Grid Generation for Multidisciplinary Design and Optimization of an Aerospace Vehicle ¾ Issues and Challenges

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Slides are available from MDOB web site:

http://fmad-www.larc.nasa.gov/mdob/MDOB

Outline

- Objective
- Motivation
- Geometry/grid processes for high-fidelity MDO
- Issues & challenges

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 (and system components)

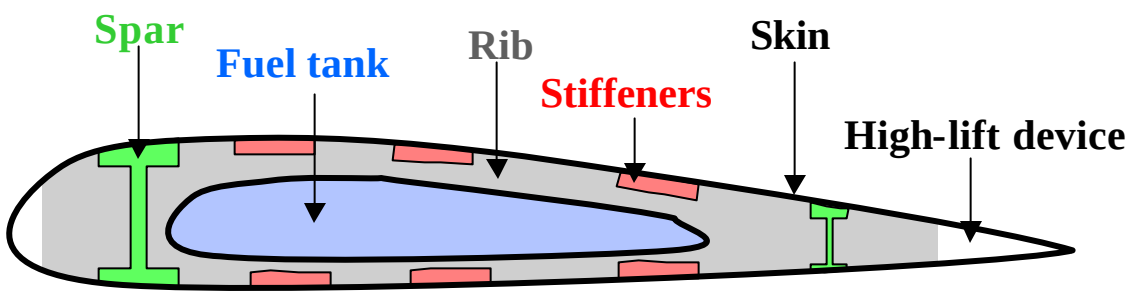
Objective

- Identify grid generation issues of particular importance to MDO
- Challenge the grid generation community to develop tools suitable for automated multidisciplinary analysis and design optimization of aerospace vehicles

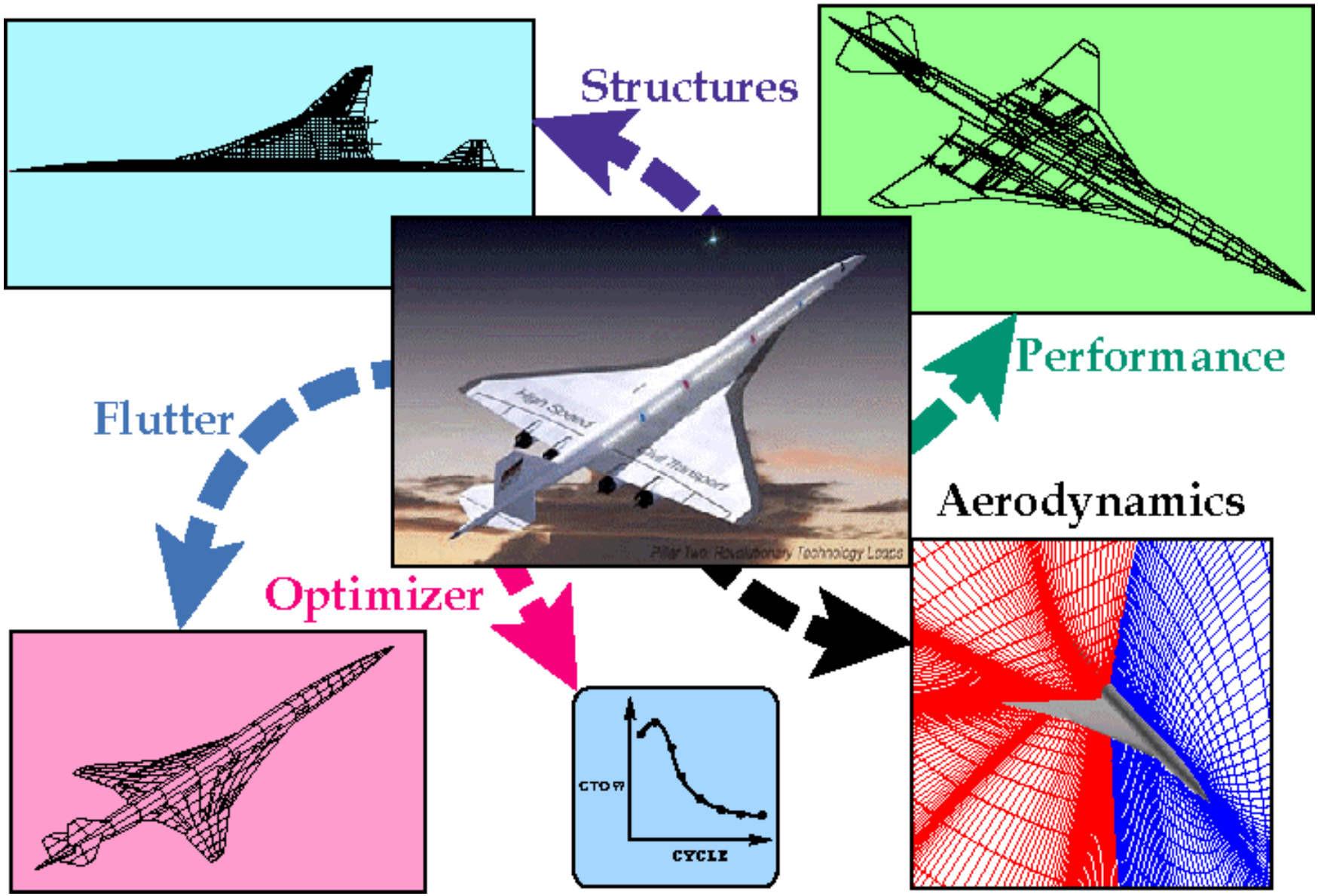
Motivation

High-Fidelity MDO of an aerospace vehicle :

