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TRANSIENT THERMAL ANALYSIS OF A CAR BRAKE SYSTEM

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Problem Statement

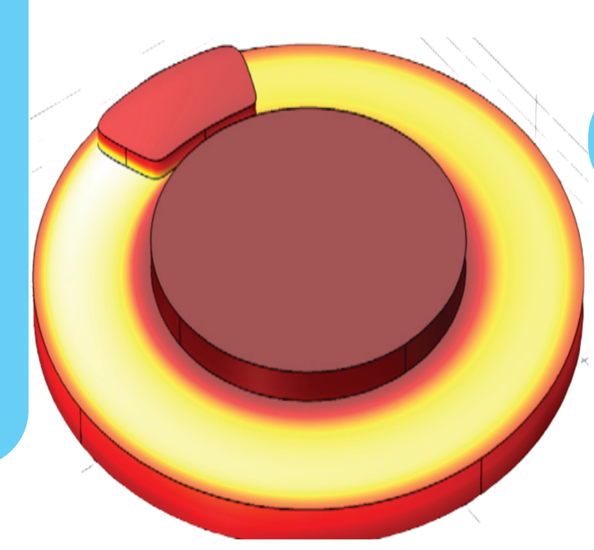
This Project focuses on investigating the crucial role of car brake systems in ensuring safety and control by converting kinetic energy into heat during braking. It emphasizes the significance of understanding the
transient thermal behavior of these systems to optimize design, prevent overheating, and ensure consistent braking performance. The study employs computer modeling, numerical simulations, and data analysis,
primarily utilizing the Finite Difference Method, to analyze heat conduction within braking components. The ultimate goal is to enhance braking system designs, improve safety, and mitigate overheating chal-

Objectives

- Comparing the numerical model with the physical model of the brake system.
- Making suitable assumptions.
  Deriving governing equations from first principles.
- Setting initial boundary conditions.
- Selecting appropriate parameters and values.
- Choosing a suitable numerical analysis method.
- Writing a computer program to solve the equations and obtain numerical solutions.
- Visualizing temperature profiles initially and after simulation.
- Analyzing temperature evolution at specific locations.
- Examining temperature changes at the center point with respect to fric-

Assumptions

- Steady-state conditions before braking events.
- Uniform initial temperature across brake components.
- Negligible heat conduction in the axial direction of the brake components.
- Simplified geometry for numerical efficiency.
- This analysis is done when the brakes have been applied, but the automobile has not stopped, and due to the friction, the heat is generated, and its propagation is shown in the 3D plot.
- The temperature variation across a tiny piece of the brake disc is similar to the temperature variation across the brake disc; therefore, instead of applying the Numerical analysis on the complete brake disc, we have taken one small area, which can be considered as a thin metal plate/sheet.



Boundary Conditions

1. $T = 400\ ^\circ C$, at $y = 0$
   At any other point $T = 25\ ^\circ C$
2. $T = 400\ ^\circ C$, at $y = 0$
   $T = 25\ ^\circ C$, at $y = L_y$
   $T = 25\ ^\circ C$, at $x = 0$ and $x = L_x$
3. $Q =$ frictional heat generation during braking.
   $Q = \mu.F.\nu$, where $\mu = 0.55$ (coefficient of friction of the surface)
   $F =$ Normal force applied on the brakes
   $V =$ Velocity of braking surface

Table 1: Parameters Related to the Problem

Variable	Value	Unit
Q	1000-5000	W/m^2
c	460-1200	J/Kg.C
α	1.17	cm^2/s
R	8.314	J/mol.C
k	400	J/m.s.C

Algorithm Used

A time-stepping loop is implemented to update the temperature array using the Forward Euler method iteratively.
Nested loops traverse the interior grid points, applying finite difference calculations to update the temperature at each point.

