The Role of Geometry in the Multidisciplinary Design of Aerospace Vehicles

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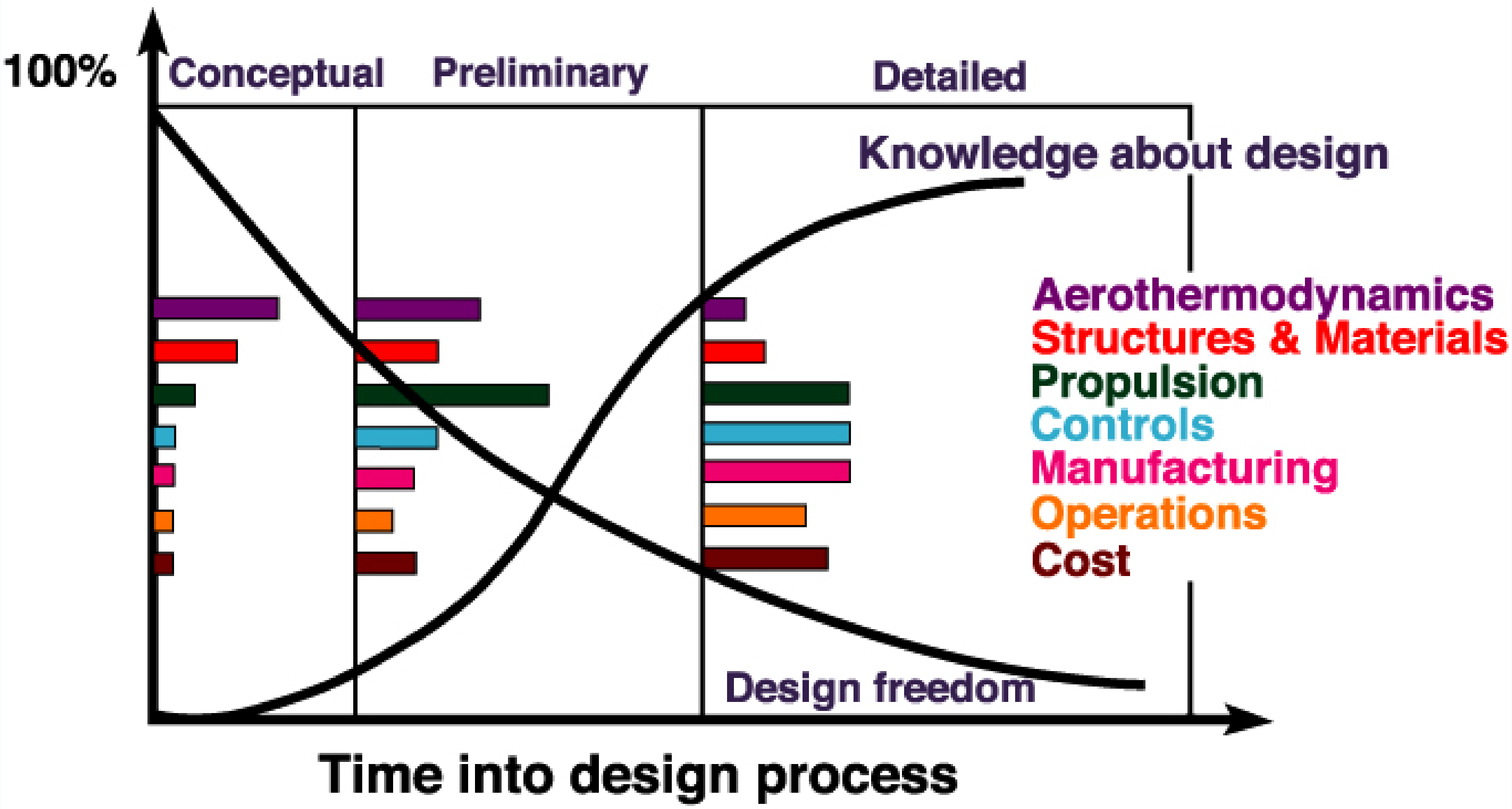
http://fmad-www.larc.nasa.gov/mdob/
(after January 31, 2002)

Outline

- Geometry Model Illustrations for 3 Design Phases
  - Conceptual Design
  - Preliminary Design
  - Detailed Design
- Observations
- Geometry Modeling for Multidisciplinary Design Optimization in a Preliminary Design Research Project
- More Observations

Traditional Aerospace Design Practice

Uneven Distribution of Knowledge & Efforts

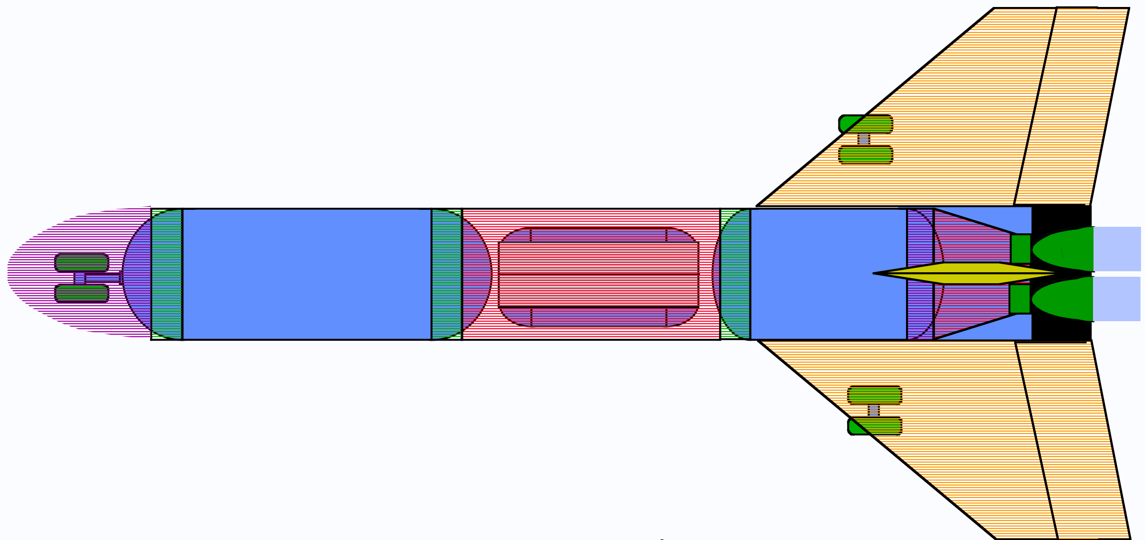


Design Phases

- **Conceptual Design**
  - Conceptual vehicle design defines the large-scale features of the vehicle. The major components and subsystems are named, and rough estimates are given for their size and shape.
- **Preliminary Design**
  - Preliminary design defines the intermediate-scale features of the vehicle. This includes the actual size, shape, and location of the aerodynamic lifting and control surfaces, the size and shape of the payload area, consistent with design constraints, conceptual design details of the propulsion system, and intermediate level details of the structural subassemblies.
- **Detailed Design**
  - Detailed design defines all information necessary to manufacture the vehicle. Based on preliminary design information, the final design determines all fastening and joining details and produces mechanical drawings for all parts and subassemblies.

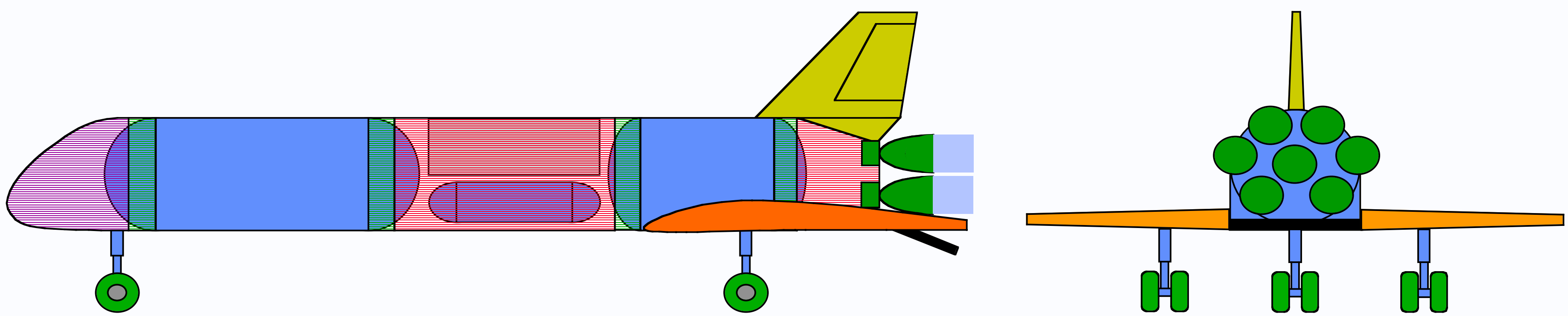
Conceptual Design Example

Generic Reusable Launch Vehicle



- Vertical Take-off
- Horizontal Landing
- Winged Body
- Circular Fuselage
- Internal Payload Bay
- Single Vertical Tail
- RS-2200 Engines

non-watertight



20 parameters (conic sections & NACA airfoils)

