International Journal of Engineering Research And Advanced Technology (IJERAT)
ISSN: 2454-6135 [Special Volume. 02 Issue.01, May-2016]

Optimization of Best Device Shape in Subsonic Fluidic Thrust Vectoring Nozzle

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ABSTRACT

The Fluidic Thrust Vectoring (FTV) is emerging as a significant technology for high-performance air vehicles. The technology can improve aircraft's manoeuvrability by manipulating the nozzle flow to deflect from its axial direction. The objectives of this study are to investigate the effect of a mechanical strut on the primary flow and to optimize the aft-nozzle device shape along with the best secondary injection port in a 2D subsonic nozzle.

Key Words: *Fluidic thrust Vectoring, Strut, Nozzle*

1. INTRODUCTION

Thrust vectoring, also **thrust vector control** or **TVC**, is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor in order to control the attitude or angular velocity of the vehicle.

In rocketry and ballistic missiles that fly outside the atmosphere, aerodynamic control surfaces are ineffective, so thrust vectoring is the primary means of attitude control. For aircraft, the method was originally envisaged to provide upward vertical thrust as a means to give aircraft vertical (VTOL) or short (STOL) takeoff and landing ability. Subsequently, it was realized that using vectored thrust in combat situations enabled aircraft to perform various maneuvers not available to conventional-engine planes. To perform turns, aircraft that use no thrust vectoring must rely on aerodynamic control surfaces only, such as ailerons or elevator; craft with vectoring must still use control surfaces, but to a lesser extent.

Most currently operational vectored thrust aircraft use turbofans with rotating nozzles or vanes to deflect the exhaust stream. This method can successfully deflect thrust through as much as 90 degrees, relative to the aircraft centerline. However, the engine must be sized for vertical lift, rather than normal flight, which results in a weight penalty. Afterburning (or Plenum Chamber Burning, PCB, in the bypass stream) is difficult to incorporate and is impractical for take-off and landing thrust vectoring, because the very hot exhaust can damage runway surfaces. Without afterburning it is hard to reach supersonic flight speeds. A PCB engine, the Bristol Siddeley BS100, was cancelled in 1965.

1.1 ADVANTAGES & DISADVANTAGES OF FLUIDIC THRUST VECTORING

1.1.1 Advantages:

- Lighter.
- Economical.

- Increases Survivability.

1.1.2 Disadvantages:

- Less directional changing capability.

2. NEED FOR FTV AND DEFINING THE PROBLEM:

Fluidic Thrust vectoring is essentially a method of diverting the exhaust flow from an engine nozzle at a specific angle (most usually in the pitch direction) via the use of the *coanda* effect. The Coanda effect is the tendency of a moving fluid to adhere to a solid curved surface. Due to the presence of the Coanda surface, entrainment by the secondary jet is inhibited on the side nearest to the surface.

3. SOLUTION TO THE PROBLEM

A subsonic convergent nozzle is to be modified to get the benefits of the Fluidic Thrust Vectoring. The work involves studying the fluidic thrust vectoring by Throat Skewing method.

An aft nozzle device was designed for the given nozzle considering the parameters such as Thrust and Total Pressure Loss with thrust deflection angle for pitching of aircraft being the priority.

The parametric studies for different aft nozzle geometries are done using Fluent.

The optimum position of the secondary injection is analyzed by introducing struts at various positions.

4. OBJECTIVE

- To optimize the shape of the contour and position of the secondary injection point which produces 6° deflection for a convergent nozzle of NPR 3.

5. SCOPE

- To design the contour which will not affect the performance (thrust and pressure loss) of nozzle when deflection is not required.
- To optimize the position of secondary injector. The secondary injector is replaced by strut to simulate the depth of penetration.
- To study the thermodynamic parameters which affect the thrust vector angle.

