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Application of digital image correlation to vibration analysis of the composite air inlet during acoustic loading

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Abstract. The air inlet duct of the jet engine is loaded both by flight loads from acceleration and also by vibrations caused by high sound levels of the jet engine. The polymer composite is efficient due to good damping properties and resistance to fatigue cracks. In order to evaluate the properties of this structure, an experiment with acoustic loading by a set of speakers was performed. The vibrations were measured using digital image correlation (DIC) system with high speed cameras. Two frequencies were measured and displacement of the area of 200 x 90 mm was evaluated in three dimensions. The measured data will be used for the finite element model benchmark.

Introduction

Carbon fibre-reinforced polymer (CFRP) laminates are used in aerospace due to their effective strength to weight ratio. The airframe must fulfill requirements on aerodynamics, structural resistance and fatigue resistance [1]. The fatigue loading has two main sources, mechanical loading and acoustic loading [2]. The acoustically induced vibrations from the engine are important aspect that affects the durability of the part. The use of composite material is therefore a smart choice because of the better damping and fatigue resistance properties compared to metal [3]. Any design of airframe structures must be supported by strength analyses and composite material properties must be tested on different complexity levels [4]. The coupon level was already tested by the fracture toughness evaluation [5]. Flat panels were tested and evaluated numerically on the structural detail level [6, 7, 8]. Similarly, authors in paper [9] investigated numerically acoustic fatigue and dynamic response of composite panels under acoustic excitation.

This paper describes local vibration measurement during testing of the component level considering the acoustic loading. The vibration source of the jet engine was simulated using a set of speakers. The laminate vibrations can induce matrix cracking or delamination growth from potential manufacturing or in-service flaws caused for example by impact damage [10, 11]. The mapping of the displacement amplitudes is therefore needed to evaluate the resistance of the structure to the damage growth and to fulfil damage tolerance philosophy.

Materials and Methods

The air inlet (Fig. 1) to be used in a jet plane was manufactured from the prepreg Hexply 8552/AGP193-PW which consists of AS4 carbon fibre fabric and high performance tough epoxy matrix for use in primary aerospace structures. The average thickness in the measured critical region was 2.5 mm.

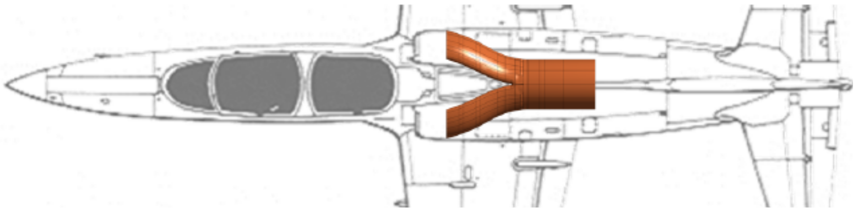

Fig. 1: Air inlet position in a jet plane

Experimental setup is visible in Fig. 2. It consists of the steel test fixture with clamped air inlet ducts and 4 speakers Tesla TVM ARA-389-00/4 with peak power of 300 W attached to the inlet by transition parts. Two amplifiers Dynacord S1200 were used, each with two channels.

