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Operational Characteristics of Liquid-piston Heat Engines

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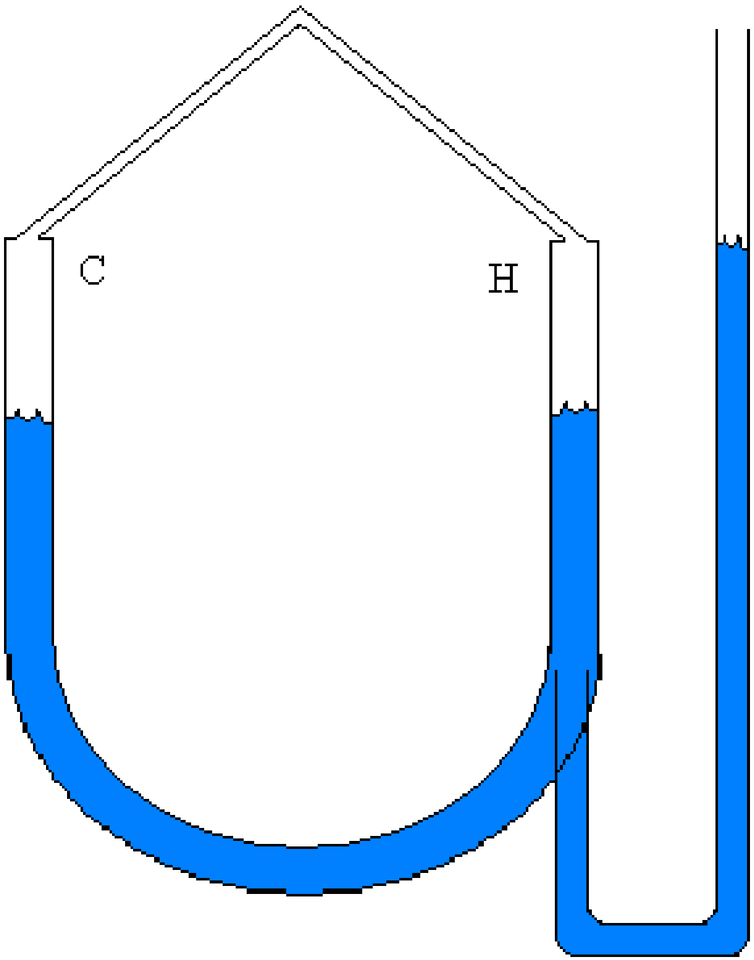
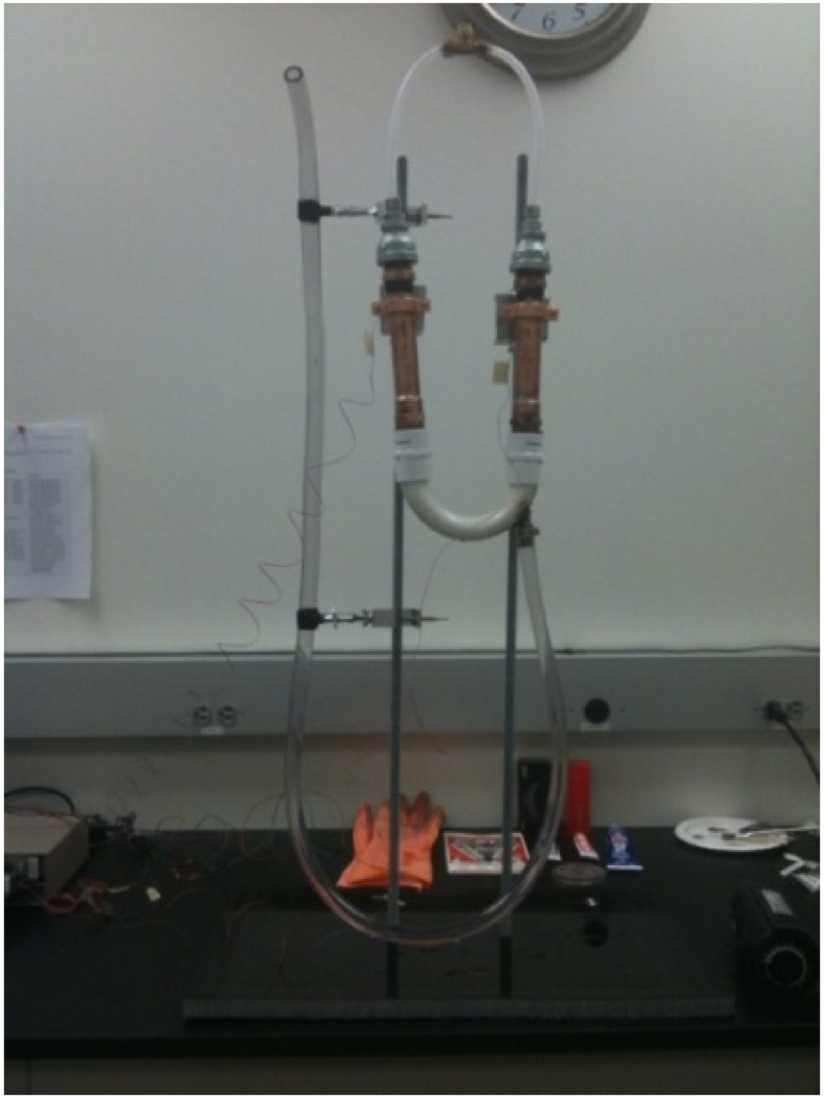
Abstract

