A Survey of Shape Parameterization Techniques

Jamshid Samareh

MDO Branch
NASA Langley Research Center

Slides: http://fmad−www.larc.nasa.gov/mdob/MDOB

CEAS/AIAA/ICASE/NASA Langley
International Forum on Aeroelasticity and Structures Dynamics
Williamsburg, Virginia
June 22−25, 1999

j.a.samareh@larc.nasa.gov

Outline

- ✔ Introduction
- ✔ Multidisciplinary Shape Parameterization
  - ✂ Basis Vector
  - ✔ Domain Element
  - ✂ Partial Differential Equation
  - ✔ Discrete
  - ✂ Polynomial and Spline
  - ✔ CAD−Based
  - ✂ Analytical
  - ✔ Free Form Deformation
  - ✔ Multidisciplinary Aero/Struc Shape Optimization Using Deformation (MASSOUD)
  - ✔ Summary
- ✂ Field Grid Movement and Sensitivity Derivatives
  - ✂ Structured Field Grid Movement
  - ✂ Unstructured Field Grid Movement

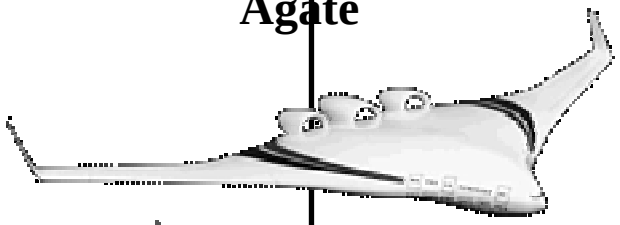
j.a.samareh@larc.nasa.gov

Agate

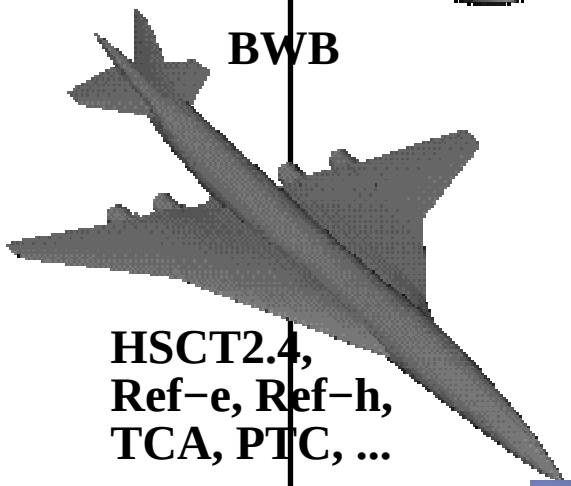
F16

Boxwing

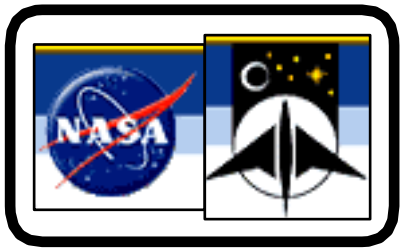
HL−20



BWB



HSCT2.4,
Ref−e, Ref−h,
TCA, PTC, ...



DC−XA

Hyper−X

X33

X34

Commercial RBCC

j.a.samareh@larc.nasa.gov

Introduction

- Sizing optimization (fixed shape and topology)
  - cross−sectional area
  - thickness

✔ Shape optimization (fixed topology)
  - model coordinates

- Topology optimization
  - material distribution
  - structural layout

j.a.samareh@larc.nasa.gov

Background

Previous survey papers focused on: (Haftka and Grandhi 1986, Ding 1986)

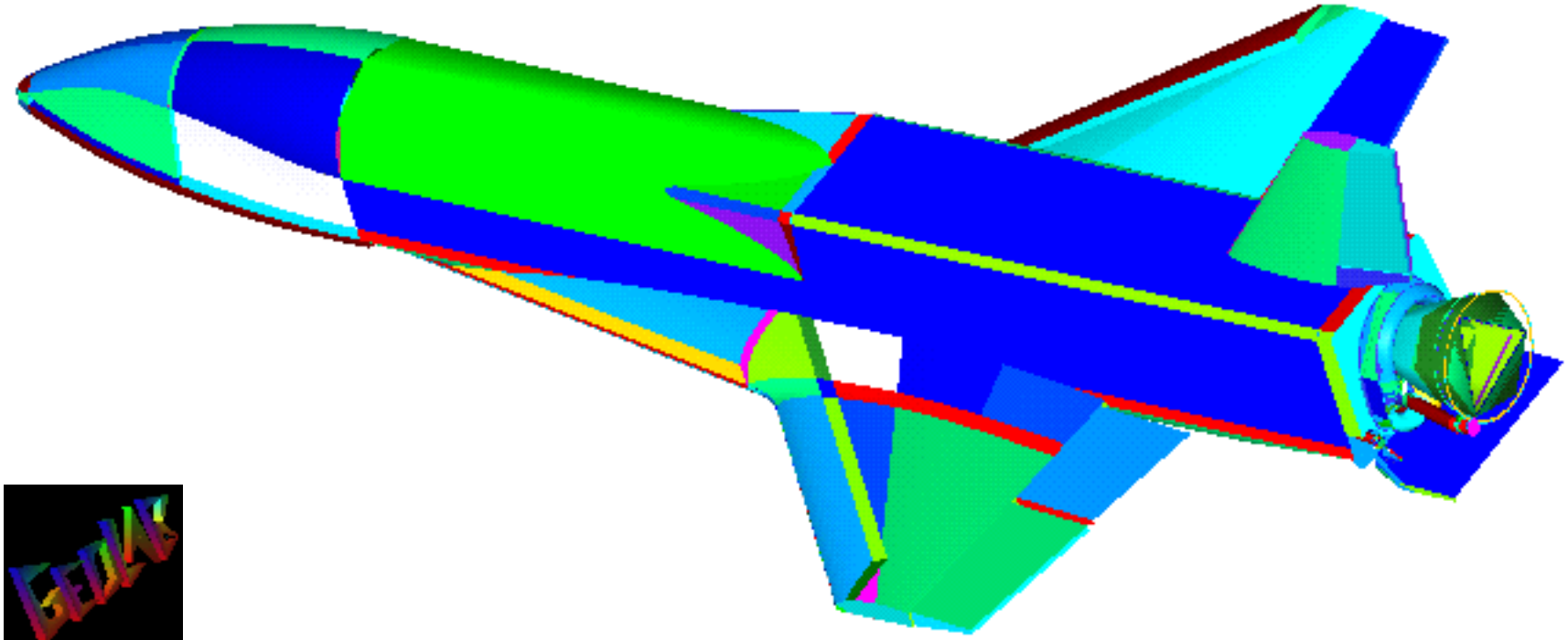
- **formulation of structural shape optimization**
- **single discipline (structures)**
- **simple geometry**

Current survey focuses on:

- **shape parameterization**
- **multiple disciplines**
- **high fidelity**
- **complex shape**

j.a.samareh@larc.nasa.gov

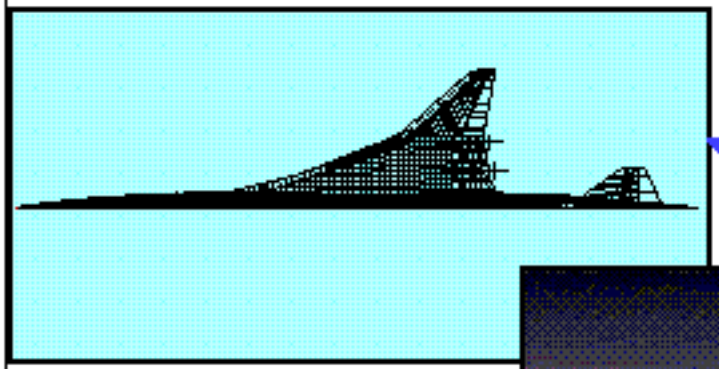
Complex Geometry



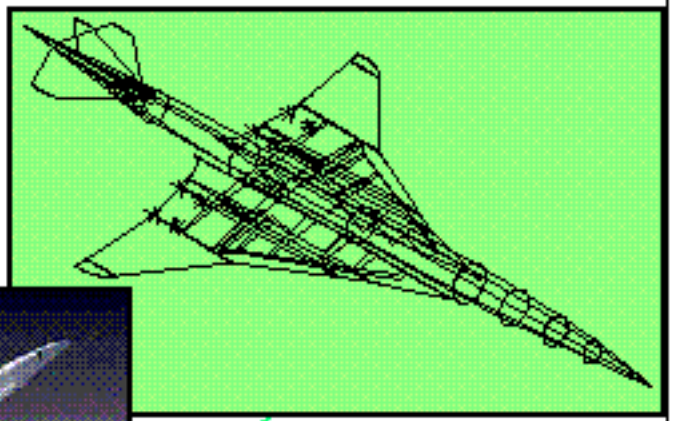
"X34" Candidate Model (23, 555 Curves & Surfaces)

