Internal Flow Analysis on Sweeping Jet Actuator

Sushanth Gowda B C, Vinuth N, Poornananda T, Dhanush G J, T Paramesh

Abstract*: *Sweeping Jet Actuator (SWJ), when pressurized with high pressure fluid, emit continuously but spatially oscillating jets, which are self-induced and self-sustaining. The initiation and interaction of the internal flow and jet oscillation process of a actuator is well defined in this study. Transient as well as steady numerical analysis over a range of inlet velocities was performed. The velocity magnitude and total pressure contours are shown to justify the complex flow field within the sweeping jet actuator by varying the height and width of the feedback channel geometry

Index Terms*: *CFD, Internal Flow Analysis,Sweeping jet Actuators.

I.INTRODUCTION

In this era, Airline companies anchor their business in minimizing the operational cost per passenger, keeping in mind about the exponential growth of passenger traffic. The next generation aircraft performance would be improved with an upgraded aerodynamic design and technologies which strongly contribute to product cost and operability since operational effectiveness, sustainability and fuel cost are concerns for today's civil aviation. The promising technology to prevent boundary layer separation is offered by Active Flow Control (AFC) technology which could be solution for airframe weight and drag reduction. The community has shown a great interest towards active flow control technology especially for fluidic oscillators. Actuators are intrusive devices with electric signal input and flow disturbance output. Sweeping Jet Actuator is an adherent of fluidic oscillator where the momentum in local flow field gets increased by fluid injection or suction phenomenon. The Coanda effect plays an important role where a jet attaches itself to either sides of an actuator as the fluid passes through it.

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This increases the pressure inside the feedback loops and pushes the jet to other side. With liquids as working fluid, the earlier designs have been used for applications like windshield washers, sprinklers etc.The fluidic oscillator is favorable being amenable to range of size and frequency for large disturbances.

Lack of feedback control in basic and simple versions requires external flow source which ended up as a disadvantage. Harry Diamond Laboratories (USA) developed the first fluidic oscillator more than fifty years ago, which later became outmoded due to electronic alternatives. Soon after, new designs with one feedback loop as well as without feedback channels encountering two interacting jets are developed.Separation control, noise control, and combustion control are some of the applications for new solutions developed.

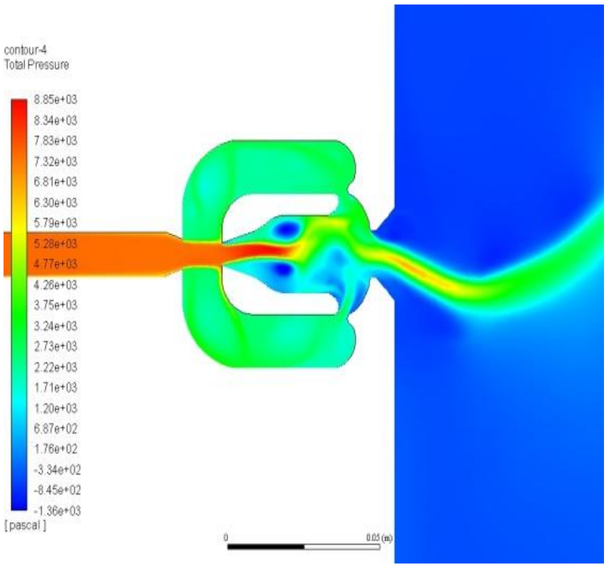

Fig 1. Sweeping jet actuator Simulation Contour

A recent study employing piezo-electric material as secondary system to control oscillations ended up having a disadvantage where oscillations were uncontrollable by natural internal flow.Vertical tail, being a critical and obligatory surface during crosswind landing and during engine failures, utilizes a greatest advantage of oscillators. Being a large surface, the airflow around the tail is so strong during the cruise and plane can be controlled in its path by minimal rudder deflection but during takeoff and other lower speed maneuvering, large rudder maneuvering is necessary.

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An experiment conducted bySeeleet.al[11] on wing tunnel with an intention to notice the rudder effectiveness employed with Sweeping Jet Actuator in the tail of aircraft with twin engine shown that fifty percent of controllability can be increased by placing the actuators on the rudders.Another examination on time dependent internal and external flow using PIV data, Rene et.al[17] provided a good guide line for optimization and future development of oscillator devices.New designs and methodologies for Sweeping Jet Actuators can be understood by internal flow physics with CFD simulations.This paper is aimed to connect geometric features of Sweeping Jet Actuators with an outlet flow, so as to get some relation between dimension and output frequency magnitude of velocity flow.

II. MOTIVATION AND OBJECTIVES

Although use of Sweeping Jet Actuators have been proven as an efficient and effective way for flow separation control, further improvement is required prior to their placement into actual applications. Generally, there is no proven methodology for design of Sweeping Jet Actuators on hand. Size of feedback channel, flow rate, design of coanda surfaces, exit nozzle angle etc. are some of the parameters that influence the performance of actuators. Further, dependence of sweeping frequency on feedback geometry has no available systematic study.