- Liquid piston Stirling engines (sometimes termed "fluidyne" engines) have been studied, proposed, and applied in a variety of energy conversion applications. They are attractive for low capital costs and simplicity of construction.
- This paper describes test results from a solar-powered fluidyne engine utilizing a Fresnel lens for concentrating solar energy, and from a combustion powered engine equipped with an orifice-style dynamometer for controlled loading of the engine.
- Temperature, pressure, and volume phasing along with indicated work and brake work are presented and discussed. The Fresnel lens provided ample power for sustained operation of the engine, and engine cycles and operational characteristics of the solar powered engine are discussed. Operating without load, the dynamic mechanical response showed no delay from the thermodynamic expansion due to temperature changes of the working fluid.
- The function and capacity of the orifice-style dynamometers were evaluated for testing various configurations of liquid-piston engines under load. Engine cycles and operating characteristics of the loaded engines are presented and discussed. Relative sizes of indicated work and brake work are explored as functions of engine configuration.

The working fluid is enclosed in the sealed space above the liquid. The liquid in the U-tube acts as a displacer piston which moves the working fluid from a hot side heat exchanger to a cold side heat exchanger. These heat exchangers are denoted as H and C in the figure. As the gas in the working space shifts from side to side, it is heated and cooled causing the system pressure to increase and decrease. At the bottom of the sealed U-tube, a second liquid column is connected, and also configured in a U-tube shape. The second column (known as the output column, tuning column, or tuning line) remains open to atmospheric pressure. As the working fluid pressure rises and falls, the liquid in the output column is displaced accordingly.