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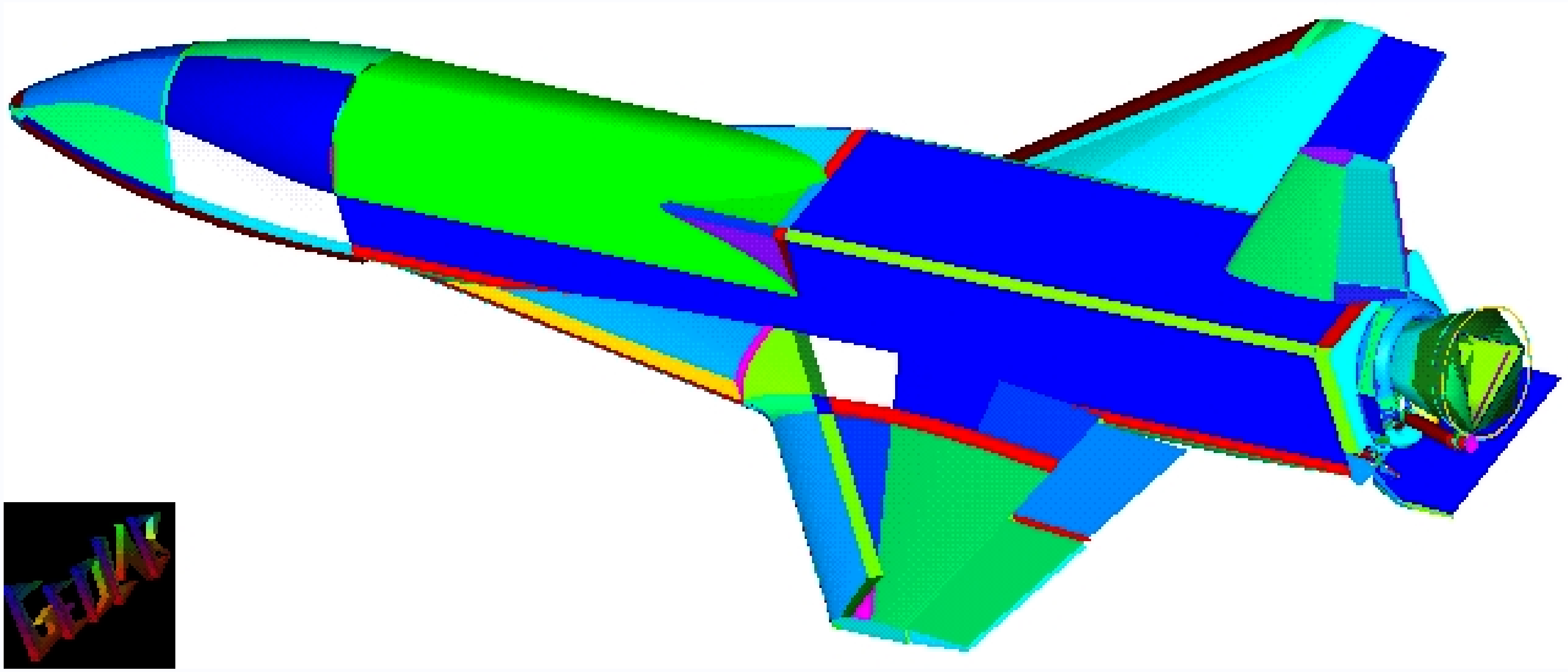
Preliminary Design Geometry