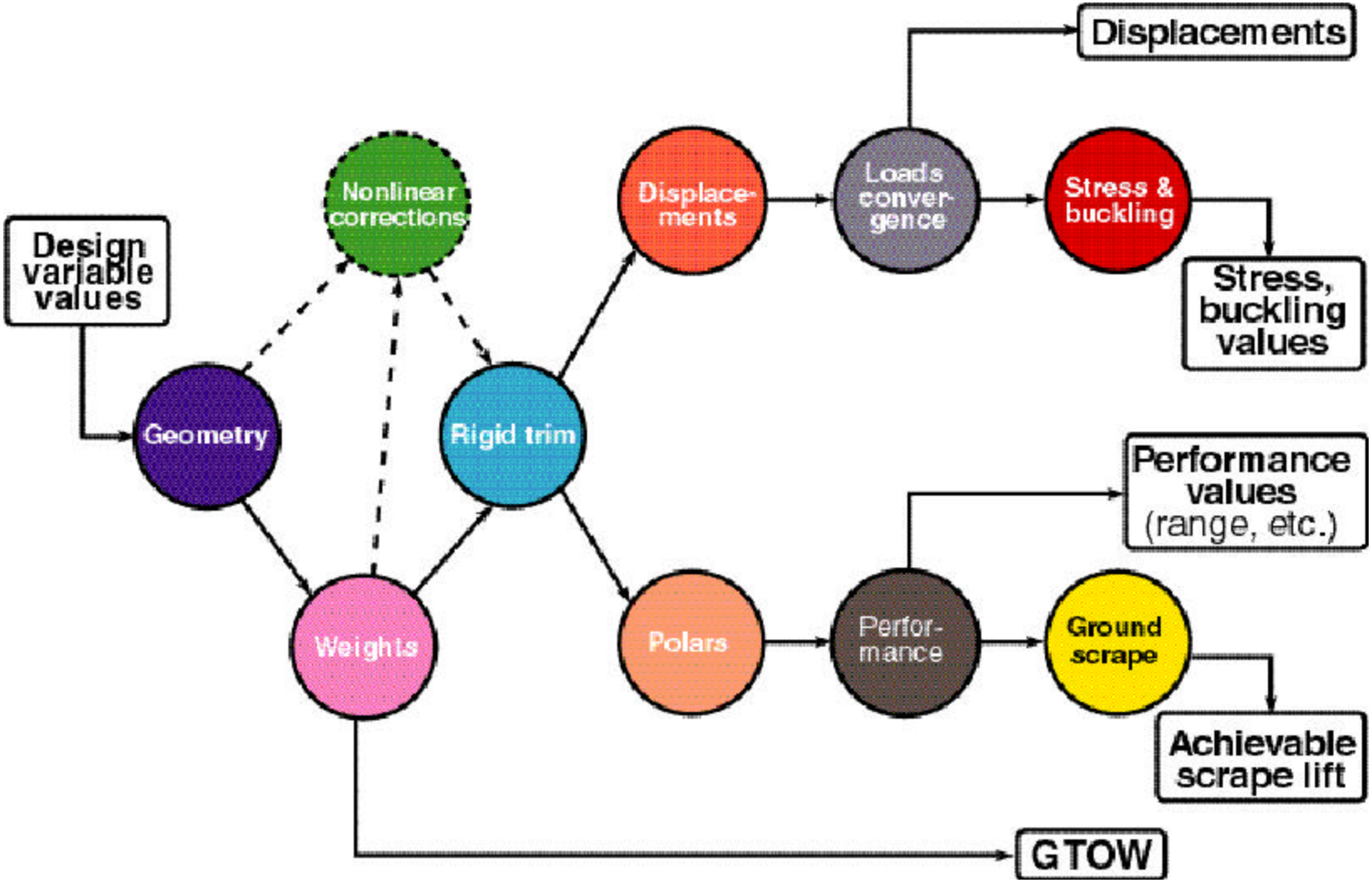
- Has complex geometry with many details
- Requires consistent shape parameterization across all disciplines
- Requires rapid and automatic grid generation tools
- Requires sensitivity derivatives
- Has many disciplines and processes (e.g,. CFD & CSM)



High-Fidelity MDO of an Aerospace Vehicle



Processes for Multidisciplinary Analysis of an HSCT



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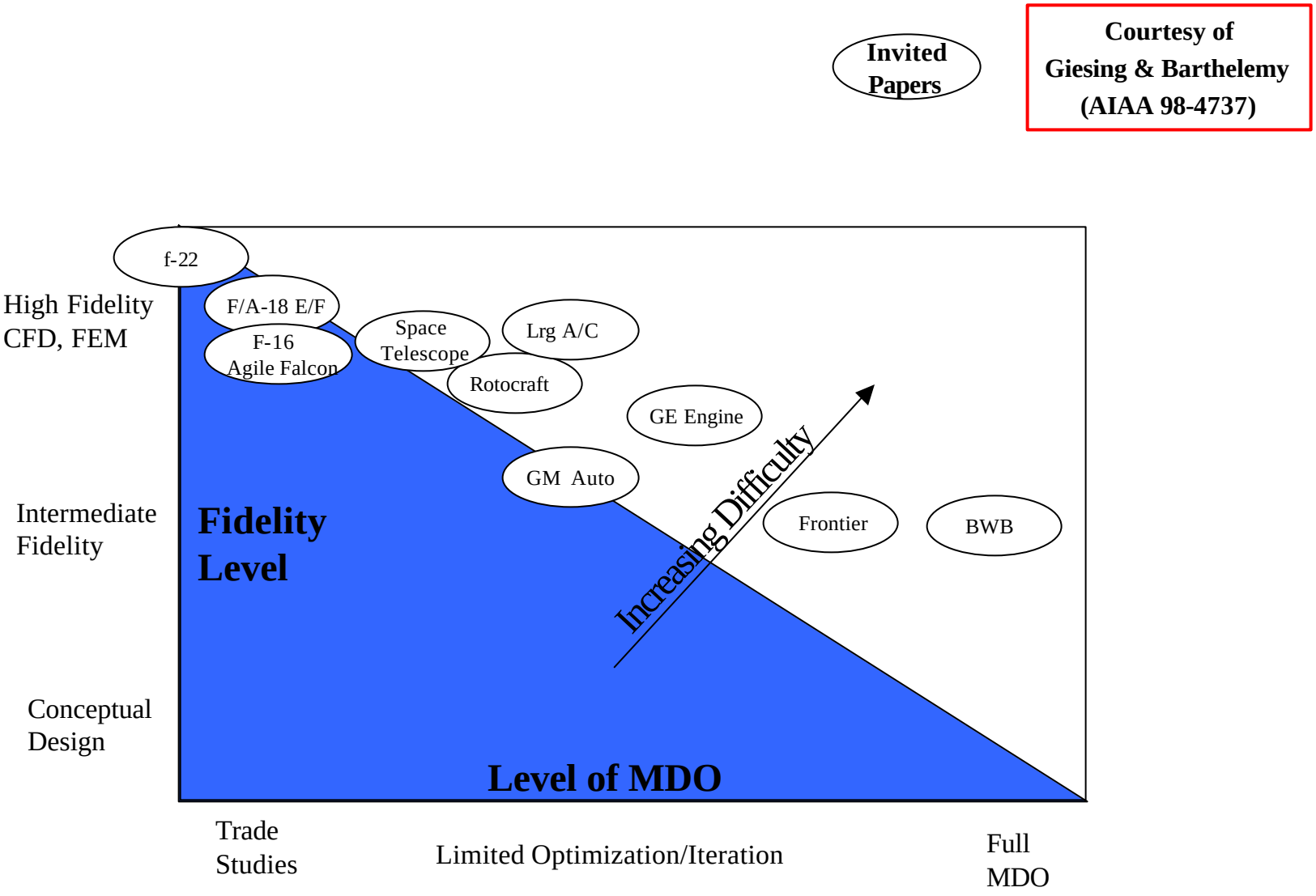
Summary of 10 Invited Papers on industrial experience with MDO



