Multidisciplinary High-Fidelity Analysis and Optimization of Aerospace Vehicles, Part 1: Formulation

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  - L. L. Green
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Outline

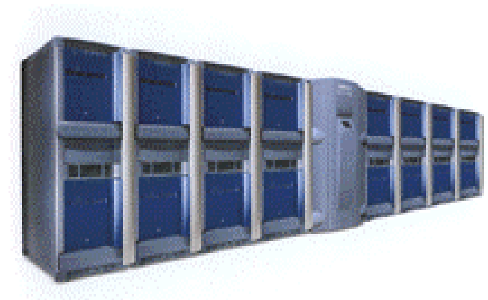
- Background
- Problem Definition
- Analysis Formulation
- Current Status
- Software Engineering Issues
- *Validation
- *Results
- Summary

* Presented in Part 2: Results

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:

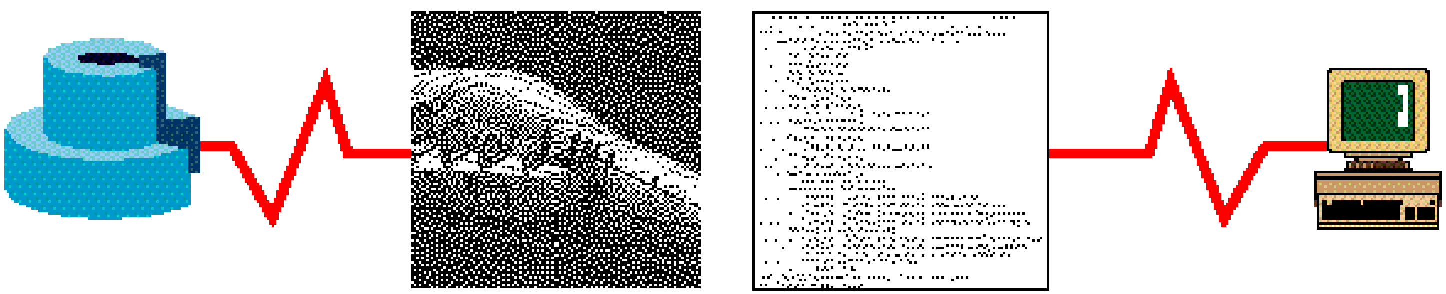
- **Evolved into the HSCT4.0 application**
  - **Research endeavor in both MDO and HPCC**
  - **Unique combination of disciplinary breadth and depth in MDO research**

Concept

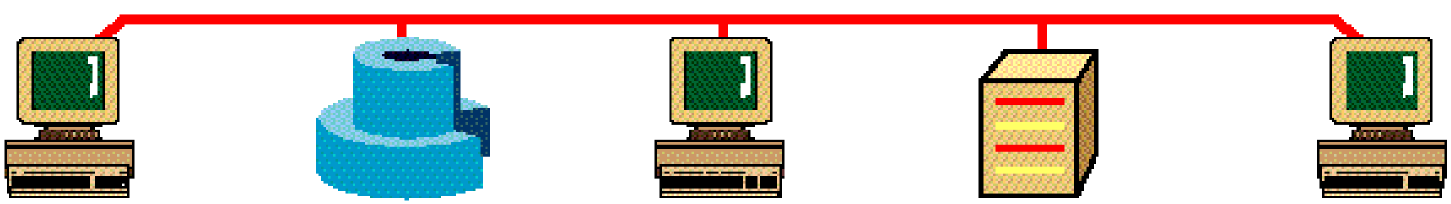
Develop a Programming Environment for:

Group of users with diverse specialties

Multiple programs targeted for appropriate computers



Computers and data distributed over network

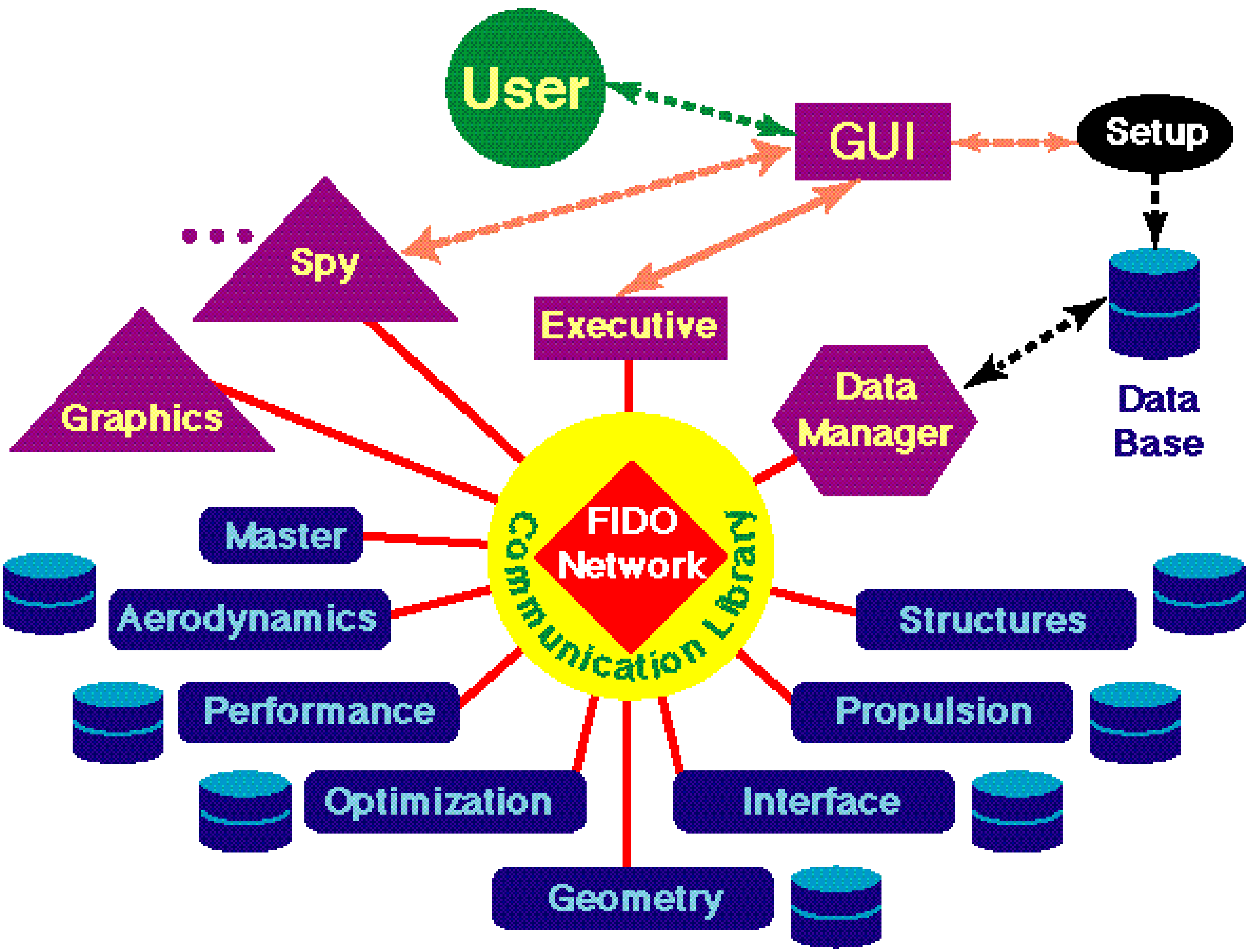


Working together simultaneously on parts of the same problem

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)

FIDO Execution System



CJOpt Building Blocks
(CORBA-Java Optimization Environment)

- **Common Object Request Broker Architecture (CORBA)**
  - **Software industry standard**
- **Java computer language and Application Programming Interfaces**
  - **Supports object-oriented programming**
- **SQL compliant database (miniSQL)**
  - **Common data, file name repository**

History of HSCT Applications

Application (years)	HSCT2.1 (‘94 – ‘96)	HSCT3.5 (‘95 – ‘97)	HSCT4.0 (‘97 – ‘99)
Emphasis	**Framework evolution**		**Application**
Design Variables	**5**	**7**	**271**
Constraints	**6**	**6**	**O(10,000)**
Major Legacy Code Complexity	Low	Low–medium	Medium–high
Analysis Processes (without looping)	**10**	**20**	**70**
Analysis Control			
Major Loops	Weight Conv., Trim	Weight Conv., Aeroelastic, Trim	Weight Conv., Aeroelastic, Trim
Load conditions	**2**	**2**	**8**
Mission conditions	1	1	10
Processes (with loops)	O(10)	O(100)	O(1000)
Total time	**O(minutes)**	**O(hours)**	**O(1 day)**

