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# Calibration of International Space Station (ISS) Node 1 Vibro-Acoustic Model

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April 2014

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## 1. 0 Introduction

The objective of the present investigation is to correlate the vibration data measured by NASA using acoustic emission, at specific sensor locations on Node 1 of the International Space Station (ISS), to corresponding values predicted by Comet EnFlow, an analysis software based on Energy Finite Element Method (EFEM) that was developed previously as a result of an SBIR funding from NASA LaRC. The report is arranged as follows: Section 2 provides a brief description of measured data, Section 3 describes the computational model, Section 4 describes the results and brief remarks are provided in the final section.

## 2.0 Measured Data

The measured data was provided by NASA and a brief description of the data is provided in this section. The Node 1 Model is shown in Figure 1. The vibrations are measured using a series of acoustic emission sensors that have been placed at the locations as shown in Figure 2; Sensor 13 is the source location that corresponds to input excitation at the wall. The coordinates of the sensor location are presented in Table 1.

**Figure1. Node 1 Structure**

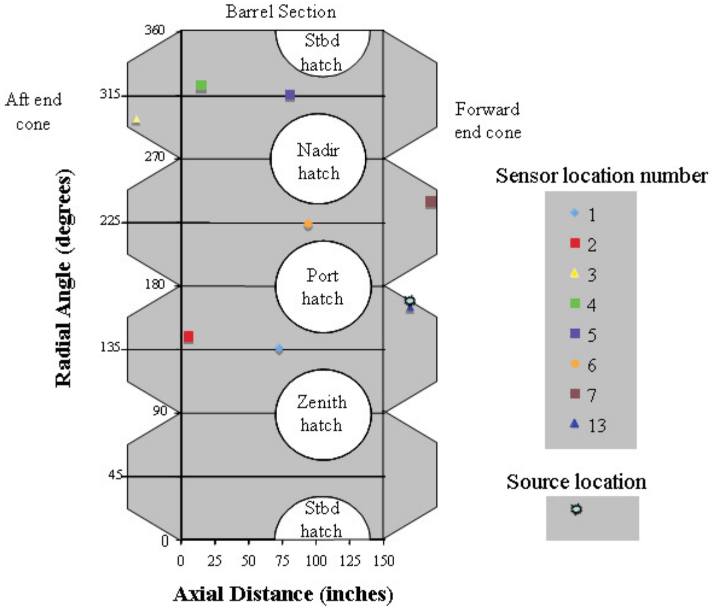

Figure 2. Sensor Locations

| R= | 80.25 | barrel section | ID R=80.25<br>Starboard hatch<br>centerline = 0° | | cone section | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Detectors | | Axial distance (in) from aft end | Radial (degrees) | | Radial distance (in) from cone outer edge | Radial (degrees) | Radial distance (in) from "cone apex" |
| | 1 | 73 | 135.71 | | | | |
| | 2 | 5.5 | 144.15 | | | | |
| | 3 | | | Aft cone | 43.24 | 280.5 | 46.47 |
| | 4 | 14.75 | 322.19 | | | | |
| | 5 | 81.00 | 315.85 | | | | |
| | 6 | 94.25 | 224.15 | | | | |
| | 7 | | | Forward cone | 42.74 | 262.2 | 46.97 |
| | | | | | | | |
| | 13 | | | Forward cone | 20 | 181 | 69.71 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Source | | | | Forward cone | 20 | 180 | 69.71 |

Table 1. Coordinates of Sensor Locations

The B225.5 acoustic emission sensors are utilized for measurement. The averaged power spectra density of the sensor voltage at measurement locations is provided in Figure 3. Note that the data at location 2 is not included since the corresponding receiver channel was not working properly. The most signal energy is between 40 kHz and 160 kHz. The calibration results at these frequencies are plotted in Figure 4. The curve indicates the flat response from 60 kHz to 180 kHz with 57 dB (708 V/µm) calibration factor. The flexural velocity at these measurement locations are computed from data from Figure 3 and Figure 4 which are reported in Section 4.0.

