Design and Numerical Analysis of Tubo-Annular Combustor

SK. Nayeem[1] | G.V.V. Satyanarayana[2] | U. Jaya Sai Rahul[3] | R, Srinivas[4] | M. Venkata Teja[5]

[1,2,3,4,5]Department of Mechanical Engineering, Godavari Institute of Engineering and Technology (A), Rajahmundry.

Abstract: The combustion chamber in gas turbines and jet engines including ramjets and scramjets is called the combustor. The combustor is fed with fuel and high-pressure air by the compression system thereby combustor burns the mixand feeds the hot, high pressure exhaust into the turbine. The tubo-annular combustors are completely surroundedby the airflow that enters the liners through various holes and louvers. Due to the reduction of fuel consumptionand new global emission limits, improvements to lean combustion technologies in aero engine combustors areunavoidable Near to the lean limits, combustion tends to be unstable resulting instabilities, which pose a major threat to modern gas turbines. control, has proven useful for the mitigation of such instabilities. Usually, passive methods are used instead ofactive controls, as they feature high reliability at low costs. In this thesis, design and acoustic analysis using CFD is performed for a tubo-annular combustor of gas turbine to compare the noise level with and without acoustic damper.

Keywords – CFD, Gas Turbine, Combustor.

DOI of the Article: https://doi.org/10.46501/GIETME17

Available online at: http://ijmtst.com/vol7si05.html

As per UGC guidelines an electronic bar code is provided to seure your paper

To Cite this Article: SK. Nayeem; G.V.V. Satyanarayana; U. Jaya Sai Rahul; R, Srinivas and M. Venkata Teja. Design and Numerical Analysis of Tubo-Annular Combustor. *International Journal for Modern Trends in Science and Technology* 2021, *7*, pp. 103-108. https://doi.org/10.46501/GIETME17

Article Info. Received: 12 June 2021; Accepted: 16 July 2021; Published: 20 July 2021

INTRODUCTION:

Combustion chamber:

A combustion chamber is an enclosed space inside of a combustion engine in which a fuel and air mixture is burned. Burning fuel releases a gas that increases in temperature and volume. When you heat a gas, the atoms in the gas start bouncing off each other with more energy and vigor. The hard bouncing causes them to get thrown out farther and the whole gaseous cloud expands. Some engines don't allow the gas to expand when heated by confining the gas within a set volume. Since the gas can't expand, the pressure increases. Other engines are designed to use the increase of pressure to drive exhaust gases out at high speed. Engines are designed differently to increase either the volume, pressure, or velocity of the gaseous mixture to generate work.

A Combustion Chamber is the area within the Cylinder where the fuel/air mix is ignited. As the Piston compresses the fuel/air mix and makes contact with the Spark Plug, the mixture is combusted and pushed out of the Combustion Chamber in the form of energy. The Cylinder houses many of the important components of an Internal Combustion Engine including the Injector Nozzle, Piston, Spark Plug, Combustion.

DIFFERENT TYPES OF COMBUSTION CHAMBERS;

A few representative types of combustion chambers of which there are many more here are many more Variations Variationsare enumerated and discussed bel are enumerated and discussed bel are enumerated and discussed below: 1. T-head combustion chamber. head combustion chamber. head combustion chamber. 2. L-head combustion chamber. head combustion chamber. head combustion chamber. 3. I-head (or overhead valve) combustion chamber. head (or overhead valve) combustion chamber. head (or overhead valve) combustion chamber. 4. F-head combustion chamber. head combustion chamber. head combustion chamber. It may be noted that these chambers are designed to obtain the objectives namely: ain the objectives namely: A high combustion rate at the start.A high combustion rate at the start. e start. A high surface- A high surface-to-volume ratio near the end of burning. volume ratio near the end of burning. volume ratio near the end of burning. A rather centrally located spark plug., and others.

