Final work : Structural modeling of propeller for multi-disciplinary design optimization

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Title of the work: Structural modeling of propeller for multi-disciplinary design optimization.
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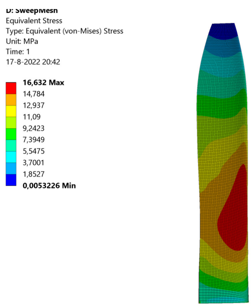
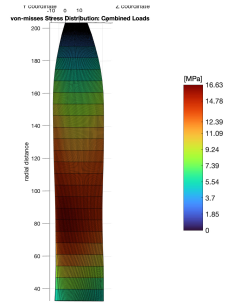
Summary: Aircraft propellers have been an essential propulsion source since the origins of aviation. In order to allow aviation to continue to remain a viable means of mass transportation, the aircraft of tomorrow should become more energy-efficient, have less greenhouse gas emissions and have a lower noise signature. Due to their high propulsive efficiency and the introduction of electric propulsion in aviation, there is a renewed interest in propeller design. However, conventional propellers are often considered noisy compared to turbofan engines. On top of that, further propulsion integration into the air-frame, for instance, Boundary Layer Ingestion, results in additional sources of propeller noise due to increased non-uniform inflow. In order to meet the challenges mentioned and develop novel energy-efficient propellers with a low acoustic footprint, a multi-disciplinary framework is being developed to optimize the propeller design. Present work focuses on the structural analysis of the propeller blade in a steady rectilinear flight operation to predict the blade stresses and ensure that the optimized blade can withstand the aerodynamic and centrifugal loads.

The structural model is based on the Euler-Bernoulli beam theory for bending loads and the Saint-Venant theory for torsional loads in the blade. The proposed low-level structural model is more robust, fast, and efficient in terms of computational time and power than structural FEM simulations and can thus be easily integrated into a multi-disciplinary design optimization framework, including aerodynamics and aeroacoustics. The model is sensitive to changes in the blade's planform (chord, twist, and sweep) and airfoil geometry. In addition, to build confidence in the results the low-fidelity model was validated against high-fidelity structural (Fluid-Structure interaction) simulations of the propellers in both propulsive and regenerative regimes.

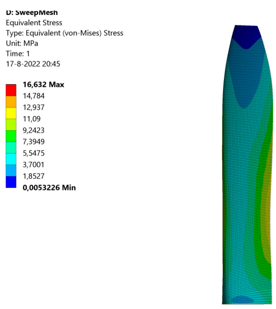
The sensitivity analysis was performed using various geometrical and operational parameters such as advance ratio, propeller pitch, and blade sweep. Expected outcomes from the sensitivity study were achieved, concluding that the centrifugal loads dominates over aerodynamic loads, and further consolidating the structural model and demonstrating that the low-level model performs satisfactorily in estimating the stress distribution. The proposed structural model serves as the foundation for aeroelastic analysis, which includes unstable aerodynamic loadings, which were not considered in the current work.



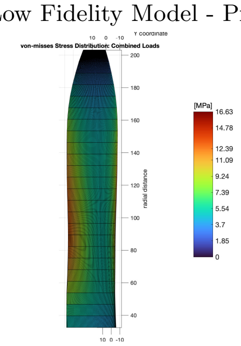
(a) High Fidelity Model - Pressure Side



(b) Low Fidelity Model - Pressure Side



(c) High Fidelity Model - Suction Side



(d) Low Fidelity Model - Suction Side

Figure 1: Comparison of high-fidelity and low-fidelity model: Propulsive regime operation