Near-Field Pressure Signature Generated by a Launch Vehicle In Supersonic Powered Flight

(A Status Report)

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Outline

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- CFD Approach
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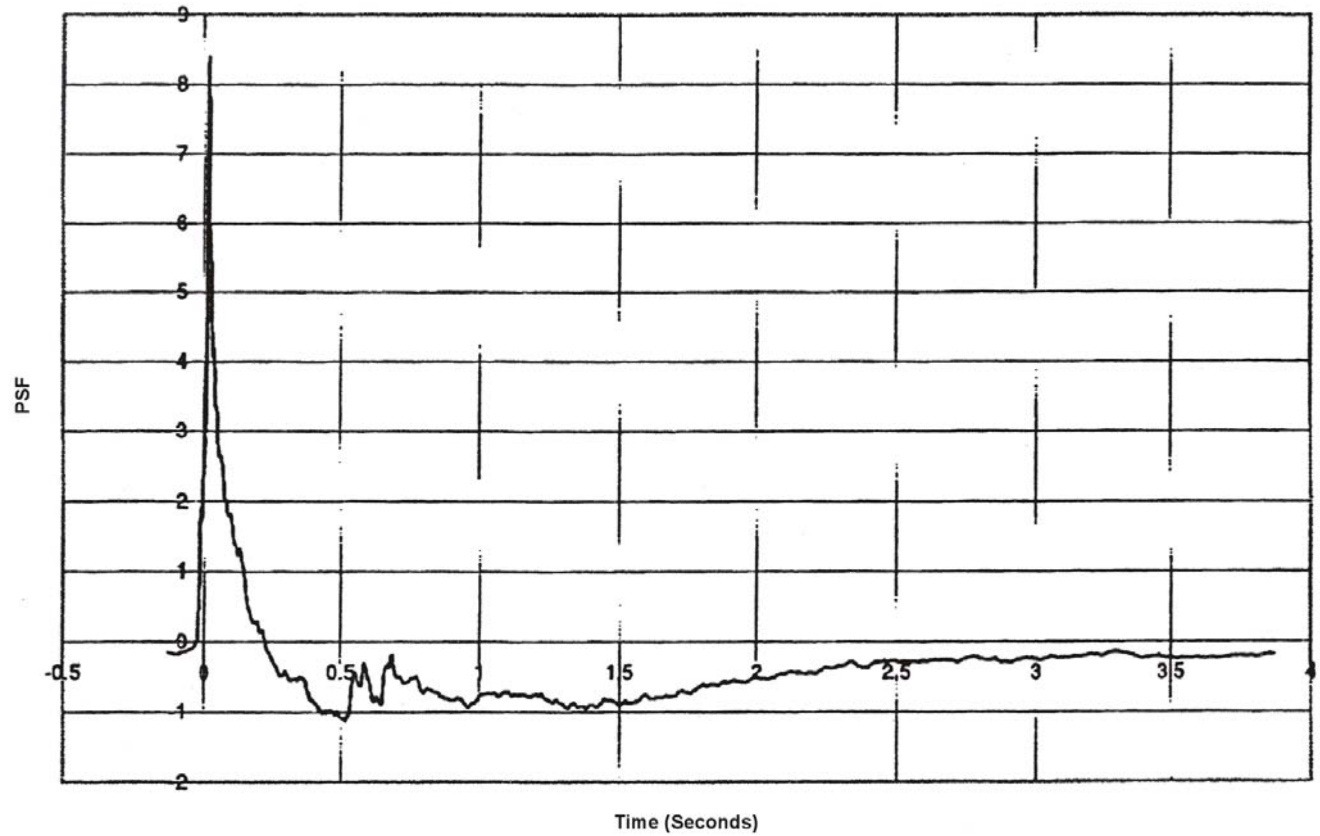
Introduction

- Objective: To obtain a near-field pressure signature around a launch vehicle in supersonic powered flight to be used as input for sonic boom analysis.
- Motivation:
  - Focused boom signature predicted by PCBOOM3 does not agree in shape with Titan IV-K22 data recorded at Crook Point on San Miguel Island.
  - One possibility is that the near-field pressure distribution used as input to PCBOOM3 is not sufficiently realistic.

