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

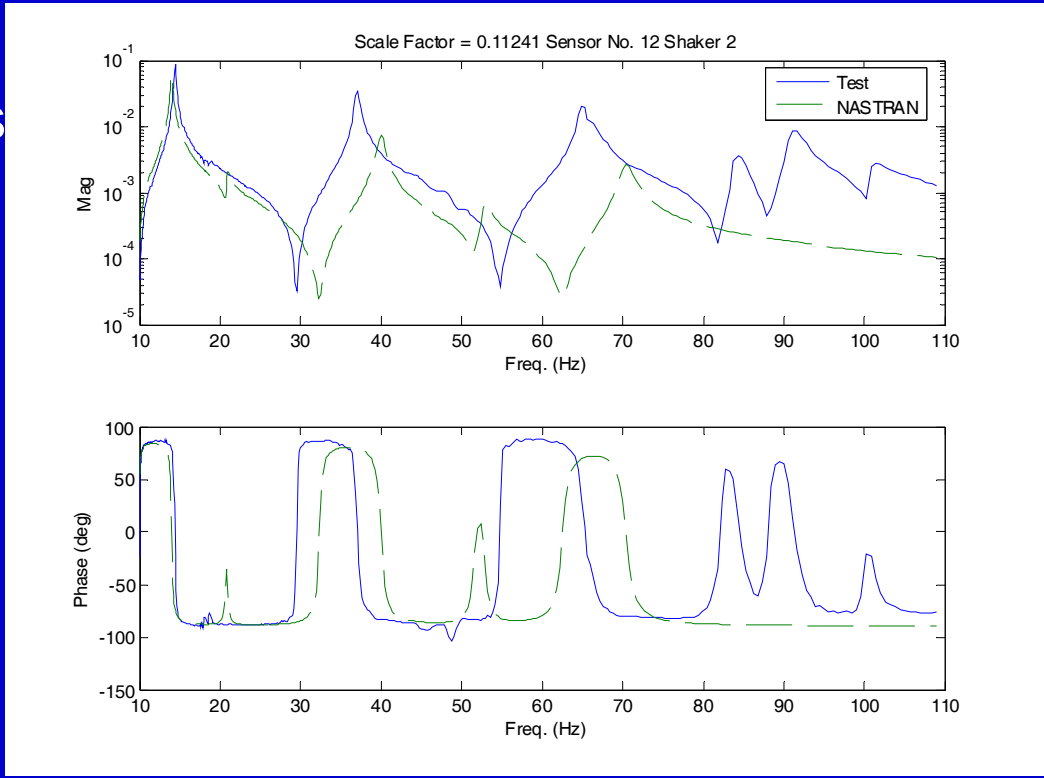
***TSU= Tennessee State University**

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

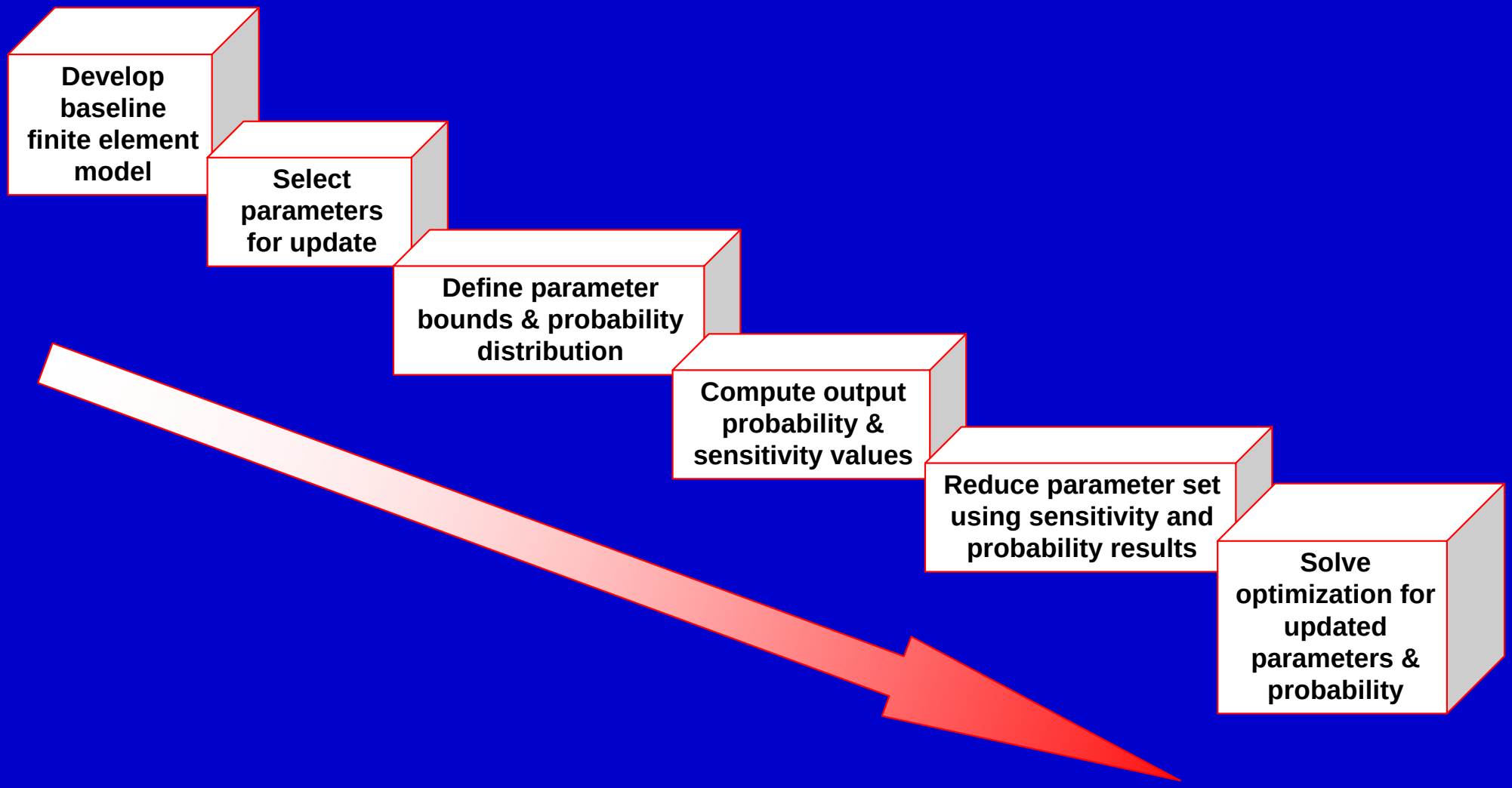
Initial Model
Shaker No. 2



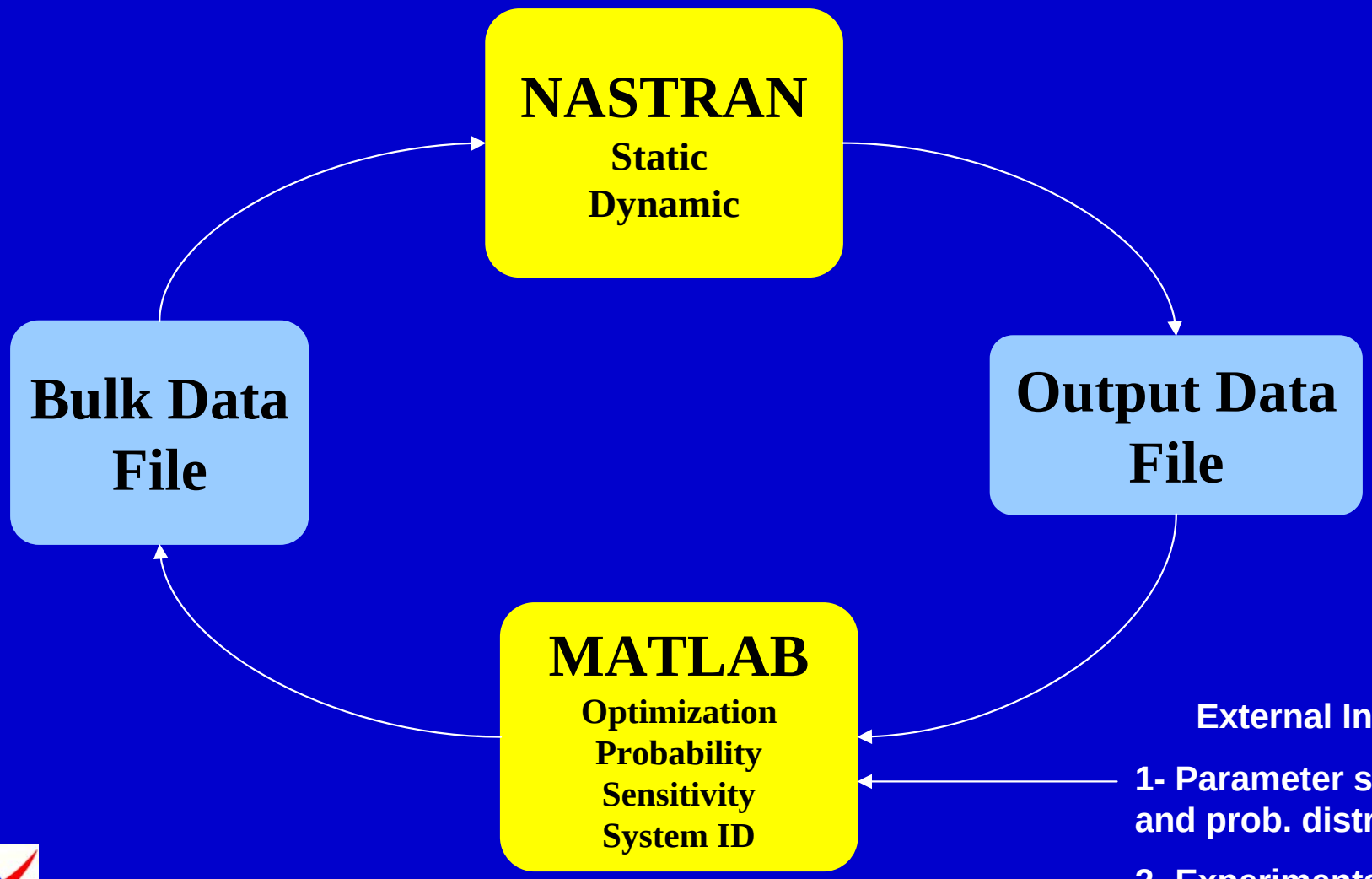
