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Integration of a Guided Wave-based SHM System in a full-scale Structural Test

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1 Abstract

Guided-wave-based Structural Health Monitoring (GW-SHM) has proven effective in detecting common damage types in composite structures, including delaminations and structural debonding. This study explores the application of GW-SHM for aircraft composite structure testing. The work begins by establishing the rationale for employing GW-SHM in this context, followed by a description of the piezoelectric transducer network developed for the test requirements. The study then details the integration strategies that allow the GW-SHM system to operate effectively within current full-scale testing frameworks

A comprehensive dataset was generated through full-scale testing of a composite fuselage panel, incorporating realistic impact damage scenarios, multi-axial mechanical loading conditions, and temperature variations. Analysis of this dataset reveals how temperature, mechanical load, and damage collectively influence the guided-wave propagation. Building on these findings, the study develops and validates a Gaussian Process-based damage detection method designed to perform reliably under these challenging test conditions.

Keywords: Guided Waves, SHM, aeronautic structures, composite structures, structural testing, environmental and operational conditions

2 Introduction

The damage tolerance approach in aircraft design requires structures to withstand defined loads with allowable damage until detection through maintenance. For composite structures, this means demonstrating residual strength after fatigue testing and with introduced damages for certification. Full-scale testing serves as a key validation method for this damage tolerance approach. This work explores using GW-SHM during full-scale testing to monitor impact damage on a composite fuselage structure, offering benefits like reduced test downtime and monitoring intervals.

3 Experimental Setup

A full-scale composite fuselage structure used for this work is representative for a passenger door surrounding area of a wide-body fuselage, such as A350. A GW-SHM system was designed and installed on the fuselage panel. The distinguishing features of this GW-SHM system are a robust transducer network, a reliable transducer connection and a modular network concept [1]. The instrumented panel was tested under representative loads using the test rig described in [2] and shown in Fig. 1. A hydraulic test rig applied a loading sequence resembling full scale fuselage fatigue tests. The resulting dataset contains 27 load combinations derived from the basic load cases.

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4 Results

This study analyzes the GW-SHM system's response under dynamic multi-axial load conditions representative of fuselage structures. The dataset reveals how guided wave propagation varies along a selected actuator-sensor path (Fig. 1) as a function of x-direction force (Fx) and z-direction moment (Mz) across 27 load cases.

Building on the Gaussian Process (GP) approach from [3], this work extends its application from single load cases to multi-axial load scenarios by incorporating Fx, My, and Mz as independent variables in the GP model. The data-driven GP detection method inherently distinguishes between environmental/operational influences, such multi-axial loading and temperature, and impact damage.

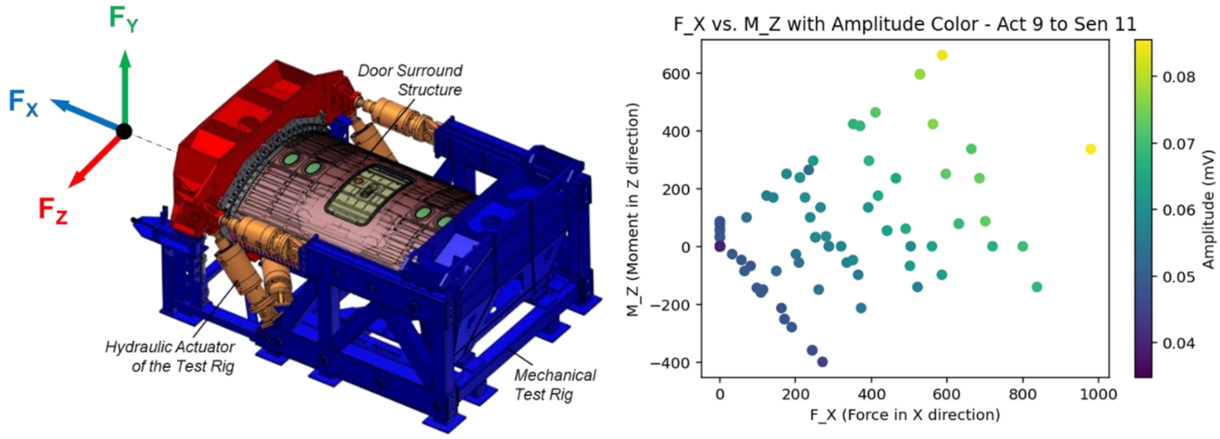

Fig. 1. Test set-up: Door surround structure panel in test-rig [2]

5 Conclusion

A full-scale test with multi-axial loading, temperature variations, and impact damage generated a comprehensive dataset that provides sufficient complexity to evaluate new approaches for realistic load conditions. This work offers valuable data to assess the opportunities and challenges of implementing GW-SHM in composite aircraft structures under varying operational conditions.

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