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Real-Time Predictive Crack Growth Monitoring in Aircraft Aluminum Structures Using Smart Strain Gauge Networks

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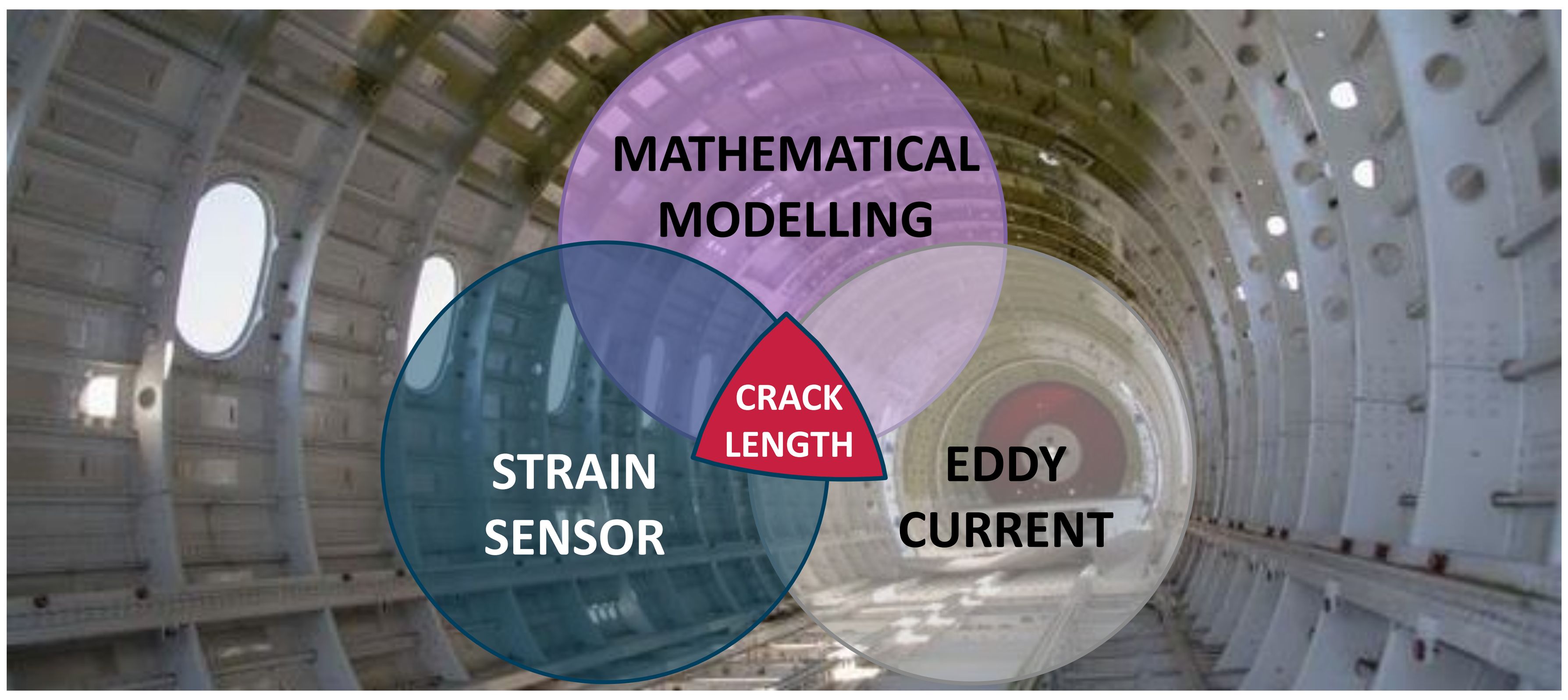
INTRODUCTION & AIM

Structural Health Monitoring (SHM) is essential in aerospace to detect cracks in fuselage components. Traditional methods (ultrasound, acoustic emission, guided waves) are costly and lack real-time monitoring.

