Test-Analysis Correlation With Design Optimization

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Introduction

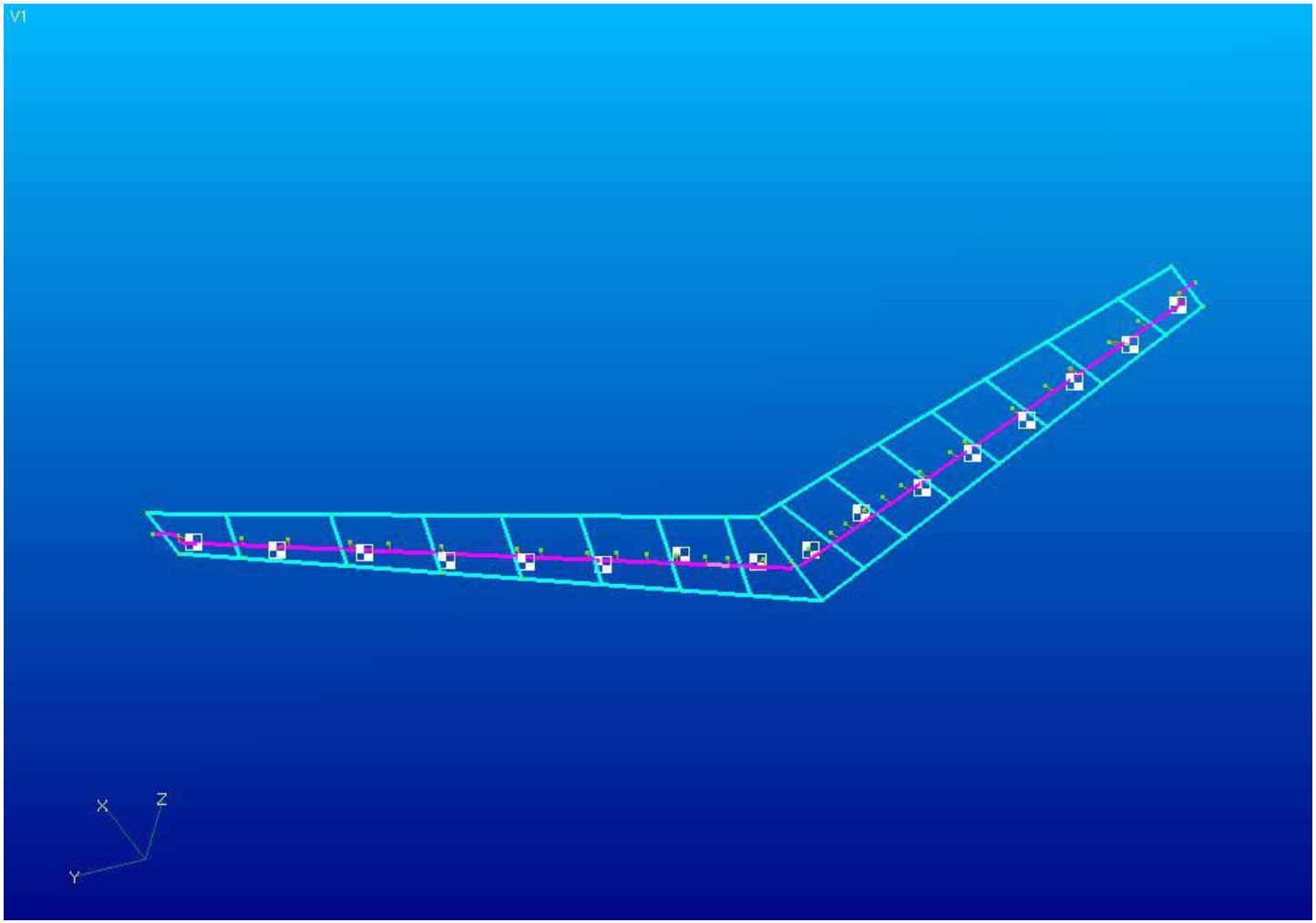
- Correlation of finite element model (FEM) with test data is still a necessary step in FEM validation
- This discussion concerns the development of a process for FEM correlation with test data assisted by Design Optimization techniques
- This process matches frequencies and mode shapes
- GENESIS is the design optimization program

Test Article

- Horizontal stabilizer of business jet
- The FEM is a symmetric lumped mass-beam model constructed to provide for bending in two planes (vertical and fore-aft) and torsion
- The vibration test consisted of 51 survey vectors arrayed to obtain bending and torsion modes
- Analysis of the test data extracted the first seven flexible modes; four vertical bending, one fore-aft bending, and two torsion

