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Computational analysis of serpentine inlet with different inlet cross sections

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ABSTRACT: The computational analysis of the serepentine inlet is carried out for the Serpentine inlet with the circular cross-section ,elliptical cross section, rectangular cross section , filleted rectangular cross section and also for Serpentine inlet with circular cross section at the entry is taken ,it can be seen that the total pressure remains constant in the front and then reduces steeply but there is a gradual increase in total pressure from the second turn but in the case of static pressure after the second turn the static pressure further reduces causing a mild acceleration of the flow.The distortion level is negligible in the case of the circular cross section.By comparing all the cross section's inlets , Elliptical inlets have less distortion and high total pressure recovery which is succeeded by the Serpentine inlets with Semi-circular cross-section

KEYWORDS: Serpentine inlet, Cross section, Inlets , Serpentine duct, Cross ,optimization

I. INTRODUCTION

Serpentine inlets have been in use for a really long time and they have a wide range of applications as well. They are used in commercial aircrafts due to its ability to reduce the inlet size , in fighter aircrafts for its low infra-red signature and also in Unmanned aerial vehicles for its compactness. Thus , it can be clearly seen that the application area of these inlets is wide spread.But there is no enough literature available which has done a comparative study of the effect of designing different cross sections at the entry of the inlet on the behavior of the flow through the Serpentine

The computational analysis carried out includes carrying out a comparative study of the effect of varying inlet entry cross section on the flow characteristics and the performance of the Serpentine inlet . On the successful completion of the first phase, the optimized serpentine inlet configuration is obtained

The design of experiments is the design of any task that aims to describe and explain the variation of information under conditions that are hypothesized to reflect the variation.

Design factors	Shapes of inlet
1.	**Circular**
2.	**Elliptic**
3.	**Square**
4.	**Rectangular**
5.	**Semi-circular**

II. METHODOLOGY

The simple base-line ducts taken for consideration are the straight inlet duct and the constant area circular cross sectional serpentine inlet duct.

The straight circular duct is taken as the baseline design for the circular constant cross section serpentine inlet.The constant cross section is not usually used for the subsonic inlets.Diffusers are commonly used.But the constant cross section is used only to find the flow structure at different sections of the inlet and how the static and total pressure varies at different location of the subsonic inlet

While computing there are 5 steps involved to obtain the results they are

1. Geometrical design
2. Domain creation
3. Discretization
4. Solving
5. Post processing.

Though these are the common steps involved for all the computation, the gird independent and convergence studies varies for each geometry

Geometry is designed as per the prescribed dimensions using Catia v5 software, imported into the analysis software and meshed in Ansys Fluent.

The boundary conditions mentioned are the velocity inlet and the pressure outlet , the model which is used is the k-omega SST turbulence model .

The computation is carried out on the cylinder so as to make a reference to compare the results obtained from the serpentine ducts.The length to diameter ratio for both the inlets are exactly the same.

The computation for all the geometrical shapes is carried out using the same procedure using same boundary conditions with the inlet velocity of Mach 0.1 which corresponds to 68.03m/s .

Firstly the model is created using the Catia software taking into considerations of the dimensions taken.They are then imported to the Ansys fluent and meshed using a variety of sizings to obtain a body fitted mesh.The mesh sizes are refined and tested for the grid independent and grid convergence studies.

The inlet , outlet and the walls are named and then the meshed geometry is solved in the solver with the boundary conditions of velocity inlet and pressure outlet.

The velocity of the fluid at the inlet is taken as Mach 0.2 i.e the velocity of 68.03 m/s and the stagnation pressure is considered to the atmospheric pressure.

The planes are created at the centre of the duct to visualize the pressure changes. The total pressure variations at the outlet of the duct i.e, the aerodynamic plane is also found at the inlet.

In addition to the contour plots, the graphical representation of the changes of the centreline static pressure and total pressure is also obtained.In few graphs it can be seen that the total pressure and the static pressure curves may seem undesirable , it is because of the fact that the graphs are just the centreline parameter changes and not the average values.

