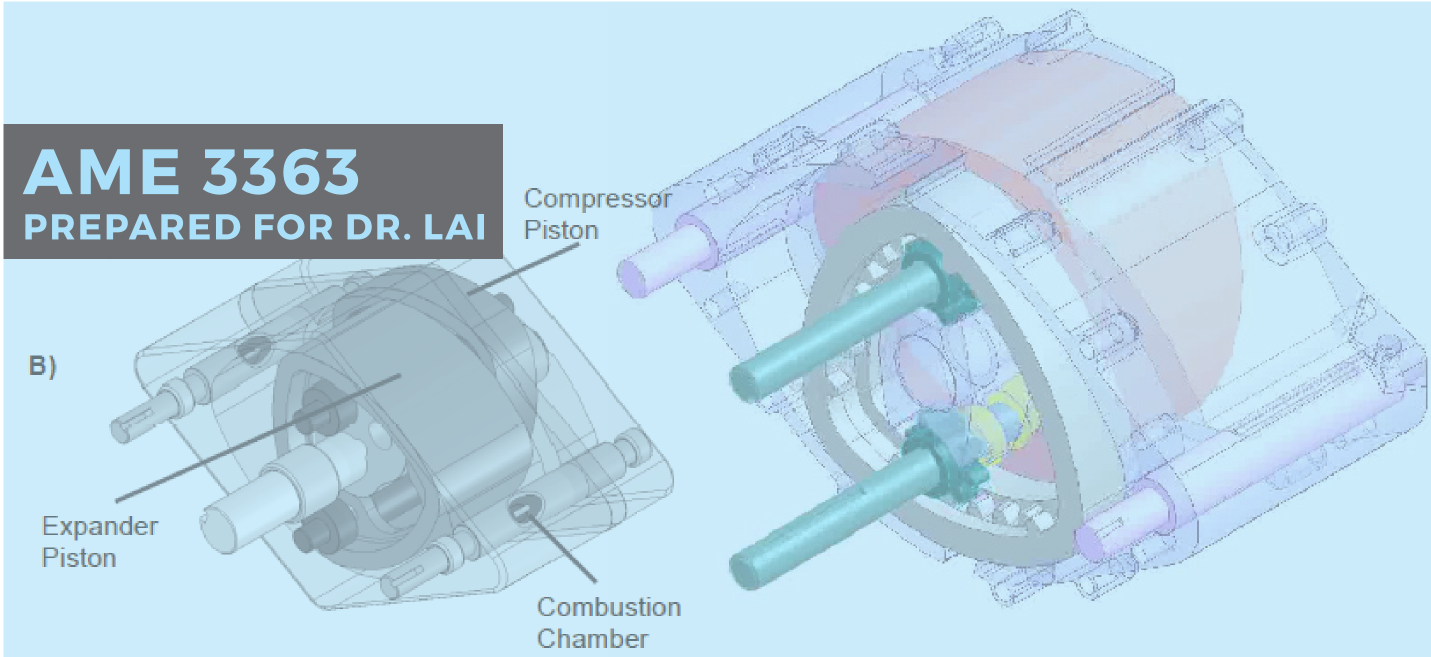

AME 3363

PREPARED FOR DR. LAI

THE ECCENTRIC WANKEL ENGINE

THE INNOVATIVE APPROACH TO THE OTTO POWER CYCLE AND STILL IMPROVING

A thermodynamic power cycle is often an idealized model of the process undergone by a device to generate power. The device will have several stages modeled in most cases as ideal processes to describe the state of the working fluid throughout the cycle. Common power cycles are Brayton, Rankine, Otto and Diesel cycles.

