Effect of Swirler in a Micro Gas Turbine Engine

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***Abstract*— In conventional gas turbine engine there are so many difficulties to obtain proper combustion. Aswirlerisusedformixingairandfuelforcombustionandstabilizi ngtheflame.Inordertostabilizethe flame,theincominghigh-speedairmustbedeceleratedtoavelocitybelowtheturbulentflame speed.The flame stabilizes along the locus of points where the air velocity is equal to the flame speed. There are so many ways to mix fuel air and stabilize the flame for proper combustion that will not only improve the fuel efficiency by combustion of fuel but also reduces the emission and pollution significantly by creating the internal and central recirculation zone. This paper is presents the study of micro gas turbine engine with different configuration of swirler. The incorporation of swirler can divide stream flow into multiple streams to obtain high turbulence inside the combustor for proper mixing of air with fuel and efficient performance in combustion and also swirler is used to stabilize flame by producing high turbulence. In this micro combustor we use inner and outer annulus to induce turbulence intensity and to stabilize the flame inside thecombustor.**

Keyword*— Swirler, proper mixing, swirling flow, proper combustion, inner and outer annulus, flame stability

INTRODUCTION

GAS TURBINEENGINE

The gas turbines are one of the most widely used power generating technologies. Gas turbine is a type of internal combustion engine in which burning of an air fuel mixture produces hot gases that spin a turbine to produce power.

THE GAS TURBINE CYCLE

The basic principle of the airplane turbine engine is identical to any and all engines that extract energy from chemical fuel. The basic 4 steps for any internal combustion engine are:

1. Intake of air (and possiblyfuel).
2. Compression of the air (andpossibly
3. Combustion, where fuel is injected (ifit

places. Gas turbines are also Brayton engines. This also has three components: a gas compressor, a burner (or combustion chamber), and an expansion turbine.

As a result of this fundamental difference, the turbine has engine sections called:

1. The inletsection
2. The compressorsection
3. The combustion section (thecombustor)
4. Theturbine(andexhaust)section.

Actual Braytoncycle:

1. Adiabatic process -Compression fuel).
2. Isobaric process - Heataddition
3. Adiabatic process -Expansion

was not drawn in with the intake air) and burned to convert the stored energy.

4. Expansion andexhaust,

In the case of a piston engine, such as the engine in a car or reciprocating airplane engine,the intake,compression,combustion,andexhauststeps occur in the same place (cylinder head) at different times as the piston goes up anddown.

In the turbine engine, however, these same fourstepsoccuratthesametimebutindifferent

4. Isobaric process - Heat rejection

Figure 1.1 Gas Turbine Engine

The turbine section of the gas turbine engine has the task of producing usable output shaft power to drive the propeller. In addition, it must also provide power to drive the compressor and all engine accessories. It does this by expanding the high temperature, pressure, and velocity gas and converting the gaseous energy to mechanical energy in the form of shaft power. A large mass of air must be supplied to the turbine in order to produce the necessary power. This mass of air is supplied by the compressor, which draws the air into the engine and squeezes it to provide high-pressure air to the turbine. The compressor does this by converting mechanical energy from the turbine to gaseous energy in the form of pressureand temperature.

If the compressor and the turbine were 100% efficient, the compressor would supply all the air needed by the turbine. At the same time, the turbine would supply the necessary power to drive the compressor. In this case, a perpetual motion machine would exist. However, frictional losses and mechanical system inefficiencies do not allow a perpetual motion machine to operate. Additional energy must be added to the air to accommodate for these losses. Power output is also desired from the engine (beyond simply driving the compressor); thus, even more energy must be added to the air to produce this excess power. Energy addition to the system is accomplished in the combustor. Chemical energy from fuel as it is burned is converted to gaseous energy in the form of high temperatures and high velocity as the air passes through the combustor. The gaseous energy is converted back to mechanical energy in the turbine, providing power to drive the compressor and the output shaft.

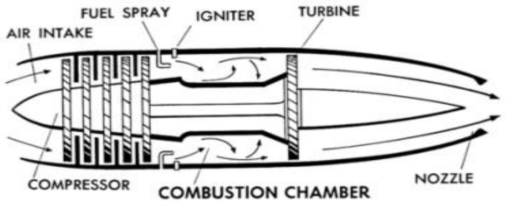
1.2 Micro-combustion

Micro-combustion is the sequence of exothermic chemical reaction between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species at micro level. The release of heat can result in the production of light in the form of either glowing or a flame. Fuels of interest often include organic compounds (especially hydrocarbons) in the gas, liquid or solid phase.

The major problem of micro-combustion is the high surface to volume ratio. There is a growing interest in developing small scale combustors to power these micro-devices due to their inherent advantages of higher energy density, higher heat and mass transfer coefficients and shorter recharge times compared to electrochemical batteries. The energy density of hydrocarbon fuels is 20-50 times greater than Li-ion concept based electrochemical batteries. Micro combustors are an attractive alternative to batteries.

The energy density of hydrocarbon fuels is 20-50 times higher than the most advanced Li-ion concept based electrochemical batteries.Micro-combustors are an attractive alternate to batteries as they have large surface area to volume ratio, due to which, significant amount of heat is transferred through the walls which leads to flame quenching. However, the increased rate of heat transfer through solid walls is advantageous in the case of steam reformers used for hydrogen production.

1.2.1 Micro combustion chamber



Micro combustion chambers are the devices in which combustion happens at a very small volume, due to which surface to volume ratio increases which plays a vital role in stabilizing the Flame stabilized by cyclone.

1.2.2 Micro turbine

In a gas turbine engine, the combustor or combustion chamber is fed high pressure air by the compression system. The combustor then heats this air at constant pressure. After heating, air passes from the combustor through the nozzle guide vanes to the turbine. In the case of a ramjet or scramjet engines, the air is directly fed to the nozzle

1.2.3 Swirler

Swirlers are consisting of various vanes which are designed in such a way that it converts axial momentum of the flow into the tangential momentum which ultimately helps in the air fuel mixing. As swirl vanes rotate its turns flow into rotating motion and forms a low pressure zone such as internal recirculation zone and external recirculation zone which will help in mixing fuel air and stabilizing the flame in combustion chamber.

The primary zone airflow pattern is of prime importance to flame stability. Many different types of air flow patterns are employed. But one feature common to all is the criteria of a toroidal flow reversal that entrains and recirculates a portion of hot combustion products to mix with the incoming air and fuel. These vortices are continually refreshed by air admits through holes pierced in the liner walls, supplemented in most cases by air flowing through swirlers and flare-cooling slots, and by air employed in atomization.

One of the most effective ways of including flow recirculation in the primary zone is to fit a swirler in dome around the fuel injector. Vortex breakdown is a well-known phenomenon in swirling flows; it causes recirculation in the core region when the amount of rotation imparted to the airflow is high. This type of recirculation provides better mixing than is normally obtained by other means, such as bluff bodies, because swirl components produce strong shear regions,high turbulence and rapid mix rates. It is used in many practical combustion devices to control the stability and intensity of combustion.

Type of SwirlGenerator

a. Axial guide vaneswirler

For the study of the axial guide vaneitisimportanttotakesomedatafrom the pre performed experiments. In these experiments PIV method is used to analyzetheflowarea.Fromexperimentsit can be seen that the velocity with average magnitude for the sufficient time period. The reporting cross section lies downstream with respect to the swirl generatorbutfromthesuddenexpansionit is still at upstream. The results of these data suggest no reverseflow.

b. Tangential inletswirler

The tangential inlet swirl is especially used for its feature of low pressure loss and swirl intensity. Experimental studies from a performed experimentdonebytheJiajunChen,Brian S. Haynes and David F. Fletcher. In their experiments the important feature thatwas founded out is achieving axisymmetric flow in the strong swirl no.0.8.

c. Rotating pipeswirler

The rotating pipe swirlers are not used in combustion because it hasn't found wide application on the practice.

