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• Boeing Delta II Rocket...Stage 1

- Nozzle Throat Diameter: 40.175 cm

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- 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 (P₀): 5160 kPa
 - Combustion temperature (T₀): 3455 K
 - $-\gamma = 1.2220$
 - $-M_W = 21.28 \ kg/kg-mol$
 - Propellant Mass: 97.08 Metric Tons
 - Stage 1 Launch Mass: 101.8 Metric Tons

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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)
 - o 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 \rightarrow Contraction/Expansion section has Rc = 0.75•D_{throat}

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Part 2, Aerospike Contour Analysis

For Aerospike Nozzle use Sonic Throat section, assume axisymmetric 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



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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



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Part 2, Aerospike Contour Analysis (4)

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



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UtahState UNIVERSITY Part 3, Truncated Aerospike

Truncate Spike Such that pressure at truncation Point equals $= P_{sl}$ (101.325 kPa)







MAE 6530 - Propulsion Systems II

Example Calculate Launch Thrust



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$$T_{spike} = T_{throat} + T_{ramp} + T_{base} =$$
172.156 + 808.459 - 37.9658 = 942.649 kNt

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UNIVERSITY 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*, $P_{truncation} = 101.325 kPa$

UtahState UNIVERSITY Part 4, Performance Comparisons

Thrust Comparisons









| UtahState UNIVERSITY Part 5 Nozzle Comparison Summary | | | | | | | | |
|--|--------------------------|-------------------------|--------------------------------------|---------------------------------|-------------------------------------|--------------------|---------------|-------------------------------------|
| Nozzle Config. | Launch Thrust, kNt | Vacuum Thrust, kN | Design Altitude Thrust, kNt | Launch I _{sp} , sec | Vacuu m I _{sp} , sec | Design Isp, sec | Length, cm | Design Thrust/Lengt h, kNt/cm |
| RS-27A Minimum Length Nozzle | 844.67 | 1040.55 | 973.29 | 234.39 | 288.75 | 270.08 | 83.05 | 11.721 |
| RS-27A Normal Nozzle | 844.67 | 1085.95 | 1018.69 | 246.99 | 301.35 | 282.68 | 107.29 | 9.495 |
| RS-27A Bell Nozzle | 965.80 | 1161.68 | 1094.42 | 268.00 | 322.36 | 303.69 | 150 | 7.296 |
| RS-27A Full Aerospike Nozzle, 77.168% | | 1161.65 | 1094.42 | | 322.33 | 303.67 | 267.6 | 4.090 |
| RS-27A Truncated Aerospike Nozzle | 942.85 | 1138.75 | 1071.48 | 261.59 | 315.98 | 297.31 | 63.15 | 16.967 |