Improving 1D Data with 3D CFD

Improving 1D Thermo-Fluid System Automotive Engine Data with 3D Computational Fluid Dynamics

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When working with larger cooling systems that incorporate several components such as heat exchangers, thermostats, coolant pumps and different cooling cycles like oil and coolant, a 1D CFD simulation tool is the common choice for thermal analysis. However, when considering an automotive engine cooling system, which is rather more complex when you take into account their transient behaviors with corresponding drive cycles and system reactions with all components, it becomes even more complex on any changes in flow rates or temperatures.

Moreover, such systems can only be as accurate as the data that is supplied to them. One way to improve accuracy would be to get 3D component data and characteristics from measurements. If however components are still in the design stage, building a prototype and measuring them can be extremely expensive. To facilitate this, Mentor offers a direct interface by coupling CAD embedded CFD software FloEFD™ with system simulation software Flowmaster®, resulting in a CFD characterized model as a component in the Flowmaster system.
A recent paper for the SAE World Congress [1] demonstrates the use of coupled 1D-3D CFD simulation for an automotive engine block (see Figure 1).

The Problem

It is well known that bringing an automotive engine up to normal operating temperature quickly after starting is the best way to improve vehicle efficiency. The engine and complementary components, along with the coolant and oil, all start out cold. By confining the heat to the engine during the warm up period, efficiencies during the startup cycle of a vehicle can be improved.

A combination of 1D and 3D CFD can be utilized to determine the optimal design of such an engine. Each type of simulation has its virtues, whilst 1D simulation can run long transient simulations quickly it can lack some detail. 3D CFD simulations on the other hand can accurately simulate details of solid components but it tends to be slower in regard to transients.

An engine system has many components and as a consequence when the design develops not all the pieces are ready at once. As well as this, obtaining vital data can take time, so an efficient design process incorporating engine cooling data obtained through testing can be supplied to the 1D simulation tool for analysis. Should the component require modifications through the design cycle, testing will need to be repeated. Conversely, if testing has not yet been performed and all that is available is empirical data to quantify the engine, then accuracy could come into question. The net effect is that these types of approaches can be time consuming or inaccurate. In this instance the engine block and head were available as CAD models and the majority of the details of the 1D model were already in place making a 1D-3D approach ideal.

How CFD was used

A CAD model of the engine block and head was used for the 3D simulation. Figure 2. shows the coolant and oil flow paths in the engine (in blue). When setting up the

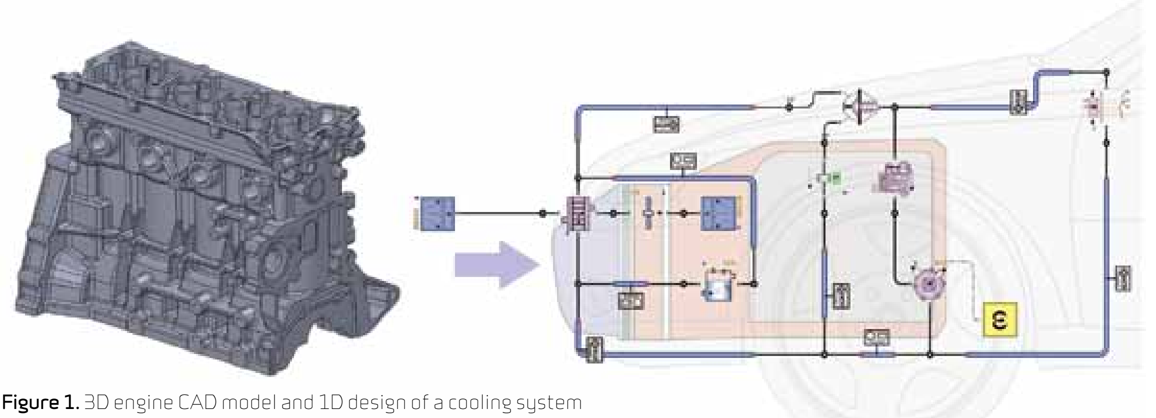

Figure 1. 3D engine CAD model and 1D design of a cooling system

power boundary conditions in the model, the portion of heat that is dissipated from the combustion into the cylinder walls was applied as a constant. The value of heat used for this dissipation was developed from earlier experimental data and the imposed drive cycle. Goals were set in the model to automatically capture flow versus heat transfer coefficients for each fluid. Air around the engine and head also contributed to the engine cooling through natural convection. Once the base case was setup, an array of nine models was run using a parametric study in FloEFD. The model was created to vary coolant and oil flow. Heat dissipations in the motor were also varied. Once the array of nine CFD models was run, the data was then compared to empirical data according to Dittus-Boelter correlations.