The Otto Cycle is a thermodynamic power cycle that is modeled as a multi-stage process.
Stage 1: the working fluid undergoes isentropic compression via a compressor.
Stage 2: the working fluid is modeled as accepting heat input simplifying the combustion process which occurs ideally in a constant volume.
Stage 3: the working fluid undergoes isentropic expansion through a turbine; the turbine representing

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UNIVERSITY OF OKLAHOMA
COLLEGE OF AEROSPACE AND MECHANICAL ENGINEERING

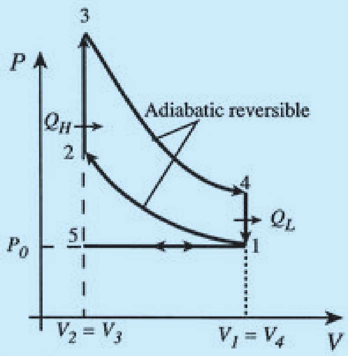


FIG. 1 - IDEAL OTTO CYCLE [1]

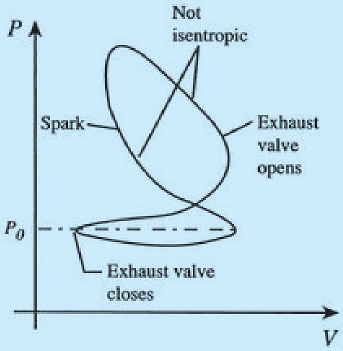


FIG. 2 - REAL OTTO CYCLE [2]

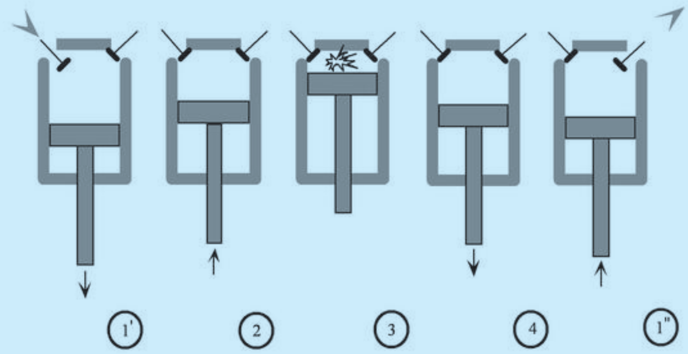


FIG. 3 - TRADITIONAL 4-STROKE OTTO CYCLE PISTON AND CYLINDER ENGINE OPERATION [3]

the piston and crankshaft assemblies used in most real Otto cycles for power generation.

Stage 4: the working fluid is modeled as rejecting heat to return it back to the initial temperature while maintaining a constant volume; this is another simplification of Otto cycle devices.

The idealized thermodynamic Otto Cycle's four stages are isentropic compression, constant volume heat addition, isentropic expansion, constant volume heat rejection (Fig. 1). The Otto cycle's four stages for an actual (non-ideal) device are intake, compression, combustion, exhaust. (Fig. 2 and 3)

An inventive adaptation of the Otto Cycle is the Wankel Engine, sometimes referred to ambiguously as a "rotary engine." The Wankel Engine began with Felix Wankel who received his first patent for the engine in 1929 although a working prototype was not realized until 1957 [4].

FINDING THE OTTO CYCLE IN THE WANKEL ENGINE

INTAKE: Air fuel mix comes through a port and not a valve simplifying the mechanics of the engine

COMPRESSION: As the rotor spins the air fuel mix is compressed in a smaller volume where the spark plug ignites the mixture

COMBUSTION/POWER: This ignition will create the combustion phase and power to keep the rotor spinning

EXHAUST: The rotor spins expanding the volume and uncovers the exhaust port, expelling the spent gases from the housing in preparation for spinning past the intake port to repeat the cycle

[cdxetext]

