CFD Based Parametric Study of a Subsonic Flush Intake for Cylindrical Fuselage.

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Abstract—**Recent studies indicate that the performance of a flush intake depends upon its critical geometric parameters. These critical parameters are: side edge angle, ramp angle, intake duct shape & size. In this paper a numerical study is carried out to maximize the air flow quality on the aerodynamic interface plane (AIP) i.e. pressure recovery (σ) and distortion index (Δσ) under given flight conditions for a non-planar side entrance. CFD simulations are performed on different geometric iterations of side edge angle & ramp angle and finally single flush intake geometry optimized for maximum pressure recovery and flow quality is extracted.**

NOMENCLATURE

AIP = Aerodynamic Interface Plane
D = Diameter of engine at AIP
σ = Mass average total pressure recovery
Δσ = Circumferential total pressure distortion index
P_f= Mass average total pressure of free stream.

$P_{avg360deg}$ = Mass average total pressure over entire AIP.
$P_{min\ 60\ deg}$= Mass average total pressure on worst 60 deg sector.
M_o= Free stream Mach
R22-S8 = Geometry with ramp angle of 22 deg& side edge angle of 8 deg.
Alpha= Angle of attack in deg
Beta= Side slip angle in deg.

I. INTRODUCTION

Flush intakes are extensively employed in commercial aircrafts for auxiliary air supply such as bleed air for air conditioning, however flush intakes for engine supply are not in vogue but are increasingly gaining attention. Various research papers published by journals such as AIAA, JPP etc. are available for flush intake design. Flush intakes for specialized air vehicles can achieve lower drag, weight and also minimize the foreign object damages compared to conventional intakes. As this type of intake is completely embedded in air vehicle body so the outside boundary layer is almost entirely ingested into the intake which results in less pressure recovery and low flow quality (i.e. high total pressure distortion index). To improve the critical performance metrics of total pressure recovery and flow distortion of this type of intake it is necessary to obtain the parametric trends of key geometric design variables. Operation of flush intake depends upon the strength of the counter rotating vortices generated by side edges of the submerged inlet. These two counter rotating vortices are the important phenomenon responsible for the entrainment of outer flow into the intake however the strength of these vortices varies with side edge angle and ramp angle. So to optimize the performance of flush intake it is important to study the behavior of flow by varying these critical geometric parameters. To maximize the air flow quality on the aerodynamic interface plane (AIP) the pressure recovery (σ) should be maximized and the distortion index (Δσ) be minimized under given flight condition of Mach ranges from 0.5 to 0.9 at sea level. Previously some work had already been done on flush intake with different geometric parameters of side edge angle & ramp angle for planner side entrance [Ref: 1], however in current study these parameters are studied for flush intake with cylindrical entrance. Therefore CFD simulations are performed on different side edge angles& ramp angles.

II. GEOMETRY

Afuselage of cylindrical shape with semi-circular nose is used as a CFD model integrated with different geometric iterations of flush/ submerged intakes. The length of the cylindricalfuselage from the nose to the intake leading edge is 11.5D. The fuselage diameter is 1.75D.The geometric details are shown in figures:1(a) & 1(b). Twenty different geometries of flush intakewith different combinationsof side edge angles and ramp angles were used with this cylindrical fuselage. Ramp angle is varied from 20 deg to 26 deg and side edge angle is varied from zero to 12 degree as shown in figures 2(a) & 2 (b).

