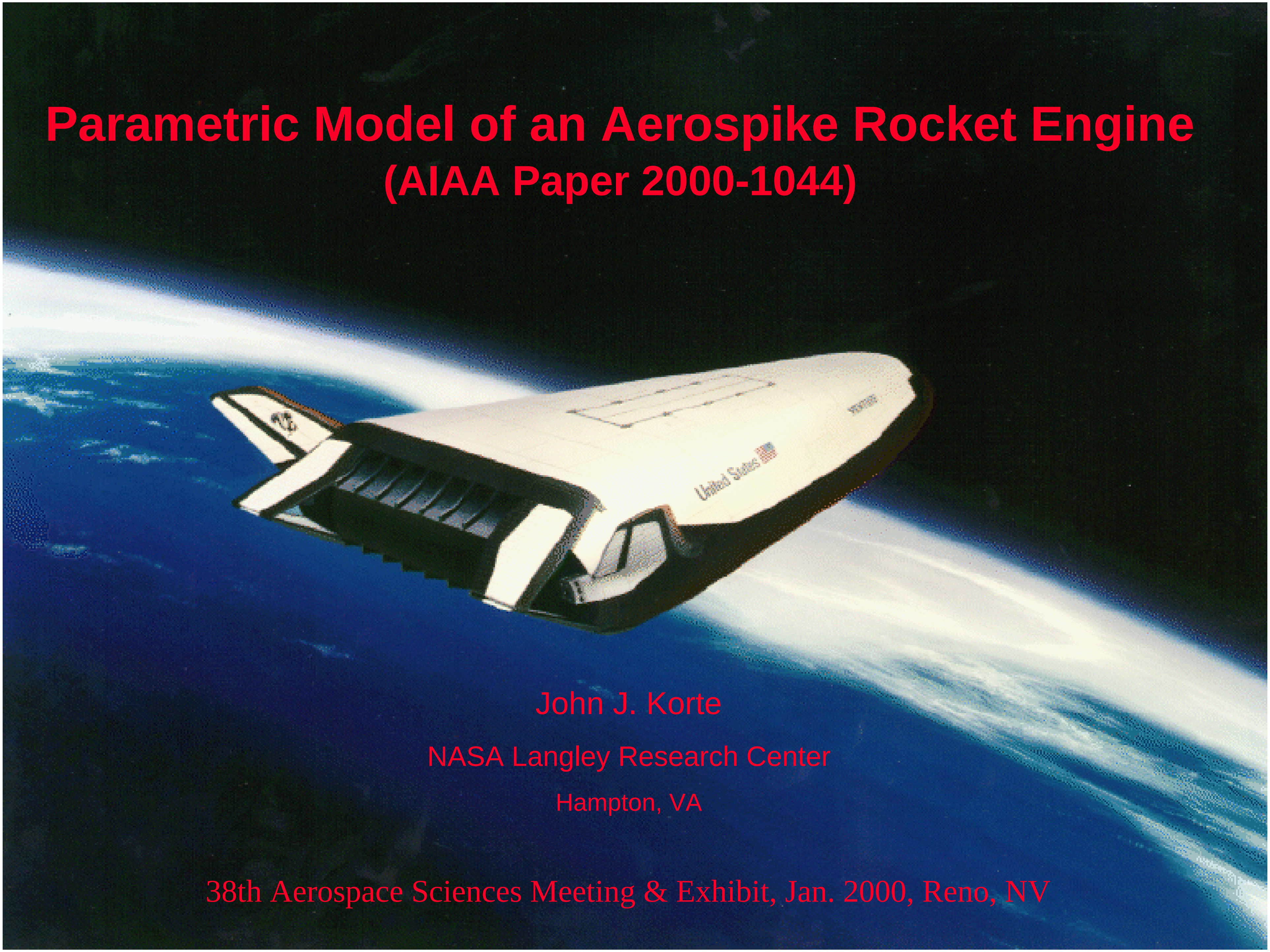

Parametric Model of an Aerospike Rocket Engine
(AIAA Paper 2000-1044)

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38th Aerospace Sciences Meeting & Exhibit, Jan. 2000, Reno, NV

Outline

- Motivation/Background
- Conceptual Vehicle Design
  - Engine Requirements
- Parametric Model Components
  - Engine Model
  - Typical Performance
  - Rubber Engine Optimization with iSIGHT™ MDO Framework
- Summary

Motivation/Background

- NASA LaRC Task from Lockheed Martin Skunkworks
- Team Member in Maturation for VentureStar Vehicle Concept
  - NASA LaRC focus on Vehicle Conceptual Design
    - Trajectory: performance based on **trimmed** trajectories
    - Weights
    - Aerodynamics
    - Aerothermal
    - Structures
    - TPS
    - Packaging
    - Controls
  - Needed Engine Data-
    - Bell Nozzle Rocket Engine Data Not Applicable (gimballing)
    - Aerospike Engine uses Thrust-Vector-Control (more complex to model)
      - Limited data provided on Aerospike Engines

Aerospike Engine Data Provided

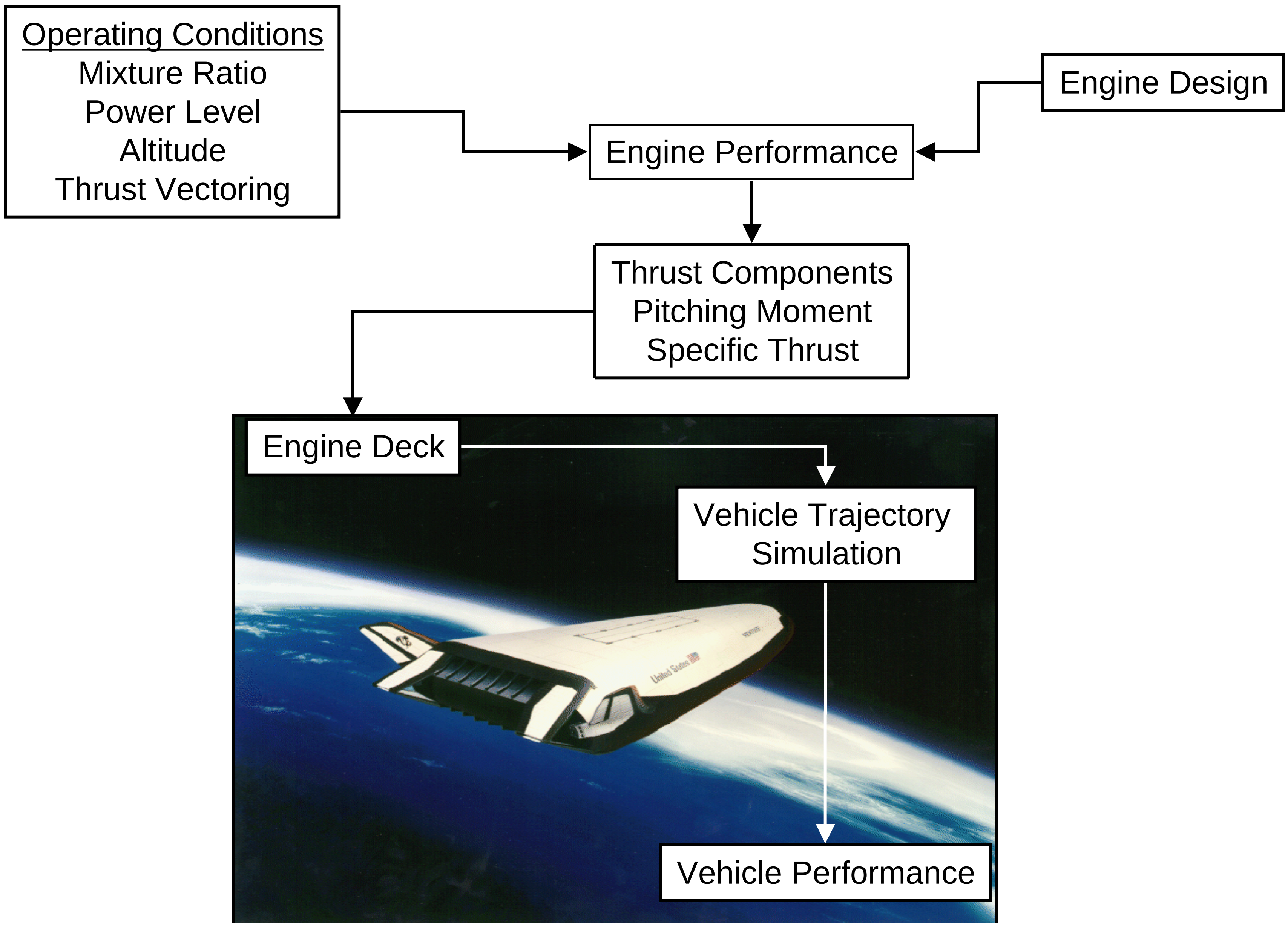
- Limited Aerospike Engine Data for VentureStar
  - Current focus was on X-33 by Propulsion Contractor
  - Engine data limited to 5 points on trajectory for engine design