TUBO-ANNULAR COMBUSTOR

The tubular combustor, also known as the 'can' combustor, consists of a flame tube enclosed within a cylindrical liner positioned concentrically, as shown in Fig. 1.1. The inter-connector or crossover tubes are required to ensure light-up of all the cans during start-up by the flame spreading via the interconnector tubes. The cylindrical liner ensures that each flame tube has its own combustion air supply. These combustors were heavy and incurred a high-pressure loss, eventually giving rise to the tuboannular combustor. Tubular combustors were used in the very early gas turbines such as the Whittle W2B and the Jumo 004.

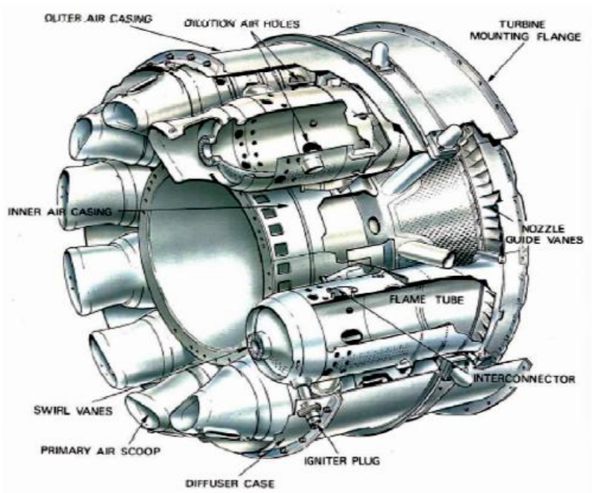


Fig 1.1.*Tubo-annular combustor*

The main difference between the tubular and tuboannular (can-annular) combustor is the common air supply to all the flame tubes. This is achieved by placing the flame tubes within a single cylindrical casing as shown in Fig. 1.2

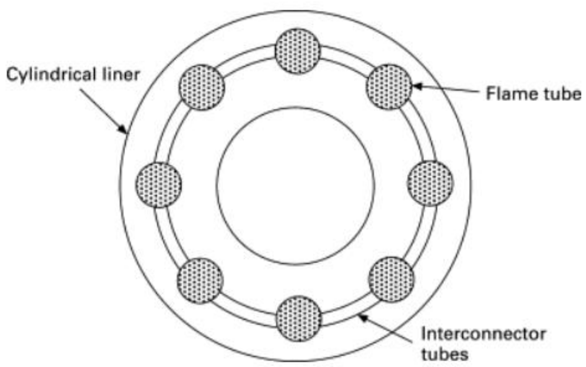


Fig 1.2.*Tubo-annular combustor*

Such an arrangement results in a more compact and lighter combustor. However, it is more difficult to achieve a satisfactory distribution of combustion air between the flame tubes when compared with the tubular combustor. Nonetheless, tuboannular combustors have been used extensively

2. LITERATURE REVIEW:

ValterBellucci et.al – had done "Thermo acoustic Modelling of a Gas Turbine Combustor Equipped with Acoustic Dampers". In this work, the TA3 thermo acoustic network is presented and used to simulate acoustic pulsations occurring in a heavy-duty ALSTOM gas turbine. The combustion system is represented as a network of acoustic elements corresponding to hood, burners, flames and combustor. The multi-burner arrangement is modelled by describing the hood and combustor as Multiple Input Multiple Output (MIMO) acoustic elements. The MIMO transfer function (linking acoustic pressures and acoustic velocities at burner locations) is obtained by a three-dimensional modal analysis performed with a Finite Element Method. In particular, the flame transfer function model is based on the time-lag concept, where the phase shift between heat release and acoustic pressure depends on the time necessary for the mixture fraction (Formed at the injector location) to be convected to the flame. By using a state-space approach, the time domain solution of the acoustic field is obtained. The non-linearity limiting the pulsation amplitude growth is provided by a fuel saturation term. Furthermore, Helmholtz dampers applied to the gas turbine combustor is acoustically modelled and included in the TA3 model.

