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Thermal Analysis of Aero Engine Gas Turbine Combustor

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Abstract: -- **This project study discusses the combustor liner metal temperature prediction methodology for aero gas turbine. All modes of heat transfer for thermal analysis is considered. Radiation due to combustion gas, conduction due to presence of low conductivity thermal barrier coating and the liner and convection due to combustion gas and cooling air are estimation. Combustor liner metal temperature is an important input for determining the creep life.The objective of the present study is thermal analysis of combustor liner to estimate the metal temperature distribution for a given cooling configuration. Heat loads coming on the liner is calculated to carry out Finite Element analysis using commercial software ANSYS. The geometrical model is generated and meshing is done with suitable elements for thermal analysis. The analysis is carried out for different design steady state conditions to evaluate the maximum metal temperature. 1D analysis is carried for the convective and radiative fluxes from energy balance and 1D metal temperature is estimated. Parametric analysis is carried out to study the effect liner metal temperature with different aerodynamic and geometric parameters like gas temperature, thermal barrier coating thickness, coating conductivity, and combustion gas pressure. It was observed that with increase of thermal barrier coating thickness the liner metal temperature was decreased as the conductive flux was reduced. Emissivity of gas increased with the increase of gas pressure, gas temperature and increase of air/fuel ratio. Increase of gas emissivity increases the liner metal temperature.**

Key words**: Combustor liner, Thermal barrier coating, adiabatic film cooling.**

I. INTRODUCTION

The combustor systems of the modern high efficiency and low emission turbine engines have been under continuous development and improvements under last few decades. While firing temperatures have been improved to gain efficiency simultaneous requirement have been forced to reduce emission levels especially for power producing gas turbine todays combustion system aims to limit nox emission to 9 ppm or less
on dry fuel to achieve such a stringent conditions it is necessary to maintain the combustion zone temperatures low as possible which in turn requires more air to be utilized in the pre mixing process and reaction zone. Mark Van Roode, Jeff Price analysed the usage of ceramic matrix for combustor liner instead of conventional metals because of their high temperature durability, which results in high operating temperature and hence high efficiency.
.Over 67000h of operating experience have been acquired from field tests of CMC combustor liner. In absence of EBCs, MI SiC/SiC liner are more durable than CVI SiC/SiC liner. Ceramic oxide based EBC improve Sic/SiC CMC liner life by a factor of 2-3. Thedurability of baseline Si/mullite/BSAS is enhanced by mixing BSAS with mullite in intermediate coating layer.E. Ufot et al studied the effect of convection heat transfer coefficient on the temperatures of combustor liner surface and the amount of heat transferred through the combined effect of radiation, convection and conduction. They showed that the convective heat transfer coefficients can influence the quantity of radiative HT in the combustor liner of gas turbines and for higher heat transfer coefficients, higher will be the quantity ofheat transferred. So higher wall temperatures are achieved. Also temperature difference between the liner outer and inner wall surface temperatures will increase proportionally with heat transfer coefficients.Yousef s h and Riad M evaluated fuel type (c/h ratio) and operation conditions on liner wall temperature. Effect of increase in c/h ratio on liner wall temperature is much greater for combustor with fuel rich primary zone than for those in which primary zone is fuel weak. This is because of the fact that in fuel rich primary zone most of the heat is transferred to liner wall by radiation which is proportional to 〖T_g〗^4 . On the contrary in fuel weak primary zone most of the heat is transferred by forced convectionG. Manoj Kumar et al (2015) studied the impact of different convection heat transfer coefficients on the temperature distribution on the liner inner and outer interfaces through the combined effect of convection and conduction at the surface and also the effect of Thermal barrier coating (TBC) layer over the liner surface on heat transfer.They showed that with the increase in heat transfer coefficients of inner surface, the temperature difference between combustor liner inner and outer wall also increases. With introduction of thermal barrier coating (TBC) layer on

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the liner, they found reduction in temperature distribution between inner and outer layer of combustor.

