HSCT Design Capability
MDO and High Performance Computing

Final Review

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NASA HPPCP CAS Workshop 2000
NASA Ames Research Center
Mountain View, CA

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Presentation Outline

Overview – Joe Rehder

Discipline Summary – Vivek Mukhopadhyay

Computational Framework – Joe Rehder

Software Engineering – Andrea Salas

Lessons Learned/Future Plans – Joe Rehder

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Publications

- *AIAA 2000-0418 - Multidisciplinary High-fidelity Analysis And Optimization Of Aerospace Vehicles, Part 1: Formulation - J. L. Walsh, J. C. Townsend, A. O. Salas, J. A. Samareh, V. Mukhopadhyay, and J.-F. Barthelemy
- *AIAA 2000-0419 - Multidisciplinary High-fidelity Analysis And Optimization Of Aerospace Vehicles, Part 2: Preliminary Results - J. L. Walsh, R. P. Weston, J. A. Samareh, B. H. Mason, L. L. Green, and R. T. Biedron
- Distributed, Heterogeneous Computing Environment for Multidisciplinary Design & Analysis of Aerospace Vehicles - Raj Sistla, Gus Dovi, and Phillip Su - 5th National Symposium on LARGE-Scale Analysis, Design and Intelligent Synthesis Environments, Oct 12–15, 1999, Williamsburg, VA

*PDF versions of full papers available at http://techreports.larc.nasa.gov/ltrs/

Presentation slides for all papers available at http://fmad-www.larc.nasa.gov/mdob/MDOB/

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Objective of LaRC HPCCP CAS Grand Challenge Application

- Demonstrate high performance computing on a model MDO problem, including:
  - Multilevel N-S CFD analysis & sensitivity
  - FEM structural analysis & sensitivity
  - Mission performance, including multipoint objective function
  - Other disciplines, including cost, to be included as resources permit

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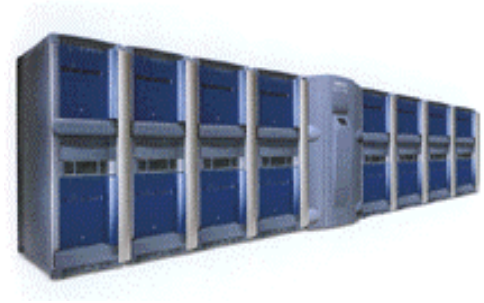
Background

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

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Build on Past Successes

- 1992 Demonstration of hard-coded framework (FIDO)
- 1994 Communications Library added
  - Weston, R. P., Townsend, J. C., Eidson, T. M., and Gates, R. L., "A Distributed Computing Environment for Multidisciplinary Design," *Proceedings of the 5th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Part 2, Panama City, FL, 1994, pp. 1091–1097
- 1996 Medium-fidelity codes added
  - Krishnan, R., Sistla, R., and Dovi, A. R., "High-Speed Civil Transport Design Using FIDO," NASA CR-1999-209693, Oct. '99
- 1998 Object-oriented environment
  - Sistla, R., Dovi, A. R., and Su, P., "A Distributed, Heterogeneous Computing Environment for Multidisciplinary Design & Analysis of Aerospace Vehicles," *5th National Symposium on LARGE-Scale Analysis, Design and Intelligent Synthesis Environments*, Oct 12–15, 1999, Williamsburg, VA
- 1998 Software configuration management
  - Townsend, J. C., Salas, A. O., and Schuler, M. P., "Configuration Management of an Optimization Application in a Research Environment," NASA / TM-1999-209335, June 1999
- Past HSCT analyses (proprietary)

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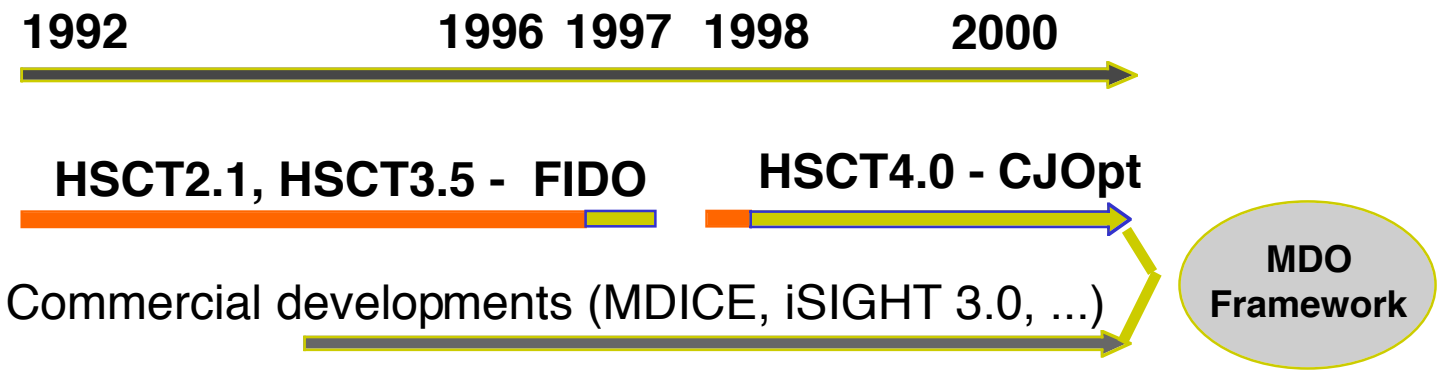
Framework History



% effort devoted to framework related issues
% effort available for application

FIDO : **F**ramework for **I**nterdisciplinary **D**esign **O**ptimization
CJOpt: **C**ORBA - **J**ava **Opt**imization

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History of HSCT Applications

Application (years)	HSCT2.1 ('94 – '96)	HSCT3.5 ('95 – '97)	HSCT4.0 ('97 – '99)
Design Variables	5	7	271
Constraints	6	6	31868
Major Legacy Code Complexity	Low	Low-medium	Medium-high
Analysis Processes (without looping)	10	20	~70
Major Processes	Weight Conv., Trim	Weight Conv., Aeroelastic, Trim	Loads Conv., Trim, Performance
Load conditions	2	2	8
Mission conditions	1	1	10
Process (with loops)	O(10)	O(100)	O(1000)
Total time	O(minutes)	O(hours)	O(1 day)