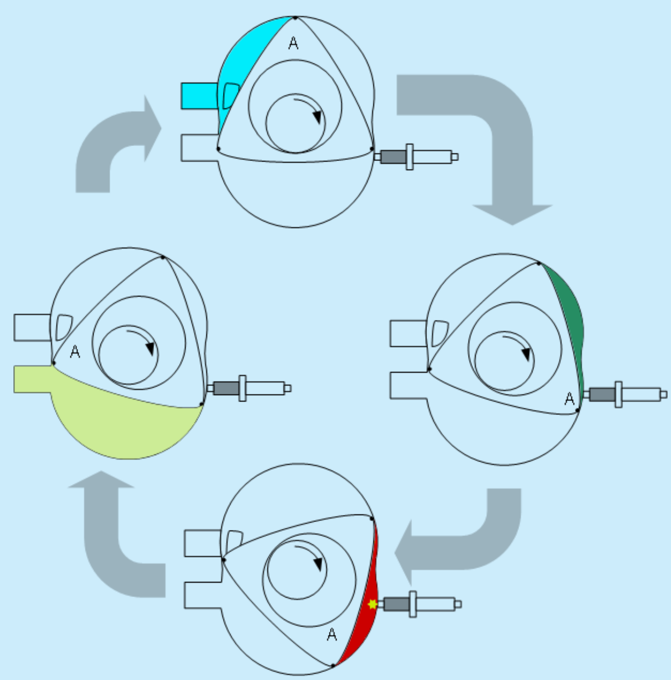


FIG. 4 - WANKEL ENGINE COMPLETING FOUR STAGES OF OTTO CYCLE

The eccentric nature of the Wankel Engine is itself the innovation. Wankel's design utilizes a rotor instead of a piston; the rotor is a triangular shape seemingly formed by three equal convex arcs that enclose its shape around its center. The rotor rotates or orbits the driveshaft similar in motion to planetary gear inside of an epitrochoid curved housing [5]. As the rotor spins in the housing it slides on what is called the eccentric which is rigidly attached to the driveshaft. It's the rotational motion that makes the Wankel engine quite distinctive from piston engines in operation since the piston comes to rest and reverse direction four times within its cycle where the Wankel engine continually rotates in the same direction providing smooth operation and very little vibration [6]

IMPROVING AND DEVELOPING WANKEL ENGINE TECHNOLOGY

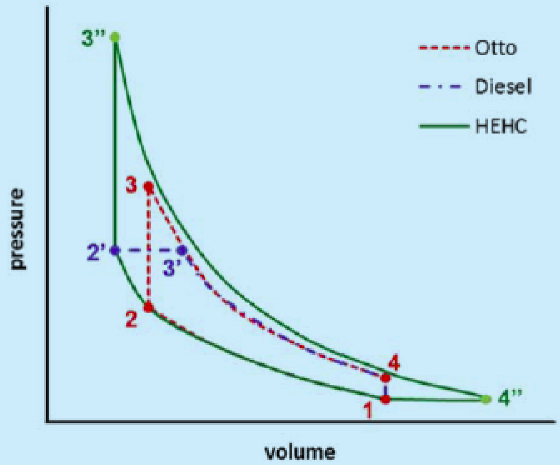
Improvements suggested by Horacio A. Trucco in a technical paper published by SAE in 2012 involve trapping exhaust gases in the vaporization chamber to superheat the liquid fuel as it's injected. The fuel vapors then exit the vaporization chamber by way of a transfer port mixing with fresh air from a new intake cycle. The air-fuel mixture is compressed and ignited via a sparkplug. All of this improves efficiency and burns off more of the waste gases' harmful emissions that are trapped and used to superheat the fuel.[7]

STANDARD PISTON VS WANKEL ENGINE

Advantages:	
Wankel	**Piston engines**
Higher operating speeds* ***Absence of vibration* *Fewer number of components* ***Smaller footprint* ***Higher Power to Weight ratio	***Highly Developed* ***Less concerns for fuel efficiency* ***Piston seals not as expensive to service or replace with less maintenance***

Disadvantages:	
Wankel	**Piston engines**
Piston engine's widespread domination discourages Wankel engine's development* ***Currently not as fuel efficient* ***Rotor must have good seals	***Much larger footprint* ***Much higher number of components with valves and camshafts* ***Vibration present* ***A lot heavier***