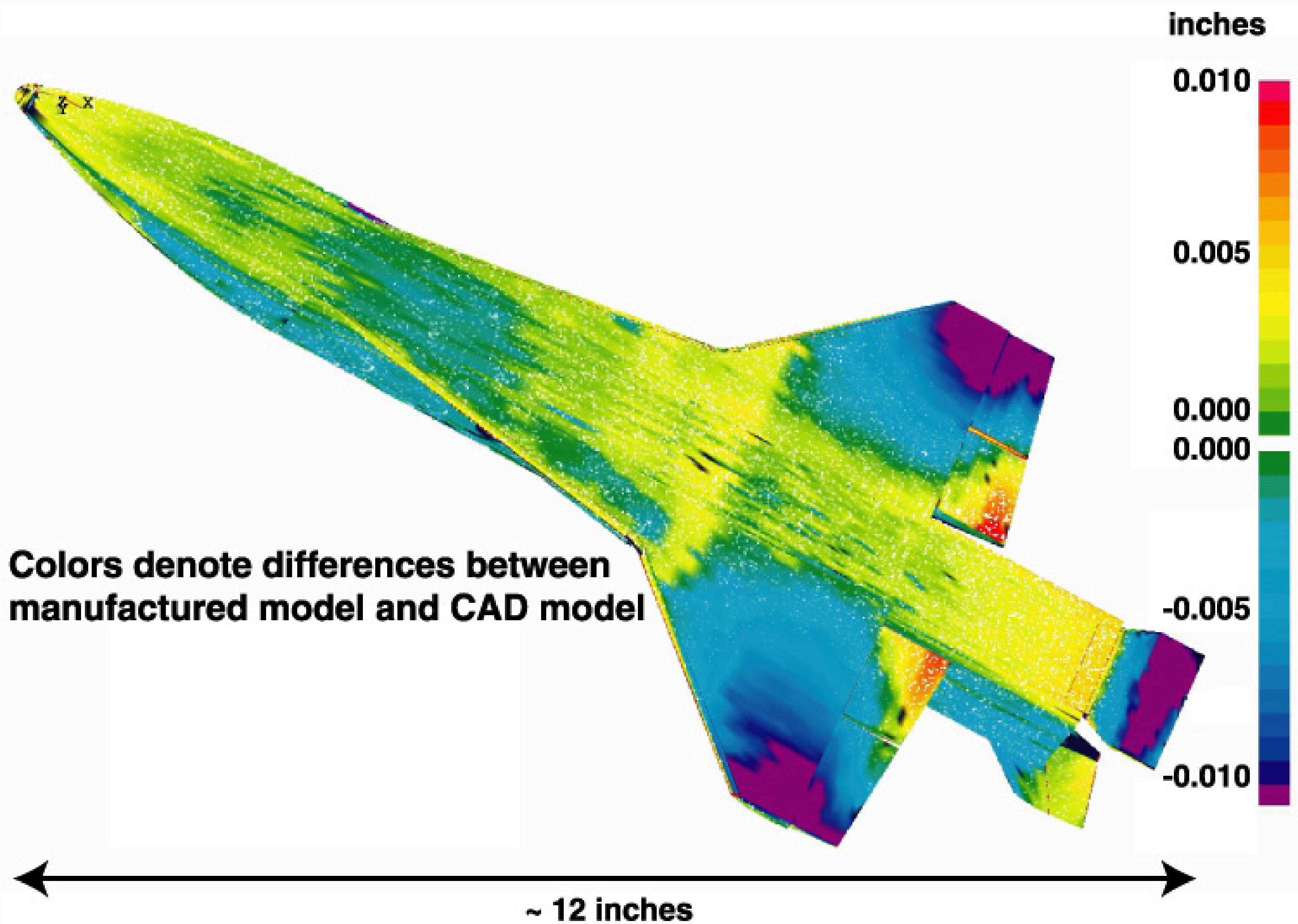
X34 CAD Model



23,555 curves and surfaces

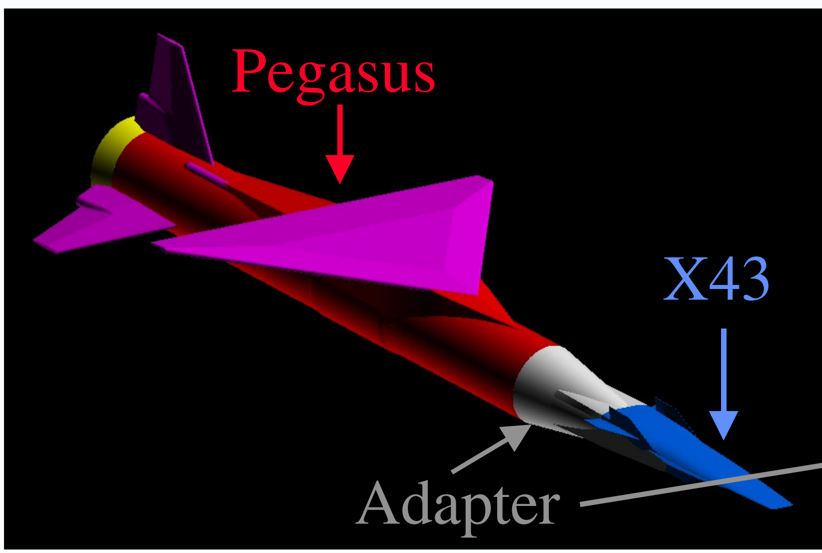
Manufactured Models ≠ CAD Models

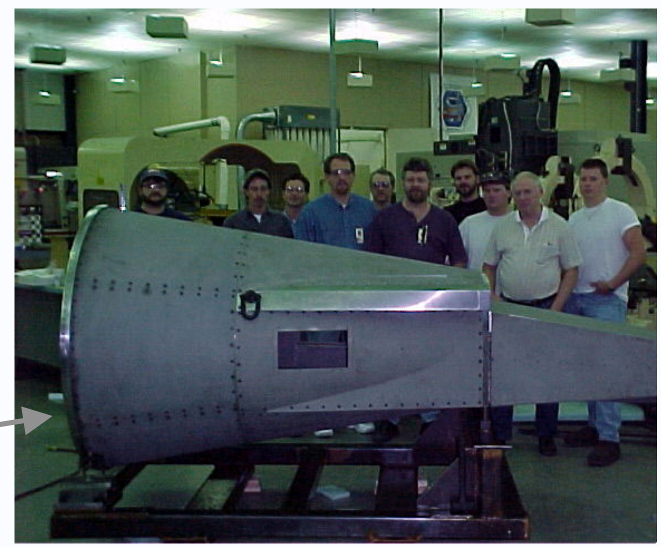
Stereolithographic Measurements of X34 Wind Tunnel Model



