Design Of Cooling Configuration For Military Aeroengine V-Gutter

Batchu Suresh, S. Kishore Kumar

Abstract: Military aircraft engines employ afterburner system for increasing the thrust required during combat and take-off flight conditions. V-gutter is employed for stabilisation of the flame during reheat. For fifth generation aero engine the gas temperature at the start of the afterburner is be-yond the allowable material limits of the V-gutter so it is required to cool the V-gutter to obtain acceptable creep life. The design of cooling configuration for the given source pressure is worked out for different rib configurations to obtain the allowable metal temperature with minimum coolant mass flow.1D network analysis is used to estimate the cooling mass flow and metal temperature for design flight condition. CFD analysis is carried out for four cooling configurations with different rib orientations. Out of four configurations one configuration is selected for the best cooling configuration.

Index Terms: Adiabatic film cooling, Thermal barrier coating, Overall film cooing effectiveness, Thermal design of cooling configuration, CHT analysis.

NOMENCLATURE:

A -Area of passage(m^2)
Cp - Specific Heat (J/kg-K)
C_d - Co-efficient of discharge
P - Density (Ns/m^2)
ϵ - emissivity
h - Heat Transfer coefficient (W/m^{2}-K)
L - Length (m)
Re - Reynolds number
T - Temperature (K)
M - Mass Flow rate (kg/s)
K - Conductivity (W/m-K)
K -Pressure loss coefficient
M - Mach Number
Q - heat flux (W/m^2)
σ - Stefan-Boltzmann constant (W/m^2 K^4)
f_s - Friction factor
P - Pressure (kg/m^3)
V - Velocity (m/s)
D_h - hydraulic diameter (m)
Nu - Nusselt number
Pr - Prandtl number

Subscript

g -gas
c -coolant, convective
w -wall
o -outlet
I -inlet
s -smooth

1 INTRODUCTION

The gas temperature for aero engines is increasing beyond the allowable material temperatures to increase its thermal efficiency with Turbine Entry Temperature crossing 2100K. This will result in increase of afterburner entry temperature of over 1100K. High temperature Nickel based alloys currently used in afterburner region cannot with stand this temperature so it is required to cool the V gutter.

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Radial V gutters are being used widely in modern aero engine for ease of maintenance. EJ 200 [1] aero engine for Euro fighter, RM 12 engine and F414 engine are adopted cooled radial V gutters. Klas et al[2] discussed basic understanding of cooling, ignition and combustion arrived in the process of developing the cooled radial flame holder for F404/RM12 engine. They have explained that the main reason for designing a cooled radial flame holder was to increase life compared to uncooled annular flame holder. Hakan et al[3] have developed a cooled V gutter to increase the flame holder life and there by lower the afterburner life cycle cost. Generally cooled V gutter are radial without any circumferential ring for ease of designing a cooling system.

V GUTTER GEOMETRY

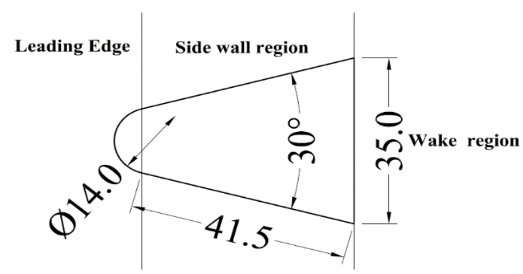

Figure.1 *V-gutter cross section with zones and dimensions*

Figure.1 shows the cross section details of the regions of the V gutter. The heat load coming on the V-gutter is the highest at wake portion of the V-gutter, due to anchoring of flame and the heat has to be removed to maintain the metal temperature within allowable limits. V gutter is portioned into two portions to remove the heat effectively. With two regions the coolant is allowed to scrape the surface of the V gutter especially at the wake region and removing the heat. V-gutter passage is divided into two portions called A1 and A2 where A1 is cooled with simple convection and A2 with simple convection initially later analysis is carried out with tabulators to enhance the convection and mimimise the coolant requirement. Figure.2 shows the A1 region cools the leading edge and some portion of side walls. A2 region cools the wake region and a portion of side wall region. The mass flow through the cooling configuration is calculated using 1D network model with given coolant sink and source to divide the V gutter into A1 and A2 region. Different configurations are analysed with 1D network model initially to arrive at preliminary configuration. CHT analysis is carried out to estimate the metal temperature and mass flow required.

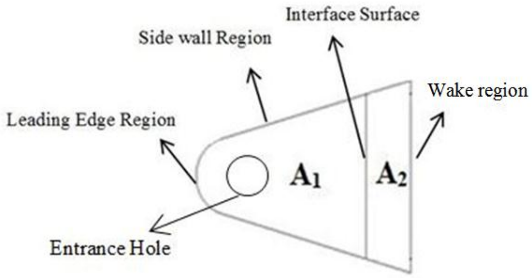

Figure.2 *V-gutter cross section with zones*

The geometrical details of the V gutter for which the cooling configuration is designed is given in Table.1. The aerodynamic data considered for the analysis is given in Table.2.