In the baseline cylinder configuration duct , the analysis is carried out just to check the comparison of the flow in the straight duct with that of the duct with 2 turns. This gives us the idea about how the static pressure , total pressure as well as the velocity magnitude. Since it is just a straight duct without any divergence, it can be observed that the total pressure remains constant but the static pressure as well as the velocity varies. The flow through any duct observes resistance in terms of wall shear stresses and the friction as a result of which boundary layer is produced thus producing loss of dynamic pressure and the rise in static pressure. The velocity magnitude reduces from the inlet till the outlet with no observable fluctuations .This is carried out just to ensure that the model taken is suitable for the internal flow

GEOMETRY

The cross section at the entrance of the inlet is the circle and this cross section is sweeped using the multi-section solid operator so the cross-sections at any definite position is a morphed feature of the combination of both the entrance and exit cross-sections respectively.

There are variety of sketch and part design operators used in the design of the model.The main important parameters required for the successful design of the serpentine inlet are obtained from extensive literature survey.

Firstly the spline is drawn by drawing two circles of equal radius separated by the considered height difference between them.Secondly,the circles are trimmed and the tangents to these circles are extended horizontally as well as vertically such that the L/D ratio ,Aspect ratio as well as the R/D ratios are taken to be the ones obtained from literature.Then two cross sections are drawn at the start and the end of the spline by creating two new planes at these points.The one at the exit of the inlet is by default taken as circle and the one for the entrance varies as per our study variations.Finally after two cross sections are created,multi-section solid is used join these two cross sections using the spline created as the support or the back-bone to the entire serpentine duct.The serpentine inlet ducts with almost no divergence and this is the base line for the other serpentine ducts which employs other cross sections .Divergence is not given for the duct.IT could be seen that the total and static pressure does not cary much at other sections of the serpentine duct as much as at the first and second turn of the ducts.At the inside of the second turn two regions of low total pressure is obtained.These regions corresponds to the counter-rotating vortices created due to the centrifugal force and the adverse pressure gradient.

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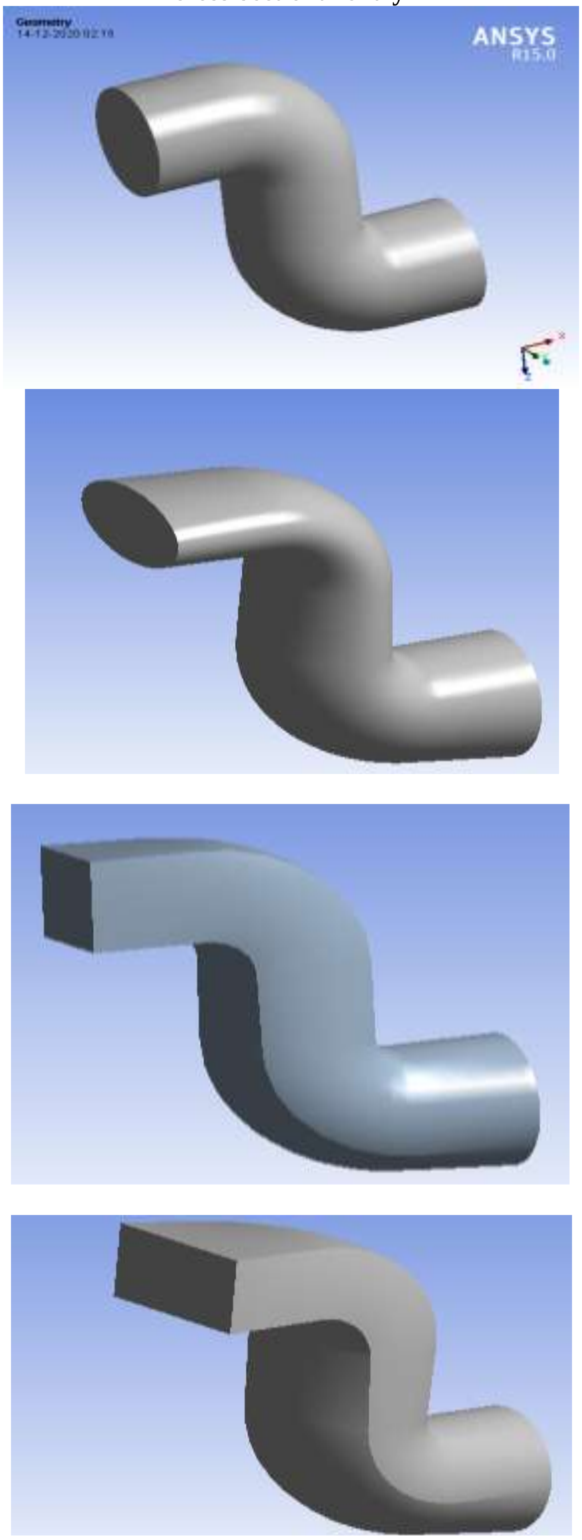
Figure 1: Geometry of Serepntine inlets with circular,elliptical ,squared,rectangular and semi-circular cross-sectional entry