Focused Sonic Boom Waveform (Crook Point)



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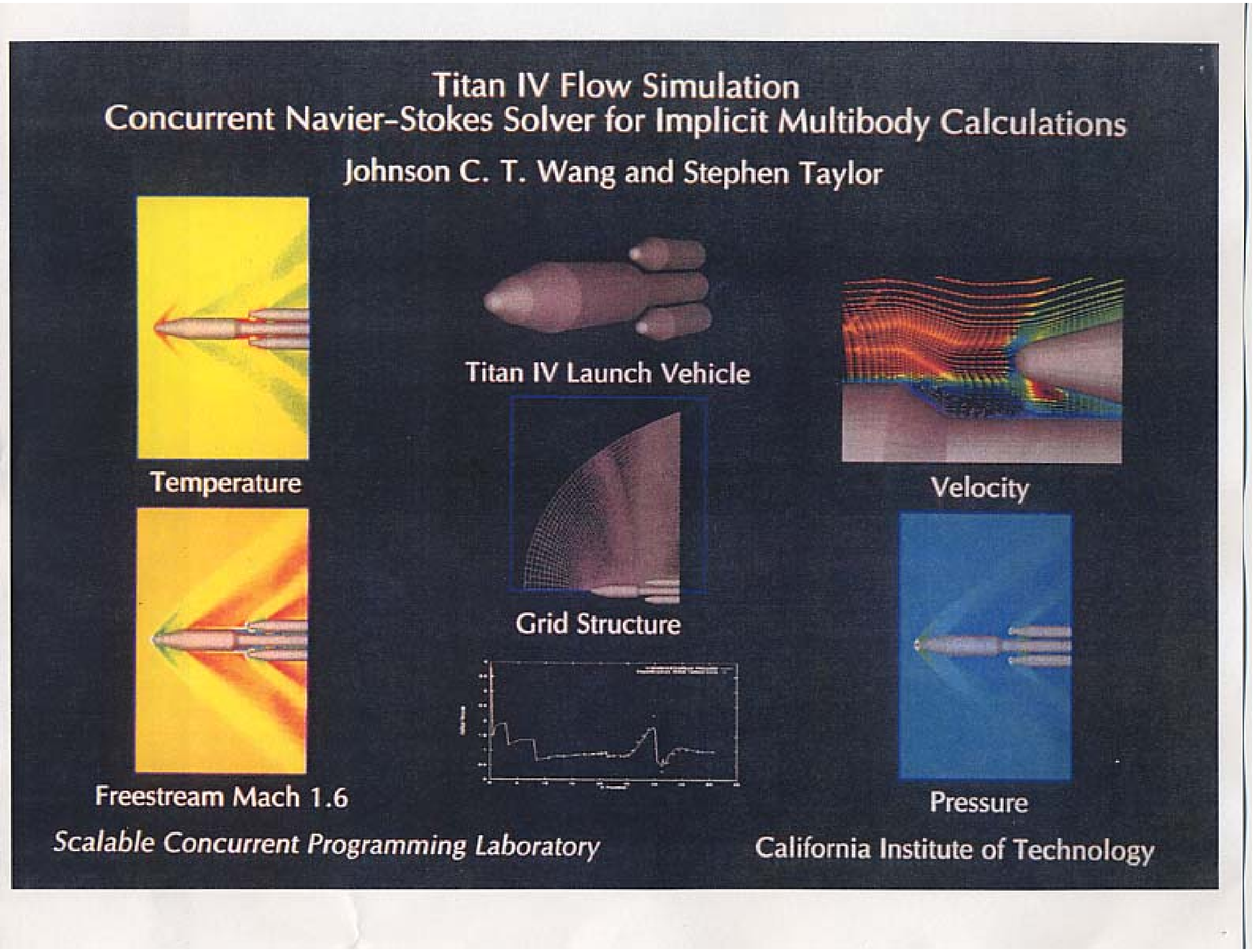
CFD Approach

- Code Description:
  - **Name:** ALSINS (Aerospace Launch Systems Implicit/explicit Navier-Stokes) code
  - **Algorithm**: Finite Volume with TVD scheme of Harten-type for convective fluxes and Central-difference scheme for viscous fluxes computation
  - Options used for this study: Full Navier-Stokes in 3-D, Turbulent (Baldwin-Lomax model) near the vehicle, two gases (air and exhaust gas), multi-block
- Code Validation: ALSINS has been applied for numerous launch vehicle flowfield simulations. The results have been published in more than 30 journal and conference papers. An example is shown in the next chart.

