



Increasing Engine Efficiency through Extreme Compression

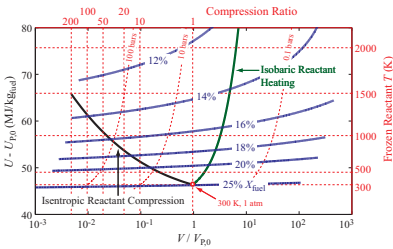
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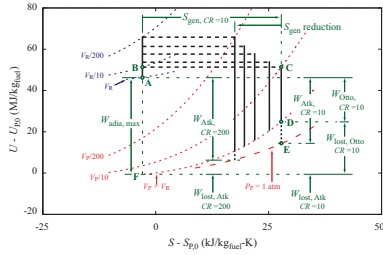


Motivation

One of the most substantial loss mechanisms in current, simple-cycle, unrestrained, reactive engines is combustion irreversibility. A large fraction (~20%) of the energy 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.

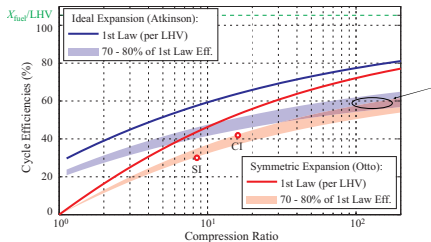


Exergy destroyed due to unrestrained reaction at different initial states for stoichiometric propane/air modeled as an ideal gas. Includes the effects of variable specific heats, reaction, & dissociation.



Ideal Otto and Atkinson cycles for stoichiometric propane/air on a U-S diagram. Compression ratios shown include 10, 20, 50, 100, and 200:1.

At a compression ratio of 200:1, the work lost due to combustion irreversibility can be reduced to one-half that from the 10:1 compression ratio case.



At 100:1 compression ratio we can potentially realize simple cycle efficiencies near 60% – significantly higher than current devices¹. The goal of this project is to design and build a device that will test the feasibility of increasing efficiency by using extreme compression.

¹Heywood, *Internal Combustion Engine Fundamentals*, 1988, p.196

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:

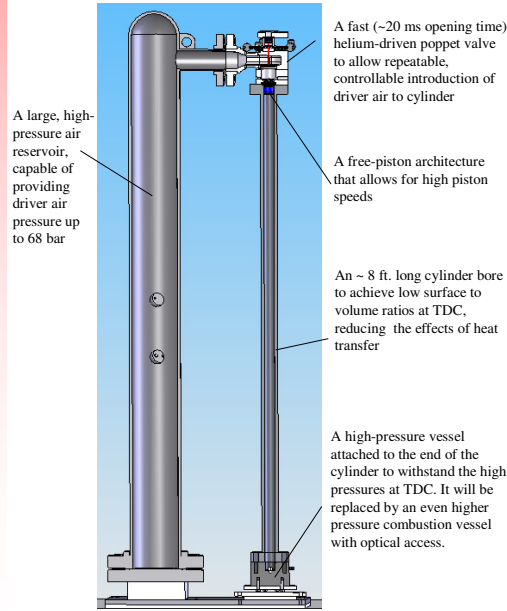
- Typically the higher temperatures lead to greater heat transfer losses
 - Design engine with a low surface-to-volume ratio at 100:1 CR (e.g. a long stroke)
 - Increase expansion speed to extract sensible energy as work before it is transferred out as heat (aim for piston speeds of ~Mach 0.3, ~100 m/s at room temperature)
- High pressures lead to very high forces
 - Use two pistons to balance the forces
- Pre-mixed or early injection strategies will react too early
 - Use high-pressure direct injection system to phase combustion



Basic concept drawing of device design

Experimental Design

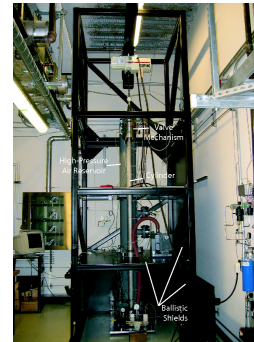
We have designed an experimental apparatus to study the feasibility of achieving reduced combustion irreversibility by performing the reaction at high internal energies. The apparatus contains:



Current Work: Non-Combusting Experiments

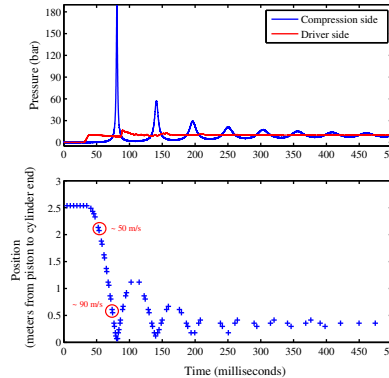
Non-Combusting Experimental Goals:

- To refine components such that we can:
 - Predict and repeatably achieve a given compression ratio
 - Achieve the desired high piston speeds
- To develop a piston position sensing system to determine the volume profile
- To design the larger infrastructure required to run such a large experiment safely



A photograph of the experimental setup in our lab at Stanford. We are currently testing the repeatability of achieving various compression ratios. Next, we will incorporate our high-pressure test section to start combusting.

Current Experimental Results:



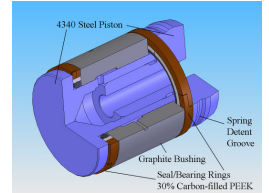
Pressure data are captured by quartz dynamic pressure transducers. Position data are captured by magnetic variable reluctance sensors placed at intervals along the cylinder bore.

The above data are for a driver air pressure of 10.3 bar, resulting in:

- Peak pressure of 190 bar, corresponding to an isentropic, adiabatic compression ratio of 46
- Mean piston speed during first compression of ~60 m/s

These results are in the range of our modeling predictions, and indicate that the basic device design is capable of achieving high compression ratios and piston speeds.

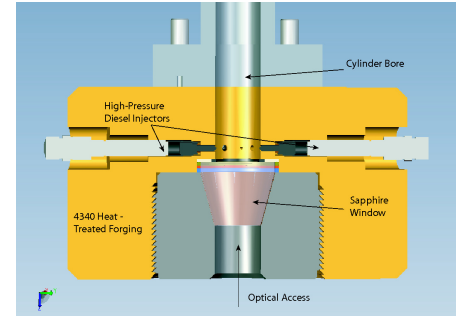
Having successfully tested the basic functionality of the device, we are currently iterating on the piston design to refine repeatability and to characterize gas blowby. The piston design at right produced the data shown on this poster.



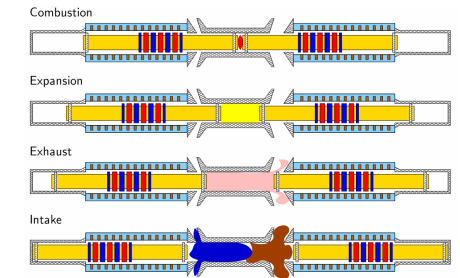
Future Work

We are currently manufacturing the new high-pressure combustion section that attaches to our cylinder. The section will:

- Be tested and rated to at least 1400 bar
- Be capable of optical access through the base of the vessel
- Contain five high-pressure fuel injectors



Concept Drawing of Engine Design with Work Extraction



A concept drawing of how a high-compression ratio, free-piston engine would work in practice. Diagram taken from Van Blarigan and Aichlmayr, "Optimized Free Piston Engine Generator", DOE National Laboratory Advanced Combustion Engine R&D Merit Review and Peer Evaluation, April 2005.

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