Visualisation

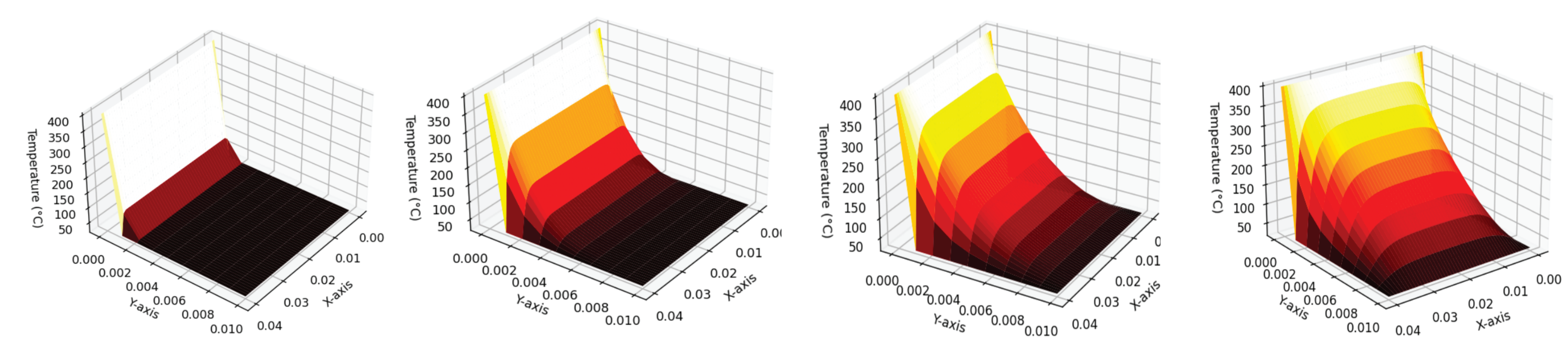
- The code includes visualisations of temperature evolution over time using 3D surface plots and contour plots.
- Temperature profiles are plotted initially, at specific time steps, and finally.

Temperature Evolution at Specific Locations

- The code tracks the temperature evolution at specific locations, such as the centre and corner of the brake components.
- Plots depict how temperatures change at these locations over the simula- tion period.

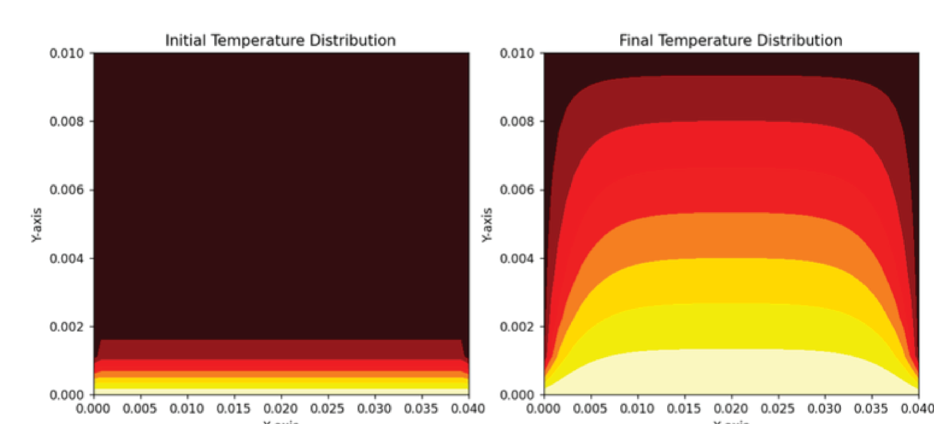
Heat Generation(Q) Sensitivity Analysis

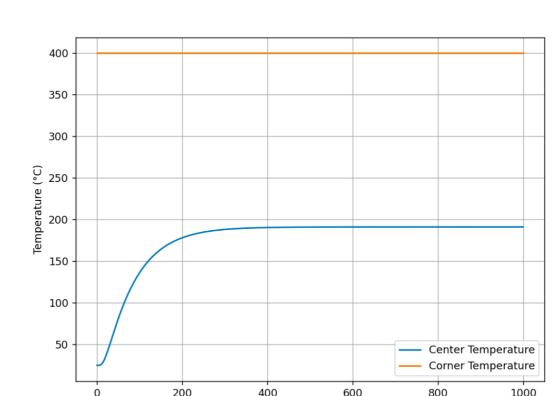
- The code conducts a sensitivity analysis by simulating temperature dis- tribution for different values of the heat generation term Q.



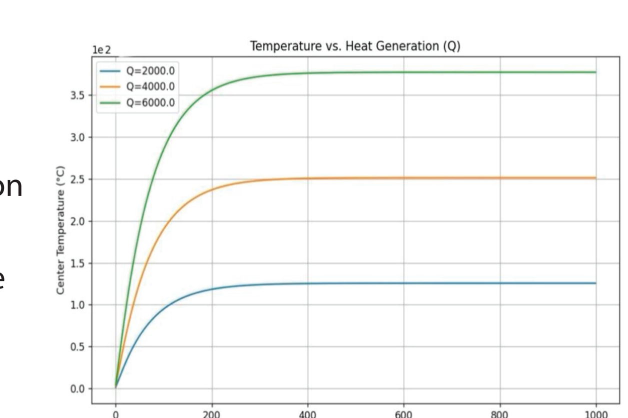
Results and Discussions

- The code models and visualizes temperature changes over time in a brake system, depicting temperature varitions at different locations. It presents an intial temperature difference graph and a final steady-state distribution, revealing the system's thermal equilibrium pro-





- By monitoring temperature changes at specific locations in the brake system, we can assess how different regions respond to heating and cooling, providing valuable insights into potential thermal damage.
- Observing temperature changes in the brake system by varying heat generation rates reveals a direct correlation, where higher Q values lead to faster temperature increases aiding in material and design selection for diverse brake intensities.