The main objective of this work is to develop an experimental and mathematical approach to monitor crack propagation in aeronautical structural **aluminum 6082-T6** using a strategically placed **strain gauge network**, and to predict crack length in real time from measured strain variations, aiming to improve SHM practices in fuselage-like components while significantly **reducing aircraft downtime and maintenance costs**.



METHODS

PHASE I

STATIC TEST

- Unnotched specimens
- Circular notched specimens
- Circular notched specimens with pre-crack

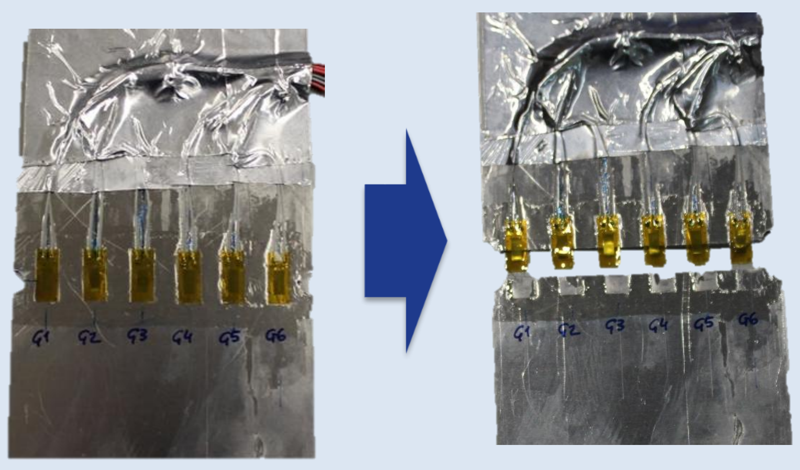
PHASE II

FATIGUE TEST

Circular notched specimens with pre-crack (3, 3.5, 4 kN)

CRACK LENGTH MESUREMENTS

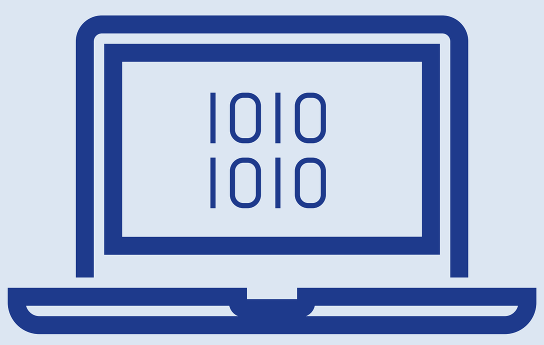
Through strain sensors and Eddy current inspection



