Numerical Simulation on the Pattern Factor of the Annular Combustor

[1]Balakrishnan B.M., [2]Mohana Priya G., [3]Revathi M.

[1](Department of Mechanical Engineering, Mahendra Engineering College, Salem)

[2](Department of Mechanical Engineering, Mahendra Engineering College, Salem)

[3](Department of Aeronautical Engineering, V.S.B. Engineering College,Karur)

ABSTRACT

Combustor in a Combustion system plays a vital role in controlling pressure loss distribution, durability, stability and performance. The design of combustion chamber involves complex coupling of aerodynamics, thermodynamics and chemical kinetics of reaction. There are various parameters which decide the successful design of combustion chamber, one of them is the exit profile factor or pattern factor. The life of turbine blade is decided by the exit temperature profile; hence it is vital key to be studied. In this project three different designs will be consider with some modifications implemented based on the result of different cases are simulated upto better exit temperature profile results. Therefore for every point we are trying to optimize the temperature profile at the exit.CFD tool will be extensively being used for studying this purpose. CAD tool (CATIA V5) will be used to modify the combustion chamber, Later geometry will be meshed using GAMBIT and subsequently submitted to CFD solver FLUENT so as to get the flow field result.

Keywords: Annular combustor, pattern factor, GAMBIT, FLUENT, CFD

I.INTRODUCTION

In Industry, Gas turbine has a vital development for the past four years. A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder. 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.

A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process

The objective of the combustor in a gas turbine is to add energy to the system to power the turbines, and produce a high velocity gas to exhaust through the nozzle in aircraft applications.

1.1 TYPES OF COMBUSTOR

- **Can Combustor**
- **Cannular Combustor**
- **Annular Combustor**

1.1.1 Can Combustor

Can combustors are self-contained cylindrical combustion chambers. Each "can" has its own fuel injector, igniter, liner, and casing.

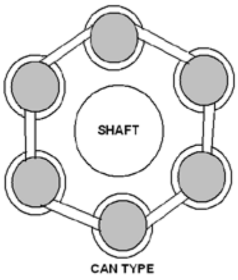

Fig. 1.1. Arrangement of can-type combustors for a gas turbine engine

1.1.2. Cannular Combustor

Like the can type combustor, can annular combustors have discrete combustion zones contained in separate liners with their own fuel injectors. Unlike the can combustor, all the combustion zones share a common ring (annulus) casing

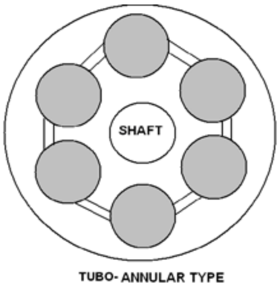

Fig. 1.2 Cannular combustor for a gas turbine engine.

1.1.3 Annular Combustor

Annular combustors do away with the separate combustion zones and simply have a continuous liner and casing in a ring (the annulus). There are many advantages to annular combustors, including more uniform combustion, shorter size and less surface area.

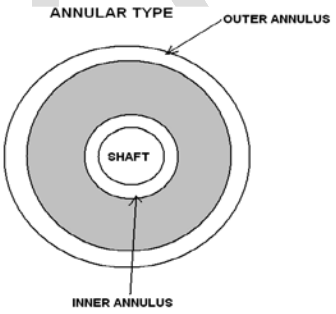

Fig. 1.3 Annular combustor of a gas turbine engine.

1.2 COMBUSTOR PERFORMANCE PARAMETER:

There are few parameters which decide the quality of the combustor performance and are often useful in comparison of combustors.

1.2.1 Pressure Loss:

It's the overall stagnation pressure loss across the combustor; this pressure loss is mostly due to frictional loss and due to overall total temperature rise.

$$\mathbf{P_{total} = P_{cold} + P_{hot}}$$

Its Significance: Any loss in stagnation pressure indicates loss in work output across the turbine. Maintaining low pressure drop is important since a 1% increase in pressure loss can lead to as much as 1% increase in specific fuel consumption depending on engine cycle.

So, it's of paramount importance to have a combustor with minimum pressure loss.

Total Pressure loss (%) =

$$\frac{p_{0\_inlet} - p_{0\_exit}}{p_{0\_inlet}} \times 100$$

1.2.2 Combustion Efficiency :

It's the percentage of available chemical energy in the fuel which is converted to heat energy within combustor with that of theoretical quantity available at that air/fuel ratio.

