4.1 Final publishable summary report

Executive Summary

Flap systems are highly efficient lift providing elements in low speed flight. A potential measure to shift the stall onset to higher limits can be found in an Active Flow Control (AFC) approach by pulsed blowing. The majority of corresponding research aims at understanding the aerodynamic phenomenon allowing broad bandwidth investigations to find optimum configurations. In the course of this project the systems aspects were addressed with respect to the active flow control actuator system. For that a core flow control actuator system is required, which is sufficiently robust while providing high control authority to fulfil the requirements imposed on an aircraft scale application.

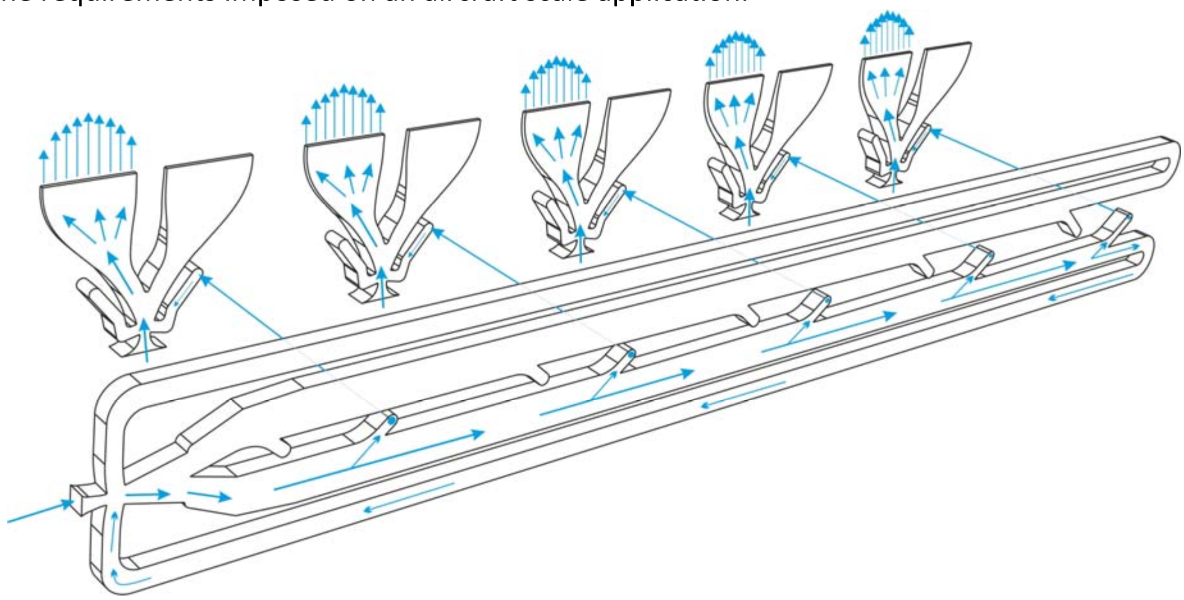


figure 1: principle of staged flueric actuator system

This core actuator system (see figure 1) was developed and matured by TUB in the project DT-FA-AFC and integrated into the overall flow control architecture within FloCoSys in close cooperation with SFWA partner EADS-IW and with continuous exchange with the partners in CfP project AFCIN. The efforts lead to the successful test of an aircraft scale flueric (incorporating no moving or electrical components) flow control system, which was extensively tested at EADS-IW's site in Ottobrunn. The insights gained from those tests furthered the understanding of the necessities of a civil aircraft flow control system. The work provided input for ongoing SFWA CfP project robustAFC.

Summary description of project context and objectives

Flap systems are highly efficient lift providing elements in low speed flight. However, their mechanically complex arrangement within the wing trailing edge poses drawbacks in system weight, manufacturing, and maintenance efforts. One goal is to allow for a smaller and less complex flap which then in turn is higher loaded aerodynamically. A potential measure to shift the stall onset to then necessary higher limits can be found in an Active Flow Control (AFC) approach by pulsed blowing. There are many successful demonstrations of how an active flow control can enhance flow separation characteristics, mostly on model scale . The majority of this research aims at understanding the aerodynamic phenomenon allowing broad bandwidth investigations to find optimum configurations. In order to not only provide these control means but also to achieve an effective and efficient solution on aircraft scale other disciplines must be involved, preferably already in an early stage of the development process. In this project the systems aspects were addressed with a focus on the core subsystem flow control actuator, which was integrated - in close cooperation with SFWA partner EADS-IW - into the architecture of the overall flow control system.
The innovative step from research to application with realistic arrangement of these subsystems and numerous components is based on an optimal interaction and implementation of all components in a complete system. It is therefore an additional benefit beyond the current state of the art to come closer to the ACARE Vision 2020 goal of a more energy efficient aircraft flight operation.

This projects main objective was the equipping of a real-scale aircraft flap with AFC-technology and the integration of core actuator system and compressed air generation, distribution, and conditioning system. This required on the one hand considerations like structural integration on concept level (like attachments and space allocation for air intakes, compressors, chambers, routing of tubing / wiring, etc.) in combination with system architecture design respecting overall aircraft and safety requirements (multiplication of elements due to reliability needs, interfacing / interaction with other aircraft systems like energy supply and monitor / control networks) on the other hand. For this concept TUB provided the core active flow control actuator subsystem derived from other projects such as “DT-FA-AFC” also coordinated by TUB. Therefore adaptation of the developed technology to the requirements of a real-scale actuator system was necessary, starting from the definition of one working point for the actuator, iterative loops of actuator design with a major focus on interfaces, and the adaptation and conduction of ground tests.
Therefore the project provided a multidisciplinary approach to the complex task of integrating a novel technology into existing aircraft architecture.

