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CFD Analysis of recirculating flows induced by Axial Swirler

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Abstract

The main objective of this paper is to investigate the flow through axial Swirler. Air swirler can control the combustor performance by assisting in the fuel-air mixing process and producing recirculation region which act as flame holders and influences residence time. Such analyses are necessary for predictions and optimization of real gas combustors Thus, proper selection of a swirler is needed to enhance combustor performance and to reduce NOx emissions. Four different axial air swirlers were used based on their vane angles i.e., 30°, 40°, 50°, 60°.The model geometry has been created using CATIA Software, meshing and analysis were carried out in Ansys – Fluent 13.The K-Ɛ and RSM (Reynolds stress model) turbulence model are to be used to model the turbulence and results were compared for the effect of swirlers and mass flow rate on the flow field.

Keywords— *Combustor, Axial swirler, Turbulence, recirculation, Combustion efficiency*

1. Introduction

The combustion chamber is a turbo-engine component to which fuel supplied by feeding nozzles, is mixed with air flow coming from the compressor, after the fuel has been injected into the flow, the flow will enter the flame region. It does this with quite a high velocity. To make sure the flame isn't blown away, flow reversal can be applied in the primary zone. This causes the flow to reverse direction. The best way to reverse the flow is to swirl it. This is done using swirlers. The two most important types of swirlers are axial swirlers and radial swirlers .The most important advantage of flow reversal, is that the flow speed varies a lot. So there will be a point at which the airflow velocity matches the flame speed. (The flame speed is the speed, relative to the airflow, at which the flame can move.) This is the point where the flame anchors.

2. Air Swirler

A basic requirement of all gas turbine engines is that the flame stay lighted over a wide range of operating conditions. This is especially for aircraft combustor which has to cope with the adverse condition of low pressure and temperature, occasionally the ingestion of rain or ice. The primary zone airflow pattern is of primary importance to flame stability. Many different type of air flow pattern are employed, but one feature common to all is the creation of toroidal flow reversal that entrains and recirculates a portion of the hot combustion product to mix with the incoming air and fuel. These vortices are continually refreshed by air admitted through holes pierced in the linear walls, supplemented in most cases by air flowing through swirler.

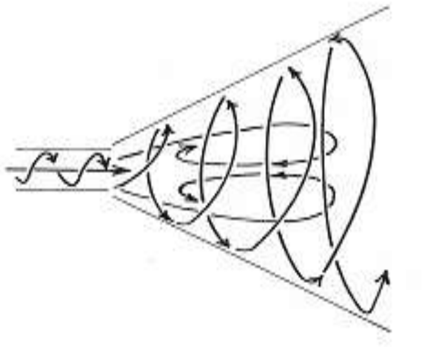

Fig. 1 Recirculation zone created by air swirler

3. Recirculation Zone

Swirl develops the radial pressure gradient and axial pressure gradient in the flow, these pressure gradient are responsible for the formation of the recirculation zone. The central toroidal recirculation zone (CTRZ) occurs due to the swirl strength. Central recirculation zone (CTRZ) is in the form of toroidal vortex .Low pressure region is created in the downstream of the combustor. In that region centrifugal force is created, this pushes the flow away from the centre axis. Because of this reason the recirculation zone is created. Efficiency of swirl flow create pressure drop along the downstream of the combustor reappears as kinetic energy of the swirling jet flow. Recirculation zone is created to provide a low velocity region, which is used to anchor the flame.

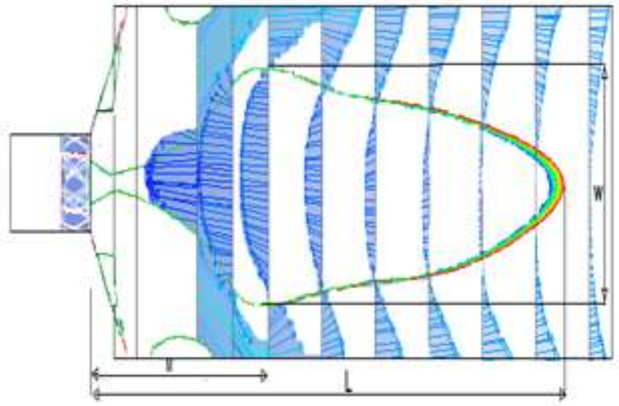

Fig. 2 Recirculation zone induced by swirler.