Approach

- 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



Computational Framework

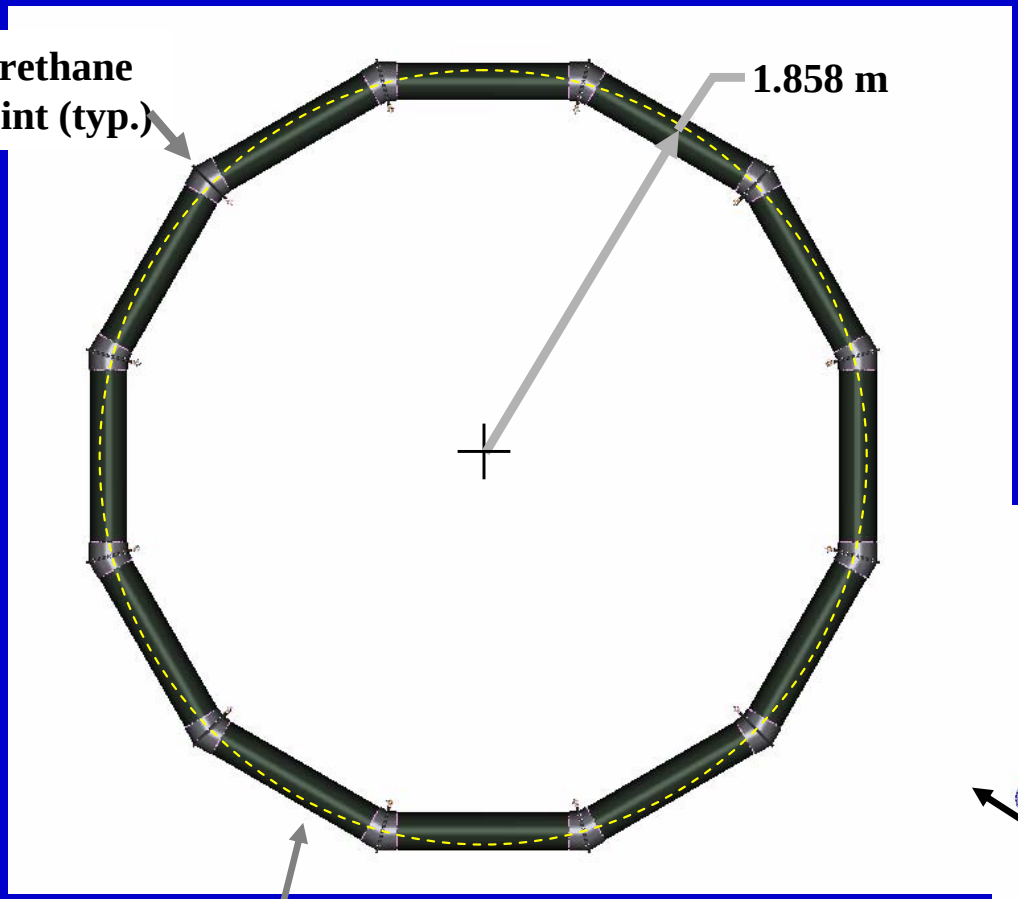


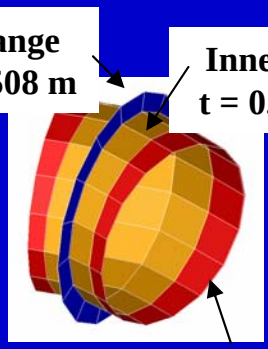
External Inputs

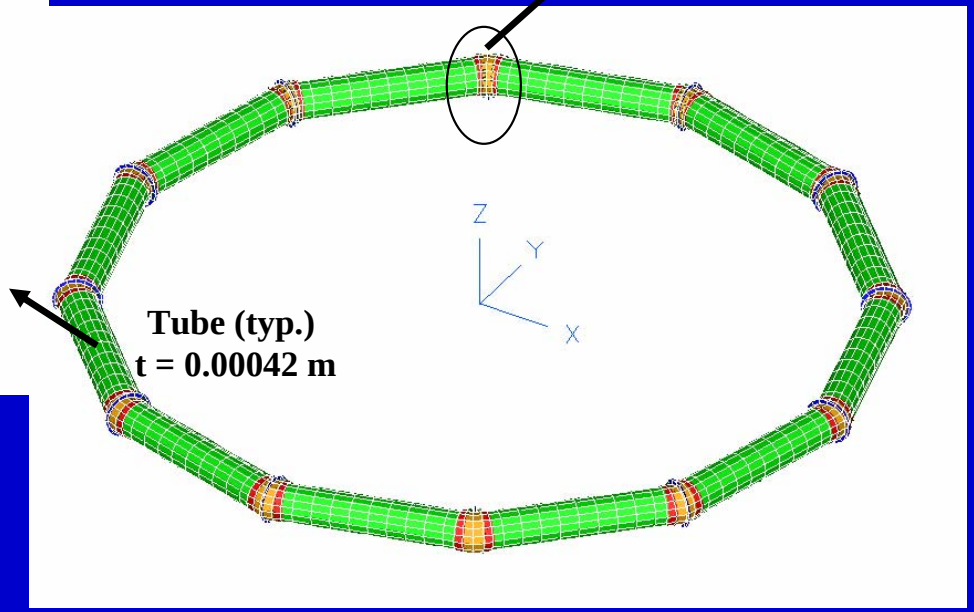
1- Parameter selection and prob. distribution

