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Design and flow analysis of S duct diffuser with submerged vortex Generators

Thenambika V*, Ponsankar S*, Prabhu M K*
*(Department of Mechanical Engineering, Bannari amman institute of technology, Sathyamangalam)

ABSTRACT
S-duct diffusers are widely used in air-intake system of several jet aircrafts to get less drag and lowering the engine position compared to straight through design. In this study the distorted flow condition parameter like static pressure recovery and total pressure loss are investigated by adding vortex generators. Geometry selected based on fox and Kline on linear area-ratio from inlet to exit. Modeling CATIA V5 is used for design of diffuser and ANSYS fluent are employed in the investigation of S-Duct and S-Duct with SVG in different locations for the Mach number values of 0.6 and 1.0 to improve the total pressure recovery of the S- duct. From the results 3 SVG pairs attached to both the sidewalls at plane-4 and SVG in top and bottom of inflexion planes offers the best performance. The design objective is to improve the static pressure recovery of the S-duct and reduce the total pressure loss.
Keywords: Air Intake, S Duct Diffuser, Submerged Vortex Generators, Mach number, Total Pressure Recovery.

I. INTRODUCTION

S-duct diffusers are widely used in air-intake system of several military aircrafts. It is one of the important types of curved diffuser. In order to overcome a challenge of air-intake design is to ensure that an aircraft engine is properly supplied with air under all conditions of aircraft operation [1]. A vortex generator (VG) is an aerodynamic surface, consisting of a small vane that creates a vortex. Vortex generators delay flow separation and aerodynamic stalling, thereby improving the effectiveness of wings and control surfaces [2]. The diffuser was designed as suggested by Fox and Kline and based on linear area-ratio from inlet to exit [3, 4]. Computational fluid dynamics (CFD) to simulate inlet flow and predict inlet performance and, together with experiments and statistical methods, is a useful tool in designing new inlets [5]. In this studies where multiple vortex generators must be evaluated, it is very time consuming and impractical to generate structured computational grids for each vortex generator. Therefore, it is highly desirable to be able to model the effects of the vortex generators without including their geometry in the computational methods used [6, 7]. It is also established that the renormalized group k–ϵ model predicts better than the standard k–ϵ turbulence model [8]. The functions of a well designed diffusing duct are to decelerate the flow efficiently and increase the static pressure with minimal total pressure loss and distortion at compressor face of the engine [9]. In this study the flow condition parameter like static pressure recovery and total pressure loss are investigated by S duct diffuser with submerged vortex generators.

II. GEOMETRY PARAMETERS

The geometry of S duct diffuser along with the coordinate system used it is shown in **Fig 1**. The area normal to the centerline, similar to the straight diffuser, is then maintained to generate the geometry of the curved surfaces of the diffuser [14].

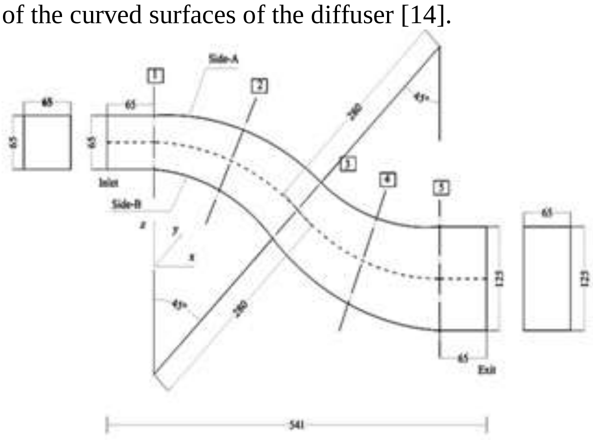

Figure 1 geometry of S Duct diffuser

Inlet area- 65 × 65 mm^2 , Area ratio -1.923 ,Radius of curvature = 280 mm ,Turning angle β = 45º , Centerline length = 440 mm , Maximum height (h2) =5 mm, Inflexion plane =12 mm.

