How To...

Characterize an Automotive Thermostat for Thermo-fluid System Simulation

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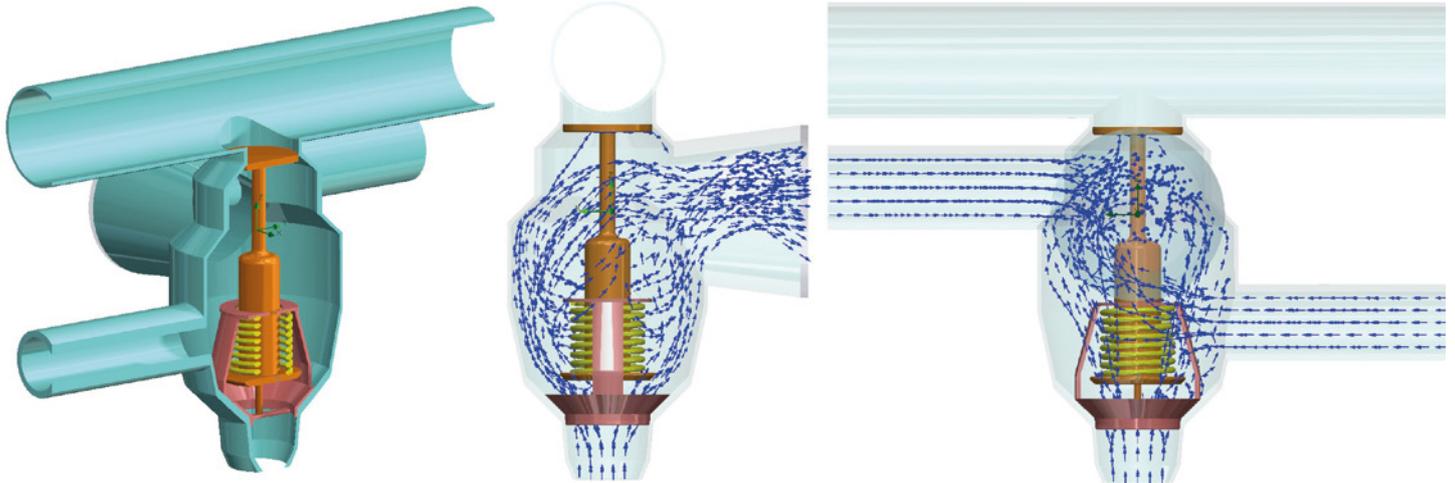

Figure 1. Thermostat Model in FloEFD

Automotive thermostats are one of the most important components in a vehicle thermal management system. It is responsible for maintaining an acceptable working temperature in the engine both to prevent catastrophic failure and keep it operating as efficiently as possible. As vehicles have become more complex with their cooling systems, so too have thermostats. These parts are no longer as simple as a single flow path in and then either flow to bypass or the radiator. It is easy for these components to now have at least three or four inlets and multiple outlets.

This increased complexity creates more complex 3D flow patterns that are not accounted for in any standard FloMASTER component model. Engineers could try to replicate the number of flow arms using discrete losses, but this does not allow for the interaction of the effect on pressure drop that the differing flow rates in all the arms have in reality, e.g. Venturi effects. This is where applying simulation based characterization can increase the accuracy of automotive cooling circuit simulations. In fact this is something Sudhi Uppuluri of Computational Sciences Experts Group has expressed,

