Multidisciplinary Optimization in Airframe Design

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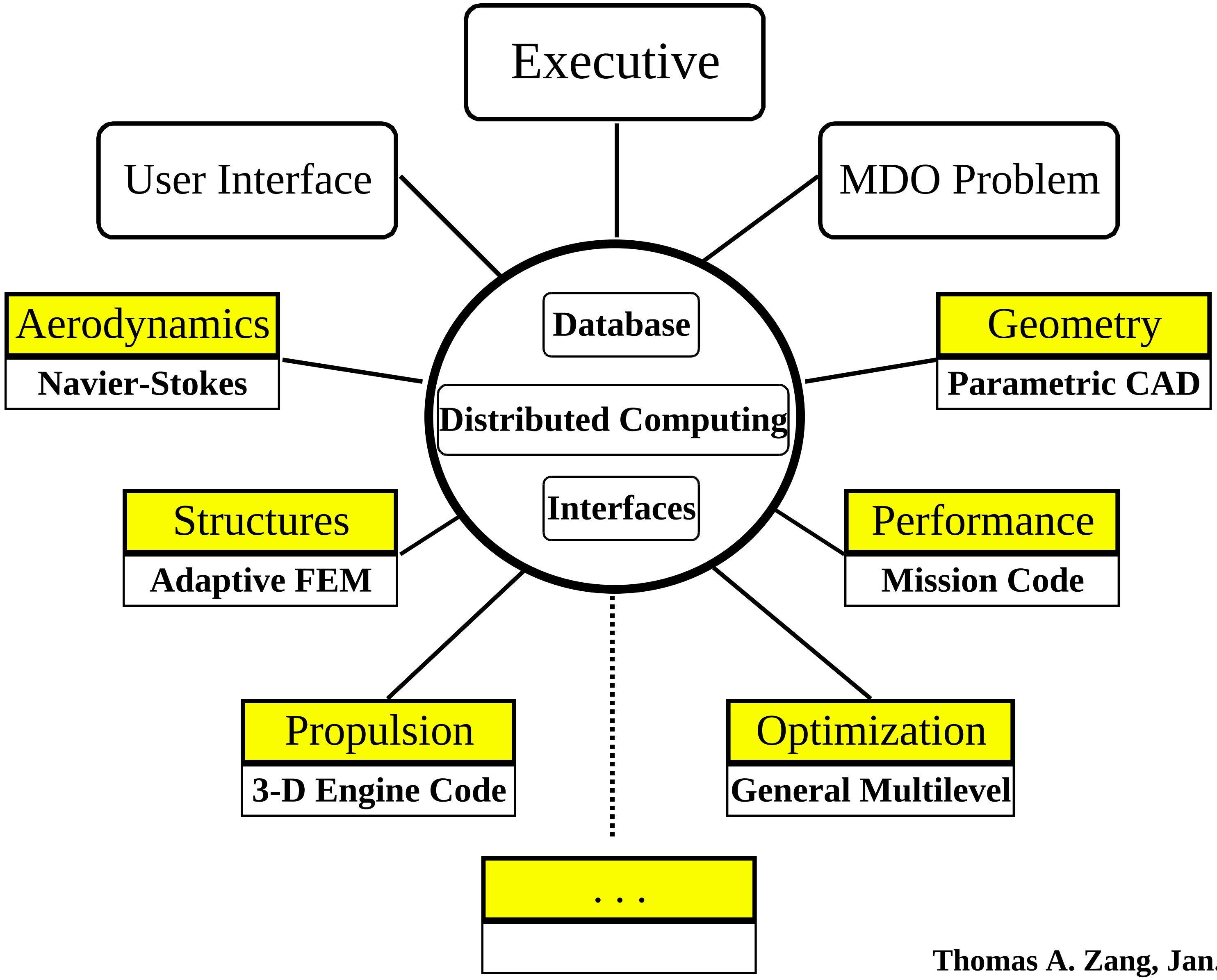
Outline

- LaRC HPCCP Design Environment applied to HSCT
- Generic Tools
  - Process Management (DeMAID)
  - Automatic Differentiation (ADIFOR/ADJIFOR)
- Geometry Models
- Frameworks / Environments
- Cost-Performance Optimization

Contributors to the IDS Vision

- *Systems Analysis*
- *Discipline Technologies*
- **MDO Technology**
  - – **Interdisciplinary Modeling**
  - – **Approximations**
  - √ **Sensitivity Analysis**
  - – **Decomposition**
  - – **Design Space Search**
  - – **Multidisciplinary Optimization**
  - √ **Cost-performance Optimization**
- **Information Technology**
  - √ **Product Data Models**
  - √ **Knowledge-Based Systems**
  - – **Ultra-fast Computing**
  - – **Collaborative Tools**
  - √ **Design Frameworks/Environments**

LaRC HPCCP HSCT Application Goal



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LaRC HSCT Applications

Application	HSCT 2 (1994)	HSCT 3 (1997)	HSCT 4 *(1999)*
Design Variables	5	7	271
Constraints	6	6	31868
Major Codes			
Aerodynamics	Wingdes	ISAAC	CFL3D, USSAERO
Structures	ELAPS	COMET	GENESIS
Performance	Range equation	Range equation	FLOPS
Propulsion	Engine deck	Engine deck	ENG10
Analysis Processes (without looping)	10	20	70
Analysis Control			
Major Loops	Weight Conv., Trim	Weight Conv., Aeroelastic, Trim	Aeroelastic, Trim
Load conditions	2	2	7
Mission conditions	1	1	10
Process (with loops)	O(10)	O(100)	O(1000)
Total time	O(minutes)	O(hours)	O(1 day)
Optimization Cycle			
(ndv+1) #analysis processes	O(100)	O(1000)	O(100,000)
Total time/cycle	O(10 minutes)	O(3 hours)	O(3 days)

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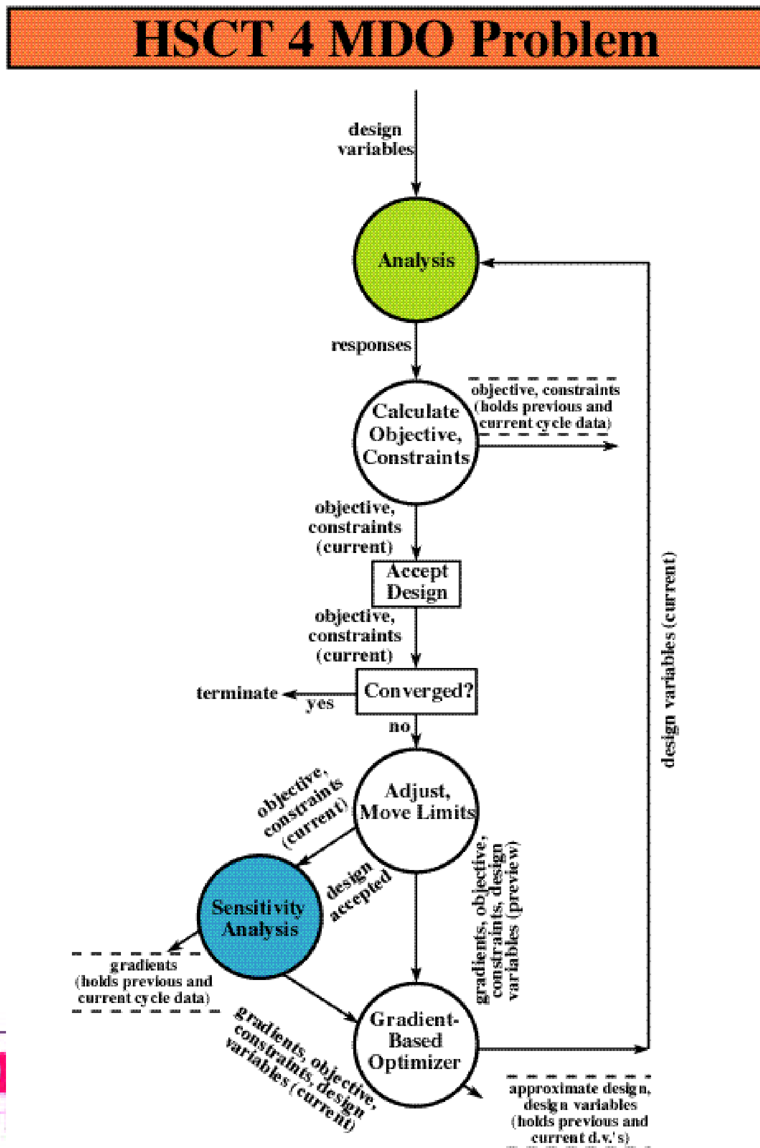
LaRC HSCT Applications

