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CFD Acoustic Analysis of Combustor With Porous Insert Dampers in A Gas Turbine

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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 mix and feeds the hot, high pressure exhaust into the turbine. The tubo-annular combustors are completely surrounded by the airflow that enters the liners through various holes and louvers.

Due to the reduction of fuel consumption and new global emission limits, improvements to lean combustion technologies in aero engine combustors are unavoidable. Near to the lean limits, combustion tends to be unstable resulting in thermo acoustic instabilities, which pose a major threat to modern gas turbines. The use of acoustic dampers, like porous insert as a passive control, has proven useful for the mitigation of such instabilities. Usually passive methods are used instead of active 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, Acoustic Analysis, Gas Turbine, Combustor.

I. INTRODUCTION

A gas turbine is an internal combustion engine that operates with rotary motion to convert natural gas or other liquid fuels to mechanical energy. There are three main components namely an upstream rotating gas compressor, a downstream turbine on the same shaft and a combustion chamber or area, called a combustor, in between compressor and turbine.

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 to turbine through the nozzle guide vanes and in 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 next mix in more air to complete the combustion process. Combustors play a crucial role in determining many of an engine operating characteristics, viz. fuel efficiency, levels of emissions and transient response.

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. Unsteady heat release and acoustic perturbations leads to thermo acoustic instabilities, which show an undesirable impact on pressure, velocity and heat release in the combustor. Such instabilities occur when the unsteady heat release fluctuations are in phase with the acoustic pressure fluctuations. A major source of acoustic noise in combustion is due to the impact of unsteady heat release.

For the effective and safe design of new aircraft engine combustors operating in the lean regime, the knowledge of the underlying acoustic properties and especially the ability of predicting and suppressing the occurrence of undesirable thermo acoustic instabilities are of fundamental importance.

In gas turbines operating with lean premix flames, the suppression of acoustic pulsations is an important task related to the quality of the combustion process and to the structural integrity of engines. Pressure pulsations may occur when acoustic resonance frequencies are excited by heat release fluctuations independent on the acoustic field. Heat release fluctuations can also be generated by acoustic fluctuations in the premixed stream. On this basis, several authors have proposed the use of acoustic passive dampers, in order to hinder the onset of instability or, at least, to reduce the amplitude of the pressure oscillations. The passive device will produce two main actions, cooperating

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to stabilize the system: dissipating the acoustic energy produced by thermal fluctuations and modifying the phase between acoustic pressure and heat release in order to reduce the production of acoustic energy.

Sk. Md. Azharuddin et.al [1] had done Numerical Analysis of Combustor Flame Tube Cooling to understand the combustion of Jet aviation gas in aircraft's combustor. The authors concluded that the flow velocity was minimum in primary zone due to swirling effect but reverse is the case for temperature profile as temperature is maximum in primary zone and decreases towards the outlet due to cooling effect of cooling slots provided on the combustor walls. P. Sravan Kumar et.al [2] had performed the Design and Analysis of Gas Turbine Combustion Chamber. The authors found 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. Ana Costa Conrado et.al [3] had examined basic design principles for gas turbine combustor". His work shows a methodology for gas turbine combustor basic design. The authors observed 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 [4] 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. K. V. Chaudhari et.al [6] discussed the challenges in designing high performance combustion systems with a more sophisticated analysis process. A technical discussion on combustion technology status and needs will show that the classic impediments that have hampered progress towards near stoichiometric combustion still exist. The authors concluded that simulation with ANSYS can be used for design of combustion chamber for numerical investigations of annular type combustor with k-ω model.

II. METHODOLOGY

Tubo-Annular combustor model is designed using Solid Works software and boundary conditions are applied to analyse the acoustics, temperature profile & velocity profile of the combustor using CFD.

Combustor Design considered the following points.

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 of Turbofan engine is designed using Solid Works software.