The total divergence angle for the equivalent straight diffuser is 7.38º. A constant area of 65 × 65 mm^2 pipe was attached at the inlet of test diffuser for smooth air inflow [12]. Similarly, another 65 mm long and a constant area of 65×125 mm^2 tailpipe are used at the exit of diffuser before it discharges the fluid into atmosphere. It also helps in improving the performance of the diffuser by reducing the atmospheric effect at the exit. The S-duct diffuser modeled by using CATIA tool it is shown in **Fig 2** and also combination of S duct diffuser with submerged vortex generator is shown in **Fig 3**

TABLE 1 Description of SVG design parameters

β^o	B_1/δ	B_2/δ	H_1/δ	H_2/δ	l/δ	λ/δ
18.0	0.417	1.0	0.208	0.417	0.883	1.667

β^o-half angle of SVG(degree)
B_1,B_2-sidewall B
δ-boundary layer thickness(mm)
H_1, H_2-height of two walls (mm)
l-slant length(mm)
λ-spacing between two successive SVG(mm)

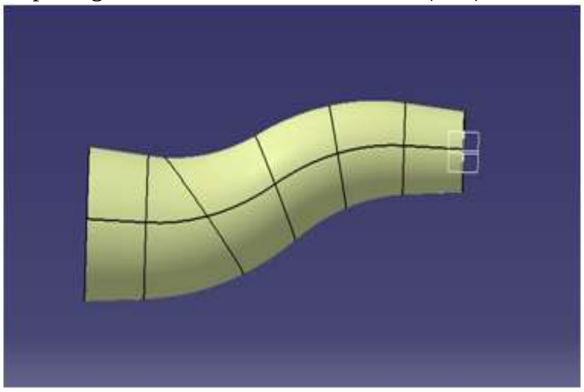

Figure 2 S- duct design by using CATIA V5R20

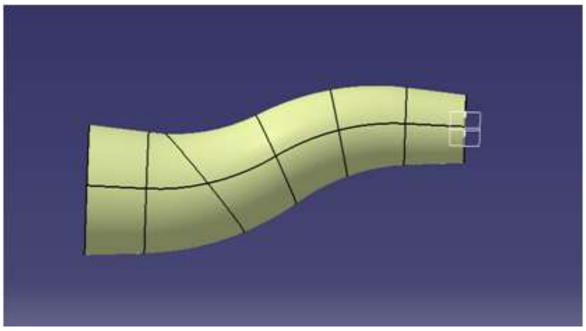

Figure 3: Design of s –duct with submerged vortex generators by using CATIA V5 R20

III. DESIGN METHODOLOGY

In present study the flow characteristics of S duct diffusers of different curvatures.

1. Collection of the basic geometrical data of a S duct- diffuser and submerged vortex generators from the literature survey and developing a 3-D model of the duct diffuser using CATIA V5 design tool.
2. Calculating the design parameters and boundary conditions.
3. Flow Analysis is done by using ANSYS Fluent.

IV. INLET CONDITIONS

4.1 Mesh model:

1. Solver type: pressure based
2. Problem model: Standard k epsilon

4.2 Boundary conditions:

1. skewness factor *(Sk)* - 1.878.
2. Reynolds number of 0.68×10^5
3. inlet flow velocity of 15.79 m/s
4. Inlet hydraulic diameter -65 mm.

4.3 Results:

The results that are taken for the present work are as follows:

1. Static pressure recovery
2. Total pressure loss

V. RESULTS AND DISCUSSION

Simulation is carried out using commercial software ANSYS FLUENT 14.0. The static pressure Recovery coefficient distribution along the diffuser is shown in the below Fig 4(a, b, c) at mach number 6.0

