Multidisciplinary High-Fidelity Analysis and Optimization of Aerospace Vehicles, Part 2: Preliminary Results

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  - J. C. Townsend

Outline

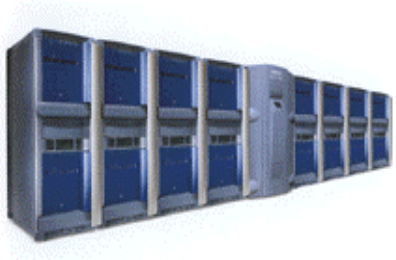
- Background
- Problem definition
- Analysis formulation
- *Current status
- *Software engineering issues
- Validation
- Results
- Summary

*Presented in Part 1: Formulation

Background

1992 NASA LaRC decisions:

- **Began research in Multidisciplinary Design Optimization (MDO) with high-fidelity analysis codes**
  - **Exploit High Performance Computing and Communication (HPCC) as Grand Challenge application focus**
- **Selected High Speed Civil Transport (HSCT) as focus application**
  - **Exploit synergy with the High Speed Research (HSR) program**



By 1999:

- **Evolved into the HSCT4.0 application**
  - **Research endeavor in both MDO and HPCC**
  - **Unique combination of disciplinary breadth and depth in MDO research**

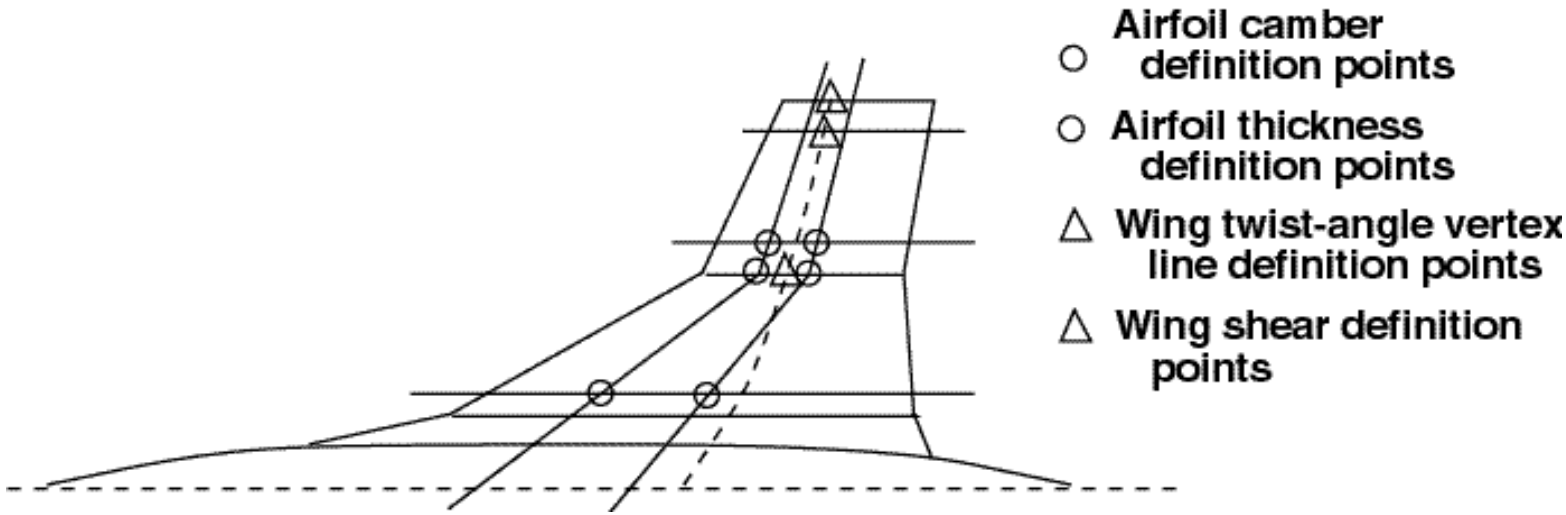
HSCT4.0 Application

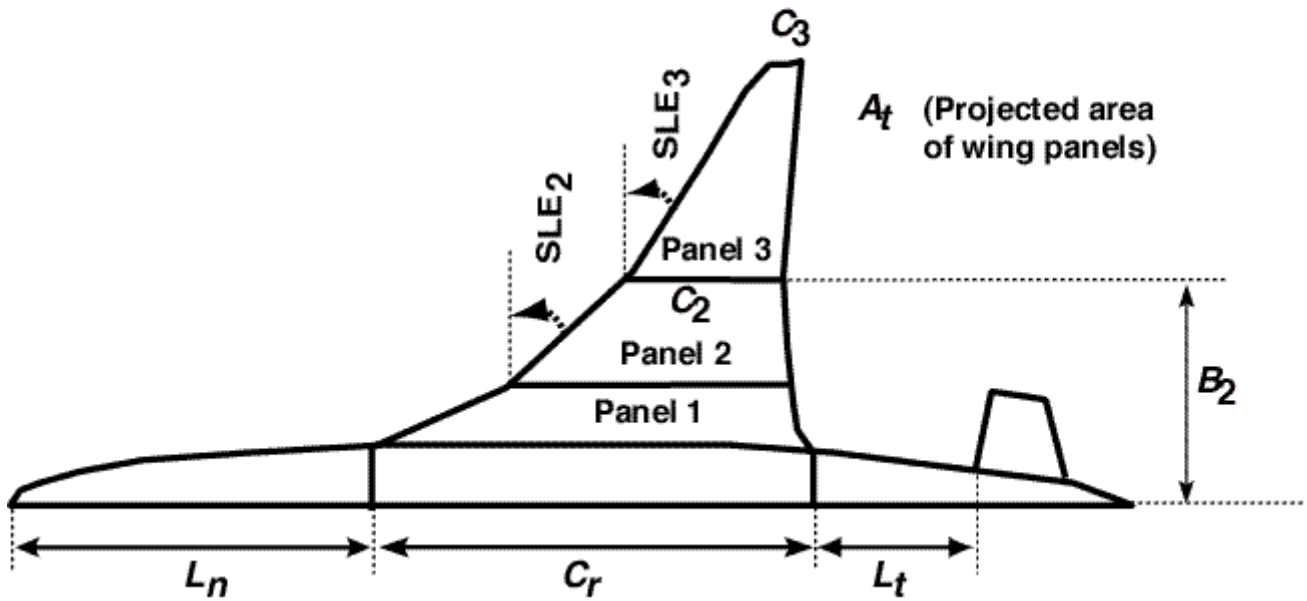
- Realistic aircraft concept
- Aerodynamic analysis
  - Linear (USSAERO using 1100-point surface grid)
  - Nonlinear (CFL3D using 600,000-point volume grid)
- Structural analysis
  - GENESIS using FEM with 40,000 DOFs
- Performance analysis
  - FLOPS
- Weights analysis
- 8 load conditions
  - Cruise
  - 6 manuever (2.5g & -1g)
  - Taxi

HSCT 4.0 Optimization Formulation

- Objective function: Minimize gross take-off weight
- Constraints - O(10,000)
  - Geometry
    - Fuel volume, ply mixture ratio, airfoil interior thickness, take-off scrape and landing scrape
  - Structural
    - Stress and buckling
  - Performance
    - Range, takeoff field length, landing field length, approach speed, time-to-climb-to cruise, and noise
- 271 Design Variables
  - Shape (27)
  - Structural (244)