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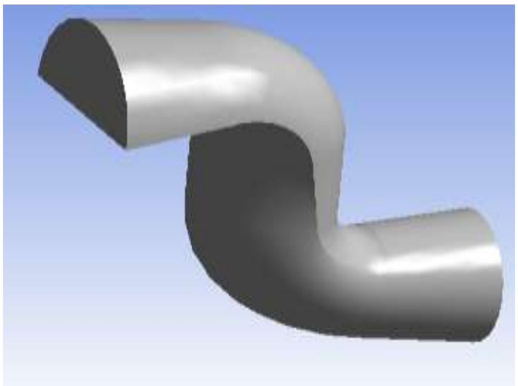


Table 1 : Geometrical parameters

S.NO	Quantity	Dimensions
1.	Length	1.25 m
2.	Major Diameter	.6 m
3.	Minor diameter	.3 m
4.	Radius of turn	.3 m
5.	Height of the inlet	.9 m
6.	L/D ratio	2.5
7.	R/D	0.6
8.	Aspect ratio	1.389

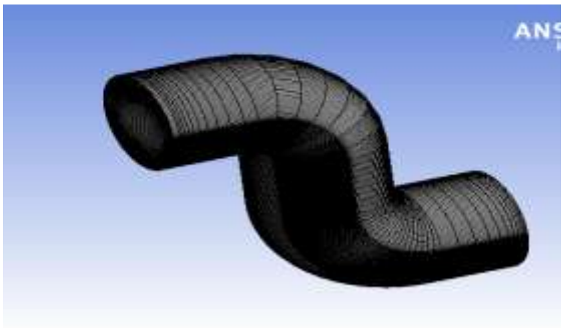
DISCRETIZATION

The meshing and the solving is done using the Ansys fluent. Grid independent and the grid convergence studies are carried out before obtaining the results

Table 2: Grid independent study table

S.no	Number of elements	Number of nodes	Mesh metrics
1	85404	91260	.959343
2	111777	118842	.960431
3	258048	270980	.963288

Figure 2: Meshing of Serepntine inlets with circular,elliptical ,squared,rectangular and semi-circular cross-sectional entry



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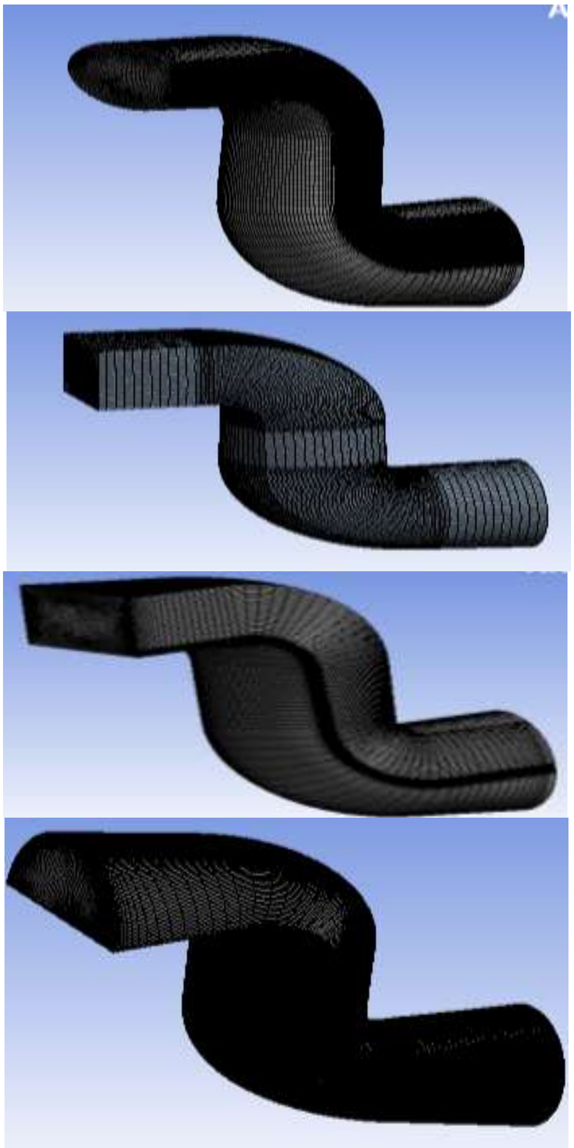

