Rotary vanes to increase turbulence in a can type combustor

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Abstract: This project presents the design of a combustor with rotary vanes at the diffuser section and analyzing it’s turbulence and velocity characteristics. Rotary vanes with 2-blade, 4-blade and 8-blade configuration are analyzed and compared. The model with the better turbulent characteristics is selected and is then compared with the conventional combustor model with swirl. Cold flow analysis is carried out to understand the turbulence of air and the velocity fluctuations inside the chamber. In this study the attempt has been made by using CFD approach.

1. Introduction
A combustor in a Gas Turbine engine is used to burn the fuel with the supplied high pressure air from the compressor section. The high temperature exhaust gas obtained from the combustion process is used for producing power and the generation of thrust. The primary goal is to obtain the maximum heat energy from the chemical energy of the fuel. In certain cases incomplete combustion process may occur due to the improper mixing of air and fuel. The incomplete combustion thus produces many toxic substances which is then expelled into the atmosphere. If we somehow achieve the complete combustion, it would result in lesser pollution and saves fuel as well. Thus creating a large turbulence inside the combustion chamber would be an efficient way in enhancing the fuel-air mixing. This would possibly result in a proper complete combustion and less emission of toxic exhaust gases. Various researches like Arturo Acousta Zamora et al [1] and Bhupendra Khandhelwal et al [2] shows the different attempts made inorder to create better combustion characteristics. Thus in order to increase the turbulence inside the combustor a rotary vane with eight blades is kept inside at the start of the primary zone. The rotary vanes are designed with the reference of Horia Dumitrescu et al [3]. The turbulence characteristics and the velocity fluctuations are measured and is compared with the characteristics of a can combustor without the rotary vanes through CFD analysis. Natik H Gor et al [5] has carried out CFD analysis of a swirl combustor. Also Mansha Kumari et al [4] has done CFD analysis on rotating swirlers.

2. Geometry
The 3D modelling of the Can-type combustor is done by using CATIA V5 software with and without the rotary vanes of 2-bladed, 4-bladed and 8-bladed configuration for computational analysis. Fig.1 shows the can combustor with a swirler at the inlet. Only the primary and the secondary zones of the combustor is designed for the analysis. Fig. 2 shows the combustor model with the swirler at the inlet.
and the diffuser section with rotary vanes with 2-blade, 4-blade and 8-blade configuration. Also the basic dimensions of the can combustor is shown in the fig. 3.

![Can combustor with swirler at the inlet.](image1)

**Figure 1.** Can combustor with swirler at the inlet.

![Can combustor with rotary vanes inside.](image2)

**Figure 2.** Can combustor with rotary vanes inside.

![Dimensions of the Can-type combustor.](image3)

**Figure 3.** Dimensions of the Can-type combustor.
3. Computational procedure

A commercial CFD software, CFX is used for the simulation. It solves the three dimensional RANS equation using Finite volume approach. Also one of the following turbulence models viz. k-ε, k-ω or SST turbulence model, etc is solved along with the RANS equations. The software has four major modules

a) CFX Build
b) Pre-processor
c) Solver
d) Postprocessor

The appropriate system of equations governing the turbulent flow of a compressible gas inside the combustor may be written as:

Continuity equation:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k} (\rho u_k) = 0
\]

\(k = 1, 2, 3\)

Momentum equation:
\[
\frac{\partial}{\partial t} (\rho u_i) + \frac{\partial}{\partial x_k} (\rho u_i u_k) + \frac{\partial p}{\partial x_k} = \frac{\partial \tau_{ik}}{\partial x_k}, \quad i, k = 1, 2, 3
\]

Energy equation:
\[
\frac{\partial}{\partial t} (\rho E) + \frac{\partial}{\partial x_k} (\rho u_k H) = -\frac{\partial}{\partial x_k} (u_k \tau_{jk}) + \frac{\partial q_k}{\partial x_k} \quad j, k = 1, 2, 3
\]

Where \(\rho, u, p, E\) and \(H\) are the density, velocity components, pressure and total energy and total enthalpy respectively.

The finite volume approach is utilized by the solver, in which the conservation equations in differential form are integrated over a control volume described around a node, to obtain an integral equation.

An unstructured grid (fig.4) with 429181 nodes and 195681 elements is generated with the help of Ansys meshing software. The properties of the mesh was selected by studying its effects on the overall solution obtained.

Figure 4. Meshing of the Can combustor.
The boundary conditions are specified as follows. The inlet is defined as the velocity inlet of 30 m/s and the outlet is defined as the pressure outlet. 3D transient analysis is carried out on the combustor model. The better turbulence model which predicts the turbulent characteristics with accuracy is used after an intense study and research. The average static pressure was set to match the inlet total pressure.

Table 1. Computational Method.

| Solver                  | Pressure based  |
|------------------------|-----------------|
|                        | 3D model        |
|                        | Transient analysis |
| Model                  | k-epsilon model |
| Boundary conditions    | Velocity inlet with 30 m/s |
|                        | Pressure outlet  |
| Initialization         | Standard Initialization |
|                        | Computed from Inlet |
| Solutions Obtained     | Turbulence Intensity |
|                        | Velocity Magnitude |

Table 1. shows the general view of the CFD analysis that has been carried out. The velocity magnitude and the turbulence intensity is obtained from the computed data. The combustor setup with the rotary vanes having 2-blades, 4-blades and 8-blades are analyzed and compared to find out the configuration that produces the better turbulence inside the chamber. And it is also compared with the conventional combustor only with the swirl vanes. The vertical midplane is selected and the contour are obtained. The plots are made with the values obtained from the mid axis of the combustor. The percentage increment of the turbulent intensities and the decrement in velocities due to the rotor setup is also analyzed.