4. Swirl Flow

Swirling jets were used for stabilization and control of flame and to achieve high intensity combustion. The common method of generating swirl is by using by using angled vanes in the passage of air. Most conventional combustor employs the axial flow type swirlers. The swirler vanes were usually flat for easy of manufacture, but curved vane was sometimes used for their better aerodynamics properties

4.1Swirl flow generation methods

Swirl flows are generated by three principal methods:

a) Tangential entry (axial-plus-tangential entry swirl generator)

b) Guided vanes (Swirl vane pack or Swirler)

c) Direct rotation (rotating pipe)

4.2 Swirl Flow Characterisation

Swirl flow is a main flow produced by air swirled by the swirler. Swirl is to decrease the velocity gradient cause's rapid decay of the velocity in the flow field with increase of swirl flow. Swirling flow induces a very high turbulent recirculation zone. Swirl flow has a centrifugal force to accelerate the flow. Air is introduced tangentially into the chamber, forced to change its path which is due to the formation of recirculation zone. Strength of the flow is dependent of swirler vane angle and supplied air pressure. One of the effective ways of inducing flow recirculation is to fit swirler in the dome around the fuel injector. Vortex breakdown causes recirculation in the core region .When the amount of rotation imparted to the flow is high. The swirl component produce strong shear, high turbulence and rapid mixing thus having control over stability, intensity of the combustion, size and shape of the flame region. Swirl has a better aerodynamic properties, Swirl can promotes high combustion efficiency, easy ignition, recirculation zone, residence time stability and blow off limits.

5. Computational Method

In this study, to understand the effect of swirl angle on the flow field produced by axial swirler, four different configuration of swirler with varying swirl angle of 30°, 40°, 50°, and 60° were taken. In all the cases of swirler configuration constant pressure drop of 0.5 bars were maintained. Turbulence is modeled using both RSM and K-Ɛ turbulence model, and results were compared with each other. To predict the effect of inlet Reynolds number on the flow field, four different cases of swirler were selected with of Reynolds number (24700, 62800, 125000, 190000 and 250000). In this part also both RSM and K-Ɛ turbulence models were used and the results were compared.

5.1 Swirler Dimensions

Parameters of interest to axial swirler designers are depicted by below. They include:
Vane angle $^{\theta}{}_{v}$ - 30°, 40°, 50°, 60°
Inner hub radius R_{hub} -10mm
Outer swirler radius R_{sw} -30mm
Vane thickness t_v, -1.5mm
Vane length c_v,-5mm
Number of vanes n_v -8

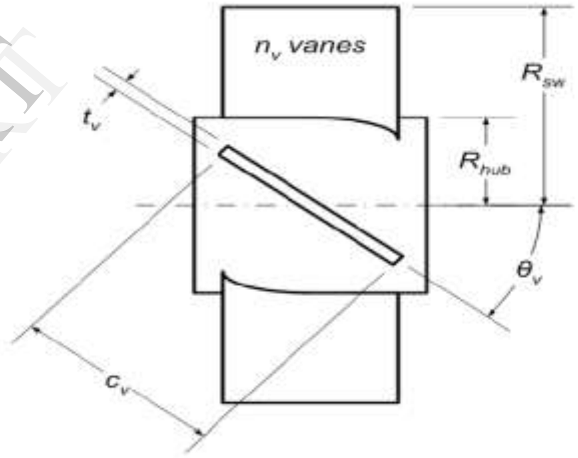

Fig 3 Swirler Dimensions

5.2 Computational Domain Details

The geometry considered for the study consists of an inlet pipe of length 100mm and of diameter 30mm, swirler is fixed with inlet pipe. Swirler consists of 8 vanes of thickness 1.5mm and height of 8mm. All the eight vanes are symmetrical about center axis. A divergent extension is provided at the swirler exit to support the strength of tangential velocity produced by swirler. A long circular duct consists of diameter 25mm and length is about 600mm fixed with divergent extension, a convergent type of nozzle is attached to prevent the reversal of flow from the atmosphere into the domain.