2- Experimental data

Torus Description and Nomenclature







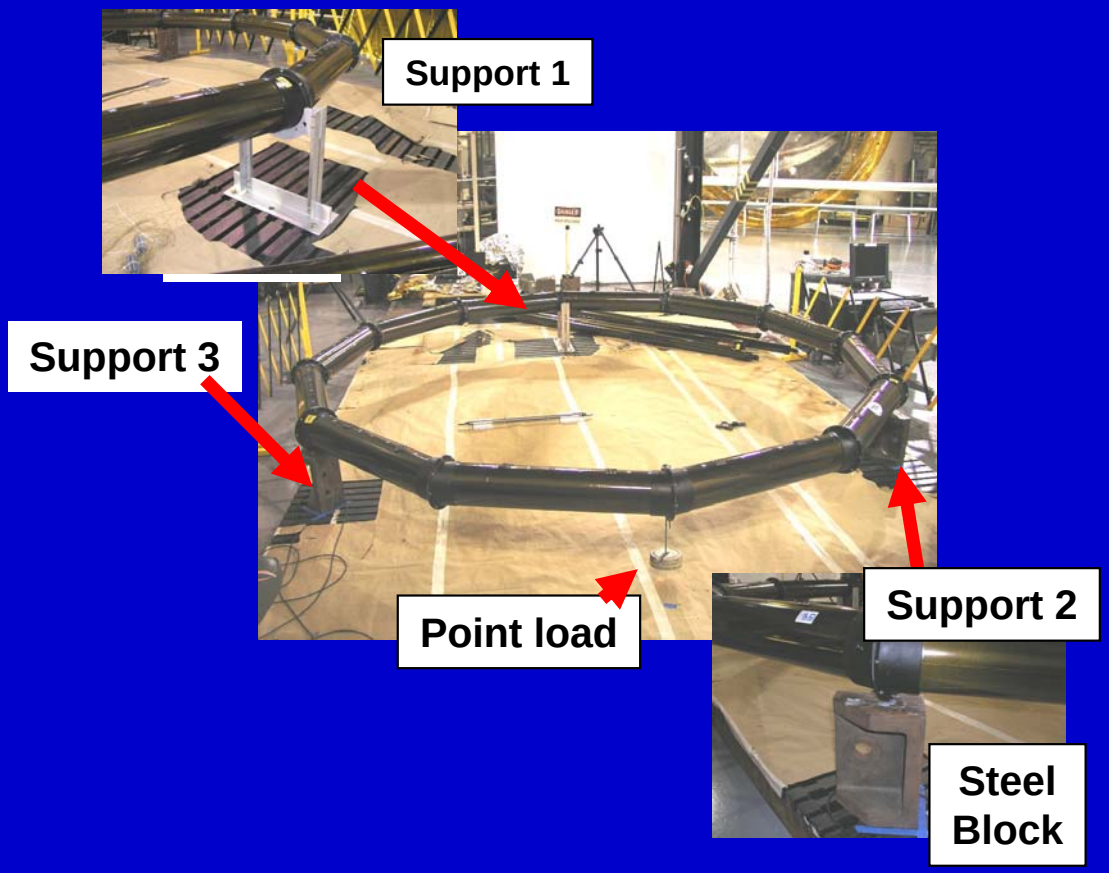
Main Sources of Modeling Uncertainties

- **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**

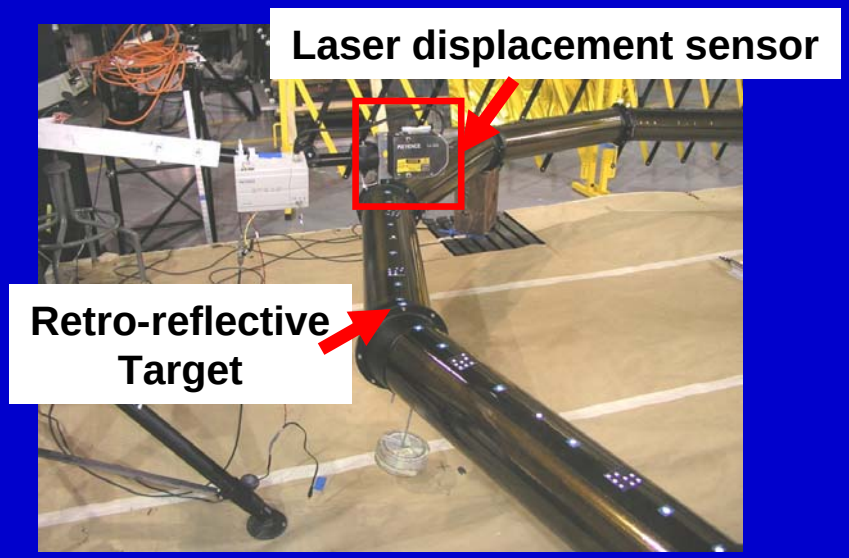
STATIC TEST RESULTS

Static Test Configuration

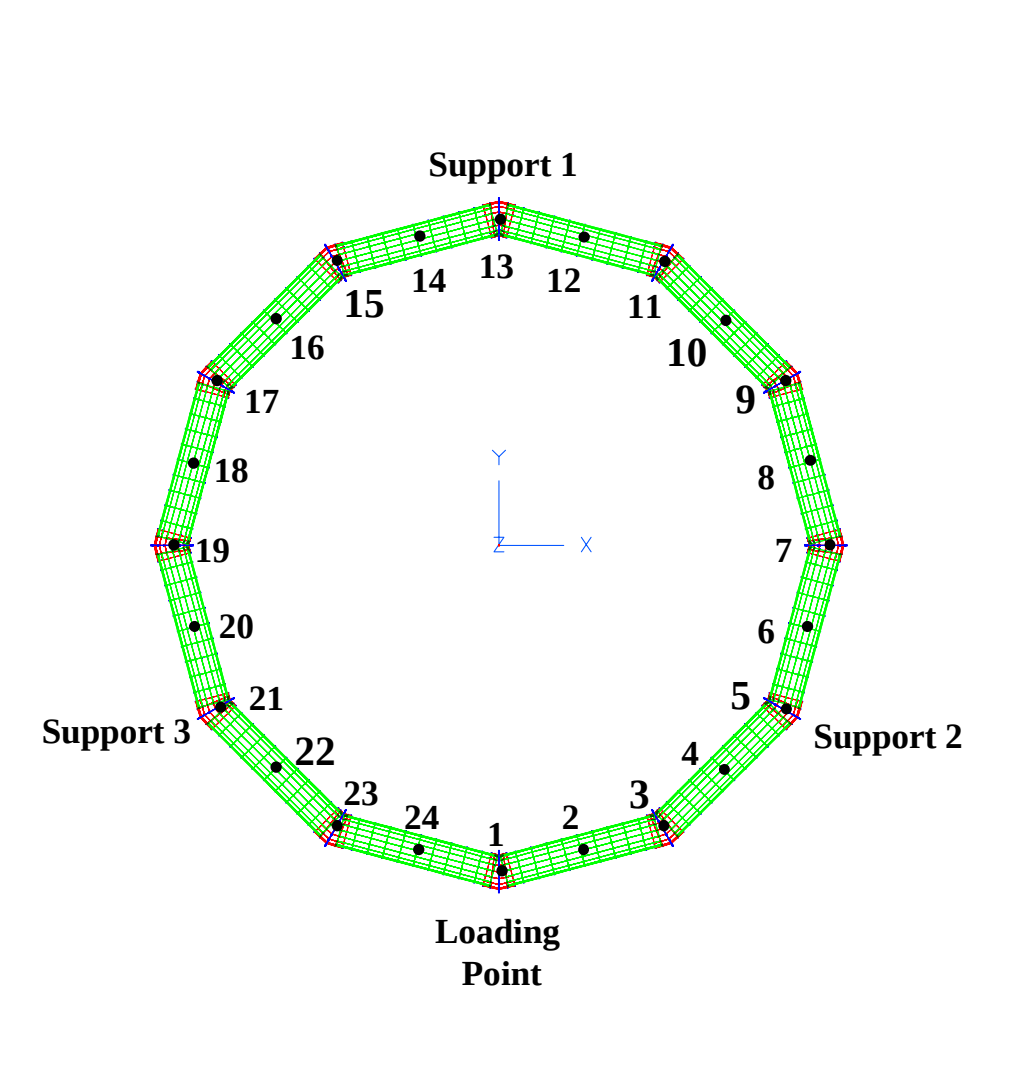
