Stage 1 Properties

- Boeing Delta II Rocket…Stage 1
  - **Nozzle Throat Diameter: 40.175 cm**
  - **Nozzle Expansion Ratio: 15.25:1**
  - **Conical Nozzle, 30.5 deg exit angle**

- Combustion Properties:
  (RS-27A Rocketdyne Engine)
  - Lox/Kerosene, Mixture Ratio: 2.24:1
  - **Chamber Pressure (P_0): 5160 kPa**
  - **Combustion temperature (T_0): 3455 K**
  - **γ = 1.2220**
  - **M_W = 21.28 *kg/kg-mol***

- Propellant Mass: 97.08 Metric Tons
- Stage 1 Launch Mass: 101.8 Metric Tons

Part 1, Conventional Nozzle Contour Analysis

- **Plot Nozzle Contours for:**
  - Conventional RS-27A Nozzle (30.5 deg conical exit)
  - Minimum Length Conical Nozzle (no factor of safety)
  - Bell Nozzle, 2/3rd Maximum Turning Angle Safety factor
    - Bell exit angle = 0 deg, L_{Nozzle} = 150 cm
    - Use "P, S, Q, T" Bell fit for expansion section

- Nozzle Throat Diameter: 40.175 cm
- Nozzle Expansion Ratio: 15.25:1

Assume for all Conventional Nozzles →
Contraction/Expansion section has Rc = 0.75•D_{throat}

Part 2, Aerospike Contour Analysis

For Aerospike Nozzle use Sonic Throat section, assume axi-symmetric design, full spike length .. For Aerospike Nozzle use Sonic Throat section, assume axi-symmetric …. design, full spike length .. Design a Conical *aerospike nozzle replacement* for the RS-27A Nozzle

... ii) Calculate and plot full-3-D design spike contour,

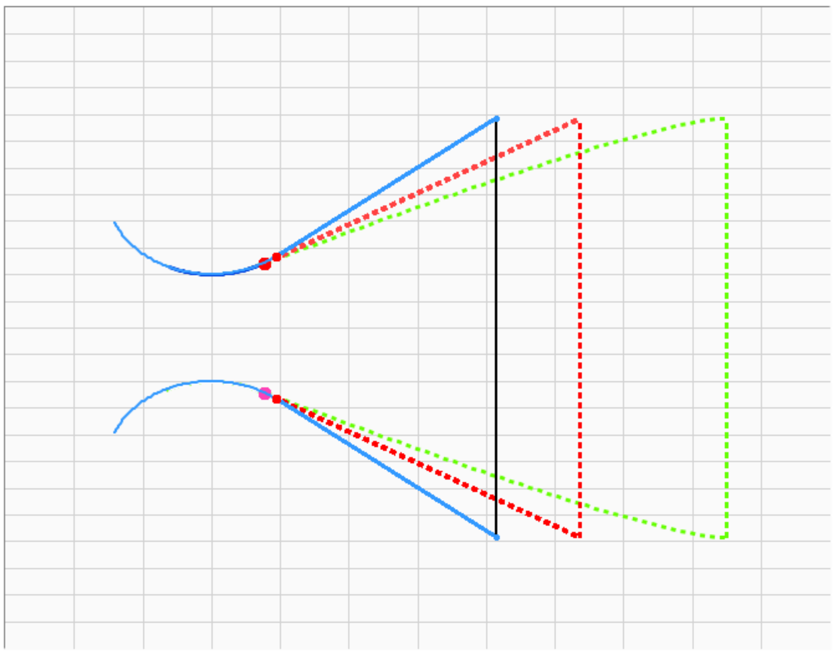
- **Nozzle Throat Diameter: 40.175 cm**
- **Design Expansion Ratio: 15.25:1**

Re-derive the Conical (3-D) Aerospike Contour Design Rules (*Slide 31)* for a two dimensional (Linear) Nozzle (show derivation)

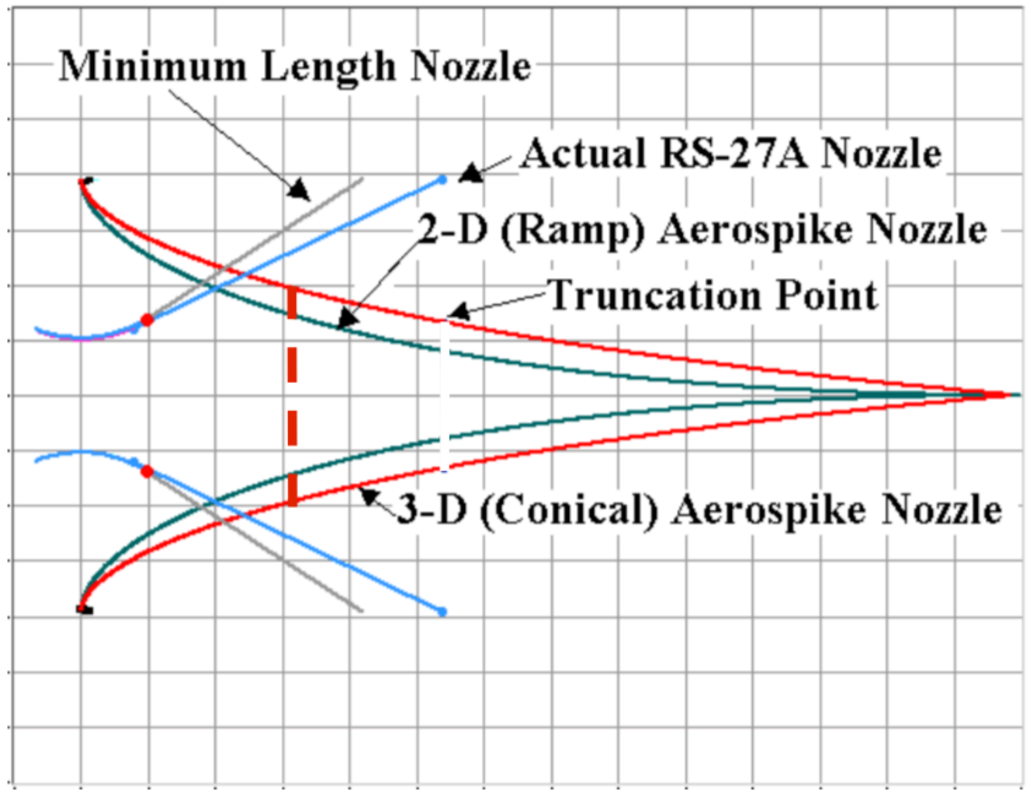
Compare 2,-D, 3-D Spike Contours with RS-27 A Nozzle Contour