6. NOZZLE GEOMETRY DESIGN

The two dimensional, convergent fluidic thrust vectoring nozzle is made according to the prescribed dimensions. Three nozzle shapes with different dimensions are made (1) 6&10 (2) 6&15 and (3) 6&20 where 6 is the divergence angle at the entry of aft-nozzle part and 10, 15, 20 are the angles at the converging part of aft-nozzle for different geometries. Each shape has a pressure inlet, mid interiors, walls, secondary interior, nozzle interior and a pressure outlet. Pressure at the inlet is 3 bar and the ambient pressure outside nozzle being 1 bar. The nozzle pressure ratio (NPR) is 3 and exit Mach number is <1. Mechanical struts are introduced at different positions in the device (0.25L, 0.5L, 0.75L, and 0.9L) and for each case the thrust pitching angle and the pressure loss are calculated. The three different geometries are shown in figure 5.1, 5.2 and 5.3. Different strut positions are indicated in figure 5.4, 5.5, 5.6 and figure 5.7. Once the position which gives maximum pitching angle and minimum pressure loss is found, for that particular position different depth of penetration (10%, 20%, 30%, 40%, 50%) is given to find the variation of thrust pitching angle and pressure loss with depth of penetration.

6.1 GRID DIAGRAM OF GEOMETRY:

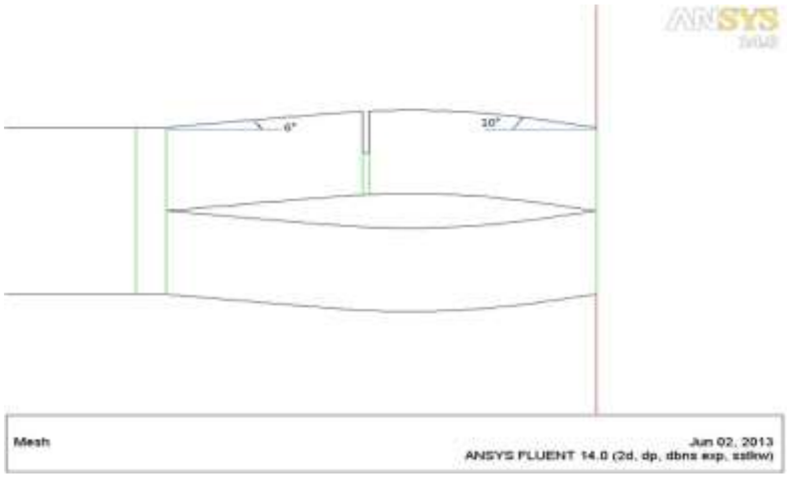
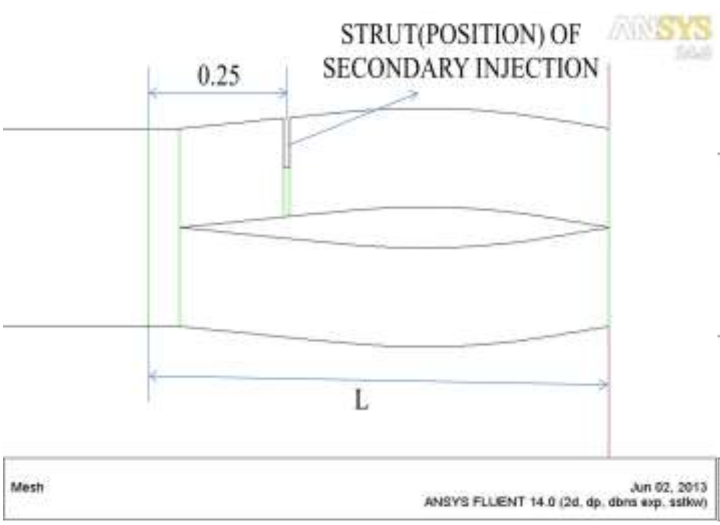


