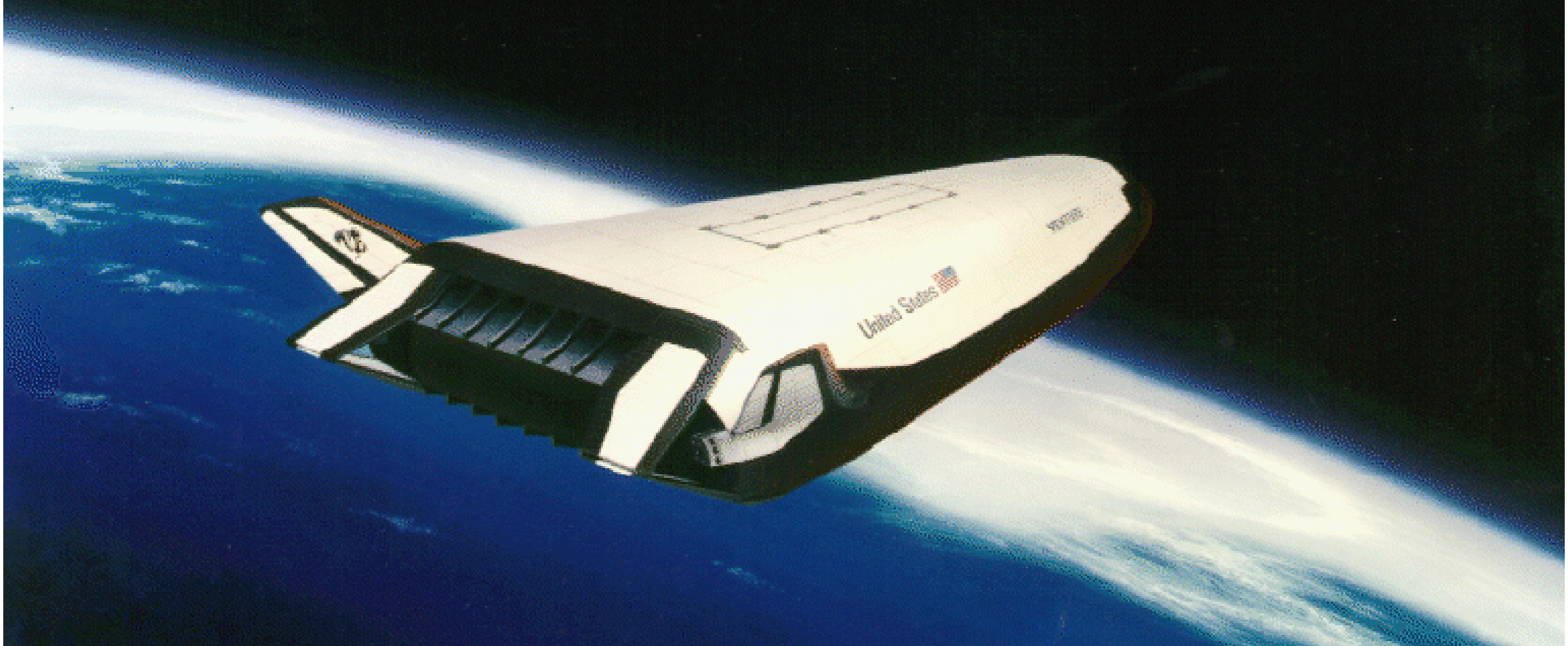
Multidisciplinary Approach to Linear Aerospike Nozzle Optimization

(AIAA Paper 97-3374)