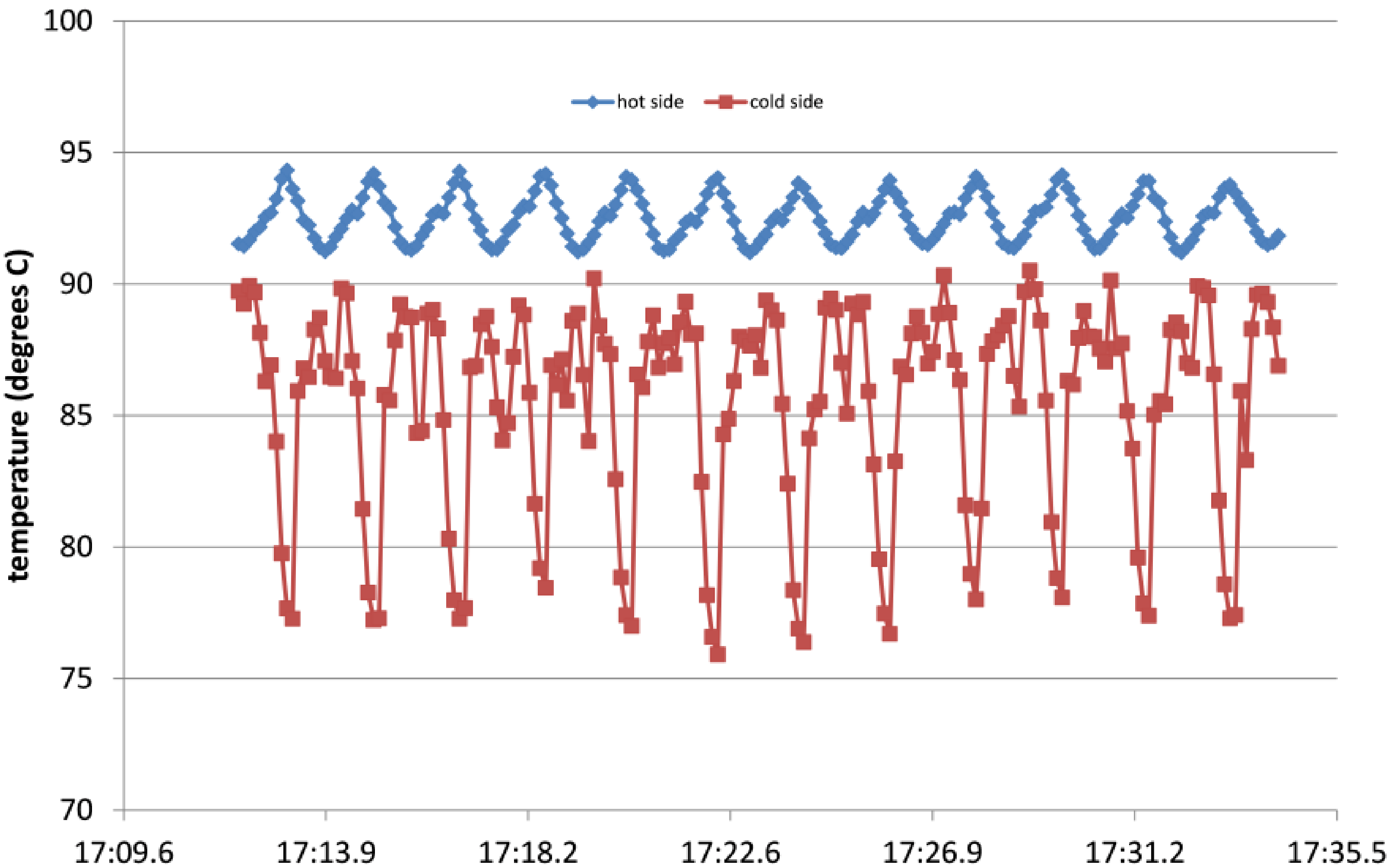


Fluidyne engine, left, and Fresnel lens and mounting stand, right, for the solar powered test fixture