Heat released in combustion Heat available in fuel

$$\eta_C = \frac{\text{Heat released in combustion}}{\text{Heat available in fuel}}$$

$$\eta_C = \frac{T_P - T_A}{T^* - T_A}$$

Its Significance: It highlights the success of combustor design, its specific fuel consumption ratio of fuel consumption rate to net engine thrust are proportional to combustion efficiency.

1.2.3 Pattern Factor :

It is also called Temperature Traverse Quality.-One of the most important and at the same time, most difficult problems in design and development of gas turbine combustion chambers that of achieving a satisfactory and consistent distribution of temperature at exit gases discharging into turbine.

Pattern factor highlights the overall temperature distribution factor.

Pattern Factor = $$\frac{T_{\text{Max exit}} - T_{\text{Avg.exit}}}{T_{\text{Avg.exit}} - T_{INLET}}$$

It's Significance**:** It affect the power output of the engine and the life and durability of the turbine blade downstream of combustor.

1.2.4 Radial Pattern Factor or Profile Factor:

It indicates the radial temperature distribution profile.

It is obtained by adding together the temperature measurement around each radius of the liner and then dividing by the number of locations at each radius, i.e by calculating arithmetic mean at each radius.

Radial Pattern Factor (at Dist. R) =

$$\frac{T_{0\,\text{Avg.@ radial distance R}} - T_{0\_\text{Avg.exit}}}{T_{0\_\text{Avg.exit}} - T_{0\_INLET}}$$

Its Significance: It directly indicates the quality of temperature profile at the combustor exit.

The desired average radial distribution of temperature profile is that which peaks above the mid-height of the blade.

The objective is to provide lower temperature at the turbine blade root, where mechanical stresses are highest, and at the tip of blade which is most difficult to cool.

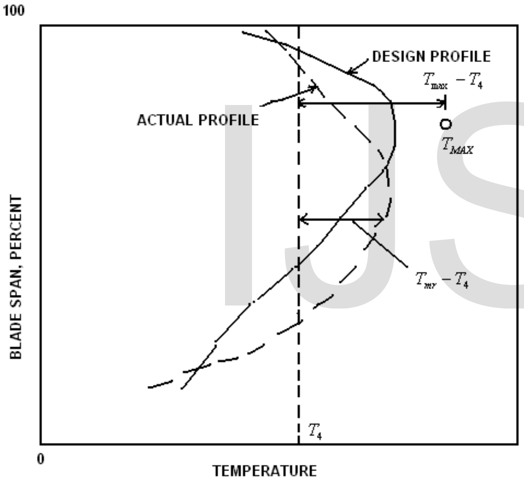

Fig. 1.4 Showing the Temperature Profile at exit of Combustor.

1.2.5 Stability Limit :

Any combustion chamber has its own rich and lean limits of air/fuel ratio beyond which flame is unstable

Its Significance*:* Any instability in flame takes the form of rough running, which may set up aerodynamic vibration which reduces the life of chamber and may cause turbine blade vibration problem.

1.2.6 Combustion Intensity:

It indicates the size of combustion chamber and the rate of heat release. It’s defined by formula below:-

$$\textbf{Combustion Intensity} = \frac{\text{Heat Release Rate}}{\text{Combustion volume} \times \text{Pressure}}$$

1.2.7 About Swirler Aerodynamics:

The importance of re-circulation in primary zone has already been discussed. And one of the most effective ways of inducing flow re-circulation is to fit swirled in the dome around the fuel injector.

Vortex breakdown causes re-circulation 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 combustion and size and shape of flame region.

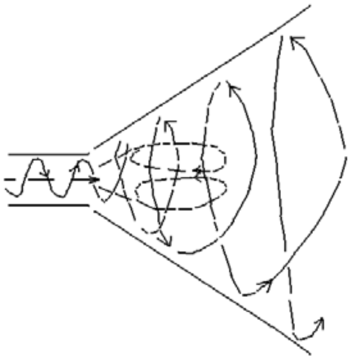

Fig. 1.5 Showing recirculation induced by strong swirl.