Part 2, Aerospike Contour Analysis (2)

RS27-A Nozzle Comparisons



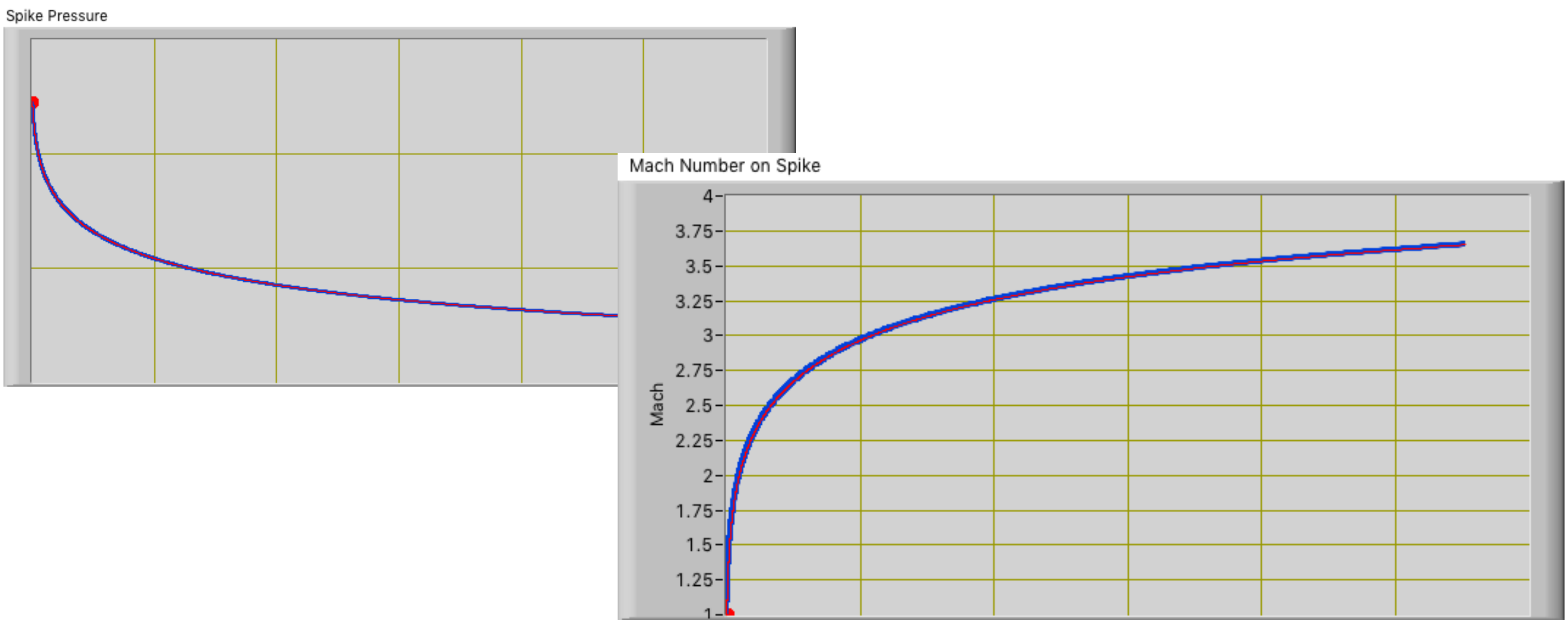
Example Comparisons



Part 2, Aerospike Contour Analysis (3)