Table.1 *Geometrical deatils of the V gutter*

Leading edge Diameter	0.014 m
Side wall region length	0.0415 m
Length of wake region	0.035 m
Radial Length of the V gutter	0.3m
Angle included between side walls	300

Table.2 *Aerodynamic conditions for the analysis*

Core flow gas Pressure	3.528 bar
Core flow gas Temperature	1140 K
Core flow Temperature near wake region	1300K
Core inlet Mach number	0.25
Bypass coolant pressure	3.92 bar
Bypass coolant temperature	492 K
Bypass coolant flow	21.4 kg/s

Heat loads on the V gutter

Leading edge

Gas side heat transfer coefficient on the surfaces of V-gutter at leading edge is estimated using Lowery and Vachon[4]correlation. 5%turbulence intensity is used. The convective flux coming on the Leading edge portion of the V gutter is given in equation (3)

$$q_c = h_g(T_g - T_w) \quad (1)$$

$$q_c = 1599 * (1140 - 1100) \quad (2)$$

$$q_c = 63.94 \text{ kW/m}^2 \quad (3)$$

Sensitivity analysis is carried out for heat transfer coefficient with aerodynamic parameter like gas pressure, temperature, Mach number, turbulence intensity and leading diameter. Figure.3 shows variation of leading edge heat transfer coefficient with gas pressure. With increase in gas pressure the heat transfer coefficient is increased due to increase of density and Reynolds number.
Figure.***3*** shows the variation of leading edge heat transfer coefficient with gas Mach number. With increase in Mach number the heat transfer coefficient is increased due to increase of Reynolds number.

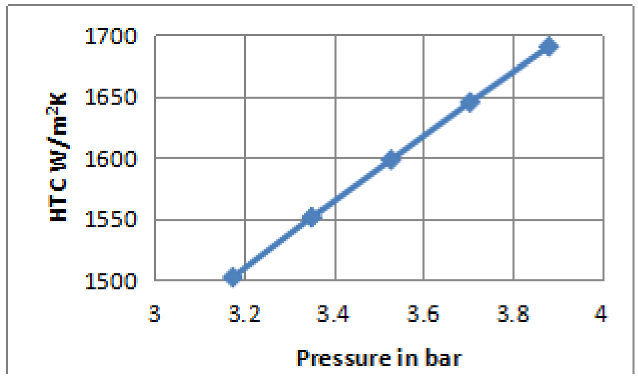

Figure.3 *Variation of Leading edge Heat Transfer Coefficient with gas pressure.*

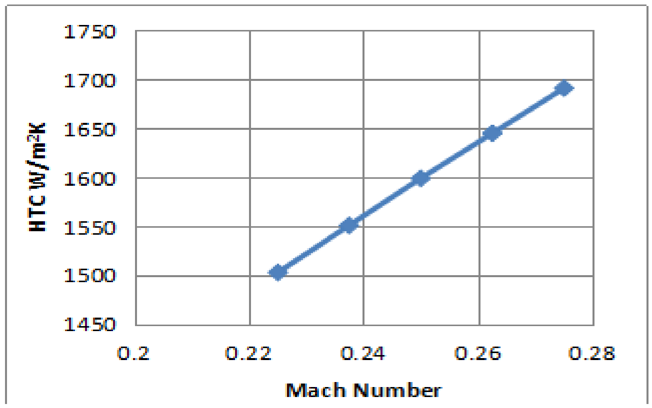

Figure.4 *Variation of leading edge heat Transfer Coefficient with gas Mach number.*

Sensitivity analysis is carried out by changing each parameter by 5% of the base value to find their effect on the leading edge heat transfer coefficient. Table.3 shows the sensitivity analysis carried out for leading edge heat transfer coefficient. It is obvious that the Pressure and Mach number are critical parameter affecting the heat load at the leading edge.

Table.3 *Sensitivity analysis for leading edge heat transfer coefficient.*

Regions	Variables	% change of variables	% change in hg
Leading Edge	Pressure	±5	±6
	Temperature	±5	1
	Mach Number	±5	±6
	Turbulence Intensity	±5	±2
	Dia of Leading edge	±5	4

Side wall region:

As the flow approaches the leading edge , flow diverges and flows over the side wall is assumed as a turbulent flow over a flat plate. To estimate the heat transfer coefficient on the side wall region turbulent flow over a flat plate is used[5]. The total flux coming on the side wall is given in the in equation 5

$$q_c = 878 * (1140 - 1100) \quad (4)$$

$$q_c = 35.12 \text{ kW} \quad (5)$$

Table.***4*** shows the sensitivity analysis of side wall heat transfer coefficient with different aerodynamic parameters. Pressure and Mach number are the critical parameters affecting the convective heat transfer coefficient compared to gas temperature and length of the side wall.