LITERATURESURVEY

[1] Ian A. Waitz, GautamGauba and Yang-Sheng Tzeng ("**Combustors for Micro-Gas Turbine Engines**", Received October 14, 1996; Revised September 11, 1997; Online December 04, 2007) described the development of a hydrogen-air microcombustor. Their combustion concept investigation is based upon introducing hydrogen and premixing it with air upstream of the combustor. The wide flammability limits of hydrogen-air mixtures and the use of refractory ceramics enable combustion at lean conditions, obviating the need for both a combustor dilution zone and combustor wall cooling. Their entire combustion process is carried out at temperatures below the limitations set by material properties, resulting in a significant reduction of complexity when compared to larger-scale gas turbine combustors. A feasibility study with initial design analyses is presented, followed by experimental results from silicon carbide and steel microcombustors. They operated combustors for tens of hours, and produced the requisite heat release for a microengine application over a range of fuel-air ratios, inlet temperatures, and pressures up to four atmospheres. Issues of flame stability, heat transfer, ignition and mixing are addressed. A discussion of requirements for catalytic processes for hydrocarbon fuels is alsopresented.

[2] Yongqiang Fu, San-MouJeng and Robert Tacina,("**characteristics of the Swirling Flow Generated by an Axial Swirler"** Reno, Nevada, USA, June 6–9, 2005) described the experimental investigation was conducted to study the aerodynamic characteristics of the confined, non-reacting, swirling flow field. The flow was generatedbyahelicoidalaxial-vanedswirlerwitha short internal convergent-divergent venturi, which was confined within 2-inch square test section. A series of helicoidal axial-vanedswirlers have been designed with tip vane angles of 40°, 45°, 50°, 55°, 60° and 65°. The swirler with the tip vane angle of 60° was combined with several simulated fuel nozzle insertions of varying lengths. A two-component Laser Doppler Velocimetry (LDV) system was employed to measure the three-component mean velocities and Reynolds stresses. Detailed data are provided to enhance understanding swirling flow with different swirl degrees and geometries and to support the development of more accurate physical/numerical models. The data indicated that the degree of swirl had a clear impact on the mean and turbulent flow fields. The swirling flow fields changed significantly with the addition of a variety of simulated fuel nozzle insertionlengths.

[3] H.L. Cao, J.L. Xu,(**"Thermal performance of a micro-combustor for micro-gas turbine system", 5, May 2007)** described Premixed combustion of hydrogen gas and air wasperformed in a stainless steel based micro-annular combustor for a micro-gas turbine system. Micro-scale combustion has proved to be stable in the micro-combustor with a gap of 2 mm. The operating range of the micro-combustor was measured, and the maximum excess air ratio is up to 4.5. The distribution of the outer wall temperature and the temperature of exhaust gas of the micro-combustor with excess air ratio were obtained, and the wall temperature of the micro-combustor reaches its maximum value at the excess air ratio of 0.9 instead of 1 (stoichiometric ratio). The heat loss of the micro-combustor to the environment was calculated and even exceeds 70% of the total thermal power computed from the consumed hydrogen mass flow rate. Moreover, radiant heat transfer covers a large fraction of the total heat loss. Measures used to reduce the heat loss were proposed to improve the thermal performance of the micro-combustor. The optimal operating status of the micro-combustor and micro-gas turbine is analyzed and proposed by analysing the relationship of the temperature of the exhaust gas of the micro-combustor with thermal power and excess air ratio. The investigation of the thermal performance of the micro-combustor is helpful to design an improvedmicro-combustor.

[4] M.R. Johnson, D. Littlejohn,W.A.Nazeer, K.O. Smith, (**"A comparison of the flow fields and emissions of high-swirl injectors and low-swirl injectors for lean premixed gas turbines"**,January2005).

[5] Alberto Traverso, Aristide F. Massardo, Riccardo Scarpellini,(**"Externally Fired micro-Gas Turbine: Modelling and experimental performance"**, November 2006) described the work presents the steady-state and transient performance obtained by an Externally Fired micro-Gas Turbine (EFmGT) demonstration plant.The plant was designed by AnsaldoRicerche (ARI) s.r.l. and the Thermochemical Power Group (TPG) of the Università di Genova, using the in-house TPG codes TEMP (Thermo economic Modular Program) and TRANSEO. The plant was based on a recuperated 80 kW micro-gas turbine (Elliott TA-80R), which was integrated with the externally fired cycle at the ARI laboratory. The first goal of the plant construction was the demonstration of the EFmGT control system. The performance obtained in the field can be improved in the near future using high-temperature heat exchangers and apt external combustors, which should allow the system to operate at the actual micro-gas turbine inlet temperature (900–950 °C).This paper presents the plant layout and the control system employed for regulating the microturbine power and rotational speed. The experimental results obtained by the pilot plant in early2004areshown:thefeasibilityofsuchaplant configuration has been demonstrated, and the control system has successfully regulated the shaft speed in all the tests performed.Finally, the plant model in TRANSEO, which was formerly used to design the control system, is shown to accurately simulate the plant behaviour both at steady-state and transientconditions.

[6] P.A. Pilavachi,("**Mini and micro-gas turbines for combined heat and power**", December 2002) described The use of mainframe gas turbines for power generation has increased in recent years and is likely to continue to increase. The proportion of power generation using combined heat and power is also growing mainly due to efficiency improvements and environmentalbenefits.

Mini- and micro-turbines offer a number of potential advantages compared to other technologies for small-scale power generation, particularly for distributed power generation, although there are some technical and non-technical barriers to the implementation of the technology. There is an uncertainty about their market potential but they could be used for power generation in the industrial, commercial and residential sectors. The market potential could increase substantially if the cost, efficiency, durability, reliability, and environmental emissions of the existing designs are improved.

[7] Yongqiang Fu, San-MouJeng, ("Confinement Effect On The Swirling Flow Generated by a Helical Axial Swirler"), described the gas turbine combustor's performance, emission, operability, lineranddometemperaturelevelsandgradientsare affected by the level of confinement. An experimental investigation was conducted to study the aerodynamic characteristics of the non-reacting swirling glow field. The flo9w was generated by a helical axial vanedswirler with a short internal convergent divergent venturi, and with the tip vane angle of 60. A series of experiments have been conductedusing Plexiglas square duct of widths 1.0, 1.5, 2.0 and 2.5 inches in addition to the case of free of confinement. A two components laser Doppler velocimetry system was employed to measure the mean velocity components and Reynold stress. Measurements were carried out at twelve axial distances ranging from 3to 180mm downstream of swirler exit and the radial profiles are obtained through 2mm intervals detailed experimental data are provided to improve mechanistic understanding of the swirler generated flow field as impacted by the ratio of the test section cross section to the mixers effective area the benchmark quality dat5a are planned for validation the state of the art numerical modal in addition more advanced LES approach. The data indicates the confinement level has a clear impact on the mean and turbulent flow fields. The size of central recirculation zone increases as the confined ratioincreases.

[8] Yongqiang Fu, San-MouJeng, ("Experimental Investigation of Swirling Air Flow in a Multipoint LDI Combutor", 8-11 july 2007) described the experimental investigation of was conducted to study the aerodynamic characteristics of the non-reacting swirling flow field associated with a multipoint swirl venturi lean direct injection combustor nine fuel injector. Each individual fuel injector has a helical axial vanedswirler with a shortinternalconvergentdivergentfuelinjectorhas a helical axial vanedswirler with a short internal convergent divergent to improve combustion character. All the swirlers have same tip vaneangle of 60 with the calculated swirl number of 1.0. a new design in which the center swirler and the center fuel injector are recessed is conducted to improve the range of the flame stability of multipoint LDI combustor. Two different swirler arrangements were investigated experimentally, which include a co swirling array, where all swirlers acted in the same swirling direction and a counter swirling array, where the swirl direction altrenated for adjacent swirlers. A-3D particle image velocimetry system was employed to investigatetheinstantaneousflowstructureofthe

swirling flow and to measure the mean velocity components and Reynolds stresses. Detailed experimental data are provided to improve understanding of the multipoint swirler generated flow field. The experimental results indicate that arrays with the recessed center swirler will alter flow structure significantly. There is a short strong central recirculation zone in both co swirler and counter swirler recessed arrays. The baselinearrays have the higher turbulent activity near the swirler exit as compared with recessedarrays.

[9] Charles B. Graves, ("Radial inlet swirler with twisted vanes for fuel injector", Oct 19, 1999) described the fuel injector for a combustor of a gas turbine engine of the high shear design type is configured to include two swirlers with passages where the vanes in the inner swirler of the inner swirler in the passage which is closest to the centerline of the fuel nozzle includes a judiciously located twist and together with the proper flow ratiobetweenthetwoswirlpassagesandtheproper swirl angle of the flow stream in each of the passages provide an enhanced fuel injector with improved lean blowout and high altitude relight characteristics while assuring a stable recirculation region in the combustionzone.

