Predicting Launch Vehicle and Plume Sonic Boom using PCBoom3

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Traditional Sonic Boom Analysis

- Slender vehicles, linear flow F-function
- Fixed (or nearly fixed) vehicle geometry
- Ray tracing in horizontally stratified atmosphere
- Flat Earth geometry; Cartesian coordinates
- Aircraft perspective

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PCBoom3 Software

- Traditional ray tracing; originated from Thomas program
- Developed under NASA, USAF sponsorship
- Variety of aircraft inputs
- Computes complete footprints
- Computes focal zones
- Available from USAF AL/OEBN

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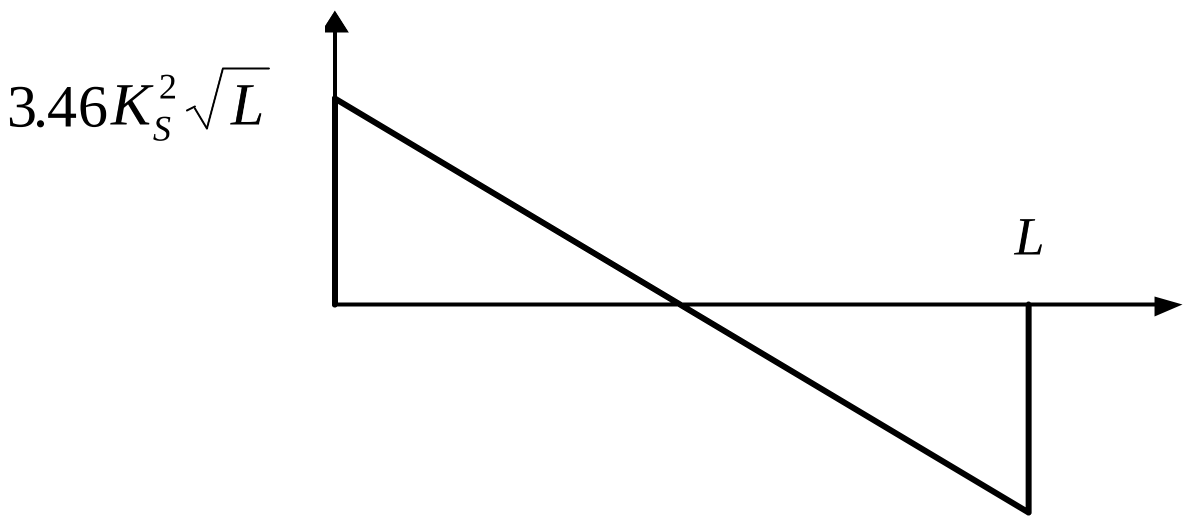
Launch Vehicles: Boost Phase

- Vertical launch, pitch over to horizontal
- Expect acceleration focal zone
- Do not expect pure N-wave booms, but:
  - Do expect N-waves if no plume
  - Expect forward half to be N-like, even with plume
- Rocket plume is a variable geometry body
- Large distances: geocoded trajectories

Obtaining F-Functions   Vehicle Alone

Expect N-wave booms at ground

Use Carlson s simple N-wave F-function:



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Sources of Shape Factor K_S

Carlson: Charts for aircraft and Shuttle Orbiter

Simple, slender bodies: Area distribution

Complex bodies:

- CFD solutions at various M, angle of attack
- Project CFD to effective source distribution
- K_S related to integral of F-fn positive phase:

$$K_S = \frac{2^{1/4} g}{\sqrt{g+1}} \frac{1}{L^{3/4}} \left[\int_0^{x_0} F(x) dx \right]^{1/2}$$

