International Forum on Aeroelasticity and Structural Dynamics
IFASD 2026
17-21 June 2026, Goettingen, Germany

EFFECT OF SWIRL RECOVERY VANES ON PROPELLER WHIRL FLUTTER

Valentina Marletta[1] **and Christopher Koch**[1]

[1]German Aerospace Center (DLR), Institute of Aeroelasticity
Bunsenstraße 10, 37073 Goettingen, Germany
valentina.marletta@dlr.de
christopher.koch@dlr.de

1 INTRODUCTION

Future commercial aircraft may incorporate open-fan propulsion systems featuring downstream stator blades designed to recover propeller-induced swirl and improve propulsive efficiency, commonly referred to as swirl-recovery vanes (SRVs). When mounted on elastic supports, such propeller configurations are susceptible to whirl flutter, an aeroelastic instability arising from the coupling between the structural pitch and yaw modes of the engine system and the gyroscopic moments of the rotating propeller. While SRVs have demonstrated potential gains in aerodynamic performance [1], their influence on the aeroelastic stability of the propeller system remains an open question. The present work employs a frequency-domain whirl flutter prediction method based on the Transfer-Matrix (TM) approach [2] to investigate the impact of SRVs on the stability margin of this configuration. This is achieved by analyzing the additional unsteady, motion-induced aerodynamics introduced by the SRVs and the associated hub loads, represented through transfer matrices, under varying operating conditions. The results indicate that, for the trim conditions considered, the presence of SRVs has a small effect on the stability of the system.

2 RESEARCH METHODS

To account for the effect of the SRVs in the flutter analysis, the TM-method [2] is extended to include the additional transfer functions of the SRVs. Eq. 1 shows the extended transfer matrices, projecting from the displacements of both the propeller and SRV hub (which can differ in position) to the loads on the propeller and SRV hub, respectively.

$$\begin{pmatrix} F_{prop} \\ F_{SRV} \end{pmatrix} = \begin{bmatrix} H_{prop\to prop} & 0 \\ H_{prop\to SRV} & H_{SRV\to SRV} \end{bmatrix} \begin{pmatrix} x_{prop} \\ x_{SRV} \end{pmatrix} \tag{1}$$

The top left component of the extended transfer matrix, $H_{prop\to prop}$, corresponds to the classical transfer matrix for an isolated propeller. The bottom right sub-matrix, $H_{SRV\to SRV}$, projects SRV motion to SRV loads and is identified using perturbation of the SRV hub motion in the steady flow field of the propeller. The coupling component $H_{prop\to SRV}$ on the bottom left represents the response of the SRV loads to a perturbation of the propeller hub motion, propagated through the perturbation of the induced velocities to the SRV. As we assume that the SRVs do not alter the propeller aerodynamics, the second coupling term is zero. The modal transformation is conducted similar to the classical TM-method [2], just using the eigenvector components of both the propeller and SRV hub nodes, respectively. The equations of motion of the system are then set up and solved in the modal space in frequency domain [2].

In order to identify the three components of the transfer matrices in Eq. 1, three simulation setups are required:

1. Response of the propeller hub loads to propeller hub excitation
2. SRV hub load response to a perturbation of the SRV hub motion in the steady flow field of the propeller
3. SRV hub load response to the induced velocity perturbation due to propeller hub motion perturbation

First, the isolated propeller is trimmed in axial flow to the desired operating condition. Around this state, the aerodynamic response of the propeller is evaluated by computing hub loads for a steady reference case as well as for two pulse excitations, applied independently in the lateral translation y and pitch motion θ. From these simulations, the induced velocity fields generated by the propeller are extracted and used to define the inflow conditions for the swirl recovery vanes (SRVs). The SRVs are then trimmed to the same operating condition, and the propeller-induced velocities are mapped onto the SRV element locations through spatial and temporal interpolation. With the steady inflow conditions mapped to the SRV, the SRV hub motion is perturbed (also in y and θ), and additionally two more response simulations are conducted with the unsteady inflow condition from the propeller perturbation (from step 1).

All aerodynamic simulations are performed using an existing in-house aerodynamic solver for rotating systems [3], which is based on low-fidelity engineering models. The solver employs a Blade-Element Momentum (BEM) formulation, extended to account for unsteady aerodynamic effects on the blades. This approach enables the computation of both steady and time-dependent aerodynamic loads, as well as the extraction of the associated induced velocity fields.