A re-invention of the Wankel engine similar in moving parts are the X model engines produced by the team at **Liquid Piston** with only a rotating shaft and rotor. Differing from the purely Otto Cycle Wankel engine, Liquid Piston's X engines employ their patented **High Efficiency Hybrid Cycle** (HEHC) which combines elements from Otto, Diesel, Atkinson and Rankine cycles [8]. In much the same way Felix Wankel forged a new way of implementing the Otto cycle, Liquid Piston's founders - a father and son team



Thermal efficiencies of each ideal gas cycle are explained in detail in previous papers [10, 11, 12, 13, and 14] as well as text books [15] and will not be described here. The thermal efficiencies of each cycle can be written as follows:

$$\eta_{Otto} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \qquad (1)$$

$$\eta_{Diesel} = 1 - \left(\frac{1}{\kappa}\right)\frac{(T_4 - T_1)}{(T_{3'} - T_{2'})} \qquad (2)$$

$$\eta_{HEHC} = 1 - \kappa\frac{(T_{4''} - T_1)}{(T_{3''} - T_{2'})} \qquad (3)$$

FIG. 5 - COMPARISON OF IDEALIZED POWER CYCLES TO LIQUID PISTON'S HEHC [9]

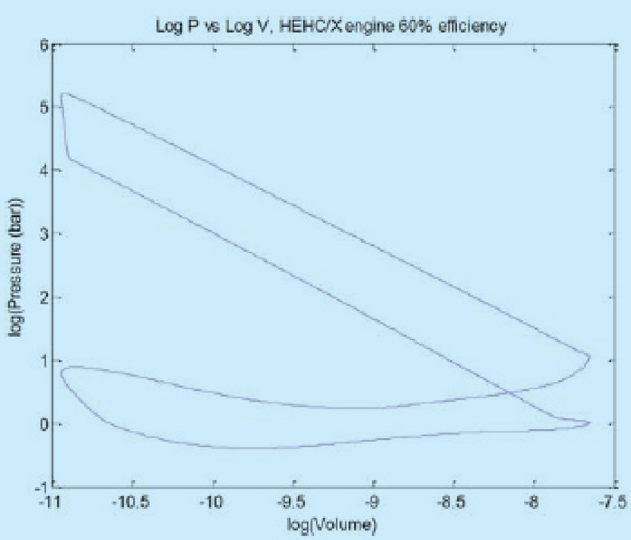


FIG. 6 - CHART OF EXPERIMENTAL DATA SHOWING 60% THERMAL EFFICIENCY [9]

- Dr. Nikolay Shkolnik and son Alexander have turned the Wankel engine inside out to develop their HEHC cycle. The X engines have seals that engage from the housing not the rotor itself, completely opposite of the Wankel engine; this allows the adaptation of their HEHC.

The High Efficiency Hybrid Cycle utilizes:

* High compression ratio and auto-ignition of fuel mixture (e.g. Diesel cycle)
* Constant volume (isochoric) combustion (e.g. Otto cycle)
* Over-expansion to atmospheric pressure (e.g. Atkinson or Miller cycle) [9] (Fig. 5 compares cycles directly)

Inspecting the HEHC leads to the possibility of ideally achieving an effieciency of 75 percent when compared to other power cycles. Testing of prototypes resulted in data supporting 60% thermal efficiency at 1800 RPM. [9]

In operation the X engine is capable of producing three power strokes per revolution by simultaneously completing all stages of intake, compres-