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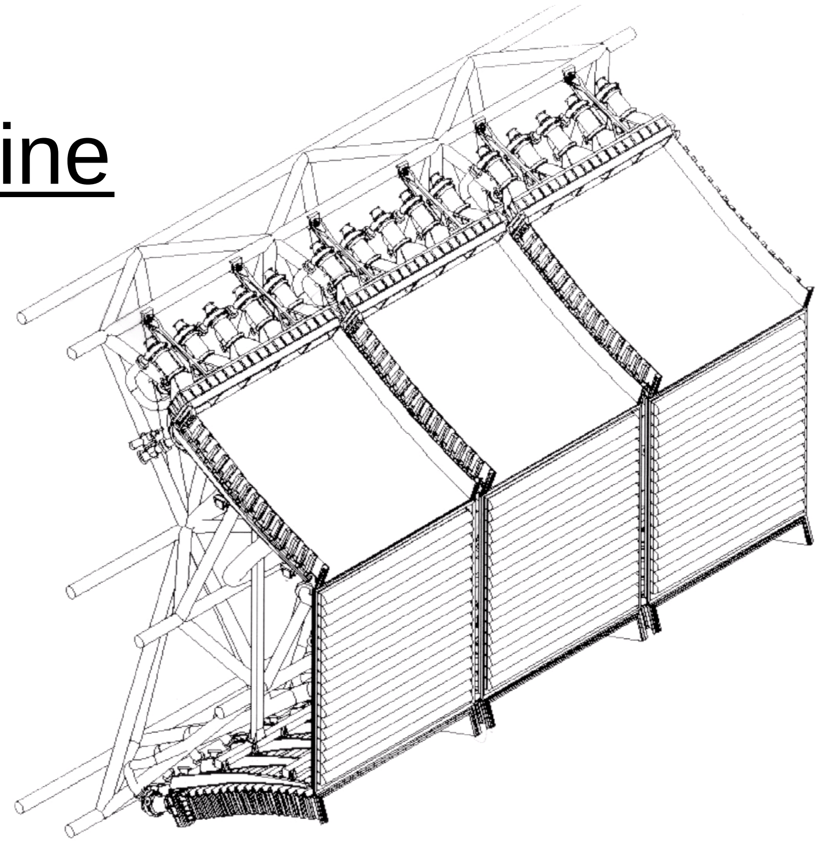
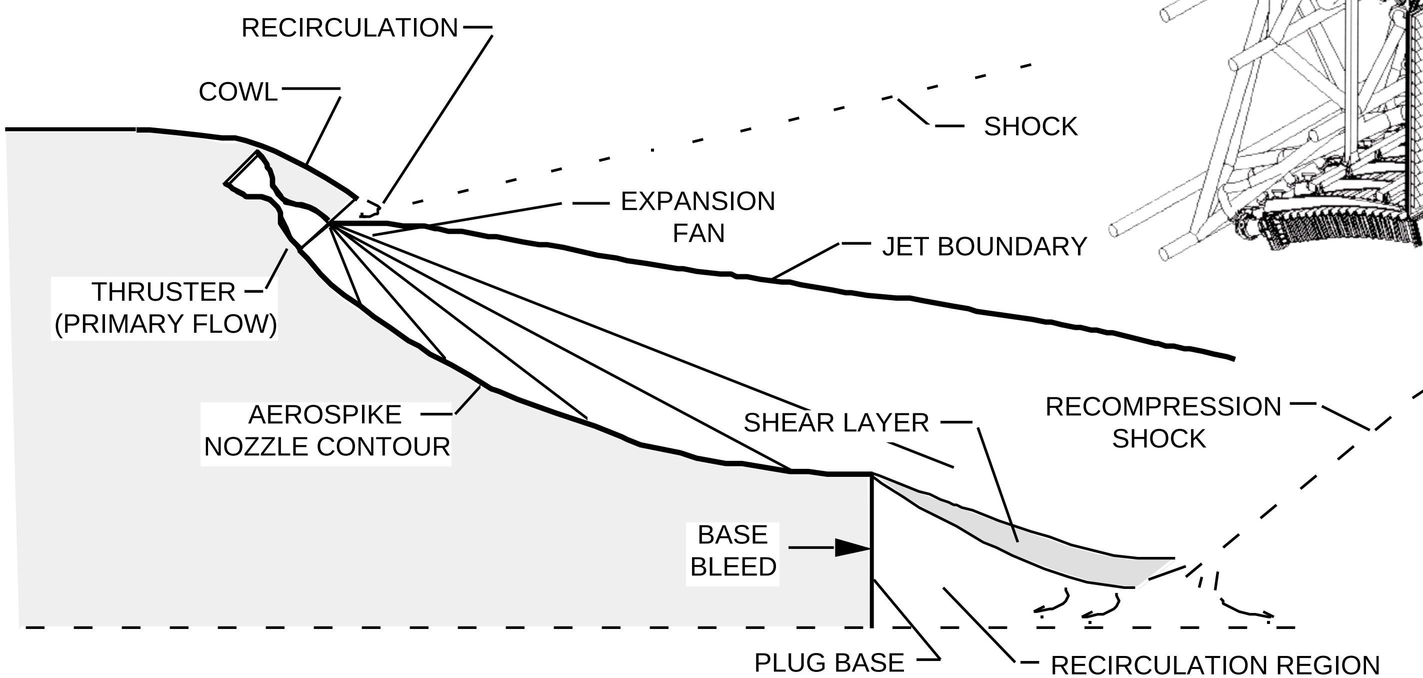
Aerospike Engine





Aerospike Nozzle Flowfield Characteristics

Outline

- Motivation/Background
- MDO Applied to Aerospike Nozzle
- Summary

Motivation/Background

- Creation of Multidisciplinary Optimization Branch in late 1995
  - in Research Technology Group at NASA Langley
  - research focus on MDO methodology and applications
- 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)
  - Created teams at Rocketdyne and NASA Langley

- Challenge
  - Extract model for developing MDO methods
  - Impact design process by providing integration methodology
    - Sample application for demonstrating MDO benefits
    - Paradigm shift needed by engineers/designers