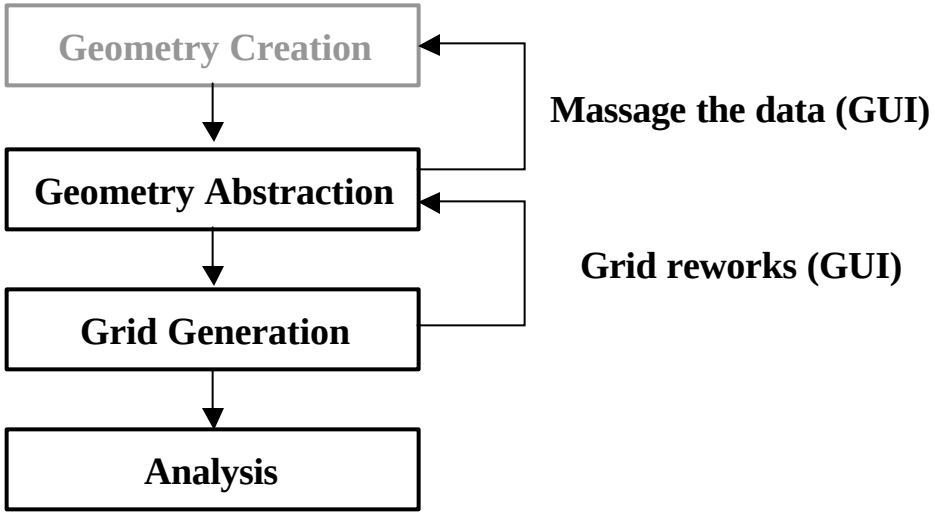
Motivation

"High fidelity analysis process is difficult or impossible to include in MDO"

- "Non Automated"
- "Very long computing time"

1998, Giesing & Barthelemy, "A Summary of Industry MDO Applications and Needs", AIAA 98-4737

Current Geometry/Grid Processes for High-Fidelity **Analysis**



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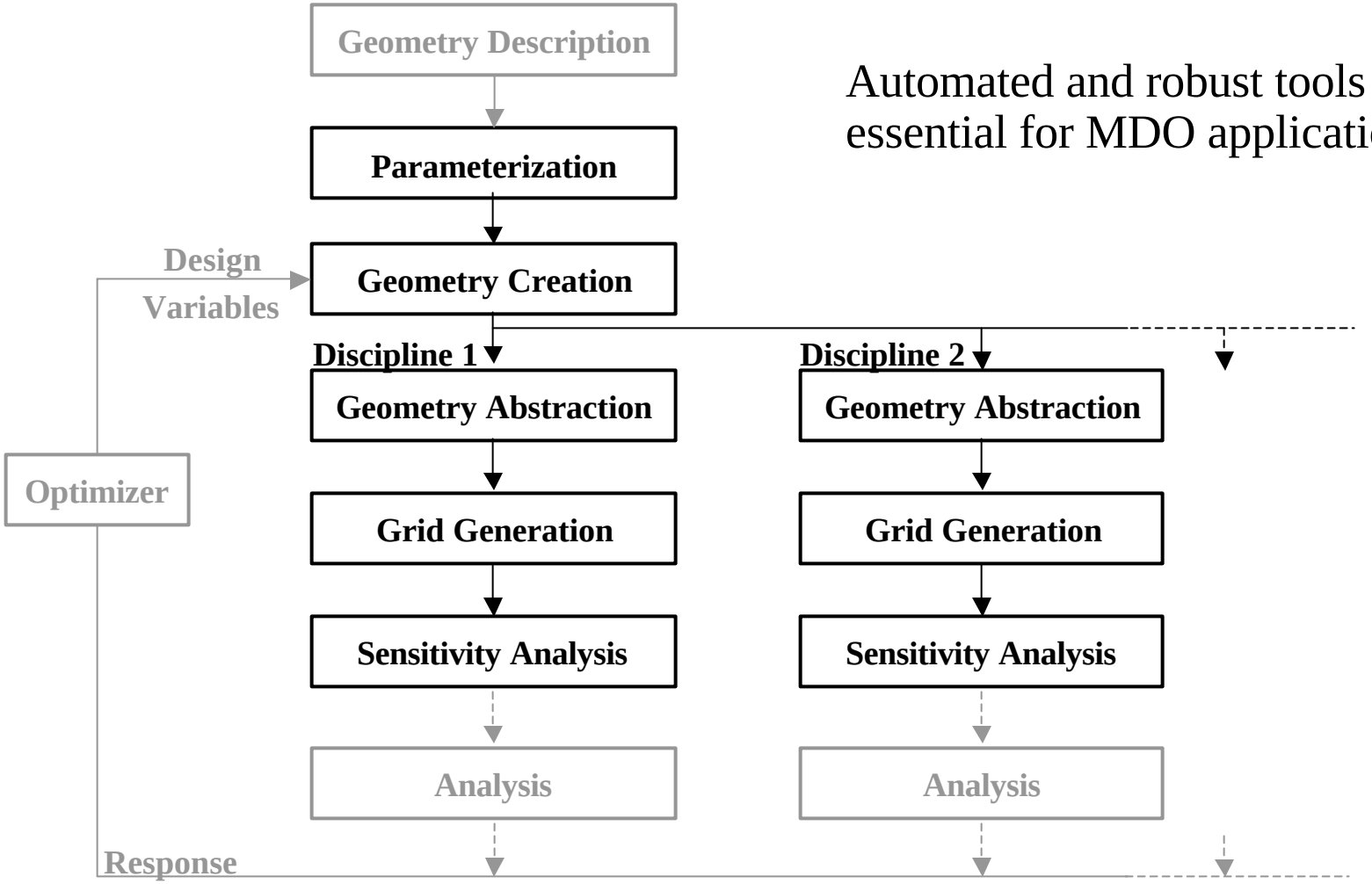
Geometry/Grid Processes for High-Fidelity **MDO**