5.3 Geometry and Grid details

The three dimensional flow regions along with swirler with appropriate swirl angle was modelled using software CATIA. Three dimensional unstructured grids was generated using tetrahedral mesh in Ansys work bench. The grid cells were refined in the critical regions, like swirler inlet and exit, in anticipation of high velocity and pressure gradient. The solutions were predicted by using Ansys Fluent 13.

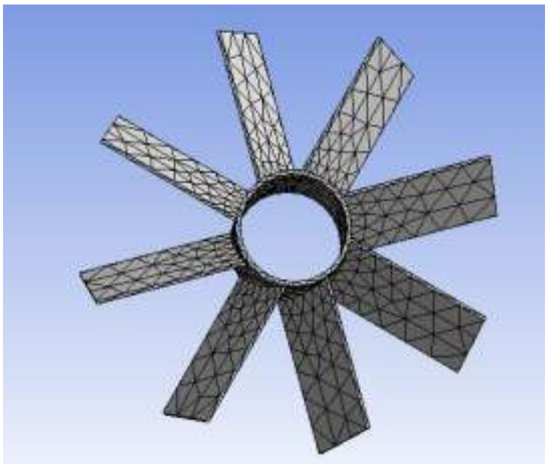

Fig 4 Computational grid of axial swirler

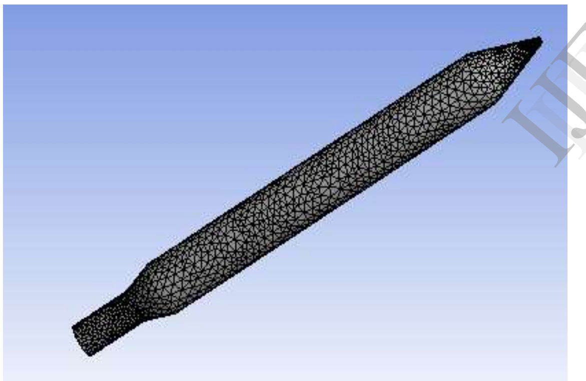

Fig.5 Computational grid of domain

Swirler angle	Nodes	Elements
30^o	5952	26418
40^o	5963	26437
50^o	5923	26057
60^o	6054	26450

Table 1. Swirler angle with corresponding nodes and elements

6. Assumptions and Boundary conditions

The assumptions and boundary conditions are essential and is a critical part in modelling a flow accurately. In this the flow is assumed to be steady, isothermal and turbulent.

Inlet

At the inlet of the computational region, the inlet boundary condition is defined as mass flow inlet.

Condition	**Value**
Flow regime	Subsonic
Pressure	1.5 bar
Flow direction	Normal to boundary
Temperature	300 K
Hydraulic Diameter	26mm
Turbulence Intensity	10%

Table 2.Inlet Boundary Condition

Outlet

The exit boundary is defined as pressure outlet .For the inlet and outlet constant pressure drop of 0.5 has been maintained. The details of the outlet boundary condition are provided in Table 3

Condition	**Value**
Flow regime	Subsonic
Outlet pressure	1 bar
Hydraulic Diameter	35.68mm
Turbulence Intensity	15%

Table 3.Outlet boundary condition

Mass Flow rate

For mass flow rate across the different cases of swirler mass flow inlet boundary condition was chosen at inlet with varying mass flow values of 0.01, 0.025, 0.05, 0.075 and 0.1 kg/s was given to vary the inlet Reynolds number.

Mass flow rate (kg/s)	Reynolds number (Re)
0.010	24700
0.025	62800
0.050	125000
0.075	190000
0.100	250000

Table 4 Reynolds number effect on mass flow rate

7. Effect of Reynolds number on axial velocity

Axial velocity distributions of all five cases of Reynolds number along the axial direction for both the K- Ɛ and RSM model were shown in the figure 6 and 7 respectively, it indicates that reverse flow axial velocity within the recirculation increases with increase in Reynolds number. Higher Reynolds number cases producing stronger recirculation zone with increase in size. But continuous increase in inlet velocity will increase the size CTRZ, after some limit it will form open recirculation zone, which may not able to hold the flame. This maximum velocity limit is called stability limit of that particular swirler. Exit axial velocity predicted by RSM model was almost constant. But exit axial velocity predicted by K-Ɛ model was not constant.