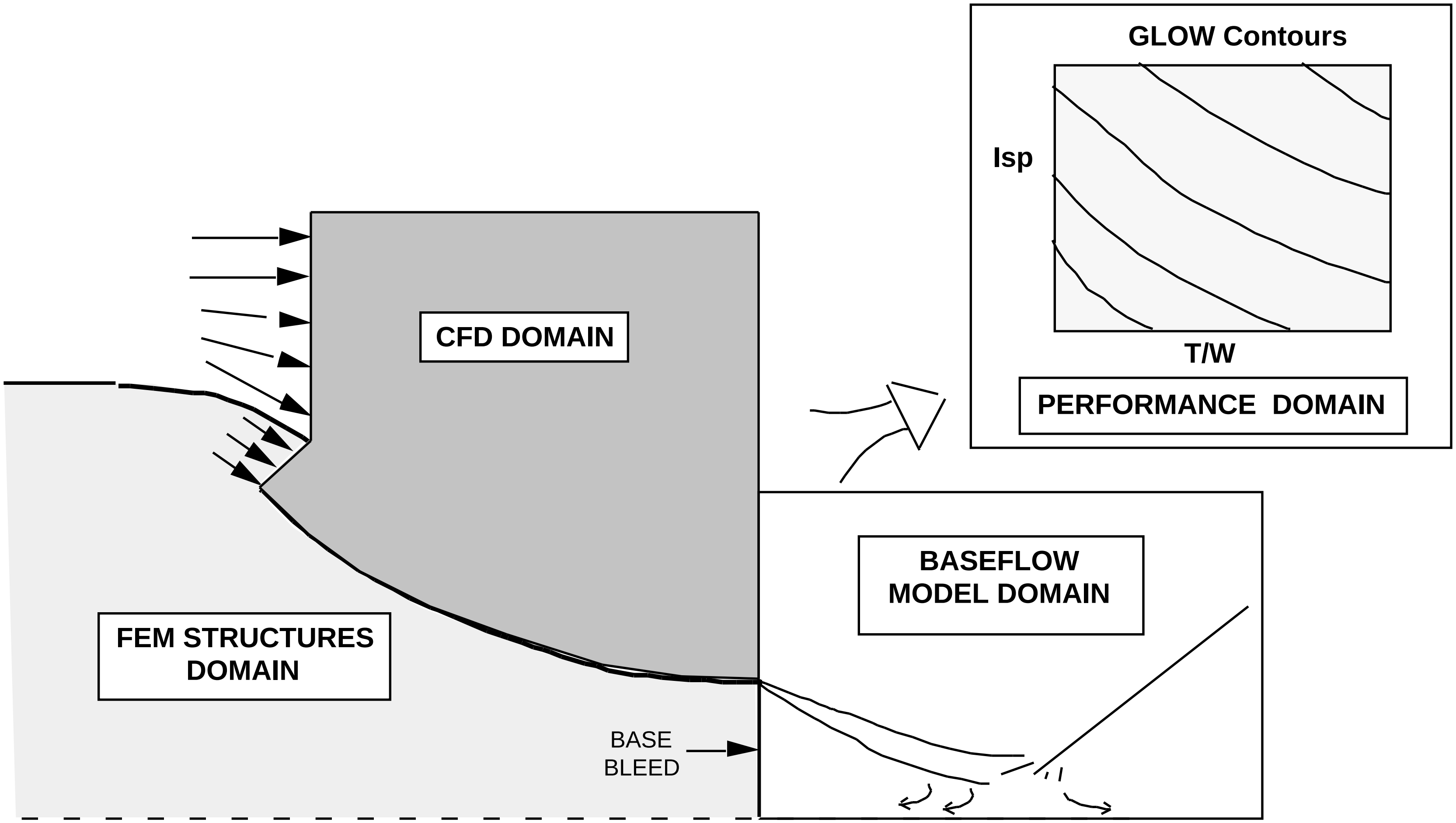
MDO Definition

Multidisciplinary Design Optimization (MDO) is a methodology for the design of complex engineering systems and subsystems ***that coherently exploits the synergism of mutually interacting phenomena***

$$\Delta_{\text{Design}} = \left(\sum_i \Delta_{\text{Discipline } i}\right) + \Delta_{\text{MDO}}$$

“Δ_{MDO}”