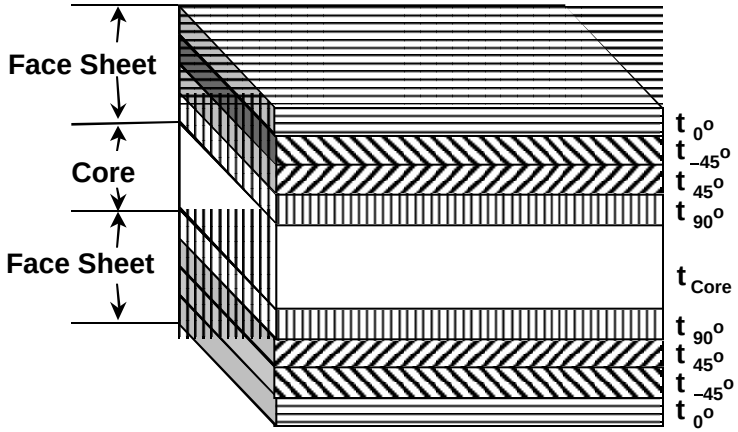
HSCT 4.0 Shape Design Variables

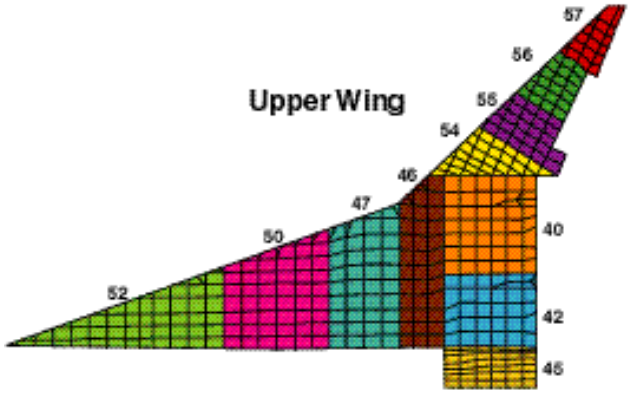


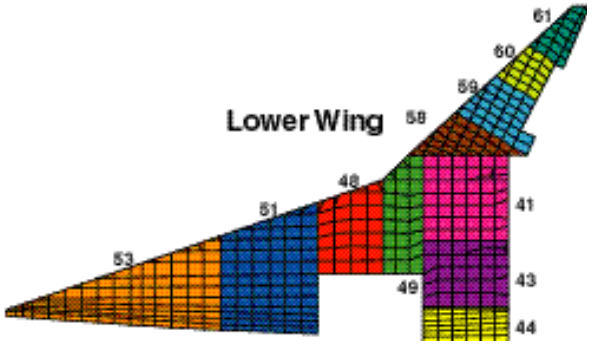


HSCT 4.0 Structural Design Variables

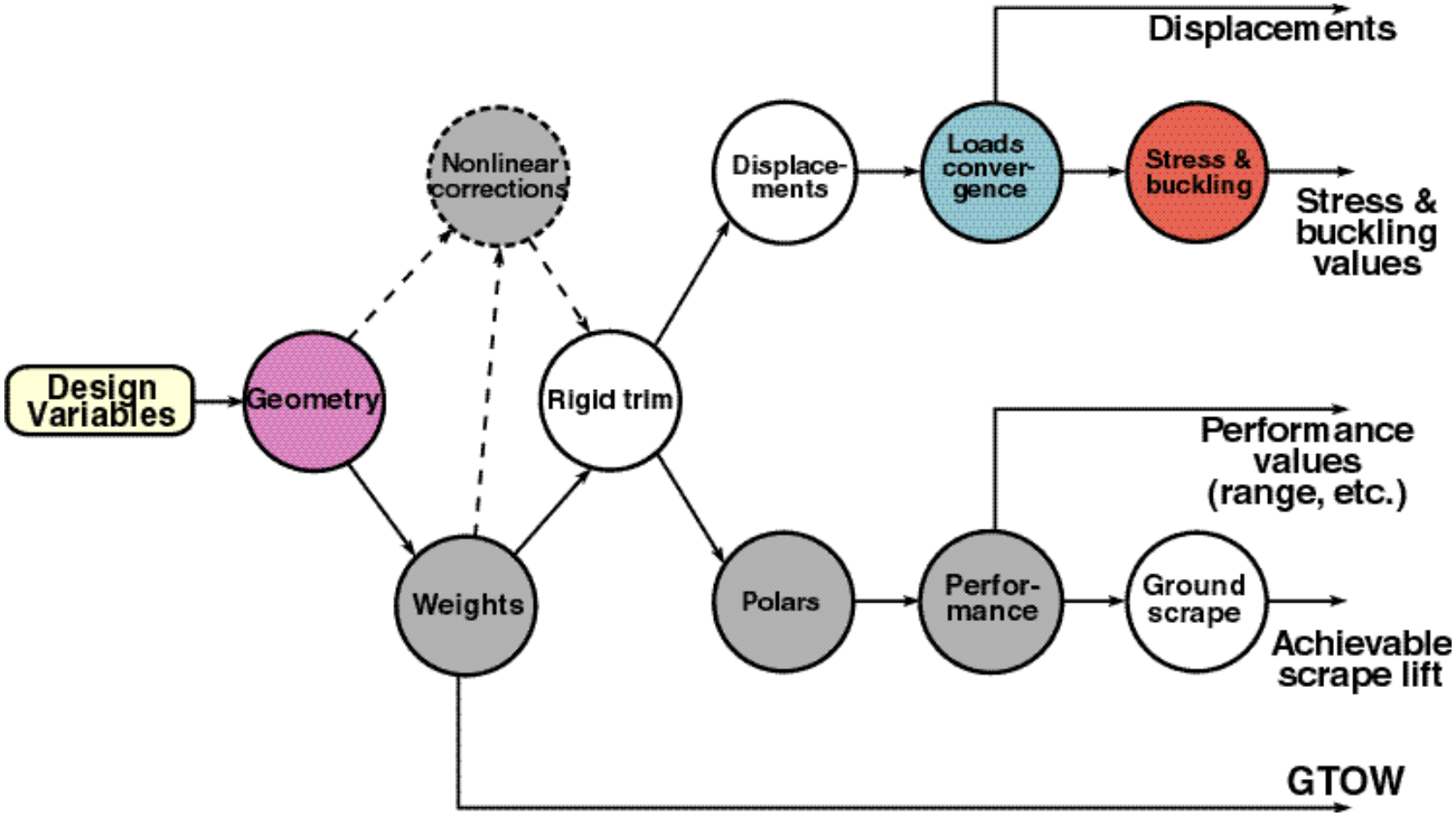
- 4 DVs per zone
  - 0º ply thickness
  - 90º ply thickness
  - 45º ply thickness
  - Core thickness
- 61 design zones







