46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-XXX

A CASE STUDY FOR SIMULATION ASSISTED GUIDED WAVE STRUCTURAL HEALTH MONITORING OF AEROSPACE STRUCTURES

Elizabeth D. Gregory[1], William C. Schneck III, Cara A.C. Leckey
NASA Langley Research Center
Hampton, VA

Paul Swindell
William J. Hughes Technical Center, FAA
Atlantic City, NJ

ABSTRACT

A baseline crack case was observed in a laboratory setting and analyzed using Acellent Technologies, Inc.'s Structural Health Monitoring software. That baseline crack as well as other crack configurations were simulated using in-house, elastodynamic simulation code at NASA Langley Research Center. The results of the simulation code were analyzed using Acellent's software. This work demonstrated the ability of simulation to augment laboratory tests by providing a population of flaw configurations that would be prohibitively costly and time consuming to test in the laboratory.

Keywords: Structural Health Monitoring, Simulation, Ultrasonic, Nondestructive Evaluation

1. INTRODUCTION

This work expands upon previously reported work comparing laboratory guided wave (GW) structural health monitoring (SHM) data with simulated data for an aluminum fuselage section undergoing testing at the FAA[1]. The test configuration consisted of 12 individually actuated piezoelectric transducers (PZT), as seen in Figure 1. This experimental configuration was simulated for different crack lengths and orientation. The simulated data was analyzed by Acellent Technologies, Inc.'s SHM system to provide an assessment of damage intensity and location. This comparison demonstrates the sensitivity of SHM assessment software to damage state.

The baseline test case was conducted in the laboratory. By comparing results from different crack configurations (sizes and orientations) it is possible to create a population of possible states that can be gleaned from evaluation data beyond the severity and location that is currently provided by the SHM software. This work is an incremental step to solving the inverse problem.

2. METHODS

Both the laboratory tests and the simulations were completed on an aluminum (2024) fuselage panel with frames and stringers. The flaw under consideration is a cut through the skin and a single stringer between two bays. Table 1 describes all the flaw configurations considered in this work.

TABLE 1: DAMAGE/FLAW CONFIGURATIONS

Length (in)	Orientation (degrees)	Tested	Simulated
0.5	0		x
1.0	0	x	x
1.0	22.5		x
1.0	45		x
1.0	-45		x
1.0	67.5		x
1.5	0		x
2.0	0		x

2.1 Laboratory Tests

The FAA testing was performed in the Full-Scale Aircraft Structural Test Evaluation and Research Lab (FASTER) at the FAA William J. Hughes Technical Center in Atlantic City, NJ. Figure 1 shows the location of the ultrasound transducers. The 1 inch long vertical cut is through the skin and stringer between transducers 1, 6, 9, and 10. One transducer is actuated and then the that transducer and the other act as receivers. This is repeated for each transducer for a total of 144 data sets.

---

[1] Contact author: Elizabeth.D.Gregory@NASA.gov

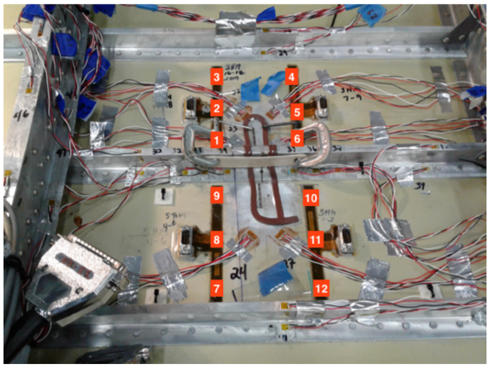

FIGURE 1: NUMBERED UT TRANSDUCERS FOR THE TEST AND SIMULATIONS.

2.2 Simulations

The simulations discussed in this work are performed with an elastodynamic finite integration technique (EFIT) custom code for modelling GW SHM in metallic aerospace components. EFIT is a staggered grid finite difference approach that was applied to elastodynamics in the 1990s [2, 3].

The EFIT code was parallelized using message passing interface (MPI) between non-uniform memory access (NUMA) nodes and Open Multi-Processing (OpenMP) for parallelizing within the node.

The material properties used in the simulation are described in Table 2. The cell size and time step size are determined by the material properties. Thus, the cell size cannot be increased to reduce overall simulation size. These limitations make parallelization critical to performing simulations in the timely manner with computing resources available.