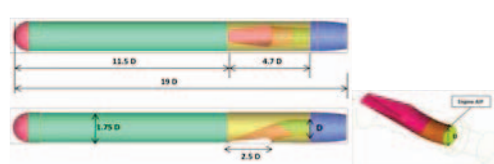

Figure.1 (a) Geometric model details

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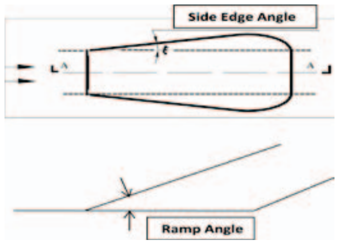
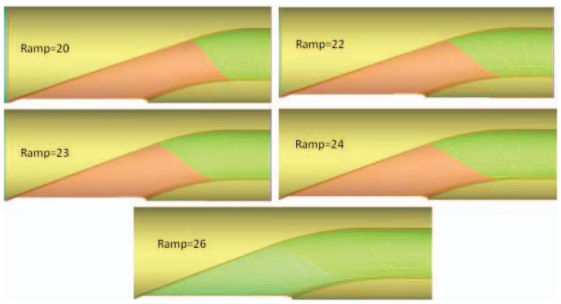
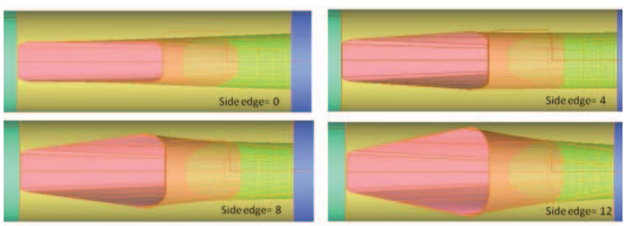


Figure.1 (b) Geometric parameters



(a) Ramp angle variations



(b) Side edge angle variations

Figure.2 Geometies of intake with different ramp and side edge angles.

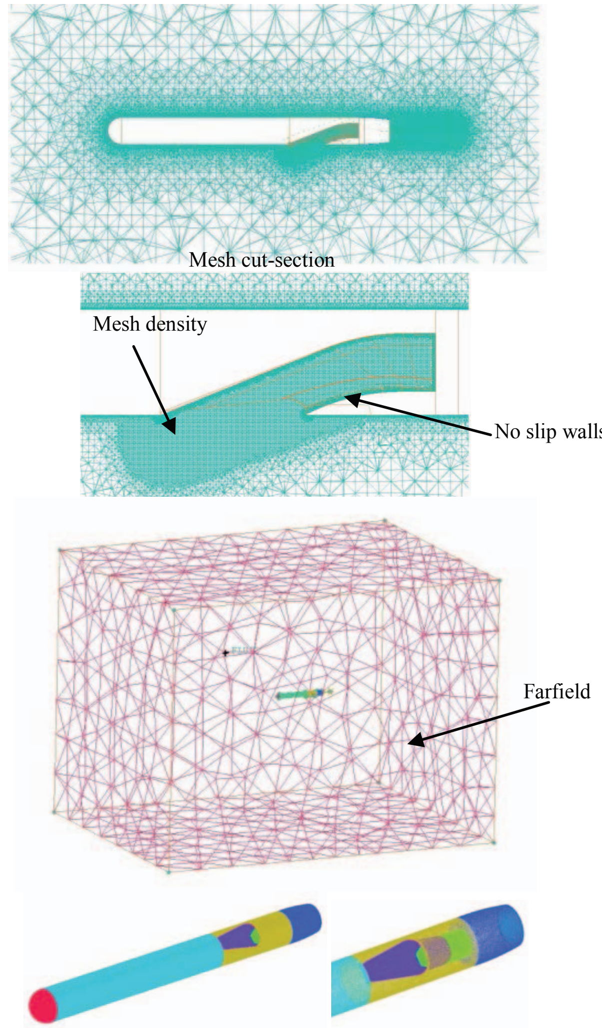


Figure.3 Computational domain and Grid

III. GRID GENERATION

For this complex geometry a 3D unstructured grid is generated in ICEM. To minimize truncation errors and grid optimization grid independency study was done & an optimum mesh of 3.3 million cells was used for CFD simulations shown in figure: 04. Mesh densities were used to capture the vortices and flow behavior in the intake.

IV. NUMERICAL APROACH

3D CFD simulations were carried out in Fluent& for subsonic flow analysis Spalart-Allmaras (1eqn) model is used for density based steady state flow conditions. To eliminate the boundary effects on CFD results a large rectangular domain with a length of 40m and 30m width is formed. Adiabatic no slip conditions were applied on walls and for the pressure outlet condition on the engine AIP of intake is imposed. CFD simulations were carried out with free stream condition of 0.6 Mach in farfield.