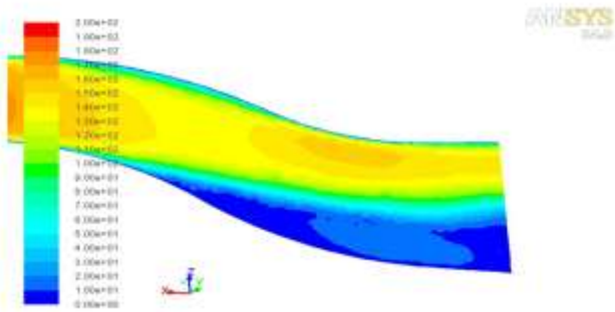

Figure 4 (a) .Flow analysis for the velocity contours in s-duct (Mach 0.6)

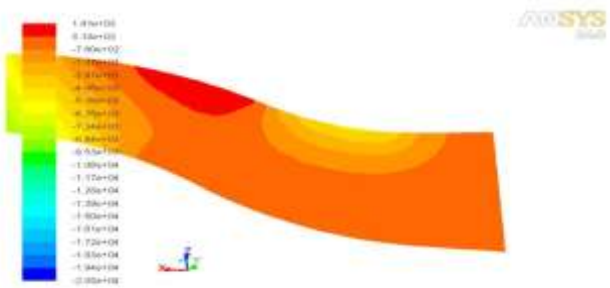

Figure 4 (b) .Flow analysis for the contour of static pressure in S-duct (mach 0.6)

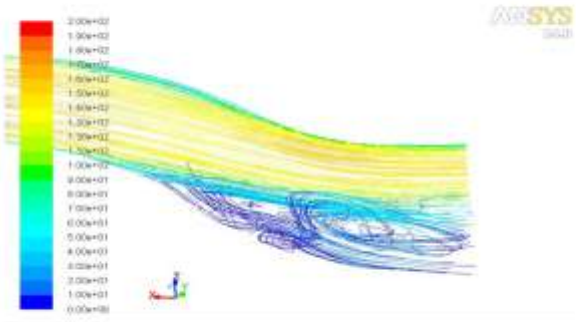

Figure 4 (c) Flow analysis for the path lines colored by velocity in S-duct (Mach 0.6)

There are various combination of SVG in the diffuser were investigated, namely,

1. 3 + 3 SVG attached on top and bottom surface and placed before inflexion plane (plane-2).
2. 4 + 4 SVG attached on top and bottom surface and placed at inflexion plane (plane-3).
3. 5+ 5 SVG attached on top and bottom surface and placed after inflexion plane (plane-4).
4. 3 + 3 SVG attached on both side walls and placed at all the planes (planes-2, 3 and 4) separately.

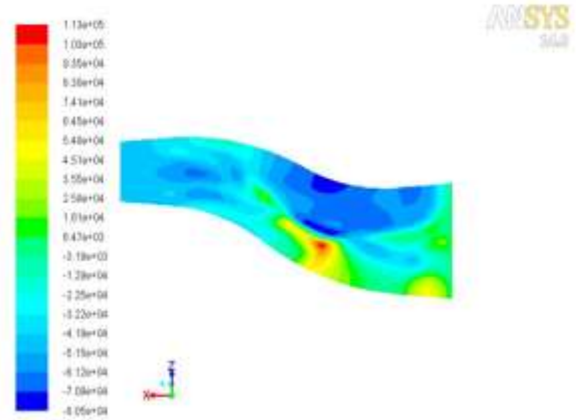

Figure 5 (a) .Flow analysis for the contours of static pressure in S-duct with SVG (Mach 0.6)

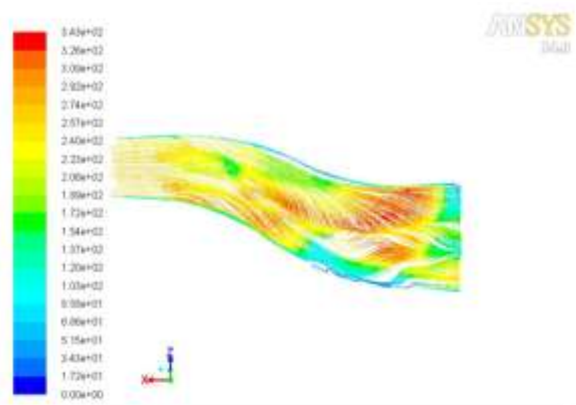

Figure 5 (b) Flow analysis for the path lines colored by velocity in S-duct with SVG (Mach 0.6)

