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ACTIVE FLOW CONTROL IN TWIN AIR-INTAKE USING VORTEX GENERATORS JETS

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ABSTRACT

The paper refers to a comparative study of various configuration of Vortex Generator Jets (VGJ) used for active flow control in twin sir intake. Various configurations have been tested and different parameters like static pressure recovery, total pressure loss, distortion in flow, magnitude of cross-flow etc have been compared to find an optimum performance configuration. Out of all the configuration, when jets were perpendicular to the plane of the duct gave an optimum performance.
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Keywords*:* Active Flow Control, Twin Air-Intake, Vortex Generator Jet (VGJ), Flow Distortion, Static Pressure Recovery

1. INTRODUCTION

Modern combat aircrafts use twin air-intake system to ingest atmospheric air into it for successful combustion in the gas engines. Such air-intake being Y-shaped has two prominent limbs, which are attached to either side of the aircraft fuselage. Twin air-intake is characterized by flow complications and non-uniformity due to various reasons, like asymmetric flow conditions resulting from high maneuver of aircrafts, the inflexion present in the curvature of individual limbs, and the flow diffusion along the length of the air-intake. An experimental study is presented here for improving the outlet flow pattern of a mild-curved (20°) twin air-intake (Fig. 1). Among various active flow control techniques found in literatures, vortex generator jets (VGJ) are used in this case.

Active flow control techniques are used to improve the performance parameters of the air-intake. The control technique involves the use of Vortex generator jets (VGJ) on the duct walls, the VGJ used in the study are shown in Fig. 2. A comparative study is carried out between different configurations of VGJ as shown in Fig. 3. The are two important control issues in diffusers are separation control, which leads to higher pressure recovery and lower total pressure loss; whereas secondary flow control leads to uniformity in flow. The prime focus in the present study remains separation control since the primary objective of the diffuser itself is to achieve a better static pressure recovery; secondary flow control performance parameters have also been considered but are of minor importance.

2. EXPERIMENT

A study has been carried out on a diffuser with diffuser angle 20^0 non-fused duct as shown in fig.1 the co-ordinate system used for the duct is marked in fig.1. The duct has two inlet limbs namely Rare and Front limb, according to our nomenclature:
Imagine yourself to be standing against the flow.

- The right hand limb of the duct is called rare side now the inner wall on the right limb is called **RARE INNER or RI** and the outer side is called the **RARE OUTER or RO.**
- The left hand limb of the duct is called front side now the inner side on the right limb is called **FRONT INNER or FI** and the outer side is called the **FRONT OUTER or FO.**

The Y-duct are characterized by flow complications and non-uniformity due to inflexion in curvature along the direction of flow. Active flow control techniques were used to improve the performance parameters of the diffuser. The control technique involved use of Vortex generator jets (VGJ's) on the duct walls, a comparative study was carried out between different configuration of VGJ's. The two important control subjects in diffusers are separation control which leads to higher pressure recovery and lower total pressure loss, and secondary flow control which leads to uniformity in flow. Our primary focus in study has been separation control since the primary objective of the diffuser itself is to achieve a better pressure recovery, secondary flow control performance parameters have also been considered but were of secondary importance.

According to our investigation separation control could be achieved only if jets were used on the side walls, hence 2 jets were placed on each side wall. So a total of 8 jets were placed on walls namely FI, FO, RI & RO according to our nomenclature. The Velocity ratio(VR) of the jet velocity to the inlet velocity was kept constant as 2, variation was made in the angle of jets to the side wall in two planes namely yaw and pitch plane. The plane of the side wall was assumed as the yaw plane and the plane perpendicular to it was the pitch plane. Different combinations of yaw and pitch angles were selected according to the study done by Sullery et al. 2006 & Johnson et al 1990. The combinations were:

1. **PITCH ANGLE :** Two values of pitch angle were taken 90^0 AND 45^0
2. **YAW ANGLE:** In case where pitch angle is 90^0 yaw angle has no meaning but in case of pitch angle 45^0 various yaw angles were taken. The combinations of yaw angle with pitch 45^0 have been shown in fig.2.