Sr. No	Mesh Variation	Mesh Elements	Pressure Recovery
1	Coarse	1.9 million	93.50
2	Fine 1	2.33 million	94.84
3	Fine 2	3.0 million	94.91
4	Fine 3	3.307 million	94.99
5	Fine 4	6.6 million	94.99
6	Fine 5	8.5 million	94.99

Figure: 4 Mesh independency

V. METHODOLOGY

The CFD simulations were performed on all the geometric iterations to optimize the flow quality at engine Aerodynamic Interface Plane (AIP).The mass-average total pressure recovery (σ) is calculated on engine AIP by this formula.

$$\sigma = Pavg360/ P_f * 100\%$$

For the quality and uniformity of flow at engine face the circumferential total pressure distortion index (Δσ) is calculated as follows:

$$(\Delta\sigma) = (1 - P_{min\ 60\ deg}/ P_{avg360})* 100\ \%$$

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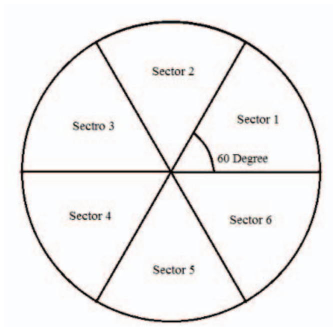


Figure5: Sectors of 60 degree at engine AIP

For the calculation of circumferential total pressure distortion index engine AIP is divided into 6 sectors each of 60 degree angle. Circumferential distortion index is calculated on each sector.

VI. RESULTS AND DISCUSSION

The CFD simulations were performed on different geometric iterations of side edge angle and ramp angle variations and results for pressure recovery (σ) and circumferential total pressure distortion index (Δσ) at engine AIP were compared as shown in figures 6(a) & 6(b). The maximum pressure recovery is attained at engine AIP of the model with the geometric parameters of side edge angle of 8 deg and ramp angle of 22 deg. As the ramp angle is increased from 20 deg to 22 deg the pressure recovery increases however when ramp angle further increased from 22 deg to 26 deg reduces the σ. The individual effects of side edge angle & ramp angle are studied first & then combination effects generated to finalize the optimum geometry. The final geometry of flush intake with ramp angle of and 22 deg side edge angle of 8 deg (R22-S8) for the maximum pressure recovery (σ) and minimum total pressure distortion index (Δσ) is selected for the performance evaluation of intake at different flight conditions i.e. Mach, pitch, &side slip angle variations. The patterns of counter rotating vortices for different section planes are shown in figure: 22. The total pressure, static pressure contours and velocity vectors at section planes are shown in figures from 8 to 12.

