Guided Wave-based Structural Health Monitoring for a Composite Aircraft Fuselage under Mechanical Load

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Abstract: The introduction of composite materials in aeronautics has brought numerous advantages, along with unique damage and failure modes. The structure health is currently ensured with an increase in non-destructive inspection activities and a damage-tolerant design. Among other techniques, Guided Wave-based Structural Health Monitoring (GW-SHM) has gained interest as a cost and time effective alternative to traditional non-destructive techniques. One of the main challenges for GW-SHM is the influence of environmental and operational conditions. Aircraft structures undergo a broad range of mechanical load conditions, affecting the GW-SHM system.

A full-scale CFRP door surrounding structure was instrumented with a GW-SHM system and tested under mechanical load. The test object has a dimension of 4100 x 5700 mm and covers 9 frames, 17 stringers, 4 windows and the door surround structure. A hydraulic test rig was used to apply three load cases in quasi-static conditions on the structure: tension, lateral bending and vertical bending.

A network of robust piezocomposite transducers to monitor the structure has been designed and manufactured during the project. The network is organized in arrays, which include the transducers, cabling and a connecting base plate for optimized sensor installation. A multiplexing module is directly connected to the base plate enabling a fast and reliable sensor connection, a drastic cable weight reduction, and a modular design.

The load influence on the GW-SHM system has been analysed: on the transducer network as well as on the damage identification performance. The transducers were monitored using electromechanical impedance throughout the test campaign in order to check for debonding from the structure and piezoceramic breakage. Finally, a data-driven approach to damage identification has allowed the detection and localization of barely visible impact damage introduced during the test campaign.

GUIDED WAVE-BASED SHM FOR A COMPOSITE AIRCRAFT FUSELAGE UNDER MECHANICAL LOAD

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ECNDT 2023

DLR

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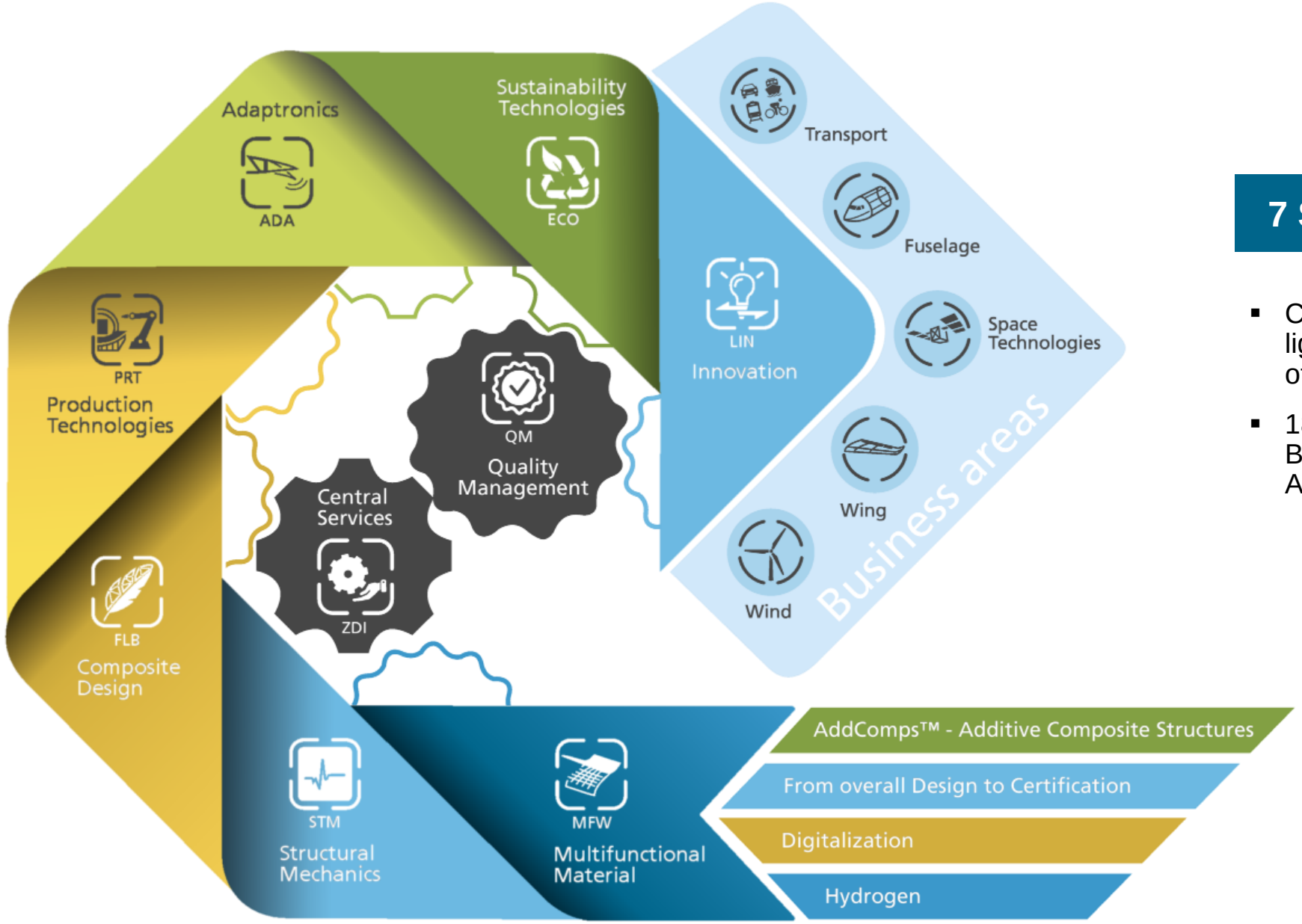


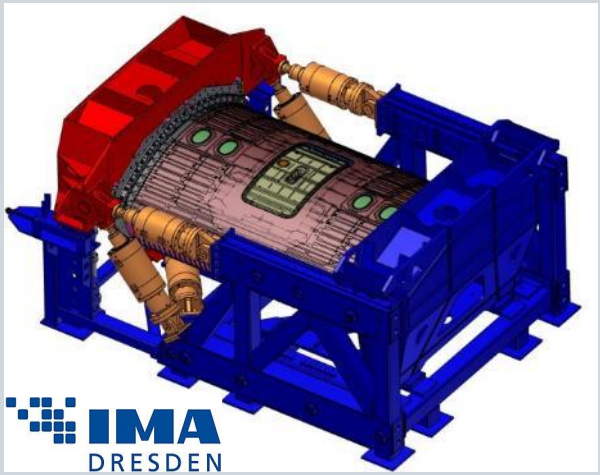
7 Scientific Departments

- Complete process chain for the lightweight system construction of the future
- 180 employees in Braunschweig, Stade, Bremen, Aachen, Cochstedt

