Increasing Engine Efficiency through Extreme Compression

M.N. Svrcek, G.B. Roberts, C.F. Edwards
Advanced Energy Systems Laboratory, Department of Mechanical Engineering, Stanford University

Motivation

One of the most substantial loss mechanisms in current, simple cycle, unstrained, reactive engines is combustion irreversibility. A large fraction (~20%) of the exergy of the fuel resource can be destroyed during the combustion process. The goal of this project is to substantially reduce the combustion irreversibility thereby increasing the overall efficiency.

Basic Design

New design choices are required to construct a device capable of these high compression ratios. Post-combustion pressures are greater than 1000 bar, while post-combustion temperatures are greater than 3000 K. A few of the obstacles and their design implications include:

• Typically the higher temperatures lead to greater heat transfer losses
  → Design engine with a low surface-to-volume ratio at 10:1 CR (e.g., a long stroke)
  → Increase expansion speed to extract work before it is transferred out as heat
• High pressures lead to high forces
  → Use two pistons to balance the forces and increase expansion rate
  → Pre-mixed or early injection strategies will react too early
  → Use high-pressure direct injection system to phase combustion

Emissions Measurement Apparatus

Gaseous Emissions Sampling System

The ability to measure concentrations of NO\textsubscript{x}, CO, CO\textsubscript{2}, and unburned hydrocarbons has recently been added. The cylinder walls are electrically heated to 90 °C to prevent water and HC condensation.

Optical Soot Measurement

Soot particles resulting from combustion absorb and scatter light transmitted across the cylinder via optical fibers and sapphire windows. The attenuated signal is measured after the cycle has completed and the soot is well mixed, providing an integral measurement of soot over the whole cycle.

Experimental Design

We have designed an experimental apparatus to study the feasibility of achieving reduced combustion irreversibility by performing the reaction at high internal energies. The apparatus contains:

• A fast (~20 ms opening time) air-driven poppet valve to allow repeatable, controllable introduction of driver air to cylinder
• A large, high-pressure air reservoir, capable of providing driver air pressure up to 68 bar
• A free-piston architecture that allows for high piston speeds
• As ~ 2.5m long cylinder bore to achieve low surface-to-volume ratios at TDC, reducing the effects of heat transfer
• A high-pressure combuster attached to the end of the cylinder to withstand the high pressures at TDC
• A sapphire window port for optical access to combustion

As originally designed, the piston oscillated in the cylinder until friction stopped it. The sapphire windows showed that considerable heat transfer occurred in the exhaust, which led to poor heat transfer efficiency and a low efficiency peak of 60%.

At 100:1 compression ratio we can potentially realize simple cycle efficiencies near 60% — significantly higher than current devices. The goal of this project is to design and build a device that will test the feasibility of increasing efficiency by using extreme compression.

Recent Results

Emissions sampling revealed that the high-pressure fuel injector clamps caused fuel flow variation when clamped in-cylinder. The clamps were redesigned to provide repeatable flow, and the light-load diesel data were retained. With a correct fuel calibration, the indicated efficiency peaks at 60%.

Special thanks to GCEP (Global Climate Energy Project) for funding this research, and to Scott Sutton and Ken Hencken.