j.a.samareh@larc.nasa.gov

Multidisciplinary Optimization



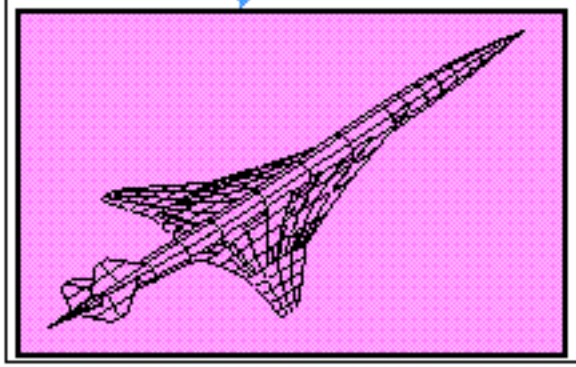
Structures



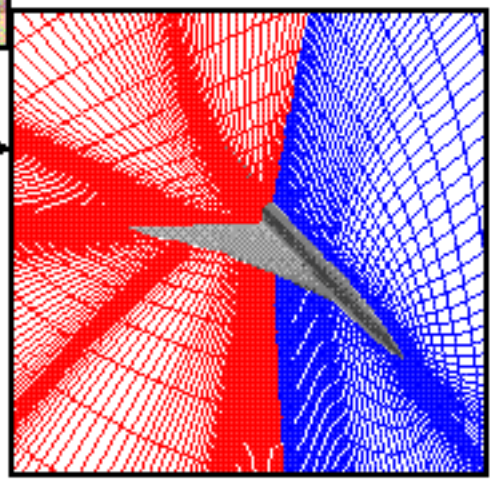
Performance

Flutter

Aerodynamics

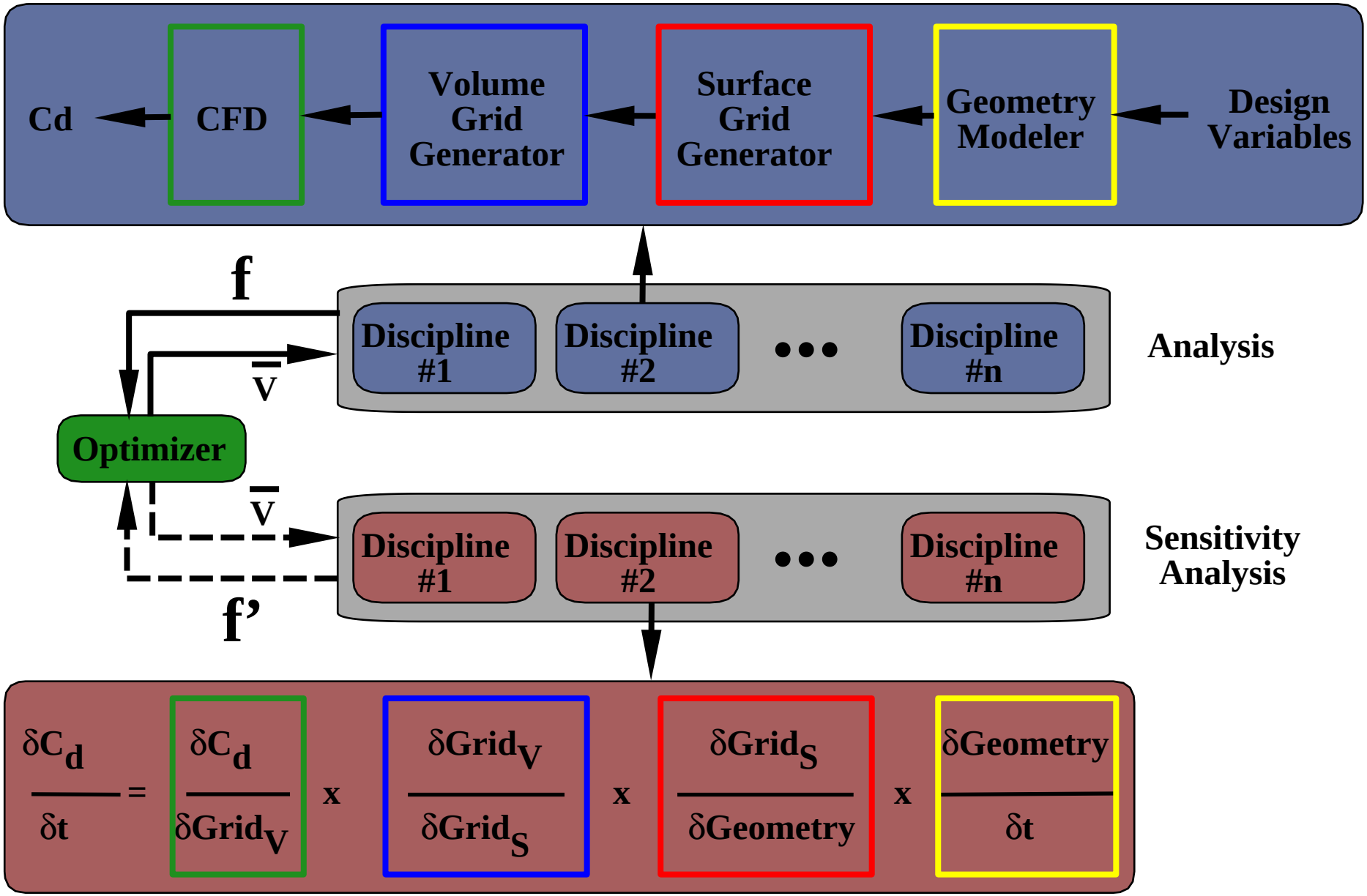


Optimizer



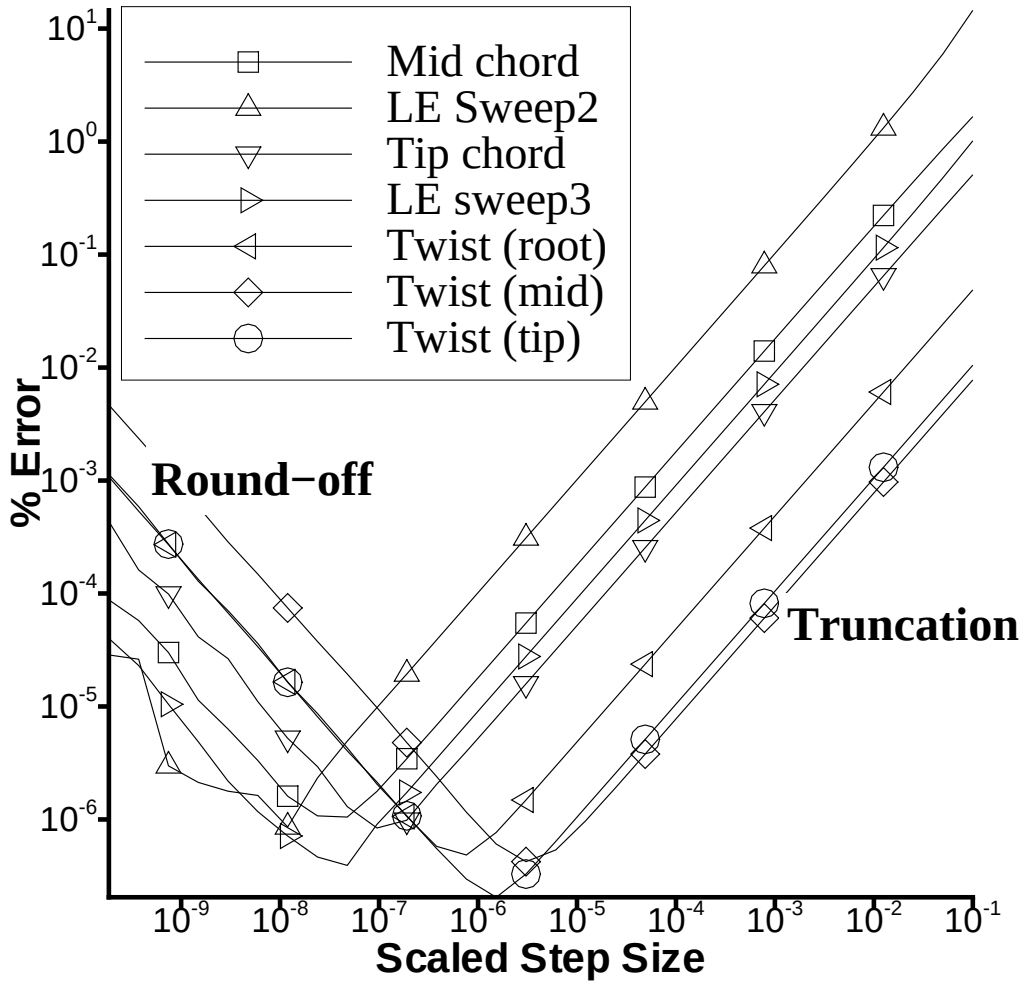
j.a.samareh@larc.nasa.gov

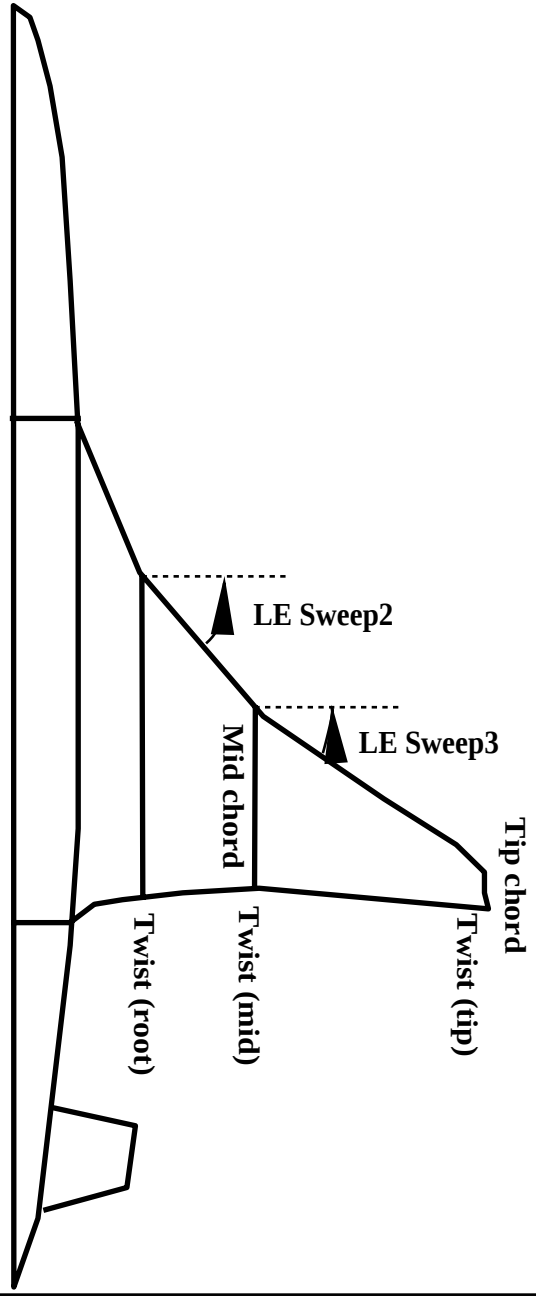
Multidisciplinary Shape Optimization (MSO)