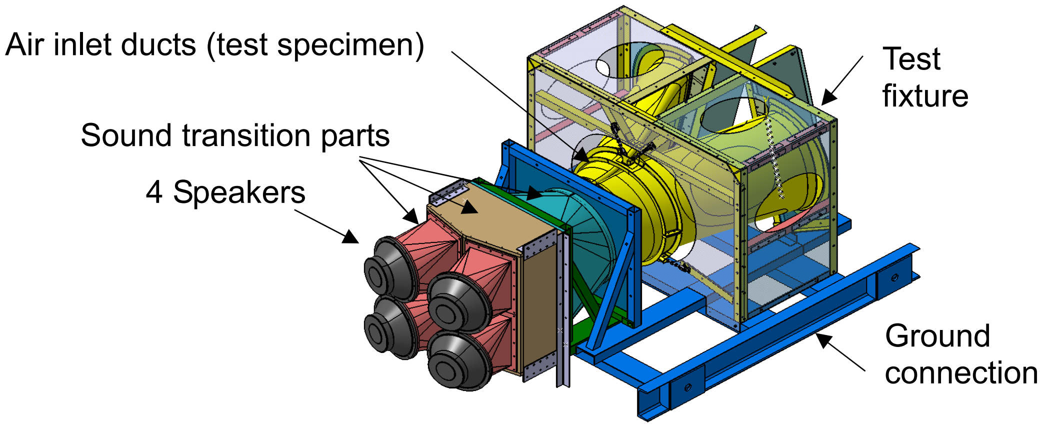

Fig. 2: Experimental setup of an air inlet in a test fixture

Two resonant frequencies were chosen based on a white noise measurement. First 84 Hz and the second was 118 Hz. These constant frequencies were used with sound levels needed to measure significant amplitudes of the laminate. An optical system used for the full-field displacement measurement of the measured part was based on digital image correlation (DIC). The Mercury software from Sobriety Company with two high-speed Phantom video cameras was used. The cameras had resolution of 1280 x 800 pixels. They were set to 2000 frames per second. The measured region with the dimensions of 200 x 90 mm is visible in Fig. 3. The Mercury software has several modules used for vibration evaluation such as Fast fourier transform (FFT), power spectral density, octave analysis and Campbell diagram.

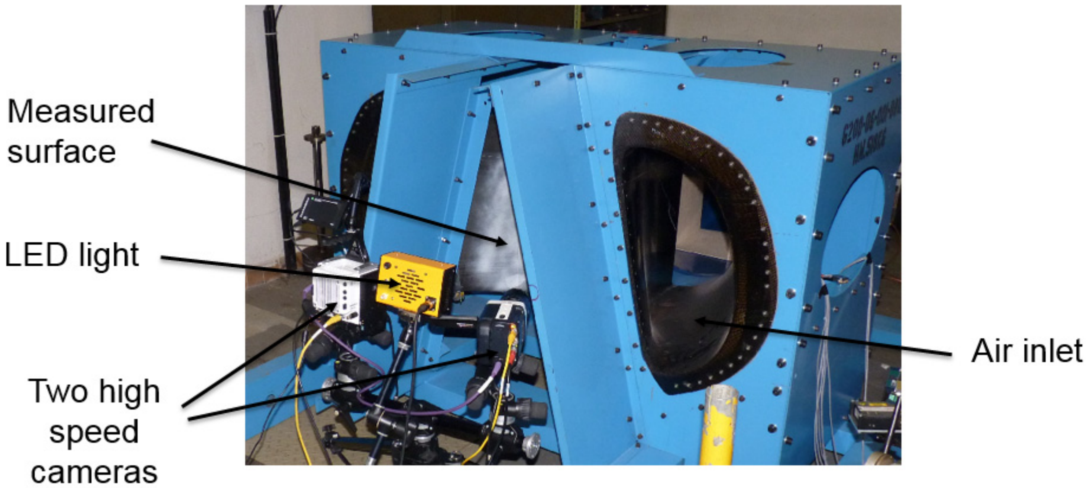

Fig. 3: Air inlet in a fixture with a pair of high-speed cameras focused on the measured surface

Results

Displacement in the normal direction to the surface was the value needed to be evaluated. The displacement was evaluated on the whole measured region which provided the shape for the vibration for the chosen frequency (Fig. 4a, b). For selected points, displacement in time was evaluated (Fig. 4c, d).