Fig 1 Geometry

6.2 VARIOUS STRUT POSITIONS FOR 6&10 MODEL



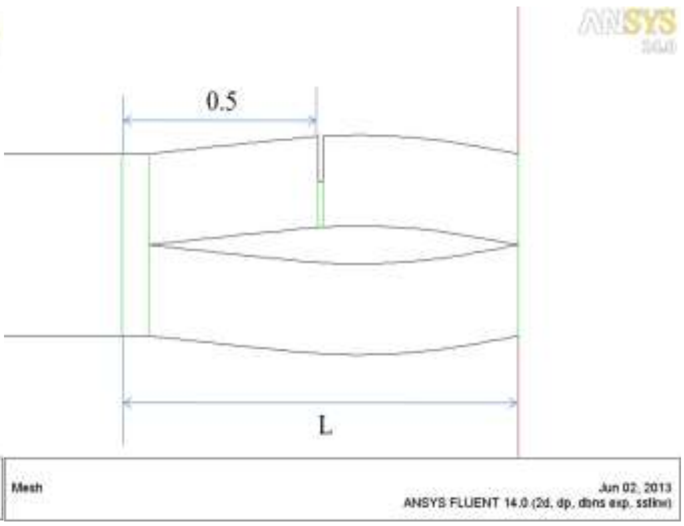
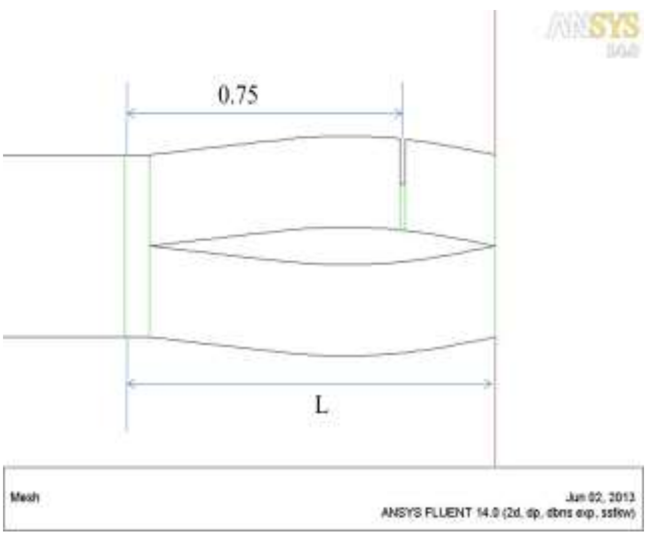


Fig 2 0.25L Strut Position

Fig 3 0.5L Strut Position



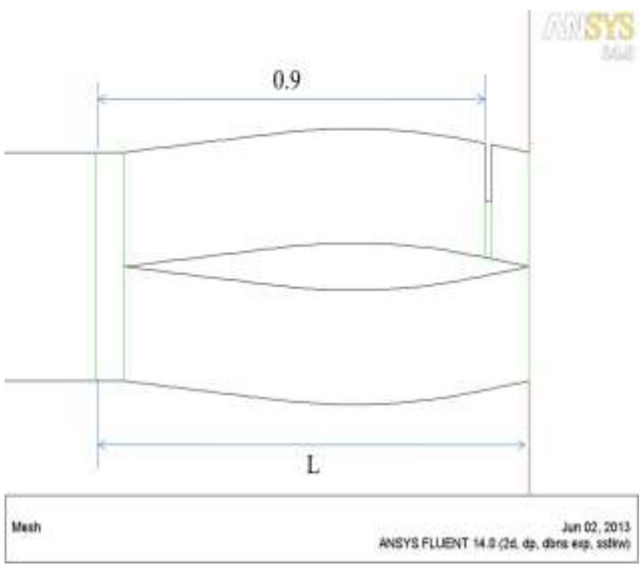


Fig 4 0.75L Strut Position

Fig 5 0.9L Strut Position

7. RESULTS AND DISCUSSION:

7.1 COMPARISON OF PREMILINARY RESULTS

7.1.1 Deflection and pressure loss values in degree for various strut positions with 50% jet blockage:

Initially the three models 6&10, 6&15 and 6&20 are considered. Here 6 is the divergence angle of the aft-nozzle portion in degree and 10, 15 & 20 are the convergence angle of the aft-nozzle portion in degree. For these three

	0.25L Position		0.5L position		0.75L position		0.9L position	
	Deflection (degree)	Pressure loss (%)	Deflection (degree)	Pressure loss (%)	Deflection (degree)	Pressure loss (%)	Deflection (degree)	Pressure loss (%)
6 and 10 model	3.03	24.6	2.22	25.44	0.1	23.02	3.2	23.4
6 and 15 model	4.6	25.94	6.3	25.45	1.8	24.15	3.0	23.979
6 and 20 model	5.6	25.6	5.43	25.68	4.28	24.32	2.7	23.25

models a mechanical strut is placed at four positions to study the behaviour of the fluid as explained earlier. The table 1 explains the comparison of deflection and total pressure loss obtained for different configuration.