Detailed Design

Pegasus - X43 Stack



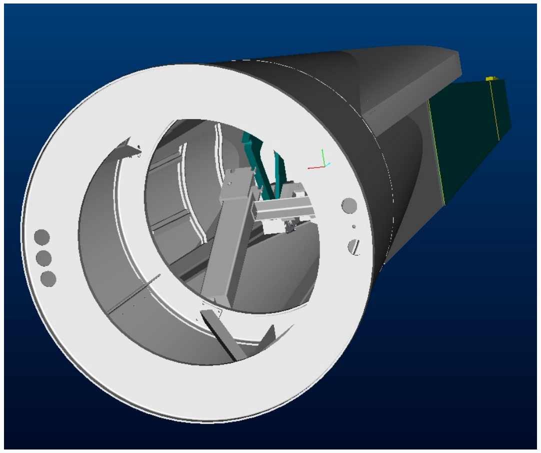


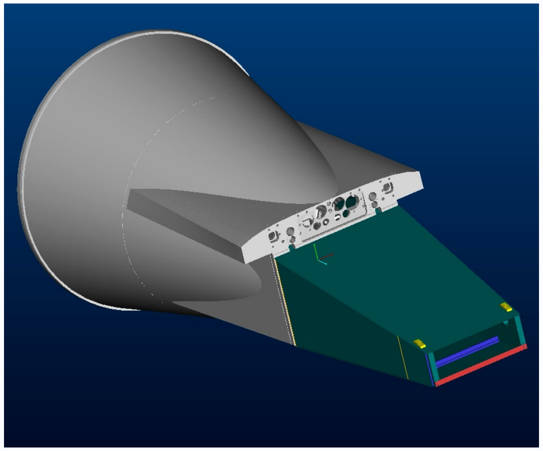
Detailed Design Geometry

X43 Adapter

Structures

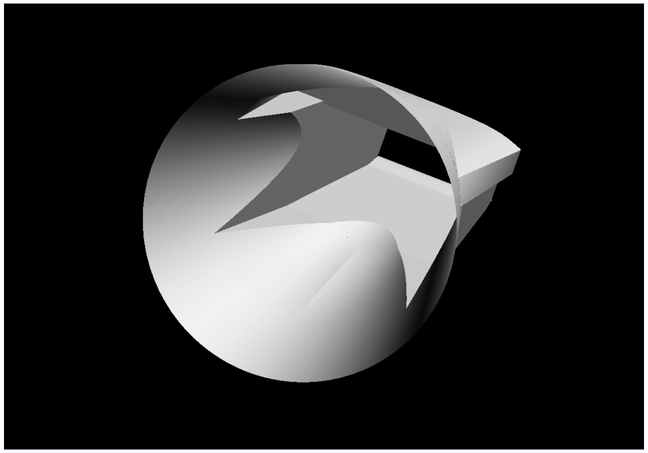
112 parts/subassemblies & 815 surfaces

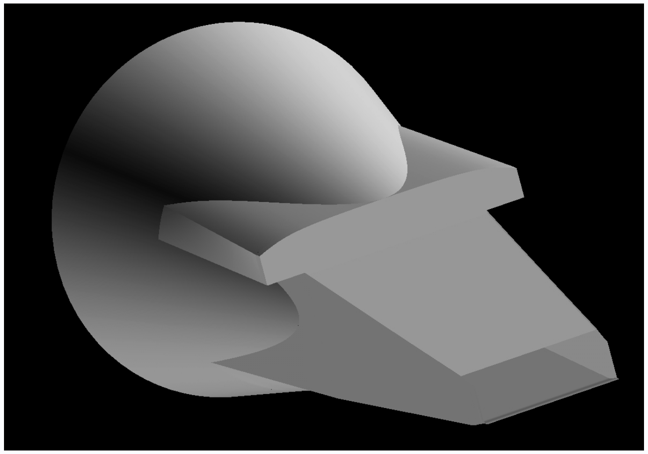




Aerodynamics

78 surfaces for outer mold line

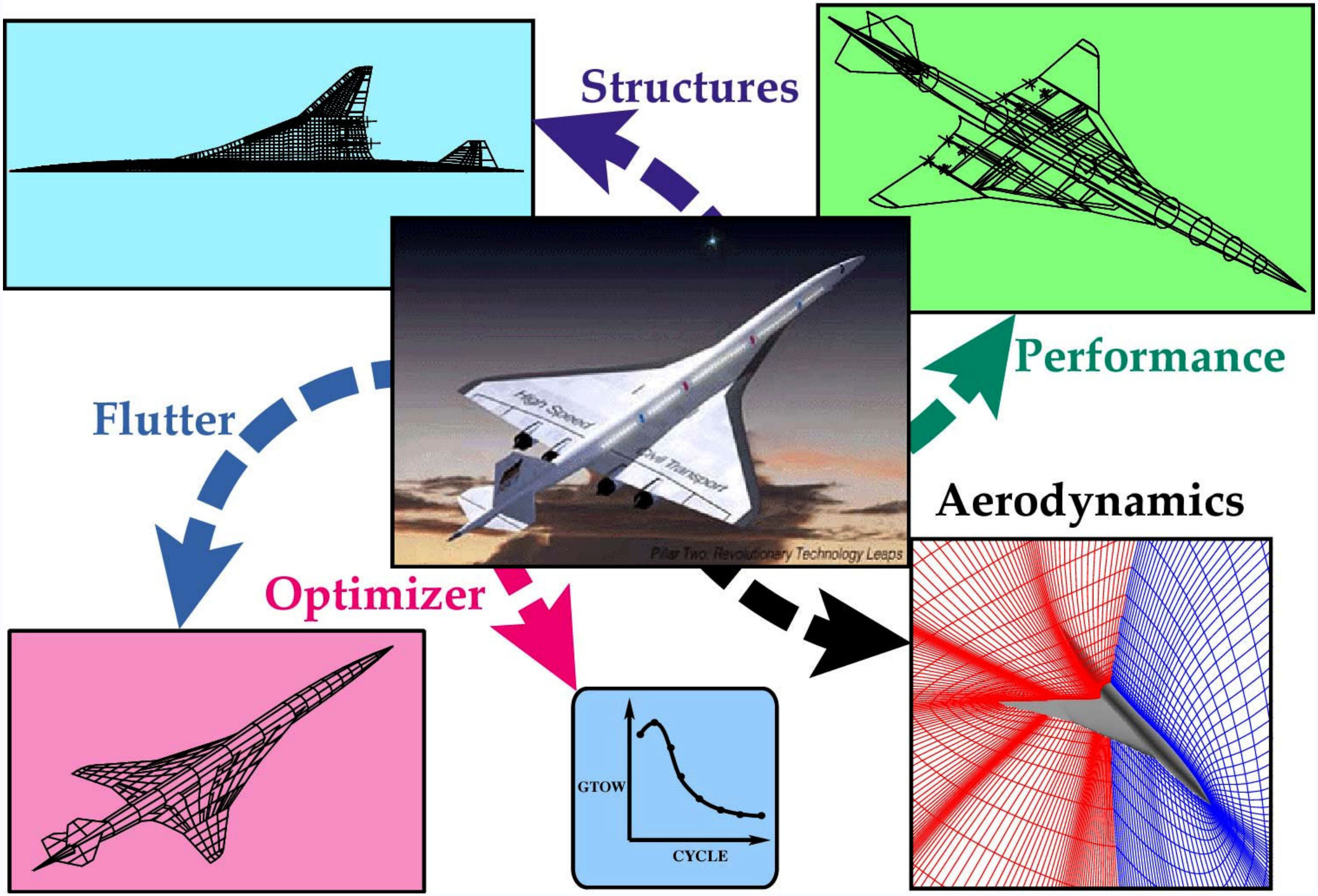




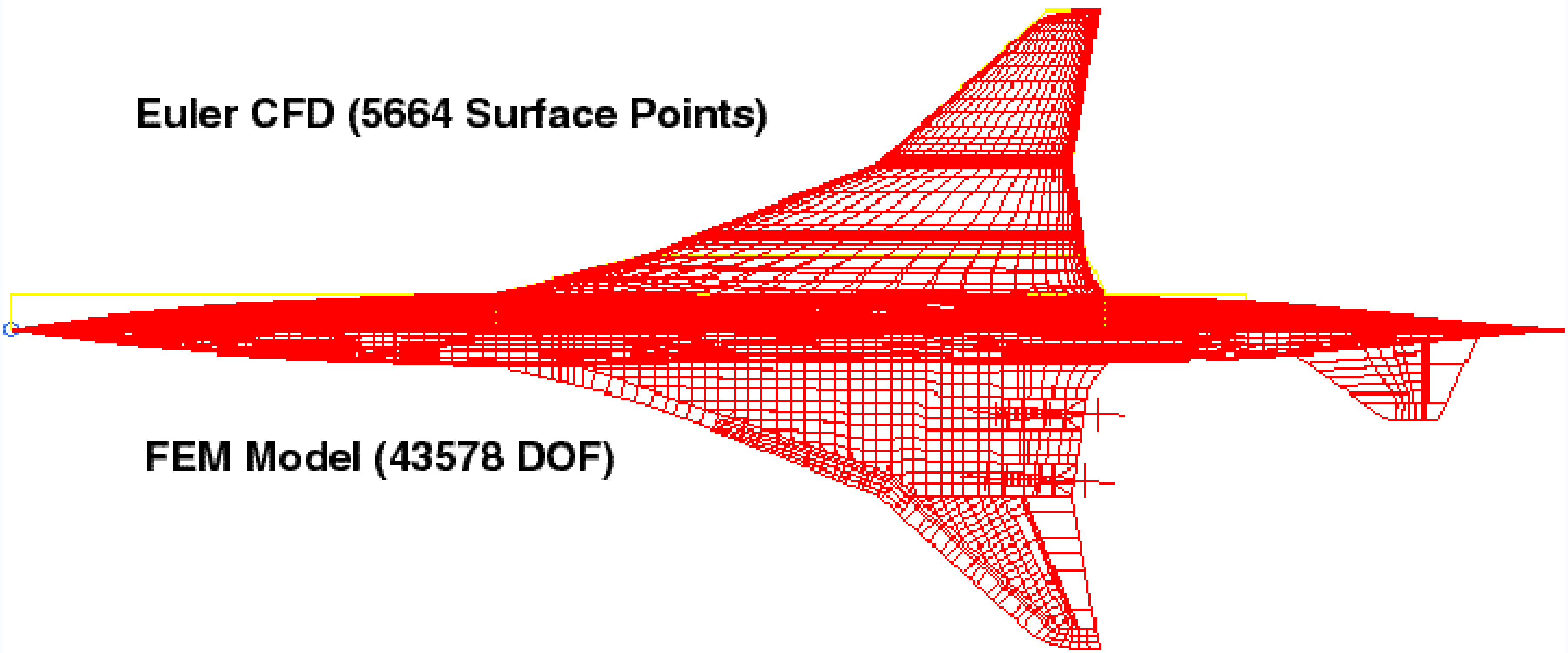
Observations

- An aerospace vehicle contains millions of parts
- As the design process progresses, increasing fidelity is required of the analysis and therefore of the geometry model
- CAD models contain hundreds of surfaces which are not necessarily suitable directly for aerodynamic analysis —days or weeks of massaging are needed
- The geometry of the actual vehicle differs from the idealized geometry model in significant respects — this inherent variability leads to uncertainty in how well the analysis results predict the actual vehicle

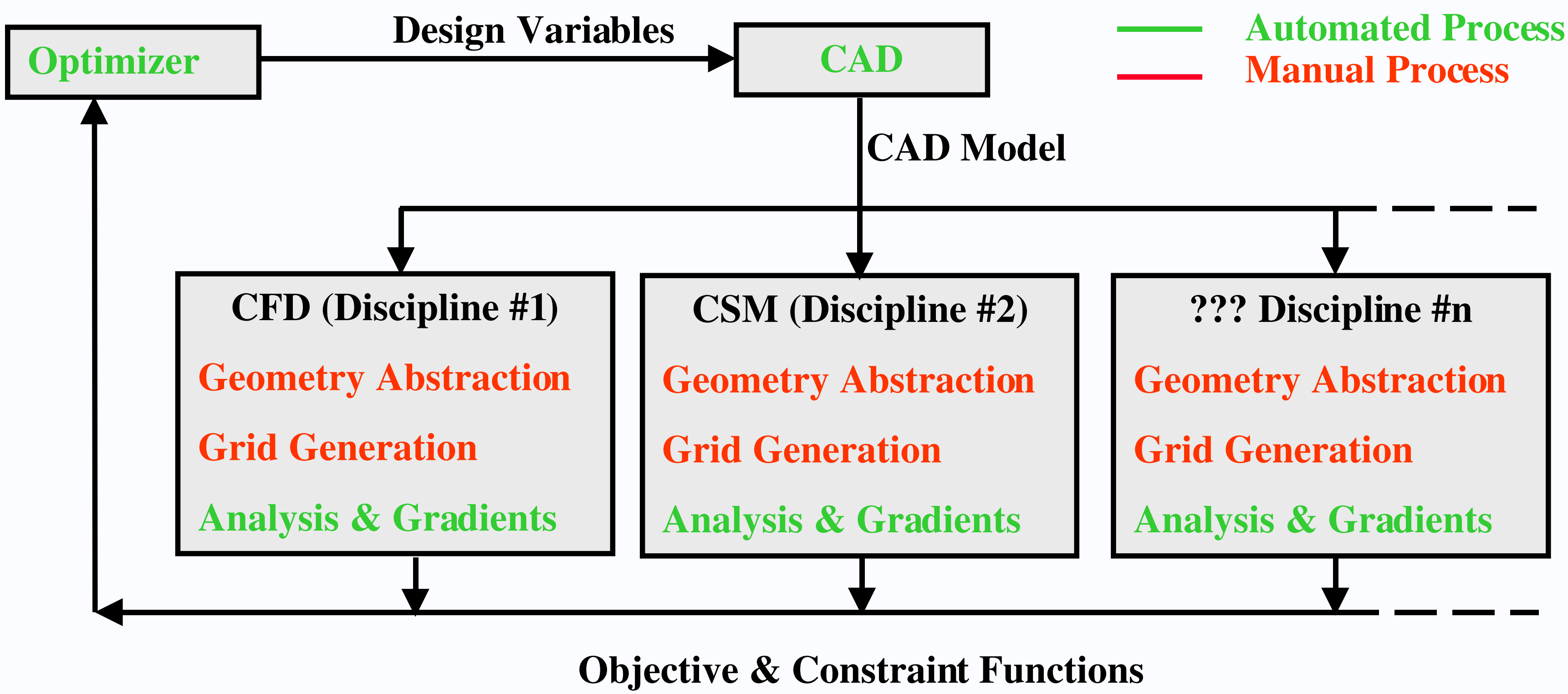
Geometry Models for a High Speed Civil Transport



Parameterized HSCT Model
(27 DVs)



