Rethinking the Design Process

iSIGHT Framework

Presentation to TFAWs 2001

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Product Creation: A Brutally Multidisciplinary Challenge!

Collaboration Across Engineering Disciplines, Organizations, Product Components and Lifecycle Stages

- **Airframe Structure**
  - Aerodynamics
  - Heat Transfer
  - Structural Mechanics
  - Structural Dynamics

- **Propulsion**
  - Engine Cycle
  - Aerodynamic
  - Structural Mechanics
  - Combustion
  - Structural Dynamics
  - Weight

- **Mission**
  - Fuel Burn
  - Economic Analysis
  - Range
  - Takeoff Gross Weight

- **Electronic**
  - Guidance/Control
  - Communications
  - Electric Power Supply

- **Noise**
  - Airport Noise
  - Cabin Noise

- **Cost**
  - Manufacturing Cost
  - Inventory/Financial Cost
  - Product Lifecycle Cost
Design Data Islands

Product Creation Process

- CAD
- Loads
- Kinematics
- CFD
- Materials

In-house legacy codes

Barriers to Speed and Productivity

COST MODELING

September 12, 2001

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Engineous History

A catalyst for engineering innovation!

1st. Generation
1979

“Software Robot” at MIT
Invented by Dr. Tong

2nd Generation
1983

Engineous at GE
>10 Years - $12 Million

3rd Generation
1996

1996 - Engineous founded
2001 - iSIGHT 6.0 released

1996 - Engineous founded
2001 - iSIGHT 6.0 released
Engineous People – Educational Snapshot

70 People Worldwide
- 61 Degreed Engineers
- 42 w/Advanced Engineering Degrees
- 10 Doctorate Level
- Industry Specific Experts- Automotive and Turbo Machinery. Substantial background at GM, GE, Cray Research, and NASA.
- Dr. Siu Tong – Founder and Chairman
  Over 20 years experience in the technology industry as a senior manager and in product research and development.
Helping Our Customers

Engineous Deploys Resources and Technology to:

1. Help our clients integrate their diverse design tools
2. Automate their iterative design processes
3. Accelerate finding the best design solution
Manual Design Evaluation Process

Manual Design Process
• Time consuming
• Error prone tasks
• Engineers spend more time preparing

Results
• Produces limited number of designs
• Produces questionable design quality
• Fewer design alternatives
iSIGHT - Software Robot

- Engineer defines simulation process
- Engineer defines goals and constraints
- Robot applies design intelligence
- Automates and iterates design process
- 24 hour workday

Results

- Increased evaluations
- Improved quality
- Engineers spend more time evaluating
- Multiple design alternatives
- Saves valuable engineering time
- Greater product knowledge
Design Automation

iSIGHT
- Integrates the Process
- Automates the Execution
- Evaluates the Alternatives

Typical Manual Iterative Process

*How does iSIGHT Modify Designs?*

- By Applying Design Intelligence to the iterative process through Design Study Tools
  - Deterministic
  - Stochastic

- Design Concept
- Build Computer Model
- Adjust Input File(s)
- Run Model
- Review Output File(s)
- Meets Requirements?
  - Y
  - N
- Final Design
Complete Design Exploration Engine

- Central Composite
- Full Factorial
- Orthogonal Array
- Latin Hypercube
- Parameter
- Database

- Rule-based
- Exploratory (GA etc)
- Gradient-based
- Mixed Variable

- Monte Carlo
- Taguchi Robust Design
- Reliability Analysis
- Reliability-based Optimization
- Design for Six Sigma

- Taylor Series
- Response Surface
- Variable Complexity

Design of Experiments
Optimization
Quality Engineering
Applying Models

Stochastic Methods
Deterministic Methods
New Design Process

Constraint
Boundary
Initial Design
Search for solution
Optimization
(Approximations)
Robust/Reliability Design (Quality Engineering)
Feasible (safe)
Infeasible (failed)

DOE: Critical Factors And Initial Design

Initial Design
GUI Interface

- Task Manager
- Define Constraints
- Monitor
- DOE Post-Processing
Connectivity
A Sampling of Applications in Use at Our Customer Sites