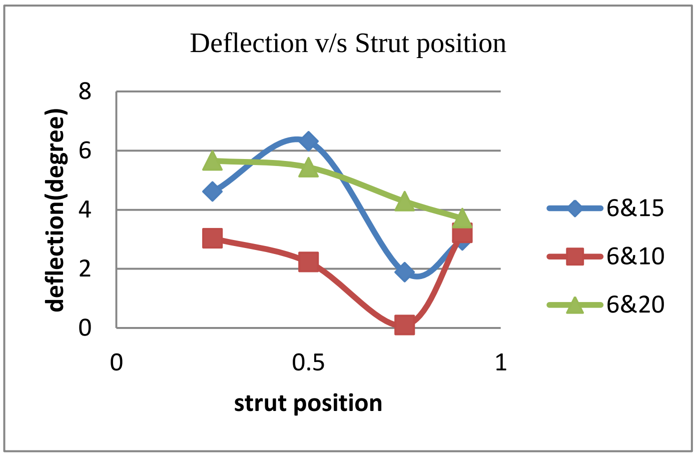
Table 1

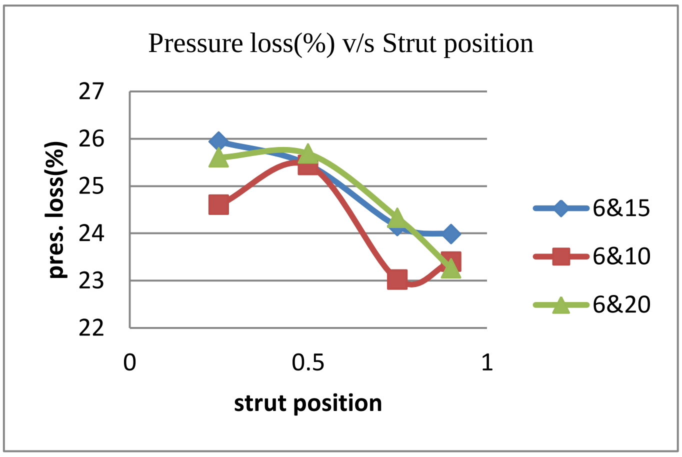
The graphical comparison of above three configurations for pressure loss and deflection values produced against strut position is shown in figure 6 and 7. The deflection values in degree are plotted in y-axis against strut position in x-axis and pressure loss in percentage in y-axis against strut position in x-axis.

Fig 6

Fig 7

It is clearly seen that strut placed at 0.5L position i.e. at mid position gives the maximum Thrust Vector Angle. For further analysis, mid nozzle position is taken and the results are compared to find the best position.





7.1.2 Comparison of 3 models for which mechanical strut placed at mid-nozzle position:

From table 2 it is observed that the 6&10 and 6&15 degree model same pressure loss but deflection achieved in 6&15 degree model is higher. The 6&20 is having better deflection than 6&10 model but the total pressure loss is higher among all. Though the pressure loss for all three models is marginally same, the deflection achieved for 6&15 degree model is more. The total pressure loss is directly proportional to the efficiency of the engine. So it is preferred to take configuration having minimum pressure loss. So from this 6&15 degree model is taken for further analysis.

	Deflection (degree)	Total Pressure loss (%)
6 and 10 model	2.2	25.44
6 and 15 model	6.3	25.45
6 and 20 model	5.4	25.68

Table 2

The graphical comparison for above three configurations for deflection in degree v/s aft nozzle exit angle and pressure loss v/s aft nozzle exit angle is shown in figure 8 and 9.

