Vibration Analysis of Acoustic Load on Composite Air Inlets

Composite materials are increasingly used in aerospace applications due to their high **tensile strength**, **lightweight composition**, and **resistance to fatigue and environmental stress**. These qualities make them ideal for structural parts like air inlets. However, composites often exhibit **lower durability under vibrational and acoustic loading**, which poses potential performance issues. Assessing their behavior under such dynamic conditions is essential to improve **aircraft reliability, performance, and safety**.

Objective

This case study explores the application of **Digital Image Correlation (DIC)** for **vibration analysis** of composite materials subjected to acoustic loading. The primary goal was to evaluate **vibration parameters and deformation** on composite air inlets used in trainer jets when exposed to sound-induced excitation replicating jet engine noise.

Description of the Case Study

To simulate real-world operating conditions, a **composite air inlet** from a jet trainer aircraft was placed in a specially designed acoustic chamber and subjected to **acoustic excitation** using four high-powered speakers. The goal was to simulate the **vibrational stress** caused by engine noise and determine the **vibration mode shapes**.

Fig 1: Experimental setup

MERCURY RT

Test setup

- **Excitation Source:** Four speakers set to key resonant frequencies: 84 Hz, 118 Hz, and 238 Hz
- **Cameras:** 2× **Phantom High-Speed** cameras
- **Resolution:** 1200×800 pixels
- **Frame Rate:**
    - 2,000 fps for 84 Hz and 118 Hz
    - 3,000 fps for 238 Hz
- **Calibration Grid**: 4 mm
- **Lighting:** Single strong LED light
- **Software:** MercuryRT with 3D DIC and Vibrography modules

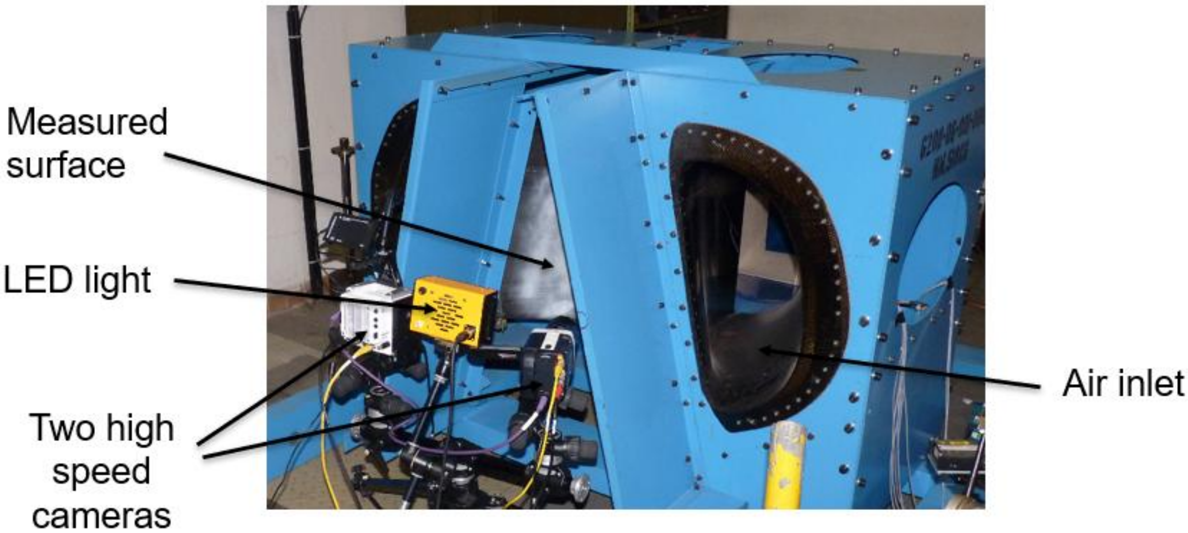

Fig 2: Test setup

Optical Measurement Results

❖ Using **3D DIC**, the full-field displacement and strain fields were captured. Displacement in the **Z-direction** (**out-of-plane**) was measured across all three test frequencies.