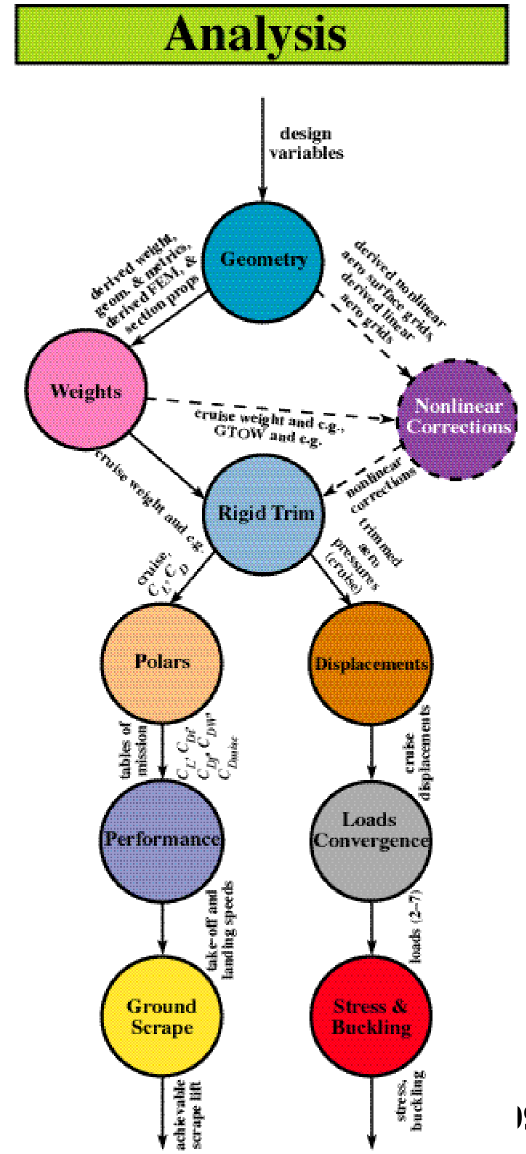
Application	HSCT 2 (1994)	HSCT 3 (1997)	HSCT 4 *(1999)*
Design Variables			
Geometry	3	3	27
Structures	2	4	244
Total	**5**	**7**	**271**
Constraints			
Geometry	-		216
Aerodynamics	2		-
Performance	-		10
Weights	-		2
Structures	4		4520 (per load condition)
Total	**6**		**31868** (7 load conditions)