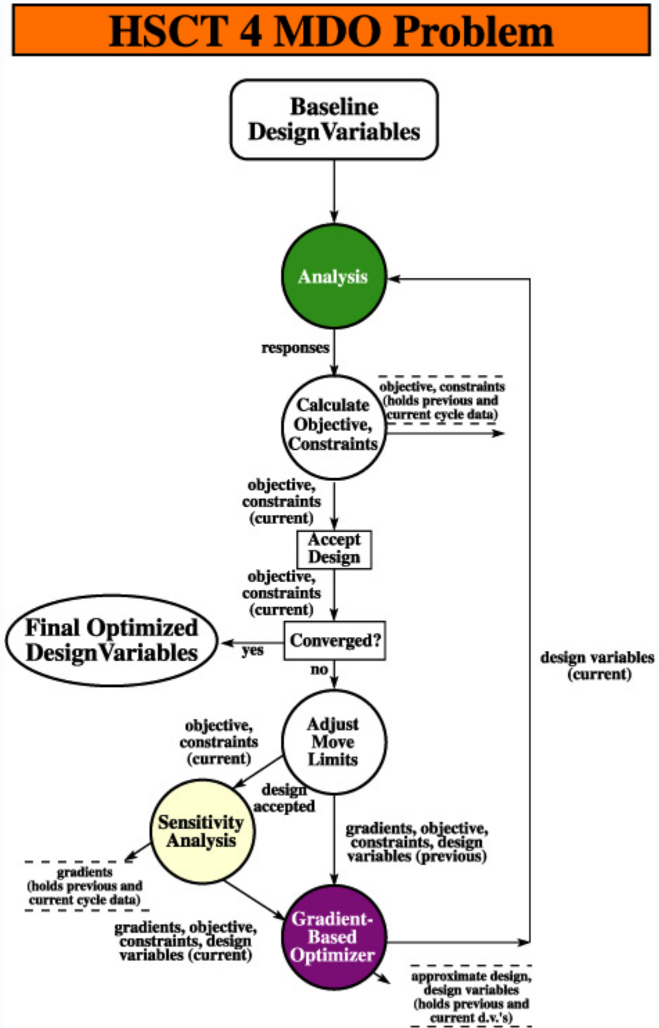
Geometry Goal

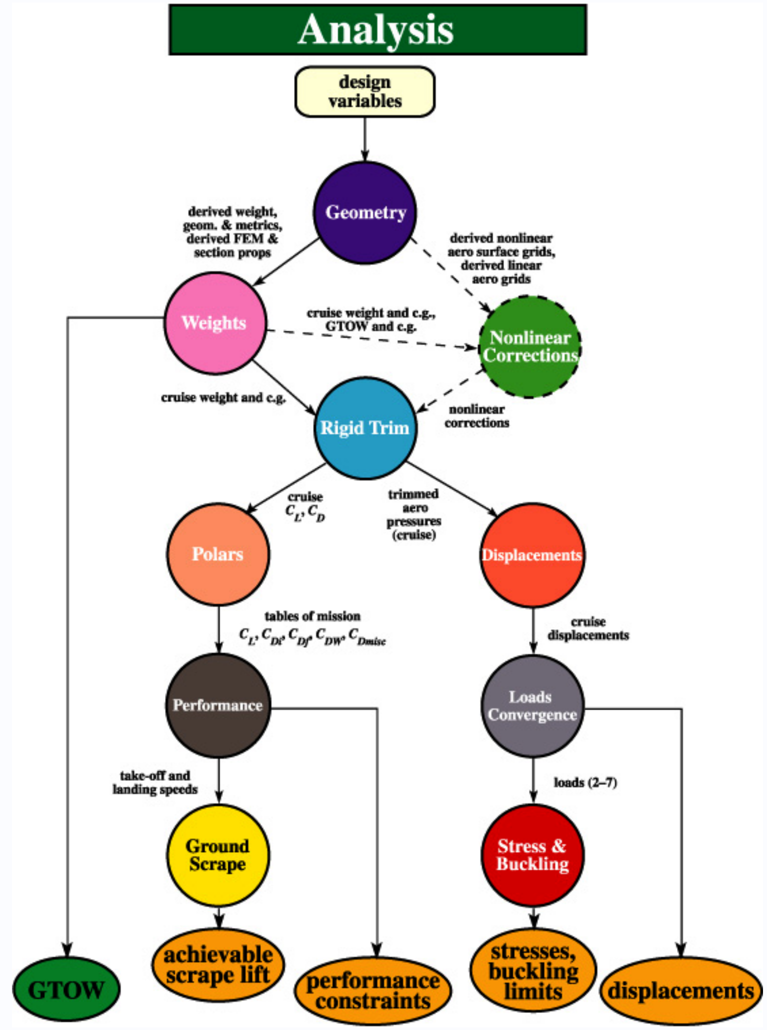


Geometry Modeling Issues for HSCT4

- **7 different processes need geometry models**
  - Linear aerodynamics (USSAERO)
  - Nonlinear aerodynamics (CFL3D)
  - Finite-element structural analysis (GENESIS)
  - Fuel
  - Weights
  - Performance (FLOPS)
  - Groundscrape
- **Vehicle deflects under loads**
- **Aero and structural models have different surfaces**
- **Geometry model needs to be parametric**
- **Sensitivity derivatives are needed for optimization**