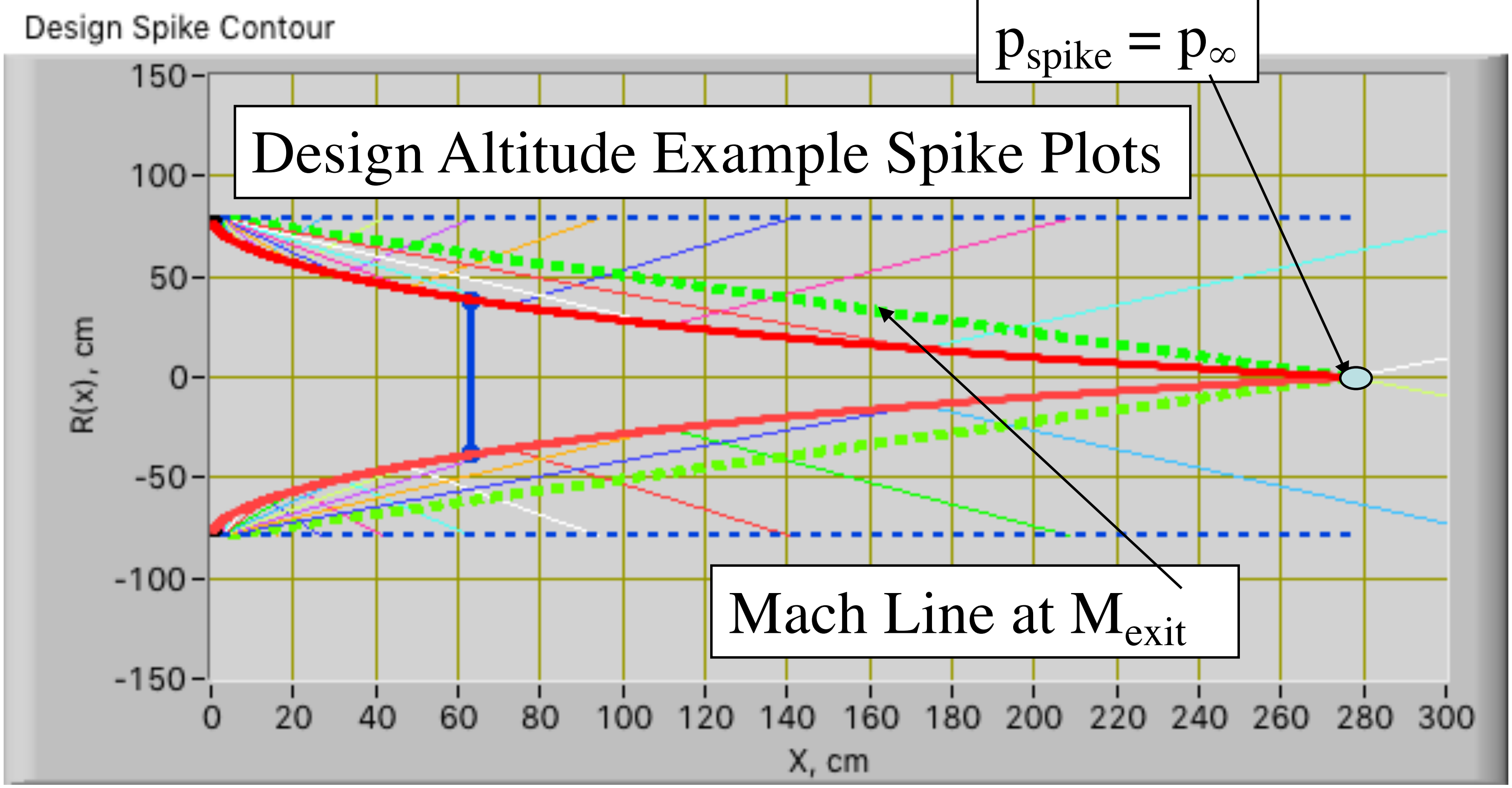
Example Spike Plots

Calculate design altitude for this expansion ratio (15.25:1) *plot design mach number and pressure profile along spike,* *assume* expansion ratio and chamber properties identical to RS-27A



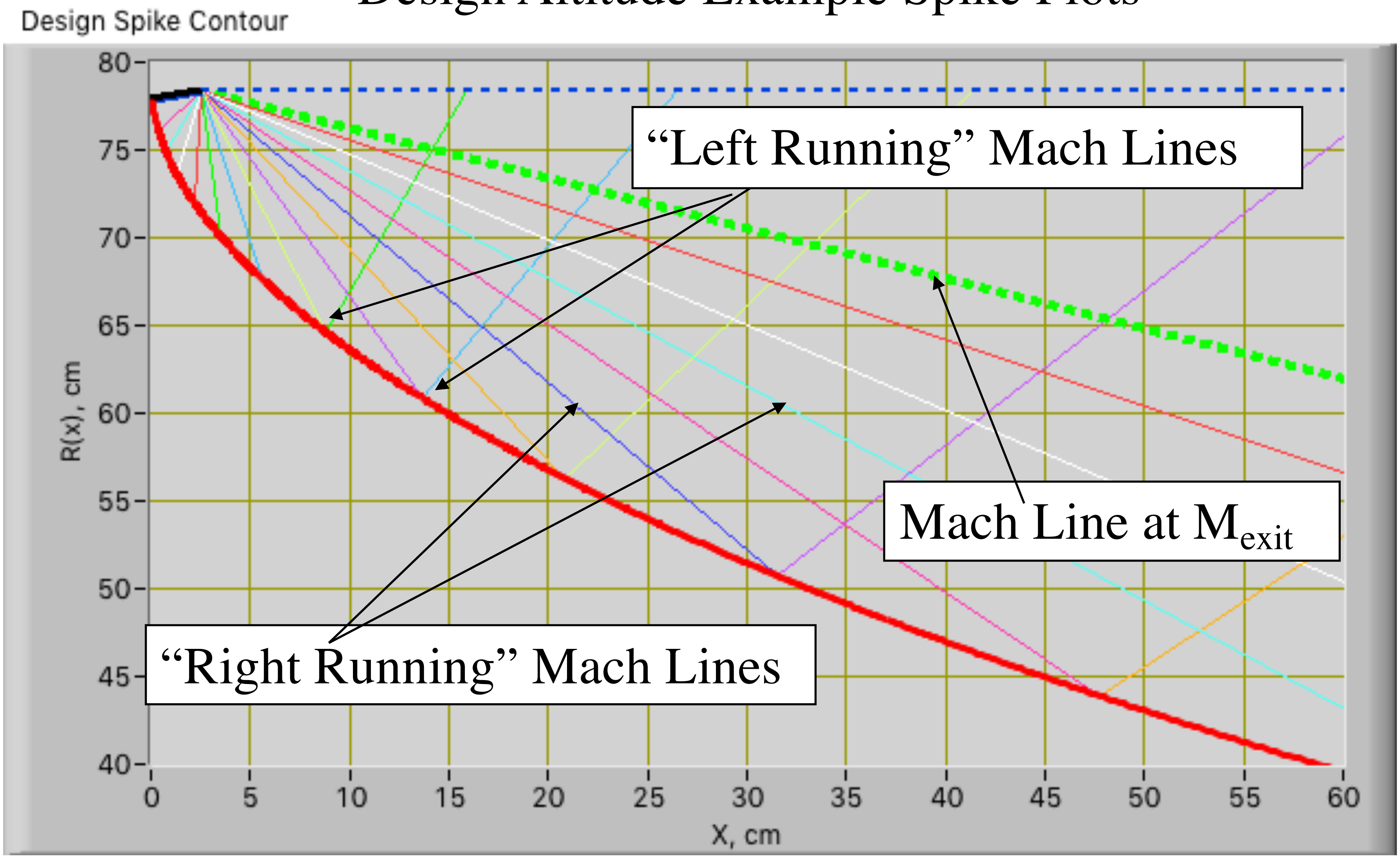
Part 2, Aerospike Contour Analysis (4)

Plot Characteristic Lines from Throat/Cowl Expansion and Show their Intersection with Spike Surface