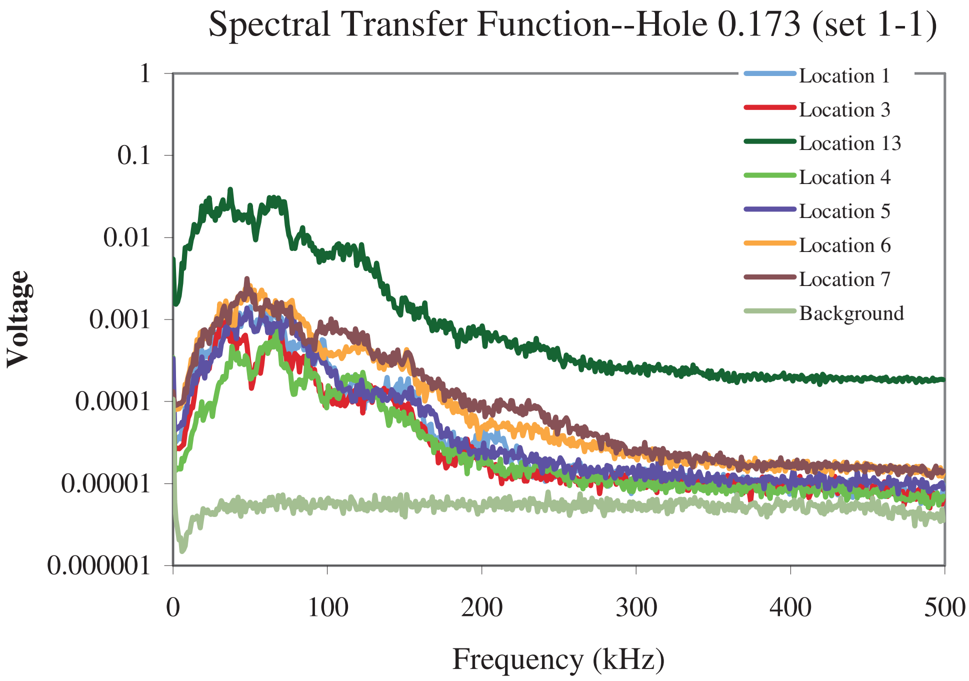

**Figure 3. Power Spectra Density of Measurement Data**

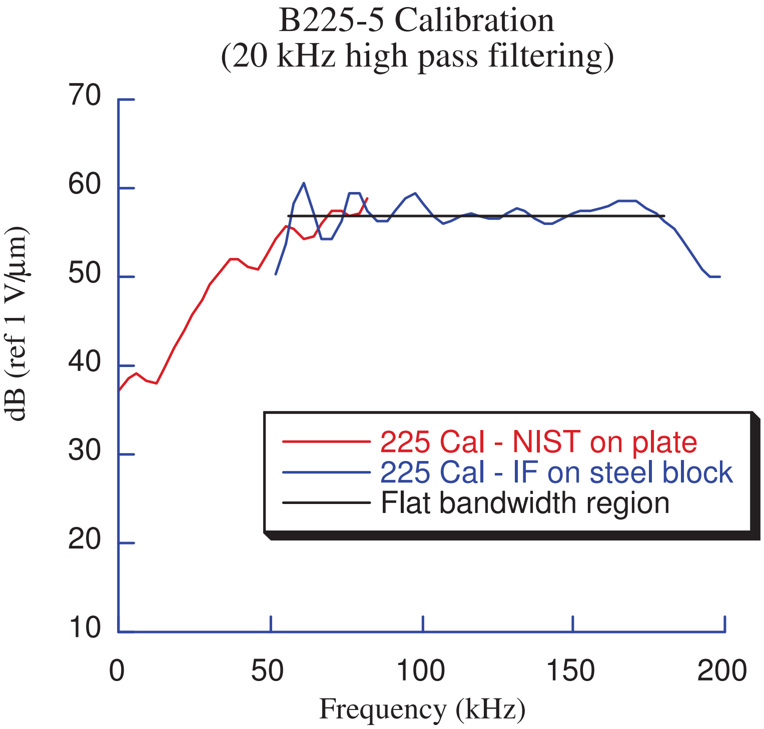

**Figure 4. Conversion Factor from Voltage to Displacement**

### 3.0 EFEM Modeling of Node 1 of the Space Station

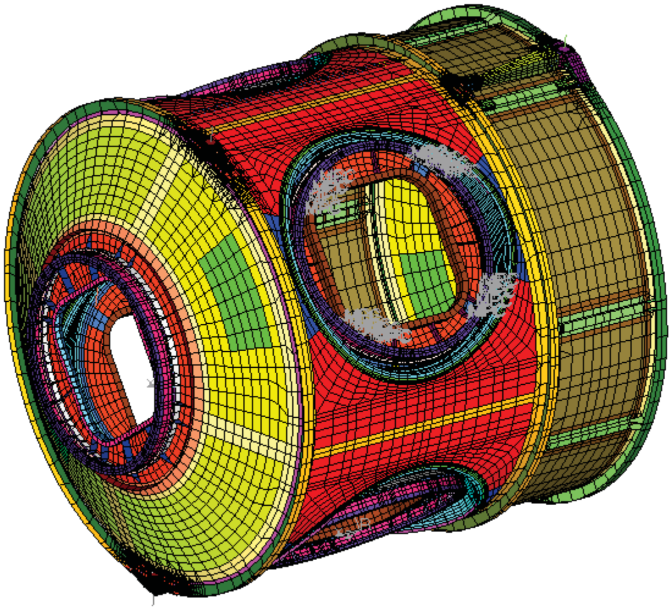

**Figure 5. The FEM model of Node 1 for Stress Analysis**

A very dense finite element (high fidelity) model of Node 1 (see Figure 5) that was originally created for stress analysis was provided by Boeing. The model also included material and geometry properties except damping coefficients. This model consisted of 61167 elements and 54517 nodes. Comet EnFlow is based on finite element method for high frequency vibroacoustic analysis. In this method, energy density is used as the primary variable. Since the energy density does not vary spatially very much, the mesh density requirements are much less and as a result a low density (intermediate fidelity) finite element model is appropriate. Thus, the original FEM model is coarsened and simplified for EnFlow analysis. Specially, the small parts, such as, clips, small overlap plates etc., are replaced by equivalent plates. In addition, the multiple attachments on the four hatch area and aft and forward end cone have less effect on the wave propagation on the wall of the Node 1. These elements are neglected and the effects are considered via modifying the properties of the supporting plates. Finally, the rigid bar elements are neglected since no vibration energy is transported through them.

The modified finite element model for EnFlow analysis is shown in Figure 6. EFEM requires the generation of joint element at geometric and material discontinuities. The joint elements (see Figure 7) are automatically created the graphical user interface utility of Comet EnFlow. The new model including the joint element is comprised of 11126 elements, 15851 nodes and 3342 joint elements. Note that solutions in vibroacoustic analysis are required at many frequencies. As a result of the reduction of the model, the solution times become reasonable.

