Firewall-Hamed Alsubhi

Firewall is one of the important safety components that is required by the competition such that it acts like a primary shield against fire and explosion from the engine. The current firewall is made of 6061 Aluminum which is one of the most widely used alloys in word because of its good corrosion resistance and weldability. One of the main concerns with the current firewall that emphasizes the need to enhance it is that it is not complying with the thermal resistance requirements listed in the handbook such as adding insulation layers made from non-flammable, heat resistant and non-permeable surface material in order to ensure that the maximum temperature of the firewall surface parallel to the driver compartment does not go beyond 60 C. Also, there are two technical issues with the current firewall that need to be resolved which are finding a way to remove the firewall easily from the vehicle and coming up with a solution for the firewall's sharp corners. All addressed concerns do not require to redesign the main firewall base (the Al 6061 panel) because it already follows a purposeful geometry, and the location of the fuel tank is kept unchanged, so the improvements will be implemented into the existed firewall panel.

Thermal analysis will drive our way to design for the thickness of insulation layers needed to put in the firewall to meet the competition heat resistance requirements. The design process started off by removing the firewall from the vehicle and taking the necessary measurements. Once measurements are taken, the boundary conditions and firewall's regions of concern are determined. Afterwards, a primary thermal analysis for the current firewall is done to have a starting point that would lead on the way to the optimal solution. More thermal analysis sets followed such that each set is done for a certain insulation material. Engineering Equations Solver software (EES) is used to approach the thermal analysis as it can run parametric studies and comparisons on it easily.

Obtaining the minimum insulation thickness that requires to keep the firewall surface adjacent to the driver compartment as maximum as 60 C is the goal. Choosing the final insulation material is dependent on the many things, including the thickness required, weight and cost. The selected material would be the one that minimize mass, thickness required and cost. Finally, a section will be dedicated to address the suggested solutions for the firewall's technical issues (removability and sharp edges).

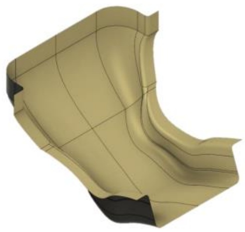
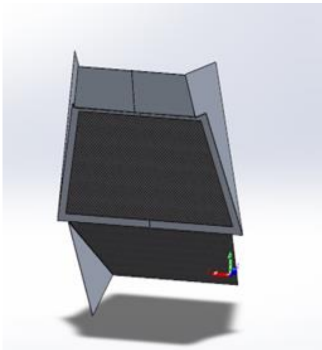
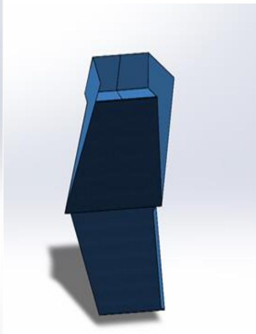
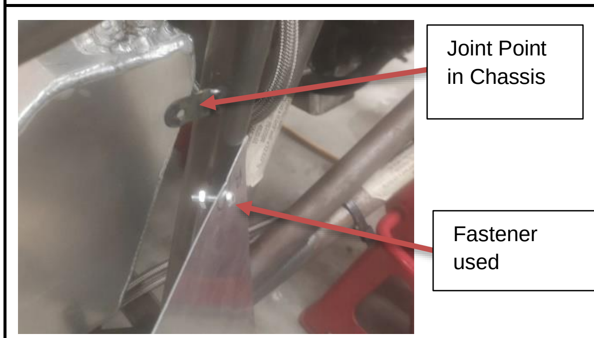
  	Pros: -The firewall and the seat are connected as one-piece which would make it easier to remove -All heat resistance requirement is accounted for in the seat itself. Cons: -This solution cannot be applied for our case because the seat is already designed and making a new seat with the firewall on it is very expensive. Source: https://www.ergofoundation.org/images/Bailey_Herbstreit_%20Seat_and_Firewall.pdf

Table 1: Researched designs with pros and cons

<table>
<tr>
<td>




</td>
<td>The images in the left show the current assembly of the firewall as well as the actual one installed in the car. The current firewall is made of Al 6061 and made as 4 main separate pieces. The current firewall follows a well purposeful geometry and does not require to reassemble. The two middle pieces are the parts of interest, and the insulation layers will be added to.</td>
</tr>
<tr>
<td>


</td>
<td>This image shows the sharp edges of the current firewall that would cut you easily if you made. Section (2) of this paper shows a suggested solution for the problem</td>
</tr>
<tr>
<td>


</td>
<td>The firewall is rigidly mounted using the fasteners shown in the image. The issue embodies in the difficulty to remove it from the car to access the engine compartment Section (2) of this paper shows a suggested solution for the problem</td>
</tr>
</table>

