Computational study of Coanda based Fluidic Thrust Vectoring system for optimising Coanda geometry

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Abstract. This paper presents the study which was intended to identify the optimum geometries for different operating conditions of a Coanda bases Fluidic Thrust vectoring using ACHEON nozzle (Aerial Coanda High Efficiency Orienting Nozzle). This computational study was done utilising the software ANSYS. The study is aimed at optimising the Coanda surface by identifying the most appropriate geometry of the Coanda surface for different operating conditions. The radius of curvature of the coanda surface has been modified for different studies and also different levels of truncation of the coanda surface has also been done. In this study a variation in the radius is from 52.73 mm to 62.67mm.

Keywords. Thrust vectoring, ACHEON (Aerial Coanda High Efficiency Orienting Nozzle), Coanda effect

1. Introduction
The aircraft industry has an urgent necessity to reduce fuel consumption and emissions for delivering efficient competitiveness driven by the legislative and commercial requirements of today [1]. The apt place to begin this work would be the propulsion system. If the propulsion system could provide the vehicle’s direction control in addition to providing a propulsive force it would help greatly in working towards the above mentioned goals. A thrust vectoring propulsion system can fulfil this function. By vectoring the direction of the thrust by various mechanisms it is possible to control a vehicle's pitch, yaw, and roll motions. One of these mechanism can be installed and used on any chemical propulsion system [2]. The purpose of a thrust vectoring system is: for correcting or altering a flight path; to perform a rotation of the vehicle; or to adjust misaligned thrust of a fixed nozzle. The movement which will result in lowering or raising of the nose of a vehicle is called pitching and those that turn the nose sideways are called yaw and rotations about the prime axis of the vehicle is called roll [3]. Installing thrust vectoring systems will considerably reduce the weight, complexity and maintenance cost of an aircraft by avoiding moving parts. It will make the designing simple and the product easy to manufacture [4]. Since the basic principles used to create these control are based on the behaviour of fluid flows these methods are called Fluidic methods.
2. Coanda effect
The working of an ACHEON system rely on two effects namely jet interaction and the Coanda effect [5]. The tendency of a fluid to adhere to a curved surface (Figure 1) is called as the coanda effect. This phenomenon occurs because of the reduction in pressure caused by the high velocities of the jet [6]. The balance of forces on the fluid cause the adhesion of the jet fluid on the curved surface [7]. These forces that which causes these adhesion are the radial pressure and the centrifugal forces. The contact pressure of the fluid jet with the wall is lower than the ambient pressure when the jet comes in contact with the wall. It is lower because of the viscous drag phenomena created by the interaction of the fluid with the wall surface [8]. The difference in pressure observed here is the primary cause for the fluid’s attachment to the curved wall surface.

![Figure 1. Coanda effect](image)

3. ACHEON and its working
The ACHEON creates a vectoring of thrust by the interaction of two primary jets followed by the adhesion of the resulting secondary jet to the coanda surface. The whole process successfully happens without the necessity of any moving parts [10]. The primary jets continually exert an entrainment force on each other. The design is in a way, so as to permit a deviation of the secondary jet in a controlled dynamic fashion [11]. This secondary jet is the sum of the two primary jets [6]. The control of the vectoring of the jets happen in this way, if both the primary jets are of the same velocity then there won’t be any deflection of the resulting secondary jet from the symmetric axis but if not then the primary jet with the higher velocity entrains the other causing the flow to deflect from the symmetric axis [9]. The attachment of the deflected flow to the wall surface is a result of the coanda effect. To withstand adverse gradients of pressure created by this process, a cylindrical surface is chosen [12]. The general design of the nozzle is shown in figure 2.
The basic requirement of this system is a duct split into two channels by a central septum. Two primary jets feed the nozzle and the deflection of the outflow jet is a function of the momentums of the two primary input jets [13]. The term m.1 represents the mass flow rate of the flow with the higher [14] momentum and m.2 represents the mass flow rate of the flow with the lower momentum [15]. These two channels converge into a region where the mixing process begins to occur. Following this there is an outflow where the walls seamlessly connect to two coanda surface.

The dimensions of the ACHEON apparatus chosen for this study has been shown in Figure 3. The variation in geometry of the nozzle is of the coanda surface. The radius of curvature of the coanda surface has been modified for different studies [16]. In this study a variation in the radius is from 52.73 mm to 62.67mm. Also different levels of truncation of the coanda surface has also been done.
4. CFD Analysis

The computational fluid dynamic simulations have been performed using Ansys Fluent CFD code. Numerous simulations have been performed. The 2D planar nozzle geometry used in these simulations is shown in Figure 3. Performing the simulations for different mass flow rates has ensured a model independent of the geometric parameters.