PowerLevel	Mixture Ratio	Altitude	ISP	Thrust
100%	High	0’	*	*
100%	High	100k	*	*
87%	Low	100k	*	*
65%	Low	170k	*	*
20%	Low	Vacuum	*	*

* proprietary data

- Needed Thrust-Vectoring Data and Additional Points for Trajectory Analysis

Conceptual Vehicle Design
(Engine Data Requirements)



Trimmed Trajectory Engine Data Requirements (Typical)

- 6 power levels (20, 40, 60, 80, 100, 109%)
- 4 mixture ratios
- 12 altitude points
- 3 thrust vector control settings (-15, 0, +15%)

- Total of 864 cases per data file.

Solution

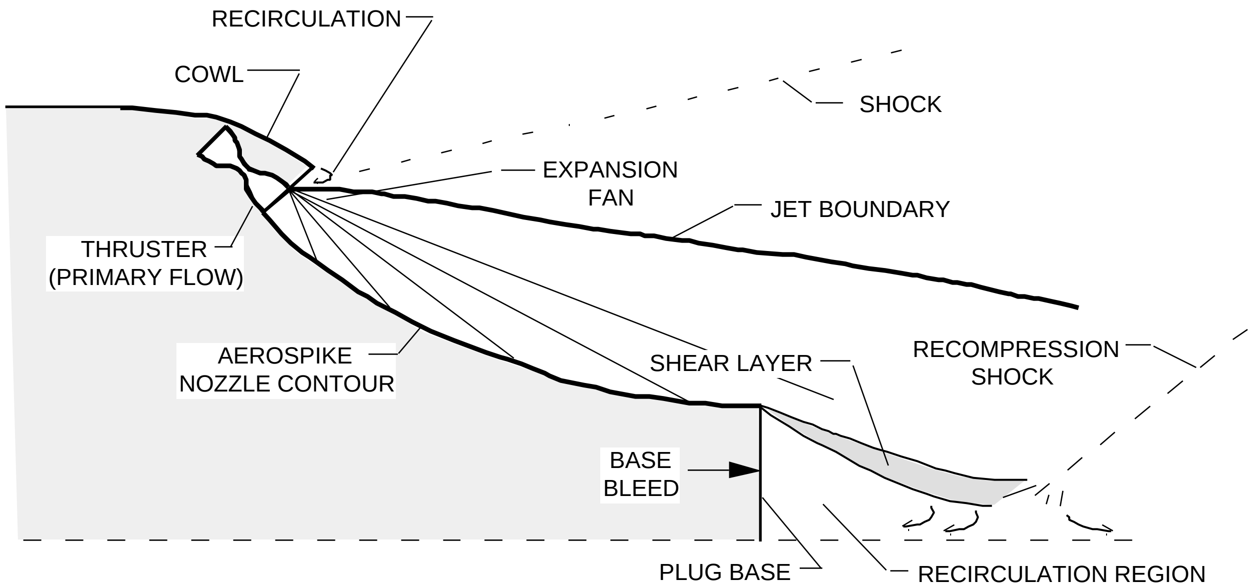
- Background
  - Space Act Agreement between Rocketdyne & NASA Langley
    - focus on advance propulsion design methods
    – utilizing optimization methods
    - Selected aerospike nozzle design as sample problem (1/96)
    - Reported in AIAA 97-3374
- Modify aerospike nozzle sample problem for use in conceptual vehicle design
  - Generate data needed for computing trimmed trajectories in system studies
    - Requires TVC information & detailed performance map
  - Developed in-house Aerospike Parametric Model

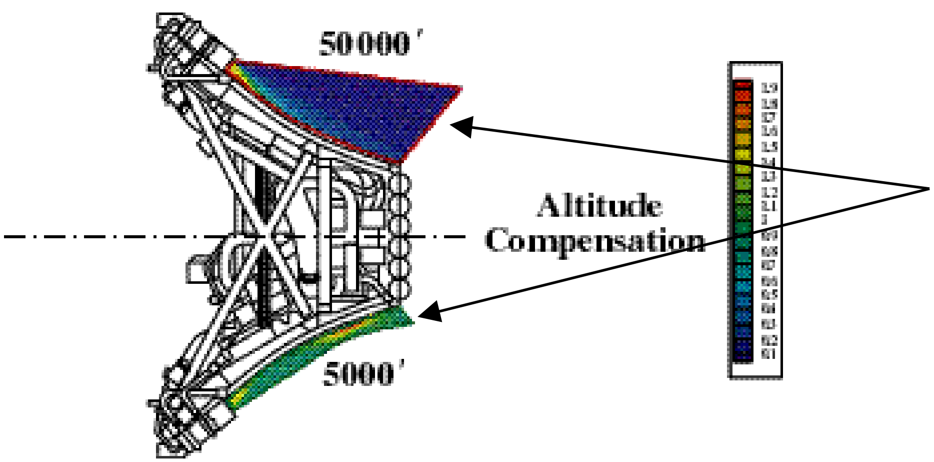
Aerospike RLV Engine Requirements (Typical)

RS-2200 Engine	At Sea Level	In Vacuum
Thrust, lbf	520,000	564,000
Specific Impulse, sec	342	456
Propellants	Oxygen, Hydrogen	
Mixture Ratio (O/H)	6.0	5.5
Chamber Pressure, psia	2,250	1,950
Cycle	Gas Generator	
Area Ratio	193	
Throttling, Percent Thrust	20~100	20~84
Dimensions, inches		
Forward End	294 wide x 96 long	
Aft End	120 wide x 96 long	
Forward to Aft	175	

<www.boeing.com/space/rdyne/x33/rlv/rs2200/eng_data.htm>
(Nov. 15, 1999)

