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Efficient and Environmental Friendly NO_x Emission Reduction Design of Aero Engine Gas Turbine Combustor

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ABSTRACT

Aircraft gas turbine (GT) engine's typical combustor is designed and its combustion process is investigated for efficient performance and NO_x emission characteristics. Flow simulation of combustion process through the combustor is analyzed in computational fluid dynamics (CFD) solution. The expected reaction of air fuel mixing by kerosene and highly compressed air is achieved through the effect of swirler kept in front of air inlet and inclined angle of swirl vanes. The theoretical and CFD solution is compared with the experimental results on the advanced combustor design and is validated for NO_x reduction.

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INTRODUCTION

The reduction of NO_x exhaust in gas turbine combustion chamber can provide an advantage of having a lower environmental impact. In particular, the use of kerosene as fuel is an important research area because no CO, UHC are produced in ideal combustion. However, kerosene combustion produces more NO_x than traditional fuels because of its higher flame temperature. Kerosene has a higher flame propagation velocity and a wider air-fuel ignition range than CH_4, and its employment in premixed combustion can cause problems of flashback and explosions. So, from an industrial point of view, kerosene can be used in non-premixed combustion systems and the methods for reducing pollutant emissions can be borrowed from those used in diffusive gas turbine combustion chambers fired with CH_4, with the advantage that for kerosene, there are no limits due to CO or UHC production. The permissible temperature range to meet both CO and NO_x limits is 1600K to 1730K (Giorgio M.Mcbeath, 1999).

Modifications of gas turbine combustion chamber are investigated Channwala and Digvijay in order to reduce NO_x emissions with kerosene operation (S.A. Channwala and Digvijay Kulshreshtha, 2010). It is interesting to study minor modifications limited to the burner and maintaining changes in maximum ram dial dimension in order to modify the design. It is continued at this present investigation to reduce the NO_x by specific modifications in combustor design. The major description of gas turbine engine performance especially combustor emission reduction is investigated.

The rapid increase of computational fluid dynamics (CFD) Analysis in recent years has a major impact on the design and development process and greatly increasing the understanding of complex flow also reduces the amount of trial and error. In this present investigation; ANSYS is used, it is software that uses to analyze heat and mass transfer, chemical reactions and related phenomena by solving numerical approximation and governing mathematical and chemical reaction equations (Canadian associates,2003).The result of CFD analysis is relevant in conceptual studies of new design, detailed product development, troubleshooting and redesigning .Therefore by using ANSYS CFX 'virtual prototype' of the system or device can be build & analyze. The results of such analysis can be applied to actual physics and chemistry models. At this work, the experimental work result is taken into the account of input boundary condition to predict the NO_x reduction in new designed Combustor M-70.

MATERIAL AND METHOD

The combustor has been modeled and rotational casing effects on combustion characteristics are studied. This alters the air distribution and also the combustion behavior. A shorter but wider recirculation zone and high temperature region were found in the primary zone at the higher speed of rotation. This will benefit the

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performance of gas turbine (Liu and Shih 2009). The feature of combustor performance is shown in fig.1, which actually specialize the NO_x, performance of normal combustor chart shows the importance of air fuel mixture ratio; air gets imported from compressor and fuel injected through a specified volume, gets combusted efficiently under stoichiometric ratio. But the actual emissions are CO, CO_2, NO_x and other chemical components as shown in fig.1.Pollutant formation mechanism for an engine performs a real combustion of kerosene in combustion chamber according to the report by Louis (Louis,2011).

