Multidisciplinary Optimization Methods for Preliminary Design

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AGARD Interpanel (FDP+PEP) Symposium
"Future Aerospace Technology in the Service of the Alliance"
April 1997, Paris, France.

Outline

- Definitions
- Requirements for using MDO in Preliminary Design
- Preliminary Design MDO Examples
- Summary

MDO Definition

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

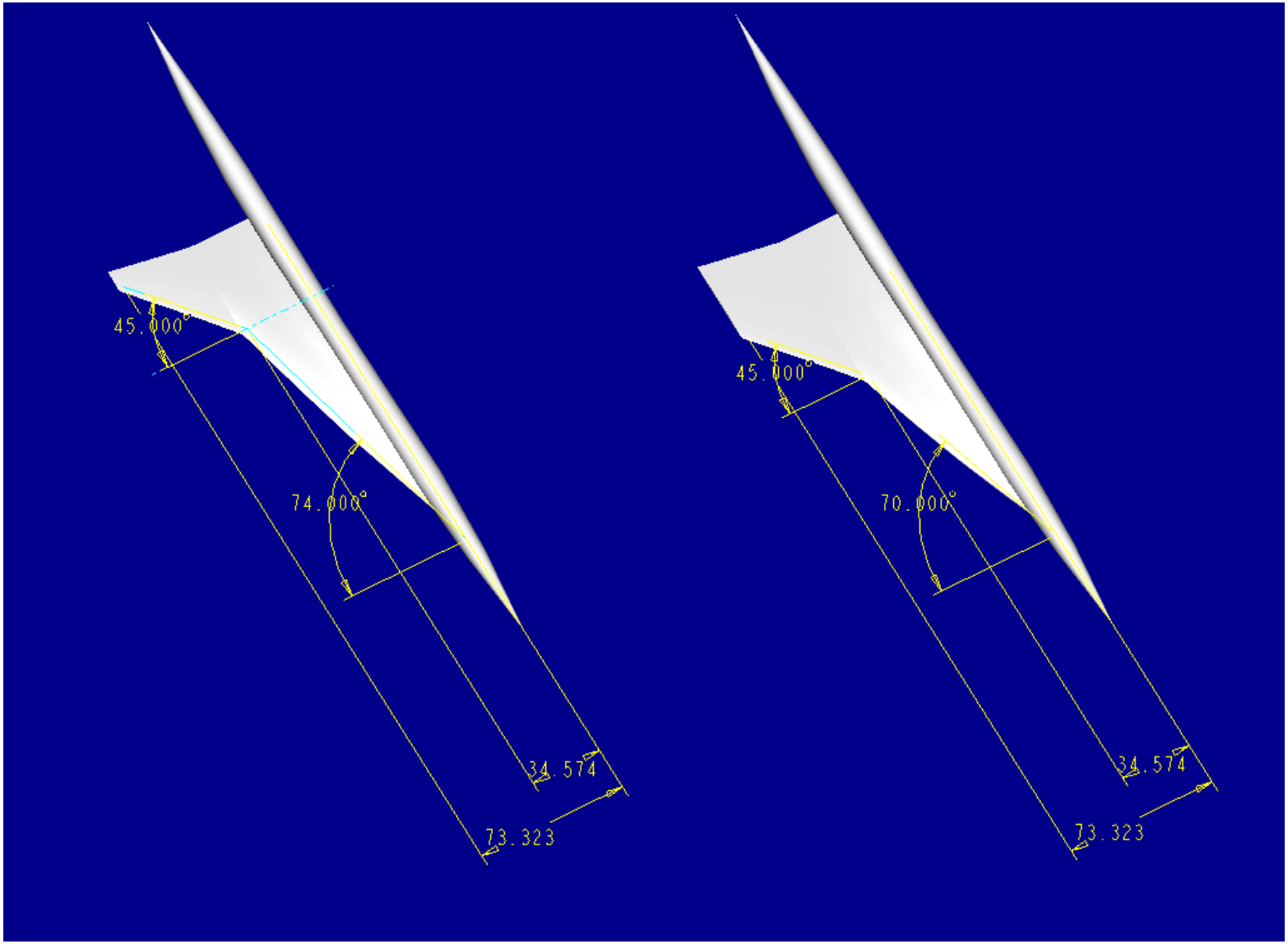
$$\Delta_{\mathbf{Design}} = \left(\sum_{\mathbf{i}} \Delta_{\mathbf{Discipline\ i}}\right) + \Delta_{\mathbf{MDO}}$$

$$\text{“}\Delta_{\mathbf{MDO}}\text{”}$$

MDO Conceptual Elements

Information Science & Technology	Design-Oriented MD Analysis	MD Optimization
Product Data Models	**Mathematical Modeling**	***Discipline Optimization***
Data & S/W Standards	**Cost vs. Accuracy Trade-off**	***Optimization Procedures***
Data Management, Storage & Visualization	**Smart Reanalysis**	**Design Space Search**
S/W Engineering Practices	**Approximations**	***Decomposition***
Human Interface	***Sensitivity Analysis***	

Product Data Model Example
(CAD Parametric Geometry Model)

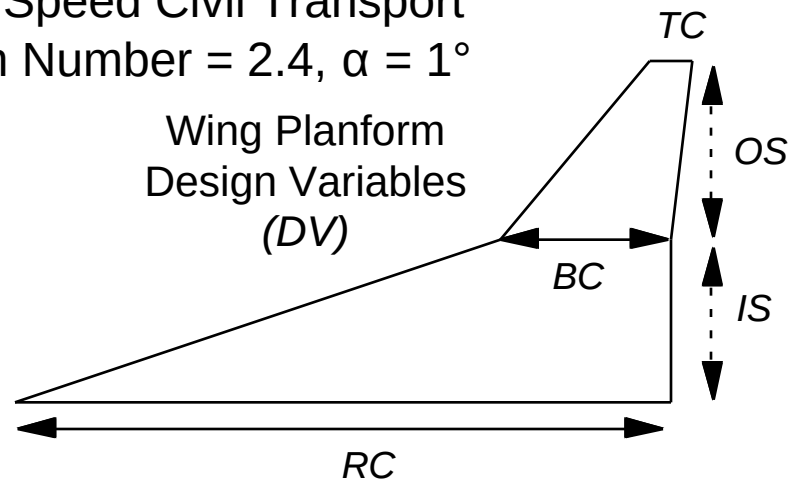


Sensitivity Analysis

- Computing derivatives of objective with respect to the design variables
- Methods
  - Finite differences
    - time consuming
    - difficult to pick Δ
  - Analytic
    - hard to code
    - changes with each application
    - fast
  - Automatic differentation
    - easy to use
    - accurate
    - can be time consuming