Computational analysis

Figure 3:Total pressure contour plots across the center plane

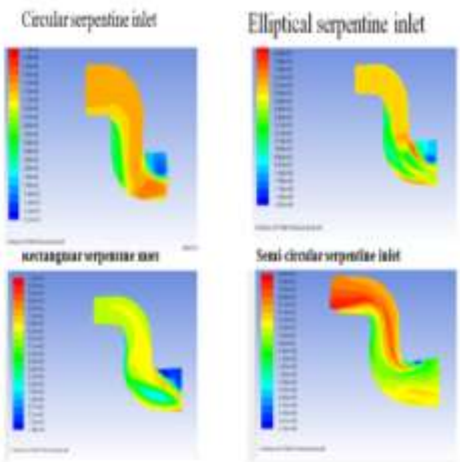

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Figure 4:Static pressure variation across the center plane

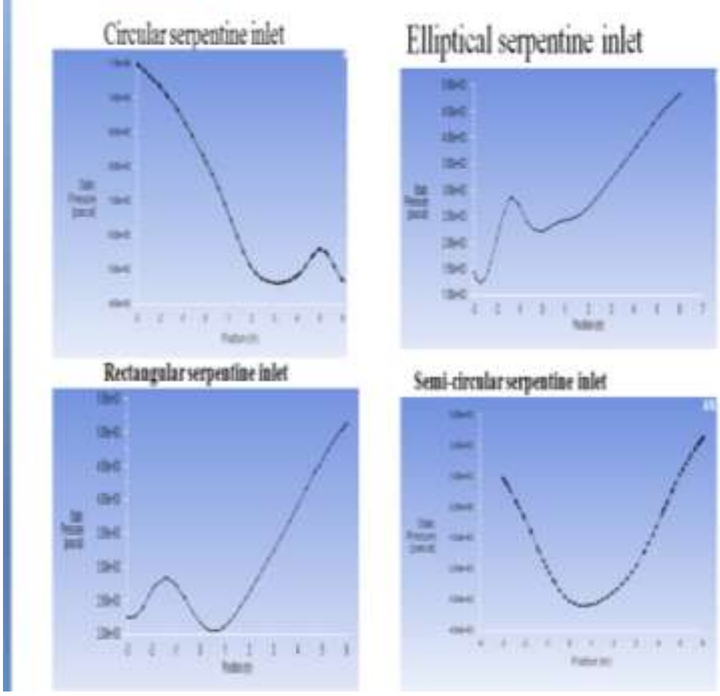

Figure 5:Total pressure variation across the center plane

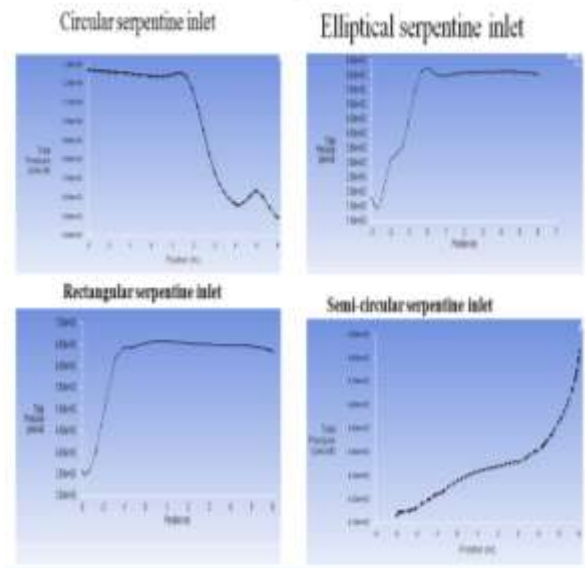

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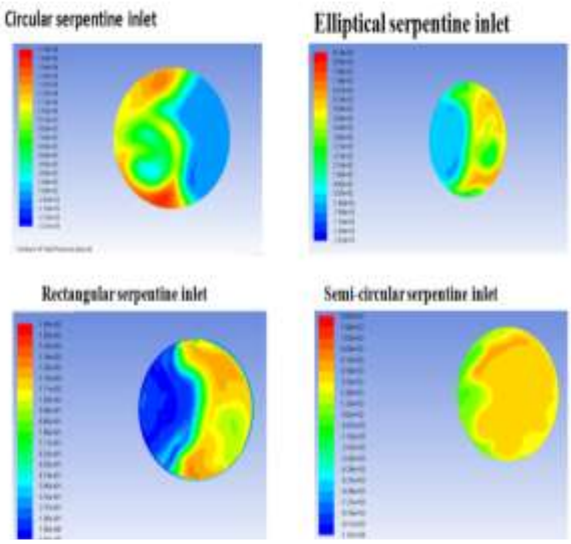
Figure 6:Total pressure variationat the exit plane



From the total pressure variations diagram obtained at the aerodynamic interface plane i.e the plane at which the inlet meets the compressor of the jet engine. There are regions where the total pressure is really high and also regions in which the total pressure is really low as well as pressures in between both these values.The distortion is really high for the circular cross sectional Serpentine duct.

As for the graph is concerned ,static pressure rise is achieved at the centreline of the duct is good for the inlet and it is desirable but the total pressure cannot rise because at all cases the total pressure will be lower because of frictional and viscous losses.Thus the total pressure rise in the center may be compensated by the total pressure loss towards the periphery

The variations with respect to z axis also shows pressure rise in the centreline which shows that velocity also reduces considerably along the duct but the pressure gradient is so high,which makes it unfit for obtaining optimum performance from the inlet..

As the flow passes through the two curves, ie along the vertical direction ,there is a considerable increase in static pressure too.

From the contour plots of the elliptical – circular serpentine duct ,it could be inferred that the flow uniformity is ensured when the Aspect ratio of the cross section is increased which means that as the cross section becomes oblong,the flow quality and pressure recovery factor is improved significantly which is in accordance with the literature review.

The static pressure as well as the total pressure reduces along the horizontal as well as the vertical direction,there are pressure fluctuations but the flow separation as well as counter rotating vortices are reduced.

III. RESULTS AND DISCUSSION

Shape of the inlet cross -section	**Distortion coefficient**
Circular serpentine inlet	2.074
Elliptical serpentine inlet	1.56
Rectangular serpentine inlet	2.01
Squared serpentine inlet	2.04
Semi-circular serpentine inlet	1.50