[10] Ying Huang, Vigor Yang, ("Effect of swirl on combustion dynamics in a lean-premixed swirl-stabilized combustor", received January 2005,) described the effect of inlet swirl on the flow development and combustion dynamics in a lean-premixed swirl-stabilized combustor has been numerically investigated using a large-eddy-simulation (LES) technique along with a level-set flame let library approach. Results indicate that when the inlet swirl number exceeds a critical value, a vortex-breakdown-induced central toroidal recirculation zone is established in the downstream region. As the swirl number increases further, the recirculation zone moves upstream and merges with the wake recirculation zone behind the center body. Excessive swirl may cause the central recirculatingflowtopenetrateintotheinletannulus and lead to the occurrence of flame flashback. A higher swirl number tends to increase the turbulence intensity, and consequently the flame speed. As a result, the flame surface area is reduced. The net heat release, however, remains almost unchanged because of the enhanced flame speed. Transverse acoustic oscillations often prevail under the effects of strong swirling flows, whereas longitudinal modes dominate the wave motions in cases with weak swirl. The ensuing effectontheflow/flameinteractionsinthechamber issubstantial.

[11] David G.Lilley,("Annular Vane Swirler Performance", March-April 1999) described the flow field immediately downstream of anannular vaneswirler is investigated to aid in computer modelling of flow field and in the developmentand evaluation of turbulence model for swirling combined flow. The swirler studied is annular with a hub-to-chord ratio of 0.68. Measurements of time mean axial radial and swirl velocities are made at the swirler exit plane using a five holepitot probe technique with computer data reduction. The time mean velocity components measured at the swirler exit plane show clearly the effect of centrifugal forces, recirculation zones and blade wakes on the exit plane velocity profiles. Non axisymmetric is present in all swirl cases investigated.Assumptions of flat axial and swirl profiles are found to be progressively less realistic as the swirl vane angle increases, with axial and swirl velocities peaking strongly at the outer edges of the swirler exit and significant nonzero radial velocitiespresent.

[12] R. Thundilkaruppa Raj, V. Ganesan, ("**Study on the effect of various parameters on flow development behind vane swirlers**",September 2008) described the swirler design for combustion applications is different from that for propeller applications. In the former swirl flow is generated by the application of tangential component to the axial flow whereas in the latter swirl is generated bytherotatingpropellers.Thereforeitcomesunder the category of rotating flows. Quite a few studies have been carried out on vane generated swirl flows over the past four decades. Majority of the studies were based on experiments. Over the last one decade, attention has been focused on the numerical predictions. Due to the advent of fast digital computers, nowadays the CFD studies are becoming the part of the design methodologies.This study mainly focuses attention on arriving at best vane angle from aerodynamic aspects for the combustion applications. As there are large number of flow and geometric parameters involved arriving at the best design by experimental methods is rather difficult compared to CFD analyses. The important geometric parameters are vane angle, vane numbers and hub to tip ratio. The flow parameter involves the selection of appropriate turbulence model for the prediction. The uniqueness of this study is in arriving at the best vane angle using appropriate turbulence models for both weak and strong swirl. To this end experimental and numerical studies have been carried out. It is found that no single turbulence model is able to handle both weak and strong swirl. From this study it is concluded that for weak swirl standard k–ε model is sufficient whereas for strong swirl one has to resort to Reynolds stress model. The characteristics of swirl flow are evaluated by means of size of the recirculationzone,masstrappedintherecirculation zone and also the pressure drop. Over the range of vane angle investigated the best vane angle is found to be45°.

[13] P. Palies , D. Durox , T. Schuller& S. Candel, ("Experimental Study on the Effect of Swirler Geometry and Swirl Number on Flame Describing Functions", Received 11 Aug 2010, Accepted 03 Nov 2010) described the response of swirling flames submitted to acoustic velocity disturbances when the rotation of the flow is produced by an axial or a radial swirler. The objective is to compare responses obtained in these two cases. The response is characterized in terms of the flame describing function (FDF), which generalizes the classical flame transfer function concept by considering not only the frequency but also the amplitude of the velocity disturbances. Results indicate that for both types of swirlers, the dynamicsisessentiallysimilarforthegainsandthe phases of the FDF. It is also found that the swirl number value markedly influences the gain response. The characteristic shape of the FDF, with a local minimum and maximum, are found in both cases and these features correspond to mechanisms already described previously: swirl number fluctuations and vortex rollup of the flame. Swirl number fluctuations are induced by the interaction of the incident acoustic disturbances with the swirler. This generates in the two cases a transmitted acoustic wave and a convective vorticity wave. This last wave is characterized by azimuthal velocity perturbations. The mode conversion process giving rise to the latter type of disturbance was already demonstrated in the case of an axial swirler. It is here examined in the radial swirler geometry. It is shown that the mode conversion processes in the two geometries are quite similar and that they produce similar effects on the flame dynamics andresponse.

[14] C. Stone.S. Menon, ("Swirl control of combustion instabilities in a gas turbine combustor",received2002)describedtheimpactof premixes swirl number, *S*, and overall fuel equivalence ratio, *Φ*, on the stability of a model swirl-stabilized, lean-premixed gas turbine combustor has been numerically simulated using large-eddy simulations methodology. Through the use of a premixed flame let model (*G* equation), unsteady vortex flame and acoustic-flame interactions are captured. It is shown that for large values of *S*, that is, those sufficiently highly for vortex breakdown to occur, the fluctuatingpressure amplitudes, p', are attenuated significantly (over 6.6 dB reduction). The reduced p' amplitudes are accompanied by reduced longitudinal flame-front oscillations and reduced coherence in the shed vortices. Similar p' reduction levels are achieved through changes in *Φ*. Compared to the leanest equivalence ratio simulated (Φ=0.52), p' at stoichiometric is reduced by 6.0 dB. The response of the combustion process to explicit swirl modulation is also investigated. Open-loopcontrol through swirl variation is demonstrated for a lean mixture with significant reductions in fluctuating mass flow rate and p' after a convective time delay.

[15] Shanwu Wang, Shih-Yang Hsieh, and Vigor Yang,("**Unsteadyflowevolutioninswirlinjector with radial entry. I. Stationary conditions",** received January 2005) described the vertical flow dynamics in a gas-turbine swirl injector were investigated by means of large eddy simulations. The flow enters the injector through three sets of radial-entry, counter-rotating swirl vanes. The formulation treats the Favre-filtered conservation equations in three dimensions along with a sub grid-scale model, and is solved numerically using a density-based, finite-volume approach with explicit time marching. Several methods, including proper orthogonal decomposition,spectral analysis, and flow visualization, are implemented to explore the flow dynamics in the complex three-dimensional flow fields. Various underlying mechanisms dictating the flow evolution, such as vortex breakdown, the Kelvin–Helmholtz instability, and helical instability as well as their interactions, are studied for different swirl numbers. The flow field exhibits well-organized motion in a low swirl-number case, in which the vortex shedding arising from shear instabilities downstream of the guide vanes drives acoustic oscillations of the mixed first tangential and first radial mode. The flow field, however, becomes much more complicated at high swirl numbers, with each sub-regime dominated by different structures and frequencycontents

METHODOLOGY

This chapter explains the overall methodology carried out during the project execution of Combustor-Swirler simulation. It includes the CAD model preparation, Domain Discretisation, Boundary Conditions and Solution Convergence.

CAD MODEL PREPARATION

Five different configurations of swirlers have been generated using standard CAD tool. The diameter of the Swirler is taken as 115 mm and the outer casing diameter of micro gas turbine is kept as152mm.Totallengthofmicrogasturbineengine is449mm.

The below figure shows the basic model that has been considered as a baseline for the present numerical analysis. It has a 40 straight rectangular passage which is 10mm height and 5mm width.

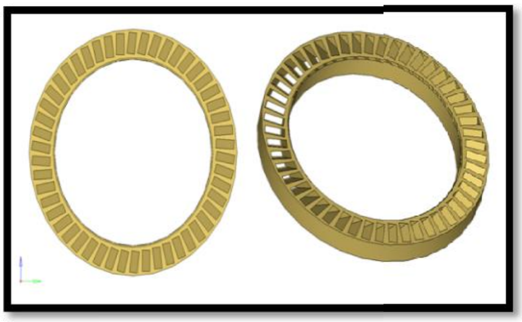


Figure 3.1 CAD Detail of Swirler Baseline Configuration with Straight Passage.