P. Sravan Kumar et.al - had performed the "Design and Analysis of Gas Turbine Combustion Chamber"

This paper presents the design of combustion chamber followed by three dimensional simulations to investigate the velocity profiles, species concentration and temperature distribution within the chamber and the fuel considered as Methane (CH4).

Authors concluded that:

- The turbulent intensity is high in the immediate vicinity of the ramp injector indicating a superior air-fuel mixing. The high value of mass fraction of NO formed indicates an efficient combustion process.
- The sudden rise in temperature observed near the tip of the injector indicates the generation of shocks which help in superior air-fuel mixing. As predicted, the results obtained from this study show an enhanced air-fuel mixing and a proper combustion which can be attributed to the geometry of the ramp injector considered in this study.

Ana Costa Conrado et.al - had examined "Basic design principles for gas turbine combustor ". This work shows a methodology for gas turbine combustor basic design. The methodology emphasis is on the practical rather than theoretical aspects of combustor design. Criteria for selecting a suitable combustor configuration are examined followed by design calculations for the dimensions of the casing, the liner, the diffuser, and the swirler. Calculations of gas temperature in the various zones of the combustor & liner wall temperatures in presence of film cooling are performed along with design calculations for dimensions of the air admission holes.

Ana Costa Conrado et.al concluded that:

- It is easier to refine an initial configuration by a detailed computational calculation than a complex calculation for all design steps.
- A combustor chamber designed using the computational program was presented to show the capacity to design a practical system.

Georg A. Mensah et.al - had done "Acoustic Damper Placement and Tuning for Annular Combustors: An Adjoint-Based Optimization Study ". This paper discussed the principal challenges of the effective placement and the design of the impedance of acoustic dampers in annular chambers. This includes the choice of an appropriate objective function for the optimization, the combinatorial challenges with different damper arrangements, and the numerical complexities when using the thermo acoustic Helmholtz equation.

As a key aspect, the paper proposes a new adjoint-based approach to tackle these problems. The new algorithm establishes algebraic models that predict the effect of acoustic dampers on the growth rates of the thermo acoustic modes. The theory is exemplified on the basis of a generic annular combustor model with 12 burners.

Georg A. Mensah et.al concluded that:

An adjoint-based method for the optimum positioning and tuning of multiple acoustic dampers has been derived. As a key aspect, the method utilizes the truncation rule. Application to a model problem indicates that this rule is applicable to solutions of the thermo acoustic Helmholtz equation. The method also rests on a multi-parameter formulation of the first-order Eigen value perturbations.

SOLUTION METHODOLOGY

4.1. Combustor Design

- Combustor design and development efforts rely very heavily on previous works.
- Design rules usually involve empirical correlation of data from previous designs.
- CFD simulations are also used in conjunction with the empirical correlations.
- Ongoing efforts are aimed to reduce reliance on empirical correlations and development tests. Computational models will play an increasing role in future combustor designs.
- Design rules actually used in industry tend to vary from manufacturer to manufacturer.
- Based on the literature review,Tubo-Annular combustor model similar to the Turbo-Union RB199 Turbofan engine used in PanaviaTonado aircraft is designed using Solid Works software.

4.2. Combustion Intensity

- The heat released by a combustion chamber or any other heat generating unit is dependent on the volume of the combustion area. Thus, to obtain the required high-power output, a comparatively small and compact gas turbine combustion chamber must release heat at exceptionally high rates.

4.3 Combustion Efficiency

- The combustion efficiency of most gas turbine engines at sea level take-off conditions is 100 percent, which reduces to 98 percent at altitude cruise conditions because of the reducing air pressure, temperature and fuel/air ratio.

