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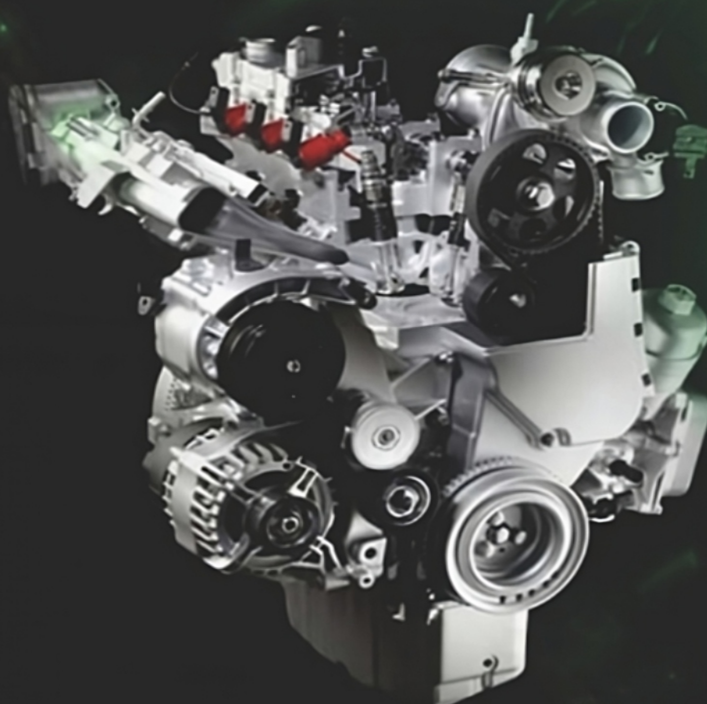

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EFFECT OF SWIRL ON COMBUSTION CHARACTERISTICS IN NON-PREMIXED GAS TURBINE COMBUSTOR

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ABSTRACT

To stabilize the flame and reduce the pollutants, a combustion chamber needs to have recirculation. Air swirlers induce a swirling flow in order to ensure recirculation inside the combustion chamber. The flow field inside the combustor is influenced by the liner's dimensions and shape, the wall side holes' dimensions and shapes, and the primary air swirler's placement. The main consideration while developing swirlers is the swirl number (Sn). To obtain recirculation, swirl (Sn) needs to be greater than 0.6. This paper aims to optimize the design of a swirler considering the key elements of a non-premixed combustion chamber. CFD models are used to simulate this recirculation phenomenon. The findings show that at greater levels of swirl intensities, substantial radial and axial pressure gradients are created near the nozzle exit, leading to axial recirculation in the form of a central toroidal recirculation zone. Recirculation zone is also desirable for high combustor fficiency and uniform exit temperature profile. The mixing characteristics can be improved by the use of swirl in non-premixed combustion.

Keywords: Combustor, Swirl number, swirling flow, CFD Analysis

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NOMENCLATURE			
S_n	Swirl number	t_v	Vane Thickness
NOx	Nitric oxides	N_v	No. of Vanes
H_2	Hydrogen	**Greek Symbols**	
A_{sw}	Swirler Area	ρ	Density (kg/m^3)
D_{sw}	Swirler diameter	σ	Solidity
D_{hub}	Swirler hub diameter	**Abbreviations**	
θ	Vane angle	CFD	Computational fluid dynamics
c	Vane chord		
s	Vane space		

1. INTRODUCTION

The combustion chamber is the part of a system which mainly determines the efficiency and reliability of operation of the engine. The enhanced aerodynamic mixing process taking places inside the combustion chamber due to swirler are complex. The construction of the combustion chamber of a jet propulsion engine is an extremely difficult task due to the nature of smaller diameter and in length. The better progress of solution to this problem requires an understanding of the mixing processes taking place in a combustion chamber. To obtain the uniform temperature at exit, the combustion device is designed for continuous operation with controlled heat release. This points out that the design of gas turbine combustor is primarily related to stable combustion with high efficiency and better temperature quality at exit To achieve stable combustion, The design procedure is carried out in such a way that the stable combustion can be achieved and also the combustion reaction starts and ends in the primary zone. Afterwards, the next zone helps to attain uniform and sustainable temperatures for turbine blades. One of the important criteria in primary zone design is the mixing procedure of fuel with accurate proportion of air.