4. Results and Discussion
The parameters that are mainly focussed in this research are Velocity magnitude and Turbulence intensity. The variation of these two parameters are obtained in the form of Contours and graphs. The three rotor configurations are compared and the one with the low axial velocity and high turbulence intensity is selected, which is suitable for better combustion process. The selected rotor configuration is then compared with the conventional can combustor with a swirler at the inlet.

The contour diagrams shown in this paper describes the velocity magnitude and the turbulent intensity of the can type combustor on its vertical midplane through its axis. Also the pathlines are obtained inorder to know the numbers and placement of the recirculation zones formed.

The velocity contours of the three different bladed configurations are obtained and it can be seen that the 8-bladed rotor decreases the velocity to a maximum extent. The minimum velocity obtained at the exit plane of the can-type combustor is 4.32 m/s, 6.37 m/s, 18.7 m/s by 8-bladed, 4-bladed and 2-bladed rotor configurations which can be inferred from figure 5, figure 6 and figure 7 respectively.

Similarly, the turbulence created by the different configuration of rotary vanes are obtained and analyzed. It can be seen that the maximum turbulence intensity produced by the 2-bladed, 4-bladed and the 8-bladed rotor is 25.9%, 45.2% and 41.5% and is shown in figure 8, figure 9 and figure 10 respectively. Also from the contour plots we can see that the 8-blade rotor produces better turbulence in a larger area in the chamber when compared with the other two rotor configurations.
Figure 5. Velocity contour of 2-bladed rotor.

Figure 6. Velocity contour of 4-bladed rotor.

Figure 7. Velocity contour of 8-bladed rotor.

Figure 8. Turbulence intensity contour of 2-bladed rotor.

Figure 9. Turbulence intensity contour of 4-bladed rotor.

Figure 10. Turbulence intensity contour of 8-bladed rotor.
From the above results obtained, it can be inferred from the graphs shown below (Fig.11 & Fig.12), that the 8-bladed rotor in the combustor has the better characteristics than the other two rotor configurations.

![Figure 11. Comparative plot of turbulence intensity across the mid axis of the combustor with rotary vanes.](image1)

**Figure 11.** Comparative plot of turbulence intensity across the mid axis of the combustor with rotary vanes.

![Figure 12. Comparative plot of Velocity variations across the mid axis of the combustor with rotary vanes.](image2)

**Figure 12.** Comparative plot of Velocity variations across the mid axis of the combustor with rotary vanes.

The above two plots Fig.11 and Fig.12 shows the variation of Turbulence intensity and Velocity magnitude respectively along the axial length of the combustor. The grey line, orange line and the blue line in the plots shows the characteristics of the 8-bladed, 4-bladed and 2-bladed rotary vanes respectively. From the comparative study the 8-bladed rotor inside the can combustor is chosen to have the better characteristics than the other two configurations, since it produces the maximum turbulent intensity and lowest velocity magnitude than the other two rotor configurations.

Also the 8-bladed rotor configuration is compared with the conventional can-type combustor with swirl and its turbulence and velocity characteristics are compared and analyzed.
The below two figures (Fig.13 & Fig.14) shows the velocity magnitude and turbulence intensity variation in the vertical mid plane of the combustor. It can be seen that the rotor setup produces an additional turbulent intensity of 16% and could reduce the velocity to the lowest of 4.32 m/s.

**Figure 13.** Velocity contour of Swirler setup.  
**Figure 14.** Turbulent intensity contour of swirler setup.

**Figure 15.** Turbulence intensity comparison of the combustor with swirler and rotary vane.

**Figure 16.** Velocity magnitude comparison of the combustor with swirler and rotary vane.
The above plots Fig.15 and Fig.16 shows the variations of Turbulence intensity and Velocity magnitude along the axial length of the can combustor with and without the rotary vanes. The recirculation zones are also obtained for both the combustor configurations. Fig. 17 shows the recirculation zones produced by the swirlers, and there are only two recirculation zones near the walls. In the Fig. 18 we can see that there are four recirculation zones created, two recirculation zones are in the diffuser section and two recirculation zones are created in the mid axis region next to the rotary vanes. Since the recirculation has happened in the central core region of the combustor, the fuel-air mixing can be enhanced which could lead to a proper and a complete combustion.

5. Conclusion

The effect of the rotary vanes with 8-blades in a can type combustor is analyzed and its turbulence and velocity characteristics are studied. With the help of CFD procedure the following observations are made,

- The 8-bladed rotor can produce better turbulence than the 4-bladed and 2-bladed rotors.
- The 8-bladed rotor can reduce the velocity to the minimum of 4.6 m/s
- Additional turbulent intensity of 16% can be achieved with this rotor setup.
- There is a 72% reduction in the axial velocity magnitude which would result in the increased stay time of the fuel-air mixture inside the combustor.
- Turbulence intensity increases with the increase in the number of blades in the rotor.
- Recirculation zones can be produced in the central core region of the combustor with the rotary vane setup.
6. References

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