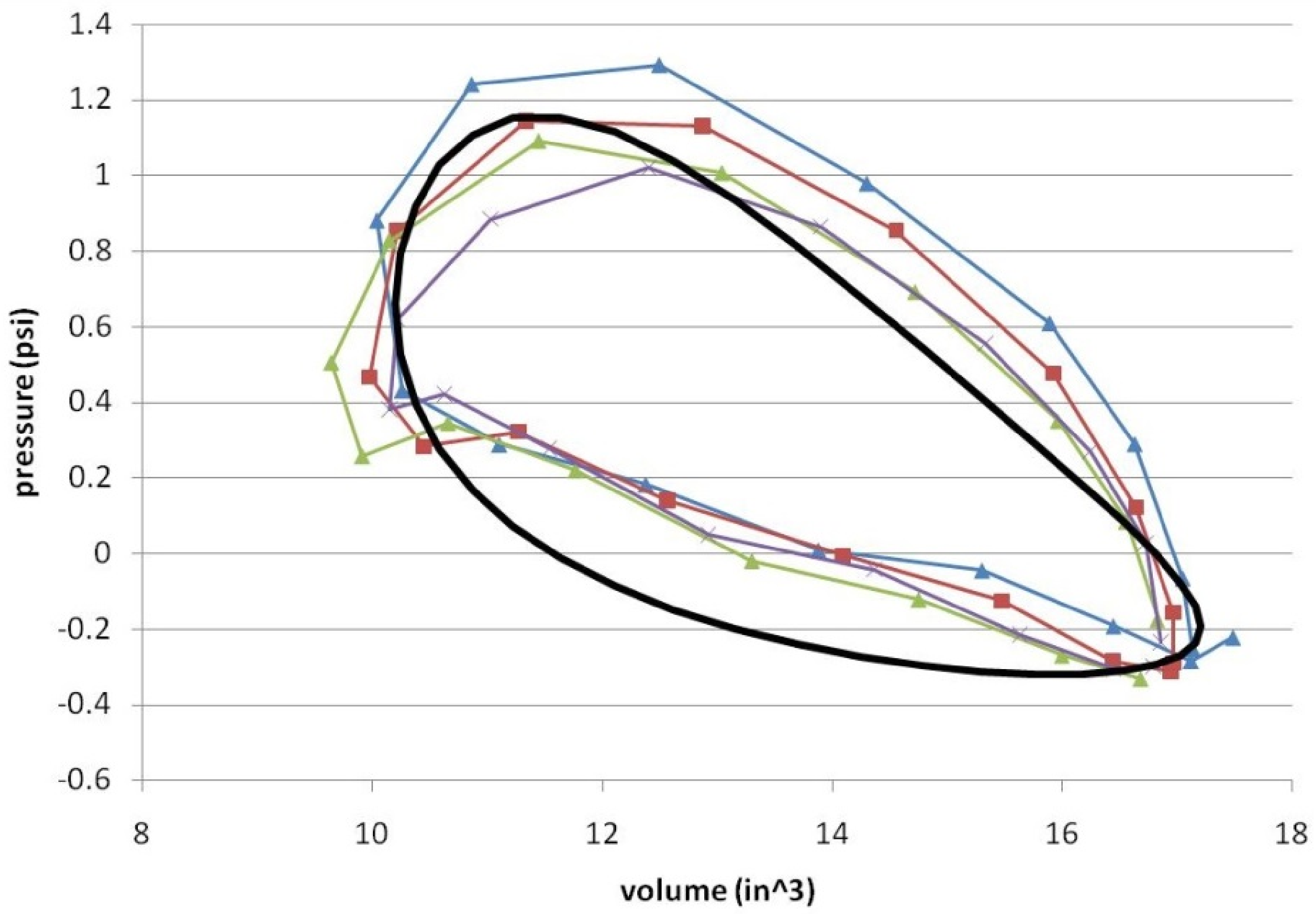


Fluidyne engine for the combustion powered test fixture with an orifice-style dynamometer

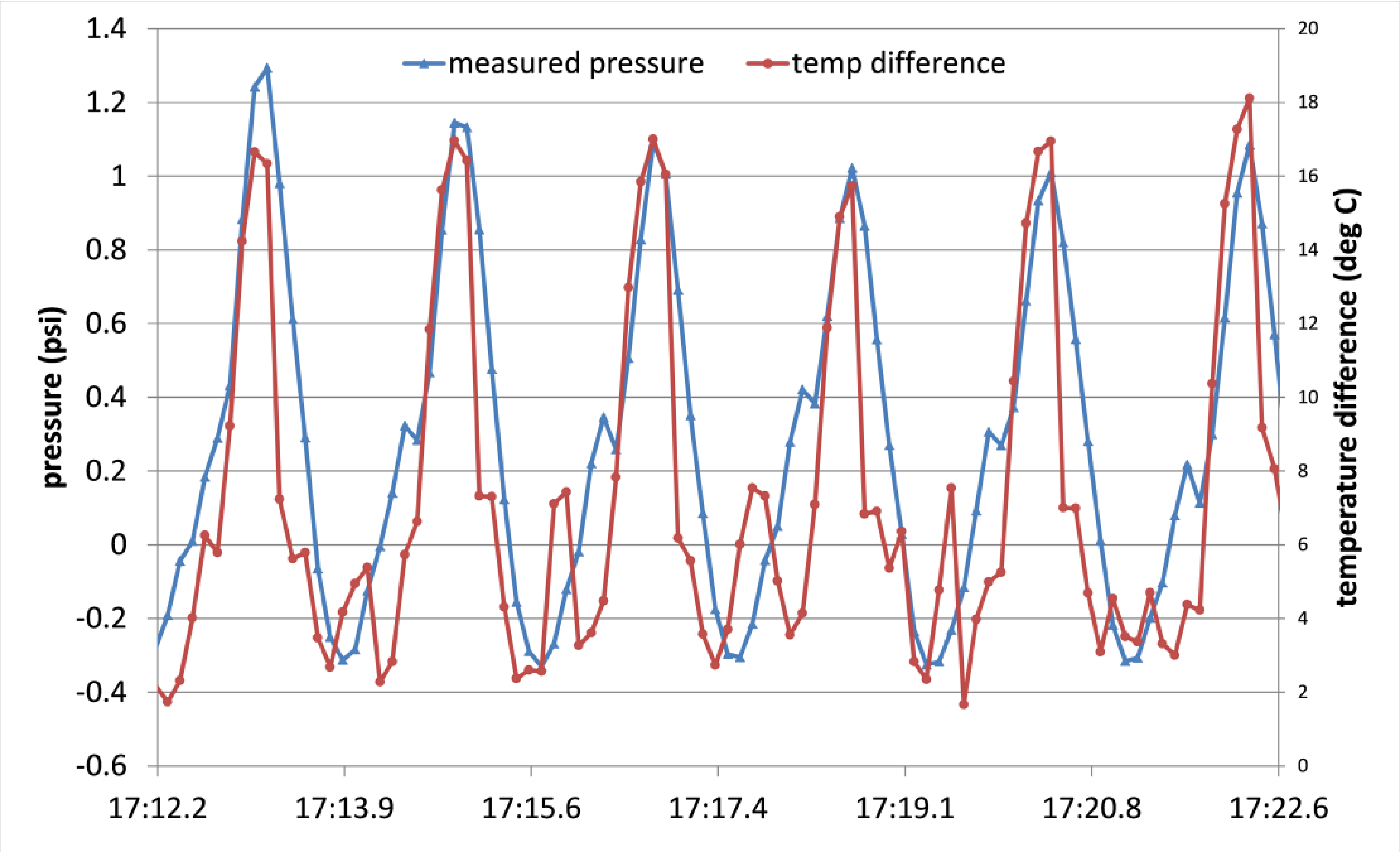
About 20 seconds of temperature data from a single test of the first (solar powered) test fixture. As expected, the temperature fluctuations from the two thermocouples are out of phase with one another.