A Sample of Code Validation: Simulation of Titan IV Multi-Body Flowfield using Caltech's Intel Paragon Parallel Computer



Results

- Simplified model problem as first step (Pathfinder)
  - Single Titan IV core body (length = 170 ft) with exhaust from a single SRM
  - Flow-field computed to 1520 feet aft of nose (1350 feet aft of exit plane)

- Free stream conditions: **(trajectory time = 94 sec, altitude = 100,400 ft)**
  - $M_\infty = 3.3343$, $\gamma_{air} = 1.4$, $R_{air} = 1716\ ft^2/sec^2/{}^\circ R$
  - $P_\infty = 0.1587$ psia, $\rho_\infty = 3.2567 \times 10^{-5}\ slug/ft^3$, $T_\infty = -50.88\ {}^\circ F$
- Nozzle exit conditions:
  - $M_e = 3.22$, $\gamma_e = 1.185$, $R_e = 1953\ ft^2/sec^2/{}^\circ R$
  - $P_e = 11.638$ psia, $\rho_e = 2.836 \times 10^{-4}\ slug/ft^3$, $T_e = 3026\ {}^\circ R$

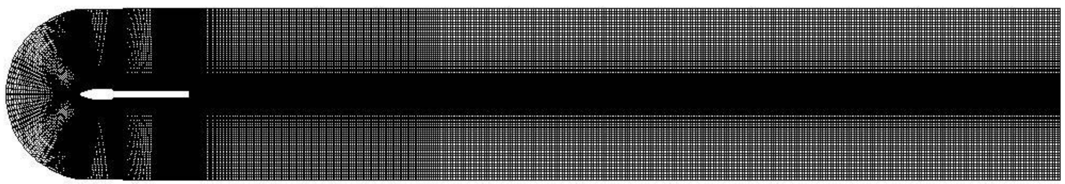
- Computational grid:
  - Two computational grid systems are used, each having a total of 806,736 grid points in 4 blocks.