4.4 Combustor dimensions of geometric model based on literature review

Combustor length – 560 mm

Combustor dia. – 140 mm

4.5 Modelling of Tubo-Annular Combustor

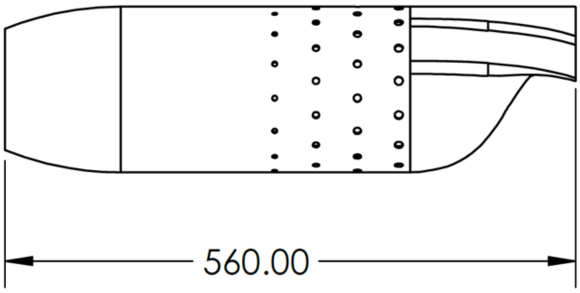
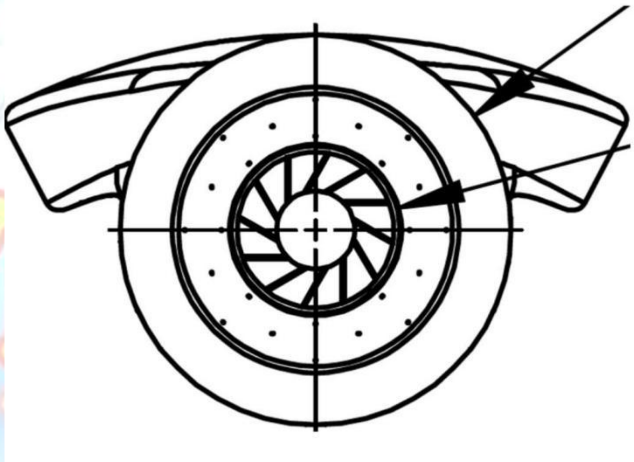