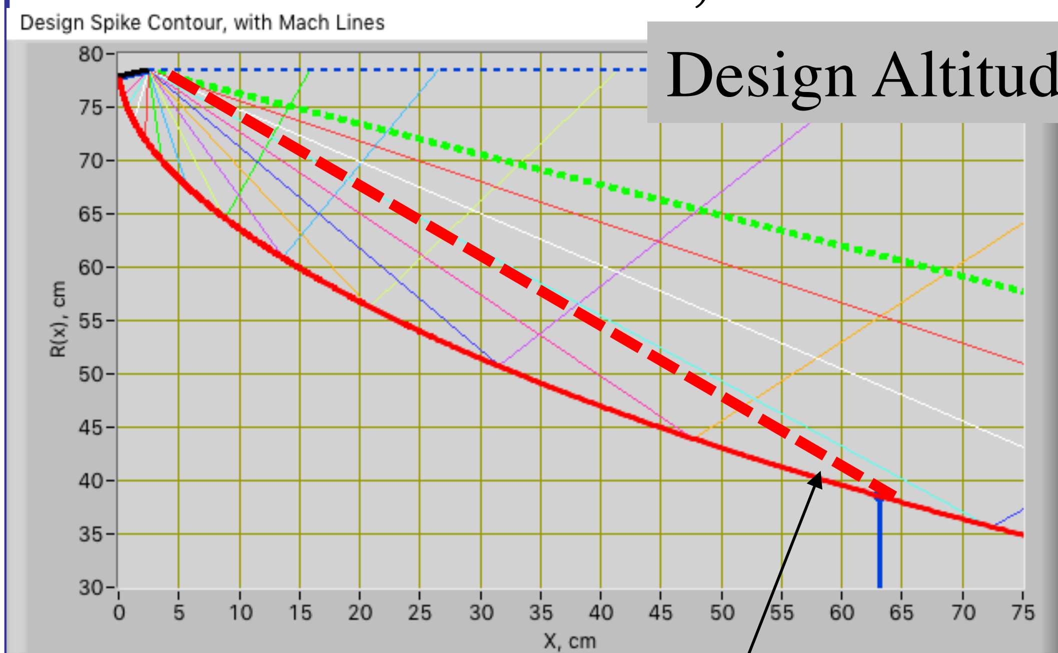
Part 2, Aerospike Contour Analysis (5)