II. HEAT TRANSFER ANALYSIS

For the purpose of analysis, a liner may be regarded as a container of hot flowing gases surrounded by a casing, with air flowing between the container and the casing. The liner is heated by radiation and convection from the hot gases. It is cooled by radiation to the outer casing and by convection to the annulus air. Under steady state condition the incoming flux should be equal to the outgoing flux. The liner temperatures is such that the internal and external heat fluxes at any point are just equal. From the energy balance the metal temperature of the liner is estimated as follows.

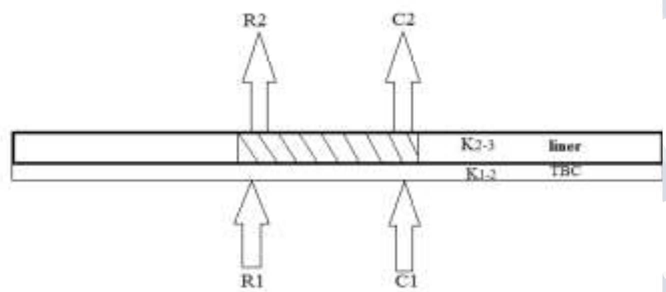

Figure 1: Heat Transfer across a Combustor Liner

We have,

$$R_1 + Q_{c1} = R_2 + Q_{c2} = Q_{cond\ 1-2} + Q_{cond\ 2-3}$$

Where, R_1 = Radiation flux from gas to liner surface.

Q_{c1} = Convection flux from gas to liner.

R_2 =Radiation flux from liner to casing.

Q_{c2} = Convection flux from liner to casing.

$Q_{cond\ 1-2}$ = Conduction flux through coating.

$Q_{cond\ 2-3}$ = Conduction flux through liner.

Radiation from gas to liner surface: (Internal Radiation)

This is the component of heat transger that is mostly affected by fuel type and the net radiation heat transfer from gas to liner is given by

$$R_1 = 0.5 * 5.67e^{-8} * (1 + \in_w) * \in_g * T_g^{1.5} * (T_g^{2.5} - T_{w1}^{2.5}) \frac{w}{m^2}$$

For luminous flame the emissivity of gas is given by

Emissivity of gas $[\in_g] = 1 - e^{-(290*P*(f*l_b)^{0.5}*T_g^{-1.5})*l}$

The beam length l_b depends upon size and shape of gas volume.

For outer liner l_b=1.2D

For inner liner l_b=1.0D

L is the luminosity factor which largely depends upon the C/H mass ratio of fuel. The correlation which is simple and relatively accurate is

L=336/ (%H^2)

Radiation from liner to casing:External Radiation

This increase as the liner wall is increased and are often neglected at lower temperatures. The radiation heat transfer from liner wall to the outer casing can be approximated by assuming grey body surfaces with emissivity's $\in_w$ and $\in_c$ and assuming that T_{w3} and T_c are approximately uniform in axial direction.

$$R_2 = \in_w * 5.67e^{-8} (T_{w3}^4 - T_c^4)$$

***Convection from liner to casing:* External convection**

Cooling air flowing through the outer annulus takes away the heat from the top surface of the liner by convection. The net convective heat flux from liner to casing is given by

$$Q_{c2} = h_c * (T_{w3} - T_c)$$

Convection from gas to liner: (Internal convection)

In the core of the combustor the gases involved in the heat transfer are at the high temperature and are undergoing rapid physical and chemical change. Apart from radiation heat transfer, convective heat transfer from gas to liner also takes place. The net convection heat transfer from the gas to the liner is then given by

$$Q_{c1} = h_g * (T_{ad} - T_{w1})$$

III. COMBUSTOR LINER GEOMETRICAL MODEL

The below figure represents a typical combustor model. It consists of 12 rows of cooling rings and each row having certain number of film cooling holes having diameter (d). The mass flow rate enters the combustor through the core. Nearly mass flow of 22.78% of Wci enters the core, 37.54% of Wci flows through inner annulus, and 39.68% of Wci flows through outer annulus. The material used for combustor casing is INCO-718 and for combustor liner C-263.