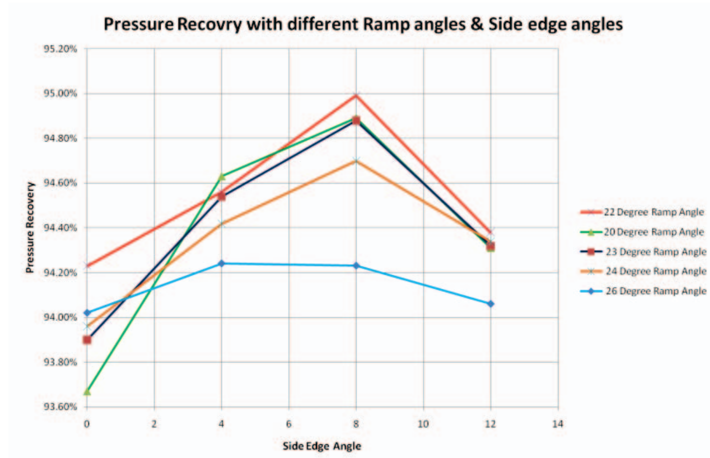


Figure.6(a) Pressure recovery Vs Side edge angle

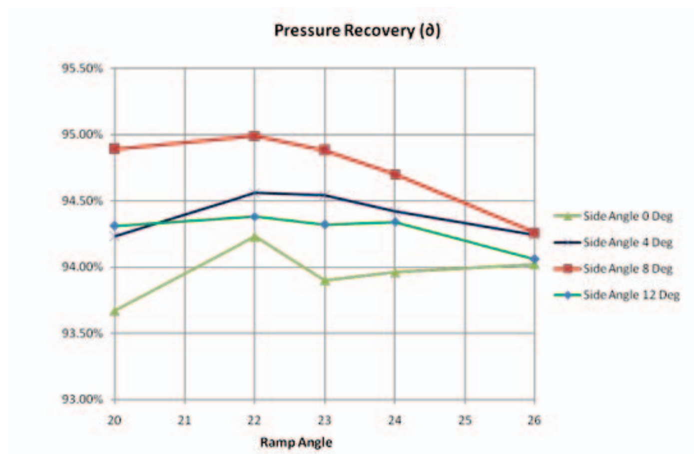


Figure.6(b) Pressure recovery Vs Ramp angle

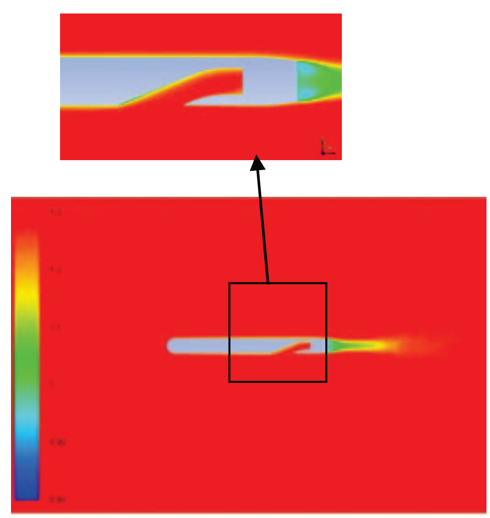


Figure.7 Contours of total pressure (atm)

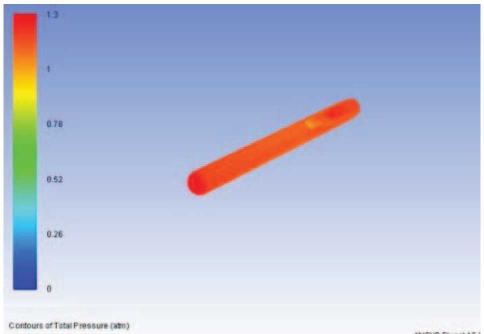


Figure.8a Contours of Total pressure (atm)

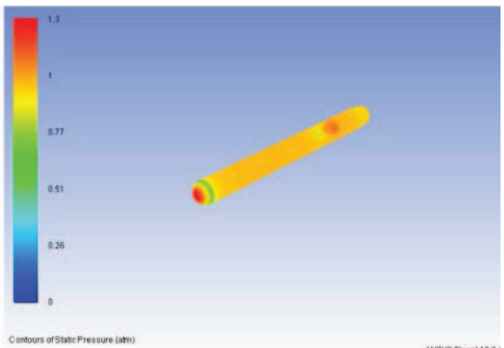


Figure.9a Contours of Static pressure (atm)

Figure.10a Mach Contours

Figure.11 Contours of static pressure (atm)

Figure.8b Contours of Total pressure (atm)

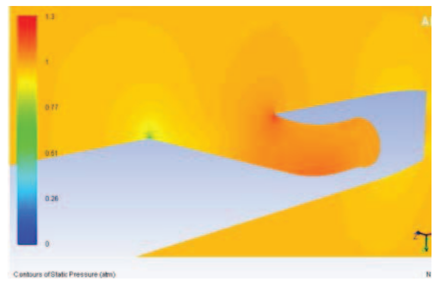


Figure.9b Contours of Static pressure (atm)

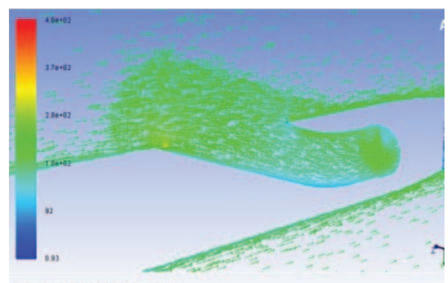


Figure.10b Velocity vectors

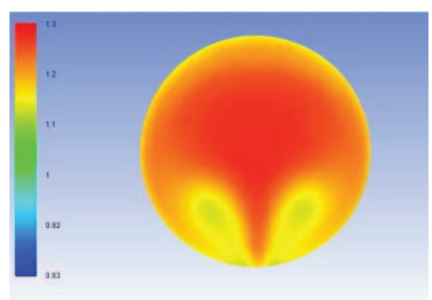
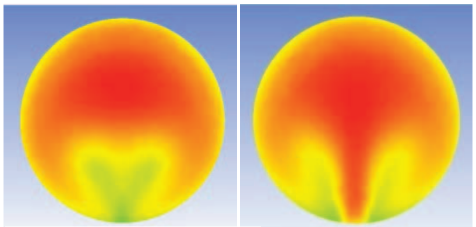