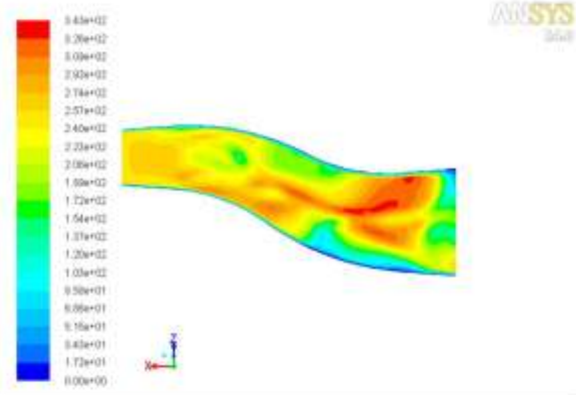

Figure 5 (c) .Flow analysis for the contours of velocity in S-duct with SVG (Mach 0.6)

The mean velocity contour of bare S-duct diffuser at the inlet (plane-1) is shown in Fig. 6 (b).This results measured in the inlet velocity profile is not uniform, but a skewed one with a skewness factor *(Sk)* of 1.878, which shows to the actual flow condition at the air-intake system during the perfect maneuver of aircraft. The predicted mean velocity contours at plane-5 for all the combinations of SVG are, however found almost similar and are shown in Fig.6(b)

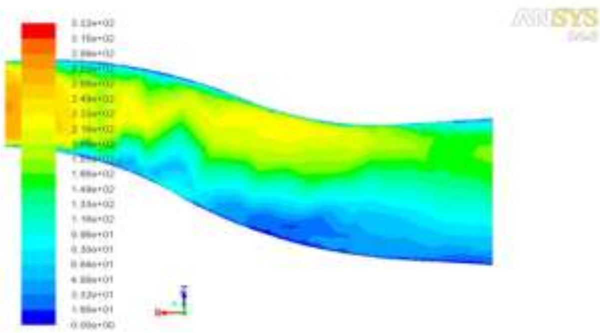

Figure 6 (a) .Flow analysis for the contours of velocity in S-duct (Mach 1.0)

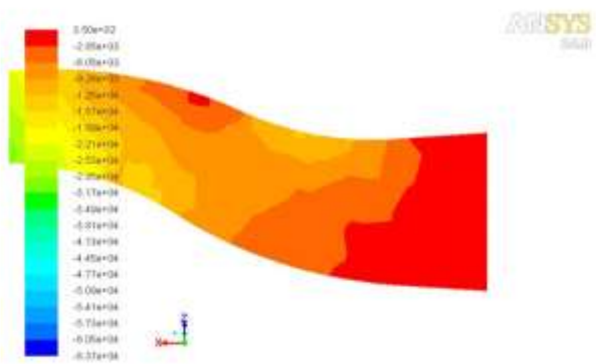

Figure 6 (b) .Flow analysis for the contour of static pressure in S-duct (mach 1.0)

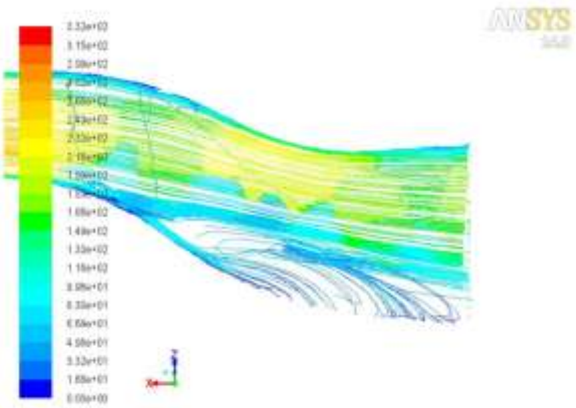

Figure 6 (c) .Flow analysis for the path lines colored by velocity in S-duct (Mach 1.0)

The Fig 7(a) shows that static pressure with SVG combination at level of mach no 1 with plane 2. Velocity display with different contours n the region and path lines shown that sidewall of plane 3 it is available in Fig 7(b, c).