Torus static test set-up



Instrumentation set-up



Input Load and Sensor Location for Static Tests

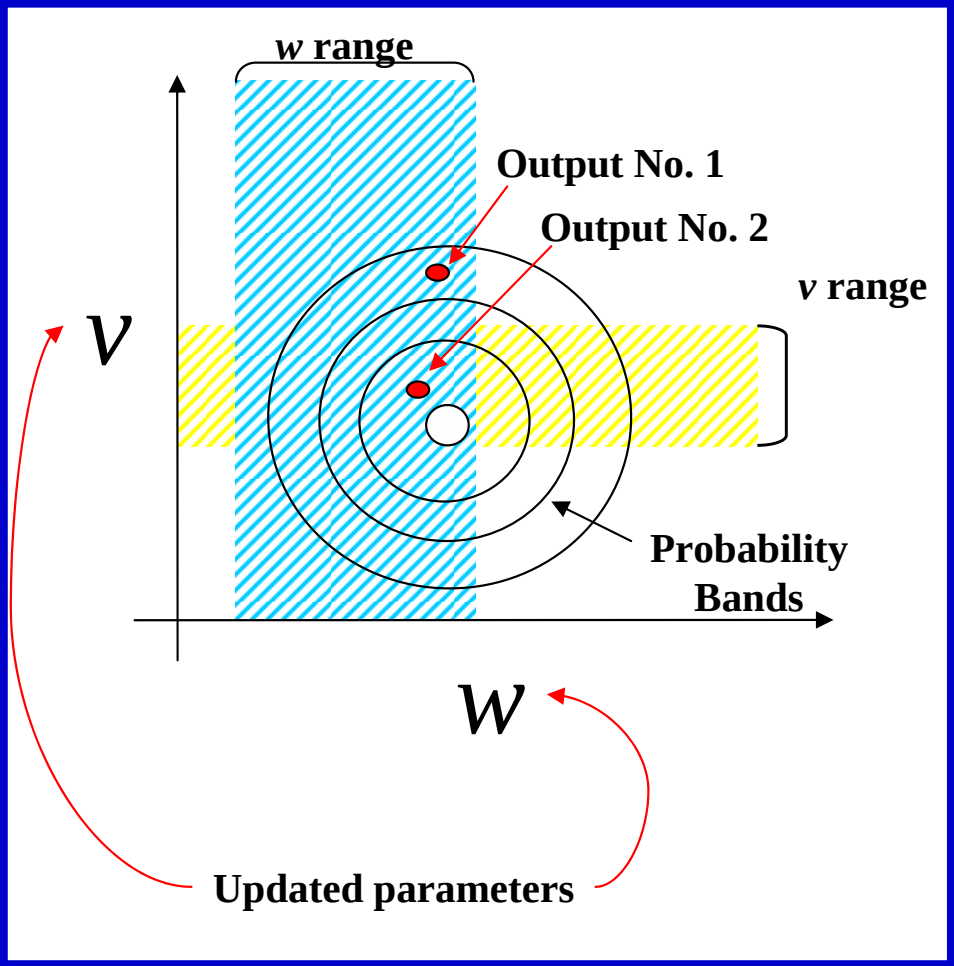


Static Test Parameters Selected for Update

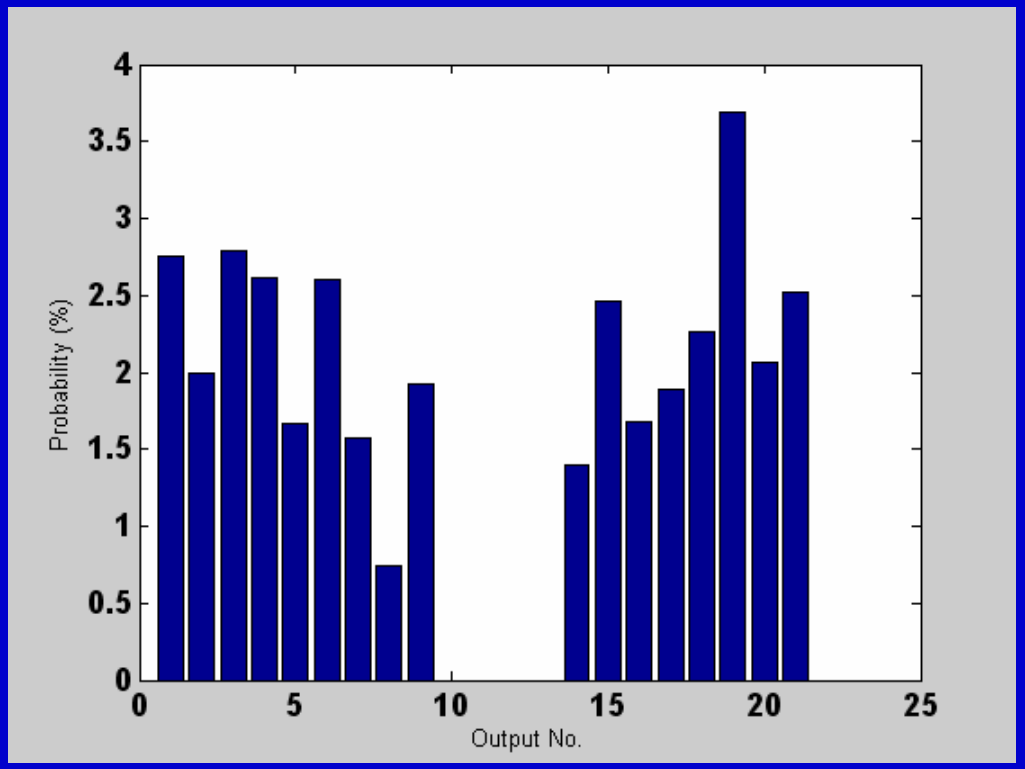
1. Torus tube thickness

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?