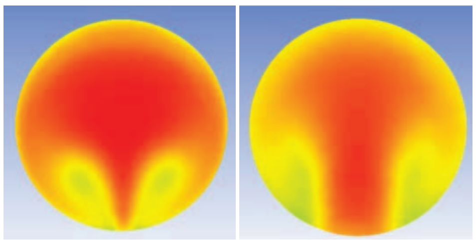
Figure.12 Contours of Total pressure at engine AIP (atm)

A. Effect of Side Edge Angle.

Total pressure contours at AIP for different side edge angles (0 to 12 deg) and fixed ramp angle (22 deg) are shown in figure: 13. The different flow patterns on AIP shows the strength of vortices and uniformity of flow at engine face. For side edge angle 8 deg the pressure recovery is maximum and distortion index is minimum at engine face (AIP) as compared to other side edge angles where the flow is non uniform and less pressure recovery.



Side edge angle = 0 deg   Side edge angle = 4 deg



Side edge angle = 8 deg   Side edge angle = 12 deg

Figure.13 Total Pressure Contours at engine AIP for differrent side edge angles.

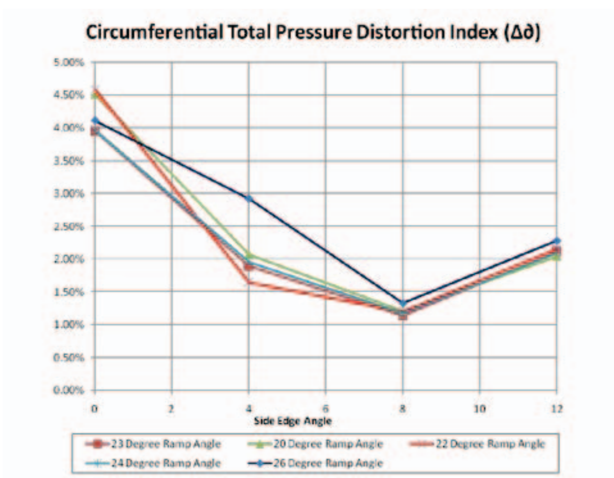
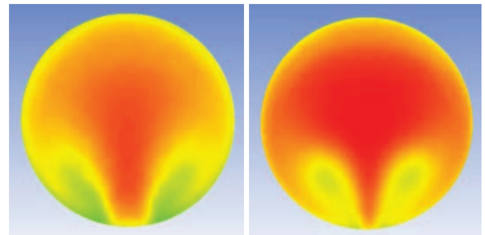


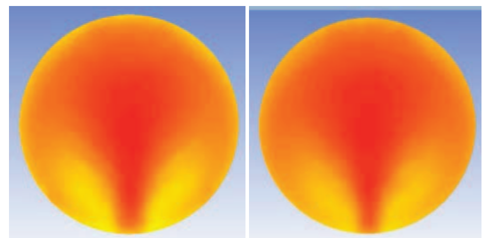
Figure.14Total pressure distortion index Vs Ramp & Side edge angles.

B. Effect of Ramp Angle.

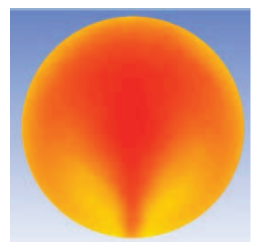
Variation in ramp angles affects the pressure recovery and distortion index at engine AIP. Total pressure contours with different ramp angles (20 to 26 deg) for a fix side edge angle (8 deg) are shown in figure: 15. Pressure recovery is maximum for the 22 degree ramp angle with minimum circumferential total pressure distortion index.



