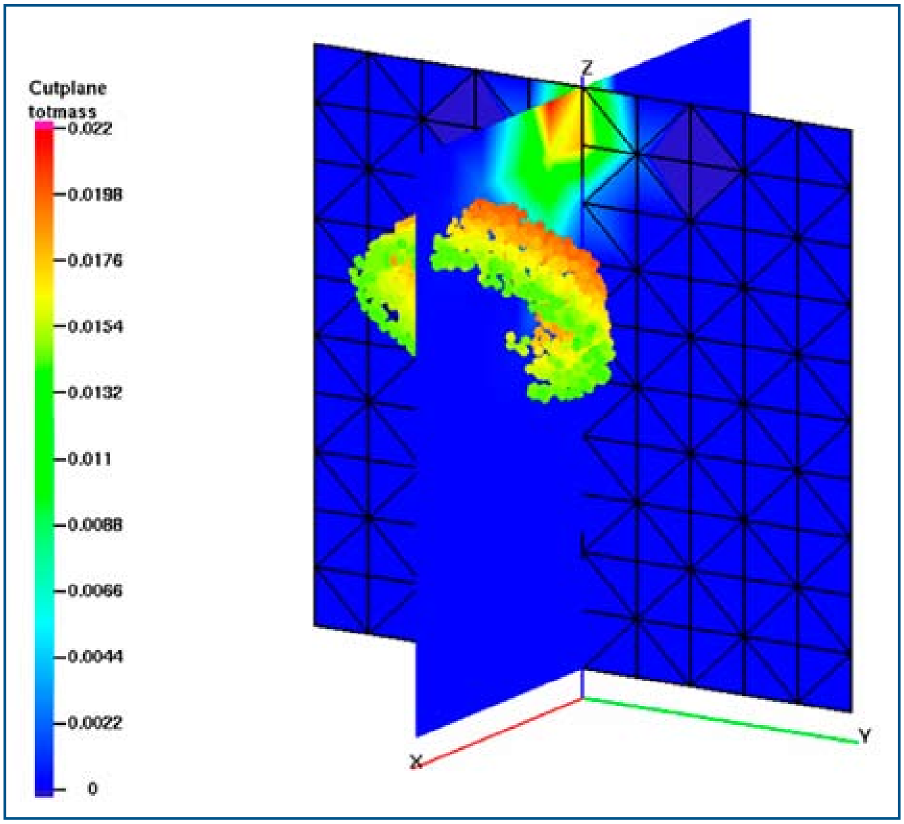
Modeling of Combustion Processes Improves Engine Efficiency

Background

Vehicle fuel economy is heavily dependent upon engine efficiency, which in turn largely depends on the way fuel is burned within the cylinders of the engine. Higher in-cylinder pressures and temperatures lead to increased fuel economy, but they also create more difficulty in controlling the combustion process. Poorly controlled and incomplete combustion can cause higher levels of emissions and lower engine efficiencies. In order to optimize combustion processes, engine designers have traditionally undertaken manual engine modifications, conducted testing, and analyzed the results. This iterative process is painstakingly slow and costly and does not lend itself to identifying the optimal engine design specifications. In response, scientists from the Los Alamos National laboratory (LANL), with support from DOE, initiated development in 1983 of an advanced computational fluid dynamics (CFD) modeling code (KIVA) that accurately simulates the in-cylinder processes of heat engines.



Spray simulation of a fuel composed of two species (iso-octane and toluene) in an unstructured tetrahedral mesh. The colors on the mesh reflect the concentration of the combined fuel. The particles are the liquid fuel droplets color-coded according to their temperatures (light green-coldest, dark orange-hottest).

The Technology

KIVA is a three-dimensional, multicomponent model capable of simulating multiphase (liquid and gaseous) flow under steady-state and transient conditions. KIVA solves unsteady equations of motion coupled with equations simulating the fuel spray based on user-defined engine specifications (e.g., compression ratios, engine speed, fuel injection timing, and duration). KIVA is a valuable tool for modeling liquid phase fuel penetration and vaporization leading to a better understanding of combustion propagation. In order to maximize the efficiency of an engine, it is necessary to burn as much of the fuel as possible.

Los Alamos National Laboratory has developed an efficient version of KIVA called KIVA-4 that can simulate the engine environment with unstructured grids. Previous versions of KIVA could only simulate an engine with structured grids. A grid is a set of cells that fill the cylinder and port volumes where the fluid equations are solved. Unstructured grids can use many different cell types (hexahedra, tetrahedra, prisms, and pyramids) to construct an engine grid, while structured grids use only hexahedra. Generating a grid can be a time-consuming process in engine simulations. However, unstructured grids can be generated more quickly than structured grids, thus reducing the amount of time a user spends generating a grid.

In addition, KIVA-4 extends the capabilities of previous versions of KIVA by allowing spray simulations to be performed with a liquid fuel composed of many fuel species. Gasoline and diesel fuel are composed of hundreds of hydrocarbons. KIVA-4's ability to model a vaporizing fuel with multiple fuel species will enable a user to more closely match actual gasoline or diesel fuel.

Commercialization

The KIVA modeling code was introduced in 1985 and has quickly become the industry standard for multidimensional combustion modeling. KIVA's code has been integrated into most of the top CFD modeling programs and is used by the automotive and heavy-duty diesel engine industries to develop energy-efficient, emission-compliant internal combustion engines. For example, General Motors has used KIVA in the development of direct-injection, stratified charge gasoline engines as well as the fast burn, homogeneous-charge gasoline engine. Cummins Engine Company uses the KIVA code to help engineers examine fuel spray-airflow interactions in heavy-duty N-series diesel engines. Furthermore, KIVA can be easily adapted for a variety of other applications such as gas turbines, ramrockets, continuous spray combustion, and Bunsen burner flames. A beta version of KIVA-4 has been distributed to the University of Wisconsin, Wayne State University, the University of Michigan, and the University of California at Berkeley. The beta version was also distributed to Caterpillar, Ford, Detroit Diesel, General Electric and International Truck, as well as Sandia National Laboratories-Livermore, Oak Ridge National Laboratory, and Lawrence Livermore National Laboratory. Universities (e.g., the University of Wisconsin) are also using KIVA to develop their own submodels (atomization models for spray break-up and conduction in the metal engine parts).

Benefits

Using KIVA in engine design can

- Increase engine efficiency by up to 10%
- Reduce development time by 60%

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