PHASE III

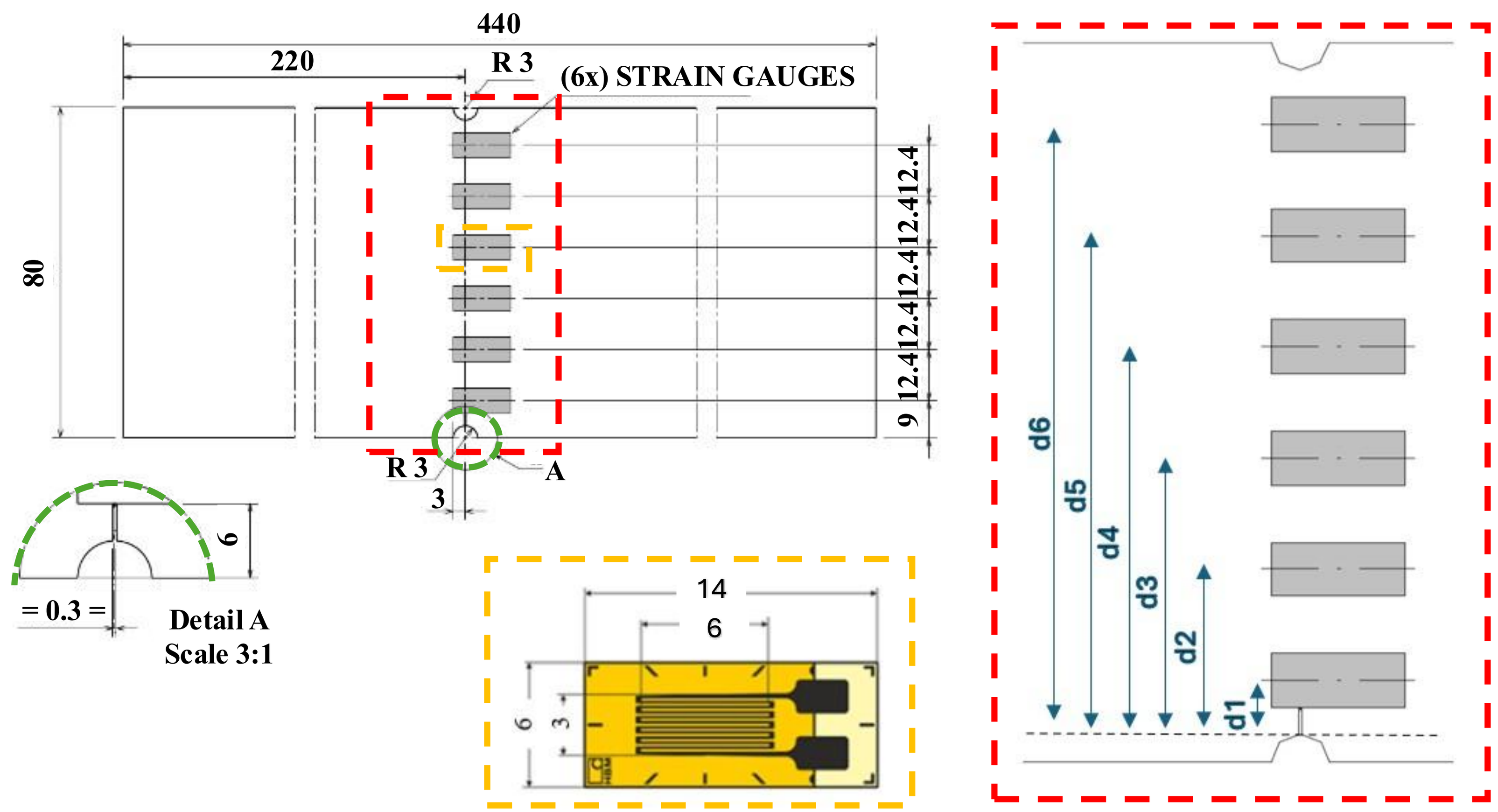
DATA ANALISIS

- Development of Predictive Modelling of Crack Propagation
- Validation of the mathematical modeling



RESULTS & DISCUSSION

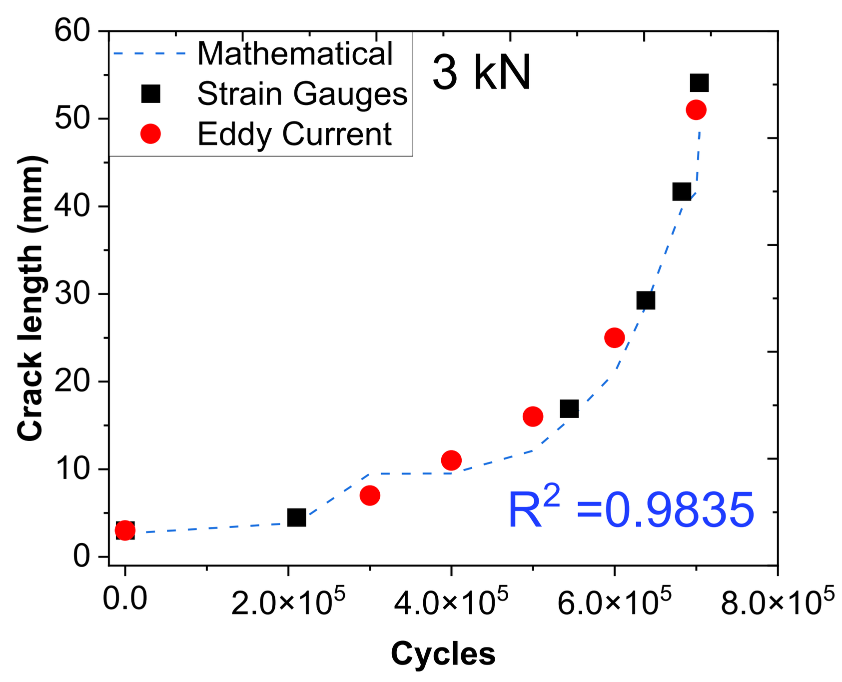
The results demonstrate the capability of the strain gauge network to effectively monitor and predict crack propagation in aeronautical aluminum specimens under fatigue loading. Six strain gauges were strategically positioned along the expected crack path, allowing continuous measurement of strain evolution as the crack advanced. Crack length was periodically validated using eddy current inspections, providing a reliable experimental reference.