Summary description of the main S&T results/foregrounds

All tasks proposed were completed successfully within SFWA CfP project *FloCoSys*. Here, prominent results are described. A more extensive report on results is found in the final deliverable D01 "Report on actuator concept, design, ground test results, and transfer of the technology developed to downscaled wind tunnel model".

Within the scope of the project the proposed flueric actuator system (developed within DT-FA--AFC) was integrated into a realistic aircraft flow control architecture and tested successfully in a large ground tests (core FloCoSys activity). The work was performed in close cooperation with SFWA partner EADS-IW.

The core flueric actuator was chosen for its robustness and high control authority. It consists of two stages: a driving stage and an outlet stage. The driving stage is based on a fluidic oscillator, which generates a periodic pressure signal at its outlets by self-induced switching. This pressure signal is routed to the control ports of the fluid diverters in the outlet stage. There, it actively forces the flow through the outlet stage to switch between two corresponding outlet channels of one actuator element. One driving stage is capable of driving numerous elements in the outlet stage The system therefore provides pulsed air jets without moving parts. Only a supply of pressurized air is necessary.

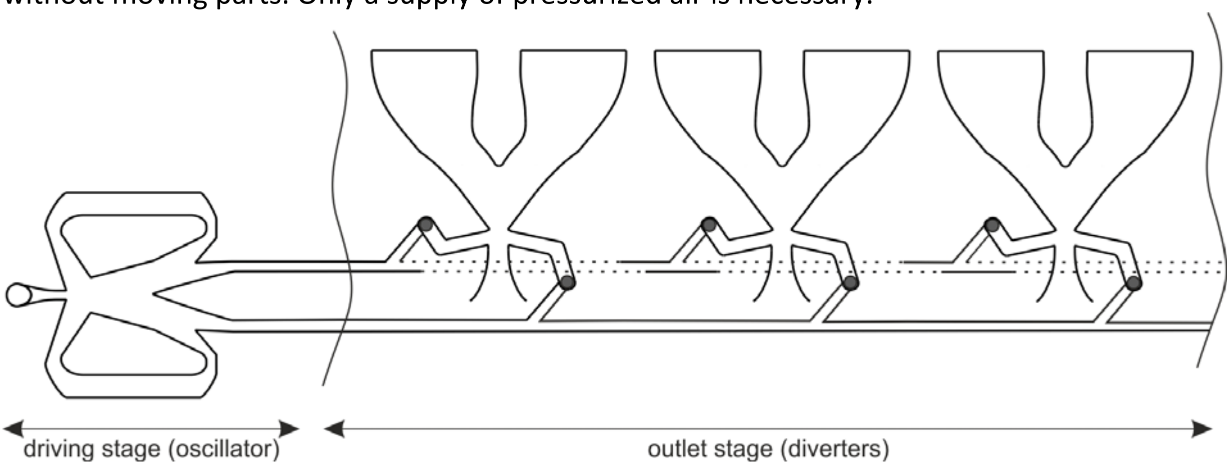


figure 2: sketch of staged flueric actuator concept

The staging of two fluidic components is advantageous compared to only one stage of fluidic oscillators which could produce air jets directly, as the fluidic diverters in the outlet stage are much more energy efficient than pure oscillators.

The main development work for the core actuator system was performed in the SFWA project DT-FA-AFC. Here, an overview over the development steps and resulting designs is given.

The first step was the design of a single actuator element for the outlet stage. It was decided to use a curved wall type fluidic diverter with a straight actuator chamber mounted at the outlet of the interaction zone. It's initial operating point is defined by a mean output velocity of 100m/s, a frequency of 100Hz and a momentum coefficient of 0.1% in accordance with the requirements for the model aircraft provided by Lengers/Scholz. The working frequency was later changed to 130Hz.

The operating point for the aircraft scale AFC system in terms of pressure and mass flow supply was agreed to be pt,inlet = 490mbar and mAFC = 3.72 kg/sec for the entire aircraft flow control system.

One driving stage is employed per 5 fluidic diverter elements (one outlet stage array). The outlet actuator consists of a core switching body and an attached actuator outlet nozzle.