FACAT

Grid A

Xmax = 1520 ft

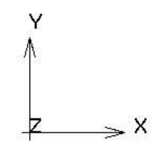
Ymax = 133 ft

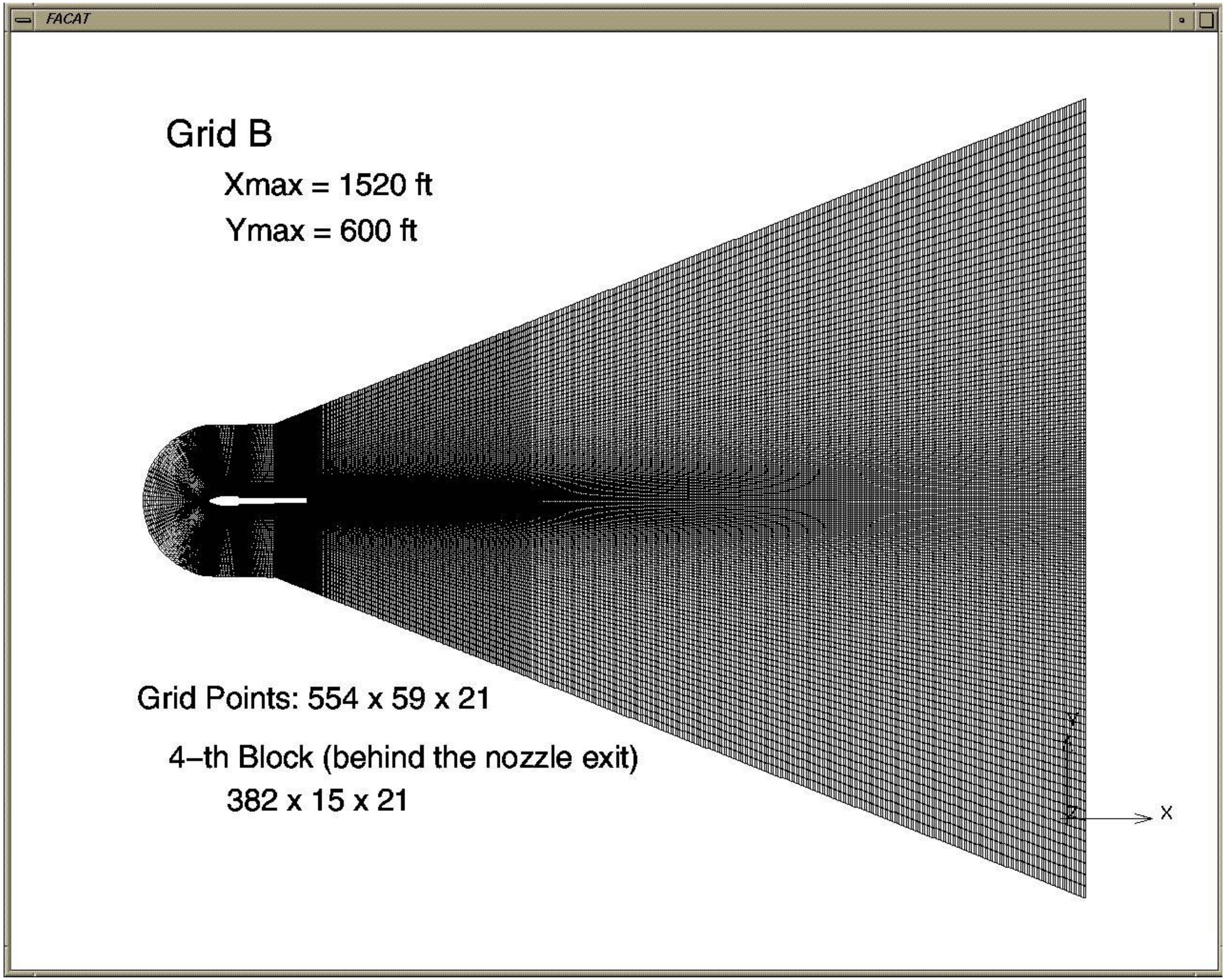


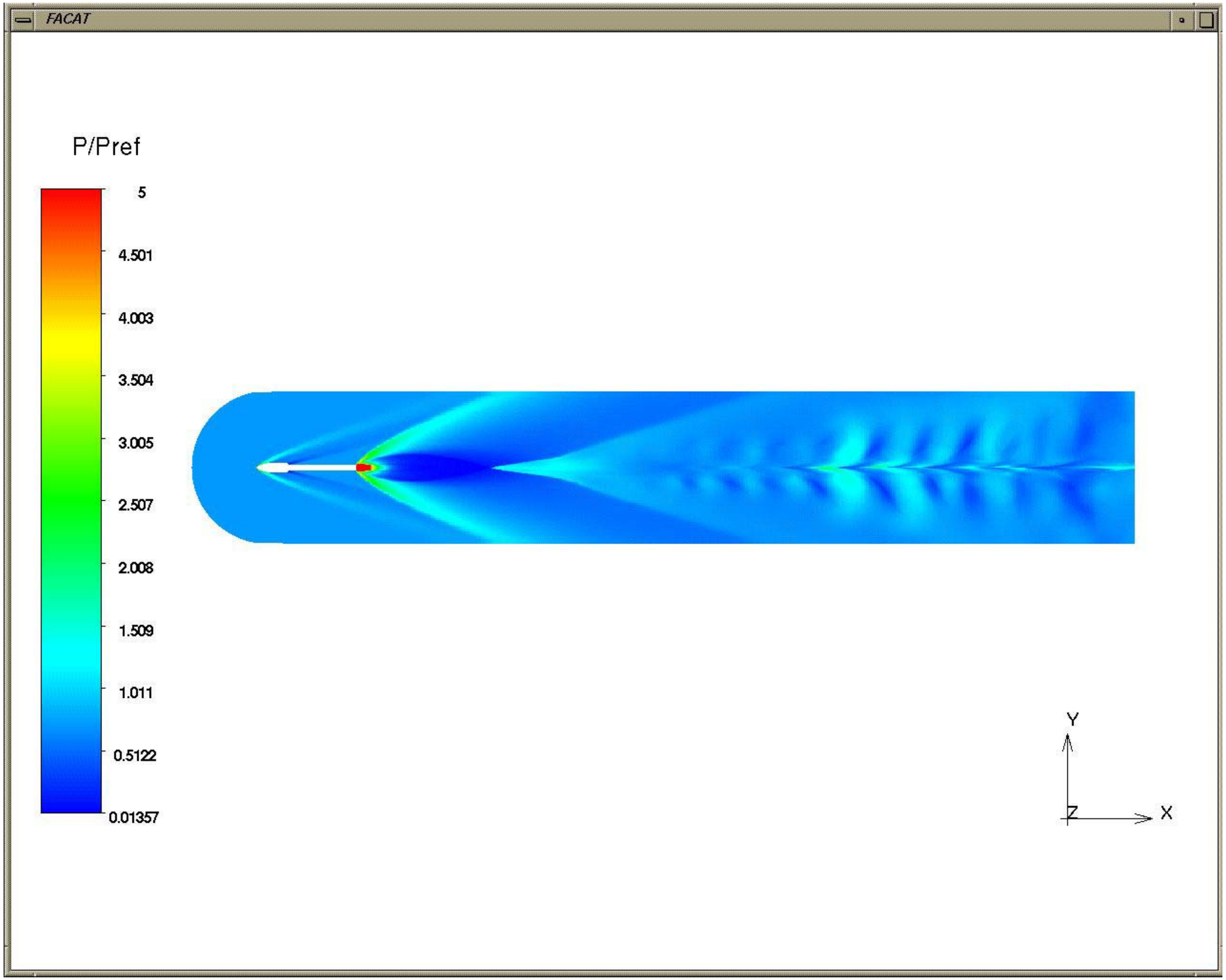
Grid Points: 554 x 59 x 21

4–th Block (behind the nozzle exit)

382 x 15 x 21




FACAT
Grid B
Xmax = 1520 ft
Ymax = 600 ft
Grid Points: 554 x 59 x 21
4–th Block (behind the nozzle exit)
382 x 15 x 21
Y
Z
X