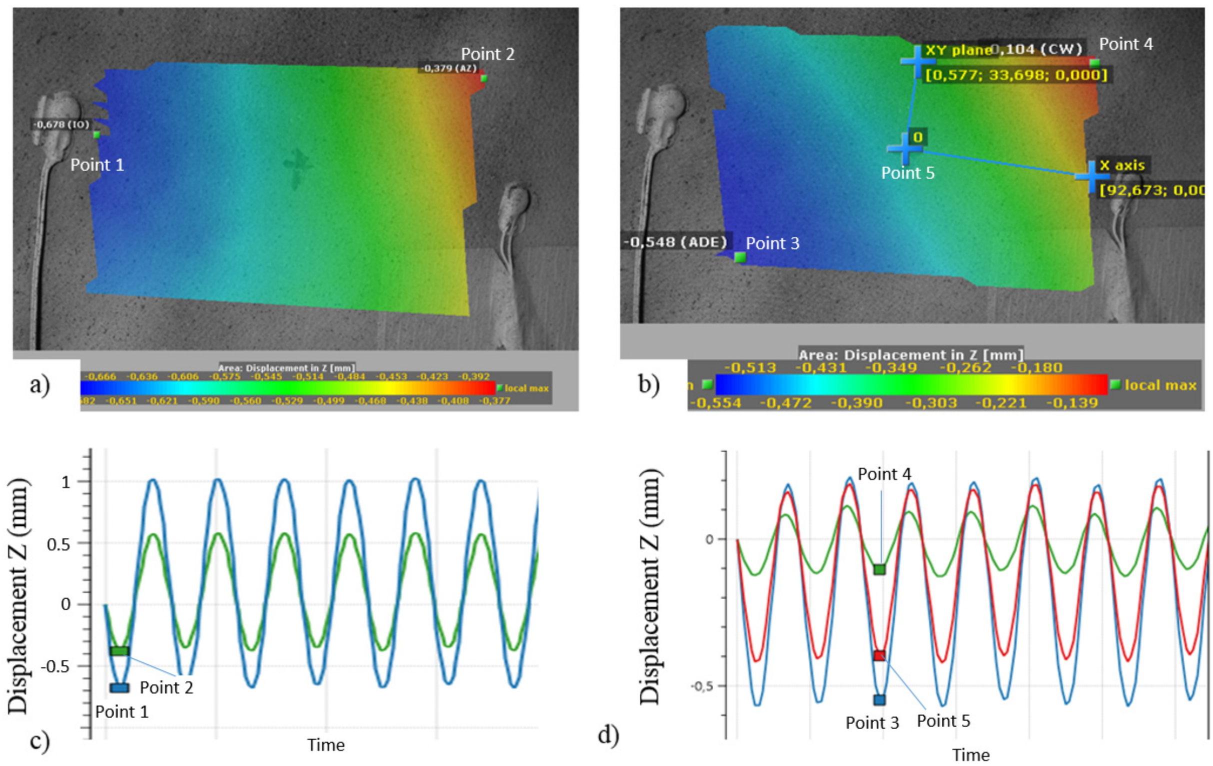

Fig. 4: a) Amplitude graph for a) 84 Hz and b) 118 Hz; c) example of selected point displacement in time for c) 84 Hz and d) 118 Hz.

The function of FFT was applied on the vibrations in the area which resulted in the amplitude graph (Fig. 5). A phase graph was also used to confirm that these frequencies hanged the vibration shape of the structure (Fig. 6). These variables will be used for whole inlet FE model calibration.

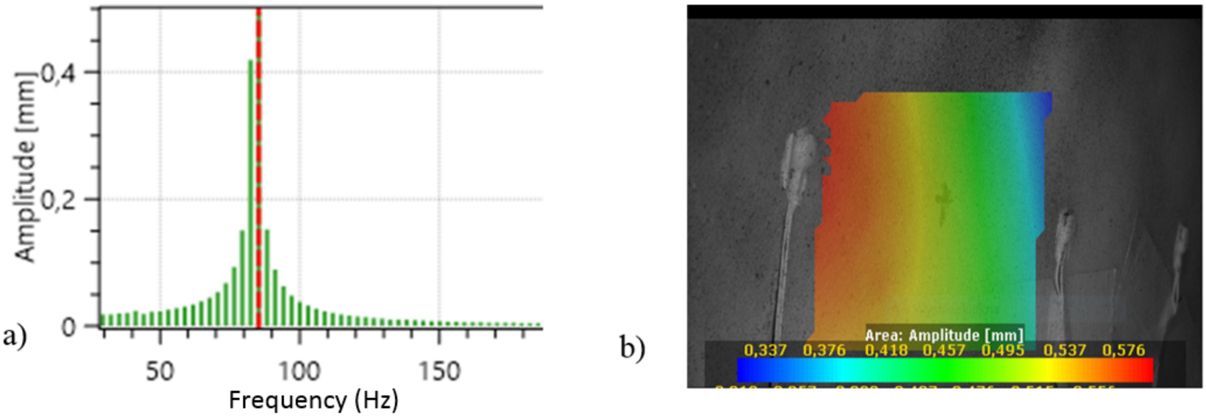

Fig. 5: a) Amplitude graph (displacement Z averaged over the are a) for 84 Hz and b) the full-field view