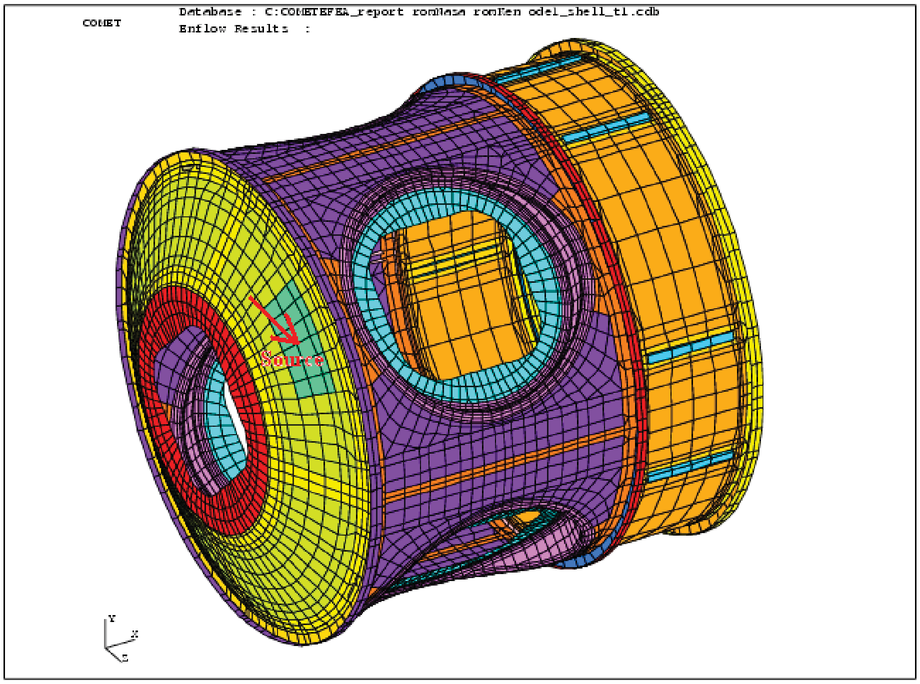

Figure 6. The FEM model of Node 1 for EnFlow Analysis

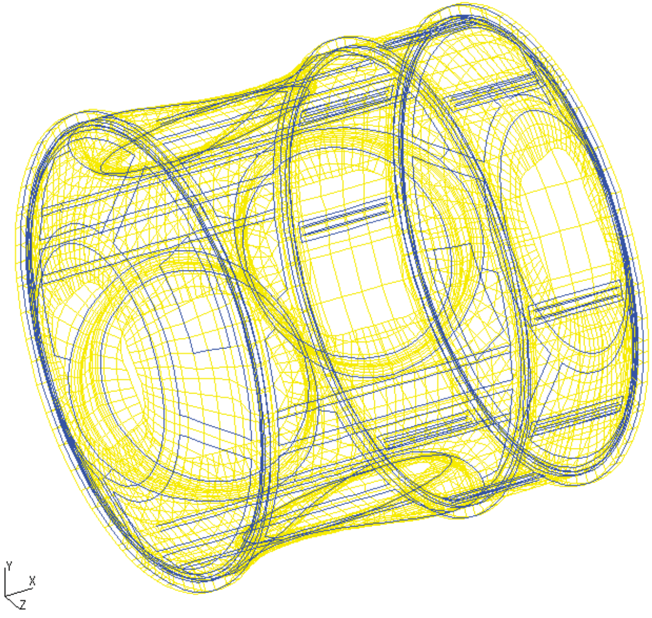

Figure 7. The Joint Location in Node 1 EnFlow Model

## 4.0 Correlation of Experimental Data to EFEM Predictions

Comet/EnFlow is used to predict the noise distribution due to the wave propagation from the source location (sensor 13). In this study, the noise corresponds to flexural velocity on the wall of Nodal 1.

The flexural velocity at sensor 13 which is close the source location is converted to flexural acceleration and utilized as the excitation on the corresponding node of the EnFlow model. The flexural velocity at center frequency of 1/3 octave band from 40 kHz to 160 kHz is computed.  The damping coefficient is linearly distributed over the whole frequency range which is shown in Figure 8.

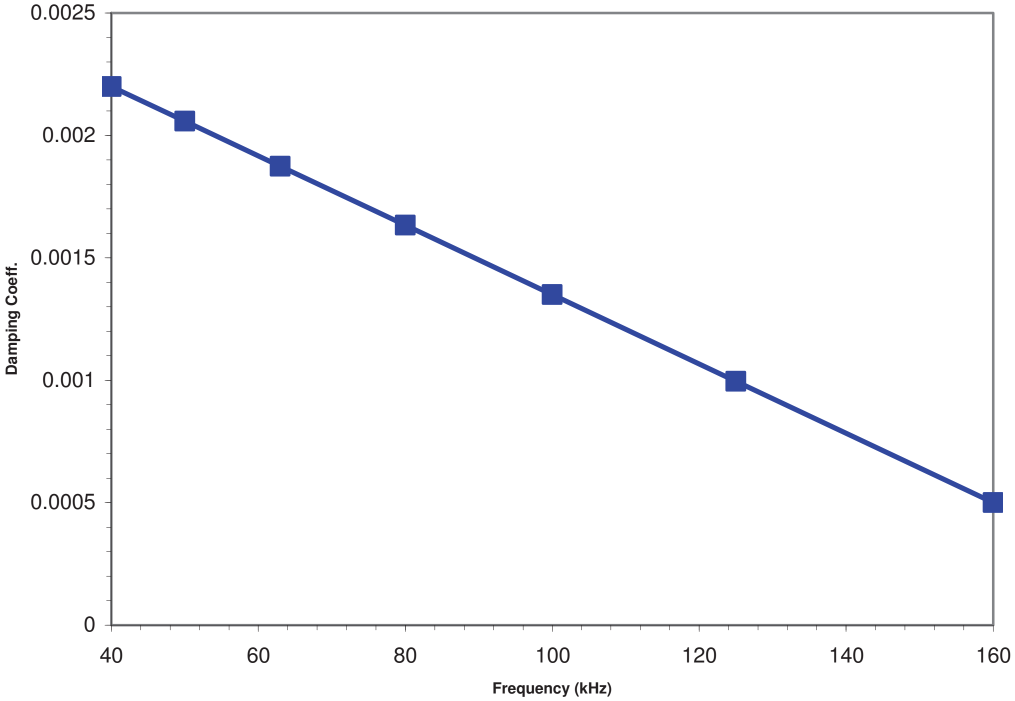

**Figure 8. Damping coefficient over the frequency range**

The flexural velocity distribution at 40 kHz is shown in Figure 9. It can be observed that the magnitude of the velocity decreases along the distance to the source location. The flexural energy intensity plot over the model in Figure 10 displays how flexural energy propagates on the wall of the  model.