The cases are as follows and further in the discussions they are referred to by their case numbers.

1) **Case-0**: DUCT WITHOUT JETS
2) **Case-1**: PITCH 90^0
3) **Case-2**: PITCH 45^0 AND YAW 90^0 (JETS FACING EACH OTHER)
4) **Case-3**: PITCH 45^0 AND YAW 180^0 BOTH
5) **Case-4**: PITCH 45^0 AND YAW 0^0 BOTH
6) **Case-5**: PITCH 45^0 AND YAW 45^0 CONVERGING JETS.

4. EQUATIONS, UNITS AND NOMENCLATURE

- Coefficient of ideal static pressure recovery:

$$C_{spi} = 1 - 1/\left(A_r\right)^2 \quad (1)$$

- Coefficient of actual static pressure recovery:

$$C_{sp} = \left(P_{se} - P_{si}\right)/0.5\rho U_{avi}^2 \quad (2)$$

- Effectiveness of diffuser:

$$\xi = C_{sp}/C_{spi} \quad (3)$$

- Coefficient of total pressure loss:

$$C_{tl} = \left(P_{ti} - P_{te}\right)/0.5\rho U_{avi}^2 \quad (4)$$

- Non-uniformity index:

$$S_{io} = \left(\sum V_{yz}\right)/\left(n * U_{avi}\right) \quad (5)$$

- Mean standard deviation in the axial velocity at outlet:

$$\sigma_{xo} = \sqrt{\sum\left(V_x - V_{xav}\right)^2/n} \quad (6)$$

- Distortion coefficient:

$$DC_{60} = \left(P_{te} - P_{t60}\right)/0.5\rho U_{avi}^2 \quad (7)$$

3. TABLES AND FIGURES

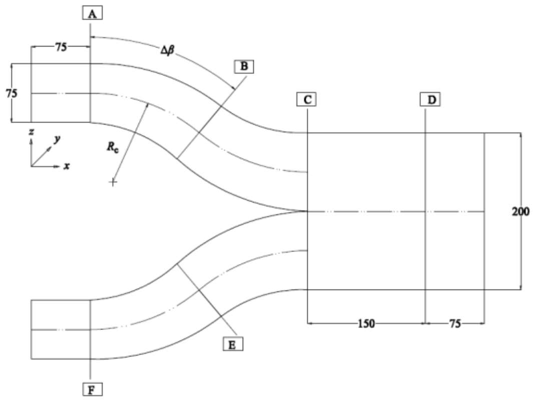

Fig 1. Schematic diagram of a twin air-intake

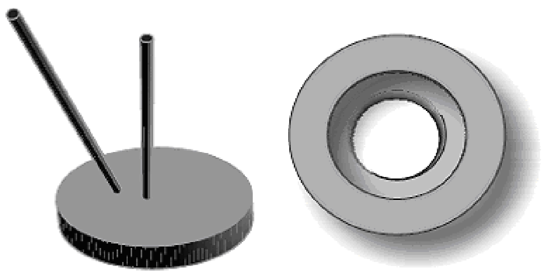

Fig 2. Vortex generator jet system for changing yaw and pitch angles.

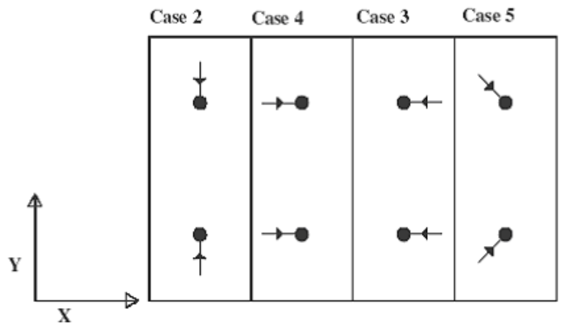

Fig 3. Different jet configuration of VGJ in the yaw plane (*x-y*) for pitch angle 45°