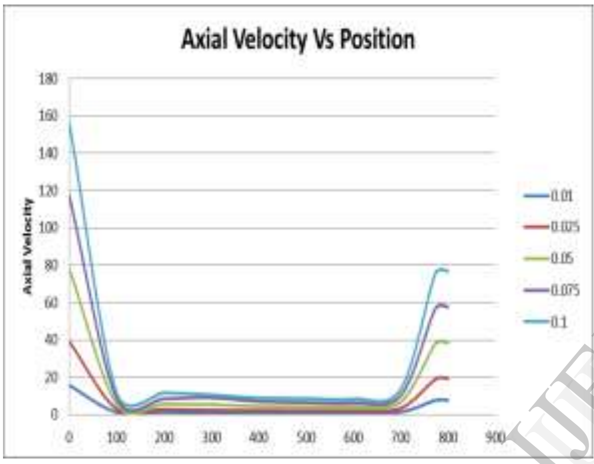

Fig. 6 Reynolds number effects on axial velocity along axial distance for K-Ɛ model.

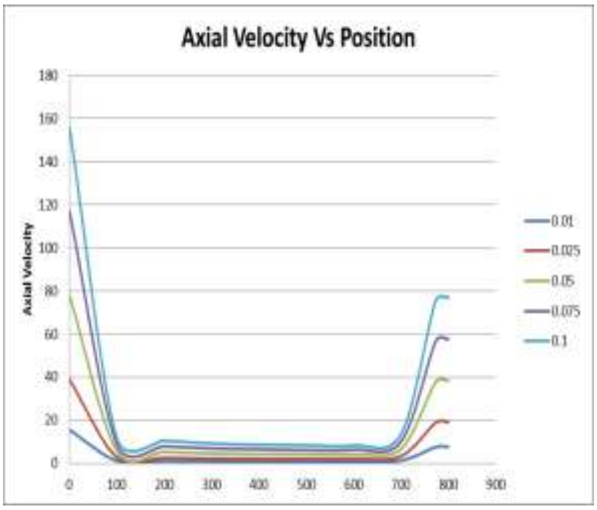

Fig.7 Reynolds number effects on axial velocity along axial distance for RSM method.

8. Effect of Reynolds number on Turbulence Intensity

Turbulent intensity distributions of all five cases of Reynolds number along the axial direction for both the K-Ɛ and RSM model were shown in the figure 8 and 9 respectively; it indicates that turbulent intensity with in the CTRZ increases with increase in Reynolds number. With increase in inlet Reynolds number the inlet kinetic energy increases. This increase in kinetic energy produces higher turbulence in the flow. So intensity of turbulence increases with increase in inlet Reynolds number. RSM model gives uniform profile for different Reynolds number case. But K-Ɛ model gives different forms of profile.

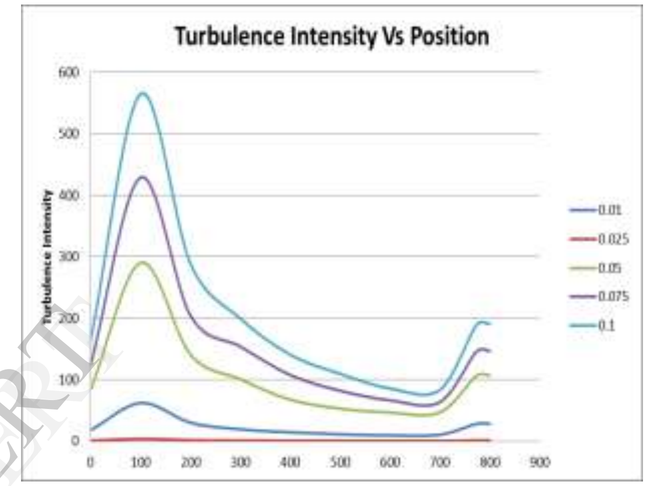

Fig.8 Reynolds number effects on turbulence intensity for K-Ɛ method.

