MATRIX FIN BASED TRANSPLY EFFUSION COOLING SYSTEM

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1) INTRODUCTION

Various methods are used to maintain the temperature of combustion liner within the safe range, most of these methods involve film cooling technology where the boundary layer formation characteristic of the fluid is used to prevent hot fluid within the combustion chamber coming in direct contact with the liner wall. Based on the design and fluid interaction with the liner wall these are classified between forced convection and transpiration cooling system.

The latest cooling technology being film cooling technology where annulus air is used as coolant, the annulus air is made to pass through the porous or multi-holed combustion liner where a boundary layer is formed inner side of the liner which protects the wall from coming in direct contact with the combustion zone hot environment.

Alloys of Aluminium have various applications in the aerospace field because of its high melting point (upto 2700º) and its light weight. These alloys can be used to

2) OBJECTIVE

1.To obtain design parameters for the matrix fins and transply effusion cooling system.

2.To optimize the matrix fin pattern and study the heat transfer characteristics.

3.To manufacture the optimized matrix fin design.

3) MATERIAL PROPERTIES

Table 1: Various properties of different alloys of aluminium

Properties/Alloys	AlSiC	AlBN	1050A	6060A/6061A/6063A
Density(g/cm³)	3.01	2.28	2.71	2.71
Melting Point(°C)	*2700	*2973	650	610
Thermal Expansion(/K)	8*10-6	1.2*10-6	24*10-6	23.4*10-6
Modulus of Elasticity (GPa)	200-230	45	71	70
Thermal Conductivity (W/m.K)	190–200	740	222	218
Tensile Strength (MPa)	350-500	400	105 - 145	70-180
Composition	37% Al63% SiC	30-40% Al60-70%BN	Aluminium: 99.5% min. Copper: 0.05% max. Iron: 0.4% max.	6060A is Aluminum: 97.9 to 99.3% Chromium: 0.05% max. Copper: 0.1% max.6061A is Aluminum: 95.9 to 98.3% Chromium: 0.35% max. Copper: 0.4% max.AA 6063 is an aluminum alloy, with magnesium and silicon as the alloying elements.

4)Basic concepts of convective heat transfer

Hydrodynamic diameter is the ratio of the four times the cross-section area to the wetted perimeter

$$D_e = \frac{4A}{O} = \frac{4\cdot \text{cross section of fluid in the channel}}{\text{perimiter in contact with fluid}}$$

Nusselt number is used to find the convective heat transfer coefficient which is given by the

$$Nu_l = 0.0361\cdot\left[1+12.77\cdot\sin^2(2\beta)\right]\cdot Re_l^n\cdot Pr^{0.4}\cdot\left(\frac{T_w}{T_f}\right)^{-0.55}$$

$$n = 0.8\cdot\left\{1+0.2\cdot\left[\left(\frac{4\beta}{\pi}-1\right)^2-1\right]\right\}$$

5)MATLAB Code

In MATLAB coding, since the height of the fin is fixed (0.7mm) and the only variables are thickness and the spacing between fins:

```
hf=0.0007;
p=1.185;
v=20;
u=18.385*10^-6;
len=0.0707;
k=0.02634;
a=[];
j=1:0.1:4;
for t=0.0003:0.00001:0.00087
    a=[];
    for i=1:0.1:4
      g=i*0.001375-t;
      d=(4*hf*g)/((2*hf)+g);
      Re=p*v*d/u;
      Nu=0.0367*(Re^0.88)*(0.702^0.4)*(1.678^-0.55);
      No=0.050/(t+g);
      A=2*hf*len+2*(t*hf)+(t*len);
      H=Nu*k/len;
      x=H*A*No;
      disp(['At thickness= ', num2str(t), ', Factor = ', num2str(x)]);
      a = [a; x];
   end
      plot(j,a);
      hold on
end
```