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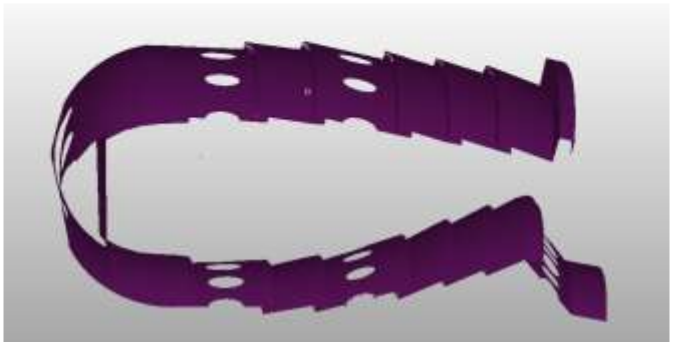

Figure 2: Geometric model of combustor

The below figure shows the finite element model of and typical gas turbine combustor. Meshing was carried out using the commercially available Hypermesh V12 software. The model consists of element type shell 131 having 236757 nodes and 232877 elements. Shell 131 is a 3D layered shell element having through thickness thermal conduction capability. This element has 4 nodes and con be used for steady state or transient thermal analysis.

Figure 3: 3D FE Model of Combustor Chamber Liner

IV. RESULTS AND DISCUSSION

Variation of Metal, Coating, Metal Coolant Temperature wrt Axial Length of Combustor: Finite element analysis was carried out using ansys software and the below graph shows the variation of outer and inner liner metal temperatures with respect to axial length of combustor.

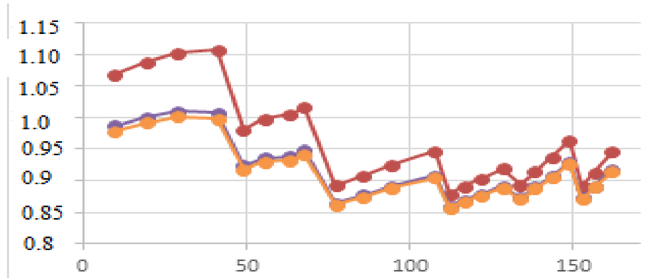

Figure 4: Inner liner temperature distribution

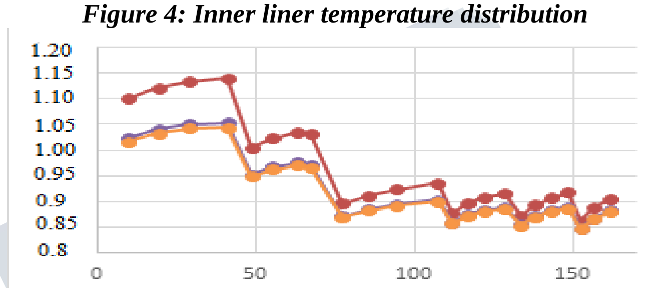

Figure 5: Outer liner temperature distribution

2-D ANSYS ANALYSIS:

Ansys analysis is carried out. Shell 131 element is used. 2 layers of elements have been used. 1st layer consists of the liner elements with 1mm thickness and the 2nd layer holds the coating elements with 0.5mm thickness. Conductivity of liner elements and coating elements are 20 w/mk and 0.5 w/mkrespectively. The below temperature contours refers to the peak liner temperature across the combustor liner.