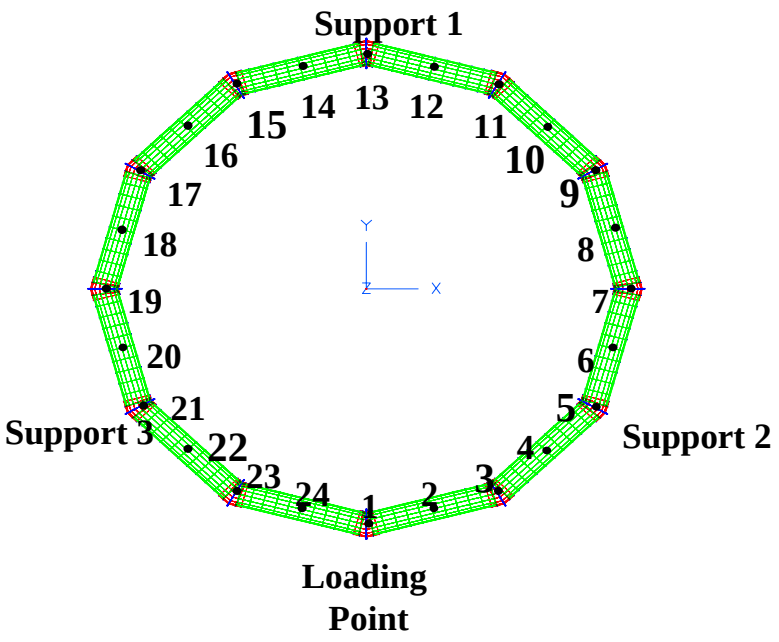
Linear Torus Solution

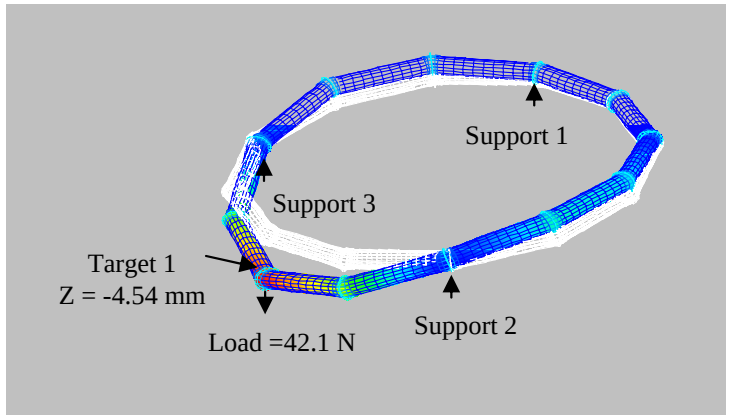


Sample Space 300 points

Displacement Results: Test, Baseline, and Updated Model

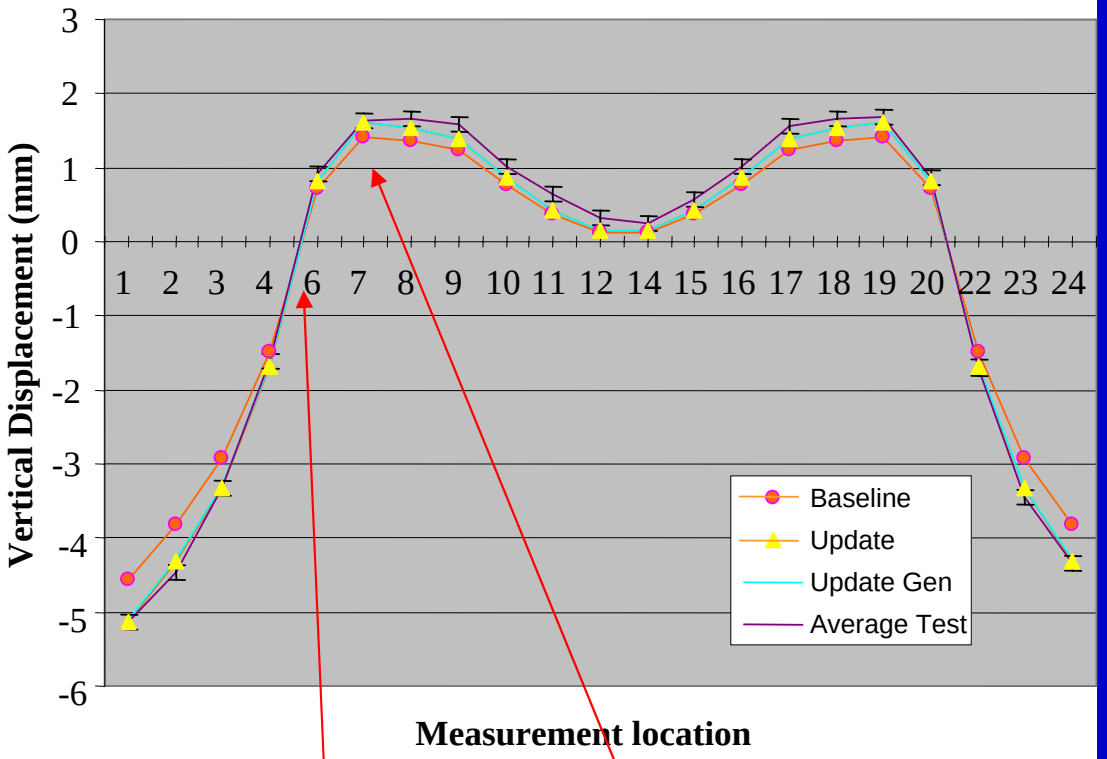
Measurement locations





Torus structure displacement under load

Torus static test results



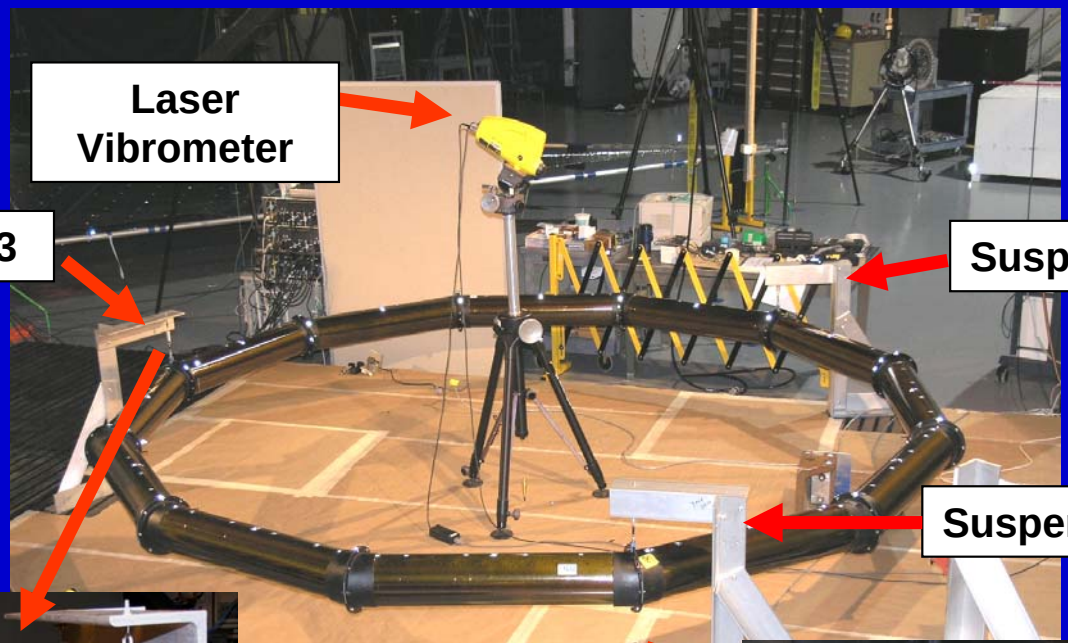
$\sigma/\mu=1.1$ $\sigma/\mu=0.01$

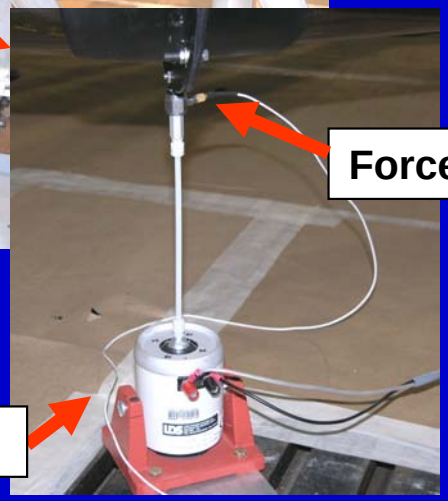
Static Update Summary

Parameters	Baseline	Lower Bound	Upper Bound	Optimum FMIN	Optimum Genetic	% Change FMIN	% Change Genetic
Tube E1,E2	6.16E+10	5.5E+10	6.77E+10	6.16E+10	5.83E+10	0	5.4
Joint E	3.03E+09	2.73E+09	3.33E+09	3.03E+09	3.21E+09	0	-6.1
Tube thickness	0.000432	0.0003024	0.000496	0.000376	0.0003912	13	9.4
Outer joint thickness	0.00317	0.00253	0.0038	0.00379	0.00352	19.6	-11.0
Inner joint thickness	0.00634	0.00507	0.00761	0.00507	0.00527	20.0	16.9
Flange thickness	0.01016	0.0086	0.01168	0.01157	0.00873	-13.9	14.1