6) MATLAB Results

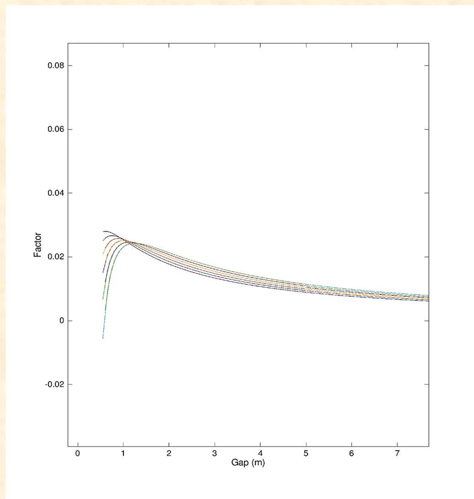

Fig 1: Maximum point of heat transfer for different thickness of the fin

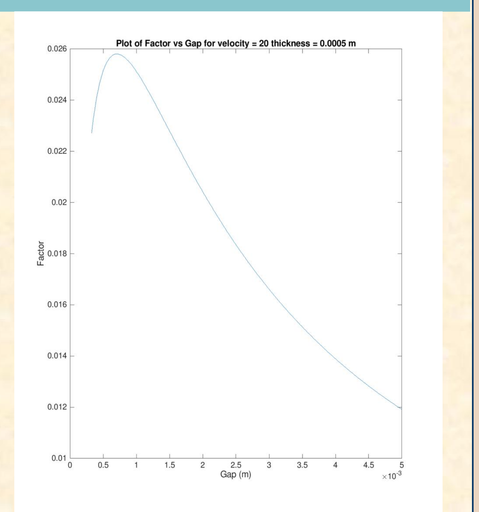

Fig 2: Optimum point for the 5mm thickness

From the graph it is observed that the optimum point for maximum heat transfer is obtained. The optimum dimensions are thickness is 0.5 mm and the gap between fin is 0.875mm. these dimensions of the fin are used to incorporate in the effusion cooling system to design the matrix fin effusion cooling system.

7) Optimized Design

The final optimized design has been obtained from the MATLAB simulations and the parameters taken from the research papers:
Fin Height = 0.7mm
Fin Thickness = 0.5mm
Distance Between Fins = 0.865mm
Hole Diameter = 0.5mm
Streamwise Pitch = 1.03mm
Spanwise Pitch = 0.91mm
Thickness of Effusion Plate = 0.5mm
A test area of 20mm X 20mm was taken for the analysis. It consisted of 100 holes and 20 fins.

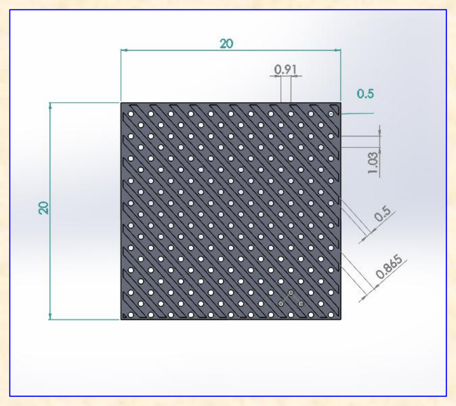

Fig 3: Top view of the matrix fin design

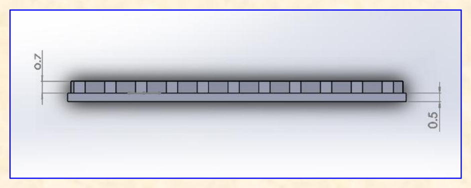

Fig 4: Side view of the matrix fin design

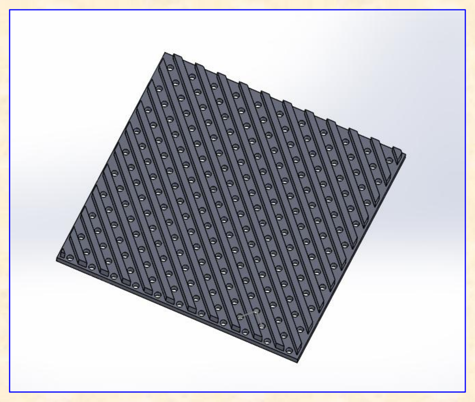

Fig 5: Isometric view of the matrix fin design

8) Thermal analysis of the optimized model

We created fluid domain in ANSYS fluent which encloses the model completely and in that we have two inlets and two outlets each one is for cold annulus fluid and hot liner fluid. Below is the image of the ANSYS Fluent model with the boundary conditions. We have velocity as the inlet boundary conditions and pressure as the outlet boundary conditions.

