

Characterizing Thermal Interactions Between Engine Coolant, Oil and Ambient for an Internal Combustion Engine

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ABSTRACT

This paper discusses a streamlined approach for characterizing the heat flows from the combustion chamber to the engine coolant, engine oil circuit and the ambient. The approach in this paper uses a built-in flow and heat transfer solver in the CAD model of the engine to derive heat transfer coefficients for the coolant-block interface, oil-block interface and the block-ambient interface. These coefficients take into account the changing boundary conditions of flow rate, temperatures, and combustion heat to help characterize the complex thermal interactions between each of these sub-systems during the warm-up process. This information is fed into a larger system model of the engine to get a more accurate prediction of the engine warm-up and the effect of various fuel economy improvement strategies being evaluated. One of the key benefits shared in this paper is the practicality of the process that can be replicated on every production vehicle simulation model.

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INTRODUCTION

With the new fuel economy targets approved by lawmakers in the United States, there is a significant focus among car manufacturers to explore various fuel economy strategies, generally combining many of these strategies together to improve the fuel economy performance. These fuel economy strategies can be quickly evaluated in complete system models developed in Matlab, Flowmaster, Gamma Technologies or many other available commercial codes. The details of these models will not be discussed here only a brief outline is provided in the following section. A detailed description of such models can be found in [1,2,3].

One of the major challenges of these models is that they are only as accurate as the input data that is fed to them. And this input data is hard to come by especially in the initial

design phases where much of the engine design detail has not been finalized. One of such critical inputs is the heat transfer coefficient from the engine cylinder block

There are many ways of arriving at the heat transfer coefficient depending on the stage of the design and availability of the data. This paper discusses one such approach that uses both 1D and 3D Computational Fluid Dynamics (CFD) in combination in a later part of the design cycle when an initial prototype of the engine and test data on combustion heat is available. This enables the use of a simple CFD heat transfer model where the combustion heat from test data can be applied directly to the cylinder liners without the need to run combustion calculations to get the cylinder wall temperatures. Below is the brief description of the model set-up.

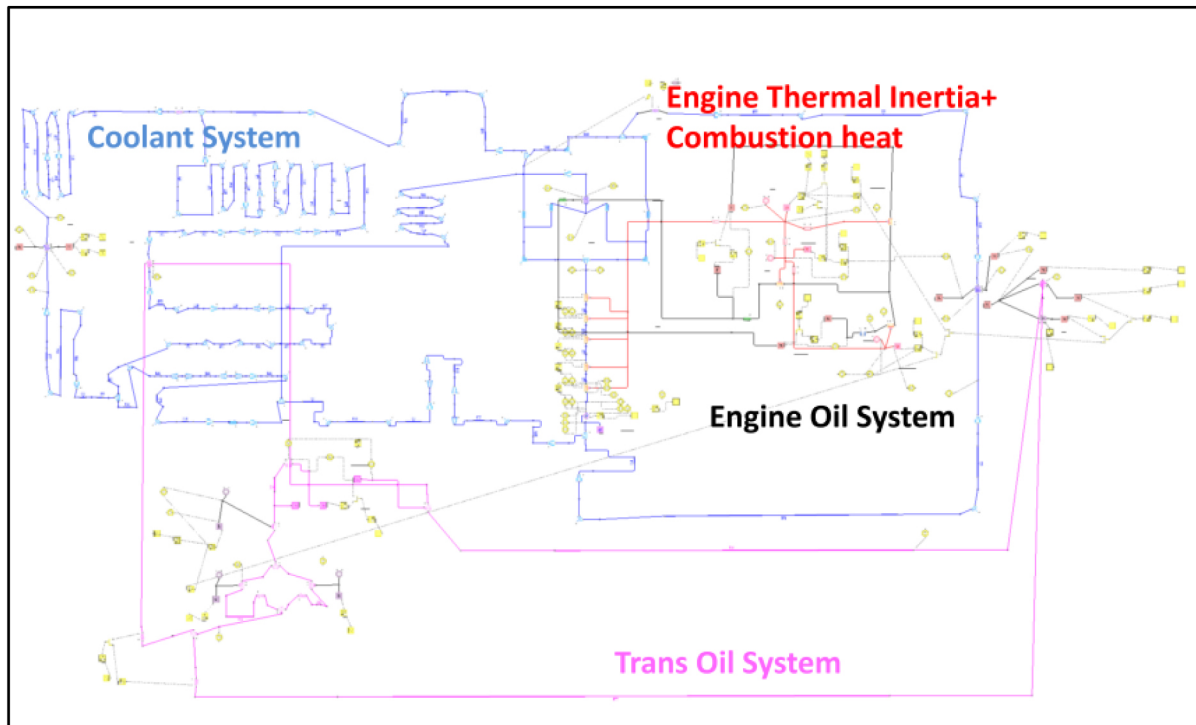


Figure 1. Engine Thermal model in Flowmaster

MODEL DESCRIPTION

The system analysis has traditionally been done through 1D CFD simulation supported by either experimentally obtained data of the components or via a 3D CFD analysis of the specific components or sub-systems. The system level analysis is only as good as the quality of the data for each of the components. Utilizing 3D analysis can be a quick, effective, and accurate way to approach drive cycle simulation. At any point in the design process, details from the 3D models can be used to improve and enhance the system model. Using Computer Aided Design (CAD) design details in a component level analysis, and passing this data to the system level analysis, will improve the fidelity of the overall analysis. This is done using a combination of 1D simulation and 3D simulation by harnessing the strengths of each tool. The discussion in this paper specifically focusses on how the heat transfer calculation from a 3D CFD analysis can complement and improve the fidelity of calculations of the 1D lumped parameter system models.

1D Engine Thermal Model

The overall 1D system model of the engine was developed in Flowmaster, a commercial-off-the-shelf software commonly used in the industry. The model includes four separate sub-systems - the engine structure, engine cooling circuit, engine oil circuit and the transmission oil circuit [1,7].

This engine thermal model uses various boundary conditions from the larger vehicle simulation model such as

vehicle velocity, engine torque and engine rpm. Since the model is a transient thermal model, these boundary conditions can be provided as a trace of time for a particular drive cycle. The boundary conditions are used by the engine thermal model to look up the instantaneous combustion heat, frictional heat, coolant and oil flow rates, and calculate the temperatures in various sub-systems.

These temperatures, such as the engine block temperature, coolant temperature, and oil temperature are then fed back into the larger vehicle model so they can be taken into consideration for the fuel economy calculation.

Modeling of the thermal interactions, especially calculating the heat transfer coefficients from the engine block to the coolant and oil can be more involved. This is because, to accurately determine the heat transfer coefficient, the temperature of the engine surface exposed to the fluid must be known. In the case of the coolant, this is the temperature of the cylinder liner. These temperatures are hard to determine as they are dependent on numerous parameters including the temperature of the combustion gas and the geometric dimensions of the material to name a few.

Typically, these temperatures and heat transfer coefficients are determined by a detailed combustion code that calculates the combustion process and the gas temperatures. In the current approach, the heat rejected to the coolant from the combustion chamber was known. This is determined by testing the initial prototype of the engine and generating a map of heat generated by the engine as a function of engine rpm and Brake Mean Effective Pressure (BMEP). Since the heat generated is already known, a