Ramp angle = 20 deg   Ramp angle = 22 deg



Ramp angle = 23 deg   Ramp angle = 24 deg



Ramp angle = 26 deg

Figure.15 Total Pressure Contours at engine AIP for differrent ramp angles.

C. Effect of Free stream Mach.

Pressure recovery drops rapidly with increase in free stream Mach from 0.5M to 0.9M and total pressure distortion index also increases at engine AIP with increase in free stream Mach as shown in figure: 16& 17.

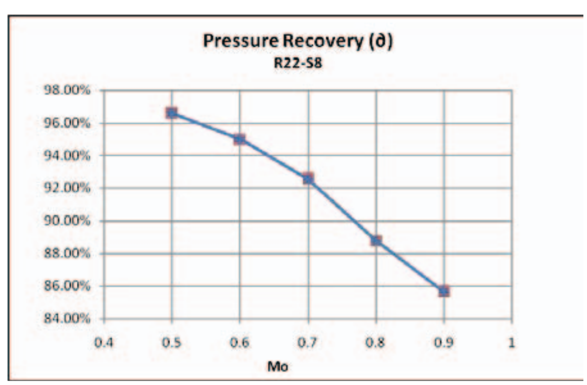


Figure:16 Pressure Recovery Vs Freestream Mach.

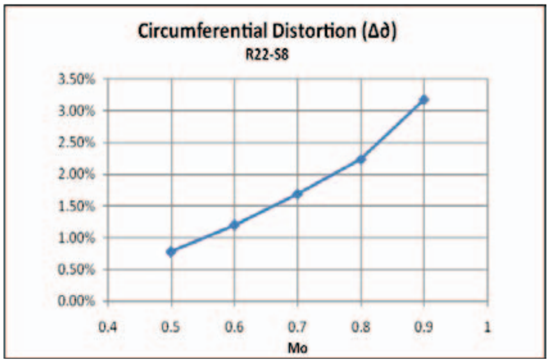


Figure:17 Circumferential Total Pressure Distortion Index Vs Freestream Mach.

D. Effect of Angle of attack & side slip angle.

Pressure recovery increases as the angle of attack increases from zero to 12 deg because at high angle of attack the capture area increases & projection to incoming air develops ramming effect. However the pressure recovery varies slightly almost remains constant by the change in side slip angle as shown in figures 18 & 19. The circumferential distortion index increases from 1% to 5.5% as beta angle changes from 0 to 8 deg. This indicates11the flow uniformity is severely affected at AIP by the change in side slip angle as shown in figure: 21.The distortion index remains less than 2%for the variation in angle of attack.