Design Altitude Example Spike Plots



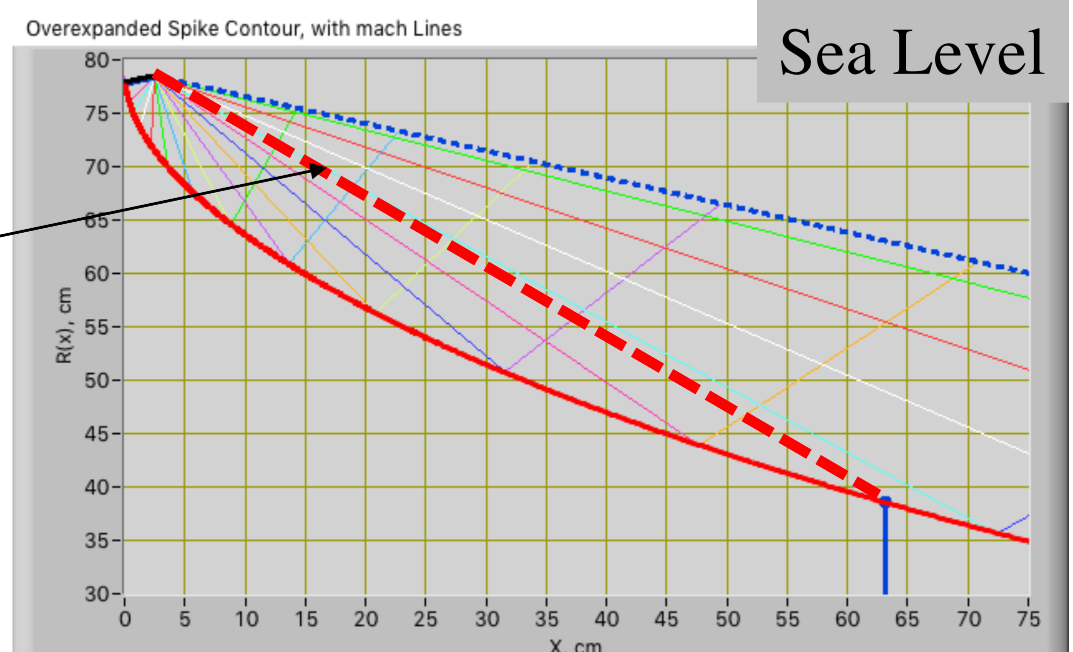
Part 3, Truncated Aerospike

Design Altitude



$$p_{spike} = p_{sea\ level}$$

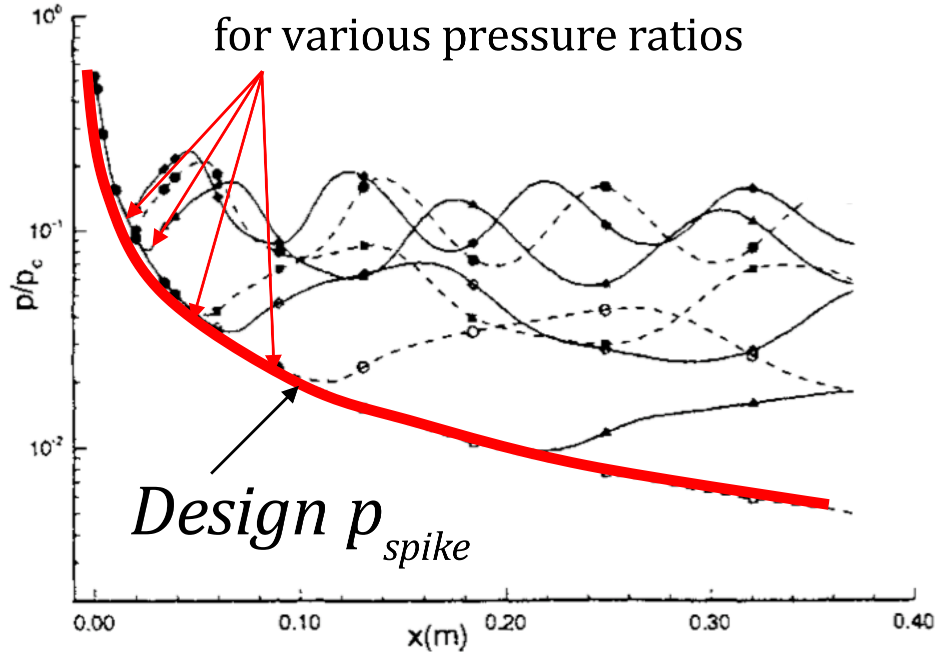
Sea Level

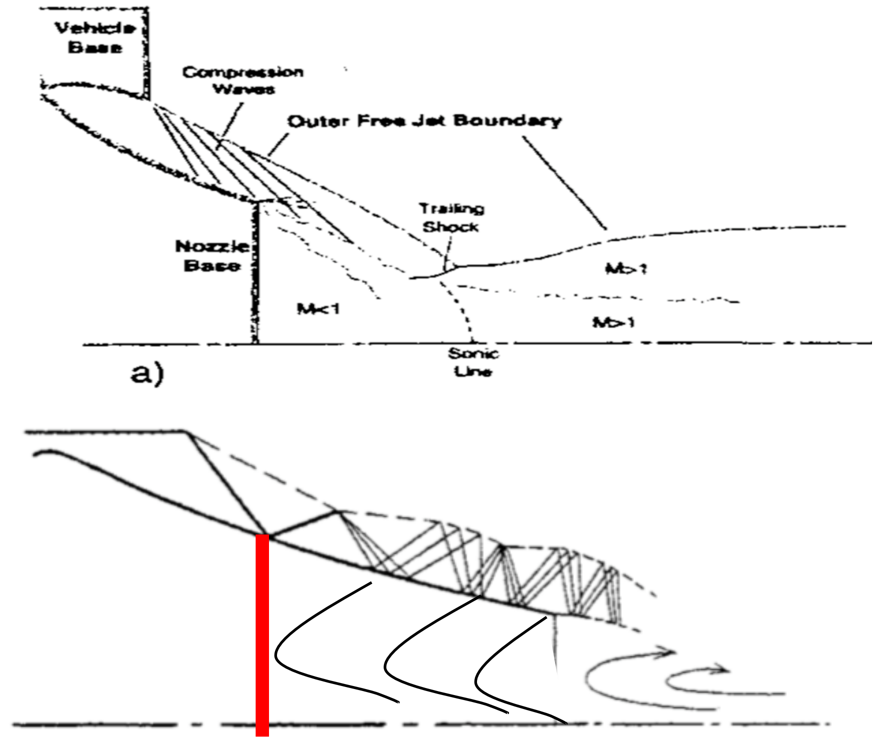


Part 3, Truncated Aerospike (2)