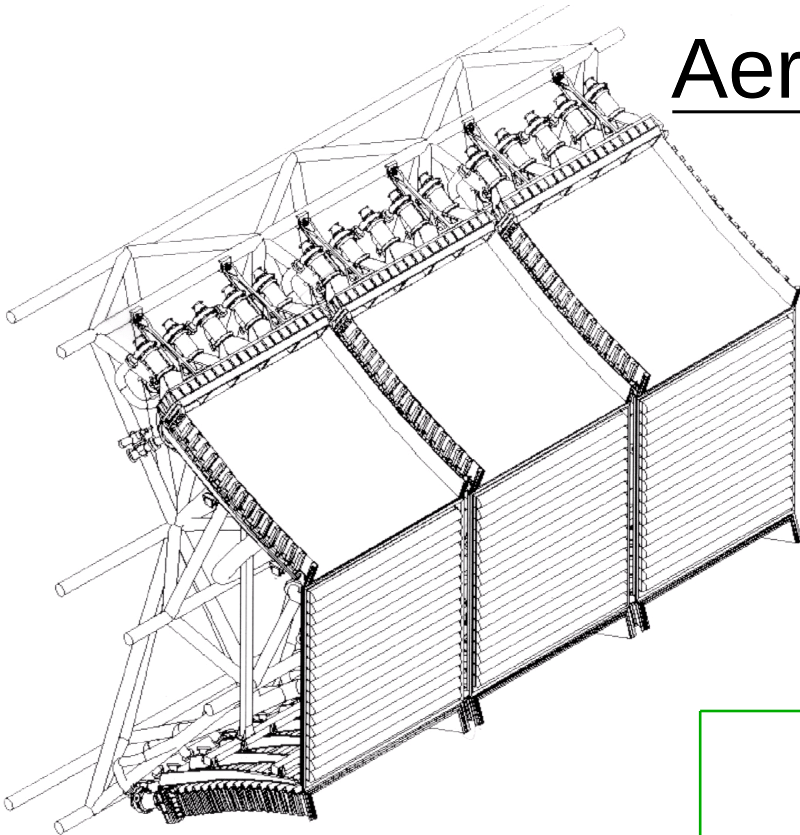
Aerospike Nozzle Flowfield Characteristics



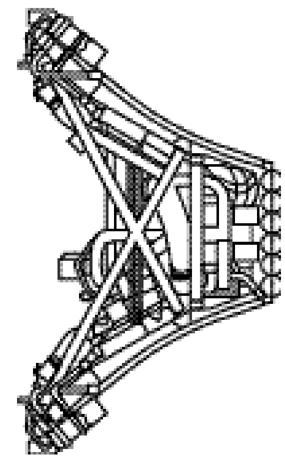


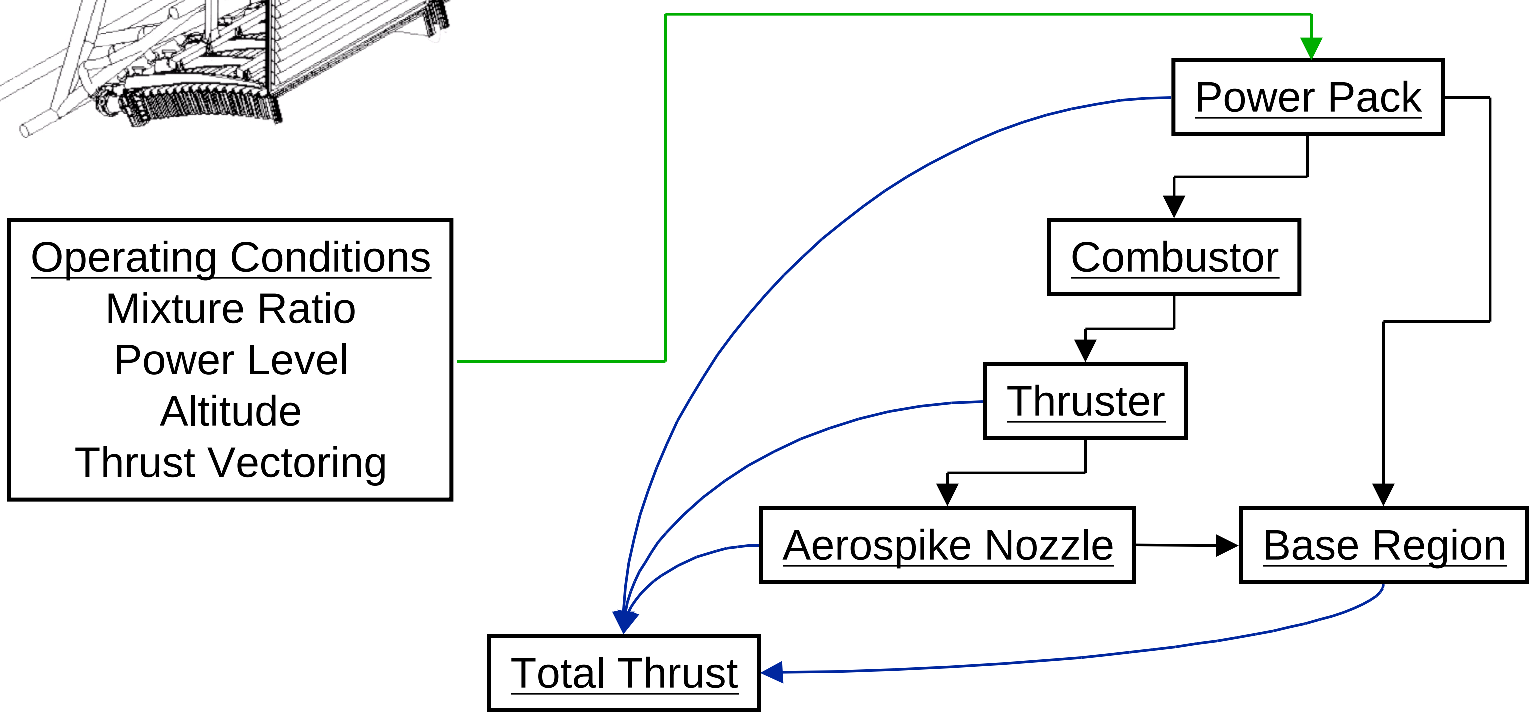
Typical CFD Pressure Contours
For Aerospike Nozzle

