Advanced Mirror Technology Development (AMTD) II Modal Test of A 1.5 m Glass Slumped Mirror

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Abstract

The Advanced Mirror Technology Development (AMTD) project is in Phase 2 of a multiyear effort initiated in Fiscal Year 2012 to mature toward the next technology readiness level critical technologies required to enable 4-m-or-larger monolithic or segmented ultraviolet, optical, and infrared (UVOIR) space telescope primary-mirror assemblies for general astrophysics and ultra-high-contrast observations of exoplanets. As part of AMTD II, a free-free modal test was performed of a light weighted slumped 1.5 m mirror made of Corning Ultra Low Expansion (ULE®) material. The test article and support structure were suspended via bungee to simulate a free-free environment. Modes were excited by roaming an instrumented modal test hammer and responses were measured. Predicted and measured frequencies are presented as well as Modal Assurance Criteria (MAC) results to compare the mode shapes. The finite element mirror model used for pre-test predictions and posttest comparisons was provided by the mirror vendor, Harris Corporation. The mirror FEM included deformations of the ribs that were a result of the slumping process. Modal test frequencies matched predictions within the 5% target with the exception of one mode and that pair differed by 5.2%. Of the seven modes measured and predicted, four had MAC values meeting the target of ≥ 0.90, one was just under and two were notably below the target.

Keywords: Modal test, Slumped mirror, Dynamics, Modal predictions, Space Telescope

Introduction

NASA Marshal Space Flight Center’s (MSFC) Advanced Mirror Technology Development (AMTD) program was initiated in the fall of 2011. As part of AMTD a free-free modal test of a slumped 1.5 m glass Ultra Low Expansion (ULE®) mirror was performed in September 2017. The test objectives were to measure modal frequencies and mode shapes up to 1,000 Hz. Measured frequencies were compared to those predicted and the Modal Assurance Criteria (MAC) was used to compare measured to predicted mode shapes. No attempt to update the FEM based on test data was made. Figure 1-a shows the mirror and 1-b shows it suspended via bungee.

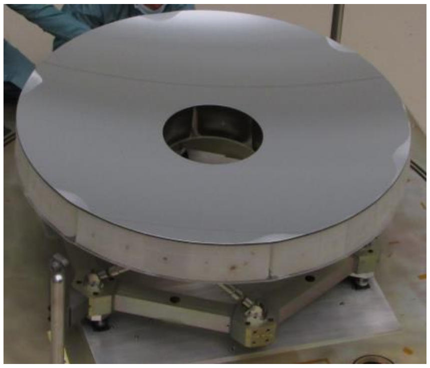

Figure 1-a. 1.5 m Mirror

Figure 1-b. Test Article Suspended by Bungee

Pre-Test Analysis

Finite Element Analyses (FEA) were performed prior to tests. The mirror Finite Element Model (FEM), without handling and support structure and kinematic mounts, was provided by Harris Corporation. Figure 2-a shows the mirror FEM and Figure 2-b and 2-c exhibit internal geometric effects of slumping. Ribs were deformed some amount relative to their pre-slumped form.