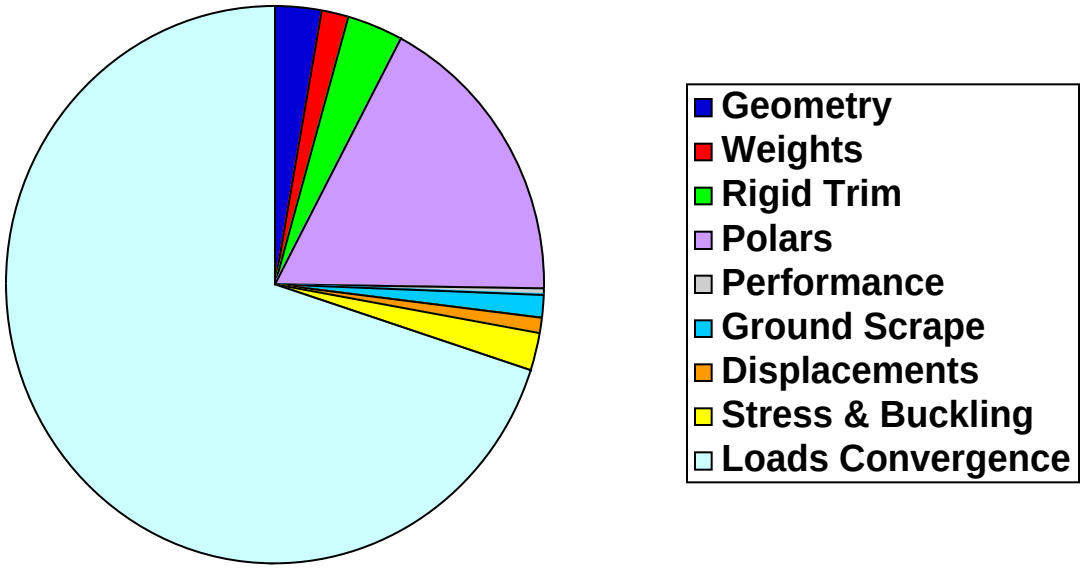
HSCT 4.0 Analysis



Integrated with CJOpt environment

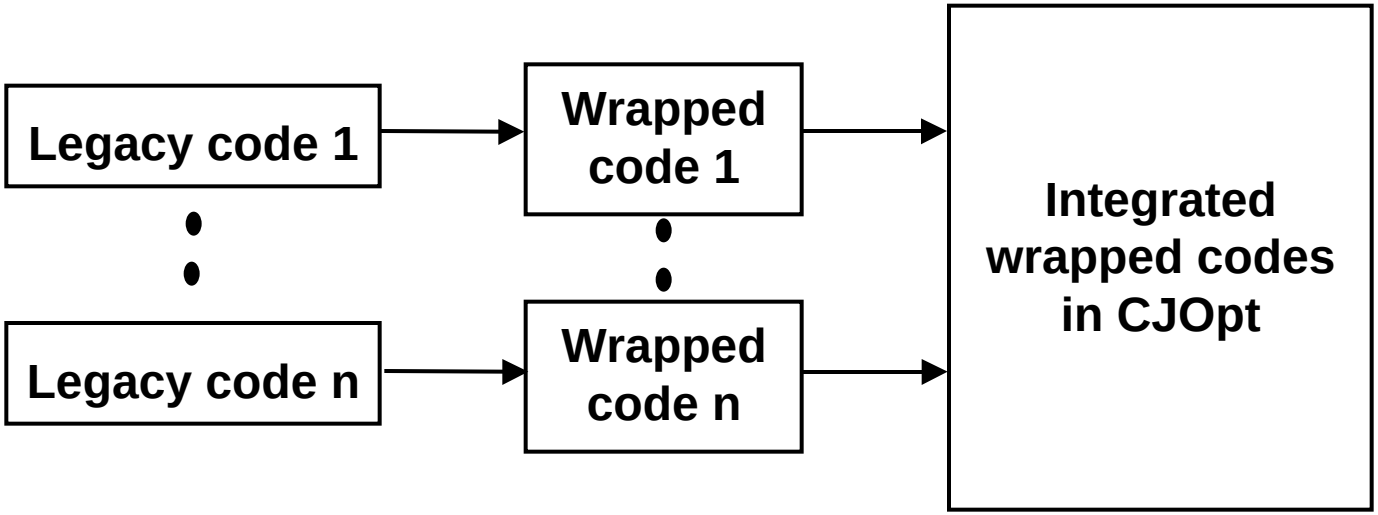
Integrated HSCT4.0 Analysis

- Large amount of data generated within CJOpt in each analysis cycle
  - 300 files
  - 200 MB
- 5 hrs wall clock time for HSCT4.0 Analysis Process
  - Exclusive of Nonlinear Corrections Process

