# 

# **CL246 - Heat Transfer End Term Report 2022**

**Optimizing Heat Transfer   
In Headgear**

**GROUP 17**

200020073 Love Jaiswal Generator

200020099 Pratham Sanghvi Generator

200020098 Prashul Vaishnav Solver

200020063 Jeewan Chandra Joshi Solver

200020007 Abhishek Malyan Planner

200020137 Shubham Sharma Planner

200020016 Agrim Gupta Ideator

200020165 Vishal Kumar Meena Ideator

**Instructors:**

Prof. P. Sunthar, *Department of Chemical Engineering*

Prof. Venkat Gundabala, *Department of Chemical Engineering*

**ACKNOWLEDGEMENT**

We left no stones unturned for the successful completion of the project. The completion of this undertaking would not have been possible without the assistance of so many people whose names may not all be enumerated. Their contribution is sincerely appreciated and significantly acknowledged.

We take this opportunity to express our profound gratitude and regards to our course instructors, **Prof. Venkat Gundabala** and **Prof. P. Sunthar,** for all their guidance, monitoring, and encouragement throughout this project. We would also like to thank them for their critical comments and advice, which boosted every team member’s morale to give their best possible to this project.

We also extend our acknowledgment to our **batchmates** and **friends** for all their technical support and timely critique, which helped us to finish the project within the deadline.

**Table of Contents**

| Content |
| --- |
| ACKNOWLEDGEMENT |
| INTRODUCTION |
| USER STORY |
| PROBLEM STATEMENT   1. Problem Description 2. Technical Problem Statement |
| Design Explanation   1. Current market available model 2. Our proposed model |
| Solution & Methodology  Thermal analysis of market **available** helmet   * Control Volume 1 * Control volume 2 |
| Thermal analysis of our **proposed** helmet   * Control Volume 1 * Control volume 2 |
| Conclusion |
| Appendix |
| BIBLIOGRAPHY |

**INTRODUCTION**

Headgear generally refers to everything one can wear on the head. Most studies focus on headgear designed to have specific impact protective properties. Such headgear is often referred to as a helmet.

Riding a motorcycle gives riders a sense of freedom on the open road. However, there are serious dangers involved in riding without a helmet. A bike does not provide the structural protection that a car does to keep drivers safe in the event of an accident. Motorcyclists need to take extra precautions to protect their bodies. The most important place to start is by protecting the head.

Without protection, the head is vulnerable to a traumatic impact in an accident, even when traveling at low speeds. Two-wheeler rider deaths comprise 34–71% of all accident deaths in India. Worldwide, road traffic crashes contribute to nearly 1.35 million deaths and 50 million non-fatal injuries every year. One-fourth of road traffic deaths are among motorcyclists.

Modern helmets are constructed from plastics, and premium price helmets are made with fiberglass reinforced with Kevlar or Carbon fiber. They usually have fabric and foam interiors for both comfort and protection. Helmets are constructed from EPS foam and an outer shell to protect EPS.

Drivers and passengers wearing helmets increase their chance of survival significantly over non-helmet wearers in case of an accident.

It is crucial for motorcyclists to understand the risks of riding without a helmet.



USER STORY

India is home to numerous road accidents, and it is due to negligence in most cases. Motorcycle crashes are the cause of severe morbidity and mortality, primarily because of the lack of safety provided in a car and increased chances of head injuries. The mortality rate due to motorcycle accidents in India has been a staggering 27%, leaving behind countless injured and left disabled for life.

Wearing a helmet has an effective role in protecting against head injuries. Nevertheless, motorcyclists usually have no tendency to wear a helmet when driving in cities. When asked why they did not wear a helmet, 71.4% of the people responded with a ‘feeling of heat’ among other issues.

Hence, our group has set out to solve this problem by designing a helmet that ensures increased heat transfer without compromising the safety of the motorcyclist. We start by researching the basic structural design and understanding how heat transfer works and how we can enhance it in our new design to help keep the helmet cool even under the scorching sun. We hope we can get more clarity on the shortcomings of the traditional helmet and find a suitable solution that will encourage more people to wear a helmet.



# **PROBLEM STATEMENT**

3.1 Problem Description

The upper layer of headgear, from sun irradiation, gets warm-up, raising the upper body temperature. Also, because there is not much ventilation between the fabric and head, the vapours (sweat) get accumulated, which does not allow the cooling of the head (since evaporation of sweat helps in cooling the temperature of the skin). These two can be the effects that keep increasing the head equipment temperature when it is worn for a longer time than simultaneously raising the head temperature. This may lead to uneasiness and could cause distress to the wearer. The methodology is to plan a distant better headgear show which might keep the headgear cool for a longer duration of time. Or it may well be expressed that the sum of heat generated in a specific sum can be diminished with regard to the ordinary helmet.

The design of the currently available headgear available in the market and the model we are discussed in the next section.



3.2 Technical Problem Statement

Consider the helmet is shaped to be **hemispherical**. Given the below data about headgear and description of the market existing helmets and our model, we propose to calculate:

1. Calculate the surface temperature above the head in both cases.
2. Calculate the temperature of the skin in both cases. Using this result gives a judgment about using the given model over the market available model.

**NOTE:** Show the complete solution starting by constructing a control volume of the headgear and explicitly highlighting the modes of heat transfer. Assume that the Headgear is made up of Carbon fiber.

Take the following data as the known variables.

*Emissivity of carbon fiber:* ***ε = 0.98,***

*Absorptivity of carbon fiber* ***: 𝛂 = 0.65 m2/s,***

*Stefan’s constant****: 𝛔 = 5.67 × 10-5 W/m2.K4***

*Conductivity of air:*  ***Kair = 0.025 W/(m\*K),***

*Inner radius of headgear* ***: r1 = 13.125cm,***

*Outer radius of headgear* ***: r2 = 17.125cm,***

*Solar constant* ***: Gsun = 1380 W/m2,***

*Area of head:*  ***A = 0.050 m2,***

*Conductivity of Thermocol:* ***Kthr = 0.0245 W/(m.K),***

*Temperature of Thermocol:* ***Th = 37o C,***

*Ambient air temperature:* ***Ta = 40℃,***

*Wind speed (Air velocity):* ***u∞ = 40 km/h,***

*Specific Heat Capacity of Carbon fiber:* ***Cpc = 900 J/kgK****,*

*Transmissivity of glass fiber:*  ***= 0.98,***

*Specific heat of skin:* ***Cps = 3390 J/kg.K,***

*Latent heat of vaporization of sweat:*  ***h****fg* ***= 2260 KJ/kg,***

*Density of air:* ***𝞺 = 1.225 kg/m^3***

# Design Explanation

# Current market available model:

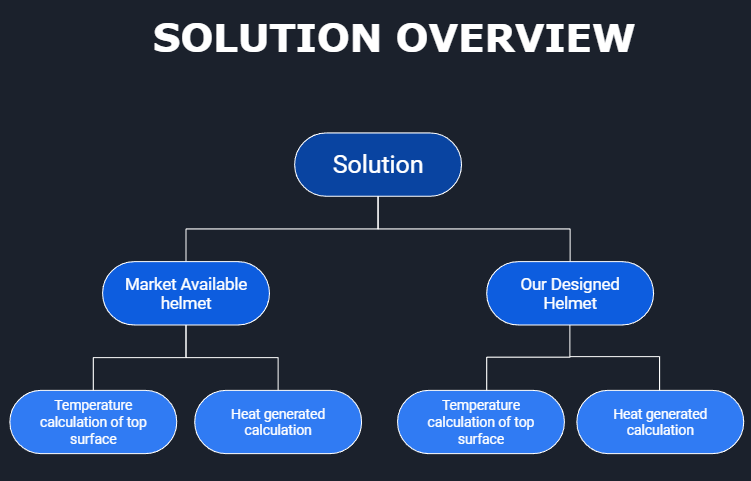
1. Usually consists of a shell made up of fiberglass, polycarbonate, or carbon fiber. It is the outermost layer and takes maximum impact during hit
2. There is no system for air ventilation in the current helmet, which would decrease the rider's discomfort.
3. A comfort liner is present. An antibacterial fiber is used to absorb sweat. Cheek pads are made of the same material as comfort fiber and are present to keep the helmet in place while riding the bike.
4. A visor is current to shield the face from dust and rain while providing visibility to the rider.

II. Our proposed model:

1. The model consists of a radiative shield of the lead blanket above the carbon black layer, which is headgear material to reduce the radiation through radiative shielding. The shielding layer remains in contact with the headgear surface.