Four numerical and two experimental studies were done to examine the internal flow field of oscillators. However, one numerical study employing a power flow solver is used for interior flow field study of an oscillator. Understanding the jet oscillation process, physics of internal flow, and mechanism of pressure drop is the main objective of this paper, which is based on the time-variant numerical analysis. Controllable frequency, flow control actuator effectiveness with minimum pressure loss accompanied with design methodologies is possible with these understandings. Transient and steady state velocity, temperature and pressure plots, systematic mesh study is included in this paper

III. SIMULATION SETUP

A numerical study is performed using standard CFD Ansys fluent software. The primary jet flow is along the X-axis and the Y-axis indicates for the spanwise direction. The sweeping jet comes out through a single exit nozzle of a two-dimensional computational domain. The numerical and experimental examination was done by Vatsaet.al[13] on three different oscillators for flow control applications. A type-II curved or sweeping actuator is employed. Since there was not a sufficient description for reproduction of actuator geometry, same geometry is replicated from Raman et.al[14] using CAD software which is then mounted up to exit nozzle throat height of 6.35mm.

The nozzle exit plane is provided with semicircular domain of 150mm radius. Further the actuator inlet is provided with straight two-dimensional channel to possess a fully advanced flow at converging nozzle upstream. A static pressure of 101325 pa is assumed at the inlet. No-slip and No-penetration is chosen as boundary condition for velocity and an isothermal wall with temperature 298.16 K. The ambient condition is assumed for pressure outlet where p_∞ =101325 pa and T_∞=298.16 K.

An Ansys meshing software is used to create computational mesh and to perform the grid size and mesh quality inspection. Seven layered inflation method with a growth rate of 1.5is used to create the boundary layer grid. An orthogonal quality of 0.9906 with standard deviation of 0.025 is found.CFD Ansys fluent software is used to solve the governing equations for conservation of mass, momentum and energy assuming fully turbulent and compressible flow.

Table 1: Boundary conditions

	Symbol	Unit	Case 1	Case 2	Case 3
Outlet static temperature	T	K	298.16	298.16	298.16
Outlet static pressure, downstream	P	P_a	101325	101325	101325
Exit nozzle throat height	h	Mm	6.35	6.35	6.35
Inlet channel height	H_i	Mm	16.21	16.21	16.21
Mass flow rate	m	lb/s	0.010	0.015	0.020
Inlet mach number	M_i		0.060	0.102	0.152
Inlet velocity	V_i	m/s	20	35	50

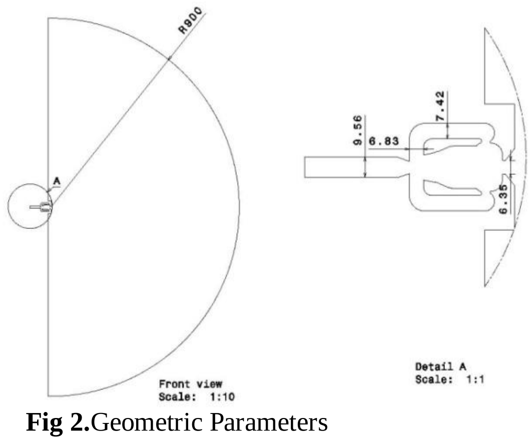

Fig 2. Geometric Parameters

IV.RESULTS

A fixed time step of $\Delta t=10^{-5}$ seconds are employed for simulation of a fully turbulent and compressible flow. Time dependent simulations are done using the second order implicit scheme.Turbulent kinetic energy, second order upwind scheme for density and momentum are done using second order discretization for time dependent simulation started with steady state results. The appropriate turbulent model is determined using steady state calculations along with numerical parameters.Both k-€ and SST k-ωwith and without wall functions are reviewed. In time accurate solutions, SST k-ω is used as it offers more accurate solution.

A. Mesh study

Table 2: Mesh parameters

	Element size (m) ( )x10^{-4}
Mesh 1	5
Mesh 2	2
Mesh 3	6
Mesh 4	9
Mesh 5	15
Mesh 6	25