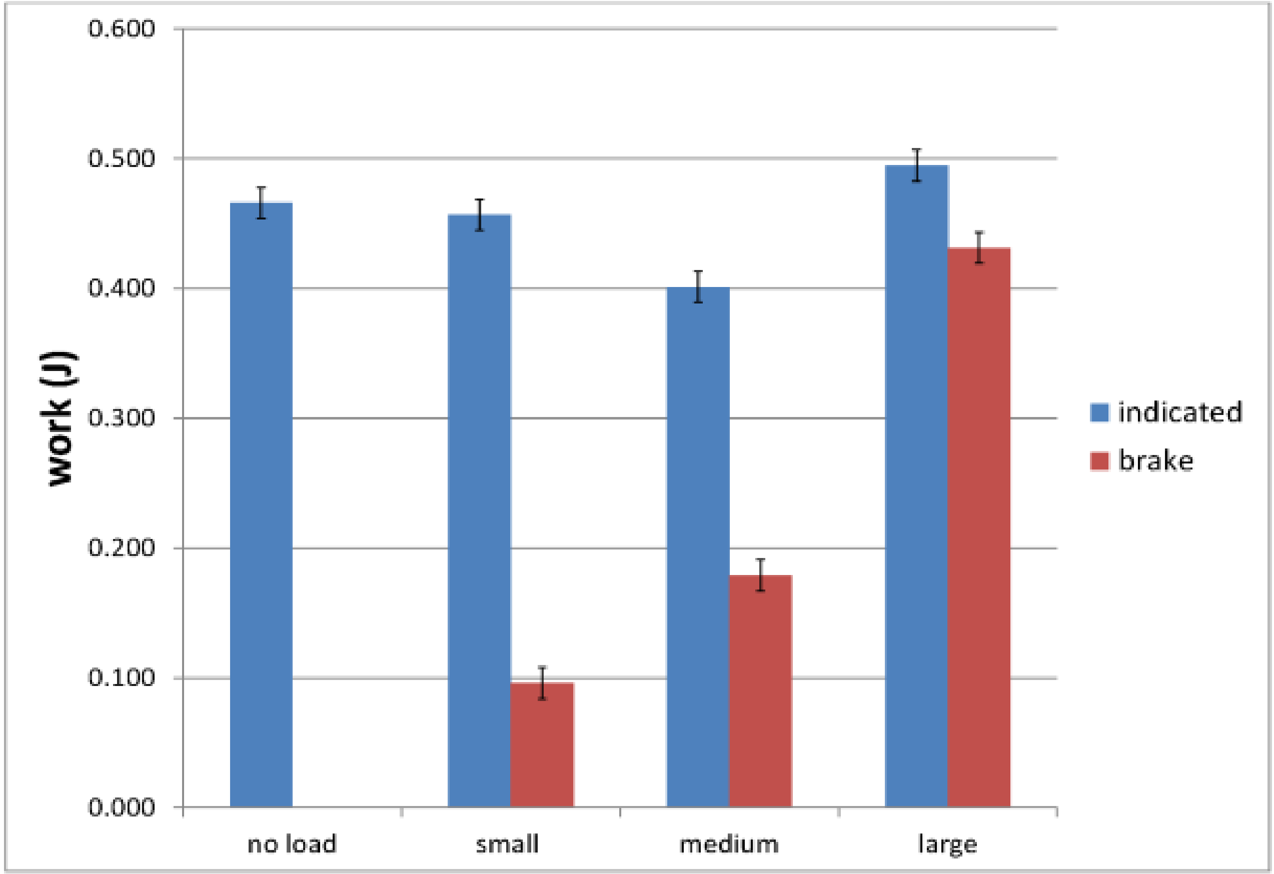
Actual working space pressure and volume measurements for four cycles. Overlaid in the figure with a heavier black line and no symbols, is a simple P-V prediction based on idealized sinusoidal motion of the displacer piston and output piston and scaled to fit the measured volume and pressure fluctuations.