j.a.samareh@larc.nasa.gov

Errors in Finite Difference Approximations





j.a.samareh@larc.nasa.gov

Shape Parameterization

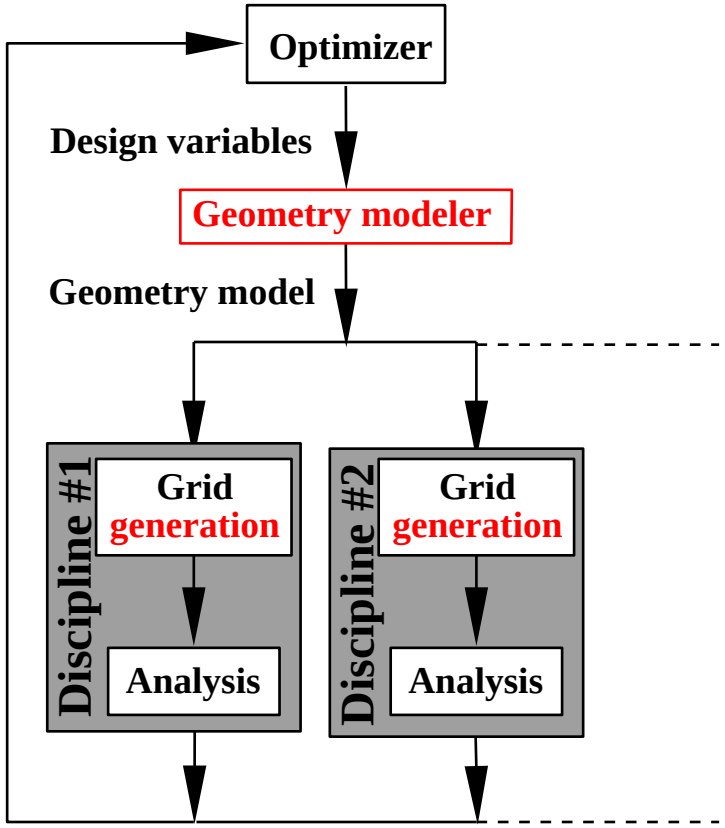
Parameterization tools must:

- **parameterize the whole problem, not just one discipline**
- **parameterize all models consistently (e. g., structures, aero, ...)**
- **handle high−fidelity models (e. g., CFD, FEM, ...)**
- **be automated (affordable design cycle time)**
  (grid generation is still manual and labor intensive for most disciplines)
- **provide accurate sensitivity data**
  (gradient−based optimization)
- **suitable for shape optimization processes**

j.a.samareh@larc.nasa.gov

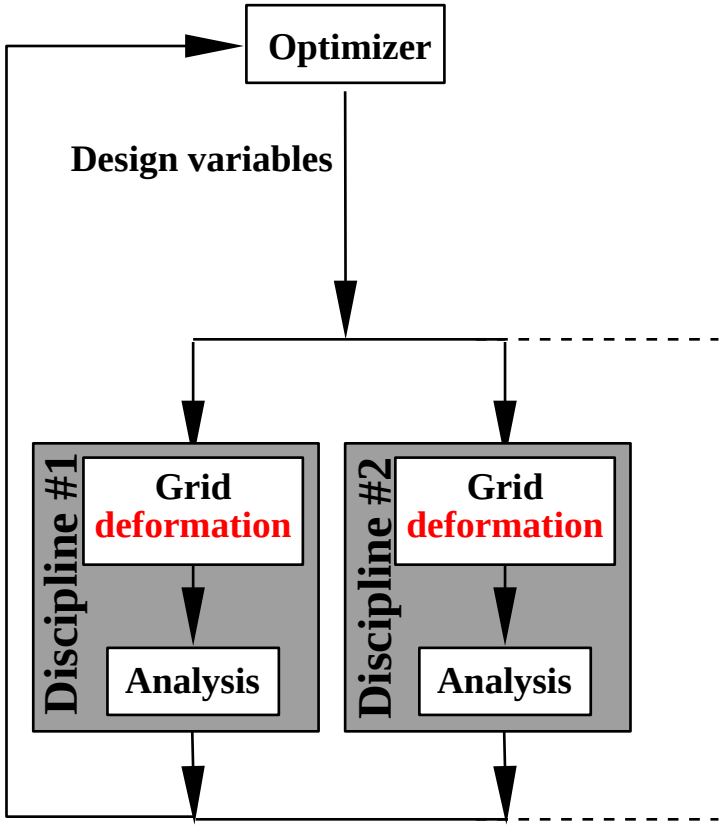
Shape Optimization Processes

Parameterize the geometry model



Partial Differential Equation
Polynomial and Spline
CAD−Based
MASSOUD

Parameterize the analysis models



Basis Vector
Domain Element
Discrete
Analytical
Free Form Deformation
MASSOUD

j.a.samareh@larc.nasa.gov

Important criteria for MDO applications of complex, 3D models

Consistent: Is the parameterization consistent across multiple disciplines?

Airplane shape design variables: Are the design variables directly related to the airplane shape design variables such as camber, thickness, twist, shear, and planform?

Compact: Does the parameterization provide a compact set of design variables?
10s vs 1000s

Smooth: Does the shape perturbation maintain a smooth geometry?

Local control: Is there any local control on shape changes?

Analytical sensitivity: Is it feasible to calculate the sensitivity analytically?

Grid deformation: Does the parameterization allow the grid to be deformed?

Setup time: Can a shape optimization application be set up quickly?
hours, days, weeks, months?

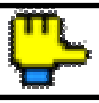
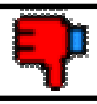
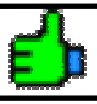
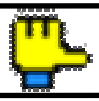
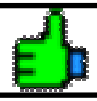
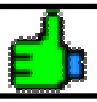
Existing grid: Does the parameterization allow the existing grid to be reused?
Does it require to reverse engineer the baseline design parameters?

CAD: Is there a direct connection to the CAD system?

j.a.samareh@larc.nasa.gov

Summary of Shape Parameterization Techniques

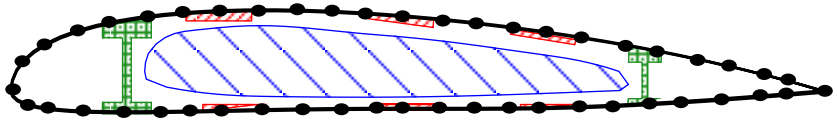
(important criteria for MDO applications of complex, 3D models)

Criteria \ Approaches	Basis vector	Domain element	PDE	Discrete	Polynomial and spline	CAD	Analytical	FFD	MASSOUD
Consistent parameterization									
Airplane shape DVs									
Compact set of DVs									
Smooth geometry									
Local control									
Analytical sensitivity									
Grid deformation									
Setup time									
Existing grids									
CAD connection									