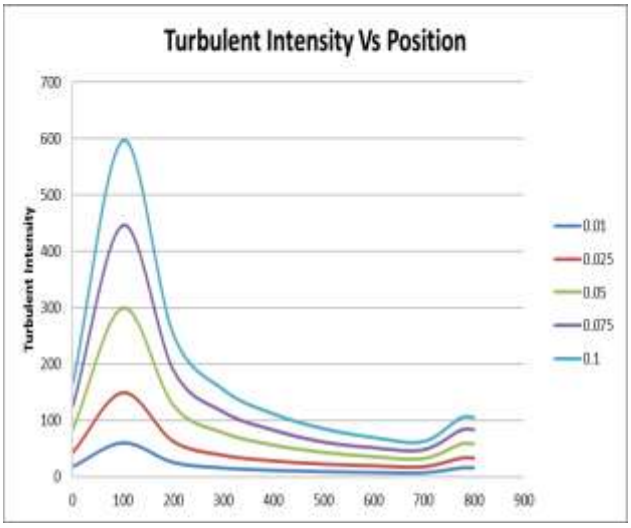

Fig. 9 Reynolds number effects on turbulence intensity for RSM method.

9. Conclusions

Complete investigations of various factors on the performance of flow through axial swirler with different swirl angle configuration were studied. The change in swirl angle had a large effect on the flow field. For a various values of Swirl angle at constant pressure drop across the swirler, variation in the mass flow rate, velocity variation and intensity of turbulence inside the reverse flow region were predicted by using the turbulence model RSM and K-Ɛ. The effect of Reynolds number (24700, 62800, 125000, 190000 and 250000) on the flow field for single swirler was predicted using the turbulence model RSM and K-Ɛ. It was observed that increase in Reynolds number has a significant effect on the flow field, and the results of 30° RSM model were better than K-Ɛ at higher Reynolds number cases.

10. References

[1] Beer and Chigier, N.A., Combustion aerodynamics, Applied science pub., London 1972

[2] David G.Lilley “Modeling of combustor swirl flows”, ACTA Astronautical, Volume 1, PP.1129-1147.November 1974

[3] R.ECharles, J.I.Emdee, L.J.Muzio, G.S.Samuelsen ,”The effect of inlet Conditions on the performance and flow field structure of a non-premixed swirl-stabilized distributed reaction”, International journal of combustion, 1986.pp.1455-1461.

[4] J.L xia,B.L,Smith,A.C Benim,J.Schmidli and G.Yadigaroglu ,”Effect of inlet and outlet boundary conditions on swirling flows”, Computers and fluids,Volume26,No.8,1997,PP.811-82

[5] Aldo Coghe, Giulio Solero,” Gianfranco Scribano, ”Recirculation phenomena natural gas swirl combustor”, Journal of thermal and fluid science,2004,PP.709-714.

[6] Ying Huang and Vigor Yang “effect of swirl on combustion dynamics in a lean premixed swirl stabilized combustor”, combustion institution, 2005, PP.1775-1782.

[7] S.Bharat Krishna and V.Ganesan “CFD Analysis of flow through vane swirler (1) journal-MC, Volume 86, April 2005.

[8] R.Palm, S.Grundmann, M.Weismuller, S.Saric, S.Jakirlic, C.Tropea ”Experimental characteristics and modeling of inflow condition for a gas turbine swirl combustor”, International journal of heat and fluid flow

[9] A.Panduranga Reddy, R.I.Sujith, and S.R.Chakravarthy “Swirler flow field characteristics in a sudden expansion combustor geometry, Journal of propulsion and power, Volume 2. No.4, July-August 2006.

[10] R.Thundil Karuppa Raj and V.Ganesan “Experimental study of recirculation flows induced by vane swirler”, Indian journal engineering and materials sciences, Volume 16, February 2006,PP .14-22

[11] Saravanamuttoo, H.I.H., Rogers, G.F.C., & Cohen, H. 2001. ‘*Gas Turbine Theory’*. 5edn. New York: Prentice Hall.

[12] Dodd’s, W.J., & Bahr, D.W. 1990. *Combustion System Design*. Chap. 4, pages 343–476 of: Mellor, A.M. (ed). ‘*Design of Modern Turbine Combustors*’. New York: Academic Press.