Aerospike Rocket Engine

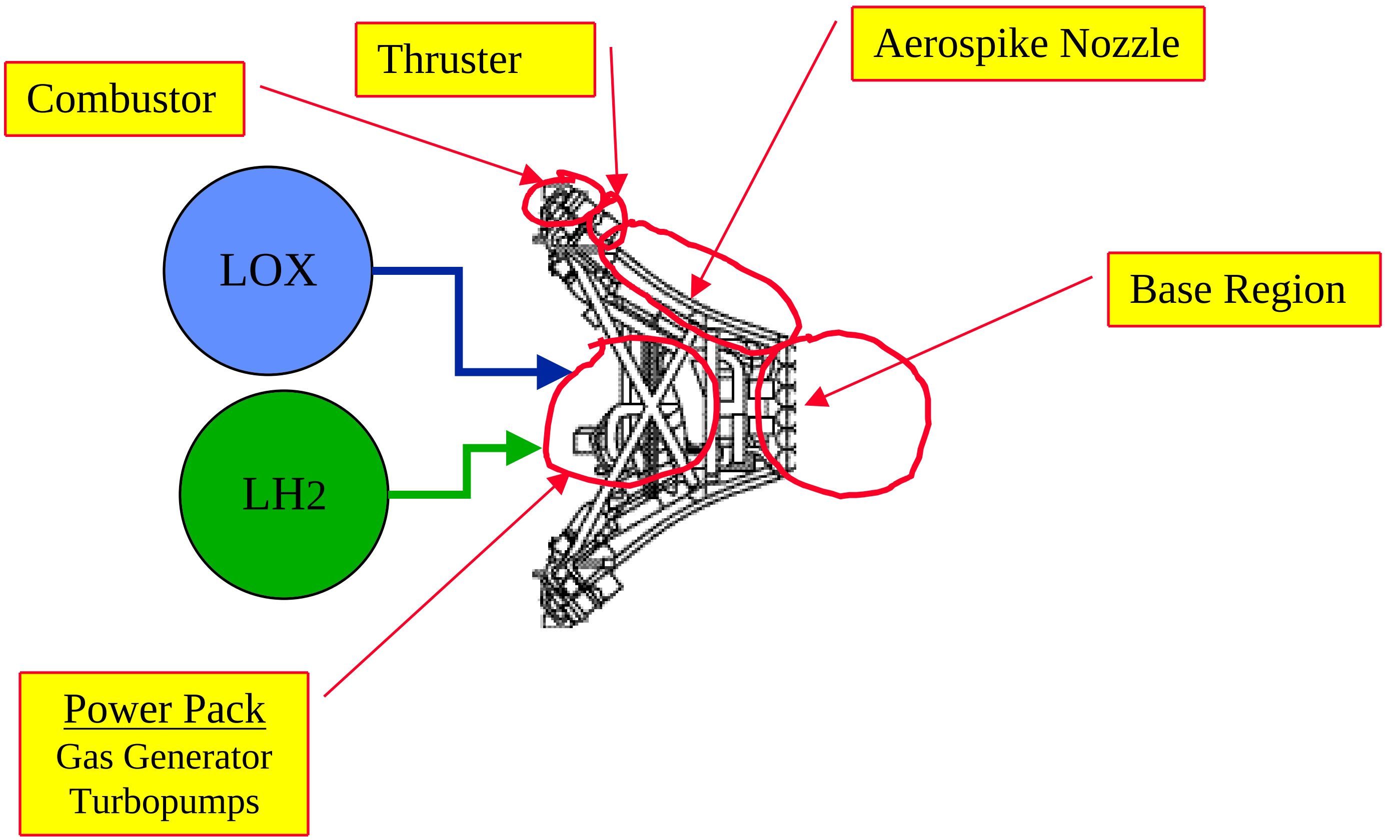


Major Engine Elements
Power Pack
Combustor
Thruster
Nozzle Ramp
Base Region





Major Aerospike Engine Elements



Power Pack: Gas Generator Cycle

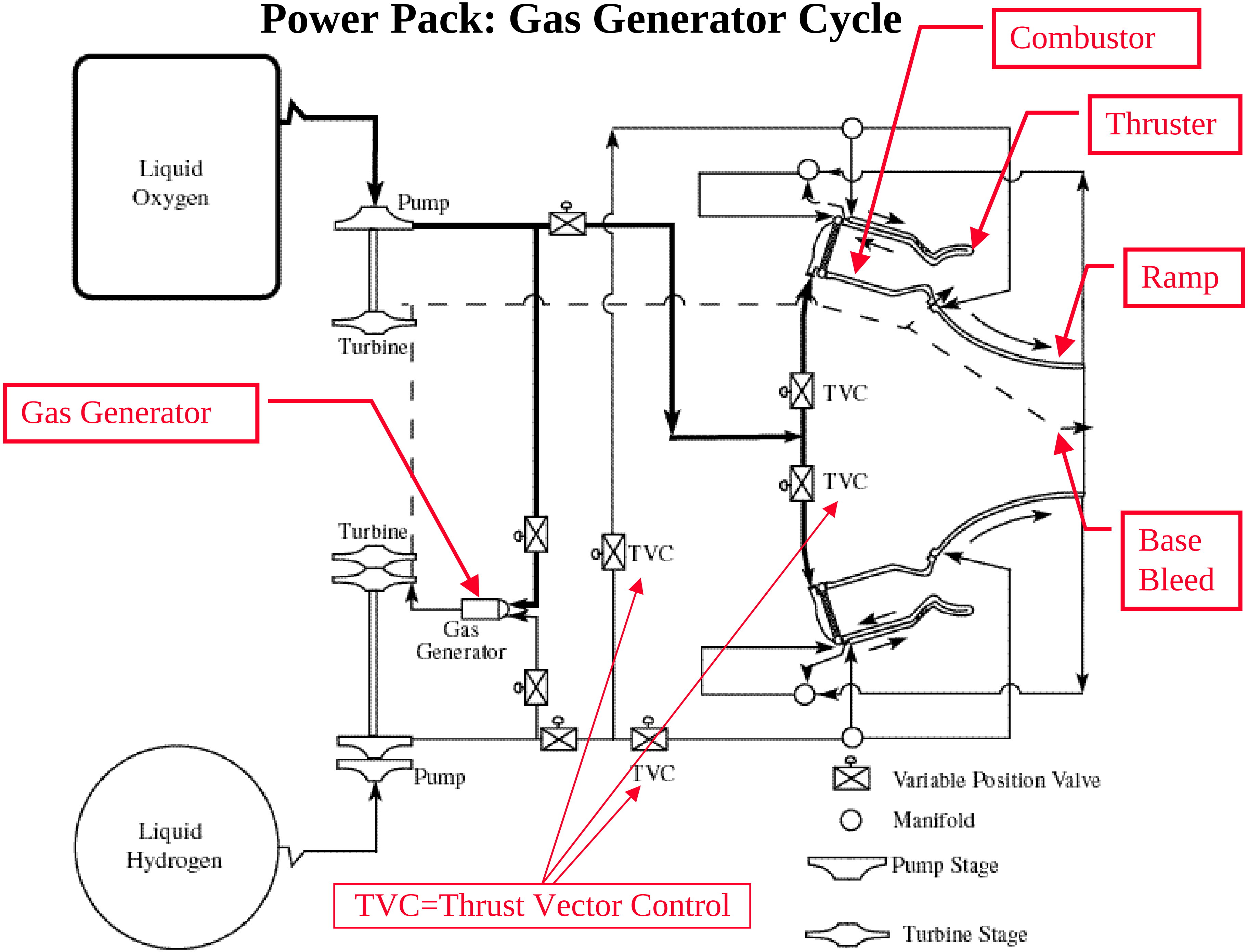
Power Pack

- gas generator
- Turbines
- Pumps
- Valves

Detailed Cycle Analysis Programs

- Pressure drops, energy requirements

Power Pack: Gas Generator Cycle



Aerospike Engine Parametric Model

- Gas Generator (GG) (Algebraic Model)
  - Input: MR, PL
  - Output: MRc, mass flow ratio of gg, gg thrust components
- Combustor (Equilibrium Reaction)
  - Input: MRc, PL
  - Output: Htotal, Species
- Thruster (1-D Equilibrium Expansion)
  - Input: Htotal, Species, Area Ratio
  - Output: Static Properties at Exit, thrust components
- Aerospike Nozzle (CFD Calculation, effective gamma)
  - Input: Static properties at thruster exit, thruster angle, aerospike contour
  - Output: surface pressure distribution, thrust components
- Base Region (Algebraic Model)
  - Input: Maximum recovery, efficiency
  - Output: Base pressure, thrust

