Numerical study of sweeping jet actuators

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Abstract. A Sweeping Jet Actuator emits spatially oscillating jets without any moving parts which are self-induced and self-sustaining. These pulsating jets are used to control flow separation over the bodies such as aircraft wing which eventually reduces the overall drag on the wing and ultimately the efficiency of the flight is increased with no complexity since there are zero moving parts in the system. Here, we intend to characterise various fluidic oscillators (angled and curved) designs and to analyse the characteristics of the flow numerically using ANSYS (fluent) Software with the aim of finding an effective one for use in flow separation control. After analysing various parameters, it was concluded that the curved oscillator was found to be efficient in oscillating the flow.

1. Introduction

Future aircrafts are in the need of Active Flow Control to suppress the boundary layer separation, enhance mixing and minimize the noise, thereby enhancing the aerodynamic efficiency of the lifting surfaces. In recent past, Sweeping Jet Actuators or Fluidic Oscillators are being researched upon as a part of Active Flow Control. These Sweeping Jet Actuators (SWJA) are robust and reliable with mechanically no moving parts and purely uses pressurised air under high velocity to create oscillating motion due to Coanda effect of the sweeping jets (Raghu 2013). They generally increase the momentum of the local flow field by fluid injection in the feedback channels. Two typical designs of sweeping jet actuators are presented in Fig 1. Their working principle is mainly based on flow deflection because of the Coanda effect. As the fluid enters SWJA, the jet attaches itself to one side of the mixing chamber (MC) due to the Coanda effect. As a result of that, pressure increases in the feedback channel due to which the jet is deflected inside the mixing chamber towards the other side. This process is repetitive in nature and is purely self-induced and self-sustaining, so an oscillating jet is created at the nozzle exit which sweeps from one side to another side.

In the last few years, a significant number of studies have been published involving SWJA, their working principle, and parametric effects and their application in flow separation and control. A review of their working principle and their application in flow control is given in ref. [1]. and [2]. SWJAs of two different designs have been experimentally investigated in ref. [3]. using PIV. Various designs of SWJA are investigated numerically using 2D-RANS and DNS in references [3-7]. These studies are mainly aimed at investigating the dependence of oscillation frequency on various inlet parameters such as Reynolds number, mass flow rate, shape and size of the actuator. The numerical investigations are mainly aimed at investigating the effect of three dimensionality on the oscillation frequencies. The oscillation frequency of SWJA is two dimensional and weakly depends on the third
dimension. Also, the oscillation frequencies increase linearly with mass flow rate and Reynolds number.

2. Methodology
In the present study, we aim to compare the flow field and the oscillation frequency of two different SWJA designs given in fig 1. The two types of dual feedback actuators - "curved fluidic oscillator" (Fig. 1, left) and the "angled fluidic oscillator" (Fig. 1, right) are studied using CFD analysis to obtain an efficient design that exhibits significant flow control characteristics. Numerous studies have employed the curved oscillator design, and others used the angled oscillator design. Despite their use in various applications, the SWJAs lack a comparative analysis regarding their flow dynamics and performance. Such an analysis will help in choosing a suitable design for any desired application. As a first step towards this understanding, we numerically investigate the angled and curved SWJA in the present work and evaluate their flow characteristics in order to determine the efficient one.

![Figure 1. Types of Dual Feedback SWJAs (Source: Ref. [3]).](image)

3. Numerical Analysis
The geometrical design of the actuator was created using the CATIA V5 software using the necessary parameters based on the previous studies. Since the size of the SWJA that were studied earlier was smaller than the current model, the geometry is scaled down in such a way that the exit width is 25mm for both the actuators. The major difference between both the actuators lies in the geometry of the mixing chamber where the corners of the angled oscillator are pointed and sharp, whereas the corners of the curved oscillator are blunt and rounded as shown in figure 2.

![Figure 2. Geometry of SWJAs used for the numerical simulations. All the dimensions are scaled w.r.t the actuator exit width i.e., exit width is 1.](image)

The CFD software, ANSYS Fluent, which uses finite volume method for discretizing the Unsteady Reynolds Averaged Navier-Stokes (URANS) equations were used for the numerical investigation.
Ansys meshing software was used to mesh the SWJAs and a grid independent study has been performed. The mesh parameters are given as follows.

| Table 1. Grid parameters |
|--------------------------|
| Grid                     | Curved   | Angled   |
| Advanced sizing           | Unstructured | Structured |
| Relevance centre          | Curvature  | Curvature|
| Cells                     | Coarse   | Medium   |
| Faces                     | 21043    | 26132    |
| Nodes                     | 23306    | 21318    |

The pressure-velocity coupling has been done using SIMPLE method. A second-order scheme has been used to discretize the pressure terms. The momentum, turbulent kinetic energy and specific dissipation rate terms were discretized using a second-order-upwind-scheme. A second-order implicit scheme was used for transient formulation. In RANS analysis, an SST turbulence model has been used for turbulence closure. SST model is highly suitable to model flows involving flow separation.