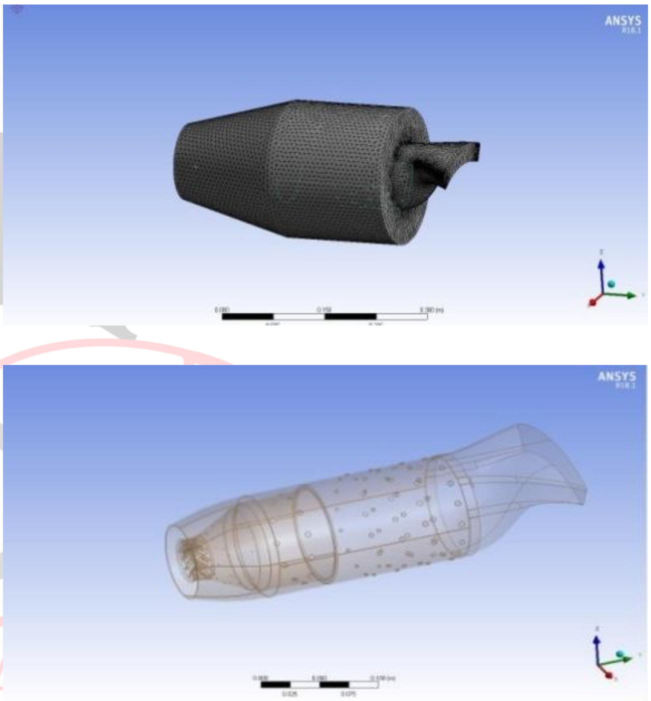

Fig.1. Modeling of Turbo-annular combustor

Boundary conditions and input conditions considered in the analysis are shown in Table 1.

Table 1. Boundary conditions and input conditions

S.No.	Parameter	Value / Opted one
1	Solver	Pressure based steady state
2	Viscous model	Standard k-e, standard wall function
3	Air Inlet velocity	140 m/s
4	Temperature	550 K
5	Fuel inlet velocity	8 m/s
6	Combustor material	Nimonic-75
7	Fuel type	Jet A
8	Meshing elements	Quadrilateral

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III. RESULTS

Turbo-union Engine combustor [1], which is of tubo-annular type, has been modelled using solid works. The tubo-annular combustor dimensions and boundary conditions are considered based on the literature review [1]. Boundary and inlet conditions are given for analysing the velocity, temperature and acoustic power level of the tubo-annular combustor model using CFD, in order to determine the effect of porous insert damper made up of rock wool and glass fibre.

Velocity profile**:**From the results of CFD analysis, the following velocity stream line profiles are obtained. The velocity profiles are explained for without porous damper, Rockwool porous damper and Glass fibre porous damper.

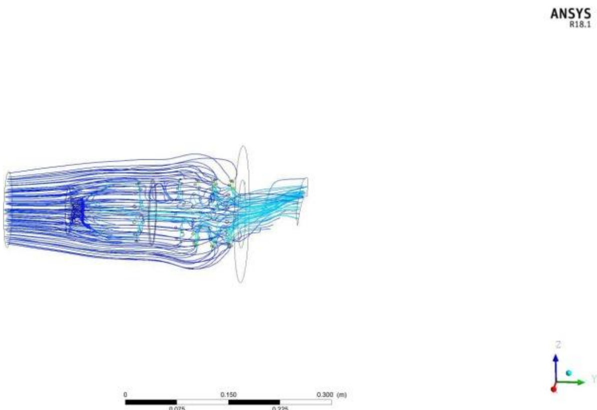

Fig. 2 Velocity stream lines profile without porous damper

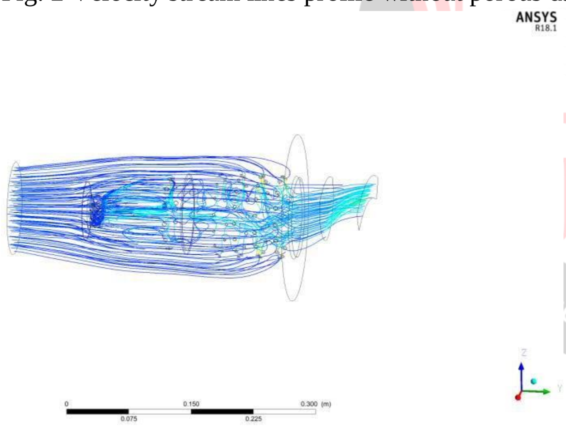

Fig. 3 Velocity stream lines profile with Rockwool porous damper

Table 2. Velocity profile values

Combustor Arrangement	Velocity across combustor (m/s)			
	Inlet	Secondary Zone	Dilution Zone	Outlet
Combustor without porous insert damper	140	254	236	212.89
Combustor with Rockwool porous insert damper	140	256	236	186.225
CombustorwithGlassfibre porous insertdamper	140	256	236	194.8201

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 is added to cool down the temperature of combustion products to suit turbine blade conditions.

