High-performance Synthetic Jet Actuator for Aerodynamic Flow Improvement Over Airplane Wings

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Abstract:
In the framework of a French National Program, the project ASPIC aims at using synthetic jet actuators to improve aerodynamic performance of aircrafts. The partnership between Cedrat Technologies (CTEC) and the French Aerospace Lab (ONERA) in this project has led to design, manufacture and test a high efficiency innovative synthetic jet actuator. This device relying in part on an ONERA patent is actuated by a CTEC amplified piezo-actuator (APA). Its aim is to provide a high speed synthetic jet compatible with flow control application on aircrafts or any other vehicle. Latest available test results and experimental performances of the ASPIC synthetic actuator are presented in this document: in particular, a peak exit velocity of 135m.s^{-1} during suction, and of 150m.s^{-1} during blowing, with an optimal actuation frequency bandwidth between 200 and 300Hz.

Keywords: Aircraft, Active Flow Control, Control Surface Efficiency, Piezoelectric Actuators, Synthetic Jet Actuator

Introduction

Flow control aims at improving civil and military aircraft performance by locally modifying the flow. For the flow control there are mechanical and fluidic technologies the latter presenting today the biggest potential.
It usually deals with blowing air locally at high speed, through slots or holes. The blowing phase can be continuous or pulsed. In both cases, the energy required is a major constraint because the overall energy balance is not always favourable.
Synthetic jet technology is an alternative to continuous or pulsed jets. It consists of creating high frequency alternating suction and blow phases. The advantage of this solution is that no air supply is required since the air is sucked from the main flow (zero-net-mass-flux): it is therefore a technology with a very high application potential and several studies have already shown the contribution of synthetic jets with significant performance gains.
For the last 10 years, ONERA has been studying the design of high-performance synthetic jet actuators, some of them based on piezoelectric actuators developed by CTEC.
In the framework of a French National Program, CTEC and ONERA have developed a new prototype of an efficient, robust, reproducible, synthetic jet actuator which is sufficiently compact to facilitate the certification of flow control solutions for various applications.
In this project, the actuator will be tested in a wind tunnel on a large scale model. In this case, the aim is to increase the lift coefficient of a vertical tail, and therefore the controllability of the aircraft. Consequently, this improvement will reduce the size of this part and therefore the friction drag of the aircraft. Recent flight tests [1] have shown that sideforce generated by the vertical tail may be increased by approximately 14% at 30-degrees rudder deflection.

ASPIC features

There are many studies that aimed at improving the characteristics of synthetic jet actuator so that it is efficient enough for flow control application on wind tunnel models. ASPIC actuator (see Fig. 1) is an innovative device because:

- The volume of the cavity in which the air is sucked and blown is accurately controlled by using a rigid and airtight piston
- The motion of this piston is created with piezo ceramics on which a mechanical amplification is applied in order to get high velocity and high amplitude displacement
- The high power density of the actuator

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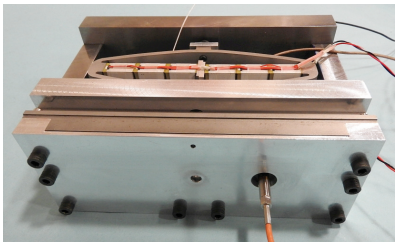

Fig. 1: *ASPIC synthetic jet actuator*

The wind tunnel model is a half size vertical tail of a business jet. Eight ASPIC actuators will be integrated into the model. Eight slots with a section of 1x166mm² are distributed on the right side of the tail along its 1.5m height. As a matter of fact, in terms of volume, the ASPIC actuator could be integrated in a full size business jet vertical tail in order to improve aerodynamic performance of both sides of the vertical tail.

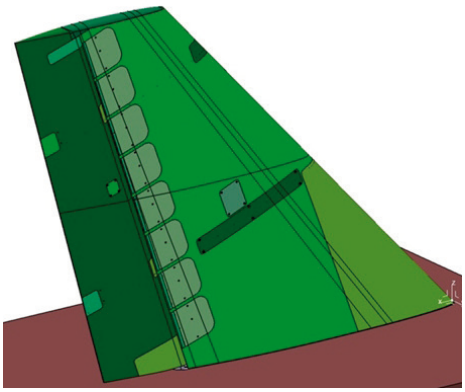

Fig. 2: *ASPIC Wind Tunnel model*

Determination of synthetic jet actuator specifications

The fluidic actuator has been designed by ONERA. The aerodynamic effects of a synthetic jet are strongly dependent on the jet velocity and the area of the slot. The area for the piston has been increased at a maximum regarding the volume available in the wind tunnel model and the potential volume available in the vertical tail of a business jet aircraft. It leads consequently to determine, on one side the stroke and the blocked force needed for the APA and on the other side, the stroke and the stiffness of the mechanical amplification between the APA and the piston.