Table 3: Dimensions

Case	D1(mm)	D2(mm)	h(mm)
A	7.42	6.83	6.35
B	9.42	8.83	8.35
C	10.42	9.83	9.35

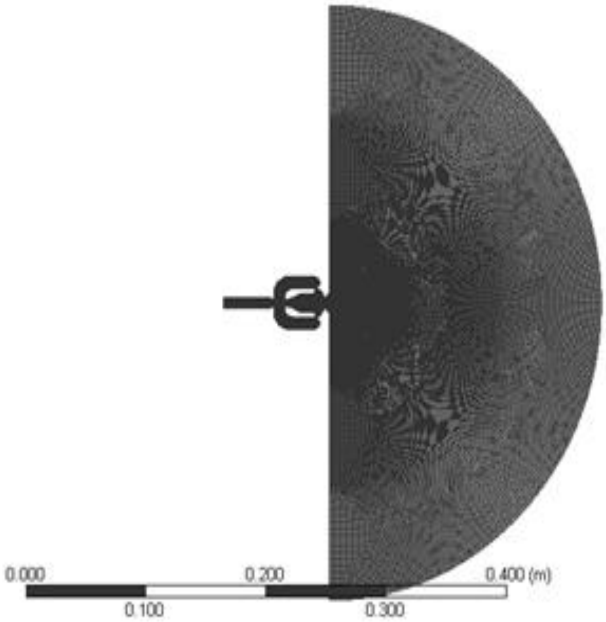

Fig 3. Computational Mesh Setup for Simulation

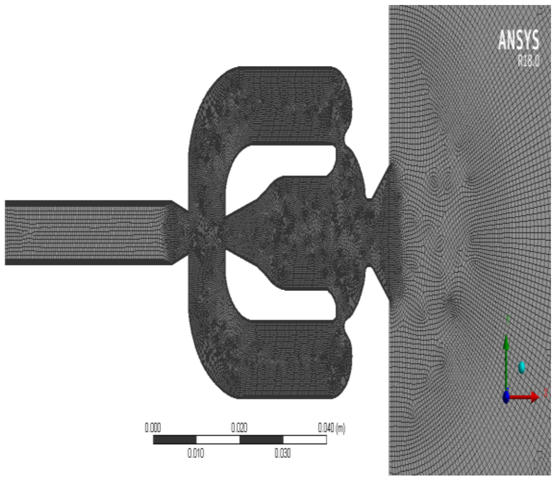

Fig 4. Close-up view of Actuator

Using SWJ actuator geometry, mesh study and simulations are performed with a semicircular domain of 4R attached to it. Uniformly sized elements with a predefined circular area are created using body sizing function in meshing software. During meshing process, the user interaction can be minimized using this method due to the complexity of actuator geometry. Number of elements range from 60000 to 90000 on an average. Using mass flow rate of 0.015 lb/s, simulations are run on time dependent state for velocity magnitude over 10000 steps with $\Delta t=1x10^{-5}$.

B. Effect of feedback channel geometry on velocity and jet oscillation frequency

The geometry of SWJ actuator is defined as parametric geometry where feedback channel width and height are chosen as lead criterions for initial studies. Since geometry is symmetrical to X-axis, both top and bottom channels are sketched to have similar dimensions. New geometries with various feedback channel height (D1) and width (D2) are created, meshed and simulations are performed using chosen, mass flow rate.

Time history of velocity magnitude for various geometries is recorded. For all the cases, jet oscillation frequencies can be found using FFT analysis.

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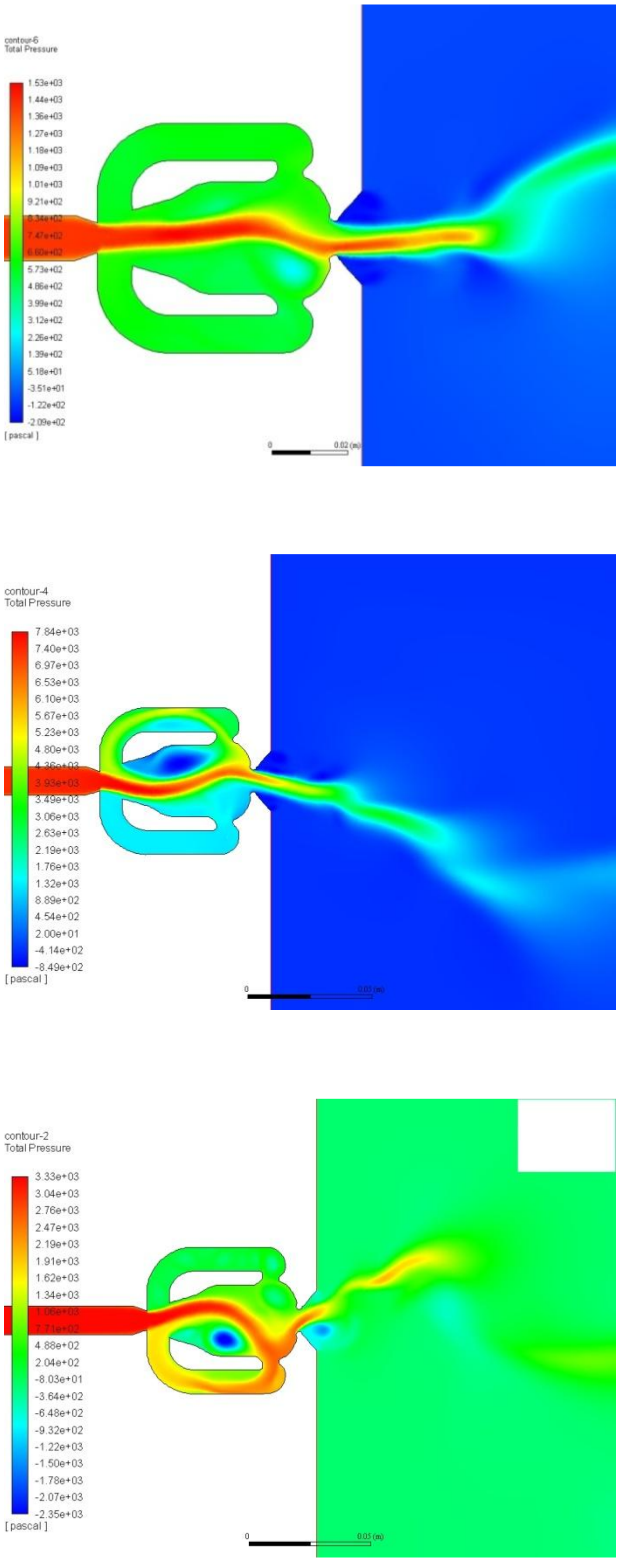