Table.4 *Sensitivity analysis for side wall heat transfer coefficient.*

Regions	Variables	% change of variables	% change in hg
Side Wall	Pressure	±5	±8
	Temperature	±5	2
	Mach Number	±5	±8
	Length of Side wall	±5	2

Wake region:

Wake region during reheat mode will be exposed for both convective and radiative and heat transfer from hot gases is calculated. The heat transfer is estimated using Andrew [6] and Hajime [7] is used and value obtained is 937 W/m2K. In wake region the total heat flux is the sum of convective heat transfer and radiative heat transfer.

Total heat flux, $q_t = q_c + q_r$ (6)

Convective flux is 187.4 kW/m^2

Radiation heat flux using Lefebvre [6]

$$q_r = 0.5 \times \sigma \times (1 + \epsilon_w) \times \epsilon_g T_g^{1.5}\left(T_g^{2.5} - T_w^{2.5}\right) \quad (7)$$

$$q_r = 146.163\ \mathrm{kW/m^2} \quad (8)$$

$$q_t = 333.6\ \mathrm{kW/m^2} \quad (9)$$

The equivalent heat transfer coefficient, $h = \frac{q_t}{(T_g - T_w)}$

$=\frac{333.6\times10^{03}}{(1300-11100)}$=1668 W/m2K (10)

Figure.***5*** shows the variation of Heat transfer coefficient with Mach number in the wake region. With increase in Mach number the heat transfer increases due to increase in Reynolds number.

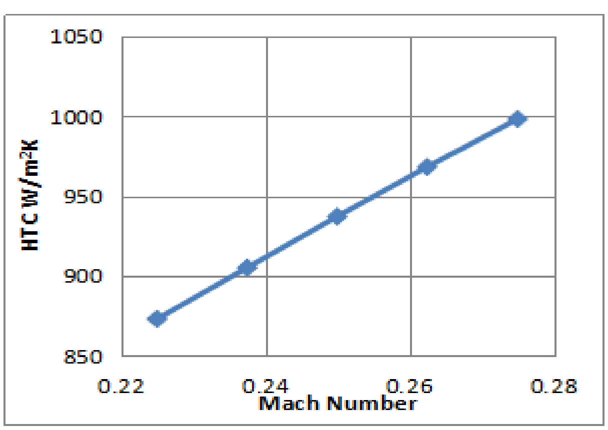

Figure.5 *Variation of Convective Heat transfer coefficient with Mach number in Wake Region*

Table.***5*** shows the sensitivity analysis of wake side heat transfer coefficient with different aerodynamic parameters. The Pressure and Mach number are the critical parameters affecting the heat transfer coefficient compared to gas temperature and length of the wake region.

Table.5 *Sensitive analysis of wake side Heat Transfer Coefficient*

Regions	Variables	% change of variables	% change in hg
Wake region	Pressure	±5	±7
	Temperature	±5	4
	Mach Number	±5	±7
	Length of wake region	±5	4

Table.*6* shows variation of gas emissivity with gas pressure, Fuel/Air ratio and gas temperature. Gas temperature is most sensitive parameter affecting the gas emissivity.

Table.6 *Sensitivity analysis of gas Emissivity*

Parameter	% Variation of Parameter	% Change in emissivity
Pressure	±5	±9
Temperature	±5	14
F/A ratio	±5	±4

The consolidated heat loads are tabulated in Table.***7*** for all regions. The heat flux is maximum at wake region compared to side wall and leading edge. The heat flux at the wake region is due to convection and radiation. The total heat load is maximum on the side wall because the side wall area is more.

Table.7 *Heat loads coming on the V gutter surface.*

Region	Heat transfer coefficient W/m2-K	Area m2	Heat load W	Flux kW/m2
Leading edge	1599	0.132	843.7	63.94
Side walls	878	0.0249	874.6	35.12
Wake region	1668	0.00105	350	333.6

1D FLOWNETWORK

The coolant mass flow and temperature is calculated for zones A1 and A2 with flow network as shown in the Figure.***6***. The pressure drop takes place at the entrance of the hole along the duct and at the exit hole of the V gutter. A1 region has 10mm hole at the entrance and exit of the V gutter. The mass flow rate is assumed initially and iterated till the coolant static pressure at the exit is equal to the gas static pressure.

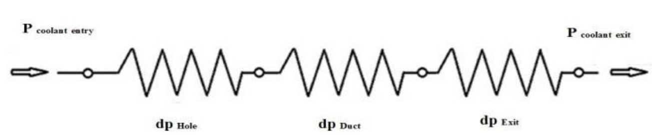

Figure.6 *Flow network for Area A1and A2*

The density of air changes with pressure loss along the V gutter length and temperature rise due to heat flux from core hot gas. So, the values of density, velocity and viscosity are estimated at average film temperature. Duct cross section is equivalent to trapezoidal cross section. The heat transfer coefficient in the A1 and A2 region is estimated using Dittus-Boelter equation for simple convection.