Automatic Differentiation of 3-Dimensional Navier-Stokes Flow Code (CFL3D)

High Speed Civil Transport
Mach Number = 2.4, α = 1°



Aerodynamic Coefficients	
C_L	Lift
C_D	Drag
C_Y	Side Force
CM_Y	Pitching Moment

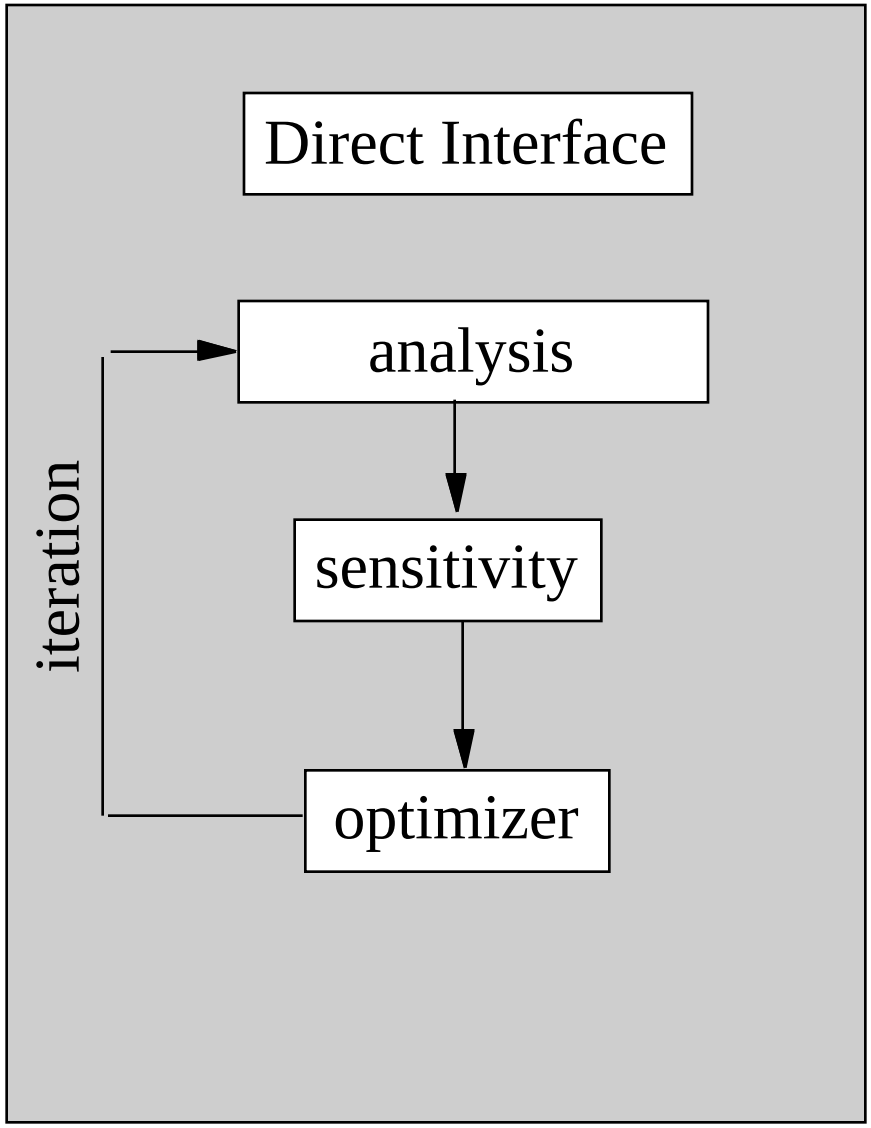
Sensitivity Derivatives - Derivatives of Aerodynamic Coefficients
With Respect to Wing Planform Variables

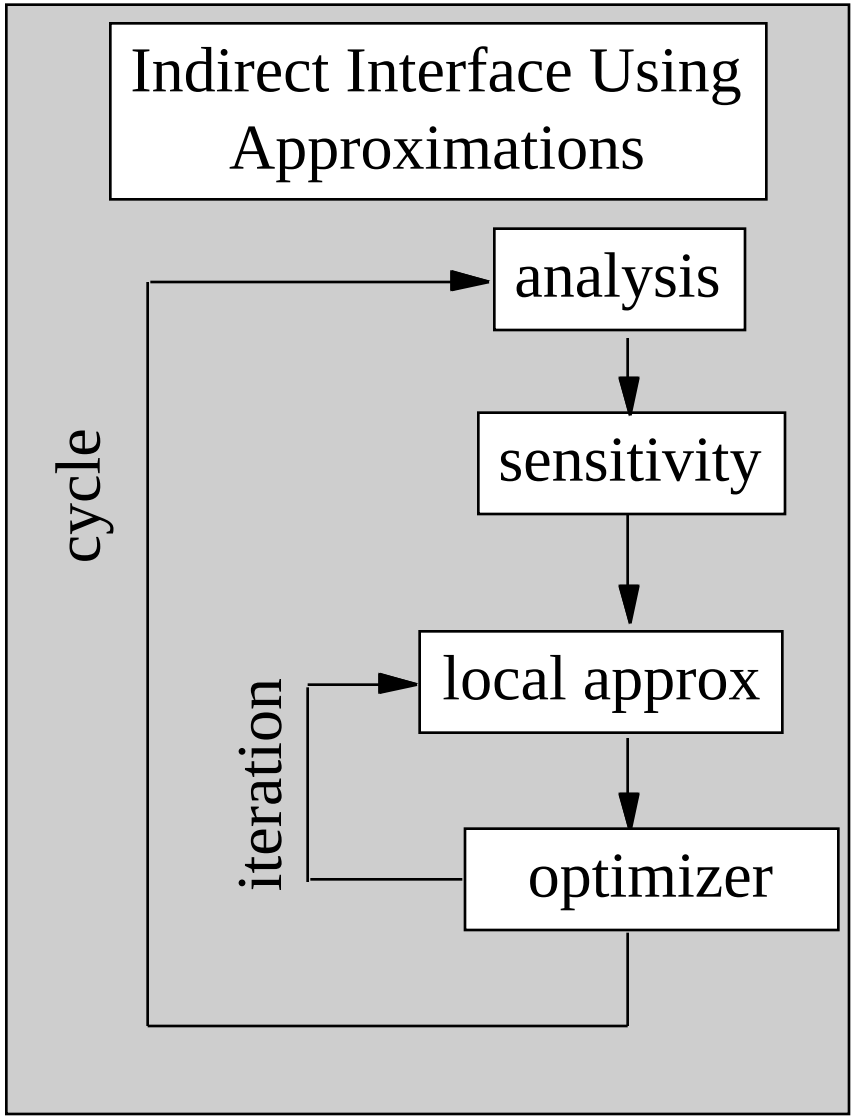
$$\frac{\partial CL}{\partial DV} \quad \frac{\partial CD}{\partial DV} \quad \frac{\partial Cy}{\partial DV} \quad \frac{\partial CMy}{\partial DV}$$

