Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 1, Number 4; October, 2014 pp. 11-15

http://www.krishisanskriti.org/jbaer.html

Improvisation of Combustor Wall Cooling Effectiveness Using Multiholed Plate

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Abstract: **Improvisation in conventional cooling methods needs to be done in efficient cooling of combustion chamber walls where high thermal stresses are involved in present day aircraft engines. Film cooling is utilized to increase the effectiveness of combustion chamber wall cooling. Usage of multi holed plate has resulted in considerable reduction of cold air consumption from compressor for effective film cooling of combustion chamber walls. Proposal is studied using software's CATIA and Computational Fluid Dynamics.**

1. INTRODUCTION

An efficient technology for cooling the combustion chamber metal walls is found scarce. Multiholed plate in the combustion chamber walls remain a satisfactory, efficient low-cost solution to the problem. In film cooling, cooler air is injected through discrete holes on the surface of combustion chamber walls to provide a coolant film that protects the inner walls from the detrimental effects of the hot combustion gases. The film of air can be made to get well attached with the surface of the walls by introducing the air film in an appropriate manner that could raise the effective rate of convection.

2. HEAT TRANSFER

In a modern combustor, the temperature of the gases released by the combustion process may peak over 2100°C; this is much higher than the melting point of the combustor flame tube and turbine blades. Therefore, the designer must adequately cool all the metal surfaces exposed to the hot gases and improve structural integrity and durability.

3. HEAT-TRANSFER PROCESSES

Film Cooling

Although many methods of supplementing the removal of heat from the liner involve a film of cooling air on the inner surface of the liner wall, the name film cooling is usually reserved for those schemes that employ a number of annular slots through which air is injected axially along the inner wall of the liner to provide a protective film of cooling air between the wall and the hot combustion gases.

The cool film is gradually destroyed by turbulent mixing with the hot gas stream, so normal practice is to provide a succession of slots at about 40–80 mm intervals along the length of the liner. The main advantage of the method is that the cooling slots can be designed to withstand severe pressure and thermal stresses at high temperatures for periods up to several thousand hours

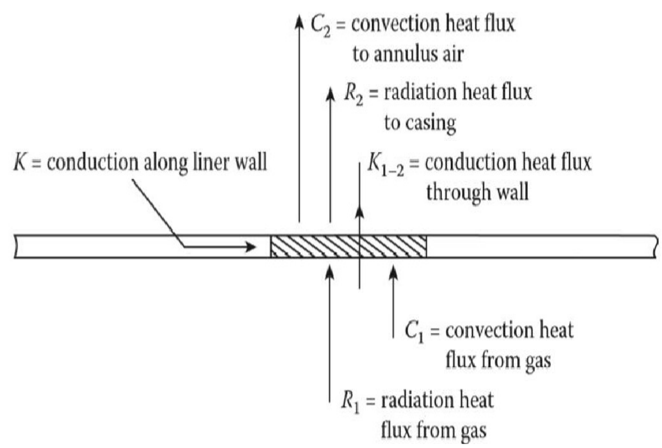


Fig. 1. Basic heat transfer in liner

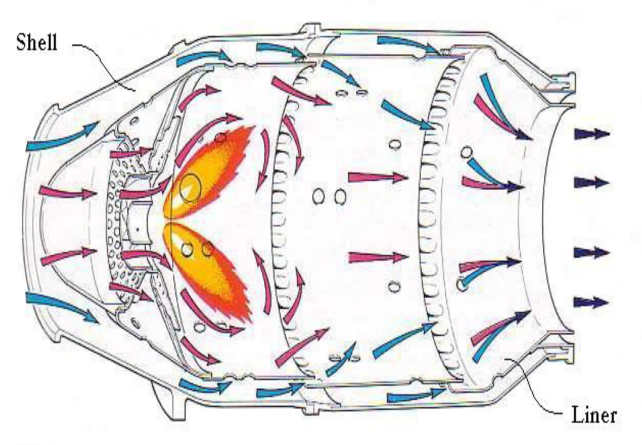


Fig. 2. Film Cooling

Calculation of film-cooled Wall temperature:

Calculation of film-cooled wall temperatures involves eq.1.1, 1.2, 1.3, the internal-convection component, C1 as in eq.1.2 is altered because the coolant flow changes both the velocity and temperature of the hot gas near the wall. Dealing with velocity first, we have for 0.5<m <1.3,

Nu=0.069(Re*x/s) 0.07 eqn 1.1

C1=0.069*Ka/x*Rex0.7 (Tw-Tw1) eqn 1.2

Rex=Uaρa*x/μa eqn 1.3

Internal convection

In the primary zone, the gases involved in heat transfer are at high temperature and are undergoing rapid physical and chemical change. Further difficulty is introduced by the existence within the primary zone of steep gradients of 6 temperature, velocity, and composition. The primary zone contains, by design, a reversal of flow, so that only in a region adjacent to the wall does the direction of flow correspond to the assumed pipe analogy.