$p_{spike} = p_{\infty}$

for various pressure ratios

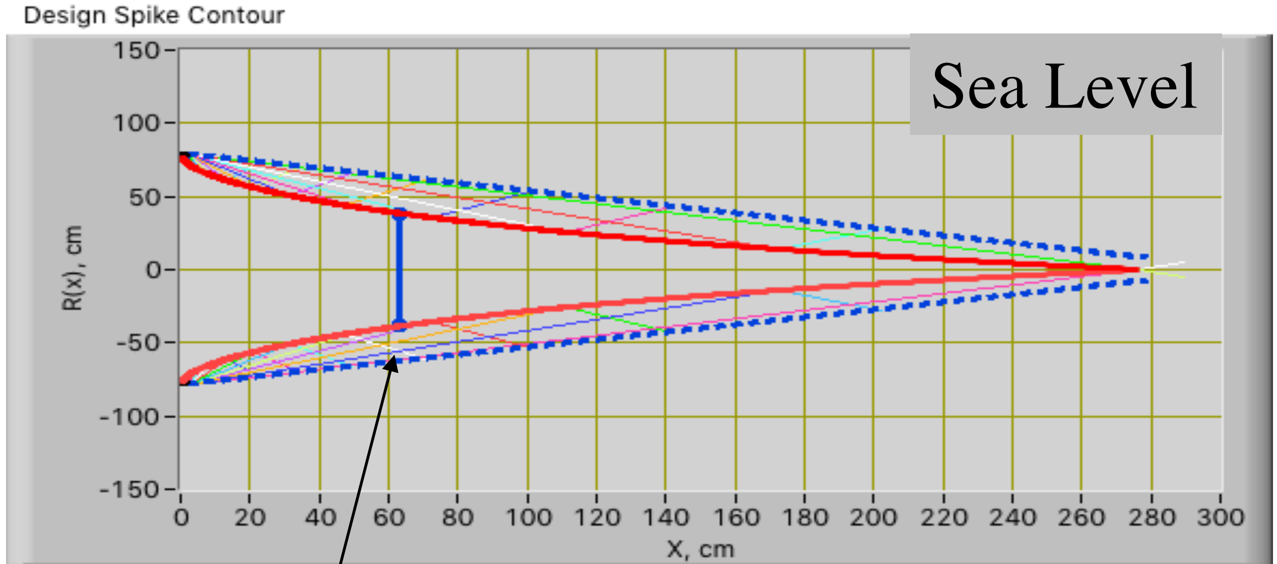


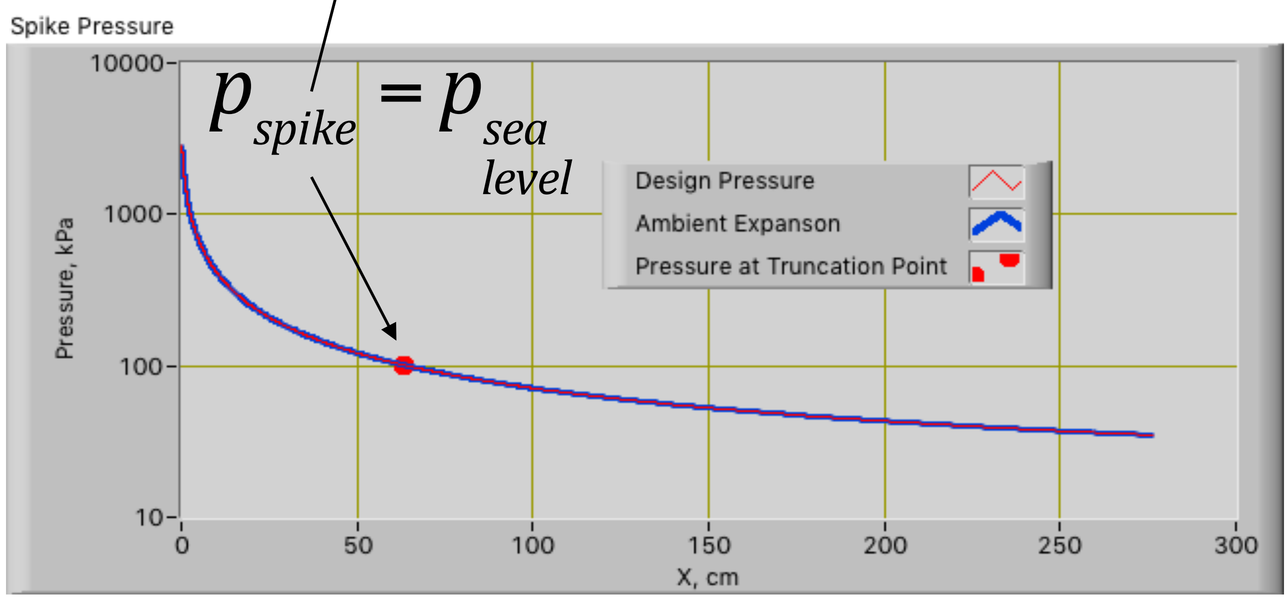


Part 3, Truncated Aerospike

Truncate Spike Such that pressure at truncation Point equals $= P_{sl}$

(101.325 kPa)





Calculate base pressure using "Rocketdyne Model" from Onofri, pg.

$$p_{base} = 0.58 \cdot P_0 \cdot \left(\frac{C_{F,\max,d} - C_{F,core}}{\varepsilon_{base}} \right) = 0.58 \cdot \left(\frac{F_{,\max,d} - F_{,core}}{A_{base}} \right)$$

$F_{,\max,d} \rightarrow$ *Full Ramp Thrust, Design Condition*

$F_{,core} \rightarrow$ *Accumulated Thrust at Truncation Point, Design Condition*

Truncated Thrust terms

- Base Pressure, kPa: 19.9261
- Base Drag, kNt: -37.9658
- RampThrust, kNt: 808.459
- TotalThrust, kNt: 942.649
- Isp, sec: 261.595

Thrusts

- Fmax,d, kNt: 1094.38
- Fcore, kNt 2: 1078.35

Example Calculation

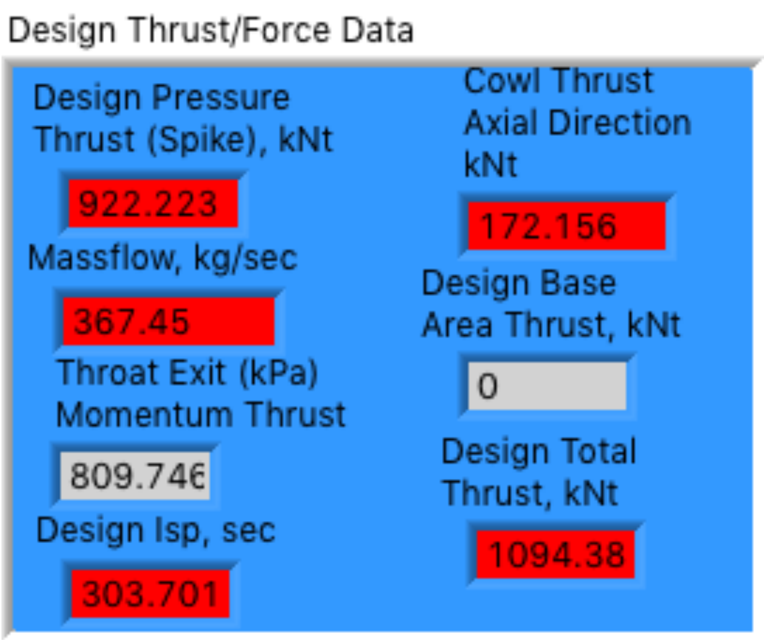
$$P_{base} = 0.58 \frac{(1094.38 - 1078.35)}{4664.17 \cdot 0.0001} = 19.9337 \text{ kPa}$$

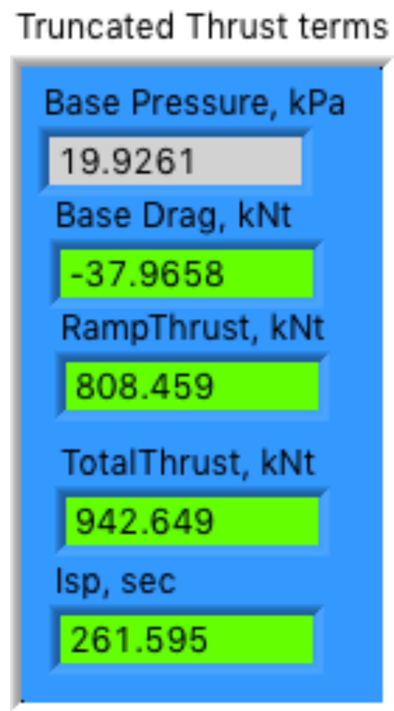
Data at Truncation

- R value at truncation, cm: 38.5312
- Theta at truncation, deg: 14.2576
- Mach Number at Truncation: 3.06432
- Spike Surface Pressure at Truncation, kPa: 101.325
- Spike Surface Temperature at Truncation, deg. K: 1691.72
- Spike Surface Velocity at Truncation, deg. K: 2754
- Spike Truncated base area cm^2: 4664.17
- Spike Truncated Length cm: 63.16