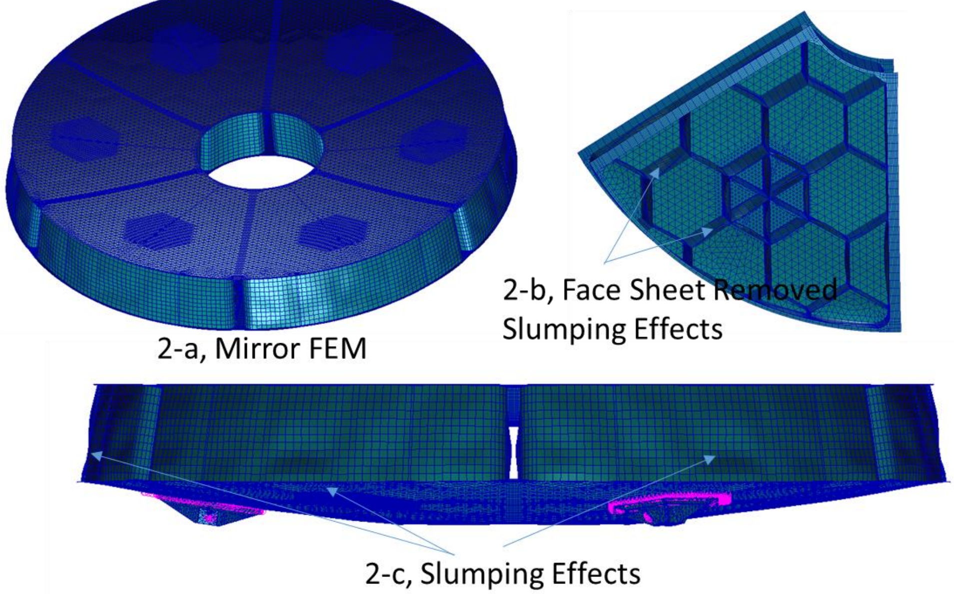

Figure 2, Mirror FEM

A photograph of the mirror showing a location where ribs had deformed due to slumping to the extent that they were touching is presented in Figure 3. It should be noted that while the FEM does include geometry of geometric deformations associated with slumping they are not to that degree. That being the case, reservations with respect to how closely the FEM predicted mode shapes and those measured would match existed going in.

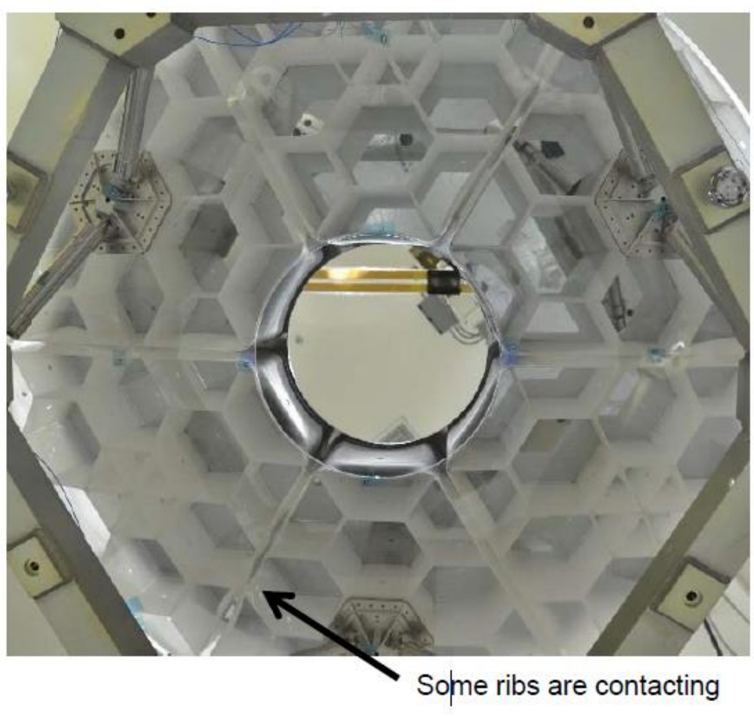

Figure 3. Deformations Due to Slumping – Ribs in Contact

The mirror was attached to a Harris Corporation provided support structure via 6 struts that facilitated a kinematic mounting scheme. Figure 4 shows this arrangement. A FEM of the support structure was created and integrated with the mirror FEM. The integrated model was utilized in free-free eigenvalue analyses to predict frequencies and mode shapes.