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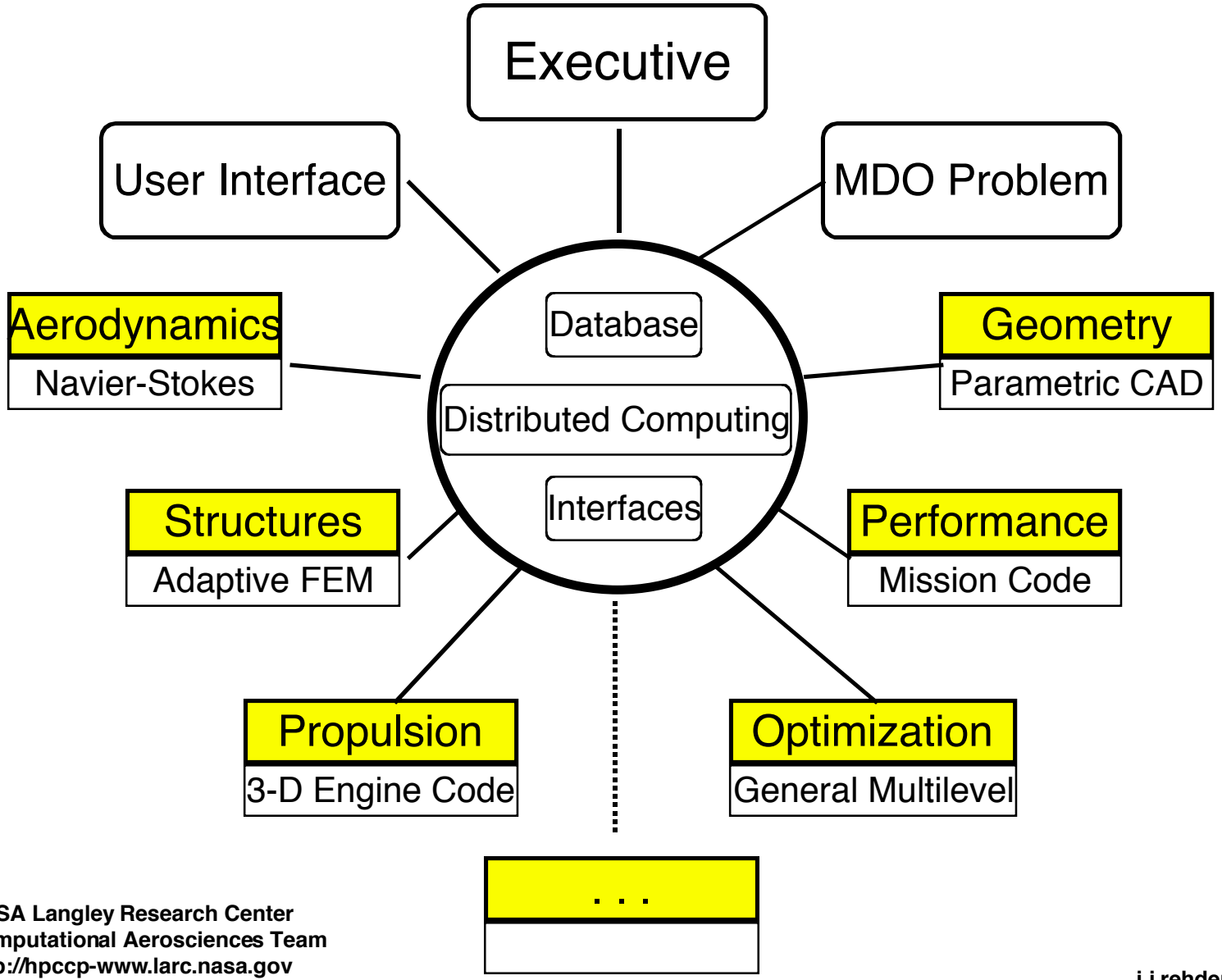
HPCCP HSCT Application Goal



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Project Status

- Framework for Interdisciplinary Design and Optimization (FIDO) developed
- Implementation of HSCT2.1, and HSCT3.5 complete
- HSCT4.0
  - Multidisciplinary analysis capability complete
  - Developed CORBA/Java environment for distributed computing, CJOpt
  - Optimization for standalone aero and standalone structures only, not for full vehicle
  - Software Engineering – Requirements, design, and user documentation, system in configuration management
  - Terminated after HSR cancellation

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Team

CAS	MDOB	ACMB	CMSB	CSC
Sobieski, J.	Walsh, J.	Mason, B.	Biedron, R.	Sistla, R.
Rehder, J.	Weston, R.			Dovi, A.
Giunta, A.	Samareh, J.			Su, P.
	Green, L.			Shan, R.
	Salas, A.			Murthy, T.
	Townsend, J.			
	Barthelemy, J-F.			
	Mukhopadhyay, V			

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HSCT4.0 Analysis and Preliminary Results

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HSCT4.0 Analysis Features

Structures: Finite Element Method (GENESIS), ~40,000 DOF

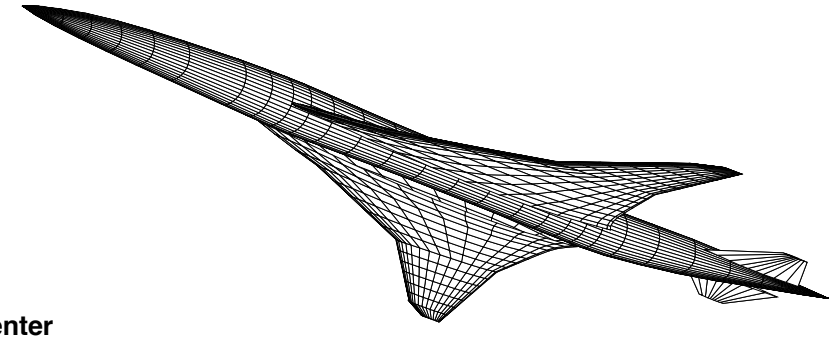
Aerodynamics: Linear aero (USSAERO) ~ 1100 surface grid points

Nonlinear Aero: Euler/N-S (CFL3D), NL corr. Vol.grid ~600,000 points

Weight/Performance: Mission analysis and Database (FLOPS)

Design Variables: 244 Structural and 27 Geometic Shapes

Constraints: Performance, Weights,Buckling, stress & geometric ~ 30,000 @8 load conditions



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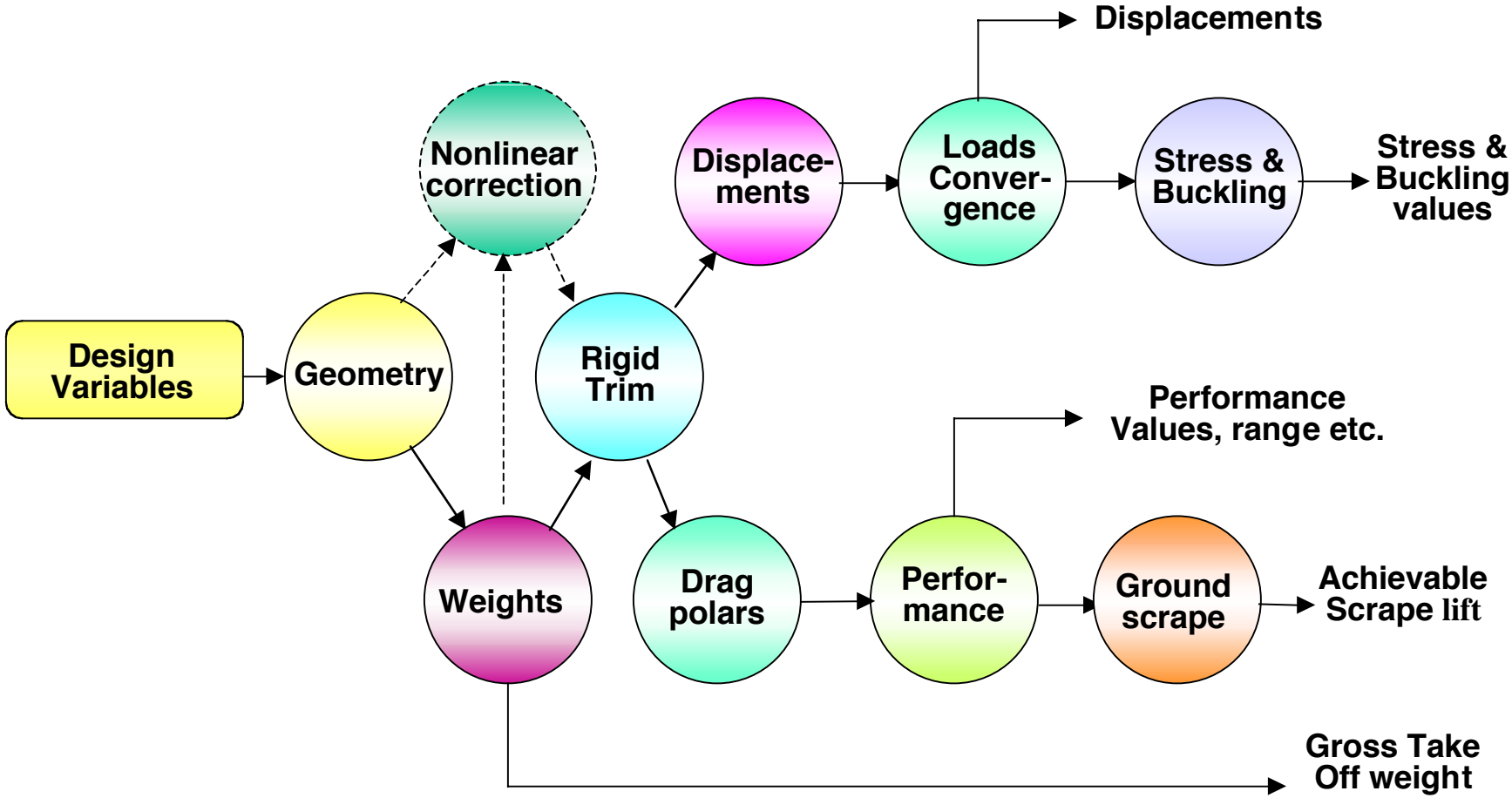
Analysis