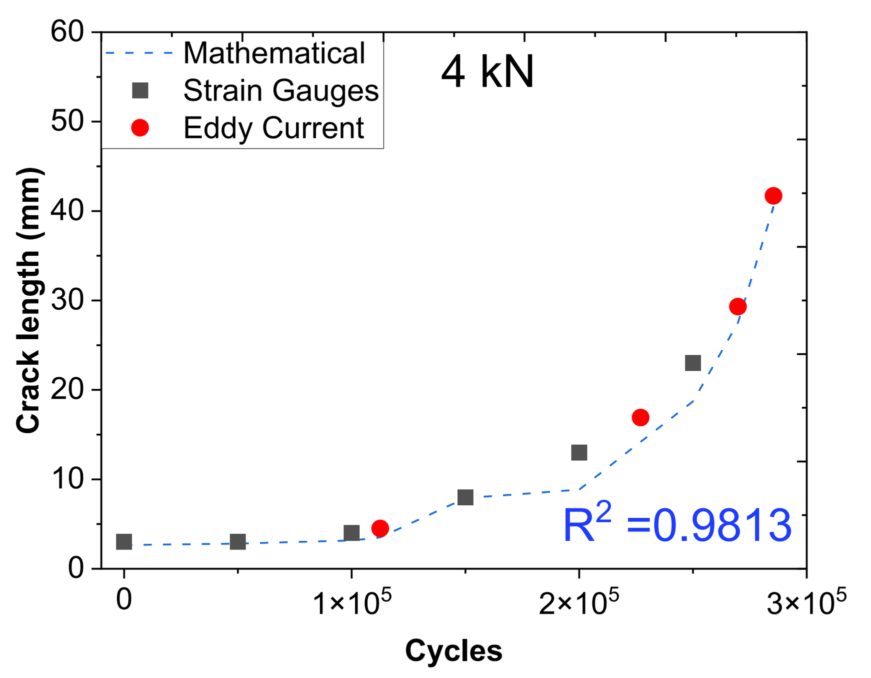


The comparison between strain gauge monitoring, eddy current measurements, and the proposed mathematical predictive formula shows an **excellent agreement** throughout the crack growth process.

$$\frac{\varepsilon_n}{\varepsilon_{nom}} = \left[1.12274 - 0.231318\left(\frac{a}{b}\right) + 10.5503\left(\frac{a}{b}\right)^2 - 21.71\left(\frac{a}{b}\right)^3 + 30.3816\left(\frac{a}{b}\right)^4\right]\left(\sqrt{\frac{a}{d_n - a}}\right)\left(\frac{b-a}{b}\right)$$

The mathematical model accurately reproduces crack propagation trends under different load levels (3 kN and 4 kN). The strong coincidence between predicted and experimental crack lengths is confirmed by high correlation coefficients ($R^2 = 0.9835$ and $R^2 = 0.9813$), demonstrating the potential of this approach for **real-time and cost-effective SHM in aerospace structures.**





CONCLUSIONS

- The model effectively monitors crack growth in aluminum structures.
- The proposed mathematical model shows excellent agreement with eddy current measurements, achieving high prediction accuracy ($R^2 > 0.98$).
- The method offers a low-cost solution for aerospace SHM.

ACKNOWLEDGEMENTS

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