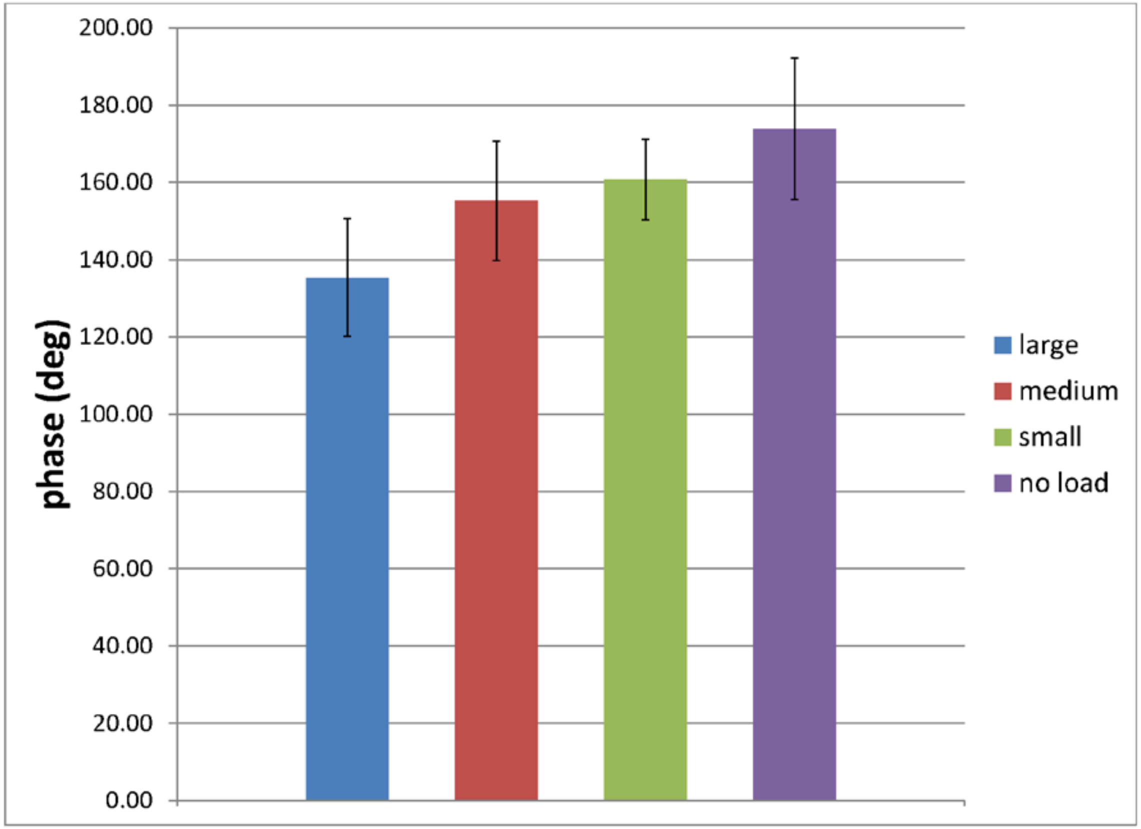
A plot of the temperature difference between the hot side and the cold side, overlaid onto a plot of the measured pressure. The temperature difference fluctuations are exactly in phase with the pressure fluctuations confirming that the dynamic mechanical response of this unloaded engine closely tracks the thermodynamic expansion of the working fluid.