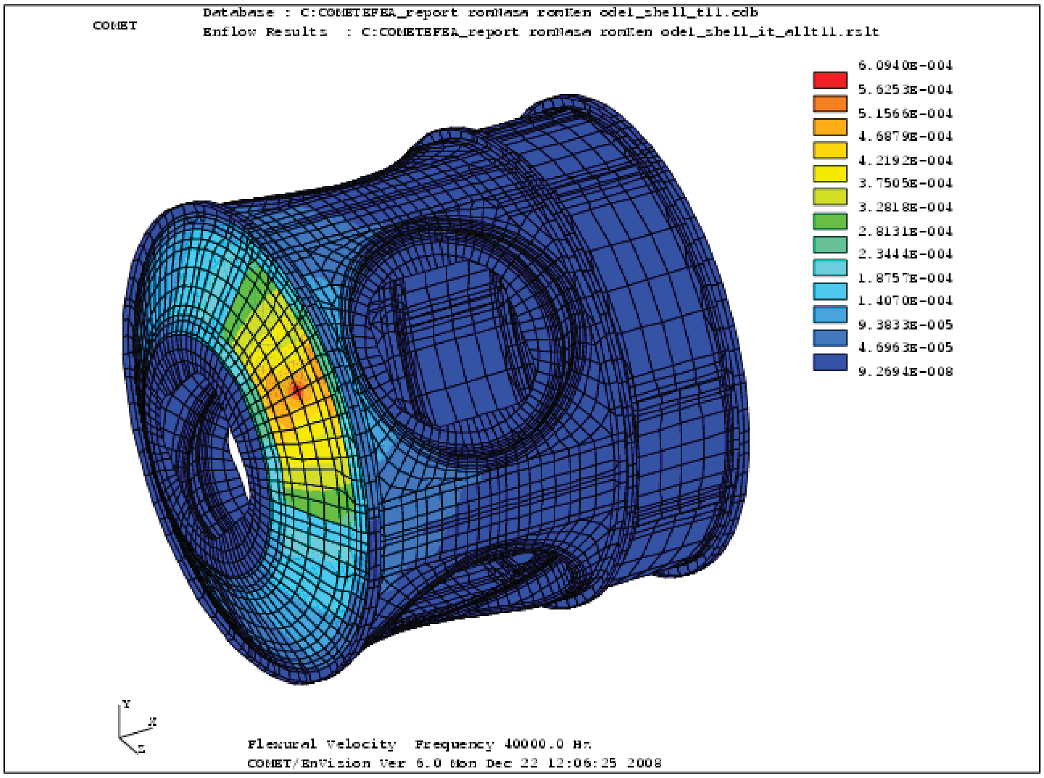

Figure 9. The Flexural Velocity Distribution at 40 kHz

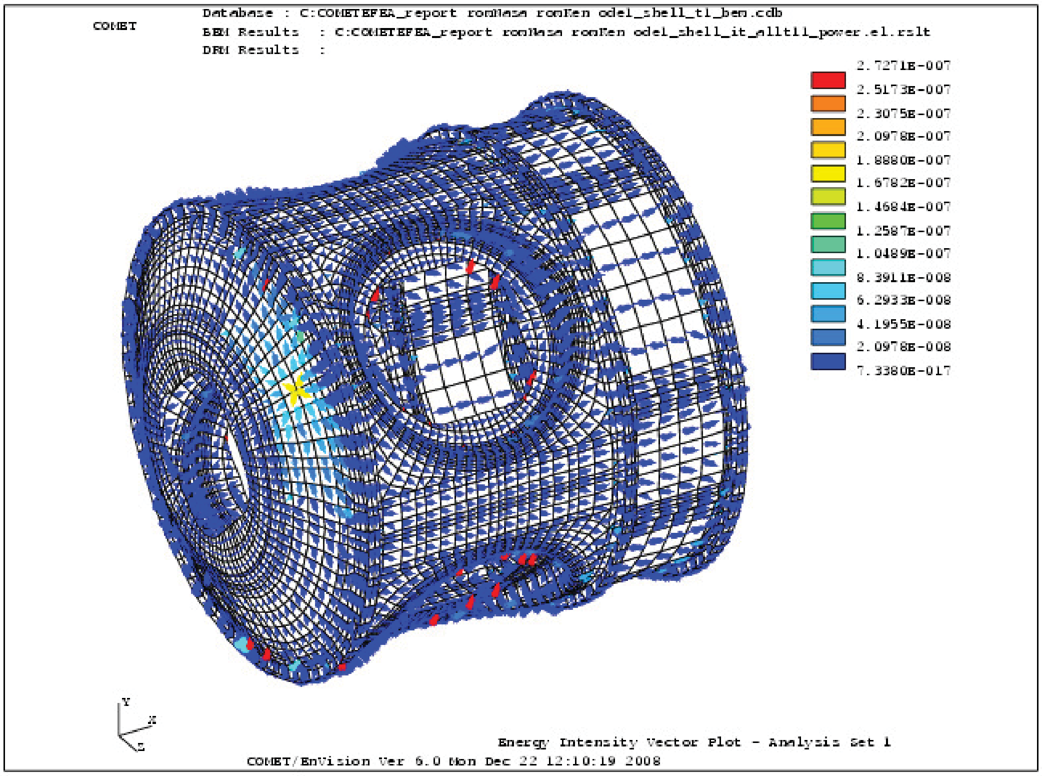

Figure 10. The Flexural Energy Intensity Vector Plot at 40 kHz

The flexural velocities computed by Comet EnFlow at the sensor locations are shown from Figure 11~ Figure 17. These figures are arranged in the sequence of distance from the sensors to the source. The measured flexural velocity at the center frequencies is obtained via averaging over the 1/3 octave band and also plotted in the corresponding Figures.