HSCT4.0 Analysis



Integrated with CJOpt environment

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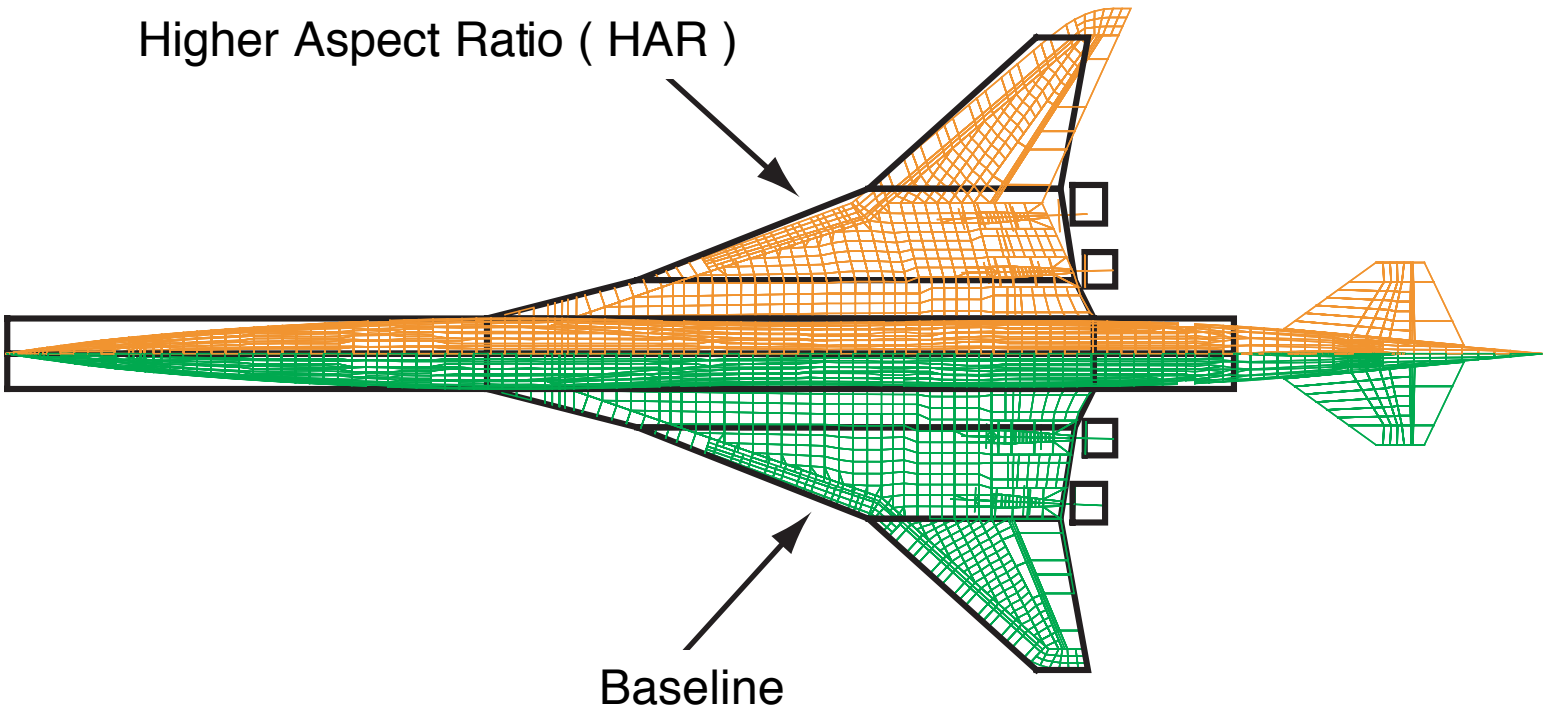
Geometry

Geometry Process Results
(sample)



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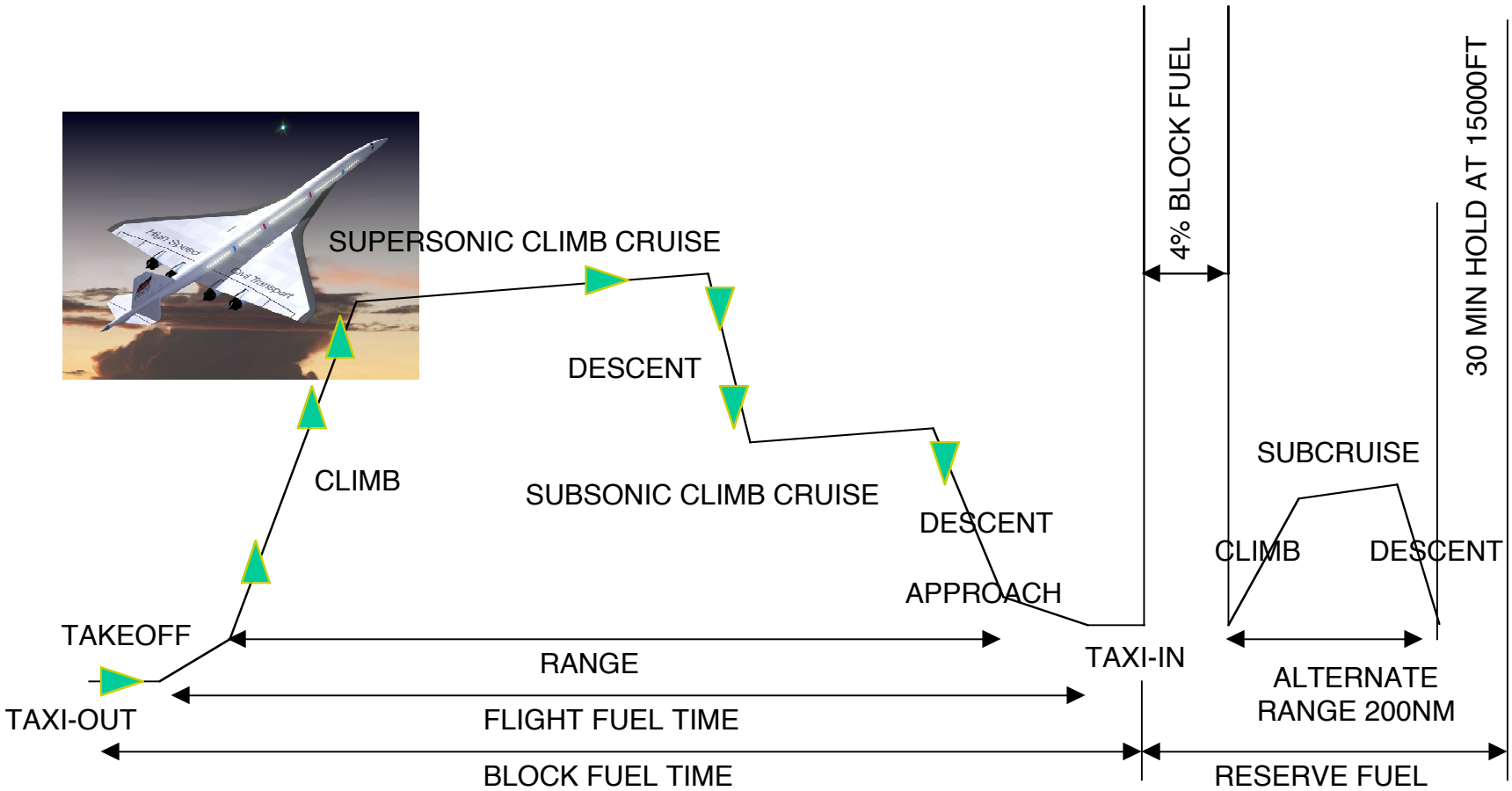
Perfor-
mance

