Gust load alleviation with a Coanda-type flow actuator

Numerical simulation of time-varying active flow control for gust load alleviation on an aircraft wing

K. Khalil, S. Asaro, L. Klug, A. Bauknecht, *Institut für Strömungsmechanik, TU Braunschweig*

In Short

- RANS and Unsteady RANS simulations
- Coanda-type flow actuator implementation on aircraft wing for gust load alleviation
- Mutual interactions between Coanda-type load alleviation and laminar flow control
- Validation of wind tunnel experiments of gust generator and Coanda-type flow control wing.

Future air transport systems will need to fulfill much stricter environmental requirements, as e.g. outlined by the strategic European Aviation Roadmap described in the European Commission's Flightpath 2050 report, where a goal of 75 % reduction in CO_2 emissions per passenger-kilometer is defined by the year 2050 [1]. Together with a continuing increase in air transport volume by about 4–5 % annually [2], this goal can only be reached through application of new technologies that allow for substantial reductions of structural weight, aircraft drag, and fuel consumption.

This research project is part of the Cluster of Excellence SE^{2}A (Sustainable and Energy Efficient Aviation, EXC 2163/1) and investigates technologies for actively alleviating dynamic wing loads induced by gusts and maneuvers encountered by transport aircraft. If these peak aerodynamic wing loads can be suppressed, a safe reduction of wing weight – and consequently fuel consumption and emissions – becomes feasible. New technologies in the form of fluidic flow actuators have the potential to provide fast, efficient, and highly adaptive lift redistribution that alleviates these loads.

The first phase of the project involved low cost 2D Reynolds-Averaged Navier–Stokes (RANS) simulations of various potential flow actuation concepts for both sub- and transonic flight conditions [3], through that phase the Coanda-type actuator was identified as the most promising system for both cruise and low-altitude conditions. In the following phase; though compute project nii00166, this actuator was further improved to lower the performance loss of the clean airfoil when the Coanda jet is switched off, and restore the lost performance through minimal dual blowing of the actuator in-flight. Figure 1 [4] depicts an example case at design flight Mach number $M_\infty = 0.78$ with angle of attack $\alpha = 1.25°$ and

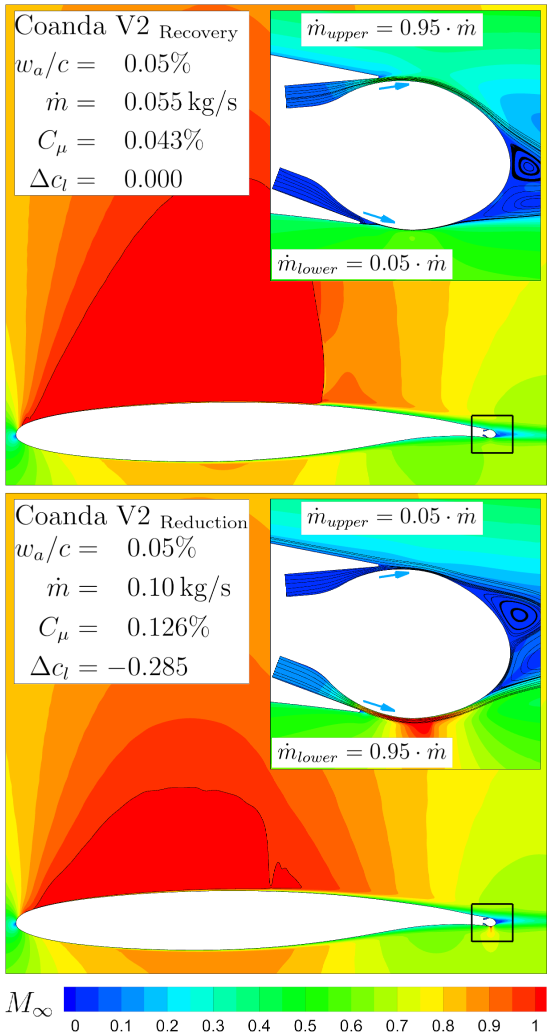

Figure 1: *Flow field around an improved dual-slot CoandÄ airfoil with blowing for baseline performance recovery (left) and active load alleviation (right), after [4].*

actuator slot height of $w_a/c = 0.05\,\%$. The improved Coanda V2 design achieves performance recovery of the clean airfoil through dual slot minimal blowing as indicated by the top figures, and achieves load reduction through the lower jet mainly as displayed by the lower figure. Additionally, the temporal behavior of the flow control was studied in the project using Unsteady RANS simulations with and without gust interactions to demonstrate the load alleviation capability of the system.