❖ 84 Hz

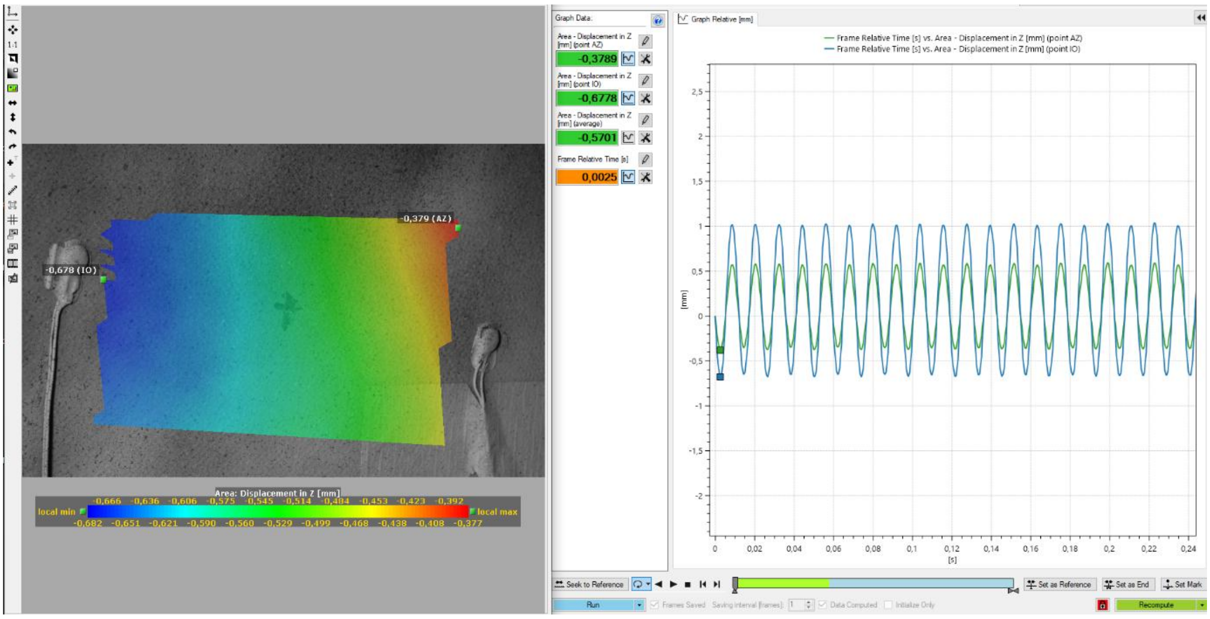

Fig. 3: Min displacement at 84 Hz

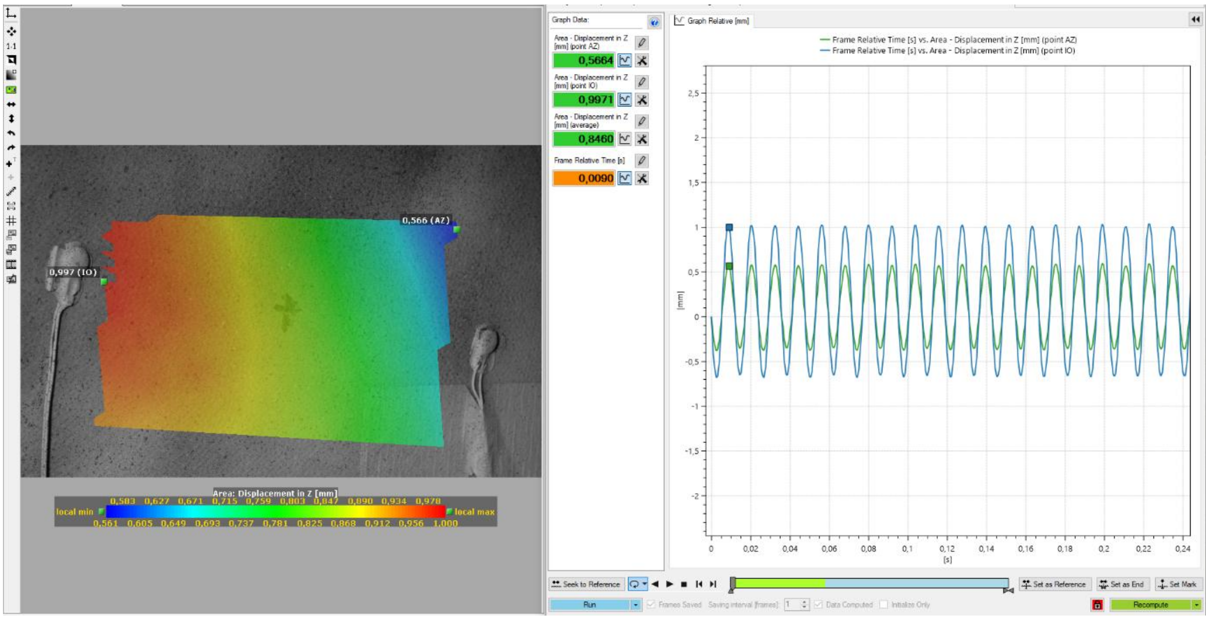

Fig. 5: Max displacement at 84 Hz

❖ 118 Hz

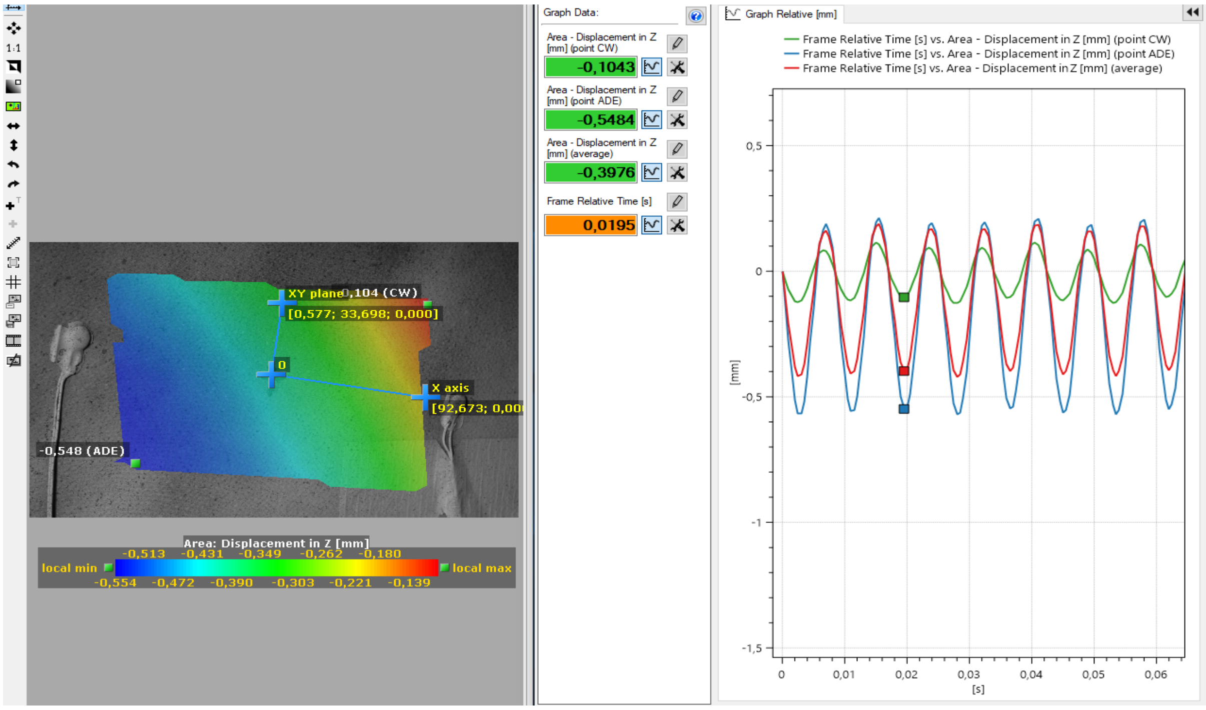

Fig. 6: Min displacement at 118 Hz

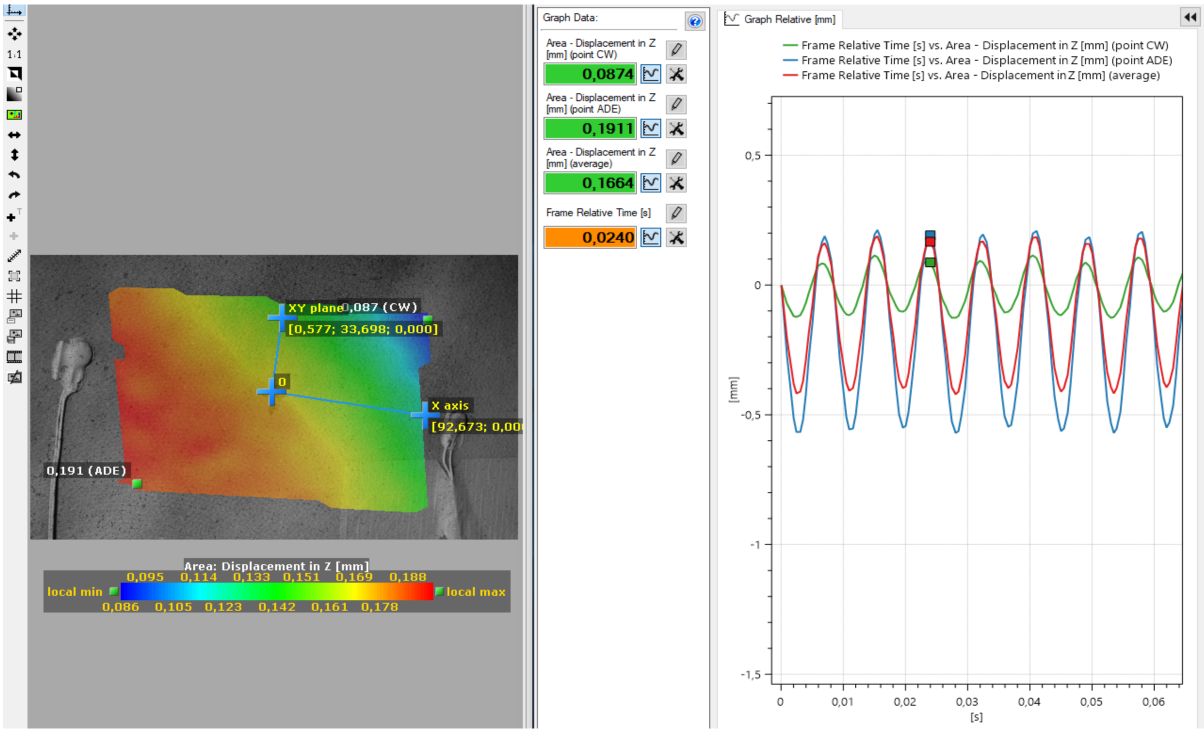

