TOWARDS ROBUST WHIRL FLUTTER PREDICTION IN PROPELLER AIRCRAFT: A CRITICAL REVIEW OF MODELING PARAMETERS

Christopher Koch*, Holger Hennings

DLR Institute of Aeroelasticity
Bunsenstraße 10, 37073 Göttingen
Germany

ABSTRACT

Propeller or similar concepts with open rotors such as unducted single fans are viable options for the next generation of efficient short- to medium range aircraft. Unlike conventional turbofans, these aircraft configurations with propellers face an additional aeroelastic challenge: predicting and preventing whirl flutter instabilities during the design of the aircraft structure. In the design process, the assessment with respect to whirl flutter stability is, e.g., part of trade-offs between engine mount stiffness for enhanced aeroelastic stability and softer mounts for improved vibration isolation. Understanding the driving factors for propeller whirl flutter stability and the associated uncertainties early in the design process helps therefore to improve the overall design.

While previous publications [1-4] investigated the impact of individual modeling and workflow parameters on whirl flutter stability results based on numerical simulation, this paper synthesizes these findings within the broader framework of a comprehensive aircraft flutter assessment process. It evaluates how the inclusion or omission of specific physical phenomena, modeling fidelity levels, and coupling strategies affect both the accuracy of stability predictions and the overall computational cost. Furthermore, the paper identifies critical knowledge gaps in current methodologies, discusses their implications for design reliability, and proposes targeted research directions to address them.

Methods

The flutter process discussed in this paper is illustrated in Fig. 1 and outlines the three main components (right to left) of aircraft structural modeling, aircraft aerodynamic modeling (comprising the classical flutter workflow for transport aircraft), and the unsteady propeller model based on the Transfer-Matrix approach [1]. The focus of Fig. 1 is on highlighting the additional overhead introduced by the inclusion of the propeller dynamics in the flutter assessment. Specifically, this includes the generation of transfer matrices for all relevant points within and beyond the flight envelope, as well as the computation of additional generalized aerodynamic forces (GAFs) when aerodynamic interactions between the propeller and airframe are considered. While the computational cost of generating transfer matrices is typically negligible for simplified propeller models—such as those based on Houbolt or Reed theory [5]—this cost increases significantly with more advanced, high-fidelity propeller models. Thus, the choice of propeller modeling approach

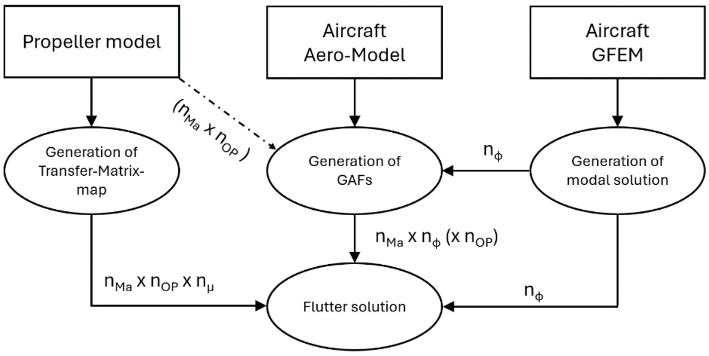

Figure 1: Sketch of the flutter workflow including propeller contributions and number of computations for each step

directly impacts both the efficiency and reliability of the overall flutter assessment process. The parameters considered in this paper (together with the related individual studies) comprise:

- Propeller aerodynamic modeling [1,2]
- Propeller blade flexibility [1-3]
- Aerodynamic interaction between propeller and wing [4]
- Propeller operating point (Power-Setting, Failure cases) [3]

The paper will discuss these parameters with respect to their influence on computational cost and modelling capability. For comparison, sensitivities to uncertainties in the engine suspension (e.g., due to temperature dependency of the engine shock mounts) will be used.

Results

As a representative case study, the generic turboprop aircraft model from Noël et al. [3] is employed to demonstrate the impact of key modeling features on whirl flutter stability. This is a full, free-flying aircraft model using doublet-lattice method (DLM) aerodynamics. Qualitative sensitivities of whirl flutter stability to various modeling choices are illustrated in Fig. 2, highlighting that blade elasticity and the appropriate selection of propeller aerodynamic modeling fidelity are critical drivers of the stability assessment. In contrast, aerodynamic interaction, especially in subsonic flow, exhibits only marginal sensitivity.

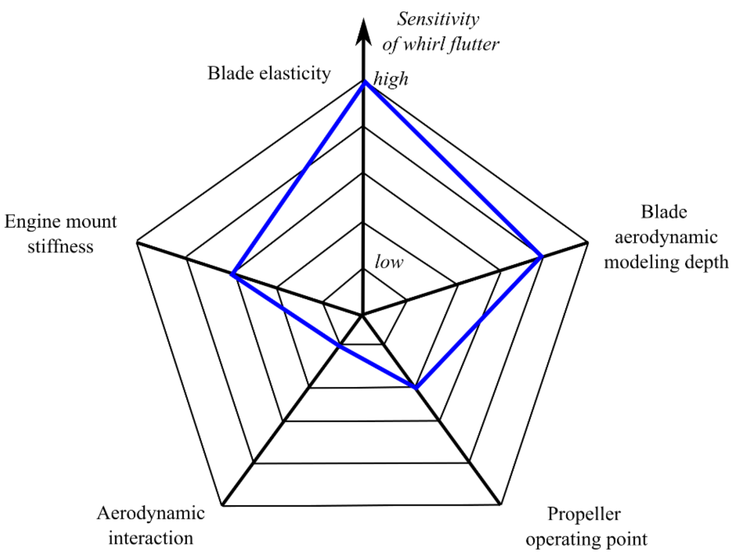

Figure 2: Qualitative Sensitivity of propeller whirl flutter with respect to modelling parameters

References

[1] C. Koch, "Whirl Flutter Stability Analysis Using Propeller Transfer Matrices," Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), 2024. doi: 10.57676/BF00-1962.

[2] C. Koch, "Sensitivity of Propeller Whirl Flutter With Respect to Blade Parameters," in *AIAA SCITECH 2025 Forum*, Orlando, FL: American Institute of Aeronautics and Astronautics, Jan. 2025. doi: 10.2514/6.2025-0430.

[3] J. Noël, C. Koch, B. Stickan, H. Bleecke, and J. Arnold, "Influence of blade elasticity on the whirl flutter stability of a propeller-driven aircraft," in *International Forum on Aeroelasticity and Structural Dynamics (IFASD) 2024,* Den Haag, NL, Jun. 2024.

[4] C. Koch, "Unsteady aerodynamic interaction for the flutter stability analysis of a propeller-wing system,", manuscript in review

[5] W. Rodden and T. Rose, "Propeller/nacelle whirl flutter addition to MSC/nastran," in *Proceedings of the 1989 MSC World User's Conference*, Anaheim, CA, Jan. 1989.