HSCT 4.0 Design Problem

Level 1 Process



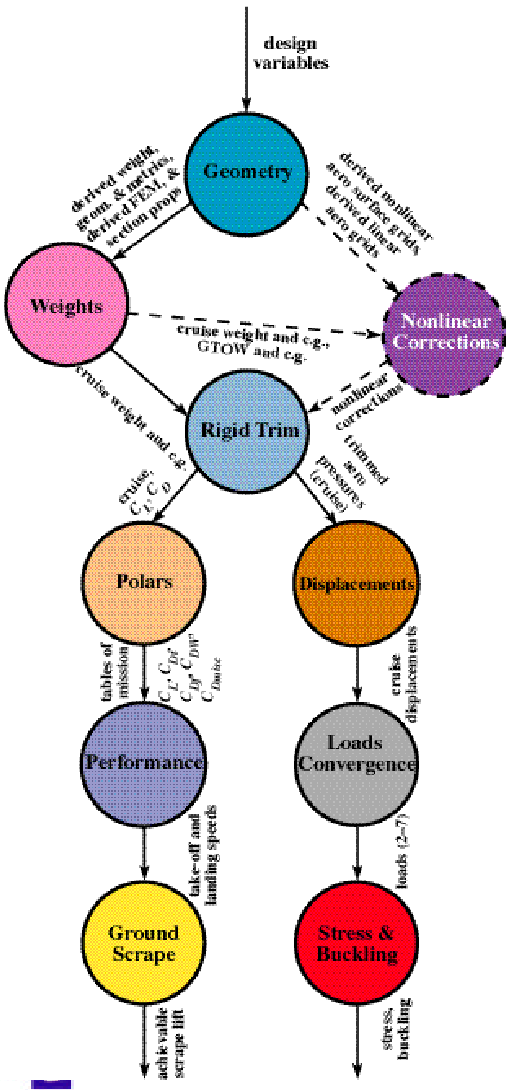
Level 2 Analysis Process



HSCT 4.0 Design Problem

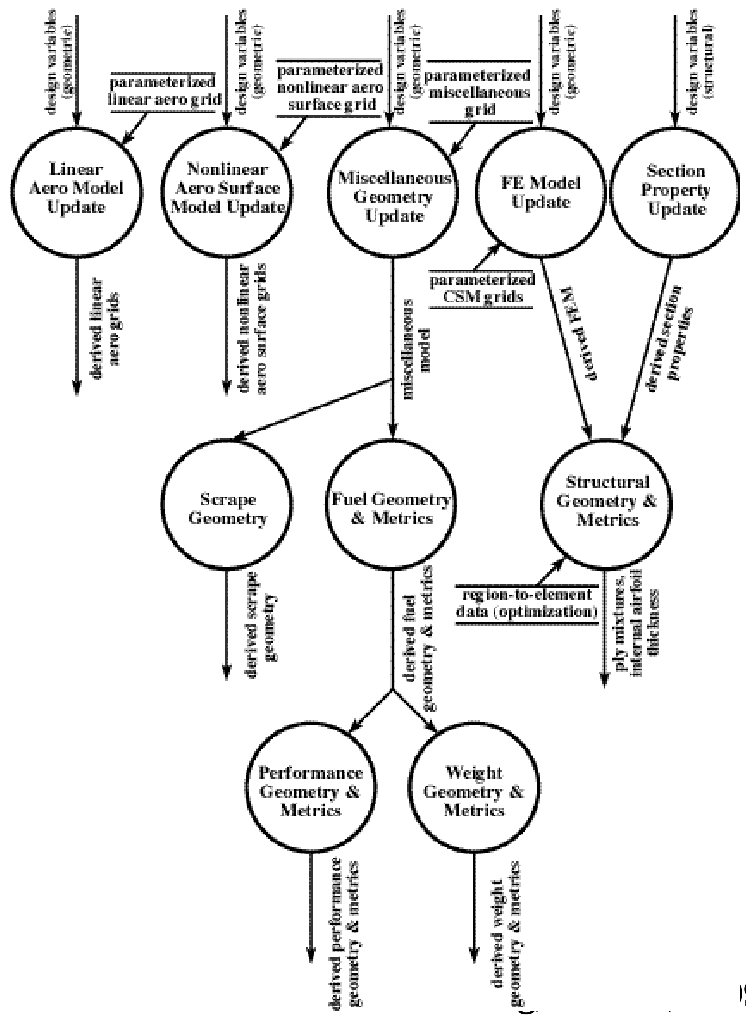
Level 2 Analysis Process

Analysis



Level 3 Geometry Process

Geometry



HSCT 4.0 MDO Comments

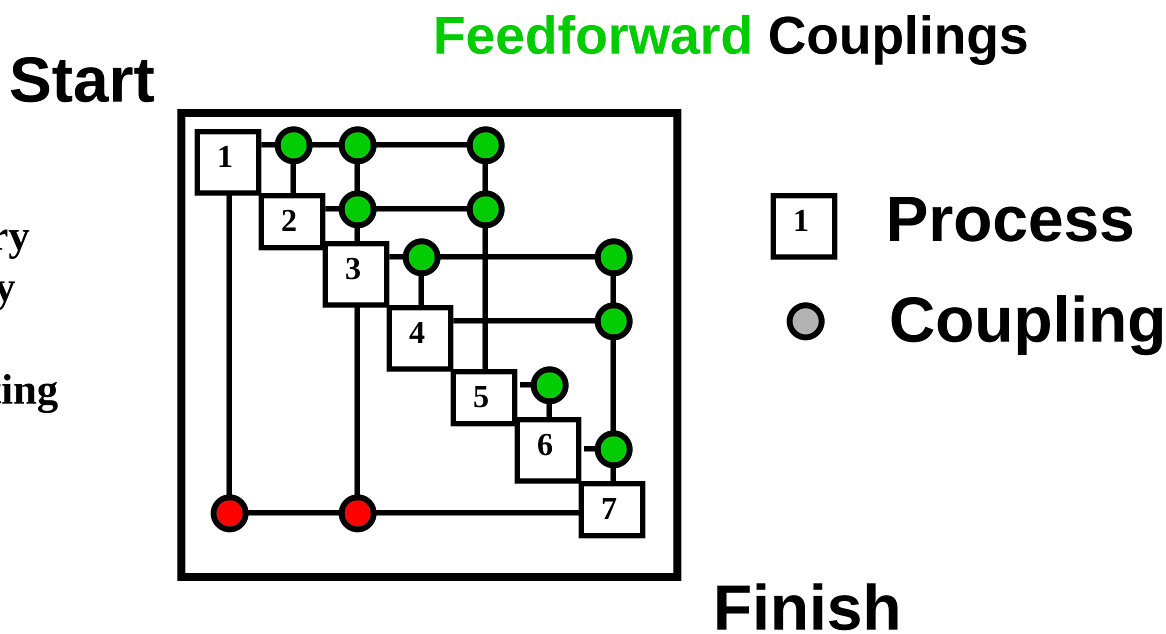
- Despite its complexity there are many important effects which are not included in the HSCT 4.0 MDO problem (and recall that the aerodynamics is primarily linear)
- Nevertheless, LaRC projects that it will take 3 days to run a single optimization cycle utilizing the massively parallel Origin 2000 at ARC
- Moreover, standard practice in the aircraft industry is to examine 5,000 load cases — 3 orders of magnitude greater than the 7 in the HSCT 4.0 MDO problem
- An IDS for Preliminary Design must be capable of handling the intense computational burden and the sheer number of individual and iterative processes
- An IDS must incorporate accurate, reliable approximation methods to have any impact on real designs
- An important issue is finding the optimal sequencing of the thousands of processes in the design problem

DeMAID

A Knowledge-Based System for Design Process Management

Design Structure Matrix Representation

1 Aero
2 Trajectory
3 Geometry
4 Sizing
5 Aeroheating
6 TPS
7 Weights



Feedback Couplings
(Estimate and iterate)

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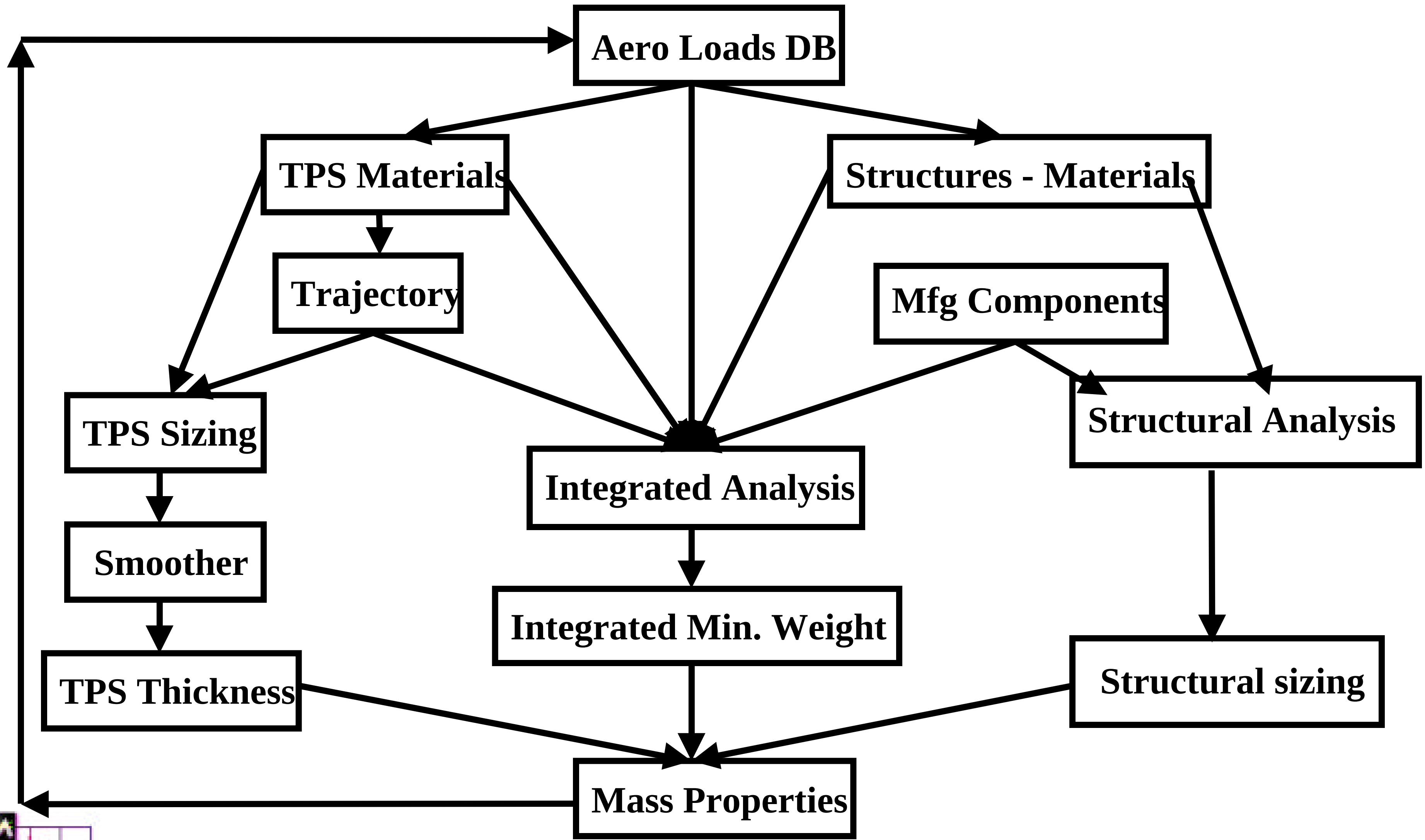
TPS Structures Sizing - Process Flow Chart



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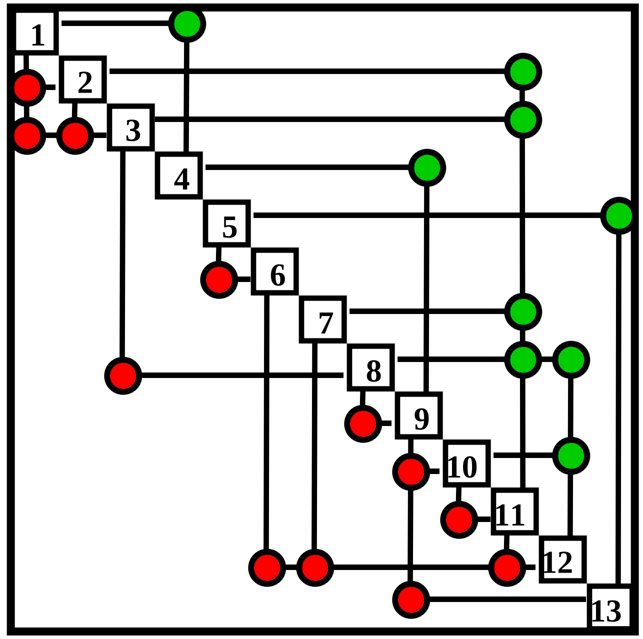
TPS Structures Sizing Process via DeMAID