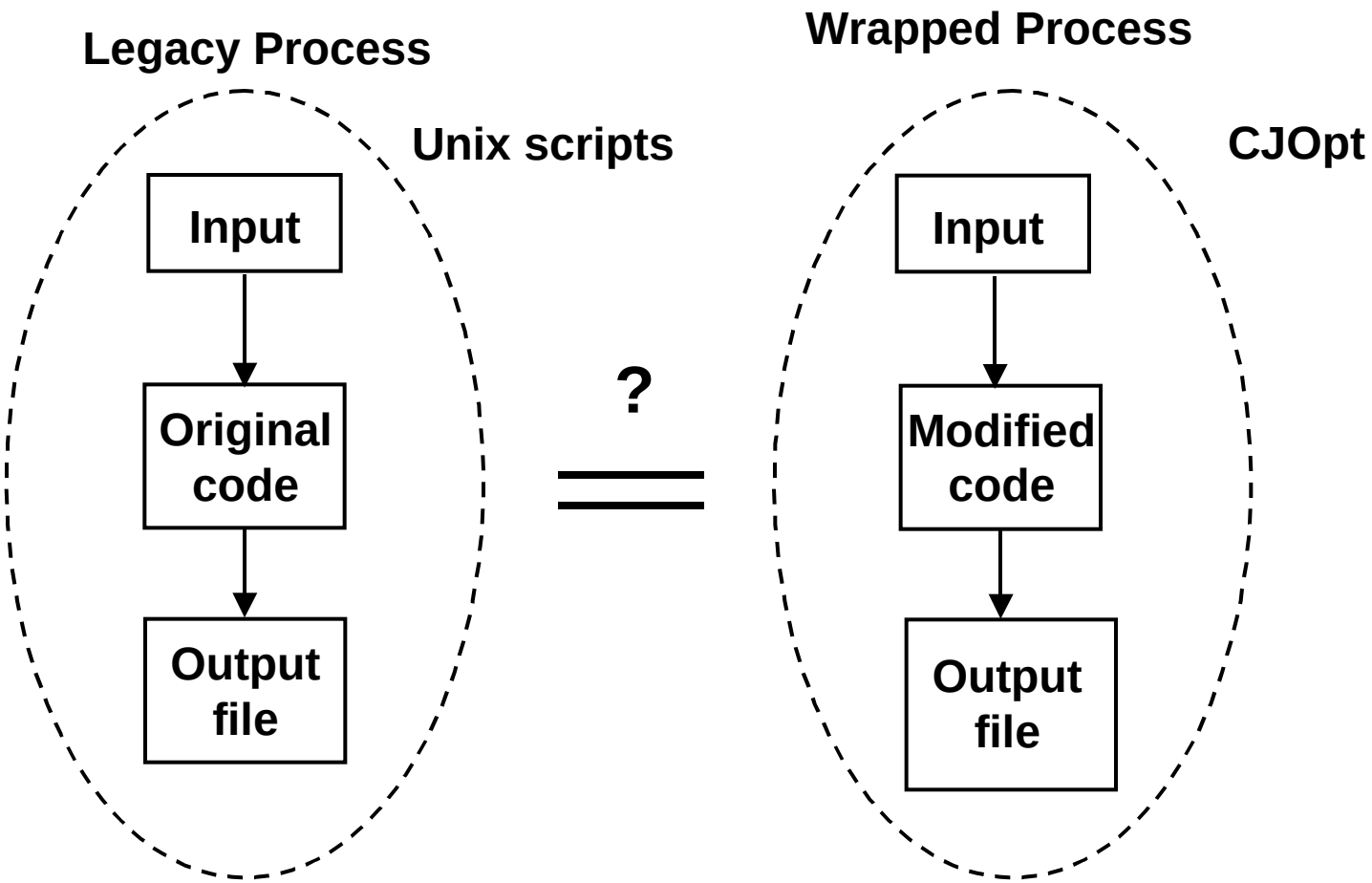


Additional 4 hrs to complete Nonlinear Corrections Process

Steps in MDO Integration Process



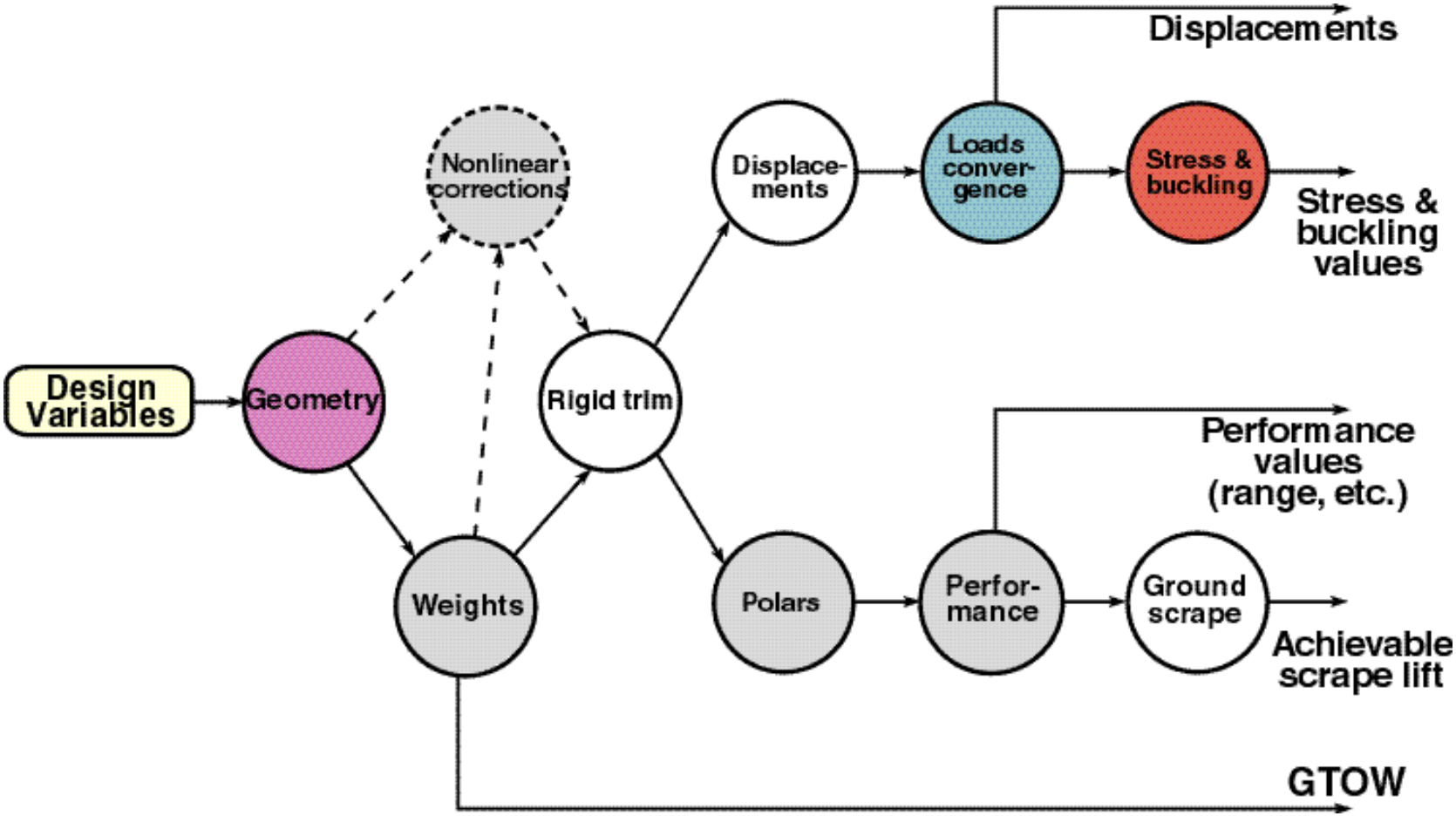
Wrapping Validation



Analysis Validation Plan

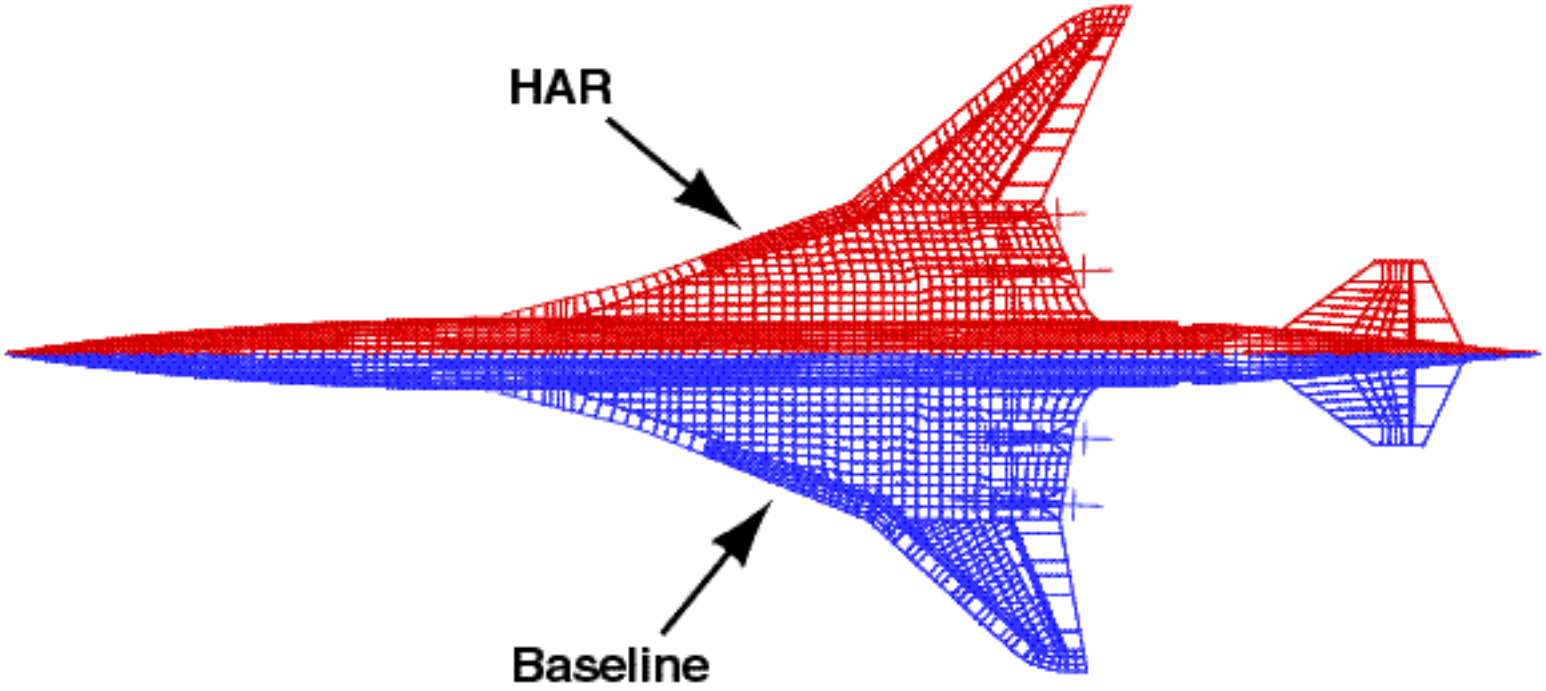
- 2 test cases (initial design variable values)
  - Baseline
  - Higher Aspect Ratio (HAR)
- Verify integrated CJOPT output files match identically with output files obtained from executing "standalone legacy codes"
- Ensure results are reasonable from an engineering standpoint