Typical Mission Profile



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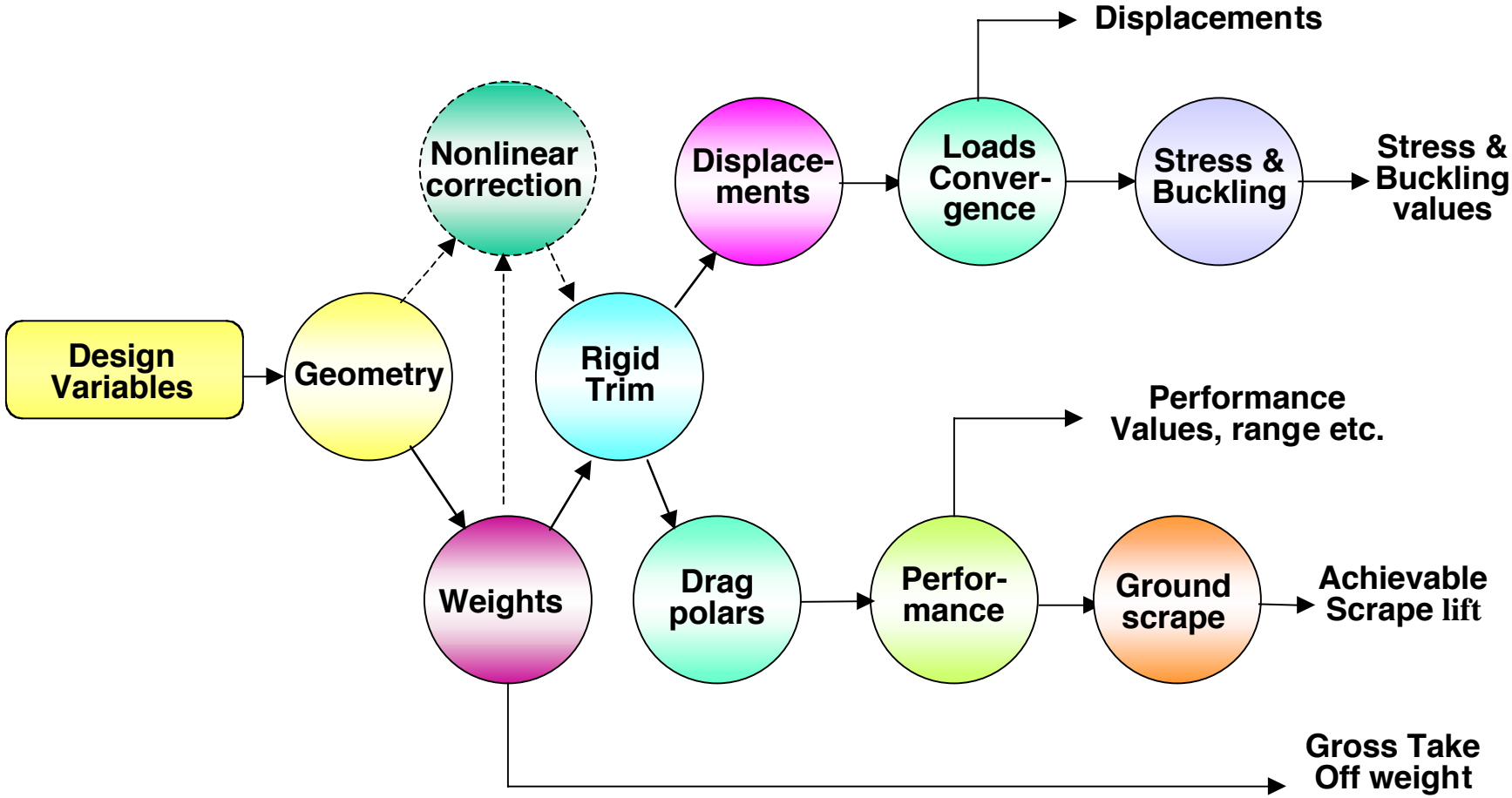
Analysis

HSCT4.0 Analysis



Integrated with CJOpt environment

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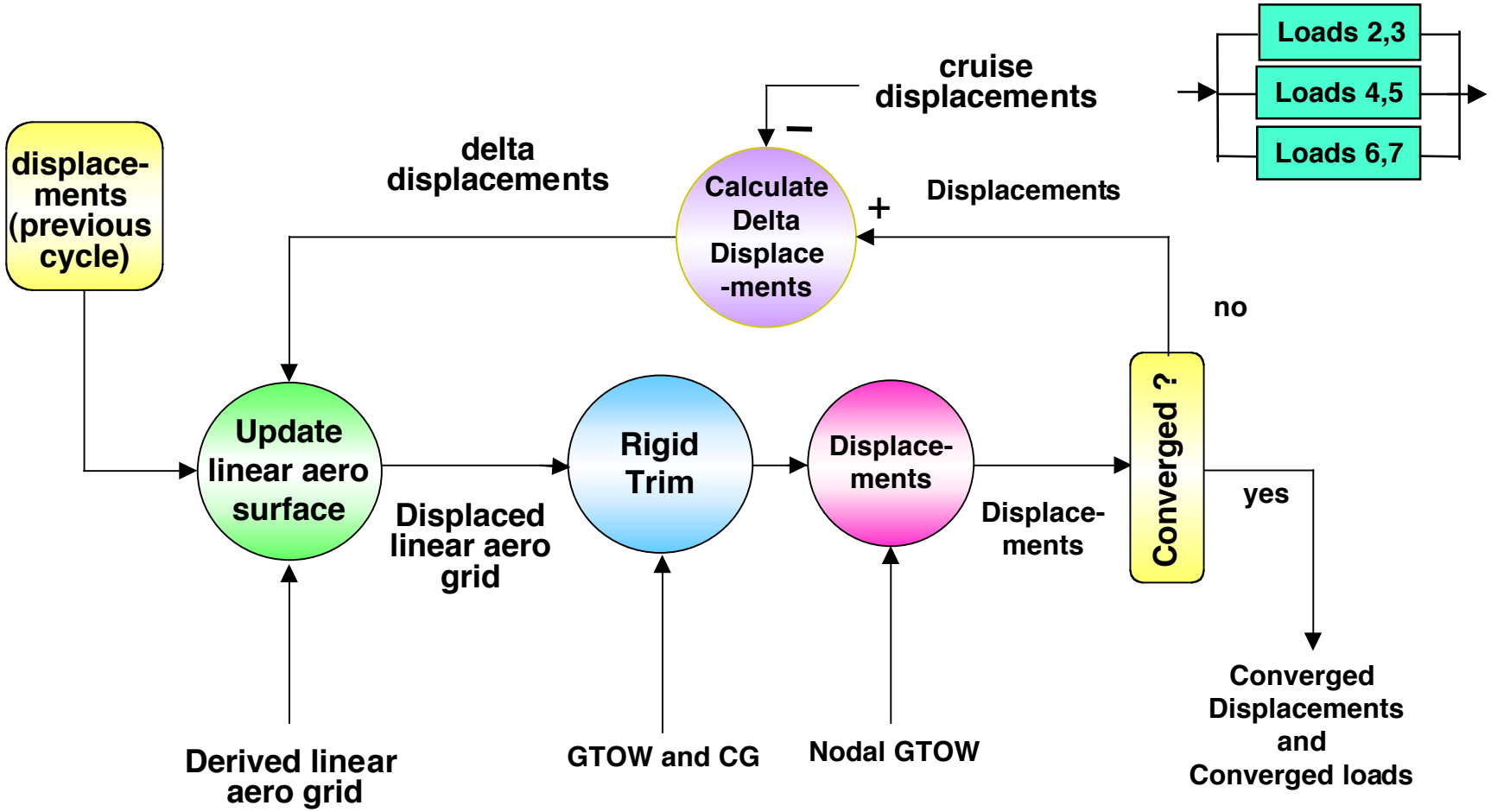
Loads Conver-gence