Swirlers are made up of a number of vanes that are placed in such a way that they transform the axial momentum of the flow into the tangential momentum, which ultimately aids in the mixing of the air and fuel. Swirl vanes transforms flow into rotational motion as they revolve, creating low pressure zones like internal and external recirculation zones which will aid in mixing the fuel and air in the combustion chamber and stabilize the flame. The vane angle of a swirler influences the flame behavior and the pollutant emissions [1-3].

The installation of a swirler in a dome around the fuel injector is one of the most efficient ways to incorporate flow recirculation in the primary zone. In swirling flows, vortex breakdown is a prominent phenomenon that, when the airflow is given a lot of rotation, results in recirculation in the core region.

This paper aims at understanding the importance of swirler and its effect to predict the dynamics of the flow inside a model of a micro gas turbine combustor. Recent studies on gas turbine combustion chambers has led to better understanding of the internal physical processes occurring in the combustor.

2. DESIGN OF SWIRLER

Swirling flows can be produced using many different configurations in which air is injected into a cylindrical chamber. Two main types of swirlers are [5]:

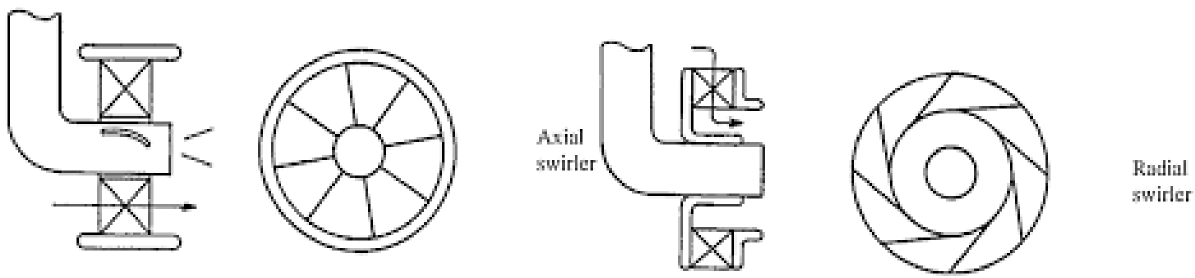


Figure 1. various types of air swirler [5]

2. 1. Swirl Number The primary factor taken into account in swirler design is the swirl number (S_n). The angular momentum axial flux (G_t) to the axial momentum axial flux (G_x) ratio is known as the swirl number. The swirl number can be calculated using equation given below [6]:

$$S_n = \frac{G_t}{G_x R}$$

Where R is the hydraulic radius.

2.2. Swirler Area The link between the frontal annular area and the space filled by the vane profiles is represented by the frontal area (A_{sw}) of the swirler. This variable can be calculated using equation given below [8]:

$$A_{sw} = \frac{\pi}{4}(D_{sw}^2 - D_{hub}^2) - \frac{n_v t_v}{2}(D_{sw} - D_{hub})$$

In order to calculate the swirl number (Sn) in an annular swirler with a constant vane angle, Beer and Syred [9] suggested the equation given below:

$$S_n = \frac{2}{3}\left(\frac{1 - \left(\frac{D_{hub}}{D_{sw}}\right)^3}{1 - \left(\frac{D_{hub}}{D_{sw}}\right)^2}\right)\tan\theta$$

$$S_n = 0.78$$

Swirl number is important in the design of swirlers as it provides a criterion for recirculation. Better mixing is achieved with this form of recirculation than is often possible with other methods. Recirculation is obtained if swirl (S_n) is greater than 0.6. Design of axial swirler initiated with swirler mass flow rate at inlet conditions and additional requirement also considers inner radius.

The components of an axial swirler were specified in a standard notation by Lefebvre and Ballal [10]

TABLE 1. Geometrical parameters of swirler

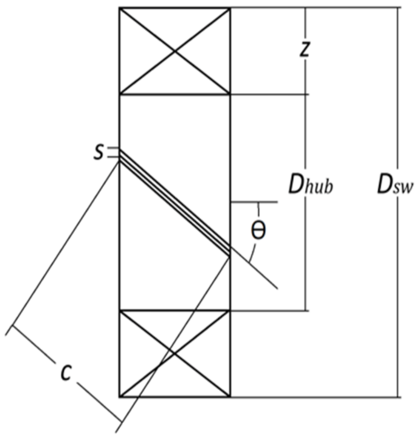


Figure 2. Geometrical specifications of the primary components of an axial

D_{sw}	Swirler diameter
D_{hub}	Swirler hub diameter
θ	Vane angle
c	Vane chord
s	Vane space
z	Annular space length formed by the hub diameter and the swirler diameter

Another factor that influences swirler design is solidity. It is referred to as the vane chord length to vane pitch ratio. The following equation describes the solidity for an axial swirler as a function of the vane angle [11].

$$\sigma = c \sin\theta / s$$

The development of a high-intensity swirl number is preferred when the designed swirler's solidity value is less than 1.