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Vehicle-Plume Combination

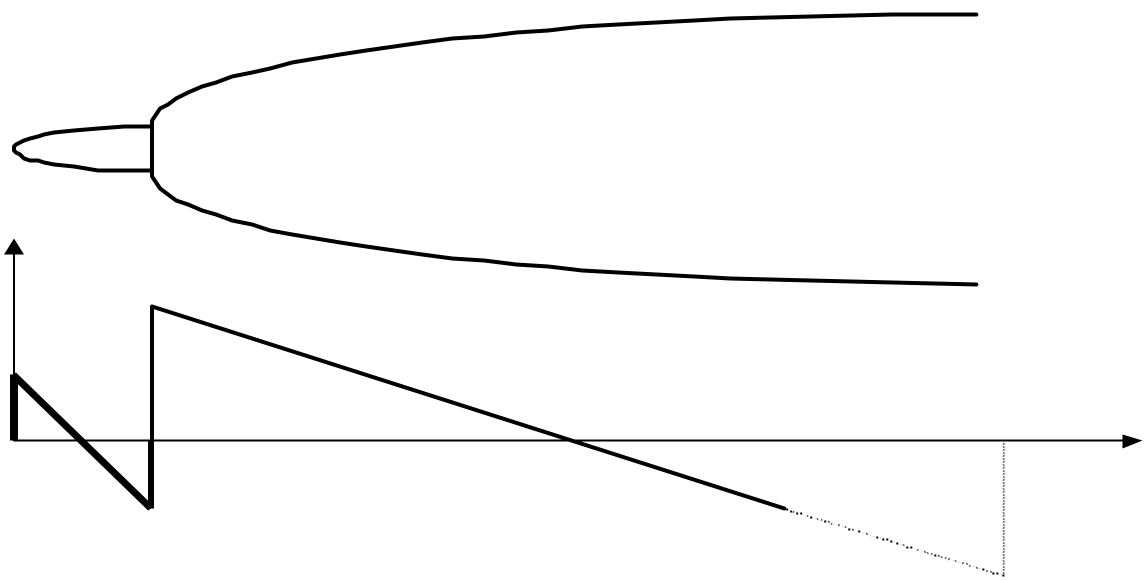
Predict F-function separately for vehicle and plume