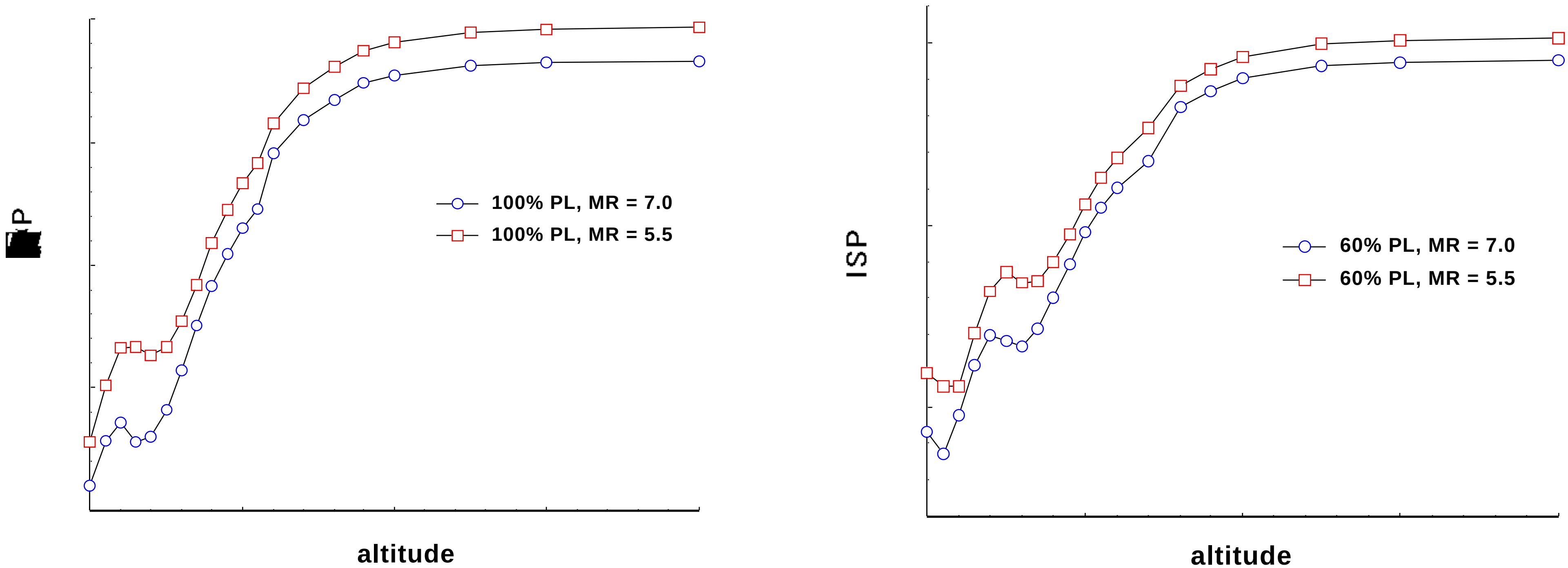
Aerospike Engine Parametric Model (Cont’d)

- Thrust Accounting
  - Input: Ideal thrust components, loss factors
  - Output: Thrust and Moment estimates
- Trajectory File
  - Input: Trajectory Points (MR, PL, Altitude), TVC Level, Thrust & Moment estimates
  - Output: Data file for POST code

Typical Results

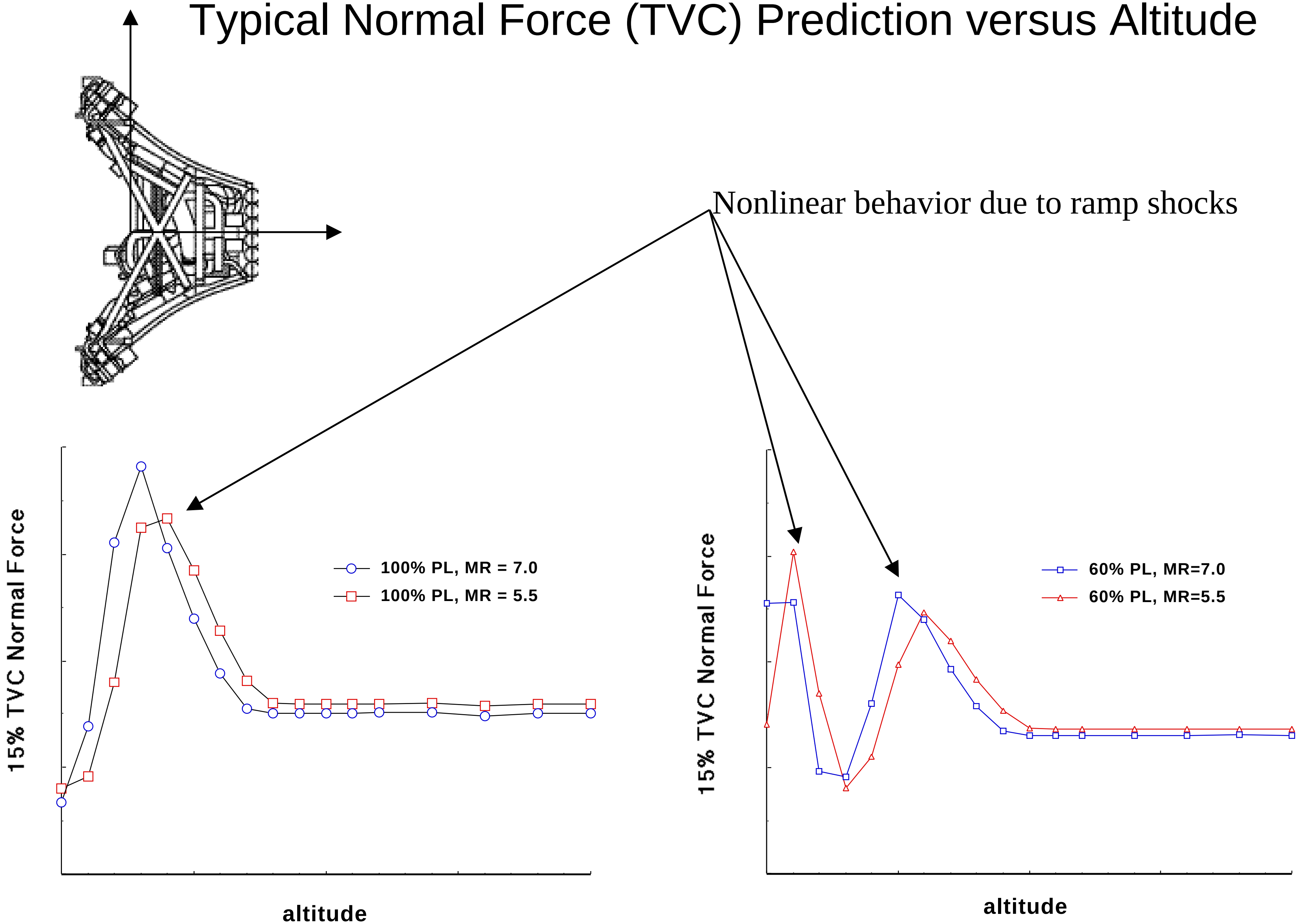
- Generate POST Input Deck
  - 6 Power Levels
  - 4 Mixture Ratios
  - 22 Altitude Points
  - 3 TVC Levels
- Example of Aerospike Performance Trends
  - ISP vs. Altitude
  - Max normal Force (TVC) vs. Altitude
  - Max pitching Moment (TVC) vs. Altitude

