

GUST LOAD ALLEVIATION (GLA) CONTROLLER SYTHESIS USING HIGH-FIDELITY TRANSONIC AERODYNAMICS

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ABSTRACT

Gust Load Alleviation (GLA) is a technique which aims to reduce the loads inflicted on the wing caused by disturbances of the airflow surrounding the aircraft, such as gusts or atmospheric turbulence. Active control strategies aiming to reduce the aforementioned loads have been thoroughly investigated in the recent years. Accurate modelling of the underlying aeroelastic phenomena is needed in order to properly assess the issue and to provide an adequate control strategy. As a result, the present work develops the aeroservoelastic model for the airfoil NACA64A010, using a high transonic aerodynamic model.

Whereas the Doublet Lattice Method (DLM) is a current standard practice in the industry due to its low computational cost, it fails to account for aerodynamic effects related to thickness, shock wave formation or viscosity [1]. Furthermore, according to Tijdeman [2] the principle of superposition does not hold upon entering the transonic regime and the aerodynamic perturbations depend on the steady mean state. In order to account for these effects and to obtain a precise aerodynamic description, DLR's CFD, TAU and Flow Simulator Forced Motion (FSFM) Linear Frequency Domain (LFD) [3] solvers, have been used for the computation of the high-fidelity unsteady aerodynamics. This precise aerodynamic modelling allows to account for the effect of the steady angle-of-attack (AoA) in the aeroelastic response to gusts and its influence in the controller modelling and tuning.

Controller synthesis requires a time-domain description of the system to be controlled, a state space system. Meanwhile the structural model shall be described by a three degree-of-freedom (heave, pitch and flap) second-order system, the Generalized Aerodynamic Forces (GAF) are obtained in the frequency domain. FSFM solves the aerodynamic field in a way such that the output is a sampled signal which contains, for each reduced frequency k , the values of the transfer function of the GAF. Techniques using Rational Function Approximation (RFA) introduce an error due to the least square fit. Thus, the tangential interpolation method based on the Loewner framework, presented in [4], is used to obtain a reduced order, time continuous aerodynamic model. Figure 1 compares the GAF-sampled LFD responses with aerodynamic models obtained through tangential interpolation for three angles of attack, as well as the DLM, all at Mach 0.8.

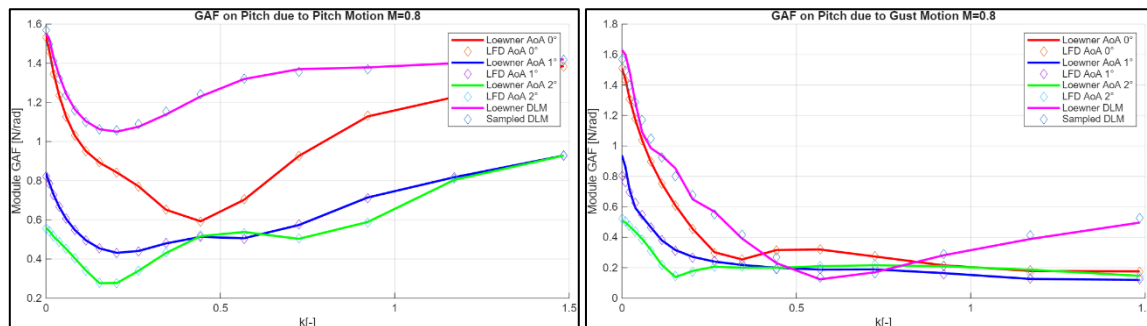


Figure 1. GAF LFD and Loewner interpolated model for three angles of attack and DLM, for pitch at Mach 0.8

Within this context, the present work aims to develop a controller suitable for Gust Load Alleviation, considering the steady angle-of-attack of the flow. The load alleviation behaviour is commonly studied through the variation in the Wing Root Bending Moment (WRBM) caused by the disturbance. As the present work considers an airfoil, an estimation of the WRBM can be done through the variation heave GAF value, which would contribute to the build-up of the WRBM in the corresponding 3D configuration.

