1.1 Piezo-Actuators for Synthetic-Jets

1.1.1 Technology Review by the University of Twente

Review Summary:

References:

This report exposes the synthetic jets as a technology to improve rotorcraft performance inside
Green Rotorcraft project.

[2]: D. Sturzebecher, W. Nitsche, Active cancellation of Tollmien-Schlichting instabilities on a wing
572-583
Sturzebecher details in his publication the Tollmien-Schlichting instabilities (T-S instabilities)
that trigger the flow regime transition between laminar and turbulent. It then presents various
actuator types and configurations to show the benefits of some solutions and configurations.

[3]: Guang Hong, Effectiveness of micro synthetic jet actuator by flow instability in controlling laminar
separation caused by adverse pressure gradient, Sensors and actuators A 132, 2006, 607-615.
This article studies a micro synthetic jet to prevent a laminar separation in the flow boundary
layer. It uses a piezoelectric diaphragm inside a cavity and analyse the efficiency of the actuation
for various frequencies with and without cross-flow conditions.

[4]: A.S. Yang, J. J. Ro, M.T. Yang, W.H. Chang, Investigation of Piezoelectrically Generated
This paper investigates the design, the manufacturing and the modelling using finite element
code of a slot actuator using a piezoelectric diaphragm. Focus is made on the agreement between
the actuator made and the modelling concerning the velocity profile at the exit of the slot actuator.

[5]: D. Greenblatt, J.I. Wygnanski, The control of flow separation by periodic excitation, Progress of
The above publication reviews the improvement of controlling flow separation on airfoils
aerodynamic performances and the methods to control this separation. The review is especially
focused on periodic flap excitation.

Concept

Synthetic jets actuators also known as zero mass flux jets aim at delaying the transition between
laminar and turbulent flow regime along an airfoil and consequently improve the airfoil aerodynamic
performances. The principle is to send flow at high velocity inside the boundary layer over the airfoil
[1].

Actuators

Complex mechanisms used to be designed to send flow inside the boundary layer. Zero mass flux
actuators present a much more elegant solution to integrate this technology. They simply consist of a
membrane inside a cavity that resonates. Doing this, the membrane is pumping air in and out of the
cavity. Therefore the actuation is composed of two phases: an actuation phase and a recovery phase.
The important parameters are therefore the actuation frequency and the cavity size. Two main types of
actuators can be distinguished: the slot actuator where the cavity is vertical and the orifice is a thin
rectangle perpendicular to the flow direction (cf. Figure 1); the other type of actuator has a horizontal cavity underneath the airfoil skin with a small circular orifice (cf. Figure 2).

Figure 1: Slot actuator.

Figure 2: Synthetic jet actuator with a circular orifice.

Piezoelectric diaphragm for synthetic jets

Most of the publications concerning synthetic jets actuators are considering coil actuators to drive the vibrating membrane like a loudspeaker [1]. The main reasons are their small mass, their good frequency response and their cost-effectiveness. Their only drawback is the space required to integrate them. Piezoelectric diaphragms can be a viable alternative because it shares the same advantages as coil actuators with an improved integration capability thanks to its small size. A piezoelectric diaphragm consists of a membrane made of a flexible material onto which a piezoelectric disc is bonded [3]. The piezoelectric disc excites the membrane bending modes by contracting and extending at a define drive frequency (cf. Figure 3).

The two types of actuators mentioned previously have been realised with piezo-diaphragms. The following table will present the technical details of the two actuators realised and their power consumption.

Slot actuator [3]:
- Cavity size: 50 mm diameter with 10 mm thickness
- Orifice size: 35.5 mm long with 0.5 mm width
- Piezoelectric disk: 30 mm diameter with 0.15 mm thickness
- Driving voltage: 60 V (peak to peak)
- Driving frequency: 648 Hz
- Peak axial velocity: 27 m/s.
According to Sturzebecher article, one row of slot actuators could be sufficient to efficiently damped most of the instabilities [2]. Therefore, one meter of blade with no space between two actuators leads to a maximum power consumption of approximately 185 W at the driving frequency.

Actuator with circular orifice [4]:
- Orifice size: 0.5 mm diameter
- Piezoelectric disk impedance: 140 nF
- Driving voltage: 14 V (peak to peak)
- Driving frequency: 100-1500 Hz

A detail study about the number of this type of actuator to effectively damped instabilities over the full width of airfoil is unfortunately missing. A rough estimation of the spanwise distance between two actuators to be efficient is 10 mm, which is approximately the stationary wave length of cross-flow vortices [2]. Therefore the maximum power consumption is 25 W for one meter of wingspan at the highest driving frequency.

**Piezoelectric stacks for membrane actuators**

Membrane actuators are another way to achieve the damping of T-S instabilities. Here the actuator is directly underneath the airfoil skin. This configuration has a strong and obvious advantage compared to the others synthetic jets devices: it does not have any orifice or slot that can be jammed or damaged. Sturzebecher comparison of these various types of actuators shows that the membrane actuator performs better [2]. The membrane itself is the main design critical component. It need to be tough enough to sustain the external conditions and yet flexible enough to not require an enormous amount of energy to be excited. Although mentioned in Sturzebecher article, neither dimensions nor characteristics are specified for this actuator. Depending on the membrane flexibility, piezoelectric diaphragm could be sufficient for this concept.

**Control strategies**

Experimentation in wind tunnel has shown that synthetic jets constantly driven at some specific frequencies can have a positive effect on the aerodynamic performance [5]. However, much better performance increase is achieved when the synthetic jets are actuating in combination with feedback control. For that, arrays of sensors are required before and after the actuators row. Sturzebecher publication details streamwise repeated control to completely cancel T-S instabilities. Here three rows of synthetic jets actuators are required with four rows of sensors [2]. Therefore the power consumption will depend on the control strategy selected.

**Maturity:**

Among experiments to study the feasibility of synthetic jets actuators some publications focus on the use of piezoelectric diaphragms. They show the study, the manufacturing and the modelling of those components demonstrating the relevance of such a type of actuator within synthetic jets actuators. The synthetic jet actuators have the maturity to jump from lab study to commercial product. Piezoelectric diaphragms for synthetic jet actuators appear to be in the same state.

**Conclusion:**

Piezoelectric diaphragms are relevant solutions for synthetic jets actuators. Although there is no example
of integration within rotor blades yet, their characteristics make them suitable for this purpose. The piezoelectric diaphragm is a light and compact vibrating membrane that can achieve many cycles ($10^9$) before failure.