3 RESULTS

As a preliminary step towards the aeroelastic stability assessment, once-per-revolution (1P) hub loads are computed by applying a steady one degree pitch perturbation, which induces an asymmetric inflow on the system. The resulting response provides an initial indication of the effect of the SRVs on the hub load characteristics.

Fig.1 shows a comparison of these hub loads for the propeller and the swirl-recovery vanes (SRVs). The right figure presents in-phase components, while the left figure contains the (smaller) off-axis components [3]. The SRV loads are decomposed into two components: those due to a steady pitch condition and those induced by the propeller's unsteady 1P inflow. It can be observed that the pitch motion of the SRVs (purple) is the dominant contributor to the overall hub loads, while the effect of the unsteady inflow perturbation (orange) is minor.

According to results presented in [4], the vertical force F_z has a stabilizing influence on whirl flutter, whereas the moment M_z, originating from the coupling between pitch and yaw, acts as the primary destabilizing mechanism. Consequently, the increase in F_z induced by the SRVs is of the same order of magnitude as that of the propeller, while the rise in the destabilizing M_z is small.

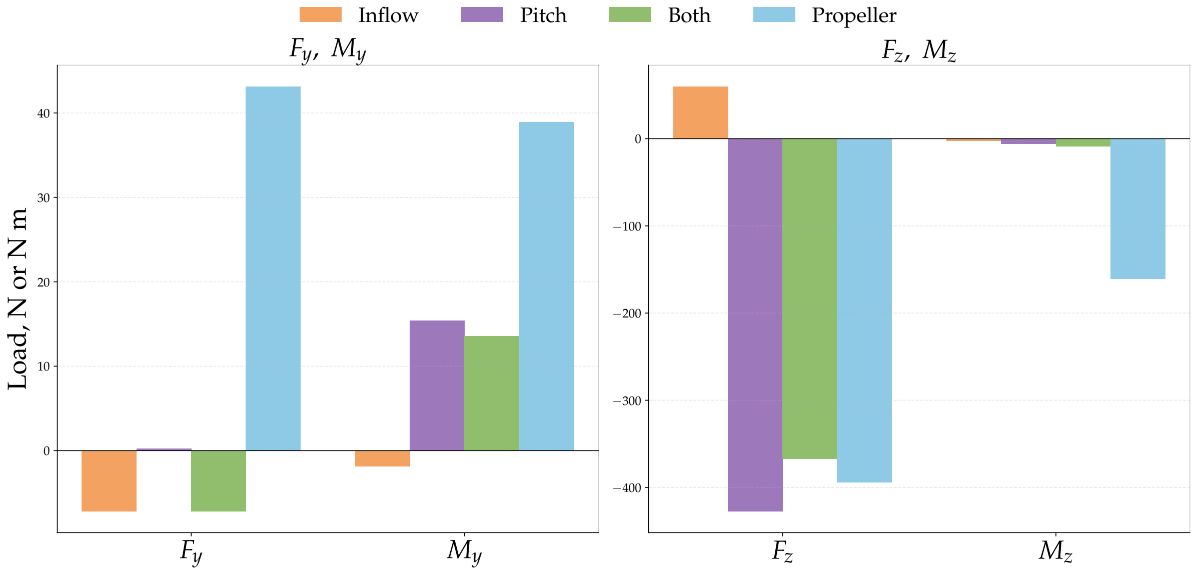

Figure 1: Comparison of 1P hub loads for the propeller and the SRVs

Additionally, transfer matrices and stability boundaries are computed for a two-degree-of-freedom (DOF) propeller–SRV–pylon system, using a five-bladed rigid propeller with R_{prop}=1.25 m radius previously employed in studies by one of the authors [2]. The SRVs consist of four stator blades located 0.5 R_{prop} downstream of the propeller, while the hinge point of the nacelle system is 0.85 m behind the propeller plane [2].