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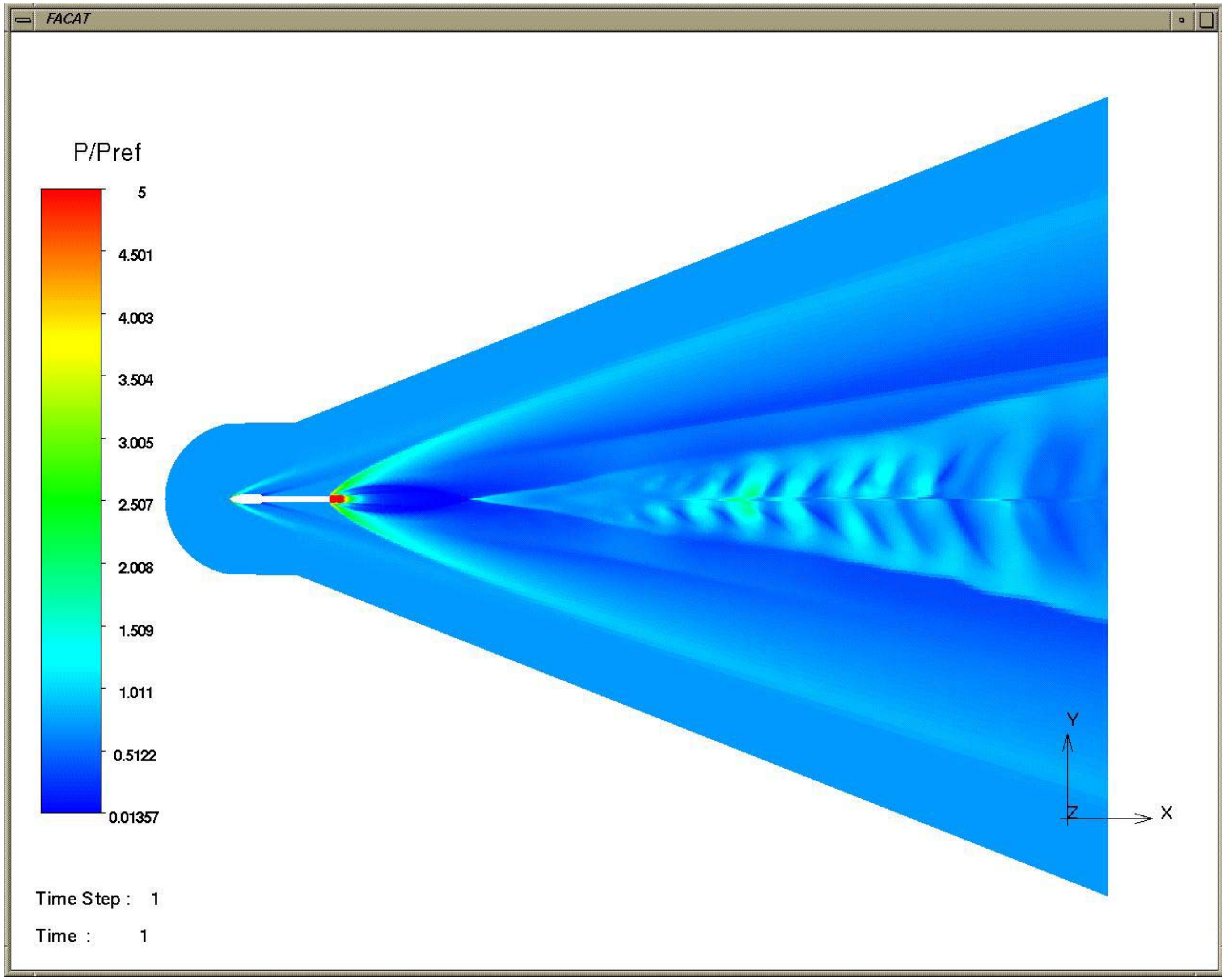
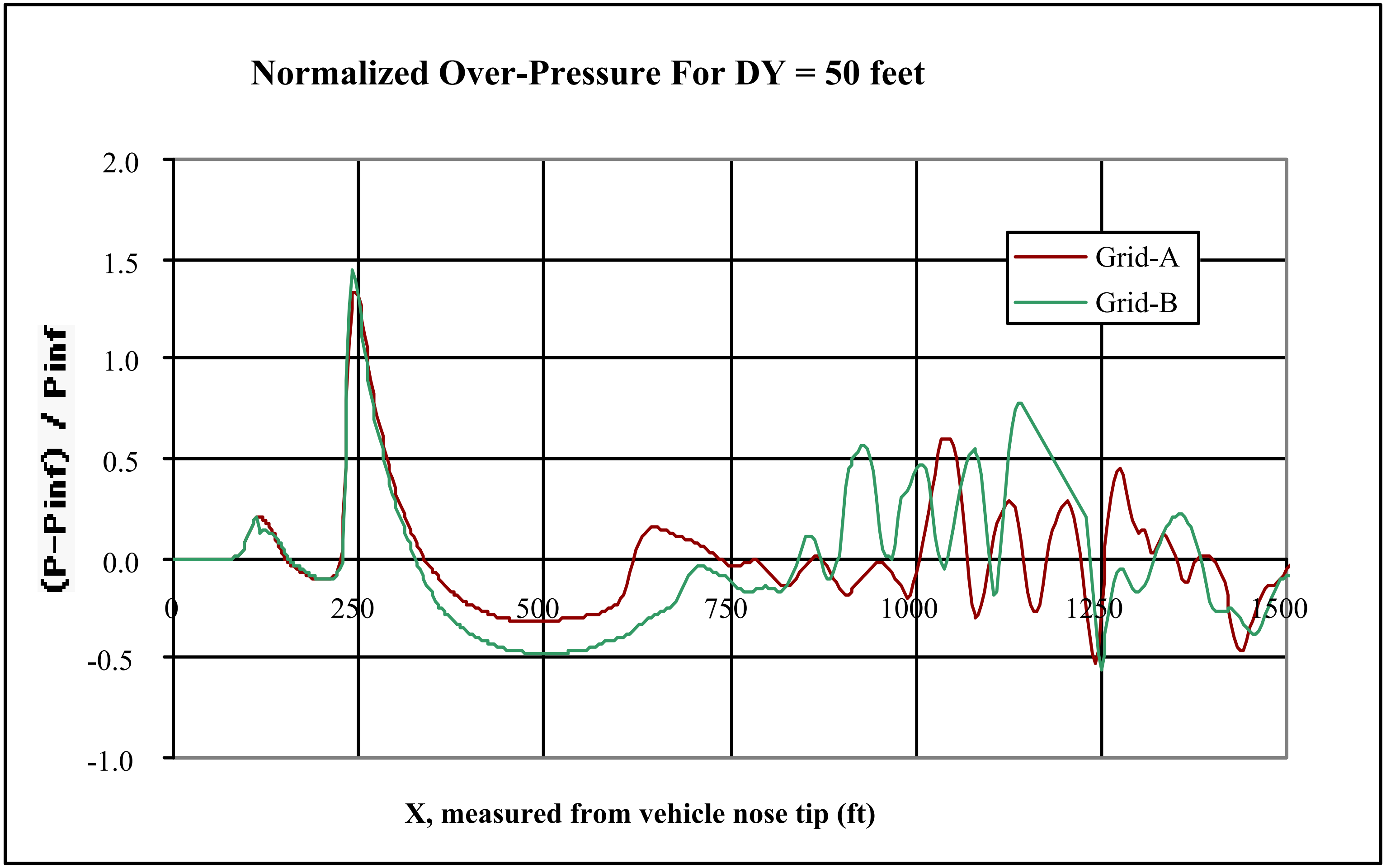