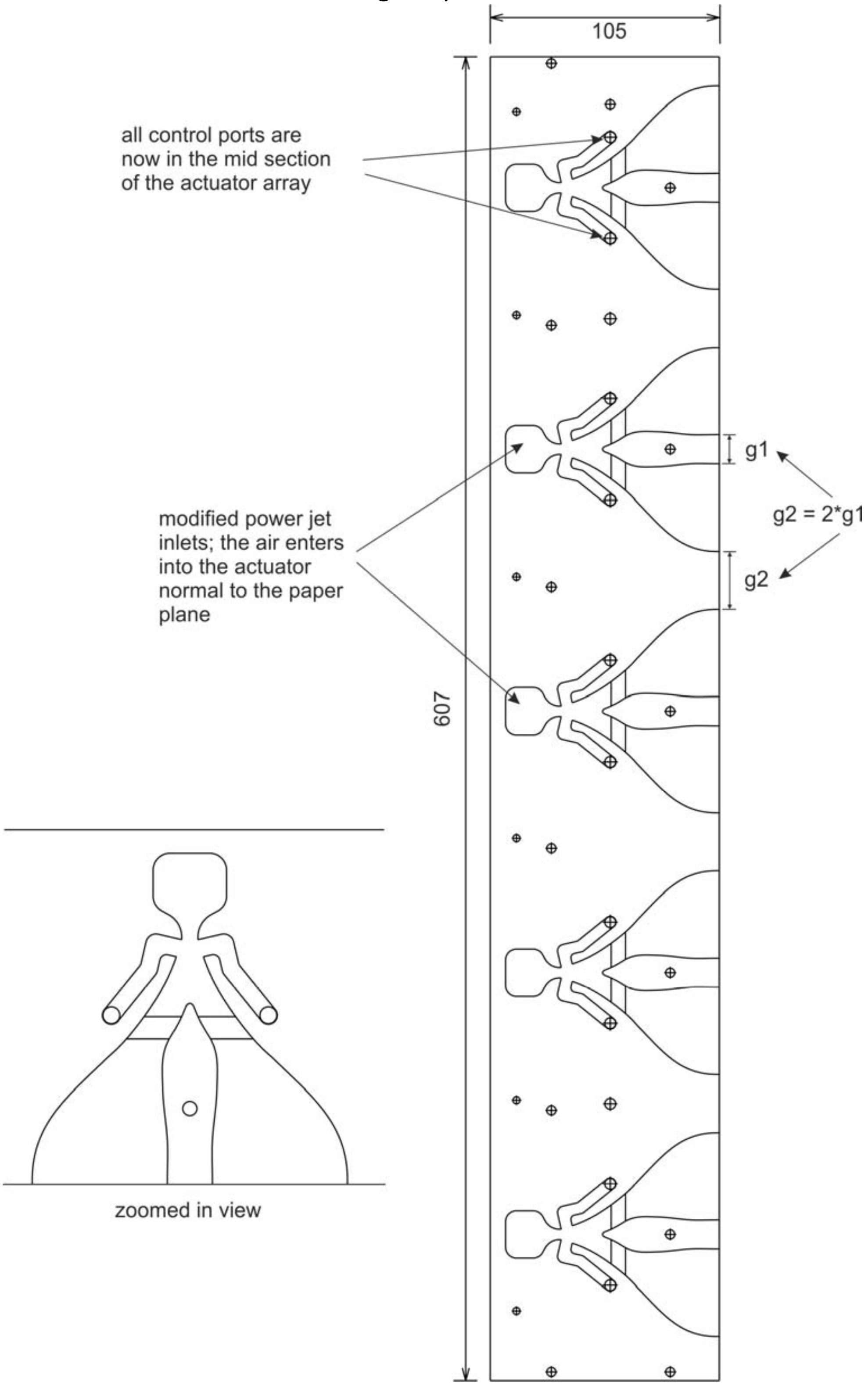


figure 3: CAD drawing of flueric actuator system outlet stage

For the ground tests TUB and EADS-IW designed a generic trailing edge flap AFC demonstrator. It represents the leading edge installation and consists of 15 elements of the outlet stage actuators as well as 3 driving stages. The span measures a total of 2100mm. Besides the core actuator elements (driving stage and outlet stage) a modified Z-spar (for mounting the flueric actuator) and a modular plenum (air supply) were designed and manufactured. The outlet stage is screwed on the Z-spar and therefore is sealed on one side.