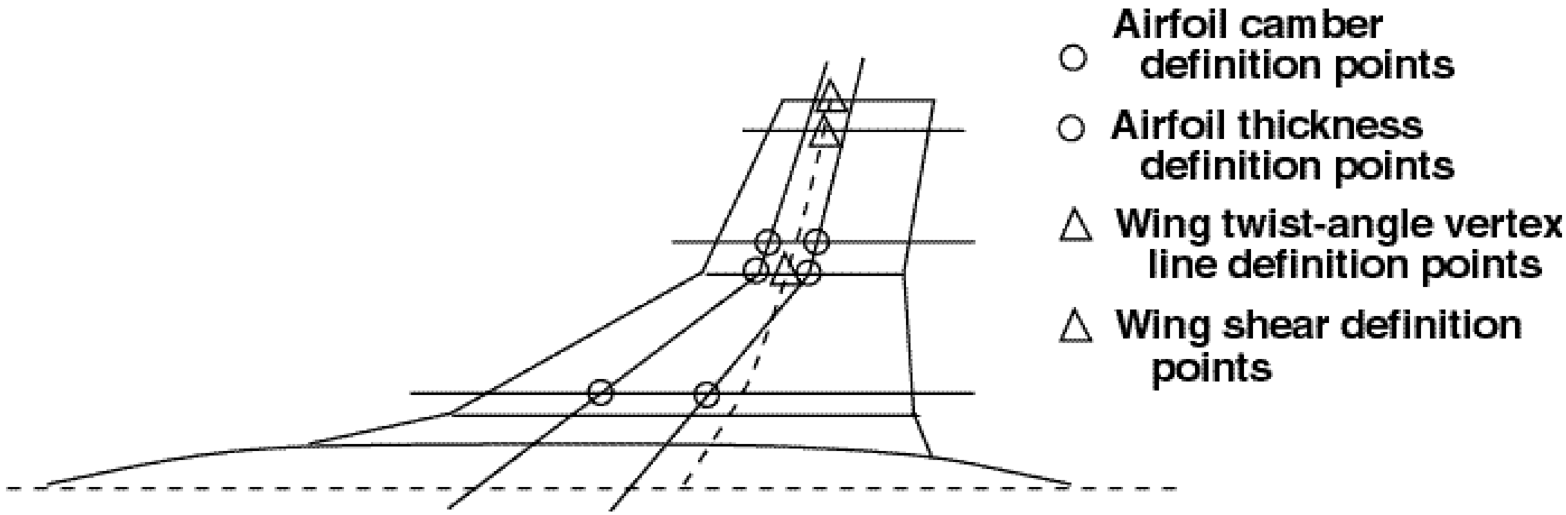
HSCT4.0 Application

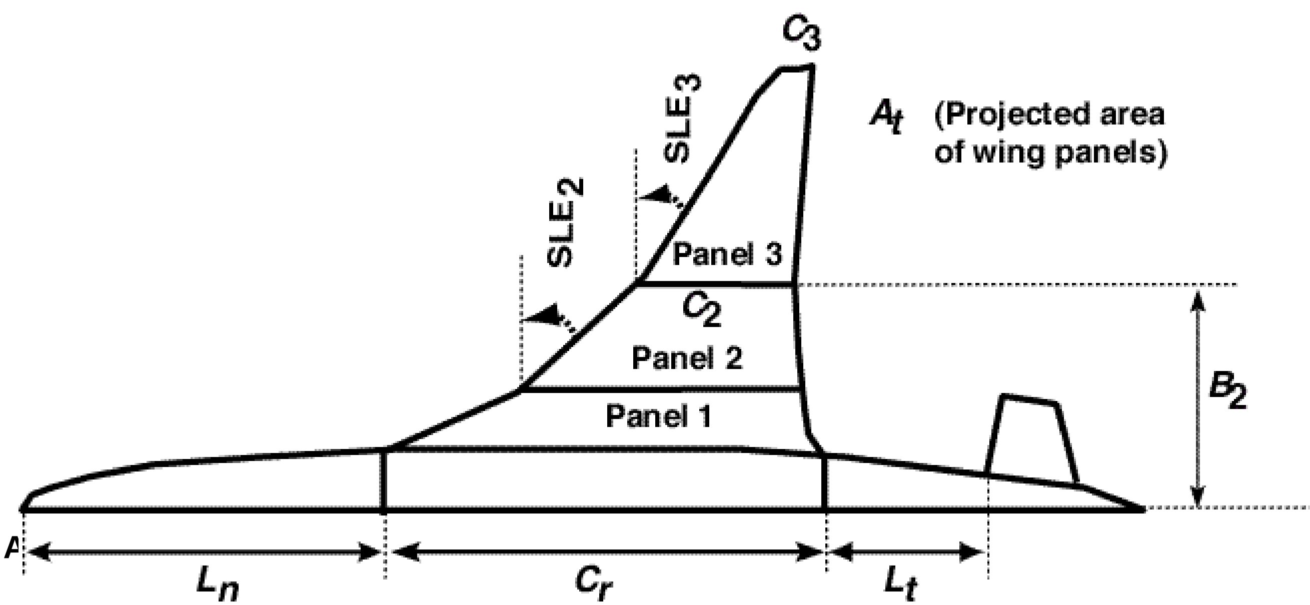
- **Realistic aircraft concept**
- **Aerodynamic analysis**
  - **Linear (USSAERO using 1100-point surface grid)**
  - **Nonlinear (CFL3D using 600,000-point volume grid)**
- **Structural analysis**
  - **GENESIS using FEM with 40,000 degrees of freedom**
- **Performance analysis**
  - **FLOPS**
- **Weights analysis**
- **8 load conditions**
  - **Cruise**
  - **6 maneuver (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)**

