



Structural acoustic characterization of a tenor trombone



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Abstract

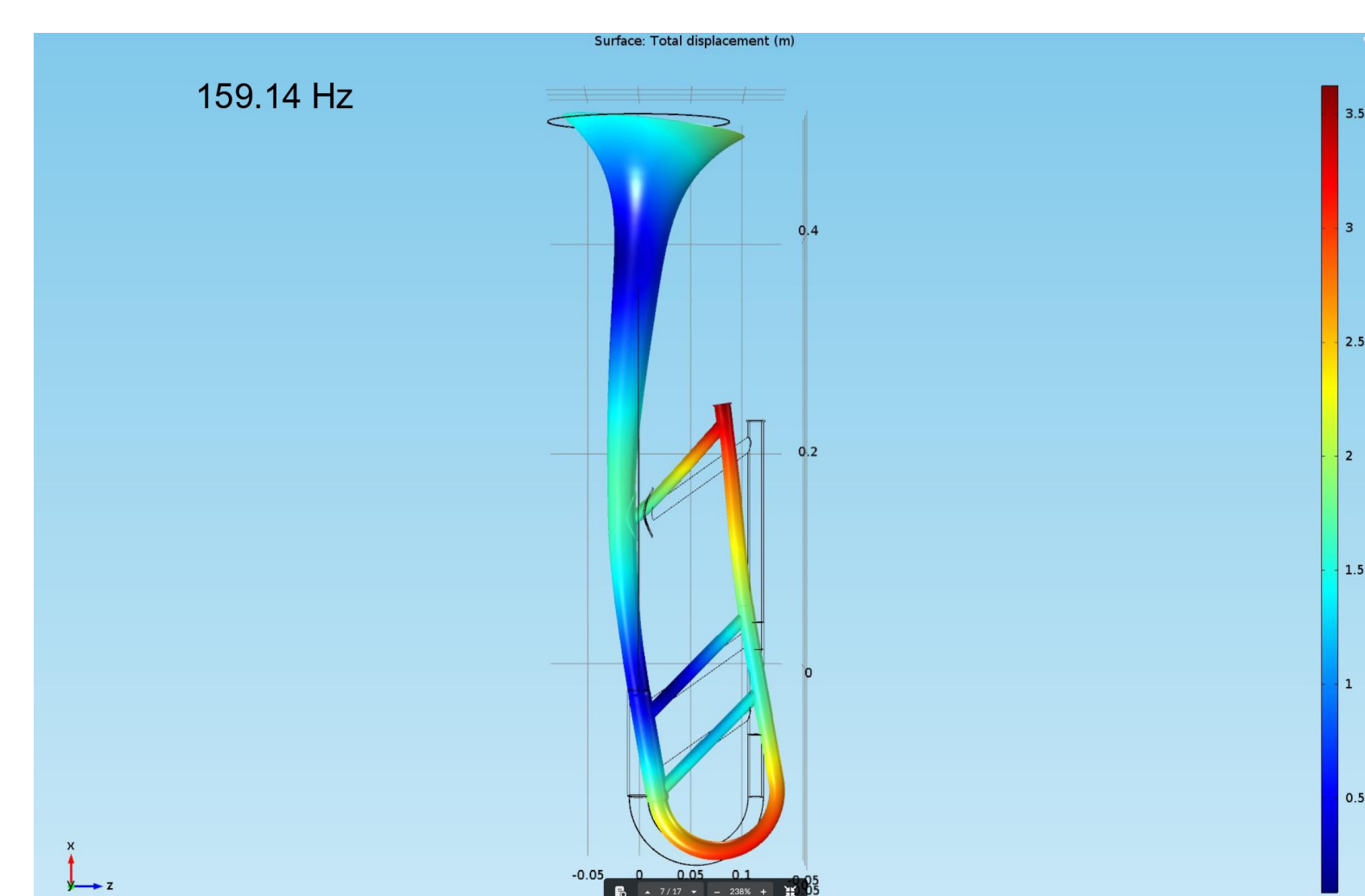
An analysis of the sound-producing characteristics of a tenor trombone has been initiated at TCU. Focus of the effort will be on the model Conn 44H "Vocabell" tenor trombone due to its unique rimless bell. A numerical model of the instrument using Autodesk Inventor has been created. The model was then analyzed using COMSOL Multiphysics.