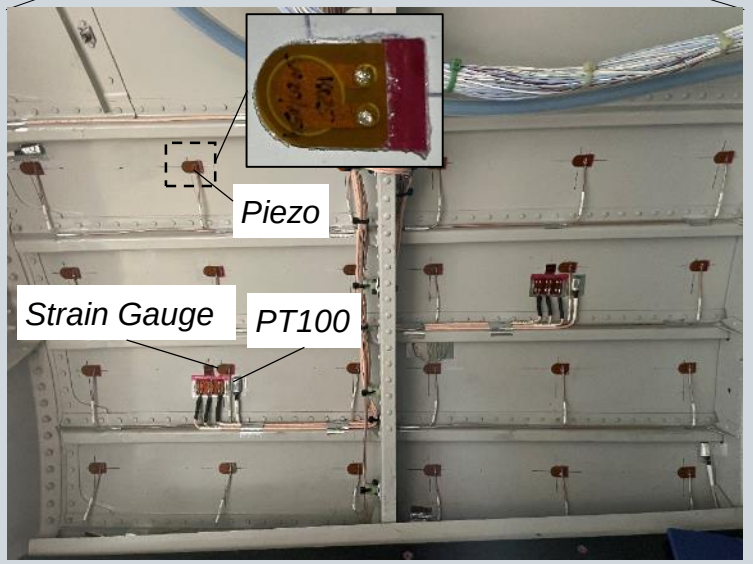
Guided Wave-based SHM Project Overview

Wind Turbine Rotor Blade On-Board SHM

Structure Test of Door Surround Structure

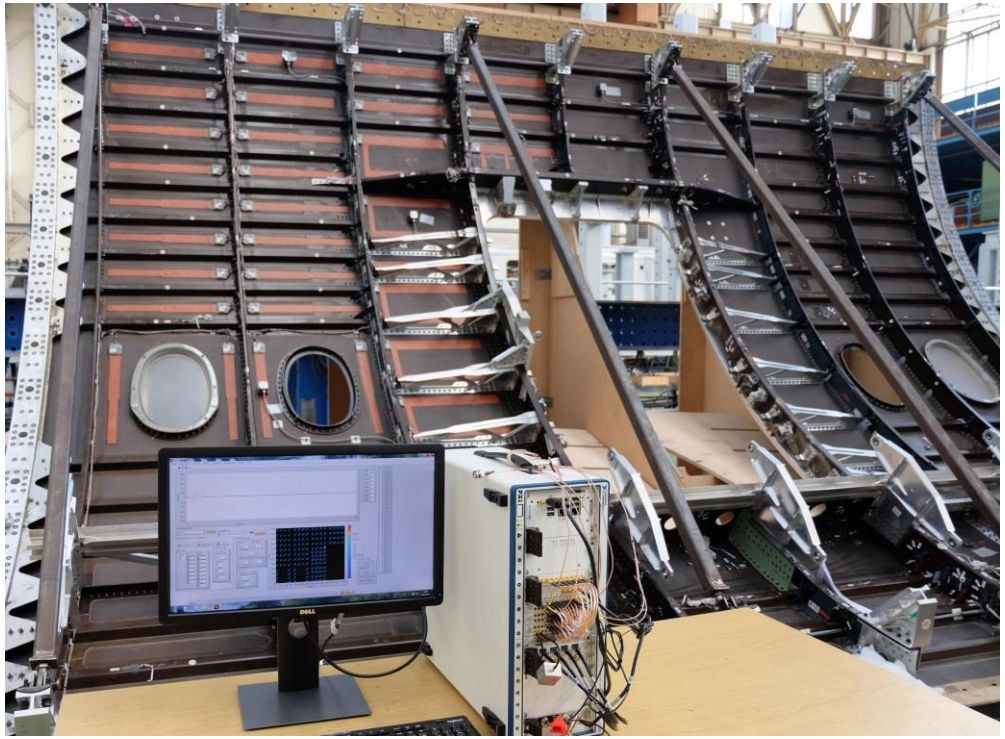


Flight Test on DLR iStar Falcon 2000LX

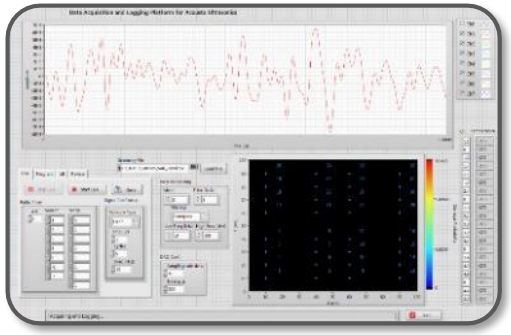


The Guided Wave-based SHM System

Door Surrounding Structure with GW-SHM System

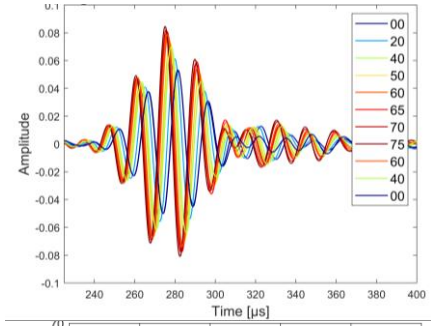


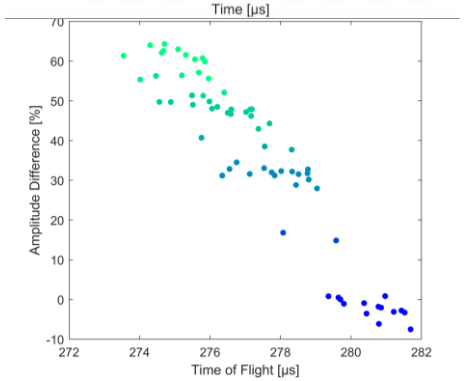
Data Acquisition



NI hardware platform
DLR software

Signal Processing

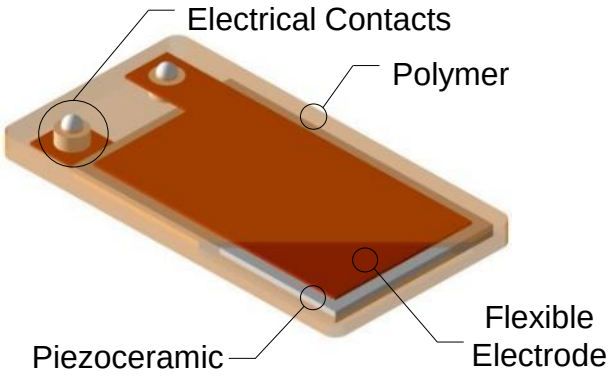




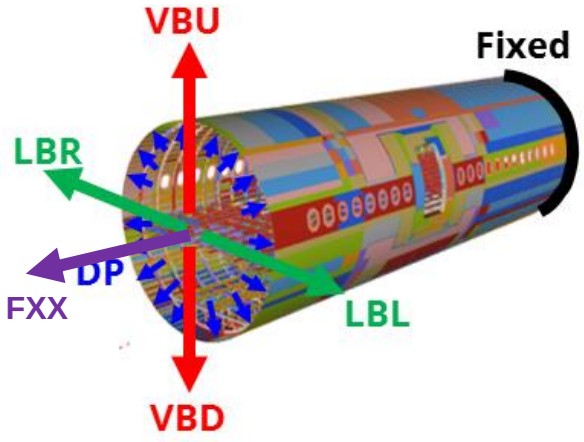
SHM transducer network

SHM Transducer Network

- DuraAct™ technology
- Improved damage tolerance and lifetime
- Piezocomposite array integrating piezoceramic transducers, wires & connectors
- Robust and reliable installation during or after structure manufacturing
- Base Plate integrated into the piezocomposite hosting multiplexing electronics
  - Optimized sensor connection
  - Cable reduction through multiplexing
- Manufacturing and installation by Invent GmbH

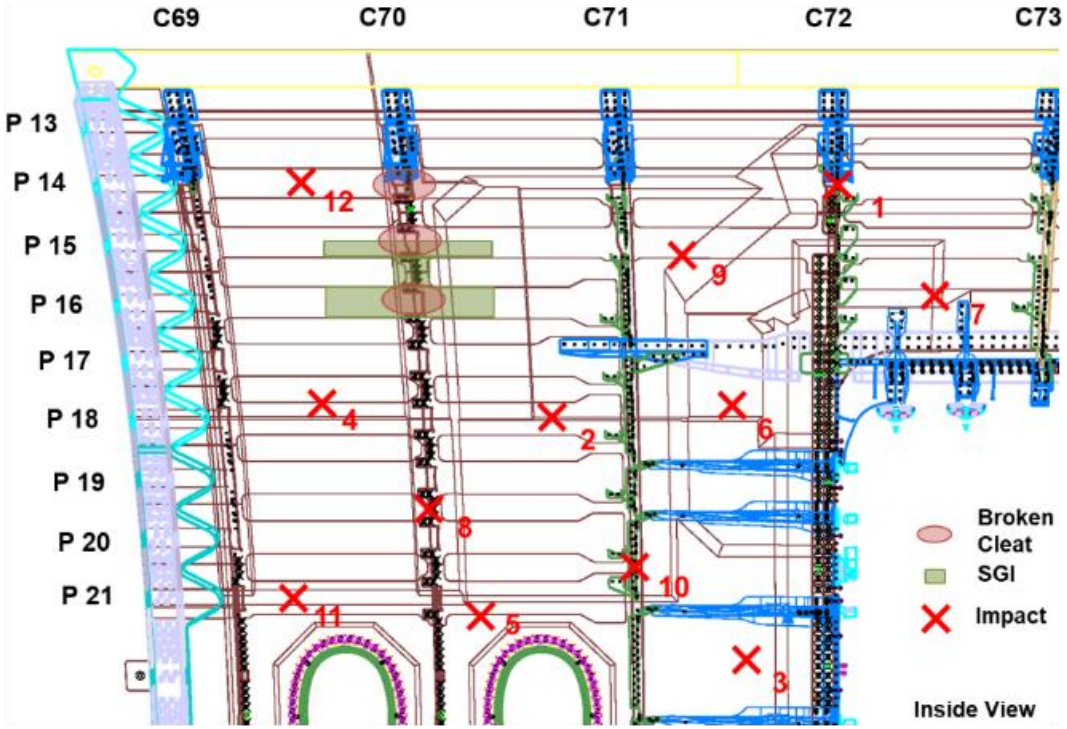


Structure Test | Experimental Setup



Basic load cases at barrel level

VBU	Vertical Bending Up
VBD	Vertical Bending Down
LBR	Lateral Bending Right
LBL	Lateral Bending Left
FXX	Tension