Table .3 Temperature profile values

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

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

Acoustic analysis

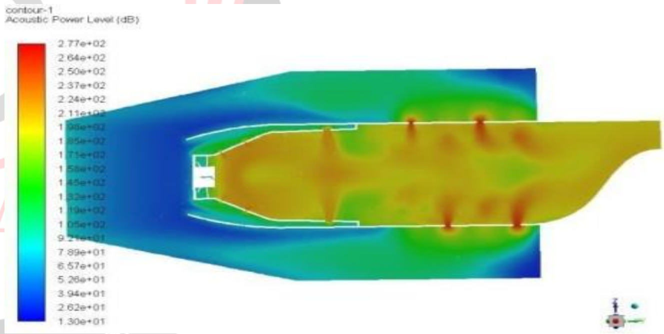

Fig. 4 Acoustic power level distribution of combustor without porous damper

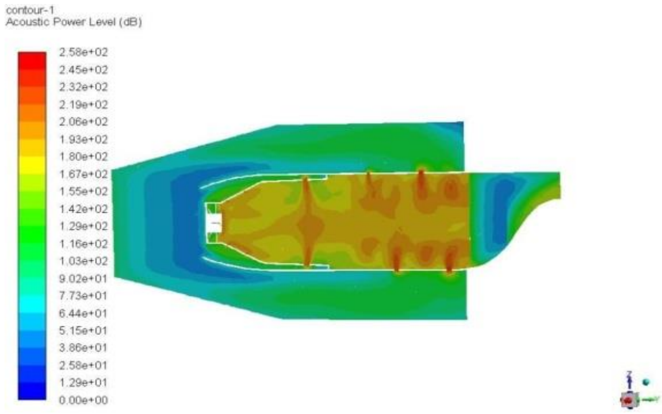

Fig. 5 Acoustic power level distribution of combustor with Rockwool porous damper

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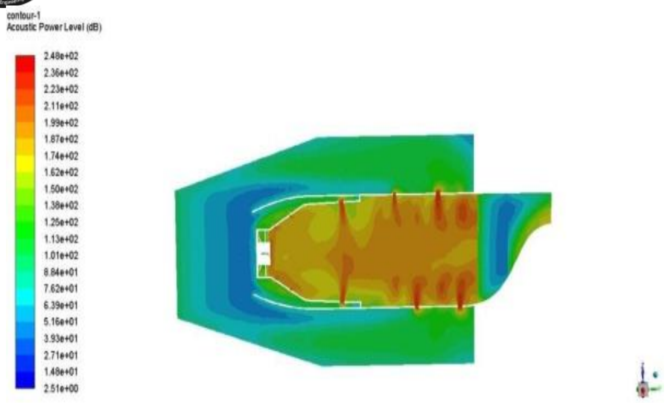

Fig.6 Acoustic power level distribution of combustor with Glass fibre porous damper