Swirl number, Vane angle, and hub to tip ratio are crucial geometrical geometric parameters. The optimal vane angle for the range of vane angles investigated is discovered to be 45° [12].

TABLE 2. Design Parameter for Swirler

Hydrogen Inlet Pressure	2 bar
Air Inlet Pressure	3 bar
Air Inlet Temperature	300 K
Hydrogen Inlet Temperature	300 K
$\dot{m}_{air}$	$4.2382 \times 10^{-4}\ kg/s$
$\dot{m}_{fuel}$	$1.37 \times 10^{-5}\ kg/s$
ρ_{H_2}	$0.2469\ kg/m^3$

TABLE 3. Geometric Dimension of Swirler

Outer diameter (D_{sw})	37 mm
Inner diameter (D_{Hub})	20 mm
Thickness of vane (t_v)	1 mm
Chord (c)	7 mm
Van Space (s)	10 mm
Number of vane	10
Vane Angles (θ_v)	45º

Accordingly, design is carried out and the dimensional drawing is shown in Figure 3.

2. 3. The typical range of values are

Vane angle (θv) = 30º to 60º

Vane thickness (tv) = 0.75 to 1.5 mm

No of vanes (Nv) = 8 to 16

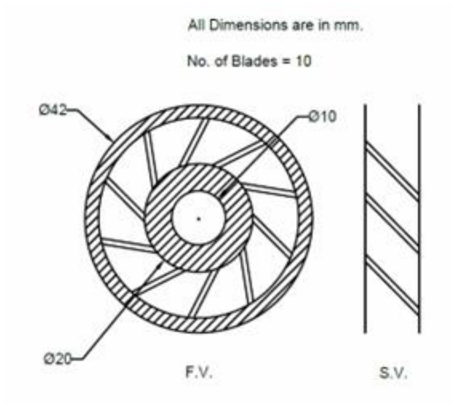


Figure 3. Swirler Dimensional Drawing

3. NUMERICAL MODELS

3. 1. Modeling of Geometry

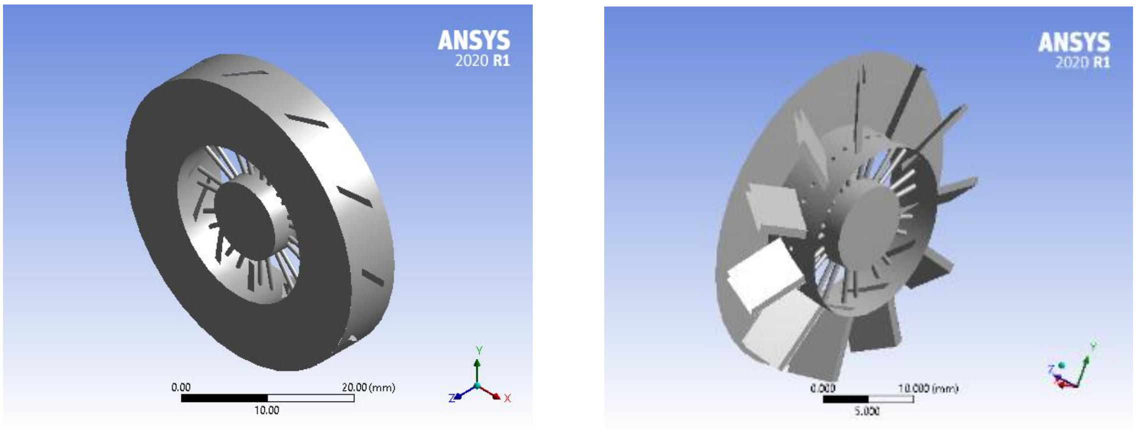
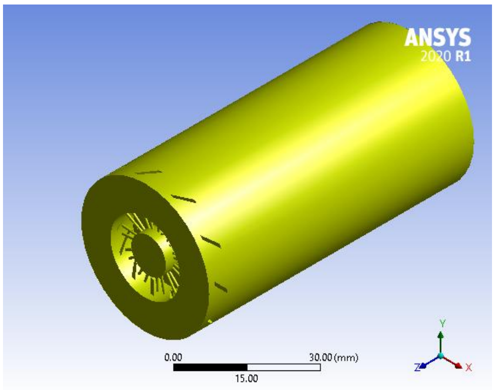