% truncation: 77.1683

Example Calculate Launch Thrust





$$T_{spike} = T_{throat} + T_{ramp} + T_{base} =$$

$$172.156 + 808.459 - 37.9658 = 942.649 \; kNt$$

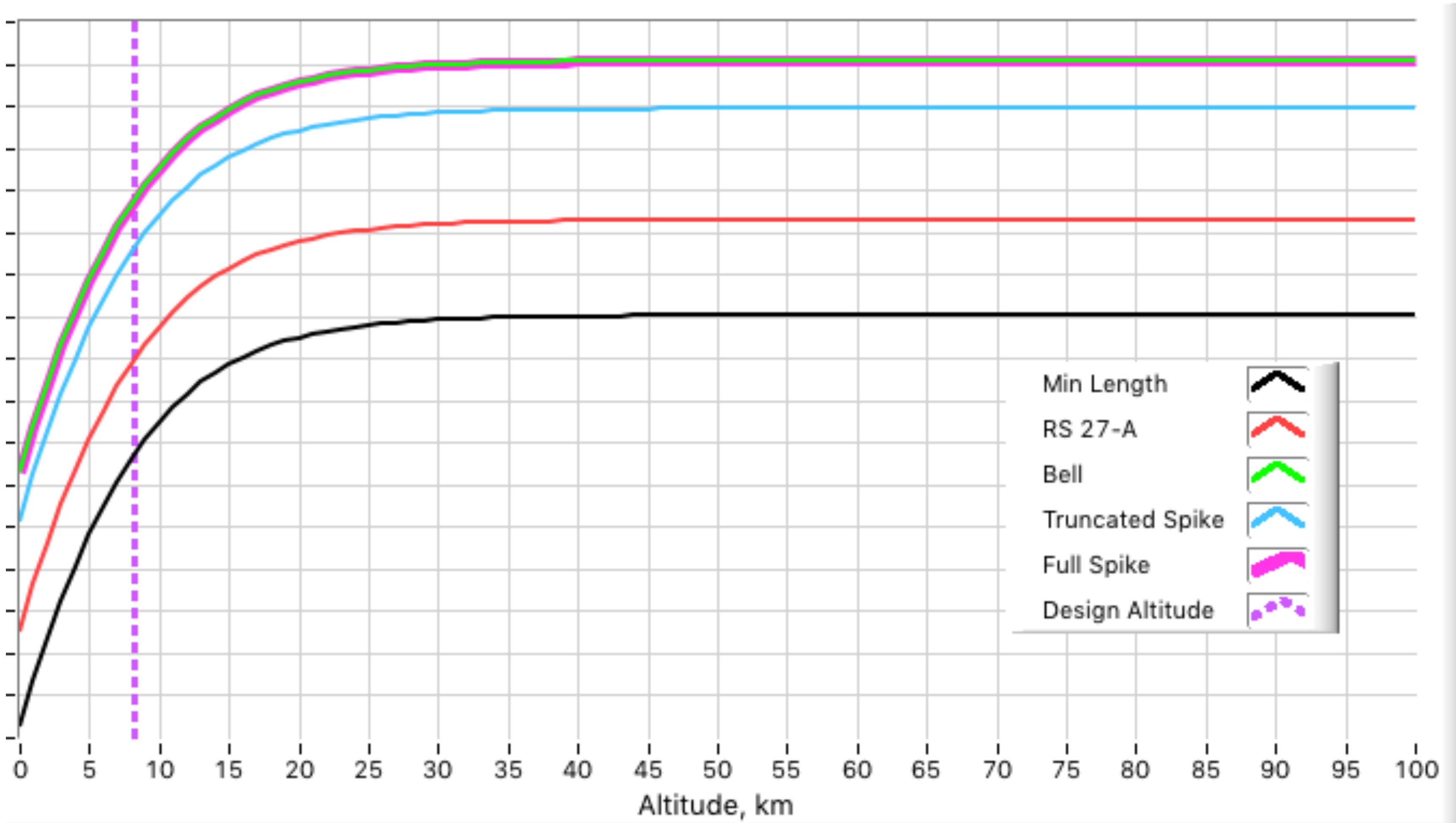
Part 4, Performance Comparisons

Plot delivered Thrust and I_{sp} as a function of altitude from sea level RS-27a design altitude to 100 km altitude

- *Actual RS-27A Nozzle*
- *Minimum Length Conical Nozzle*
- *Bell Nozzle*
- *Full 3-D Aerospike Nozzle (design Altitude to 100 km)*
- *Truncated Aerospike, $P_{truncation}$ = 101.325 kPa*