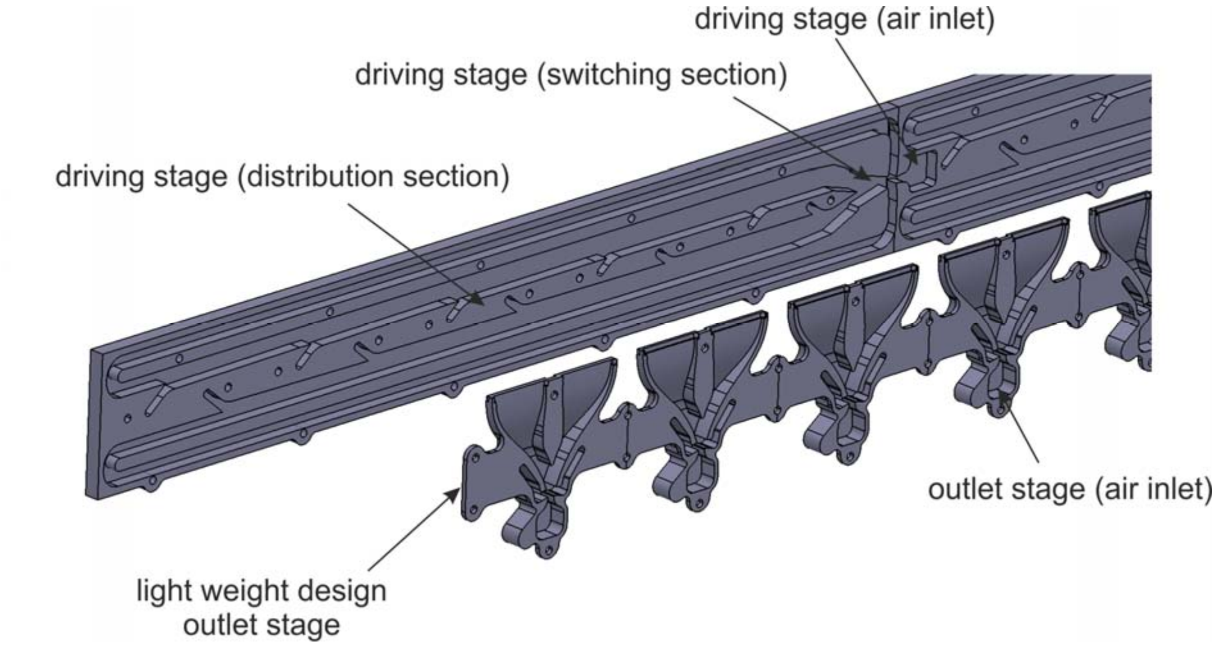


figure 4: core flueric actuator system - driving and outlet stage

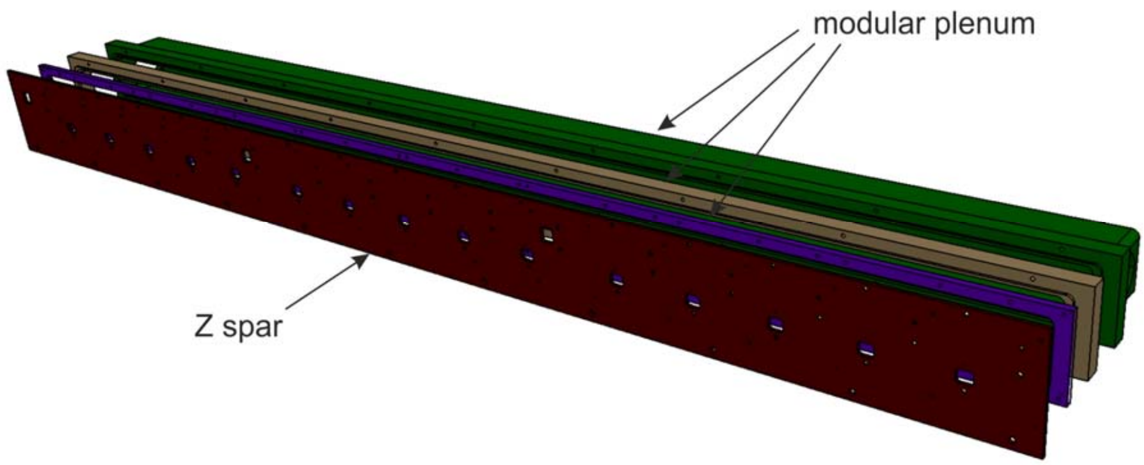


figure 5: core flueric actuator system - Z-spar and plenum

In cooperation with project partner EADS-IW system ground tests are set up to evaluate the flueric actuator system and the AFC system as a whole for design and off-design operation. Test scenarios were for example:

- span wise homogeneity of air jets for different plenum volumes and with and without artificial blockage within the plenum
- dynamic pressure of air jets for different inlet pressures
- simulation of failure case "leakage"
- simulation of failure case "one engine inoperative"
- single sided and both sided pressurization of the plenum

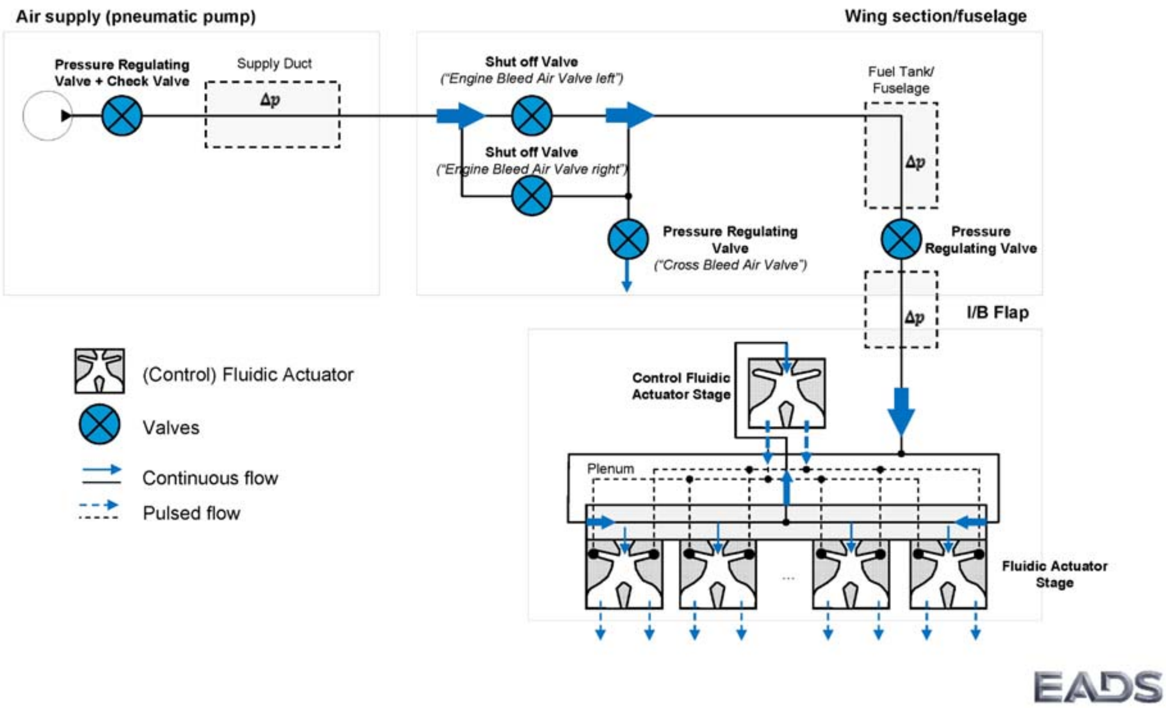


figure 6: system test rig (source EADS-IW)