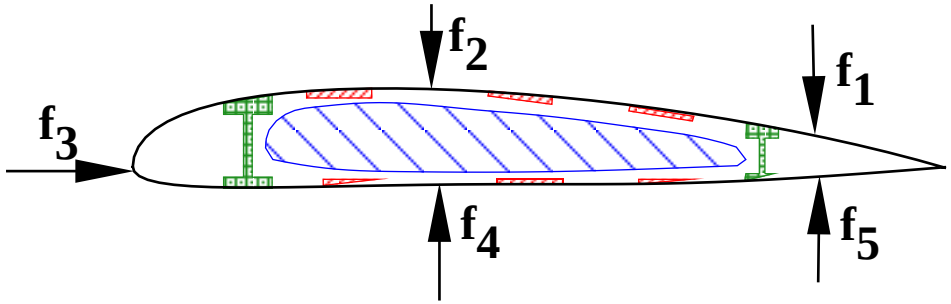
j.a.samareh@larc.nasa.gov

Discrete Approach

Consistent parameterization	👎
Airplane shape DVs	👎
Compact set of DVs	👎
Smooth geometry	👎
Local control	👍
Analytical sensitivity	👍
Grid deformation	👍
Setup time	👍
Existing grids	👍
CAD connection	👎



Design variables: points on CFD surface grid

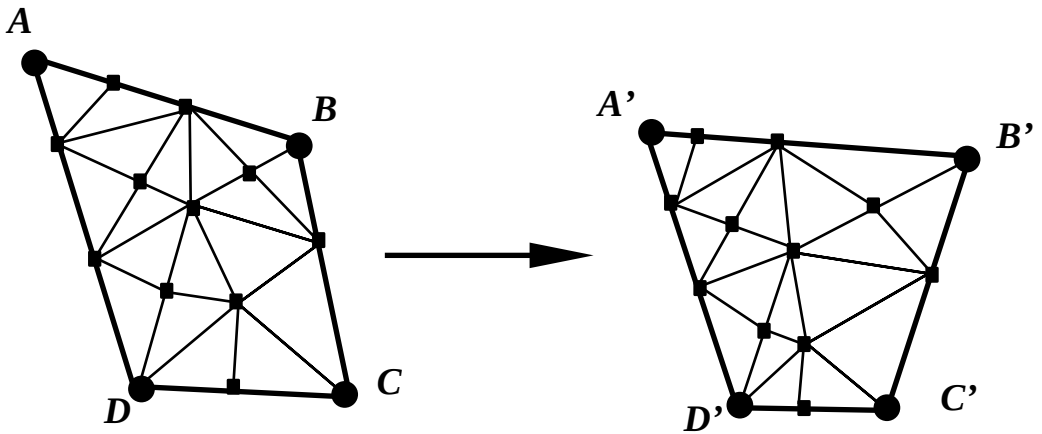


Design variables: fictitious loads acting on the model (natural design approach). The relationship between changes in design variables and grid−point locations is established through a finite element analysis.

j.a.samareh@larc.nasa.gov

Domain Element Approach

Consistent parameterization	👍
Airplane shape DVs	👎
Compact set of DVs	👍
Smooth geometry	👍
Local control	👍
Analytical sensitivity	👍
Grid deformation	👍
Setup time	👍
Existing grids	👍
CAD connection	👎



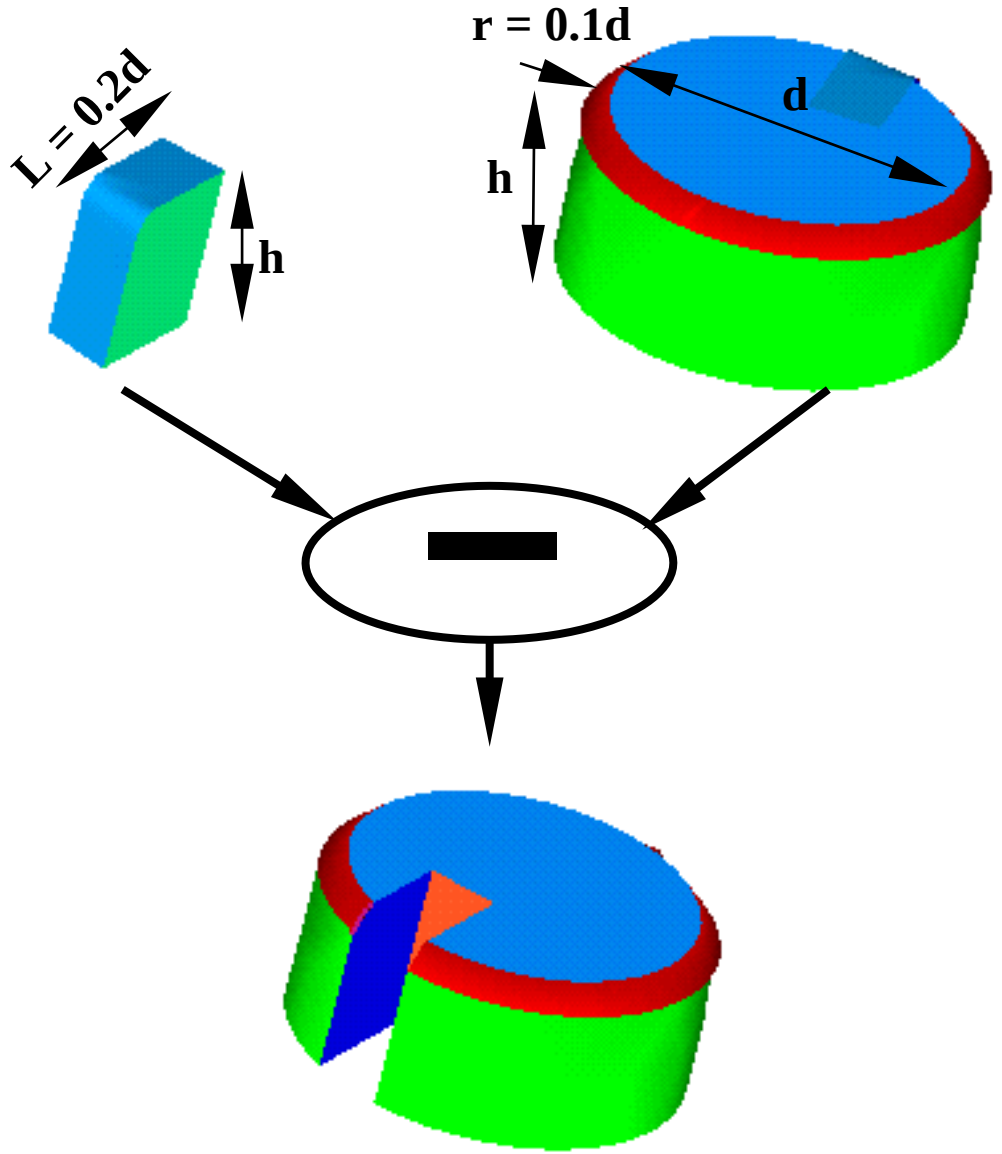
a) Baseline model **b) Deformed model**

Design Variables: $(X,Y)_{A,\ B,C,D}$

j.a.samareh@larc.nasa.gov

CAD Approach
Feature−Based CAD

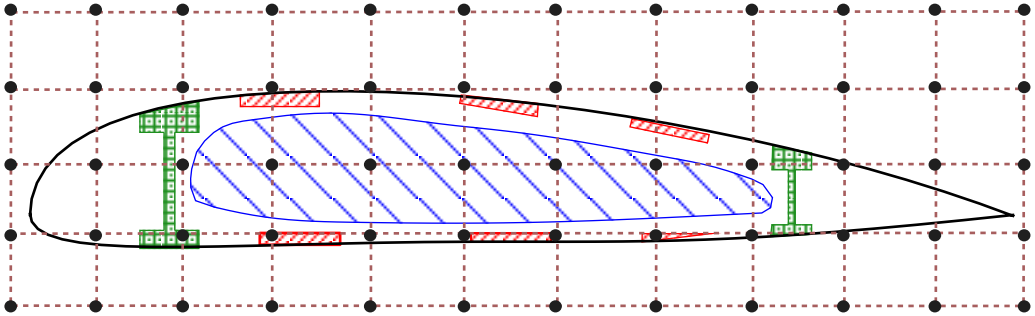
Consistent parameterization
Airplane shape DVs
Compact set of DVs
Smooth geometry
Local control
Analytical sensitivity
Grid deformation
Setup time
Existing grids
CAD connection