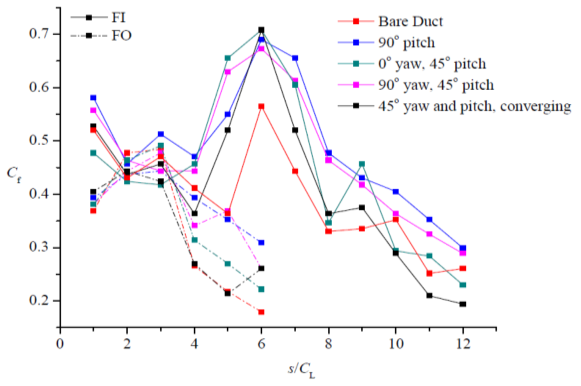

Fig 4. Shear stress variation along the front limb of the duct.

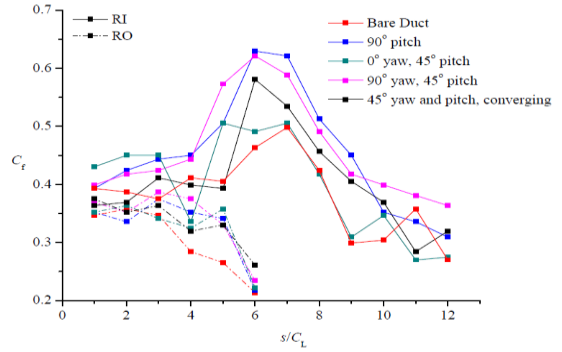

Fig 5. Shear stress variation along the rear limb of the duct

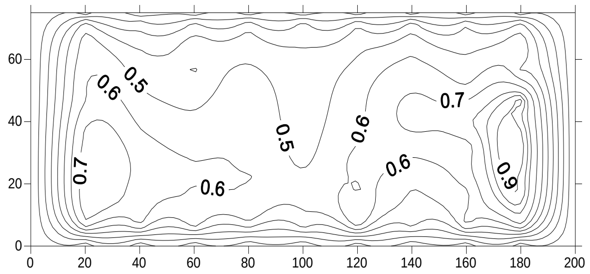

Fig 6. Pressure contours on the outlet for CASE-0

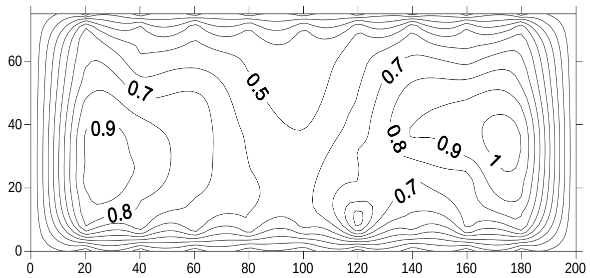

Fig 7. Pressure contours in the outlet for CASE-1

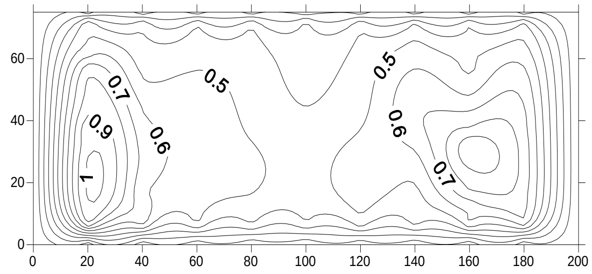

Fig 8. Pressure contours in the outlet for CASE-2

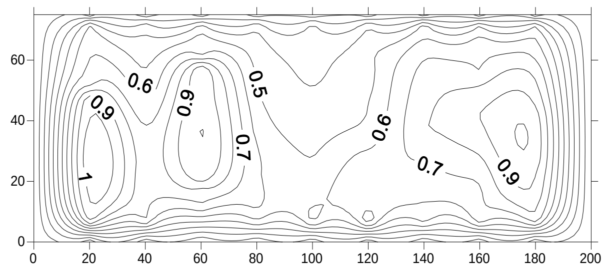

Fig 9. Pressure contours in the outlet for CASE-3

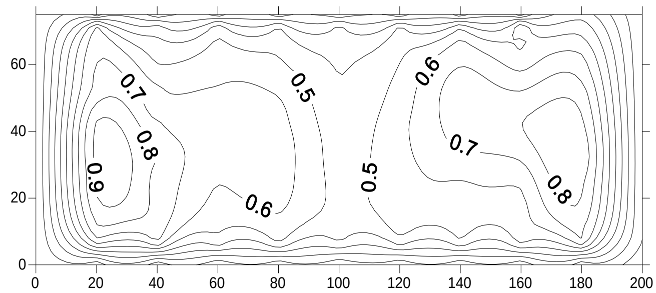

Fig 10. Pressure conyour in the outlet for CASE-4

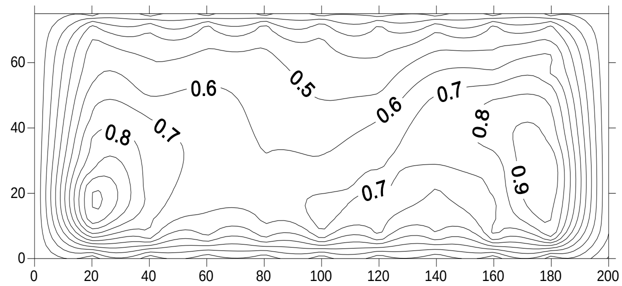

Fig 11. Pressure conyour in the outlet for CASE-5

Table 1: Values of different parameters for various cases.

S.no.	PARAMETER	CASE-0	CASE-1	CASE-2	CASE-3	CASE-4	CASE-5
1)	C_{sp}	**0.299**	**0.320**	**0.292**	**0.314**	**0.303**	**0.322**
2)	C_{actual}	**0.438**	**0.438**	**0.438**	**0.438**	**0.438**	**0.438**
3)	ζ	**0.68**	**0.73**	**0.67**	**0.72**	**0.69**	**0.74**
4)	C_{tl}	**0.316**	**0.188**	**0.321**	**0.240**	**0.268**	**0.254**
5)	S_{io}	**0.270**	**0.198**	**0.235**	**0.198**	**0.240**	**0.270**
6)	σ_{xo}	**1.764**	**1.528**	**1.793**	**1.697**	**1.481**	**1.635**
7)	DC_{60}	**0.268**	**0.264**	**0.263**	**0.261**	**0.251**	**0.254**

Table 2: % increase in coefficient of friction over full range scale for different cases on the four side walls.

S.no.	Side of duct	CASE-1	CASE-2	CASE-3	CASE-4	CASE-5