EMPERICAL CORRELATIONS

The available correlation available in open literature is used for mass flow and metal temperature estimation. Pressure drop across the hole at entry [8] is given by

$$\Delta P_{Hole} = \left[\frac{m}{C_d \times A_{hole}}\right]^2 \times \frac{1}{2\rho} \qquad (11)$$

Pressure drop across the duct entry [9] is given by

$$\Delta P_{entry} = k\, \rho V^2/2 \qquad (12)$$

Where k is coefficient of contraction, k = 0.5 Pressure drop along the duct is given by

$$\Delta P_{Duct} = \frac{4 * f_s \times L \times V^2 \times \rho}{2 \times D_h} \qquad (13)$$

The Friction Factor in smooth ducts can be estimated by formula available in open literature as given below. Blasius equation[10] can be used when 30000<Re<1000000.

$$f_s = 0.046 Re^{-0.2} \qquad (14)$$

Pressure drop across the hole [11] exit is given by

$$\Delta P_{Exit} = k \frac{\rho v^2}{2} \qquad (15)$$

The heat transfer performance in smooth ducts can be evaluated by Reynolds number and Prandtl number. The heat transfer coefficient can be found by using different formulae available in [5]literature.

I. Dittus-Boelter Equation

$$Nu_s = 0.023 * Re^{0.8} Pr^{0.33} \qquad (16)$$

Coolant temperature rise along the duct is estimated by enthalpy increase of the coolant which is due to heat transfer from the V gutter to the coolant. The coolant temperature rise is estimated using

$$q = m * C_p * (T_{c,out} - T_{c,in}) \qquad (17)$$

Convective heat flux from gas to coating is given by

$$q_{c,\,coat} = h_g * (T_g - T_{coat,\,g}) \text{ W/m}^2 \text{ K} \qquad (18)$$

Radiative heat flux [12] from gas to coating is given by

$$q_{r,coat} = 0.5 * \sigma * (1+\varepsilon_w) * \varepsilon_g * T_g^{1.5} * (T_g^{2.5} - T^{2.5}_{coat,\,g}) \text{ W/m}^2 \text{ K} \qquad (19)$$

Heat transfer for the coating

$$q_{coat} = K_{coat} * (T_{coat,g} - T_{m,i}) / t_{coat} \text{ W/m}^2 \text{ K} \qquad (20)$$

From energy balance at the coating outer surface

$$q_{c,\,coat} + q_{r,coat} = q_{coat} \qquad (21)$$

Heat transfer across the metal

$$q_{metal} = K_m * (T_{m,i} - T_{m,\,c}) / t_m \text{ W/m}^2 \text{ K} \qquad (22)$$

From energy balance at the interface

$$q_{metal} = q_{coat} \qquad (23)$$

Convective heat flux from metal to coolant is given by

$$q_c = h_c * (T_{m,c} - T_c) \text{ W/m}^2 \text{ K} \qquad (24)$$

From energy balance

$$q_c = q_{coat} \qquad (25)$$

Solving the equations (21), (23) and (25) the gas side coating temperature $T_{coat,g}$, interface metal temperature $T_{m,i}$, coolant side metal temperature $T_{m,\,c}$ are calculated

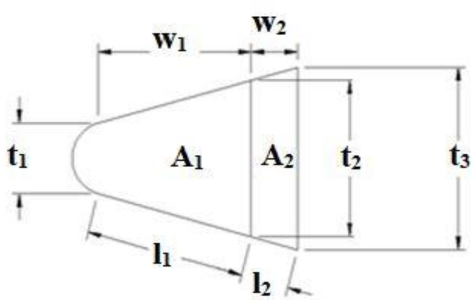

Figure.7 *Notation used for the analysis*

Figure.7 shows the parameters used for cooling configuration of the cooled V gutter. The width w2 of the V gutter is initially selected as 3mm and analysis is carried out to estimate the coolant mass flow and metal temperature for A1 and A2 region. The analysis is carried out by varying width w2 from 3mm to 18mm. The A1 region has entry hole of 10mm diameter which reduces the coolant flow.Figure8 shows the variation of total coolant mass flow obtained and highest metal temperature for A1 and A2 region with width w2.With increase in w2 from 3mm to 18 mm the coolant mass flowing through A2 increases due to increase in cross sectional area. The velocity in A2 will depend on mass flow and cross sectional area increase which affects the heat transfer coefficient. With increase in w2 the heat load continuously increases due to increase in side wall surface area. The A2 metal temperature is affected by increase in heat load and available coolant heat transfer coefficient. Initially with increase in w2 the metal drops drastically later it is stabilised at w2=10mm after that it increases slowly.
Table.***8*** shows the metal temperature and coolant mass flows for different configuration with w2. With increase in w2 the metal temperate of A1 reduces continuously. With increase in w2 the A1 heat transfer surface area reduces so gas heat load coming on the A1 area also reduces so A1 metal temperature also reduces .The controlling area for A1 is the inlet hole area so the mass flow through it hardly changes and velocity increases due to reduction of cross sectional flow A1 area. The metal temperature is dictated by heat load and coolant side heat transfer coefficient. At w2 of 10mm the maximum metal temperature reached for A1 is