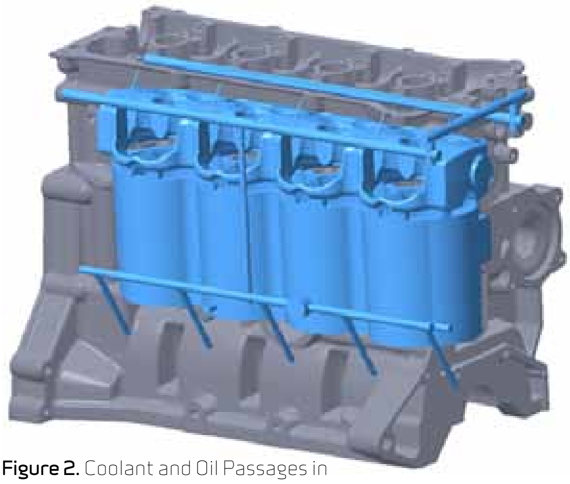

Figure 2. Coolant and Oil Passages in Detailed 3D CFD Model

Solution & Results

The 3D CFD simulation was setup in a short time and the results from the parametric study were imported as a new component into Flowmaster for the overall system simulation of the transient drive cycle. The graph in Figure 3 below shows a significant difference in the methods used to quantify the heat transfer from the engine to the coolant. Heat transfer coefficients from the engine to the coolant had differences as high as 20% between hand calculation and 3D CFD simulations. This shows that the overall accuracy when using 3D CFD simulation data is far more accurate than hand calculations. The overall process of characterizing a component for a range of working parameters as shown here enables the system designer to evaluate any changes in the system with the same component over and over much faster than a direct 1D-3D coupling where a 3D transient simulation can be the major bottleneck in the overall calculation time.

Concluding Thoughts

As demonstrated here, the detailed simulation approach versus conventional engineering hand calculations can be significantly different. Use of a validated 3D CFD tool such as FloEFD, as opposed to a single empirical formula can greatly improve the accuracy of the data used in any 1D simulation like with Flowmaster. A single empirical formula can fail to capture all of the details and differences within a detailed engineering design. As can be seen in Figure 4, there are many complex details in the engine geometry and in its consequent performance results that a single formula cannot capture.

The perceived advantage of the empirical formula is that it takes less than half an hour to develop. However, in the amount of time it takes to look up the formulas, a model could be setup and a run initiated in FloEFD. From there it is only a matter of a few days of computing time to create the data from the 3D simulation. A trade off that is well worth it for the vast improvement in accuracy. Since FloEFD is embedded within most CAD tools, any design changes to the engine and block make it easy to capture the performance changes. If there are any changes to the engine or block, the 3D simulation could be re-run with no additional setup, thereby keeping the data current. This allows the engine and block to be developed concurrently with the 1D simulation.

As we follow along this analysis method we will see a difference in the 1D modeling. A follow-on paper is expected to be delivered that highlights the differences in the 1D analysis.

Reference:

[1] SAE 2013 World Congress "Characterizing Thermal Interactions Between Engine Coolant, Oil and Ambient for an Internal Combustion Engine" Sudhi Uppuluri, Computational Sciences Experts Group; Joe Proulx, Mentor Graphics; Boris Marovic, Mentor Graphics (Deutschland)GmbH; Ajay Naiknaware, CSEG, LLC

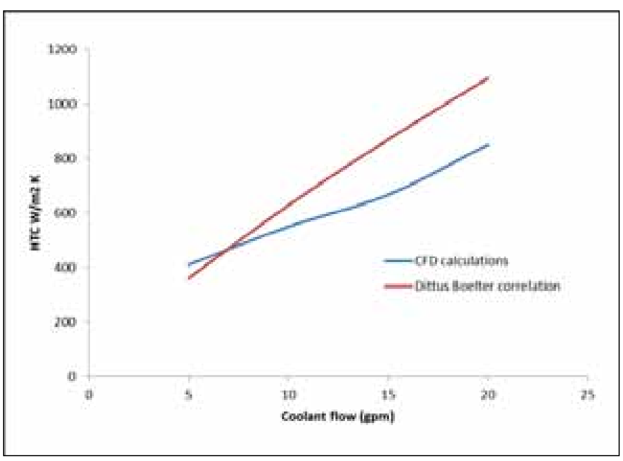

Figure 3. Comparison Chart of Empirically Derived and 3D Simulation Derived Heat Transfer Coefficient.

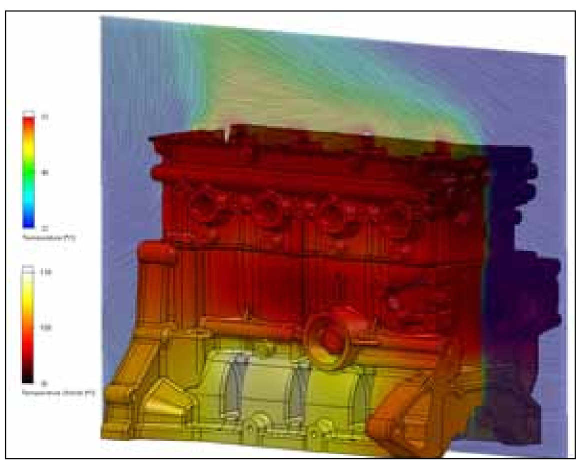

Figure 4. Surface Plot of Temperature from 3D Simulation