TABLE 2: SIMULATION AND MATERIAL PROPERTIES

Material	Aluminum 2024
Density (ρ)	2780 g/m^3
Lamé parameter 1 (λ)	51.75 GPa
Lamé parameter 2 (μ)	26.66 GPa
Cell size (Δq)	0.1 mm
Time step (Δt)	7.869 μs
Simulation time	30,000 time steps

Figure 2 shows the velocity in the z direction (mostly out of plane) for a transducer 9 actuated case for the baseline, 1 inch, 0 degree cut. The red box shows one of the reflections from the cut.

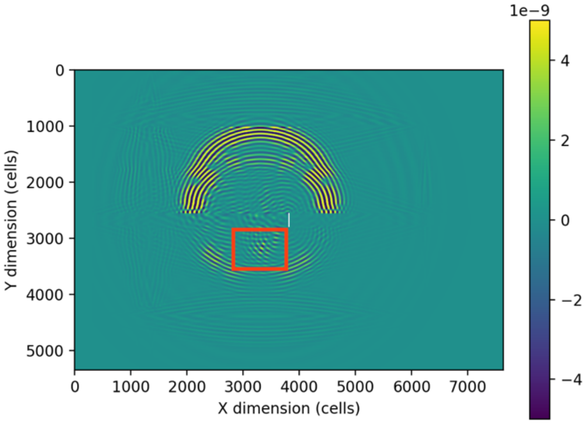

FIGURE 2: OUT-OF-PLANE VELOCITY FOR THE SIMULATED VOLUME FOR A SINGLE ACTUATED TRANSDUCER.

3. RESULTS AND DISCUSSION

The Accellent SHM software analyzes the 144 data sets to create a two-dimensional damage map like those seen in Figures 3 and 4. Accellent's specific algorithm is proprietary so the exact method they use to assign a damage index is not known.

Figures 3 and 4 show the results for a 1 inch vertical (0°) cut. Figure 3 is the damage intensity for the experimental data and Figure 4 is for the simulation data. The laboratory test data is noisier than the simulation data, and therefore the simulation data provides a "tighter" area of high damage index.

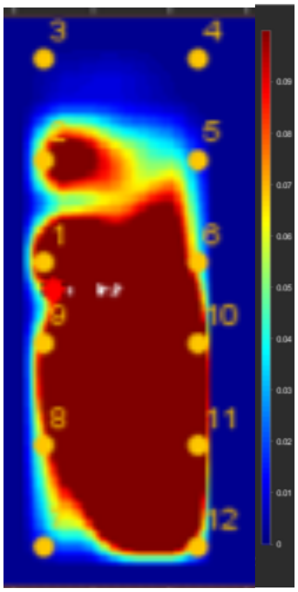

FIGURE 3: RESULTS FROM THE ACELLENT DAMAGE INDEX SOFTWARE BASED ON EXPERIMENTAL DATA.

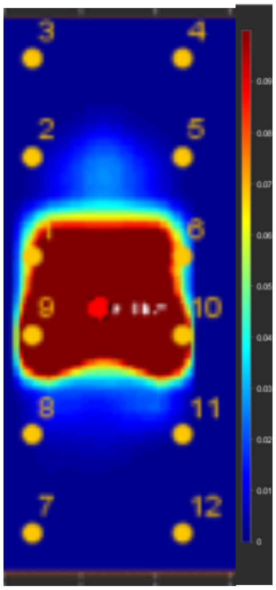

FIGURE 4: RESULTS FROM THE ACELLENT DAMAGE ASSESMENT SFOTWARE BASED ON SIMULATION DATA.

4. CONCLUSION

Simulations can be used to augment laboratory tests to create a population of damage or flaw results that can help to characterize damage and flaws beyond those tested in the laboratory. By creating this population, it is possible to begin to address the complex inverse problem.

ACKNOWLEDGEMENTS

This work was supported by the FAA and the High Performance Computing Incubator Project at NASA Langley Research Center.

REFERENCES

[1] Gregory, Elizabeth, Schneck, William, Leckey, Cara and, & Swindell, Paul, "Simulation Assisted Guided Wave Structural Health Monitoring of Aerospace Structures", *Review of Progress in Quantitative Nondestructive Evaluation*, Burlington VT, July 15-19, 2018.

[2] Fellinger, Phillip, Marklein, René, Langenberg, Karl Jörg, and Klaholz, Steven. "Numerical modeling of elastic wave propagation and scattering with EFIT - elastodynamic finite integration technique." *Wave Motion* Vol. 21 (1995): pp. 47–66.

[3] Marklein, René. "The Finite Integration Technique as a General Tool to Compute Acoustic, Electromagnetic, Elastodynamic , and Coupled Wave Fields*," Review of radio science* (1999), pp. 201–244.