1070K and with 0.0186 kg/s and for A2 the metal temperature is 1070K with 0.0966 kg/s. Total mass flow requirement is 0.1150kg/s. W2 of 10mm is considered for further analysis because the metal temperate is for A1 and A2 region is 1070K which is lower than 1085K.Figure.9 shows the cross section of the V gutter with the dimensions at the leading edge, side wall region and wake region for which CHT analyses is carried for estimation of metal temperature.

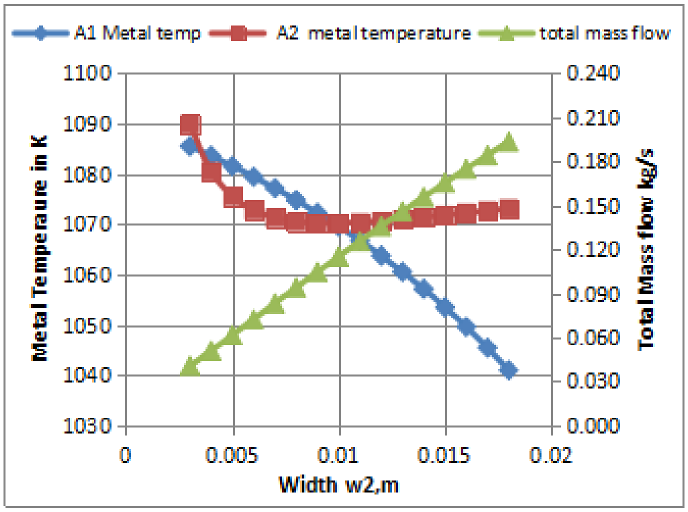

***Figure .8** Shows the variation of coolant mass flow requirement and metal temperature with width w2*

***Table.8** The metal temperature and coolant mass flows for geometry with different W2.*

		A1		A2		
S no	W_2,mm	mass flow, kg/s	Tmetal,K	mass flow kg/s	Tmetal,K	Total mass,Kg /s
1	0.003	0.0186	1086	0.0220	1090	0.041
2	0.004	0.0186	1084	0.0323	1081	0.051
3	0.005	0.0186	1082	0.0430	1076	0.062
4	0.006	0.0186	1079	0.0538	1073	0.072
5	0.007	0.0186	1077	0.0646	1071	0.083
6	0.008	0.0186	1075	0.0754	1071	0.094
7	0.009	0.0186	1072	0.0860	1070	0.105
8	0.01	0.0186	1070	0.0966	1070	0.115
9	0.011	0.0186	1067	0.1070	1070	0.126
10	0.012	0.0186	1064	0.1172	1071	0.136
11	0.013	0.0186	1061	0.1273	1071	0.146
12	0.014	0.0186	1057	0.1371	1071	0.156
13	0.015	0.0186	1053	0.1468	1072	0.165
14	0.016	0.0186	1050	0.1564	1072	0.175
15	0.017	0.0186	1045	0.1657	1073	0.184
16	0.018	0.0186	1041	0.1748	1073	0.193

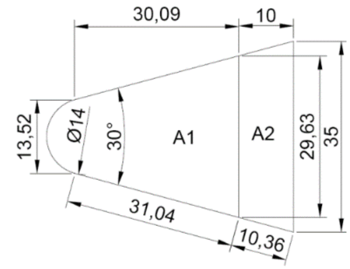

***Figure.9** Dimension of the V gutter for A1 and A2 regions*

CHT ANALYSIS

1D analysis of cooled V gutter showed that with width w2 of 10 mm the metal temperature for A1 and A2 region the metal is order of 1070K. To verify the metal temperature and coolant mass flow requirement CHT analysis is carried out for following four configurations

1) Configuration-I: Single chamber with smooth surface
2) Configuration-II: Two chamber with A1 and A2 smooth surface
3) Configuration-III: Two chamber with A1 smooth surface and A2 with 45^0 ribs.
4) Configuration-IV: Two chamber with A1 smooth surface and A2 with broken V ribs.