Fig. 7: Max displacement at 118 Hz

❖ 238 Hz

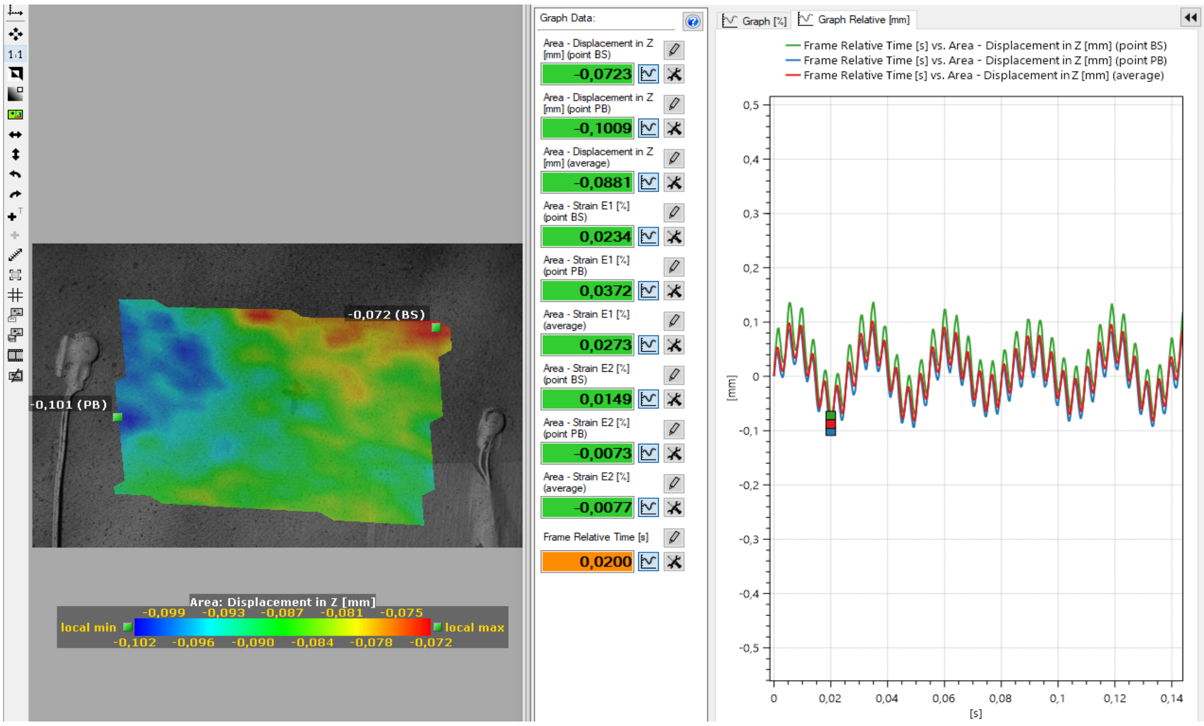

Fig. 8: Min displacement at 238 Hz

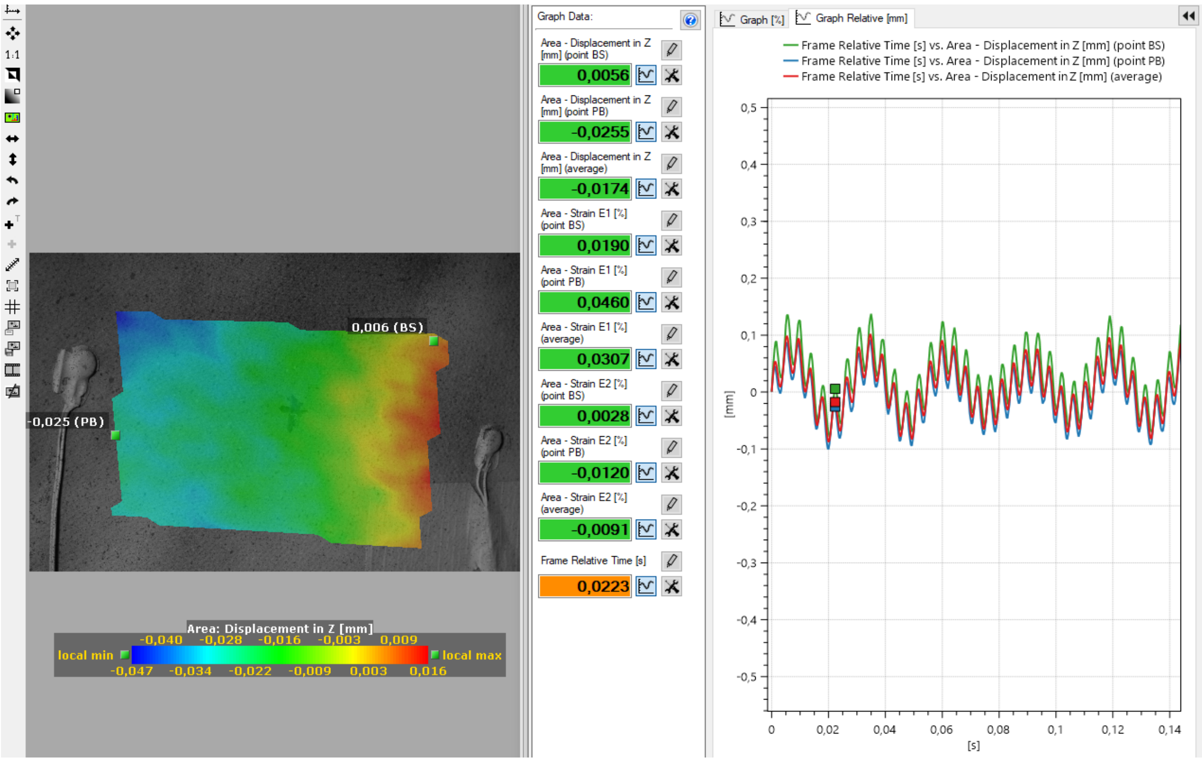

Fig. 9: Max displacement at 238 Hz

Vibrography Results

❖ The **Vibrography module** in MercuryRT enables full-field, non-contact **vibration analysis** using DIC and high-speed cameras. It visualizes **Operational Deflection Shapes (ODS)** and offers tools like spectral graphs and Campbell diagrams for detailed insight into dynamic structural behavior.

The images presents the amplitude and phase response at the selected frequency. On the left, you see the **Amplitude Graph** and **Phase Graph**, plotting displacement in the Z-direction across frequency. On the right, **color maps overlay the reference image** with computed amplitude (top) and phase (bottom), displaying the deflection shape and vibration phase distribution at the selected frequency.