Numerical simulation of the flow inside the actuator

The numerical simulations have been performed with the ONERA CFD software *elsA* [2]. This software solves the Navier-Stokes equations on structured multiblock grids. In the present case, Unsteady Reynolds-Averaged Navier-Stokes (URANS) simulations have been performed using the arbitrary Eulerian-Lagrangian (AEL) formulation on a deformable grid in order to take into for the piston sinusoidal motion Figures 3 and 4 show different views of the structured grid.

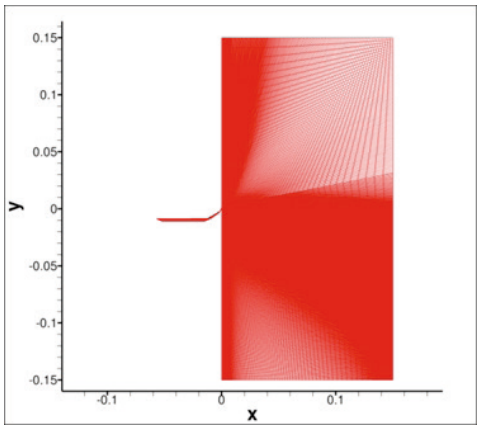

Fig. 3: *Global view of the 2D mesh*

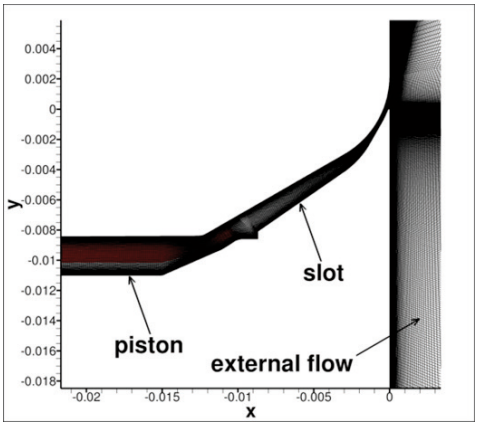

Fig. 4: *Detailed view of the mesh in the slot region*

Fig. 5 and 6 show the velocity field at two instants during the period: peak blowing velocity (top) and peak suction (bottom).

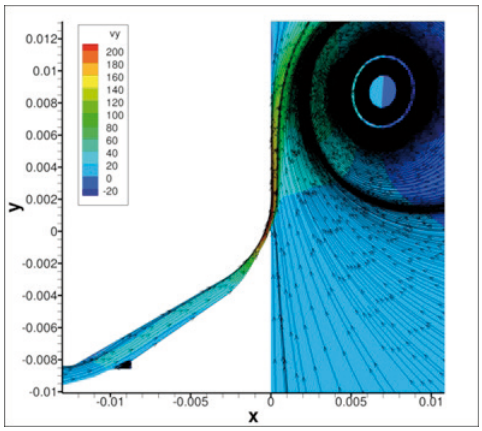

Fig. 5: *Velocity field at the peak blowing time*

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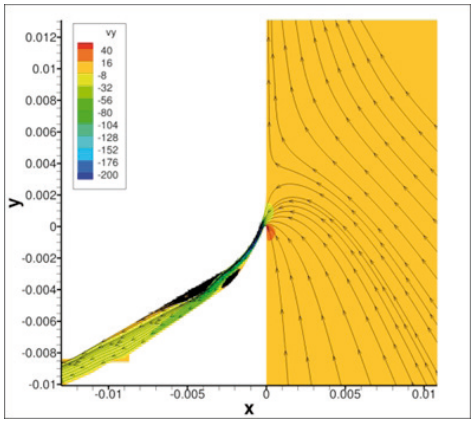

Fig. 6: *Velocity field at the peak suction time*

A simple model has been developed to optimize the stroke and the force acting on the piston, the slot width, and the cavity volume at the end of the blowing phase (i.e. the dead volume, which also includes the volume of the slot).

It consists in an isentropic model of the flow inside the actuator cavity that treats the volume filling as a series of isentropic and adiabatic compressions and expansions and flow through the slot as inviscid has been used. This reduced-order model enables to compute the velocity signal at the slot exit.

Mechanical and fluidic characterization

The ASPIC prototype has been tested at ONERA to measure the actuator performance in quiescent air condition. Two unsteady pressure sensors have been installed in order to measure the absolute stagnation cavity pressure: one in the middle of the actuator cavity and one close to the slot. The prototype is also instrumented with a high sensitive linear displacement DVRT® (Differential Variable Reluctance Transducer) sensor in order to measure the operating APA stroke and an eddy current probe system to measure the operating piston stroke.

Many different parameters have been tested during the characterization in order to optimize the jet velocity (mass and stiffness of the resonant system, geometry of the cavity, dead volume, geometry of the slot, input signal and etc.).

The test campaign has led also to characterize the jet produced by the actuator (airflow velocity during the alternating suction and blow cycles, homogeneity of speed over the span, etc.) on the different configurations.