Time to Compute Sensitivity Derivatives (for 4 digits of Accuracy)

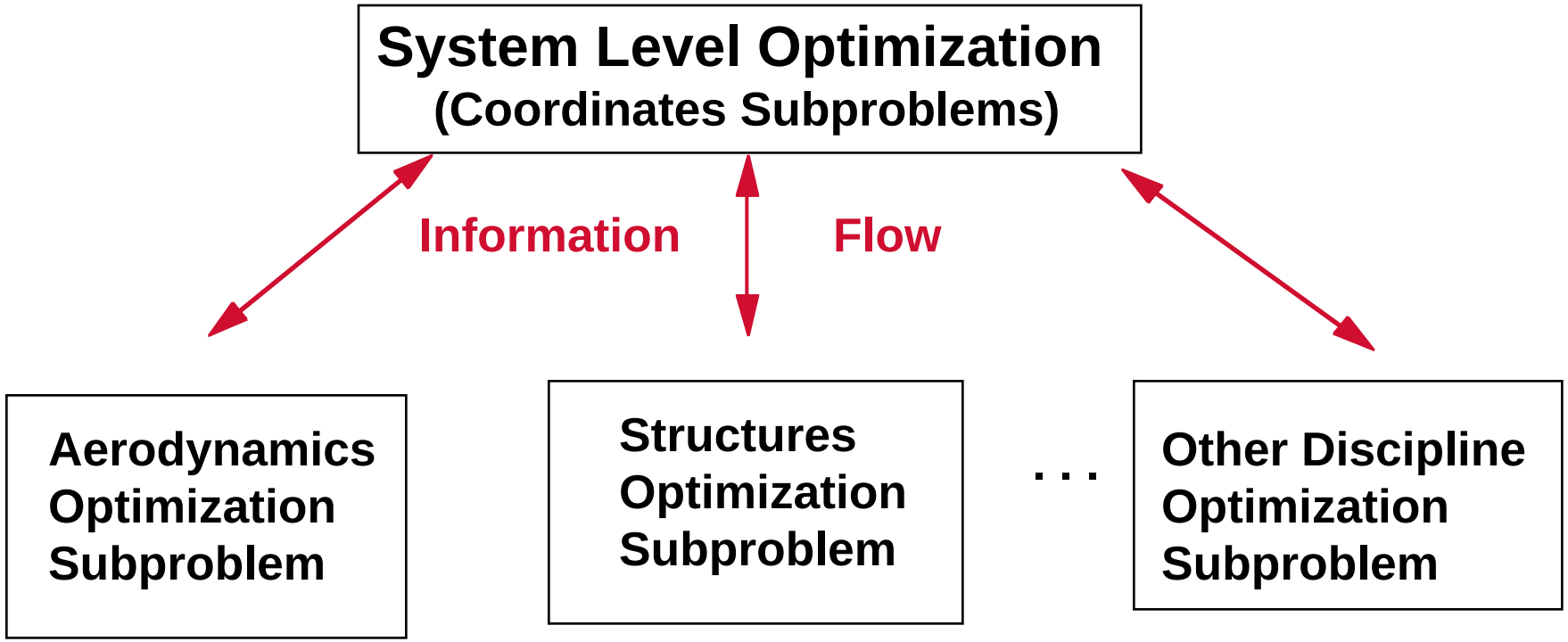
Automatic Differentiation (Residual reduced 4 orders) = 10.75 units
Finite Difference Method (Residual reduced 11 orders) = 15.00 units

Optimization Procedures





Decomposition



Preliminary Design

- Conventional Process
  - CAD-based geometry
    - surface
    - internal layout
  - Higher-order analysis
    - CFD
    - Finite Element
  - Discipline analysis & optimization
    - sequential or loosely coupled
    - discipline-based figure of merits (i.e., weight, thrust, drag, lift, etc.)
- Emerging MD Enhancements
  - Parametric CAD definition
  - Fully coupled multidiscipline analysis
  - Multidisciplinary optimization
    - Figures of merit
      - system performance and cost
      - multi-objective

Requirements for MDO Enhancements of Preliminary Design

- Information Science & Technology
  - heavy duty hardware; fast CPU(s), large memory & disk space
  - common parametric geometry model
  - software support
    - integration of proprietary, legacy, commercial, and research codes
      - code robustness, compatibility, & low algorithm noise
    - configuration control and data management
    - collaborative work environment; person-person/machine
- Design-Oriented MD Analysis
  - well posed interfaces for disciplines
    - automated grid generation (CFD, FEM)
  - discipline & MD sensitivities
- MD Optimization
  - MDO problem definition
    - design variables, objective(s), constraints
  - MDO strategy

Preliminary MDO Examples

- Aerospike Rocket Nozzle
  - Direct Optimization Approach
- High-Speed Civil Transport (HSCT)
  - Approximation Optimization Approach