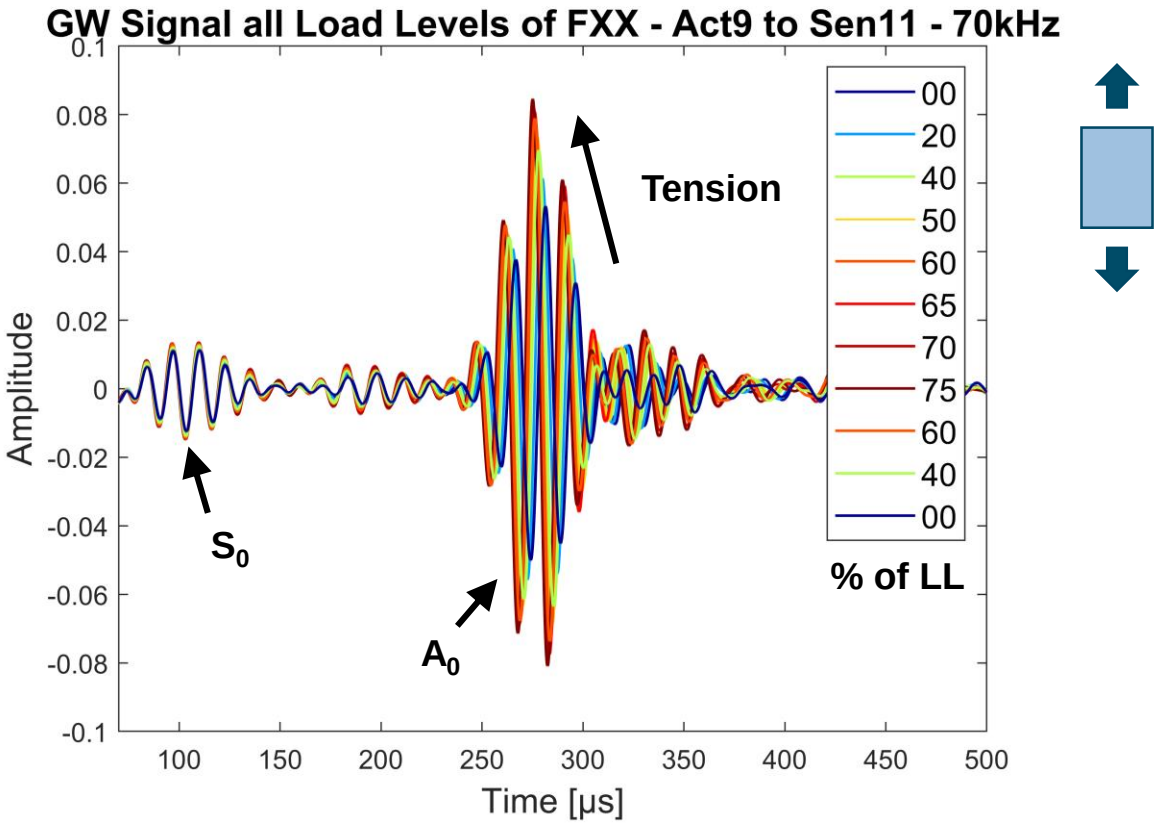


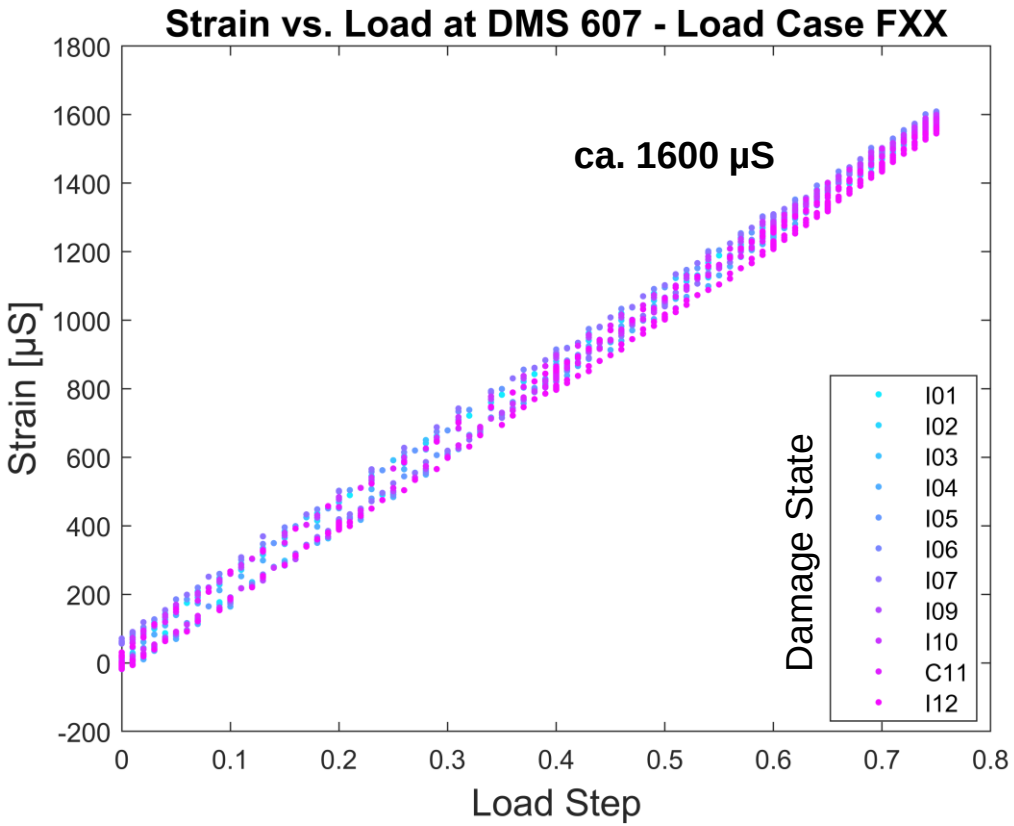
Impact positions on fuselage structure

Test Campaign Parameters					
Load Case	FXX	LBL	VBD		
Load Level	0	40	60	75	% of Limit Load
Damage	Delamination	Debonding			

- Representative composite fuselage structure
- Representative flight loads
- Realistic barely visible impact damage