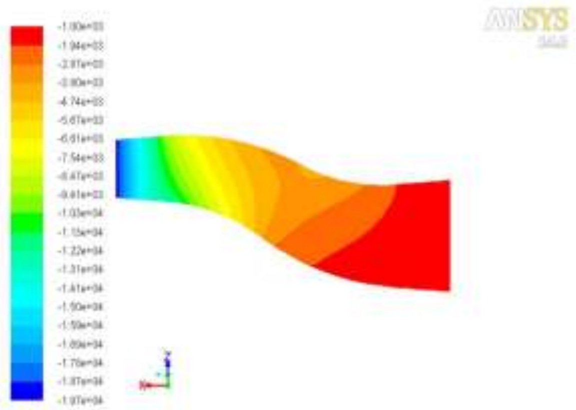

Figure 7 (a) .Flow analysis for the contours of static pressure in s-duct with SVG (Mach 1.0)

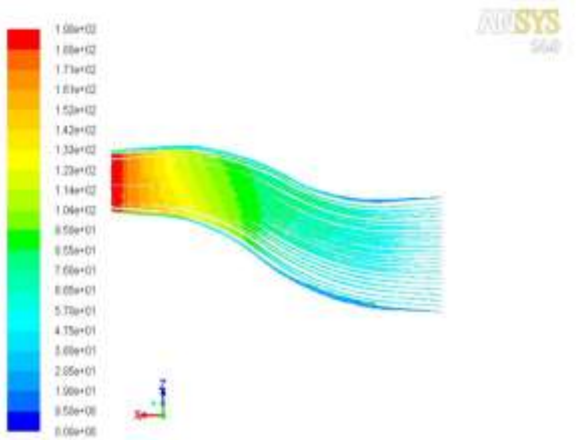

Figure 7 (b) .Flow analysis for the path lines colored by velocity in S-duct with SVG (Mach 1.0)

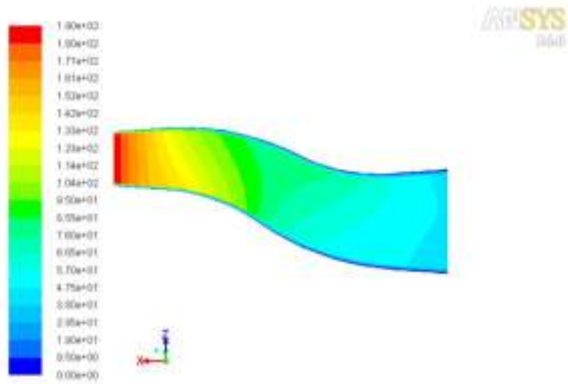

Figure 7 (c) .Flow analysis for the contours of velocity in S-duct with SVG (Mach 1.0)

4.1 Static Pressure Recovery (CSP)

Static pressure recovery coefficient (CPR) is described as the ratio of rise in average static pressure with respect to the inlet to the average dynamic pressure at inlet. Precisely,

$$C_{PR} = (P_S - P_{Si}) / p_d$$

CPR is computed for both uniform and skewed inflow conditions, and found no appreciable changes; hence CPR values for all SVG combinations with skewed inflow condition are plotted here Fig 8 (a, b). In the initial phase up to plane-2 ($x/C_L = 0.30$) is observed, but then it decreases due to the flow separation till the reattachment occurs somewhere after the plane-3 ($x/C_L = 0.755$), after which it increases steadily up to the exit. It can be seen that CSP for the duct with any combination of SVG is more than the bare duct [9].