1.2.8 About Swirl Cup Design:

Swirl cup is a stabilizing device; it's placed in annulus around fuel injector. The primary use of swirl cup is to increase the angle of spray and decay of axial velocity of jet, just similar to swirler.

It thereby increases the rate of entrainment and rate of mixing of air and fuel jets, providing improved flame stabilization, giving a wide turndown ratio. Swirl Cup acts as fuel-air mixing device.

It is found that fuel injector cone angle and gas jet penetration significantly effects NOx emission.

Swirl cup is used to have better mixing and better jet penetration. Main driver for evolutions in this area is the desire to design a combustor better, faster and cheaper.

One of the key elements to achieve highly efficient combustor is to design a swirl cup capable of delivering fuel/air mixture with a right level of mixing and distribution of spray.

Swirl cup model is expected to have high efficiency at low power, low NOx and smoke emission at high power.

1.2.9 Need of Combustion Chamber

To understand the need of Combustion Chamber lets go back to the very "First Law of Thermodynamics" which states that when a system executes a cyclic process, the algebraic sum of work transfer is proportional to the algebraic sum of Heat Transfer.

$$\oint d\,W \propto \oint d\,Q$$

Heat and Work are different forms of same entity called Energy, which is conserved, energy which enters a system as heat may leave the system as work, or energy which enters the system as work may leave as heat.

So, if you want to get some work out of the system, you need to provide some heat to it, and also (dQ - dW) is independent of the path of the process, it represent a change in properties of the system.

It refers to as Internal Energy. This Heat can be added at different conditions at constant volume or at constant pressure.

The Ideal cycle for the Simple Gas Turbine is the Joule cycle (or Brayton cycle) it works on Constant Pressure heat addition process. It's represented in Simple Block diagram (Fig. 1.1).

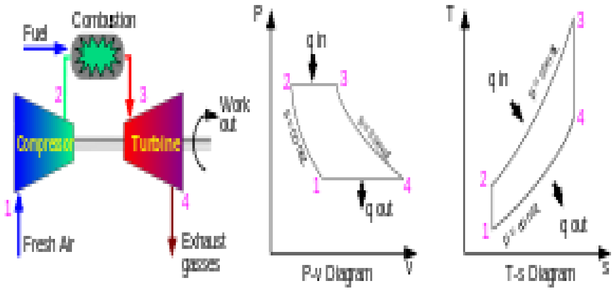

Fig 1.10 Idealized Brayton Cycle

The Constant pressure heat addition process 2-3 is done inside combustor where combustion of given fuel takes place.

2. DESIGN OF COMBUSTOR

In stage-1 design, the simple combustor with one row of primary holes, secondary holes, dilution holes, respectively are only considered as liner cooling holes.

Dome cooling holes are avoided in stage-1 design to study the effect of temperature on dome section.

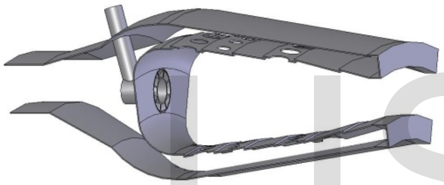

Fig 2.1 Designed Stage-1 Annular Combustor

In stage-2 design, two rows of dome cooling holes of totally 30 holes(each row 15 holes) are considered along with primary, secondary. dilution holes.

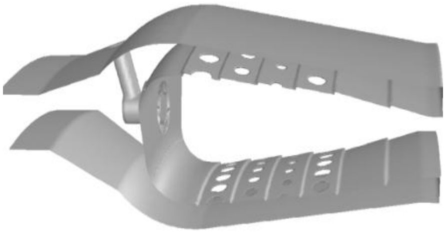

Fig 2.2 Designed Stage-2 Annular Combustor

In stage-3 design, the liner cooling holes are same as stage-2 design but there is slight change in design geometry

i.e, lower liner at exit is elevated upward and the upper liner at exit is straightened.