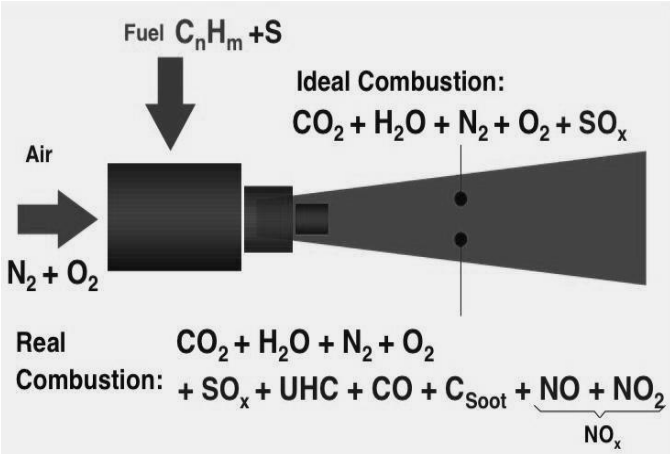

Fig. 1: Description of NO_x problem.

$C_{12}H_{26}+O_2+N_2+S \Rightarrow CO_2+H_2O+N_2+O_2+CO+UHC+C+NO_x+SO_x$ + Heat.

The above reaction shows CO, UHC, NO_x, SO_x are present in combustion emission. It should be reduced to make the combustion; eco-friendly in gas turbines. There is a possibility to achieve reduction in NO_x emission through combustor design changes (Digvijay et al., 2009) and is carried out in this present work.

A.1. Design and Analysis of Combustor Model M-70:

The combustor model development is carried out in CATIA V5 which is feature based parametric solid modeling design software that takes advantage of easy to create 3D solid models. The can type combustor model developed in the software was shown in fig.2. It has six holes in primary zone, eight holes in secondary zone and ten holes in dilution zone. Here, the combustor length is 230mm, the dilution zone has 106.2 mm dia and the holes are 11.8 mm dia, secondary zone has 98.4 mm dia and the holes are 5 mm dia , the primary zone has 90.4 mm dia with the holes having 4 mm dia also inlet swirler has 33 mm dia.

Later this model is imported into ANSYS ICEM CFD software for defining boundary conditions and for meshing purpose. The combustor model is meshed by using volume mesh shape and surface mesh shape. The injection port taken as mass flow inlet and combustor turbine shield is taken as the pressure outlet. The analysis is carried in ANSYS CFX by improving the meshed file saved in ICEM CFD and fig.3 shows the static pressure condition along the combustor during analysis.

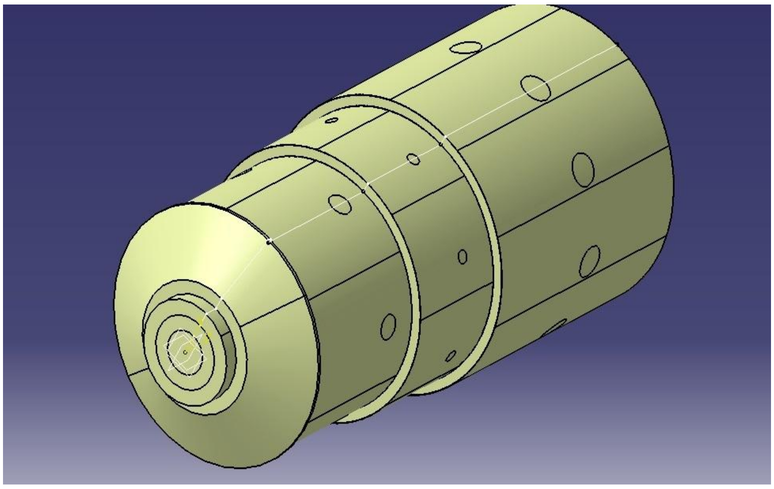

Fig. 2: Design of combustor in CATIA.

