (Inches)
-300.0
-200.0
-100.0
0.0
100.0
200.0
300.0
Y (Inches)


PAYLOAD BAY DOOR PRESSURE COMPARISONS
ORBITER X-STATION (X0) = 905 inches
CP
0.4
0.3
0.2
0.1
0.0
DATASETS:
IVBC-3PL
STS-5 TAP V07P9126 (XO=885)
STS-5 TAP V07P9128 (XO=915)
NASA/Ames CFD
BURST
(-CP)
CRUSH
(+CP)
800.0
700.0
600.0
500.0
400.0
300.0
200.0
Z (Inches)
-300.0
-200.0
-100.0
0.0
100.0
200.0
300.0
Y (Inches)

PAYLOAD BAY DOOR PRESSURE COMPARISONS
ORBITER X-STATION (X0) = 1214 inches



Status

- Preliminary CFD results have been instrumental in gaining insight into the present design aero database. Even with the large advances in SSLV geometry modelling, all three aero data sources (flight, wind tunnel, and CFD) are required to completely understand Shuttle ascent aerodynamics and structural loads.

- On-going CFD Activities:
  - Add the SRB attach ring and IEA box protuberances into the SSLV grid system.
  - Add more realistic aft attach hardware to the geometry model to better simulate blockage effects.
  - Add $\gamma = \gamma(T)$ to the F3D flow solver.
  - Grid the vertical tail and include in the geometry model.
  - Grid the SSMEs and incorporate the SSME plumes into the solution.