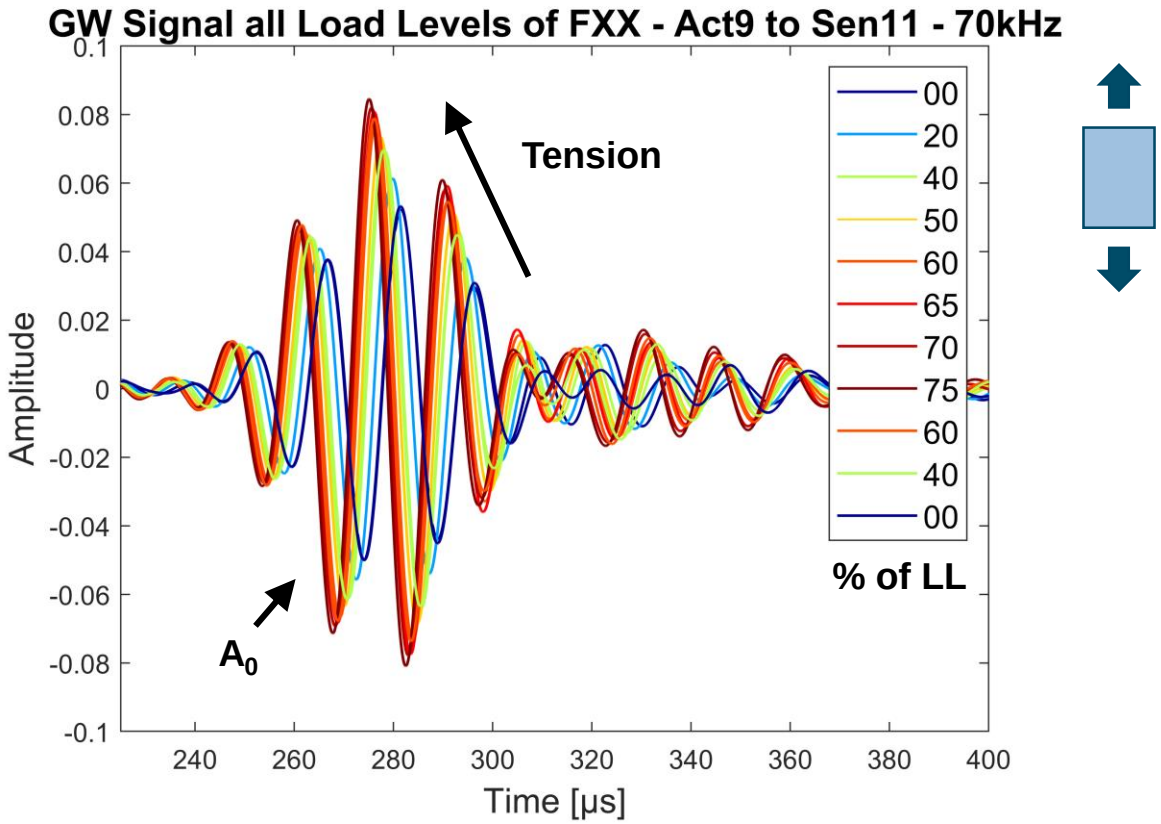
Effects on Guided Waves | Tension

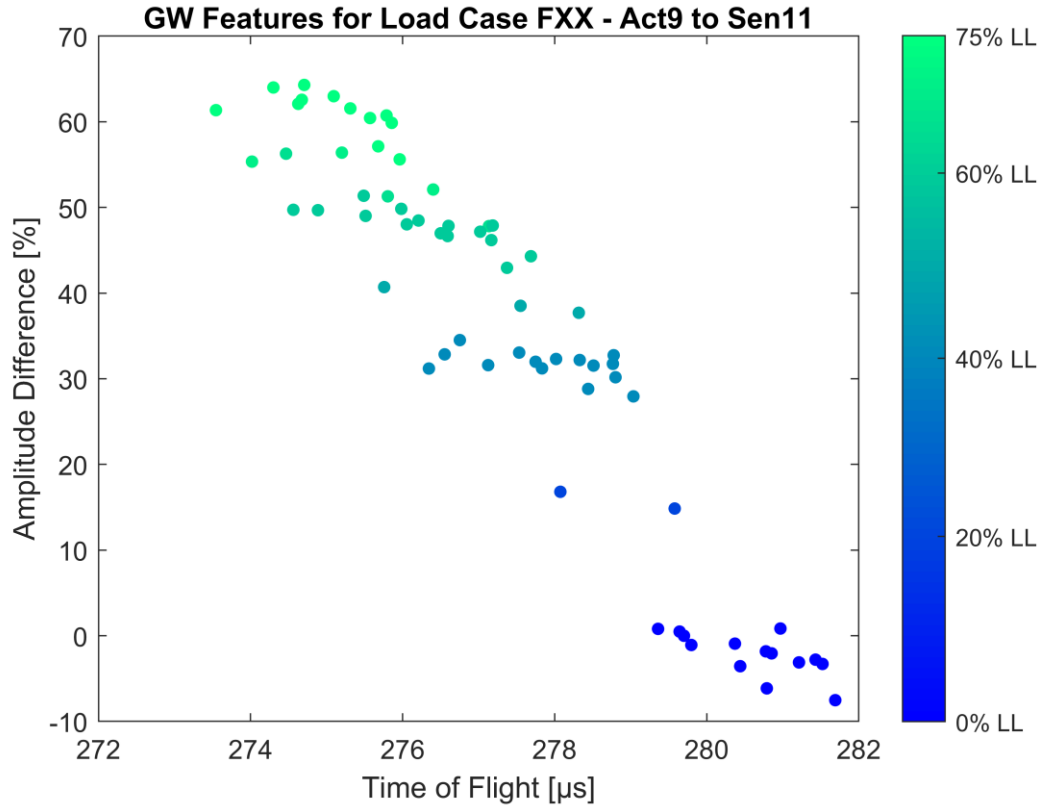




- Strain gauge near the actuator-sensor path for reference
- Strain gauge signal plotted for all load cycles over all damage states → check reproducibility of strain values
- Effects of Tension on GW at 70kHz for A_0-mode → Amplitude increase & ToF decrease

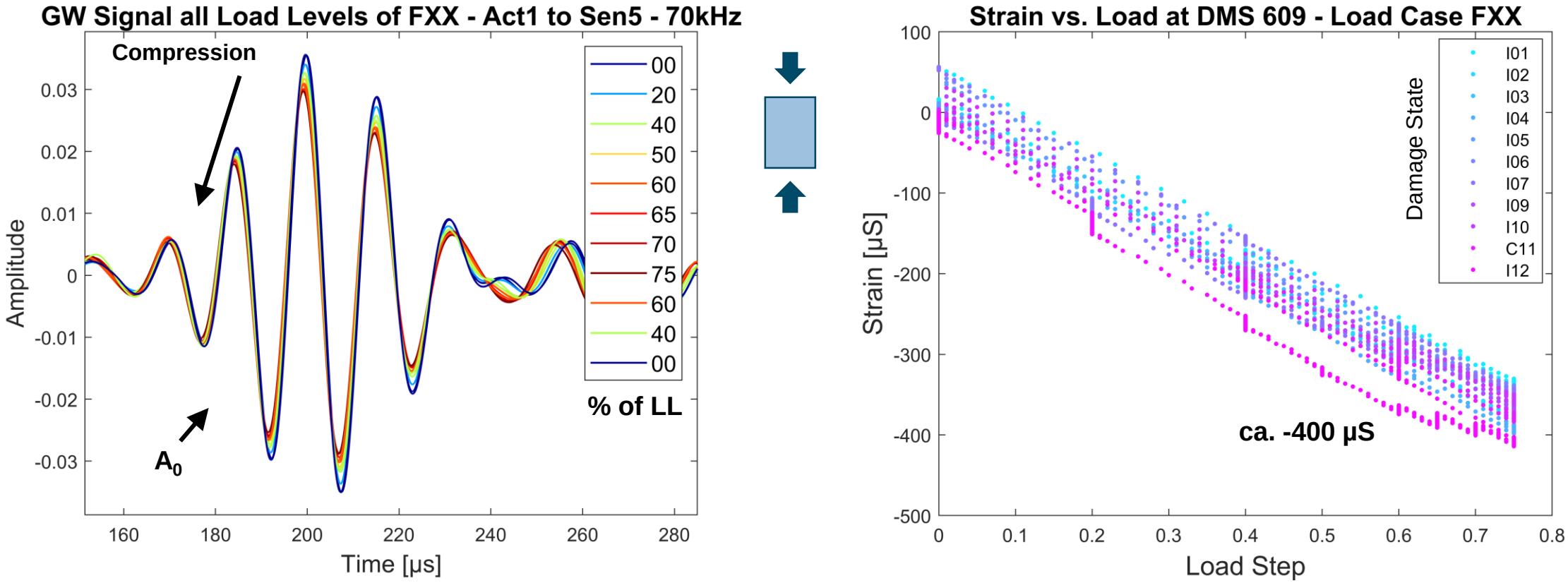
Effects on Guided Waves | Tension





- Effects of Tension on GW at 70kHz for A_0-mode→ Amplitude increase & ToF decrease
- Amplitude Difference vs. ToF of A_0-mode plotted over all load cycles for all damage states
  - 60% amplitude increase & 6µs ToF decrease due to load conditions
  - 5% amplitude & 2,5µs ToF variability not attributable to load conditions

Effects on Guided Waves | Compression



- Strain gauge near the actuator-sensor path for reference
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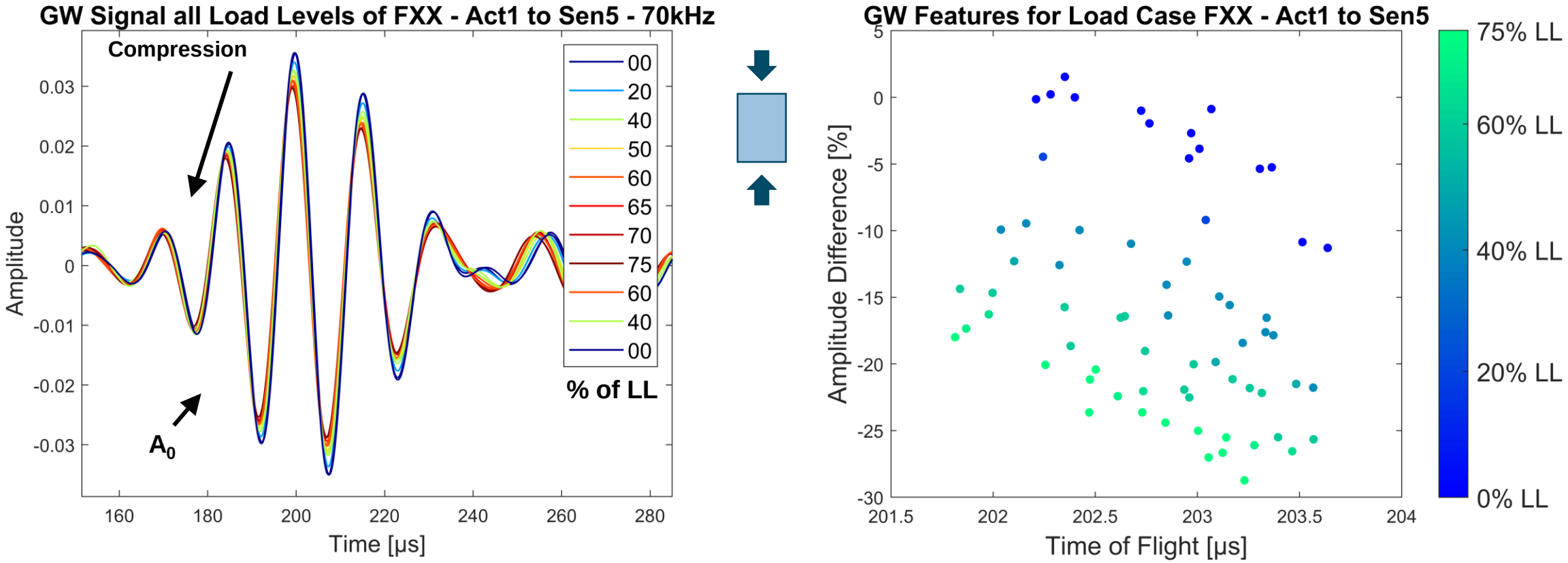
- Effects of Compression on GW at 70kHz for A_0-mode → Amplitude & ToF decrease

