Static and Dynamic Model Update of an Inflatable/Rigidizable Torus Structure (Work In Progress)

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Background

• The TSU* Hexapod is a generic test bed that incorporates design features of structures that can be packed for launch and deployed in space.

• Inflatable/rigidizable structures can be inflated to more than 12 times their packaged size enabling new space mission scenarios.

• However, new fabrication techniques also bring new modeling challenges.

*TSU= Tennessee State University
Objective and Motivation

Objective-To develop a mathematical and computational procedure to reconcile differences between finite element models and data from static and dynamic tests

Motivation- All missions envisioned for inflatable and rigidizable systems will require state of the art controls and accurate analytical models. In the Hexapod case, the initial model missed many important modes.
Approach

- FEM developed using commercial tools
- Static test results used to update stiffness values
- Dynamic test results used to update mass distribution
- Probabilistic assessment used to compute most likely set of parameters
- Update parameters computed via nonlinear optimization (genetic and gradient based)
- Computational tools based on MATLAB
- System ID using the Eigensystem Realization Algorithm
- Incremental update of components starting with torus
Model Update Procedure

1. Develop baseline finite element model
2. Select parameters for update
3. Define parameter bounds & probability distribution
4. Compute output probability & sensitivity values
5. Reduce parameter set using sensitivity and probability results
6. Solve optimization for updated parameters & probability
Computational Framework

NASTRAN
Static Dynamic

Bulk Data File

MATLAB
Optimization Probability Sensitivity System ID

Output Data File

External Inputs
1- Parameter selection and prob. distribution
2- Experimental data
Torus Description and Nomenclature

Urethane Joint (typ.)

Joint flange:
- t = 0.00508 m

Inner joint:
- t = 0.0063 m

Outer joint:
- t = 0.0032 m

Tube (typ.)
- O.D. 0.0181 m
- t = 0.00042 m
Main Sources of Modeling Uncertainties

- Fabrication irregularities due to materials and fabrication methods (irregular cross-section, irregular geometry, etc)
- Unknown stiffness of adhesive bonded joints
- Composite material property uncertainties, “effective single ply” and rule of mixture approximations
STATIC TEST RESULTS
Static Test Configuration

Torus static test set-up

Support 1
Support 3
Point load
Support 2

Instrumentation set-up

Laser displacement sensor
Retro-reflective Target
Steel Block
Input Load and Sensor Location for Static Tests

Support 1
Support 2
Support 3
Loading Point
Static Test Parameters Selected for Update

1. Torus tube thickness

2. Urethane joint:
   - Inner joint thickness
   - Outer joint thickness
   - Joint flange thickness

3. Torus tube orthotropic material properties:
   \( E_1, E_2 \)

4. Urethane joint modulus of elasticity \( E \)
Output Probability Statement
How probable is it to predict the measured output?

Linear Torus Solution

Sample Space 300 points
Displacement Results: Test, Baseline, and Updated Model

Measurement locations

Support 1
Support 2
Support 3

Loading Point

Torus static test results

Vertical Displacement (mm)

σ/µ = 1.1
σ/µ = 0.01

Torus structure displacement under load

Target 1
Z = -4.54 mm
Load = 42.1 N
## Static Update Summary

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Baseline</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Optimum FMIN</th>
<th>Optimum Genetic</th>
<th>% Change FMIN</th>
<th>% Change Genetic</th>
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<tbody>
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Dynamic Test Results
Dynamic Test Configuration
Shaker and Sensor Locations for Dynamic Tests

Suspension 1
Shaker 1Z

Suspension 2
Shaker 2Z

Suspension 3

Shaker4 XY

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Sample Set of Identification Results (Drive Point 1 & 2)

Shaker No. 1

Shaker No. 2
Principal Values for Experimental Frequency Response Functions
### Dynamic Update Summary*

<table>
<thead>
<tr>
<th>Parameter^</th>
<th>Lower Bound</th>
<th>Nominal Value</th>
<th>Upper Bound</th>
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</table>

* list of parameters not based on statistical analysis
Principal Component Comparison
Test/Nominal/Updated

Maximum Principal Value

Minimum Principal Value
Orthogonality of Test/Analysis Modes

ERA Identified Modes

Analysis Modes

Orthogonality of Test/Analysis Modes

Animation of Test Mode

Animation of Analysis Mode
Work To Be Done

- Establish repeatability of test data
- Complete probabilistic assessment of dynamic FRF to verify parameter selection
- Compute updated parameters for dynamic case using non-gradient based optimizer
- Verify computational accuracy with refined FEM
- Implement error localization algorithm to examine potential FEM problem areas
- Compute Modal Assurance Criterion using reduced mass matrix
- Re-test with increased sensor count to improve spatial resolution for test and analysis modes
- Refine system ID results to improve areas near FRF zeros
Concluding Remarks

• Computational procedure using MATLAB in place

• Initial updates completed using static and dynamic tests results

• Updated solution for static case is in good agreement with test

• Selected parameters for static analysis showed low output probability values when used to predict observed solution

• Two step approach using output probabilities followed by optimization provides good physical insight into the problem

• Dynamic test and analysis results need to be re-visited

• Procedure computationally intensive but well suited for multi-processor systems