Cooled V gutter configuration

Configuration-I is a single channel with smooth surface with entry hole of 22.6 mm. Figure.10 shows the geometrical model with all dimensions for configuration-I. Cooling configuration of cooled V gutter for Configuration –II, III and IV with dimensions are shown in Figure.11. All the three configurations have same dimensions with the entry hole of diameter 10mm with width w2 of 10mm. Configuration- II is smooth surface without ribs in A2 region, configuration –III has 45^0 parallel ribs in A2 and broken V ribs are present for configuration-IV has. Figure.12 shows the shape and details of the rib for configuration III at the wake region. Figure.13 shows the geometric shape of the broken V rib for configuration IV. The height of the rib e is 1.15mm and the Pitch of the ribs P is 11.567 mm is considered to maintain e/Dh = 0.078 and P/e = 10 mm [13] because it gives the higher heat transfer enhancement and V shaped ribs are better compared to other configurations [14]

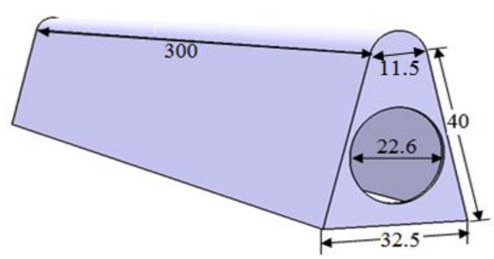

***Figure.10** Geometric model and with dimensions of Configuration-I*

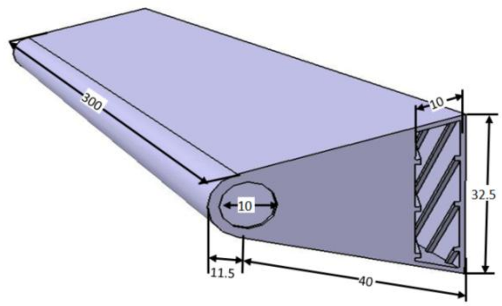

Figure.11 *Geometric dimensions for Configuration-II ,III and IV.*

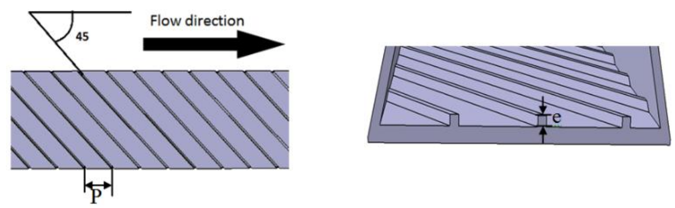

Figure.12 *Geometric shape of the ribs for configuration III at the wake region.*

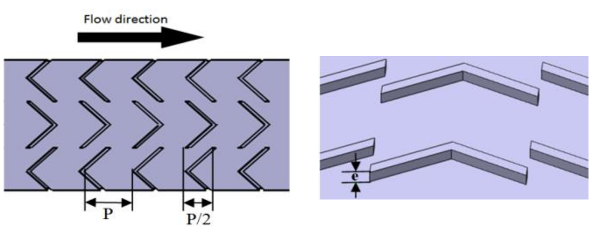

Figure.13 Geometric shape for configurations IV at the wake region.

Numerical method of solution

Commercially available ANSYS Fluent CFD software is used as a tool to analyse the cooling configuration for V-Gutter. The flow is three dimensional, compressible and assumed steady. The discretisation of the flow and the turbulence equations are second order upwind scheme and are solved through the segregated implicit method. The convergence criteria for the residual of each calculated parameter is less than 1x10-6, the analysis has been carried out with realizable k-ε turbulence model. In this study, computations are carried out until the residual plateau is reached. The analysis is carried out in IBM parallel core cluster machine with 10 parallel processors with 45GB RAM.

Computational Domain

The flow domain studied is shown in
Figure.**14** with dimensions. The thickness of metal considered is 1mm and thermal barrier coating at the wake region is taken as 0.5mm. Entry and outlet domain of 150mm and 100mm respectively are considered for the V gutter for the analysis. The length 300mm is considered for the main V gutter portion. The heat flux is given in this portion of the domain for A1 and A2 regions in terms of heat transfer coefficient.

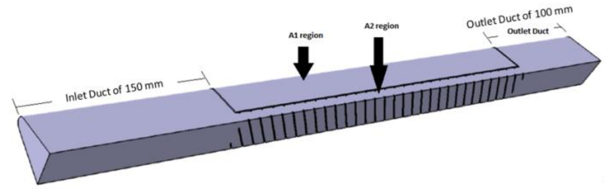

Figure.14 *Computational flow domain of the cooled V gutter*

Boundary Condition

Boundary conditions that are considered for the model are given in Table.9. The heat loads coming on the V gutter are given in the form of heat transfer coefficient and gas temperature. The thermal conductivity of the material used is 22.5 W/m-K and for coating 1.1 W/m-k is used for the analysis.

