UPDATING THE FINITE ELEMENT MODEL TO MATCH GROUND VIBRATION TEST DATA

Summary

A simple and efficient approach for updating analytical finite element models (FEM) to match analytical frequencies and mode shapes to the experimental ground vibration test (GVT) data is introduced in this study. The proposed model updating procedure is based on a series of optimizations. This approach has been successfully applied to create an equivalent beam FEM for the inboard and outboard B-52H (The Boeing Company, Chicago, Illinois) airplane engines and the X-37 Advanced Technology Demonstrator Drogue Chute Test Fixture (DCTF) with the X-planes pylon. The goal was a simple model capable of being analyzed in a captive-carry configuration with the B-52H mother ship. This study has shown that natural frequencies and corresponding mode shapes from the updated FEM achieved at the final optimization iteration have excellent agreement with corresponding measured modal frequencies and mode shapes.

Objective

The primary objective of this study is to develop and validate a simple and efficient technique for including the measured GVT data into the analytical FEM. If measured mode shapes are to be associated with a FEM of the structure, the FEM will likely need to be adjusted to reduce the structural dynamic modeling errors in the flutter analysis; by so doing, flight safety can be improved as well.

Approach

Discrepancies between the GVT and the analytical results are common. In this approach, discrepancies in frequencies and mode shapes are minimized using the series of optimization procedures. Three optimization steps were used in turn to refine each model: the mass properties were set, the mass matrix was orthogonalized, and the natural frequencies and mode shapes were matched. Design variables for the optimization can include structural sizing information (thickness, cross-sectional area, area moment of inertia, torsional constant, etc.), point properties (lumped mass, spring constant, etc.), and material properties (density, Young's modulus, etc.).

B-52H Mother Ship

Frequencies and modal assurance criteria (MAC) values before and after model updating are given in table 1. It should be noted that a maximum of 14 percent frequency error before model updating is reduced to a maximum of 0.03 percent frequency error after model updating. In table 1, the minimum MAC value after model updating is 83. Therefore, we may conclude that analytical frequencies and mode shapes for the inboard and outboard engine nacelles have excellent agreement with the engine nacelle component GVT data. The FEM for the remaining B-52H structural components will be used in an "as is" condition, since the GVT data is unavailable.

X-Planes Pylon and X-37 DCTF Model

Frequencies less than 5 Hz are in the range of interest for the captive carry flutter analysis. The number of modes matched varied depending on the number of frequencies below 20 Hz (4 times higher than the frequency of interest) and with the ease with which the mode shape could be matched. Frequencies and MAC values after the model updating are shown in table 2. The GVT frequencies are also given in table 2. Overall, excellent matching for the frequencies and mode shapes was accomplished in this model updating procedure.

Status

The equivalent beam model that resulted from this study, while consisting of only about one percent of the number of nodes of the full detailed model, matches the first four natural frequencies and mode shapes of the GVT data. The model complexity is on the same order as that of the B-52H airplane, which makes combining them mathematically viable.

The first three frequencies of the X-planes pylon and the X-37 DCTF structures are close to the frequency range of the captive carry flutter analysis, therefore it is required to perform the model validation and model updating for the high fidelity flutter analysis. The B-52H airplane with the X-planes pylon and the X-37 DCTF is flutter-free within the flight envelope.

Table 1. Frequencies and modal assurance criteria values for the B-52H engine nacelles before and after model updating.

	Frequencies (Hz)									
Mode	Inboard Engine Nacelle					Outboard Engine Nacelle				
	Before	Error	After	Error	GVT	Before	Error	After	Error	GVT
1	1.856	8.3%	2.025	0%	2.025	1.917	7.6%	2.075	0%	2.075
2	3.572	14%	4.139	0.02%	4.140	3.550	6.2%	3.784	0.03%	3.785
3	4.960	3.7%	5.150	0%	5.150	4.910	4.7%	5.149	0.02%	5.150

	MAC Values					
Mode	Inboard Engine Nacelle			Outboard Engine Nacelle		
	Before	After	GVT	Before	After	GVT
1	98.95	98.98	100	97.79	97.92	100
2	96.37	98.30	100	97.99	99.33	100
3	92.22	89.16	100	88.77	82.71	100

Table 2. Frequencies and modal assurance criteria values after model updating.

Mode	Equivalent Beam (Hz / percent error)		MAC	GVT (Hz)
	Guyan Reduction	Full Order		
1	4.919 / – 0.04	4.917 / – 0.08	94.4	4.921
2	7.218 / – 0.01	7.217 / – 0.03	84.7	7.219
3	7.940 / – 0.01	7.939 / – 0.03	50.6	7.941
4	25.08 / – 0.05	24.05 / – 4.1	82.3	25.09

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