MDO Applied to Aerospike Nozzle Design

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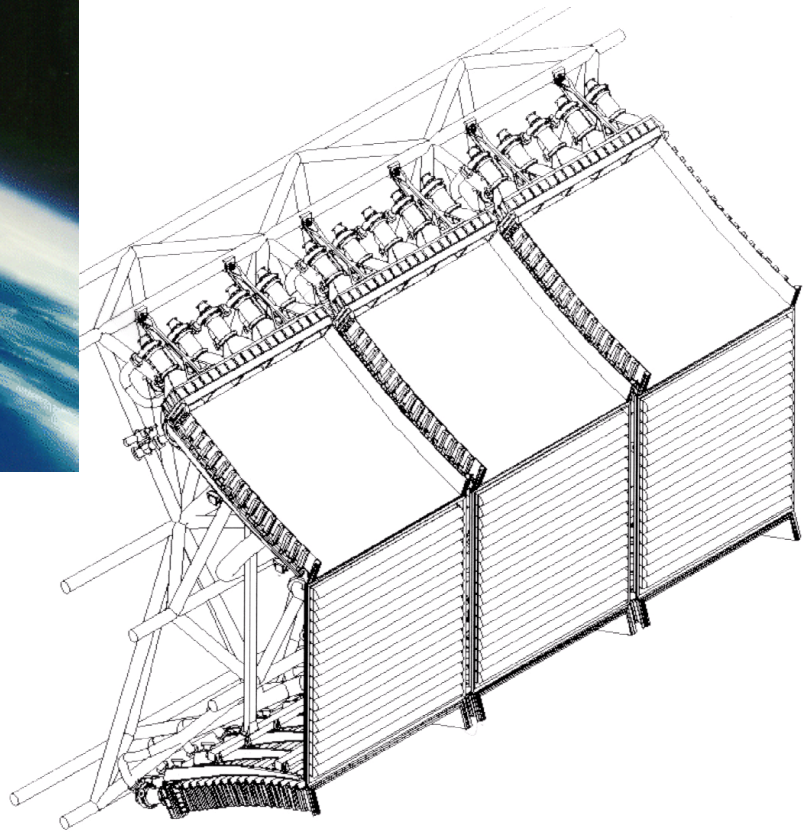