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From the computational analysis of the cylinder it could be seen that the total pressure decreases whereas the static pressure increases.Across any taken cross section along the duct the pressure variations can be considered to be uniform in the cylinder.This is the desirable variation

The total pressure contours obtained for all the serpentine inlets designs are taken and a comparative study of the total pressure variations are studies .In addition to that the reasons for these pressure fluctuations can be inferred .It could be seen that the least amount of total pressure variations can be seen for the rectangular serpentine inlet

But the pressure fluctuations does not really play a significant role in the performance of the inlet. It is the total pressure recovery that plays a significant role in determining the overall performance of the engine.The pressure fluctuations correspond to the points of flow separations. These points can be taken as the control points for placing to flow control devices at these points.The desirable pressure change is that the pressure should reduce gradually as it flows through the duct.SO according to this , ellipse is a preferred cross-section

The Aerodynamic interface plane is the exit of the inlet which is also the entrance to the compressor. The pressure distribution in this plane is really important .If there is pressure gradient present in this system ,it will lead to pressure fluctuations ,distortion and inclination of the flow.This inclined flow may be greater than some of the blade's stall angle and this may lead to compressor failure.So comparison of this parameter across the serpentine inlet ducts with various cross section is essential to arrive at an optimum cross section.The pressure distribution for the circular cross section serpentine inlet shows great amount of distortion but the distortion in the exit plane of rectangular cross section is also high.Then the pressure distribution is somewhat uniform in Elliptical serpentine inlet .So elliptical is mostly preferred followed by which semi-Circular cross sectional inlet is preferred.

The static pressure rise achieved by elliptical and circular serpentine inlet is high compared to others.

So from design point of view serpentine inlet with elliptical cross section is taken as the optimized cross section.

IV. CONCLUSION

Looking back on this project, the overall From the computational analysis carried out so far, the optimized cross section for the serpentine inlet has been arrived successfully . Also the center-line curvature is also designed which gives optimum pressure recovery compared to the other cross sections.So, the elliptical cross section can be taken for the inlet's entrance.

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