Random Sequence

Time = 43



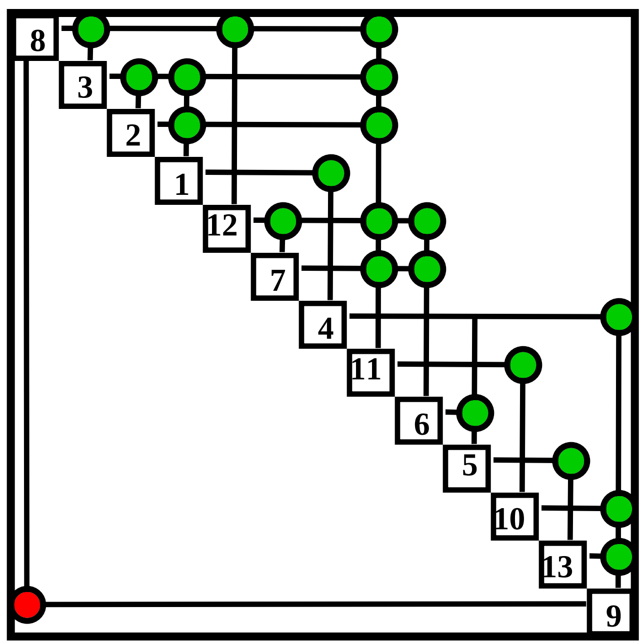
1 Structural Analy
2 Mfg Components
3 Structures - Mat.
4 Structural sizing
5 Smoother
6 TPS Sizing
7 Trajectory
8 Aero Loads DB
9 Mass Properties
10 Integrated Min. Wt.
11 Integrated Analy
12 TPS Materials
13 TPS Thickness

Assumptions

1 iteration / feedback
1 unit of time / process

Optimized Sequence

Time = 13



1 Aero Loads DB
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13 Mass Properties

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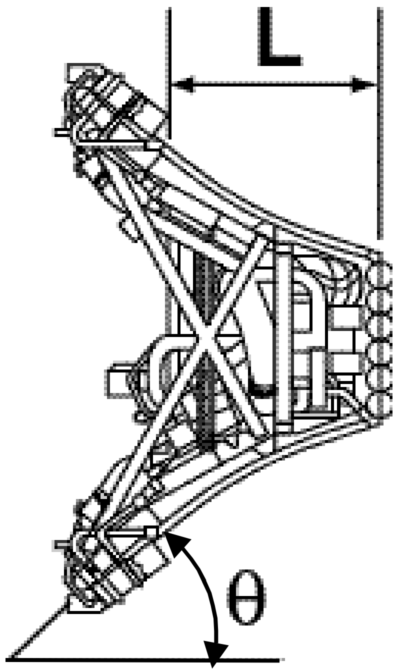
DeMAID Comments

- DeMAID technology can contribute to an IDS by automating the sequencing of the processes
- LaRC is assisting Georgia Tech in incorporating a web-enhanced version of DeMAID into their next, web-based version of IMAGE
- The technology in DeMAID is applicable to organizational re-engineering efforts
- A major practical issue in re-engineering the design process is that the optimal processes often conflict strongly with the entrenched organizational structure

Uses of Sensitivity Analysis

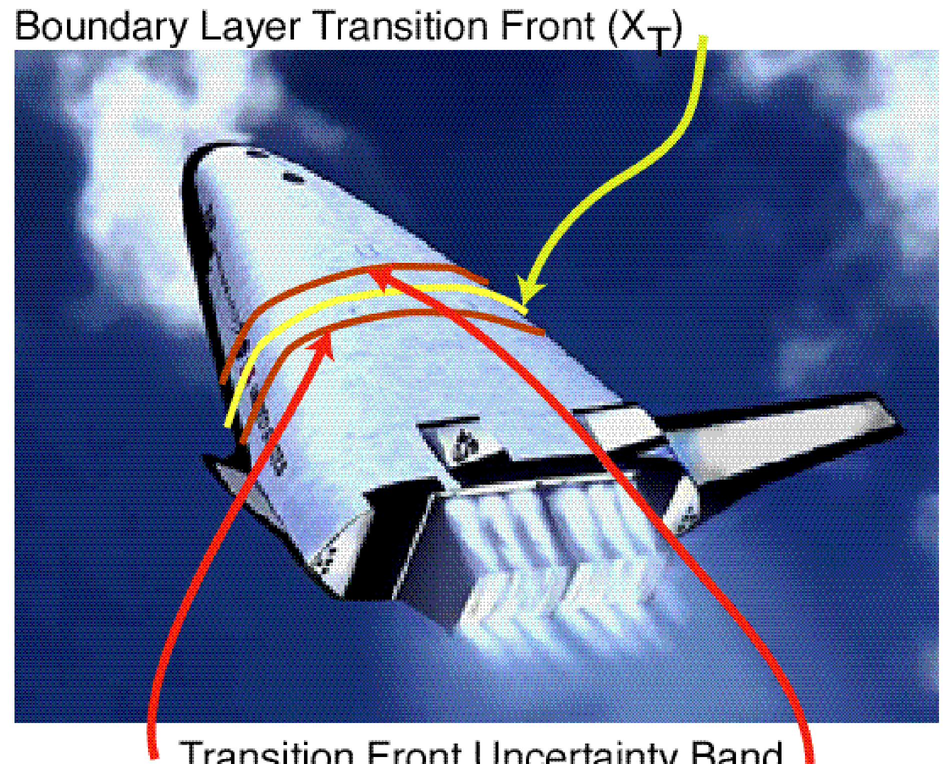
Optimization



Min G=GLOW

$$\boxed{\frac{\partial G}{\partial L},\ \frac{\partial G}{\partial \theta}}$$

Uncertainties



$$\Delta C_L = \boxed{\frac{\partial C_L}{\partial X_T}} \Delta X_T$$

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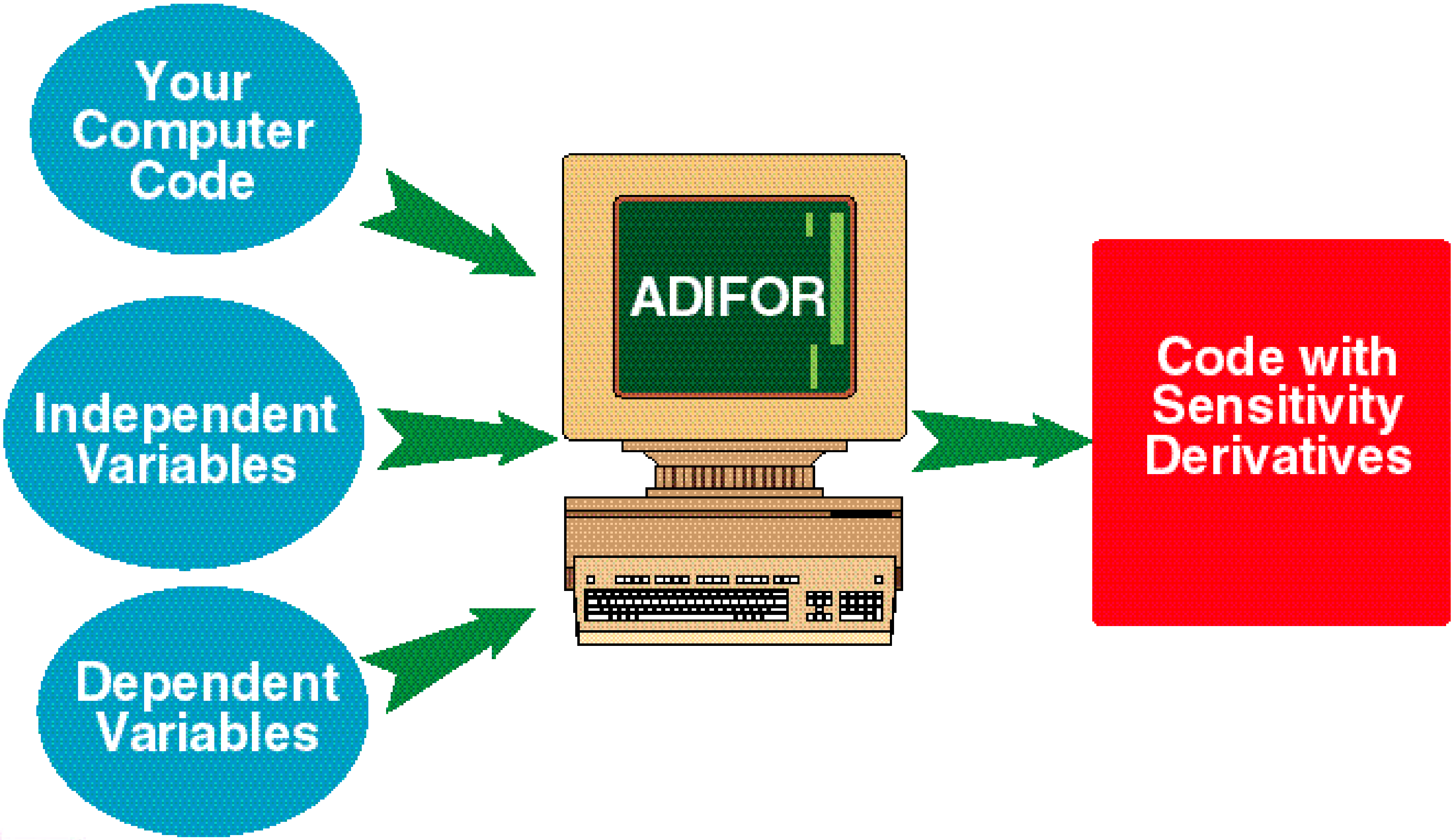
Background