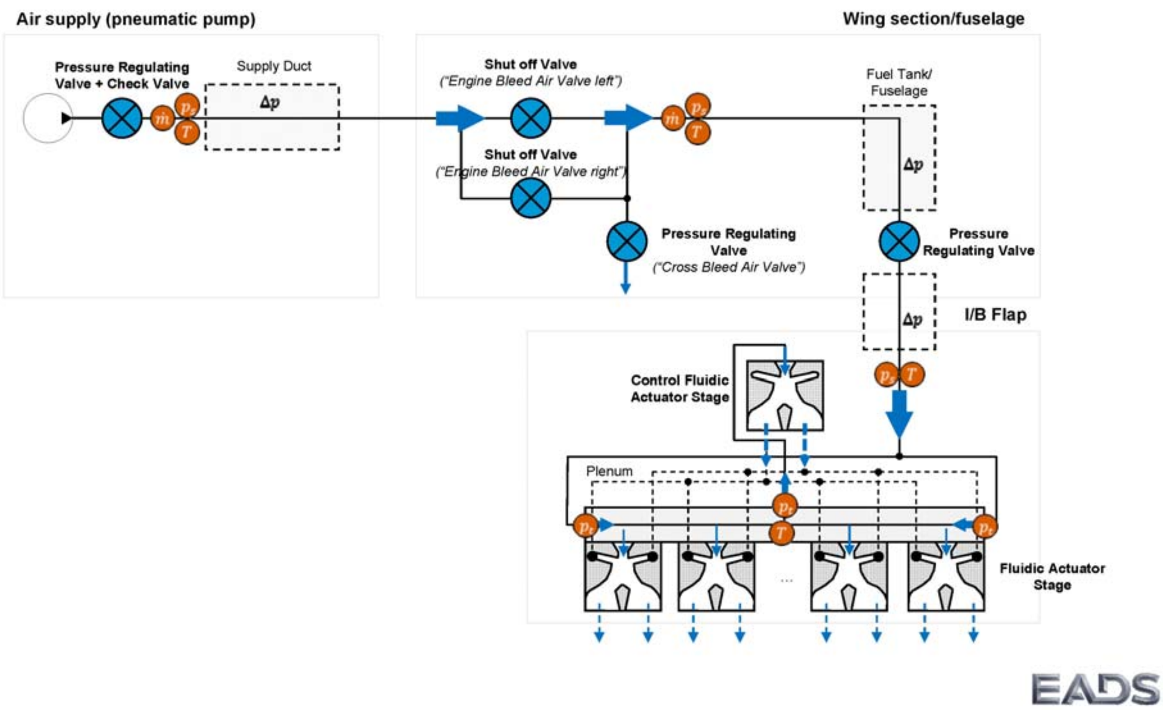


figure 7: system test rig measurement stations (source EADS-IW)

For measuring the total pressure in the plenum (inlet pressure) pitot tubes are integrated in the pressure supply. The dynamic pressure of the pulsed air jets was measured with Kulite pressure sensors mounted on a traversable rake. The sampling rate for all runs was 7.5kHz and a total of 15,000 samples was collected per sensor and position.