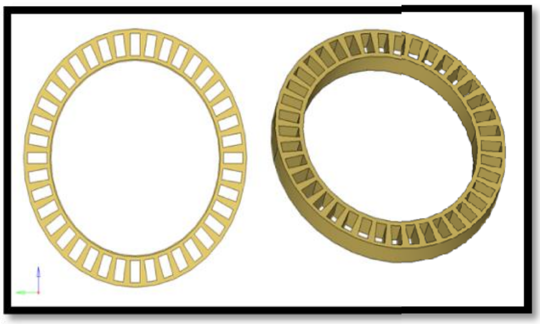


Figure 3.2 CAD Detail of SwirlerConfiguration- with Inclined Passage

The above figure shows the Swirler configuration-A used for present numerical investigation. It has inclined passages to increase the swirling effects and it has 50 inclined passage which has an inclined angle of 45 degree and the passage length is 10mm and height is 5mm.

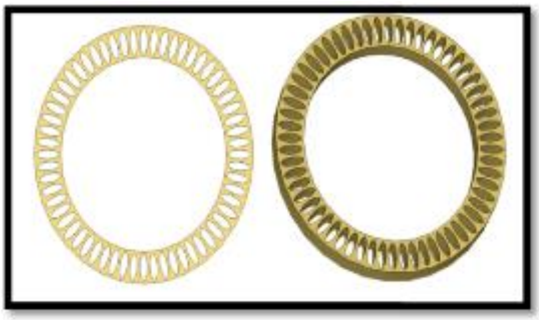


Figure3.3CADDetailofSwirlerConfiguration- B with Elliptical Passage.The above figure shows configurations B of swirler used for the computational investigation and performance comparison of combustor. It has a 60 elliptical passage in which one length is L1- 10mm and L2- 4mm. Configuration B is totally a different swirling passages when compared with the conventionalstraightpassages,ConfigurationB has elliptical flow passages through which the swirling action takes place.

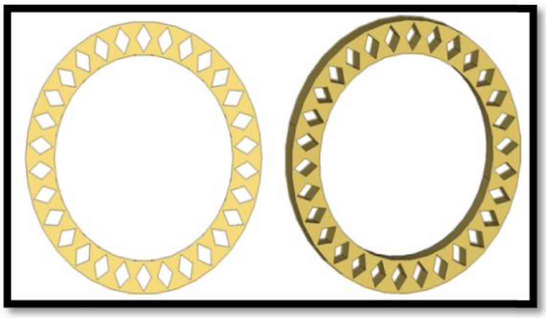


Figure 3.4 CAD Detail of Swirler Configuration- C with Diamond passage.

The above figure shows configurations C of swirler used for the computational investigation and performance comparison of combustor. Configuration C has diamond shaped swirling passages. For all these configurati ns, theswirling area is kept constant. It has lesser axial length while comparing with configuration A and it has38 passage. The height of the diamond passage is 10mm and width is 5mm.

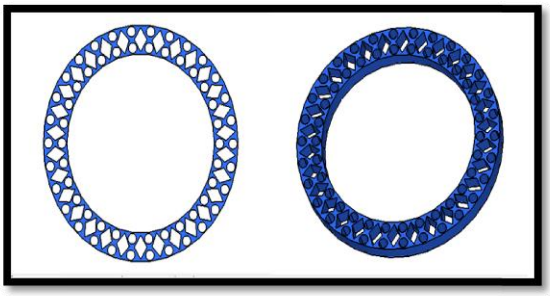


Figure 3.5 CAD Detail of Swirler Configuration-D with Diamond Passage with Circular Holes

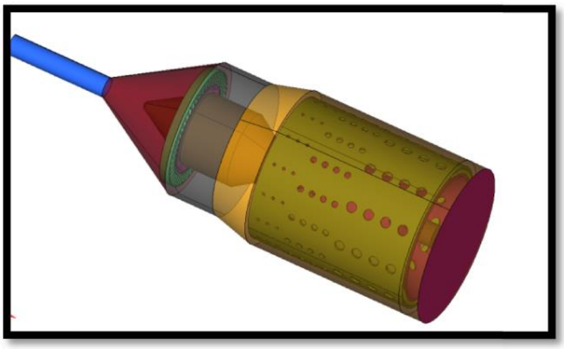


Figure 3.6 CAD Detail of Micro Gas Turbine Combustor

The above figure shows configurations D of swirler used for the computational investigationcombust and performance comparison of . Configuration D has diamond shaped with holes swirling passages, which we can call it as hybrid swirler. For all these configurations, the swirling area is kept constant and it has 38 passages and 72 holes with 3mm diameter.

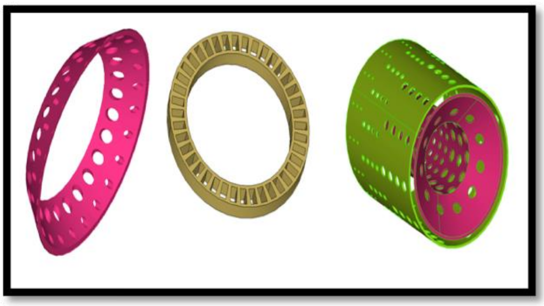


Figure 3.7 CAD Detail of Micro Gas Turbine Combustor Component.

This figure shows the complete CAD model details of micro gas turbine combustor used for investigating the Swirler effects. In this micro gas turbine engine a convergent – divergent conical solid is used to increase the mixing enhancement and combustion performance. There is two annulus one is inner annulus with extraction part attached and another one is outer annulus. Both annulus has various diameter holes for dilution.

Above figure depicts various inner components used to separate the flows through inner and outer annulus along with flow swirler and guider. Guider is used to guide the flow through the various diameter holes. Guider is attached with swirler for better flow swirling inside the engine.

Below figure depicts assemble view of the micro gas turbine and its inner components with convergent-divergentconicalsolid.

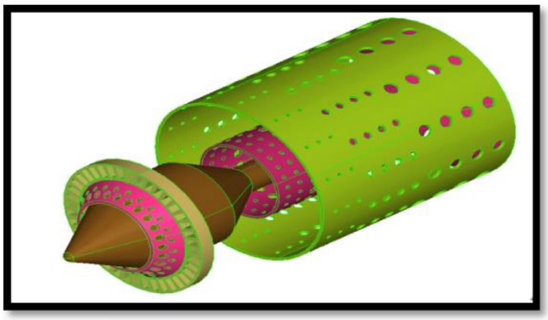


Figure 3.8 CAD Detail – Assembly of Micro Gas Turbine Combustor

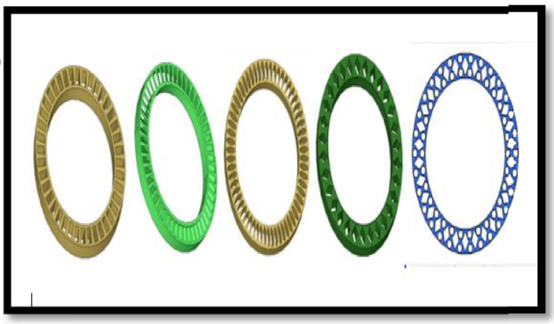
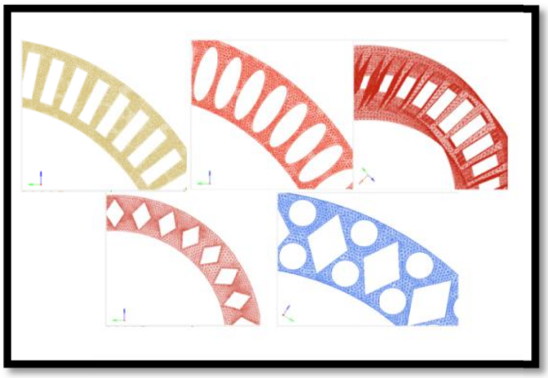


Figure 3.9 CAD Detail – Swirler Configurations Used for Present Simulation.



Above figure shows the comparison view of different types of swirler configurations used for present numerical analysis of micro gas turbine engine.