Key areas of focus include understanding the interaction between the instrument's structural vibrations and the sound radiated from the bell. The "Vocabell" design, known for its unique construction and acoustic qualities, will be critically examined to assess how its geometry and material properties influence sound production and associated frequency spectrum. Radiated sound and structural vibration measurements have been conducted on the physical instrument, providing data for model correlation and validation. Once validated, the numerical model will be used to explore more advanced concepts of brass instrument design.

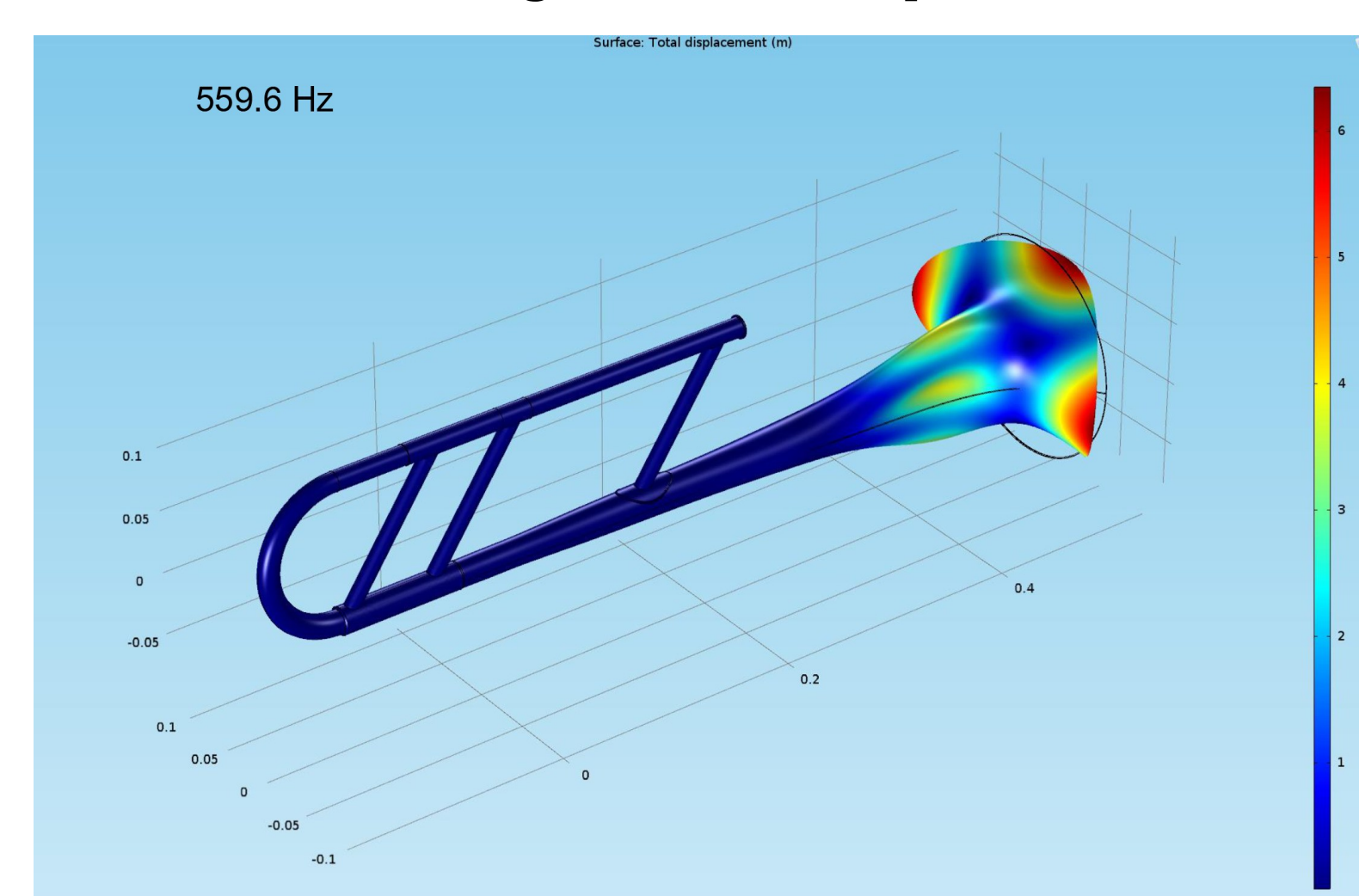
Background

The Tenor Trombone is one of the most commonly seen and known instruments from all types of wind bands¹. It produces noise via a player buzzing their lips inside the mouthpiece, and that sound travels through the length of the piping to produce its characteristic sound. The slide portion of the trombone serves to change the pitch or note of the horn, while the bell portion amplifies the sound.

