

DLM- AND CFD-BASED CONTINUOUS TURBULENCE ENCOUNTER FOR A HIGH ASPECT RATIO CONFIGURATION

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ABSTRACT

Modern aircraft design increasingly aims at higher aerodynamic efficiency, particularly through the use of high-aspect-ratio wings. At the same time, recent studies indicate that aviation's climate impact might be mitigated by operating aircraft at different flight altitudes, since the formation and persistence of contrails are strongly altitude-dependent [1]. These considerations together motivate a reassessment of how aircraft loads are predicted, especially when flight trajectories begin to move beyond today's standard cruise levels.

When aircraft operate at different altitudes and speeds, however, the severity of aircraft loads and accelerations evoked by continuous turbulence is expected to vary, e.g. with decreasing flight altitude, the root mean square value of the vertical gust velocity increases and corresponding responses change [2]. Since accelerations are not only an important aspect of fatigue loads, but also an important aspect of passenger comfort and ultimately public acceptance, this adds further importance to the fidelity of the aerodynamic modeling used in the simulations.

Traditionally, loads due to continuous turbulence encounters have been computed using panel-based aerodynamic methods, such as the Doublet Lattice Method (DLM). These methods are computationally efficient and well established within industrial certification processes. However, they rely on simplified aerodynamic assumptions. In particular, they provide only a coarse geometric representation of the aircraft configuration and neglect viscous effects in the flow, resulting in an unsteady but strictly linear aerodynamic model.

In contrast, higher-fidelity aerodynamic modelling based on CFD is already frequently employed for the computation of discrete gust loads, see [3] and [4]. In this context, CFD-based approaches often rely on linearized, frequency-domain solvers. Although these methods still result in an unsteady linear aerodynamic representation, they take into account the steady base flow including a more complex aircraft geometry and more realistic flow features. Thereby, they offer a significantly higher level of physical fidelity than traditional panel-based approaches. So the first objective of the present paper is to investigate the impact of CFD-based frequency-domain modelling, in comparison with the traditional panel-based approach, on the computation of loads arising from continuous turbulence encounters.

However, with decreasing flight altitude the amplitudes of atmospheric turbulence increase across all excitation frequencies and nonlinear effects in the aeroelastic response may arise. Such effects cannot be captured by linear frequency-domain formulations, regardless of the underlying aerodynamic fidelity. Therefore, as a second step, this paper also investigates a CFD-based time-domain approach (URANS), which is capable of capturing potential unsteady nonlinear effects in the response to continuous turbulence. This allows for a more comprehensive assessment of the relevance of nonlinearities and provides insight into the limitations of linearized modelling assumptions for future high-aspect-ratio wing configurations and extended operating envelopes.

The computations in this paper are carried out for the short-medium range configuration of the DLR-F25 [5] which features a wing with high aspect ratio. The aerodynamic and aeroelastic models adopted are based on the ones that are presented by Streitenberger and Feldwisch [6].

The steady pressure distribution of the configuration is shown in Fig. 1 for the cruise condition of the aircraft with a target lift coefficient of $C_{\text{lift}} = 0.6015$ at $Ma\ 0.78$ and $Re\ 21.6\ \text{Mio}$.

The continuous turbulence spectrum is prescribed by the von Kármán spectrum (see Fig. 2), which is transformed into the time domain via a Fast Fourier Transform (FFT) that incorporates a random phase input (illustrated in Fig. 3). For time-domain unsteady URANS computations the field-velocity method [7] is employed in DLR's TAU code [8] to impose the turbulent velocity fluctuations onto the computational grid. CFD-based frequency-domain computations are computed using DLR's Linearized Frequency Domain (LFD) solver, TAU-LFD [9].

Finally, the load collectives and aerodynamic coefficients obtained from the DLM-based and CFD-based simulations will be compared, see Fig. 4, providing insight into how the higher-fidelity CFD modelling influences the aircraft's load spectrum relative to the conventional DLM.

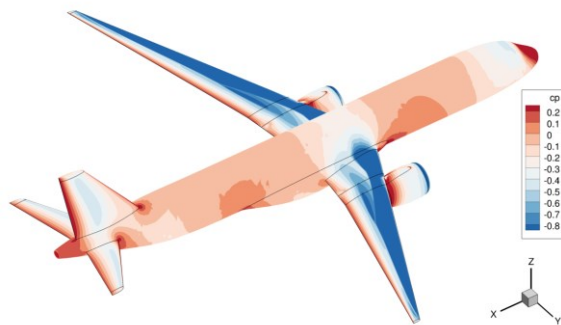


Fig. 1 Steady pressure distribution for the cruise configuration: $Ma\ 0.78$, $Re\ 21.6\ \text{Mio}$