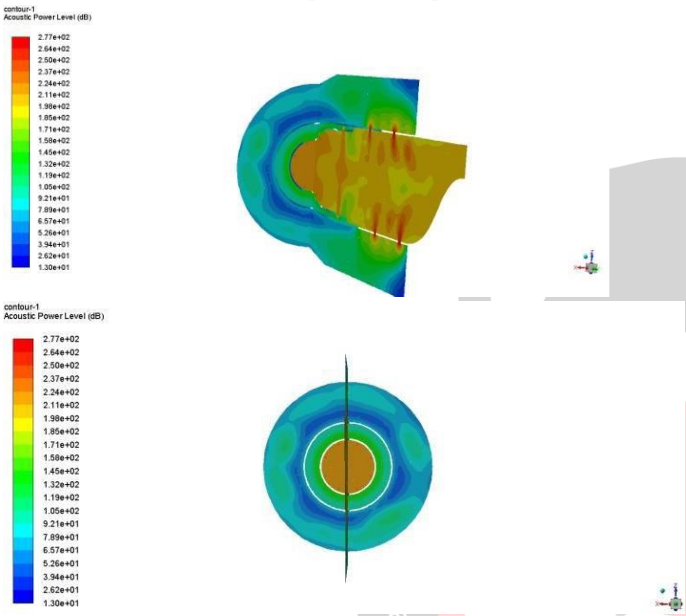

Fig. 7 Acoustic power level of combustor without porous damper at primary zone

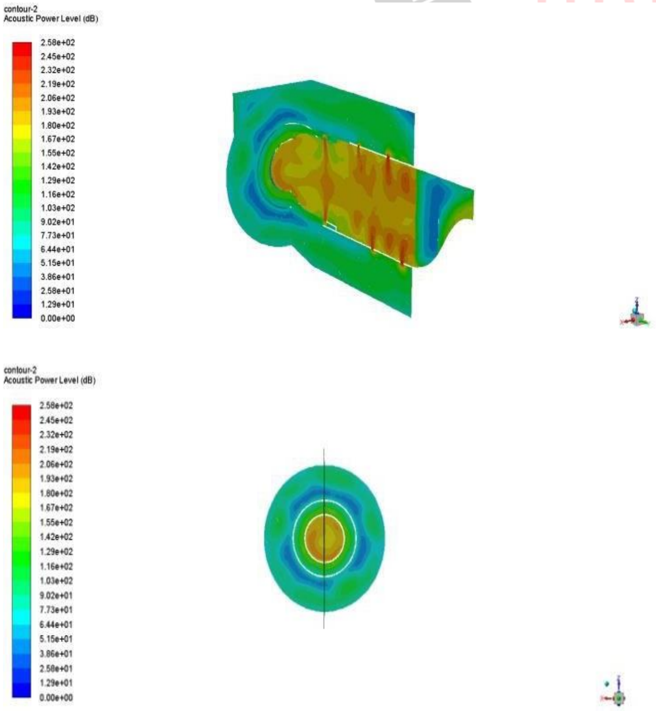

Fig. 8 Acoustic power level of combustor with Rockwool at primary zone

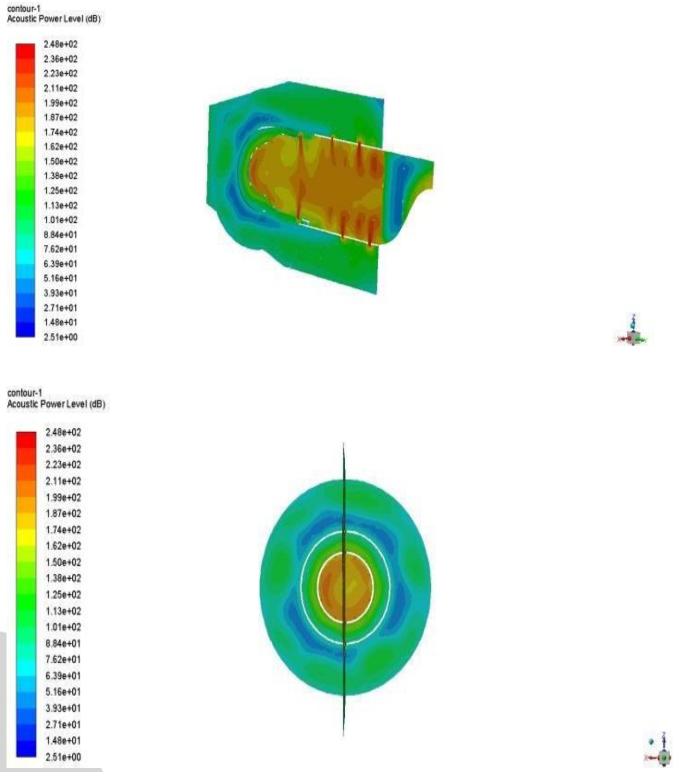

Fig.9 Acoustic power level of combustor with Glass fibre at primary zone

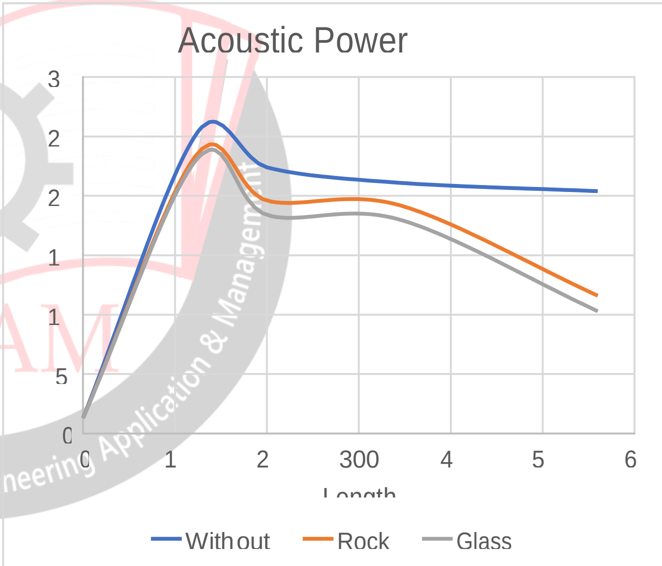

Fig. 10 Acoustic power level comparison across the combustor length

Table 4 Acoustic Power Level – Noise Values

Combustor arrangement	Acoustic power level across combustor(dB)				
	Inlet	Primary zone	Secondary zone	Dilution zone	outlet
Combustor without porous insert damper	13	254	224	211	204
Combustor with Rockwool porous insert damper	13	236	196	192	116
Combustor with Glass fibre porous insert damper	13	232	184	180	103

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From the CFD analysis, it is observed that, with the 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.

IV. CONCLUSIONS

From the CFD analysis of Tubo-Annular combustor, the following conclusions are drawn.

Comparison about reduction in noise level in Tubo-Annular combustor is done for without dampers vis-à-vis 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 generated due to aerodynamically excited vibrations is observed with use of porous insert dampers which is around 100dB.

It is observed that performance of Glass fibre is slightly better than Rockwool in controlling the noise and thermo acoustic instabilities in Tubo-Annualar combustor

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