Fig 8

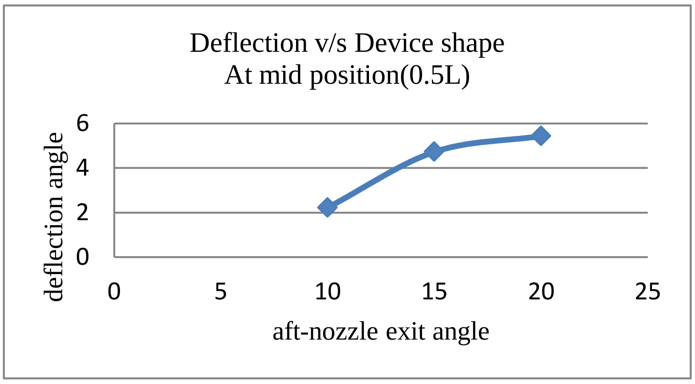
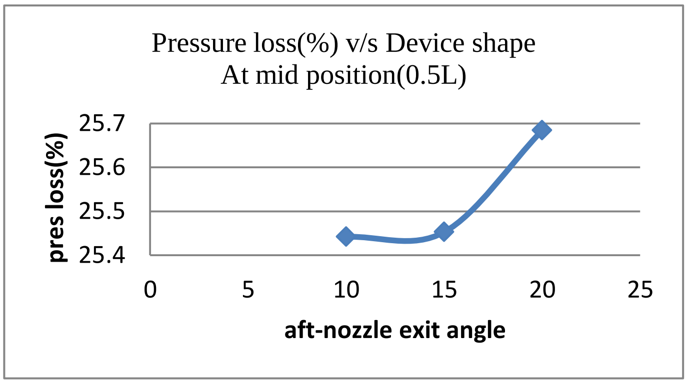


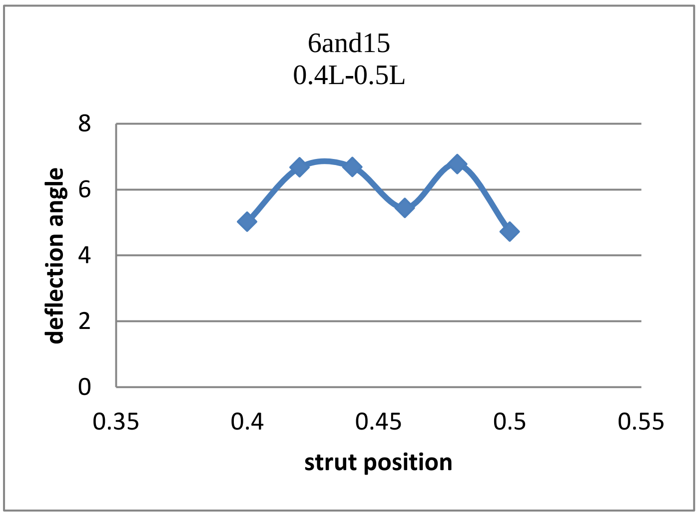
Fig 9



7.1.3 Comparison of 6 and 15 degree model for strut placed at various positions:

From the above discussion 6&15 configuration is finalized as the best shape. The study on position of strut for deflection is studied and the values are tabulated in table 3. It shows the deflection achieved for different positions of strut. It indicates that at 0.48L position it gives maximum deflection of 6.77 degree. It is also observed that the total pressure loss is almost constant.

Strut position	Thrust Vector Angle (degree)	Total pressure loss (%)
0.4L	5.02	25.23
0.42L	6.67	25.34
0.44L	6.68	25.37
0.48L	6.77	25.51
0.5L	6.3	25.45