Two major types of structural modes have been noted to exist in the bell portion of the instrument³, longitudinal and circumferential.



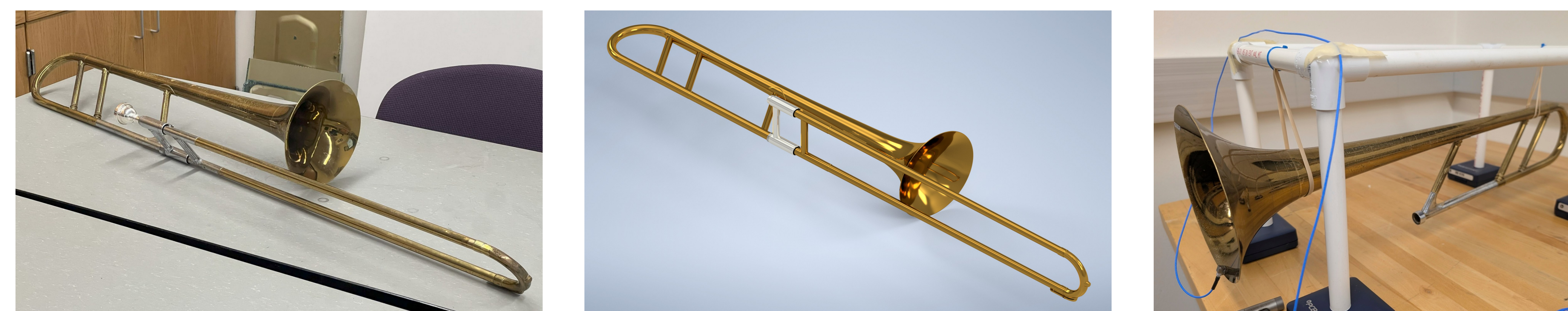
Longitudinal Example



Circumferential Example

Methodology and Procedure

A model of the Conn 44H "Vocabell" trombone was recreated in CAD using physical measurements on the horn as well as a derived equation defining the radius of the bell from a best-fit curve in excel. The model was created in the horn's fully closed position, with no tuning slides adjusted.



- The bell portion of the model was imported into COMSOL Multiphysics and a volumetric mesh of the bell was formed. The first 25 structural modes were found within the software.
- Hammer testing using both Laser Doppler Vibrometry (LDV) as well as accelerometer measurements techniques were performed to produce an experimental frequency response plot as well as find mode shapes.
- Analysis comparing the COMSOL results to the experimentally derived data was then performed, primarily linking COMSOL generated modes to experimentally generated modes by mode shape.

Data and Results

The first eleven structural modes were selected for detailed analysis.

- Not every experimentally identified mode had a corresponding mode in the COMSOL results: circumferential bell modes at 174 Hz, 228 Hz, and 532 Hz were not reproduced by the simulation, and the breathing mode at 376 Hz also lacked a matching numerical counterpart.