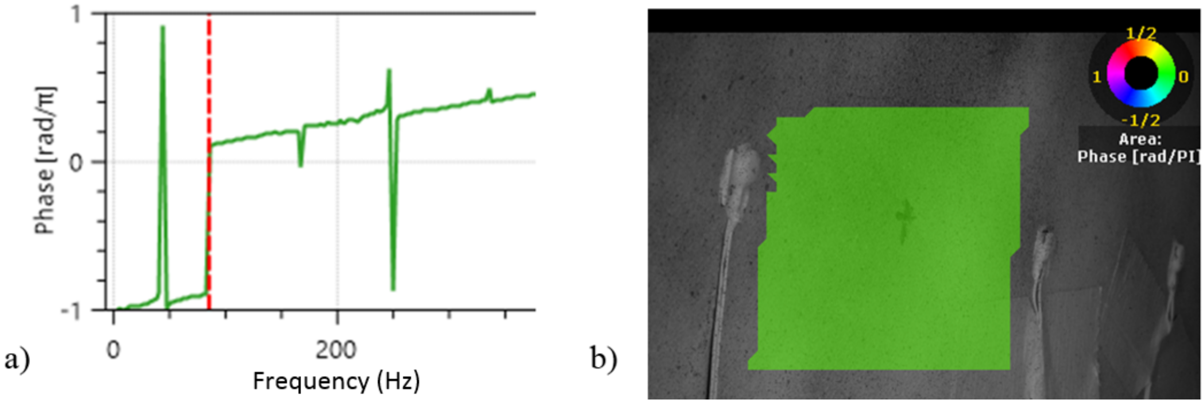

Fig. 6: a) Phase graph for displacement Z averaged over the area for a) 84 Hz and b) the full-field view

Conclusions

To conclude, the non-contact 3D vibrational measurement carried out using Mercury DIC software proved to be efficient in order to determine the vibration characteristics. Two resonance frequencies were evaluated and full-field local displacements were determined. The measured data will be used for the FE model benchmark.

Acknowledgement

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References

[1] J.P. Arenas, R.N. Margasahayam, Noise and vibration of spacecraft structures. Ingeniare. Revista chilena de ingeniería, 14 (2006) 251-264.

[2] R.G. White, Developments in the acoustic fatigue design process for composite aircraft structures, Composite Structures, 16 (1990) 171-192.

[3] B. Benchekchou, R.G. White, Acoustic fatigue and damping technology in FRP composites, Composite Structures 37 (1997) 299-309.

[4] R. Růžek, J. Běhal: Certification programme of airframe primary structure composite part with environmental simulation, International Journal of Fatigue, 31 (2009) 1073-1080.

[5] M. Kadlec, J. Šedek, Delamination Growth under Mixed Mode I - Mode II Fatigue Loading in Polymer Composite, in: EAN 2018 Experimental stress analysis, Conference proceedings of the 56th conference on experimental stress analysis, Czech Society for Mechanics, Prague (2018) 168-175.

[6] R. Doubrava, M. Oberthor, P. Bělský, J. Raška, Bird and hail stone impact resistance analysis on a jet engine composite air inlet, in: MATEC Web Conf. Volume 188 (2018), Art. No. 04006.

[7] P. Zděnek, M. Kadlec, J. Běhal, Application of laser shearography to vibration mode shape analysis of composite panel during acoustic load, in: EAN 2018 Experimental stress analysis Conference proceedings of the 56th conference on experimental stress analysis, Czech Society for Mechanics, Prague (2018) 457-463.

[8] J. Běhal, P. Zděnek, Effect of interlaminar flaw on composite panel behaviour under acoustic loading, MATEC Web of Conferences 188 (2018). https://doi.org/10.1051/matecconf/201818801005.

[9] C. Uz, T.T. Ata, Acoustic Fatigue and Dynamic Behavior of Composite Panels Under Acoustic Excitation, in: De Clerck J., Epp D. (eds) Rotating Machinery, Hybrid Test Methods, Vibro-Acoustics & Laser Vibrometry, Volume 8. Conference Proceedings of the Society for Experimental Mechanics Series. Springer, Cham (2016).

[10] R. Doubrava, M. Oberthor, P. Bělský, M. Dvořák, K. Doubrava, Experimental verification of jet engine composite inlet for bird and hail stone impact resistance, in: EAN 2018 Experimental stress analysis Conference proceedings of the 56th conference on experimental stress analysis, Czech Society for Mechanics, Prague (2018) 63-76.

[11] M. Kadlec, R. Růžek, A Comparison of Laser Shearography and C-Scan for Assessing a Glass/Epoxy Laminate Impact Damage, Applied Composite Materials 19 (2012) 393-407.