DISCRETISATION

The modelled flow domain withswirleris discretised with triangular element in HYPERMESH. The swirler profiles are captured with a minimum element size of 1mm and the combustorcasingmeshedwithanelementsizeof 3mm.The inner and outer annular passages are meshed with an average element size of 2mm and the mesh refinement is carried out with a size of 0.5mm near the holes.

Figure 3.10 Zoomed View Of Surface Mesh Of all Swirler Configurations

Above figure is represented su face mesh of all type of configuration in zoomed view forbettre understanding. Mesh sizenear the shapes are 0.3mm and outer ring surface mesh size is 1mm.

Figure 3.11 and 3.12 show the surface mesh details of outer and inner annulus respectively. The mesh refinement around the annulus holes are shown in the figure and the mesh size ear the hole is 0.3mm, 0.5mm,0.7mm.Apartfromtheholesmeshelement size is2mm.

Figure 3.10 Surface Mesh over the outer Annulus

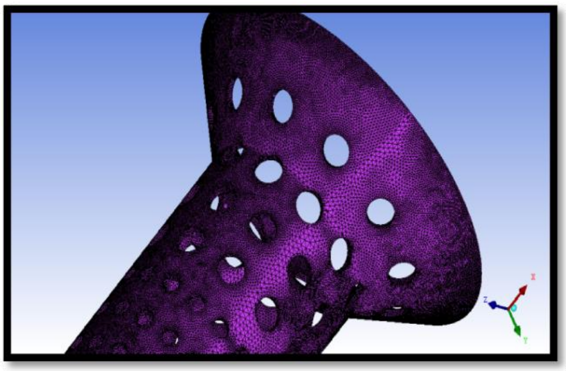


Figure 3.11 Surface Mesh over the inner Annulus

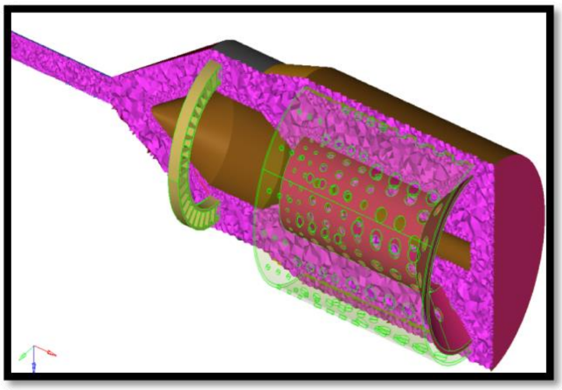


Figure 3.12 Volume mesh around the inner components of the combustor

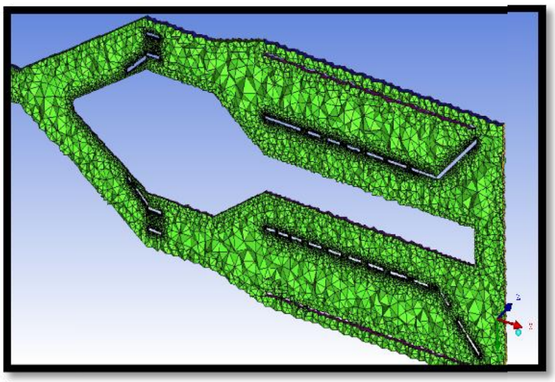


Figure 3.13 Cut Sectional View – Volume Tetrahedral Mesh.

The meshed surfaces are used to create tetrahedral elements around the swirler, inner components and the flow domain. The tetra growth rate is maintained at 1.2 and more refinement has been considered near the blade area. Figure 3.13 and show the cut sectional view of volume mesh domain.

Type of Mesh	Nodes and elements	Config-1 Inclined	Config-2 Elliptical	Config-3 Diamond	Config-4 Hybrid	Baseline Straight
Surface mesh	Nodes	204687	479985	387013	256415	219887
	Elements	411010	625314	775582	546485	441370
Volume mesh	Nodes	504218	1375699	1114823	1244510	1256411
	Elements	2405544	7748646	5503898	7845165	6251231

Table 3.1 Mesh Details

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Sl No	Description	Boundary Condition	Value
1.	**Combustor Inlet**	**elocity Inlet**	**70 m/s**
2.	**Combustor Outlet**	**Pressure Outlet**	**0 Pa**
3.	**Swirler, Casing, Annulus, CD cone, Guider Surfaces, inner and outer annulus**	**Wall**	**Standard wall with no- slip, Rotation al**
5.	**Fluid Zone**	**Air**	**Density = 1.22 kg/m³**
6.	**Turbulence**	**K-Epsilon**	**5% Intensity with Hyd. diameter**
7.	**Solver**	**Pressure Based Coupled Solver**	**---**
9.	**Flow Type**	**Steady and Incompressible**	**---**
10	**Reference Condition**	**Standard Atm. Air**	**P= 1 Atm T = 300 K**

Table 3.2 Boundary Condition

Physics Definition

The boundary conditions to the meshed file areapplied in AnsysFluent. The flowis considered as a steady low and a pressure based coupledsolverisinvokedinordertosimulatethe swirling effects. The inlet is mentioned with ‘Velocity Inlet’ boundary conditions and theoutlet is mentionedwith ‘pressure outlet’ conditions. Swirler and Annulus surfaces are given with ‘Standard Wall’ boundary conditions. Atmospheric air is used to simulate the flow. Table 3.1 shows the physics defined inAnsys-Fluent.

RESULTS AND DISCUSSIONS

Convergence History

Figure 4.1 shows the convergence of all flow equations (Continuity, Momentum and Turbulence) solved for the simulation of micro gas turbine engine unit using ANSYS Fluent solver. All the equations got converged and the convergence criteria are kept as 10^{-3}.

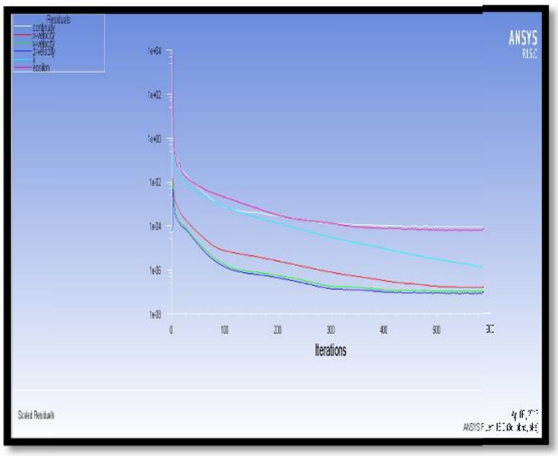


Fig4.1

CFD Results

After the solutionis converged the contours and plots are obtained using Ansys-Fluent post processing. The main objective is to get the maximum swirling effect with high turbulence without anypressure losses. Hence, thestatic pressure and dynamic pressure contoursare comparedalongwithturbulence.The%intensity of turbulence significantly varies according to various shapes of turbulence passages.

On the reslut of simulation in micro gas turbine engine for straight swirler configuration the static and dynamic pressure are shown below. The maximum value of static pressure in the swirler is 47.1pascal and the dynamic pressuer is 3.86pascal. in this numerical simulation straight swirler is a baseline to compare other configurations.