The upcoming final phase of the project involves three separate studies carried out in parallel. **Study A** continues the previous research through investigating the implementation and performance of the improved Coanda actuator on a

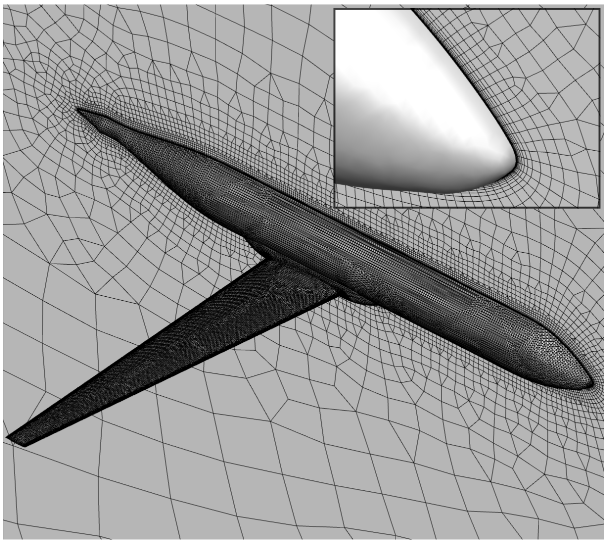

Figure 2: *Example of a produced grid for the Medium Range aircraft of the SE²A cluster.*

generic medium range aircraft configuration, displayed in Fig. 2, using time-resolved RANS. In this study, after establishing the baseline with the unactuated 3D wing and uniform actuator activation simulations, both time-varying flow control as well as spanwise-varied actuator deployment will be explored to identify optimal spanwise and temporal activation profiles that improve actuator control authority and efficiency. **Study B** investigates the interactions of Coanda-type active gust load alleviation and a hybrid laminar flow control system integrated upstream of it. Laminar flow control has the potential to significantly reduce friction drag on aircraft wings and might be present on future medium range aircraft. Currently, this technology is being investigated by different researchers in the Cluster of Excellence SE^{2}A, however the interactions of the two flow control approaches require additional study. Through this investigation, the effect of adding a Coanda-type actuator on the laminar flow control system will be evaluated, as well as the impact of the modified boundary layer on load alleviation operation both with and without gust encounters. **Study C** focuses on the comparison of URANS simulations with wind tunnel data for the purpose of CFD validation and analysis of flow details unavailable from the experimental results. The experiments are conducted in the MUB low speed wind tunnel at Technische Universität Braunschweig. A concluded first test characterized the steady and unsteady performance of a Coanda actuator integrated into the trailing edge of a supercritical airfoil [3]. This project phase will take place in parallel to a second test campaign that evaluates the interaction of an upstream gust generator with the Coanda airfoil.

WWW

https://www.tu-braunschweig.de/ism/forschung-und-arbeitsgruppen/flow-physics-of-load-reduction

More Information

[1] Darecki, M., Edelstenne, C., Enders, T., Fernandez, E., Hartman, P., Herteman, J.-P., Kerkloh, M., King, I., Ky, P., Mathieu, M., Orsi, G., Schotman, G., Smith, C., and Woerner, J.-D., Flightpath 2050 - Europe's Vision for Aviation, *European Commission technical report EUR 098 EN*, 2011. doi: 10.2777/50266

[2] Horn, M., Fischer, S., Dual-Bell Altitude compensating nozzles, *NASA-CR-194719, 1994*.

[3] Khalil, K., Asaro, S., Bauknecht, A., Active Flow Control Devices for Wing Load Alleviation, *Journal of Aircraft*, 2020, pp. 1-17. doi: 10.2514/1.C036426.

[4] Bauknecht, A., Beyer, Y., Schultz, J., Asaro, S., Khalil, K., Römer, U., Steen, M., Cavaliere, D., Fezans, N., Novel Concepts for Active Load Alleviation, *AIAA Scitech 2022 Forum*, San Diego, CA, USA, Jan. 3-7, 2022.

[5] Asaro, S., Bauknecht, A., Experimental Characterization of a Dual-Slot Coanda Actuator for Load Reduction, *AIAA Scitech 2022 Forum*, San Diego, CA, USA, Jan. 3-7, 2022.

Project Partners

Leibniz University Hannover, German Aerospace Center (DLR)

Funding

DFG Cluster of Excellence SE^{2}A (Sustainable and Energy Efficient Aviation) under Germany's Excellence Strategy EXC 2163/1 with project ID 390881007