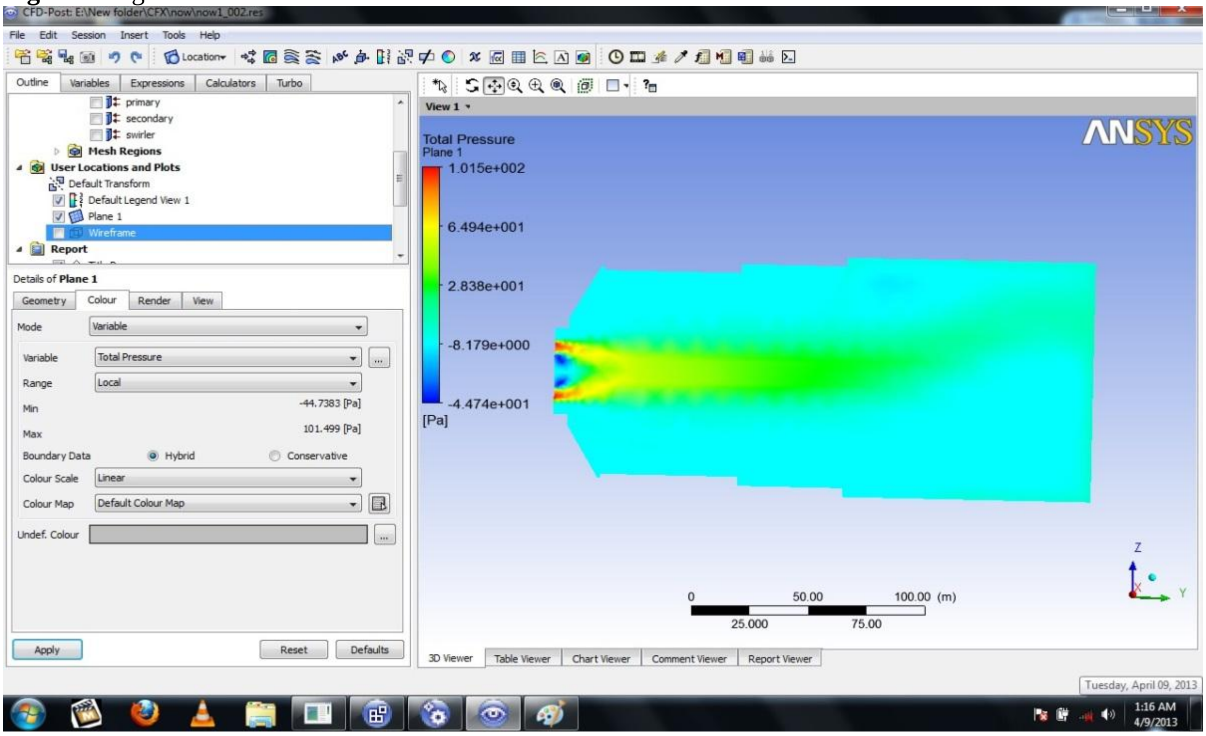

Fig. 3: Static Pressure for M-70.

A.2. Typical Experimental setup:

An experimental work has been done through a simple constructional arrangement with the components; as shown in fig.4. A swirler is placed on the front section of the developed working model of the combustor M-70 as shown in fig.5. The specifications involved in the arrangement are mentioned in the following.

Blower: 0-15m/s speed Mass flow rate variable
Injector: Volume flow rate measured by Pressure feed system
Igniters: Ignition time variable (manual)

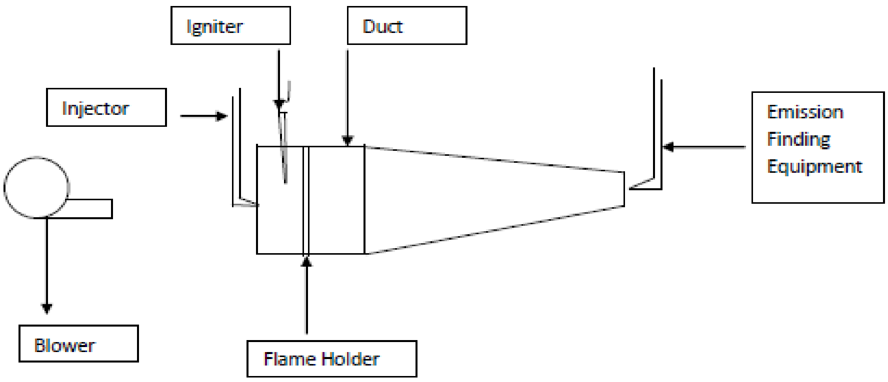

Fig. 4: Experimental setup for NO_x finding in the combustor.