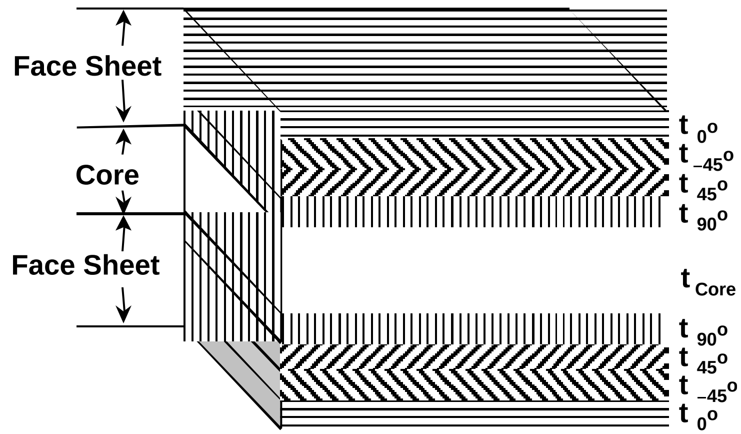
HSCT 4.0 Shape Design Variables

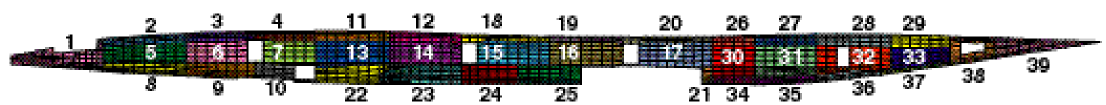


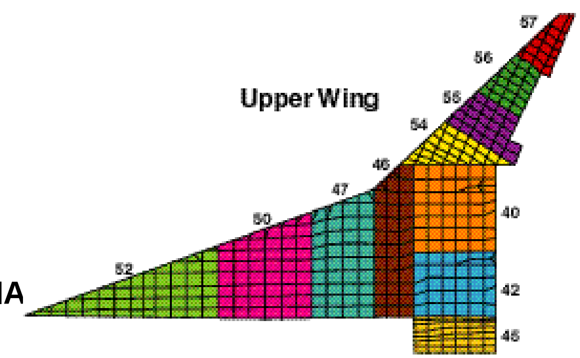


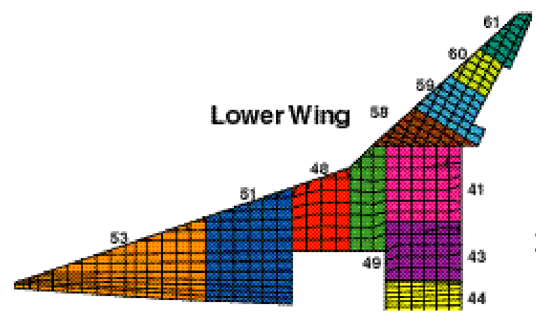