# Air vents are created of a particular type in the periphery of the headgear (reason of the same is explained in hypothesis), which provide airflow through it. These vents start at the front and end at the back of the helmet and are designed to take water vapor generated inside the helmet due to body heat along with airflow.

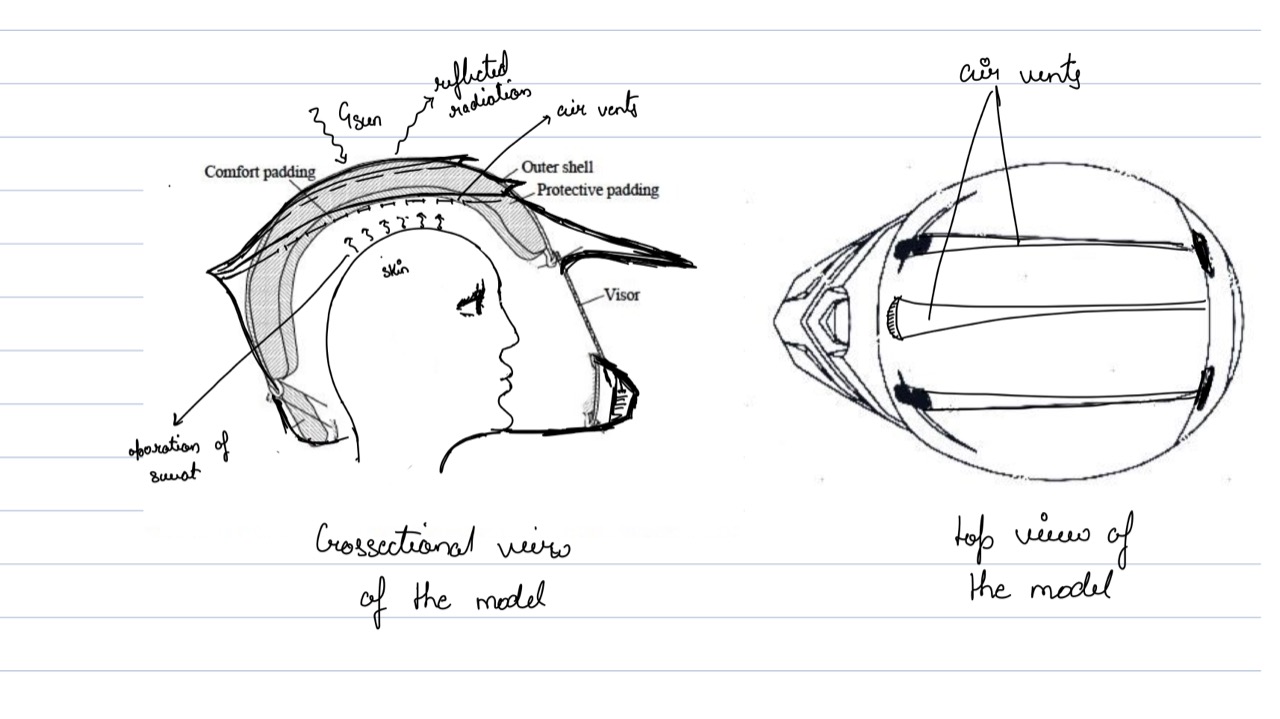
RoadMap of the solution



NOTE : Control volume is defined for each part of the solution

# **Solution & Methodology**

## **Thermal analysis of market available helmet**

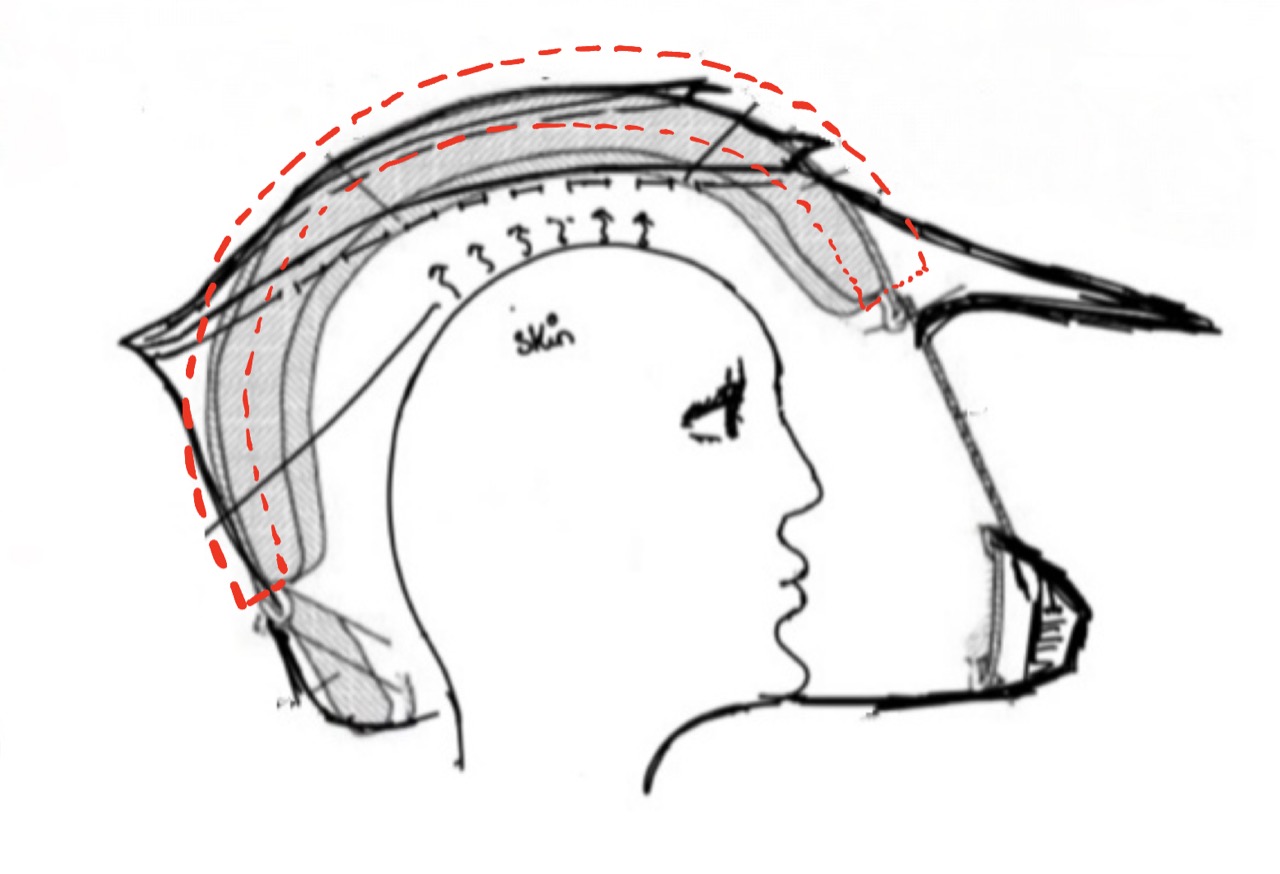


**Control Volume - 1**

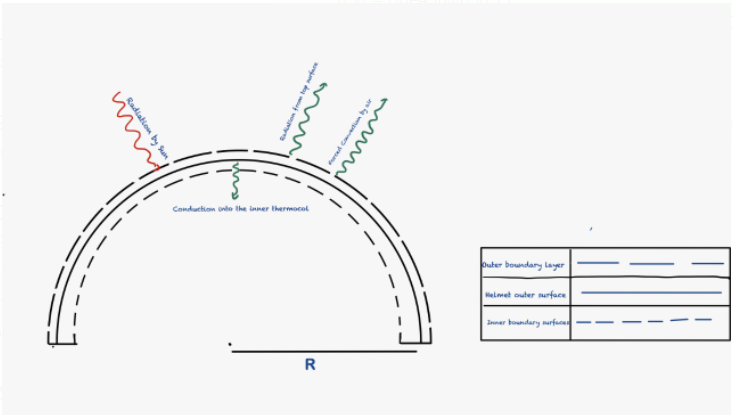
In the first part of the solution, we obtain the temperature profile of the temperature of the top surface of the helmet as a function of time. Our entire solution would be using the below schematic diagram to define the control volume.

### **Schematic diagram and Control volume**

* 1. Schematic diagram 1:



* 1. Simplified Geometry and control volume:



* **Assumptions**

In this control volume, we are taking some assumptions which would simplify the problem.

