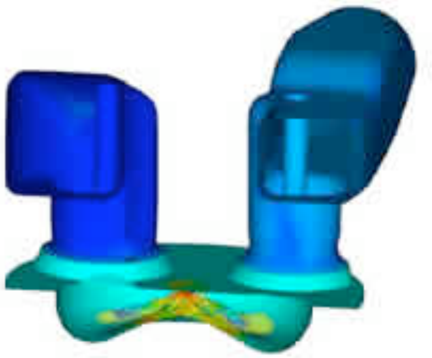
ERC Uses CFD Visualizations on Quest For Cleaner, More Fuel-Efficient Engines

By Kathleen Wheatley

Researchers at the University of Wisconsin-Madison Engine Research Center (ERC) are using computational fluid dynamics (CFD) and high-end visualization software to develop new computer models that enable a greater understanding of combustion and fuel flow and distribution in internal combustion engines. The research promises cleaner, more fuel-efficient engines in the future.

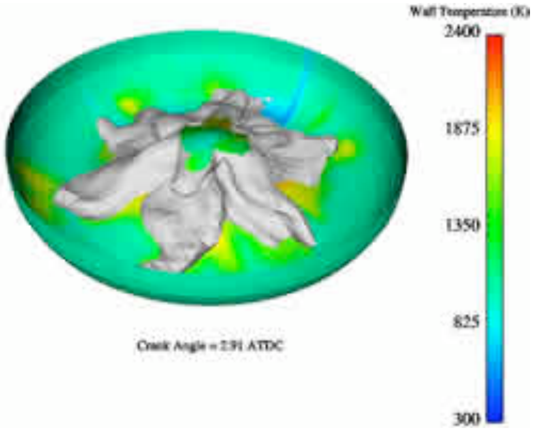


The new combustion models permit ERC researchers to perform CFD calculations on PCs and SGI workstations, rather than conducting time-consuming and expensive laboratory experiments. The computational results are fed into high-end visualization software that helps the ERC team interpret the results.

"Visualizing simulation results often helps confirm the predictive capability of a model and permits researchers to more easily identify areas where the model needs improvement," says Shrikanth Rao, a graduate student in mechanical engineering working with Professor Christopher J. Rutland at the ERC. "The ability to isolate a specific problem area is particularly important with CFD simulations of chemically reacting turbulent flows, since these models can be as large as 300,000 computational grid cells."

Simulating Diesel Combustion

Computing resources do not allow researchers to resolve all the details of the turbulent flow inside an engine, so Rao and Rutland rely on turbulence models to approximate the details of these effects. The two use a dynamic structure Large Eddy Simulation (LES) turbulence model to simulate diesel combustion rather than the traditional viscosity-based model.

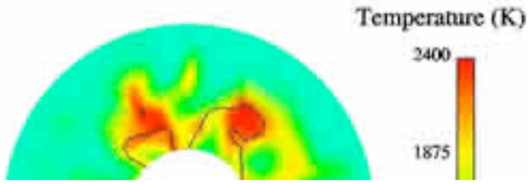


The traditional turbulence model holds that viscosity is greater in turbulent flow than in laminar, or streamlined, flow. A traditional model is fine for determining the simple flow structure, but cannot accurately characterize the details of turbulence and turbulent mixing.

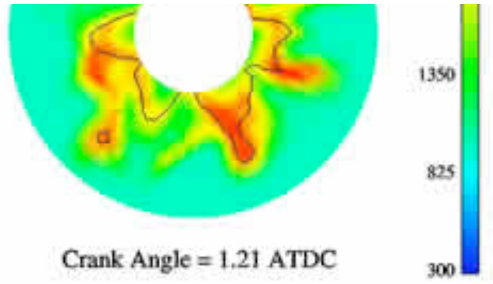
LES models allow for more complex geometric configurations and flow problems where different types of physics interact. This allows Rao and Rutland to obtain a more realistic representation of flow details and precisely capture transient effects and large-scale flow structures.