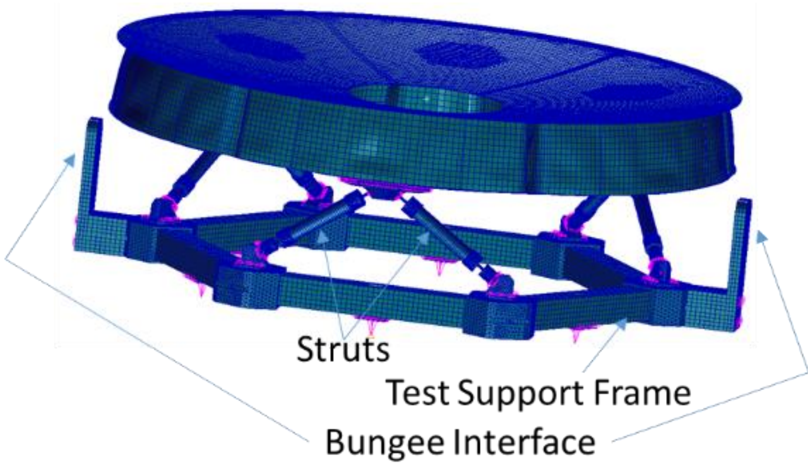

Figure 4. Mirror and struts integrated to the support structure

Table 1 presents the predicted modal frequencies and Figure 5 shows the mirror's predicted mode shapes.

Table 1. Pre-Test Predicted Modal Frequencies

Mode	Frequency (Hz)
1	395.4
2	398.9
3	646.1
4	682.4
5	834.0
6	834.8
7	864.1

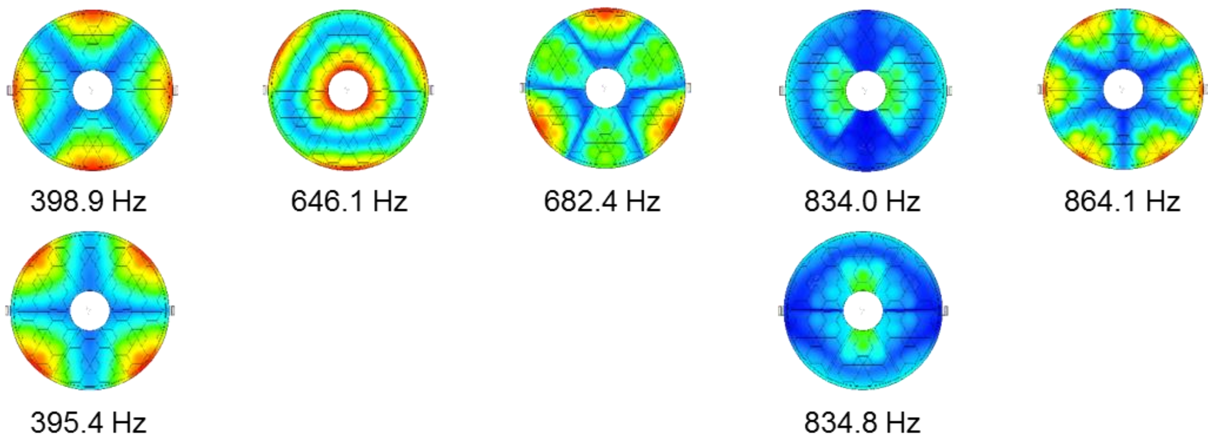

Figure 5. Pre-Test Predicted Mode Shapes

Modal Tap Test

The mirror and support structure, while suspended via bungee, was tapped at 42 locations with an instrumented modal test hammer. Each location was tapped 5 times and results were averaged. Twenty two of the 42 locations were on the back of the ULE® mirror. Those locations are depicted in Figure 6.

Test results were deciphered to identify the modes associated with the ULE® mirror. Those results were compared to predicted frequencies and that comparison is presented in Table 2. As seen below in Figure 7, test mode 1 is comparable to predicted mode 2. This is not uncommon for modes of a symmetric structure.

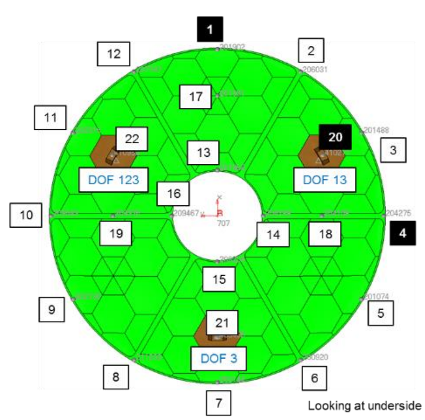

Figure 6: Mirror Accelerometer and Tap Locations

Note 1: Uniaxial accelerometers were at 1, 4, and 20
Note 2: All 22 locations were excitation locations
Note 3: The "DOF" labels designate the degrees of freedom reacted by the

supports at that location

Table 2. Comparison of predicted and measured modal frequencies:

Modal Frequency, Hz		Difference	
Predicted	Test	Hz	%(of Test)
398.9	414.4	15.5	3.7
395.4	417.2	21.8	5.2
646.1	678.7	32.6	4.8
682.4	707.5	25.1	3.5
834.0	864.1	30.09	3.5
834.8	868.9	34.1	3.9
864.1	877.1	13	1.5

Post Test Analysis

Measured and predicted mode shapes were plotted. Graphical comparisons of plotted mode shapes are presented below in Figure 7.

Mode shapes being less intuitive to quantitatively compare than modal frequencies, mathematical methods of doing so have been devised. A common way to compare how well a measured mode shape matches the corresponding analytically predicted mode shape is the Modal Assurance Criteria (MAC). The result of this process are presented in matrix form. If perfect correlation existed all diagonal terms would be 1.0 and all off diagonal terms would be 0.0. In practice, diagonal terms greater than 0.9 and off diagonal terms less than 0.1 are acceptable (1).

Measured mode shapes were used in conjunction with those predicted and Modal Assurance Criteria (MAC) data were computed. Figure 8 presents the MAC matrix.

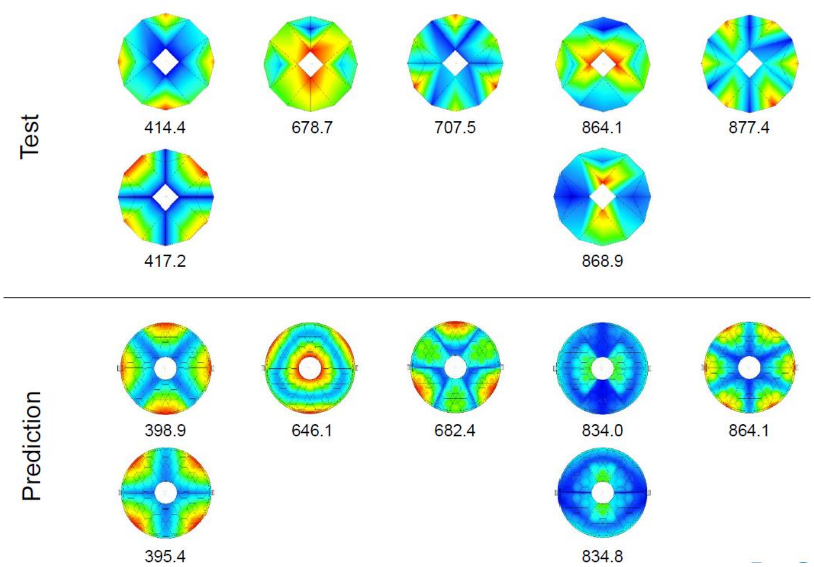

Figure 7. Mode Shape Comparison

Mode	1	2	3	4	5	6	7
1	0.96	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.65	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.91	0.01	0.00	0.00	0.00
4	0.00	0.00	0.07	0.92	0.00	0.01	0.00
5	0.00	0.00	0.00	0.00	0.62	0.00	0.07
6	0.01	0.00	0.00	0.01	0.16	0.85	0.01
7	0.00	0.00	0.00	0.00	0.01	0.01	0.94

Figure 8. MAC Matrix

Discussion

With the exception of one mode, the measured vs. predicted frequencies were within 5%. That is the recommended threshold for that comparison per Reference 2. Numerous elements of the MAC matrix are not consistent with expectations for a reasonable comparison between measured and predicted mode shapes. However, as previously stated, reservations WRT that end were held going into test.

References

1. “Modal Testing: Theory and Practice”, D. J. Ewins, Research Studies Press Ltd., 1986
2. “Load Analyses of Spacecraft and Payloads”, NASA-STD-5002, June 1996