Typical ISP Performance Prediction versus Altitude

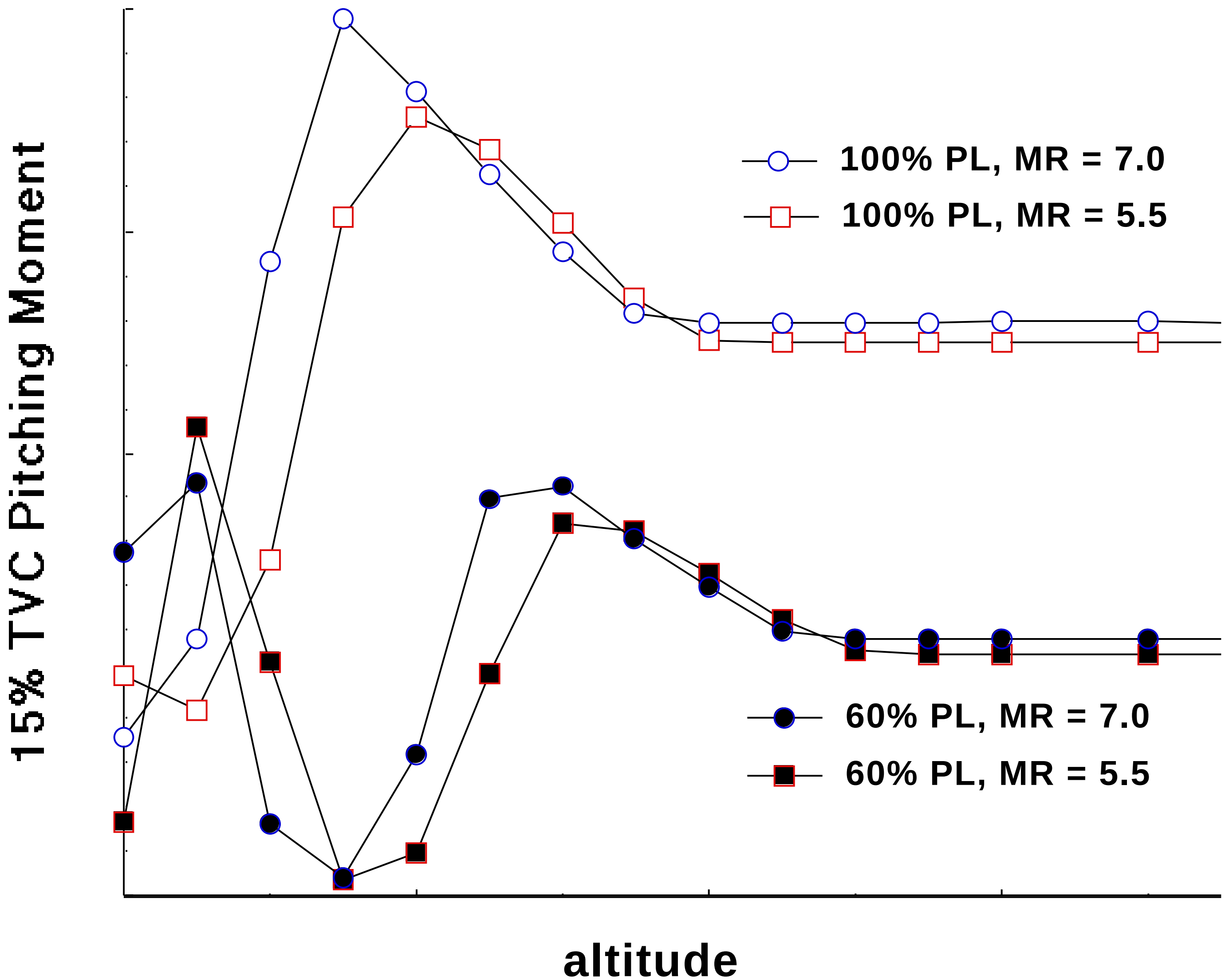


Change in location of ramp shocks with power level and altitude

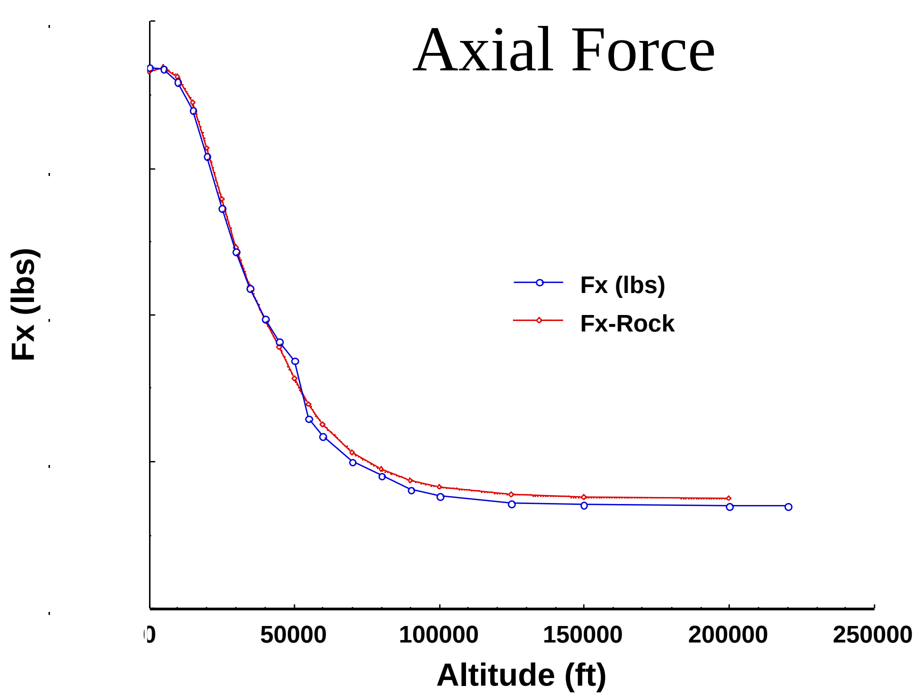
Typical Normal Force (TVC) Prediction versus Altitude

