HIGH-FIDELITY AERODYNAMIC MODELS FOR PROPELLER-WING WHIRL FLUTTER

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ABSTRACT

Whirl flutter is a phenomenon of dynamic aeroelastic instability [1] generated by the interaction between the unsteady aerodynamic loads on a spinning rotor and the gyroscopic moments induced by its rotation. Depending on inflow variables and structural parameters, a rotor can be unstable exhibiting diverging spiraling motion (fig. 1). Reliable prediction of whirl flutter instability is therefore crucial for the design of next-generation high speed propellers. Some of the typical stability boundaries that will be presented and discussed in the paper are shown in fig. 2.

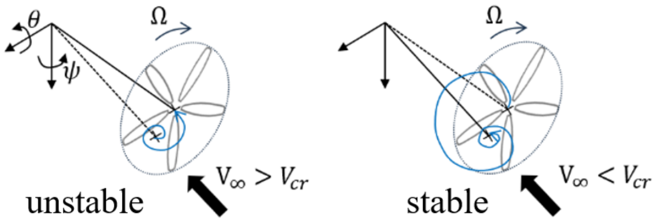

Figure 1. Whirl flutter: precession motion of the propeller is amplified if wind speed V_∞ is greater than the critical value V_{cr}.

To date, the majority of research has focused on the development of analytical models and the use of potential flow CFD solvers [2], while the application of high-fidelity CFD tools to whirl flutter makes the object of a limited number of studies. As propeller designs evolve towards highly flexible blades with more complex geometries and operation conditions in the transonic regime, however, high-fidelity tools (such as URANS models) become necessary to overcome the shortcomings of existing models.

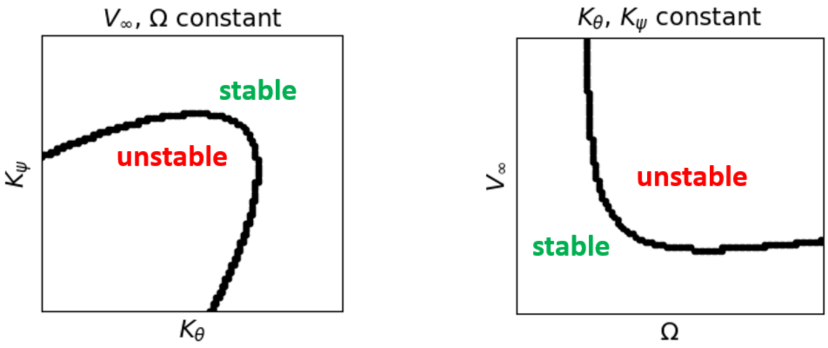

Figure 2. Typical whirl flutter stability boundaries as a function of pitch (K_θ) and yaw (K_ψ) stiffnesses, wind speed (V_∞) and propeller rotational speed (Ω).

In this work, a method to perform frequency-domain whirl flutter stability analysis of a wing-mounted propeller using high-fidelity URANS simulations is demonstrated. A thorough comparison with legacy analytical whirl flutter models and faster mid-fidelity CFD tools is provided, using the URANS solutions as reference. As an extension of a previous study by the authors [3], a more detailed analysis of the flow field and sectional loads will be performed to gain insight into the differences between the models. Finally, blade flexibility will be incorporated into the URANS simulations, thus providing a high-fidelity model for flexible-blade propeller whirl flutter. This model will be then used as validation for the analytical model recently developed in [4].

The stability problem is solved in the frequency domain following a weak-coupling approach: aerodynamic loads on the propeller and the wing are calculated either analytically or from CFD simulations and are then applied to a finite element model (FEM) of the propeller-pylon-wing structure. Concerning the aerodynamics, three types of models are considered:

- Analytical models, which are based on linearized 2D potential flow theories, applied at each blade section, and relying on strip-theory to obtain integrated propeller loads.
- Mid-fidelity models, based on 3D potential flow, implemented through the open-source code DUST.
- High-fidelity, based on the URANS method, implemented through the Safran-ONERA CFD code elsA, using the MIMAS framework [5] to perform aeroelastic simulations.

Forced response to pulsed perturbations of propeller degrees of freedom is used to convert time-domain simulations results into frequency-domain loads. The structural model used represents the W-STING and W-WING aeroelastic demonstrators from project OFELIA [6], enabling the study of isolated propeller and wing-propeller whirl flutter, respectively.

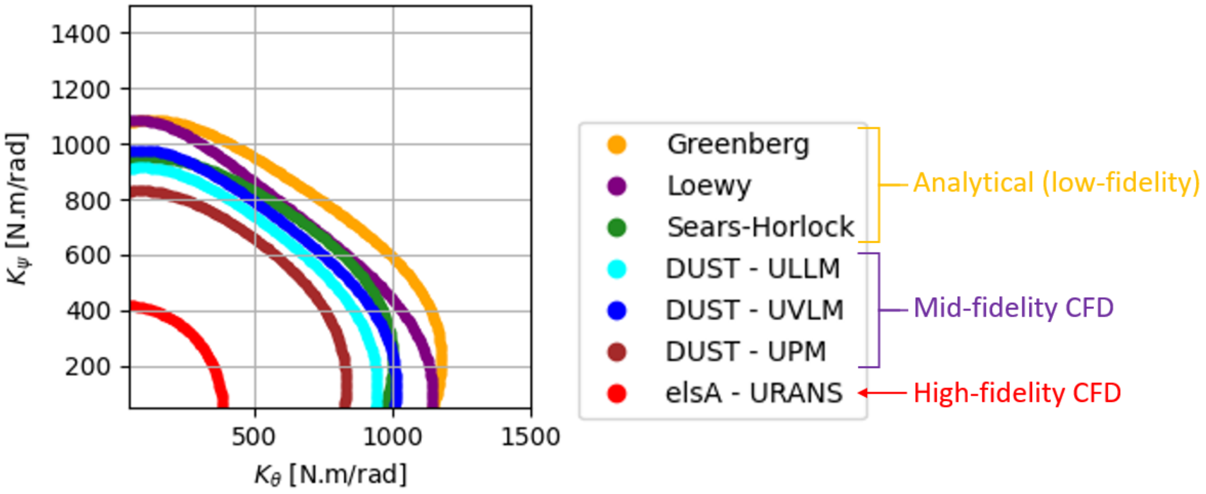

Figure 3. Preliminary results: comparison of different models for the rigid-blade propeller case.

Results reveal a non-negligible sensitivity to turbulence modelling, which needs further investigation to improve the robustness of the proposed high-fidelity methodology. A clear trend emerges from comparison with the other models (fig. 3): the use of high-fidelity URANS simulations provides better stability margins, showing that lower fidelity models are over-conservative, and are therefore suitable for fast parametric studies in the early-stage design. The expected results from the implementation of blade flexibility in the high-fidelity methodology is that it will improve propeller-wing stability, thus confirming previous studies using analytical or mid-fidelity models.

References

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