"When modeling multi-arm junctions such as automotive thermostats and pump housings, characterizing individual flow paths as parallel and independent losses can give rise to 15 to 20% error in predicting mass flow rates through an outlet. This
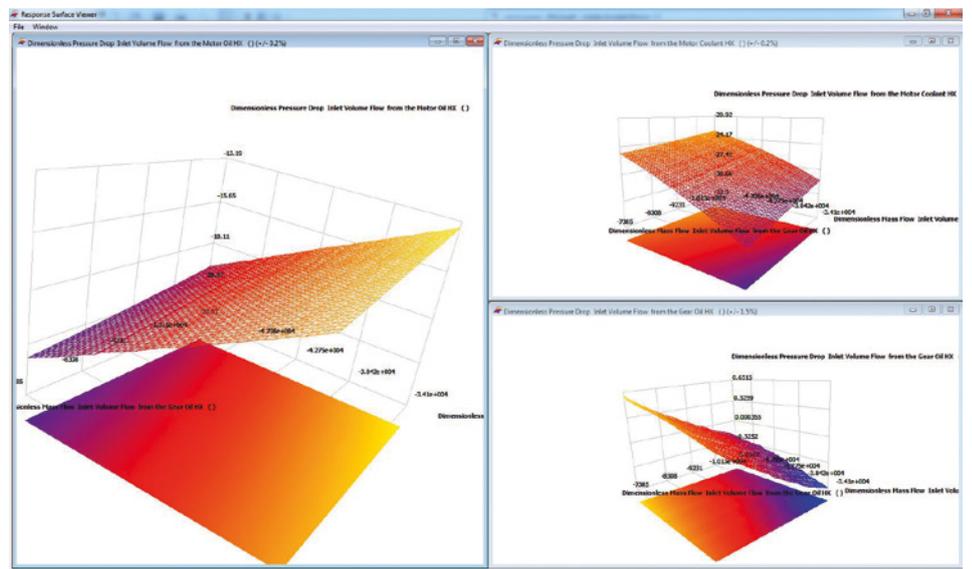

Figure 2. Response Surface Models for Pressure Drops

error is eradicated by considering the effect of changes in branch pressure drops with changing flow rates in the other branches. Using FloEFD to perform full spectrum 3D CFD characterization of the housing and integrating inter-dependent flow channel interactions into a FloMASTER N-Arm component improves simulation accuracy, confidence and trust reducing physical testing times and ultimate time to market."

FloEFD Model Setup

As an example, figure 1 shows a five arm thermostat with four inlets (from the radiator, gear oil cooler, engine oil cooler, and radiator bypass) and one outlet to the engine. The

goal is to characterize this component for use at maximum flow rate to the radiator, so an assumption can be made that the radiator bypass is fully closed. This simplifies the problem to a four-arm component with three inlets and one outlet.

The next step is to determine what the bounds of the characterization should be. At this point in the design the expected coolant flow rates should be known, and if they are not, thermal balance for each of the cooling loops could be done to estimate these values. With this information it is important to give a range of values centered on the expected flow rate. The range can

vary based on how well the system and component are known but for this example a range of +/- 20% is applied and shown in Table 1. In addition to the flow rates, a reference arm must be specified which in this case will be the thermostat outlet. This arm has an environmental pressure of 101325 Pa which will remain fixed through all of the simulations.

Design of Experiment Setup

These values can then be entered into FloEFD using the Characterization option for the type of Parametric Study. Once the values are entered, a number of experiments is required, in this case 120 simulations were run. FloEFD then creates a Design of Experiments (DoE) that randomly and equally distributes the combinations of flow rates throughout the characterization space. The DoE can then be run with the results presented as dimensionless flow rate and dimensionless pressure drop. These values have been non-dimensionalizes based on the fluid properties to remove any dependency on density and viscosity. This means when using this characterization in FloMASTER it is not critical to use a fluid with the exact same fluid properties.

Once all of the experiments are finished successfully, the Response Surface Models (RSM) can be created. These response surfaces are N-dimensional mathematical 'surfaces' that relate an output to multiple inputs. The first thing to check with the RSMs is the error in their mathematical fitting. The amount of error that is acceptable is a subjective decision, but for this scenario < 5% is considered acceptable which all three RSMs and under. If further refinements need to be done, additional experiments could have been added to the original DoE with the new points fitting into the original distribution. There is also the option to visually inspect the RSMs as shown in figure 2.

Response Surface Model Export and Import

Assuming everything is acceptable the RSMs can then be exported to FloMASTER as a ".flonarm" file. This file is actually an FMU adhering to the FMI standard, but augmented to also include additional information that is used by FloMASTER such as the area of each arm and the 3D representation of the geometry for visualization in FloMASTER.

To create the thermostat component in FloMASTER, "New FloEFD N-Arm Component" can be selected from the Launchpad. Once the file is loaded and the import is successful, the branch data and

hydraulic limits are available for review. At this point the 3D visualization is also available to identify each arm and also to create a component symbol as seen in figure 3. The 3D representation can be rotated and zoomed to get the best angle, and the camera icon at the top can be used to take the image. Once this is complete, the component will be saved into the FloMASTER database for use by anyone with access to it.