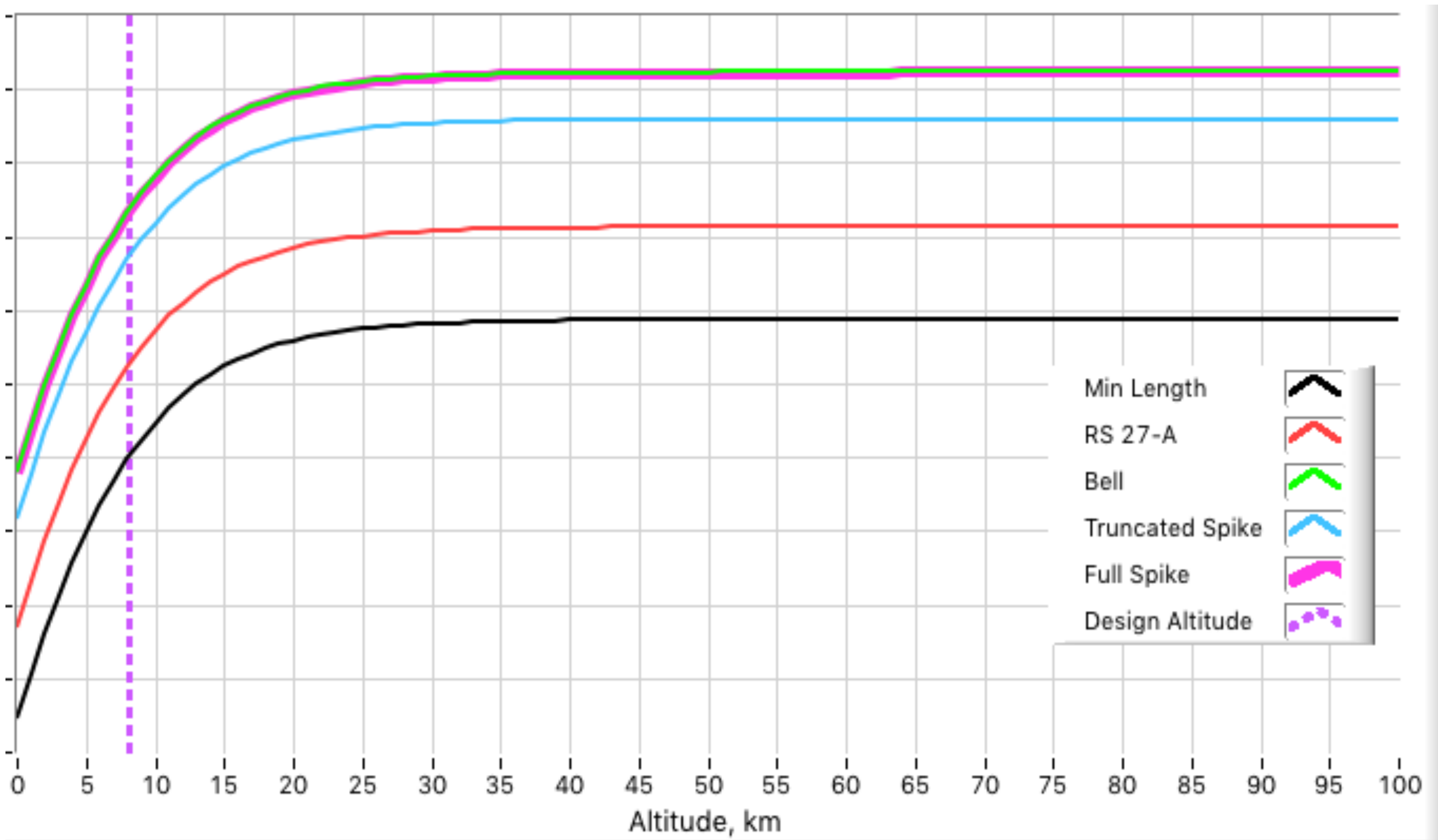
Part 4, Performance Comparisons

Thrust Comparisons

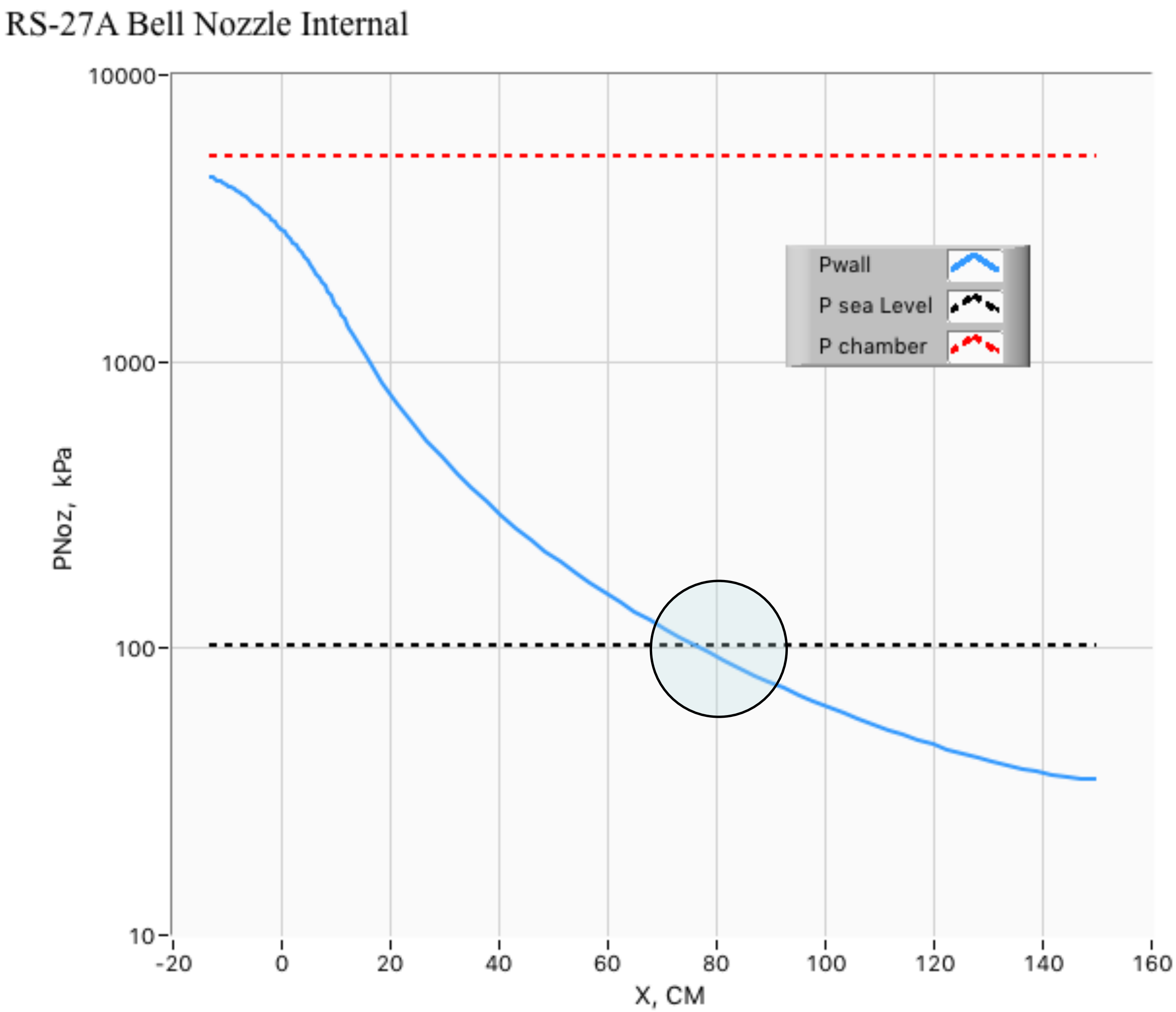


Part 4, Performance Comparisons

Thrust Comparisons



Part 4, Performance Comparisons



- Bell Nozzle Sill Likely Have Internal Shock Wave at Launch Conditions

Not Necessary to Model that event

Part 5 Nozzle Comparison Summary

Nozzle Config.	Launch Thrust, kNt	Vacuum Thrust, kN	Design Altitude Thrust, kNt	Launch I_{sp}, sec	Vacuum I_{sp}, sec	Design Isp, sec	Length, cm	Design Thrust/Length, kNt/cm
RS-27A Minimum Length Nozzle								
RS-27A Normal Nozzle								
RS-27A Bell Nozzle								
RS-27A Full Aerospike Nozzle, 77.168%	---			---				
RS-27A Truncated Aerospike Nozzle								