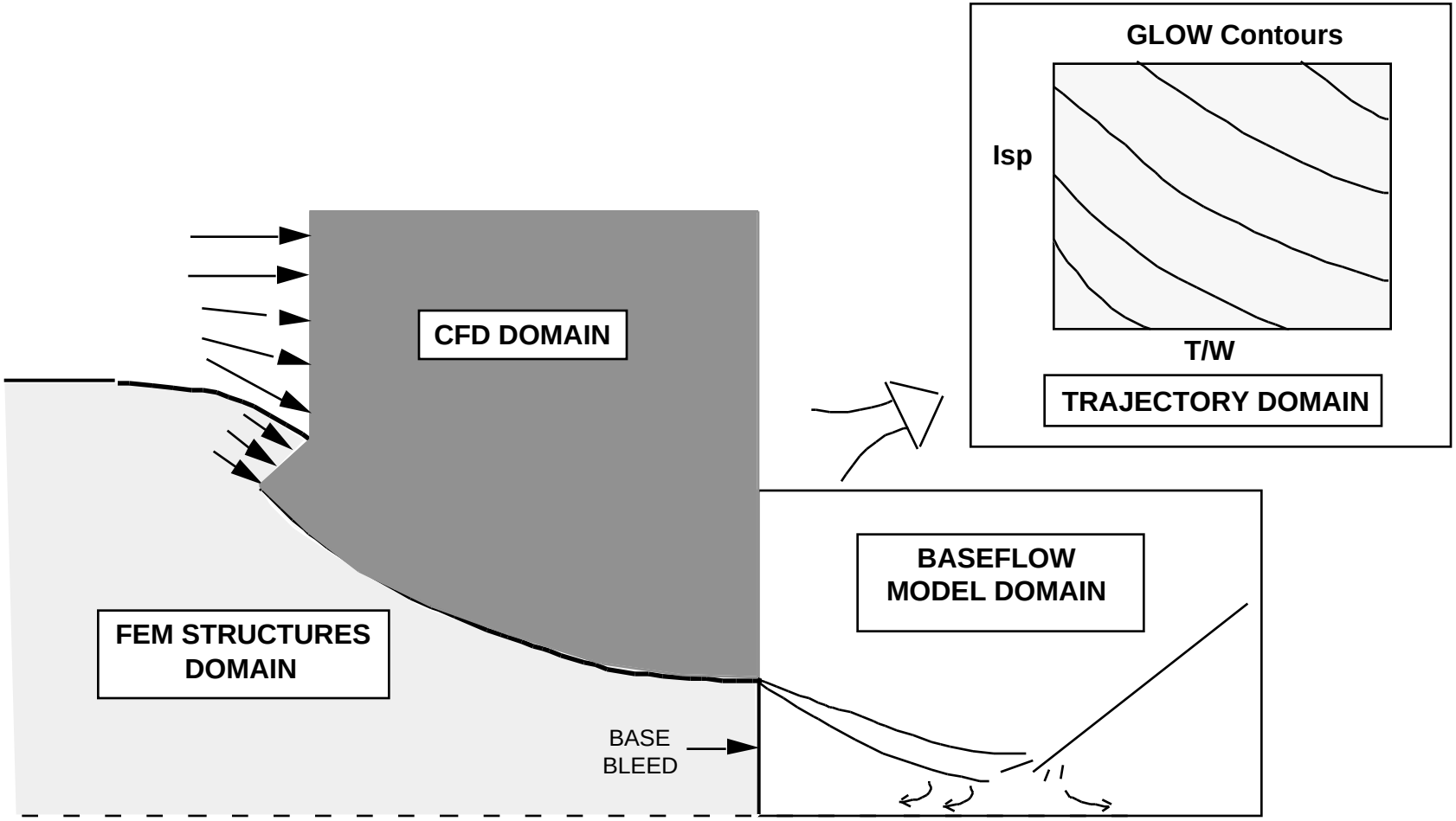
Aerospike Engine

Aerospike MDO Problem

- Objective
  - minimize Vehicle Gross-Lift-Off Weight

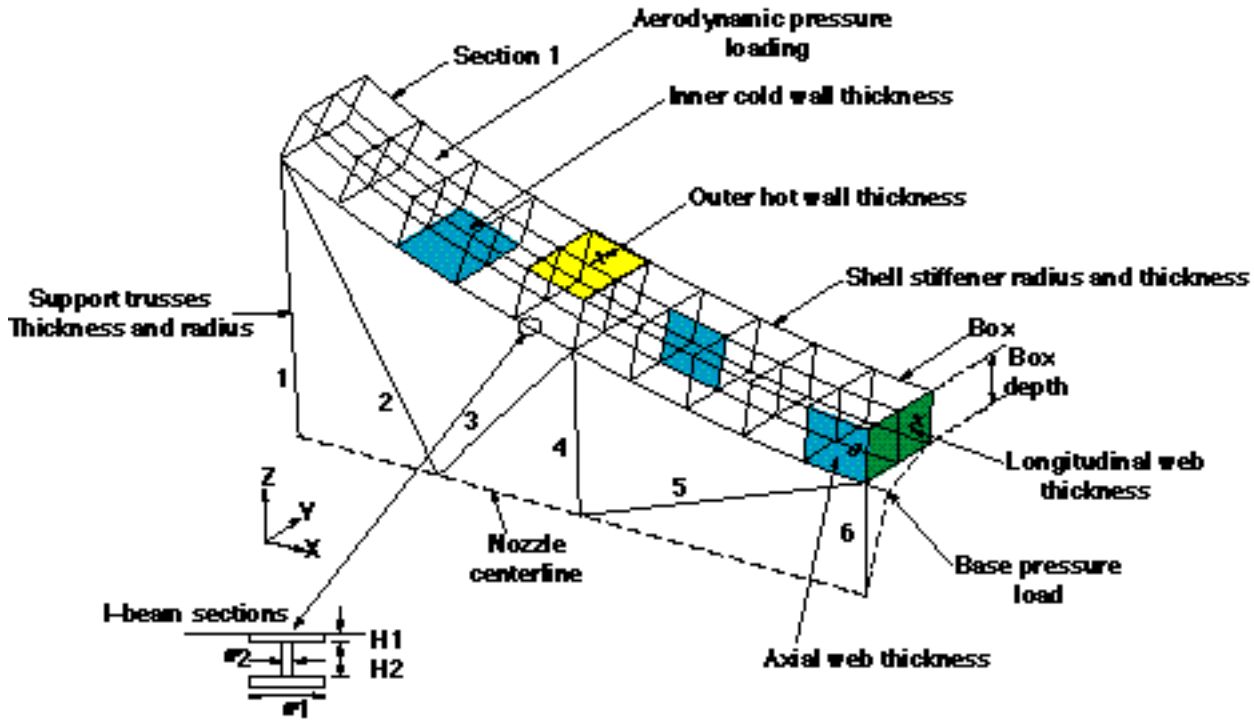
- Design Parameters
  - 5 geometry variables
  - 13 structural variables
- Constraints
  - Stresses < allowable

Aerospike MDO Domain Decomposition



Nozzle Geometry Design Variables

Aerospike Nozzle Structural Design Parameters



Aerospike Nozzle Optimization

Sequential Optimization
(Single Discipline Only)