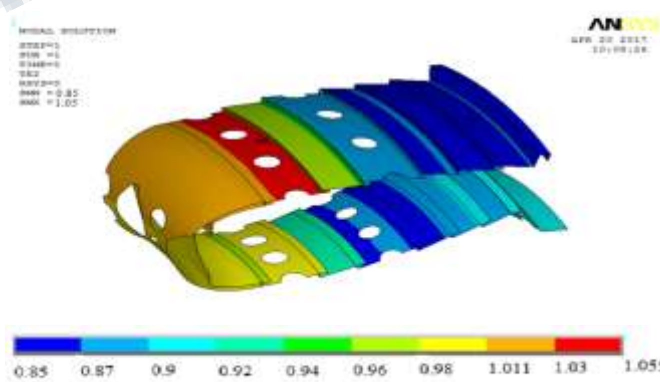

***Figure** Error! No text of specified style in document.:*
Temperature Contours of cut section of combustor liner

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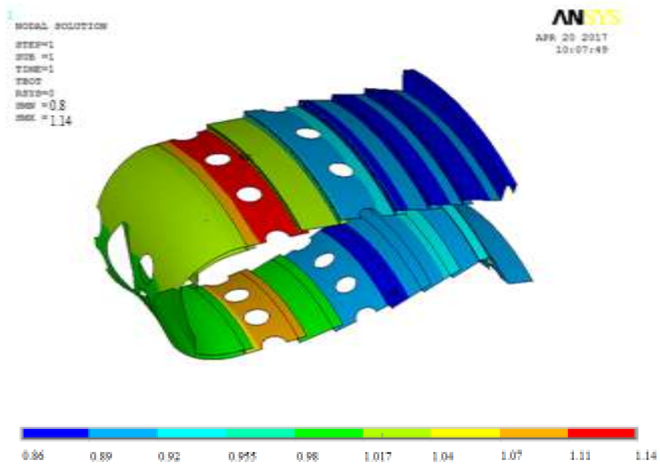

Figure 7: Temperature Contours of thermal barrier coating temperature

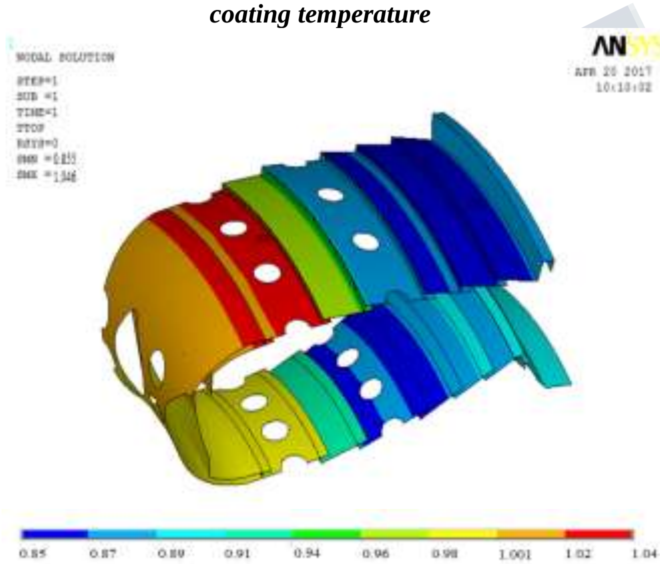

Figure 8:Temperature Contours of coolant metal temperature

V. SENSITIVITY ANALYSIS

Sensitivity analysis was carried out to see the effect of change in pressure, temperature on emissivity of gas and effect of change in pressure, temperature, emissivity and thickness on combustor liner metal temperature.

1. Effect of change in Gas Temperature:

As the temperature of combustion gases increases there is an increase in the emissivity of gas which in turn decreases the metal temperature of the liner.