To understand to which extent the steady angle-of-attack influences the aerodynamic response to a gust and the controller tuning, aeroservoelastic models for the NACA64A010 at three different angles-of-attack (0° , 1° and 2°) have been obtained. Figure 2 shows the heave GAF open loop response of the aforementioned system to a 1-cosine gust of amplitude 10 m/s, for the three different angles-of-attack.

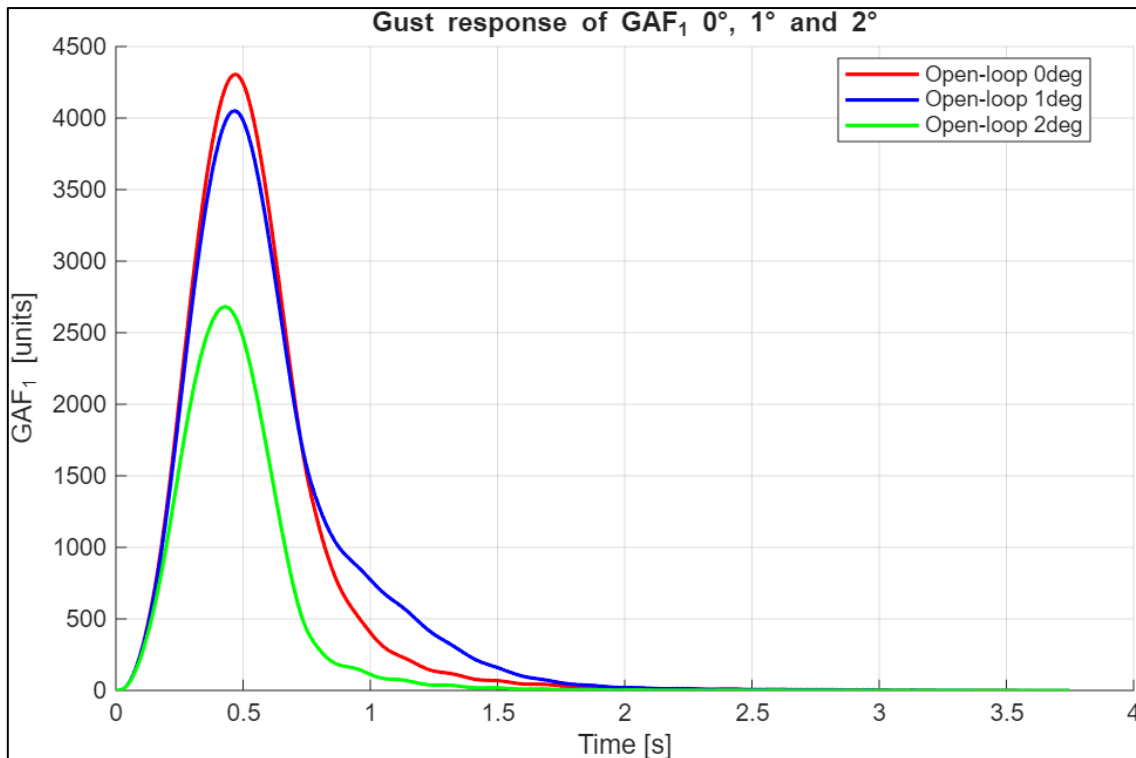


Figure 2. Aeroservoelastic open loop system response to '1-cosine' gust. GAF variation with respect to steady state in the heave direction, with respect to time, for different angles-of-attack

These systems are controlled through a hinge moment introduced in the flap degree-of-freedom. The controller structure that has been used on a first approach is the fullstate-feedback Linear Quadratic Regulator (LQR) structure, which features optimum control objectives by minimising a cost function, dependant on both the states and the inputs. It becomes obvious from Figure 2, that each of the models corresponding to an angle-of-attack requires from an independent controller, with its subsequent tuning. The tuning of the LQR controller is done via the parameter ρ , which correlates the weighting matrices Q (associated to the weighting of the states) and R (associated to the weighting of the inputs). These matrices are necessary to solve the Riccati equation, minimising the cost function accordingly. [5] The tuning goal is the obtention of the values of the parameter ρ , for which each independent system can be considered to be tuned, with the aim of minimising the heave associated lift and taking into account the maximum actuator rate of $30^\circ/\text{s}$.