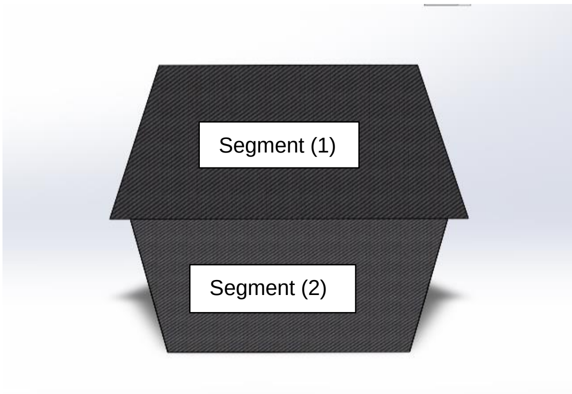
 	The image in the left shows the firewall segments into which the insulation layers will be added. -Dimensions of segment 1: A_1 = 0.2236 m^2 Thickness of 6061 Al panel= 0.635 mm a= top width =0.48 m b = bottom width = 0.67 m h = highest = 0.37m sideline length = 0.4 m -Dimensions of segment 2: A_2 = 0.1984 m^2 Thickness 6061 Al panel= 0.635 mm a_2= 0.59 m b_2 = 0.45 m h_2 =0.38 m sideline length = 0.39 m -Total Surface Area: A = 0.422 m^2

Table 2: Current setup and design parameter

Section (1): Thermal Analysis
First Set (1, 2, 3)
Second Set (1,2, 3(3-1,3-2,3-3), 4(4-1,4-2)
Section (2): Solutions For the technical problem
Conclusion
Appendix (I, II)

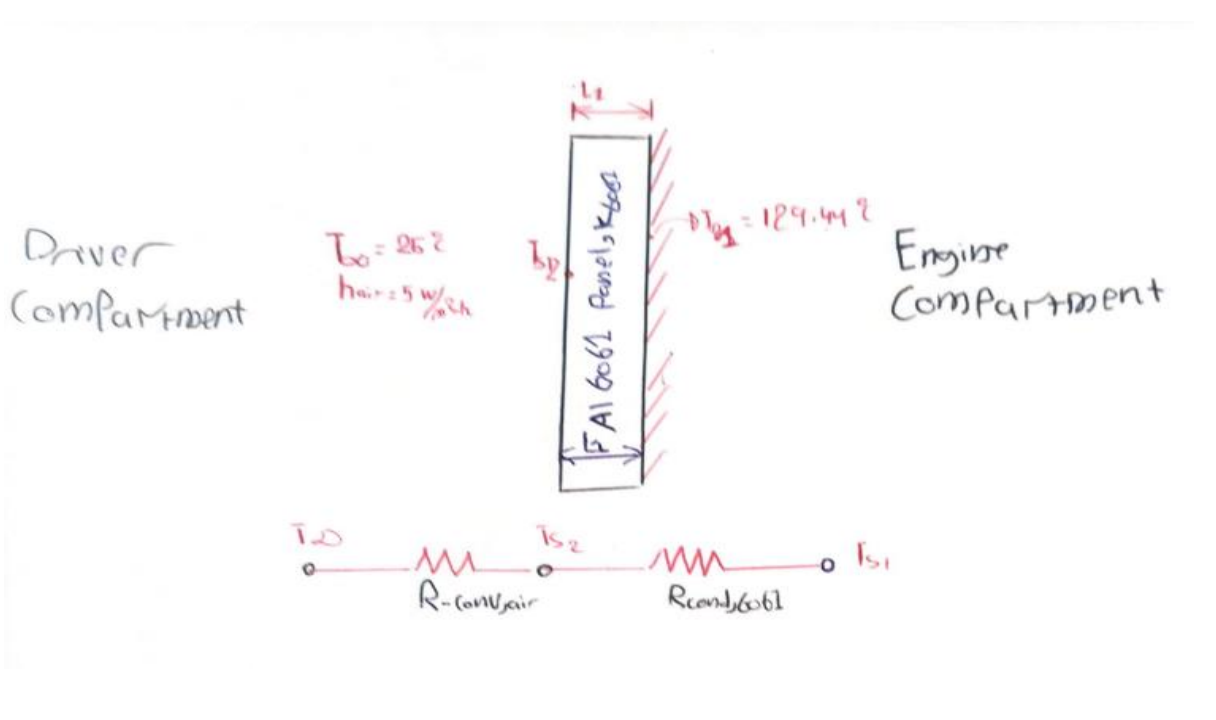
Table 3: Upcoming Content arrangement:

Section (1): Thermal Analysis to determine the thickness of insulation layer on the two segments demonstrated above

First Set: For the current firewall

1) Boundary conditions and assumptions:

The thermal resistance analogy will be used to determine the heat flux across the current firewall and evaluating the surface temperature of the side adjacent to the driver compartment. The thermal resistance network method is valid given assumptions. Below are the assumptions and boundary conditions used for the first analysis set which will be the same for the second set.