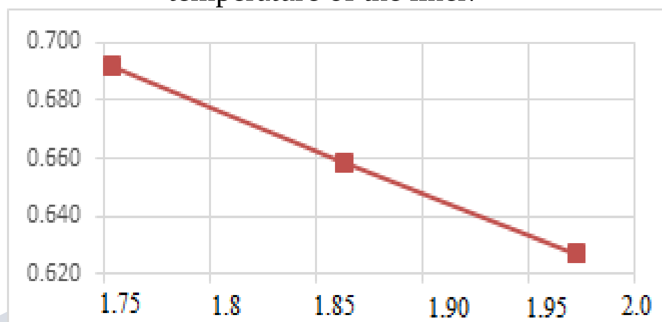

Figure 8: Gas Emissivity vs. Gas Temperature

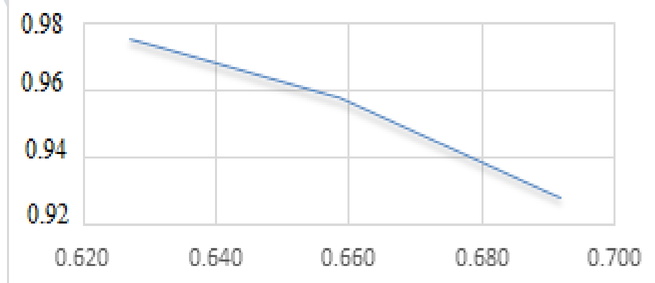

Figure 9: Liner Metal Temperature vs. Gas Emissivity

2. Effect of change in Gas Pressure:

Emissivity of gas increases with the increase in the gas pressure. This in turn leads to increase in the liner metal temperature.

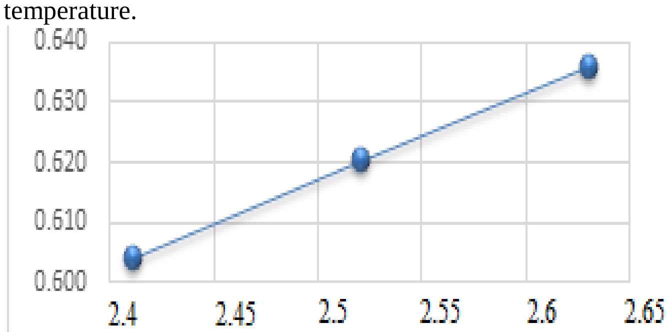

Figure 10: Gas Emissivity vs. Gas pressure

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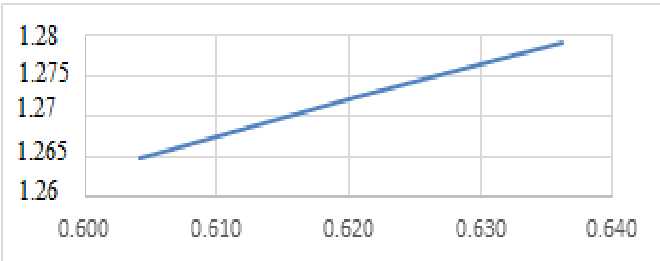

Figure 11: Liner /metal Temperaturevs. Gas Emissivity

3. Effect of fuel/air ratio:

With the decrease in the fuel/air ratio there is a decrease in emissivity of gas which in turn decreases the liner metal temperature.