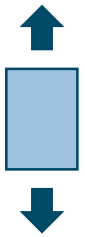
Effects on Guided Waves | Compression

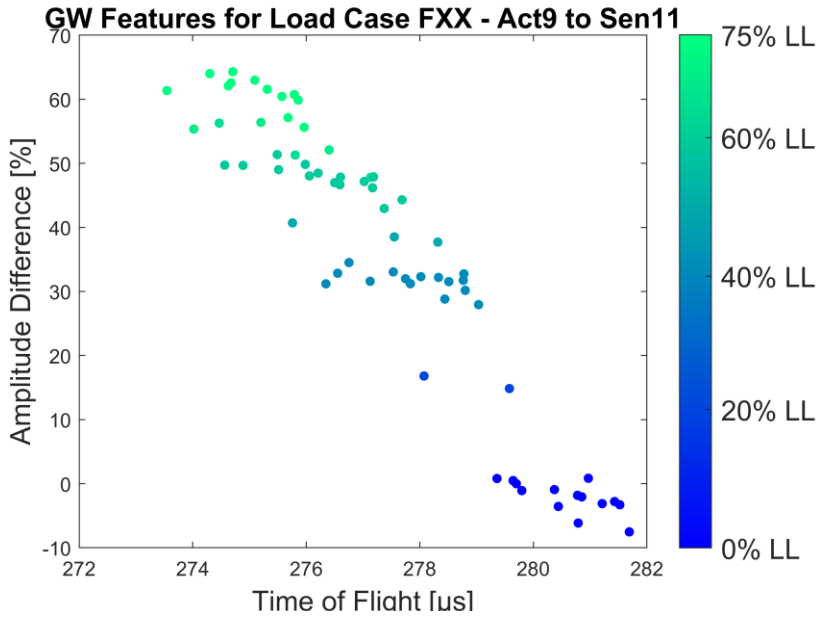


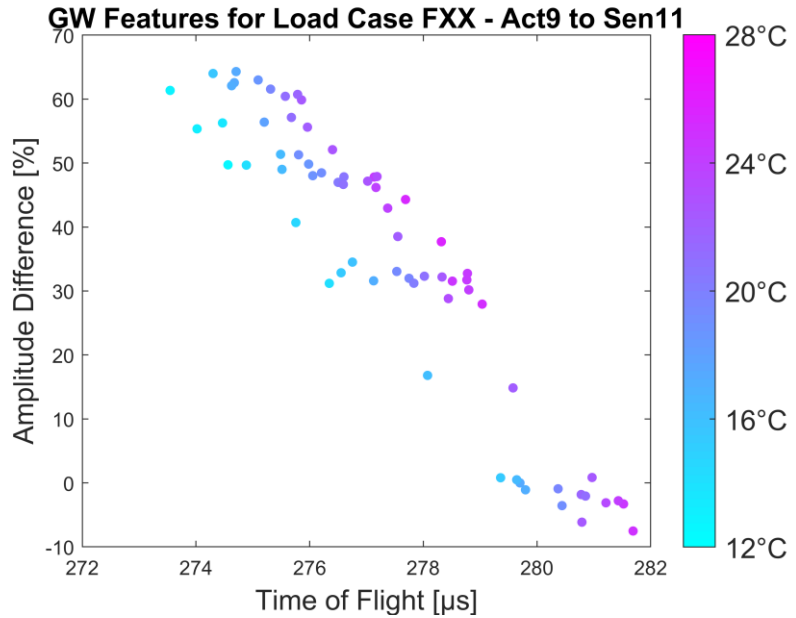
- Effects of Compression on GW at 70kHz for A_0-mode → Amplitude & ToF decrease
- Amplitude Difference vs. ToF of A_0-mode plotted over all load cycles for all damage states
  - 20% amplitude decrease & <1µs ToF decrease due to load conditions
  - 5-10% amplitude & 2µs ToF variability not attributable to load conditions

Effects on Guided Waves | Load & Temperature

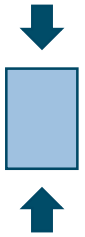
Tension

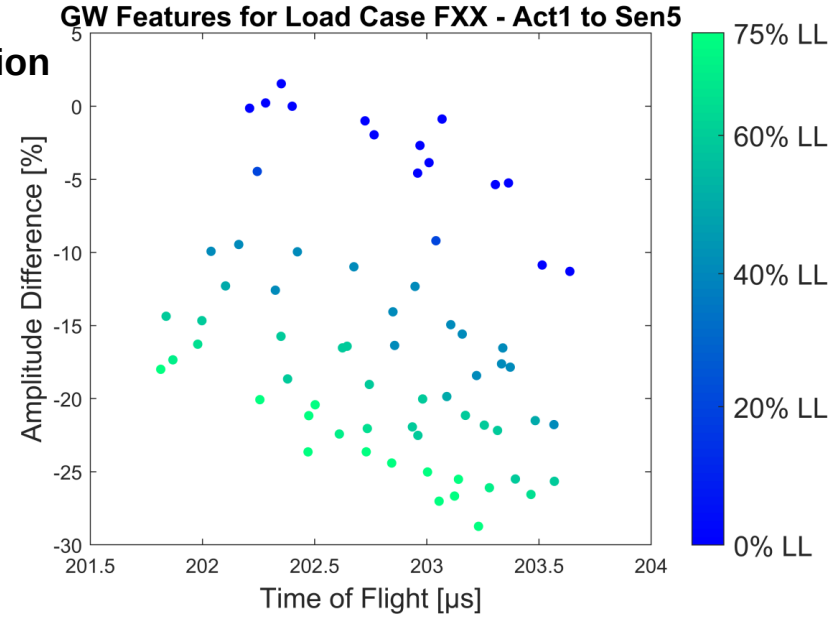


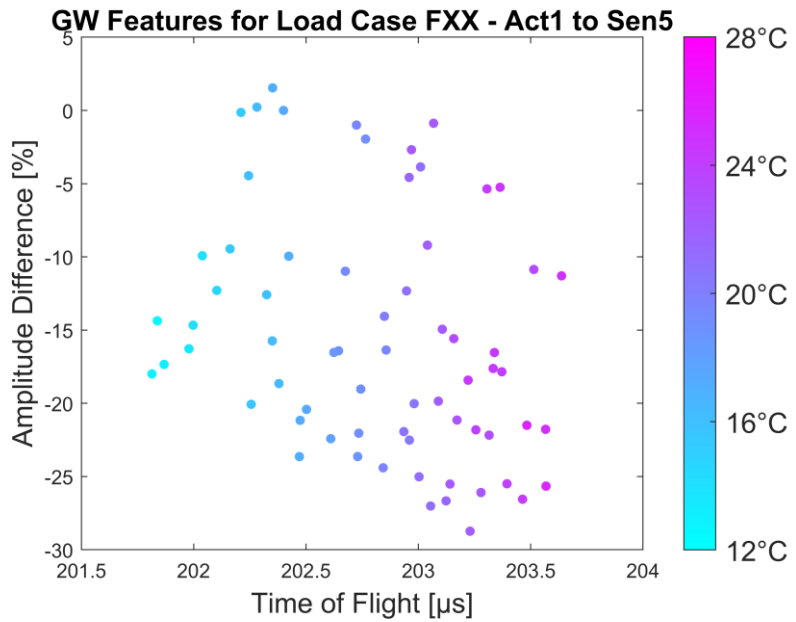




Compression







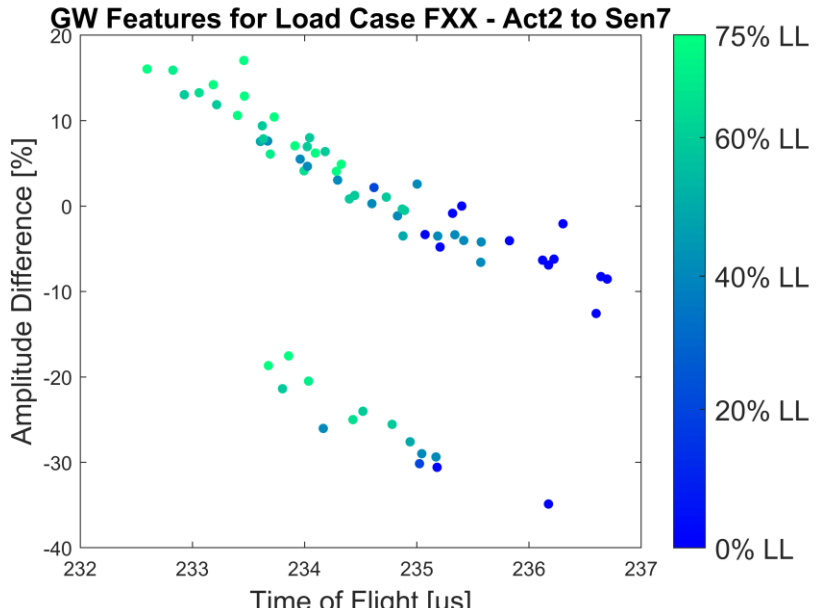
- Structure test preformed in non-climatized test hangar
- Up to 18°C in temperature variation
- Rest of variability in amplitude and ToF explained through temperature changes