HSCT4 Processes





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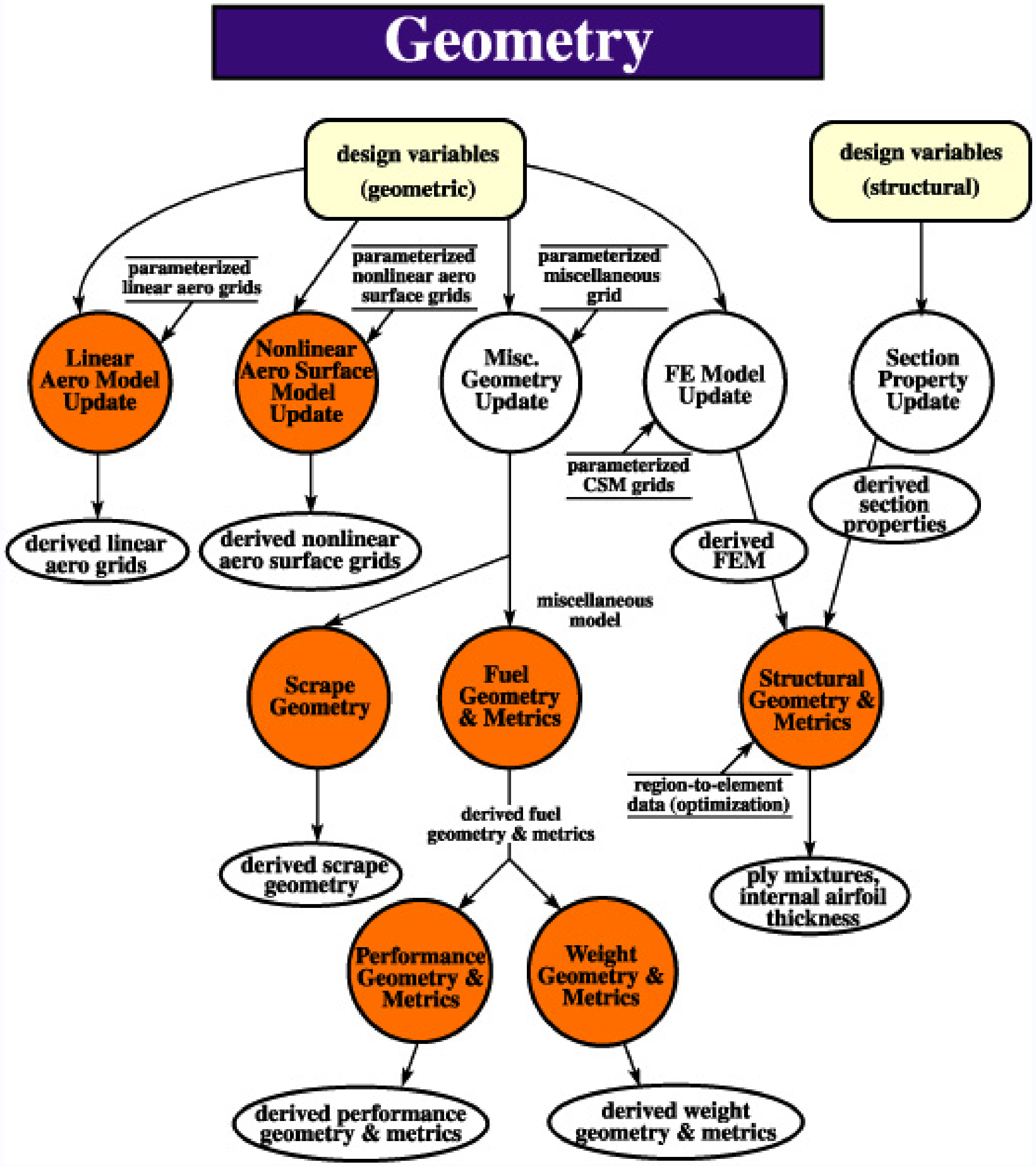
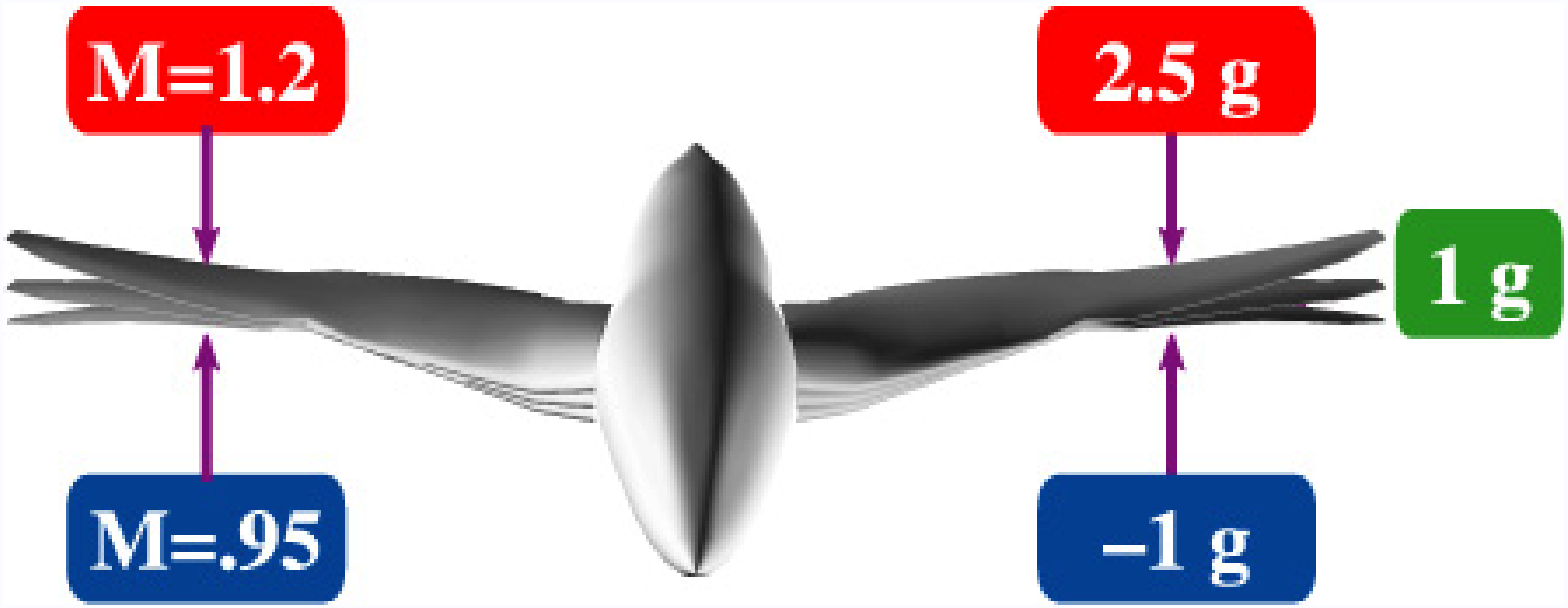
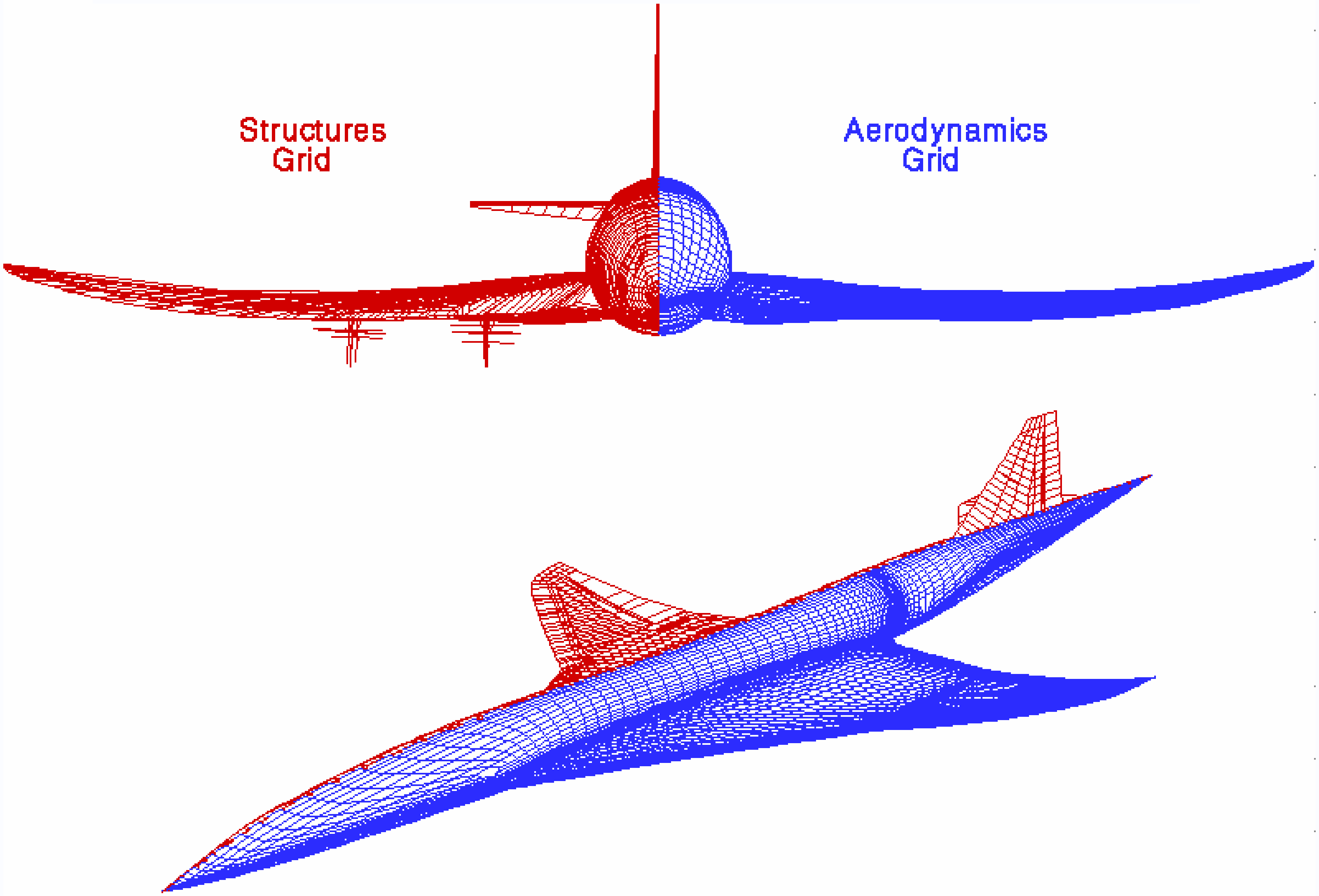
HSCT4 Geometry Processes



HSCT Under Loads



Static Aero-Structural Solution



Gradient-Based Optimization

- **Optimization Problem**
  - **Objective Function:** **F** **e.g., weight**
  - **Constraints** **G** **e.g., stress, range**
  - **Design Variables:** **$v \, \varepsilon \, V$** **e.g., wing sweep**
  - **Sensitivity Derivatives:** **$\partial F/\partial v$ & $\partial G/\partial v$**
- **Functional Dependence**
  - **F = F(Field Grid (Surface Grid (Geometry (Design Variables))))**
  - **G = G(Field Grid (Surface Grid (Geometry (Design Variables))))**
- **Chain Rule**

$$\frac{\partial F}{\partial v} = \frac{\partial F}{\partial Grid_f} \times \frac{\partial Grid_f}{\partial Grid_s} \times \frac{\partial Grid_s}{\partial Geometry} \times \frac{\partial Geometry}{\partial v}$$

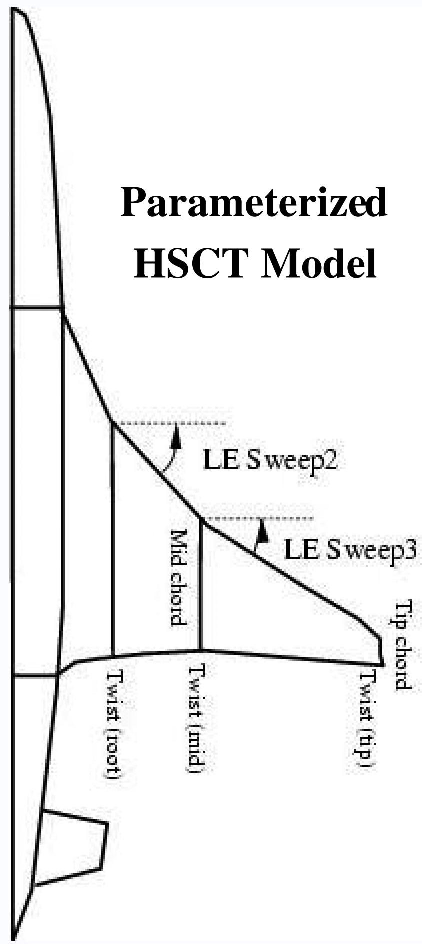
analysis code (↑ $\frac{\partial F}{\partial Grid_f}$)