Assemble the two parts one after the other

Vehicle: ordinary N-wave

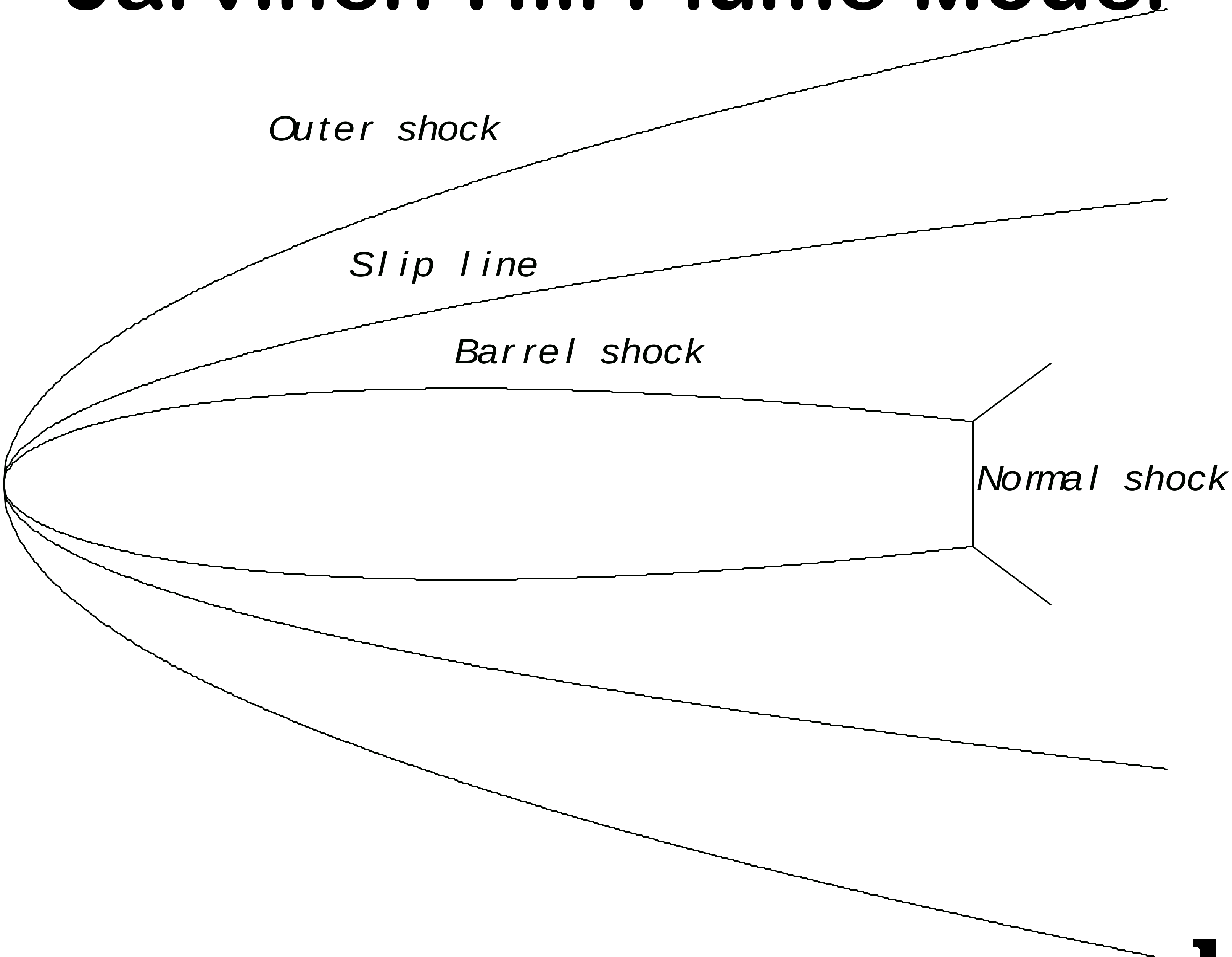
Plume   forward part estimated as partial N, rear part not yet satisfactorily modeled in PCBoom3.