Aerodynamics
Maximize Thrust

↓

Structural
Minimize Weight

↓

Base-line Solution

Multidisciplinary Optimization

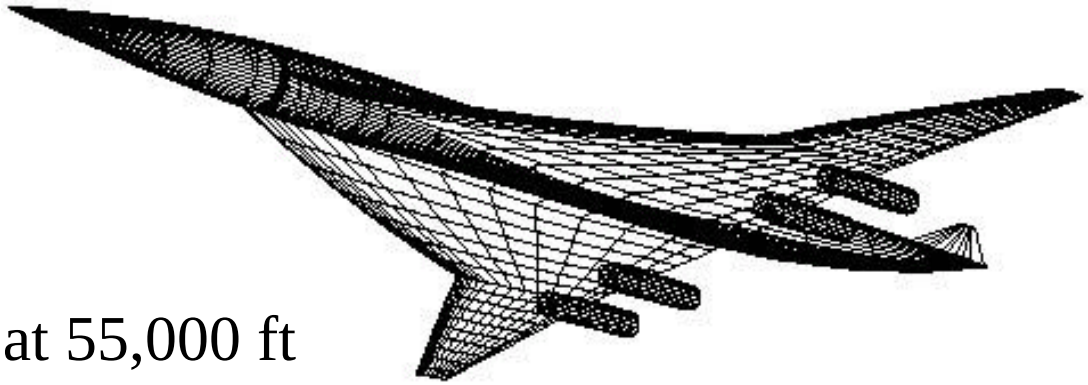
Integrated
Aerodynamics and Structures

↓

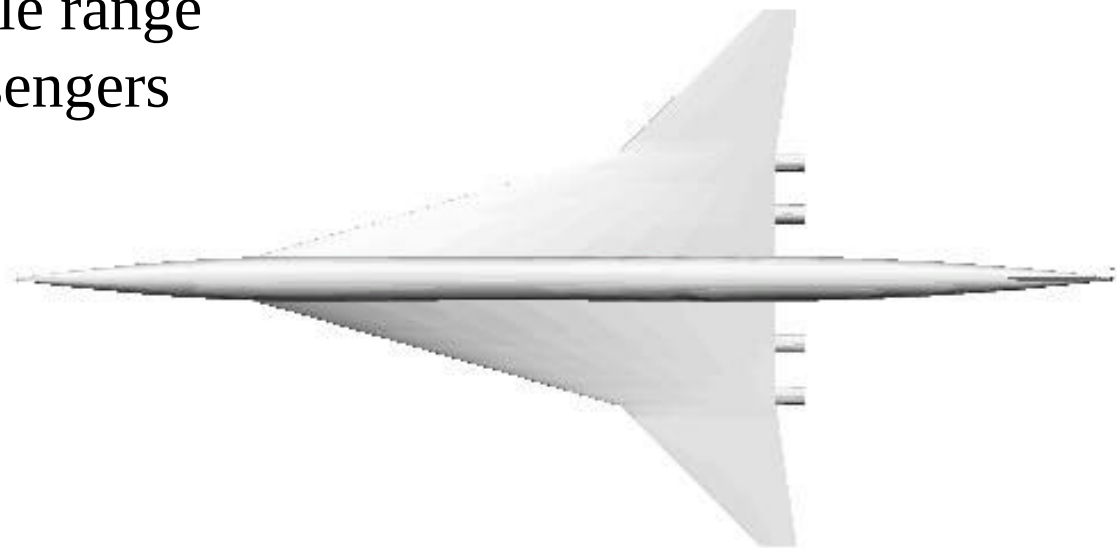
Minimize Gross-Lift-Off Weight

Aerospike Objective Function

MDO Applied to High-Speed Civil Transport (HSCT) Using FIDO

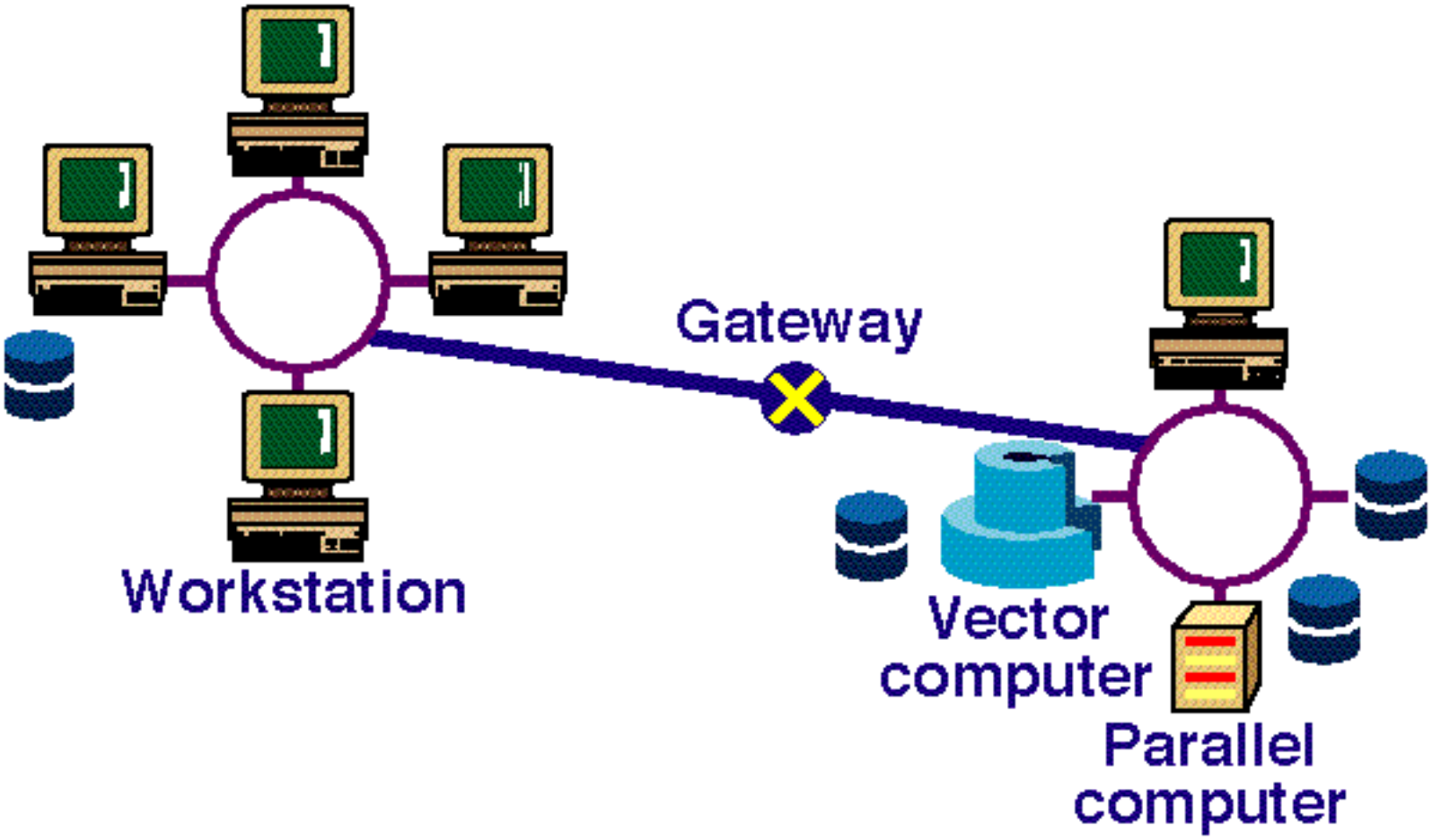


Mach 2.4 at 55,000 ft
6000-mile range
250 passengers