* There is a thin layer of air with a thickness of 0.01m between the upper surface of the helmet and the thermocol beneath it.
* The carbon layer is opaque and gray, i.e., transmissivity = 0
* The resistance between different layers and due to contact between them is negligible.
* The temperature is constant on the helmet's surface, i.e., the temperature does not change with spatial coordinates.
* The thickness of the carbon layer is taken to be negligible.
* Thermal conductivities are uniform, and other properties remain constant throughout the spatial distribution and time variation.
* Solar radiation is considered to be constant.
* **Three mode estimation of Heat transfer**

**Radiation:** As the top surface of the helmet radiates heat, radiation occurs. Which contributes to increasing the temperature of the surface.

**Convection:** Since the biker is riding and wearing the helmet, there is a flow of air on the upper surface of the helmet. This external flow of air causes convection to occur.

**Conduction:** The air gap between the two characters of the helmet serves as a conductive element of heat.

Now here, since air is a very bad conductor of heat. The conduction term here is recessive, and radiation and convection are dominant. (NOTE: even if the conduction term is not prevalent, we will consider it and show that it is negligible with respect to radiation and convection terms).

* **Energy Balance on the Control Volume**

* **Governing Equations**

The overall energy balance considering all the heat fluxes crossing the control volume. The overall heat increases the temperature of the upper surface of the helmet. Therefore the temperature of the surface varies with time.

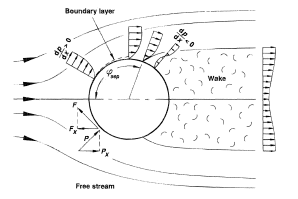
# 

The Nu correlation is used since the air is moving on the surface of the headgear, causing an external flow.

Here:

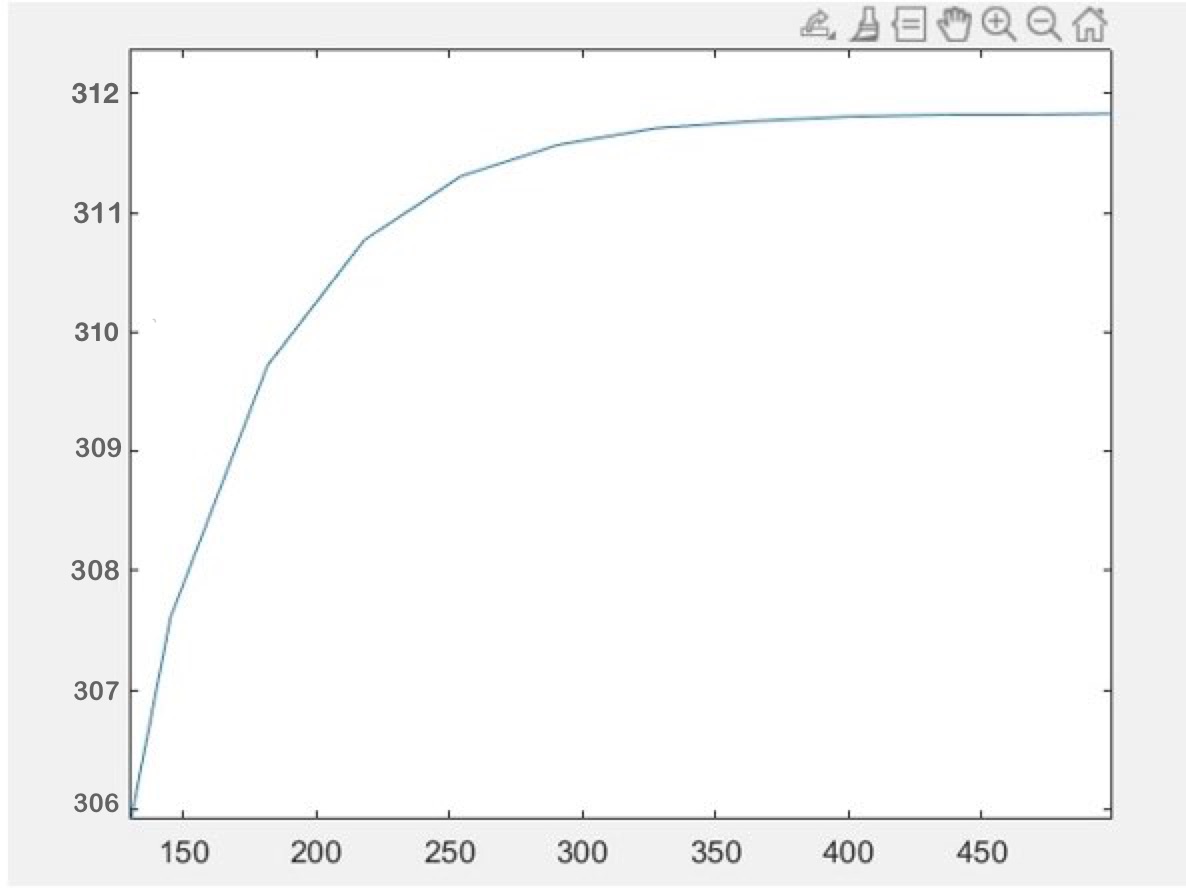
Note: Here is the conduction term which is not dominant therefore we neglect this term.

* **Bondary Layer formation :**

****

* **Temperature Profile**

On substituting the values given in the question and solving the above equation on Matlab, we get the following temperature profile.



Time (sec)

*Plot of temperature v/s time*

* **Data Table**

| S.No. | Time(s) | Temperature(k) |
| --- | --- | --- |
| 1 | 0 | 305.5 |
| 2 | 150 | 308 |
| 3 | 200 | 310.5 |
| 4 | 250 | 311 |
| 5 | 300 | 311.5 |
| 6 | 350 | 311.6 |
| 7 | 400 | 311.7 |
| 8 | 450 | 311.8 |

* **Observations**

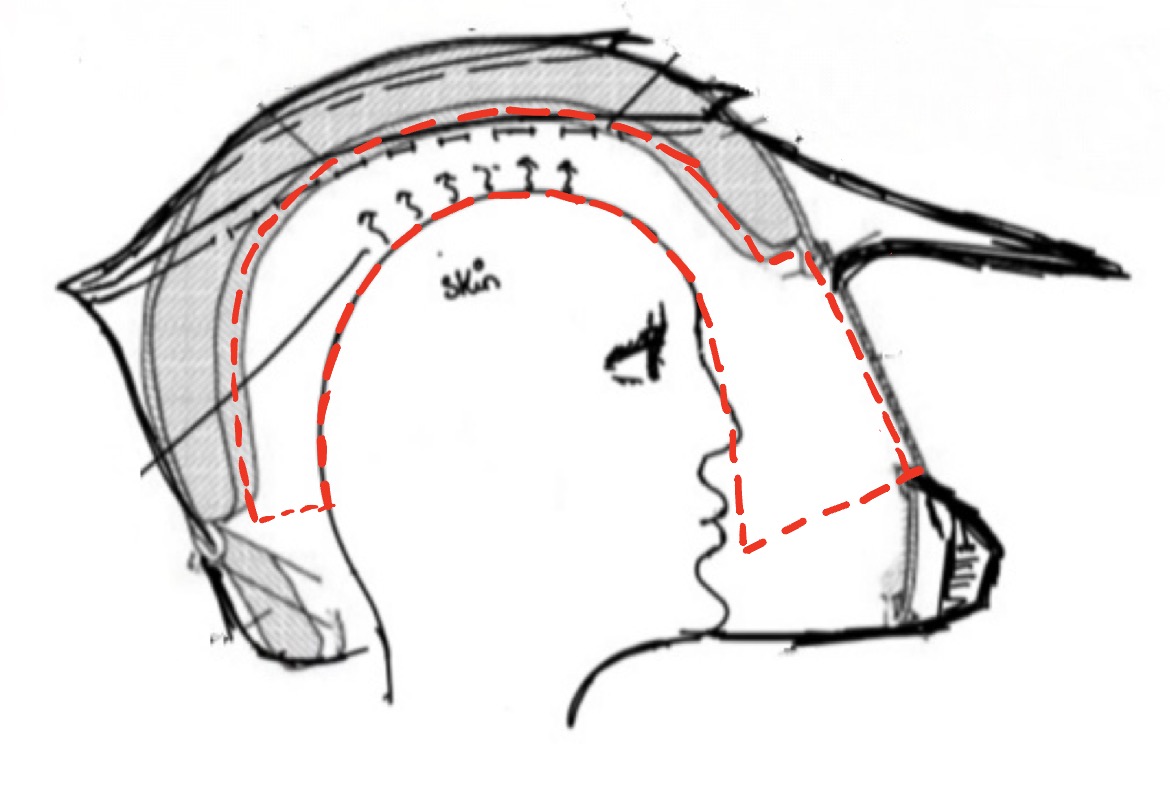
By this profile, we infer that the temperature of the top surface of the helmet becomes saturated after a particular time. The saturated temperature of the helmet is 311.8 K.