Fig 5. Total Pressure Contours for Velocity 20, 35 and 50 m/s for dimensions A

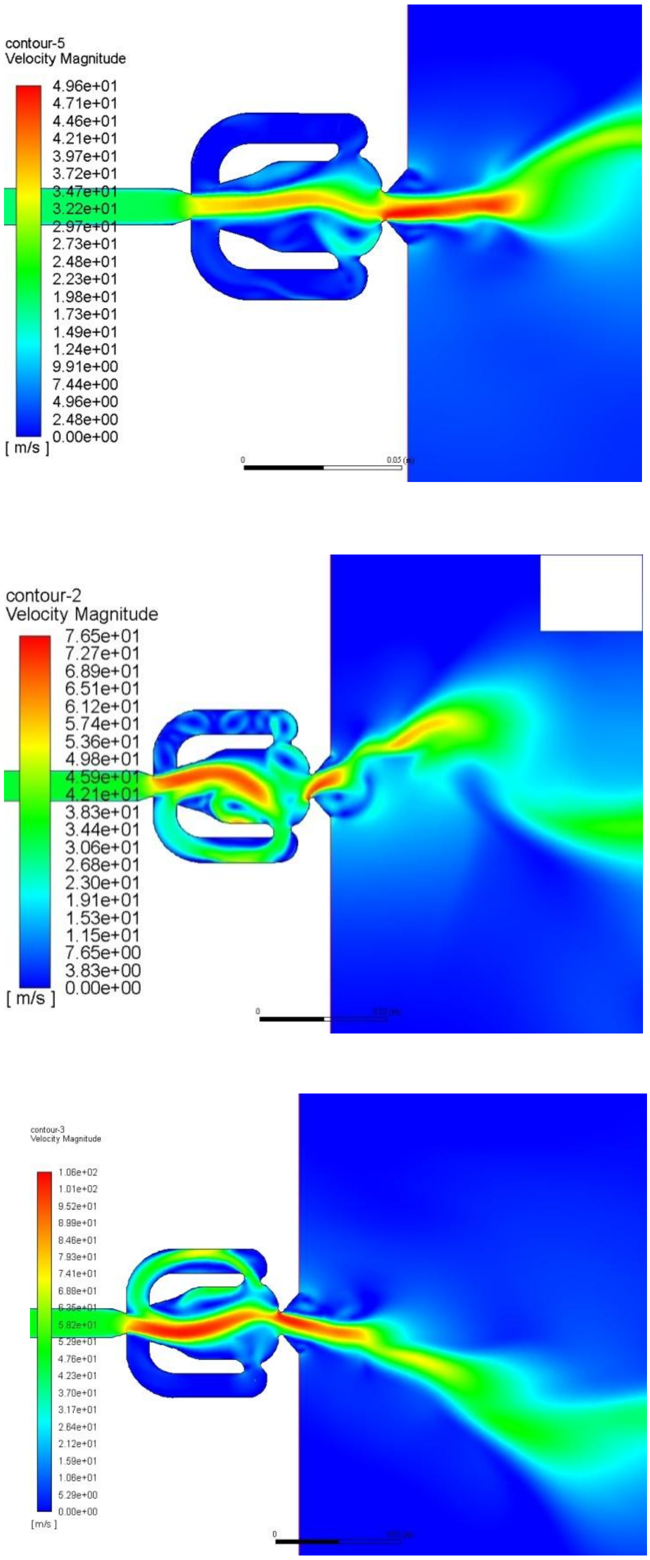
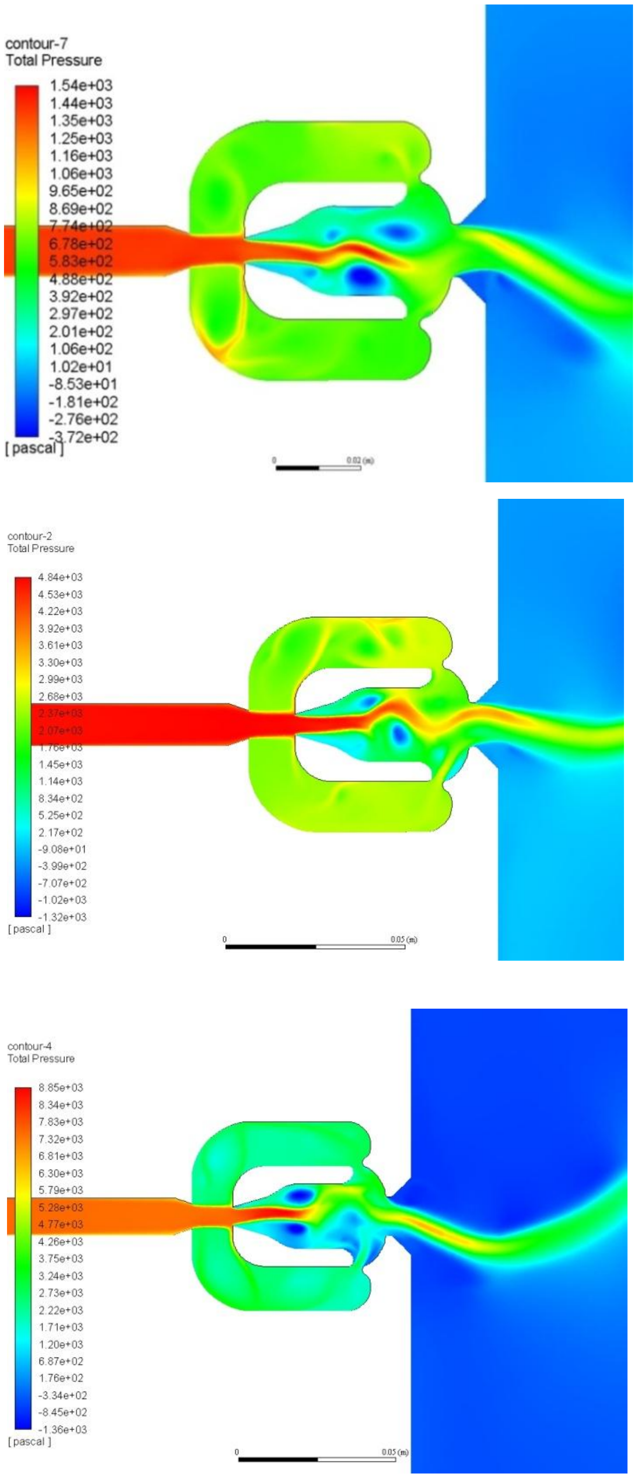