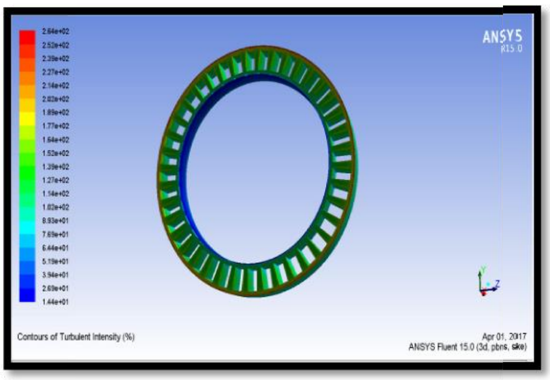


Figure 4.2 Static Pressure Distributions over the Straight Baseline Swirler

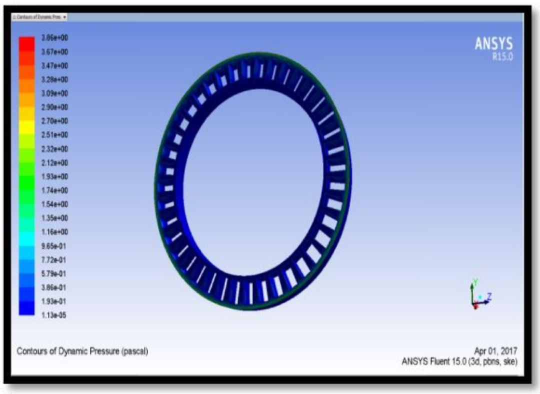


Figure 4.3 Dynamic Pressure Distributions over the Straight Baseline Swirler

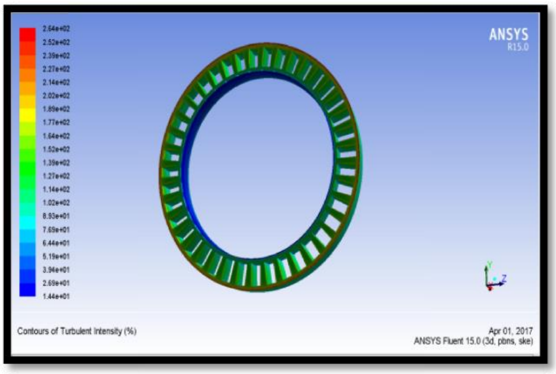


Figure 4.4 Turbulence Intensity over a straight baseline swirler

Above picture shows that we obtained turbulence intensity of straight swirler is 264% in the simulation of micro gas turbine engine with inlet velocity in 70m/s.

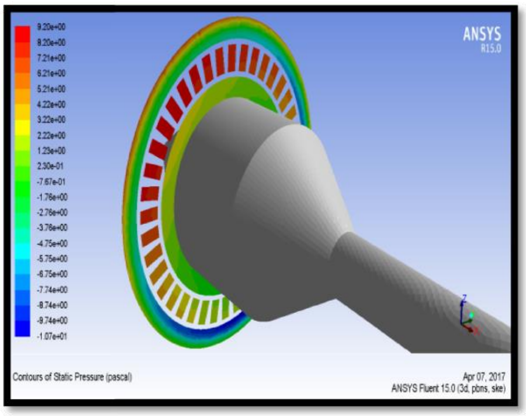


Figure 4.5 Static Pressure in Cross sectional view of Swirler with Conical Solid.

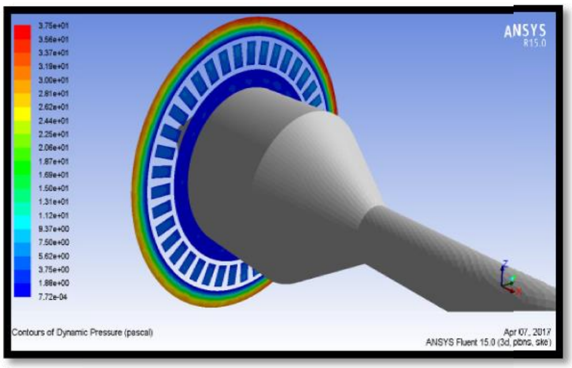
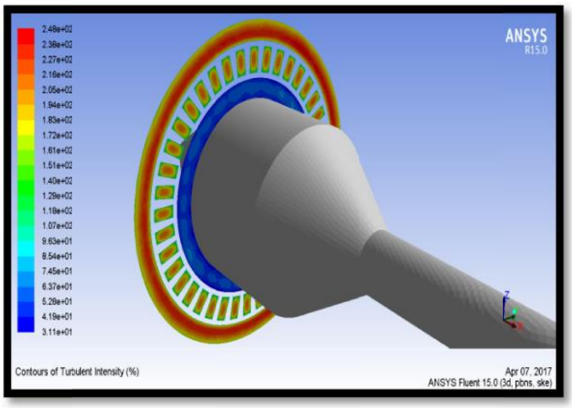


Figure 4.6 Dynamic Pressure in cross sectional View of Swirler with Conical Solid

Above two figures shows that the cross sectional view of straight swirler's static pressure rise and dynamic pressure. The static pressure is 9.20pascal and dynamic pressure is 37.2pascal.

Figure 4.7 Turbulence Intensity in cross sectionalviewofSwirlerwithConicalSolid



Above figure represented the turbulence intensity of straight swirler is 248%. While comparing with entire of swirler turbulence intensity with cross sectional swirler there is bit difference in % of turbulence.

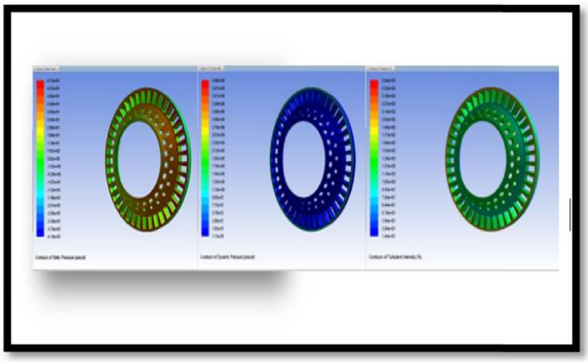


Figure4.8StaticPressureinSwirlerwith Guider

Above figure shows that the contour of static pressure, dynamic pressure and turbulence intensity in swirler with guider. In this case there is no variations in static pressure with or without guider.

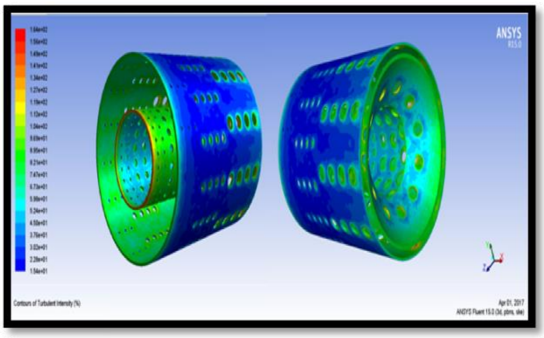


Figure 4.9 static pressure in inner and outer annulus

Above figure shows that the front and back view of inner and outer annulus static pressure difference. The value of static pressure is 14.47pascal and dynamic pressure is 9.70pascal.

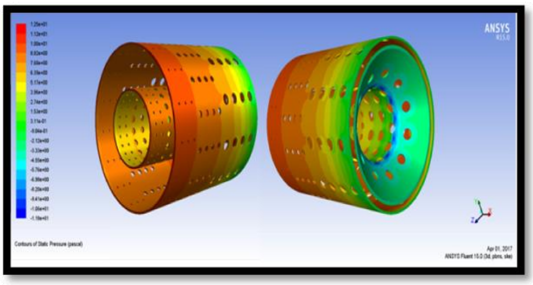


Figure 4.10 Dynamic Pressure in Inner and Outer Annulus

Above figure shows that the front and back view of inner and outer annulus turbulence intensity difference. There is good turbulence between both annulus while comparing with outer surface of annulus. Maximum turbulence intensity is 206.59% in the annulus

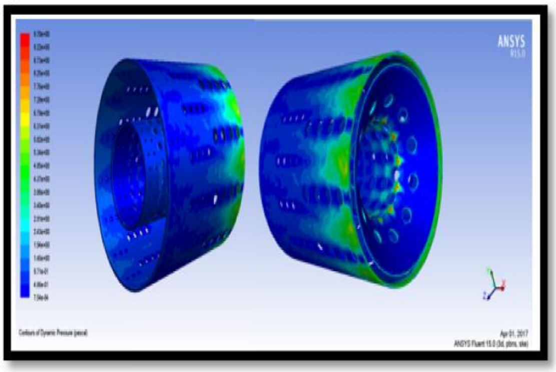


Figure 4.11 Turbulence Intensity in Inner and Outer Annulus

In the end of the simulation all five configuration of swirler value is predicted with contours. In all five configurations straight swirler configuration is kept as base line of this simulation. Now we going to compare all other configurations with the base line configurations.

For proper combustion inside the combustionchambertheremustbelowdynamic pressure andhigh static pressure and air fuel mixtureratiomustbegoodenoughforcombustion.

Inserting a swirler is creates good turbulenceeffectinsidetheturbineandtheswirling flow we can obtain for good combustion and flame stability inside the combustionchamber.