- ASCII-based I/O Files using iSIGHT GUI
  - Structures: NASTRAN, MARC, ABAQUS, ANSYS
  - Metal Forming: DEFORM, Procast
  - CFD: STAR-CD, FLUENT, CFX, TASCflow, STREAM
  - Crash/Impact: Pam-Crash, LS-DYNA, RADIOSS, MADIMO
  - Injection Molding: MOLDFLOW, C-Mold, TIMON, PLANETS, SimVis
  - Magnetics/Acoustics/Optics: CODE-V
  - Engines: GT-Power, Boost
  - Semiconductors: SPICE
  - CAD/Pre-Processor: I-DEAS, Pro/E, Unigraphics, CATIA, PATRAN, Acumen, Hyper-Mesh, Gridgen, HICAD/CADAS etc.
  - Turbomachinery: Concepts NREC COMPAL, CCAD
  - Thermo Cycle Analysis: Legacy codes at GE, Toshiba, Honeywell, P&W, etc.
  - General Math/Plotting: Mathcad, S-PLUS
  - Many Internal Programs

Virtually any Application or Simulation Code
Platform Utilization

- Unix
  - Sun, SGI, HP, IBM, etc.
- Windows
  - NT, 2000
- Linux

Parallel and Distributed Processing
- Run multiple codes in parallel
- Run parallel techniques (i.e., DOE, GA)
- Distributed and enabled across heterogeneous network
Application Examples

- Multi-Stage Power Generator Steam Turbine
- DARPA: Integrated Disk Design & Manufacturing
- DARPA AIM (Project for Accelerated Insertion of Materials)
- Airframe/Propulsion Optimization
- Navy Propeller Conceptual Design
- Aerospike Nozzle Design
- America’s Cup Yacht Design Prada’s Luna Rossa
Multi-Stage Power Generator Steam Turbine

**Problem:** Reduce time required to design power plant turbines

**Solution:** Use Engineous software to integrate 29 codes

**Result:**
- Design time reduced from 1 year to hours
- Major competitive advantage for GE Power Systems
Multi-Stage Power Generator Steam Turbine

**Preliminary Design**
- Flowpath Generation
- Axial Pre-Processing
- Predict Efficiency

**Initial Circumferential Design**
- Turbine Initialization
- Flowpath Smoothing
- Calculate Intersection
- Cirm-preprocessor I/O manipulation
- Circum-analysis
- Turbine Update

**Initial Cascade Design**
- Airfoil Generator 1
- Airfoil Generator 2
- Cascade Analysis
- Airfoil Stacking

**Mechanical Design**
- Pre-Processor A
- Pre-Processor B
- Pre-Processor C
- ANSYS
- V-Mode Identification

**Refined Cascade Design**
- Airfoil Generator 1
- Airfoil Generator 2
- Cascade Analysis
- Airfoil Stacking

**Refined Circumferential Design**
- Post-Processor 1
- Post-Processor 2
- Update Intersection
- Cirm-preprocessor I/O manipulation
- Circum-analysis
- Turbine Update
DARPA Program

- Integrated Turbine Disk Design

Objective:

Demonstrate geometry and finite element based multidisciplinary optimization (MDO) for complex product and process development
DARPA: Integrated Disk Design & Manufacturing

**Design**
- Requirements
  - Mechanical Design
  - Finished Part
  - Life Prediction
    - HCF/LCF Data
    - Part Life
  - Process Parameters
    - Geometry, Material

**Manufacturing**
- Forging
  - Die(s)
  - Billet
  - Near-net Shape Disk Forging
    - Process Parameters
    - Material Properties
    - Residual Stress
  - Finished Part
    - Residual Stress, Distortions
  - Machining
    - Process Parameters
DARPA: Integrated Disk Design & Manufacturing

- **Mechanical Design**
  - Meet Requirements
  - Minimize Weight
  - Minimize Cost

- **Forging**
  - Near Net Shape
  - Minimize Forging Operations
  - Formability

- **Heat Treatment**
  - Requisite Material Properties
  - Minimize Residual Stress
  - No Cracking

- **Machining**
  - Minimize Distortion
  - Minimize Number of Operations

- **Life prediction**
  - Required Life
The Problem: Residual Stresses Introduced during Heat Treatment lead to distortions of the Finished Part