Fig 2.3 Designed Stage-3 Annular Combustor

3. RESULTS AND DISCUSSION

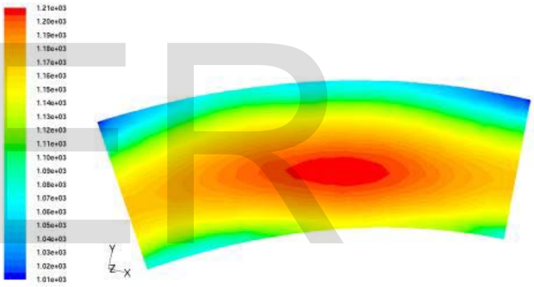

Fig 3.1 Temperature Contour For stage 1

RPF = 0.7

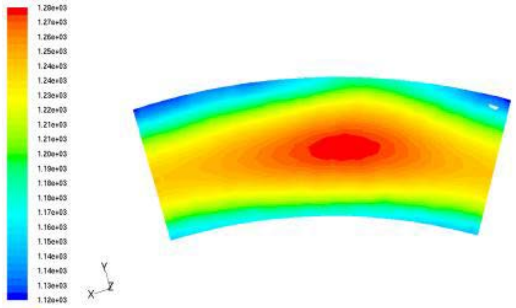

Fig 3.2 Temperature Contour For stage 2

RPF = 0.5

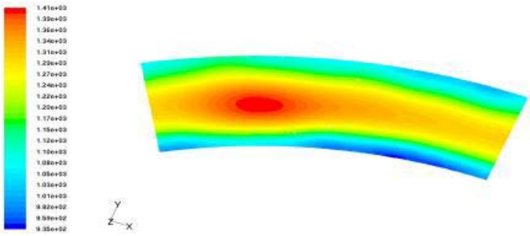

Fig 3.3 Temperature Contour For stage 3

RPF = 0.12

The temperature contour for stage 1 and stage 2 is not good but the RPF for the stage 2 is better than the stage 1. In stage 3, the temperature profile experience only less thermal stress at the turbine blade section.

4. CONCLUSION

From this report, I conclude that the thermal stress is very less at the stage 3 by comparing the three different stages of temperature profile factor. Importance of considering mass flow rate through liner holes was highlighted. The Present understanding of combustion in gas turbine combustor is very much dependent on understanding of Fluid mechanics(Turbulence), chemistry (chemical kinetics and NO_X formation) Droplet evaporation, thermodynamics So, we should never forget the fundamentals of all these and a chapter was dedicated for that purpose.

5. REFERENCE

[1] D. B. Kulshreshtha, Dr. S. A. Channiwala, and Saurabh Dikshit, *Numerical Simulation of Tubular Type Combustion Chamber, Proceedings of ASME International Mechanical Engineering Congress and Exposition,* Florida, 2006.

[2] D.S.Crocker, D.Nicklaus, C.E.Smith. (1999) '*Journal of Engineering for Gas Turbines and Power*', 121 *:89*

[3] Dr. C. Badarinath. '*Development of aero gas turbine annular combustor : an Overview*'-Combustion group, GTRE, Bangalore-93

[4] W. Shyy, M. E. Braaten and D. L. Burrus, *Study of three-dimensional gas turbine combustor flows, , Int. J. Heat Mass Transfer, vol. 32(6),* pp. 1155 – 1164, 1989

[5] Philippe Dagaut & Michel Cathonnet, *The Ignition, Oxidation and Combustion of Kerosene: A Review of Experimental and Kinetic Modeling*, Progress in Energy and Combustion Science, Vol. 32, pp. 48–92, 2006.

[6] F.Z. Sierra, J. Kubiak, G. Gonza´lez & G. Urquiza, *Predictions of Temperature Front in a Gas Turbine Combustion Chamber*, Journ. Applied Thermal Engineering, Vol. 25, pp. 1127–1140, 2005.

[7] W. Shyy, M. E. Braaten & D. L. Burrus, *Study of Three-Dimensional Gas-Turbine Combustor Flows*, Int. J. Heat and Mass Transfer. Vol. 32, No. 6, pp. 1155-1164, 1989.

[8] Lefebvre A. H., *Gas Turbine Combustion*, Taylor and Francis, 2nd ed., 1999 ISBN 1 –
56032 – 673 – 5.

[9] Saravanamutto H, Cohen H, and Rogers G, *Gas turbine theory*, 6th ed., ISBN 978 – 0 – 13 – 22437 – 6, 2008

[10] B.E.Launder and D.B.Spalding (1974) ‘*The numerical computation of Turbulent flows’*, *Computer Methods in Applied Mechanics and Engineering*, 3,269-289