The bench was specifically designed at ONERA Lille to perform this type of measurement on fluidic actuator [3]. Hot wire technique has been used to characterize those jets (see Fig. 7 and 8).

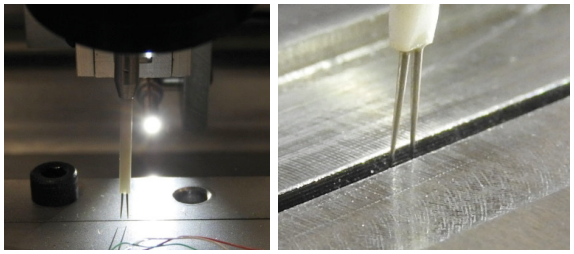

Fig. 7: *Airflow velocity measurement by hot wire anemometry*

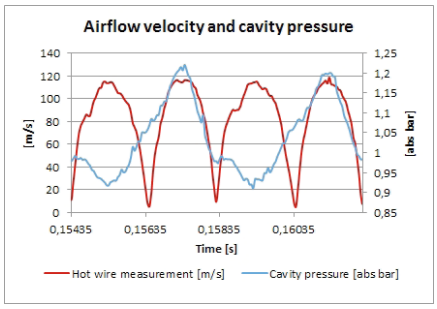

Fig. 8: *Exit jet velocity and absolute stagnation actuator cavity pressure measurements*

Measurements allow validating the ONERA first estimations on the actuator performances in specific conditions. Fig. 9 shows the estimated air jet velocity through a slot of 1x150mm² in comparison with the hot wire measurements.

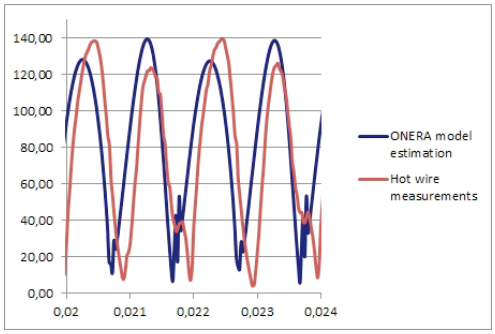

Fig. 9: *Estimation vs. measurements*

Fig. 10 shows the jet velocity improvement regarding geometry optimisation of the actuator cavity and slot geometries.

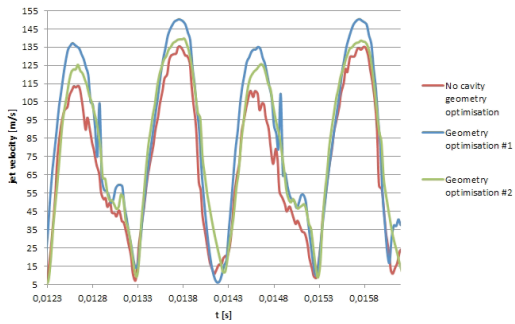

Fig. 10: *Jet velocity measurements for different cavity and slot geometries*

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For the most interesting configurations the comparison has been made between the measurement (piston displacement, cavity pressure, jet velocity) and the CFD simulation.

A last test campaign will be led to characterize the jet produced by the 8 actuators, which will be integrated into the model. To avoid any damage due to a loss of the pre-load into the APA during the tests, the actuators will be fitted with strain gages as embedded sensors. These sensors will indeed allow measuring the constraints on the ceramic stack. Temperature sensors will also be fixed on the ceramic stack to prevent any overheating of the actuator.
Fig. 11 shows a thermography of two APAs 500L in operation.

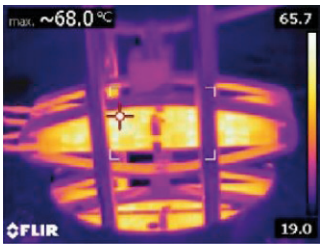

Fig. 11: *Thermography of two APAs 500L in operation*

ASPIC control and inputs signals

The input signal has been optimized to increase the displacement and the velocity of the piston. Thanks to simulations and tests, limits in terms of signal amplitude, frequency and time duration have been identified to avoid any damage due to a loss of the pre-load into the APA.

Conclusion

A high-performance synthetic jet has been designed to control the flow separation on a vertical tail. Mechanical and fluidic characterisations allow improving ONERA and CTEC reduced-order models of the actuator.
The experimental performances of the ASPIC synthetic actuator are the following ones:

- Slot dimensions: 1x150 mm²
- Peak exit velocity during suction: 135m.s^{-1}
- Peak exit velocity during blowing: 150m.s^{-1}
- Optimal actuation frequency bandwidth: between 200 and 300Hz
- Actuator volume: 164x94x57mm^3

Even if the objective is to reach a sonic regime in both blowing and suction phases, the jet velocity reached a level, which shall allow seeing improvements in the aerodynamic performances during the wind tunnel tests. Wind tunnel tests campaign will occur in November 2018 in the L1 WT facility at ONERA Lille.

Acknowledgements

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