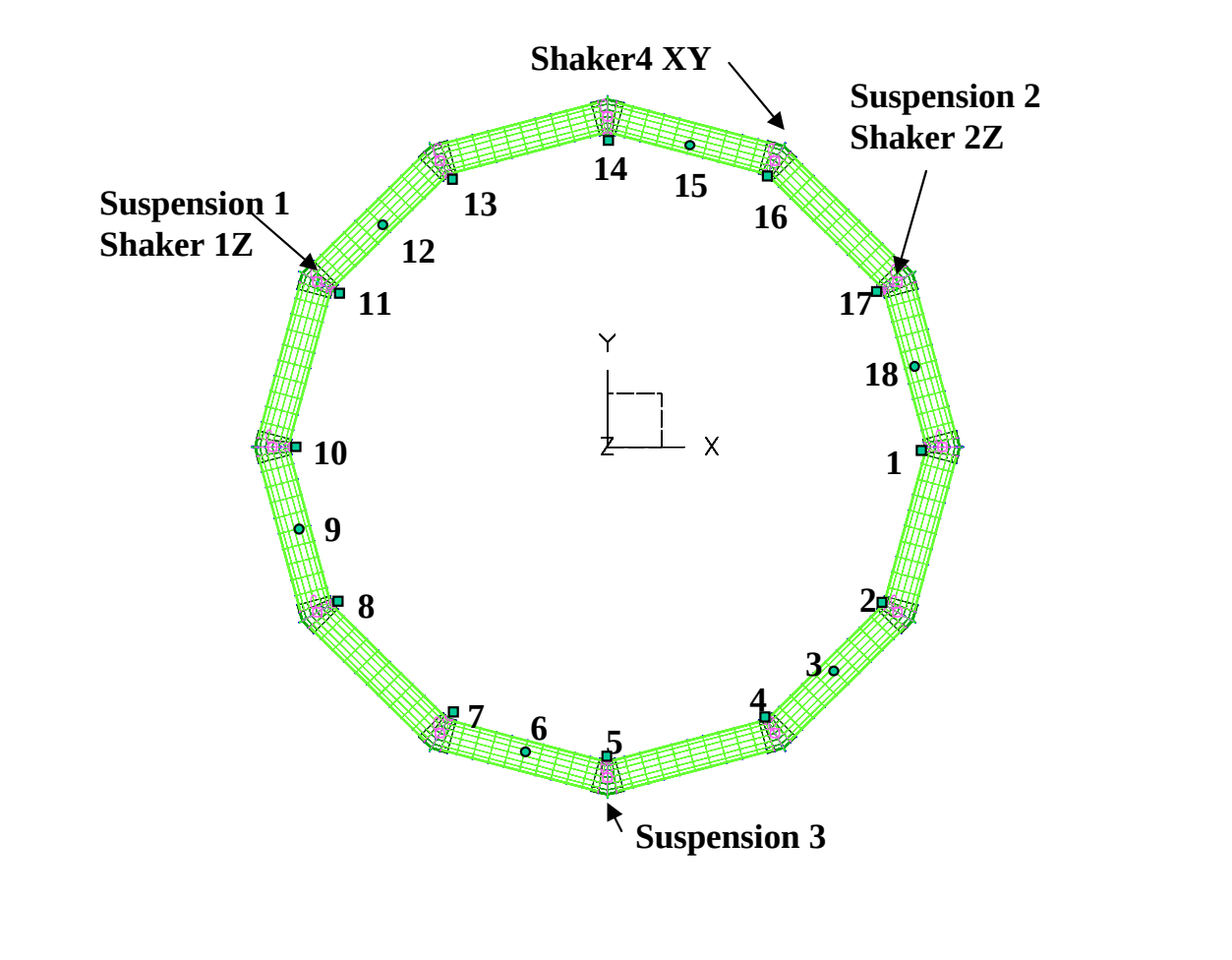
Dynamic Test Results

Dynamic Test Configuration



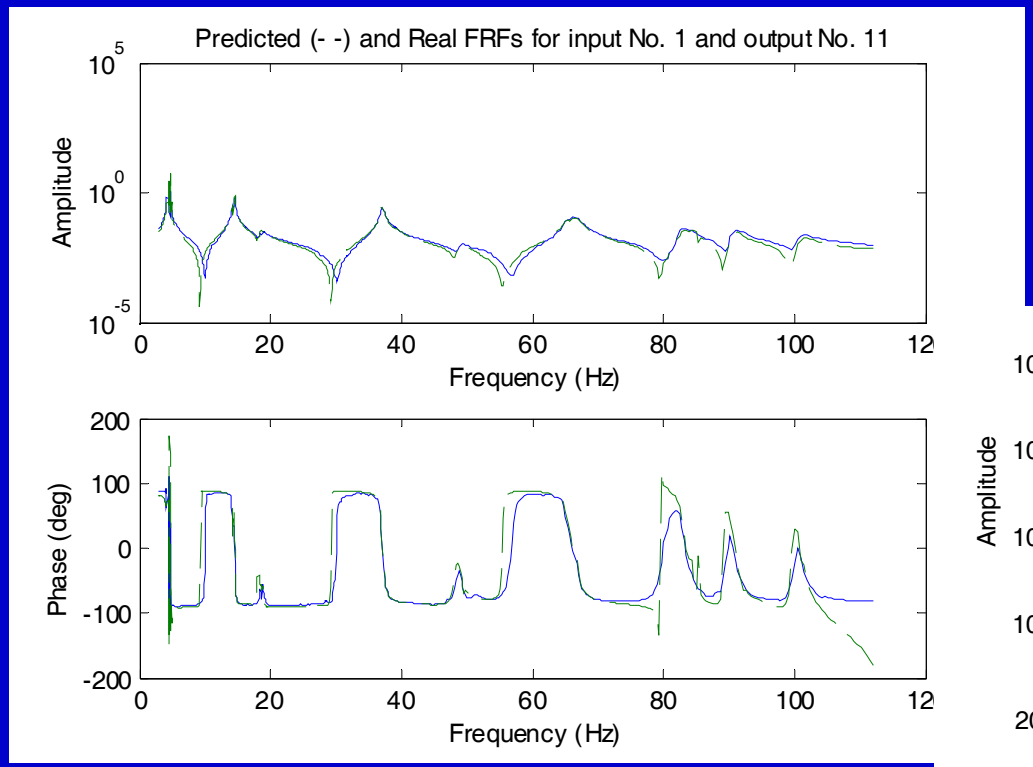


Shaker and Sensor Locations for Dynamic Tests

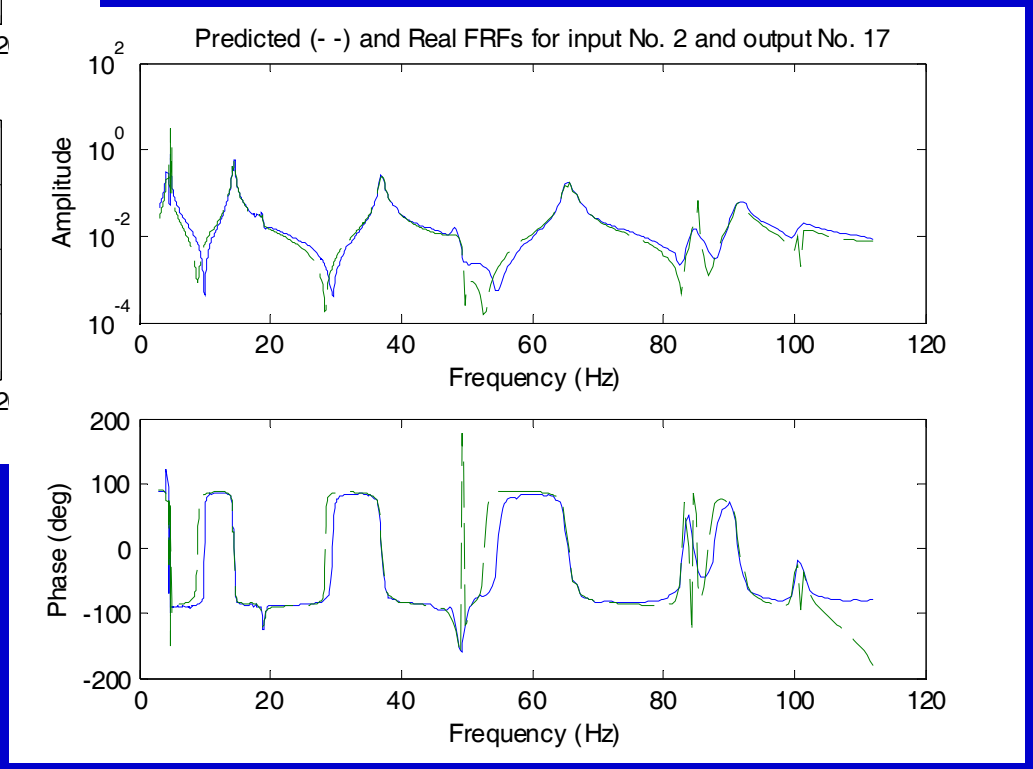


Sample Set of Identification Results (Drive Point 1 & 2)

