DATA-DRIVEN LIFETIME ASSESSMENT OF A WING SAIL SYSTEM

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MOTIVATION

Wind Assisted Propulsion Systems (WAPS) play an important role in achieving maritime decarbonization goals. In January 2023, Horizon Europe granted funding for the Orcelle Wind project. It aims to develop and build a wind-powered roll-on/roll-off (ro-ro) cargo vessel that is set to be commissioned in late 2026 or early 2027. Orcelle employs wing system technology to generate aerodynamic thrust forces for propulsion.

Within the Orcelle Wind project, UGent is responsible for the development of numerical tools for structural integrity assessment of the wing system. The motivation for this research stems from the need for early detection and identification of malfunctions and degradation in critical mechanical components of the wing system. Such pre-emptive measures are essential for ensuring the safe operation of wind-assisted vessels. Furthermore, the study aims to contribute to the advancement of safety standards for wind power technology by implementing condition-based inspection and maintenance strategies.

Figure 1: Orcelle - The world's first wind-powered Ro-Ro vessel

OBJECTIVES

Structural members of the wing system are subjected to fatigue loads in both normal operating conditions and extreme load conditions. The objective of this thesis encompasses:

1. Development of numerical tools for data-driven structural integrity assessment (fatigue degradation and lifetime) of the wing system.
2. Design and implementation of a sensor suite for load and condition monitoring of the wing system.

APPROACH

The fatigue reliability and structural integrity of the wing system depends on the fatigue reliability and failure contributions of its components. The entire wing system, illustrated in Figure 2, comprises three subsystems: the foundation, a main wing, and a flap-wing subsystem.

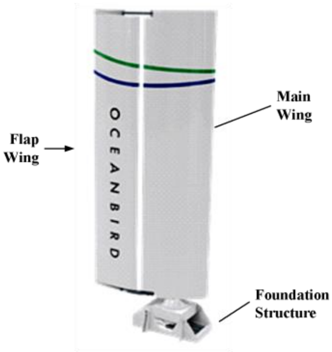

Figure 2: Oceanbird wing system 560

Finite Element Analysis (FEA) will be utilized to capture the structural response and fatigue performance of the system. Multi-scale finite element simulations will be performed of each subsystem to mitigate model

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complexity and computational costs. These simulations will take into account input load variations and material uncertainties.

Representative samples for input parameters' uncertainty will be generated through Quasi-Monte Carlo Sampling (QMCS). To address the time demands of FE simulations, surrogate models will be established using the stress field outputs of the finite element simulations. This data will then be used to determine the probability distribution function (PDF) of stress amplitudes for each component. Next, Monte Carlo Simulations (MCS) will be employed to assess the fatigue lifetime of components based on the constructed PDF, stress-based S-N curves, and constants representing material and loading conditions obtained from open-source fatigue test data. From this analysis a fatigue lifetime PDF can be obtained for each component through MCS. With these component fatigue life PDFs the corresponding component's probability of failure (PoF) will be determined. A Fault Tree Diagram (FTD) will be constructed to illustrate the hierarchical relation between the fatigue failure of the wing system (top event) and the fatigue failure of its critical components (basic events). This fault tree diagram will be represented by equivalent Bayesian networks. Subsequently, the fatigue reliability of the wing system will be estimated through the utilization of components' PoF and the Continuous Time Bayesian Networks (CTBNs) Method.

In practical operational scenarios, real-time load data will continuously stream from field sensors. Surrogate models will evaluate the structural response of components in the wing system using the sensors' load monitoring data. The obtained structural response data will integrate into the probabilistic fatigue lifetime assessment models. The integration of these approaches aims to enhance the safety and reliability of the wing system by enabling early detection of issues and implementing proactive maintenance strategies. The structural integrity assessment framework for the wing system is illustrated in Figure 3.

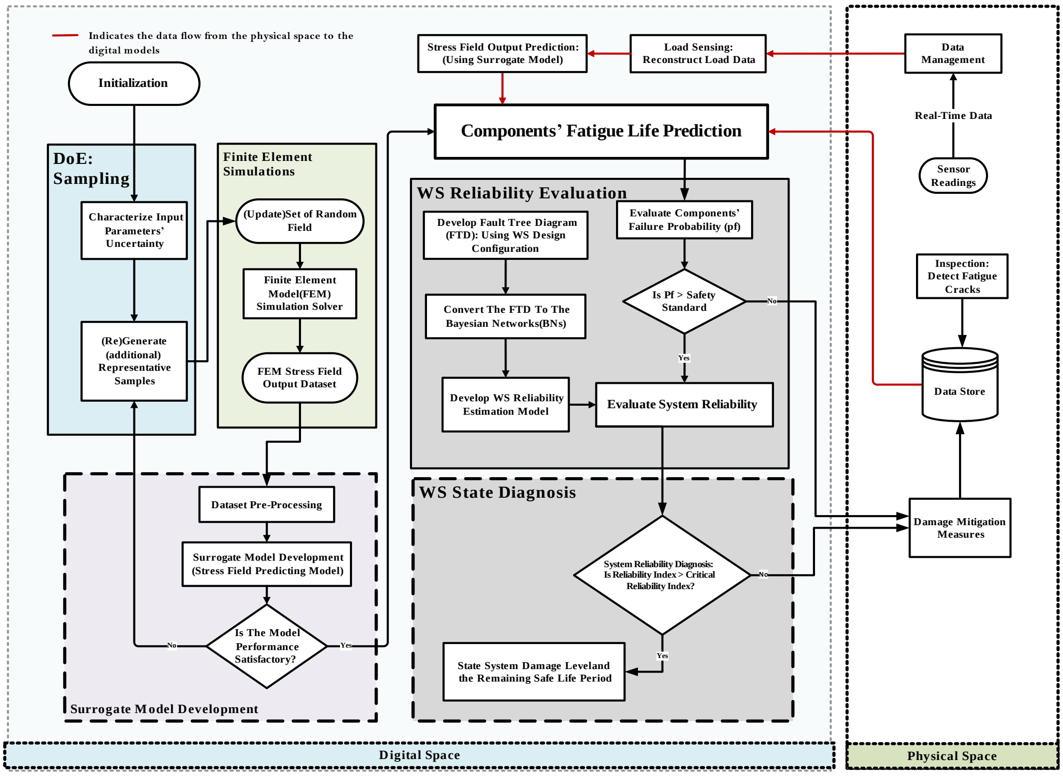

Figure 3 Data driven numerical framework for the structural integrity assessment of the wing system

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