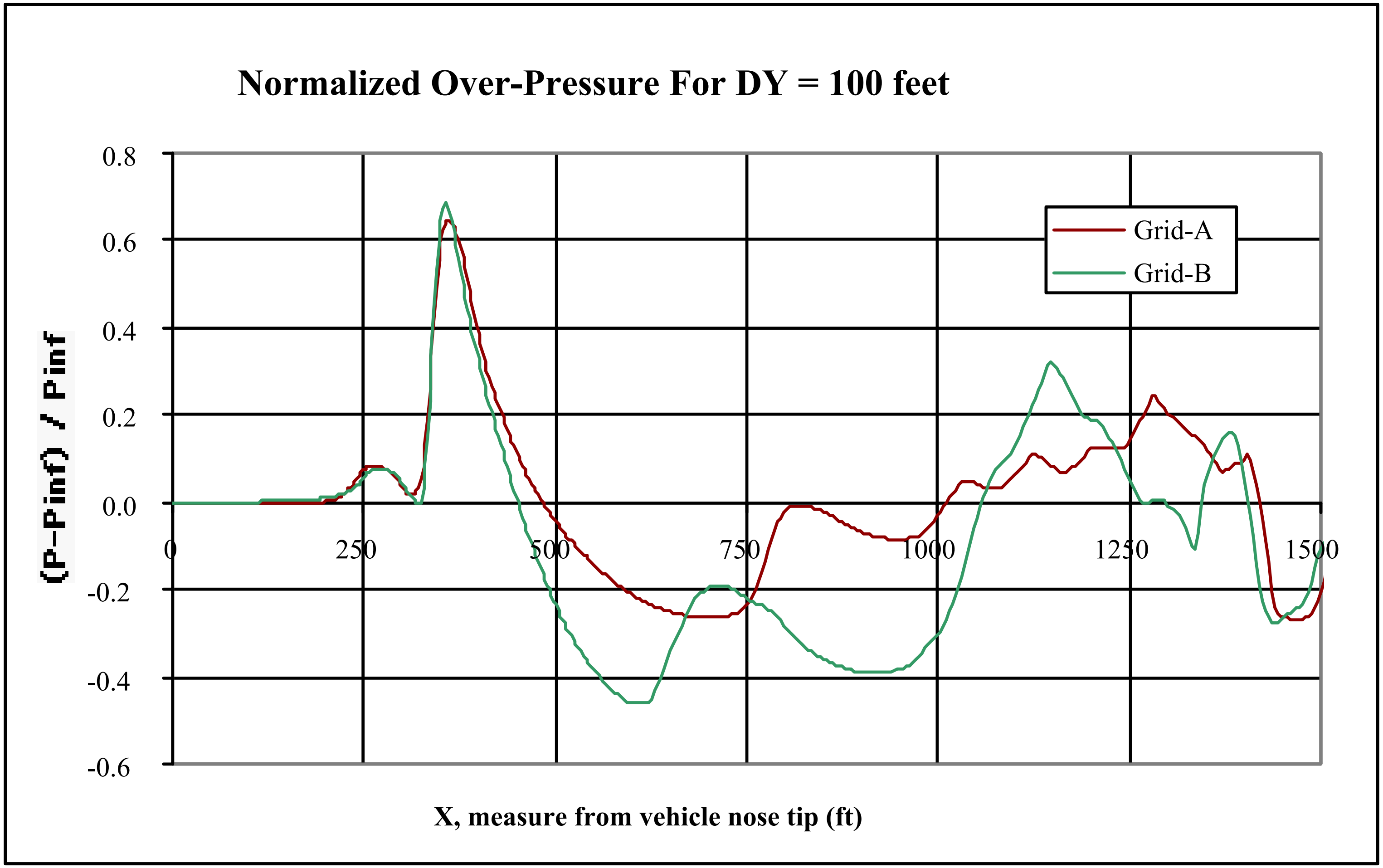
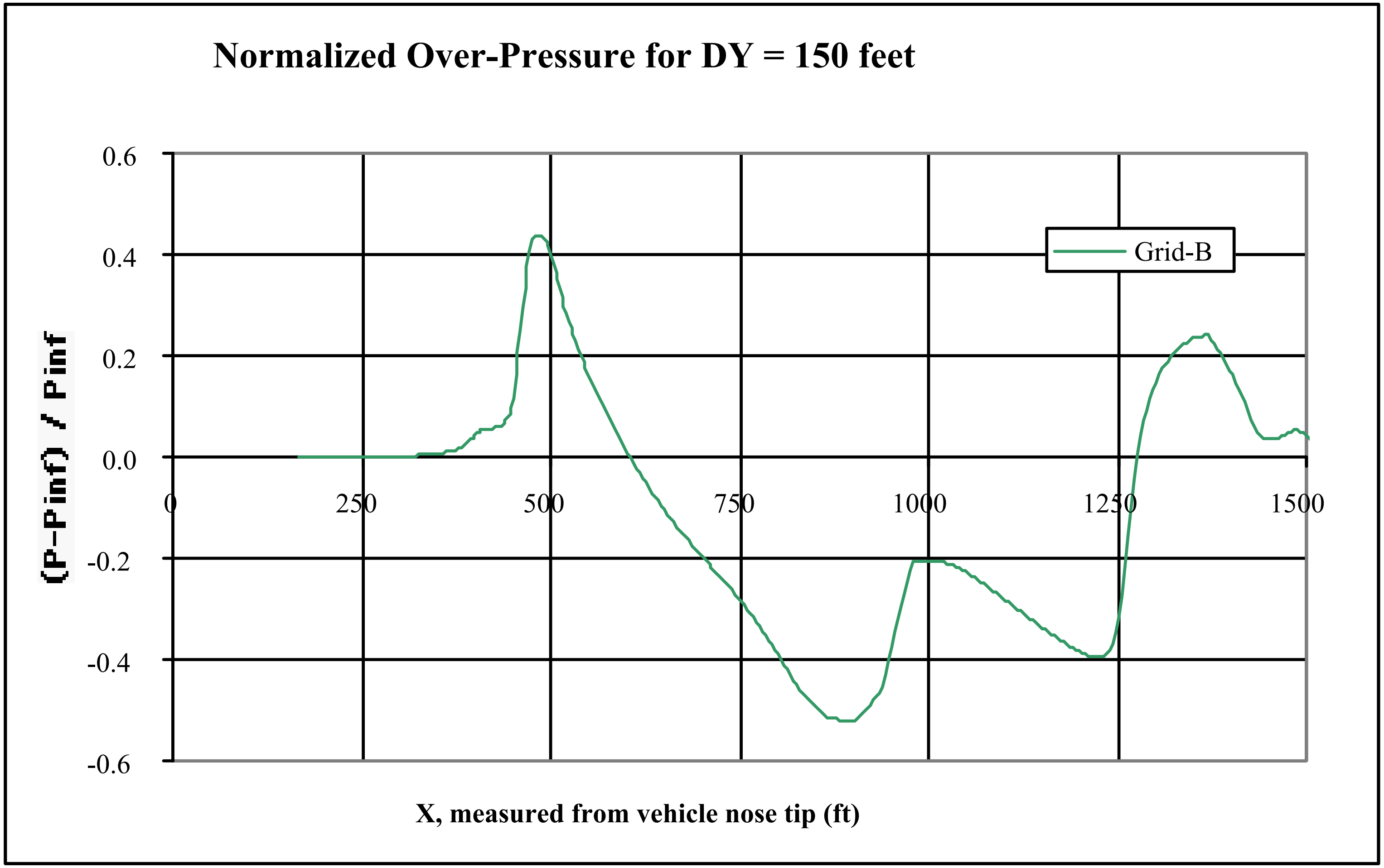