Minimize Non-uniform Cooling for Reduced Residual Stresses
Cooling Rate Constraints for Creep Performance
Surface Heat Transfer Coefficients $h_i$

The Tools: iSIGHT

Finite Element Analysis (DEFORM)
DARPA: Integrated Disk Design & Manufacturing

**Cooling Rate and Stress Results**

- Cooling Rate Distribution more Uniform
- Cooling Rate Target Met

Maximum Stresses Reduced by about 80%
Forging Die Speed Optimization

Objective:
To forge the billet into a high pressure turbine disk such that the maximum strain rate in the deformable work piece never exceeds 0.008 s\(^{-1}\) during forging.
DARPA: Integrated Disk Design & Manufacturing

Conventional Approach Results  
Optimized Approach Results

Forging Die Speed Optimization: Equivalent Strain Rate Contours
DARPA: Integrated Disk Design & Manufacturing

Forging Die Shape Optimization
The strain distributions of the initial and optimal designs. The low strain region is reduced in the optimal design. All data is normalized.

Forging Die Shape Optimization: Normalized Strain Distributions
Summary:

• Forging Optimization System Has Been Applied to Several Disks

• Demonstrated Weight Reductions of 11% (average) Over Manually Optimized Designs

• Transition of Software to Forging Vendors In-Progress
DARPA AIM (Project for Accelerated Insertion of Materials)

Goal:
Develop a rotor component design system - called “aimSIGHT” - that allows material forming process parameters to be tuned automatically to achieve desired material properties and component performance, thereby dramatically reducing the time needed to develop new materials.

Account for real world uncertainties in manufacturing process, material properties, tolerances, material behavior predictions, etc.

Team Members:
- Pratt & Whitney (Lead)
- Scientific Forming Technologies Corp.
- Ladish Co.
- Engineous Software Inc.
- Brown University
- Carnegie-Mellon University
- University of Connecticut
- Drexel University
- Lehigh University
- University of Michigan
- Michigan Technological University
- MIT
- Northwestern University
- West Virginia University
“aimSIGHT” Design System

Define/Modify Geometry

Select forging process and heat treatment parameters

Predict deformation and thermal behavior

Predict microstructure

Predict material properties

Performance & cost criteria met?

 branches to:

- Performance & cost criteria met?
- NO
- YES

Part Definition

Entire Process Driven by iSIGHT

Machining
Forging
Inspection
Material

Predict cost

Under Development

Cost Advantage™

Entire Process Driven by iSIGHT

DEFORM

Predict life

NEW

ANSYS

Predict material properties

NEW

Unigraphics

Entire Process Driven by iSIGHT

NEW
Airframe/Propulsion Optimization

The Problem:

Determine the optimal cycle and minimum engine size to match a given engine to an airframe for optimal aircraft performance.
Objective: Determine the optimal cycle and minimum engine size to match a given engine to an airframe for optimal aircraft performance.

Mission
- Maneuvers
- Cruise
- TO/LD

Engines
- F404
- F110
- F120

Airframes
- Commercial
- Fighter
- Bomber

Propulsion Installation ➔ Engine Sizing ➔ Optimum Aircraft Performance ➔ Inlet & Nozzle Selection
Integrated Airframe/Propulsion Optimization

Conclusion: Design optimization using preliminary design tools allows efficient evaluation of complex engineering systems & scenarios that can improve designs to achieve enhanced performance and reduce cycle times at lower cost.
Integrated Airframe/Propulsion Optimization

Performance Optimization
Maximum Thrust
Subject to Constraints
0.0 < ByPass Ratio < 1.0
0.4 < Fan Pressure Ratio < 1.0
0.4 < Overall Pressure Ratio < 1.0
0.2 < Inlet Airflow < 1.0
0.8 < Throttle Ratio < 1.0

Engine Performance Map
Normalized Thrust

Normalized Design Inlet Airflow

Initial Design
Thrust: 1.56, Weight: 1.08
Length: 1.25, Inlet Diameter: 1.2
Inlet Airflow: 1.5, FPR: 2.4

Final Design
Thrust: 2.0, Weight: 1.43
Length: 1.38, Inlet Diameter: 1.4
Inlet Airflow: 1.47, FPR: 1.7
Navy Propeller Conceptual Design