Automated and robust tools are essential for MDO applications

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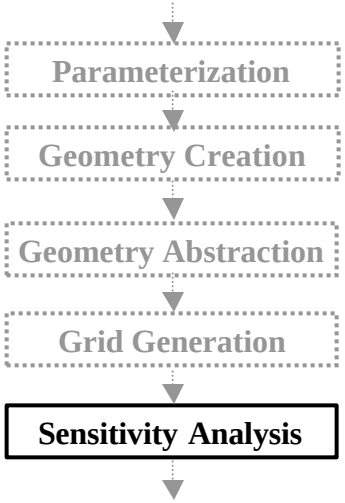
Sensitivity Analysis



$$\frac{\partial t}{\partial \bar{v}} = \frac{\partial t}{\partial \bar{R}_f} \frac{\partial \bar{R}_f}{\partial \bar{R}_s} \frac{\partial \bar{R}_s}{\partial \bar{R}_g} \frac{\partial \bar{R}_g}{\partial \bar{v}}$$

analysis code

field grid generator

geometry modeler (CAD)

surface grid generator

- Manual differentiation
- Automatic differentiation tools (e.g., ADIFOR and ADIC)
- Complex variables
- Finite-difference approximation

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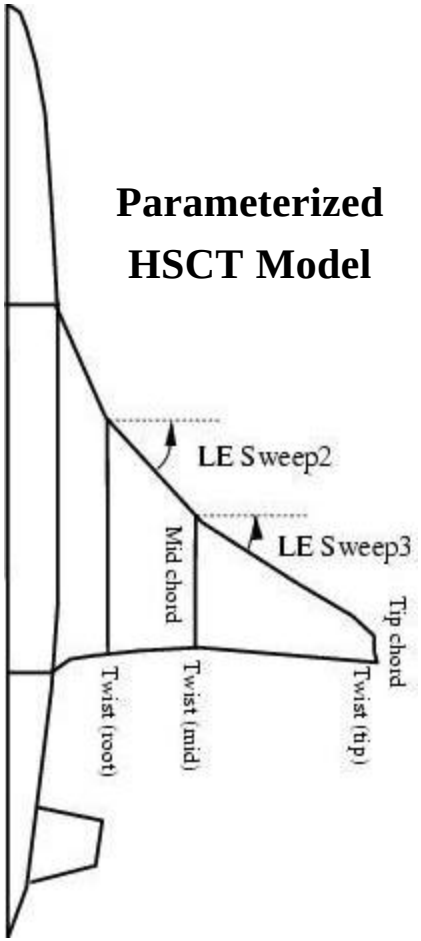
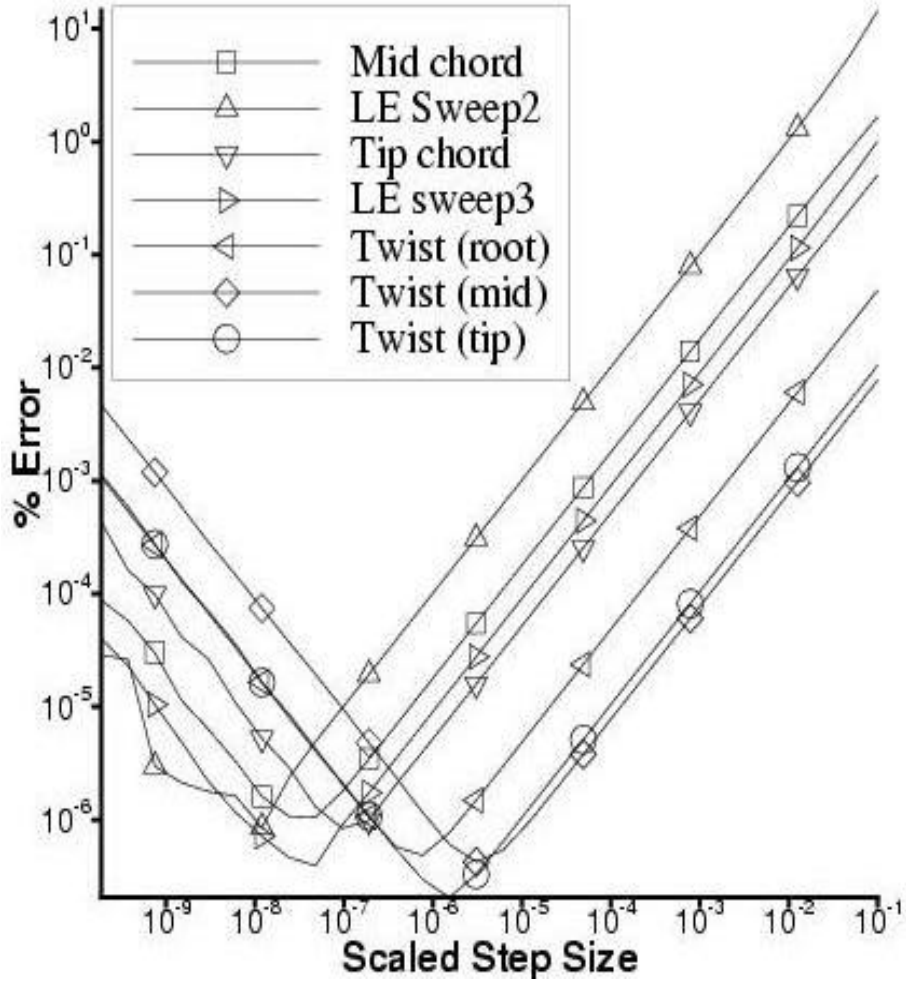
Finite-Difference Approximation Error for Sensitivity Derivatives