Coffee, Cream and Combustion

Rao uses the process of stirring cream into a cup of coffee to explain the benefits of using a LES model. "If we used the traditional model to look at the stirring process, we would only see the end result, where the cream and coffee are more or less uniformly mixed.



This means we would never realistically know how much cream is present at any given location in space because we have incorrectly represented how the cream mixes.

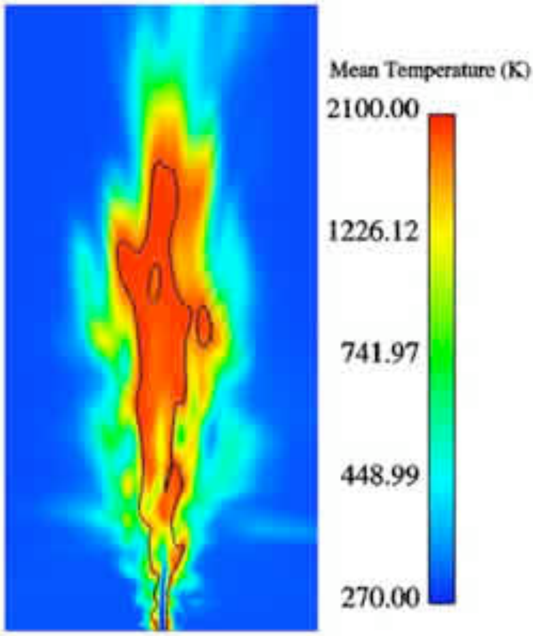


"But if we use the LES model, we would be able to see the details during the mixing - perhaps a higher concentration of cream in some places and coffee in others - giving us a better approximation of how much cream there is in each location at all times. In an engine, this would correspond to better knowing the distribution of gaseous fuel inside the cylinder, thus allowing us to more accurately predict the production of soot, for example."

Model Behavior

Opting to use LES was not a simple decision since it requires implementing the model into the ERC version of the KIVA-3V code. KIVA is a finite difference code used to design and analyze internal combustion engines. Originally developed at Los Alamos National Laboratory, KIVA uses the traditional viscosity-based model of turbulence.

ERC researchers adapted KIVA by first writing a code to average flow variables in space. Next, models were used to represent the effects of the added convection, replacing the turbulent viscosity of the traditional models with molecular viscosity. The new code captures flow details and other physical processes more accurately, according to Rao, substantially improving the predictive capability of the models.



"With this more accurate predictive model, we can use computers to examine the effects of design changes on engine performance, both in terms of emissions and efficiency," says Rao. "We hope to be able to use computers to give us a first shot at improving engine design, instead of relying solely on expensive, time-consuming experiments."

Verifying Experimental Data

During a recent implementation of the LES model, the team found that there was not enough fuel burning in the engine simulation as compared to the experimental data. Looking at the simulation results in EnSight visualization software from CEI, they were able to trace the problem back to an incorrect fuel-air mixture predicted by the model.

"We could see that near the center (axis) of the computational mesh, the LES model predicted very little flow of gases," says Rao. "This visual information allowed us to verify that the model was incorrect and make modifications to accurately capture the fuel-air mixing process."

Visualizations can also confirm that a model is correct. In a simulation involving a turbulent methane-air jet flame, Rao and Rutland used EnSight to verify that their model was accurately replicating experimental observations.

EnSight enabled the team to look at both horizontal and vertical clip planes, simultaneously visualizing and analyzing factors such as the scalar field (the distribution of fuel, air and products), the spatial gradient, areas of chemical reactions, and areas of high turbulence intensity. The clip plane feature also helped researchers determine how properties vary in different spatial directions.

Adding a Piece to the Puzzle

Being able to view flow details and verify that their models accurately reflect experimental data puts Rao, Rutland and the ERC team one step closer to gaining valuable knowledge of the combustion process.

"Having accurate codes and effective visualization tools is essential to developing reliable combustion models," Rao says. "Visualizing large amounts of simulation data in an easy-to-comprehend manner helps us reach a greater understanding of our simulation results, adding a piece to the puzzle of developing clean, efficient combustion devices."

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