4.2 Total Pressure Loss (CTL)

Total pressure loss coefficient is defined as the ratio of total pressure loss with respect to the inlet to the average dynamic pressure at inlet. It is expressed as

$$C_{TL} = (P_{Ti} - P_T) / P_d$$

The total pressure loss coefficient (CTL) increases almost linearly along the centerline length for both uniform and skewed inflow conditions as shown in Figure (b). It is important to note that the CTL values are affected by inflow conditions. For uniform inflow condition, the maximum total pressure loss coefficient for the bare S-duct diffuser is limited to 0.270, whereas, the same for a skewed inflow profile is increased to 0.822.

TABLE 2 .S-duct and S-duct with SVG their coefficient of pressure recovery and total pressure loss results

DUCT	C_{PR}	C_{TL}
Bare	**0.5186**	**0.7047**
3+3 SVG in top and bottom of plane	**0.6066**	**0.6427**
4+4 SVG in top and bottom of plane	**0.5682**	**0.6765**
5+5 SVG in top and bottom of plane	**0.6325**	**0.6116**
3+3 in both side wall (plane 2)	**0.6331**	**0.6400**
3+3 in both side wall (plane 3)	**0.6212**	**0.6785**
3+3 in both side wall (plane 4)	**0.6717**	**0.6159**

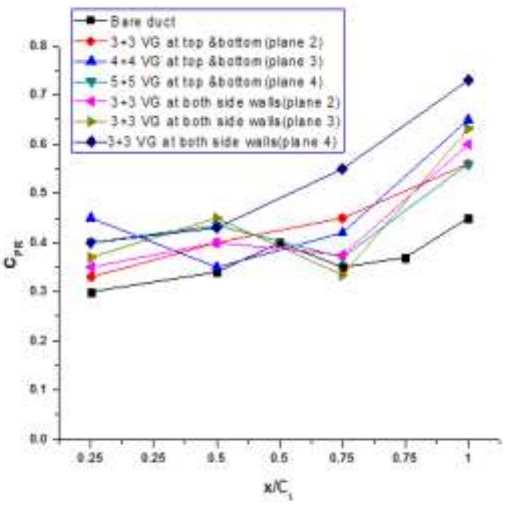

Figure 8 (a) Comparison of static pressure recovery coefficient for various SVG combinations.

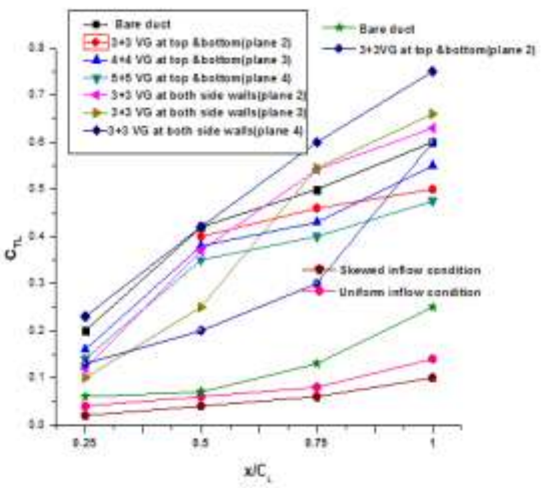

Figure 8 (b) Comparison of total pressure loss coefficients for various SVG combinations.

VI. CONCLUSION

From the study the following to be concluded;

The static pressure recovery within the S duct diffuser increases as the flow proceeds except at the initial stage of the diffuser whereas the velocity decreases as the flow proceeds. Graphs are drawn for the static pressure and total pressure loss for different SVG combination along the X/C_L which shows the static pressure recovery coefficient is increased by 29.34%, whereas, the total pressure loss coefficient is reduced by 15.78% with respect to the bare S-duct diffuser.

The S-duct and the S-duct with SVG are flow analyzed with Mach number values of 0.6 and 1.0 and in which the better flow values can be obtained in Mach 0.6.

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