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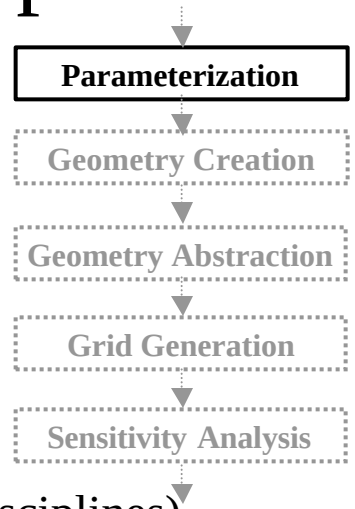
Desired Characteristics of Shape Parameterization



The shape parameterization must:

- Be **consistent** across all disciplines
- Be **automatic** (automatic grid tools are not available for all disciplines)
- Have a **short** implementation cycle time
- Provide a **compact** set of design variables (10s vs. 1000s)
- Provide sensitivity derivatives (preferably **analytical,** or accurate finite-difference approximation)

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Techniques for Shape Parameterization

(Choice of shape parameterization has impact on the MDO formulation)

- Basis vector (geometry changes are represented by a set of vectors)
- Partial differential equation (geometry is represented by PDE)
- Discrete (grid points are used as design variables)
- Analytical (geometry changes are represented by analytical functions)
- Polynomial and spline (geometry is defined by polynomial and spline representations)

Š CAD (based on commercial feature-based solid modeling CAD systems)

Š Domain element (based on macro elements)

Š Free-form deformation (based on a computer animation algorithm)

Š MASSOUD, multidisciplinary aero/structural shape optimization using deformation, (based on advanced computer animation algorithms)

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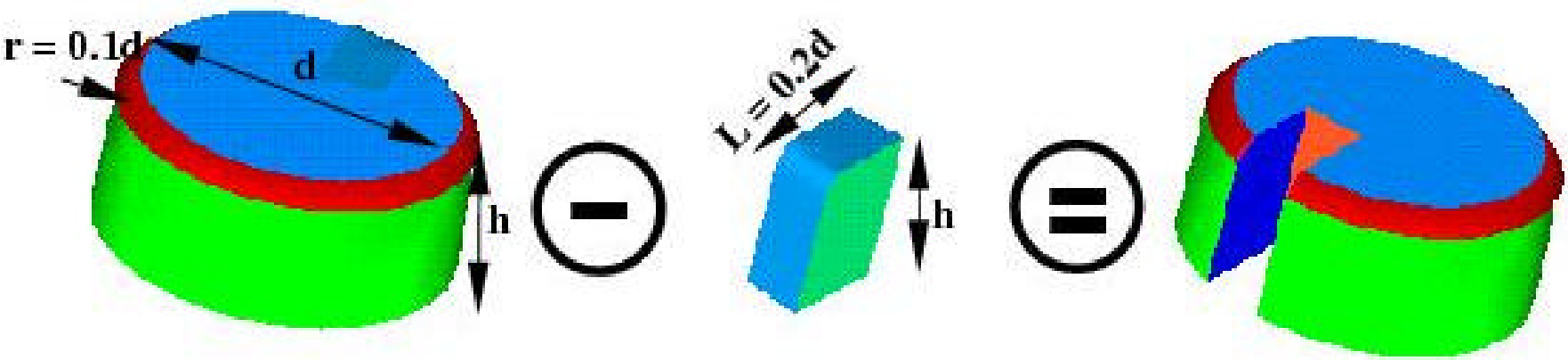
Shape Parameterization Using Feature-Based Solid Modeling CAD

- Based on Boolean operations and dimension-driven objects
- Uses simple top-down approach with high-level geometric constructions
- Uses topologically complete geometry (solids)
- Design changes are not time consuming