Picture of GVT Test Setup

Picture of FEM and GVT Wireframe



Design Objective

- Design objective is defined as the sum of the square of the differences between the analytical and measured mode shapes …

$$Minimize\ Obj = \Sigma(U_{calc} - U_{test})^2$$

Where U is the normalized mode shape displacements at the accelerometer locations

Design Variables and Constraints

- Design variables consist of the beam section properties including area moments of inertia (Ix & Iy) and torsional constant (J); 48 total variables
- Design constraints consist of the target frequencies

$$F_{calc}^{n} \leq F_{test}^{n}$$

$$F_{calc}^{n} \geq F_{test}^{n} \qquad ; n=mode\ number$$

Consistent Mode Shapes

- Test and calculated mode shapes must be consistent
- Analytical and test mode shapes are normalized to a specific grid DOF for each target mode based on the test mode shapes

```
EIGR        1000     LAN     2.0                      20   POINT
+              1   31001       3                2  131031       3
+              3  131031       3                4  131033       3
+              5   31001       1                6  131033       3
+              7  131031       3
```

- All 7 mode shapes & frequencies are optimized simultaneously

Mode Tracking

- Mode tracking insures that target modes are treated as analytical and test mode pairs regardless of frequency swapping that may occur during design optimization

MODE TRACKING TABLE - LOADCASE 1

MODE #	NEW MODE	MAC_1	MAC_2	STATUS
1	1	1.000	0.000	0
2	2	1.000	0.000	0
3	3	1.000	0.000	0
4	4	1.000	0.000	0
5	5	1.000	0.000	0
6	7	1.000	0.000	0
7	6	1.000	0.000	0

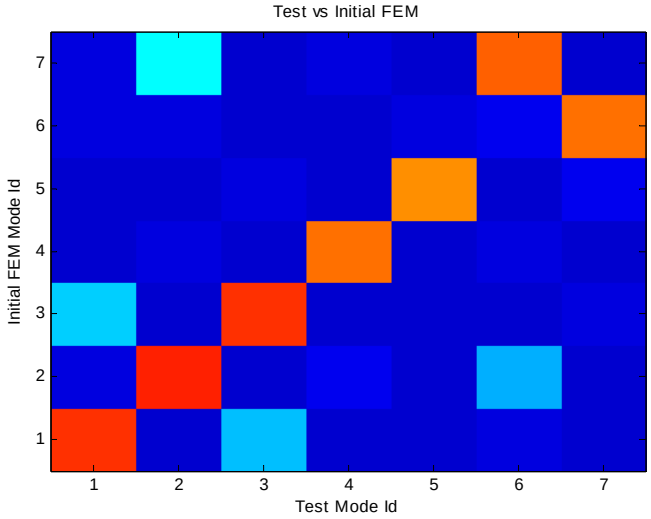
- MODTRK=ALL tracks all modes by shape regardless of frequency

Test vs Initial FEM

- Initial FEM is reasonable predictor to results
  - Frequencies within 10%
  - No missing modes
- Tuning process focus
  - Improving frequency match
  - Correcting mode order
  - Improving MAC-values

Test vs Initial FEM

Mode	Test	Initial FEM	MACii
1	21.57	21.03	0.97
2	31.01	29.23	0.98
3	55.78	52.63	0.97
4	60.28	58.72	0.89
5	63.17	64.10	0.85
6	86.23	84.50	0.90
7	90.48	81.82	0.88

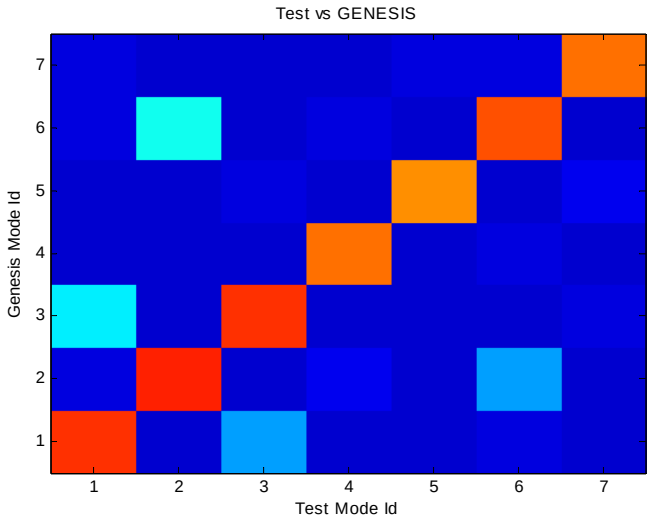


Correlation Results with Genesis

- Tuning process resulted in
  - Frequency match improved (as expected via constraints)
  - Mode shape order corrected
  - MAC-values maintained