![Figure 3: Mesh.](image)

No slip condition was imposed over the walls of the fluidic oscillator. Velocity inlet boundary condition is imposed at the oscillator inlet, and a pressure outlet condition is imposed at its exit. The time step for all the simulations is fixed at 0.0005 s such that the CFL number lies in the range 0.5-1. At every time step, the simulations are performed until the residuals attain values less than $10^{-6}$. Initially, the computations are performed for one second by which the SWJA attains a periodic state. Subsequently, the data has been saved by performing the computations for one second. The data has been analysed and plotted using CFD Post.

### 3.1 Grid Independent Study

A grid independent study is also done for simulation of both the actuators in order to ensure that the simulation results become independent of the mesh size. For each mesh size, the velocity at a fixed point near the actuator exit has been extracted and its oscillation frequency has been calculated using FFT analysis. The calculated frequencies for different mesh sizes are compared in table 2. It was found that the oscillation frequency for angled actuator becomes constant after 26000 nodes and hence the oscillation becomes independent of the grid after 26000 nodes. Similarly, the frequency remains constant after 21000 nodes for the curved actuator.
Table 2. Grid independence study.

| Nodes  | Frequency | Nodes  | Frequency |
|--------|-----------|--------|-----------|
| 18000  | 15.12     | 16000  | 16.6      |
| 26000  | 14.65     | 21000  | 15.63     |
| 35000  | 14.65     | 33000  | 15.63     |

4. Results
The numerical study has been performed with an inlet velocity of 8.5m/s with air as the working fluid. The inlet mass flow rate is 0.4kg/s per unit width and the Reynolds number based on the average velocity and the actuator exit width is 21,700.

Figure 4. Velocity field in a curved fluidic oscillator at various instances during one oscillation cycle. The time difference between two successive images is 0.2 seconds.

Figure 4 shows the velocity field for the curved SWJA at six different time instants during one oscillation cycle. Fig 5 shows the corresponding plots for an angled oscillator.
Figure 5. Velocity field in a straight fluidic oscillator at various instances during one oscillation cycle. The time difference between two successive images is 0.2 seconds.

First, we present here the flow field observed during one oscillation cycle. As the air enters the convergent inlet nozzle, it forms a jet which attaches to one side of the actuator mixing chamber because of the Coanda effect. Because of the wall curvature, the jet feeds a certain amount of fluid into the feedback channel. This volume of the feedback fluid ejects out of the feedback channel from its upstream end and forms a recirculating region. The recirculating region grows in size, thereby, pushing the jet towards the opposite wall as seen from figure 4. The jet now attaches to the opposite wall because of the Coanda effect and the process repeats itself. Thus, the jet inside the mixing
chamber and thereby, the fluid ejecting out of the SWJA oscillates periodically because of the two feedback loops leading to a self-induced oscillatory flow without any moving parts.

Both the SWJAs exhibited similar flow dynamics. However, it is evident from figures 4 and 5 that the feedback mechanism is stronger for a curved oscillator when compared to an angled oscillator. The amount of feedback fluid is high for a curved oscillator. The oscillation frequency is marginally high for a curved oscillator than an angled oscillator as shown in table 2 for similar flow inlet conditions. Also, it can be observed that the angled SWJA has smaller deflection angles than a curved SWJA, i.e., mixing will be higher in curved SWJA.

5. Conclusions
The flow field of two SWJAs has been investigated in the present study by performing numerical analysis. The flow field shows that the feedback fluid is responsible for the oscillation of the flow in SWJA. However, the flow depends on the shape of the SWJA. The amount of feedback fluid is prominent for a curved SWJA when compared to an angled SWJA. Despite of this difference, they exhibit nearly same oscillation frequencies. The deflection angle, thereby the jet spread rate is more for a curved oscillator. For applications that require higher mixing rates, a curved oscillator will be more suitable than an angled oscillator.

6. References
[1] Gregory J and Tomas M N A 2013 review of fluidic oscillator development and application for flow control 43rd AIAA Fluid Dynamics Conference 2474
[2] Raghu S 2013 Fluidic oscillators for flow control Experiments in Fluids 54 1455
[3] Ostermann F, Woszidlo R, Nayeri C N and Paschereit C O 2015 Experimental Comparison between the Flow Field of Two Common Fluidic Oscillator Designs 53rd AIAA Aerospace Science
[4] Kara K, Kim K and Morris P J 2018 Flow-Separation Control Using Sweeping Jet Actuator AIAA Journal
[5] Koklu M and Owens L R 2014 Flow Separation Control over a Ramp Using Sweeping Jet Actuators 7th AIAA Flow Control Conference AIAA Paper 2367
[6] Kuczmar M A, Culley D E and Raghu S 2009 Numerical studies of a fluidic diverter for flow control
[7] Fisher R, Nishino T and Savill M 2017 Numerical Analysis of a Bidirectional Synthetic Jet for Active Flow Control AIAA Journal 55 1064–69