4. LITERATURE REVIEW

It is evident from the fact that film cooling is highest when the coolant flow hugs the surface and does not penetrate and dissipate in the hot mainstream. The parameters such as the length of the hole (L/D), the hole exit-to-inlet area ratio (AR), the hole pitch (P/D), the hole coverage (C/P), hole compound angle (c), density ratio (DR) are suspect to have a vital impact on the film cooling performance that improvises wall cooling effectiveness (Han Chang,2012).

Extremely high temperatures and tremendous thermal gradients exist on this component, and special measures must be taken to ensure its durability (Has anNasir, 2001).

5. PROJECT METHODOLOGY

As a first step the collection of literature related to the topic is much more important so that the problem could be identified and the reason behind to implement multiholed plate shall be justified. The next step is to design a multiholed plate based on the specifications following which it is subjected to thermal analysis. The work is further proceeded by designing various multiholed plates of various specifications and temperature contour of individual designs are analyzed. As a final step the analysis result of varied designs of multiholed plates are compared and the multiholed plate with superior wall cooling effectiveness is justified as the best design that could be implemented.

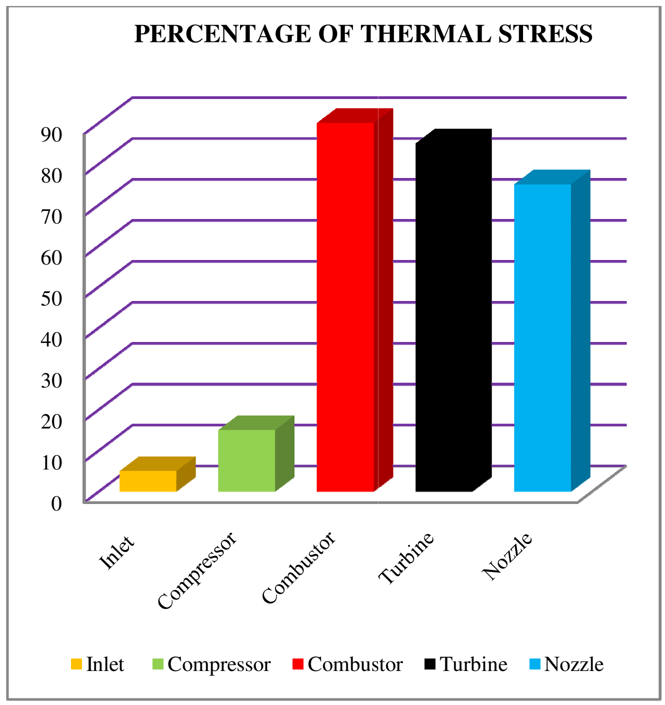
6. FAILURE MODE AND EFFECT ANALYSIS:

Failure mode and effect analysis, also known as risk analysis is an analytical technique that combines the technology and experience of people in identifying foreseeable failure modes of a product or process and planning for its elimination.

Process FMEA has four stages

- Specifying possibilities
- Quantifying risk
- Correcting high risk causes
- Re-evaluation of risk

Risk Priority Number =Probability*Severity*Occurrence
= 5.6*8.6*8.2
= 394.91



7. DESIGNING OF MULTIHOLED PLATE: GEOMETRIC PARAMETERS

90 degree plate

- Diameter of the hole(d): 4 mm
- Hole inclination angle(α):90◦
- Longitudinal spacing between holes(s): 4.5 mm
- Transverse spacing between holes(p): 4 mm
- Length of the multiholed plate(l): 180 mm
- Length of the multiholed zone: 80 mm

Complex hole geometry

- Diameter of the hole(d): 2,1 mm
- Hole inclination angle(α):90◦
- Longitudinal spacing between holes(s): 7 mm
- Transverse spacing between holes(p): 6.2 mm
- Length of the multiholed plate(l): 180 mm
- Length of the multiholed zone: 80 mm

8. MATERIAL SELECTION

Once the geometrical as well as aero thermal parameters are determined, the next important criteria is to choose the material suitable for employing based the necessities and requirements suited for gas turbine combustor liner.

Nickel Alloys:

Nickel and nickel alloys are used for a wide variety of applications, the majority of which involve corrosion resistance and/or heat resistance.A number of other applications for nickel alloys involves the unique physical properties of special-purpose nickel-base or high-nickel alloys. These include

- Low-expansion alloys
- Electrical resistance alloys
- Soft magnetic alloys
- Shape memory alloys

Inconel 713LC (Ni alloy) Chemical Composition (%):

- Ni-74 Cr-12.5 Mo-4.2 Al-6.1 Ti-0.8 C-0.05
- B-0.012 Zr-0.1 Nb-2.0

Properties:

- Density: 7.950x10^6 g/m^3
- Thermal Conductivity: 29.642 W/m.K
- Thermal Diffusivity: 5.612x10^{-6} m^2/s
- Specific Heat: 0.669 J/o.k.