The Problem:

Balancing the competing design requirements and constraints of 6 engineering groups to create the best overall propeller
## Navy Propeller Conceptual Design

### Benefits

- Better Design in Reduced Time
- Typical Single-Screw Propeller Design

<table>
<thead>
<tr>
<th>Manual</th>
<th>Engineous</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% of Time Spent Preparing Design Alternatives</td>
<td>5% of Time Spent Preparing Design Alternatives</td>
</tr>
<tr>
<td>30% of Time Spent Evaluating and Engineering Design Alternatives</td>
<td>95% of Time Spent Evaluating and Engineering Design Alternatives</td>
</tr>
<tr>
<td>Average Preliminary Design Time: 2 Months</td>
<td>Average Preliminary Design Time: 3 Weeks</td>
</tr>
<tr>
<td>Limited Number of Design Alternatives Evaluated</td>
<td>10-100 Times More Design Alternatives Evaluated</td>
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Aerospike Nozzle Design

NASA Langley

**Problem:** Minimize the Gross Lift-off Weight. Requires modeling effects of 4 domains, namely structures, CFD, baseflow, and performance domains

  - 18 design variables, 564 constraints

**Solution:** Coupled iSIGHT with multiple codes and implemented multidisciplinary feasible (MDF) strategy

**Results:**

  - “iSIGHT reduces code and file management for the user”
  - “iSIGHT reduces time required to explore variety of optimization schemes and design parameters”
Optimize yacht position (trim) to minimize drag and maximize speed for given sea surface shape.

Select trim

- Parametric Design Variables
- Sea Surface
- Pro/E Geometry
- ICEMCFD Mesh
- FLOWLOGIC CFD
- Pro/Mechanica Motion
- Converge Optimum

Min drag, max speed?

ICEMCFD Mesh
Model hull and sea shape

Create meshes

Pro/E Geometry
Simulate motion of hull in water

Calculate drag

Optimum Motion CFD
Simulate motion of hull in water

Min drag, max speed?
Automating Hull Design

- 1000’s of configurations analyzed in CFD
- **20-50** per day
- iSIGHT-based design system directly optimizes Pro/ENGINEER model

**Final result:**

_Correct new 3-D Pro/E geometry for manufacturing, no prototyping!_
The Future is now!

Internet Design Collaboration
People interactively work with the same model, sharing control and seeing the execution results of other team members.
iSIGHT Collaboration

iSIGHT Collaborator (ISC)

- Prime Contractor
- Subcontractor 1
- Subcontractor 2

System Model

HTTP-XML

Internet
Next Step

Develop a “Federated Intelligent Product EnviRonment” (FIPER) that allows companies to globally:

- Collaborate with dispersed design teams and business partners
- Establish standard language protocol for all design tools, legacy data and systems
- Access best-of-breed design and analysis tools
- Automate non-creative tasks in the design process
What is FIPER

- A NIST sponsored and funded ($21.5M) project to develop:
  - An internet-based distributed framework
    - Supports collaboration among geographically distributed engineering and business partners.
  - A service-oriented product development environment
    - Provides an open flexible design environment which allows universal availability and incorporation of existing data, tools/methods and processes as services.
    - Provides a common way to model your analysis and design process in conjunction with your product data.
Summary

iSIGHT provides a framework which:

- Enables data exchange between applications in similar or diverse disciplines.
- Automates the iterative nature of the design process.
- Applicable in all stages of the design process.
- Allows for automation and design exploration on the component, subsystem, and/or system level.
- Allows users to quickly couple and drive their design and analysis tools of choice, use “best in class” for each discipline.
- Provides a set of tools to explore design alternatives and improvements.
Conclusions

Utilization of the iSIGHT Framework throughout the design process (especially at the early conceptual design stage) has dramatic effects on:

- Lowering Costs
- Improving Safety and Reliability
- Reducing Design Cycle Time
- Improving Quality
- Improving Manufacturability

SLI (2nd gen) goals:

- Reduce cost of launch to low earth orbit to $1,000 per pound of payload
- Improve safety of loss of crew to 1 in 10,000 flights