Table.9 *Boundary conditions considered for the analysis*

Inlet		
Total inlet pressure	3.92 bar	
Outlet static pressure	3.528 bar	
Total Temperature	492K	
Turbulence Intensity	0.05	
Outlet		
Heat flux at Wall conditions		
	Temperature	HTC
Leading edge	1140 K	1599 W/m2K
Side walls (A1 & A2)	1140 K	878 W/m2K
Wake region	1300 K	1668 W/m2K

Figure.**15** shows the locations where the boundary conditions are applied for the model. The liner wall is assumed to be no slip condition and thermal conductivity of the material and coating is given. The heat transfer coefficient and bulk temperature to simulate the heat load from the gas is given on the wake region, side wall and leading edge. Wake region both convective and radiative heat loads are considered. The boundary conditions used for the analysis are given in Boundary conditions applied on the model are given in Table-9.The heat loads coming on the V gutter are given in the form of heat transfer coefficient and gas temperature. The thermal conductivity of the material used is 22.5 W/m-K and for coating 1.1 W/m-k is used for the analysis.

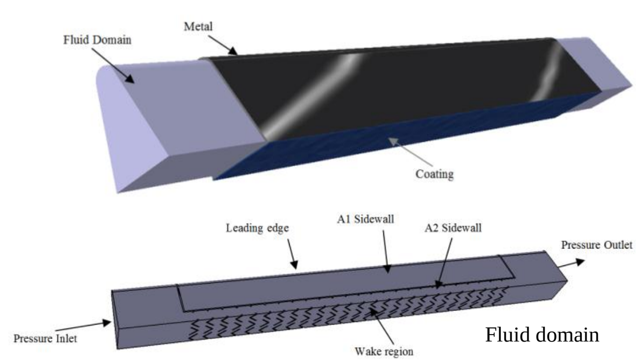

Figure.15 *Computational flow domain of the cooled V gutter*

Grid Generation

A combination of Hex and Tet grids are used to mesh the computational model as shown in the Figure.**16** . Hex grids are in the the boundary layers which is used to capture the near wall physics with a y+ value of <1. Growth ratio of 1.2 is used for modelling the grids near the wall. The grid size is gradually expanded along the core of the model. Tetrahedral grids make up the core, which are used in order to reduce the grid size. The number of cells was fixed to 3 million after considering the results of a grid independency check as shown in Figure 17. The convergence criterion for the CFD analysis is set to a residual value of 10E-6 for two consecutive iterations. The Realizable k-Ɛ model is used for the simulation of turbulence in the FLUENT commercial software.

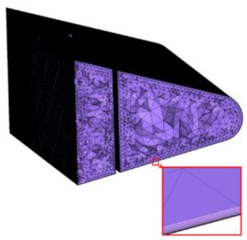

Figure.16 *Grid modelled for the V gutter.*

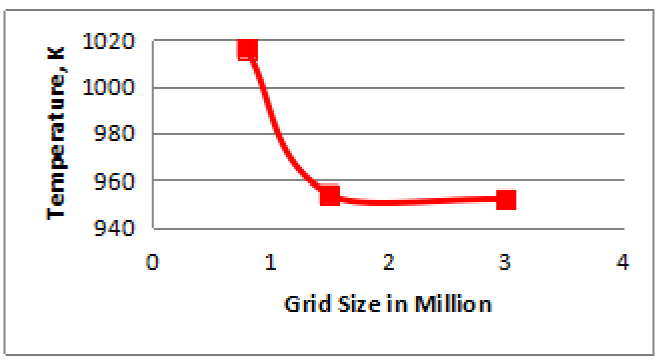

Figure.17 *Grid independent study for the V gutter plotted based on metal Temperature on A2 region.*

RESULTS AND DISCUSSION

The metal temperature of the V-gutter for four configurations are obtained from CHT analysis. The grid size of the configuration-I is 0.5 million. Metal temperature of configuration-I is of the range 711 – 1121 K and is shown in Figure.***18***. The maximum metal temperature obtained is 1121K which is more than the allowable metal temperature of 1100K. The maximum metal temperature is at wake region and this is due to higher load coming on the wake region. The total mass flow passing through the cooling configuration is 0.104kg/s. The grid size of the configuration-II is 1 million. Metal temperature of configuration-II is in the range of 662 – 1092 K and is shown in Figure.***19***. Maximum metal temperature of 1092K is shown in A1 region because of lower coolant side heat transfer coefficient at the Leading edge with two chamber configuration. The maximum metal temperature in wake region is lower than the configuration –I because of the higher coolant side heat transfer coefficient. The total mass flow required for cooling of this configurations is 0.115kg/s. The grid size of the configuration- III is 1.5 million. Metal temperature of configuration-III is in the range of 695 – 1086 K and is shown in Figure.***20***. Maximum metal temperature of 1086K is shown in A1 region. The maximum metal experienced in wake region 954K which is lower than configuration–II this is because of heat transfer enhancement due to 45^0 angled ribs. The mass flow flowing in wake region for is less compared to smooth channel because of higher pressure loss. The total mass flow required for cooling of this configurations is 0.080kg/s. The grid size of the configuration- IV is 1.5 million. Metal temperature of configuration-IV is in the range of 660 – 1064 K and is shown in Figure.***21***. Maximum metal temperature of 1062K is shown in A1 portion because of lower coolant side heat transfer coefficient. The maximum metal experienced in A2 zone is 963K . The total mass flow required for cooling of this configuration is 0.060kg/s.