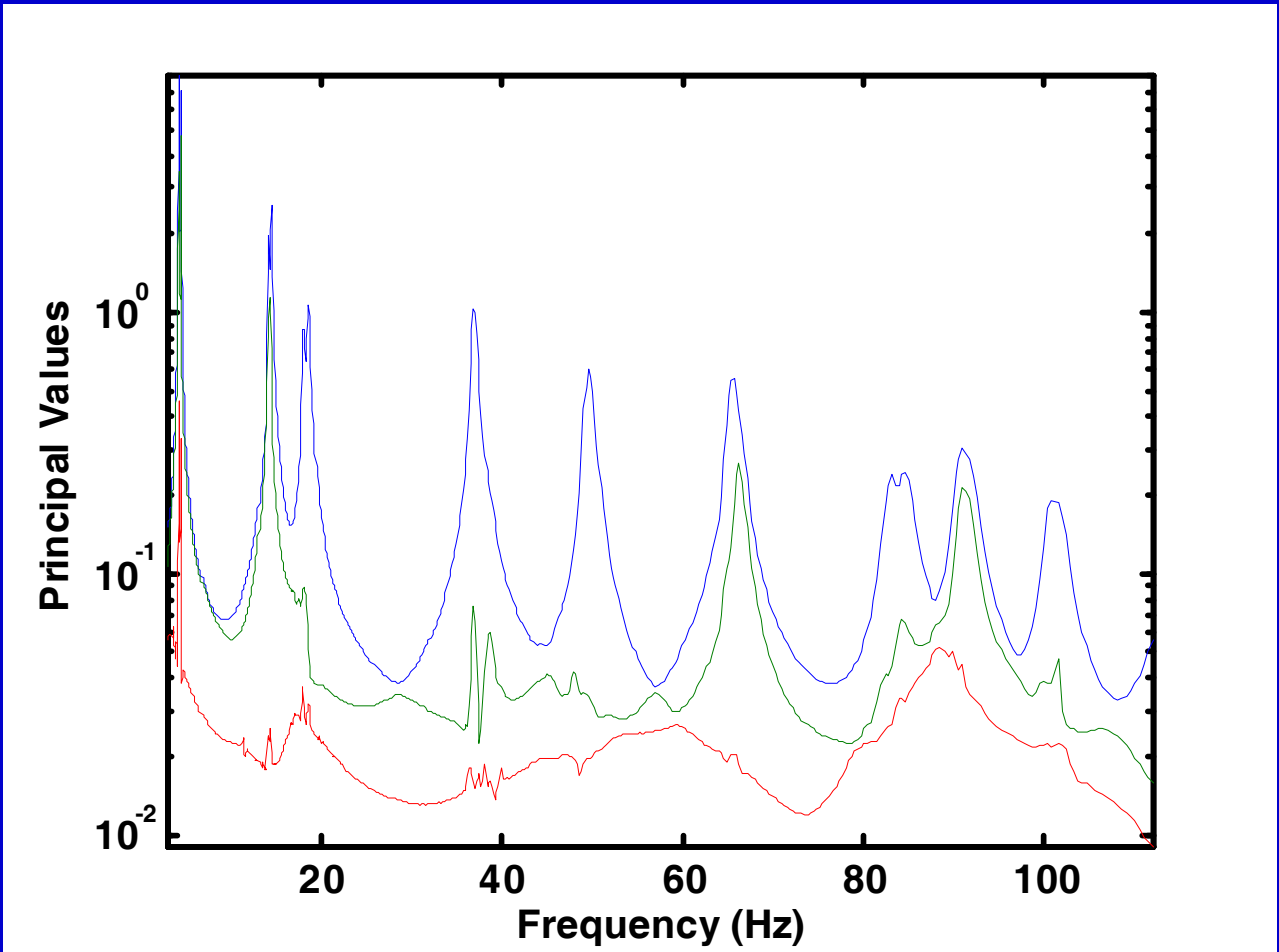
Shaker No. 1



Shaker No. 2



Principal Values for Experimental Frequency Response Functions

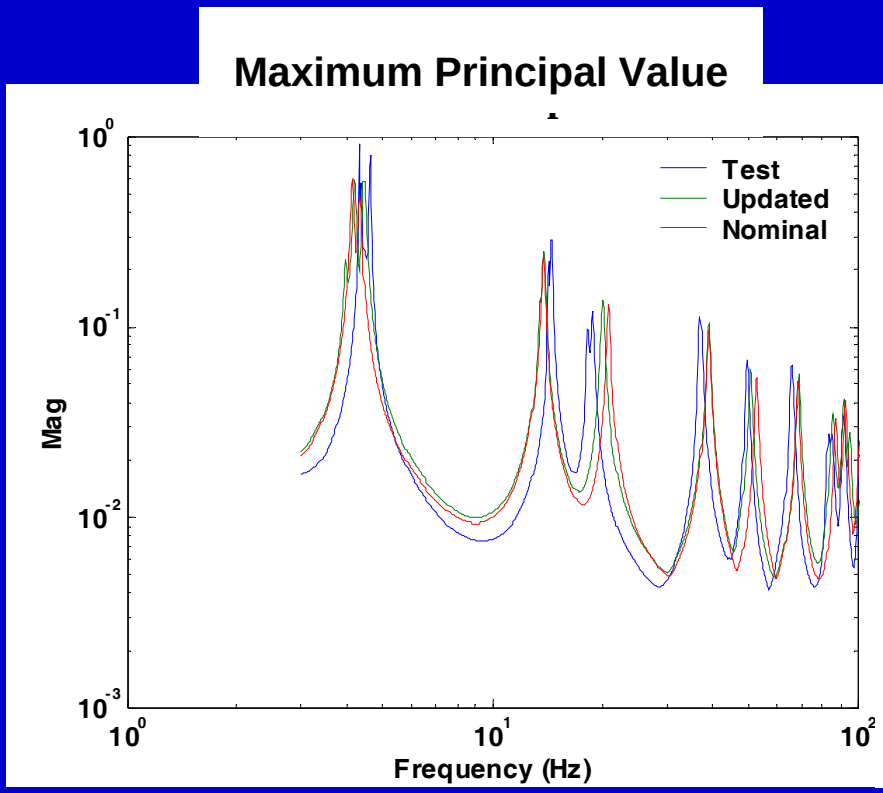


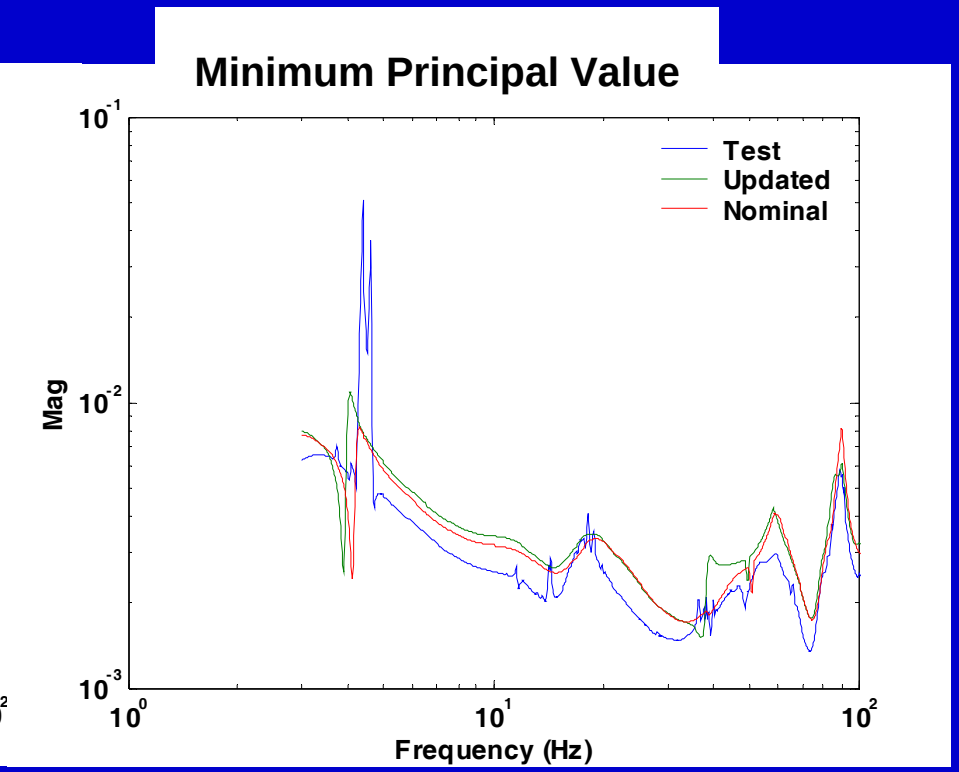
Dynamic Update Summary*

Parameter^	Lower Bound	Nominal Value	Upper Bound	Optimum Value
Spring 1	2334.8	2918.5	3502.2	2752.9
Spring 2	2334.8	2918.5	3502.2	3169.8
Spring 3	2334.8	2918.5	3502.2	2400.4
Torus tube density	1467.2	1834.0	2200.8	1770.4
Joint 5 density	955.5	1194.8	1433.8	1204.6
Joint 4 density	955.5	1194.8	1433.8	996.08
Joint 2 density	955.8	1194.8	1433.8	980.59