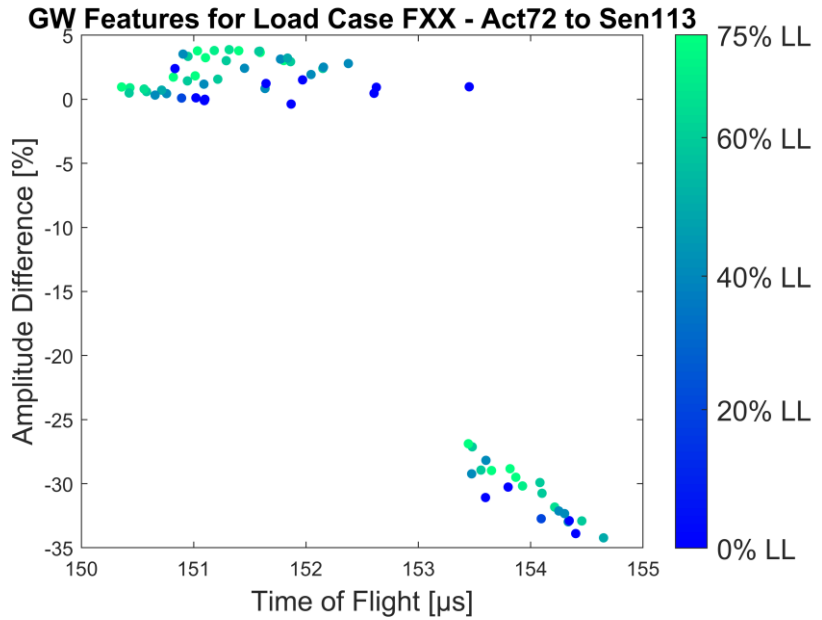
Effects on GW

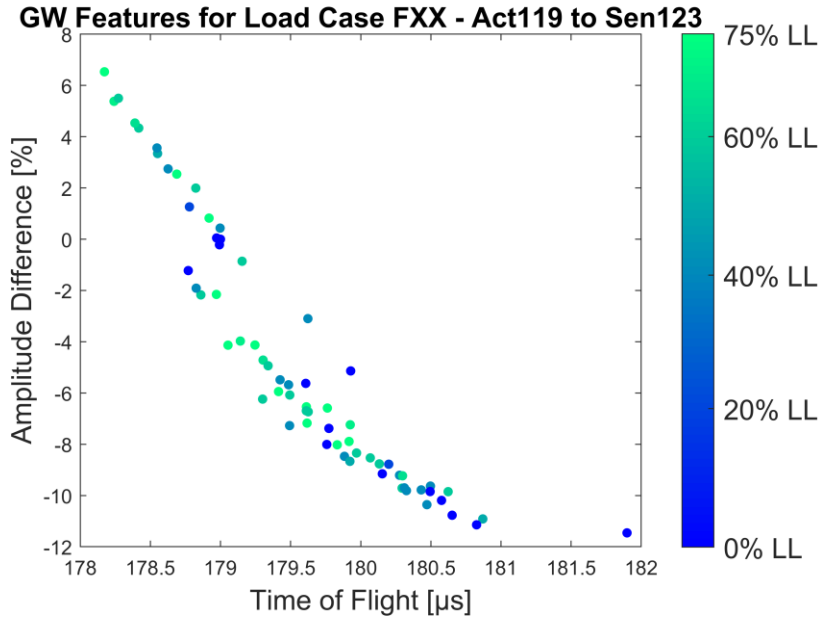
A_0-mode @70 kHz

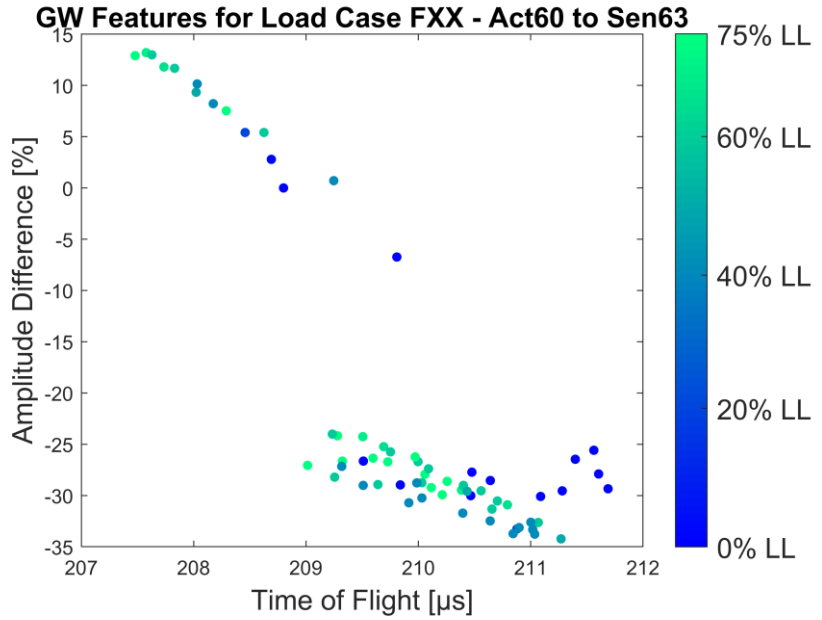
1600 µS > 12°C

Effects on Guided Waves | Damage





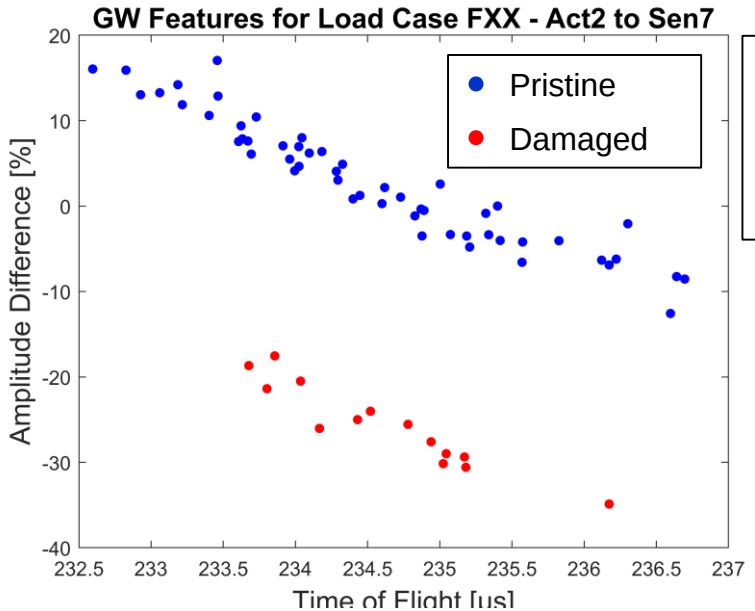




Four exemplary paths from 4 selected damage locations

Amplitude vs. ToF plot over all damage states for all load levels

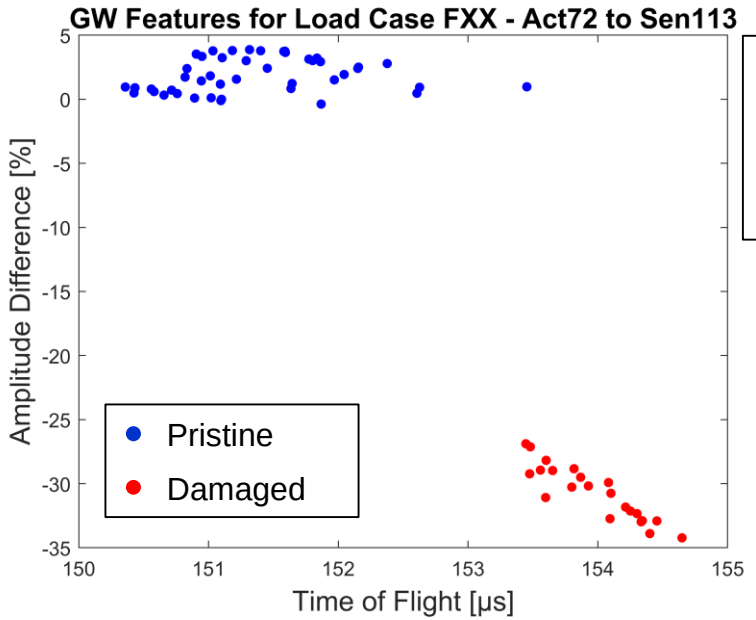
Effects on Guided Waves | Damage



Impact 12

Delamination

29 x 20 mm



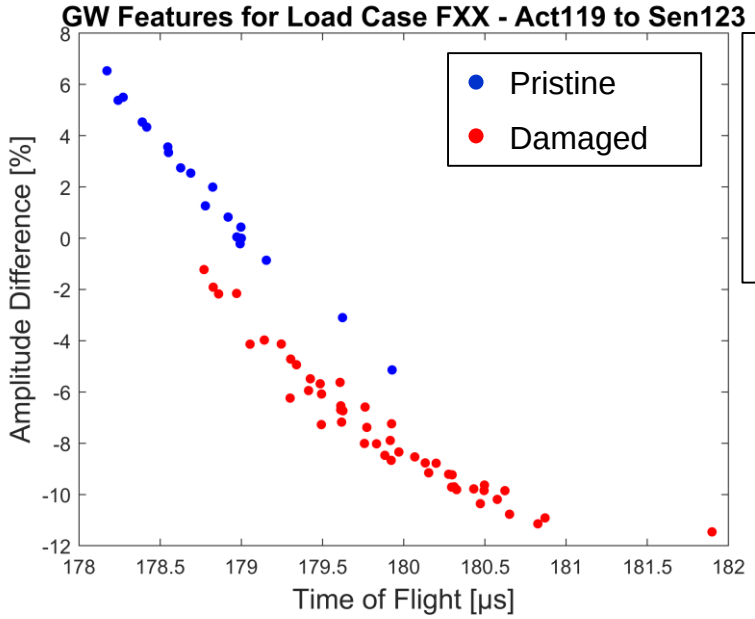
Impact 10

Delamination

43 x 32 mm

Four paths with damage presence

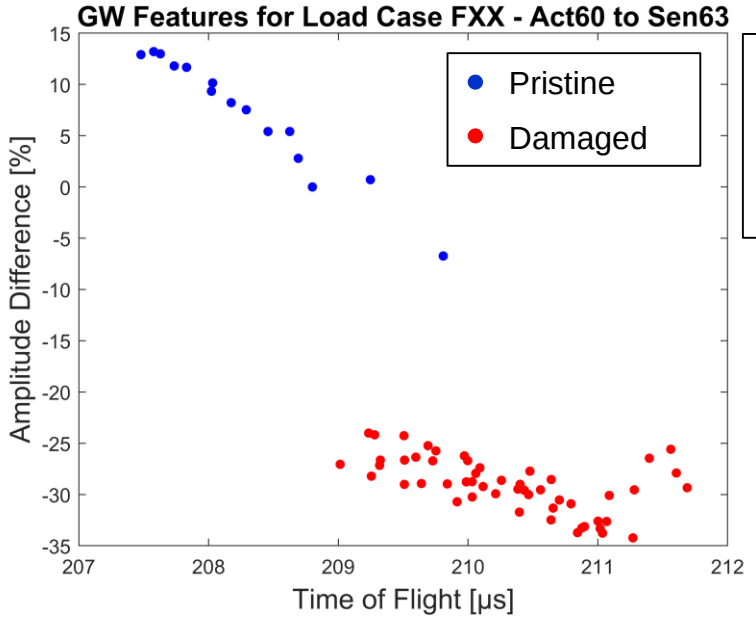
Detectable damages over changing load and temperature conditions



