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An Extreme Compression Approach to Low-Irreversibility Piston Engines

Investigators

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Objective

The major objective of this ongoing research project is to enable the development of ultra-high efficiency engines. These engines should convert a much higher fraction of the theoretical exergy limits of their chemical resources to work than the most advanced engines available today. Specifically this research is aimed at defining the combustion and wall-interface systems required for an extreme-compression engine with reduced combustion irreversibility and enhanced exergy extraction. The target is 60% simple-cycle efficiency in an engine suitable for wide-scale use in passenger-car applications.

Background

Improving engine efficiency has long been an objective of engine designers. First-law efficiency (work per unit fuel Lower Heating Value) has improved from less than 1% before 1800 (the Savery and Newcomen engines) to about 70% for compound fuel-cell/gas-turbine engines under development today. However, most simple-cycle engines are less than 50% efficient and best suited for light-duty transportation since the cost, complexity and size issues associated with compounding are avoided. Spark-ignited (SI, gasoline) engine efficiencies remain in the low to mid 30s, while small-bore direct-injection (DI, diesel) engine efficiencies are in the mid 40s. The generally low simple-cycle efficiencies in current engines can be attributed to significant exergy destruction (Figure 1) as well as loss to coolant and environment (i.e., exhaust), all of which can be significantly reduced.

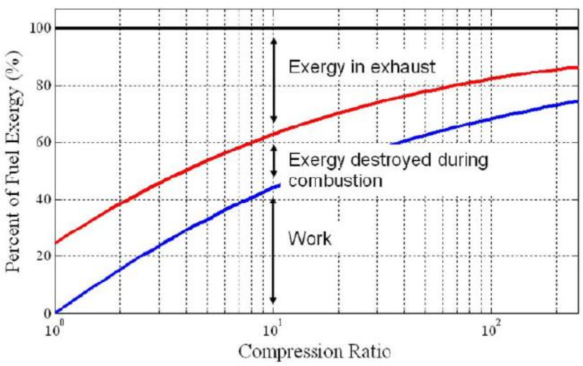

Figure 1: Combustion of uncompressed, unheated reactants destroys 25% of the work potential of the fuel. Increasing the internal energy of the reactants before combustion by about 40%—through compression, heating, or any combination of the two—can cut this loss in half, resulting in the potential for a significant increase in

The premise of this research and previous research carried out in the Edwards lab, is that a very-high efficiency (~60%) simple-cycle engine is possible based on the use of extreme compression, very high cycle rates, and multiple-piston compression. Previous recent research in the Edwards lab involved the construction of a working free-piston, extreme-compression device capable of achieving the required compression ratios and mean piston speeds, and capable of quantifying indicated performance at conditions of these extreme conditions (Figure 2). The system also provides an opportunity to quantify heat and mass losses, and a platform for testing design strategies to mitigate these losses.

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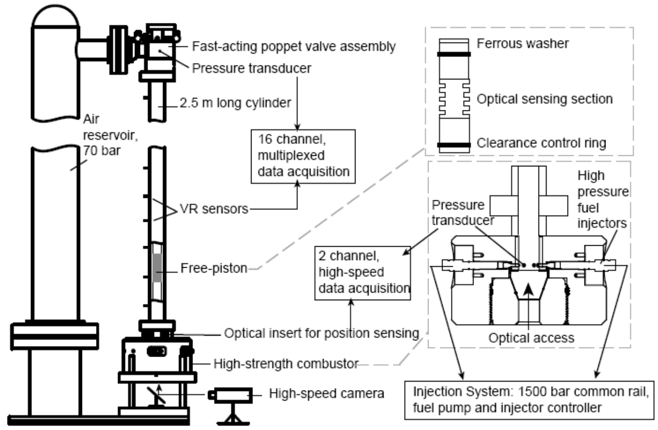

Figure 2: The extreme compression apparatus is pneumatically driven and consists of a single working piston accelerated to high speed (>100 m/s) which then compresses the working charge (air) into a high-pressure (>2000 bar), optically accessible combustion chamber. Piston position is monitored magnetically along the length of the compression tube, and optically in the vicinity of top center.

The key research challenge remaining for an extreme compression engine is design and execution of an optimal combustion strategy.

Approach

This research will use the extreme compression apparatus for continued analysis of the efficiency potential of low-irreversibility engine architectures and construction of a comprehensive set of design studies. Preliminary data from this device is shown in Figure 3.

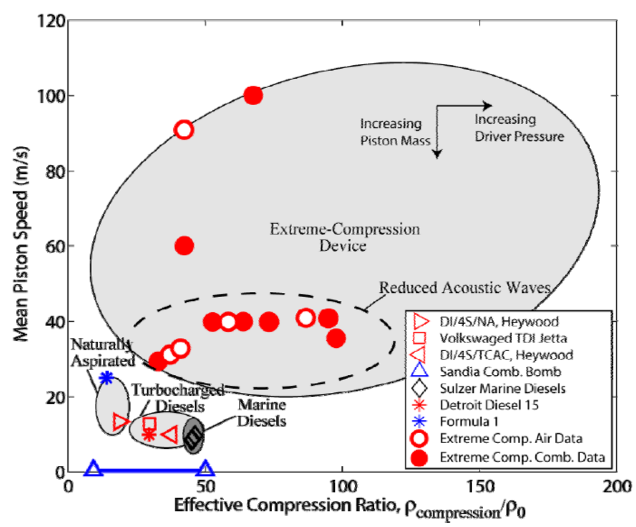

Figure 3: The range of compression ratios and mean piston speed achievable as established by the design model, and with experimental validation. Increasing the pressure of the pneumatic driver allows higher compression ratios to be achieved; increasing the piston mass (beyond the minimum of ~100 g) allows lower piston speeds to be assessed.

The panels in Figure 4 illustrate the capabilities of the full-field optical access. Using this imaging capability, fundamental efforts to quantify jet penetration, mixing rates, and autoignition characteristics will be undertaken. This research will allow systematic development of a combustion strategy. Measurement of the concomitant performance and emissions is a central goal of the next phase of research.

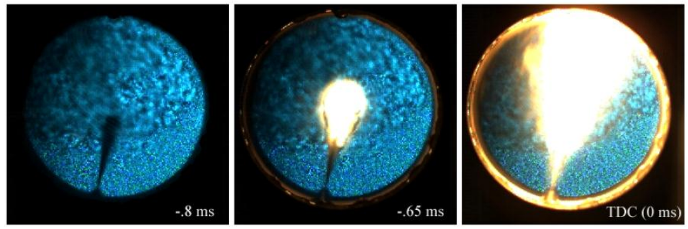

Figure 4: These images show frames from a high-speed movie (20 kHz framing rate, 20 μs exposure) of the combustion process of a single jet of diesel fuel at 30:1 compression ratio.

The images are obtained via a combination of schlieren and direct photography that permits simultaneous imaging of gas-phase density gradients, spray extinction, and combustion luminosity on a single camera.