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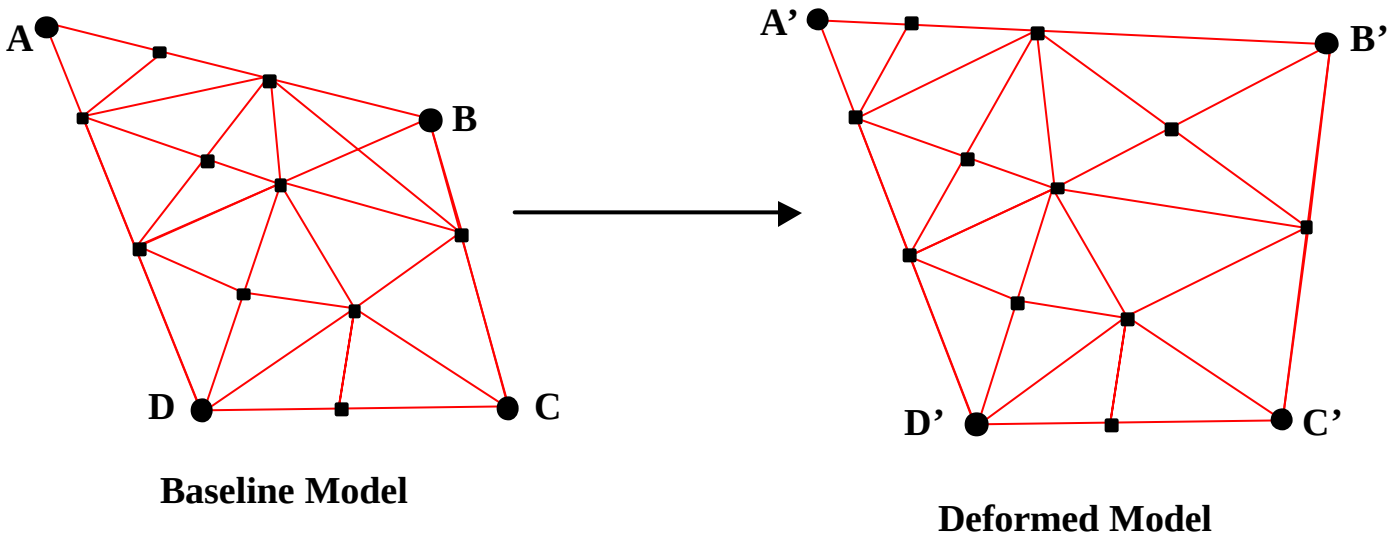
Domain Element Technique

- Based on macro elements
- Simple to implement
- Available in some commercial FE codes
- Avoids grid generation by deforming the baseline grid



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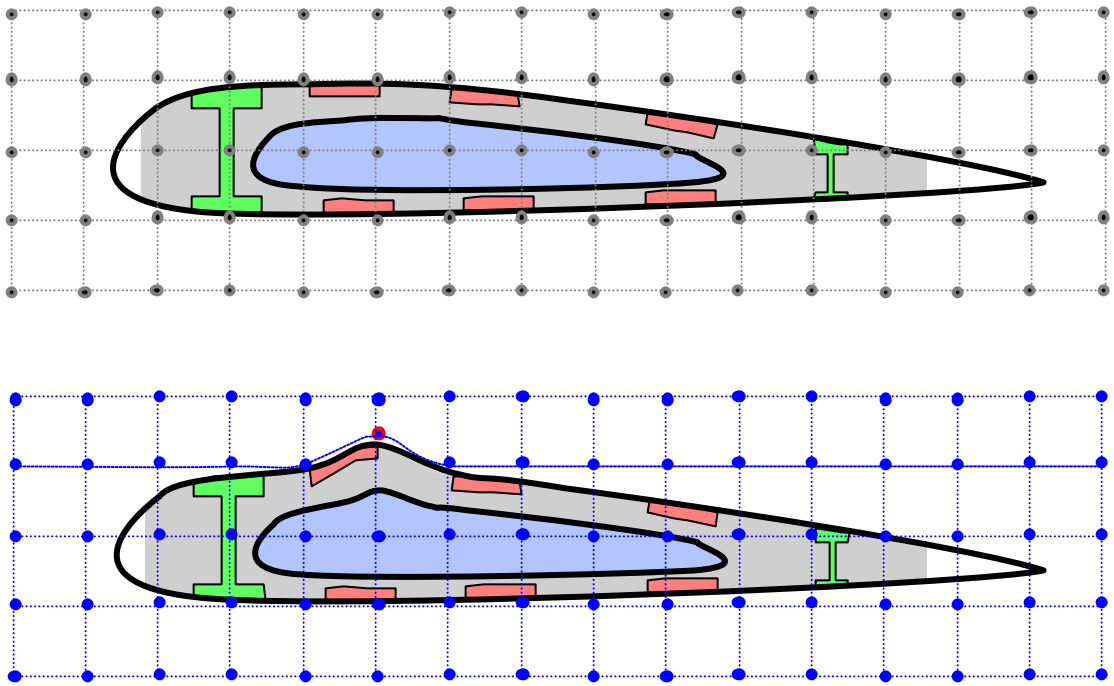
Free-Form Deformation Technique

- Based on algorithm used in computer animation
- Avoids grid generation by deforming the baseline grid



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Multidisciplinary **A**erodynamic-**S**tructural **S**hape **O**ptimization **U**sing **D**eformation
(MASSOUD)

- Parameterizes the changes in shape, not the shape itself (reduces the number of design variables)
- Parameterizes the discipline grids (avoids manual grid regeneration)
- Uses advanced soft object animation algorithms for deforming grids
  - NURBS surface (camber and thickness)
  - Free-form deformation (planform)
  - Nonlinear global deformation (twist and dihedral)