Figure 4. 3D model of swirler



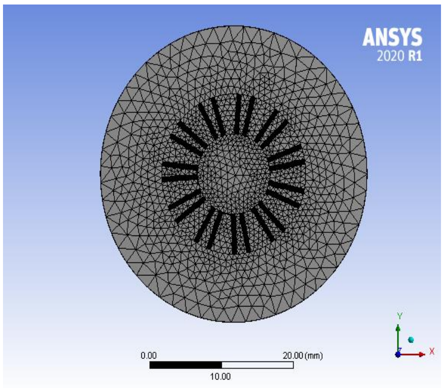


Figure 5. 3D model of Combustion chamber **Figure 6.** Mesh Details

3. 2. Grid Details

With the help of the built-in software Design Modular, the three-dimensional flow zones and swirler were modeled. Tetrahedral mesh was used in the ANSYS work bench to create three-dimensional unstructured grids. In areas where strong velocity and pressure gradients were expected, such as the swirler's input and exit, the grid cells were improved.

3. 3. Boundary Conditions of Swirler

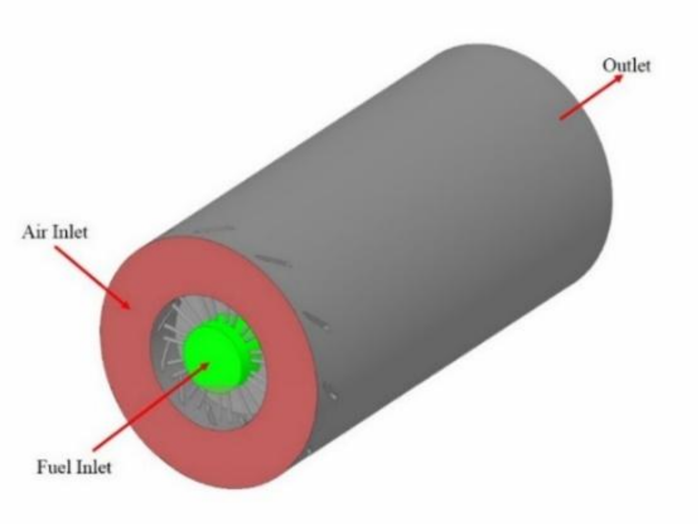


Figure 7. Boundary Conditions of Swirler

For simulations to accurately reflect real-world circumstances, the boundary conditions must be defined in a manner that is both logical and consistent. At the manifold entry and the fuel injector, masses entering the domain were subjected to a mass flow inlet boundary treatment. This method establishes a consistent mass flow rate while allowing the total pressure to change depending on the inner solution. Input conditions at air inlet according to the design conditions. This scenario is a perfect representation of the real-world experiment, in which the air is delivered at the inlet at known pressure, temperature, and velocity parameters, and let the flow naturally into the chamber with fuel injection at entrance. The direction of the inflow was fixed to normal to the boundary. The solutions presented in this paper used the standard $k - \varepsilon$ turbulence model.

4. RESULT AND DISCUSSION

The major goal is to get the highest possible swirling effect with strong turbulence and no pressure losses.

Figure 8 shows the velocity streamlines for air and fuel flow.