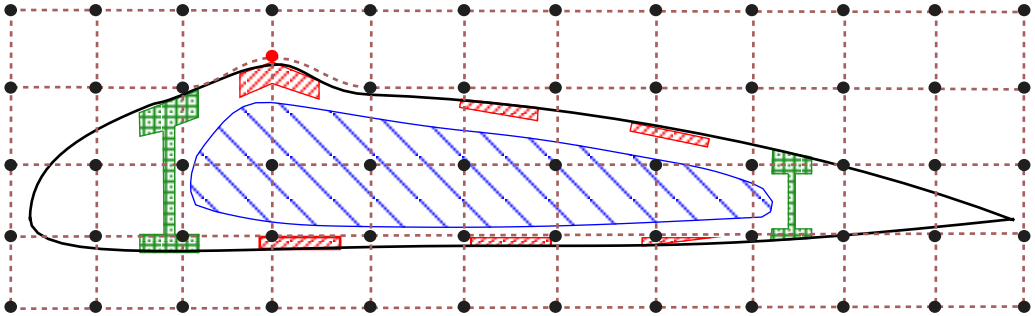


j.a.samareh@larc.nasa.gov

Free−Form Deformation

Consistent parameterization	
Airplane shape DVs	
Compact set of DVs	
Smooth geometry	
Local control	
Analytical sensitivity	
Grid deformation	
Setup time	
Existing grids	
CAD connection	





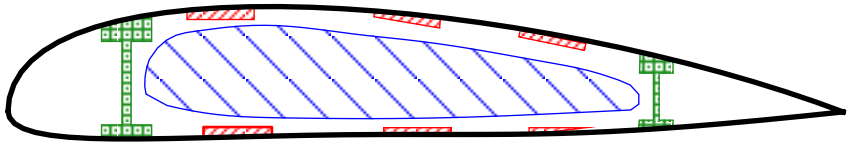
j.a.samareh@larc.nasa.gov

MASSOUD

Multidisciplinary Aero/Struc Shape Optimization Using Deformation

Samareh, J. A.: A Novel Shape Parameterization Approach, NASA−TM−1999−209116, May 1999.

- **Parameterize the discipline grids**
  (Avoids manual regeneration of grids)



Components: Aero (skin), Structures (skin, spars, ..), Weight(fuel tank), Control(.....)

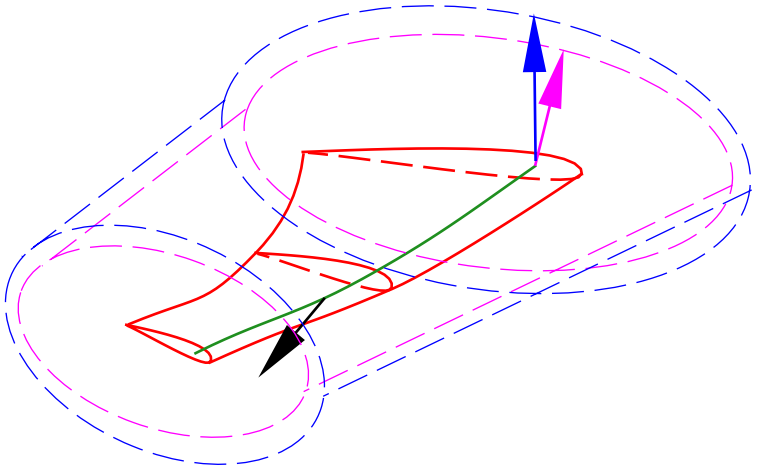
- **Parameterize the changes in shape, not the shape itself**
  (Provides a compact set of design variables)

$$G(\bar{V}) = G_{initial} + \Delta G(\bar{V})$$

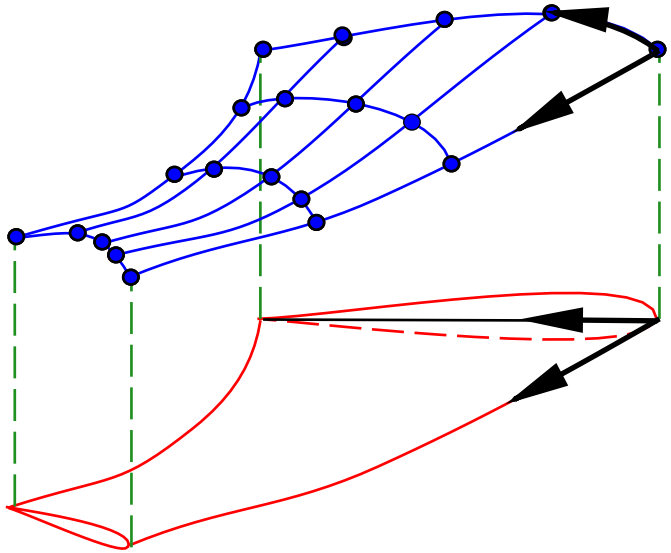
- **Use soft object animation for deforming grids**
  Computer−Animated Features: Toy Story, Bug's Life
  (Allows fast grid regeneration)
  - **Nonlinear global deformation (Twist and Dihedral)**
  - **Deformation of parametric NURBS surfaces (Camber and Thickness)**
  - **Free−form deformation (Planform)**