A.3. Theoritical Calculation of NO_x

It is simple to calculate the emission factor by green house gas method but it includes all the emission factors like CO, CO_x, NO_x and other chemical components which affect the earth's atmosphere (Canadian associates, 2003); the Emission of NO_x is given by the product of Fuel usage, Emission factor and Utilization also the Fuel usage is equal to the ratio of Output rate to the product of Efficiency and HHV of fuel. Since, HHV is heating value and fuel is kerosene, and the efficiency is 85% (Douglas L.Allaire, et al., 2007). Emission factor is a NO_x and the calculation of fuel usage is substituted with the account of density of kerosene and its consumption. The Fuel kerosene's chemical properties are considered and it has been solved for the model

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combustor M-70, the emission of NO_x per year is obtained as 94109.7528 Kilogram and it may be shown as 0.09109 NO_x ppm is comparatively reduced emission rate.

Fig. 5: Combustor – M-70.

RESULT AND DISCUSSION

Respect to the mass flow rate value, NO_x value has been plotted in table.1; where mass flow rate value assumed as 70Kg/S has been chosen in the basis of standard condition applicable to the existing aircraft combustor of Boeing 787 aircraft's jet engine.

Table 1: Mass fraction plot table for different mass flow inlet.

Sl.No	Pressure drop (Pa)	Mass flow rate (Kg/s)	Mass fraction
1.	1600	70	0.00064

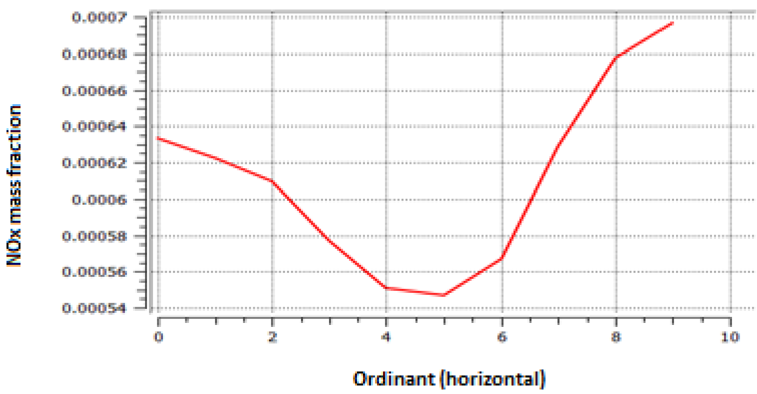

Fig. 6: NO_x plot for M-70.

In combustion chamber at primary zone NO_x value being very less due to decrease of area-velocity relation; the collaboration of molecules without combustion takes place. In Secondary zone NO_x value increases with a sudden raise due to sudden combustion takes place and is noticed in the plot shown in fig.6. being raised after primary zone. Tertiary zone is the focusing zone for NO_x; as per Zeldovich Mechanism (kerosene), the control action on NO_x is achieved at this zone by means of increasing the area, by which expansion occurs; will convert the NO_x in to other gaseous elements by reaction, which does not produce any harm effect in the atmosphere. Therefore NO_x reduction has been achieved in tertiary zone by geometric design modifications. And it is valuated against the combustion experiment on the model by the exit temperature. The reduction of NO_x emission achieved by analytical value of emission shows 0.09109 NOx ppm is less value when compared with other existing results by achieving existing fuel (*Kerosene*). But in CFD solution it is further reduced to less than that of theoretical value as shown in fig.6.

Conclusion:

Throttle sweep emission method reduce the NO_x emission in the operating conditions of the combustor, which was estimated from empirical models and physics-based model (Douglas L.Allaire, et al., 2007) but M-70 has reduced more NO_x by its design changes.Hence, the NO_x emission level is reduced when compared to other related emission reduction techniques like recirculation of unburnt gases, water or steam injection, selective catalytic reduction and dry low NO_x. The future scope is nothing but reduction of NO_x by flameless combustion (Levy, 2010).

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