Ni-base super alloys have many benefits to conventional alloys:

- Withstanding higher temperatures for longer periods of time.
- Increased fatigue and creep resistance.
- Reduce processing and element energy costs**.**

Haynes 188(Co alloy):

- Chemical Composition (%):
- Co-42 Cr-22 Ni-20 W-14 C-0.1 La-0.05

Properties:

- Density:8.98x10^6 g/m^3
- Thermal Conductivity:24.1 W/ m.K

Advantages vs. Ni--based Alloys:

- Higher melting points and flatter stress-rupture curves.
- Results in higher stress capability to higher absolute temperatures than Ni-base (or Fe-base) alloys.
- Better hot corrosion resistance in contaminated gas turbine atmospheres due to their higher Cr content.
- Better weldability and better thermal fatigue resistance than Ni-base alloys.

Disadvantages vs. Ni--based Alloys based Alloys:

- Lower strength.
- Lower ductility and fracture toughness at ambient temperatures.
- Limited opportunity for improvement of current alloys.

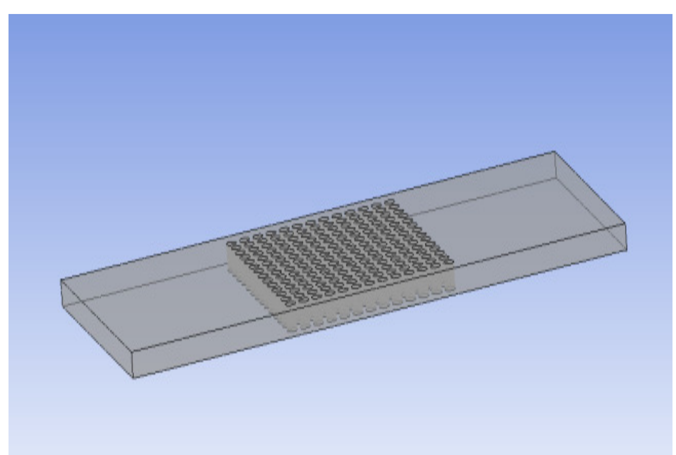
9. ESSENTIAL FULLFILLMENTS:

- High melting point and is hard-wearing even at high temperatures(Co, Mo)
- Highly non-reactive to chemicals and toxic gases reacts *very* slowly with the oxygen (Ni)

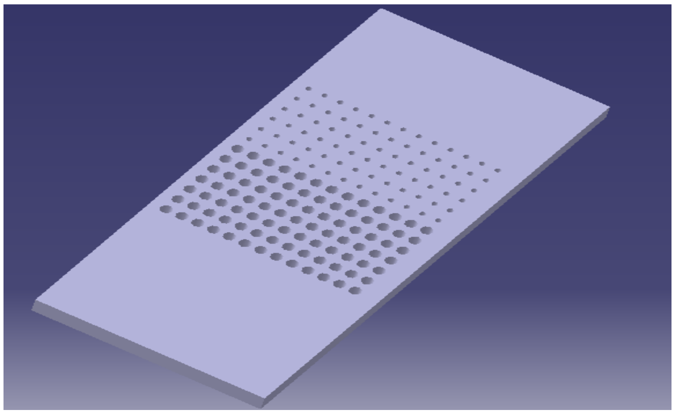
10. CATIA MODELING

The designs of the 90 o, 30o, and complex multi holed plate are modeled using **CATIA V5R19** software as mentioned in respectively.

