CFD-BASED IDENTIFICATION OF MOTION-INDUCED AIRLOADS ON A ROTOR CONFIGURATION IN HOVER AND FORWARD FLIGHT

Christoph Kaiser* and David Quero

*DLR (German Aerospace Center), Institute of Aeroelasticity,
Bunsenstr. 10, 37073 Göttingen
Germany

ABSTRACT

The identification of motion-induced airloads on an aircraft configuration is a well-established method for the assessment of flutter instabilities using linear stability theory. The objective of the process is to identify the generalized aerodynamic force (GAF) matrix which enables the coupling of the aerodynamics with the structural model in the Laplace domain. For fixed-wing configurations, several methods exist to compute the entries of the GAF matrix depending on the aerodynamic modelling. For high-fidelity CFD-based aerodynamics, particularly suited for transonic flows and mild flow separation, the state-of-the-art is the linear frequency domain (LFD) solver that returns the first-harmonic aerodynamic response to harmonic forced motion [1]. Alternatively, forced-motion simulations using either monofrequent or broadband excitation are carried out in the time domain, from which the GAF entries are recovered through input-output transfer-function identification [2].

For rotary-wing configurations, the assessment of stability must account for the time-periodic conditions, particularly in forward flight conditions due to rotation and forward motion. The complex flow conditions at the rotors, with parts of the flow field exhibit transonic or separated conditions, require the use of high-fidelity aerodynamics. Quero [3] presented an extension of the fixed-wing frequency-domain approach for flutter analysis to linear time-periodic (LTP) systems using the harmonic transfer function (HTF) matrix, also denoted as the harmonic GAF matrix, which contains higher harmonics produced by the rotor's periodic motion.

This work will establish the HTF matrix for a three-dimensional rotor configuration using CFD-based aerodynamics and monofrequent excitation [4] of rigid pitching rotor blades as well as flexible modes. Both primary flight regimes of rotary-wings, hover and forward flight, are considered. The next-generation CFD framework CODA [5] is employed to perform unsteady Euler and RANS simulations of the Caradonna-Tung configuration [6]. The Caradonna-Tung is a well-known test case used in the validation and verification of CFD solvers for rotary wings [7]. It is a two-bladed rotor with each blade having a rectangular planform and a constant NACA0012 airfoil section along the span.

Figure 1 shows the computational mesh of the Caradonna-Tung configuration, which operates with a collective pitch angle of $\theta_c = 8°$ and pre-cone angle of $\beta_0 = 0.5°$. Besides the two primary flight regimes, two rotor speeds are considered: 1250 RPM, giving a subsonic tip Mach number $\mathrm{Ma}_{tip} = 0.439$, and 2500 RPM, yielding in transonic flow with $\mathrm{Ma}_{tip} = 0.877$. Figure 2 displays the blade mode shapes employed in this study, where the flexible mode shapes are obtained from a Euler-Bernoulli beam model. First results in terms of the thrust coefficient for the hover case are presented in Figure 3. The responses for all three mode shapes are shown for an excitation frequency of 2.64 Hz with very small amplitude, where after a brief transient phase a single harmonic response is obtained, as expected.

The results of this paper will allow employing high-fidelity CFD-based aerodynamics for stability analysis of complex rotary-wing configurations.