Joint 1 density	955.8	1194.8	1433.8	1093
Joint 17 density	955.8	1194.8	1433.8	1231.4
Joint 16 density	955.8	1194.8	1433.8	1080.2
Joint 14 density	955.8	1194.8	1433.8	1433.8
Joint 13 density	955.8	1194.8	1433.8	1239.2
Joint 11 density	955.8	1194.8	1433.8	1150.5
Joint 10 density	955.8	1194.8	1433.8	1063.5
Joint 8 density	955.8	1194.8	1433.8	990.76
Joint 7 density	955.8	1194.8	1433.8	1279.8

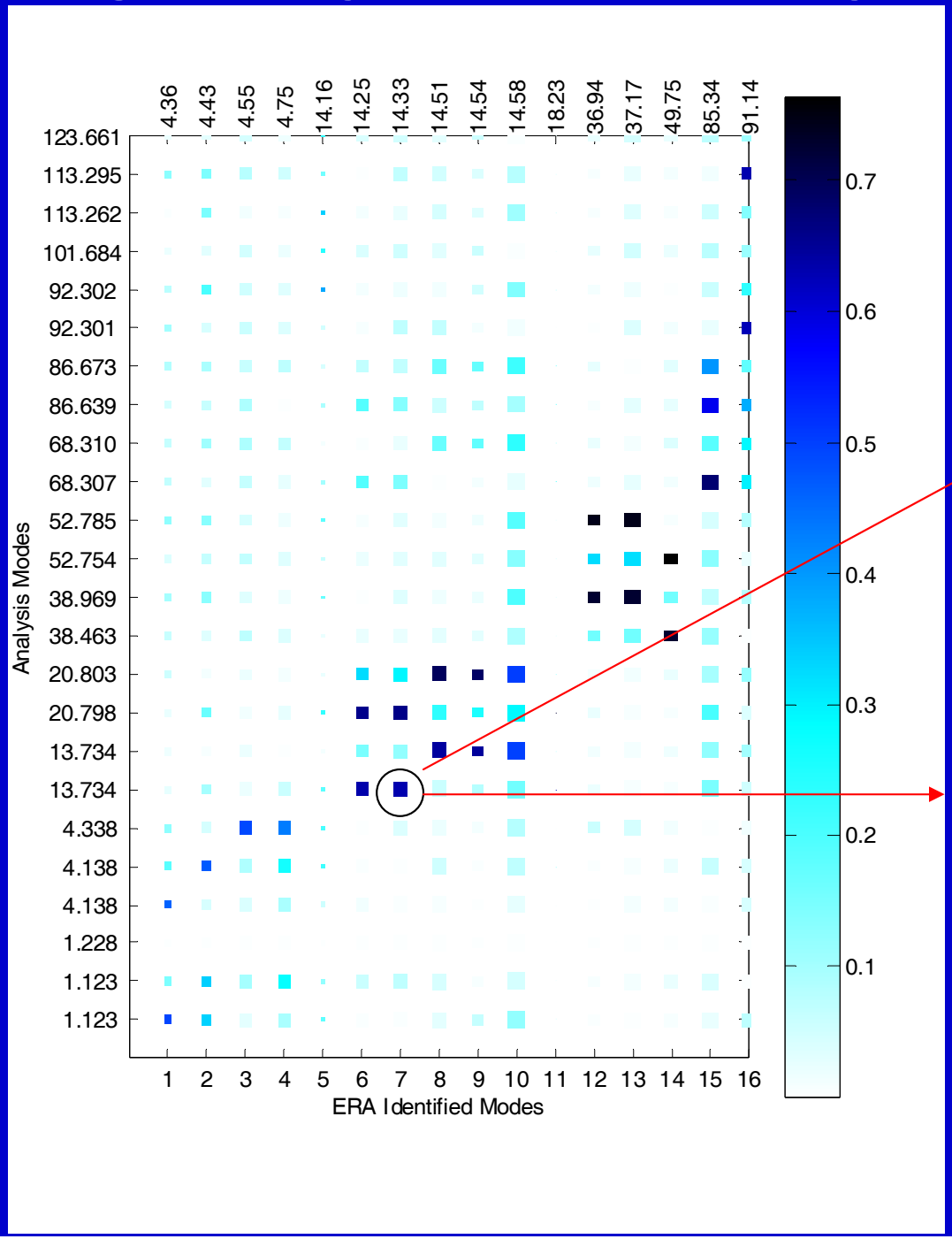
*** list of parameters not based on statistical analysis**

Principal Component Comparison Test/Nominal/Updated





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**