Combined Vehicle and Plume



Vehicle **Plume**

Jarvinen-Hill Plume Model



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Shape Factor for Forward Part of Plume

- Jarvinen-Hill Universal Plume Model:
  - Size and shape depend on Thrust, Plume Drag, and dynamic pressure. Hypersonic blunt bow.
- Tiegermann hypersonic boom model:
  - Hypersonic blunt body: p depends on D
  - Developed effective far-field N-wave
- Match Tiegermann theory to J-H plume model and Carlson theory:

$$K_S = .6079\left[\frac{D}{2p\;p_\infty}\right]^{3/8} L^{3/4}\, b^{-1/4}$$

Rear Part of Plume

- Expedient: finish off N-wave
  - OK if all we want is bow shock strength
  - Used for early analysis, including 1995 Titan
- At source: use J-H universal plume shape
  - Area distribution, linearized flow
  - Current implementation, used for EELV
- At ground: match measured plume booms
  - Objective of current project

Boom at Ground   Current Method

Tac =   80.250 sec, Phi =   .00 deg, Carpet boom

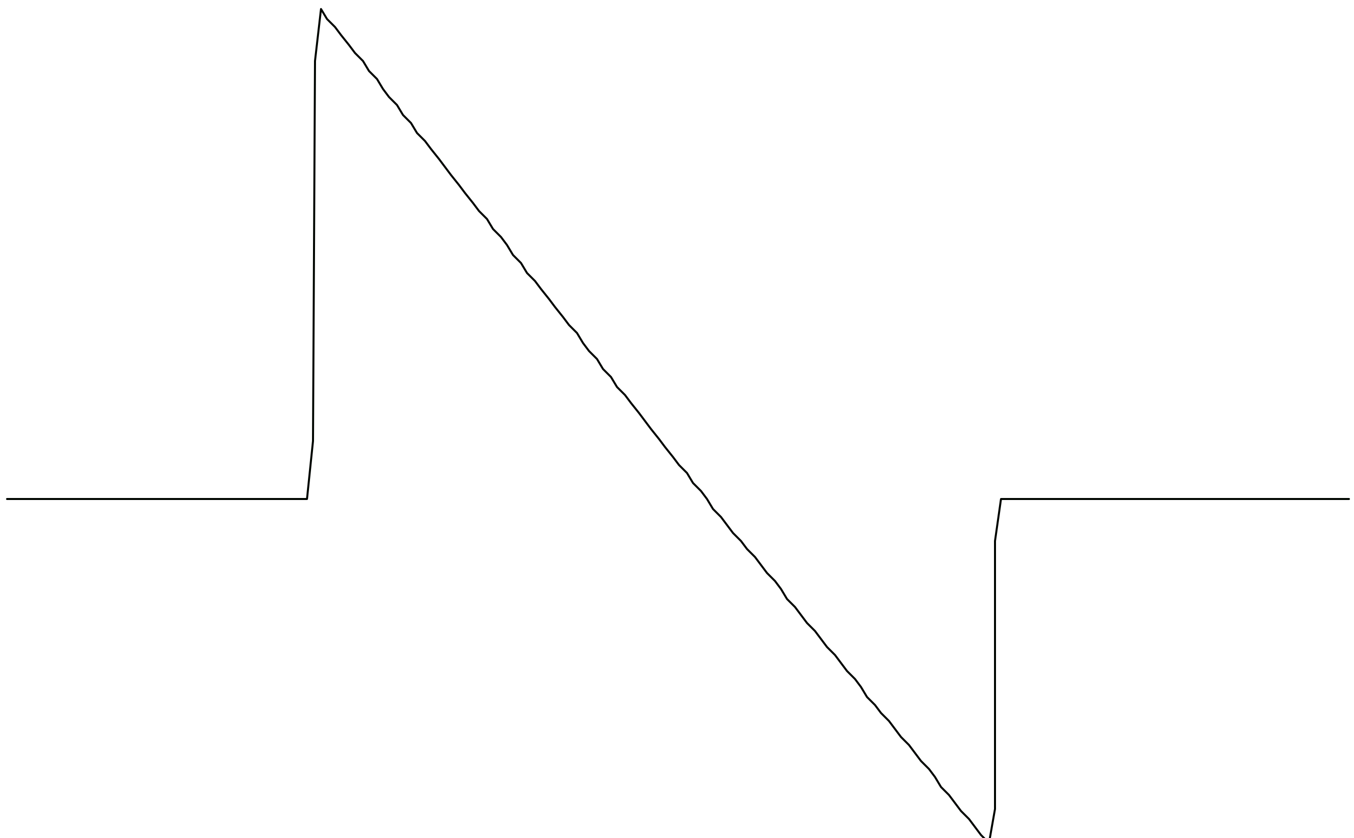
Pmax, Pmin = 3.92, -2.74 psf, Tg = 214.057 sec, Xg, Yg = 174.71,   -7.98 kf

Lpk = 139.5 dB, Lflt = 129.6 dB, CSEL = 113.4 dB, ASEL = 98.9 dB

NPTS = 200   Loud = 113.4 PLdB

Ray unit vector: .89770   -.05036   -.43773   Sound speed: 1118.2 ft/sec

Phase Vel =   1244. ft/sec;   Vpx, Vpy =   1242.   -70.