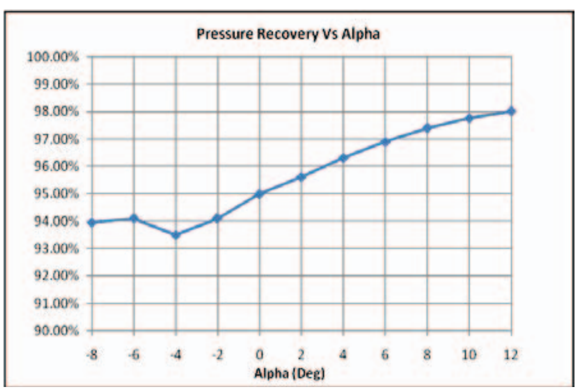


Figure:18 Pressure Recovery Vs Angle of attack

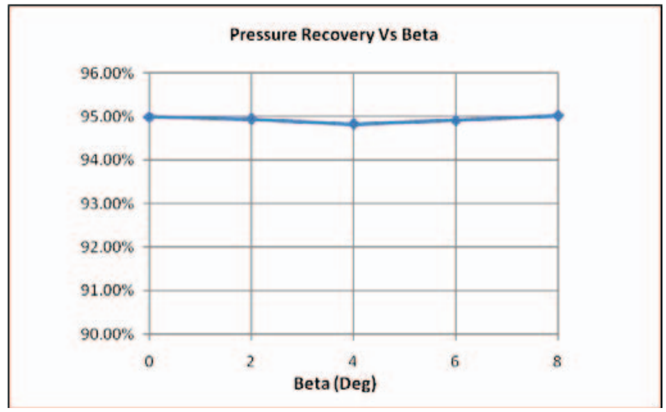


Figure:19 Pressure Recovery Vs Side slip angle Angle/Beta

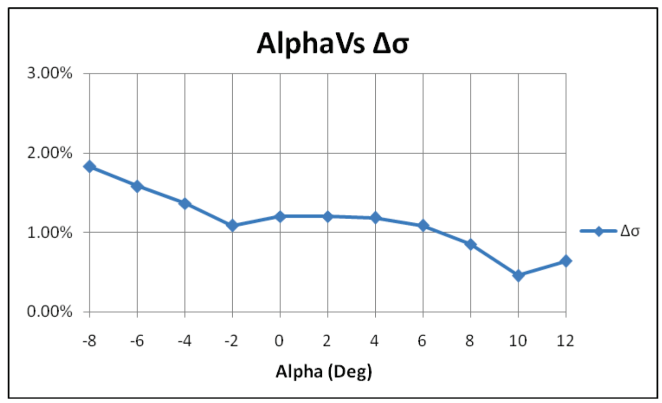


Figure:20 Circumferential Total Pressure Distortion Index Vs Angle of attack

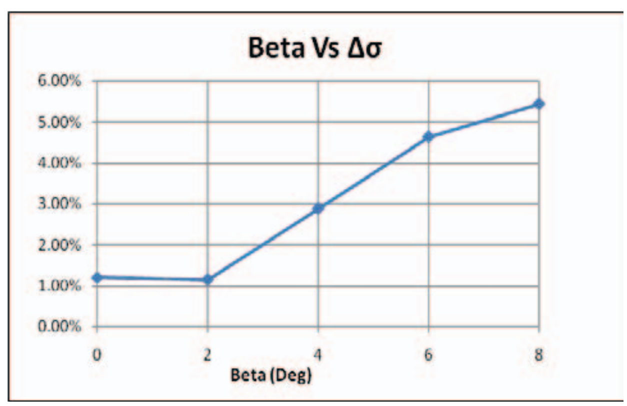


Figure:21 Circumferential Total Pressure Distortion Index Vs Side slip angle Angle/Beta

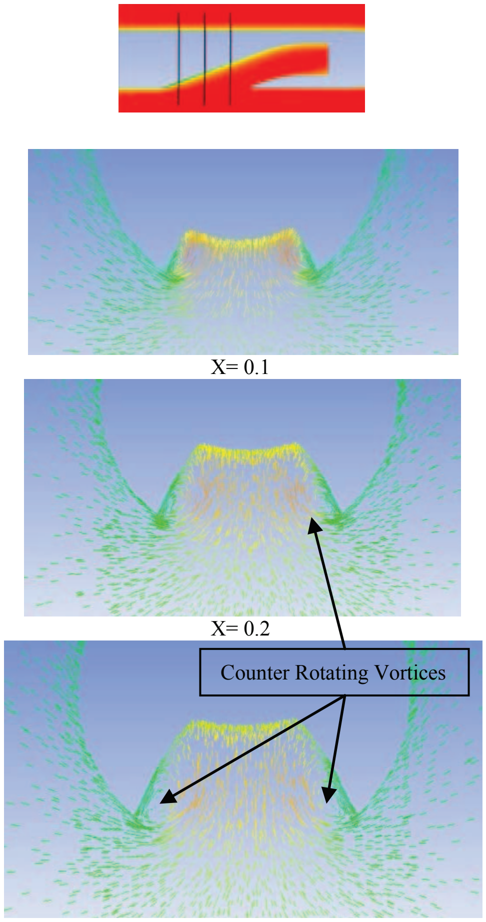


Figure:22 Velocity Vectors at different sections of x-locations

VIII. CONCLUSIONS

Areference geometry parameters [Figure:1b, Ref:1]for a flush intake are studied in the current paper. The basic geometry fom the reference paper is changed from planer side entrance to non planer circular entrance for a cylinderical body. The flush intake performance depends on the strength of counter rotating vortices which are dependent upon the flush intake geometric parameters i.e. side edge & ramp angle the study undertook optimization of theses parameters & final geometry is then selected for performance evaluation for differern flight conditions.

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