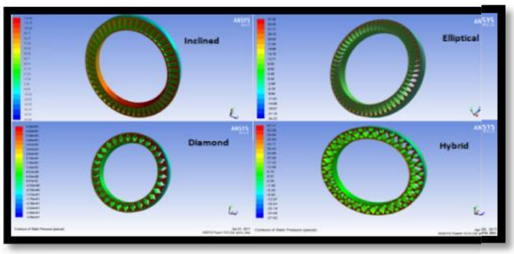


Figure 4.12 Static Pressure in all Four Configurations

Above figure describes that the comparison images of static pressure for four configuration swirler. Static pressure for corresponding four configuration is for inclined is 124pascal,forellipticalis37.33pascal,fordiamond is52.6pascalandforhybridswirleris47.1pascal.

In this values we can predict that inclined swirler is creating high static pressure then other swirlers. This value is greater than base line swirler. So inclined swirler is most efficient for creating high static pressure in the micro gas turbine engine

Below figure 4.13 describes that the comparison images of dynamic pressure for four configurationswirler. Dynamic pressure for corresponding four configuration is for inclined is 80.6pascal, for elliptical is 25.41pascal, for diamond is 32pascal and for hybrid swirler is 28.96pascal.

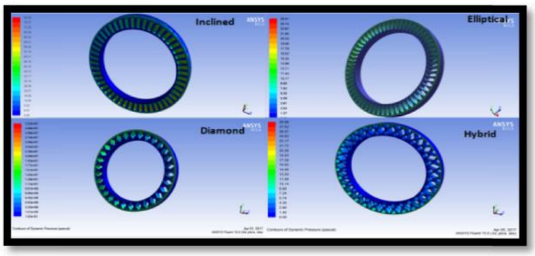


Figure 4.13 Dynamic Pressure in all Four Configurations

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In this values we can justify that inclined swirler creates high dynamic pressure but we need only low dynamic pressure for good combustion process. So otherthan inclined swirler, hybrid swirler and diamond swirler is efficient for both static pressure and dynaic pressure optimization.

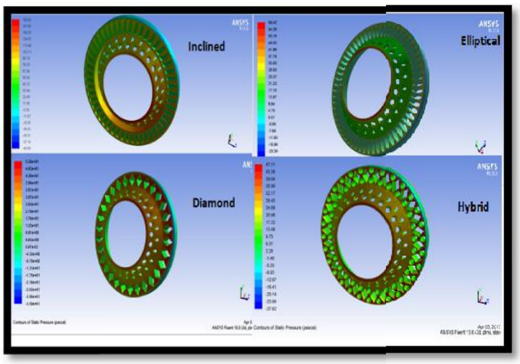


Figure 4.14 Static Pressure in all Four Configurations

Above figure describes that the comparisonimagesofstaticpressureforfour configurationswirler with guider. Static pressure for corresponding four configuration is for inclined is 159pascal, for elliptical is 58.42pascal, for diamond is 52.6pascal and for hybrid swirler is 47.1pascal.

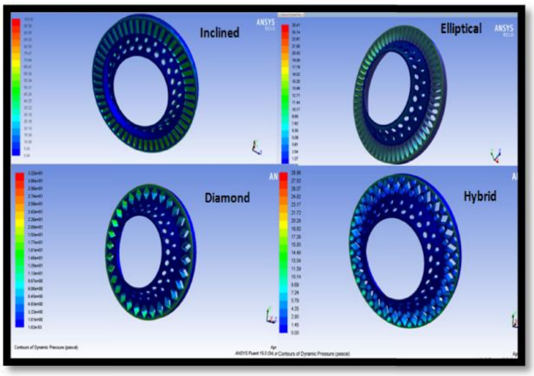


Figure 4.15 Dynamic Pressure in all Four Configuration

In this results we obtained very high static pressure rise in inclined wirler and all other configuration has same static pressure with and without swirler.

Above figure describes that the comparisonimagesofdynamicpressureforfour configurationswirler. Dynamic pressure for corresponding four configuration is for inclined is 100.43pascal, for elliptical is 25.41pascal,for diamond is 32pascal and for hybrid swirler is 28.96pascal.

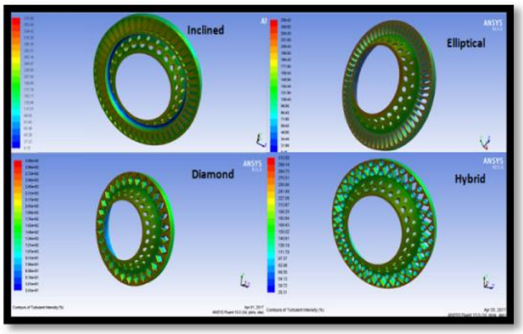


Figure 4.16 Turbulence Intensity in all Four Configurations

In this results we obtained very high dynamic pressure rise in inclined swirler and all other configuration has same static pressure with and without swirler. So finally we predict that hybrid swirler is gives significant results for both static and dynamic pressure. Yet we have to take a look in turbulence intensity of all swirlers.

Above figure helps to finalize the results of this simulation, that the turbulence effect is most important in combustion process for proper combustion and flame stability.

While comparing the results of turbulence intensity of all four configuration with base line configuration we can predict the swirler which gives significant effect in the micro combustion chamber.

Turbulence intensity of corresponding all typeswirler is for inclined 350%, for elliptical 249.19%, for diamond 300%, and for hybrid 313.55%swirler.

On the result of static pressure, dynamic pressure and turbulence intensity we can come up thatwhichswirlerisgivessignificantvaluesforthe micro gas turbine engine. But most importantthing is turbulenceinside the combustor which can stabilize the flame and helps to burn all the fuel with proper mixing.

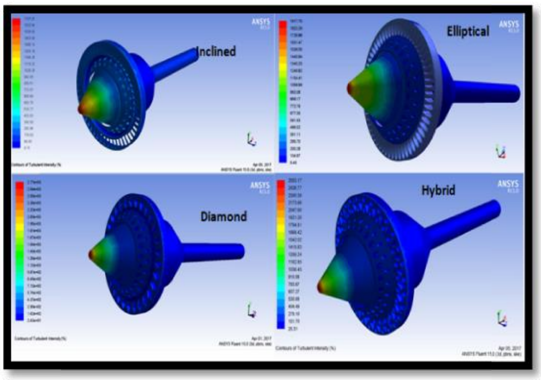


Figure 4.17 Turbulence Intensity in all Four Configurations with C-D conical solid

Above figure describes the turbulence intensity distribution over a swirler, guider and convergent-divergent conical solid. In all configuration maximum turbulence is occurred in conical section.

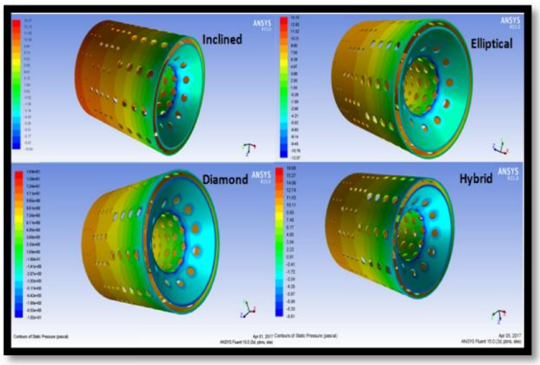


Figure 4.18 Static Pressure of Inner and Outer Annulus of all Four Configurations

Above figure describes the static pressure distribution over a inner and outer annulus. In this configuration static pressure distribution is pretty high in between two annulus.