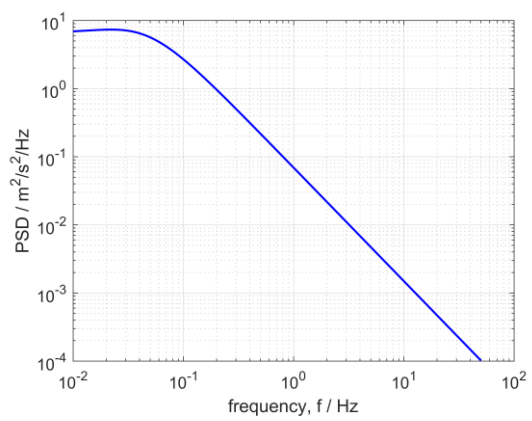


Fig. 2 Von Kármán spectrum for continuous turbulence encounter

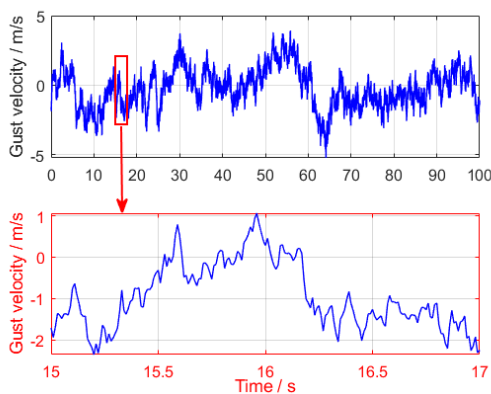


Fig. 3 Derived time-domain signal (top: full signal, bottom: snippet $t=15\dots17\text{s}$)

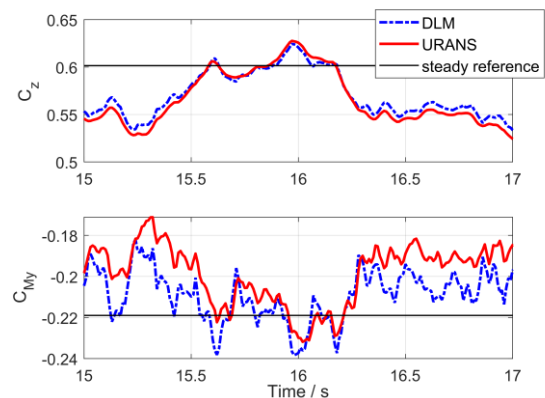


Fig. 4 Exemplary DLM- and CFD-based simulation results

References

- [1] Teoh, R., Schumann, U., Gryspeerdt, E., Shapiro, M., Molloy, J., Koudis, G., Voigt, C., and Stettler, M.. „Aviation Contrail Climate Effects in the North Atlantic from 2016 to 2021“. *Atmospheric Chemistry and Physics* 22, Nr. 16: 10919–35. <https://doi.org/10.5194/acp-22-10919-2022>.
- [2] Handojo, V., and Cumnuantip, S.. „Influence of Cruise Altitude Variation on the Turbulence Loads of a Medium-Range Transport Configuration“. In *International Forum on Aeroelasticity and Structural Dynamics*, 2024.
- [3] Bekemeyer, P. „Rapid Computational Aerodynamics for Aircraft Gust Response Analysis“. Phd, University of Liverpool, 2018. <https://doi.org/10.17638/03027827>.
- [4] Weigold, W., Stickan, B., Travieso-Alvarez, I., Kaiser, C., and Teufel, P.. „Linearized Unsteady CFD for Gust Loads with TAU“. In *International Forum on Aeroelasticity and Structural Dynamics*, 2017.
- [5] Wöhler, S., Häßy, J., and Kriewall, V.. „Establishing the DLR-F25 as a Research Baseline Aircraft for the Short-Medium Range Market in 2035“. In *34th Congress of the International Council of the Aeronautical Sciences*, 2024.
- [6] Streitenberger, K. M., and Feldwisch, J. M.. „CFD-Based Aeroelastic Maneuver and Gust Loads Analysis for a High Aspect Ratio Wing Configuration“. In *AIAA SCITECH 2025 Forum*, 2025. <https://doi.org/10.2514/6.2025-1663>.
- [7] Heinrich, R. „Simulation of Interaction of Aircraft and Gust Using the TAU-Code“. In *New Results in Numerical and Experimental Fluid Mechanics IX*, 124:503–11. Notes on Numerical Fluid Mechanics and Multidisciplinary Design. Springer International Publishing, 2014. https://doi.org/10.1007/978-3-319-03158-3_51.
- [8] Schwamborn, D., Gerhold, T., and Heinrich, R.. „The DLR TAU-Code: Recent Applications in Research and Industry“. In *European Conference on Computational Fluid Dynamics (ECCOMAS)*, edited by P. Wesseling, E. Onate, J. Periaux, 2006.
- [9] Thormann, R., and Widhalm, M.. „Linear-Frequency-Domain Predictions of Dynamic-Response Data for Viscous Transonic Flows“. *AIAA Journal* 51, Nr. 11: 2540–57. <https://doi.org/10.2514/1.J051896>.