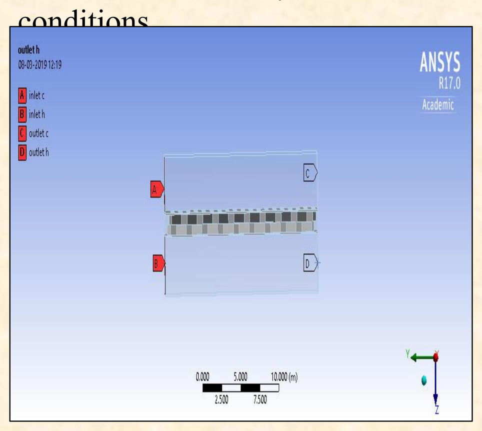

Fig: 6 Inlet and outlet representation

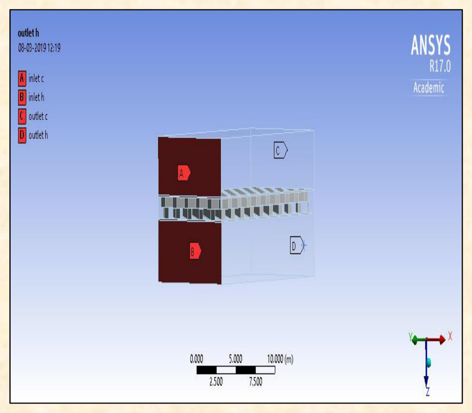

Fig 7: Inlet and outlet locations

Where inlet c is the cold fluid inlet with velocity 20 m/s , inlet h is the hot fluid inlet with velocity 11.4 m/s. Outlet c and outlet h are outlets of cold and hot fluid with pressure equal to atmospheric pressure.

8.1) Meshing

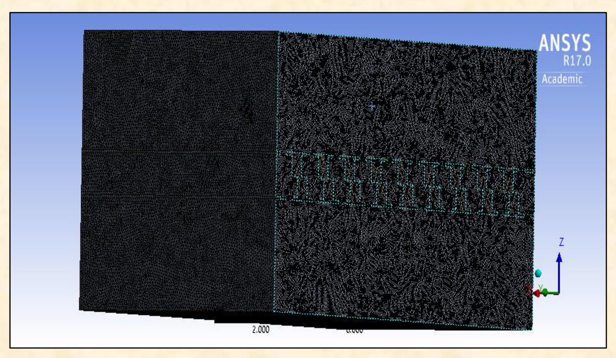

Fig 8: Final Mesh

2. Mesh Report

Table 2. Mesh Information for FFF

Domain	Nodes	Elements
fin	240554	1058423
fluid_	857418	4465805
All Domains	1097972	5524228

8.2) Effectiveness of The Model with Matrix Fin(500K)

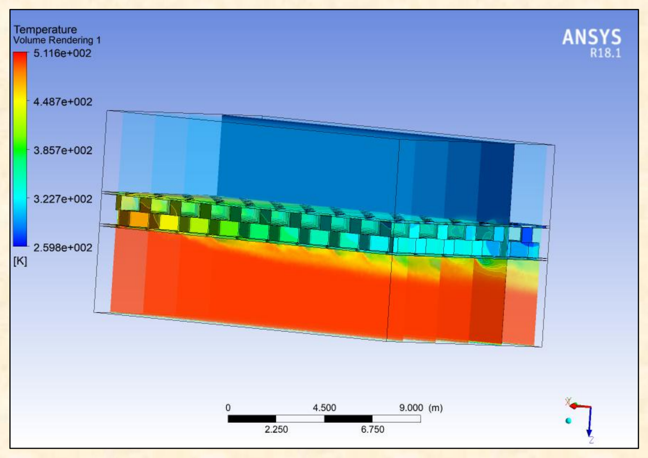

Fig 9: Temperature profile for inlet (hot) temperature 500K

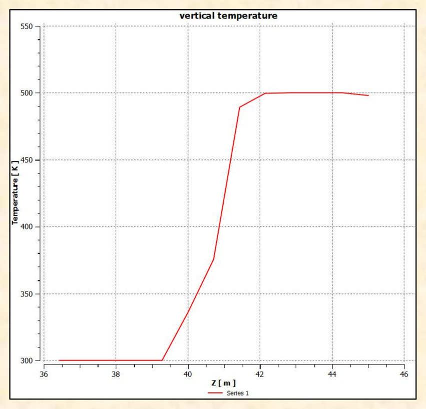

Fig 10: Temperature variation along Z direction

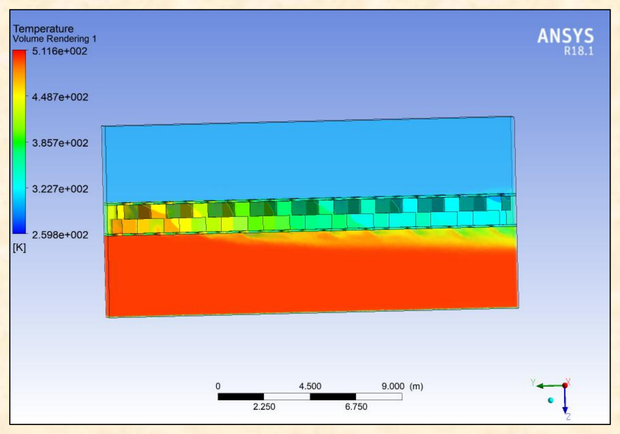

Fig 11: Temperature profile of fin cross-section for inlet (hot) temperature 500K