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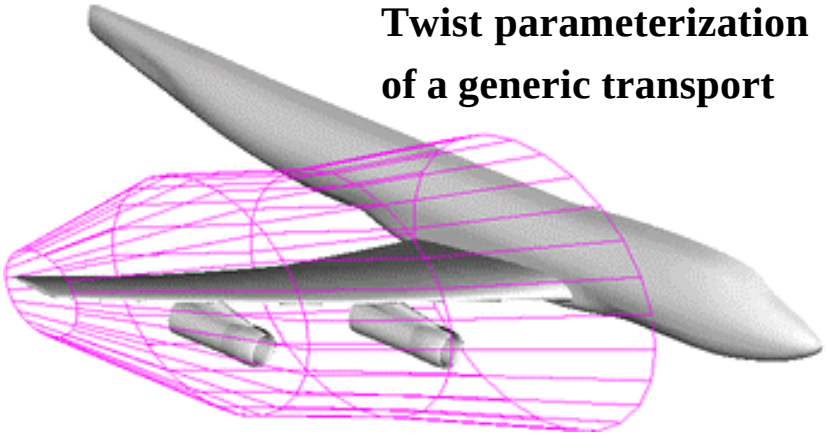
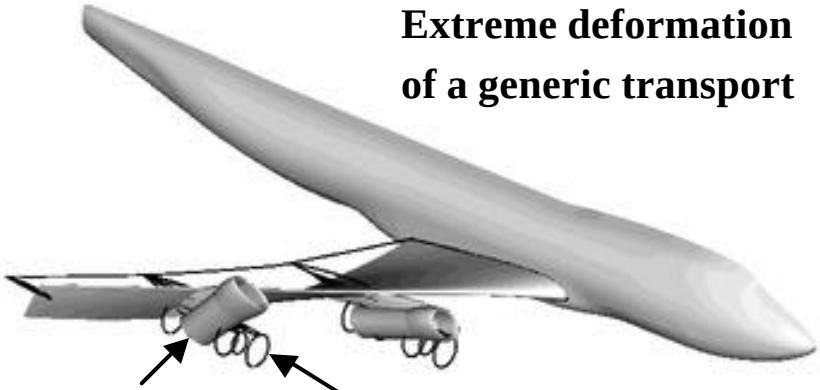
Nonlinear Global Deformation

(twist and dihedral)

Twist parameterization of a generic transport



Extreme deformation of a generic transport



Deformed Model

Baseline Model

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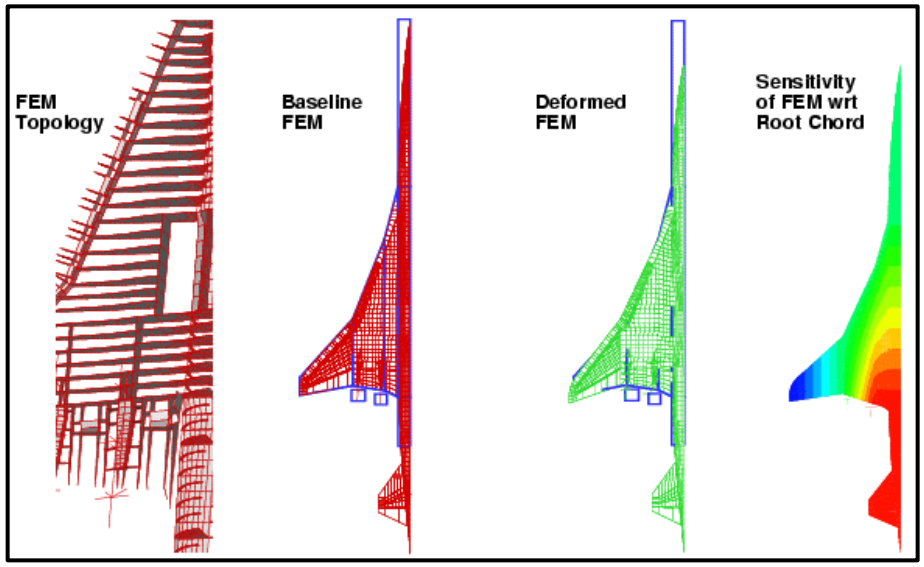
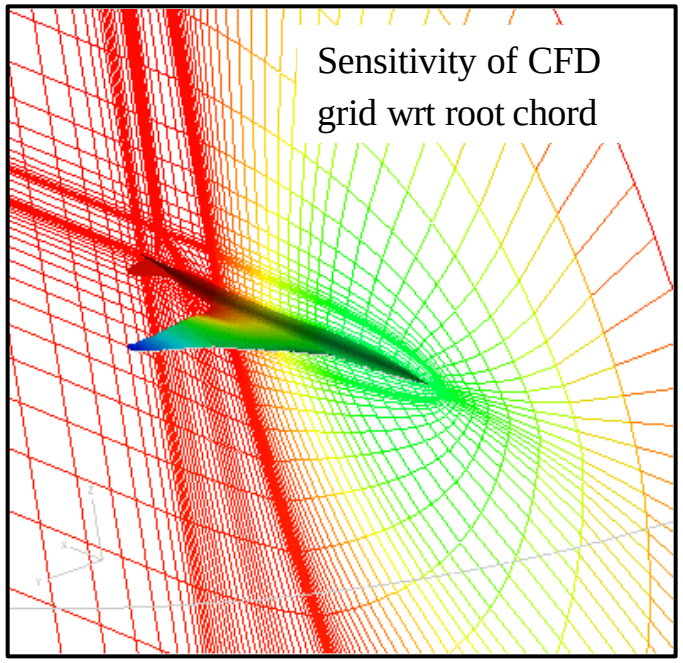
Multidisciplinary Shape Parameterization of an HSCT Model