j.a.samareh@larc.nasa.gov

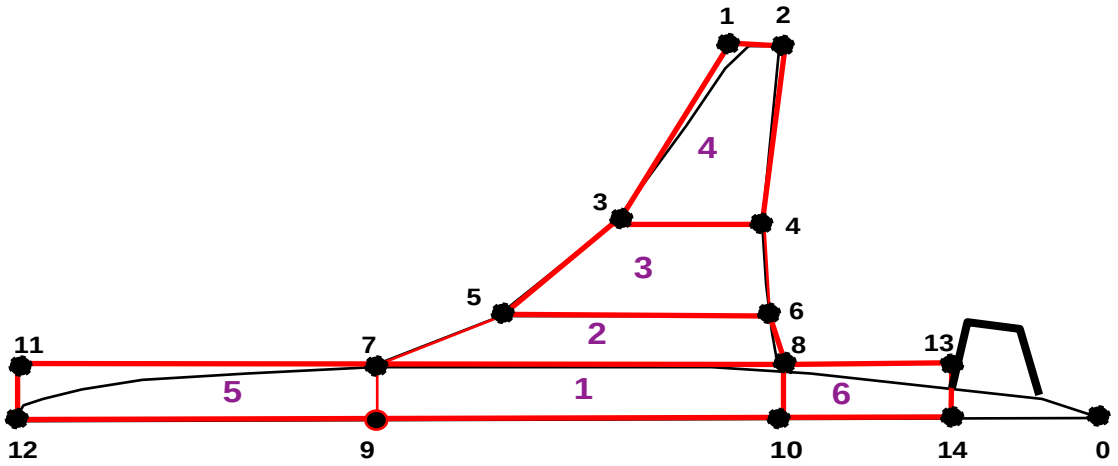
Multidisciplinary Aero/Struc Shape Optimization Using Deformation (MASSOUD)



Nonlinear global deformation
(Twist and Dihedral)



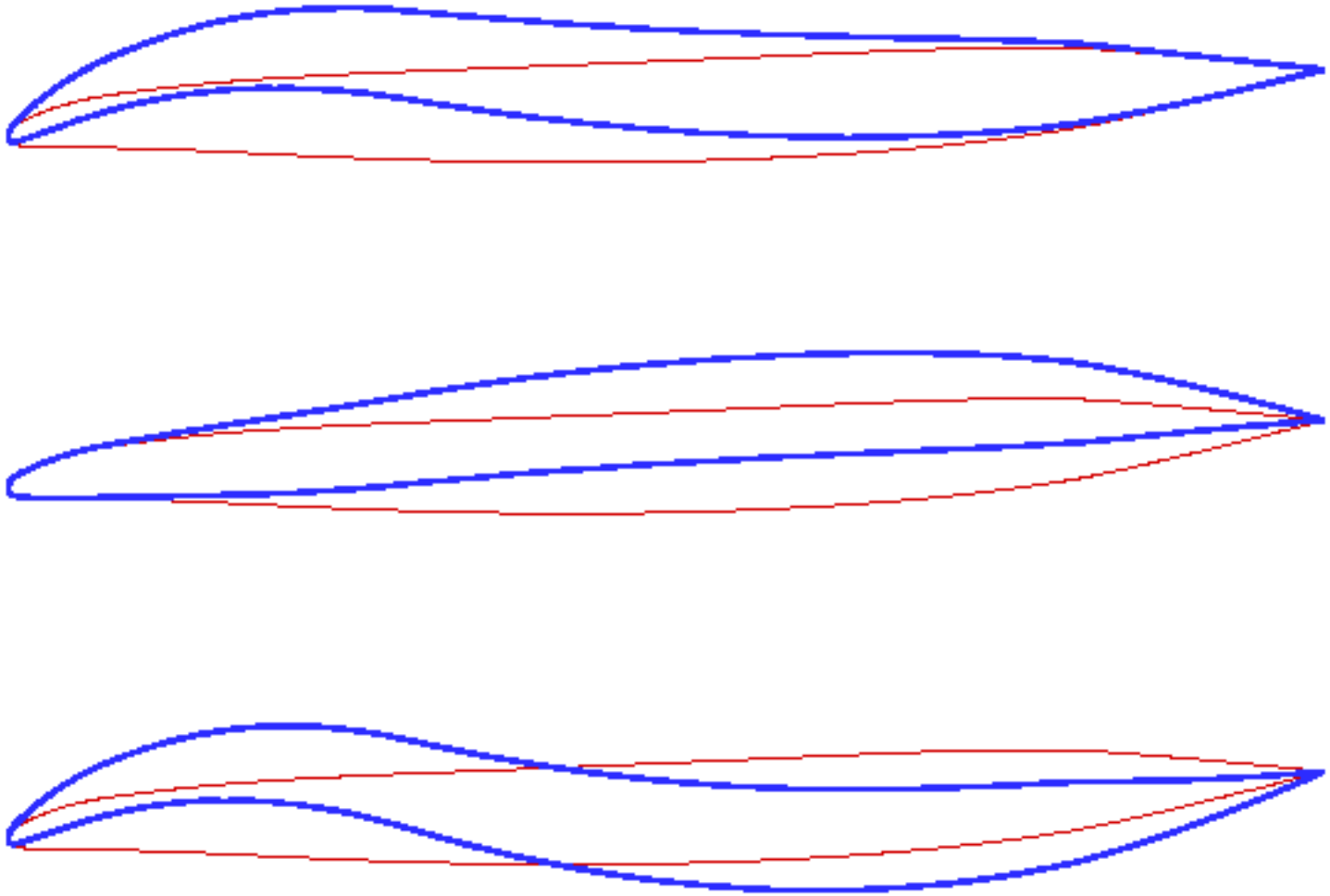
Deformation of parametric NURBS surfaces
(Camber and Thickness)



Free−form deformation
(Planform)

j.a.samareh@larc.nasa.gov

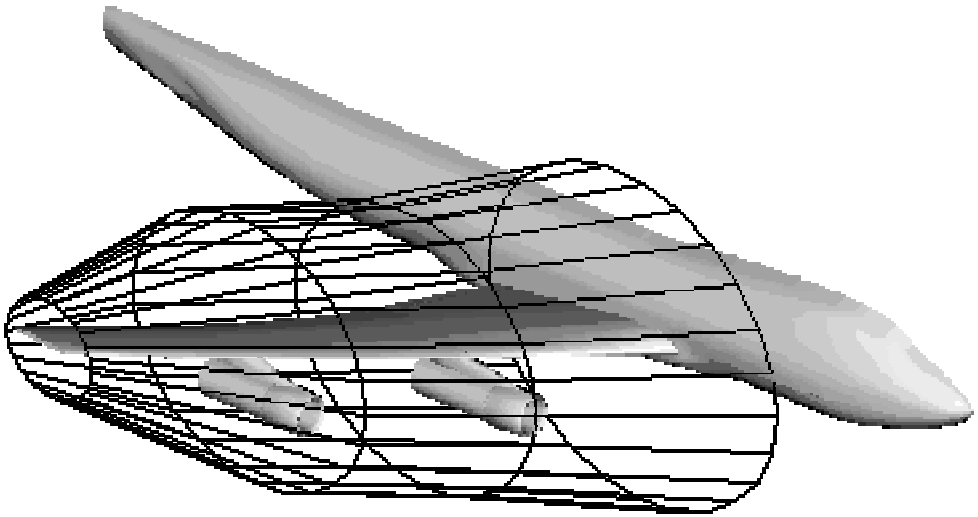
Deformation of Parametric NURBS Surfaces