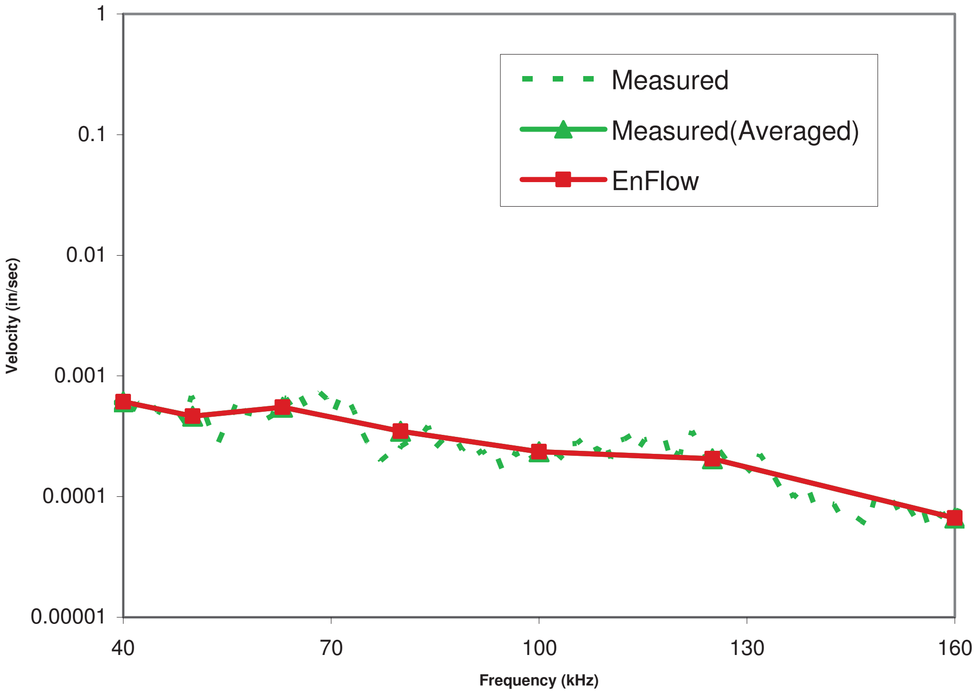

Figure 11. Flexural Velocity of Sensor 13

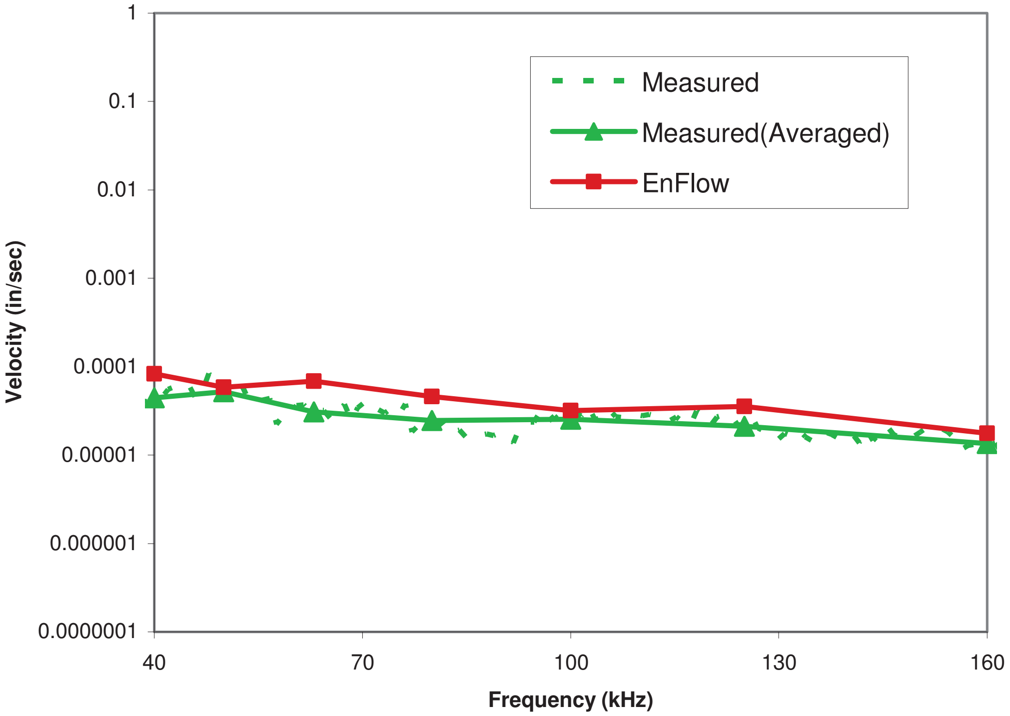

Figure 12. Flexural Velocity of Sensor 7

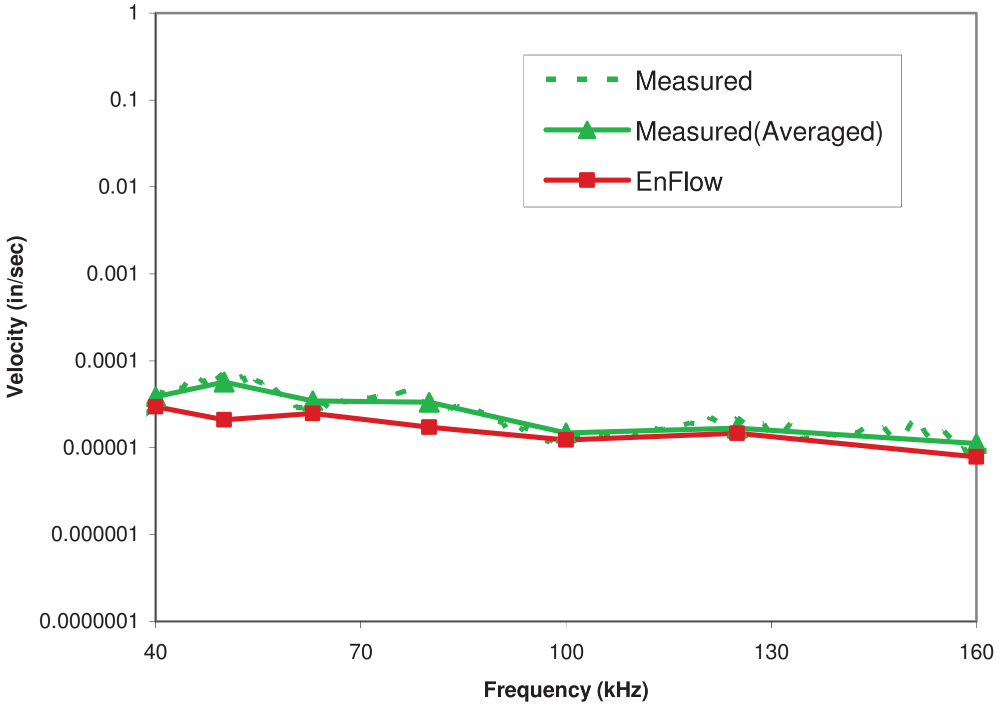

Figure 13. Flexural Velocity of Sensor 6

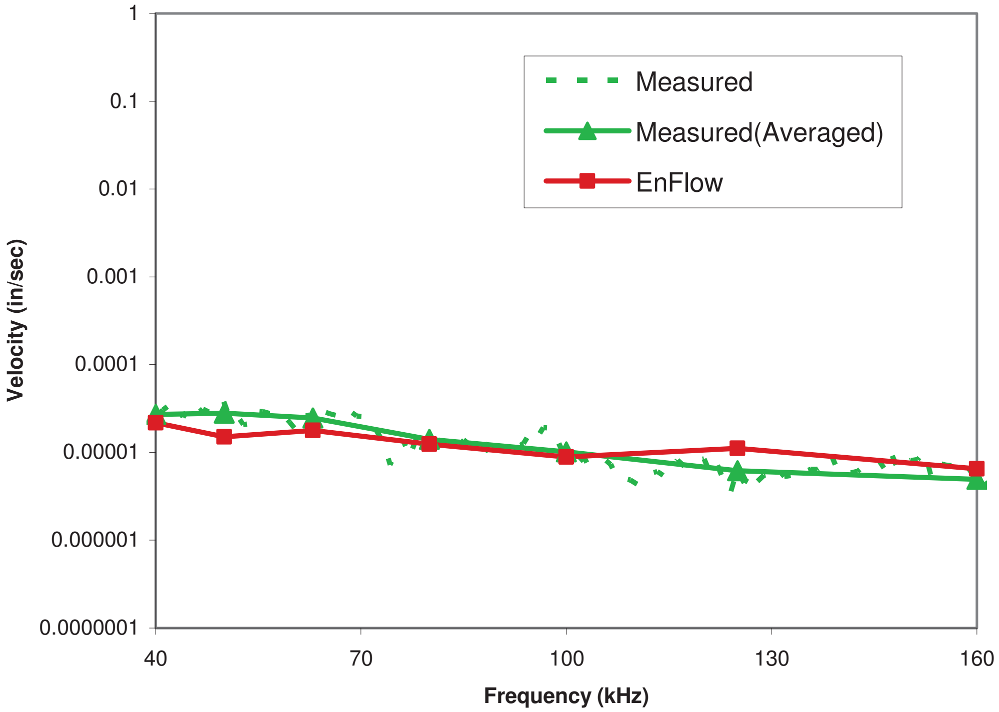

Figure 14. Flexural Velocity of Sensor 1

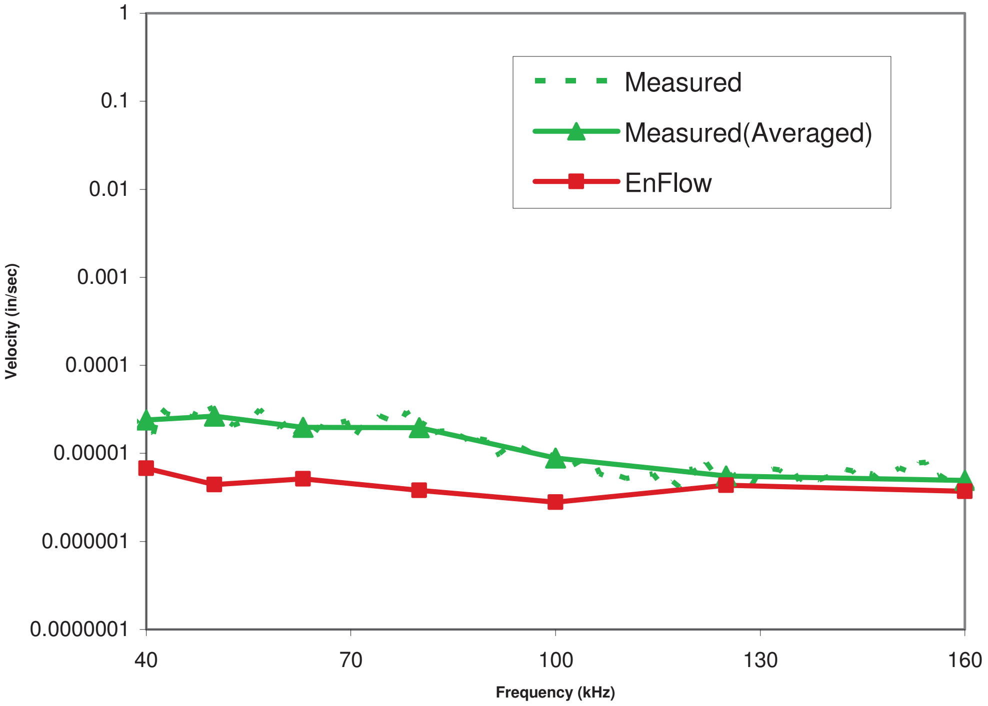

Figure 15. Flexural Velocity of Sensor 5

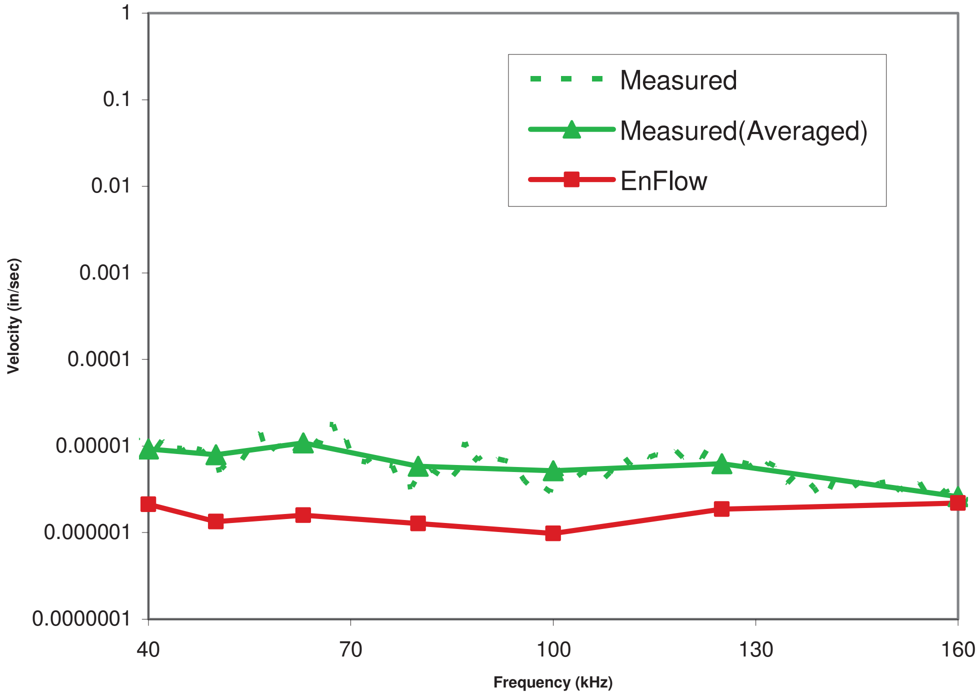

Figure 16. Flexural Velocity of Sensor 4

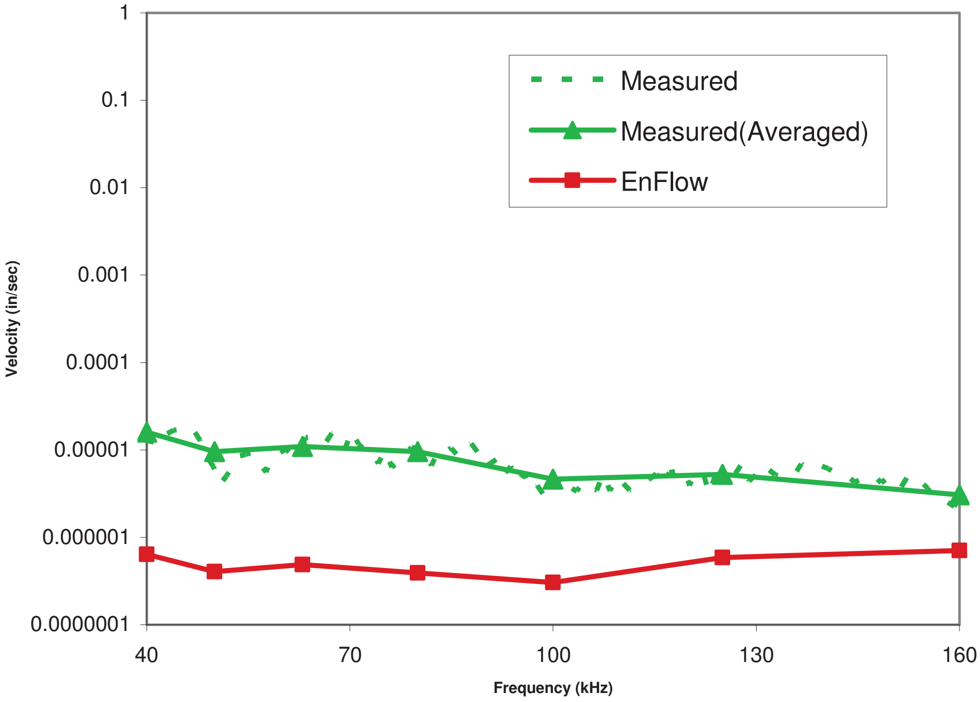

Figure 17. Flexural Velocity of Sensor 3

## 5.0 Remarks

Overall, good correlations are obtained. The flexural velocity by EnFlow at sensor 13 is identical to the measured data which indicates that the proper acceleration excitation is applied on the EnFlow model. The flexural velocity by EnFlow at sensor 7, sensor 6, sensor 1 and sensor 5 correlates well with the measured data. The Note that these four sensors are relatively close to the source location. The results demonstrate that the EnFlow captures properly the energy decay away from the source. Nevertheless, there are some differences among the measured and predicted flexural velocities at sensors 4 and 3 which are relatively far away from the source location.

In order to explore the possible causes for the differences, the measured and computed flexural velocity at all sensors are plotted in Figure 18 and Figure 19, respectively. The measured data at all sensors except sensor 3 show the energy decay to some extent with the distance to the source. While the data at sensor 3 looks unreasonably high which are above the data at sensor 4 almost over the whole frequency range. The EnFlow result demonstrates the clear energy decay phenomena due to damping for all sensors with the distance of sensors to the source. One reason could be related to measurement error. Since the signal is getting weaker as the sensor location move further away from the sources the measurement error may have been increased due to higher background noise. The measured data at sensor 4 and sensor 3 may be affected more by the background noise.