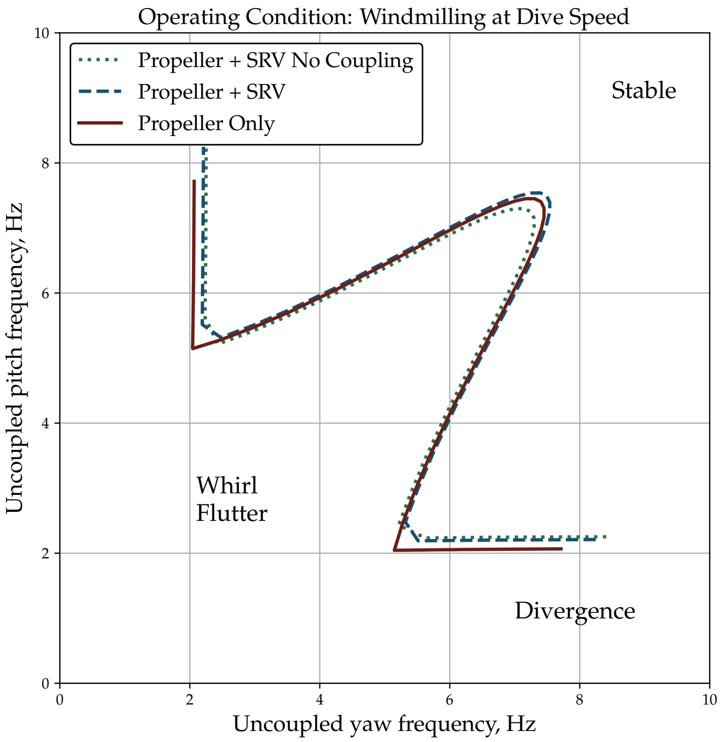

Figure 2: Comparison of whirl flutter stability map prediction for propeller only and coupled and uncoupled propeller and SRV

Figure2 presents the stability boundary of the trimmed system for windmilling condition (zero power at dive speed), separating stable and unstable combinations of pitch and yaw pivot stiffness. The dashed line, representing the case with SRVs, indicates a slight destabilizing shift of the whirl flutter boundary. However, ignoring the coupling term (bottom-left block in Eq.1) results in a stabilizing effect, as indicated by the dotted line. This shows that the coupling term plays a destabilizing role in the aeroelastic behavior of the system.

The inclusion of SRVs also leads to a shift of the divergence boundary towards less stable conditions, which can be explained by divergence being a steady instability dominated by the vertical force F_z which is increased by the presence of the SRVs.

4 GENERAL CONCLUSIONS

In general, the inclusion of swirl recovery vanes (SRVs) is found to have only a small influence on the stability of the two-DOF system with respect to whirl flutter. Although the 1P hub load response shows an increase in the primary stabilizing force F_z, its contribution to the overall stability margin remains limited due to the short lever arm relative to the hinge point. At the same time, the 1P hub loads exhibit a slight increase in the destabilizing moment M_z, ultimately leading to a slight destabilization in this configuration.

Furthermore, while the hub load study indicated that motion-induced loads on the SRVs have a more pronounced effect than the loads due to the inflow perturbations from the propeller, the whirl flutter stability boundaries reveal that the coupling of these effects leads to a destabilizing shift, requiring their inclusion.

The final paper will include a more in-depth parameter study on the SRV hub loads as well as a verification of the low-fidelity approach with mid-fidelity unsteady panel method results. Regarding whirl flutter, the effect of the SRVs on the whirl flutter behavior of the simplified 2-DOF whirl system as well as a full aircraft model [5] will be shown.

5 REFERENCES

[1] Sinnige, T., van Kuijk, J. J., Lynch, K. P., et al. (2015). The effects of swirl recovery vanes on single-rotation propeller aerodynamics and aeroacoustics. In *21st AIAA/CEAS Aeroacoustics Conference*.

[2] Koch, C. (2024). *Whirl Flutter Stability Analysis Using Propeller Transfer Matrices*. Ph.D. thesis, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Aeroelastik, Göttingen, Germany.

[3] Koch, C., Böhnisch, N., Verdonck, H., et al. (2024). Comparison of Unsteady Low- and Mid-Fidelity Propeller Aerodynamic Methods for Whirl Flutter Applications. *Applied Sciences*, 14(2). doi:10.3390/app14020850.

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

[5] Noël, J., Koch, C., Stickan, B., et al. (2024). Influence of blade elasticity on the whirl flutter stability of a propeller-driven aircraft. In *Proceedings of the International Forum on Aeroelasticity and Structural Dynamics (IFASD) 2024*. Den Haag, NL.