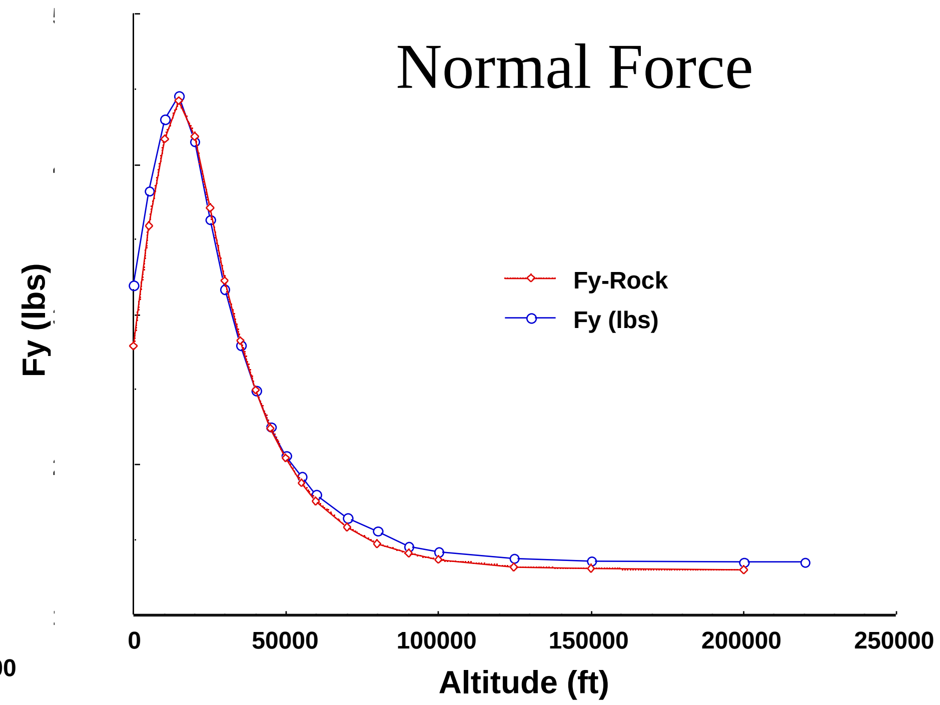


Typical Pitching Moment (TVC) Prediction versus Altitude

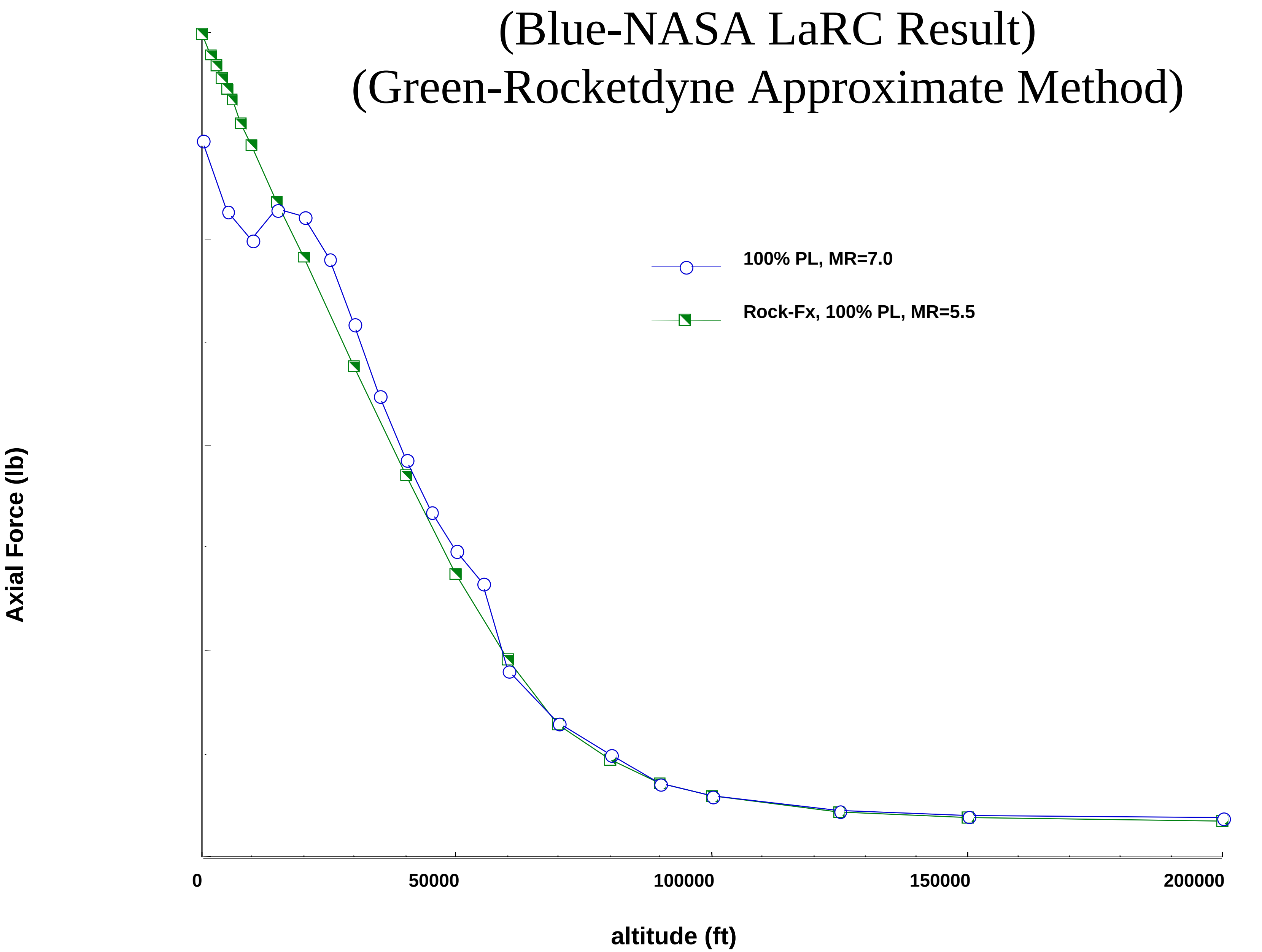


X33 Performance Comparisons
Mixture Ratio=6, Power Level = 100%
(Blue-NASA LaRC Result)