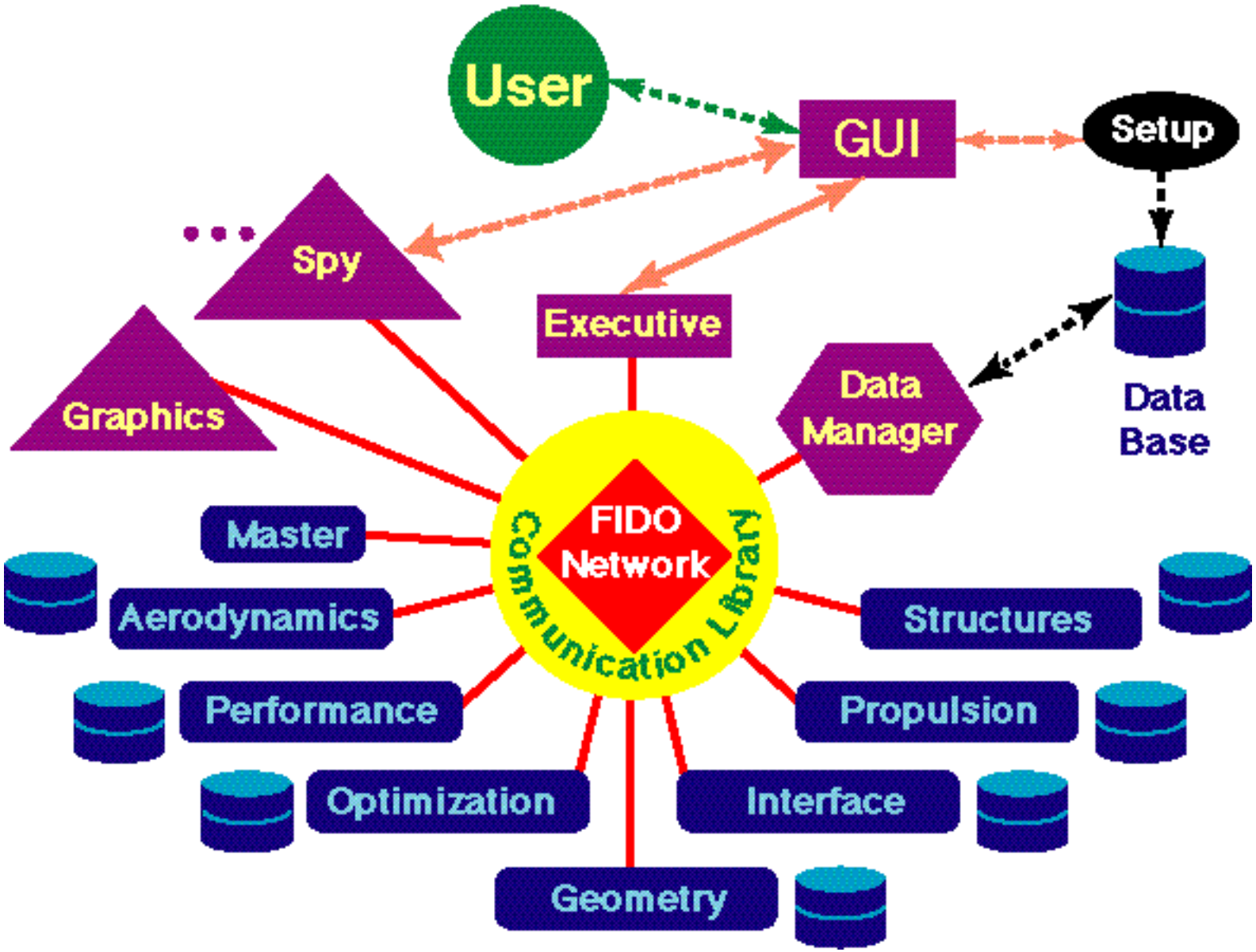


Environment

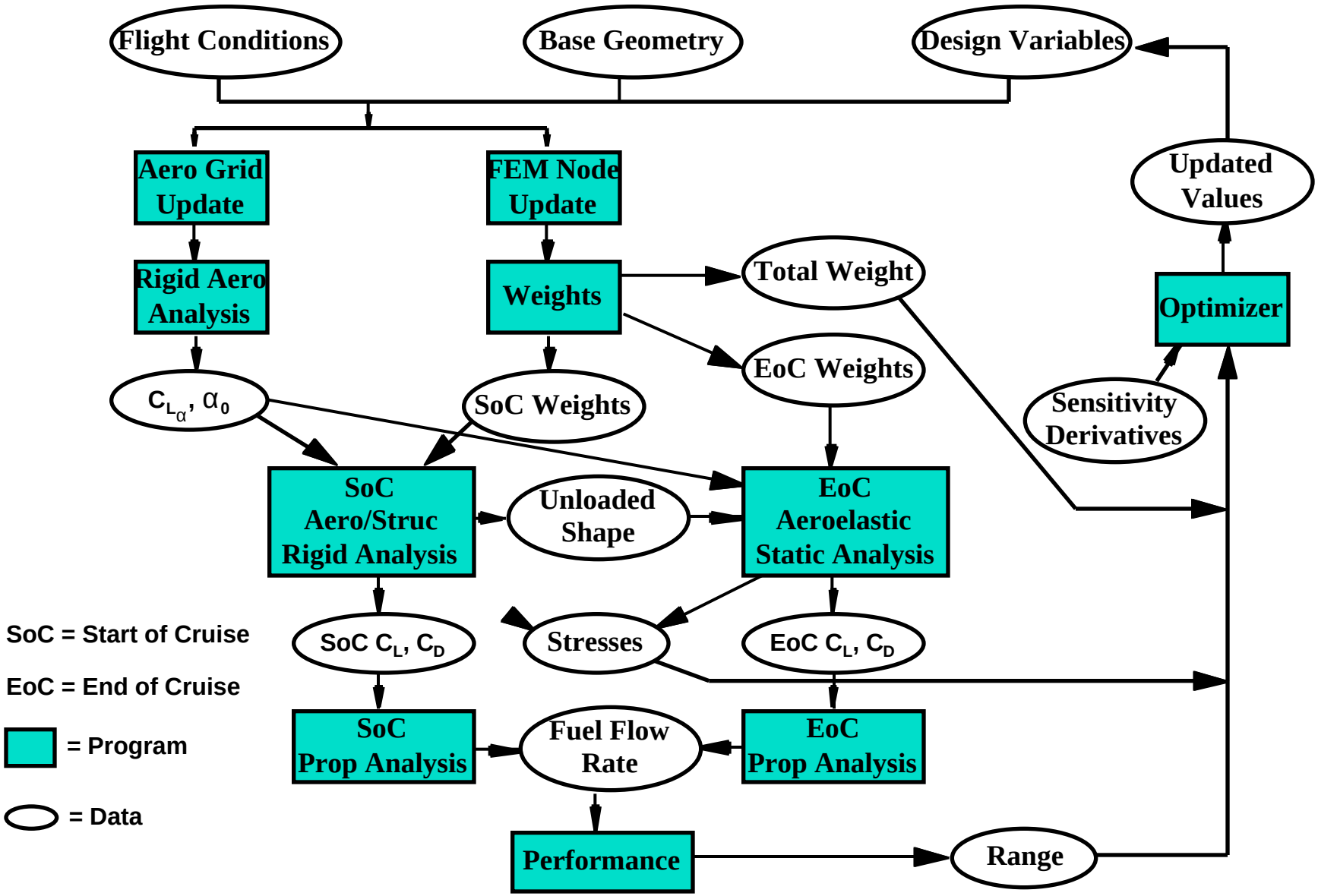
Heterogeneous Distributed Computing



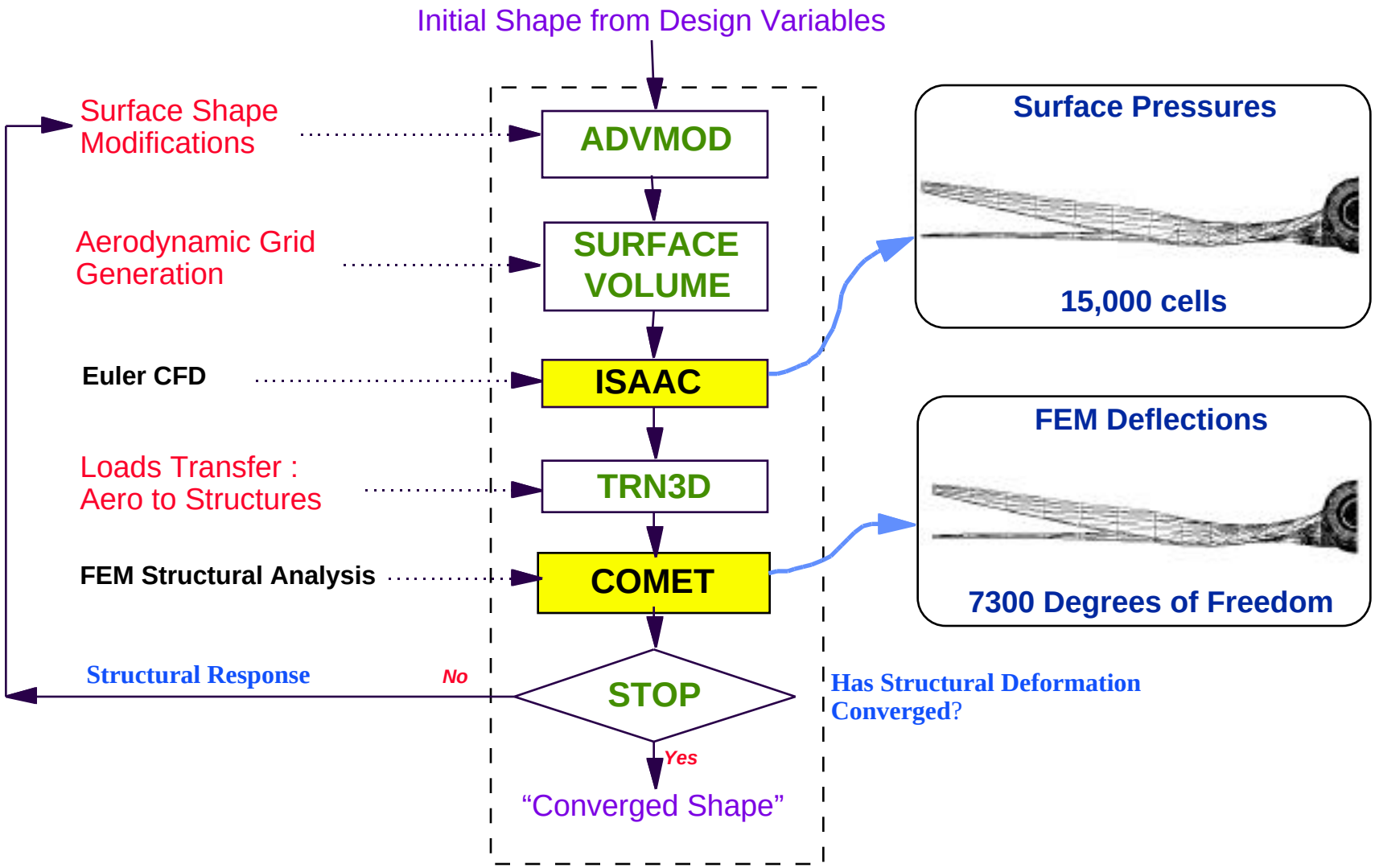
FIDO Execution System



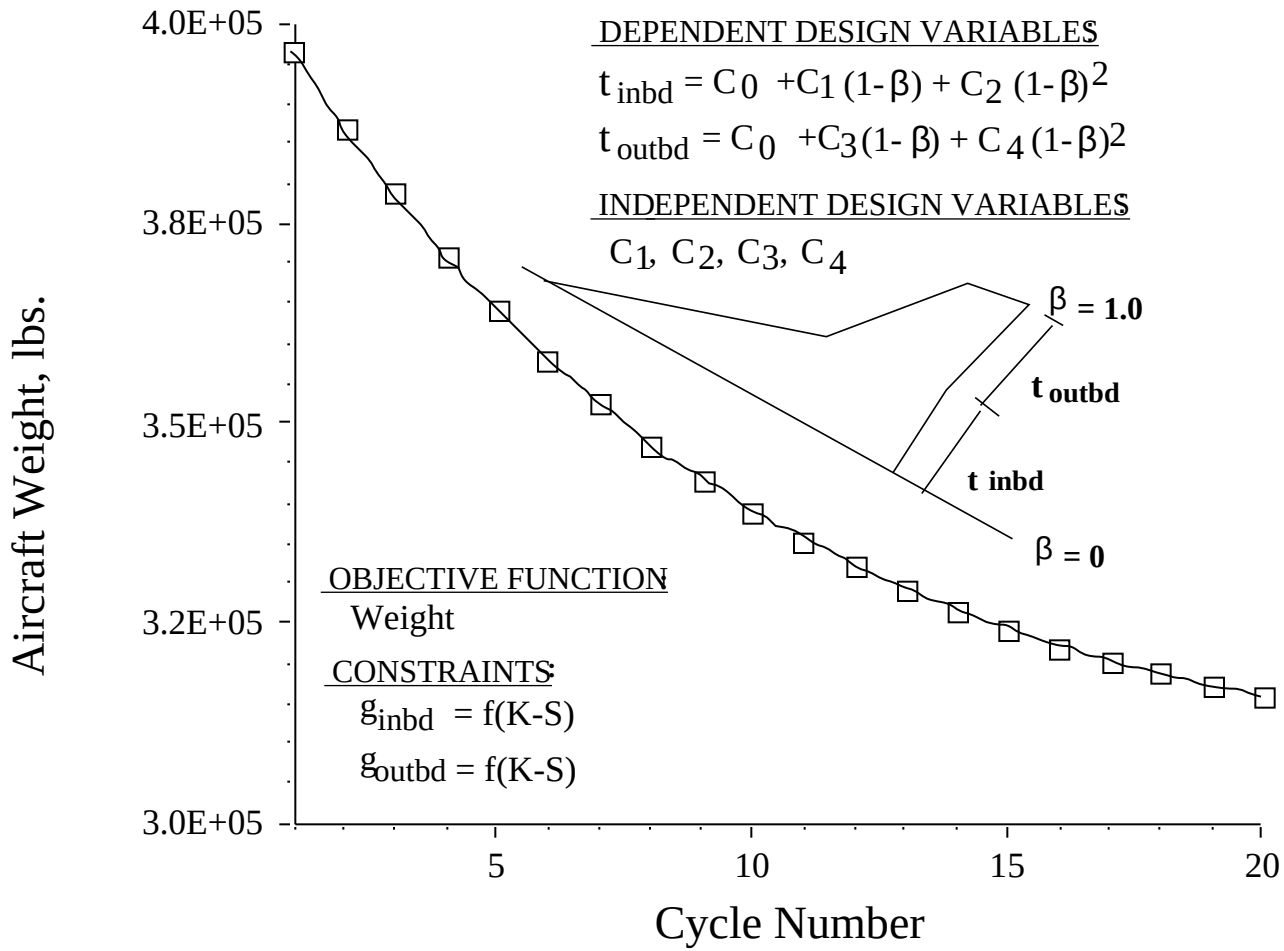
HSCT MDO Problem Diagram



Key Steps in FIDO Aeroelastic Loop



HSCT Design Optimization



Concluding Remarks

- MDO is much broader than just MD-Analysis; it contains elements from information sciences, design-oriented analysis and optimization methods
- The "$\Delta_{\mathbf{MDO}}$" is the improvement in design obtained from multidisciplinary synergy of the disciplines as demonstrated by the Aerospike nozzle application
- Application of MDO to preliminary design requires sophistication in the computational infrastructure and MDO algorithms
- Adoption of MDO in industry design process requires demonstrations which quantify
  - "$\Delta_{\mathbf{MDO}}$" improvement in design
  - reduction in time and effort in the design process