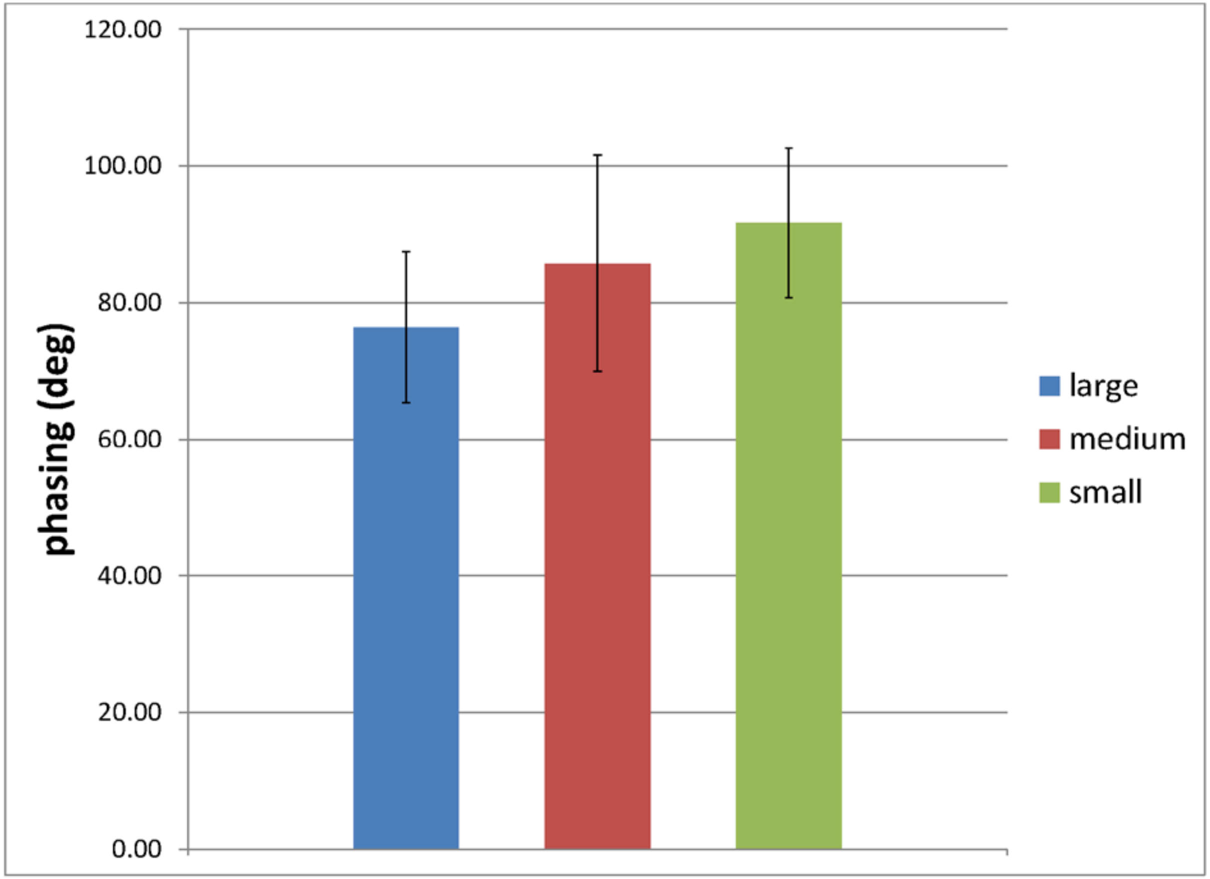
Data from the second test fixture equipped with an orifice-type dynamometer. The average brake work and indicated work per cycle for the three different loading cases, and the indicated work for the no-load case are shown. For the highest load, the brake work approaches 87% of the indicated work with no significant degradation in engine operation.



Phasing between the working space pressure and the working space volume for the three loading cases and the no-load case. For the unloaded case the pressure fluctuations are 173 degrees ahead of the volume fluctuations, and increasing load pushes the phase difference down by almost 40 degrees from the no-load case to the most heavily loaded case.