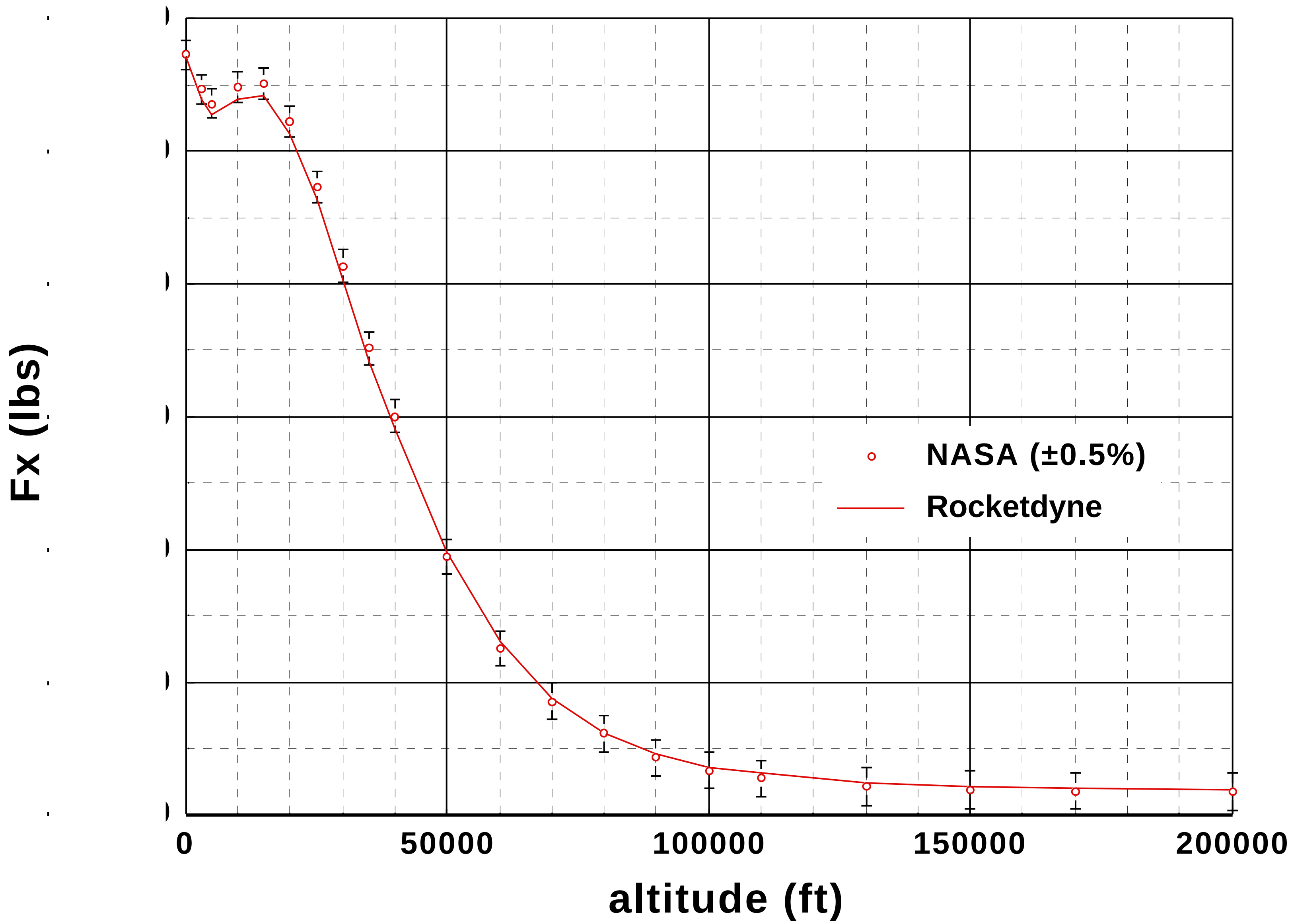
RLV Performance Comparisons-Axial Force



RLV Performance Comparisons-Axial Force

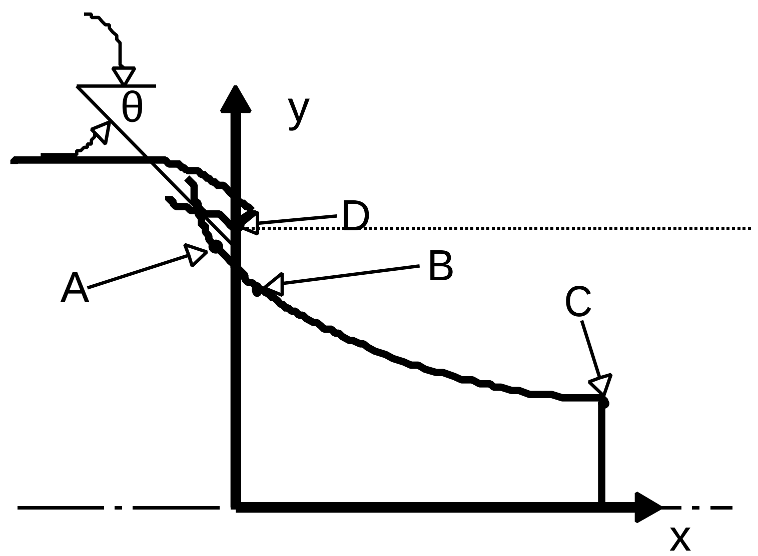
(Black-NASA LaRC Result)

(Red-Rocketdyne Full Model)

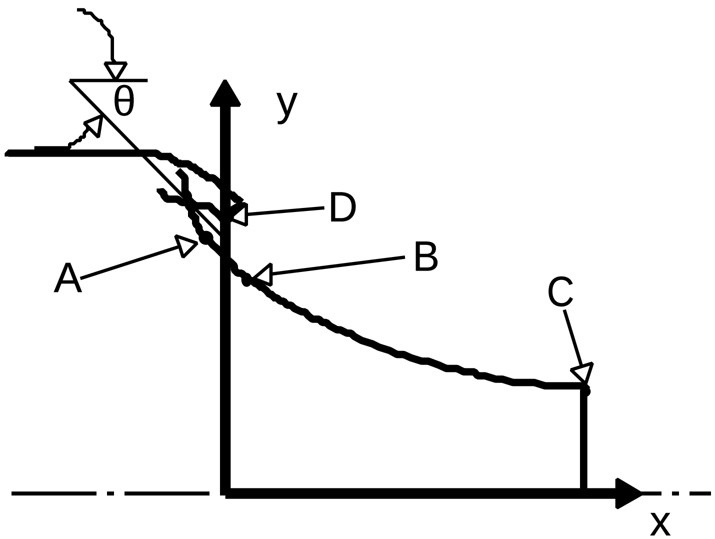


Parametric Aerospike Engine Coupled to iSIGHT Framework

- **Objective: To improve or create new engine designs**
  - **Example**
    - **Maximize Composite ISP with SL Thrust Constraint**
      - **CompISP = .21 ISPsl + 0.79 ISPvac**
      - **Slthrust = 520,000 lbs.**
      - **Design Variables**
        - **Thruster angle and Area Ratio (θ, AR_{THR})**
        - **Nozzle Contour and Engine Area Ratio (x_B, dy_c/dx, AR_{ENGINE})**
    - **Assumptions**
      - **Losses, base region, and gas generator thrust**

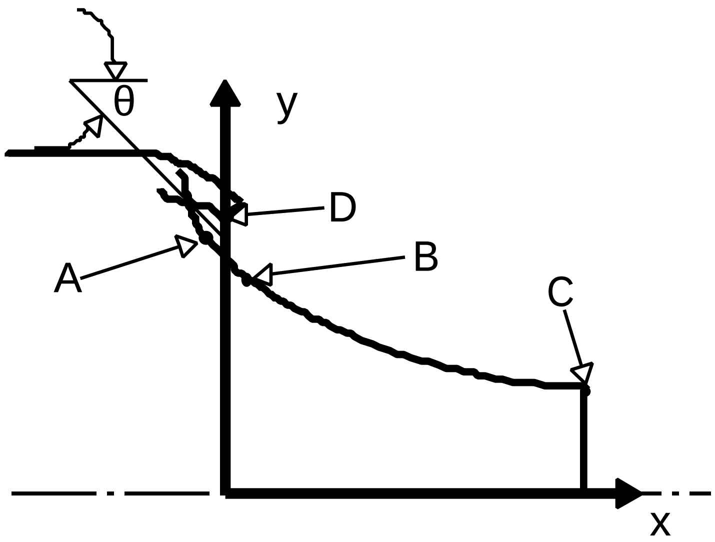


Method of Feasible Directions (Gradient Based)



	Initial Value		Final Value	
Case	1	2	1	2
<u>Parameters</u>				
x_B (in.)	10	20	10.2	20.2
dy_C/dx	−0.20	−0.10	−0.187	−0.100
θ (°)	−45.0	−20.0	−34.4	−27.5
AR_{THR}	10	20	10.8	21.6
AR_{ENGINE}	193	193	199.	197.6
<u>Constraint</u>				
SL_{THRUST}(lbf)	264,018	251,531	260,000	260,001
<u>Objective</u>				
$Comp_{ISP}$ (s)	427.4	426.8	432.0	432.1

Genetic Algorithm
(Global Optimization)



	Lower Bounds	Upper Bounds	Final Results
Parameters			
x_B (in.)	9	45	43.9
dy_C/dx	−0.20	−0.075	−0.101
θ (°)	−45.0	−20.0	−28.2
AR_{THR}	5	25	19.3
AR_{ENGINE}	170	220	198.5
Constraint			
SL_{THRUST}(lbf)	—	—	260,000
Objective			
$Comp_{ISP}$ (s)	—	—	432.6

Summary

- Conceptual engine data for aerospike engine required TVC data for computing vehicle trajectories
- A parametric model of aerospike rocket engine was developed to generate data needed for inhouse conceptual vehicle studies
- Demonstrated optimization problem solution for engine design using iSIGHT multidisciplinary framework