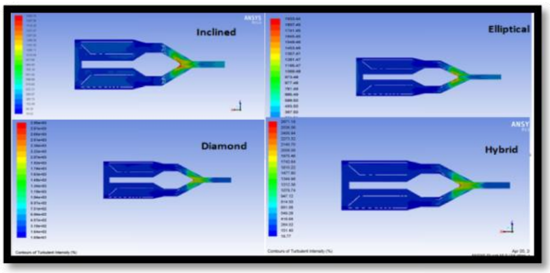
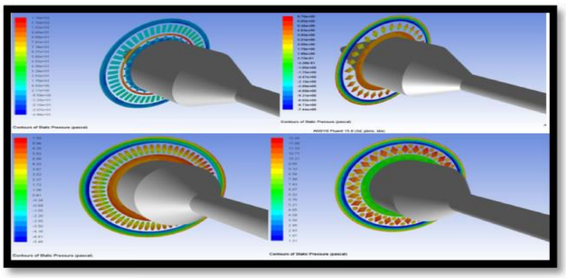


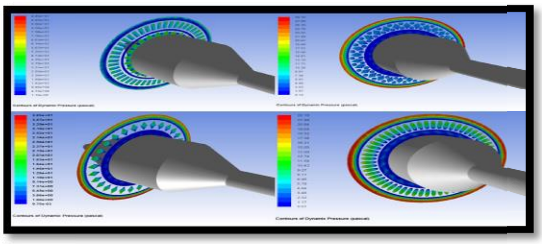
Figure 4.19 Turbulence Intensity Comparison Four Configuration in Plane View

Above figure is describes that the staticpressuredistributioninallfourconfiguration by plane view of entire micro gas turbine engine



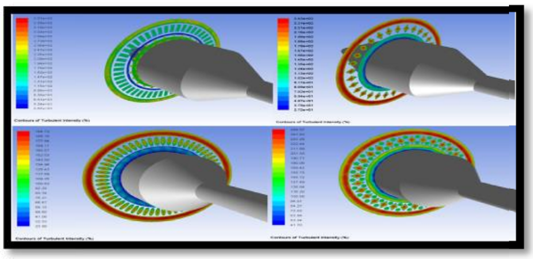
. **Figur4.20 Static Pressure of Cross Sectional Swirler for all Four Configurations**

Above figure show clear view of contour for staticpressurebycreatingacrosssectionalplanein the swirler. For better understanding Convergent-Divergent conical solid has shownhere.



Figur4.21 Dynamic Pressure of Cross Sectional Swirler for all Four Configurations

Above figure show clear view of contour for dynamic pressureby creating a cross sectional plane inthe swirler. For betterunderstanding Convergent-Divergent conical solid has shown here.



Figur4.22 Turbulence Intensity of cross sectional swirler for all four configurations

Above figure show clear view of contour for turbulence intensity by creating a cross sectional plane in the swirl r. Forbetter understanding Convergent-Divergent conical solid has shown here.

In the deep study of simulation for effect of swirler in a micro gas turbine engine, we can predict which swirler can produce more swirling effect for better combustion process.

In analysing of all these cases inclined swirler and hybrid swirler gives us most promising results than other swirlers. So now we going to compare the results of these two swirlers and going to finalize a swirler which gives eterprefomance.

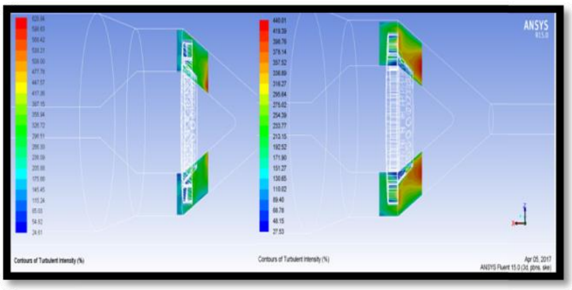


Figure 4.23 Turbulence Intensity comparison of Inclined and Hybrid swirler

Above figure shows the comparison of inclined and hybrid swirler. In this case inclined swirler turbulence intensity (628.89%) is greater than hybrid swirler turbulence intensity (440.39%). So inclined swirler gives significant result.

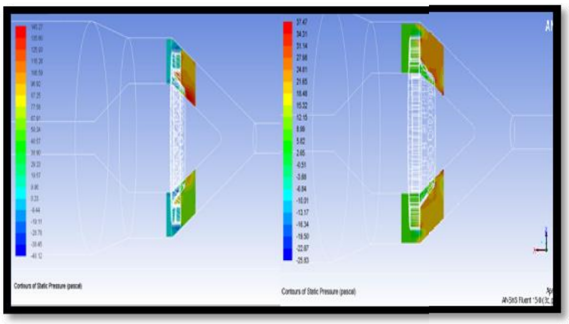


Figure 4.24 Static Pressure Comparison of Inclined and Ybridswirler

Above figure shows the comparison of inclined and hybrid swirler. In this caseinclined swirler static pressure (145.27pascal) is greater than hybrid swirler static pressure (37.47pascal).In this study static pressure is too high for inclined swirler and hybrid swirler is gives significant results.

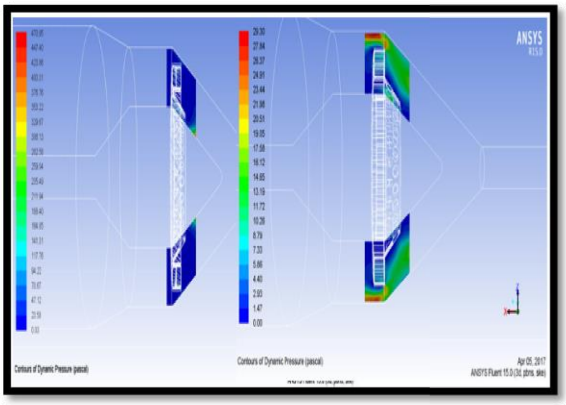
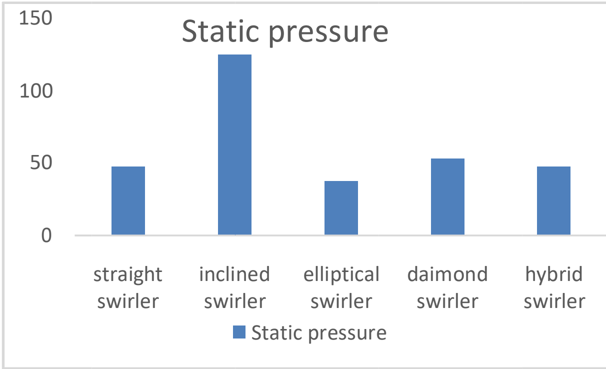


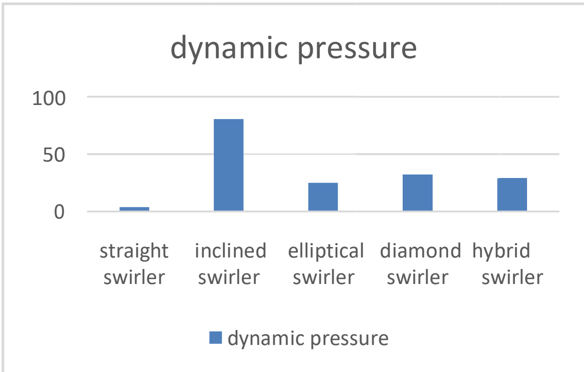
Figure 4.25 Dynamic Pressure Comparison of Inclined and Hybrid Swirler

Above figure shows the comparison of inclined and hybrid swirler. In this case inclined swirler dynamic pressure (470.15pascal) is greater than hybrid swirler dynamic pressure (29.30pascal). In this study dynamic pressure is too high for inclined swirler and hybrid swirler is gives significant results.

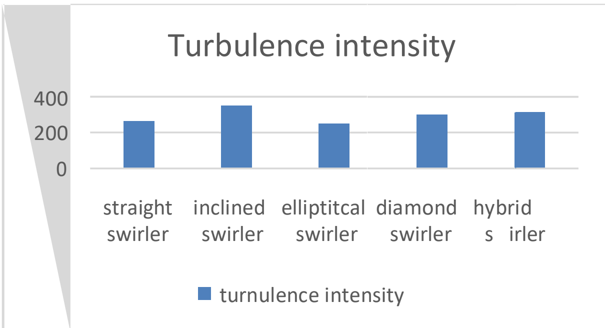
In this study of comparison we can predict that hybrid swirler is giving a promising results then all swirlers. But other swirler's also gave good results but comparing to others this configuration is good enough to create turbulence for proper mixing and good combustion.



Graph 4.1 Shows the Static Pressure Difference Between Various Configurations



Graph 4.2 Shows the Dynamic Pressure Difference Between Various Configurations



Graph 4.3 Shows the Turbulence Intensity Difference Between Various Configurations

CONCLUSION

- Thenumericalsimulationontheeffectof swirler configurations in a micro gas turbine engine has been simulated successfully.
- The numerical results predict the flowand turbulence nature accurately and give significant variations in the results.
- It is observed from the results that the turbulence intensity produced in the diamond with hole configuration is more

effective and significantly increases the swirl flow.

- The static pressure inside the combustion chamber annulus is reasonably maintained without any pressure losses in both diamond and hybrid configurations while comparing with other swirler configurations.
- The hybrid configuration reveals a promising value for dynamic pressure as low dynamic pressure if satisfactory for good combustionprocess

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