Flow control technologies for energy-efficient aviation

Multifunctional leading edges and fluidic load alleviation for future transport aircraft

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In Short

- RANS and unsteady RANS simulations of gust and maneuver interactions on aircraft wings
- Surface jet actuators for alleviation of gust-induced loads
- Multifunctional leading edge device for alleviation of maneuver-induced loads
- Technology implementation on medium range aircraft and investigation of aeroelastic effects
- Consideration of structural deformation via multiphysics approach

This document presents an overview of the two innovative research projects MUVE and HyCoNoS, which focus on advancing the sustainability of air transport. These projects aim to address the ambitious goals outlined in the European Commission's Flightpath 2050 report, which targets a 75% reduction in CO_2 emissions per passenger-kilometer by 2050 [1]. The combination of growing global air traffic and the need to reduce aviation's environmental footprint necessitates the development of novel aircraft technologies that can reduce structural weight, minimize drag, and lower fuel consumption. Both projects, MUVE and HyCoNoS, are carried out at the Institute of Fluid Mechanics at TU Braunschweig and focus on complementary aspects of sustainable aircraft design–namely, aerodynamic load reduction and high-performance, energy-efficient systems.

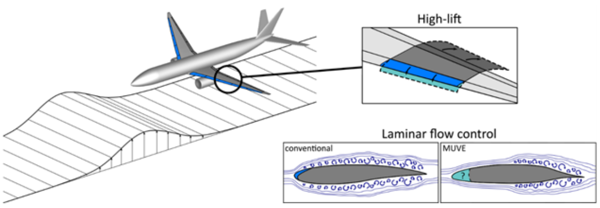

***Figure 1:** Multifunctional leading-edge device to be investigated in project MUVE.*

The MUVE project investigates the development of a multifunctional leading-edge system that integrates several aerodynamic functions into a single component. The goal is to achieve improved fuel efficiency and reduced environmental impact by combining laminar flow control, gust and maneuver load alleviation, and high-lift functionality in a single system. Laminar flow control, essential for minimizing drag, is achieved through hybrid laminar flow control techniques. These involve actively stabilizing the boundary layer at the leading edge through suction systems and maintaining this laminar boundary layer further downstream through a natural laminar flow design of the wing.

The multifunctional leading edge aims to not only support laminar flow but also provide high-lift functionality with systems such as Krueger flaps [2], while reducing the structural weight of the wing. High-lift systems are critical for take-off and landing performance but often introduce gaps and steps that disrupt laminar flow and increase drag. By minimizing gaps and optimizing aerodynamic performance, this project investigates innovative solutions for integrating high-lift components with laminar wing designs. Shape-variable or morphing wing concepts will also be explored as part of the effort to eliminate gaps and deformations in high-lift systems [3]. This flexibility could allow for improved aerodynamic performance across different flight phases while maintaining laminar flow and reducing drag.

In addition to enhancing laminar flow and high-lift performance, the MUVE project also targets the alleviation of gust and maneuver peak loads. These loads represent the maximum stresses experienced by the wing during its lifetime. By countering these peak loads, the project aims to reduce design stresses, enabling lighter structural designs and, consequently, improved fuel efficiency. The project focuses on methods for optimizing load distribution across the wing, specifically targeting the outer wing regions that are most affected by gusts and maneuvering forces. By using advanced high-lift designs and aerodynamic techniques, this project seeks to reduce load-induced bending moments and torsional stresses, ultimately contributing to the overall weight reduction and improved fuel efficiency of the aircraft.

On the other hand, the HyCoNoS project is centered on the use of fluidic actuators for active load alleviation during flight. Fluidic actuators, such as surface jet actuators, provide a dynamic and efficient means of redistributing lift across the wing to reduce the impact of gusts and maneuver loads. These actuators, particularly when strategically distributed along the span of the wing, offer the potential for significant load reduction without requiring large-scale mechanical systems. The project focuses on optimizing the geometry and activation strategy of these actuators to achieve maximum efficiency and effectiveness, particularly under varying flight conditions and across different altitudes.

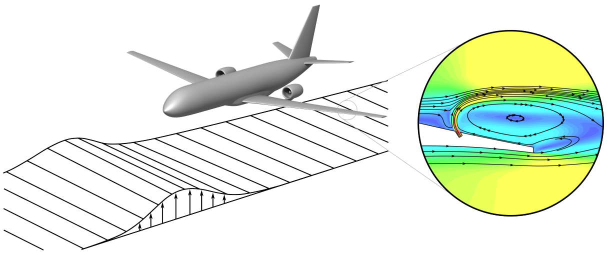

Figure 2: *Surface jet actuator on an aircraft wing section.*

The fluidic actuators are tested on a generic medium-range aircraft configuration designed within the SE^{2}A Cluster of Excellence (Sustainable and Energy-Efficient Aviation). This aircraft serves as a test case for investigating the potential of fluidic actuation in load alleviation and other advanced technologies. Through time-resolved Reynolds-Averaged Navier-Stokes (RANS) simulations, the project examines how spanwise actuator distributions and flight profiles can be optimized to minimize aerodynamic loads. These simulations will help identify critical operating conditions where actuator performance may be limited and provide insight into the most effective configurations for load alleviation. One of the key goals is to develop an optimal actuator configuration that can provide rapid, adaptive responses to gusts and maneuvers, reducing the need for large, heavy mechanical control surfaces.

The project also examines how different fluidic actuation systems interact with one another when activated in adjacent regions of the wing. Understanding these interactions is crucial for achieving effective and efficient load alleviation over the entire wing. Moreover, the project aims to explore the combination of active fluidic actuators with smart structural designs, which may exploit non-linear structural behaviors to further reduce aerodynamic loads. This hybrid load alleviation system holds the potential for combining passive and active technologies in a way that enhances the overall performance and sustainability of the aircraft. Additionally, the research investigates how the optimization of these actuators can reduce mass flow requirements, thus enhancing the overall efficiency of the system.

While project HyCoNoS is part of the SE^{2}A Cluster of Excellence, the MUVE project is within the scope of LuFo VI-3 research. The MUVE project is focused on developing aerodynamic technologies for reducing drag, supporting laminar flow, and improving high-lift and load-reduction systems, particularly through the use of multifunctional components like leading edges. In contrast, Project HyCoNoS focuses on the application of fluidic actuators for active load alleviation, aiming to create adaptive, efficient systems for dynamic load control. Although these projects are pursued separately, each contributes valuable insights into how different technologies can be used to reduce environmental impact, improve aerodynamic efficiency, and achieve significant reductions in CO_2 emissions in the aviation industry.

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https://www.tu-braunschweig.de/en/ism/research-workgroups/flow-physics-of-load-reduction

More Information

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Project Partners

HyCoNoS: Multiphysics group at IFL (TU Braunschweig); Group De Breuker at TU Delft; German Aerospace Center (DLR).
MUVE: IFL (TU Braunschweig), Universität Stuttgart, TU Hamburg.

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DFG Subject Area

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