1.1. BACKGROUND

The automotive vehicles play a vital role in the commercial and private use of human beings. During recent years the main focus in the vehicle industries are on fuel consumption, emission level and vehicle energy management. In addition to this, to attract the people and maintain market share, high powered Internal Combustion (IC) engine and streamlined body are preferred. The attempts to make streamlined body resulted in improved aerodynamic drag of vehicle which reduced the cooling airflow passing through the cooling module.

The vehicle underhood architecture study comprises both aspects of thermal analysis and aerodynamics. Khaled et al. categorized the underhood components based on their aerothermal implication as shown in Table 1.1 [1].

Table 1.1: Example of components present in underhood

<table>
<thead>
<tr>
<th>Category</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>First order (higher aerothermal implication)</td>
<td>Air inlets, air outlets, heat exchangers, fan, engine, turbo compressor, exhaust manifold</td>
</tr>
<tr>
<td>Second order (middle aerothermal implication)</td>
<td>Battery, compressor, evaporator, expander, admission collector, pump, thermostat, heater, oil/water exchanger</td>
</tr>
<tr>
<td>Third order (low aerothermal implication)</td>
<td>Distribution belt, transmission, shield under the engine, cradle, apron, thermal shield, accessories, cables</td>
</tr>
</tbody>
</table>
The vehicle designer must understand the balance between the drag due to cooling airflow and the required airflow for engine cooling. However, the interaction between underhood airflow and external aerodynamics is not yet fully understood [2]. Figure 1.1 shows a survey on cooling airflow volume trend over 200 vehicles from model years 1992 to 2001 [3]. The function of cooling airflow is to ensure the required cooling performance of heat exchanger and minimize the cooling drag component of total vehicle drag.

Figure 1.2 shows the cooling airflow path in engine compartment. The geometry of blockages and arrangement of heat exchangers in the CAP influences the engine cooling system performance. The blockages in the cooling airflow path categorized as hotspot and non-hotspot objects. The non-hotspot objects are grille, bumper, number plate, crash beam, horn. The hotspot objects are heat exchangers like condenser, CAC. The attractive grille textures and bumper along with cross members in the vehicle front make the radiator face velocity profile to highly non-uniform. Especially, at highway speed the airflow distribution over the radiator face gets disturbed.
which results in the deterioration of thermal performance. Further, the arrangement of heat exchangers (condenser and radiator) close to each other also deteriorates the thermal performance of each other.

With increased engine power and less space in the underhood compartment leads to an issue in evacuating the cooling airflow and also necessitates huge airflow to carry away the heat rejected from engine. Failure to meet the required cooling airflow tend to increase the operating temperature in the engine compartment. For these reasons, in the perspective of underhood thermal management the research has been carried out to improve and optimize the CAP in the upstream direction of the radiator.

![Cooling airflow path and cooling module](image.jpg)

**Figure 1.2: Cooling airflow path and cooling module [4]**
1.2. PURPOSE

This research project is titled as ‘Theoretical and Experimental Investigation on Cooling Airflow Path in Automotive Engine Cooling System’ and the scope of this project is to improve the design process of underhood thermal management with specific focus on cooling airflow path.

This work investigates the cooling airflow path features associated with hotspot and non-hotspot objects in terms of radiator performance. The focus of this work is to analyze the heat exchanger thermal performance with respect to various blockage types and the position of heat exchanger in cooling airflow path.

This thesis will present the methodology to evaluate the cooling airflow path along with various blockage types using 3D CFD tool and empirical correlation. Further, the level of accuracy and modeling strategy are validated through experimental testing results.

1.3 UNDERHOOD THERMAL MANAGEMENT AND COOLING AIRFLOW PROCESS

The primary responsibility of an engine cooling system is to ensure sufficient airflow passes through radiator and to ensure engine does not overheat. However, the other nearby components such as radiator and AC system should also work effectively. Thus, a better CAP is required to ensure the effective engine cooling system and AC system. Therefore, the challenge in the design of CAP is to ensure minimal blockage area and proper arrangement of heat exchanger. From the perspective of the heat transfer and engine cooling system, thermal management can be divided into three categories

i. Heat transmission from engine to coolant
ii. Engine coolant circuit
iii. Dissipation of heat from hot coolant to ambient air.

This thesis is limited only to the dissipation of heat to cooling airflow.

1.4. THE IMPORTANCE OF COOLING AIRFLOW PATH

The CAP influences the performance of engine cooling system and vehicle aerodynamic drag. Thus, the design of CAP plays a significant role in fuel consumption and vehicle performance. Pang et al. reviewed the airflow circuit of engine cooling system [5]. The impact of blockages in cooling airflow path are given below

- The blockages in cooling airflow path disturbs the cooling airflow volume and its distribution.
- The non-uniform airflow distribution over the radiator face deteriorates the thermal performance by up to 30%.
- The non-uniform airflow distribution raises the pressure drop across heat exchanger by up to 100%
- The air temperature at the exit of condenser influences the temperature of radiator coolant.

Hence, there is a significant need to understand the blockages in CAP in the upstream direction of radiator. This is required in order to enhance the radiator thermal performance in terms of air velocity distribution and its spatial location.

1.5. OUTLINE OF THE THESIS

This introductory chapter is followed by six chapters.

- Chapter 2: presents an extensive literature review related to this research work. This chapter investigates available literature related to the need and importance of cooling airflow and heat exchanger in the underhood environment. This chapter also deals with research gap, objectives and proposed methodology of this research work.
• The physical model and numerical methods are provided in chapter 3 in which the governing equations, solution methodology and meshing technique are discussed.

• Chapter 4 discusses about the experimental set up being used for the analysis.

• The analysis and results of both experimental and numerical work are presented in chapter 5.

• The obtained conclusions are provided in chapter 6.

• Finally, an outlook of future work is briefed in chapter 7.