AEROSPIKE MDO DOMAIN DECOMPOSITION



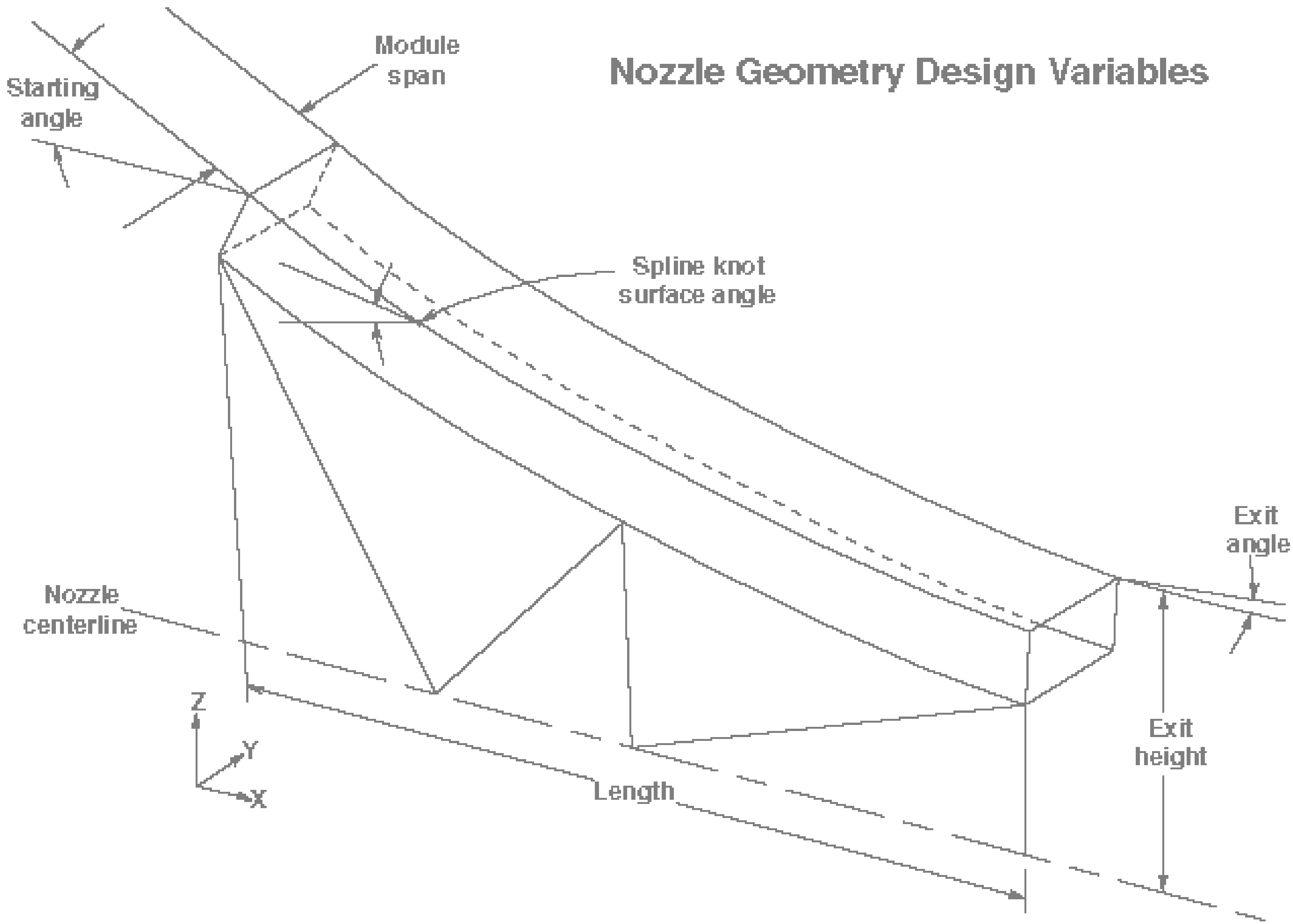
MULTIDISCIPLINARY OPTIMIZATION APPROACH

- **Objective: Design aerospike nozzle to minimize GLOW subject to structural constraints**
  - **Disciplines**
    - Aero
      - 2-D inviscid space marching
      - 1-D base flow model
      - 1-D analysis for thrust cell
    - Structures
      - 3-D FEM analysis
    - Performance
      - Curve fits of GLOW for mission-averaged I_{SP} and T/W inputs