Therefore, to solve the problem further, we take the helmet's temperature to be 311.8 K.

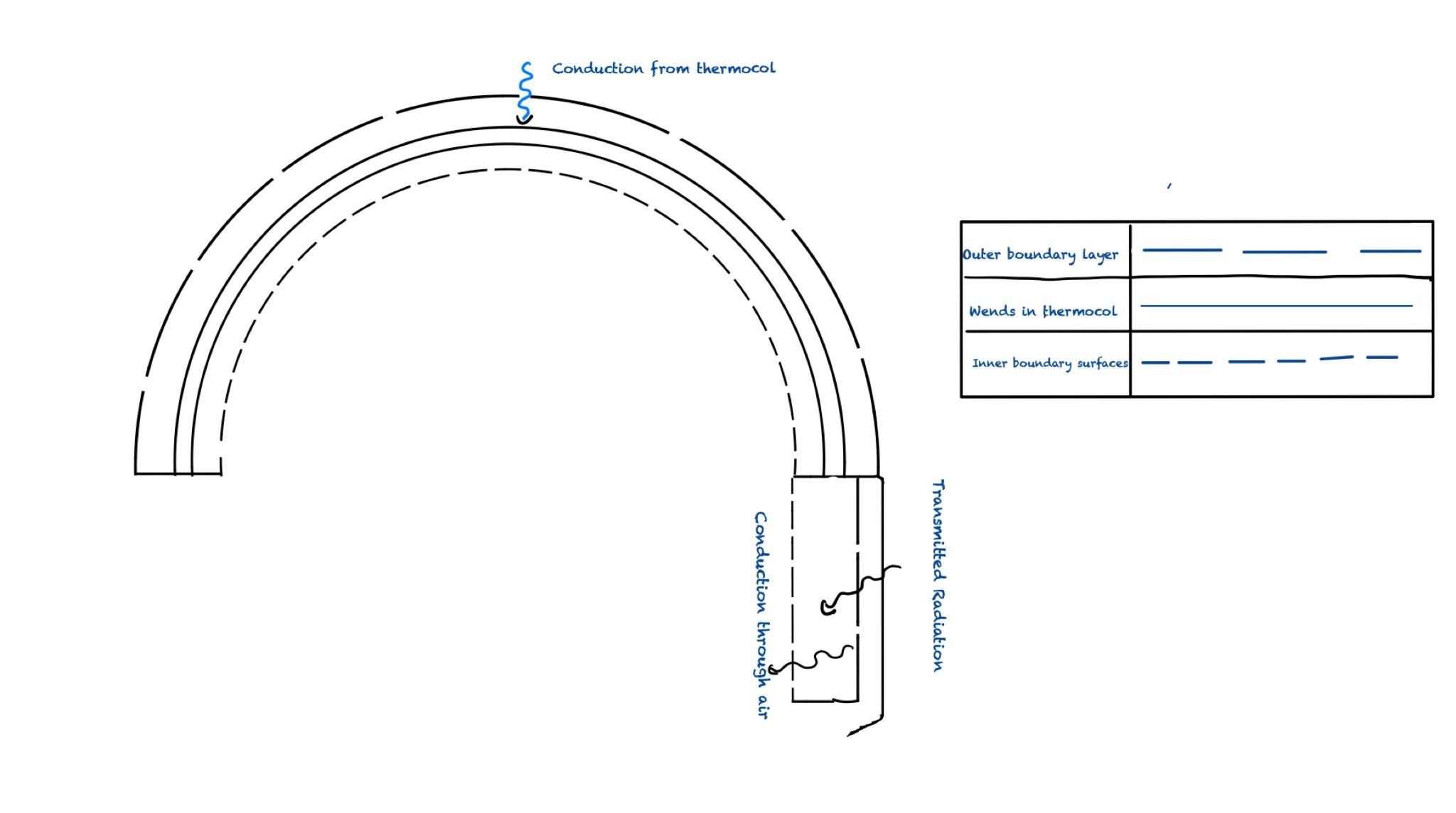
**Control Volume - 2**

Now, In the next part of the solution, we redefine our control volume and perform the energy balance to find out the temperature profile of the skin with time variation.

* **Schematic diagram and Control volume** 
  1. Schematic diagram 2:



* 1. Simplified geometry and Control volume:



* **Assumptions**

In this redefined control volume, some assumptions are taken, which are the following,

* The visor is a transparent surface with transmissivity = 1.
* The resistance between different layers and due to contact between them is negligible.
* The temperature is constant on the helmet's surface, i.e., the temperature does not change with spatial coordinates.
* The temperature of the visor is assumed to be the same as the surface of the helmet.
* Thermal conductivities are uniform, and other properties remain constant throughout the spatial distribution and time variation.
* Solar radiation is considered to be constant.
* Losses by conduction through the leaks are negligible.
* Velocity inside and outside the air vents remains uniform.
* The distance of the face from the visor is taken to a small
* **Three mode estimation of Heat transfer**

By defining this control volume, these are the modes of heat transfer that we are considering.

**Radiation:** The irradiation of the sun is directly falling on the visor of the helmet, out of which the transmission reaches the surface of the skin. This mode of heat transfer is the dominant one.

**Conduction:** There is the conduction of heat from the surface of the visor to the surface of the skin. This does not contribute much in the heating of the skin.

**Convection:** Convection occurs from the skin to the surroundings. This also contributes significantly to heat transfer.

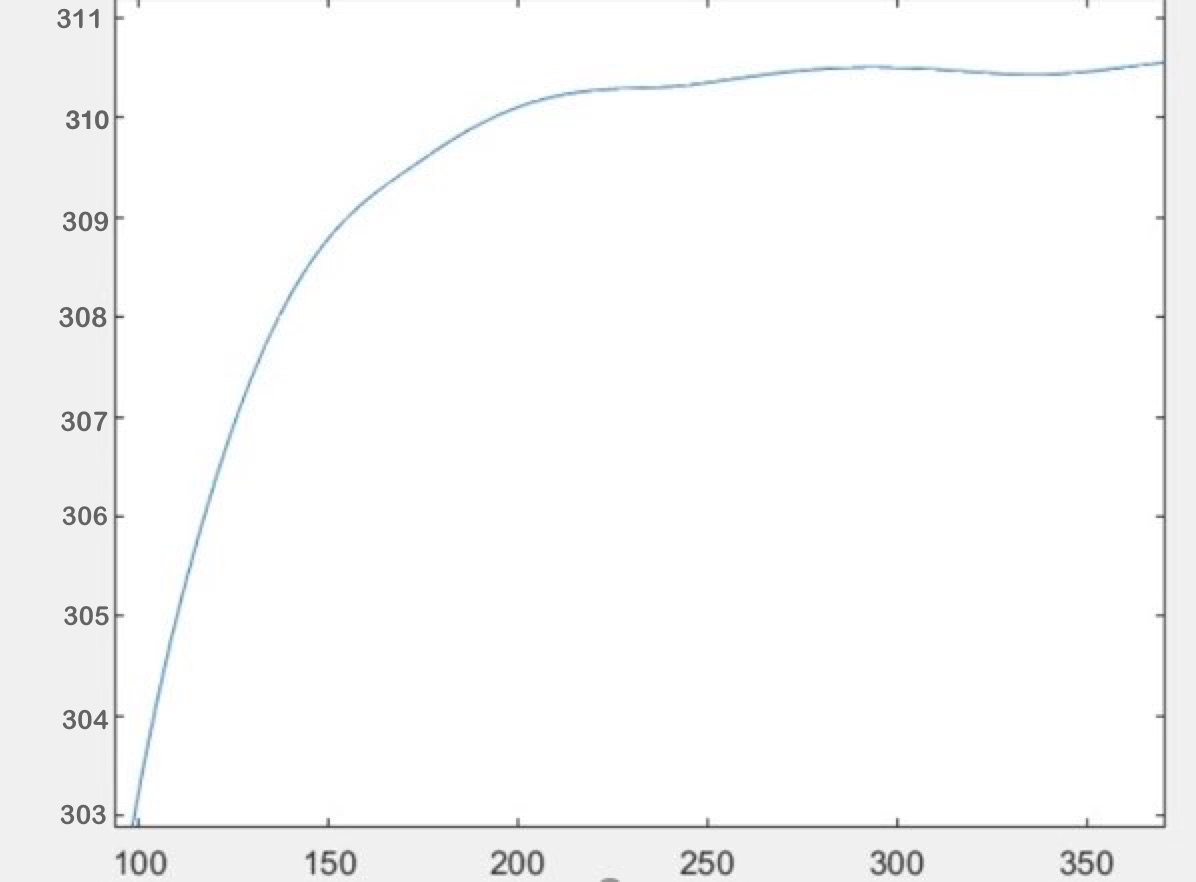
* **Energy Balance on the Control Volume**