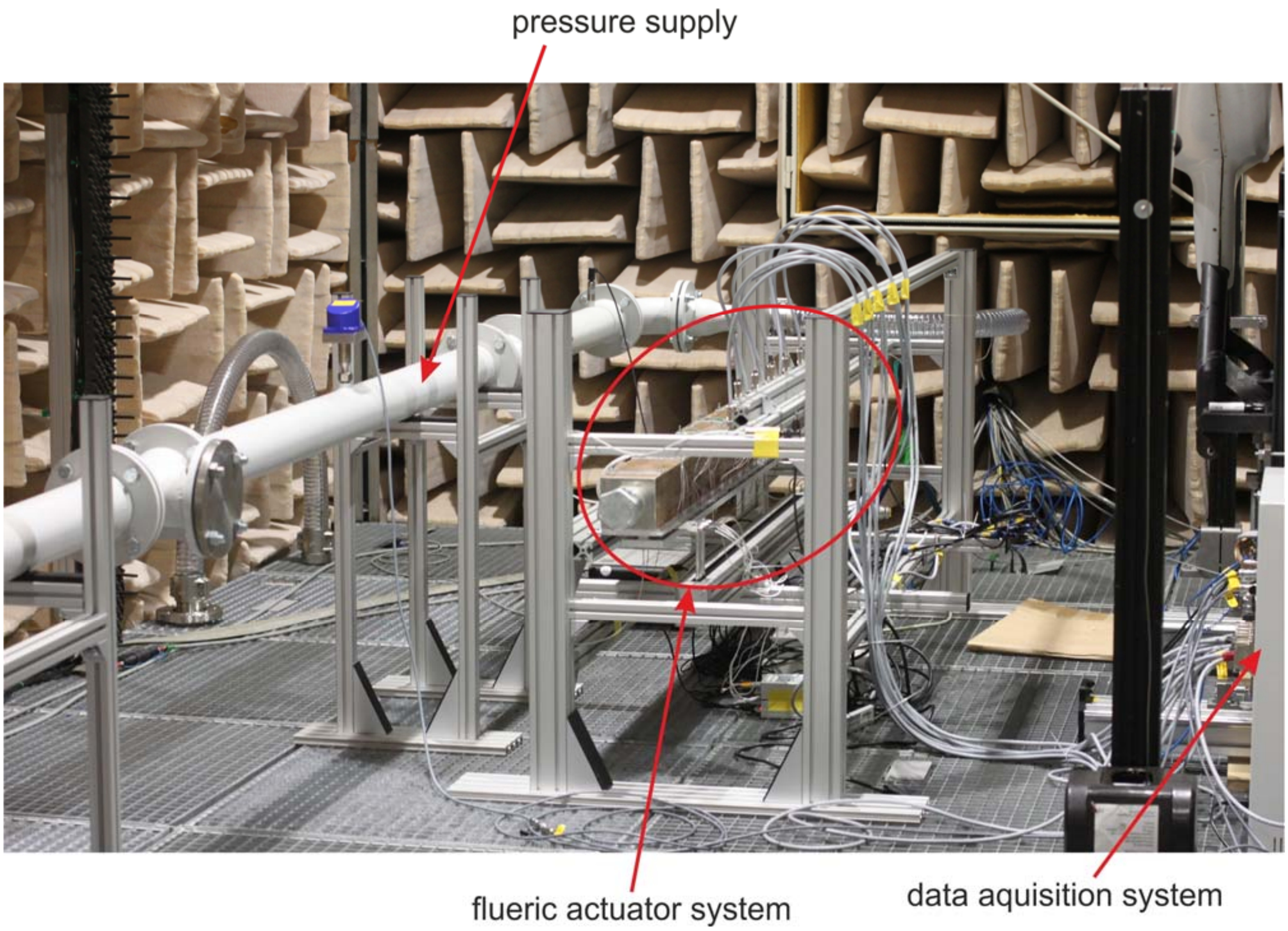


figure 8: system test rig at aeroacoustics lab at EADS-IW

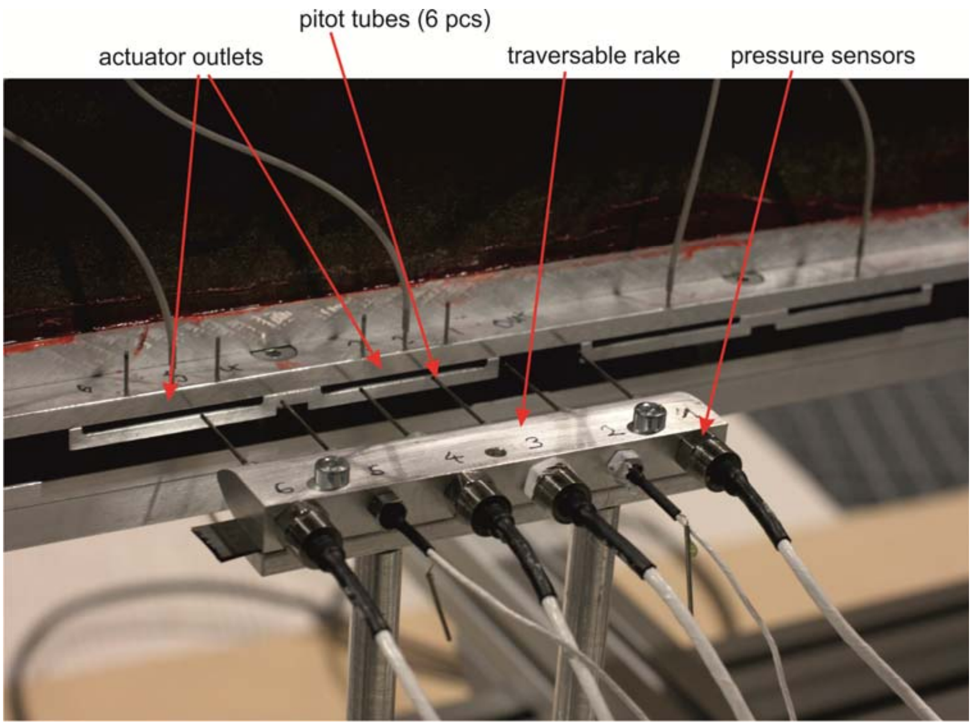
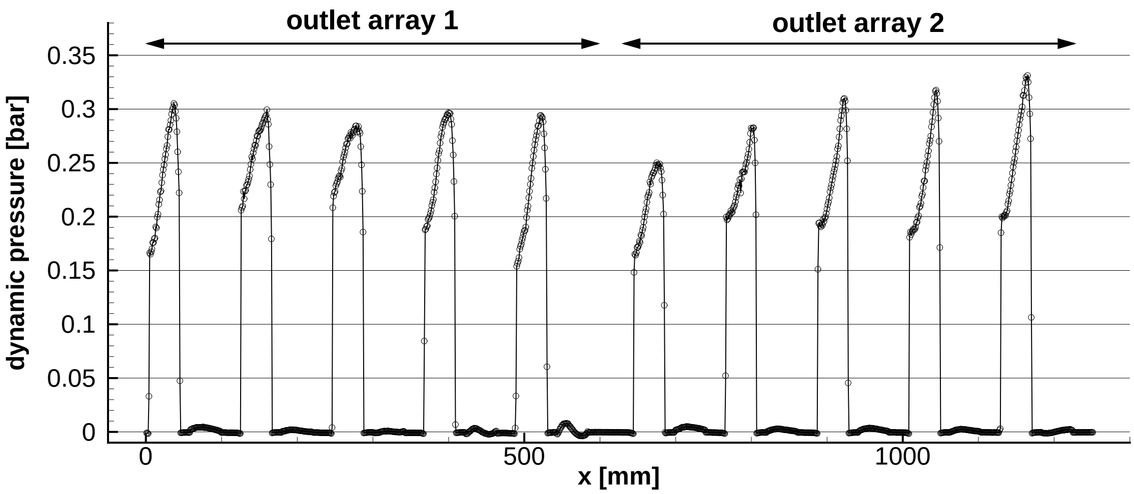