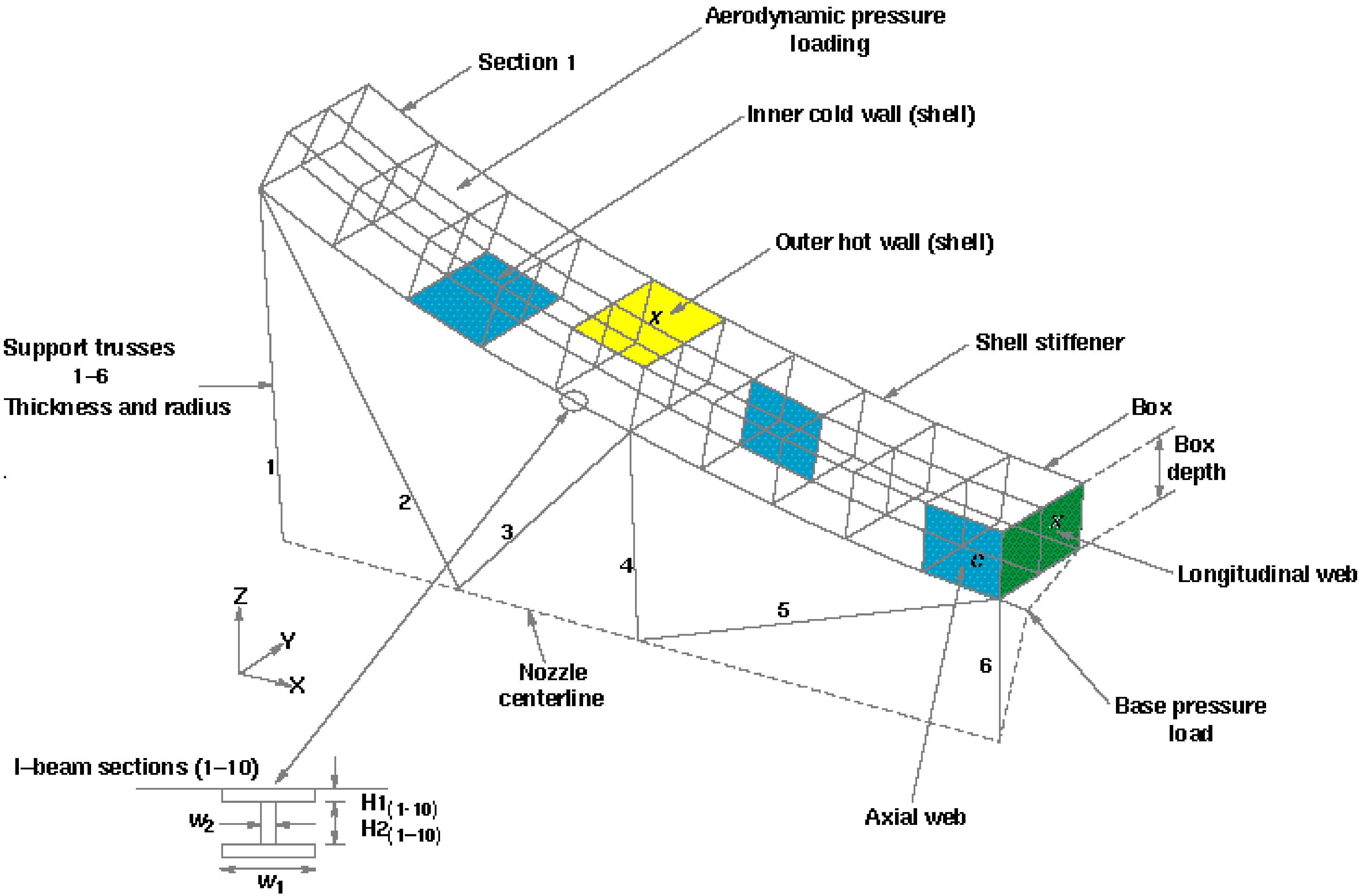
Design Problem

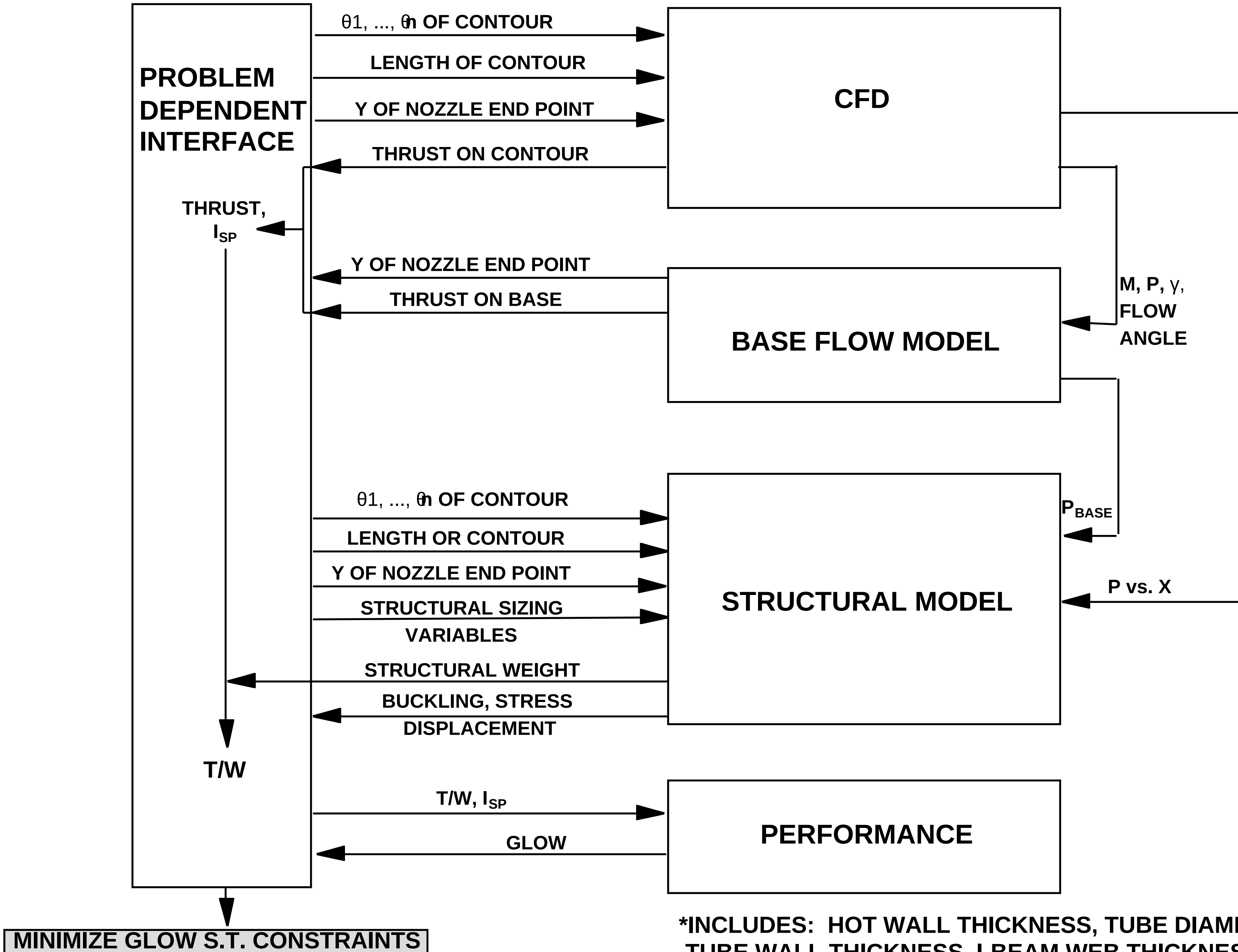
- Objective: Minimize Gross-Lift-Off-Weight
- Design Parameters (18)
  - 4 Geometry variables
    - Thruster angle
    - (2) Surface slopes
    - Nozzle base height
  - 14 Structural variables
    - I-beam parameters (4)
    - Thicknesses (7)
      - Hot wall, cold wall, axial web, long. web, stiffeners, trusses, base plate
    - Radii (2)
      - trusses, stiffeners
    - Structural box depth
- 596 Structural Constraints
  - Displacement, stress, buckling