- Sensitivities are useful in
  - Optimization applications
  - Uncertainty analyses
  - Trade studies ("what if..." questions)
- Traditional sensitivity methods
  - Finite-differences (step-size dependent)
  - Analytical (tedious, error prone)
  - Symbolic manipulators (limited scope)
- Automatic Differentiation (AD) provides fast, easy and exact method to obtain sensitivities from simulation codes

ADIFOR Process



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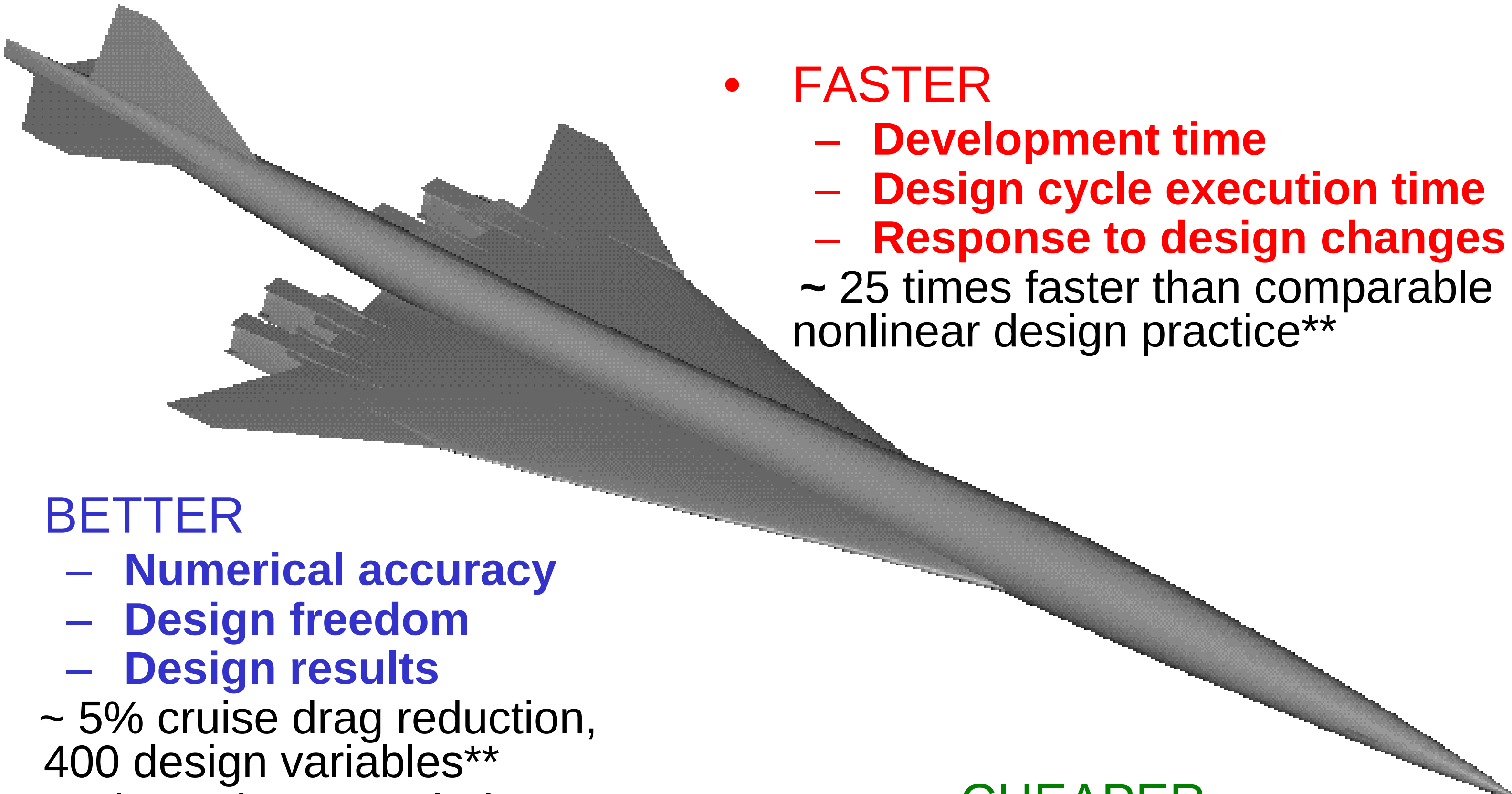
ADIFOR
Automatic Differentiation of FORTRAN

- General purpose automatic differentiation tool
- Developed by Argonne National Labs and Rice University in cooperation with NASA LaRC
- User identifies independent and dependent variables in FORTRAN source code*
- ADIFOR augments source code with code for exact derivatives via chain rule
- Augmented code generation requires 1 work day or less
- User compiles and executes augmented code (analysis and derivatives) on machine of choice

*ADIC - AD tool for C programs

High-Speed Civil Transport Optimization

With ADJIFOR*-Generated CFL3D Adjoint Computational Fluid Dynamics Code



- FASTER
  - **Development time**
  - **Design cycle execution time**
  - **Response to design changes**

  ~ 25 times faster than comparable nonlinear design practice**

- BETTER
  - **Numerical accuracy**
  - **Design freedom**
  - **Design results**

  ~ 5% cruise drag reduction, 400 design variables**

  -*unique viscous turbulent aero optimization capability***

- CHEAPER
  - **Less human resources**
  - **Less computer resources**

  ~ 10 times faster inviscid design cycle**

*** Developed by Rice University**

**** Initial Boeing Long Beach wing-body results**

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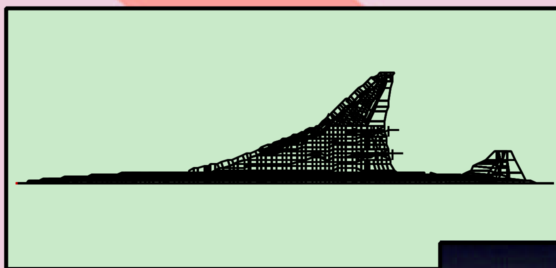
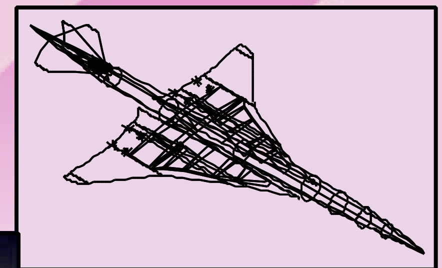
ADIFOR/ADJIFOR Comments

- It now takes just a matter of days (at most) to equip a standard FORTRAN or standard C code with exact gradients, even for full multiblock, multigrid, MPI-parallelized CFD codes
- Codes with hand-coded adjoints are bound to be more efficient, but for CFD codes they typically take 1-2 years to develop
- For the example on the previous chart, the alpha version of ADJIFOR produced 400 gradients in a run-time equivalent to 10 analyses
- The run-time is independent of the number of design variables but scales linearly with the number of output (performance) variables
- There is a substantial disk space requirement at present that makes such CFD calculations only feasible on massively parallel computers, but current improvements to ADJIFOR are addressing this
- Rice University is now preparing for the public release of ADIFOR 3 (which will include the adjoint capability), and LaRC plans to hold a workshop for interested new users in the second half of 1999

Multidisciplinary Aero/Structural Shape Optimization Using Deformation (MASSOUD)