Assumptions / Boundary Conditions	Justification if needed / Notes
1-D heat transfer	The cross-sectional area of the object in the direction of heat flow is constant
Constant materials property	Assuming thermal conductivity is constant
Steady state condition	--
Radiation Losses are negligible	Heat loss due to radiation is a major one but it can be neglected for conservatism such that it will result in having larger insulation thickness than if it was accounted for (see appendix II)
The surface temperature adjacent to the engine compartment, Ts_2, is fixed at 265 F (402.59 K)	According to a study done by SAE, the temperature of the engine outer walls can reach 256 F under limited throttle (source: https://vehq.com/how-hot-does-a-combustion-chamber-get-in-a-vehicle/).

	Fixing the surface temperature at 256 F features a conservative approach such that in an ideal situation, there would be free convection from the engine walls to the firewall (assuming the car is not moving). The insulation thickness required will be found for this fixed temperature scenario
The ambient temperature, T_inf, is set to be 25 C.	________________________________
The surface temperature of the side adjacent the driver Ts_1 will be set to 60 C	The main goal of this thermal analysis is making sure to keep Ts_1 at or below 60 C. The first set analysis will investigate how the current firewall deviates from this required temperature. The second set will be design problems to meet 60 C.
The free convective heat transfer coefficient of air , h_air is set to be 5 W/m^2-K	The convective heat transfer coefficient of free convection air ranges from 5 to 20 W/m^2-K. Selecting 5 by assuming the car is not moving(conservative)

2) Definitions of the parameters used for the first analysis set:

A [m^2]	Total surface area of the two segments
K_6061 [W/ m-K[]	Thermal conductivity of Al 6061
L_1 [m]	Thickness of the aluminum panel
T_inf [K]	The Ambient temperature
h_conv_air [W/m^2-K]	Convective heat transfer coefficient of air
Q_current [W]	Thermal power across the current firewall
Ts_1 [K]	Surface temperature of the side adjacent to Engine compartment
Ts_2 [K]	Surface temperature of the side adjacent to the driver compartment
R_total_current [K/W]	Total thermal resistance of current firewall
R_cond_6061 [K/W]	Conductive thermal resistance of Al6061
R_conv_air [K/W]	Convective thermal resistance of air

3) Calculations to find Q_current and Ts_2:

File:C:\Users\Dell\Desktop\Final Firewall\Current_Firewall_Alsubhi.EES 12/1/2022 6:31:17 PM Page 1
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```
//Case (1) :  Heat flux across the current firewall and surface Temperature, T_s_2:
A = 0.422 [m^2]
k_6061 = 166 [W/K-m]
L_1= 0.635/1000
T_inf = 298.15 [K]
Ts_1= 402.59[K]
T_delta= Ts_1-T_inf
h_conv_air = 5 [W/m^2*K]
 //Thermal Resistances connected in series:
R_cond_6061 = L_1/(K_6061*A)
R_conv_air = 1/(h_conv_air *A)
R_total_current = R_cond_6061+R_conv_air
 // Heat power across the wall and the surface temperature T_s_2
Q_current = T_delta/ R_total_current
Ts_2 = R_conv_air *Q_current +T_inf
```

$A = 0.422$ [m^2]

$k_{6061} = 166$ [W/K-m]

$$L_1 = \frac{0.635}{1000}$$

$T_{inf} = 298.15$ [K]

$Ts_1 = 402.59$ [K]

$$T_\delta = Ts_1 - T_{inf}$$

$h_{conv,air} = 5$ [W/m^2*K]

$$R_{cond,6061} = \frac{L_1}{k_{6061} \cdot A}$$

$$R_{conv,air} = \frac{1}{h_{conv,air} \cdot A}$$

$$R_{total,current} = R_{cond,6061} + R_{conv,air}$$

$$Q_{current} = \frac{T_\delta}{R_{total,current}}$$

$$Ts_2 = R_{conv,air} \cdot Q_{current} + T_{inf}$$

SOLUTION

Unit Settings: SI K Pa J mass rad

$A = 0.422$ [m^2]	$h_{conv,air} = 5$ [W/m^2*K]
$k_{6061} = 166$ [W/K-m]	$L_1 = 0.000635$ [m]
$Q_{current} = 220.4$ [W]	$R_{cond,6061} = 0.000009065$ [K/W]
$R_{conv,air} = 0.4739$ [K/W]	$R_{total,current} = 0.4739$ [K/W]
$Ts_1 = 402.6$ [K]	$Ts_2 = 402.6$ [K]
$T_\delta = 104.4$ [K]	$T_{inf} = 298.2$ [K]

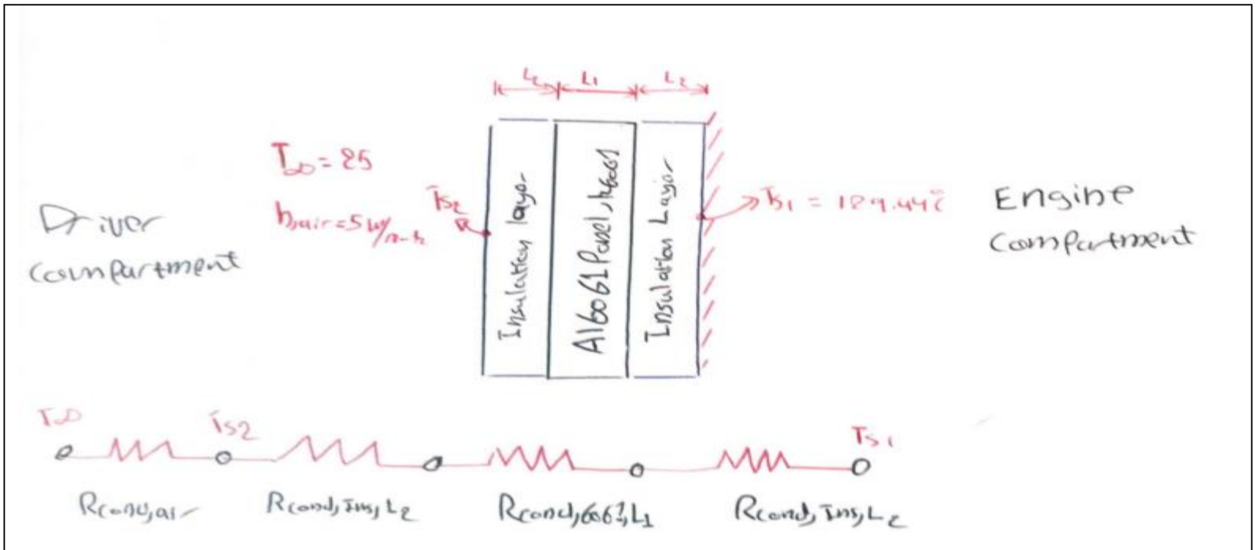
No unit problems were detected.

Results explanation: The thermal power across the firewall is found to be 220.4 W and Ts_2 is equal to Ts_1 = 402.6 (129 C) which deviates enormously from the minimum temperature that surface (2) must be kept at. This is because the current thermal conductive resistance is insufficient since it's only dependent on the Al 6061 panel which has a relatively high conductivity (K-6061 = 166 [W/m-K]). There is an inverse relationship between conductivity and thermal resistance ($R\alpha\frac{1}{K}$), and since we are not planning to rebuild the base shield of firewall (The 6061-aluminum panel), we will add a low conductivity insulation layers to the shield from both sides. Having said that, a research done to see what type of material is commonly used in automotive heat insulation applications. The research highlighted three types of material, including e-glass fiber, glass wool and carbon fiber. Each of which has low conductivity and satisfies the rules regarding the nonflammability and heat resistance. The three selected materials will be analyzed in the second set to find the minimum required insulation layer for the same boundaries and assumptions stated for the first set. The selection of the final material will be based on the thickness required, cost and weight.

Second Set: To choose the preferable insulation material

1) Boundary conditions and assumptions

The same boundary conditions and assumptions for the first set are followed for the this set as well, but the thermal resistance setup is different as the conductive thermal resistance of insulation layer is added. The new problem setup is shown below.



2) Definitions of the parameters used for the second analysis set:

A [m^2]	Total surface area of the two segments
K_6061 [W/ m-K[]	Thermal conductivity of Al 6061
L_1 [m]	Thickness of the aluminum panel
L_2 [m]	Thickness of the insulation layer per side
T_inf [K]	The Ambient temperature
h_conv_air [W/m^2-K]	Convective heat transfer coefficient of air
Q_current [W]	Thermal power across the current firewall
Ts_1 [K]	Surface temperature of the side adjacent to Engine compartment
Ts_2 [K]	Surface temperature of the side adjacent to the driver compartment
R_cond_6061 [K/W]	Conductive thermal resistance of Al6061
R_conv_air [K/W]	Convective thermal resistance of air
Q_CF [W]	Thermal power across the firewall after applying the required thickness of carbon fiber insulation
R_cond_CF [K/W]	The conductive thermal resistance of carbon fiber per side
R_total_CF [K/W]	The total thermal resistance of the firewall when carbon fiber is used as the insulation material
Q_GW [W]	Thermal power across the firewall after applying the required thickness of glass wool insulation
R_cond_GW [K/W]	The conductive thermal resistance of glass wool per side
R_total_GW [K/W]	The total thermal resistance of the firewall when glass wool is used as the insulation material
Q_GF [W]	Thermal power across the firewall after applying the required thickness of E-glass fiber insulation
R_cond_GF [K/W]	The conductive thermal resistance of E-Glass fiber per side
R_total_GF [K/W]	The total thermal resistance of the firewall when E-glass fiber is used as the insulation material

3: Calculations to find the preferable insulation material:

3_1: Calculations to find the thickness required when using carbon fiber as the insulation material:

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```
// 1st solution solution: add 2 insulation layers of carbon fiber of L_2 meters thickness, the following calculations are done
to find L_2 required to comply with the rules

//Knowns given:
A = 0.422 [m^2] // The total  surface area on which we aim to insulate
L_1= 0.635/1000  // thickness of the main aluminum firewall base
k_6061 = 166 [W/K-m]
k_CF = 0.84 [W/K-m]

T_inf = 298.15 [K]
Ts_1= 402.59[K]
Ts_2 = 333.15 [K]
T_delta= Ts_1-T_inf

h_conv_air = 5 [W/m^2*K]

//Thermal Resistances connected in series:
R_cond_6061 = L_1/(K_6061*A)
R_conv_air = 1/(h_conv_air *A)
R_cond_CF = L_2/( A*k_CF)

 // the sumation of the thermal resitsnaces in the wall
R_total_CF= R_cond_6061+ R_conv_air + ( 2*R_cond_CF)  // multiplied by 2 indicates that the firewall insulated from
both side with equal thickness of carbon fiber layer

 // Thermal power:
Q_CF= T_delta/ R_total_CF

 // Surfcae temperature 2:
Ts_2 =(-  (  2* R_cond_CF+R_cond_6061)*Q_CF ) +Ts_1
```

