AEROELASTIC DAMPING AUGMENTATION AND FLUTTER ANALYSIS FOR A HIGH-ASPECT-RATIO WING AIRCRAFT IN THE TRANSONIC FLIGHT REGIME

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1 MAIN RESEARCH QUESTION

This paper aims to demonstrate a workflow for the design and verification of Active Flutter Suppression (AFS) controllers in the transonic flight regime. The investigation is part of the DLR project ACTIVATE (Active and semi-active technologies for transonic flutter control), which main goal is to develop an understanding of active and semi-active approaches for flutter suppression at transonic Mach numbers. The workflow is demonstrated for the DLR-F25 aircraft, which is characterized by a high aspect ratio wing representing a possible future aircraft configuration.

2 RESEARCH METHOD

The DLR-F25 is a short-medium range aircraft configuration developed in the German Luftfahrtforschungsprogramm (LuFo) project VirEnfREI as a common research baseline model to benchmark future aircraft concepts [1]. In this study, the DLR-F25 TWIST04 configuration, described by Streitenberger & Feldwisch [2], is used together with a structural model for the cruise mass case (MCRUI: 100% payload, 20% fuel). The aerodynamic design shape model of the DLR-F25 TWIST04 configuration is shown in Fig. 1. The CFD grids are build for a half-model of the DLR-F25, which is later mirrored to obtain a full model, while the Nastran Finite Element (FE) model employed is adopted from [2].

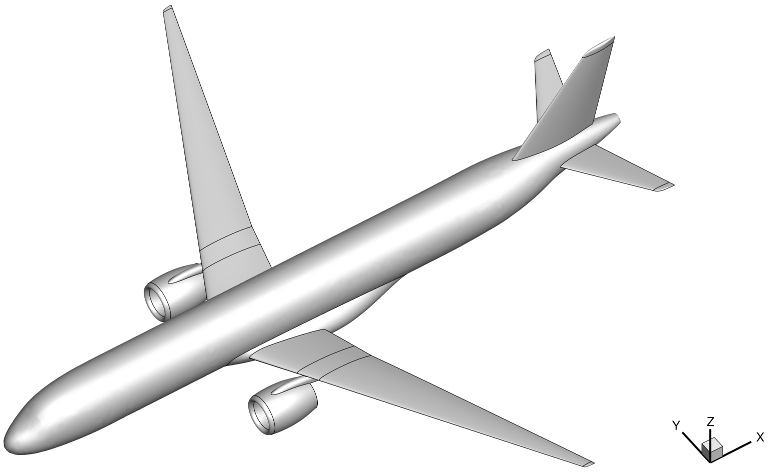

Figure 1: Aerodynamic model of the DLR-F25 TWIST04 configuration

The paper applies the workflow established in [3] to the DLR-F25: the Generalized Aerodynamic Forces (GAFs) are obtained from Linearized Frequency Domain (LFD) RANS computations to provide an accurate representation of the unsteady pressure field at various flight points. State-space models are derived to enable control activities based on this LFD data. Finally, time-domain CFD-CSM computations including the controller dynamics are used to validate the final flutter suppression controller in a non-linear, time-accurate aeroelastic simulation. Both, LFD and CFD-CSM computations are done with the DLR TAU-Code in the FlowSimulator environment.

In an initial step, steady state CFD computations are performed at different altitudes for increasing Mach numbers at the design lift coefficient. Once the trim point is known, flutter analyses are conducted to identify the flutter boundary of the configuration, which will be extended using multifunctional flap deflections commanded by the AFS controller. The flutter computations are performed both in frequency and time domain. In the former, LFD GAFs are derived starting from the previously computed steady state. They are incorporated in the equations of motion of the aeroelastic system formulated in the frequency domain. The resulting eigenvalue problem, which yields the flutter curves, is solved using the g-method by fixing the Mach number and varying the flight altitude until a matched flutter condition is found. In the time domain, the initial steady CFD data are employed for coupled CFD-CSM computations to investigate the dynamic aeroelastic stability without any linearization of the aerodynamic forces.

3 RESULTS

The steady CFD solutions are computed at specific altitudes, i.e. flight levels (FL) assuming static pressure and temperature based on the U.S. Standard Atmosphere. For all flight points defined by altitude and Mach number, a target lift computation for $C_{L,design} = 0.581$ is performed, in which the angle of attack is iterated until the target lift coefficient is obtained. Figure 2 shows the variation of angle of attack with Mach number to obtain $C_L = 0.581 \pm 0.0005$ at FL100. The relation between Mach number and angle of attack to obtain the target lift coefficient is non-linear.