* **Governing Equations**

Here:

* **Temperature Profile**

On solving the above equation on Matlab we get the following temperature profiler



time(sec)

Plot of Temperature v/s time

* **Data Table**

| S.No. | Time(s) | Temperature(k) |
| --- | --- | --- |
| 1 | 0 | 302.8 |
| 2 | 100 | 303 |
| 3 | 150 | 308.5 |
| 4 | 200 | 310 |
| 5 | 250 | 310.3 |
| 6 | 300 | 310.5 |
| 7 | 350 | 310.6 |

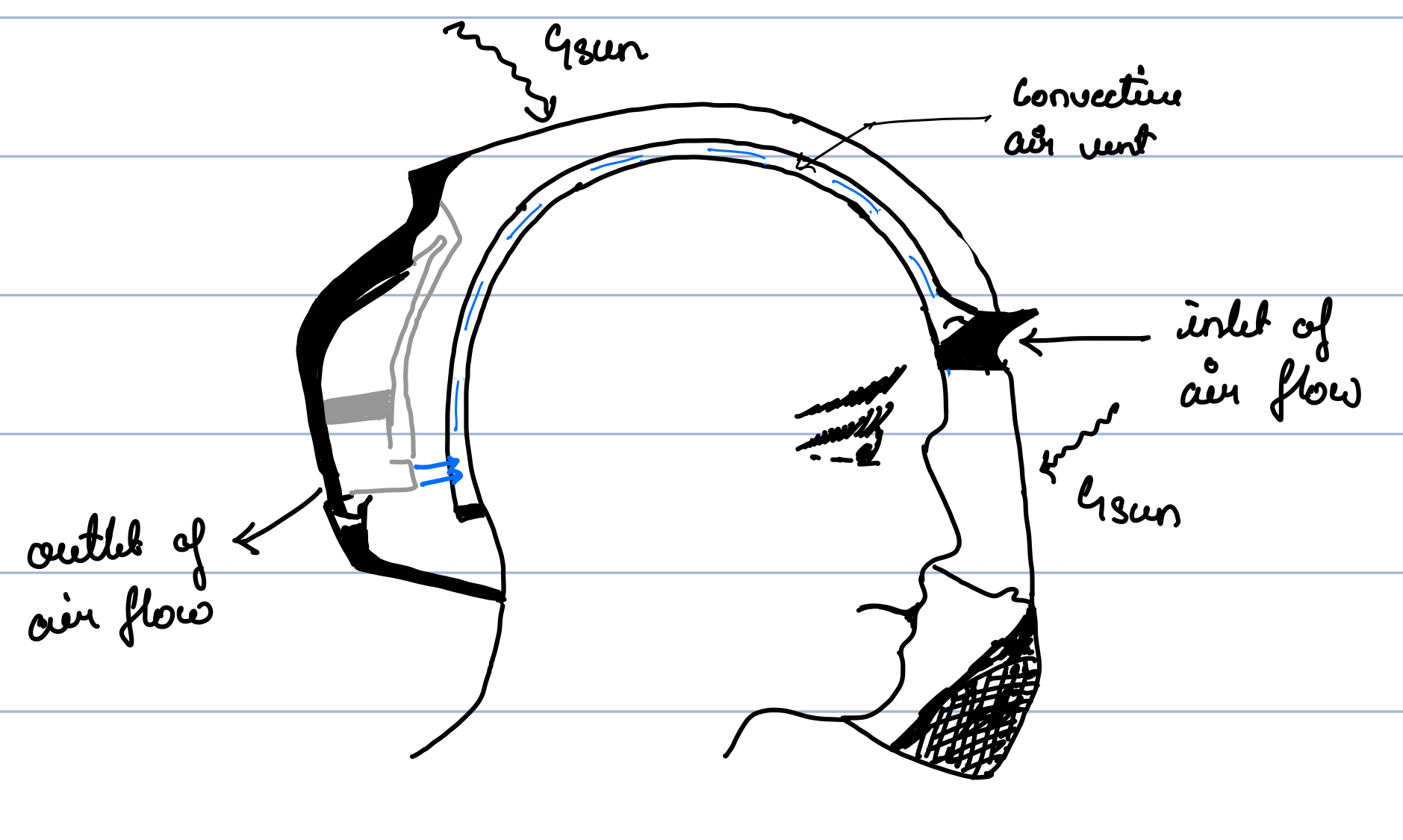
* **Observation**

By this profile, we infer that the temperature of the skin becomes saturated after a particular time. The saturated temperature of the skin is 310.6 K.

## **Thermal analysis of our proposed helmet**

We have made some changes in the existing model of the helmet to reduce the temperature of the skin.

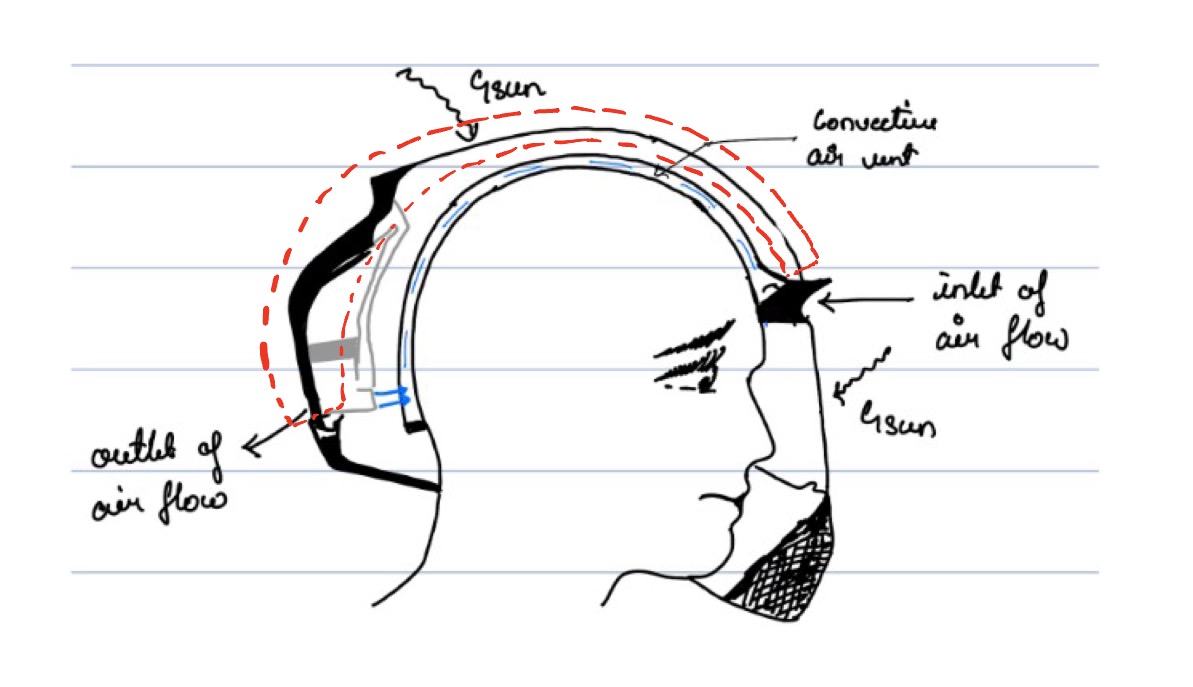
* We have implemented an air ventilation system ( vents ) which would ensure that the sweat released from the skiing gets evaporated and carried away by air.
* We are also adding a layer of the radiative shield ( of lead blanket ) on the upper surface of the helmet.



