

MANEUVER LOAD ALLEVIATION FUNCTION DESIGN EMPLOYING A LOAD ESTIMATOR

*Matheus Lopes Silva**, *Robin Vernay*, *Haythem Bouzouita*, *Valérie Pommier-Budinger*,
Yves Brière

*Airbus Operations SAS,
316 Route de Bayonne, 31300, Toulouse
France*

ABSTRACT

In the context of next-generation aircraft, high aspect ratio wings represent a key enabling technology. By reducing the induced drag, these wings allow for a substantial decrease in fuel consumption and CO₂ emissions [1]. However, enlarging the wing aspect ratio results in increased loads, notably the wing root bending moment, thus necessitating a more robust and, consequently, heavier structural design. Active load alleviation functions are a lever to reduce these loads, minimizing potential structural mass increases and allowing the benefits of aerodynamic gains to be fully exploited.

Maneuver load alleviation (MLA) functions have been long studied as a method to reduce the wing root bending moment (WRBM) during critical maneuvers. This is achieved by symmetrically deflecting the ailerons to shift the lift distribution inboard over the wing [2]. Various control techniques have been employed to this end, such as deflecting the ailerons proportionally to load factor [3], H ∞ controller [4], H ∞ controller with input saturation [5], control allocation [6,7] and Model Predictive Control (MPC) [8]. Despite these efforts, some gaps remain in the current literature. The proportional deflection-to-load-factor law, while being a simple and effective MLA technique, is prone to unneeded activations because high load factors do not necessarily correlate with proximity to the limit loads, meaning a load reduction may not be required. For control allocation and MPC, both methods necessitate online optimization, which presents obstacles to real-time implementation. Furthermore, feasible solutions are not always guaranteed when using a constrained MPC formulation [9]. Finally, with the exception of [8], existing controllers have generally not been assessed under multiple flight conditions and mass configurations.

This paper presents a new methodology for MLA design. The approach leverages a robust WRBM estimator, developed for all flight conditions and mass configurations in prior research [10], to develop a new multi-objective control system. This system integrates flight dynamics and load requirements and employs the ailerons and elevator for active maneuver load control. Additionally, the proposed control law does not require real-time optimization.

The proposed methodology is then applied to the XRF1-HARW aircraft, a platform developed by Airbus and the University of Michigan for research on highly flexible aircraft. Assessment is conducted via non-linear simulations using UM/NAST, a multidisciplinary framework developed by the University of Michigan for aeroelastic simulation [11]. Validation includes simulation of critical maneuvers, such as the Maneuver Vertical Stretch (MVS) [5], across multiple flight conditions and mass configurations.

Results demonstrate that the aircraft loads are effectively reduced to the proposed envelope under all tested conditions. Furthermore, the proposed control law successfully overcomes the identified literature gaps by: (i) Avoiding unnecessary activations (common in proportional deflection-to-load-factor laws) since the order depends directly on the WRBM estimation; (ii)

Avoiding real-time optimization; (iii) Validating the proposed strategy for the entire flight domain.

- [1] Ma, Yiyuan, and Ali Elham. "Designing high aspect ratio wings: A review of concepts and approaches." *Progress in Aerospace Sciences* 145 (2024): 100983.
- [2] White, Roland J. "Improving the airplane efficiency by use of wing maneuver load alleviation." *Journal of Aircraft* 8.10 (1971): 769-775.
- [3] Fabre, Pierre, et al. *System for Reducing the Forces Applied to the Wings and Particularly to the Root of the Wings of an Aircraft in Flight*. United States Patent US 5,186,416. United States Patent and Trademark Office. 16 Feb. 1993.
- [4] Strotteicher, Till, and Nicolas Fezans. "Automated Tuning of a Baseline Flight Control System with Maneuver Load Alleviation for an Energy-Efficient Passenger Airplane." 20th International Forum on Aeroelasticity and Structural Dynamics, IFASD 2024. 2024.
- [5] Burlion, Laurent, et al. "Longitudinal manoeuvre load control of a flexible large-scale aircraft." *IFAC Proceedings Volumes* 47.3 (2014): 3413-3418.
- [6] Hansen, John H., et al. "Load alleviation of flexible aircraft by dynamic control allocation." *Journal of Guidance, Control, and Dynamics* 45.10 (2022): 1890-1898.
- [7] Gaulocher, Sebastian L., et al. "Aircraft load alleviation during maneuvers using optimal control surface combinations." *Journal of Guidance, Control, and Dynamics* 30.2 (2007): 591-600.
- [8] Pereira, M. De Freitas Virgilio. *Constrained Control for Load Alleviation in Very Flexible Aircraft*. Diss. PhD. Thesis, University of Michigan, 2022.
- [9] Kopf, Michael, et al. "Model predictive control for aircraft load alleviation: Opportunities and challenges." 2018 annual american control conference (ACC). IEEE, 2018.
- [10] Lopes Silva, Matheus, et al. "Aircraft load estimation using a structured $H_\infty - H_2$ approach." 2025 13th International Conference on Systems and Control (ICSC). IEEE, 2025.
- [11] Cavalcanti, João B., and Carlos Cesnik. "Loads Control During Maneuvering in a Non-Still Atmosphere." *AIAA SCITECH 2025 Forum*. 2025.