HSCT 4.0 Structural Design Variables

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

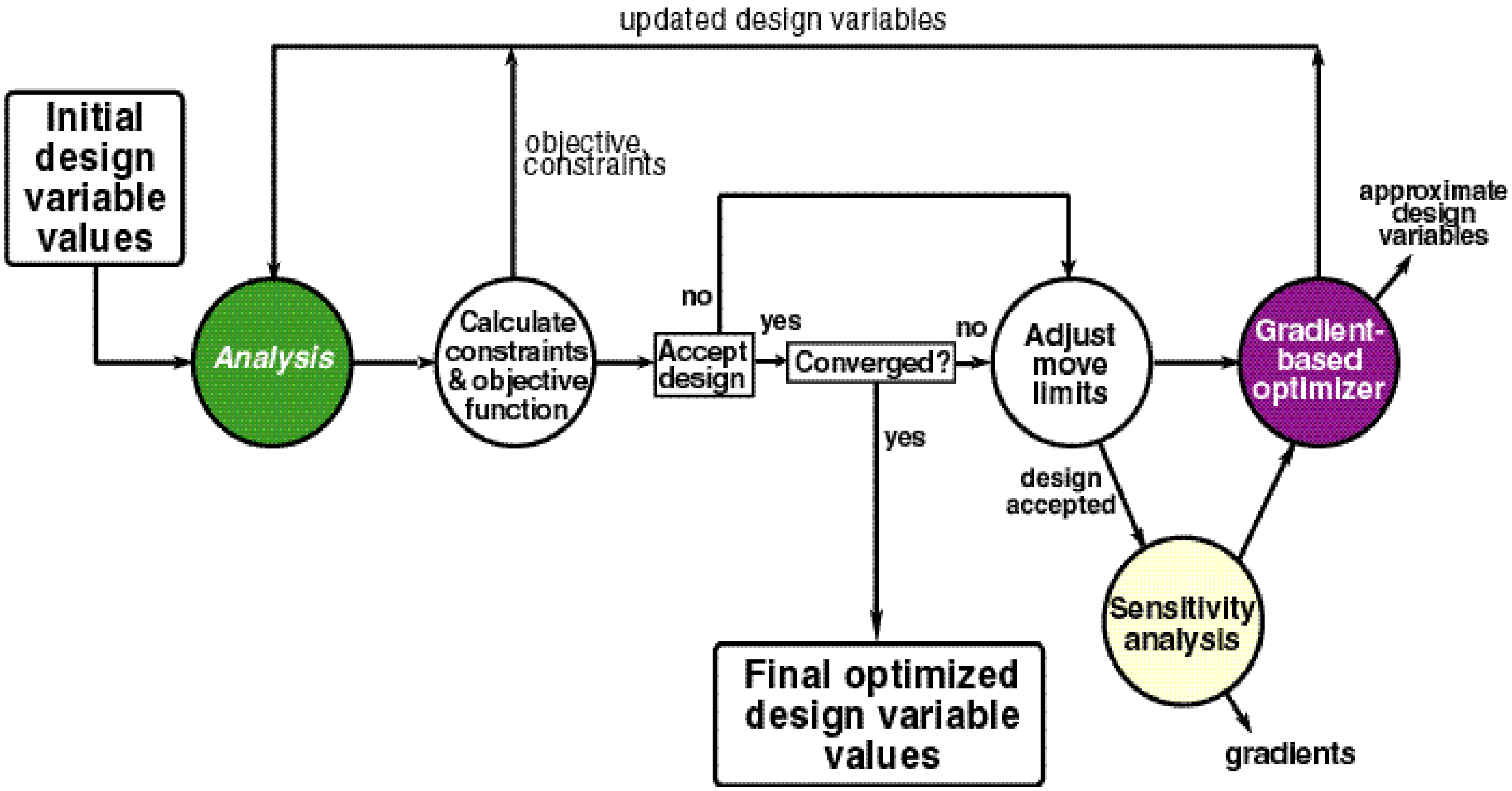




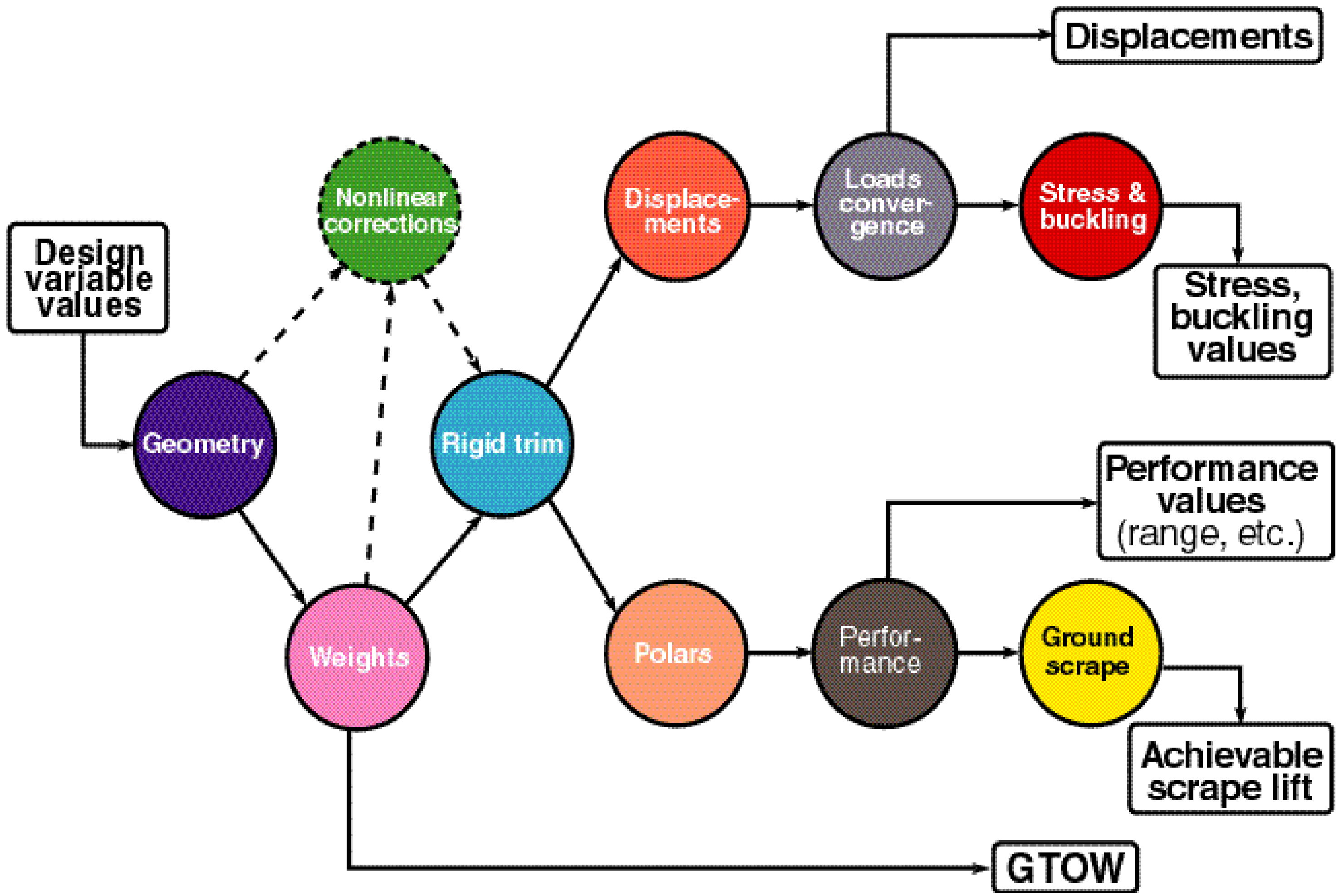