Fig. 4.1 :- Combustor Drawing view-1

Fig 4.2: - *Combustor Drawing view*



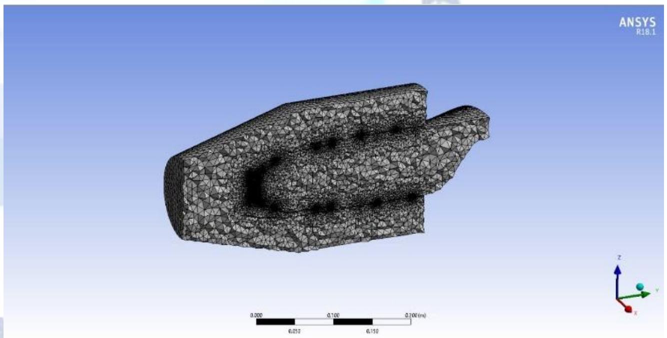


Fig 4.3: - *Combustor mesh 3d element*

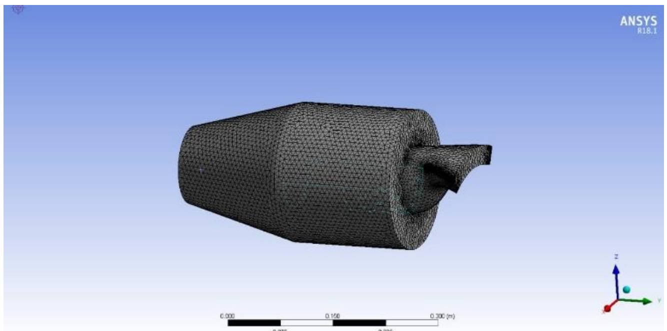


Fig 4.4.: - *Combustor 3d mesh*

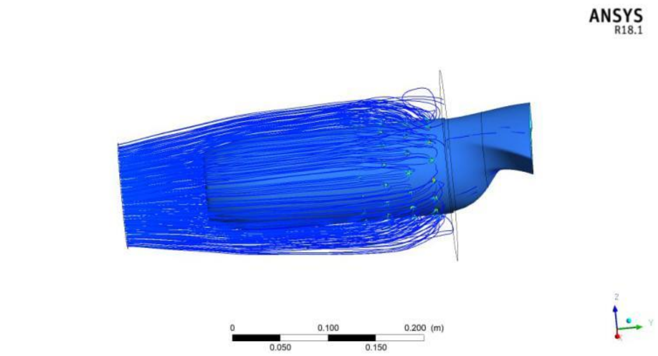


Fig 4.5: - *Combustor with glass wool*

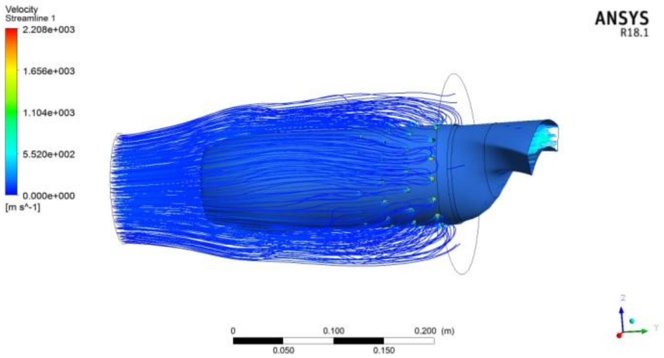


Fig 4.6: -*Combustor with rock wool*

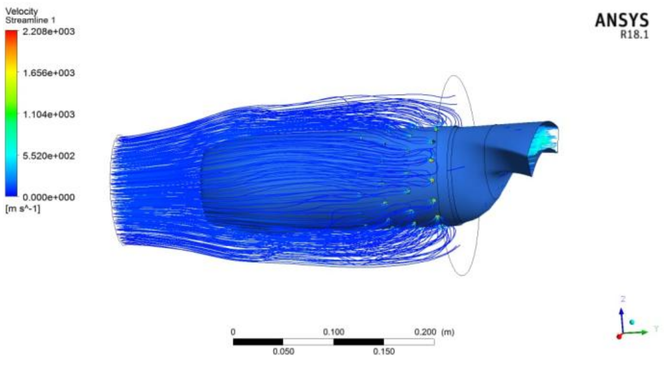


Fig 4.7: *without porous stream line*

Boundary Conditions & Setup

S.No.	Parameter	Value / Opted one
01	Solver	Pressure based steady state
02	Viscous model	Standard k-e, standard wall function
03	Air Inlet velocity	140 m/s
04	Temperature	550 K
05	Fuel inlet velocity	8 m/s
06	Combustor material	Nimonic-75
07	Fuel type	Jet A
08	Meshing elements	Quadrilateral

Table 4.1. - *Boundary Conditions.*

PROBLEM DESCRIPTION:

Combustors running at lean conditions are prone to combustion instability. Due to the reduction of fuel consumption and new global emission limits, especially for the pollutant emissions of NOx, improvements to lean combustion technologies in aero engine combustors are unavoidable. Near to the lean limits, combustion tends to be unstable. It occurs when the unsteady heat release interacts constructively with the acoustic waves in the combustor.

Objectives of the present work:

¬ In the present work, attempt has been made to Design and carryout CFD Acoustic Analysis of Tube-Annular Combustor without damper to know the noise level.

¬ To study the effect of porous insert damper made up of various materials in noise reduction using CFD Acoustic analysis

¬ To design a Tube-Annular combustor with Creo based on literature survey and design calculations. ¬ To carryout Modal Analysis of Tube-Annular Combustor with suitable materials using CFD

RESULTS AND DISCUSSION:

The inlet air velocity has been reduced by diffuser of snout and swirler vanes to accomplish combustion by igniter at primary zone and good circulation is created. After combustion initiation, due to heat release slightly velocity increased in secondary zone and slight drop is observed in dilution zone because of large amount of air isadded to cool down the temperature ofcombustion products to suit turbine blade conditions.

5.1 Velocity profile analysis:

Combustor Arrangement	Parameter	Inlet	Secondary Zone	Dilution Zone	Outlet
Combustor without porous insert damper	Avg. Velocity (m/s)	140	254	236	212.89
Combustor with Rockwool porous insert damper	Avg. Velocity (m/s)	140	256	236	186.225
Combustor with Glass fibre porous insert damper	Avg. Velocity (m/s)	140	256	236	194.8201

Table 5.1: *Velocity profile values*

5.2 Temparature profile analysis:

From the primary zone to outlet, gradual decrease of temperature is observed due to addition of air.