Fig 6. Velocity Magnitude Contours for Velocity 20, 35 and 50 m/s for dimensions A



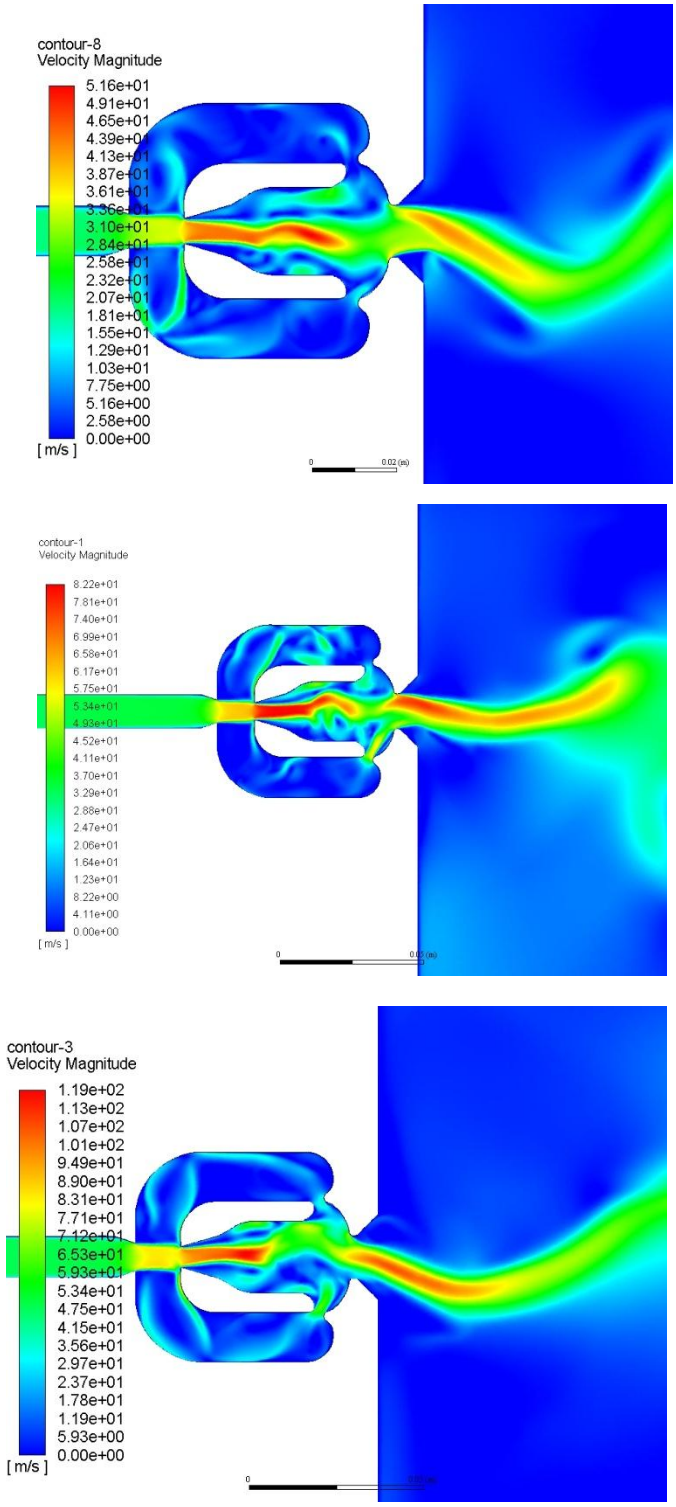
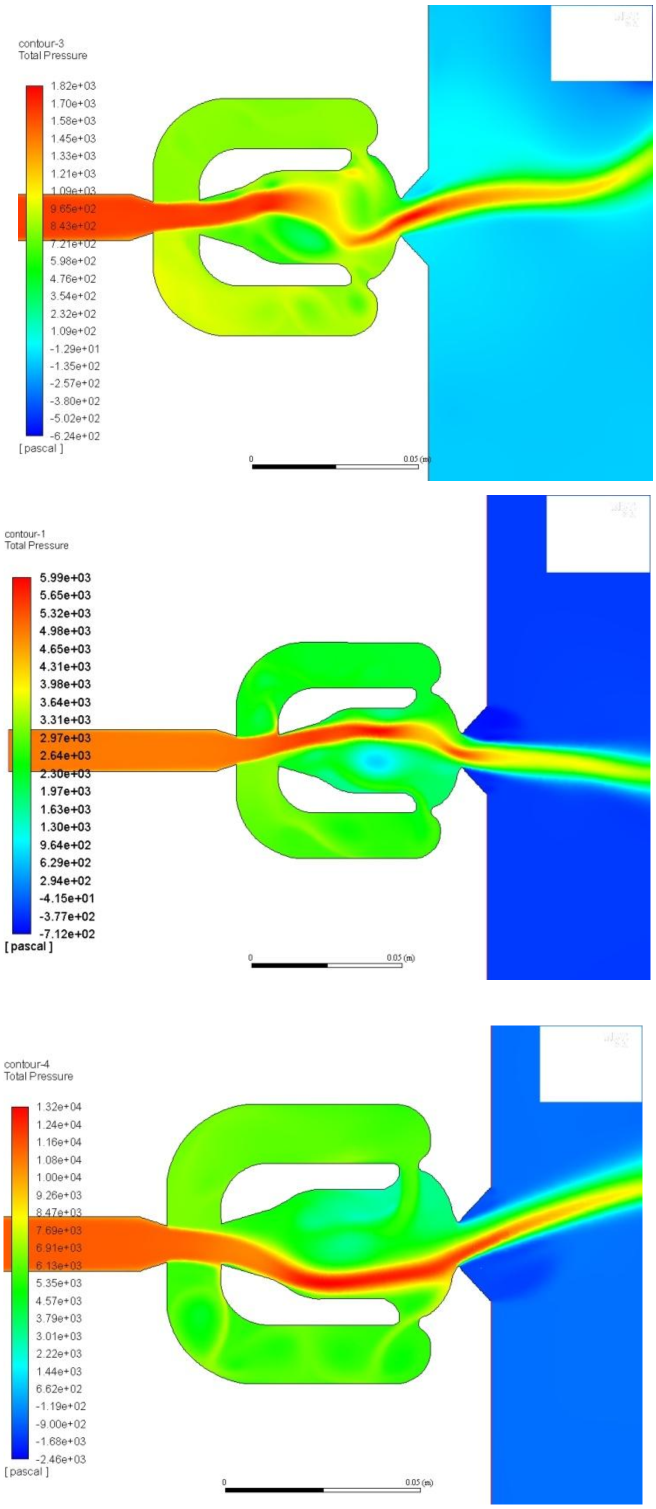