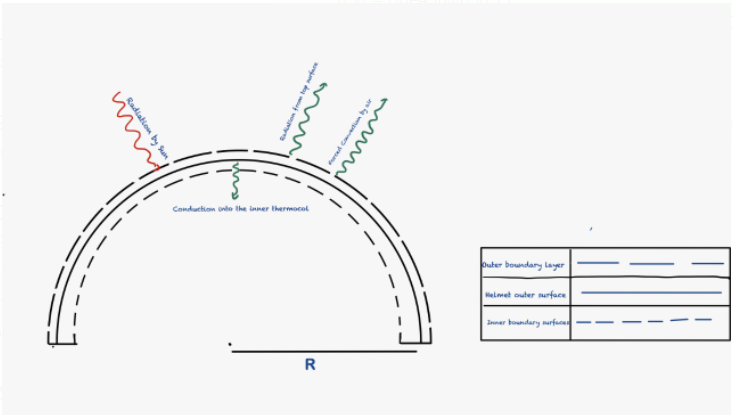
**Control Volume - 1**

* **Schematic diagram and Control volume**

Schematic diagram 1:



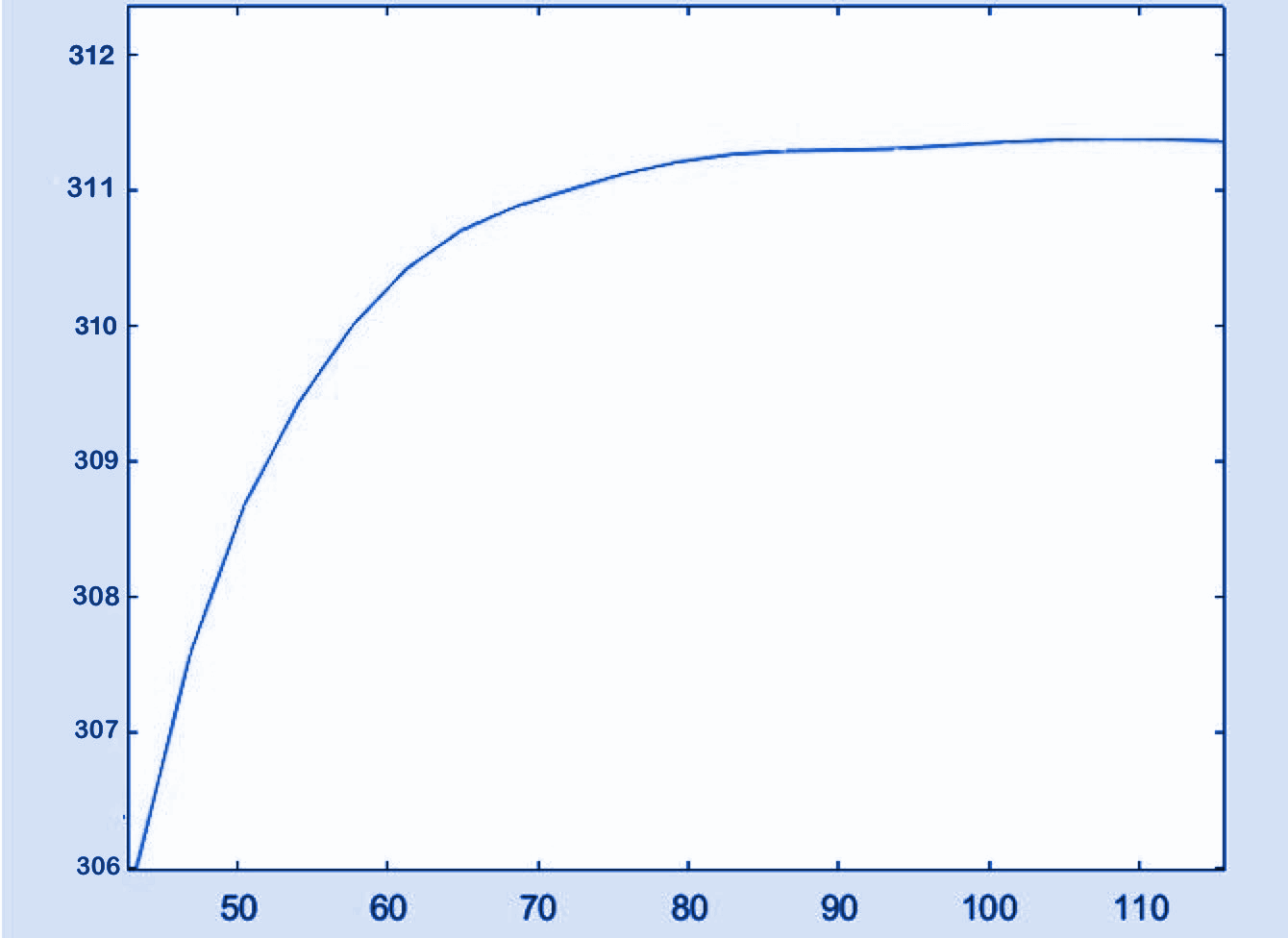
Simplified geometry and Control volume:



* **Temperature Profile**

If we perform the same calculation we did in our 1st part of the solution for the normal helmet (defining the same control volume and the heat fluxes crossing the surface of the control volume, just the difference is that the emissivity and the absorptivity of the upper surface of the helmet is different ), we get the following temperature profile.

This does not change much, just that the saturated temperature changes. The temperature profile is



Time (sec)

Plot of Temperature v/s time

* **Data Table**

| S.No. | Time(s) | Temperature(k) |
| --- | --- | --- |
| 1 | 0 | 306 |
| 2 | 50 | 310 |
| 3 | 60 | 310.7 |
| 4 | 70 | 310.9 |
| 5 | 80 | 311 |
| 6 | 90 | 311.1 |
| 7 | 100 | 311.2 |
| 8 | 110 | 311.2 |

* **Observation**

By this profile, we infer that the temperature of the top surface of the helmet becomes saturated after a particular time. The saturated temperature of the helmet is 311.2 K.

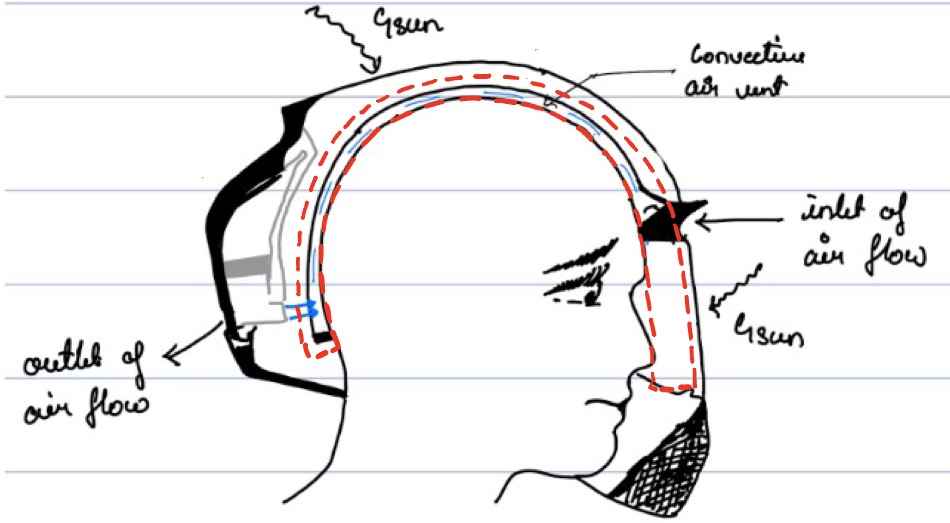
Therefore, to solve the problem further, we take the temperature of the helmet to be 311.2 K.