Other Additions for Launch and Reentry Vehicles

Near-vertical flight paths watch out for singular behavior

TRAJ2TRJ utility to convert geocoded trajectories to local flat Earth

MAPCON utility to convert local flat Earth PCBoom3 output to geocoded

Vehicle K_S from area rule or CFD near field solutions

Plume K_S from J-H model, Tiegerman hypersonic theory

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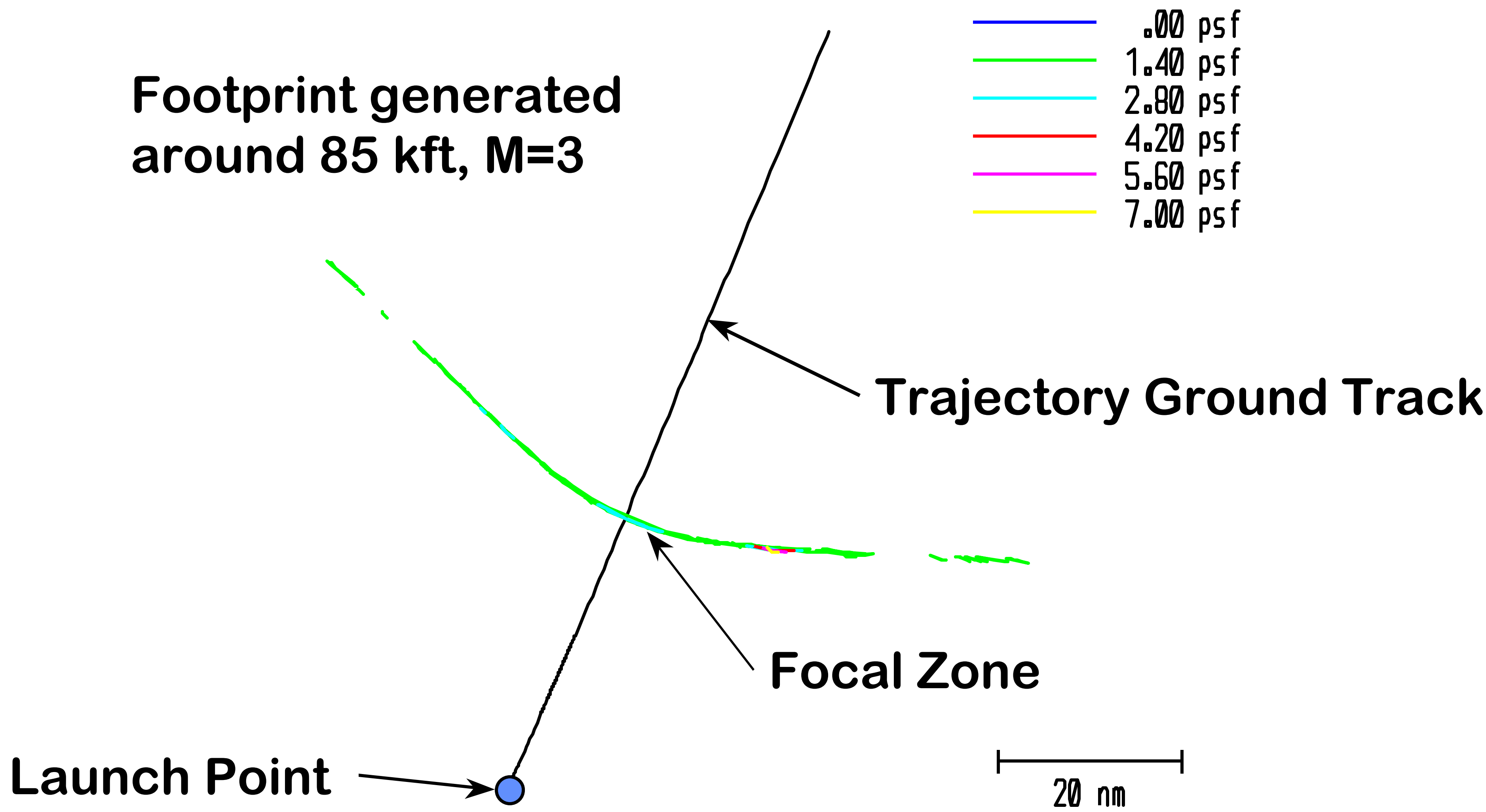
Typical Ascent Boom Footprint