FACAT
P/Pref
5
4.501
4.003
3.504
3.005
2.507
2.008
1.509
1.011
0.5122
0.01357
Y
Z
X
Time Step : 1
Time : 1



Normalized Over-Pressure For DY = 50 feet
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
(P−Pinf) / Pinf
0
250
500
750
1000
1250
1500
Grid-A
Grid-B
X, measured from vehicle nose tip (ft)


Normalized Over-Pressure For DY = 100 feet
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
(P-Pinf) / Pinf
0
250
500
750
1000
1250
1500
Grid-A
Grid-B
X, measure from vehicle nose tip (ft)


Normalized Over-Pressure for DY = 150 feet
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
(P-Pinf) / Pinf
0
250
500
750
1000
1250
1500
Grid-B
X, measured from vehicle nose tip (ft)

Summary and Conclusions

- CFD results show:
  - The waveform has a very long tail -- consistent with recorded data.
  - The dominant features of the near-field pressure signature are generated by the shock in front of the plume and the recompression of the plume at about one and half vehicle lengths downstream of the nozzle.
  - The effect of the bow shock from the vehicle nose is weak -- consistent with recorded data.
  - **Simulations need to be continued in order to ensure convergence in the far down-stream region.**

Future Work

- Extend the present work to the case with two SRMs, side-by-side on the core vehicle.
- Resolve the questions on the compression/expansion waves inside the recompression zone.
- Use results in PCBOOM3 (or PCBOOM4.)