(3-28) Measurement and Modeling of Large-Scale Flow Structures and Turbulence in a High-Speed Direct-Injection Diesel Engine

Paul Miles*, Marcus Megerle†, Volker Sick‡, Keith Richards‡, Zac Nagel‡, and Rolf Reitz‡

*Sandia National Laboratories
Livermore, CA 94551-0969, USA

†Department of Mech. Eng. and Appl. Mech., University of Michigan
Ann Arbor, MI 48109, USA

‡University of Wisconsin – Engine Research Center
Madison, WI 53706-1572, USA

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ABSTRACT

Fluid motion within the cylinder of a high-speed, direct-injection diesel engine influences the entire combustion process, from the initial fuel preparation prior to ignition to the late-cycle burn-out of unburned fuel and particulates. Multi-dimensional models are increasingly being used in the design and optimization of these engines. The ability of these models to accurately predict the in-cylinder flow structures and turbulence has yet to be proven, however, particularly under fired engine operation. In this paper, a comparison of experimental and predicted flow velocities, both before and after combustion, is presented. Experimental and predicted cylinder pressure and heat release are also compared.

The engine geometry employed has geometric characteristics typical of modern light-duty diesels targeted for automotive applications, i.e.: four-valves; a central, vertical injector; a concentric, re-entrant bowl; and common-rail fuel injection equipment. The measurements are compared with the results of computations using STAR-CD and KIVA-3V, for the induction stroke and the compression/expansion strokes, respectively. All results reported here were obtained at an idle condition, characterized by a speed of 900 rpm and a gross IMEP of 1.2 bar.

Cylinder pressure and heat-release are found to compare favorably between the experiment and the model predictions, although the predicted mass of fuel consumed in the premixed burn exceeds the measured mass burned. Similarly, the predicted in-cylinder angular momentum, obtained from a full induction stroke calculation, is found to agree to within 5% of the measured value.

Just prior to the start of combustion, both modeled and experimental swirl velocity profiles are similar to solid-body fluid rotation. However, the model predicts significantly greater axial stratification of mean angular momentum than is observed experimentally. The r-z-plane mean-flow structure within the bowl is dominated by a single large-scale vortex. The location and speed of rotation of this vortex are well predicted by the model. Although RMS velocity fluctuations deep in the bowl are well-predicted at this time, larger fluctuations than the model predicts are observed experimentally near the top of the cylinder. These larger fluctuations are notably anisotropic, with the tangential component exceeding the radial component.

After combustion, the axial distribution of mean angular momentum agrees more closely between model predictions and measurements. Large-scale, rotating structures in the r-z-plane, not present under motored engine operation, are also observed in both the measured and the predicted results. In contrast to the pre-combustion radial profile of tangential velocity, the post-combustion profile resembles that of a free-vortex, with the largest tangential velocities found at the inner radii. This type of profile suggests a source of turbulence production not found prior to combustion. At this time, the predicted RMS fluctuating velocities are considerably less than the measured fluctuations throughout the bowl. Measured fluctuations are again found to be anisotropic, although the radial fluctuations now exceed the tangential fluctuations.