Managing Uncertainty

1. Need to **KNOW WHAT YOU ARE DOING** and **HOW YOU ARE DOING IT**
   - What is your **PROCESS**?

2. Uncertainty exists due to **VARIATION**
   - Take Variation into Account with **SIMULATION**
   - **SIMULATION-SUPPORTED ENGINEERING**
Process Capture and Use Video


E-mail: ShipDesignProcess.nswccd.fct@navy.mil
Overview of the Ship Design Process Model

The Model can be Depicted Using “Boxes and Arrows”
This View of the HM&E Ship Design Processes Consists of 250 Activities, 812 Dependencies and 42 Activity Groups
Preliminary Design Focus

Expanded View of Preliminary Design Made up of Six General Design Areas:

1. Hull Systems to “Float”
2. Mission Systems to “Fight”
3. Propulsion/Power/Machinery to “Move”
4. Human Systems to “Enable”
5. Survivability to “Survive”
6. Design Integration & Management to “Integrate”
Multiple Views of Same Data

Process Diagrams “Boxes and Arrows”

Alternate WBS Views

Spreadsheets

Gantt Chart

Design Structure Matrix

3/6/2013  Approved for Public Release
Ship Design Process Model
Current State

• Captured from ONR Sponsored Ship Design Workshops

• Models HM&E Preliminary Design of Monohull Surface Combatant

• NAVSEA PAO Approved Process published on Web

• Starting point for pilot project customization with PEO-Ships programs
  • DDG-51 Flight III
  • LXR
  • Software Tool Deployment
Managing Uncertainty

1. Need to KNOW WHAT YOU ARE DOING and HOW YOU ARE DOING IT
   - What is your PROCESS?

2. Uncertainty exists due to VARIATION
   - Take Variation into Account with SIMULATION
   - SIMULATION-SUPPORTED ENGINEERING
SIMULATION SUPPORTED ENGINEERING

Analysis vs. Simulation
One run vs. Many runs

Single computer run = Analysis

Multiple computer runs = Simulation

Understanding = Knowing the topology and structure of the data cloud.
Simulation must address Variation

- Material Properties
- Loads
- Boundary and initial conditions
- Geometry imperfections
- Assembly imperfections
- Solver
- Computer (round-off, truncation, etc.)
- Engineer (choice of element type, algorithm, mesh band-width, etc.)

It’s the Way the World Is
First assumption

Second Assumption

Optimum?

Reality - Each Point:
- May be the result of a test, or an analysis.
- Is the result of different combinations of variables.
A simulation is a process in which all known uncertainties are introduced into the analysis model. The objective is to see how the product performance scatters.

Simulation provides:

• Scatter of the performance \( f = 10-12 \text{ Hz} \), not a single value \( f=11.345 \text{ Hz} \).
• The most probable performance \( f=11.6 \text{ Hz} \).
• Information on how ALL the tolerances affect the scatter of the performance.
• Information on which variables drive the response.
• Potentially dangerous behavior – outliers.
• A general understanding of how the system works
To LEARN WHAT WE DO NOT KNOW

We Need To

MINIMIZE ASSUMPTIONS

Common Foundation Assumptions:

• Continuity
• Mathematical Constructs
  • Gödel’s incompleteness theorems:
    • Any computable axiomatic system that is consistent, cannot be complete;
    • The consistency of the axioms cannot be proved within the system.
• General Over-Simplifications
MONTE CARLO METHOD

**Sources of Variability**
- Material Properties
- Loads
- Boundary and initial conditions
- Geometry imperfections
- Assembly imperfections
- Solver
- Computer (round-off, truncation, etc.)
- Engineer (choice of element type, algorithm, mesh band-width, etc.)

**Solution:**
Establish tolerances for the input and design variables.

Measure the system’s response in statistical terms.
Monte Carlo Simulation

Background

• Allows engineers to introduce hundreds of thousands of stochastic variables into the problem, and still call the solver only 100 times to obtain correct results.