HSCT 4.0 Analysis

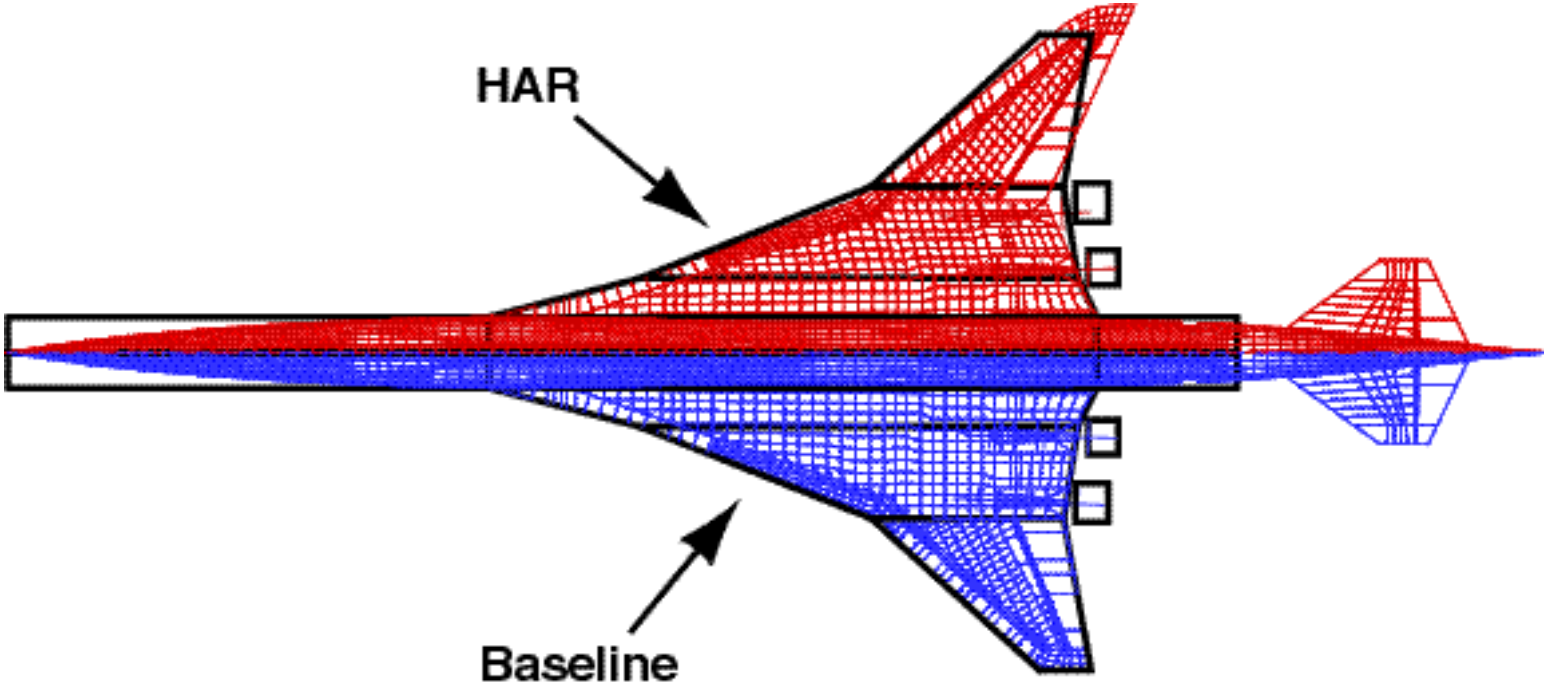


Integrated with CJOpt environment

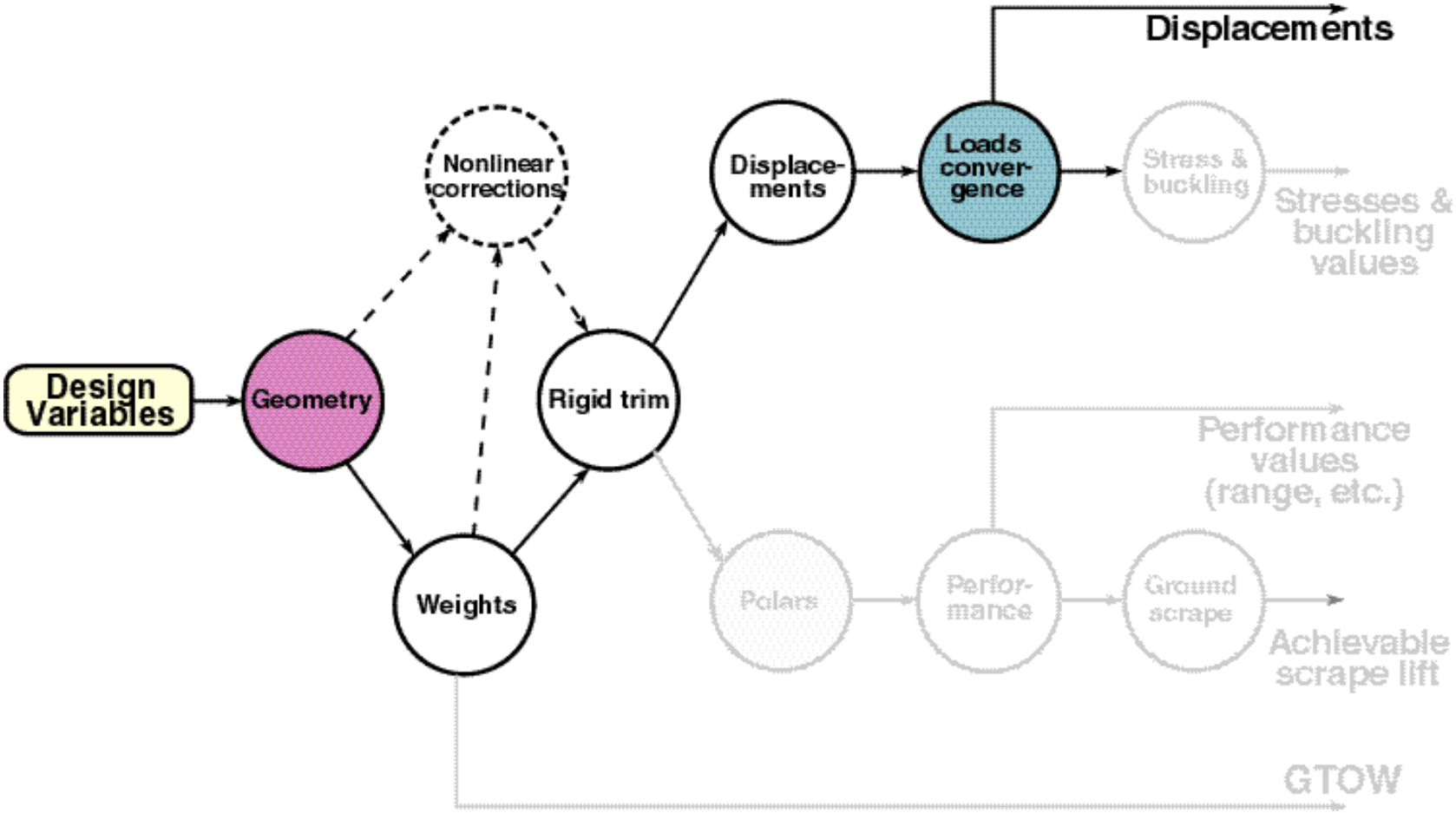
Geometry Process Results



Geometry Process Results



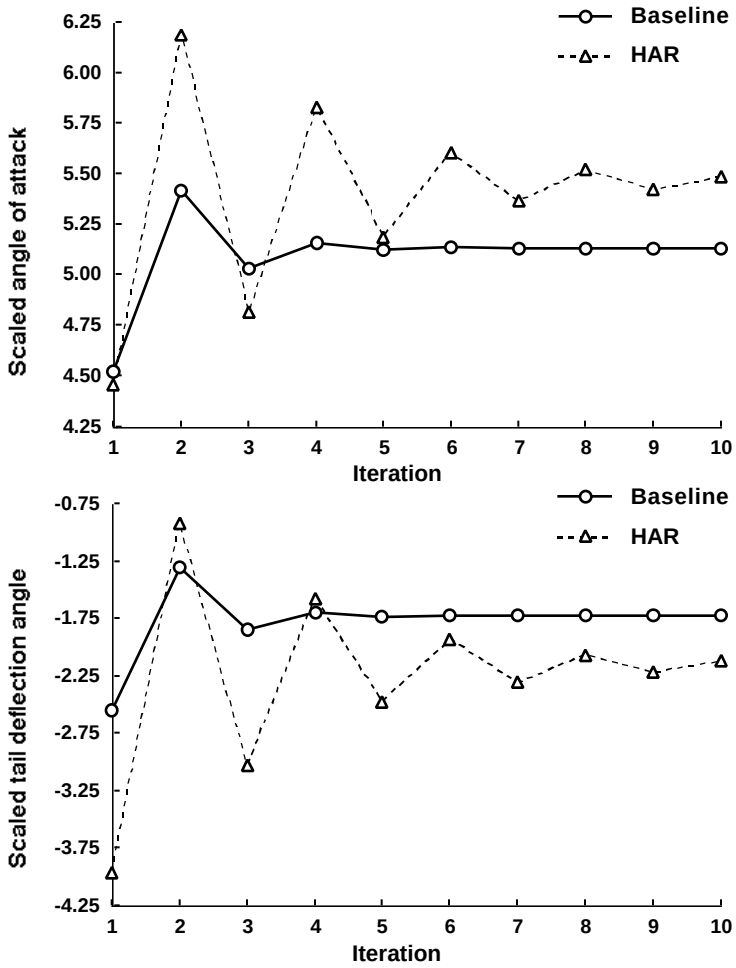
Loads Convergence Process Validation



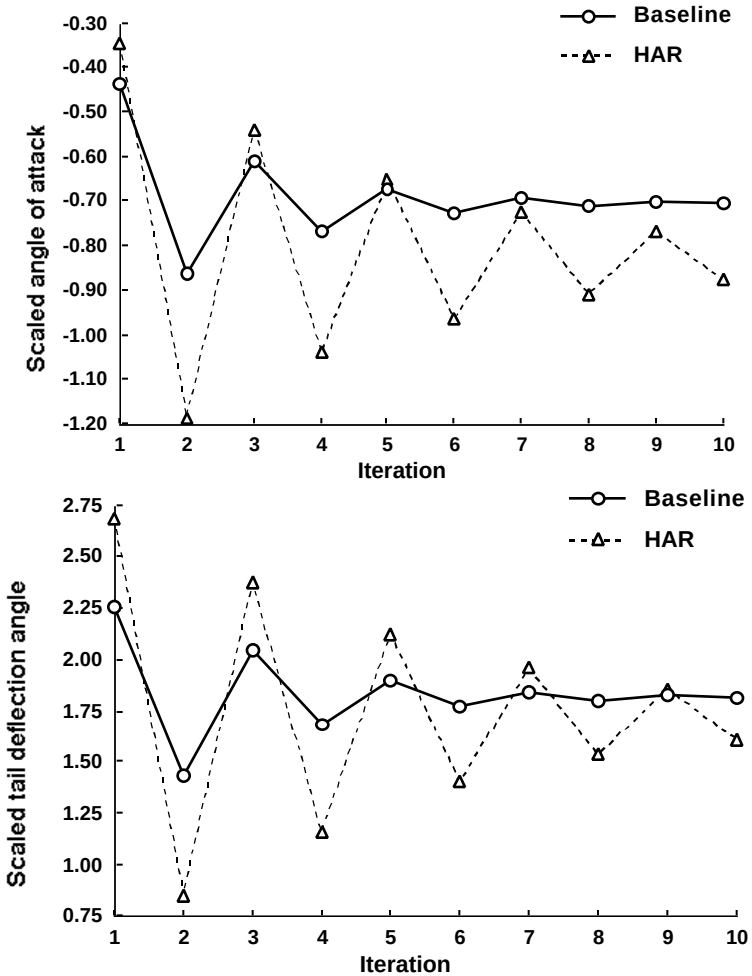
Integrated with CJOpt environment

Loads Convergence Process Results

2.5g load condition



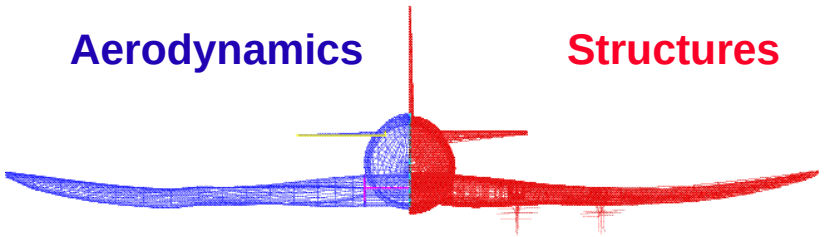
-1g load condition



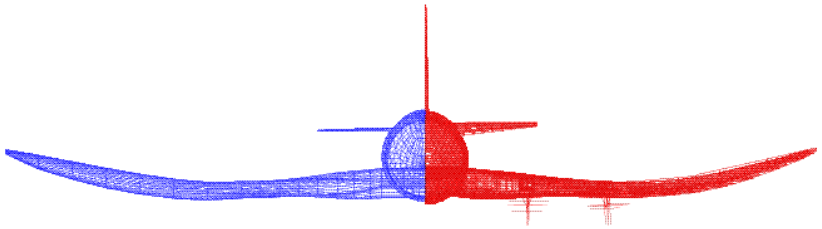
Validation done at iteration 10