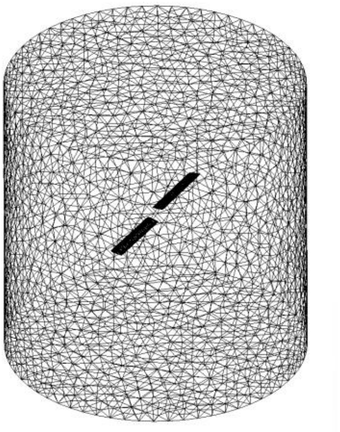

Figure 1: Computational mesh of the Caradonna-Tung rotor configuration

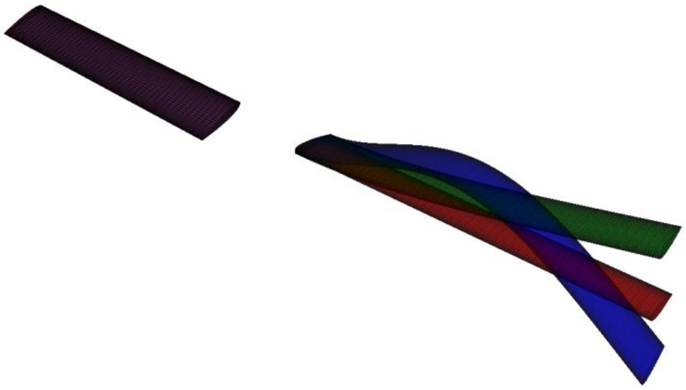

Figure 2: Rotor blade mode shapes on the CFD surface mesh: pitch (red), first bending (green), second bending (blue).

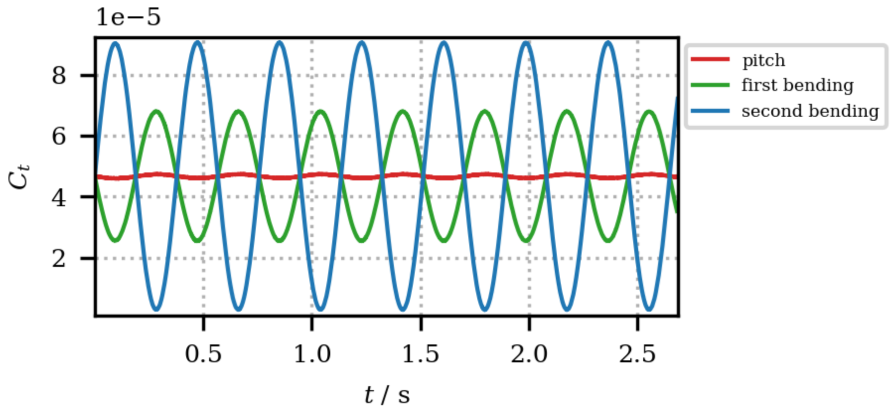

Figure 3: Unsteady response of the thrust coefficient for the excitation of the three mode shapes (Euler, 1250 RPM)

References

[1] Thormann, R. and Widhalm, M., “Linear-Frequency-Domain Predictions of Dynamic-Response Data for Viscous Transonic Flows”, AIAA Journal, Vol. 51, 2013

[2] Kaiser, C., Thormann, R., Dimitrov, D., and Nitzsche, J. “Time-linearized Analysis of Motion-induced and Gust-induced Airloads with the DLR TAU Code”, Deutscher Luft- und Raumfahrt Kongress 2015, Rostock, Germany, 2015

[3] Quero, D., “A frequency-domain flutter solver for rotary-wing aeroelasticity”, Journal of Fluids and Structures, Vol. 139, 2025

[4] Hidir, E.K., Uyanik, I. and Morgül, Ö., “Harmonic transfer functions based controllers for linear time-periodic systems“, Transactions of the Institute of Measurement and Control, Vol. 41, 2019

[5] Leicht T., Jägersküpper J., Vollmer D., Schwöppe A., Hartmann R., Fiedler J. and Schlauch T. “DLR-Project Digital-X Next Generation CFD Solver Flucs“, Deutscher Luft- und Raumfahrtkongress 2016, Braunschweig, Germany, 2016

[6] Caradonna, F.X. and Tung, C., “Experimental and Analytical Studies of a Model Helicopter Rotor in Hover”, NASA Technical Memorandum 81232, 1981

[7] Palacios, F., Economon, T.D., Aranake, A.C., Copeland, S.R., Lonkar, A.K., Lukaczyk, T.W., Manosalvas, D.E, Naik, K.R., Padrón, A.S., Tracey, B., Variyar, A. and Alonso, J.J., “Stanford University Unstructured (SU2): Open-source Analysis and Design Technology for Turbulent Flows”, AIAA SciTech, 52nd Aerospace Sciences Meeting, National Harbor, Maryland, USA, 2014