1)	**RO**	**24.77**	**26.30**	**Not considered**	**23.67**	**19.11**
2)	**RI**	**27.36**	**31.03**	**Not considered**	**27.73**	**23.72**
3)	**FO**	**26.01**	**26.80**	**Not considered**	**25.68**	**16.59**
4)	**FI**	**36.30**	**26.26**	**Not considered**	**11.18**	**17.39**

4. RESULTS AND DISCUSSION

Experiment was conducted and readings were taken at the inlet and the outlet plane using a 5- hole probe and shear stress values on the sides were taken using a flush mounting shear stress probe Dantec Dynamics made, compatible with a Dantec Dynamics CTA system.

Performance parameters taken into account are:

1) Coefficient of actual static pressure recovery (C_{sp})
2) Coefficient of total pressure loss (C_{tl})
3) Non-uniformity index (S_{io})
4) Uncertainty in the axial velocity at outlet (σ_{xo})
5) Distortion coefficient (DC_{60})
6) Increase in Skin-friction coefficient (C_f)

Effect of VGJ's on side wall shear stress

The shear stress values were taken on four planes namely Rare Inner, Rare outer, Front Inner and Front outer aong the centerline. The graph for front and rear limbs have been shown in Fig 4 and Fig. 5 **,** the graph clearly depicts that the values of shear stress increases on the outer sides and decreases on th inner sides. This is well evident from the fact that due to centrifugal action the flow gets deviated towards the outer wall resulting in rise of shear stress value on the outer walls and decrement in shear stress value on the inner wall.