Nozzle Geometry Design Variables



Structural Loading and Design Variables



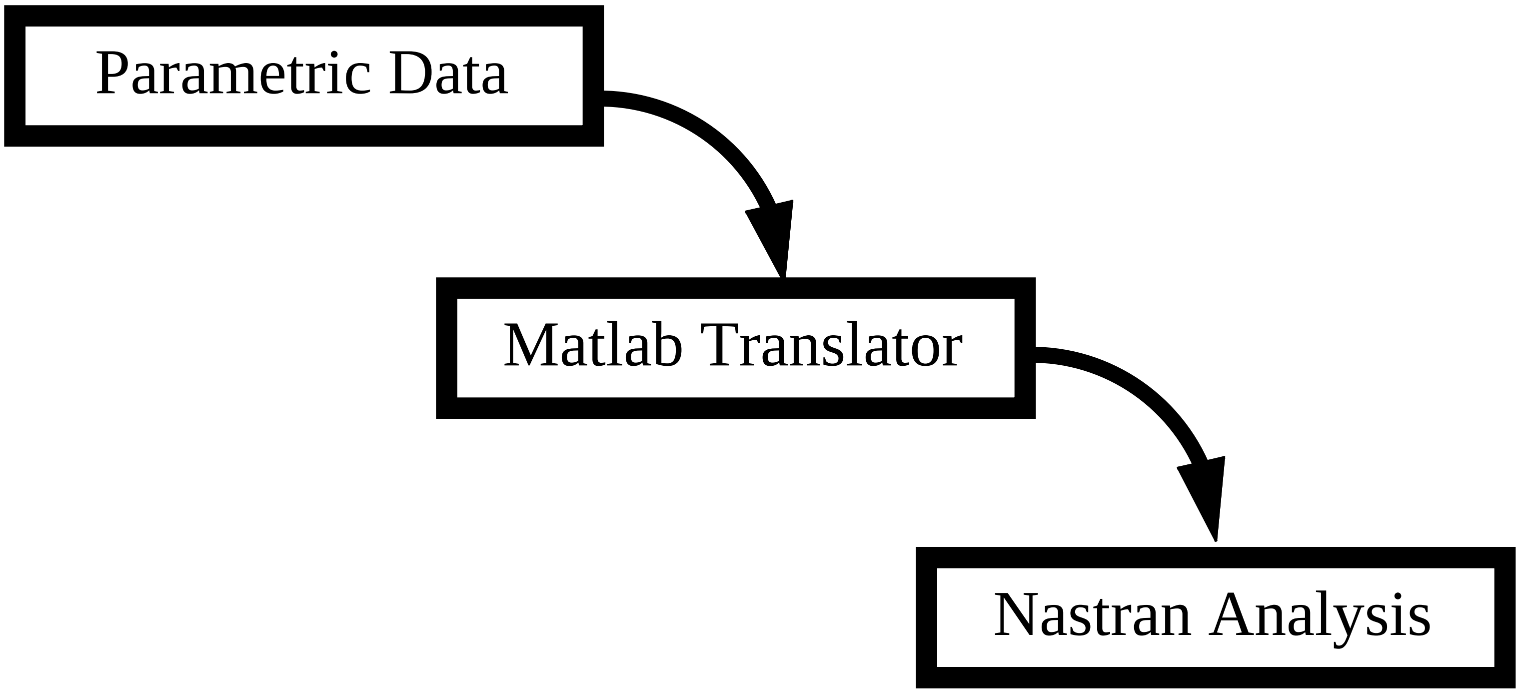


*INCLUDES: HOT WALL THICKNESS, TUBE DIAMETERS, TUBE WALL THICKNESS, I-BEAM WEB THICKNESS, ET.

CFD Analysis

- CFD Calculation
  - Effective Gamma - $\gamma(T)$
  - Spacemarching Calculation
  - Thruster flow - match p, ρ, T, Mach, and γ
  - Inflow at thruster angle
  - grid - ~2300 x 60, ~15 sec. on SPARK WS
- Inputs
  - Thruster Angle, Nozzle Length, Base Height
  - Contour definition (spline node slopes)
- Outputs
  - thrust
  - surface pressure distribution
  - base-flow inputs (exit angle, p_{exit}, M_{exit})

Aerospike Structural Analysis Data Flow



Aerospike Structural Analysis Data Flow

- Parametric Data
  - base pressure from base flow model
  - Contour data and pressure data from CFD code
  - Design variables from optimizer.
- Matlab
  - Reads parametric data and generates a Nastran model.
- Aerospike Structural Model
  - 437 Degrees of freedom
  - 40 Nastran design variables
  - 367 Design responses (stresses, displacement, buckling)

MDO Problem Solution

- **MDO Formulation:**
  - **Multidisciplinary Feasible**
- **Optimizer:**
  - **CONMIN: Constrained Function Minimization**
    - **Algorithm: Method of Feasible Directions**
    - **Gradient Calculation**

