Fueling the future: Argonne, Convergent and Cummins cooperate to discover the secrets of fuel injectors

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In the swirling, churning fireball at the heart of every internal combustion engine, complexity reigns supreme.

Valves and pistons lunge up and down at thousands of feet per second, pressure spikes to peak levels in an instant and sprays of fuel spread throughout the maelstrom in impossibly intricate patterns.

That complexity is a daunting task for anyone trying to understand the interacting forces at work in an engine. But a team of researchers at the U.S. Department of Energy's (DOE) Argonne National Laboratory has stepped up to the challenge by creating integrated modeling of one key element of that mechanical mayhem: the fluid dynamics of fuel injectors in modern engines.

Partnering with industry leaders Cummins, Inc., and Convergent Science, Inc. (CSI), and using the unique facilities and massive computing resources available at Argonne, the team hopes to take one step closer to the Holy Grail of engine design: cleaner and more efficient engines simulated, designed and optimized in virtual space before production ever begins.

"Fuel injection is the first step toward the type of simulation we want to do someday," said Sibendu Som, principal investigator and principal mechanical engineer at Argonne's Center for Transportation Research.

"It's like running a marathon. It's a long race, and you have to train for it over time, taking it piece by piece."

Som and his colleagues conducted their research under the auspices of Argonne's Virtual Engine Research Institute and Fuels Initiative (VERIFI), a program that explores multiple aspects of engine performance in collaboration with experts at some of the top companies in the automotive industry. Argonne entered into a Cooperative Research and Development Agreement for the work with Cummins and Convergent. VERIFI's work is funded by the Vehicles Technology Office of the DOE's Office of Energy Efficiency and Renewable Energy.

The work conducted by VERIFI is receiving notice from a broad spectrum of companies working on internal combustion engines, as evidenced by last week's VERIFI workshop, which brought more than 75 attendees from 30 companies to Argonne to discuss the potential impact of VERIFI's modeling approach to the industry.

Som, who said he has been fascinated by fluid dynamics since he was a child dreaming of building rocket engines, found the current state of fuel injector understanding did not encompass the true complexity of how fuel injectors function. Using existing approaches, researchers could only model the output of one injector opening at a time. Modern fuel injectors often have up to nine holes in each injector.

"People have been trying to do simulations of fuel injectors for 20 years, but no one has been able to achieve this level of understanding," said Doug Longman, manager of engine combustion research at Argonne. "The challenge is to model all the complex internal and external dynamics simultaneously. It is a huge undertaking and a real breakthrough."

Fuel injectors are designed to atomize fuel into the tiniest droplets possible, which makes the fuel burn most efficiently. Inside the injector, however, fuel can be completely vaporized in a process known as cavitation. That process is a double-edged sword in that it can boost atomization, but also can damage the injectors.

Without an effective way to simulate the inner workings of the injector, manufacturers use too much trial and error to strike a balance between the desire for atomization and the risks of damage from cavitation.

Som and his team, in collaboration with CSI and Cummins, used innovative modeling approaches harnessing the computing horsepower at the laboratory's Argonne Leadership Computing Facility, a DOE Office of Science user facility.

When the research was completed, the team had modeled the dynamics of an injector and understood how the properties of injector opening and closing influence the spray development in a dynamic fashion. Argonne worked with CSI to incorporate the findings into its Converge software.

The software was then validated through a variety of techniques, including the use of X-ray radiography data from the Advanced Photon Source, another DOE Office of Science user facility located at Argonne. The penetrating ability of the brilliant X-rays allowed an unprecedented look into the operation of the fuel injectors.

The end result is a tool that Cummins, and eventually all engine designers, can use to virtually peer into the inner workings of fuel injectors to make them more efficient. More efficient modeling will yield better engines, brought to market more quickly at a lower cost for consumers.

Provided by Argonne National Laboratory