90 DEGREE MODEL



11. COMPLEX HOLE GEOMETRY

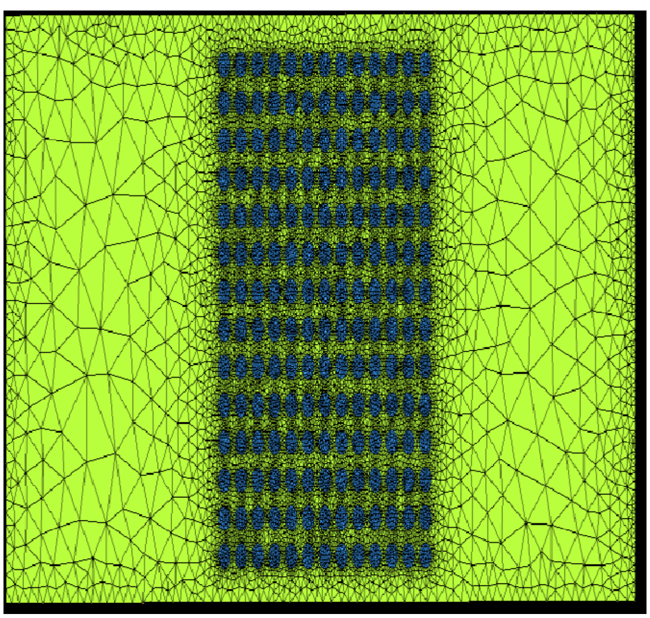


12. THERMAL ANALYSIS

The designed models are subjected to thermal analysis under aero thermal and flow conditions as mentioned in table 5. Using **ANSYS 14** in order to identify the model with effective rate of convective heat transfer under same aero thermal and flow parameters

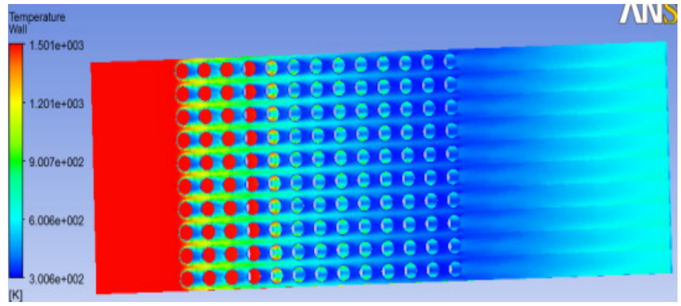
Table 5. Aerothermal properties

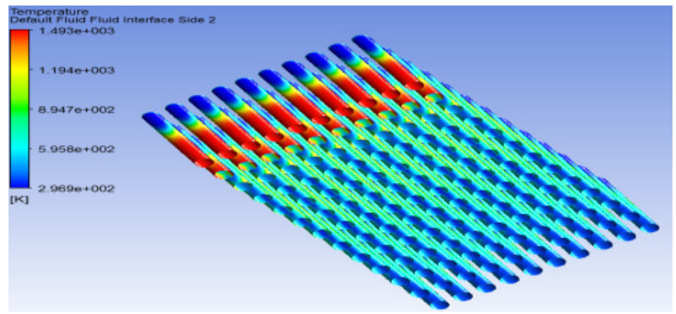
Aerothermal Parameters	Values
Pressure drop through the holes (ΔP/P)	7
ΔP (Pc-Ph)	1.2
Temperature on hot side of the plate (Th)	1500 K
Temperature on cold side of the plate (Tc)	300 K



Ansys mesh

TEMPERATURE CONTOUR OF 30 DEGREE PLATE (Ni alloy):





13. RESULTS AND DISCUSSION

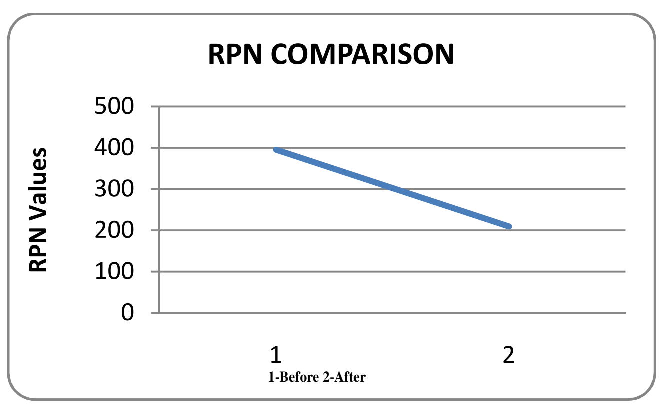
Overall comparison of the convective heat transfer of the various models

Complex hole plate (Ni alloy)> Complex hole plate(Co alloy)>30^{o} plate(Ni alloy)>90^{o} plate.

14. RECALCULATION OF RISK PRIORITY NUMBER

RPN calculated at the initial stage before the employment of best design at the combustor liner

Risk Priority Number = Probability*Severity*Occurrence
= 5.6*8.6*8.2
= 394.91



1-Before 2-After RPN chart

Typically shows the decrement in RPN thus contributing to the increase in reliability of the combustor liner (i.e. prolonged durability and sustained life).

15. CONCLUSION

We have designed a multiholed plate of with 90◦hole configuration and found that the plate region with no holes has less amount of convective heat transfer than the plate region with presence of holes and thereby came to a conclusion that multirole zone induces effective rate of convective heat transfer paving the way for increase in wall cooling effectiveness by which the RPN number gets reduced (i.e. severity, probability of cause) due to reduction of thermal stress.

16. FUTURE WORK

In future the multi holed plate is designed by combining features of 30o plate and complex plate, thereby determining their temperature contour shall give better results. The analysis could be carried out at different aero thermal and flow parameters too.

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