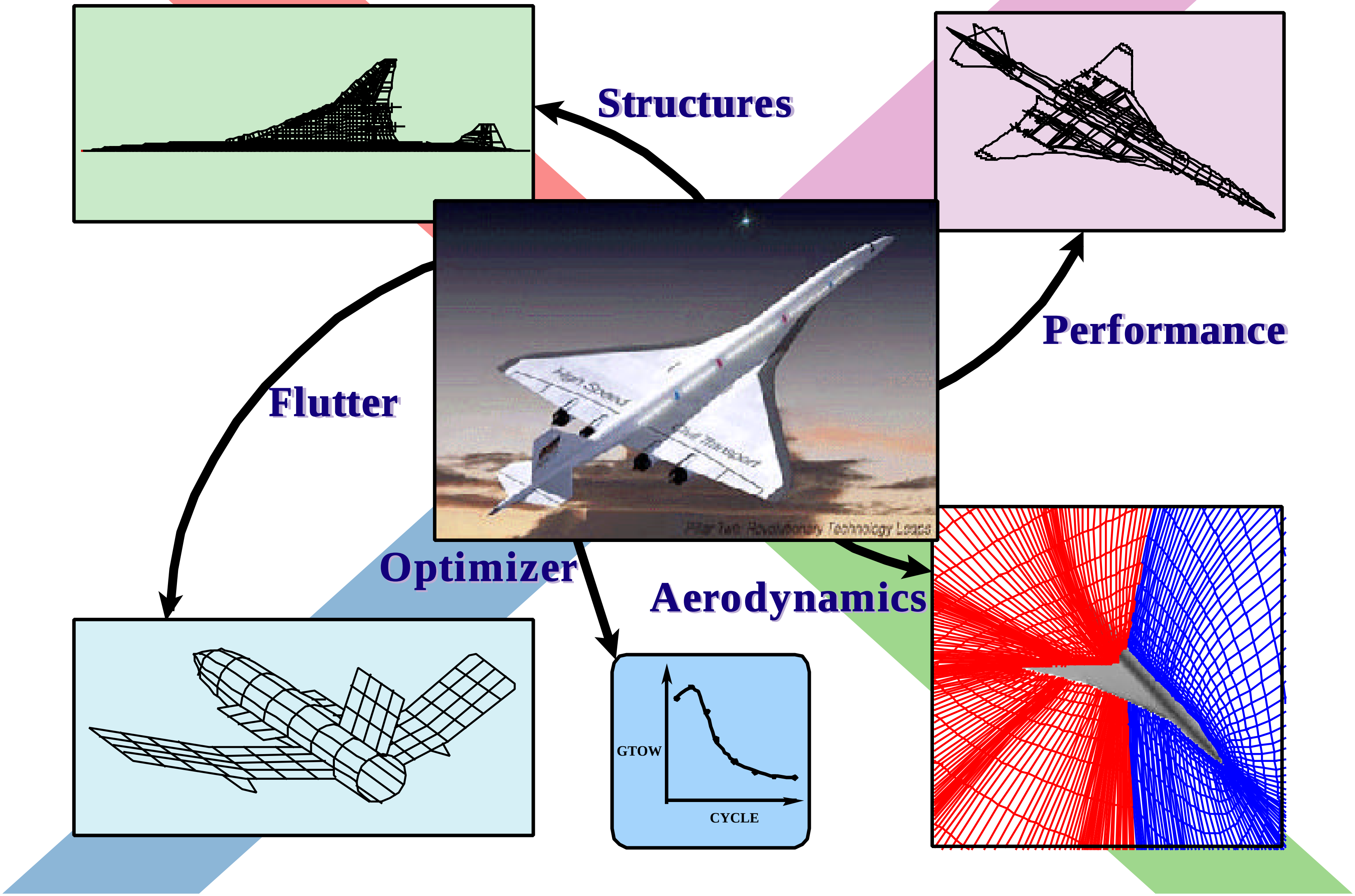
HSCT4.0 MDO Process



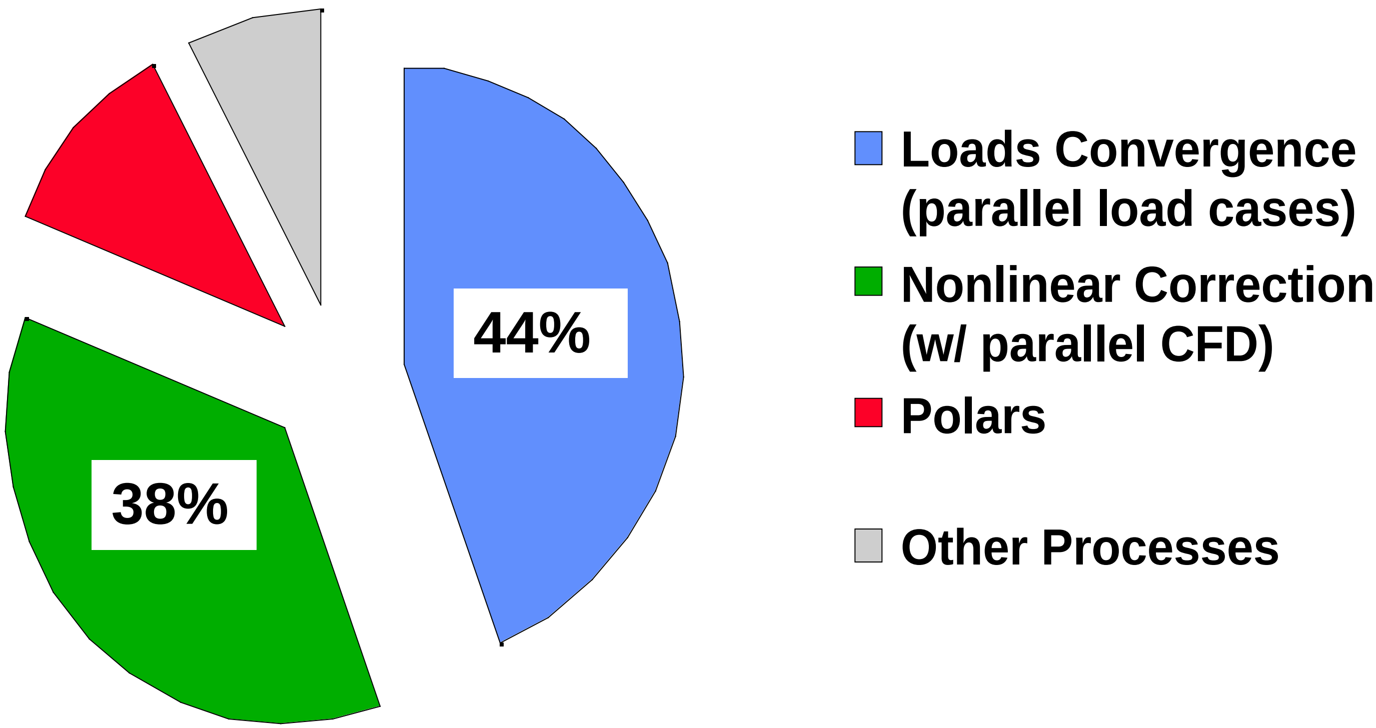
HSCT4.0 *Analysis* Process



Multidisciplinary Aero/Structural Shape Optimization Using Deformation (MASSOUD)