$A = 0.422$ [m^2]

$$L_1 = \frac{0.635}{1000}$$

$k_{6061} = 166$ [W/K-m]

$k_{CF} = 0.84$ [W/K-m]

$T_{inf} = 298.15$ [K]

$Ts_1 = 402.59$ [K]

$Ts_2 = 333.15$ [K]

$$T_\delta = Ts_1 - T_{inf}$$

$h_{conv,air} = 5$ [W/m^2*K]

$$R_{cond,6061} = \frac{L_1}{k_{6061} \cdot A}$$

$$R_{conv,air} = \frac{1}{h_{conv,air} \cdot A}$$

$$R_{cond,CF} = \frac{L_2}{A \cdot k_{CF}}$$

$$R_{total,CF} = R_{cond,6061} + R_{conv,air} + 2 \cdot R_{cond,CF}$$

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$$Q_{CF} = \frac{T_{\delta}}{R_{total,CF}}$$

$$Ts_2 = -(2 \cdot R_{cond,CF} + R_{cond,6061}) \cdot Q_{CF} + Ts_1$$

SOLUTION

Unit Settings: SI K Pa J mass rad

$A = 0.422$ [m^2]

$h_{conv,air} = 5$ [W/m^2*K]

$k_{6061} = 166$ [W/K-m]

$k_{CF} = 0.84$ [W/K-m]

$L_1 = 0.000635$ [m]

$L_2 = 0.1667$ [m]

$Q_{CF} = 73.85$ [W]

$R_{cond,6061} = 0.000009065$ [K/W]

$R_{cond,CF} = 0.4701$ [K/W]

$R_{conv,air} = 0.4739$ [K/W]

$R_{total,CF} = 1.414$ [K/W]

$Ts_1 = 402.6$ [K]

$Ts_2 = 333.2$ [K]

$T_{\delta} = 104.4$ [K]

$T_{inf} = 298.2$ [K]

No unit problems were detected.

Results: thickness required per side to keep the temperature at 60 C is L_2 = 0.1667m which is , from a first look, hard to manufacture for the given boundary conditions.

3_2: Calculations to find the thickness required when using glass wool as the insulation material:

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```
// 2st  solution: add 2 insulation layers of glass wool of L_2 meters thickness, the following calculations are done to find L_2 required to comply with the rules

//Knowns given:
A = 0.422 [m^2] // The total  surface area on which we aim to insulate
L_1= 0.635/1000  // thickness of the main aluminum firewall base
k_6061 = 166 [W/K-m]
k_GW = 0.04 [W/K-m]

T_inf = 298.15 [K]
Ts_1= 402.59[K]
Ts_2 = 333.15 [K]
T_delta= Ts_1-T_inf

h_conv_air = 5 [W/m^2*K]

//Thermal Resistances connected in series:
R_cond_6061 = L_1/(K_6061*A)
R_conv_air = 1/(h_conv_air *A)
R_cond_GW = L_2/( A*k_GW)

 // the sumation of the thermal resitsnaces in the wall
R_total_GW= R_cond_6061+ R_conv_air + ( 2*R_cond_GW)