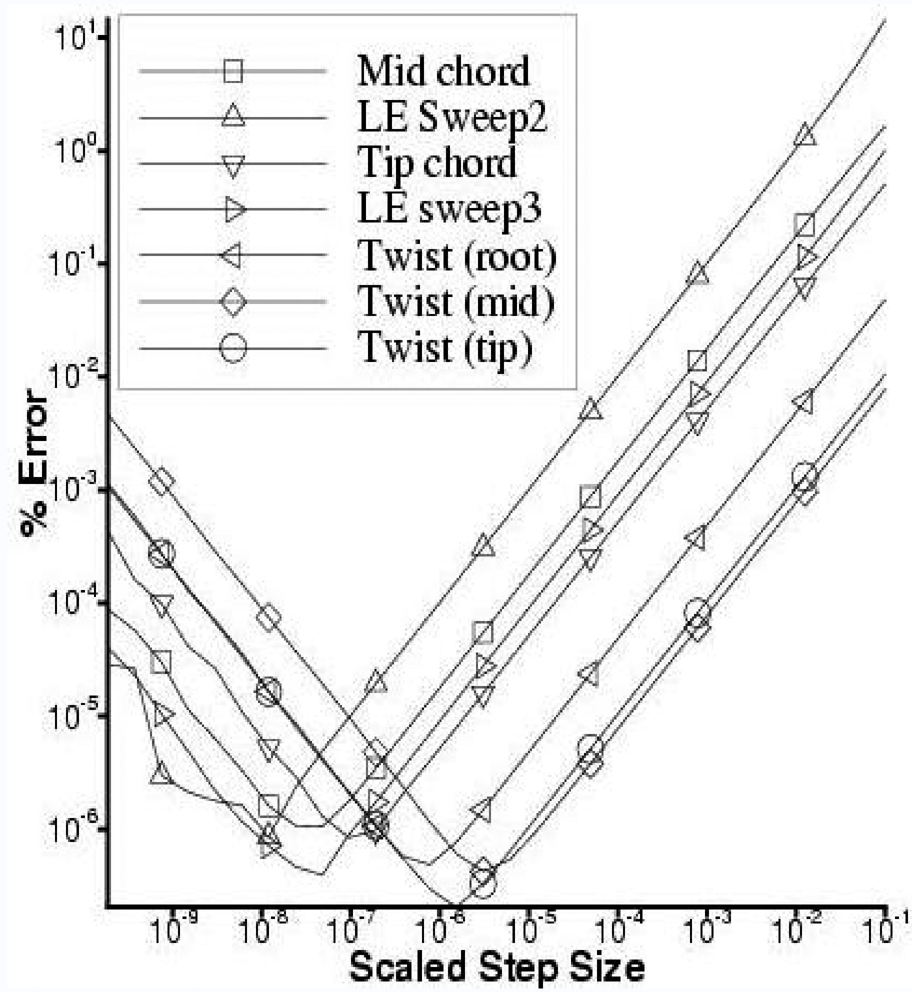
field grid generator (↑ $\frac{\partial Grid_f}{\partial Grid_s}$)

surface grid generator (↑ $\frac{\partial Grid_s}{\partial Geometry}$)

geometry modeler (CAD) (↑ $\frac{\partial Geometry}{\partial v}$)

Finite-Difference Approximation Error for Sensitivity Derivatives





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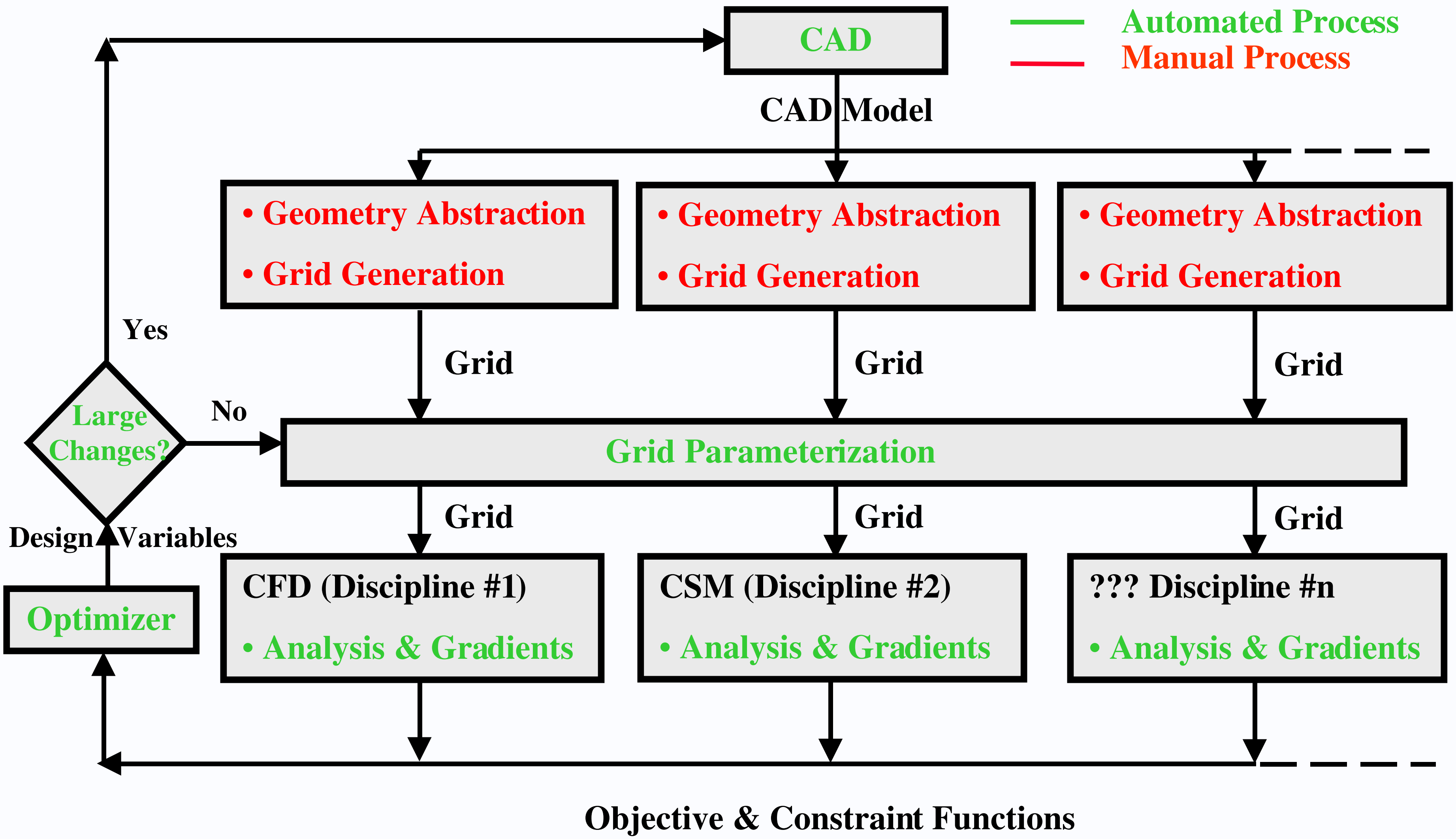
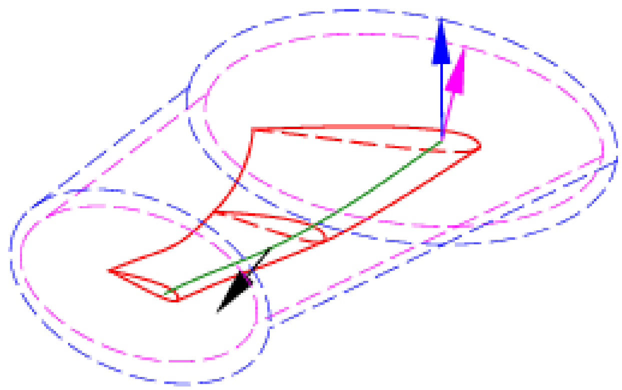
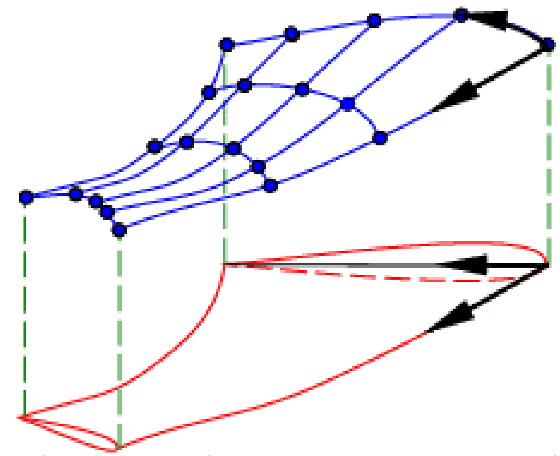
Interim Geometry Solution