Structures

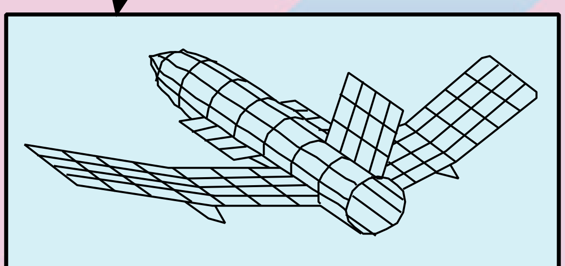


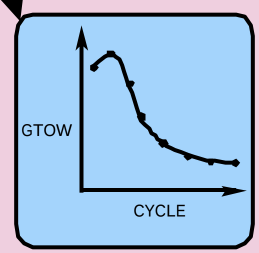
Performance

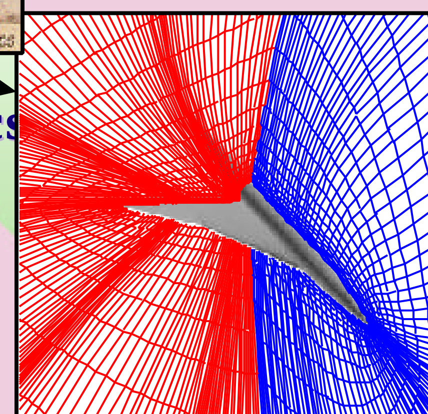
Flutter

Optimizer

Aerodynamics







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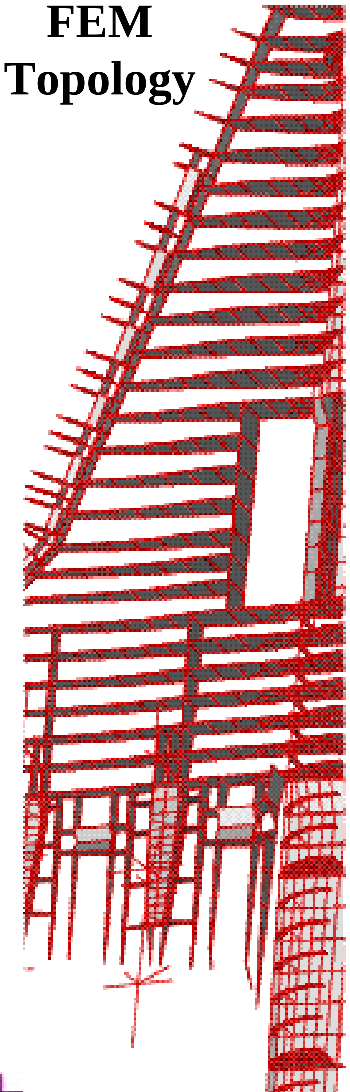
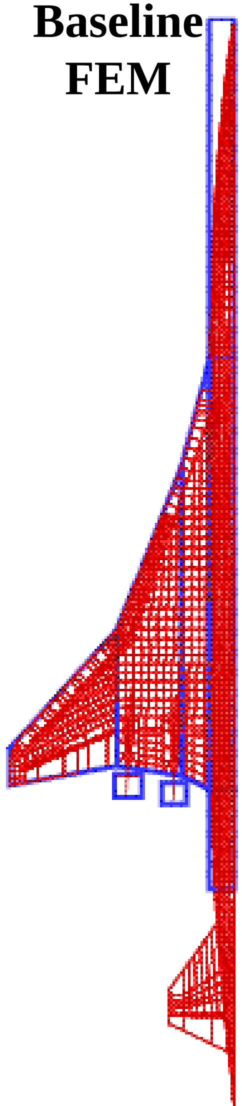
Parameterized HSCT Model

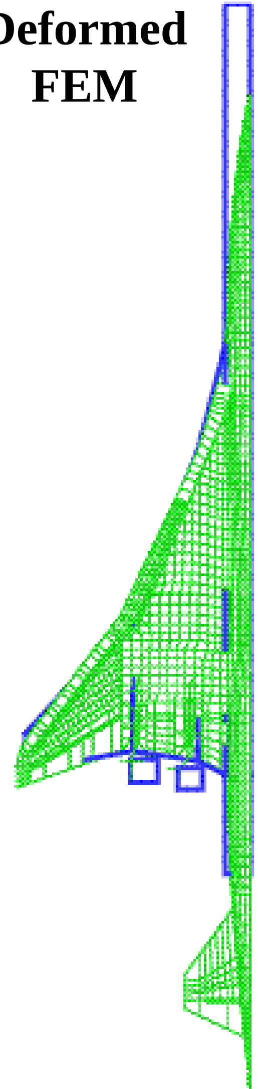
FEM Topology



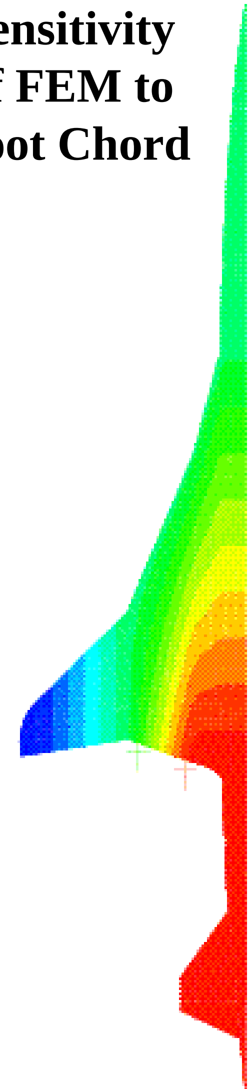
Baseline FEM



Deformed FEM



Sensitivity of FEM to Root Chord



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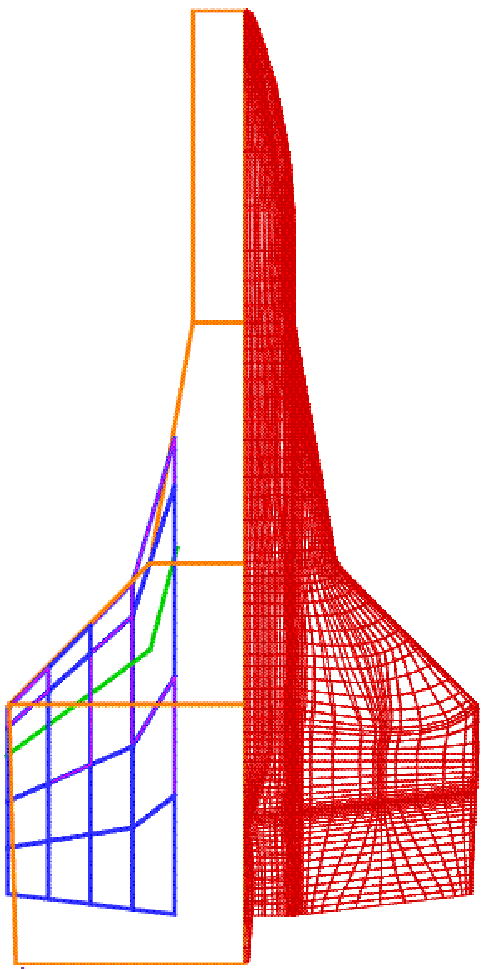
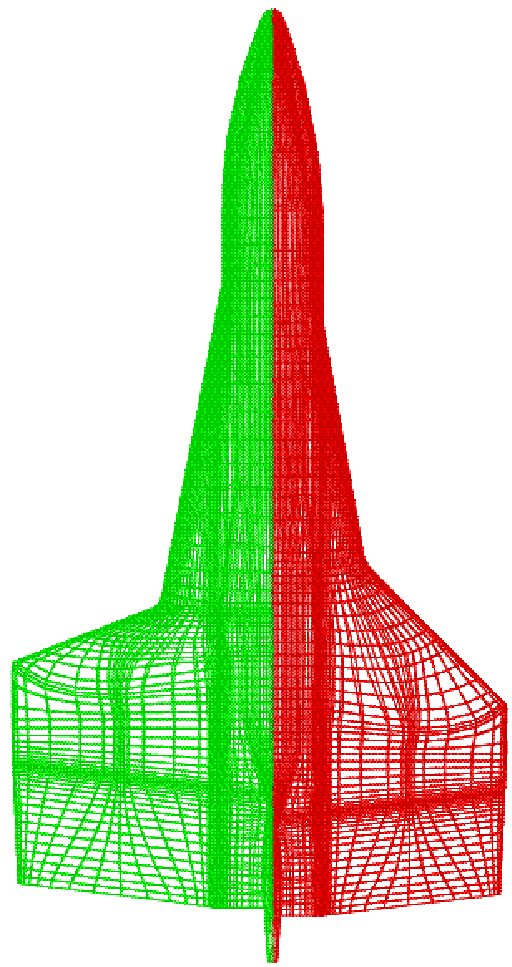
Geometry Demo for X-34