 // Thermal power:
Q_GW= T_delta/ R_total_GW

 // Surfcae temperature 2:
Ts_2 =(- ( 2* R_cond_GW+R_cond_6061)*Q_GW ) +Ts_1
```

$A = 0.422$ [m^2]

$L_1 = \dfrac{0.635}{1000}$

$k_{6061} = 166$ [W/K-m]

$k_{GW} = 0.04$ [W/K-m]

$T_{inf} = 298.15$ [K]

$Ts_1 = 402.59$ [K]

$Ts_2 = 333.15$ [K]

$T_\delta = Ts_1 - T_{inf}$

$h_{conv,air} = 5$ [W/m^2*K]

$R_{cond,6061} = \dfrac{L_1}{k_{6061} \cdot A}$

$R_{conv,air} = \dfrac{1}{h_{conv,air} \cdot A}$

$R_{cond,GW} = \dfrac{L_2}{A \cdot k_{GW}}$

$R_{total,GW} = R_{cond,6061} + R_{conv,air} + 2 \cdot R_{cond,GW}$

$Q_{GW} = \dfrac{T_\delta}{R_{total,GW}}$

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$$Ts_2 = -(2 \cdot R_{cond,GW} + R_{cond,6061}) \cdot Q_{GW} + Ts_1$$

SOLUTION

Unit Settings: SI K Pa J mass rad

$A = 0.422$ [m^2]	$h_{conv,air} = 5$ [W/m^2*K]
$k_{6061} = 166$ [W/K-m]	$k_{GW} = 0.04$ [W/K-m]
$L_1 = 0.000635$ [m]	$L_2 = 0.007936$ [m]
$Q_{GW} = 73.85$ [W]	$R_{cond,6061} = 0.000009065$ [K/W]
$R_{cond,GW} = 0.4701$ [K/W]	$R_{conv,air} = 0.4739$ [K/W]
$R_{total,GW} = 1.414$ [K/W]	$Ts_1 = 402.6$ [K]
$Ts_2 = 333.2$ [K]	$T_{\delta} = 104.4$ [K]
$T_{inf} = 298.2$ [K]	

No unit problems were detected.

Results: Thickness required per side to keep the temperature at 60 C is L_2 = 0.007936 m. See Appendix (I) for a parametric study done to find thickness of the E-glass Fiber insulation. Also, this study demonstrates the relationship of total thermal resistance versus Q and Ts-2.

3_3: Calculations to find the thickness required when using E-Glass Fiber as the insulation material

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```
// 3st  solution: add 2 insulation layers of E Glass Fiber of L_2 meters thickness, the following calculations are done to find
L_2 required to comply with the rules

//Knowns given:
A = 0.422 [m^2] // The total  surface area on which we aim to insulate
L_1= 0.635/1000  // thickness of the main aluminum firewall base
k_6061 = 166 [W/K-m]
k_GF = 0.03 [W/K-m]

T_inf = 298.15 [K]
Ts_1= 402.59[K]
Ts_2 = 333.15 [K]
T_delta= Ts_1-T_inf

h_conv_air = 5 [W/m^2*K]

//Thermal Resistances connected in series:
R_cond_6061 = L_1/(K_6061*A)
R_conv_air = 1/(h_conv_air *A)
R_cond_GF = L_2/( A*k_GF)

 // the sumation of the thermal resitsnaces in the wall
R_total_GF= R_cond_6061+ R_conv_air + ( 2*R_cond_GF)

 // Thermal power:
Q_GF= T_delta/ R_total_GF

 // Surfcae temperature 2:
Ts_2 =(- ( 2* R_cond_GF+R_cond_6061)*Q_GF ) +Ts_1
```

$A = 0.422 \quad [m^2]$

$L_1 = \frac{0.635}{1000}$

$k_{6061} = 166 \quad [W/K\text{-}m]$

$k_{GF} = 0.03 \quad [W/K\text{-}m]$

$T_{inf} = 298.15 \quad [K]$

$Ts_1 = 402.59 \quad [K]$

$Ts_2 = 333.15 \quad [K]$

$T_\delta = Ts_1 - T_{inf}$

$h_{conv,air} = 5 \quad [W/m^2{*}K]$

$R_{cond,6061} = \frac{L_1}{k_{6061} \cdot A}$

$R_{conv,air} = \frac{1}{h_{conv,air} \cdot A}$

$R_{cond,GF} = \frac{L_2}{A \cdot k_{GF}}$

$R_{total,GF} = R_{cond,6061} + R_{conv,air} + 2 \cdot R_{cond,GF}$

$Q_{GF} = \frac{T_\delta}{R_{total,GF}}$

File:(Untitled) 12/1/2022 2:52:37 PM Page 2

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$$Ts_2 = -(2 \cdot R_{cond,GF} + R_{cond,6061}) \cdot Q_{GF} + Ts_1$$