• The power lies in the fact that the cost, i.e. the number of solver calls, is independent of the number of variables in a problem.
Address the Curse of Dimension

“Monte Carlo simulation was developed by the Los Alamos team (the people who developed the nuclear bomb for the US during the 1940's). They had high-dimensional integrals to solve, and traditional methods of numerical integration failed them because of the curse of dimensionality.

What is so fantastic about Monte Carlo simulation is the fact that its precision is proportional to the square root of the number of scenarios used, and THIS RESULT IS ENTIRELY INDEPENDENT OF THE NUMBER OF DIMENSIONS OF THE PROBLEM. Effectively, Monte Carlo simulation was developed to break the curse of dimensionality. The history of World War II might have been different if it were never invented.”

Glyn Holton
Accurately Capture:

- Physics
- Loads and boundary conditions
- Material properties
- Geometry

Remember “All models are wrong. Some are useful.” J. Box
What to randomize:

• Randomize all parameters instead of the “assumed” most influential
• Selecting a limited number of parameter prejudices the result
• Only way to learn what you do not know
• Example

“It is crucial to note that the computational effort for a single FE-run is basically independent of the number of random variables introduced. Hence, considering a large number of uncertain parameters by using Monte Carlo simulation entails no disadvantage, while considering all uncertainties ensures a robust prediction of the variability.”

Prof. G.I. Schueller, Third MIT Conference on Computational Fluid and Solid Mechanics, June 2005
# Structural Material Scatter

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>CHARACTERISTIC</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Rupture</td>
<td>8-15%</td>
</tr>
<tr>
<td></td>
<td>Buckling</td>
<td>14%</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>Rupture</td>
<td>10-17%</td>
</tr>
<tr>
<td>Screw, Rivet, Welding</td>
<td>Rupture</td>
<td>8%</td>
</tr>
<tr>
<td>Bonding</td>
<td>Adhesive strength</td>
<td>12-16%</td>
</tr>
<tr>
<td></td>
<td>Metal/metal</td>
<td>8-13%</td>
</tr>
<tr>
<td>Honeycomb</td>
<td>Tension</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Shear, compression</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Face wrinkling</td>
<td>8%</td>
</tr>
<tr>
<td>Inserts</td>
<td>Axial loading</td>
<td>12%</td>
</tr>
<tr>
<td>Thermal protection (AQ60)</td>
<td>In-plane tension</td>
<td>12-24%</td>
</tr>
<tr>
<td></td>
<td>In-plane compression</td>
<td>15-20%</td>
</tr>
</tbody>
</table>

# Mechanical and Physical Property Ranges

for Cast Aluminium: G-AlSi12 (230)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's modulus</td>
<td>72000 – 75000</td>
<td>Mpa</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>27500 – 28000</td>
<td>Mpa</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>150 – 230</td>
<td>Mpa</td>
</tr>
<tr>
<td>Elongation</td>
<td>5 – 12</td>
<td>%</td>
</tr>
<tr>
<td>Fatigue</td>
<td>55 – 60</td>
<td>Mpa</td>
</tr>
<tr>
<td>Yield strength</td>
<td>70 – 110</td>
<td>Mpa</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>130 – 190</td>
<td>W/m.K</td>
</tr>
<tr>
<td>Melting temperature</td>
<td>574 – 582</td>
<td>°C</td>
</tr>
<tr>
<td>Resistivity</td>
<td>0.017 - 0.026</td>
<td>Ohm.mm²/m</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>0.5 - 1.1</td>
<td>%</td>
</tr>
</tbody>
</table>

Source: www.matbase.com - free online resource for physical and mechanical data on all major material categories
## Load Scatter (aerospace)

