MODAL STRAIN ENERGY BASED STRUCTURAL HEALTH MONITORING ON RIB STIFFENED COMPOSITE PANELS

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ABSTRACT

Previously, an evaluation study has been conducted on a Structural Health Monitoring (SHM) strategy applied to a composite aileron by deriving the Modal Strain Energy Damage Indicator (MSE-DI). MSE-DI was used to localize the impact damage location. However, this study has also shown that the damage type may have had influence on the performance of the algorithm. To test this hypothesis, two identical composite stiffened panels have been manufactured. In this paper, the one-dimensional MSE formulation is used to extract damage indicators from two identically produced panels. A Laser Doppler Vibrometer is used to measure vibrations from 253 points on each panel. Both panels were identically damaged by impacting the skin causing a delamination of the stiffener. The damage indicators for the two panels are extracted and compared to each other. The results from confirm that the MSE-DI can successfully detect damage. However, for this specific case, the localization of the damage was not accurate due to a limited number of measured bending moment mode shapes.

Keywords: Structural health monitoring, Composite damage, Modal Strain Energy Damage Indicator,

1. INTRODUCTION

Maintenance strategies in various fields of industry, including aerospace applications, are shifting from time-scheduled to condition based strategies. SHM techniques can play an important role in providing more concise information about the integrity of the target structure, while inspection time can be reduced. Within aerospace applications, impact damage monitoring on a composite rib-stiffened panel structure imposes high potential for SHM techniques [1]. However, the number of SHM applications in the field of aerospace is still limited. One reason for this is the unknown performance of each individual SHM approach related to various damage cases. An effective way to compare different SHM techniques is to evaluate their performance with identical structures to which various damage cases are applied. As a first step, two identical composite, stiffened panels have been manufactured recently. In this paper, application of the MSE-DI algorithm to the two identically damaged panels is investigated.

2. TEST ARTICLE

Two identical composite panels have been manufactured similarly to a concept evaluated within the European Clean Sky LOCOMACHS project. Automated fiber placement was used to manufacture integrated stiffening ribs with a height of over 30 mm by stacking various layers of a single thermoset tape on an uncured skin [2]. Table 1 presents a summary of technical specification of the test panels.

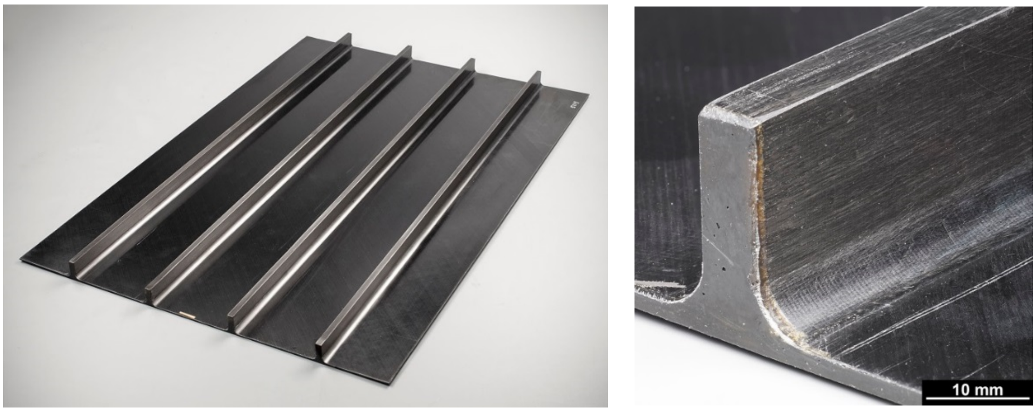

Fig. 1. Rib stiffened co-cured panel (600 x 400 mm) [2]

Table 1. Specification of the test panels (all dimensions are given in mm).

Tow[1)] width	*Length*	*Width*	*Layup*	*No. of plies*	*Remarks[2)]*
6.35	600	400	$[45/90/-45/0/45/90/-45/0]_S$	16	Skin
6.35	600	6.35	$[0]_{177}$	177	4 ribs

1) Prepreg: CYCOM 5320-1FI/IM7

2) Panels: Two identical panels are fabricated with ID number 5565 and 5567

After fiber placement and curing, the panels have been non-destructively evaluated via an ultrasonic C-scan inspection. The inspection has revealed no major debonding, voids or defects in the skin and the skin-rib connections on the panels.

Panel 5565 and 5567 have been subjected to a single impact load each. The panels were clamped on four edge sides, while stiffeners were kept unsupported such that a typical aircraft skin-stiffener condition is created. The impact was applied on the skin side, directly underneath stiffener 3 (see Fig. 2 and 3). The impact location on both panels is identical: x = 450 mm and y = 250 mm. The impact energy on panel nr. 5565 was 18 J, while panel nr. 5567 was impact loaded with 14 J. Nondestructive inspection with an ultrasonic probe revealed that both impacts have caused a similar delamination at the skin stiffener connection. The impact loading on the outer skin side has caused no visible damage from the outside. However, skin stiffener connection is deteriorated significantly over a length of 150 mm (see Fig. 3, red ellipse).