Loads Convergence Process

(Aeroelastic Analysis at 6 Load conditions)



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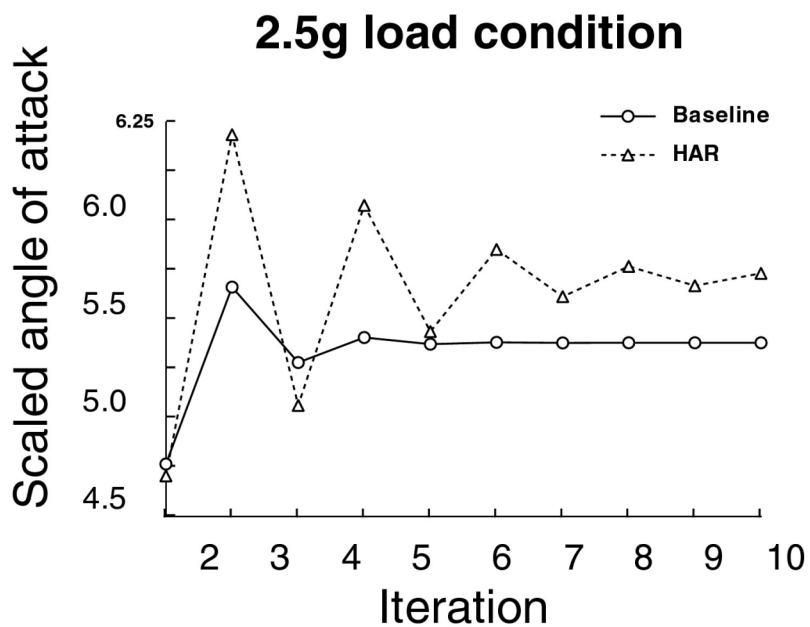
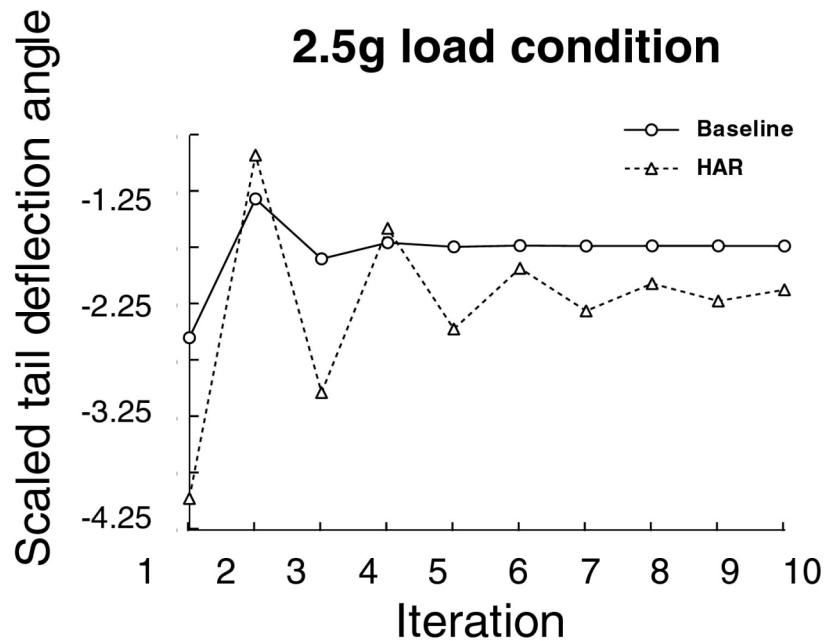
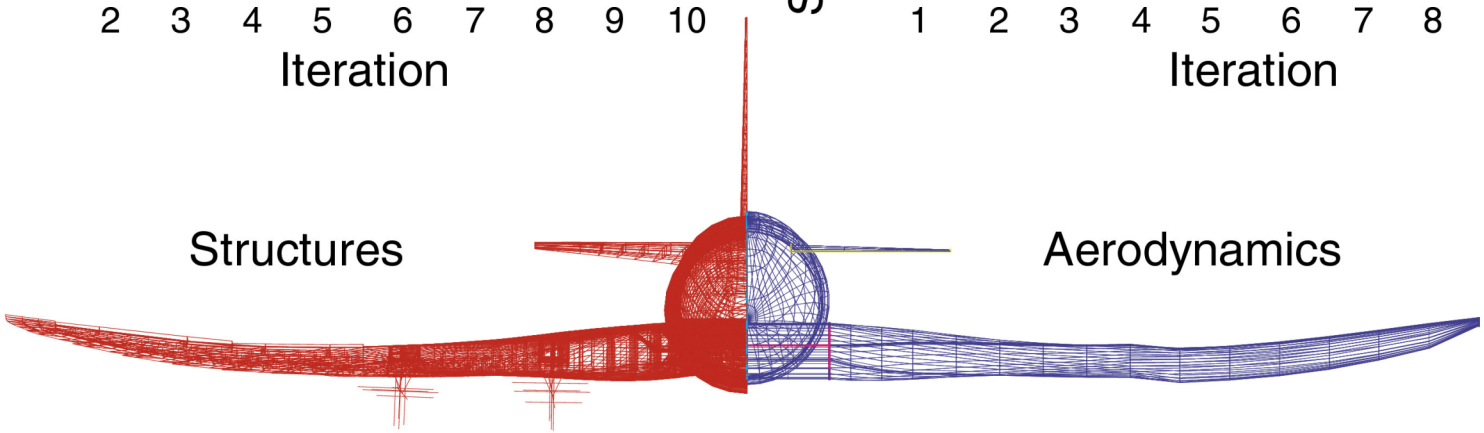
Loads Convergence

Loads Convergence Process Results (sample)







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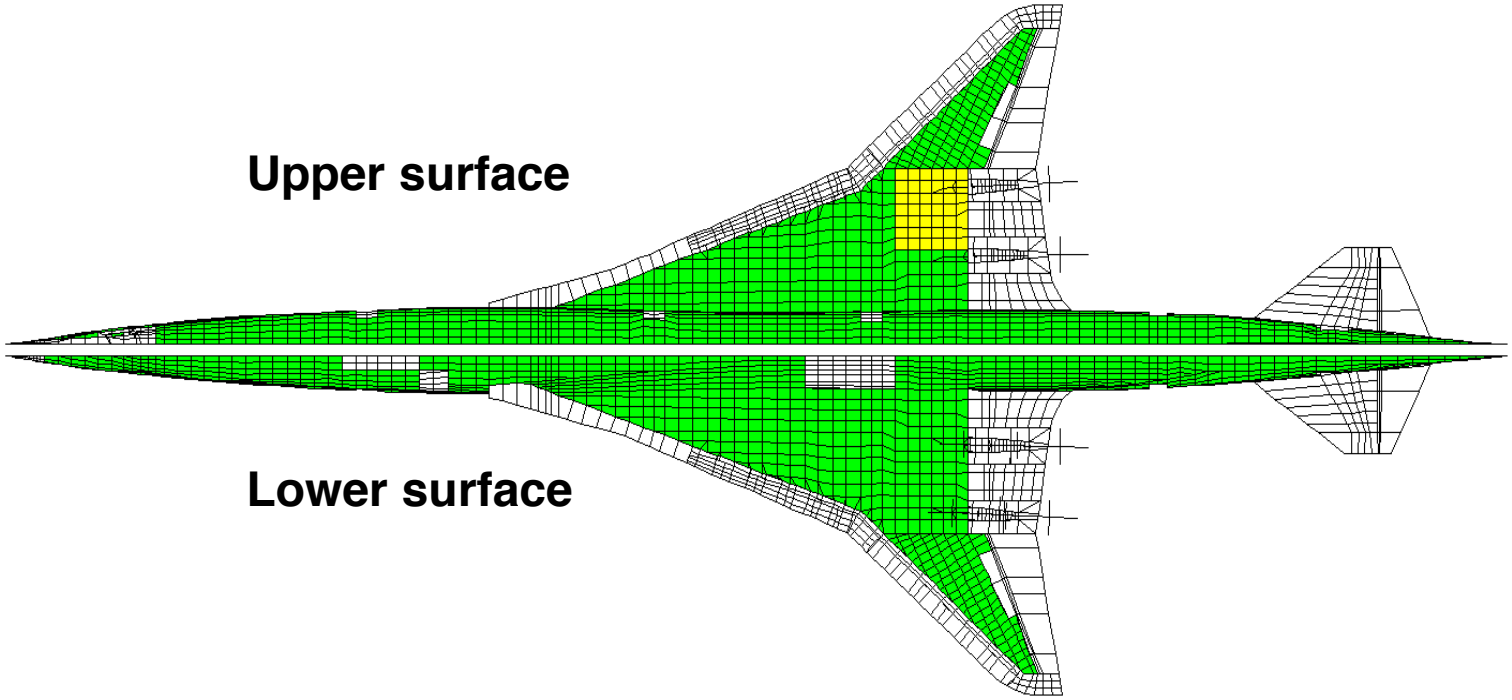
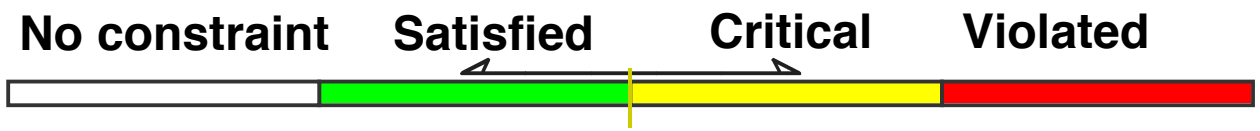
Stress & Buckling