Loads Convergence Process Results - Concluded

2.5g load condition

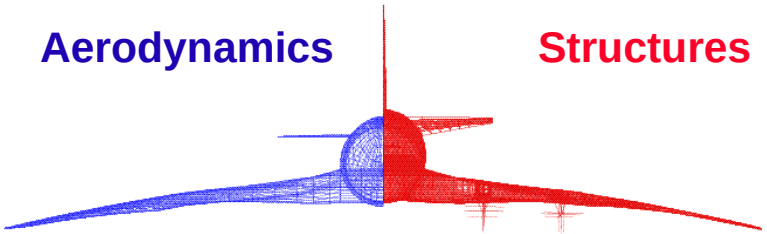


Baseline

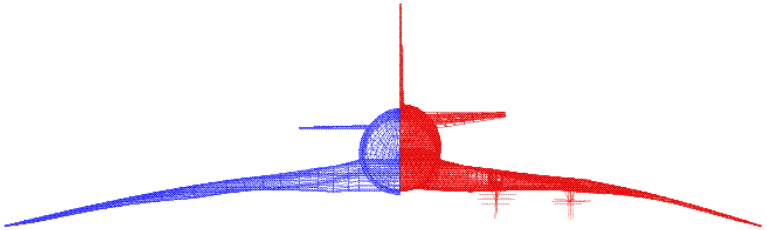


HAR

-1g load condition



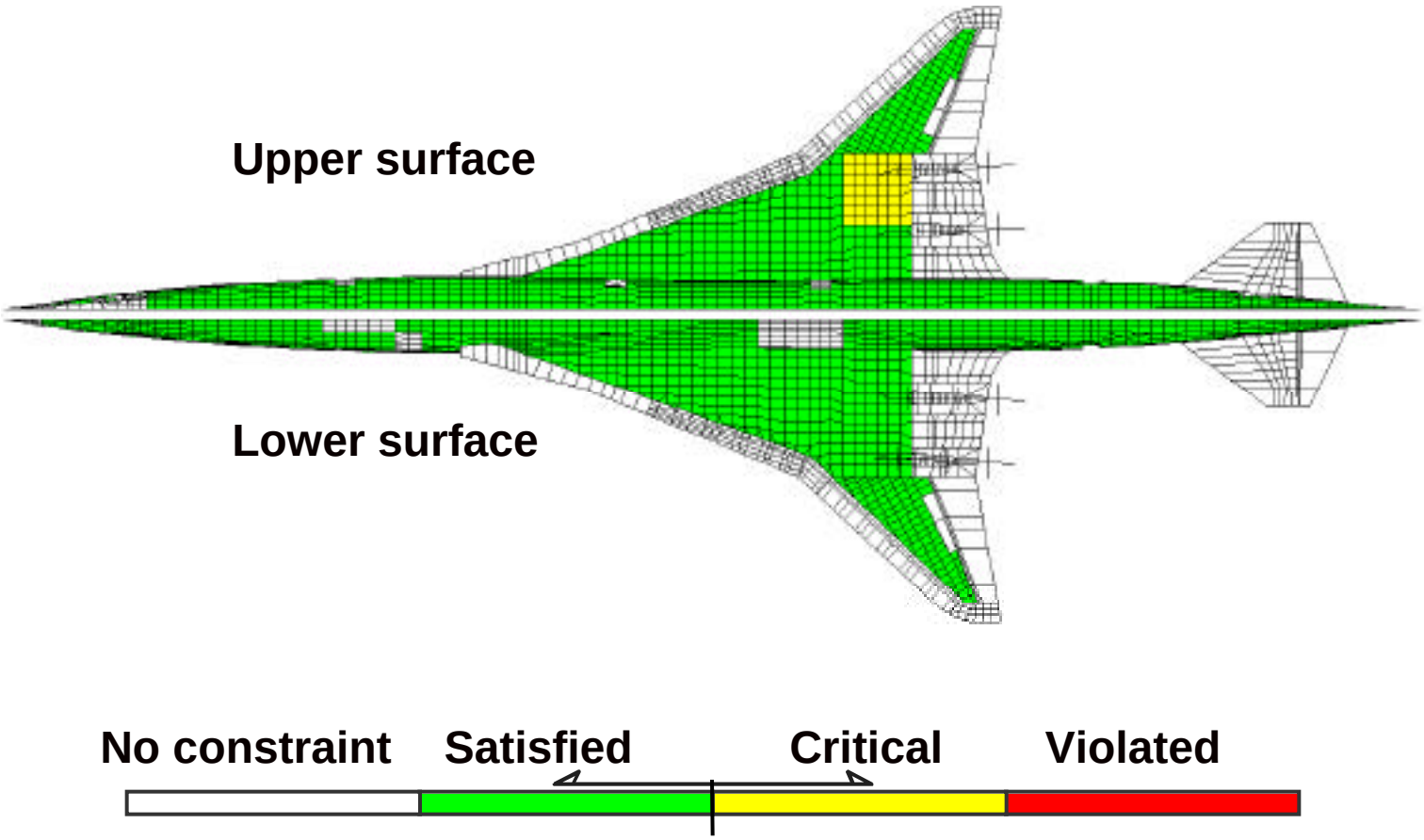
Baseline



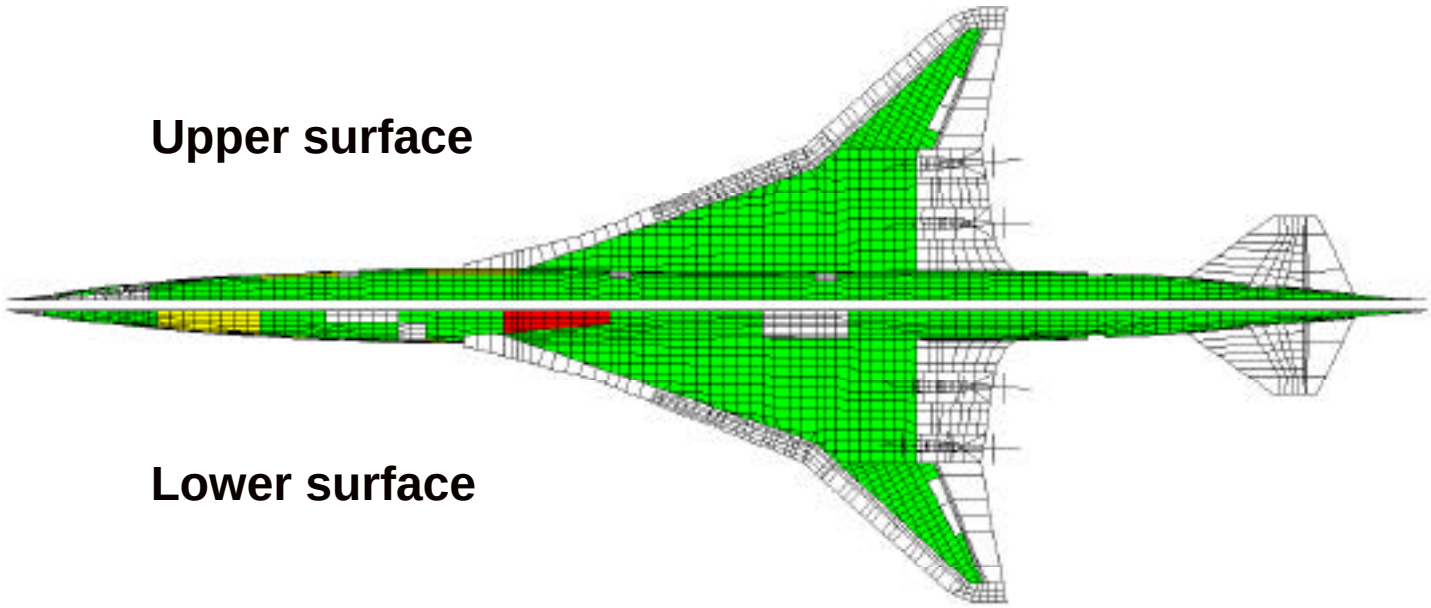
HAR

Validation done at iteration 10

Stress Failure Index Results
Baseline Configuration 2.5g Load Condition

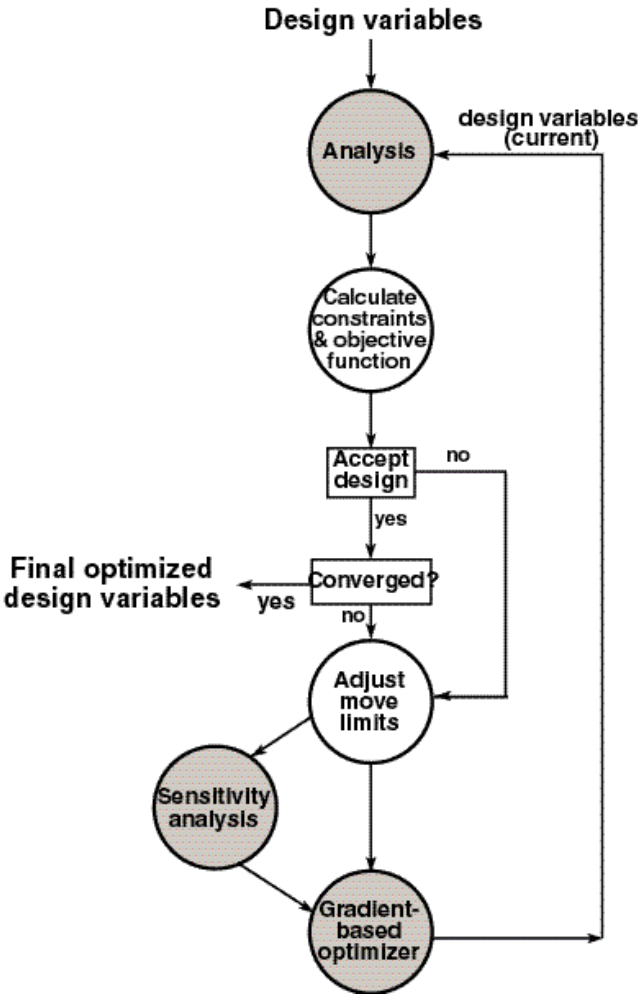


Buckling Failure Criteria Results
Baseline Configuration 2.5g Load Condition



Nonlinear Aerodynamic Shape Optimization Formulation