Average temperature = 356.011 K
Maximum temperature = 382.315 K
Minimum temperature = 331.22 K
Cooling effectiveness = (500-356.011) / (500-300)
= 0.7199

8.3) Effectiveness of The Model without Matrix Fin

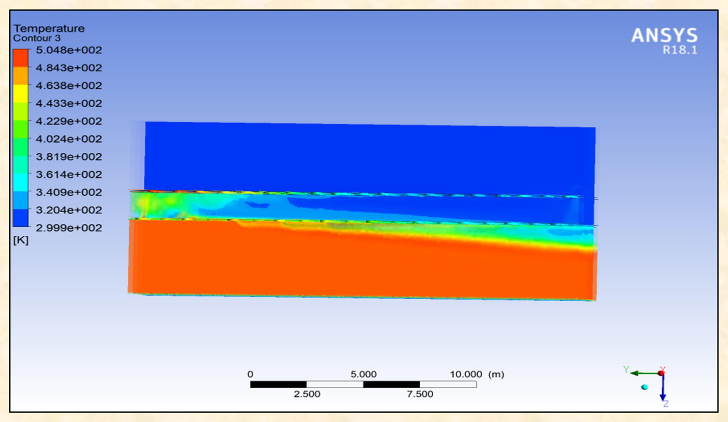

Fig 12: Temperature profile for setup without fins

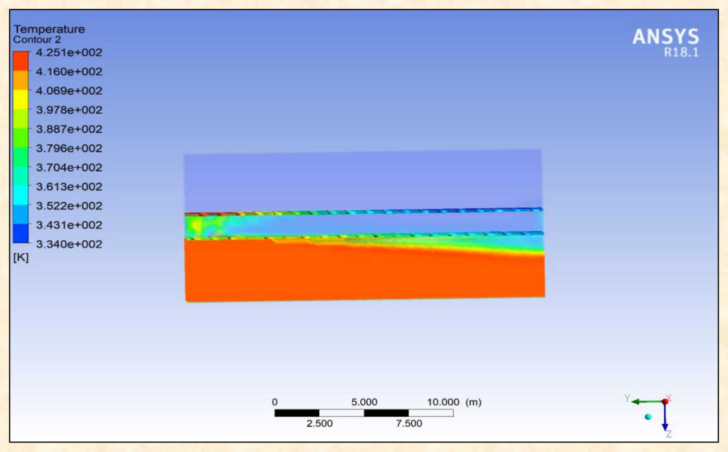

Fig 13: Boundary layer formation for setup without fins

Average temperature = 384.966 K
Maximum temperature = 425.135 K
Minimum temperature =334.105 K
Cooling effectiveness = (500-384.966) / (500-300)
= 0.5752

8.4) Effectiveness of The Model with Matrix Fin(850K)

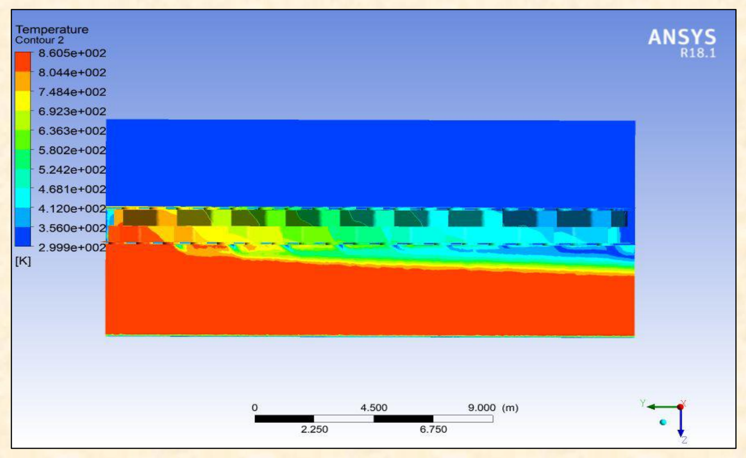

Fig 14: Temperature profile of fin cross-section for inlet (hot) temperature 850K