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



FE Model



CFD Model

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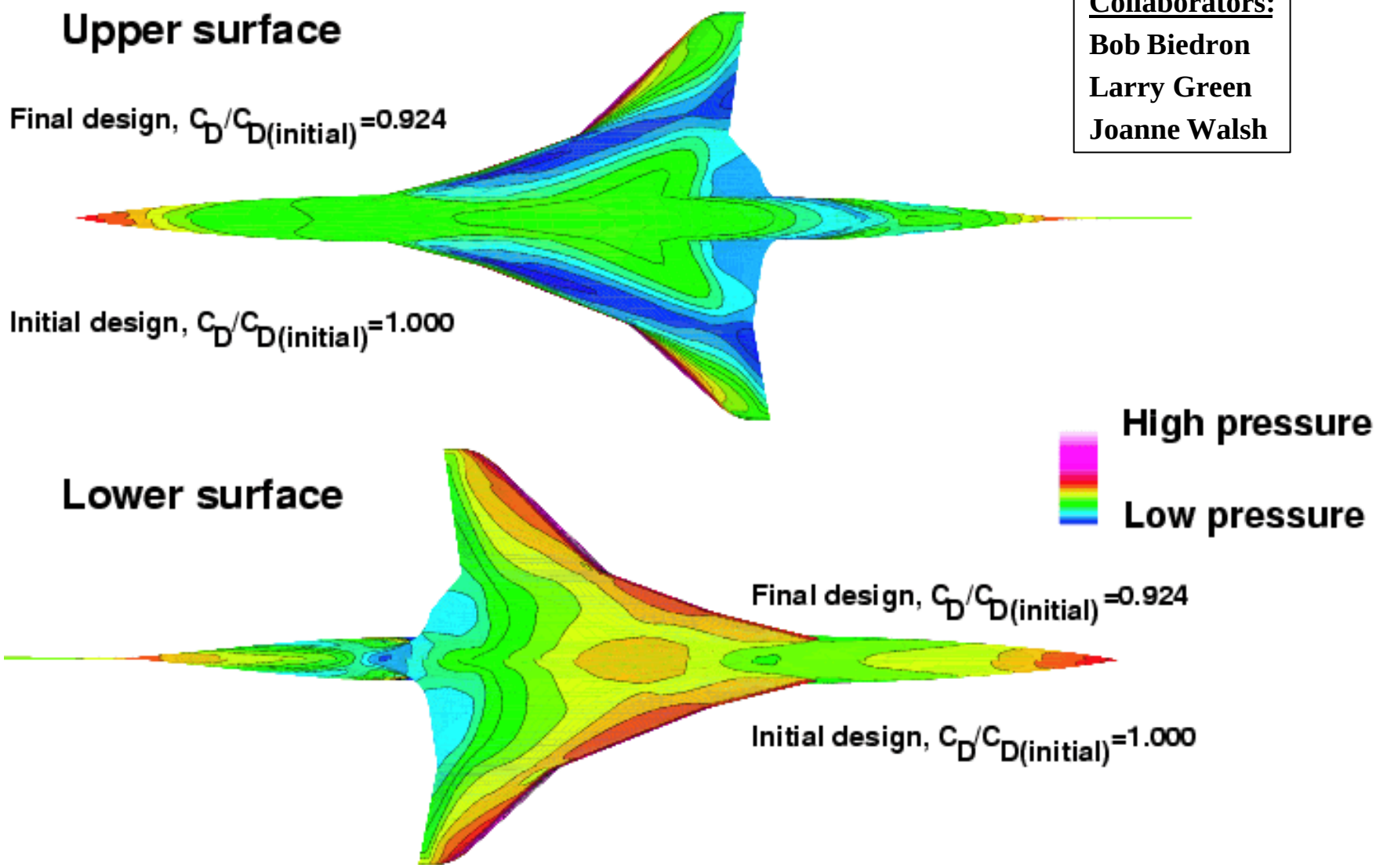
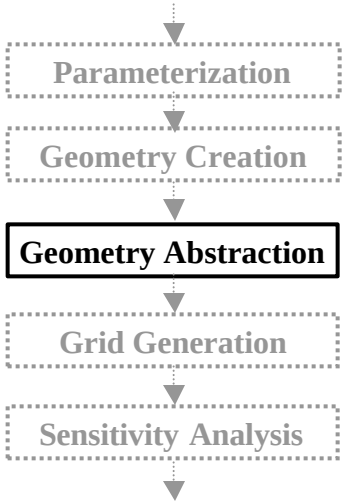
Nonlinear Aerodynamic Shape Optimization Results

Final design $C_D/C_{D(initial)}$=0.924, Fixed C_L

Collaborators:
Bob Biedron
Larry Green
Joanne Walsh

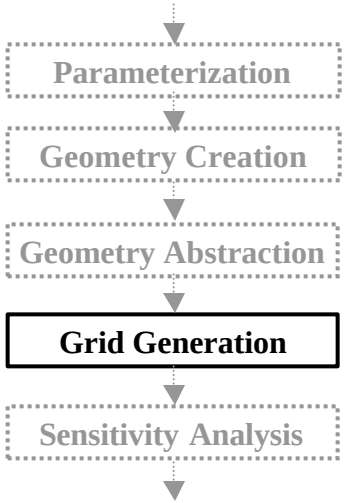


Model Abstraction



- CSM model design and abstraction
  - Dimensional reduction (solid to beams and/or shells)
- Deletion and/or suppression of small features (e.g., bolt holes)
- Modification (e.g., closing trailing edge)
- Addition (e.g., surface boundaries for gridding)
- Combination and/or split geometry parts (e.g., creating bigger surfaces for gridding)

Grid Generation



- Sensitivity analysis should be incorporated into grid generation tools
- Structured grids with fixed topology are only suitable for MDO applications with small geometry changes
- Structured grids can not be incorporated into MDO applications with moderate to high geometry changes without automatic topology creation
- Unstructured and Cartesian grids are well suited for MDO applications

Grid Regeneration and Deformation

- Techniques
  - Regenerate the entire grid
  - Regenerate the affected areas
  - Deform grid (maintains the baseline grid topology and connectivity)
- Structured grid generation can be fully automated for fixed grid topology
- Unstructured grid generation can be fully automated for a complete solid model

Issues and Challenges

"Design automation tools will thrive in the next decade" *CAD Report, January 2000*

- There are three major issues that need to be considered by grid generation community:
  - Use of GUI should be limited to problem set up and monitoring phases
  - Sensitivity analysis should be built into the grid generation tools
  - Grid generation tools must be robust (eliminating rework)

- There are three major challenges:
  - Automation of geometry abstraction
  - Automation of grid generation tools
  - CAD-based sensitivity analysis (preferably analytical)

Thank You

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http://fmad-www.larc.nasa.gov/mdob/MDOB

AIAA Technical Committee on Multidisciplinary Design Optimization (MDO)

http://endo.sandia.gov/AIAA_MDOTC/

Ten invited white paper on industrial experience with MDO and the summary paper by Giesing & Barthelemy

http://endo.sandia.gov/AIAA_MDOTC/sponsored/mao98_whitepaper.html

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