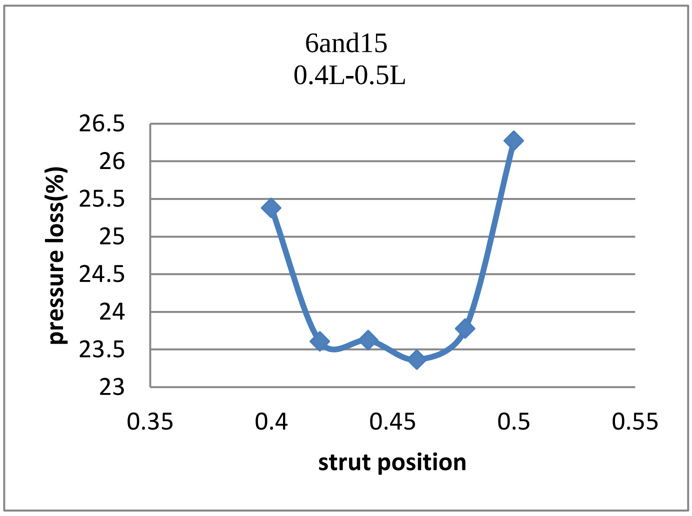


Table 3

Fig 10

Fig 11

The graphical representation of values tabulated in table 3 is shown in figure 10 and 11 in which deflection and pressure loss are plotted on y-axis and strut position on x-axis.

7.1.4 Table for different Depths of Penetration for 6 and 15 degree model:

Further the analysis was carried out for different depth of penetration as it was seen that 0.48L gives maximum deflection 0f 6.77 degree. This analysis gives the relation for the deflection to the height of the strut. The height of strut relates to the depth of penetration which will be achieved through secondary injection. The values are tabulated in table 4.

It indicates that the 50% depth of penetration gives maximum deflection, but as the depth of penetration increases the deflection decreases. It is also observed that from 5% to 20% height of strut there is no deflection observed. This indicates that to achieve a minimum deflection the secondary injection should produce a minimum depth of penetration of 25%. The table 4 also indicates that the total pressure loss increases as depth of penetration increases.

Depth of penetration (%)	Thrust Vector Angle (degrees)	Total pressure loss (%)
5	0	8.58
10	0	10.04
15	0	11.71
20	0	13.48
25	2.62	15.56
30	3.0	17.87
35	3.62	19.76
40	4.57	21.74
45	4.9	23.42
50	6.6	25.51
65	5.32	29.27

Table 4

8. CONCLUSIONS:

The objective of this project is to investigate the FTV effects of a mechanical strut as flow blockage on the primary flow in a Converging nozzle. Computational studies of FTV were carried out with an aft-nozzle model for a subsonic preliminary nozzle. In the preliminary studies the slot for the mechanical strut is decided for maximum TVA. The best device geometry is decided based on the maximum TVA and minimum pressure loss. The experiments are performed with a NPR of 3. Computations are performed for different combinations of mechanical strut locations and length of strut penetration directly into the primary flow for three different geometries.

The results of this study are summarized as follows:

- The FTV mechanism for positive thrust pitching moment is investigated. For the expected FTV mechanism, if the mechanical strut slot is on the nozzle upper wall, the obstruction forms an oblique wave which makes the primary flow turn downwards from the longitudinal axis when the primary flow interacts with the oblique wave. As a reaction force, the primary flow will turn upwards. Mid-nozzle position is found to be suitable for maximum thrust pitching angle by preliminary studies.
- The comparison of 3 geometries for mechanical strut positioned at mid-nozzle position shows that 6&15 geometry gives maximum thrust pitching angle with considerable minimum pressure loss.
- The total pressure loss and the thrust pitching angle are used to evaluate FTV performance. It is found that the pitching angle increases to maximum value as the strut slot moves far away from the nozzle entry until the mid-nozzle position and later it starts decreasing; that is to say, the thrust pitching angle is depending on the strut position. The thrust pitching angle again increases a little after 3/4th length. This is due to the induced oblique shock wave at the end of nozzle which tries to deflect the primary flow along with it. 0.48L position for mechanical strut gives maximum deflection of 6.77degrees with a total pressure loss of 25.5%.

- The nozzle internal parameter distributions are presented such as the Mach number, Density, Velocity components and Total pressure at different locations. With the introduction of mechanical strut, notable shock waves and flow separation are observed at the upstream of the primary flow.
- Different penetrations of strut into the primary flow are studied and the plots show that thrust pitching angle and pressure loss varies almost linearly with the increase in depth of penetration.
- The guidance for optimizing nozzle configuration is provided. Getting large thrust pitching angle is one of purposes to the nozzle design. In this study 6&15 model is suggested for experimental studies.
- The similar results are expected for negative thrust pitching angle by introducing the mechanical strut in the lower part of aft-nozzle device.

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