With the component in the FloMASTER database, it can be used in any model with a simple drag and drop similar to standard FloMASTER components. In this example, it is added to an automotive vehicle thermal

management model and connected to the appropriate parts of the model as seen in figure 4. An initial run results in a system that is operating well with-in the bounds of the characterization. This process allows for increased accuracy in the pressure drop through the thermostat when compared to previous ways of modeling in FloMASTER and thus a more accurate representation of the system behavior.

Download the White Paper:

Simulation Based Characterization. A 3D to 1D System Level Thermo-Fluid CFD Workflow: http://bit.ly/2nwjEmV

Parameter	Min Value (L/min)	Max Value (L/min)
Gear Oil Cooler Flow Rate	9.6	14.4
Motor Coolant Flow Rate	48.4	72.6
Motor Oil Cooler Flow Rate	39.4	59.4

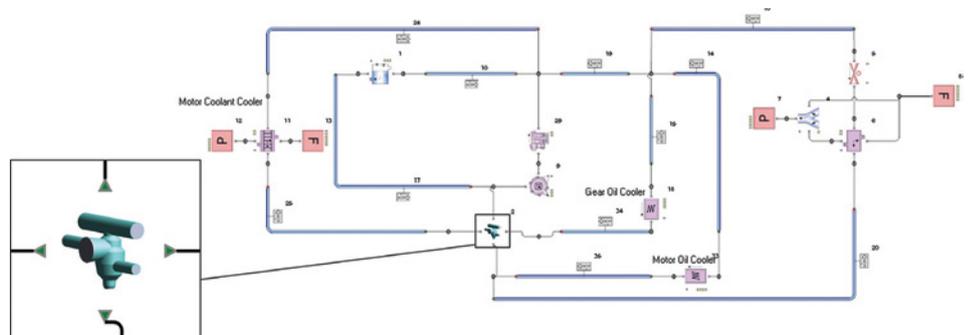**Table 1.** Oil Flow Rate Values
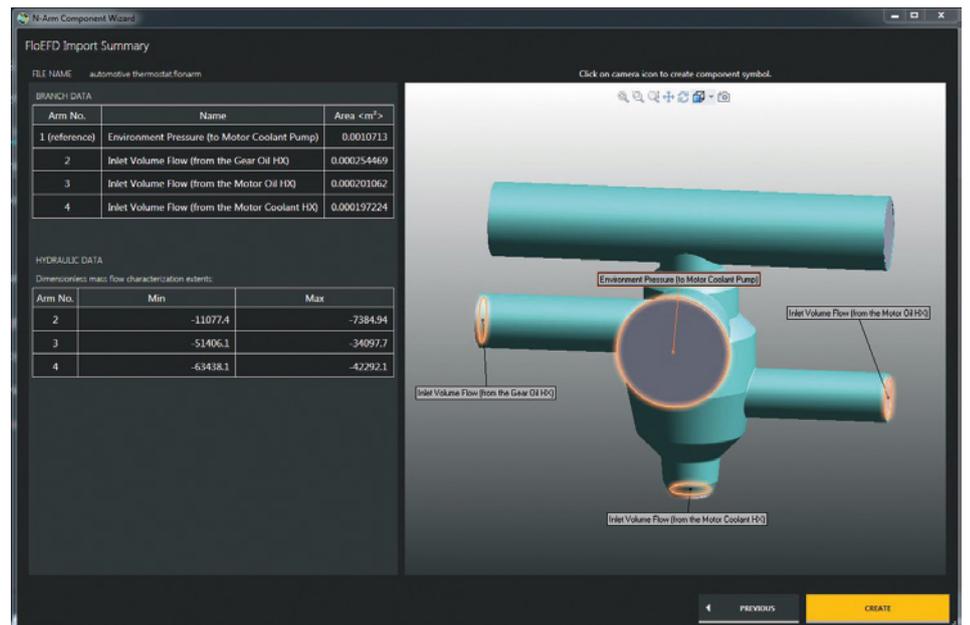
Figure 3. FloMASTER N-Arm Creation

Figure 4. FloMASTER Cooling System Model with FloEFD Thermostat

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