Numerical Analysis of Thermal Systems of a Bus Engine

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NUMERICAL ANALYSIS OF THERMAL SYSTEMS OF A BUS ENGINE

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1. INTRODUCTION

Transportation is one of the main sectors contributing to climate change via the production of greenhouse gas emissions. In particular, 27% of UK emissions are attributed to transport [1]. European Union, in order to tackle this problem, has introduced the Euro VI regulations for heavy-duty vehicles [2]. Vehicle thermal management systems have been a critical part of improving vehicle fuel economy, as more than 50% of fuel energy is going to heat. Thermal systems are very complex in terms of thermo-fluid analysis due to the different shaped and size of the components, which make experimental testing challenging [3]. Wang et al. [4] developed an integrated (1D/3D) model consisting of three sub-models, an engine cooling system including the oil circuit, a charge-air cooling system and a HVAC system. With this method, both the heat transfer and transient characteristics of the thermal systems can be simulated and analysed. Similarly, Bayraktar [5] used the integrated modelling method to analyse the powertrain and HVAC systems. The results showed that low-order modelling provides a positive first representation of a proposed system, however 3D simulations are required to analyse the system's behaviour at transient state conditions. Bolehovsky et al. [6] compared the 1D and 1D/3D simulations for an engine cooling system. The results showed that the 1D model overestimates the heat transfer rate at radiator by 10%.

2. METHDOLOGY

An integrated 0D/3D modelling approach is adopted in this research. A MATLAB based 0D model is developed which consists of six sub-models: combustion chamber model, cooling system, charge-air cooling system, lubricant system, EGR cooler and turbocharger (figure 1). All the components placed in the under-hood are modelled using laws of thermodynamics and heat transfer equations. In a bus, the engine bay is at the back in order to maximise the interior space. Radiator and charge-air cooler are at the side of the vehicle and they are exposed to highly transient and turbulent airflow. Therefore, low order modeling approaches cannot resolve property the flow and thermal characteristics of these two elements. Thus, 3D computation is required to model the effect of the external air flow as well as the internal water's cooling flow on the thermal feature of the system. In this regard, to minimise the computational time, two 3D models have been developed. One that simulates the airflow around the bus and one that analyses the heat and fluid flow of radiator and charge-air cooler in the engine bay. The first model establishes the boundary conditions for the engine bay model, which feeds data to the 0D model and complete the calculation.

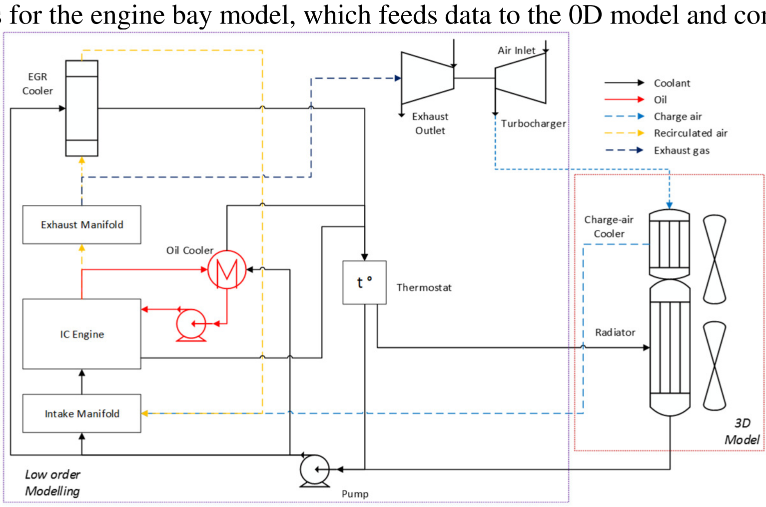

Fig. 1 Schematic diagram of the integrated model

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3. RESULTS

A closed fluid domain to replicate the wind tunnel was created to generate the airflow features in the engine bay. Figure 2 shows that the airflow captured at the grilles is significantly reduced. This results in lower heat rejection at radiator and charge-air cooler for buses comparing to cars. Thus, the main source of airflow is the fans which cause a transient and non-uniform flow at the downstream of the fans which subsequently go through the fins of the radiator and charge-air cooler (figure 3).