illustration of aerodynamic model

Parameterized Model



Deformed / Original Models



Design Variables

planform	22
twist	4
dihedral	4
thickness	25
camber	25
Total	**80**

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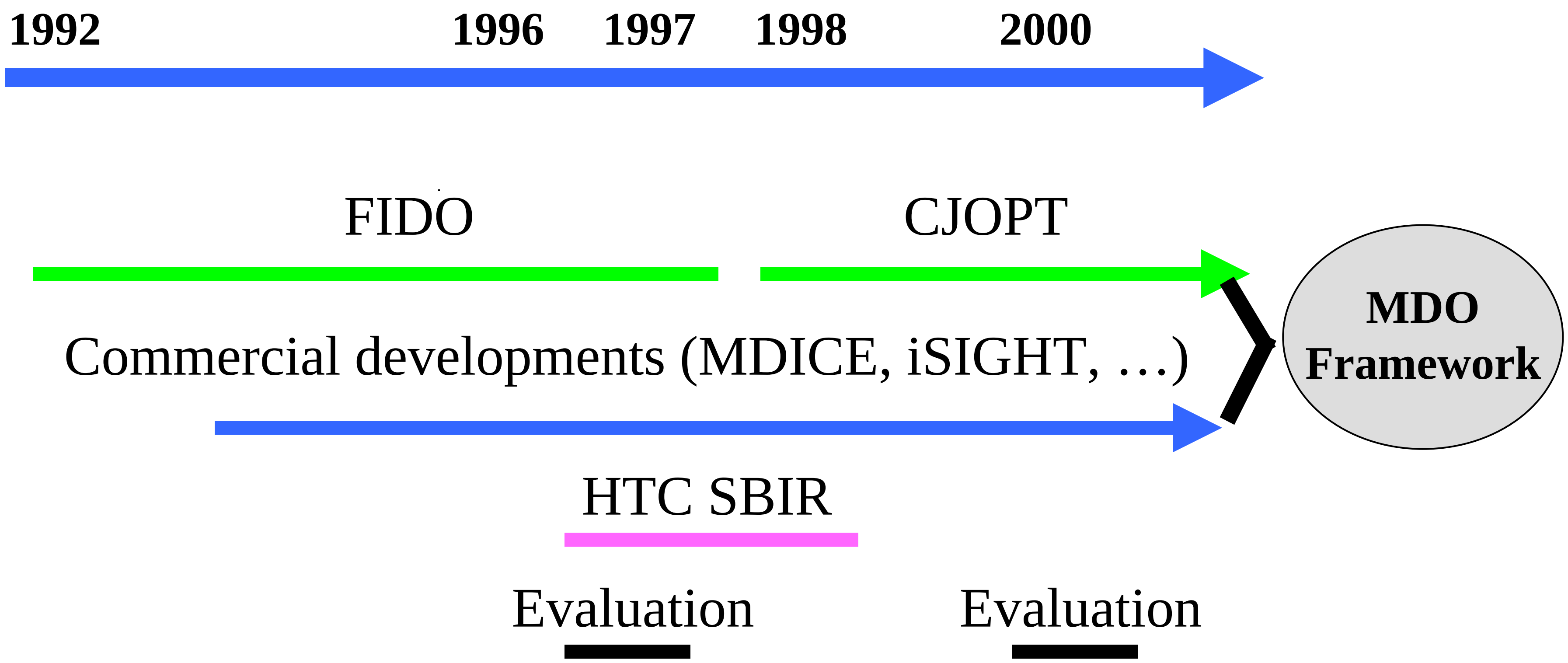
Geometry Comments

- **Geometry model sensitivities are an essential ingredient for MDO applications using gradient-based techniques**
- **The dirty secret of CAD systems is that they do not provide the sensitivities of the model (e.g., OML for aerodynamics) to the parameters other than via the brute-force, error-prone method of finite-differences**
- **At LaRC we now have exact gradients for every stage (grid generation, flow solver, post-processor) except for the geometry generation**
- **The MASSOUD system was developed to fill the hole in current CAD system capabilities**
- **Until CAD systems produce geometry model gradients, they cannot be fully integrated into an IDS**
- **The geometry/grid generation problem for structures is an order of magnitude more difficult than for aerodynamics and would greatly benefit from the application of knowledge-based systems**

LaRC HPCCP Framework Activities



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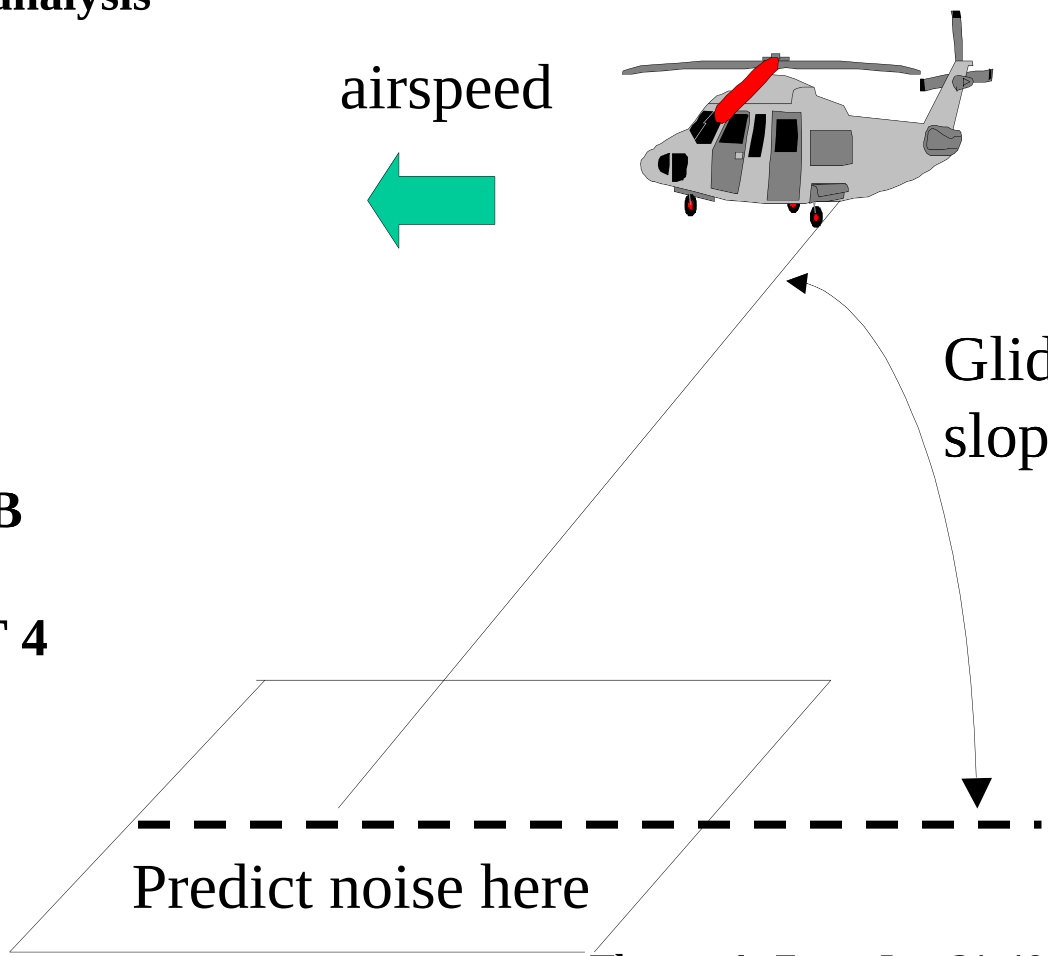
iSIGHT Success Story