Stress Failure Index Results

baseline, @2.5g (sample)





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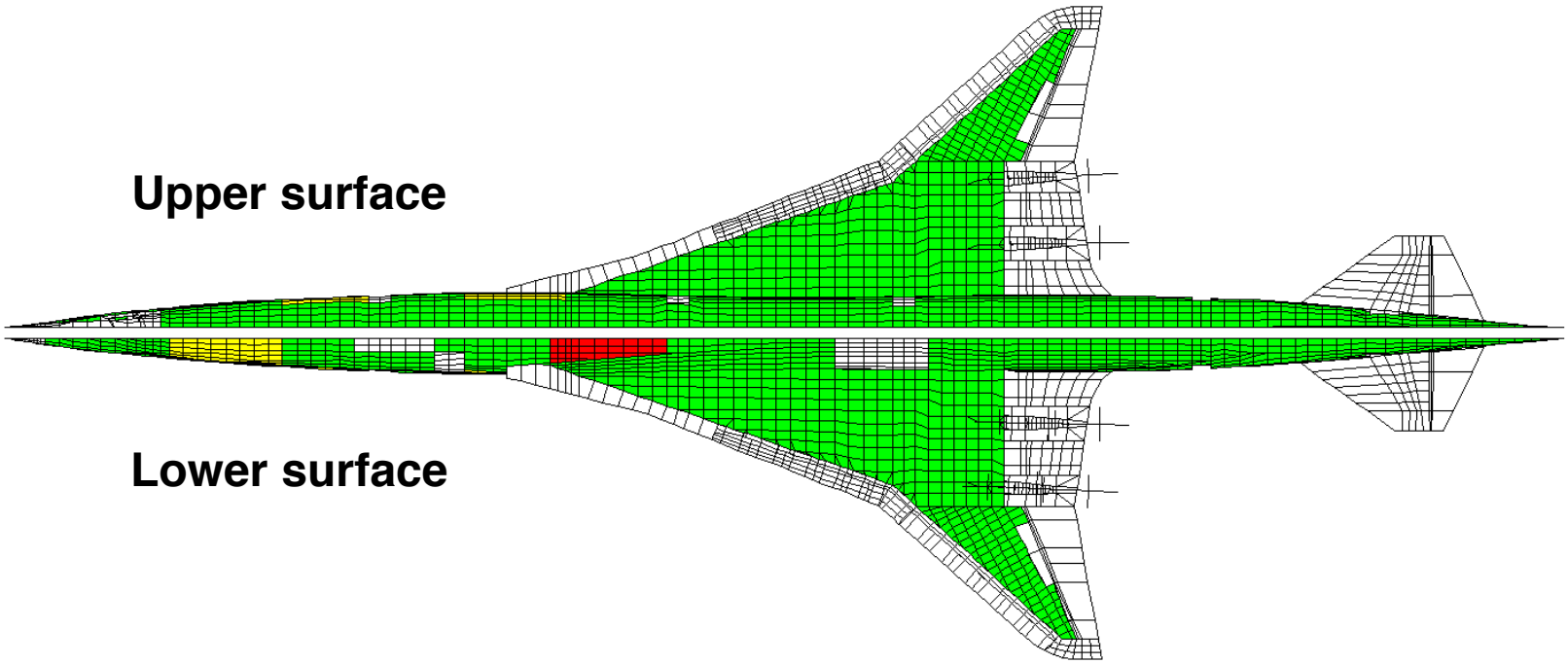
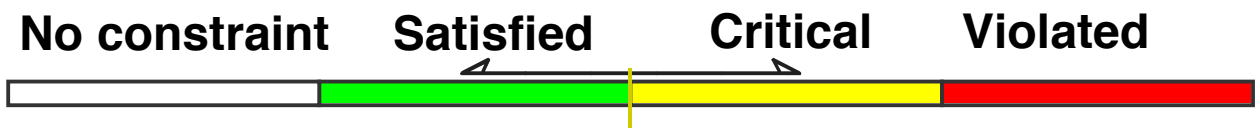
Stress & Buckling

Buckling Failure Index Results

Baseline @2.5g (sample)





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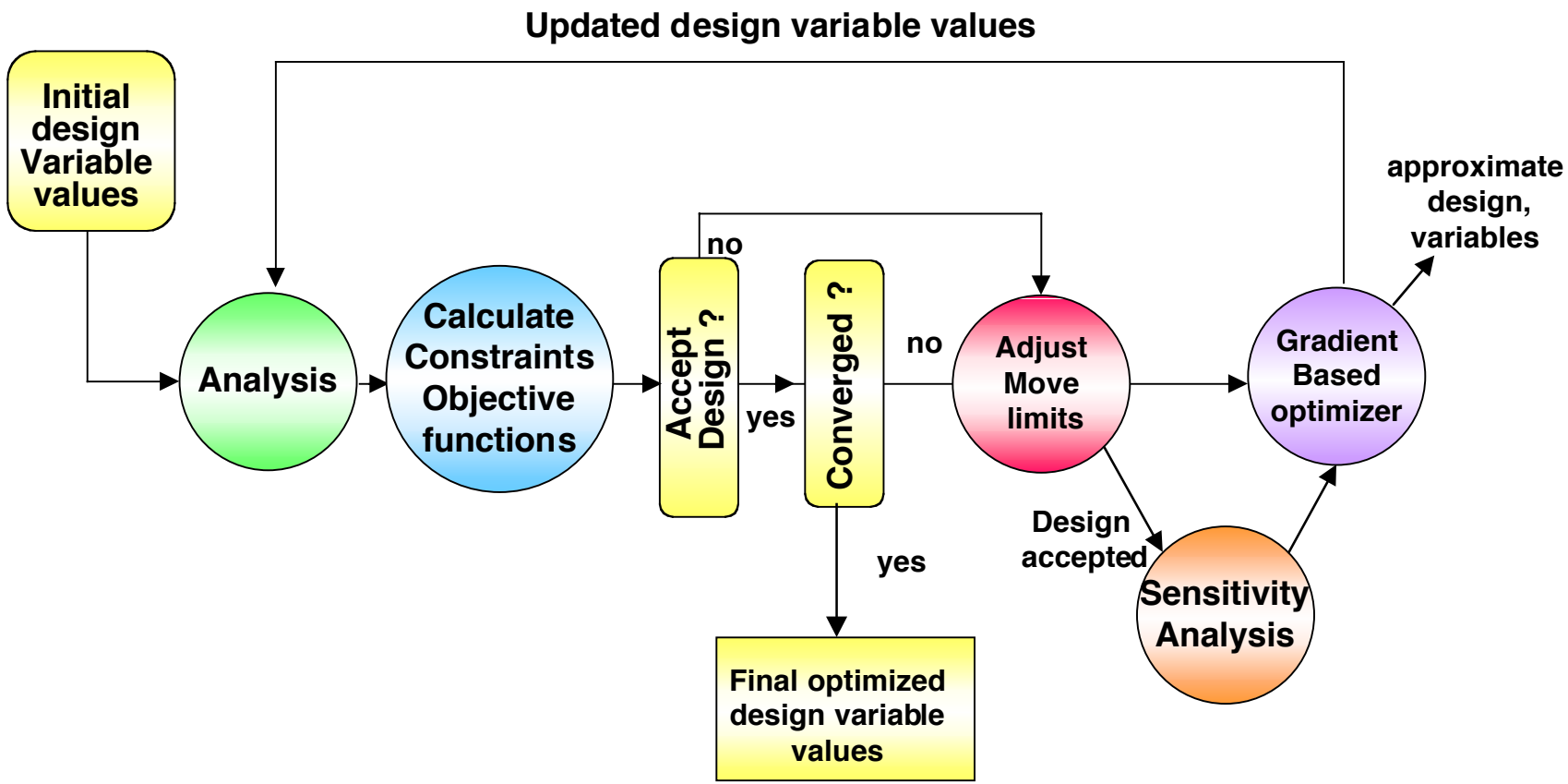
Generic Optimization Process