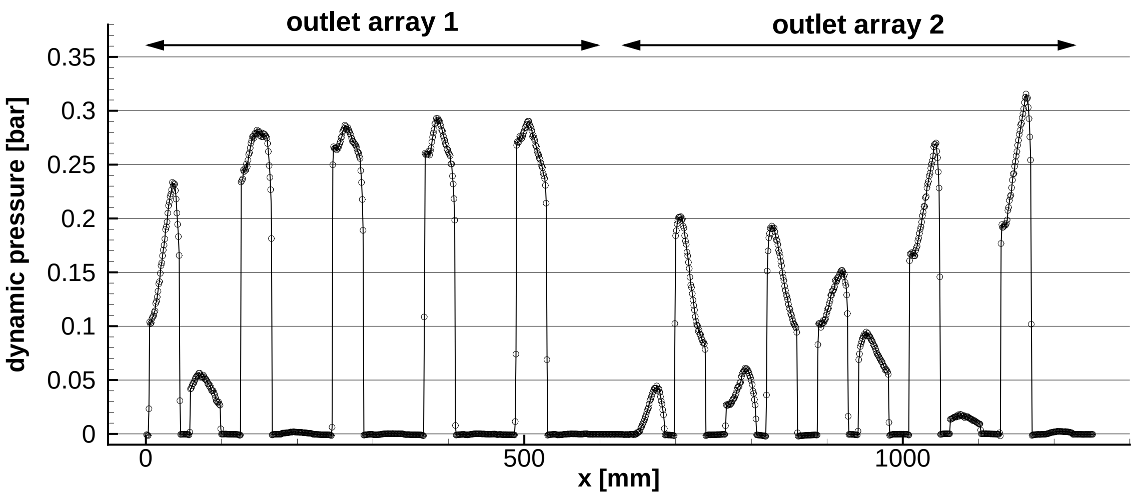
figure 9: traversable rake with 6 pitot tubes for measuring the total pressure of the air jets

The flueric actuator system integrated into the overall AFC system was extensively tested and it was found that that the velocity distribution in span wise direction is sufficiently even and that the actuators' modulation is good. At the design point the modulation is above 95% for almost the entire flueric actuator system.

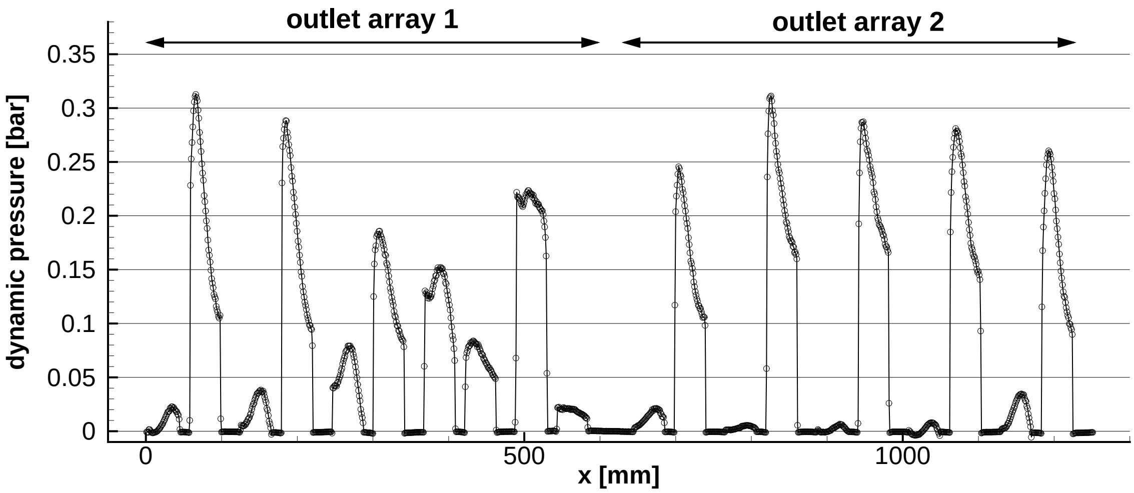
Here exemplary phase-averaged pressure data showing the dynamic pressure at the actuators' outlets for several timesteps is given to illustrate the switching behaviour of the flueric system.



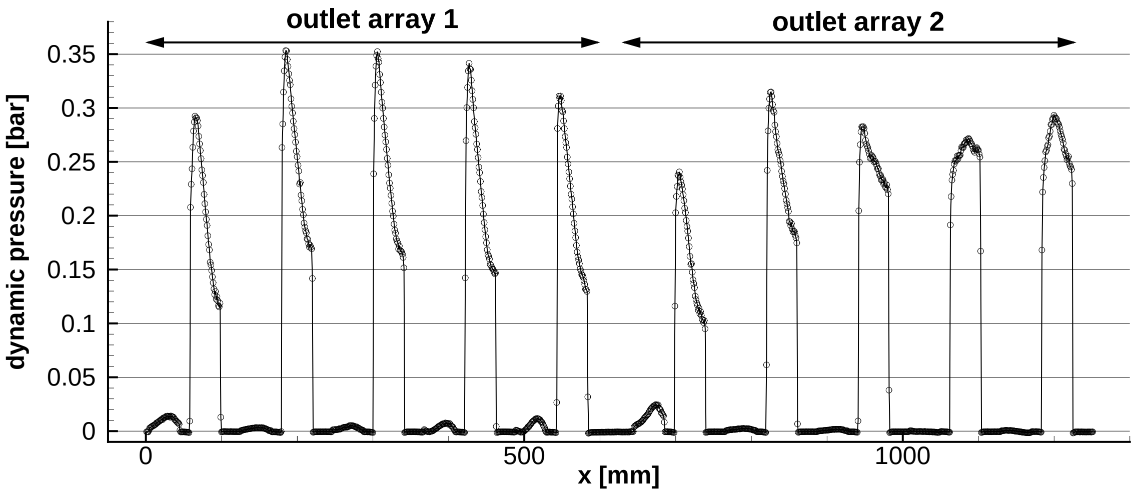
air jet exit profile for time step t0 = 0ms