Test vs GENESIS Result

Mode	Test	Genesis	MACii
1	21.57	21.58	0.96
2	31.01	31.01	0.98
3	55.78	55.78	0.97
4	60.28	60.28	0.88
5	63.17	63.16	0.85
6	86.23	86.23	0.93
7	90.48	90.48	0.89

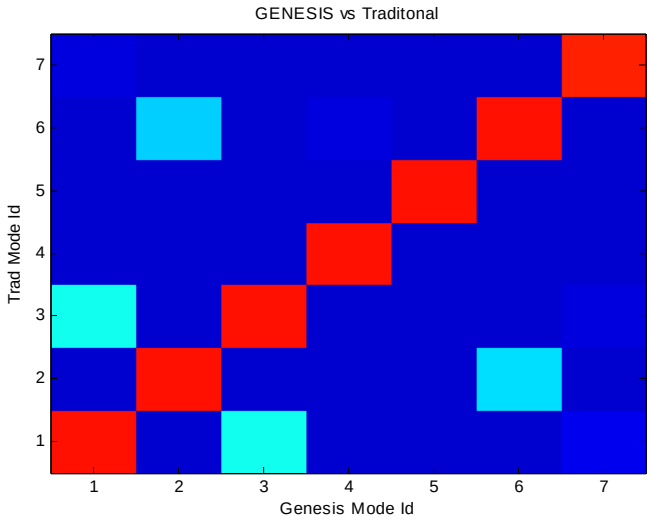


Comparison of Genesis to Traditional Method

- Frequencies match
- Mode shapes in order
- Mode shapes nearly same since MAC-values high

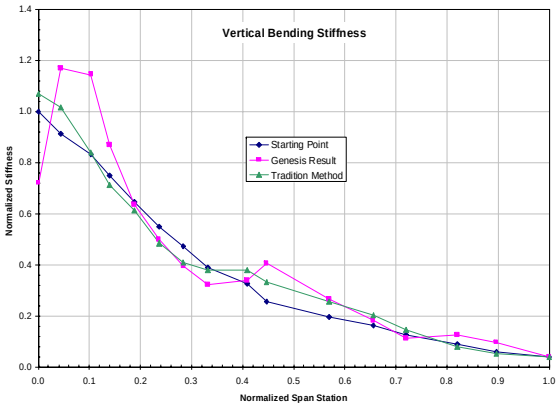
Traditional Methods vs GENESIS

Mode	Traditional	Genesis	MACii
1	21.57	21.58	1.00
2	31.00	31.01	1.00
3	55.81	55.78	1.00
4	60.26	60.28	1.00
5	63.17	63.16	1.00
6	86.24	86.23	1.00
7	90.42	90.48	0.98