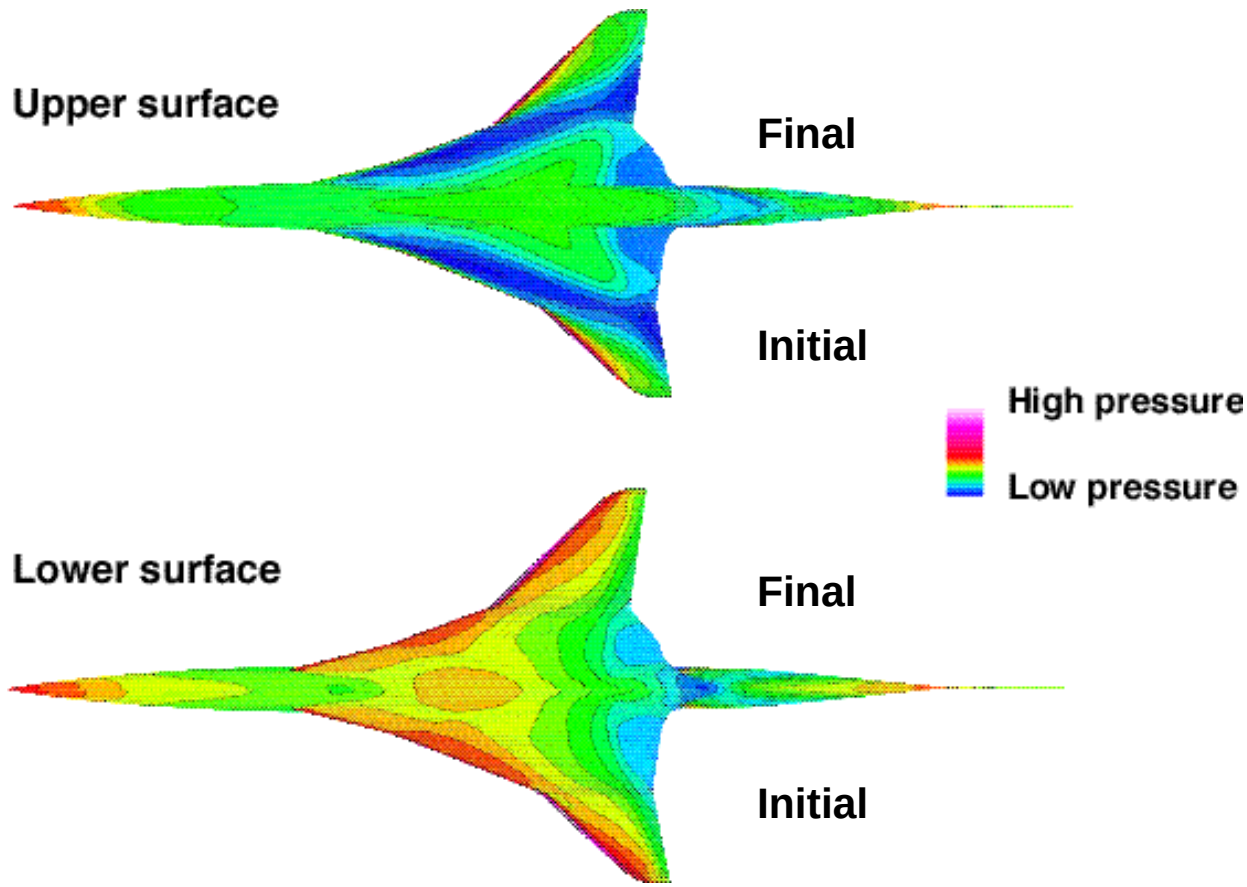
- Purpose
  - Use to determine bounds on shape design variables
  - Use to test optimization
- 27 shape design variables
- Objective function
  - Minimize C_D
- Analysis
  - Geometry
  - Nonlinear aerodynamics
  - Cruise condition
- Sequential linear programming (SLP) technique



Nonlinear Aerodynamic Shape Optimization Results

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

Fixed C_L



Validation Lessons Learned
(Large-scale MDO Research Projects)

- **Allocate adequate time up front for requirements definition including definition of validation plan**
- **Require legacy analysis process be checked out with validation cases before wrapping and integration**
- **Validate incrementally in CJOpt environment**
- **Use of formal Software Configuration Management (SCM) essential**

Summary

- **Validated formulation and implementation of HSCT4.0 with reasonable confidence**
  - **Direct validation from SCM not complete**
  - **Only used 2 test cases**
- **Presented lessons learned while conducting complex MDO problems in research environment**