SOLUTION

Unit Settings: SI K Pa J mass rad

$A = 0.422$ [m^2]

$k_{6061} = 166$ [W/K-m]

$L_1 = 0.000635$ [m]

$Q_{GF} = 73.85$ [W]

$R_{cond,GF} = 0.4701$ [K/W]

$R_{total,GF} = 1.414$ [K/W]

$Ts_2 = 333.2$ [K]

$T_{inf} = 298.2$ [K]

$h_{conv,air} = 5$ [W/m^2*K]

$k_{GF} = 0.03$ [W/K-m]

$L_2 = 0.005952$ [m]

$R_{cond,6061} = 0.000009065$ [K/W]

$R_{conv,air} = 0.4739$ [K/W]

$Ts_1 = 402.6$ [K]

$T_{\delta} = 104.4$ [K]

No unit problems were detected.

Results: Thickness required per side to keep the temperature at 60 C is L-2 = 0. 0.005952m

4: Results summary and Optimal material selection:

4_1: Summary of the Results and important material properties:

Insulation Material	Density [Kg/m^3]	Conductivity (W/m^2-K)	Cost [$/kg]	Thickness per side
Carbon Fiber	1780	8.4	55	0.1667
Glass Wool	20	0.04	3	0.007936
E-Glass Fiber	2600	0.03	180	0.005952

For the given boundary conditions, the glass wool is the preferable material to use as an insulation for the firewall because of its price and thickness. Even if the E-Glass Fiber found to have a lower thickness required than of that in glass wool, it is much more expensive than the glass wool, and it would weigh much more for the obtained thickness. The carbon fiber is excluded from the comparison because of its impossible manufacturability for the given boundary conditions as well as its high cost.

Summary of the Glass Wool Insulation Layer that will be installed:

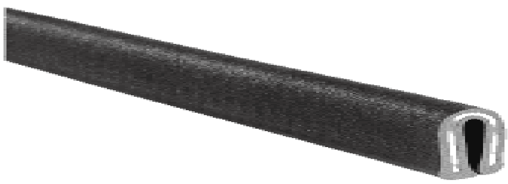
Insulation Matetrial	Density [Kg/m^3]	Conductivity (W/m^2-K)	Cost[$/kg]	Thickness per side	Total Mass in both sides[kg]
Glass Wool	20	0.04	3	0.007936	0.13395968

It’s readily available for the obtained thickness (8mm) in this store: https://www.indiamart.com/proddetail/fiber-glass-wool-24304783330.html

4_2: Statement of uncertainty and Future considerations for next semester:

The boundary conditions set to estimate the required insulation thickness was a little conservative but gives a very good feeling of the material selection. Carbon fiber is usually a preferable material for this type of applications because of its strength to weight ratio despite of its cost, but the current boundaries setup results in having unmanufacturable thickness. The fixed temperature condition in firewall surface facing the engine compartment at about 400 Kelvin, which is the temperature of the engine outer surface, is a conservative take as well, but not unlikely to happen. The heat coming from engine walls would radiate and convict so will reach at a lower temperature to the firewall. Check appendix (II) for a considerable future setup that would account for dissipated heat due to convection and radiation.

Section (2): Suggested solutions for the two technical problems:

 	**Firewall's sharp edges problem:** This problem can be easily solved by sealing the edges with rubber edge trim (sharp edge protector) as shown in the left images. This product is readily available on Amazon for a very cheap price: https://www.amazon.com
 	**Firewall's difficulty to remove:** Any suggested solution must satisfy the rules book which require the firewall to be rigidly mounted in a fixed way, without bending or moving. This problem may be resolved by using the Easy-On-Off-Hard-Top Fasteners shown in the left images. These fasteners can be removed easily and quickly by hand without any tool as well as improving the appearance. We can minimize the number of the fasteners used to mount the firewall into the chassis by selecting a new purposeful joint point. The old joint points can be sealed using any heat resistant tape since they are very tiny. This product is readily available on Amazon for different sizes: https://www.amazon.com