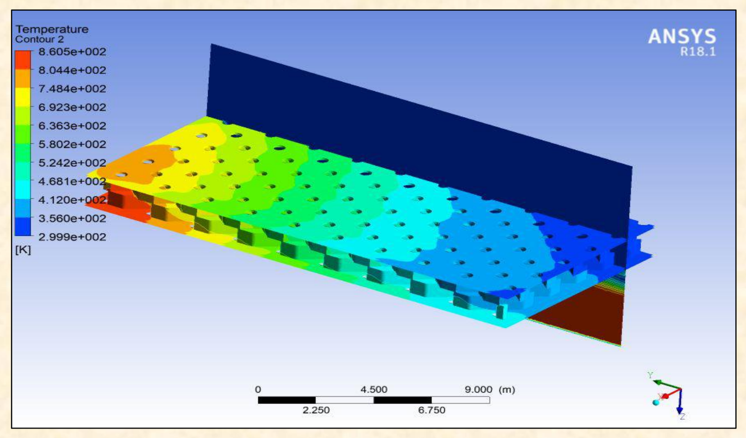

Fig 15: Temperature profile of setup for inlet (hot) temperature 850K

Average temperature = 357.612 K
Maximum temperature = 417.14 K
Minimum temperature = 319.829 K
Cooling effectiveness =(850-357.612) / (850-300)
= 0.8952

9) Manufacturing of the Matrix Fins

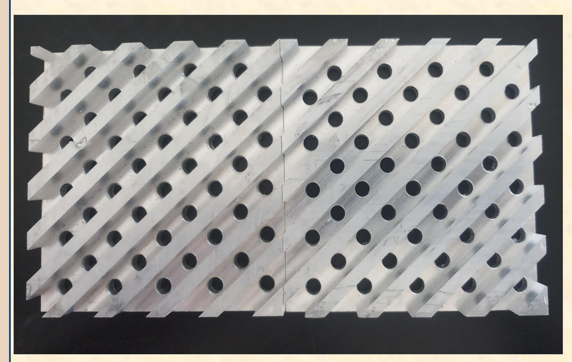

Fig 16: Top View of manufactured fins and effusion plate

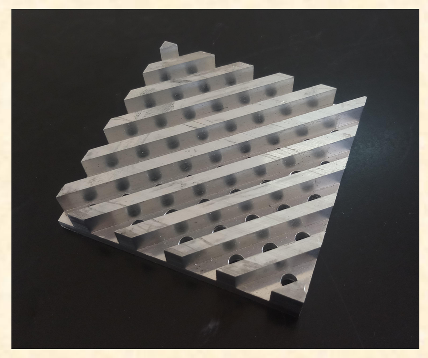

Fig 17: Isometric view of manufactured fins and effusion plate

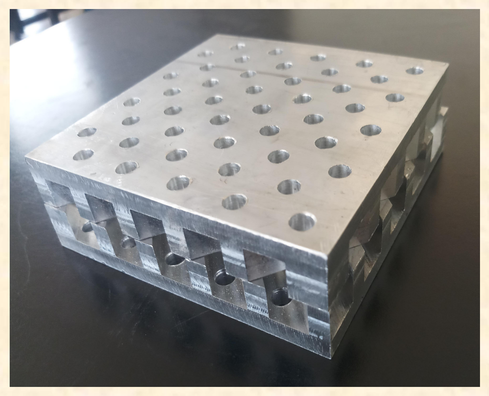

Fig 18: Transply effusion cooling system with matrix fins

With the help of Mastercam 2018, G-codes were created. These G-codes were inputted into a CNC machine. The manufactured product is shown.

14) Conclusion

There are multiple parameters whose values influence the performance of the matrix fins. To find the best combination of the parametric values, it is important to use the formulas which are applicable for the desired operating conditions. Once the right formulas are applied, the final design must be feasible and compatible with the required standards of the commercial combustion chamber design. Keeping that in mind, the final optimized design has been achieved with simulations in ANSYS proving that the new matrix fin transply effusion cooling to be more effective than the current transply effusion cooling system. An increase in cooling effectiveness by 14.47% for hot fluid temperature of 500K and 32% for hot fluid temperature of 850K (keeping cold fluid temperature at a constant value of 300K) was obtained which is a significant improvement. Furthermore, when the combustion chamber temperature increased from 500K to 850K, there was only a 1.6K rise in the average temperature of the wall which implies that it is possible to increase the temperature of the combustion chamber above the metallurgical limitations.

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