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Optimi-
zation

Nonlinear Aerodynamic Shape Optimization (stand alone)

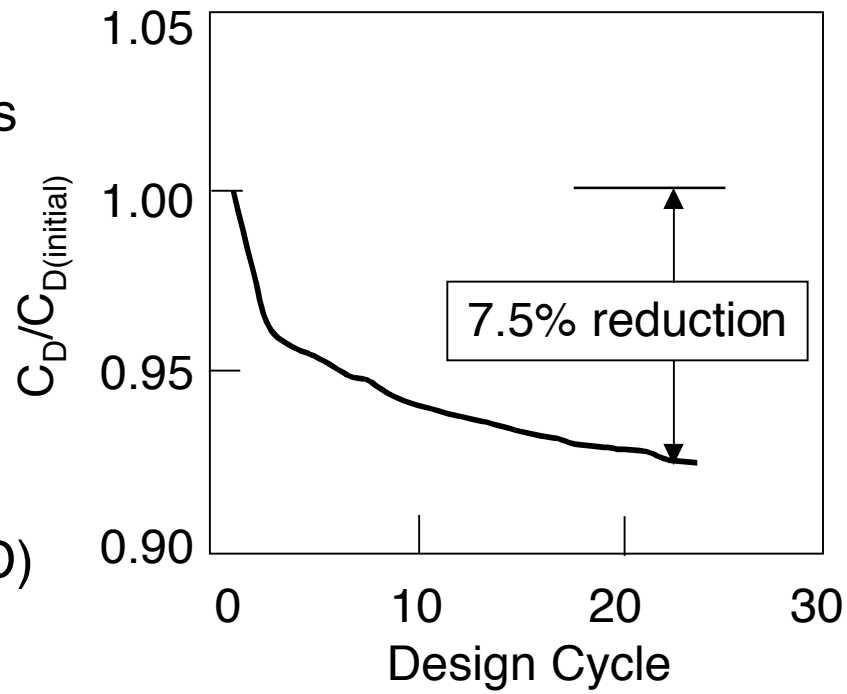
Purpose
- Determine bounds on shape dv's
- Test optimization process

27 shape design variables

Objective function
- Minimize C_D

Analysis
- Geometry
- Nonlinear aerodynamics (CFL3D)
- Cruise condition at fixed C_L

Optimization
- Sequential linear programming (CONMIN+ Linear approx.)



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Computational MDO Framework

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Material contributed by Raj Sistla, Computer Sciences Corporation

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Motivation for a Framework

- Aircraft design is multidisciplinary in nature.
- Different disciplines execute independent of each other.
- Potential exists for concurrent execution of some subtasks.
- Hardware requirements vary with the discipline.
- Large quantities of data and files generated.
- Potential exists for automating the design process.

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CJOpt History

1998	March	Recommended approach based on CORBA and Java.
	August	Work started on implementing HSCT4.0.
1999	June	Completed implementation of Analysis module in HSCT4.0.
	October	Initial implementation tested, debugged, and validated.
	Present	Validating baselined implementation from SCM

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CJOpt Building Blocks

- Common Object Request Broker Architecture (CORBA).
- Java Language and APIs
- SQL compliant database (miniSQL)
  - Central relational database.
  - Commercial SQL-compliance.
  - Objects use Java Data Base Connectivity (JDBC).
  - User-specific tables for transient data.
  - File management information stored in database.

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Programming Steps

- “Wrap” code as an object.

  Some legacy codes were modified

- Define an interface to this object.

- Write implementation for the interface.

- Write server code to register with orb. Write application using CORBA objects

  Or,

- Rmi.

- Run client application.

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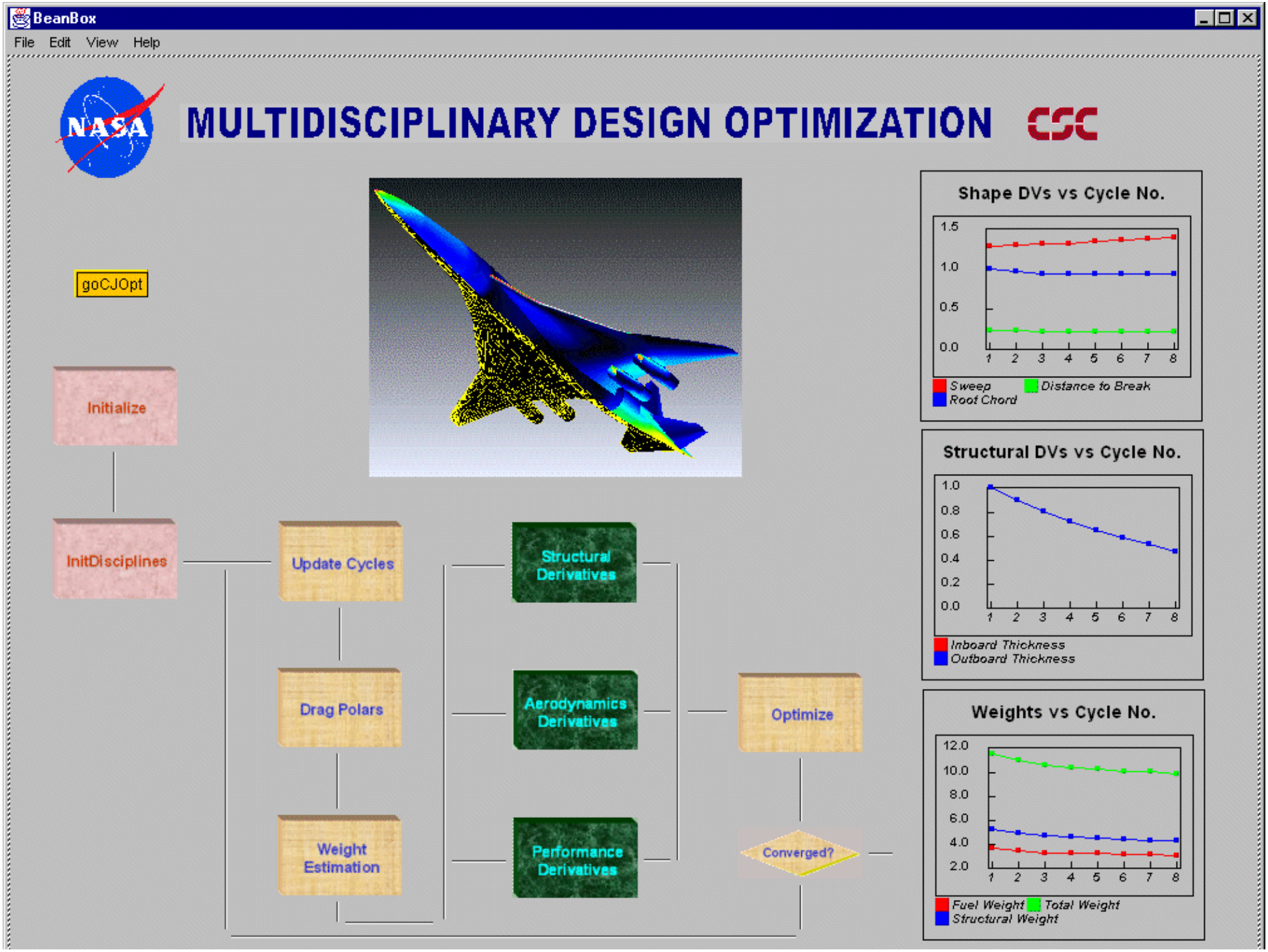
BeanBox
File Edit View Help
MULTIDISCIPLINARY DESIGN OPTIMIZATION
CSC
goCJOpt
Initialize
InitDisciplines
Update Cycles
Drag Polars
Weight Estimation
Structural Derivatives
Aerodynamics Derivatives
Performance Derivatives
Optimize
Converged?
Shape DVs vs Cycle No.
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8
Sweep
Distance to Break
Root Chord
Structural DVs vs Cycle No.
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8
Inboard Thickness
Outboard Thickness
Weights vs Cycle No.
12.0
10.0
8.0
6.0
4.0
2.0
1 2 3 4 5 6 7 8
Fuel Weight
Total Weight
Structural Weight