From the below values, it is observed that with use of fibrous porous insert damper of 50 mm thick, around 100dB noise could be reduced to avoid thermo acoustic instabilities and unwanted vibrations in the combustion chamber. Further, it is seen that performance of Glass fibre is slightly better than Rockwool in controlling the noise and thermo acoustic instabilities

Table 5.2. *Temperature profile values*

Combustor Arrange	Parameter	Inlet	Primary Zone	Secondary Zone	Dilution Zone	Outlet
Combustor without porous insert damper	Temperature (K)	550	2440	1750	1270	915.6
Combustor with Rockwool porous insert damper	Temperature (K)	550	2560	1860	1270	894.88
Combustor with Glass fibre porous insert damper	Temperature (K)	550	2500	1820	1270	900.15

CONCLUSION

Comparison about reduction in noise level in tubo-annular combustor is done for without dampers and with the use of fibrous porous insert dampers materials namely Rockwool and Glass fibre damper materials through Acoustic analysis using CFD

It is obvious that reduction in noise is observed with use of porous insert dampers which is around 100db

REFERENCES

1. SK.MD.Azharuddin, Sabin Adhikari, Syed Imtiaz, Manjunath S.V- "Numerical Analysis of Combustor Flame TubeCooling", Journal of Science, Engineering and Technology Research (IJSETR) Volume 5, Issue 7, July 2016.
2. P. Sravan Kumar, P. Punna Rao - "Design and Analysis of Gas Turbine Combustion Chamber", International Journal of Computational Engineering Research, Issue Dec, 2013.
3. Ana Costa Conrado – "BASICDESIGN PRINCIPLES FOR GAS TURBINE COMBUSTOR", InstitutoTecnologico de Aeronautica, Divisao de EngenhariaMecanicaAeronauticaPca. Mal. Eduardo Gomes 50, Sao Jose dos Campos – SP, 12228-900
4. Georg A. Mensah, Jonas P. Moeck- "Acoustic Damper Placement and Tuning for Annular Combustors: An Adjoint-Based Optimization Study",InternationalJournal of Engineering for Gas Turbines and Power– Volume 139 June 2017.
5. ValterBellucciBrunoSchuermansDariuszNowakPeterFlohr- "Thermoacoustic Modeling of a Gas Turbine Combustor Equipped with Acoustic Dampers".
6. K. V. Chaudhari, D. B. Kulshreshtha, S.A. – "Design and CFD Simulation of Annular Combustion Chamber with Kerosene as Fuel for 20 kW Gas Turbine Engine", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 6, November- December 2012, pp.1641-1645
7. Kirill V. Horoshenkov- "A Review of Acoustical Methods for Porous Material Characterisation" Department of Mechanical Engineering, University of Sheffield, S1 3JD, United Kingdom.
8. Priyanka Singh - "IMPACT OF DAMPER PARAMETERS ON THE STABILITY MARGIN OF AN ANNULAR COMBUSTOR TEST RIG", Issue 26, June -2017.
9. Harsha D A – "MODELING OF ACOUSTIC DAMPING OF PERFORATIONS ON THE COMBUSTION INSTABILITY OF ANNULAR AEROENGINE COMBUSTORS", Vol. 4 Issue 06, June-2017.
10. Michael Betz, Moritz Schulze, - "PREDICTING THE INFLUENCE OF DAMPING DEVICES ON THE STABILITY MARGIN OF AN ANNULAR COMBUSTOR", Issue 26, June -2017.
11. TimoKlenke, - "Two-way hybrid LES/CAA approach including acoustic feedback loop for the prediction of thermoacoustic instabilities in technical combustors", Issue 26, June -2017.