It is clear from Figure 2 that the influence of the steady-state angle-of-attack in the aeroservoelastic model introduces notorious changes from one model to another and thus shall be accounted for.

As a result, the H_∞ controller structure will be used, a robust control method, which is designed to minimize the worst-case effect of a disturbance and allows for the introduction of model uncertainties, in this case the angle-of-attack [6]. Figure 3 shows the open-loop and closed-loop response of the aeroservoelastic system for the three angles-of-attack, using the H_∞ controller structure.

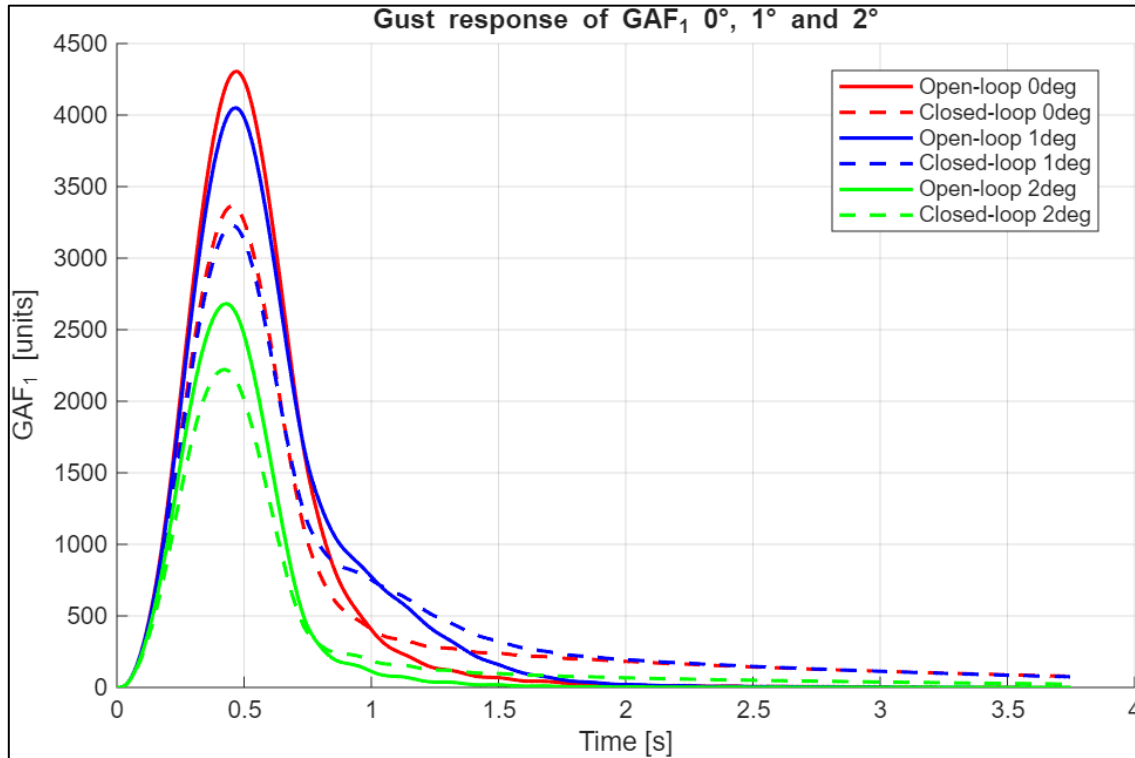


Figure 3. Aeroservoelastic system closed (H_∞) and open loop response to '1-cosine' gust. GAF variation with respect to steady state in the heave direction for different angles-of-attack

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