Impact 3

Debonding Intercoastal

19 x 8 mm

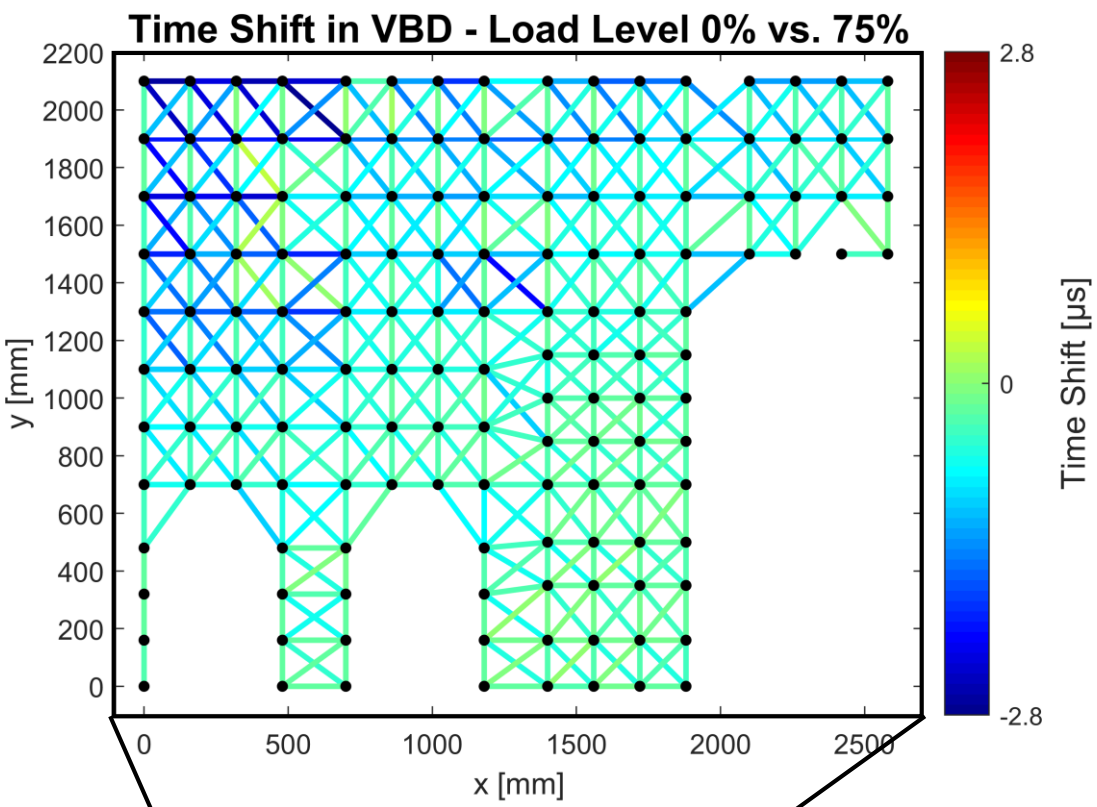


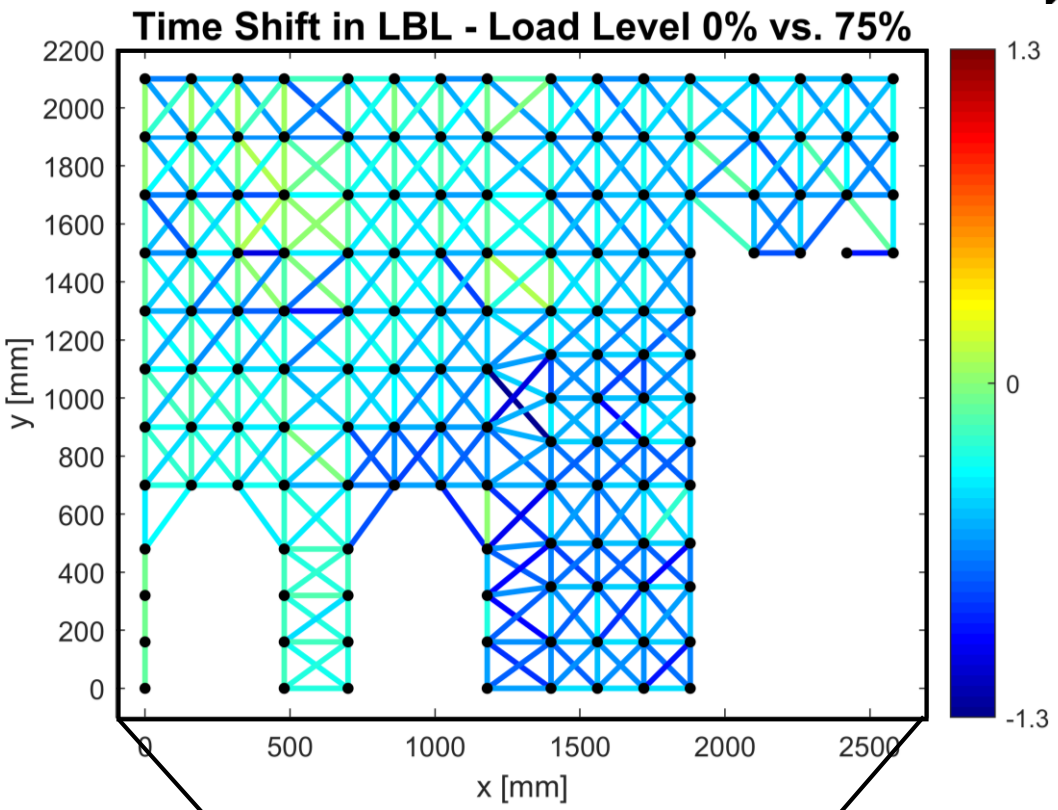
Impact 2

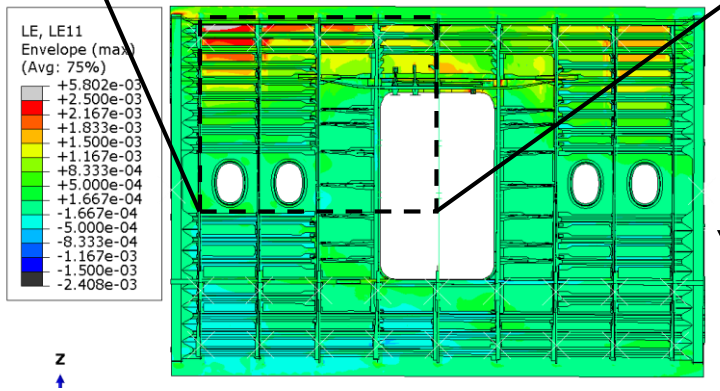
Delamination

22 x 30 mm

Effects on Guided Waves | Load Cases

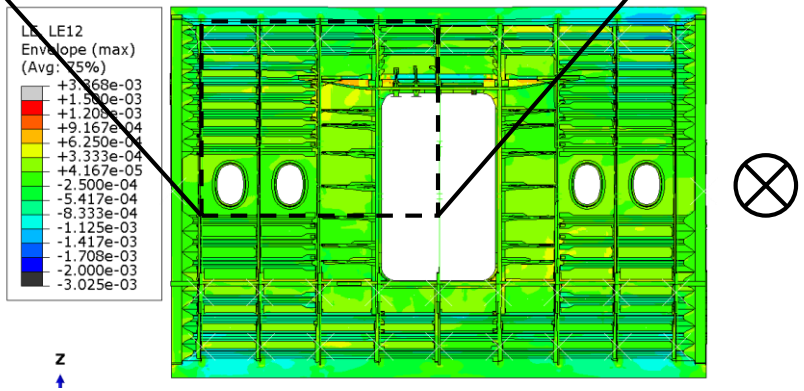






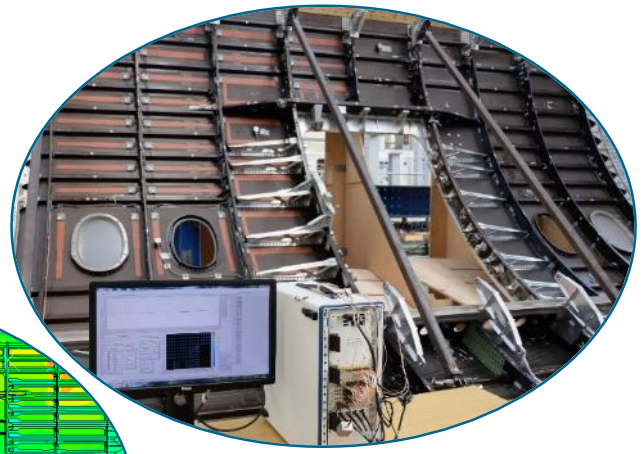
Maximal strain values for door surround structure in inner view for:

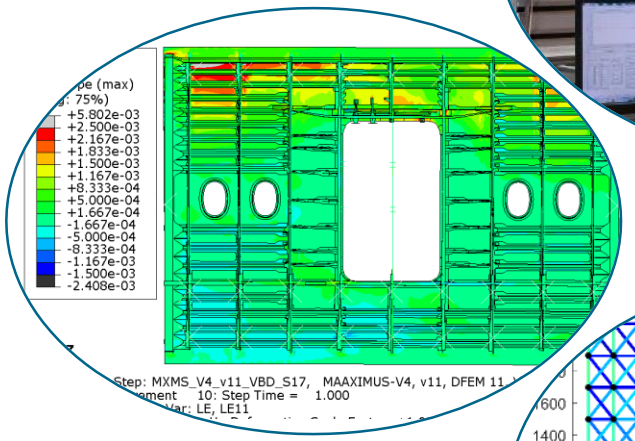
- VBD in the x direction (left)
- LBL in the xy direction (right)

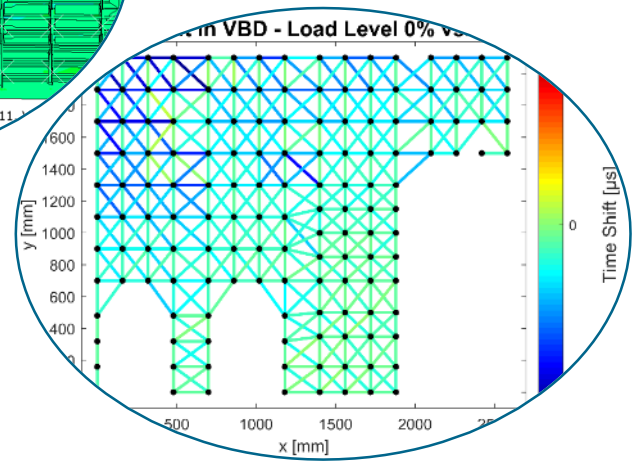


Summary