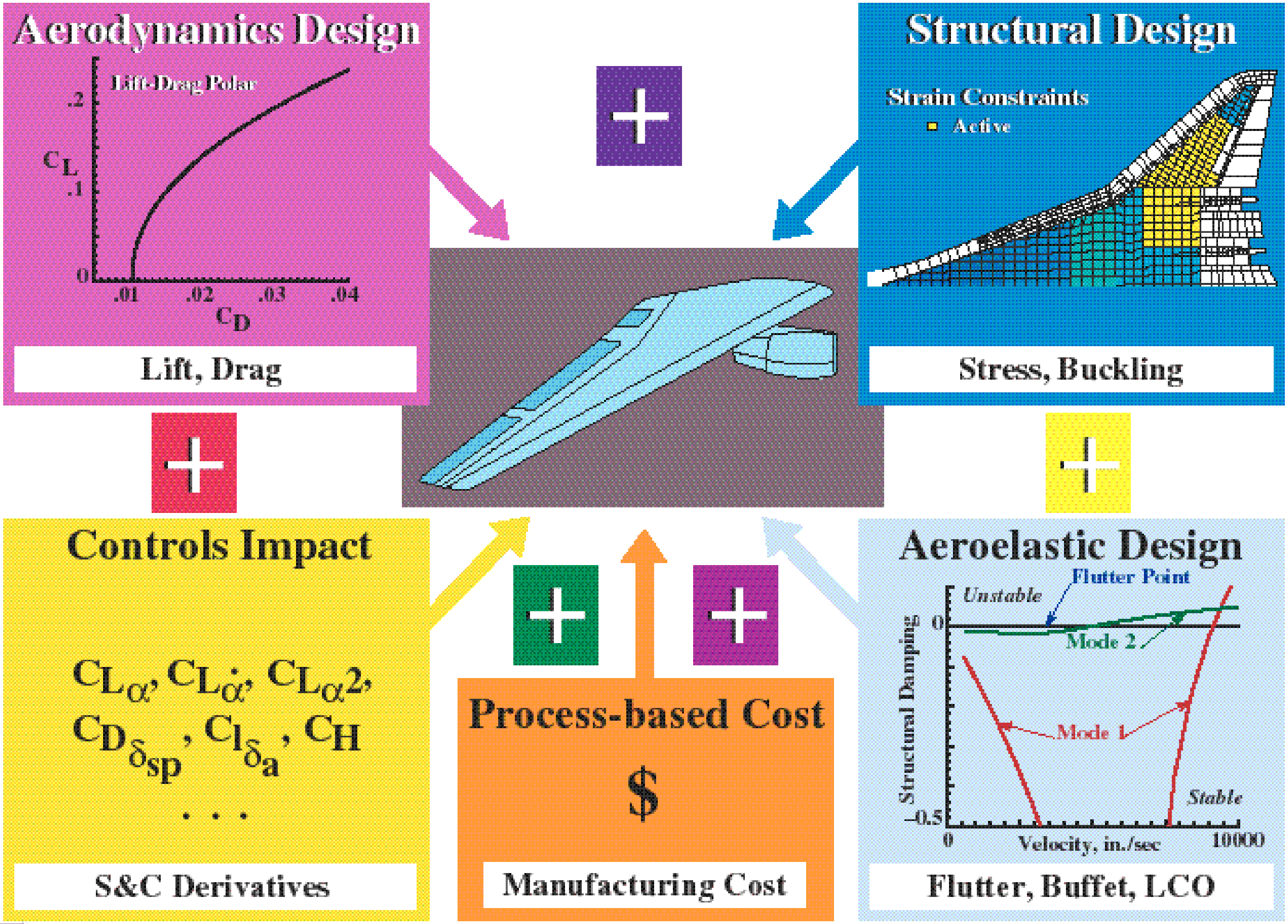
- **Rotorcraft Program Request of MDOB**
  - **Take "black box" noise analysis code**
  - **Use 5 design variables**
  - **Recommend:**
    - Optimization method
    - Approximation needed
    - Formulation
    - Testing methods
- **In less than 1 week MDOB developed the working application in the iSIGHT 4 framework**



Framework Comments

- LaRC HPCCP spent 5 years on the FIDO framework and developed extensive experience on the requirements for the framework component of an IDS
- No current commercial framework meets all of our requirements
- LaRC HPCCP's current plans are to evaluate commercial frameworks periodically and to work with vendors to incorporate our requirements
- In the interim we are implementing the HSCT 4.0 MDO problem in a CORBA-compliant fashion using JAVA & JAVABeans tools
- Do not believe that an object-oriented framework is by itself a panacea, for it currently takes inordinately long to "wrap" a complex analysis code in any generality (months for many of the complex codes in HSCT 4.0)
- Tools to assist with this "mundane" task (especially for messy but essential legacy codes) would have more impact on those laboring in the trenches of MDO application development than any other IT development

Integrated High-Fidelity Methods for Cruise Wing Design



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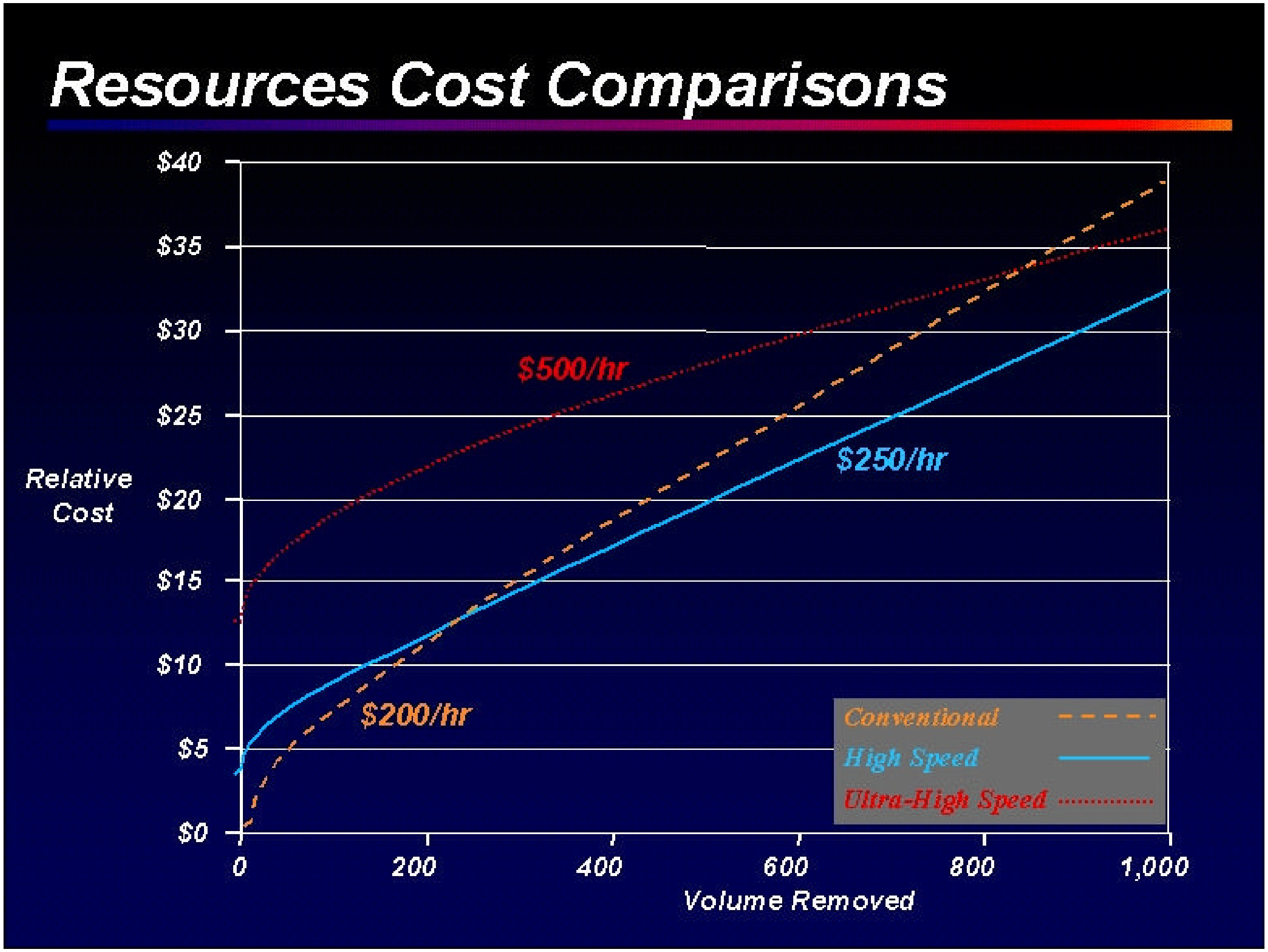
COSTRAN Example for Aircraft Fuselage

Manufacturing cost vs. volume for 3 different processes



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