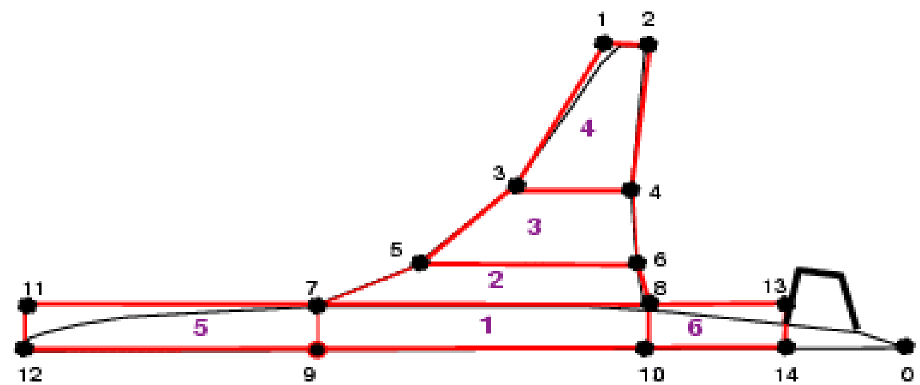
Multidisciplinary Aero/Struc Shape Optimization Using Deformation (MASSOUD)



Nonlinear global deformation
(Twist and Dihedral)

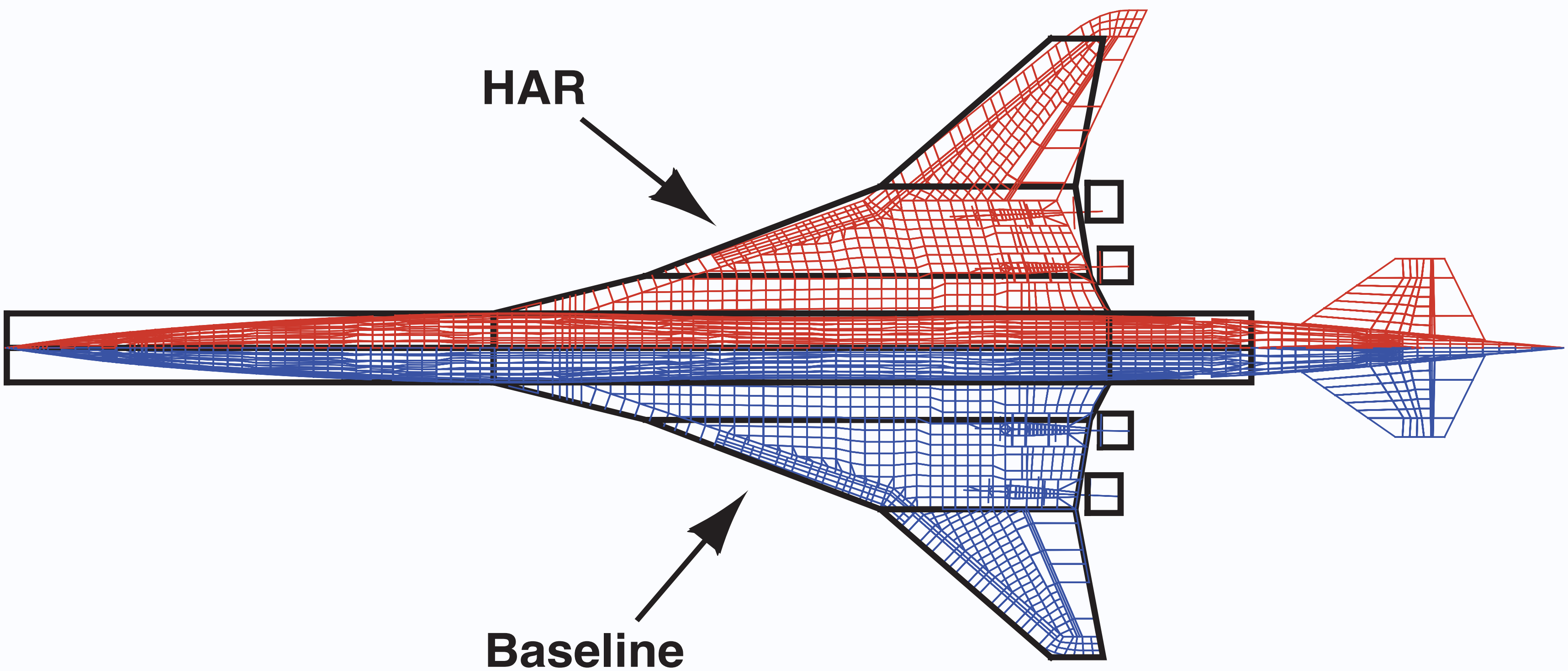


Deformation of parametric NURBS surfaces
(Camber and Thickness)



Free–form deformation
(Planform)

Geometry Process Results



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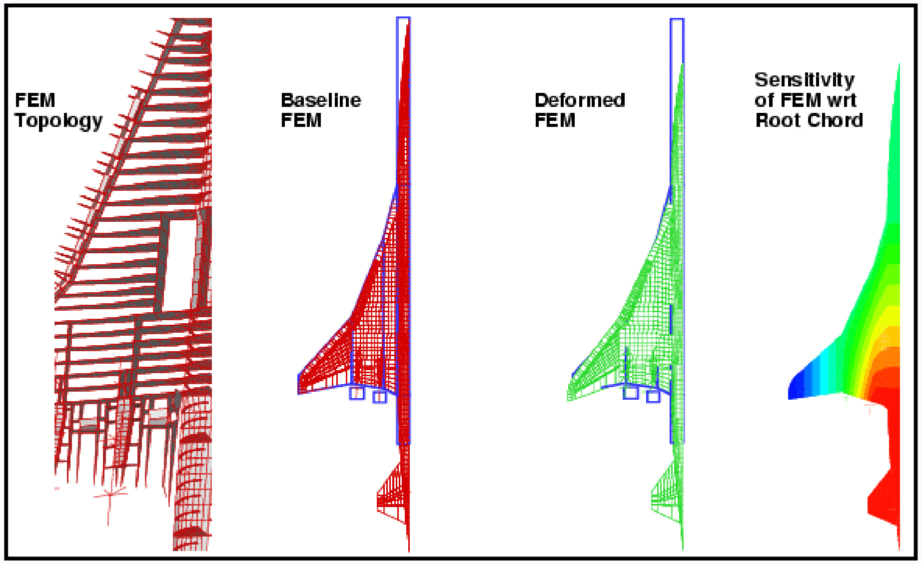
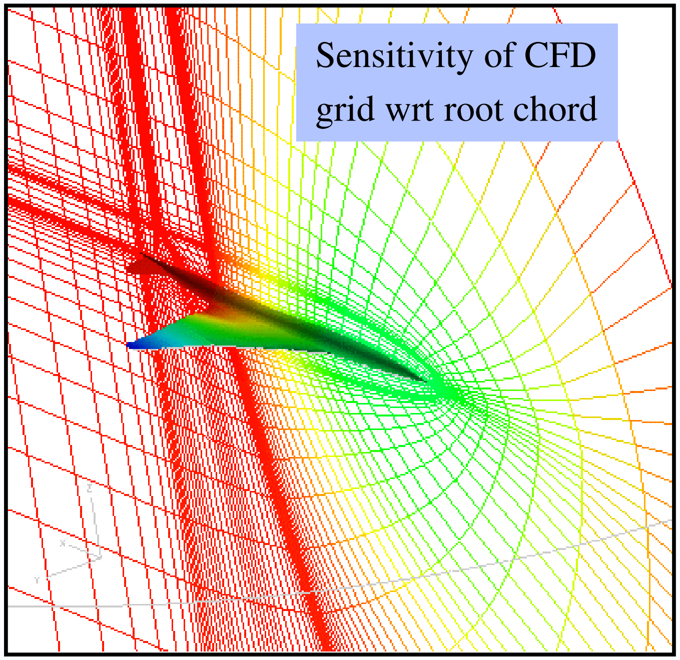
Multidisciplinary Shape Parameterization of an HSCT Model

- Automated process
- 27 aerodynamic shape design variables
- Analytical sensitivity



FE Model



CFD Model

MASSOUD‘s Pros & Cons

- **Pros**
  - Is Consistent
  - No need for grid generation
  - Easy to setup (hours)
  - Parameterization is fast (seconds on OCTANE)
  - Analytical sensitivity is available
  - Has compact set of DVs
  - Suitable for high- and low-fidelity applications
- **Cons**
  - Limited to small shape changes
  - Fixed topology
  - No built-in geometry constraints
  - No direct CAD connection

More Observations

- Different disciplines require different geometry models
- Different discipline models may contain different vehicle components
- Different discipline models may not have coincident surfaces
- Each discipline has its own requirements for smoothness
- The geometry deformation under loads is difficult to link back to the fundamental CAD geometry model
- Lack of analytical sensitivity analysis is a major barrier for using CAD models directly in optimization