Fig 7. Total Pressure Contours for Velocity 20, 35 and 50 m/s for dimensions B

Fig 8. Velocity Magnitude Contours for Velocity 20, 35 and 50 m/s for dimensions B



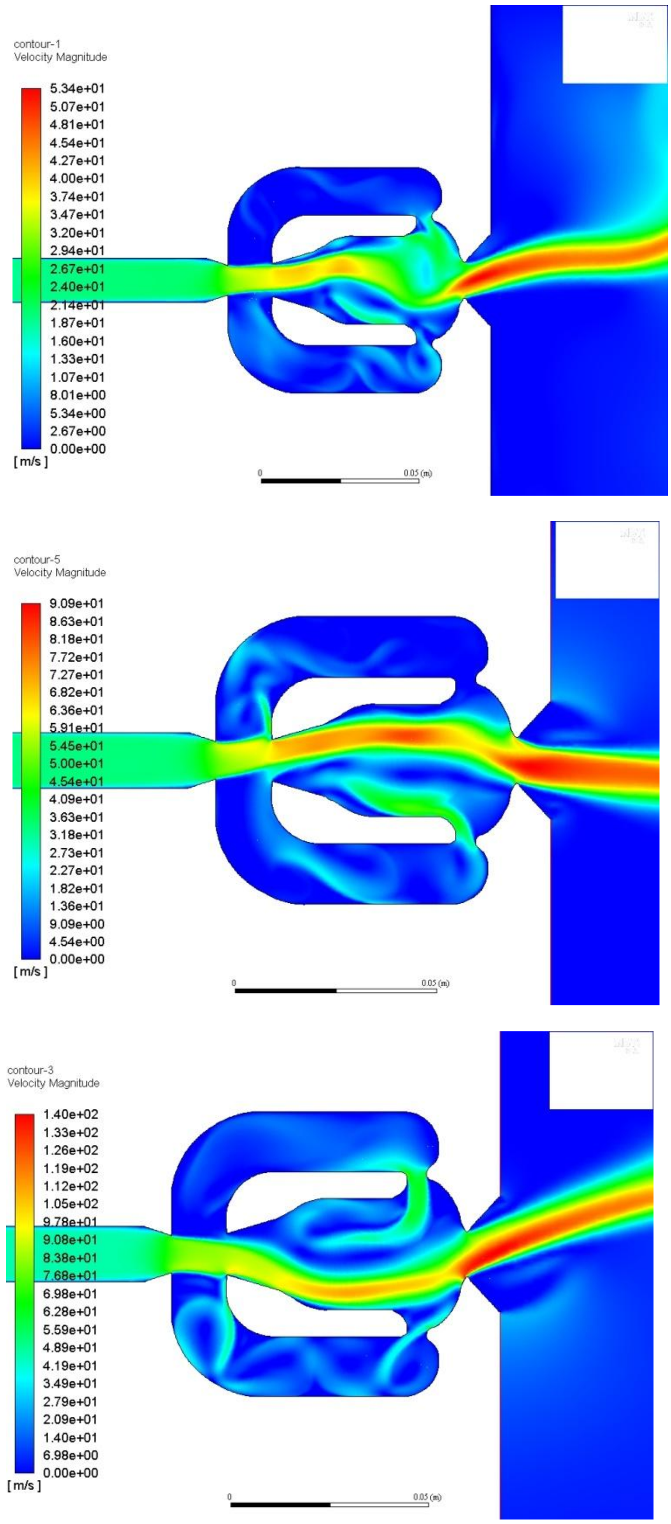


Fig 9. Total Pressure Contours for Velocity 20, 35 and 50 m/s for dimensions C

Fig 10. Velocity Magnitude Contours for Velocity 20, 35 and 50 m/s for dimensions C