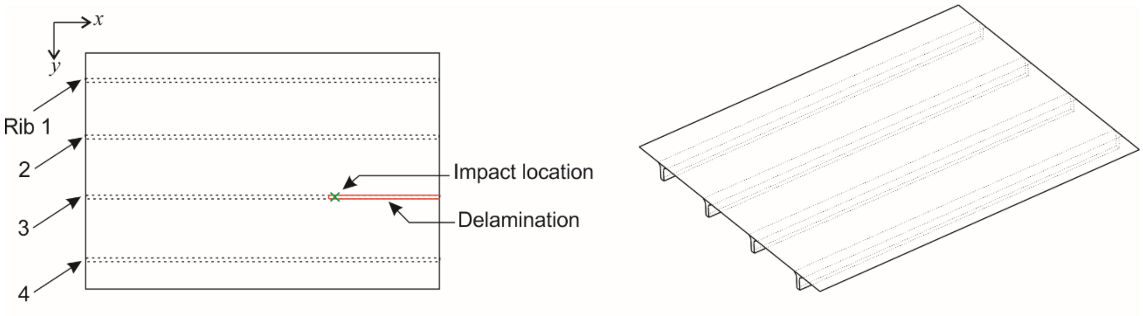

Fig. 2. Schematic drawing of the rib-stiffened panel. Delamination size and location are similar to both panels

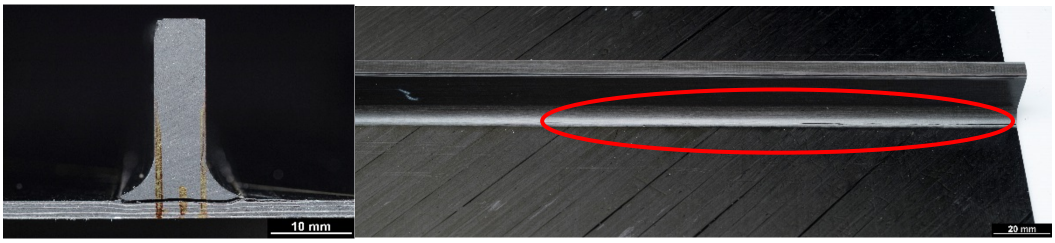

Fig. 3. Close up on the damage in panel 5565.

3. METHODS

Before and after impact loading, the natural frequencies and the Operational Deflection Shapes (ODS) are extracted by using a Laser Doppler Vibrometer and an electro-mechanical shaker. The test panels were suspended with two rubber bands allowing for a free-free condition. The shaker was strategically placed such that all lower modes were sufficiently excited. The excitation consisted of series of 5 sine sweeps from 200 to 4000 Hz while the Laser Doppler Vibrometer measured the out-of-the-plane velocity with the measurement frequency of 48kHz. The measurement grid consisted of 23 x 11 points.

In this study, only one damage feature has been calculated, namely the MSE-DI (see [3] for more details on this method). Since the bending stiffness of the panel in *y*-direction is dominant, the panel is modeled as a beam-like structure, allowing for the 1-D formulation of the modal strain energy equation in *x*-direction [4], following the considerations presented in this paper.

4. RESULTS

The natural frequencies and their corresponding operational deflection shape have been extracted from both plates before and after the impact loading. The amplitude normalized mode shape of the *y*-bending modes are taken for the normalized damage index calculation. Figure 4 presents the calculated MSE-DI for both plate 5565 and 5567.

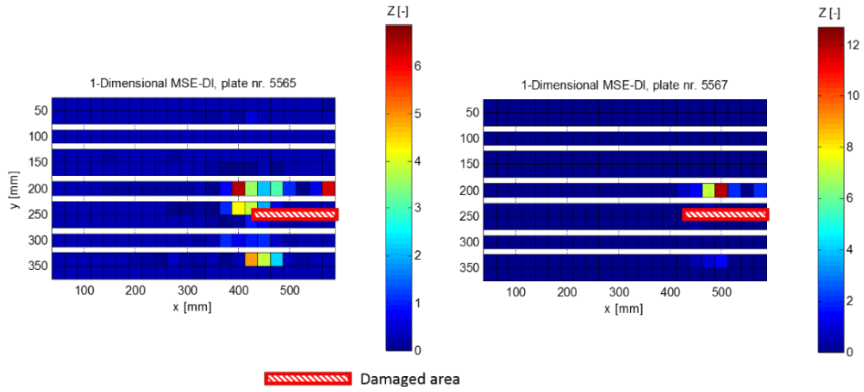

Fig. 4. MSE-DI extracted from panel 5565 and 5567

This result shows that damage has been detected successfully on both panels, although the peaks appear at different locations, indicating an inaccurate damage localization. The highest normalized damage index is found adjacent to the damaged area between stiffener 2 and 3. However, a number of additional peaks in the MSE-DI appeared in panel 5565, despite the impact being applied at the same location.

5. DISCUSSION AND FUTURE WORKS

According to Ooijevaar et al. [4], bending modes in the *y*-direction are the most informative, but they were hard to measure, due to the high bending stiffness in that direction. This, results in a limited accuracy of the damage localization, as this relies on an accurate estimate of the mode shapes. Deriving the second order of the displacement to determine the modal strain energy magnifies the localization inaccuracy. The considerations in [4] apparently do not apply for this structure, indicating a relation between methods applied and the structure; a performance index should be able to reflect this. Future work will therefore include comparing various feature extraction methods to the performance of SHM techniques. The sensitivity to external factors will also be studied, to robustness of methods in the performance indicator.

REFERENCES

[1] Kim, H. “Impact Damage Formation on Composite Aircraft Structures”. UCSD FAA JAMS Paper, Technical Review Meeting, 5 April 2012

[2] Müller, M. and Brink, W. van den, “Comparison of Integrated Rib Stiffened and L-Blade Stiffened Composite Panels Manufactured using Simple Tooling Methods”. SAMPE, Long Beach 2016

[3] Stubbs, N. and Farrar, C.R. “Field Verification of a Nondestructive Damage Localization and Severity Estimation Algorithm”, Proc. Of 13th IMAC, 210-218, 1995

[4] Ooijevaar, T.H., Warnet, L., Loendersloot, R., Akkerman, R. and Tinga, T. “Impact Damage Identification in Composite Skin-Stiffener Structures Based on Modal Curvatures”, Structural Control & Health Monitoring, 23(2), 198-217, 2016