**Control Volume - 2**

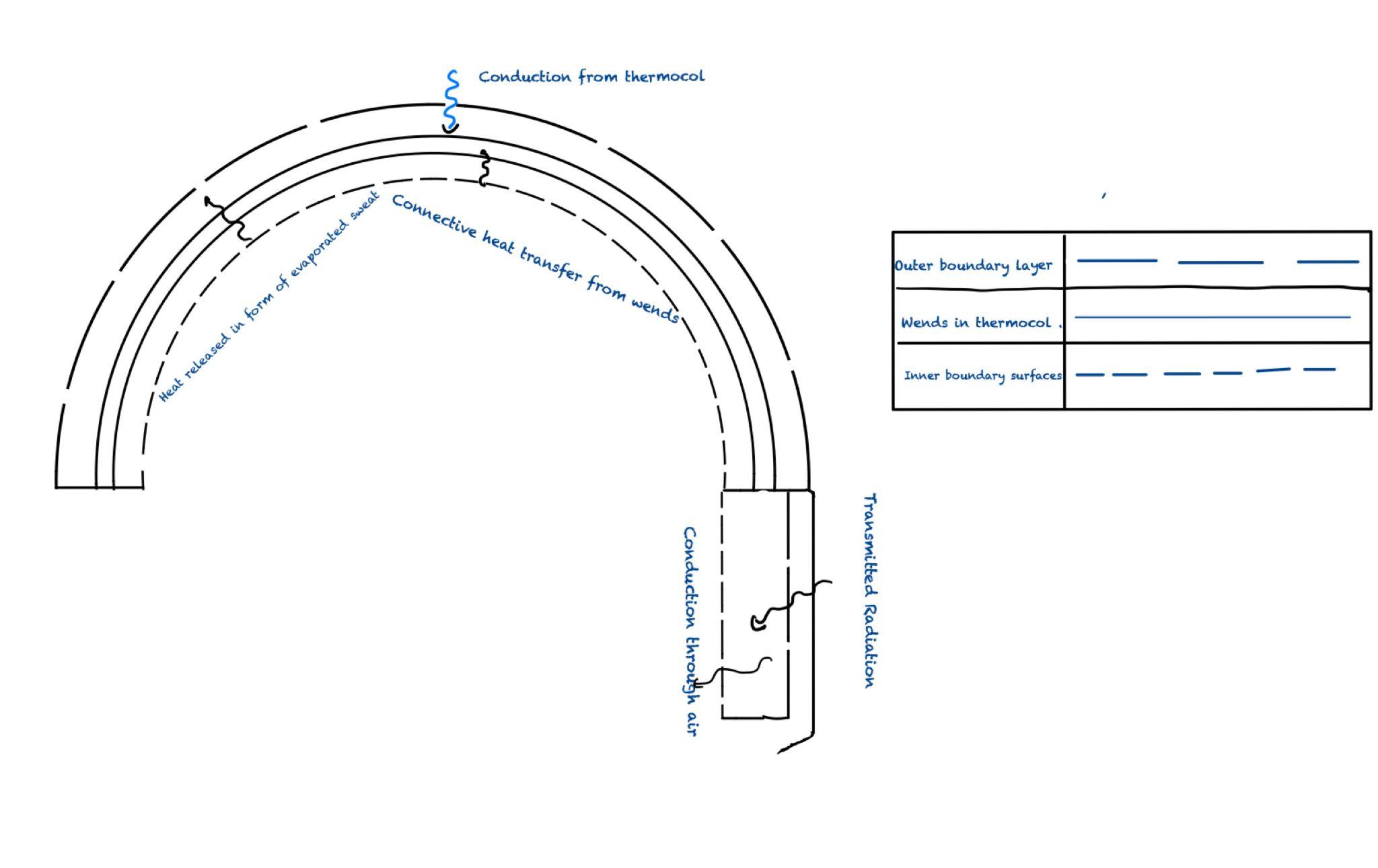
Now, In the next part of the solution, we redefine our control volume and perform the energy balance to find out the temperature profile of the skin with time variation.

* **Schematic diagram and Control volume**

Schematic diagram 2:



Simplified geometry and Control volume:



* **Assumptions**

Considering our model of the helmet, we are taking the same assumptions which took in the 1st part of the previous solution to simplify the model. We have made some additional assumptions:

* + The vapor behaves as an ideal gas, and atmospheric pressure is standard atmospheric pressure, 1 atm.
  + The holes in the vents are at a particular distance from each other.
  + Negligible viscous dissipation.
  + Effects of disturbances by riding is negligible.
  + We are assuming the temperature of the surface of the vent to be constant.
  + The cross-section of the air vents is taken to be square.
* **Three mode estimation of Heat transfer**

By defining this control volume, these are the modes of heat transfer that we are considering.

**Radiation:** The irradiation of the sun is directly falling on the visor of the helmet, out of which the transmission reaches the surface of the skin. This mode of heat transfer is the dominant one.

**Convection:** The is an internal flow of air inside the air vents, and convection occurs due to the internal flow of the air. This is a very dominant mode of heat transfer since, because of this, the evaporation phenomenon also occurs.

**Conduction:** There is the conduction of heat from the visor's surface to the skin's surface. This does not contribute much to the heating of the skin.

* **Energy Balance on the Control Volume**

* **Governing Equations**

This is the overall heat rate balance equation in which few of the terms are calculated using the below correlations. The main difference between this and the previous calculation is the addition of the terms qeva and qconv.

This is the overall mass transfer rate ( evaporation rate ) by which the sweat from the skin will evaporate and cool the surface of the skin.

)

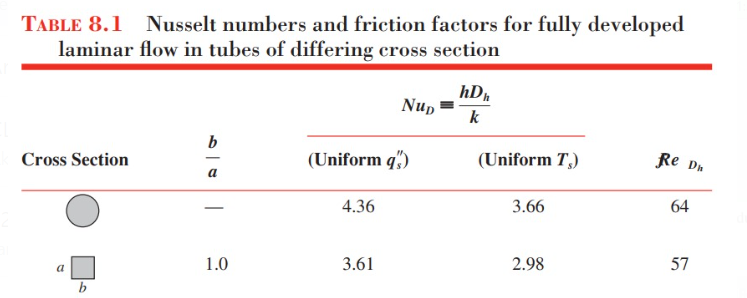
Since in our vent, the sweat is continuously being added to the air, the density is not the same throughout. Therefore we are considering that the holes are at a fixed distance.

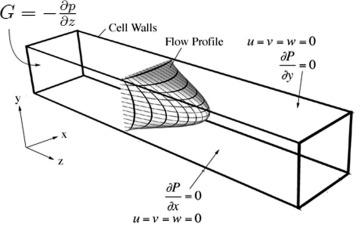
Here:

Note: Here is the conduction term which is not dominant therefore we neglect this term.

Also, we have used table 8.1 to find the Nu number of our vent. In our case, we have assumed the surface temperature of the vent to be constant.

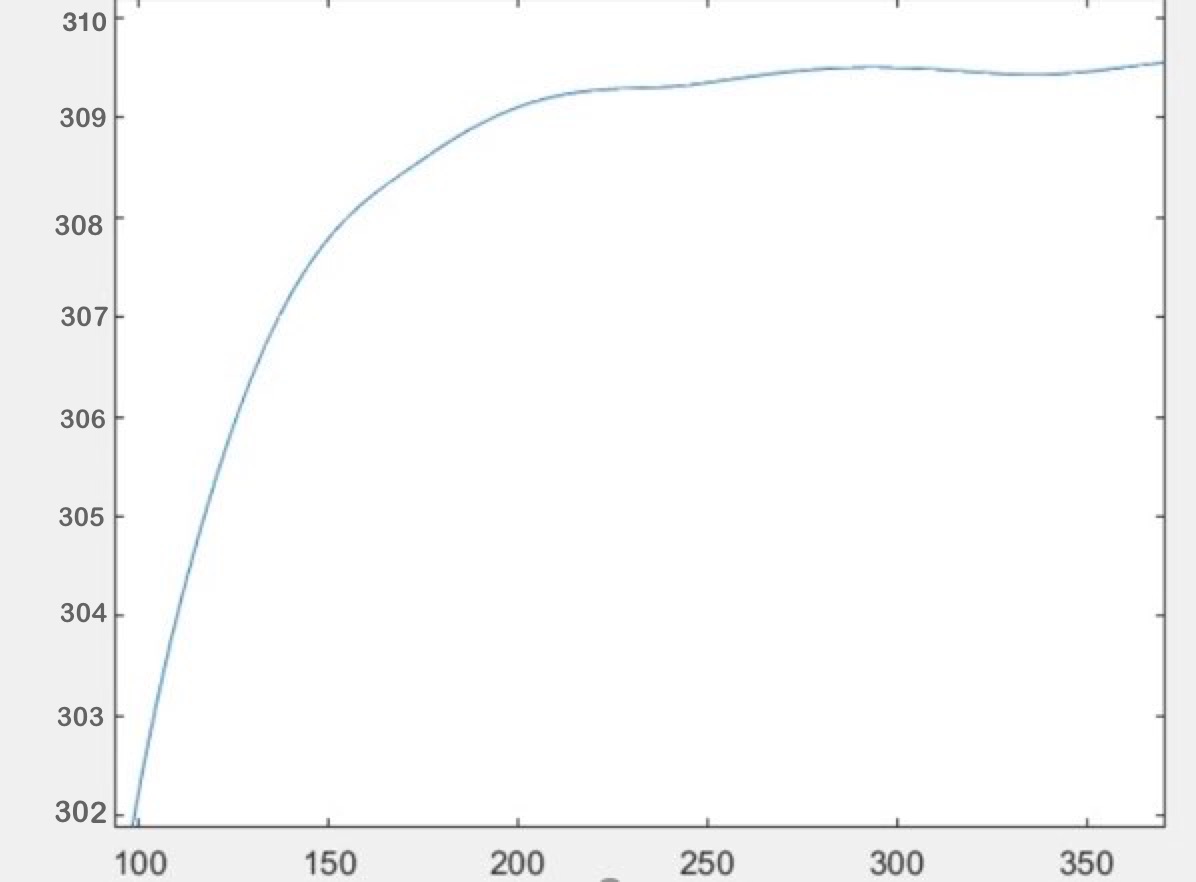
And the cross-section of the vent is a square (i.e., a=b ).