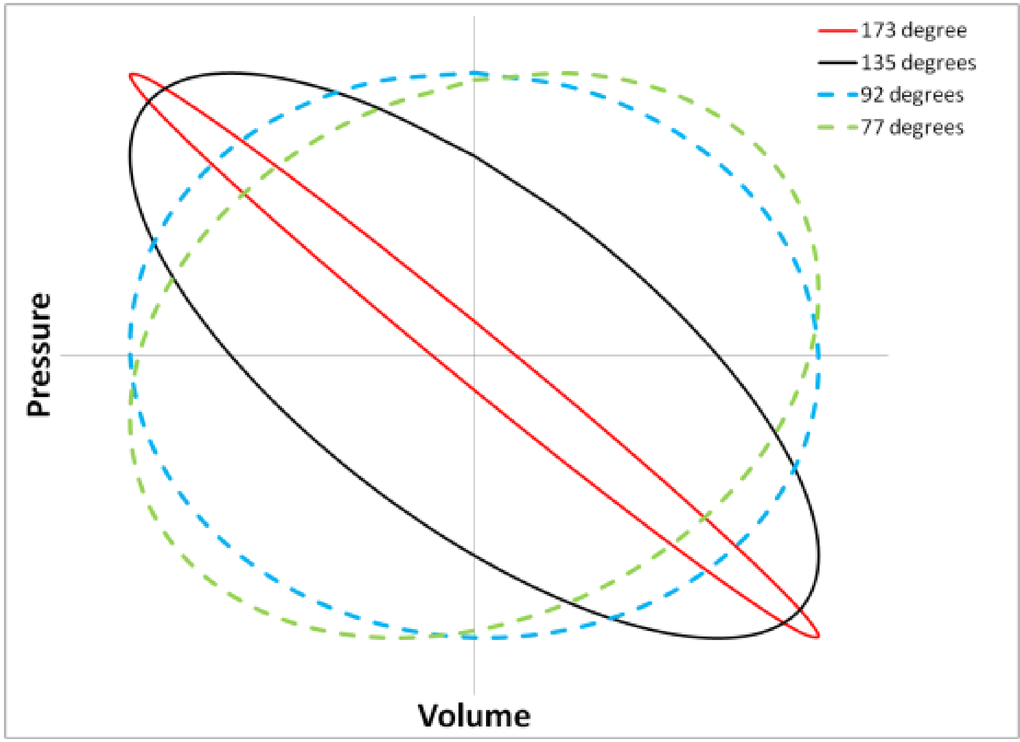


This shows the same kind of phasing information as the previous slide, except for the tuning column in this case. The pressure and volume are closer to 90 degrees out of phase, with the loading again reducing the phase difference, albeit by a smaller amount, about 15 degrees.



This figure demonstrates a qualitative comparison of the effect of phasing alone on the expected work output (either indicated or brake) of the engine. Equal scales were used to emphasize the relative shape of the P-V plot as a function of phase angle, so the figure does not present actual measured data. A phase difference of 90 degrees between the system pressure and the system volume leads to, in these comparative coordinates, a circular P-V plot which would maximize the available work for a given range of volumes and pressures. This figure shows comparative shapes for the measured phase angles from the earlier slide of phase angles for indicated an brake work.

The indicated work phasing for the no-load case of 173 degrees leads to an elongated P-V plot. The loading pushes the indicated work toward a more favorable phasing, although that effect is not evident in the cycle work results plotted earlier. Similarly, the increased loading pushes the brake work away from the optimum phasing of 90 degrees, (lower, this time) but the opposite trend is apparent for brake work in the earlier figure. Clearly, the P-V phasing is not the dominant effect in the total work output of the engine.



Conclusions

•An instrumented solar-powered fluidyne test fixture demonstrated consistent and repeatable operation and a Fresnel lens focused sunlight directly on the hot cylinder of the fluidyne with no intermediate heat exchanger was able to provide ample energy to power the fluidyne.

•Indicated work of the engine was collected with pressure and volume measurements. Since the engine was unloaded, this work only overcame frictional losses.

•The shape of the indicated work in a cycle was compared to the shape of a simple thermodynamic expansion and compression in a Stirling cycle with the same volume and pressure range imposed. It was found that the dynamic mechanical response of the unloaded engine showed no delay from the thermodynamic expansion due to temperature changes.

•A second test fixture consisted of a flame-powered instrumented fluidyne equipped with an orifice-type dynamometer.

•This fixture demonstrated the capacity to impose an independent external load on an operating engine. Only a loading regime well away from engine stall was explored.

•It was demonstrated that while external loading affected the P-V phasing of the engine, the phasing alone was not the dominant effect in either the indicated work or the brake work produced by the engine under load.