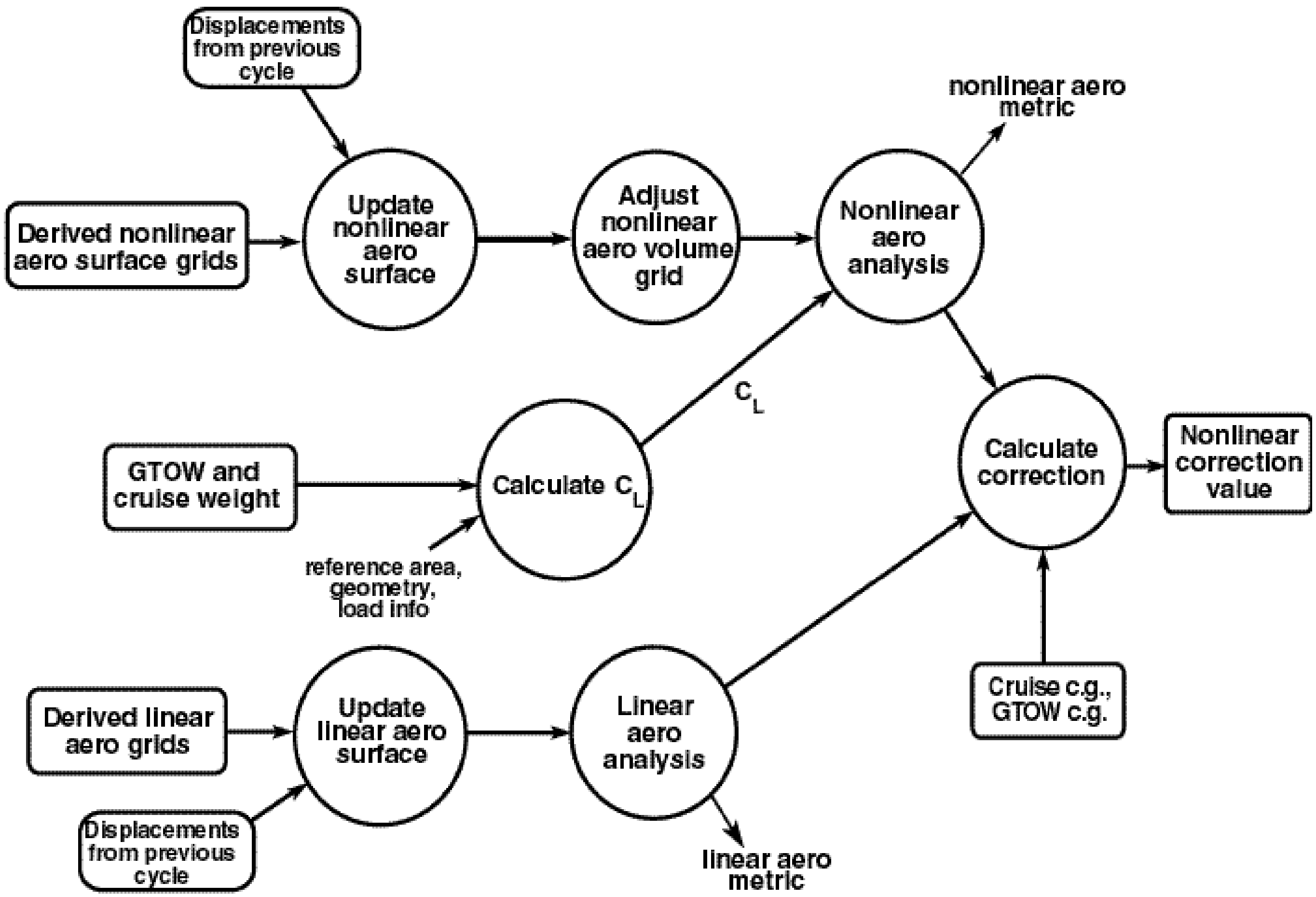
Relative Wall Clock Times* for *Analysis*



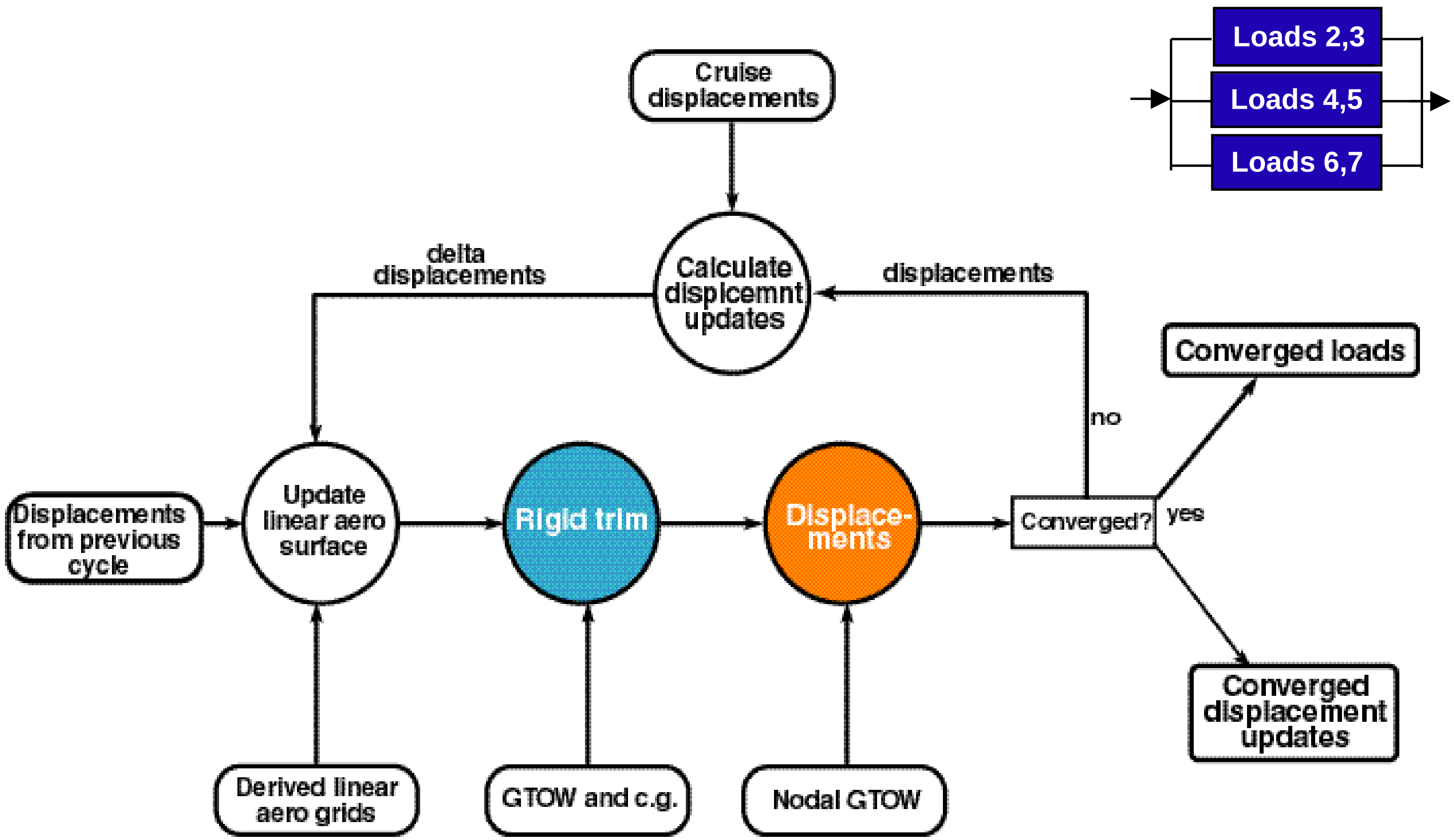
* Using coarse-grain parallel-processing on engineering workstations