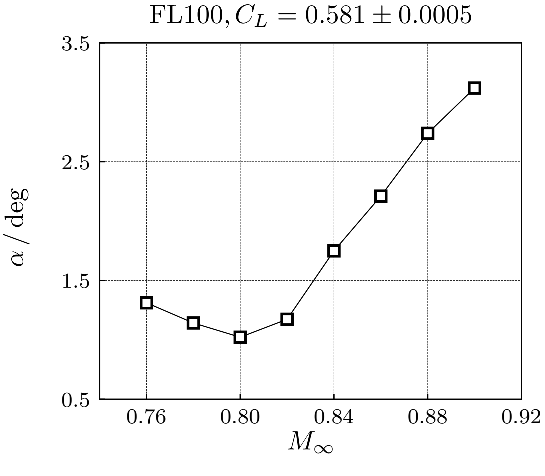

Figure 2: Angle of attack α at FL100 to obtain the design lift coefficient $C_{L,design} = 0.581$

The steady state is employed as a starting solution to derive LFD-based GAFs and initialize coupled CFD-CSM computations as described in Sec. 2. Preliminary analyses are carried out neglecting rigid body modes. Results for Mach numbers $M_\infty = 0.60, 0.75, 0.78, 0.80$ are shown in Fig. 3 with the blue lines denoting the unstable flutter points according to frequency domain predictions. The results show a fair coherence between the frequency and time domain methods. For the controller synthesis, the LFD-based state-space model enables the inclusion of transonic effects. The CFD-CSM simulation will then allow the assessment of the controller in a flow environment including non-linear transonic aerodynamics.

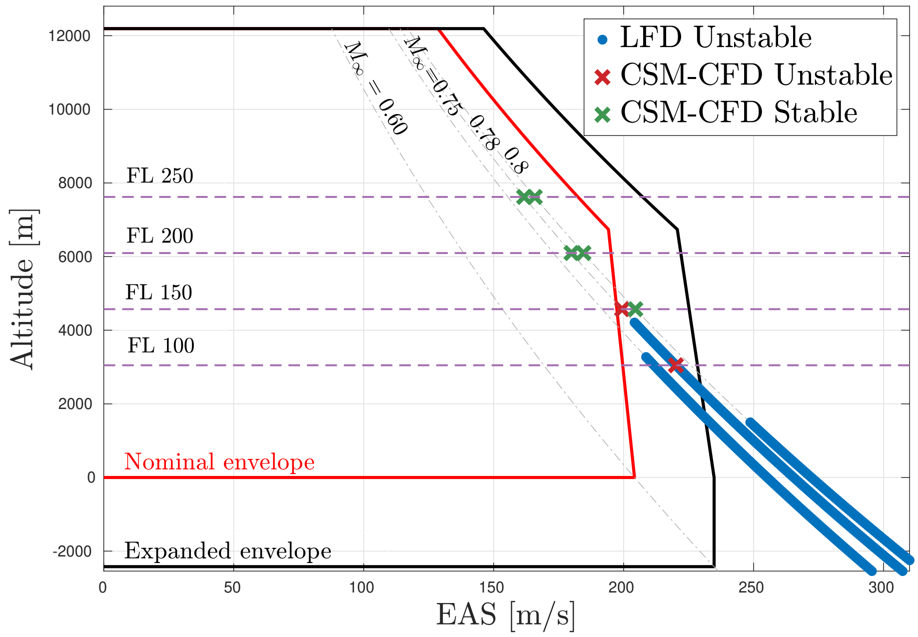

Figure 3: Flutter results based on LFD and time-domain CFD-CSM computations with 50 elastic modes w/o rigid body modes.

4 CONCLUSION

The preliminary flutter computations presented in Sec. 3 have identified the flutter boundaries, denoted by the blue lines, to be expanded via AFS technologies. Future computations will include rigid body modes and eventually more critical load cases. Based on these computations, the aeroelastic system will be further modelled in a state-space form and enhanced with sensor and actuator dynamics to permit model-based control activities. A robust controller will be derived to expand the flutter boundary. Finally, the controller will be integrated in the CFD-CSM environment to verify the stability of the closed-loop system.

5 REFERENCES

[1] Wöhler, S., Häßy, J., and Kriewall, V. (2024). Establishing the DLR-F25 as a research baseline aircraft for the short-medium range market in 2035. In *34^{th} Congress of the International Council of the Aeronautical Sciences, ICAS*. Florence, Italy.

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