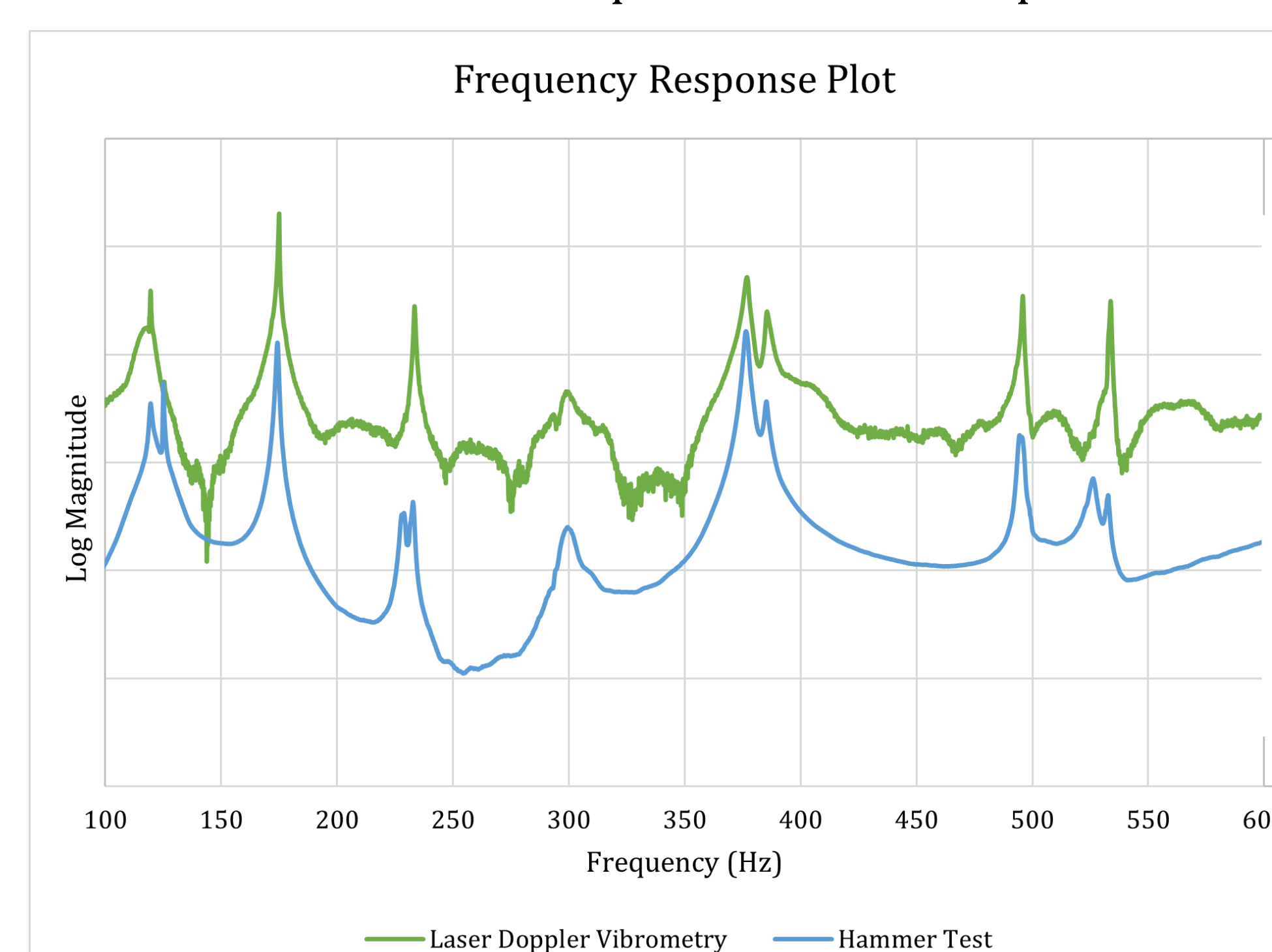
- Across the paired modes, the COMSOL-predicted modal frequencies differed from the Mode Indicator Function (MIF) values by an average of 51.7 Hz, with a maximum deviation of 74.2 Hz at mode 6 and a minimum deviation of 33.4 Hz at mode 1.

- Laser Doppler vibrometry (LDV) measurements supported the modes obtained using the MIF, although the LDV frequency response exhibited higher noise levels.

- The combined absence of several experimentally observed modes in the simulation and the systematic frequency offsets in the paired modes indicate that the current numerical model does not yet provide quantitatively reliable predictions of the bell's thin-body dynamics, underscoring the need for further refinement of geometry, boundary conditions, and material parameter definitions.