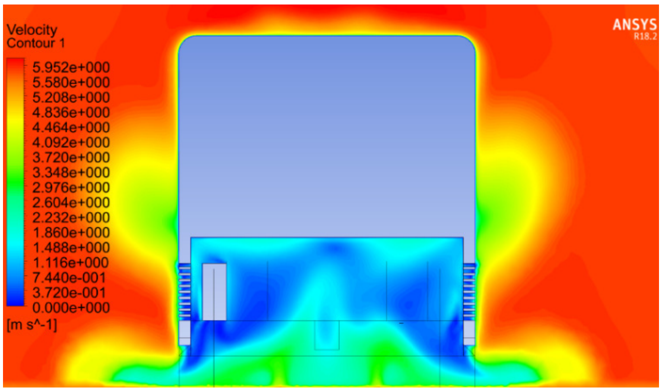

Fig. 2 Air velocity contours at the engine bay

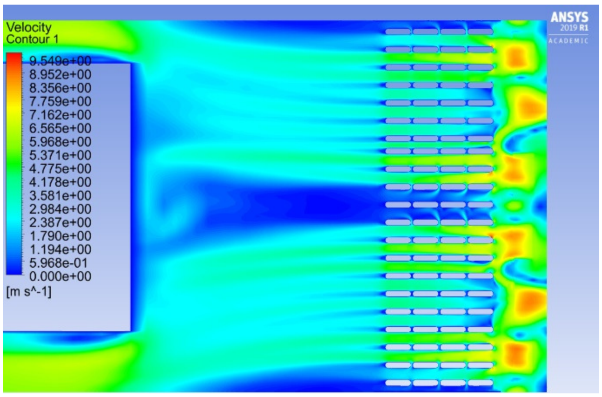

Fig. 3 Air velocity contours between the tubes

A full scale 0D and a coupled 0D/3D model were tested under the same operating condition based on the MLTB drive cycle. The bus speed was 55 km/h and the engine speed and torque were 1500 rpm and 850 Nm respectively. As it is illustrated in figure 4, the heat transfer rate at radiator and charge-air cooler is overestimated. This occurs because the OD model cannot capture accurately the airflow features at the rear of the bus, specifically at the grilles where radiator and charge-air cooler are placed. Therefore, the heat transfer coefficient between the external air and the surface of the components is not precisely estimated. Moreover, the results show that more than 50% of the heat loss can be recovered.

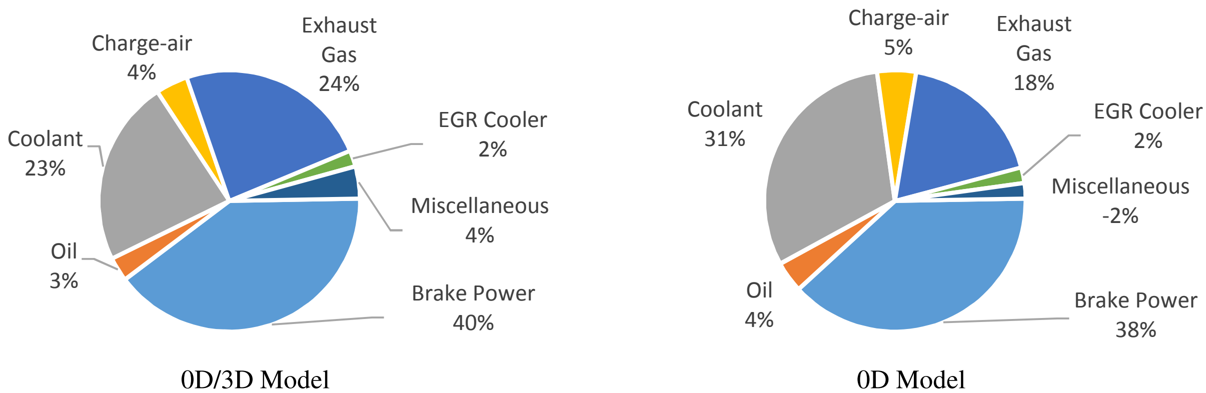

Fig. 4 Thermal Energy Balance

4. CONCLUSIONS

The integrated simulation method is implemented in vehicle thermal systems of a bus engine. A MATLAB based low-order (0D) model and 3D CFD models using FLUENT have been developed. The 0D model considers heat transfer aspects and thermodynamic laws of all the under-hood thermal systems. Through the CFD simulations the heat transfer coefficient of radiator and charge-air cooler is calculated and fed to the low-order model.

As the engine is placed at the rear of the bus, the heat and fluid flow features are difficult to be estimated using full scale 0D model. Therefore, more accurate results can be generated using the proposed approach. Moreover, parametric study can be carried out in order to reevaluate the thermal energy distribution.

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