Meshing has been performed using a 2D unstructured quad mesh which was further enhanced by inflation and boundary layer refinement. A total of 3540 nodes and 3428 elements are present. A sample of the mesh is displayed in Figure 4.

![Sample of meshing and refinement](image)

**Figure 4.** Sample of meshing and refinement

The solver is a steady state density based 2D planar. Both the one equation Spalart-Almaras and the two equation $k-\varepsilon$ turbulence models with standard wall treatment option have been utilised. These simulations have been conducted for different differential mass flows with an overall mass flows of 8kg/s. The fluid for the flow is considered as air as an ideal gas in standard conditions. The solution formulation is Explicit. A Lagrangian approach has been followed [17].

Atmospheric conditions of pressure 101325 Pascals and temperature of 300 kelvin were applied to the static ambient region which is surrounding the nozzle and flow area. The inlet conditions were mass flow inlets. The overall sum of the mass flow is 8kg/s which has been split into different differentials for different simulations over the course of this study. The flow has a 4000 Pascal overpressure than the atmospheric ambient pressure. No slip and adiabatic conditions are applied to the walls.

5. Results and Discussions

The study conducted by Michele Trancossi and Antonio Dumas [11] on Coanda Synthetic Jet Deflection Apparatus and Control provided results of mass flow vs. deflection angle for a single arbitrary radius of curvature. The results from this study was used to validate the initial computations. The results of this validations is presented in Figure 5. The average deviation from the results of Michele Trancossi and Antonio Dumas was found to be 0.09 radians. In the study by Michele Trancossi and Antonio Dumas a parameter $m.\ast$ has been introduced to represent mass flow differential by a single value.

$$m.\ast = (m.1-m.2)/(m.1+m.2) \quad [11]$$
Figure 5. Comparison of plots of deflection angle vs. m.* from this study and a reference, the study by Michele Trancossi and Antonio Dumas [11]

Figure 6. The samples of FEA images for radius 58.251mm at different thrust vectoring angle
The graph obtained by plotting deflection angles corresponding to different mass flow differentials has been shown in Figure 7. From this graph the primary observation is that different radii of curvature of the coanda surface has a profound effect on the parameter of angle of deflection. On the other hand truncating the coanda collar did not produce any beneficial effect on the deflection angle. The angle of deflection was continually deteriorating on increasing the level of truncation.

![Graph showing deflection angle vs. differential mass flow for different radius of curvatures.](image)

**Figure 7.** Deflection angle vs. differential mass flow for different radius of curvatures

The differential mass flow is the independent parameter (parameter controlled and decided by the nozzle operator) and deflection angle is dependent parameter (the output required). The deflection angle required varies with application and usage. The parameter to be looked upon here is not only the range of deflection angles attainable but also the change in deflection angles with respect to change in difference of mass flows. For example if the majority of the operating range is going to be 0 and 0.5 radians then 61.56mm radius of curvature provides the change of angle of deflection with a very small change in difference of mass flows, however if a very minute changes in angles of deflection are necessary then 57.15mm radius of curvature is advisable. Other details must also be reviewed in choosing of the appropriate radius of curvature, for example in radius of curvatures 56.04mm, 58.25mm there is always only an increase in angle of deflection of with an increase in difference of mass flows whereas in certain other radius of curvatures there isn’t a constant increase or decrease in the angle of deflection, there is an increase followed by a decrease or vice versa or both. This might not be ideal or undesirable for some applications. Also a plot of Deflection angle vs. radius of curvatures for different differences in mass flows has been presented in Figure 8.
Figure 8. Deflection angle vs. radius of curvatures for different differences in mass flows

The plot of exit velocity vs. radius of curvature of the coanda surface is shown in the figure 9. The exit velocity is the average exit velocity for all the differential mass flows for that particular radius. It can be observed that the general trend is that the exit velocity increases with the increase in radius of curvature. Higher exit velocity indicates that there are lesser thrust losses and lesser friction because there is no change in the flow inlet.

Figure 9. Exit velocity vs. radius of curvature
6. Conclusion

The present paper describes changes in parameters which happen by changing the geometry of the ACHEON. And suggestions of how to choose the appropriate geometry has also discussed in this paper. ACHEON is a modern development with lots of potential applications [11], some of which are:

- Ship and aircraft propulsion systems
- Technological systems, painting, thin film deposition and powder on mechanical parts
- Technological facilities for superficial treatments of mechanical parts with particle injection
- Industrial washing and cleaning jet of food
- Jet drying plants
- Heating or cooling air jets
- Flame systems which can change the direction of the flame without moving mechanical parts
- Ventilation systems, air conditioning and heating
- Fire Protection Systems with jet fluids that can be easily oriented directly on the flame

The potential savings in cost, material, complexity in numerous devices because of ACHEON is immense. The present study will help in a further increase in efficiency of these devices and help in hastening the design processes of these devices.

7. References

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