- Successful installation & application of a GW-SHM system for a representative fuselage structure
- Execution of structure test with 3 load cases & 12 impacts
- Representative flight loads and damage
- Combined effects of load, temperature & damage
- Damage identification under changing load & temperature
- Data set to test damage identification strategies
- Ongoing project with next structure test planned in 2024







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Acknowledgements

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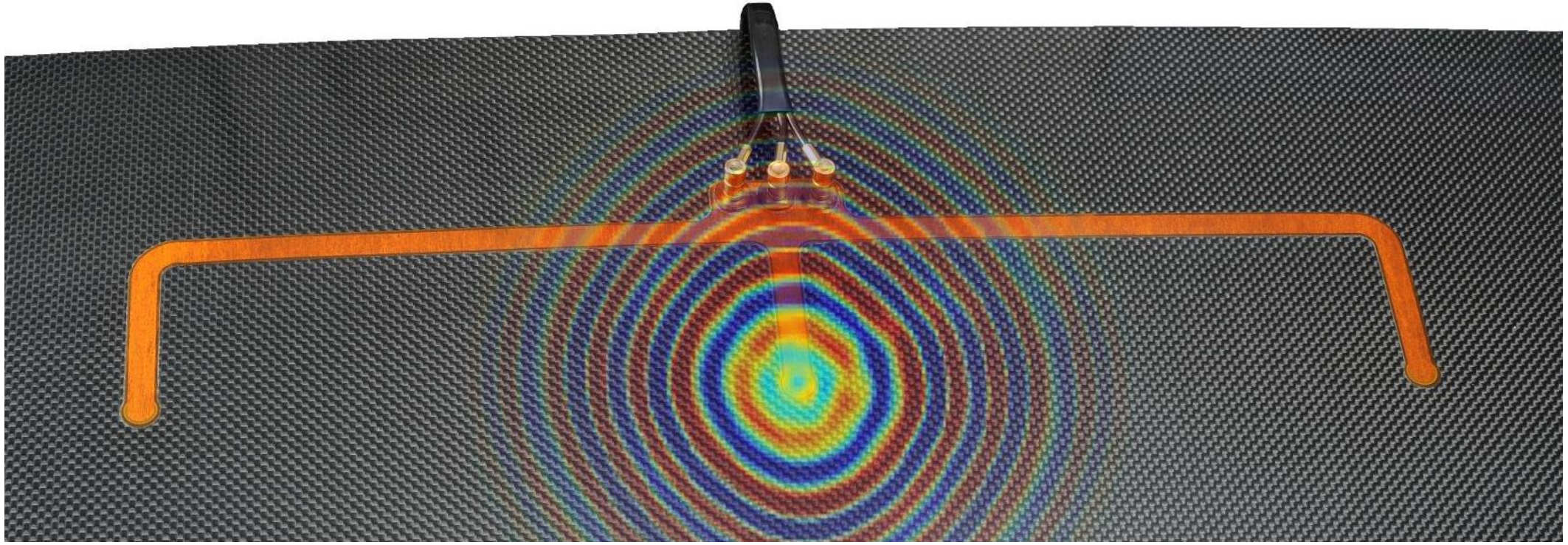
Questions?



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