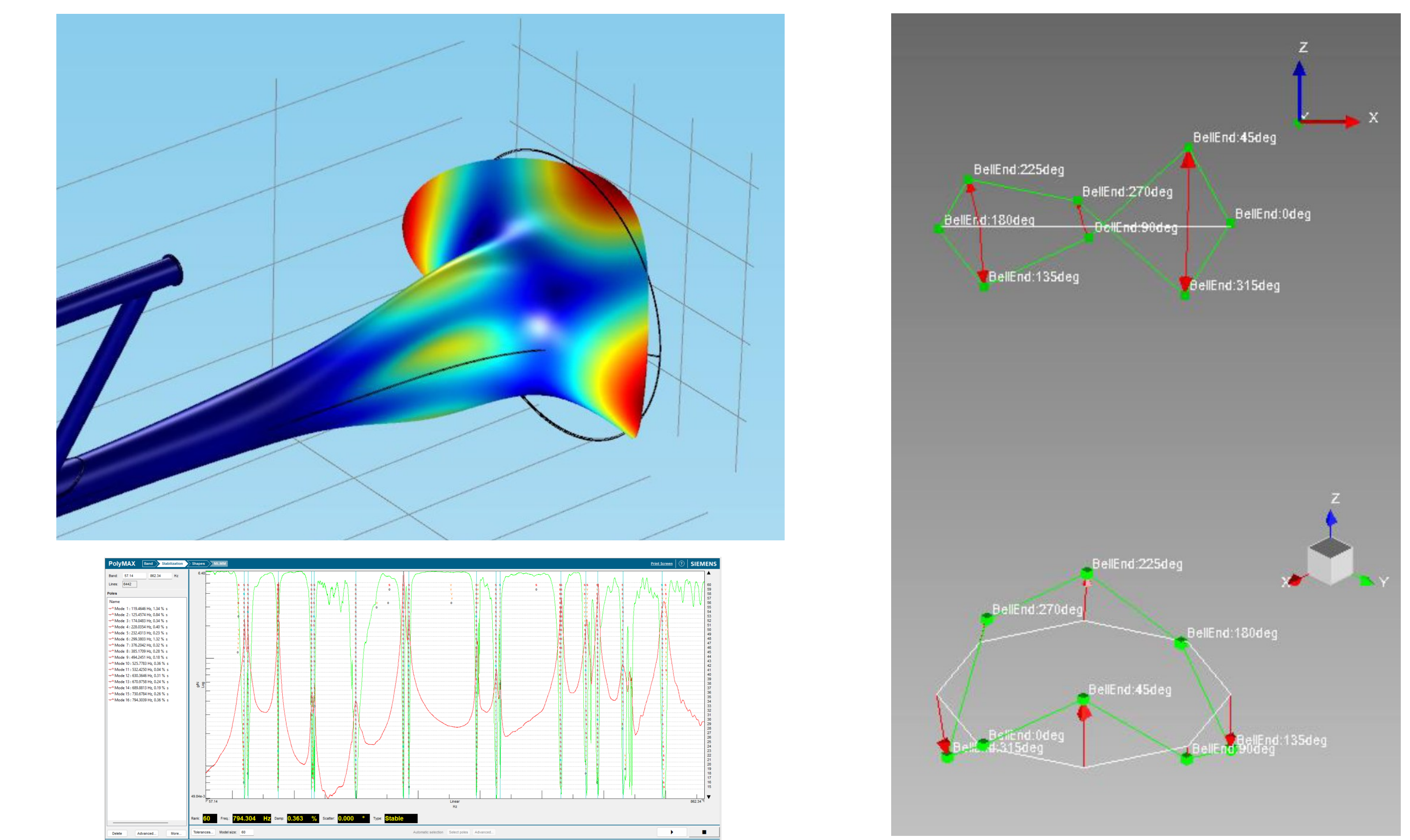
| Mode | Test (Hz) | COMSOL (Hz) | Description |
|------|-----------|-------------|--------------------|
| 1 | 119.4646 | 152.85 (1) | Breathing/Rotating |
| 2 | 125.4574 | 159.14 (2) | Breathing |
| 3 | 174.0483 | 242.56 (3) | Rotating |
| 4 | 228.0354 | X | Circumferential |
| 5 | 232.4313 | X | Circumferential |
| 6 | 299.3803 | 373.56 (5) | Breathing |
| 7 | 376.2042 | X | Breathing |
| 8 | 385.1709 | 438.27 (6) | Breathing |
| 9 | 494.2451 | 559.6 (7) | Circumferential |
| 10 | 525.7783 | 559.62 (8) | Circumferential |
| 11 | 532.245 | X | Circumferential |

Table 1: Mode comparisons and descriptions



Analysis

Example of matching COMSOL results to accelerometer test data.



Conclusions

The COMSOL Multiphysics simulation did not accurately reproduce the thin-body structural modes of the trombone bell. Notable discrepancies were observed between the experimentally measured modal frequencies and those predicted by the model, and several experimentally identified modes were absent from the numerical results. However, the simulated mode shapes closely matched the experimentally observed patterns, suggesting that the model captures the general vibrational behavior of the bell. Improving the accuracy may require refinement of input parameters, particularly the material properties, to account for factors such as the lacquer coating. Enhancing these aspects could increase model fidelity and enable more reliable analysis within COMSOL. A validated structural model would also permit a more detailed investigation into the coupling between the bell's structural modes and its acoustic characteristics.

References

1. Campbell, Murray, Joël Gilbert, and Arnold Myers. The science of brass instruments. Vol. 436. Switzerland: Springer, 2021.
2. Nief, Guillaume, et al. "External sound radiation of vibrating trombone bells." Journal of the Acoustical Society of America 123.5 (2008): 3237-3237.
3. Moore, T. R., et al. "Vibrational modes of trumpet bells." Journal of sound and vibration 254.4 (2002): 777-786.
4. Suits, Bryan. "Frequencies of Musical Notes, A4 = 440 Hz". Physics of Music — Notes. Michigan Tech University. (1998)

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