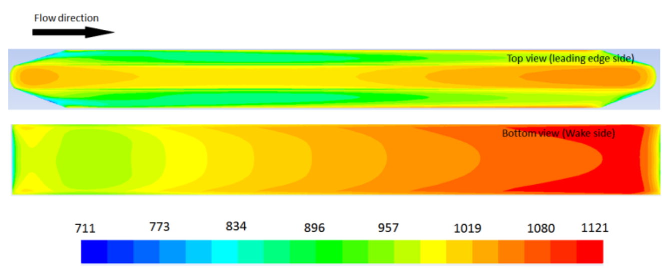

Figure.18 Temperature distribution configuration-I

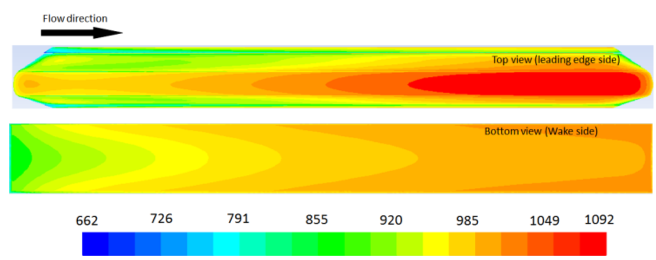

Figure.19 *Temperature distribution of configuration-II*

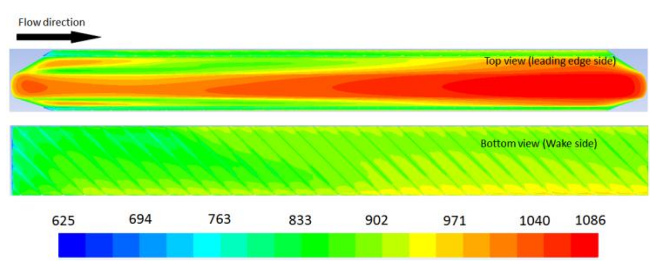

Figure.20 *Temperature distribution of configuration-III*

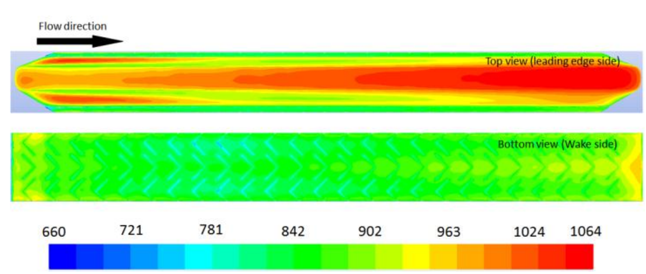

Figure.21 *Temperature distribution of configuration-IV*

Mass flow for all configurations and maximum and average metal temperature are shown in Table.10. Configuration IV is having lowest metal temperature and lowest coolant mass flow requirement compared to other cooling configurations. V shaped ribs provide better heat transfer enhancement with higher pressure loss compared to smooth surface and 45^0 angled ribs. The coolant heat transfer coefficient is maximum for broken V shaped ribs.

Table.10 *Mass flow rate and Metal temperature of different configuration.*

Configurations			1 channel smooth	2 channel smooth	2 channel 45^0 Ribs	2 channel broken-V Ribs
Mass flow rate (kg/s)	A1		0.104	0.018	0.017	0.017
	A2			0.097	0.063	0.043
Metal temperature (K)	A1	Avg.	999	1032	1023	999
		Max.	1049	1091	1085	1062
	A2	Avg.	1016	985	875	848
		Max.	1094	1045	954	963
HTC, (W/m2K)	A1		496	316	355	337
	A2			577	813	829

CONCLUSION

The heat load coming on to the V gutter are estimated at different regions like leading edge, side wall and wake region. The heat load coming on leading edge is higher than to other regions. The heat flux that is the heat load per unit area is more at the wake region due to radiation and convection. Two passage configurations are designed to make the coolant air come near to the wake region and remove heat from the metal. 1D analysis is carried out to choose the width w2 for two passage channel .CHT analysis is carried for w2 of 10mm with A2 passage smooth, 45^0 and V shaped ribs. Configuration-I which is single passage configuration is not meeting the requirement of allowable temperature 1100K. All the configurations II, III and IV are meeting the allowable temperature of 1100K. Configuration IV with broken ribs is best because the mass flow requirement is minimum and the peak metal temperature is lower than the allowable metal temperature of 1100K.

9 Acknowledgments

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