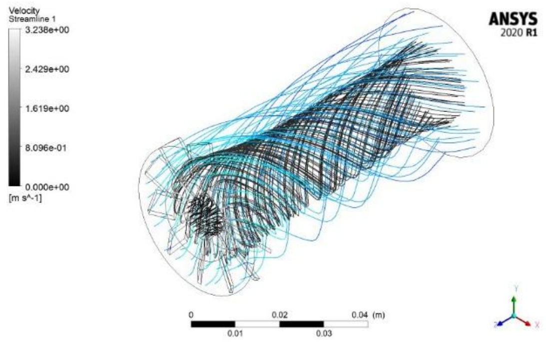


Figure 8. Velocity streamlines

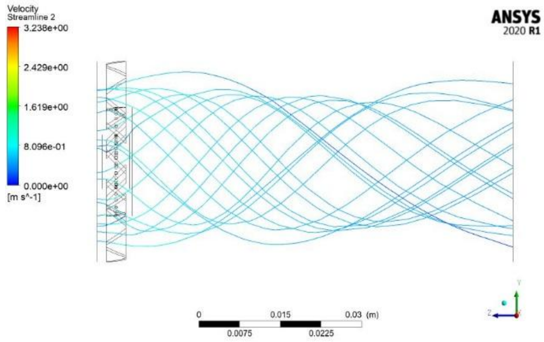


Figure 9. Velocity streamlines along yz for Air inlet

The blue streamlines were sown at the top of the chamber's casing, while the black streamlines were sown in the fuel entry apertures. It is interesting to notice the mixing of the two groups of streamlines. In this most of the mixing takes place close to the walls, some of the fuel remains in the chamber's middle. The mixing of the fuel must occur in the center of the chamber and must be completed in the lowest amount of time possible.

Figure 9 shows the velocity streamlines for the air in the yz plane by using a swirler in the combustion chamber. This depicts the revolving flow across the combustion chamber.

Therefore, there are possibilities that the stability found in the results is occurs as a result of mixed swirling structure. However, there is also hint that the mixing process is stretched more than it should. Fig. (9) Presents the streamlines for velocity will be useful in understanding the reason behind such occurrences.

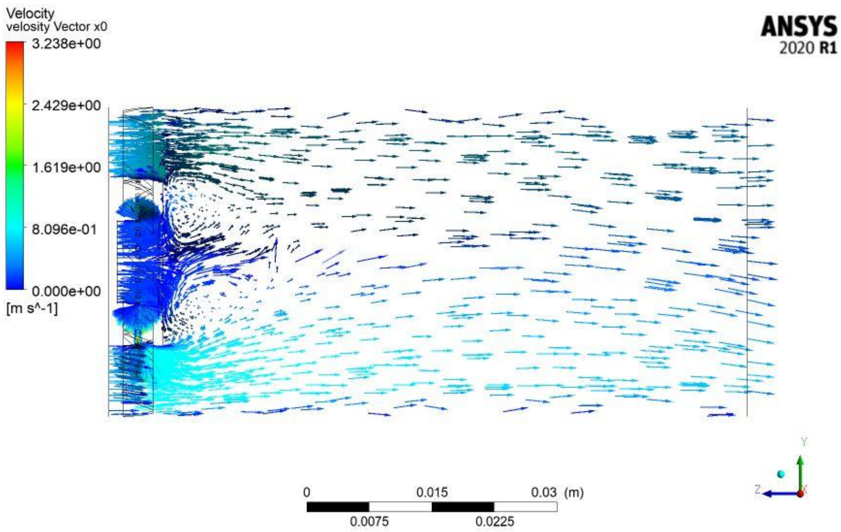


Figure 10. Velocity vectors in yz plane x = 0 mm

Figure 10 represents the way the flow behaves as it moves through the combustion chamber. The velocity path lines produced by the swirler are shown in the figure. Additionally, it is noted that the primary zone develops a high-intensity turbulence zone. The combustion chamber core also has a low-speed section that ends not far from the secondary zone. The primary zone is where the recirculation zone ends, and it is bounded by the swirler's hub.

Schmittel et al. [13] represented that utilizing swirl in non-premixed combustion can aid in lowering pollutant emissions, especially that of NO_x. The proposed method derives to the conclusion that a reduced temperature was found in the flame in the primary zone which leads to reduction in NO_x productions.

5. CONCLUSION

The findings show that at greater levels of swirl intensities (strong swirl, $S_n > 0.6$), substantial radial and axial pressure gradients are created near the nozzle exit, leading to axial recirculation in the form of a central toroidal recirculation zone. To increase flame stability as a result of toroidal recirculation zones developing in highly swirling regions. In particular, swirl is commonly employed as a support for effective clean combustion in a range of real-world applications. The function of the combustor swirler in the change the overall direction of the air flux in order to improve the mixing with the fuel. Recirculation zone is required to obtain a continuous ignition source for good lean stability as well as the complete primary zone fuel/air mixing for low smoke, high combustor efficiency and uniform exit temperature profile. As swirl is the possible factor for increasing the turbulent burning velocity at the flame base, it is stabilizing factor. Utilizing swirl in non-premixed combustion can aid in lowering pollutant emissions, especially that of NO_x.

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