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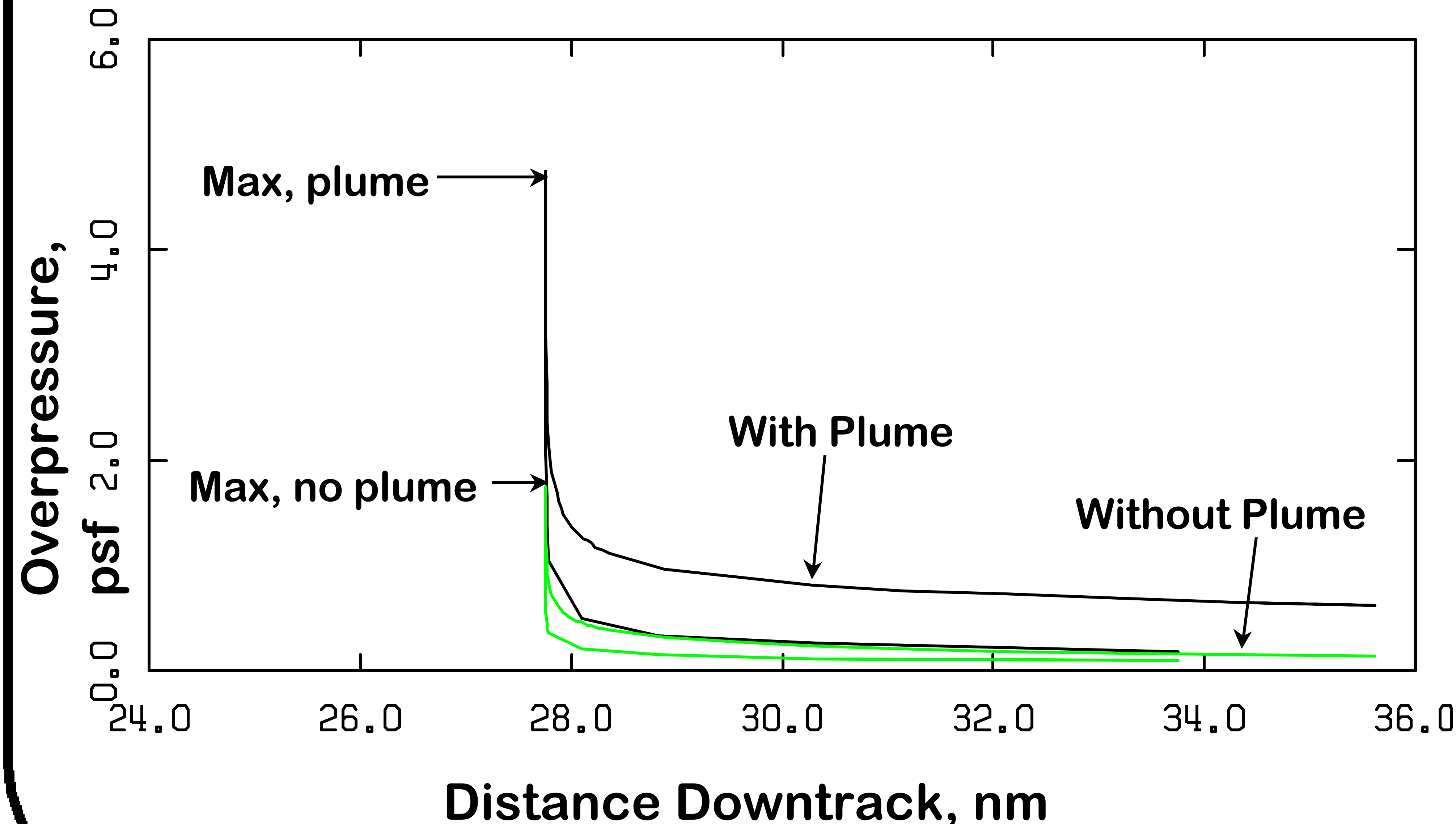
Effect of Plume on Boom



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Summary

- PCBoom3 is being used for launch vehicle sonic boom analysis
- Ascent booms have narrow footprints, focal zones
- Plume important for ascent
- Plume modeling:
  - Good results for bow shock, peak pessures
  - Rear part of plume boom at ground needs work