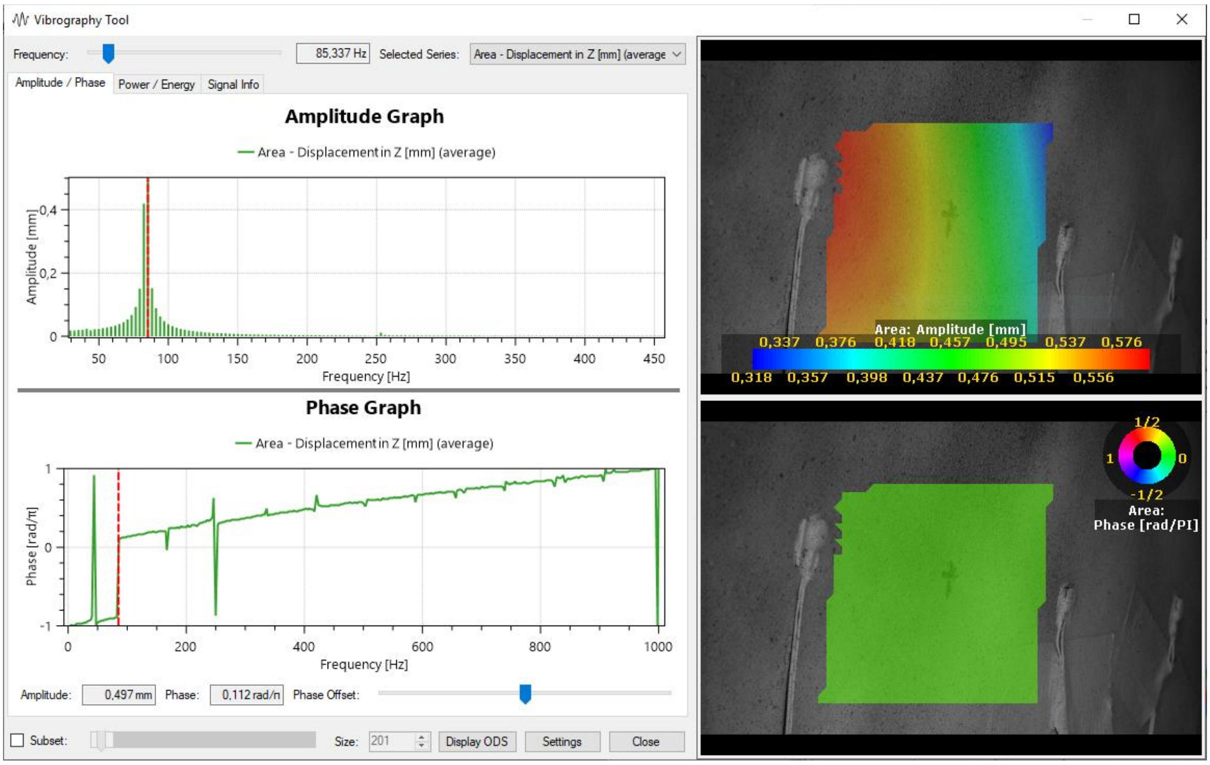

Fig. 10: Vibration analysis - Amplitude Phase Graph at 84 Hz

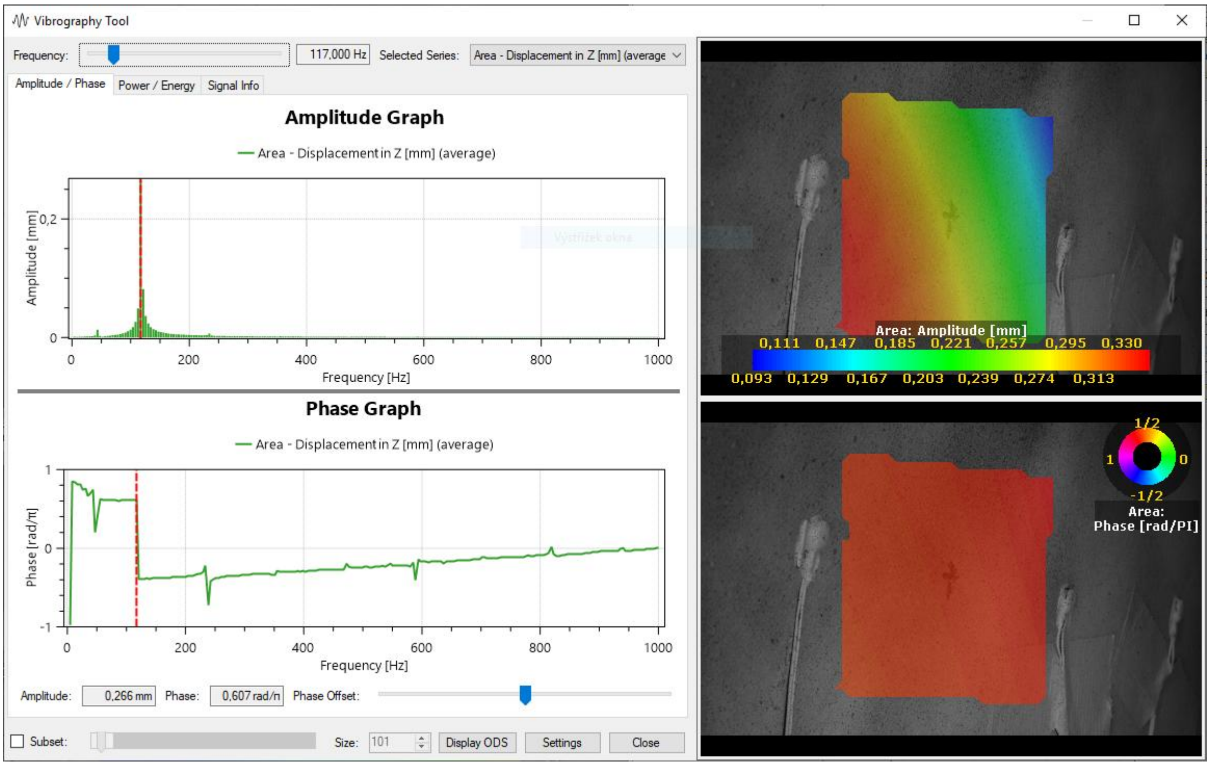

Fig. 11: Vibration analysis - Amplitude Phase Graph at 118 Hz

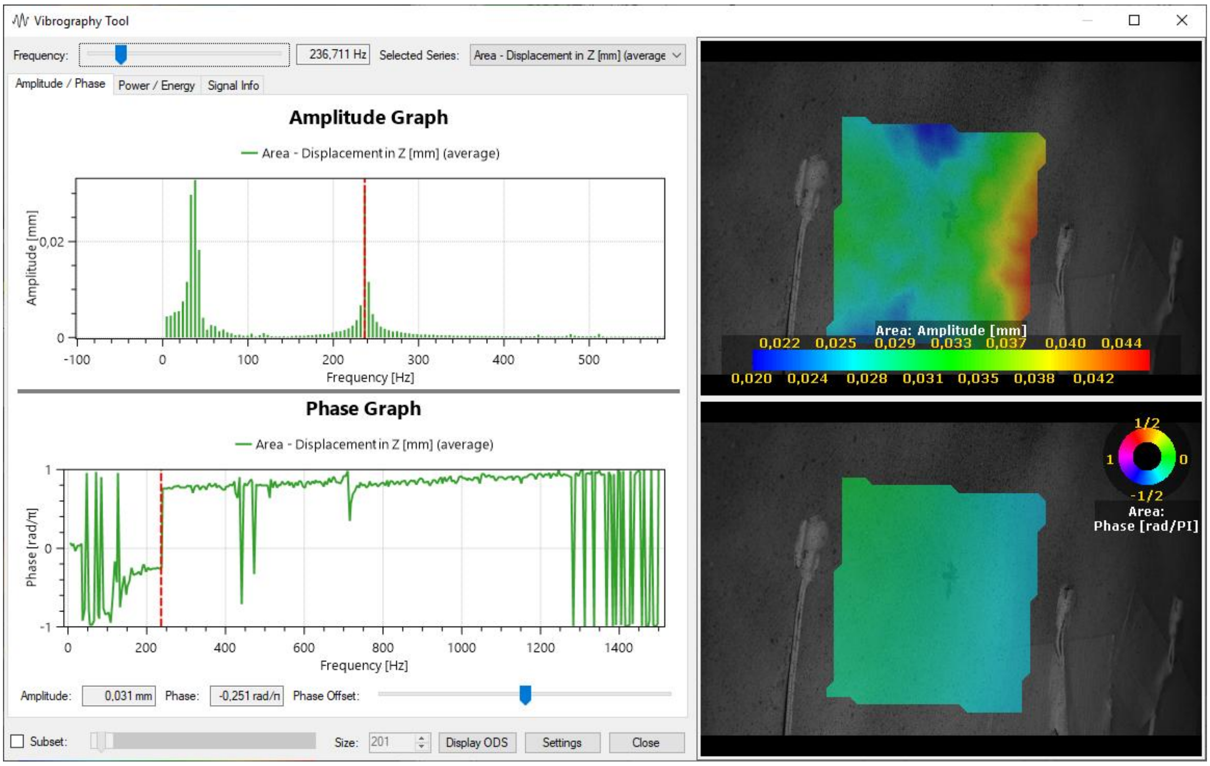

Fig. 12: Vibration analysis - Amplitude Phase Graph at 238 Hz

Speaker frequency	Resonant frequency - DIC	Deviation
84 Hz	85,337 Hz	1,591 %
118 Hz	117,000 Hz	0,847 %
238 Hz	236,711 Hz	0,542 %

Advantages of Using 3D DIC for Vibration Analysis

❖ **Non-contact, full-field measurement** of displacement and strain, eliminating the need for physical sensors on the specimen.

❖ **Accurate Operational Deflection Shapes (ODS)** visualization for identifying dynamic behavior at specific frequencies.

❖ **Detailed frequency domain analysis**, including amplitude, phase, power spectral density, and energy spectral density graphs.

❖ **Campbell Diagram support** for evaluating eigenfrequencies and resonance in rotating or oscillating systems.

❖ **High-speed compatibility** with synchronized cameras for capturing rapid vibrations.

❖ **Ideal for validating aerospace components** under realistic acoustic loading conditions.