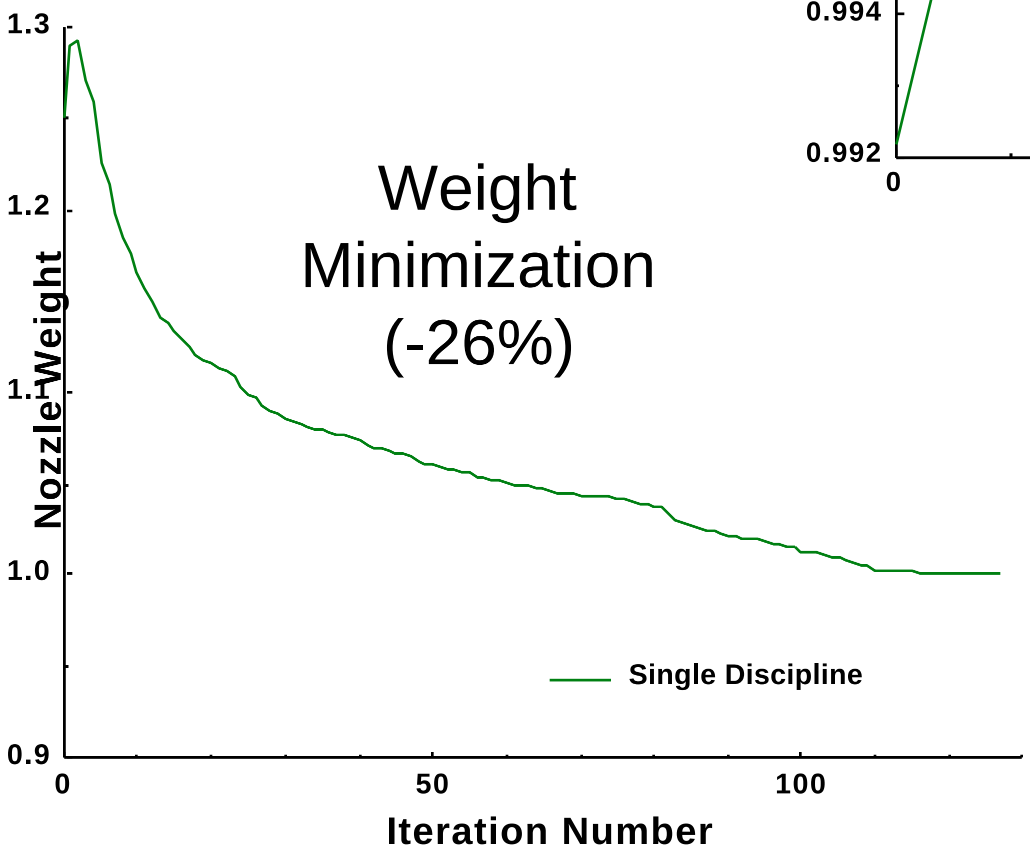
      -**calculated by CONMIN using finite difference approach**

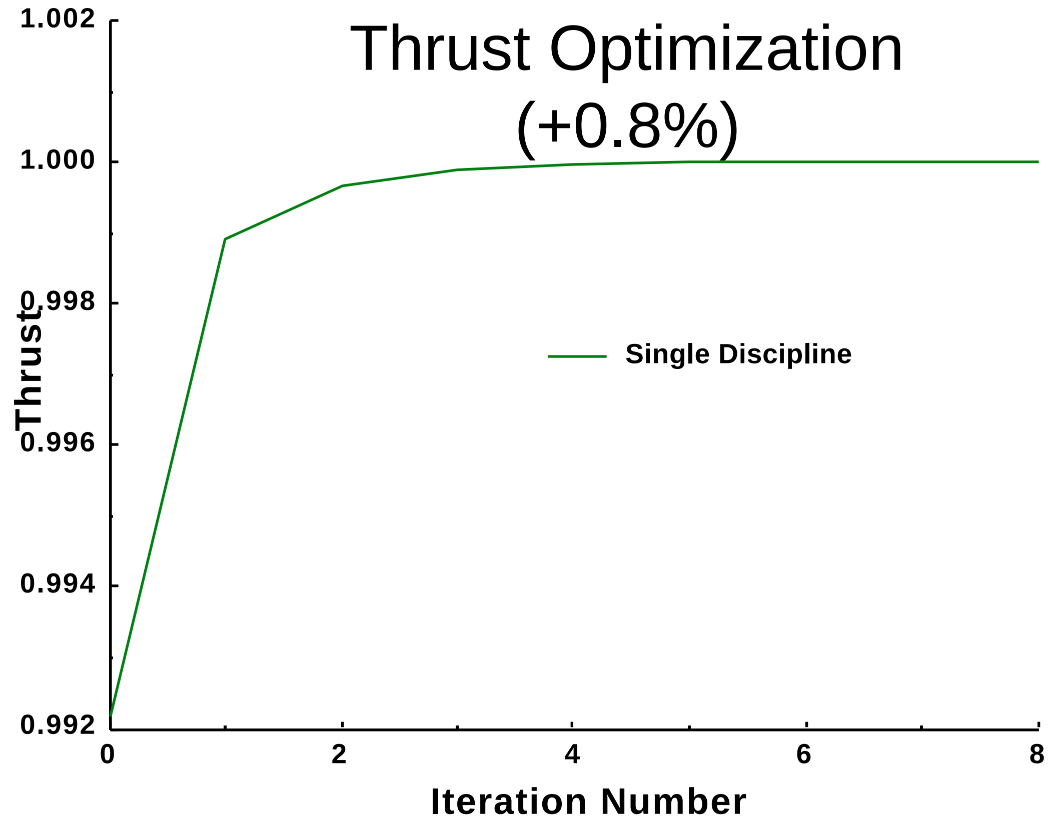
Results

- Sequential Optimization
  - Aero (Maximize Thrust)
  - Structures (Minimize Weight)