Conclusion

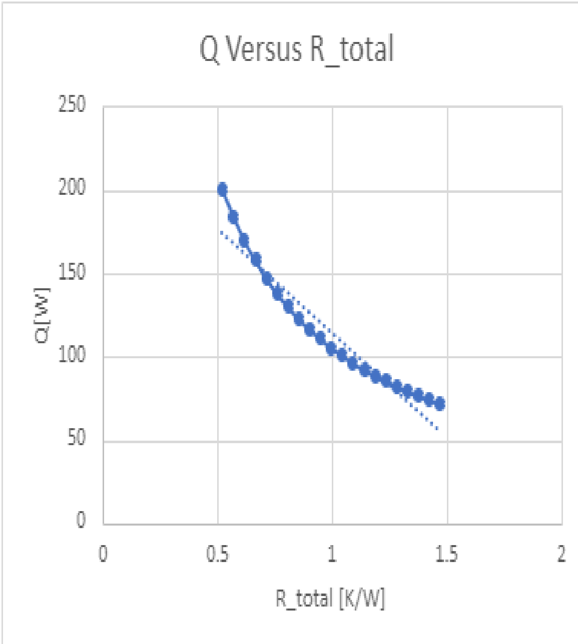
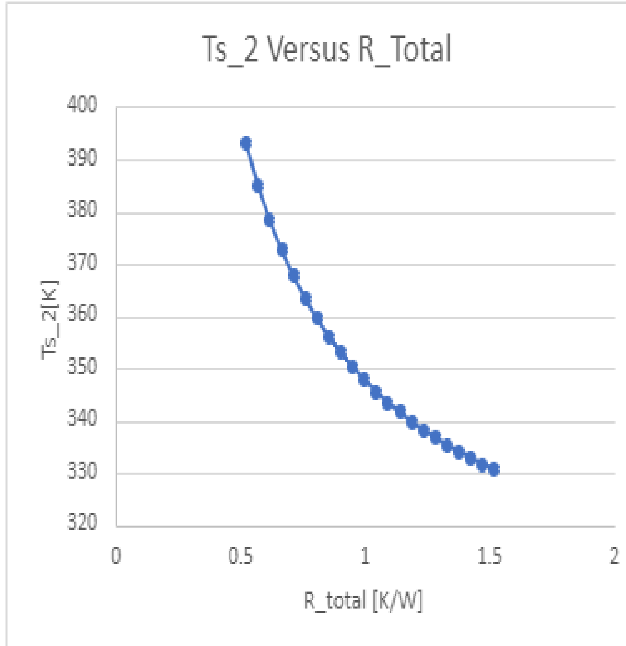
The current firewall has three main issues. The first issue is a core one since it is safety-related such that it has to do with F-SAE rules requirement regarding heat resistance which is that the firewall surface facing the driver compartment must be at or below 60 degrees Celsius. This problem is encountered by running thermal analysis to find a suitable insulation material meeting the requirement. For a given set of boundary conditions, the preferable insulation material was selected to be Glass Wool for its cheapness and light weight. The other two problems were basically technical issues and not rules-incompliant, including the fire wool has sharp edges and it’s not easy to remove. The sharp edges problem may be resolved by using rubber edge trim, and the removability issue may be resolved using the Easy-On-Off-Hard-Top Fasteners. The two solutions are readily available. Considerations may be taken in future is doing a study to account for the radiative effect and how the overall resistance increases by doing so; thus, the required thickness for the same material analyzed could get way lower.

Appendix

Appendix [I]:

Parametric study done to obtain the thickness required when using E-Glass Fiber as the insulation material for the firewall

Delta_T	104.4		T_S_1 = 402.59	
L_2(meters)	R_T [K/W]	R_GF	Q (W)	Ts_2
0.0003	0.52130243	0.02369668	200.2676	393.0968
0.0006	0.568695795	0.04739336	183.5779	385.1876
0.0009	0.61608916	0.07109005	169.456	378.4952
0.0012	0.663482525	0.09478673	157.3515	372.7589
0.0015	0.71087589	0.11848341	146.8611	367.7875
0.0018	0.758269255	0.14218009	137.682	363.4375
0.0021	0.80566262	0.16587678	129.5828	359.5993
0.0024	0.853055984	0.18957346	122.3835	356.1876
0.0027	0.900449349	0.21327014	115.9421	353.135
0.003	0.947842714	0.23696682	110.1449	350.3876
0.0033	0.995236079	0.26066351	104.8997	347.902
0.0036	1.042629444	0.28436019	100.1315	345.6423
0.0039	1.090022809	0.30805687	95.77781	343.5791
0.0042	1.137416174	0.33175355	91.78698	341.6879
0.0045	1.184809539	0.35545024	88.11543	339.9479
0.0048	1.232202904	0.37914692	84.72631	338.3418
0.0051	1.279596269	0.4028436	81.58823	336.8547
0.0054	1.326989634	0.42654028	78.67431	335.4738
0.0057	1.374382999	0.45023697	75.96136	334.1881
0.006	1.421776364	0.47393365	73.42927	332.9881
0.0063	1.469169729	0.49763033	71.06054	331.8656
0.0066	1.516563093	0.52132701	68.83987	330.8132

	
Heat flux across the firewall and temperature of the side adjacent to driver compartment decreases as the thermal resistance increases because the conductive thermal resistance increases as more insulation layer of thickness L-2 is added	

Appendix II:

Here is the suggested future setup if radiation effect is considered