Governing Equations

$$\rho c\frac{\partial T}{\partial t} = \nabla(k\Delta T)+Q \qquad \rho c\frac{\partial T}{\partial t} = \frac{\partial(k\frac{\partial T}{\partial x})}{\partial x}+\frac{\partial(k\frac{\partial T}{\partial y})}{\partial y}+Q$$

Discretization Using Finite Difference Method

$$\frac{\partial T}{\partial x} \approx \frac{T_{i+1,j}-T_{i-1,j}}{2\Delta x} \qquad \frac{\partial^2 T}{\partial x^2} \approx \frac{T_{i+1,j}-2T_{i,j}+T_{i-1,j}}{2\Delta x^2}$$

$$\frac{\partial T}{\partial y} \approx \frac{T_{i,j+1}-T_{i,j-1}}{2\Delta y} \qquad \frac{\partial^2 T}{\partial y^2} \approx \frac{T_{i+1,j}-2T_{i,j}+T_{i-1,j}}{2\Delta y^2}$$

Forward Euler Algorithm

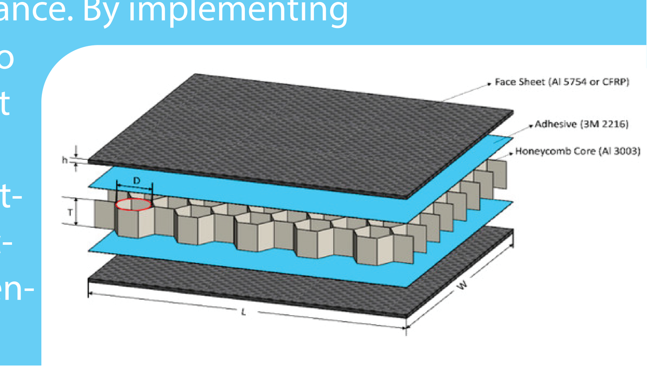
$$\frac{T^{n+1}_{i,j}-T^n_{i,j}}{\Delta t} = \frac{1}{\rho c}\left(\frac{T^n_{i+1,j}-2T^n_{i,j}+T^n_{i-1,j}}{\Delta x^2}+\frac{T^n_{i,j+1}-2T^n_{i,j}+T^n_{i,j-1}}{\Delta y^2}\right)+\frac{Q^n_{i,j}}{\rho c}$$

Error Analysis

- Material Properties Material properties (thermal conductivity, density, and specific heat) used in your simulation match the actual properties of the brake material you are analyzing. Consult material data sheets or industry standards to ensure accuracy.
- Consistency with Physical LawsThe selected parameter values align with fundamental physical laws and principles. For example, the thermal diffusivity (α = k / (ρc)) should follow the relationship between thermal conductivity (k), density (ρ), and specific heat (c).
- Stability AnalysisThe chosen time step size (dt) satisfies stability criteria for the numerical method used. An unstable simulation may produce erroneous results, so stability is crucial.

Solutions

The recurrent issue of high brake temperatures, often reaching 400°C, significantly accelerates brake system degradation and leads to frequent failures. To address this challenge, we propose a dual-pronged solution. Firstly, we advocate for the integration of a hexagonal mesh structure in the brake system. This mesh enhances material strength while maintaining a lightweight design. Secondly, we incorporate a cooling system within the brake to regulate temperature, preventing overheating and optimizing system performance. By implementing these innovations, we aim to ensure a robust and resilient brake system, effectively mitigating overheating-related degradation and enhancing overall safety and efficien-



Reference

[1] "Numerical and experimental analysis of transient temperature field of ventilated disc brake under the condition of hard braking," Numerical and experimental analysis of transient temperature field of ventilated disc brake under the condition of hard braking - ScienceDirect, Sep. 01, 2017. [Online].

[2] **"Numerical Methods for Engineers", Seventh Edition, Steven P. Chapra, Raymond P. Canale., [Online].**

[3] **"Thermal analysis of a solid brake disc," Thermal analysis of a solid brake disc - ScienceDirect, Aug. 27, 2011. [Online].**

[4] **"Structural and Thermal Analysis of Rotor Disc of Disc Brake", International Journal of Innovative Research in Science, En- gineering and Technology, Manjunath T V1 , Dr Suresh P M2, [Online].**