* **Temperature Profile**

On solving the above equation on Matlab, we get the following temperature profile.



Time (sec)

Plot of Temperature v/s time

* **Data Table**

| S.No. | Time(s) | Temperature(k) |
| --- | --- | --- |
| 1 | 0 | 301.5 |
| 2 | 100 | 302 |
| 3 | 150 | 307.5 |
| 4 | 200 | 309 |
| 5 | 250 | 309 |
| 6 | 300 | 309.1 |
| 7 | 350 | 309.4 |

* **Observation**

By this profile, we infer that the temperature of the skin becomes saturated after a particular time. The saturated temperature of the skin is 309.4 K, analytically.

# 

# **Conclusion**

We have created a realistic model of the helmet and done a comprehensive analysis of it by taking various control volumes to understand the heat transfer dynamics involved in its working. As calculated, our re-invented helmet provides a more comfortable experience to the user as the temperature of our helmet at a steady state is approximately **309.4K,** while the steady-state temperature of the market counterpart is **310.6K**. We notice a significant difference in the temperatures which shows that the new model is theoretically successful in solving the problem statement.

Hence, the modifications made to the helmet, namely the air vents and radiation shield are effective and help solve our problem while incorporating concepts of radiation and convection. We conclude that the new model is sustainable and suitable for regular use and helps riders in arid and humid regions while ensuring their safety.

**Appendix**

tspan = linspace(0,3600,1000);

A=0.01842;

alpha = 0.65;

m=0.02;

Cp=1600;

e=0.98;

Nu= 17\*10^-6;

k=28\*10^-3;

re=((40\*5\*0.04)/18)/(Nu);

Pr = 0.702;

pNu = 2 + (0.4\*(re^0.5) + 0.06\*(re^0.67))\*(Pr^0.4);

h = pNu\*k/0.04;

sig = 5.67e-8;

k1 = h\*A/(m\*Cp);

Y1 = (A\*alpha\*1380)/(m\*Cp);

K = 0.025;

delta = 0.01;

y0 = 0;

[t,y] = ode45(@(t,y) Y1-k1\*(y-313)-(e\*A\*sig\*y^4)/(m\*Cp) - K\*A\*(y-310)/(delta\*m\*Cp), tspan, y0);

plot(t,y**)**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Mu = 190\*10^-7

Nu= 17\*10^-6

K=28\*10^-3

re=40\*5/18/Nu\*0.09

Pr = 0.702

mu = 194\*10^-7

pNu = 2 + (0.4\*re^0.5 + 0.06\*re^0.67)Pr^0.4(Mu/mu)^0.25

H = pNu\*K/0.09

**BIBLIOGRAPHY**

To complete this project we used the following websites, articles, and book-

* [Design and Experiment Study of a New Thermoelectric Cooling Helmet](https://pdf.sciencedirectassets.com/278653/1-s2.0-S1877705817X00398/1-s2.0-S1877705817350130/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEAwaCXVzLWVhc3QtMSJGMEQCIG2YmuyQKF3vqAHSsoITaF7Mr8A3JrAGRCsNm2TullLeAiAzMTOomMm50gWYknls3c7OYuXBd3nWaCEWqhCfKrET4ir6Awh1EAQaDDA1OTAwMzU0Njg2NSIMxIpErWbfQAZID3RjKtcDegJhXnisVnDJbkNdNVzGV2m1506gR9%2FNp4GxVHtVX3Ow%2BuLyao%2F1lR2sHvWggXRJVDe7wtwuqxo1rlLpznusJqzSBlie%2BkJ5ozkcTiJSkcVLrUlXANaksYcDy3j1WzI0CAEnPx2EK74aed1ROFsFsSx%2BwjWFYWaLK1cKvKsBSOnxbC7pmrq2CUCbdJ%2BbNbLKig96aPIuXahND7fFhuaItkZmTwyAlyV6zWEc5iLSkPLDHGdimI6y1K9DUp5%2BJxXg%2BPRl6PNF1wrtc8PwWZN3ANJWg1o1peTzH0RnkkLb0QJdkM6yWkWJS9rcvm46iPprH%2BVYKMdHFxmGgOOlA8rnKcRgJXsIFvsGMLmiT5ReV7QoJvlaBUFH0%2BI6H0x7BhjhX5C0imYbxc4Lg2IR2IgIu7K8ryIk3HasO32Cbv5IcZAEyt31%2F3vn00eHXc2qOw4zT4phWERsaqsWUrT8DOApGwaPeYcq%2FJ9yhY5iXZ04qXdcyKPlASmspjNuo4tEGeJrtwS%2FnDkUv7hdGFi8Q3S4RS6PUzgta6%2BJwgwycJ7R4mbA8W3VfdKxPzbQnAapbFLKRc%2FMxRgd2zRdV2XWbfWUzxNfFWFued2z2mEP0tkJ6sEuRkcYhleEMPCbjZEGOqYBwj1%2BZlOIGFBDgWenaXNShjTiOqGxgtKN1fq7wBNwhXaGQa1YMIiqt1rFLp0YOshRyIYwXP3rE0U1NDfhjS8nhalM0zHaV6kJO8aw4ON5y7N6xCm%2FiZF2Ad%2BaDK7kPo5qwZWvCKPvvY4SvYkMtuX0vZyygwA7dd9%2BHH%2BxBluNUcX4xHgGL%2FhmbAwnVMeIj7QtlQtfKstOqpMI88vrcWH%2FT1kyUqCv2A%3D%3D&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20220305T124342Z&X-Amz-SignedHeaders=host&X-Amz-Expires=300&X-Amz-Credential=ASIAQ3PHCVTYRM2EFGF2%2F20220305%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=1b509f77e1c41c22be0463ecedd34dc9d1c90d08b68dea114347871cc4518b28&hash=781c436556d7ef7df419eb6c67b18e6b7210dd069e5c13a02ac0028c2967c2c3&host=68042c943591013ac2b2430a89b270f6af2c76d8dfd086a07176afe7c76c2c61&pii=S1877705817350130&tid=spdf-9719bd8a-c65f-4e1d-8641-a0b599f57fdb&sid=43d104db63f9a94d471b572-3147124c33c2gxrqb&type=client&ua=530256510253505d5400&rr=6e72f0533b948af3)
* [HELMET COOLING SYSTEM USING PHASE CHANGE MATERIAL FOR LONG DRIVE](https://www.researchgate.net/profile/Chelliah-Arumugam/publication/281637702_Helmet_cooling_system_using_phase_change_material_for_long_drive/links/55f1923d08aedecb6900918b/Helmet-cooling-system-using-phase-change-material-for-long-drive.pdf?origin=publication_detail)
* <https://www.rideapart.com/news/390235/pininfarina-roux-water-cooled-helmets/#:~:text=The%20most%20notable%20feature%20is,keeps%20the%20torso%20cooled%20off>
* <https://www.sciencedirect.com/science/article/pii/S1877705817350130>
* <https://m.youtube.com/watch?v=Zh3S74Yd8QM>
* <https://www.sciencedirect.com/science/article/pii/S0169814114001474>
* <https://www.sciencedirect.com/science/article/pii/000368709500010A>
* <https://drive.google.com/file/d/1EIvqPt5H5ssXCme79WtHsi397xFksPkV/view?usp=sharing>
* [Design of ventilated helmets: computational fluid and impact dynamics studies](http://www.vref.se/download/18.6a462c7912efb9dc85f80004550/1377188297670/2008%20Pinnoji%20-%20Design%20of%20ventilated%20helmets.pdf)

– End of Report –

**–**