HSCT4.0 *Nonlinear Correction* Process

(Computation of Correction Δs)



HSCT4.0 *Loads Convergence* Process
(Aeroelastic Analysis at 7 Load Conditions)



HSCT 4.0 Status

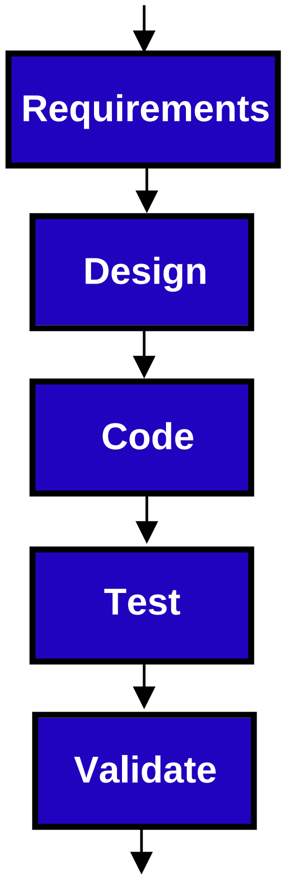
- ***Analysis* process** (~60% of effort)
  - **Formulated**
  - **Incorporated in Common Object Request Broker Architecture (CORBA)- Java environment** (CJOpt)
  - **Validated for 2 sets of design variable values**
- **Sensitivity analysis** (~30% of effort)
  - **Formulation is underway**
  - **More complex problem than expected**
- **Optimization** (~10% of effort)
  - **Process demonstrated w/ nonlinear aero optimization**
  - **Full implementation unlikely**
    - **Unexpected complexity of sensitivity analysis**
    - **Longer than expected time for *Analysis* validation**
    - **Loss of interest in HSCT with end of High Speed Research**

HSCT4.0 *Sensitivity Analysis* Status

- **Use analytical derivatives whenever possible**
  - **I.e., where source code is available**
    - ***Geometry, Weights, Rigid Trim, Polars, Performance, Ground Scrape***
  - **Derivatives should be easily obtained**
  - **Derive by hand or use automatic differentiation tools**
- **But, no analytical derivatives for some processes**
  - **Source code for GENESIS is not available**
    - **Used in *Displacements, Loads Convergence, Stress & Buckling***
  - **Processes involve iteration**
  - **Derivatives not easy to obtain for non-constant loads**
  - **Normally, loading is assumed constant**
    - **Then, methods exist to obtain derivatives**
    - **But, we do not want to assume constant loads**
    - **Shape changes invalidate normal structural optimization assumption of constant loads**

Software Engineering Issues

- **HSCT4.0 is largely a software engineering project**
  - **Initially, not recognized as such**
  - **Discipline-oriented engineers need training in software engineering**
- **Allow time for normal software development phases**
  - **Use incremental-iterative approach**
- **Any complex research project involving software needs to be managed as software project**
  - **E.g., use configuration management**



Software Configuration Management (SCM)

- **Why?**
  - **Experience showed the need**
    - **Version mix-ups**
    - **Lost change information**
  - **HSCT4.0 project complexity**
    - **Many codes, some used several places**
    - **Relatively large, diverse development group**
    - **Little experience with large software projects**
    - **Little experience with software engineering**

Expected Benefits from SCM

- Better control by storage within SCM system
  - Process code versions
    - development => test => user
  - Research data
    - input, output, and intermediate data
  - Known versions of codes used to generate research data
  - Better repeatability of results
  - Ensured ability to go back to earlier versions
- Value of automated formal software change control demonstrated for LaRC research
  - Distributed, heterogeneous computer environment

Lessons Learned in SCM for Research

- Use a commercial SCM software tool
  - Absolutely essential for this type of project
- Require use of SCM from the beginning
- Provide enough time at project start
  - Train team that had never used formal SCM
    - First time used in research software at LaRC
  - Plan how SCM should function in the research environment
- Expect a learning experience
  - Allow for "re-thinking" as more is learned about SCM
- Still learning how to use SCM in research and in heterogeneous computing environment

Summary

- **HSCT4.0 is ^very complex!**
- **Formulation of *Analysis* is complete & viable**
  - ***Optimization* still to be done**
- **CAS goals have been addressed**
  - **Parallel computing**
  - **Heterogeneous computing network**
- **Lessons have been learned useful to others managing complex research projects**
  - **Software configuration management issues**
  - **Joanne will discuss others in next talk**