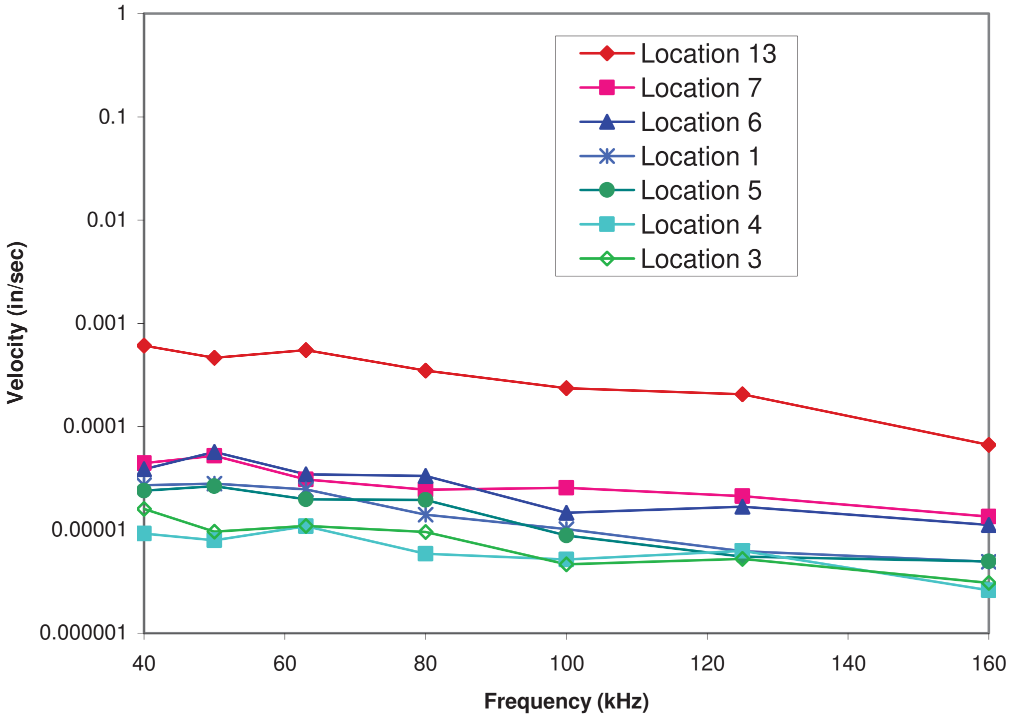

**Figure 18. Measured Flexural Velocity at All Sensors**

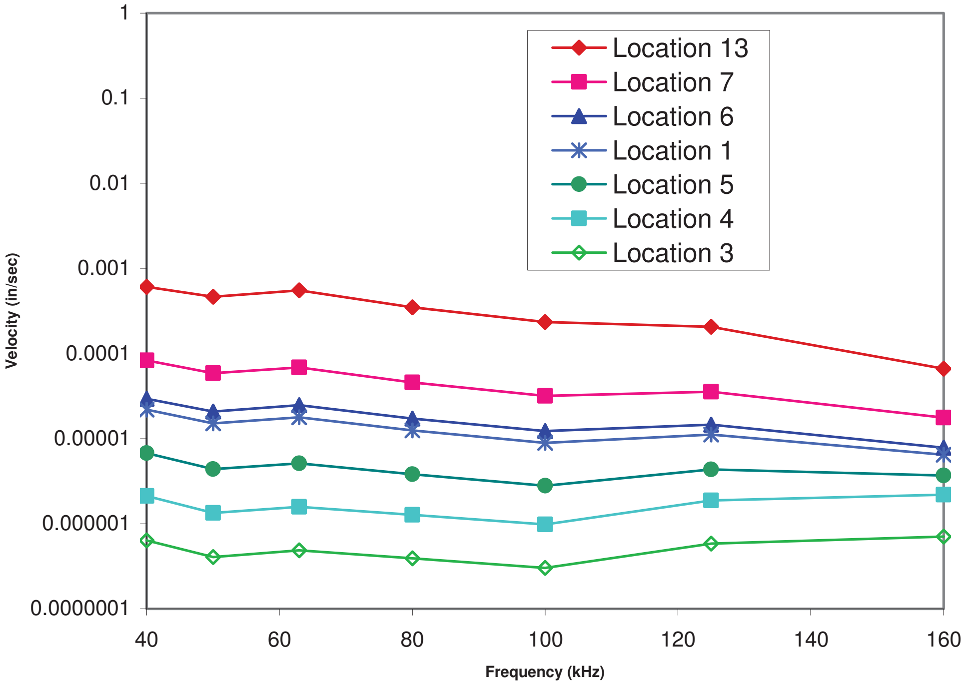

**Figure 19. Flexural Velocity from EnFlow at All Sensors**

Typically, acoustic emission data is in very high frequency range where the elastic wavelength is very small and the vibration behavior is highly sensitive to the structural detail. These characteristics make using conventional finite element method impractical. Comet/EnFlow, which is developed based on the high frequency energy finite element method (EFEM), is a suitable tool for this type of analysis. Especially, comparing to the other high frequency tool, the governing equations of EFEM is directly derived from the wave propagation model which can predict well the vibration variation over the structure subject to acoustic emission type of sources.

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**14. ABSTRACT**

Reported here is the ability of utilizing the Energy Finite Element Method (E-FEM) to predict the vibro-acoustic sound fields within the International Space Station (ISS) Node 1 and to compare the results with actual measurements of leak sounds made by a one atmosphere to vacuum leak through a small hole in the pressure wall of the Node 1 STA module during its period of storage at Stennis Space Center (SSC). While the E-FEM method represents a reverberant sound field calculation, of importance to this application is the requirement to also handle the direct field effect of the sound generation. It was also important to be able to compute the sound fields in the ultrasonic frequency range. This report demonstrates the capability of this technology as applied to this type of application.

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