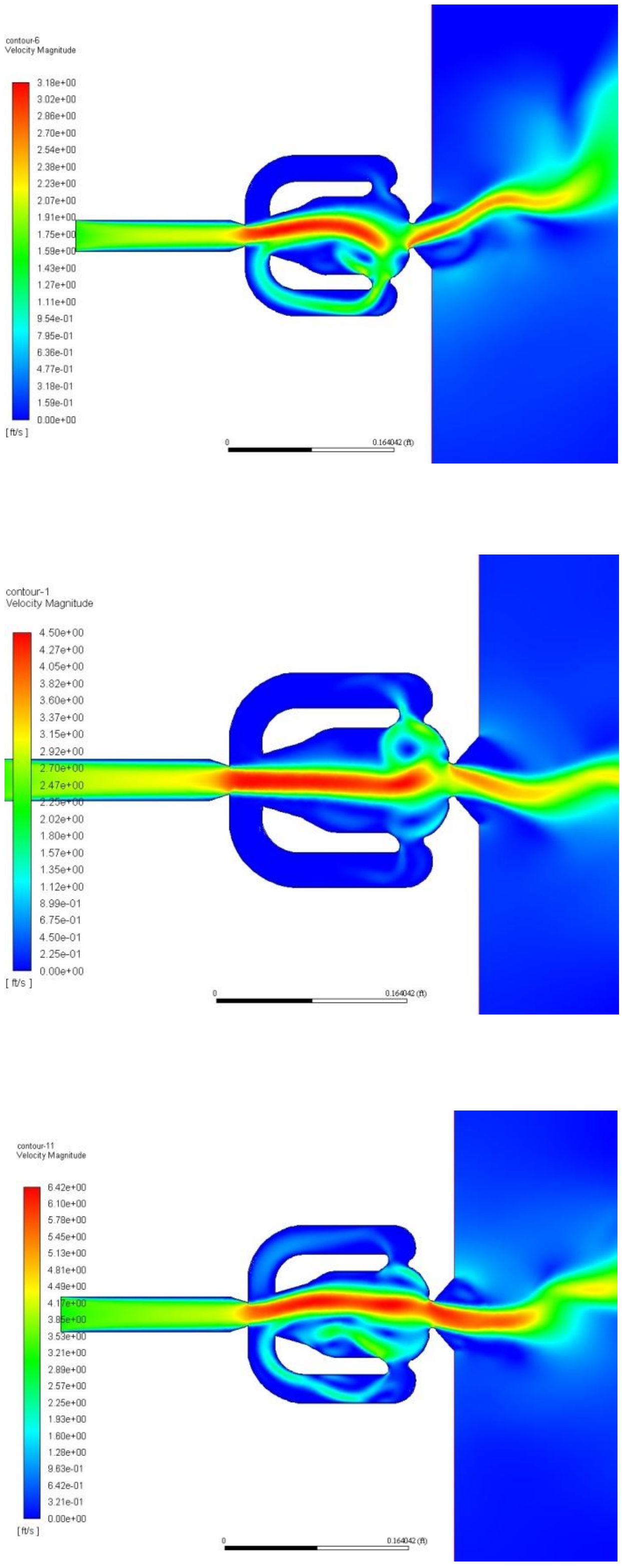


Fig 13. Velocity Magnitude Contours for Mass flow rates 0.01, 0.015 and 0.02lb/s

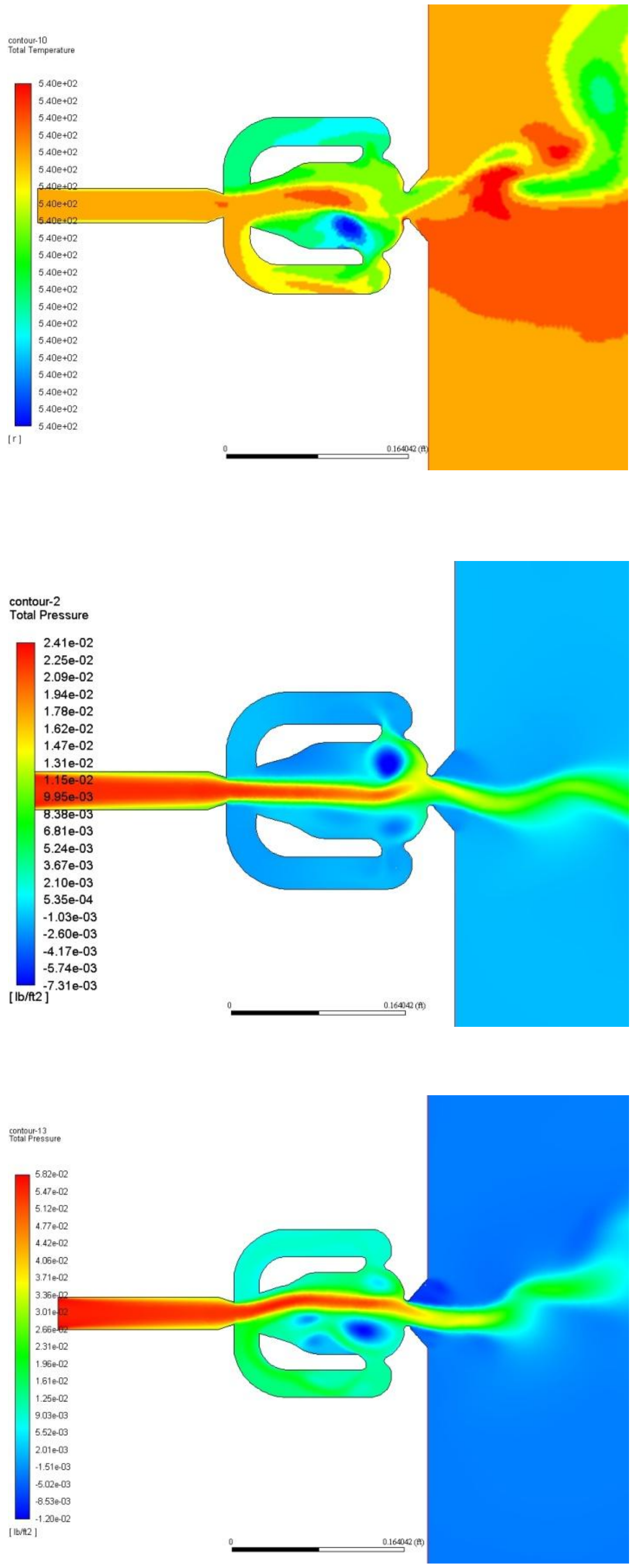


Fig 14. Total Pressure Contours for Mass flow rate 0.01, 0.015 and 0.02 lb/s

C. Mass Flow Study

The oscillation frequency and sweeping jet produced by actuator depends on the geometric parameters as well as mass flow rate at inlet. Steady state and Transient flow simulations are performed for three different mass flow rates to enlighten the physics of complex flow inside the actuator. As expected, jet velocity increased with increasing mass flow rate. For time accurate simulations, steady state cases are merged and used as initial conditional and run for large number of time steps of 20000 iterations with same step size of $\Delta t=1X10^{-5}$.Under each case velocity magnitude and temperature being time variant are recorded.

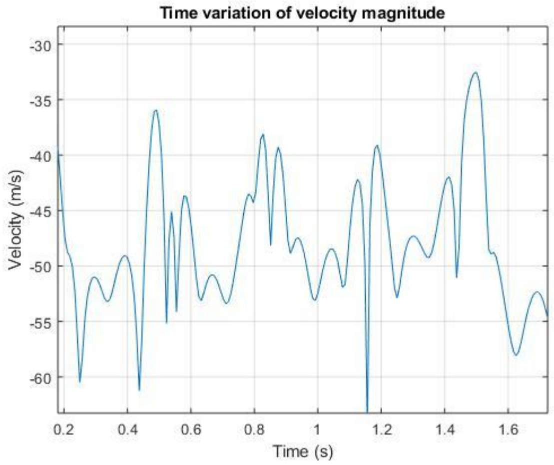


Fig 11. Velocity v/s Time. Mass flow rate = 0.010

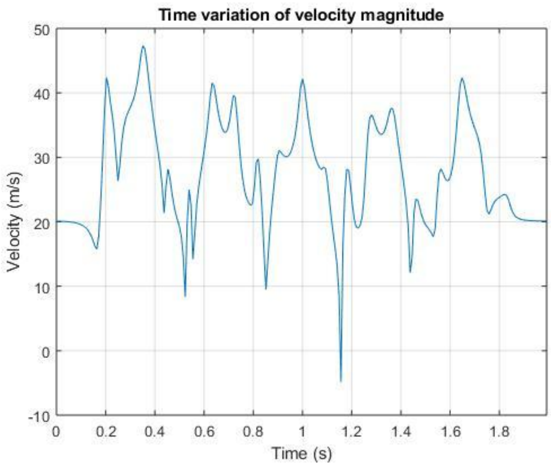


Fig 12. Velocity v/s Time, Mass flow rate = 0.015

Table 4. Maximum velocity magnitudes for different mass flow rates

Mass flow rate(lb/s)	V_{max}(ft/s)
0.010	3.18
0.015	4.5
0.020	6.42

V CONCLUSION

In order to understand the internal flow structures and oscillations of an actuator, time-accurate as well as steady numerical analysis was done using Ansys fluent software. The performance of actuators for flow separation control applications can be improved by understanding the mechanism of oscillation. The main jet, while shifting from lower to upper area of actuator surface, pushes the larger vortex in the actuator core towards exit nozzle. Then, a part of main jet branches into lower channel with high velocity whereas remaining part shift towards exit nozzle with high velocity. Another vortex formed on the lower surface grows in size and pushes the main jet upwards.

Time-dependent velocity profiles for different inlet velocities as well as various feedback channel dimensions are estimated. The frequency of sweeping oscillations depends on geometric parameters as well as on inlet mass flow rates. The geometry of actuator used has been reproduced from Raman et.al and the changes in geometries may cause mismatch in frequencies.

For future considerations, an effort will be done to obtain the minimization of pressure losses through geometric variation.

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