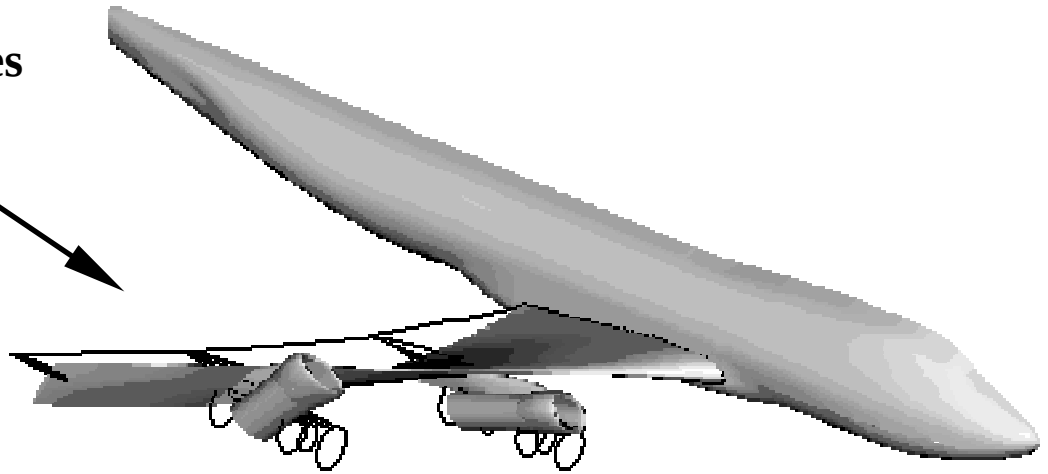
Camber: two design variables

j.a.samareh@larc.nasa.gov

Nonlinear Global Deformation
(Twist and Dihedral)



Twist: 3 Design Variables

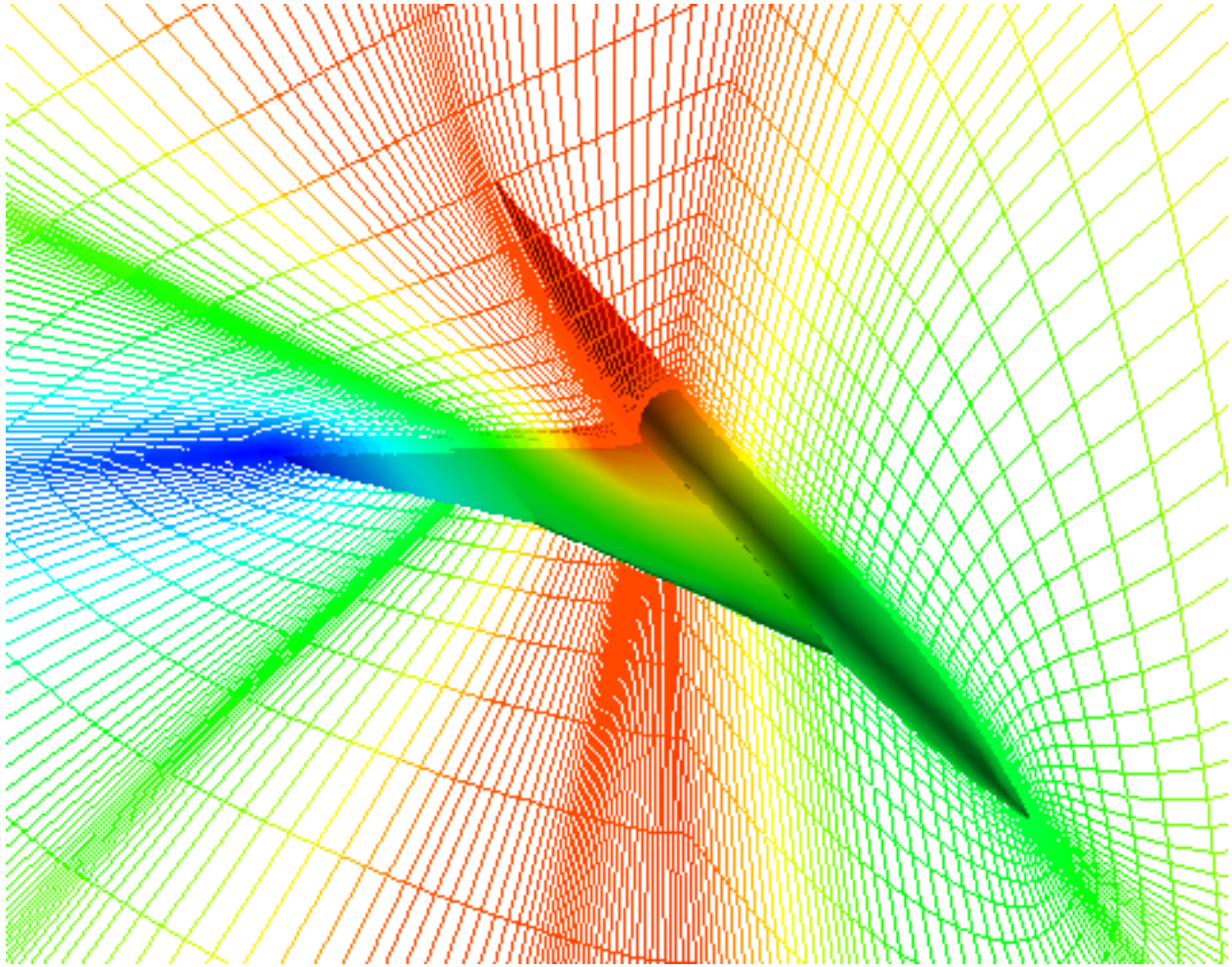


j.a.samareh@larc.nasa.gov

j.a.samareh@larc.nasa.gov

MASSOUD

Sensitivity of CFD volume grid with respect to root chord
(CSCMDO: http://geolab.larc.nasa.gov/CSCMDO/)



j.a.samareh@larc.nasa.gov

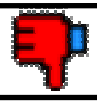
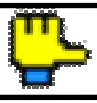
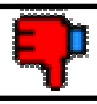
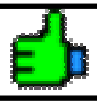
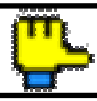
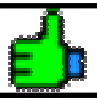
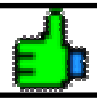
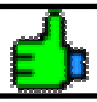
MASSOUD

Consistent parameterization	
Airplane shape DVs	
Compact set of DVs	
Smooth geometry	
Local control	
Analytical sensitivity	
Grid deformation	
Setup time	
Existing grids	
CAD connection	

j.a.samareh@larc.nasa.gov

Summary of Shape Parameterization Techniques

(important criteria for MDO applications of complex, 3D models)

Criteria \ Approaches	Basis vector	Domain element	PDE	Discrete	Polynomial and spline	CAD	Analytical	FFD	MASSOUD
Consistent parameterization									
Airplane shape DVs									
Compact set of DVs									
Smooth geometry									
Local control									
Analytical sensitivity									
Grid deformation									
Setup time									
Existing grids									
CAD connection									

j.a.samareh@larc.nasa.gov