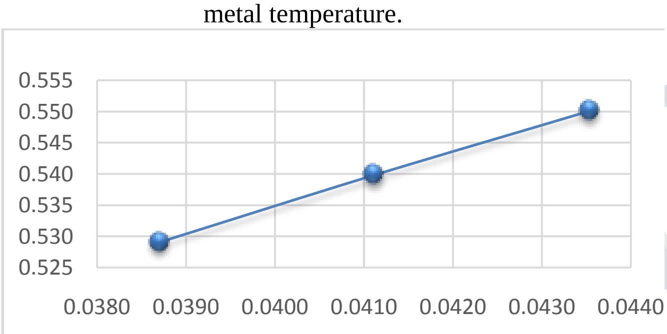

Figure 12: Gas Emissivity vs. Fuel/Air Ratio

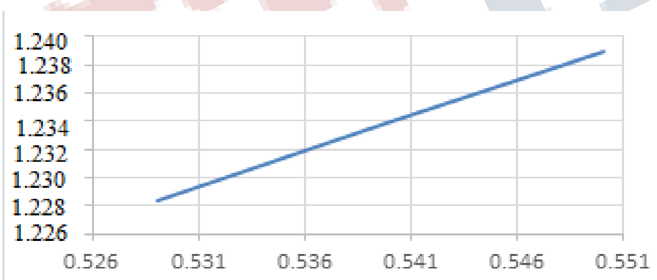

Figure 13: Liner Metal Temperature vs. Gas Emissivity

4. Effect of thickness of the coating:

Decreasing the thickness of the coating, the liner metal temperature increases since the conductive resistance decreases.

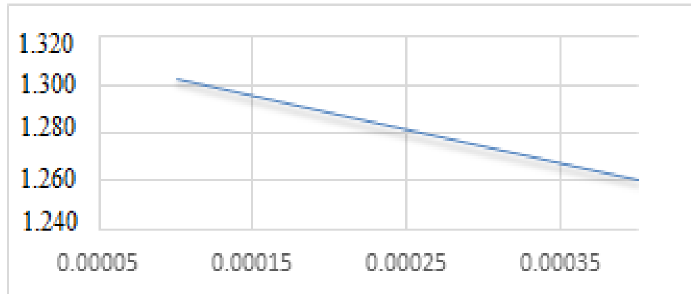

Figure 14: Liner Metal Temperature vs. Thickness of Coat

VI. CONCLUSION

Thermal analysis of combustor liner is carried to estimate the liner metal temperature distribution of film cooled combustor. Heat loads coming on the combustor liner is calculated to carry out Finite Element analysis. Convective and radiative fluxes are determined from energy balance by using 1-D analysis and metal temperatures are estimated. The following conclusions were drawn from the above analysis carried out:

1. It is observed from 1-D calculations and FE analysis that maximum liner metal temperature occurs at the primary zone of outer liner because of higher gas temperatures which is of the order 2.1K due to combustion.

2. With the presence of thermal barrier coating the liner metal temperature is reduced by 56°C. The incorporation of TBC proved to be effective in shielding the combustor liner from high temperature combustion gases.

3. Radiation is also an important mode of heat transfer along with convection and conduction which affects the combustor liner temperature. In the primary zone there is an increase of 20% in Liner metal temperature due to radiation heat transfer. 34% of total flux coming into the combustor liner accounts for radiative flux and 1% of radiative flux is going out of the combustor liner.

4. The adiabatic wall temperature is estimated using Sturguess, Wall jet and Turbulent boundary layer models. In present study only Sturguess model is

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considered due to applicability of the correlation for blowing ratio

5. Parametric analysis showed that the combustion gas temperature is a critical parameter which affected the combustor liner metal temperature. 10% increase in gas temperature, increased the combustor liner metal temperature by 8%.

6. The parametric analysis predicted that the gas pressure is a critical parameter which affected the gas emissivity. 10% increase in gas pressure, increased the gas emissivity by 5%.

7. The liner temperature is predicted with JP10 and JP8 fuels, the liner temperature is more for J10 by 3.74% when compared to JP8.

VII. NOMENCLATURE

R_i = Radius of casing, m
R_o = Radius of outer surface of outer linner, m
t_1 = Thickness of coating, m
t_2 = Thickness of liner, m
s = Slot height, m
R_1 = Radius of outer liner, m
R_2 = Radius of inner liner, m
t = Slot lip thickness, m
T_g = Gas temperature, K
P = Pressure of gas, kpa
T_a = Annulus air temperature, K
Wg = Mass flow rate in the core, Kg/s
w = Mass flow rate through cooling slot1, Kg/s
L = luminosity factor
f/a = fuel air ratio
ϵ_w = Emissivity of wall
ϵ_g = Emissivity of gas
l_b = Beam length, m
Cp= Specific heat, j/kg K
K = Thermal conductivity, w/mK
h = heat transfer coefficient, w/m^2K^4

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