<table>
<thead>
<tr>
<th>LOAD TYPE</th>
<th>ORIGIN OF RESULTS</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch vehicle thrust</td>
<td>STS, ARIANE</td>
<td>5%</td>
</tr>
<tr>
<td>Launch vehicle quasi-static loads</td>
<td>STS, ARIANE, DELTA</td>
<td>30%</td>
</tr>
<tr>
<td>- POGO oscillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- stages cut-off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- wind shear and gust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- landing (STS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transient</td>
<td>ARIANE 4</td>
<td>60%</td>
</tr>
<tr>
<td>Thermal</td>
<td>Thermal tests</td>
<td>8-20%</td>
</tr>
<tr>
<td>Deployment shocks (Solar array)</td>
<td>Aerospatiale</td>
<td>10%</td>
</tr>
<tr>
<td>Thruster burn</td>
<td>Calibration tests</td>
<td>2%</td>
</tr>
<tr>
<td>Acoustic</td>
<td>ARIANE 4 and STS (flight)</td>
<td>30%</td>
</tr>
<tr>
<td>Vibration</td>
<td>Satellite tests</td>
<td>20%</td>
</tr>
</tbody>
</table>

LOAD UNCERTAINTY
Particularly for environmental loading
there is high uncertainty w.r.t. space and time!
The Deception of Precise Geometry

Geometry imperfections should be described as random fields.
Efficient Monte Carlo Simulation

MCS is the most general and versatile method to process uncertainties

As few as 25-50 simulations provide information on the robustness and variability of the response due to uncertainties of the input parameters

Prof. G.I. Schueller, Third MIT Conference on Computational Fluid and Solid Mechanics, June 2005
Accuracy of MCS

The cost of a Monte Carlo Simulation is independent of the number of variables (problem dimension) and is dictated solely by the desired accuracy.
Monte Carlo Simulation Results

Number of 2D Views of Results = Sum of all integers from 1 to (Number of Variables - 1)

12 of the 78 2D views that resulted from a simulation with 6 outputs from a scan of 7 inputs with uniform distributions.
Understanding Results

MATHEMATICAL CHALLENGE –
• REDUCE the Multi-Dimensional Cloud to EASILY UNDERSTOOD INFORMATION

CLOUD:
• POSITION provides information on PERFORMANCE
• SCATTER represents QUALITY
• SHAPE represents ROBUSTNESS

CORRELATION
• Expresses the STRENGTH OF THE RELATIONSHIP Between Variables
Correlation Maps – Filter Complexity while Modeling Reality

Filters Variables Based on Correlation Level

Understand How Things Work

Ranks input variables and output responses by correlation level

Follows MIT-developed Design Structure Matrix model format

Input Variables

Output Variables
Identify Key Features

Learn how different combinations of product characteristics affect functionality with **Correlation or Systems Insight Maps**

**Maps Filter Complexity while Simulating Reality**

- Addresses natural variation
- Identifies what’s important
- Independent of number of variables
- Can be applied to any domain
Identify how some combinations of product characteristics cause unanticipated results or OUTLIERS.

Usually non-intuitive, Outliers can be problems or improvements.
The Importance of OUTLIERS

The unpredictable has an extreme impact.

• Described in Nassim Taleb’s “The Black Swan”

Simulation can be used to specifically identify outliers:

• A prudent course of action for:

1. Learning,
2. Becoming aware of the unexpected,
3. Preparing contingency plans.
Simulation to Information Process

PROCESS STEPS
1. Start with a model
2. Put model in process SW
3. Randomize the model
4. Run the model ≈ 100 times
5. ID Relationships & Outliers
6. Summarize Information

Results Data
Representing Reality

Outliers
Insight Map
Most Relevant Factors Report

100 runs
INFORMATION FROM SIMULATION
TO LEARN What We Do Not Know

– INPUTS
  • Fewer Assumptions
  • More Variables

– OUTPUTS
  • Identify WHAT’S IMPORTANT
  • Model and Data Verification
  • Identification of Key Characteristics
    o May be combinations of features
  • Outliers

– PROCESS
  • Scalable to people and disciplines
  • Replicable

– TOOLS need to be:
  • Accurate
    o Results readily verified
    o Independent results replication
  • Easy to Use
  • Interoperable
CNO TENETS

Warfighting First
Operate Forward
Be Ready

MANAGE UNCERTAINTY
to
MAXIMIZE Ship Availability and Readiness Cost Effectively