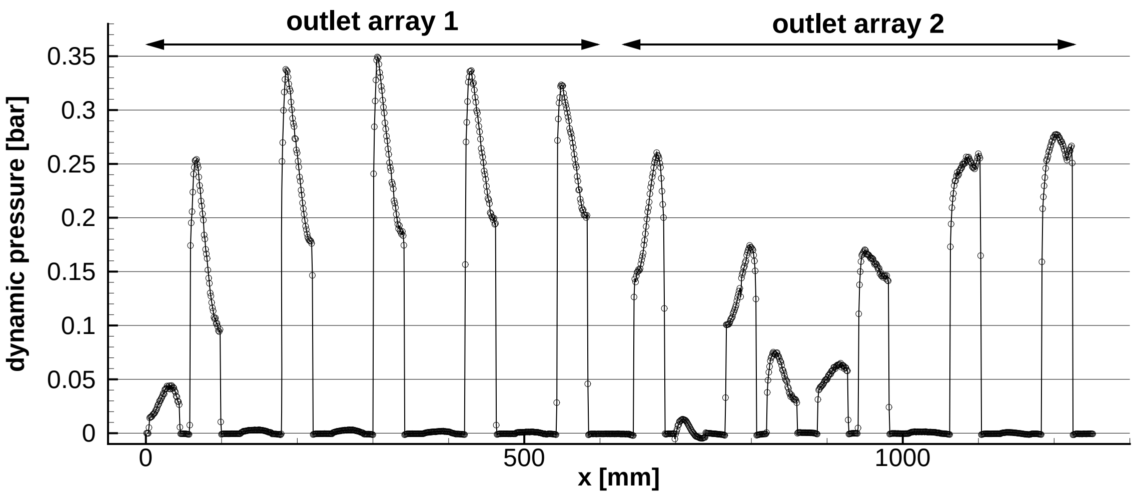
air jet exit profile for time step t = 1.3ms



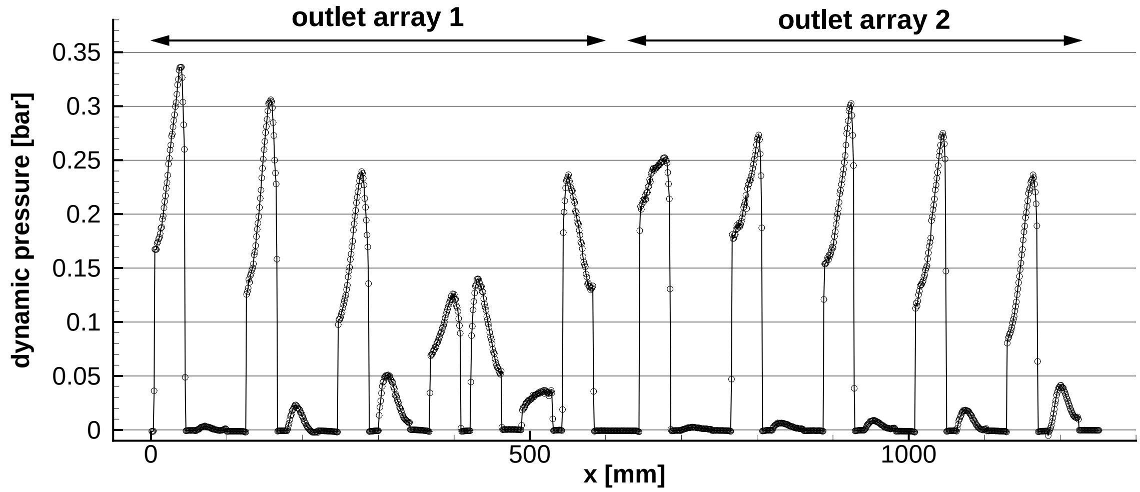
air jet exit profile for time step t2 = 2.7ms



air jet exit profile for time step t3 = 4.0ms



air jet exit profile for time step t4 = 5.4ms



air jet exit profile for time step t5 = 6.7ms

Tests included also off-design cases (higher and lower inlet pressure values) and it showed that the flueric actuator system can be operated between 400mbar and 800mbar inlet pressure without degradation of performance.

Therefore the experiments demonstrated that the core actuator and the appendant system are capable of providing pulsed air jets for flow control applications with high robustness and control authority. The flueric actuator functions with high modulation without incorporating any moving or electrical components.

Potential impact and exploitation of results

The experiments showed the feasibility of implementing an AFC system on aircraft scale. The work conducted - in cooperation with SFWA partner EADS-IW - lead to deeper understanding of how such a system can be best integrated into a civil aircraft, which solutions, e.g. for supplying the required pressurized air, are the most promising, and provided experimental data to validate the novel flueric actuator approach.

For this project the assumed business case was the replacement of a double slotted flap by a smaller single slotted flap. Besides a possible reduction of system weight, tipple down benefits are the reduction of the flap size (therefore freeing up additional space in the main wing element) and the reduction of maintenance costs (by reducing the system complexity compared to a double slotted flap).

The results of this project can serve as input for upcoming and ongoing projects. For further large scale testing or flight experiments an actuator system stands ready which is considered to be certifiable, as the core actuator system does not incorporate any moving or electrical components and is therefore extremely robust. Output from FloCoSys fed directly into the ongoing SFWA CfP project robustAFC, which focuses on the testing of flueric actuator hardware under harsh environmental conditions and is currently conducted by TUB and INCAS.

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