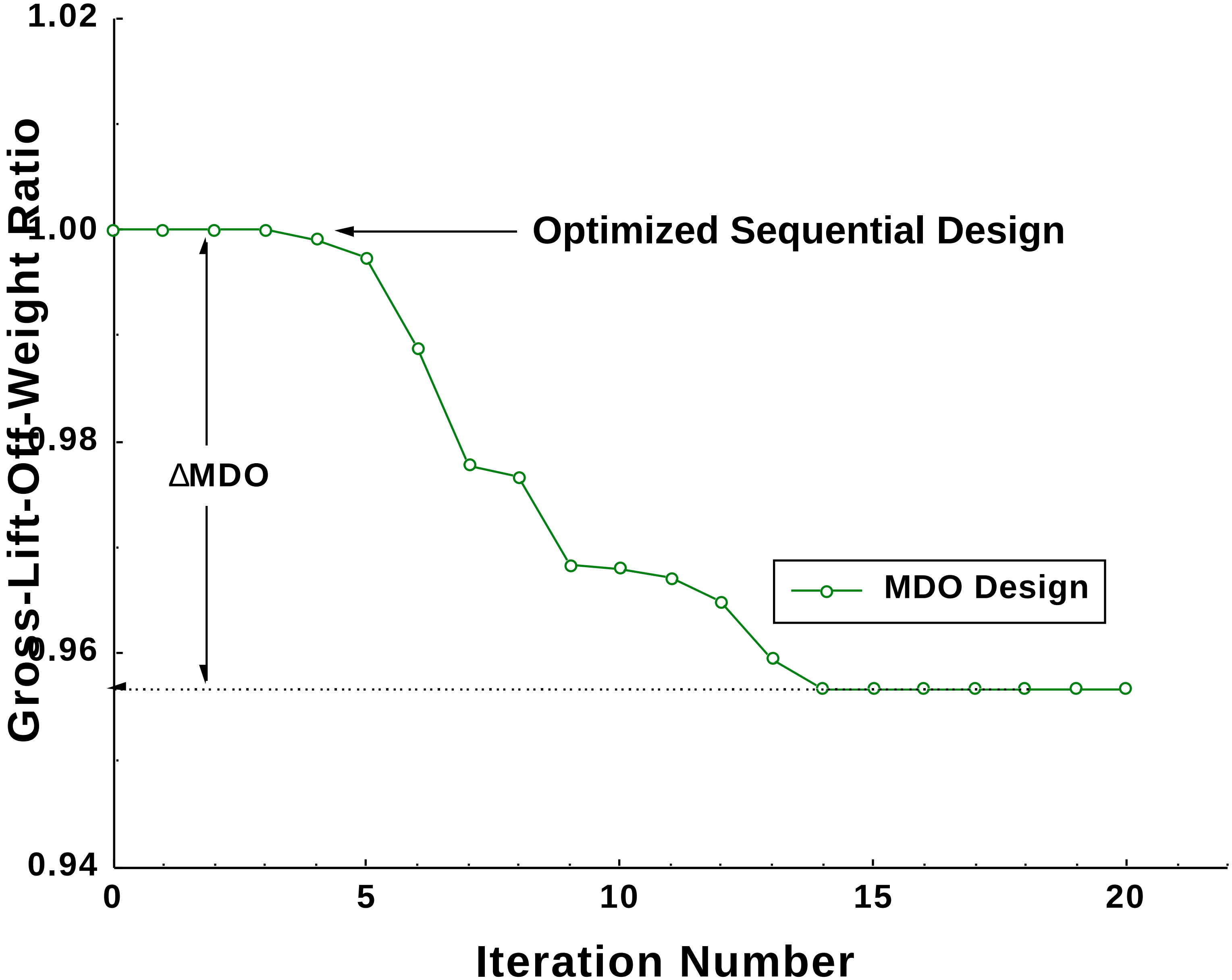
- Multidisciplinary Design Optimization
  - Minimize Gross-Lift-Off-Weight

Sequential Optimization





MDO Results



1.02
1.00
0.98
0.96
0.94
Gross-Lift-Off-Weight Ratio
Optimized Sequential Design
ΔMDO
MDO Design
0
5
10
15
20
Iteration Number

Summary

- Industry/Government cooperative research program
- Developed multidisciplinary model of aerospike nozzle
  - CFD
  - FEM
  - Performance
- Demonstrated designs based
  - Sequential Optimization
    - Design based on maximum thrust and minimum nozzle weight
  - Multidisciplinary Feasible MDO
    - Design based on minimum gross-lift-off weight
- Significant improvement obtained using MDO approach
- Future Plans
  - Demonstration of more efficient MDO Strategies
  - Refinement of MD Model by addition of thermal analysis