Framework Conclusions

- Developed a component based framework.
- Using industry standards.
- Introduced high fidelity analyses early in design process.
- Developer spared the complexity of network programming.
- User spared data and file management tasks.
- Development time reduced as each object is tested and debugged independently.
- Disciplines can be reused & replaced with ease.
- Capitalized on parallelisms in analysis with ease.
- Easy to configure and use via graphical interface. (HSCT2.1 only, not HSCT4.0)

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Software Engineering

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Background

- Past HPCCP HSCT projects identified the need for rigorous software engineering practices
  - even though it is a challenge in a research environment.

- HSCT4.0 software engineering goals
  - Apply a more formal approach to the software development
  - Improve the project documentation
  - Increase the software life-time and reuse

- Presentation content
  - Describe approach, experience, and lessons learned for various software engineering areas

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Documentation

- Approach Plan
  - Project Management Plan, Requirements Specification, Design Description, User's Manual, Configuration Management Plan, Test Plans and Test Results
- Experience
  - Some project documentation is not read by all project members
  - Difficult to reach consensus on document contents or the detail
  - Most documentation is not written at the appropriate time
  - Documentation is difficult to collect and keep up to date
  - HSCT4.0 documentation is nearly completed
- Lessons Learned
  - Project schedule milestones should include documentation
  - Documentation must be given high priority

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Life Cycle Model

- Approach Plan
  - Considered Waterfall, Incremental Development, and Evolutionary models
  - Selected Incremental Development model as a compromise
- Experience
  - Limited success at applying a life-cycle model
  - Overlapping of requirements and design
  - Prototyped the CJOpt approach using HSCT2.1
- Lessons Learned
  - Need a schedule which allows the appropriate model
  - Make more use of prototypes

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Requirements Analysis

- Approach Plan
  - Develop requirements document following IEEE guidelines
  - Apply structured requirements analysis approach

- Experience
  - Data flow diagrams have been extremely helpful
  - Documenting the requirements was not easy

- Lessons Learned
  - The schedule should allow time for requirements analysis
  - Incomplete requirements (interfaces, components, processes) will cause problems later
  - Document the minimum amount of useful information
  - Need software tools for supporting requirements definition

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Design and Implementation

- Approach Plan
  - Apply distributed object computing (CORBA/Java RMI)
  - Use a relational database to store shared information
  - Wrap legacy codes as objects for this environment

- Experience
  - Developed a prototype using the HSCT2.1 application
  - Object-oriented method revealed benefits over past methods
  - Process requirements were inadequately defined

- Lessons Learned
  - Entire team must participate in the system design
  - Design documentation must be completed earlier

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Validation

- Approach Plan
  - Check correctness of wrapping, integration, and engineering results
  - Conduct unit, subsystem, and full system tests
  - Document test plans and test results

- Experience
  - Project members were reluctant to take on subsystem tests
  - Inconsistent configuration management led to inefficient testing
  - 2 system test cases were conducted, which showed expected results

- Lessons Learned
  - Define system and integration test plans early
  - Assign test responsibilities to individuals

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Software Configuration Management

- Approach
  - Identify software tools and processes for SCM
- Experience
  - Conducted a pilot project for introducing SCM
  - Applied TRUEchange and Metrics Database software tools
  - Developed a Software Configuration Management Plan
  - Baselined HSCT4.0 analysis and supporting test scripts
- Lessons Learned
  - SCM activities must be scheduled and given priority
  - All project members must participate in SCM
  - SCM managers must interact with designers and testers

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Software Engineering Summary

- HSCT4.0 has made improvements over past HSCT projects
  - Documentation
  - Requirements
  - Design and Implementation
  - Validation
  - Software Configuration Management

- Much more experience can be gained in applying software engineering in a research environment

- Project plan and schedule should include software engineering activities

- All project members should participate in software engineering activities

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Lessons Learned and Future Plans

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Accomplishments

- Developed MDA/MDO capability on a set of HSCT configurations
  - HSCT2.1
  - HSCT3.5
  - HSCT4.0

- Developed two distributed application environments,
  - FIDO

  - CJOpt
    - Commodity parts - CORBA, Java
    - Integrated HSCT4.0 analysis
    - Demonstrated JavaBeans and Optimization on HSCT2.1
    - Demonstrated benefit of coarse-grained parallelism

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More Accomplishments

- Code enhancements
  - CFL3D, TLNS3D
  - GENESIS
  - COMET
  - ADIFOR, ADJIFOR, ADIC
  - iSIGHT
- Introduced formal software engineering methods
  - Documentation – requirements, design, user's manual
  - System in configuration management

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What more could be done
Casualties of HSR demise

- HSCT4.0 Problem
  - Optimization, demonstrate benefit of MDO
  - Include nonlinear corrections in analysis
  - Include propulsion and cost calculations
- Distributed Environment
  - GUI for problem setup
  - Problem control and visualization
- Software Engineering
  - Establish software life cycle

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Lessons Learned

- HSCT4.0 project bigger than originally anticipated
  - Technically
  - Culturally
  - Led to drastically over optimistic schedule

- Need team with…
  - Organizational commitment
  - Common understanding of what is expected from different phases of project
  - Opportunity for input
  - Central decision authority
  - Module ownership
  - No waiting – everybody is always busy

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More Lessons Learned

- Commitment to software engineering up front

Before the beginning of great brilliance, there must be chaos. Before a brilliant person begins something great, they must look foolish in the crowd.

- The I Ching

- Formal configuration management crucial

- Incremental development, prototyping

- Early identification of high performance computing opportunities
  - Don't be embarrassed by "embarrassingly parallel"
  - Get sensitivity calculations into the codes
  - Look for problems previously considered "intractable"

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FUTURE ACTIVITIES

- Technology Transfer
  - REVCON – Revolutionary Concepts
  - Revolutionary Airframe Concepts Research

- Reusable Launch Vehicle
  - MDO problem demonstration in 3 years – multi-fidelity, full vehicle
  - Subset MDO problem in 1 _ years – look for “intractable” problem
  - Build in flexibility for different vehicle concepts
  - Establish new team
  - Use COTS where possible
  - Apply lessons learned

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