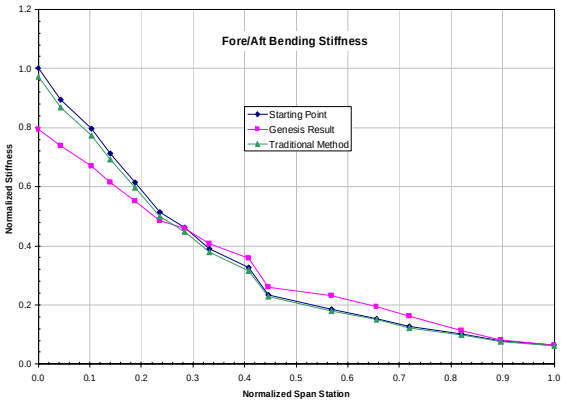


Stiffness Curve Comparisons

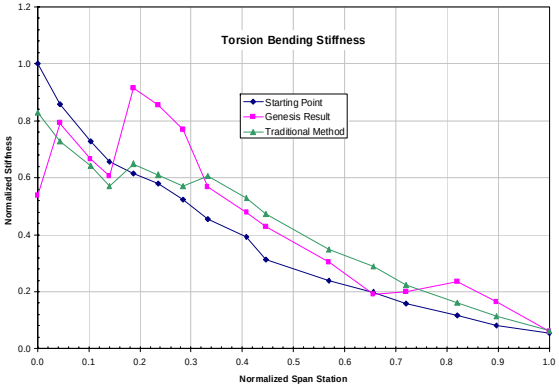
Vertical Bending



Fore-Aft Bending



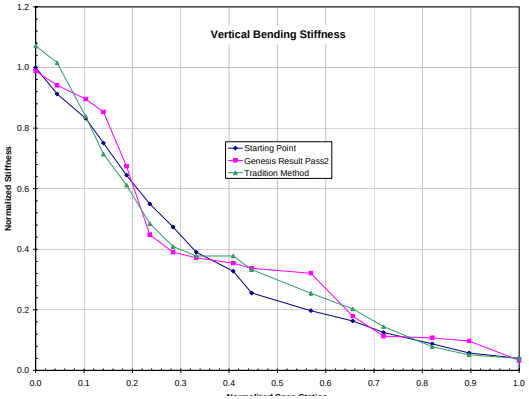
Torsion



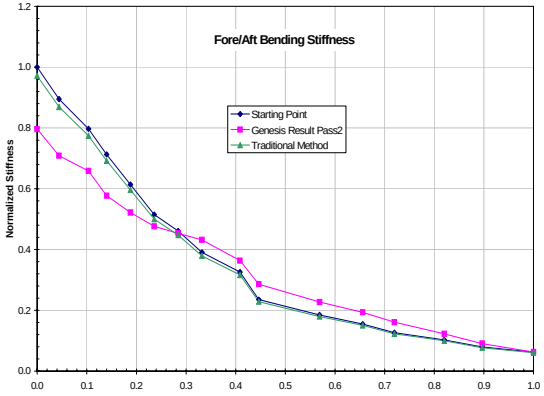
- Outbd values comparable, root values show differences, these results wouldn't yet be acceptable (ie model not yet tuned)
- Tuning process may need to include additional constraints to the stiffness curve profiles

Stiffness Curve Profile Manipulation

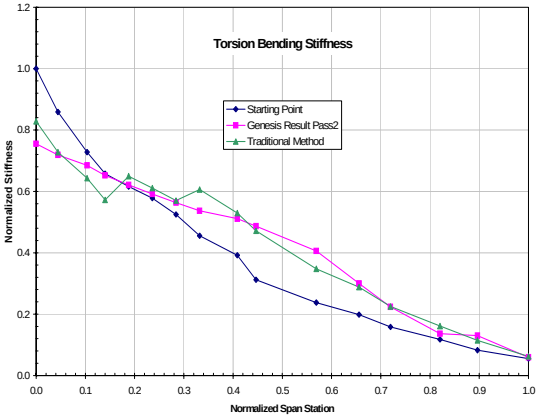
Vertical Bending



Fore-Aft Bending



Torsion



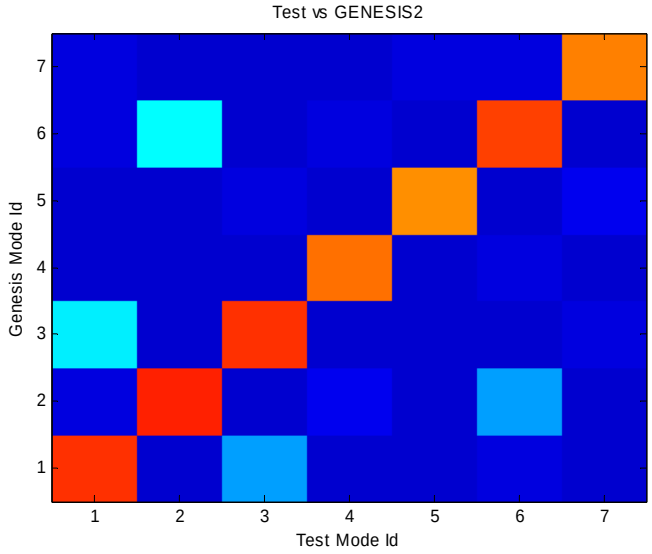
- Additional and arbitrary design constraints that force each successive outboard bar stiffness to be at least 5% less than current
- Mode shapes and frequencies match well for this case with constraints on the stiffness profiles

Results With Additional Constraints

- Equivalent Solution
  - Frequencies match
  - Mode shapes in order
  - MAC-values high

Test vs Additional Constraints

Mode	Test	Genesis	MACii
1	21.57	21.58	0.96
2	31.01	31.00	0.98
3	55.78	55.78	0.97
4	60.28	60.31	0.88
5	63.17	63.17	0.86
6	86.23	86.23	0.94
7	90.48	90.45	0.86



Conclusions

- A Test and Analysis correlation process has been developed using the structural optimization program GENESIS
- This process is capable of producing results comparable to traditional tuning methods in a fraction of the time
- Process requires, as in traditional method,
  - Limits/controls placed on variables and constraints
  - Application of engineering expertise
- Process has application to larger FEMs