The effectiveness of the VGJ's on the basis of shear stress was compared by the increase in C_f values. In the rare limb the best combination was when jet had a pitch angle of 45 and yaw angle of 90 .this case gave the greatest average % increase in the values of C_f on the inner side wall, it recorded an increase of average 5.02%. in the front limb the best combination was when pitch angle was 90 this case gave an increase of 9.58% in the value of C_f.

Effect of VGJ's on the actual static pressure recovery coefficient

The actual static recovery coefficient is one very important parameter when diffuser ducts are studied, the primary function of a diffuser is to increase the static pressure on the account of kinetic energy of the flowing mass. It is obvious that using VGJ's should increase the C_{sp} value so as to make the duct more effective. The actual static recovery coefficient is defined as the ratio of difference in the static pressure at outlet and inlet the dynamic pressure. The pressure contours at the outlet are shown in Fig. 6-11 for all the cases.

The best combination in this context was Case-5 which gave 7.73% of increase in the value of C_{pr} and

Case-1 also was quite effective with an increase of 6.99%.

Effect of VGJ's on Non-uniformity index

Non-uniformity index the measure of cross-flow velocities ,in simple words it refers to the amount of secondary flow in the flow field.

This is an important factor as secondary flow control is a major element when diffuser performance is considered. The best result was shown by case-1 and case-3 both giving the value of Non-uniformity index as 0.198.

Effect of VGJ's on Coefficient of total pressure loss (C_{tl})

The primary function of diffusers to increase the static pressure comes with a disadvantage of loss of total pressure which decreases overall effectiveness. Hence coefficient of total pressure loss should have the minimum value to give the best performance.

Case-1 shows a huge decrease in the value of total pressure loss coefficient, decreasing the value by 40.46%.

Effect of VGJ's on Uncertainty in the axial velocity at outlet (S_{xo})

Uncertainty gives us a measure of the deviation of velocity at the outlet with respect to the average outlet velocity and is given by the expression

The best combination in this context is Case-4 which gives the value as 1.481 which is quite less as compared to 1.764 for the bare duct.

5. CONCLUSION

Comparative studies on Y-20^0 non-fused diffuser duct were carried out using active flow control technique by insertion of Vortex Generator Jets on the side walls. The following conclusions are drawn from the studies.

- The insertion of jets at different configuration results in quite an improvement in the values of static pressure recovery coefficient and total pressure loss coefficient.
- The parameters like non-uniformity index , distortion coefficient and uncertainty in axial velocity also showed a little bit of improvement as expected because the primary concern of the experiment was to control separation , secondary flow control was the secondary concern.
- The C_f graph clearly shows that using jets on the duct increases the shear stress value on the duct side walls, more importantly the inner walls where probability of separation is large. The increase in C_f value gives a clear impression that separation has been controlled effectively.

Out of all the configurations taken the case that showed the optimum potential to control separation as well as secondary flow was when the jets were perpendicular to the yaw plane or the side walls i.e. CASE-1 where pitch angle is 90^0.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
A_r	Outlet to inlet area ratio	NU*
C_{sp}	Coefficient of actual static pressure recovery	NU
C_{spi}	Coefficient of ideal static pressure recovery	NU
C_{tl}	Coefficient of total pressure loss	NU
DC_{60}	Distortion coefficient for worst 60^o angle	NU
P_{te}	Total pressure at outlet	Pascal
P_{ti}	Total pressure at inlet	Pascal
S_{io}	Non-uniformity index	
U_{avi}	Average velocity at inlet	NU
V_x	Velocity in X-direction at a point	m/s
V_{xav}	Average velocity in X-direction	m/s
V_{yx}	Cross-sectional velocity	m/s
σ_{xo}	Mean standard deviation in the axial velocity at outlet	m/s
ζ	Effectiveness of diffuser	m/s

*NU means no unit or dimensionless quantity.

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