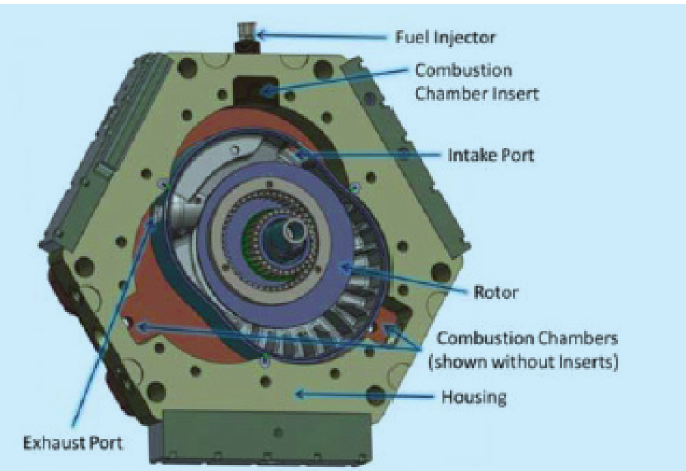


FIG. 7 - CUTAWAY VIEW OF X SERIES ENGINE FROM LIQUID PISTON [9]

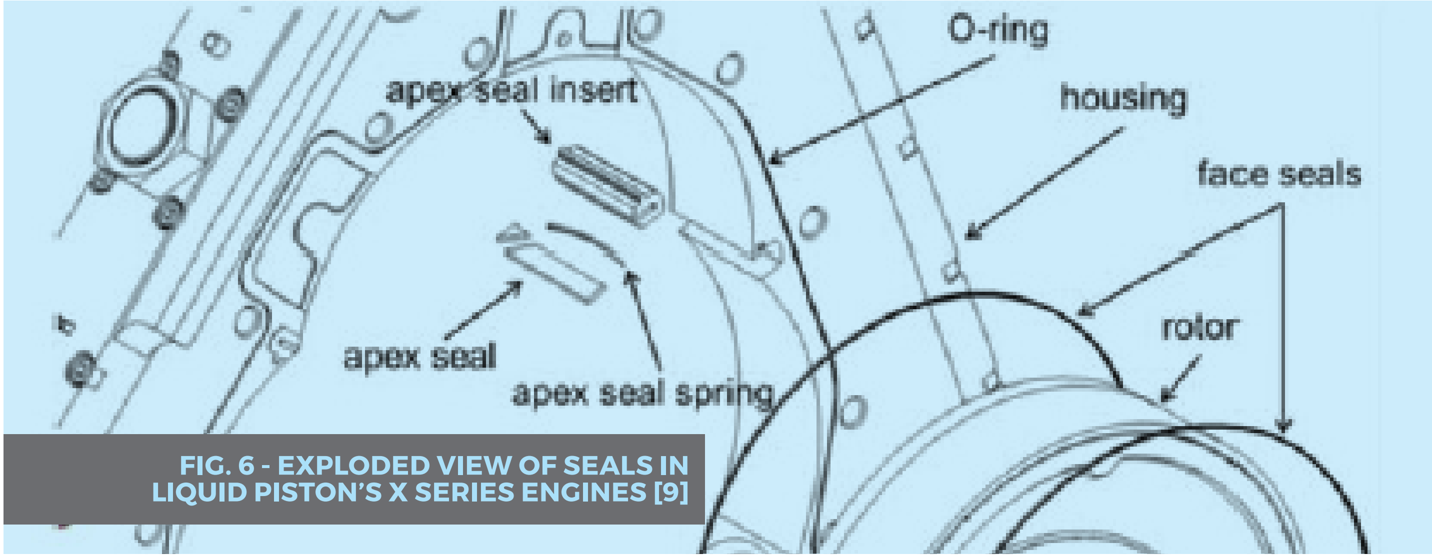


FIG. 6 - EXPLODED VIEW OF SEALS IN LIQUID PISTON'S X SERIES ENGINES [9]

sion, combustion and expansion, and exhaust for the cycle.

With increased development and full production this endgine may be used in small appliances and power tools to operate without vibration and reduced noise and emissions all while drastically decreasing the weight compared to a similar power output pistion engine. Wankel improved the application of the Otto cycle and others are building upon his groundbeaking work to improve the efficiency of the internal combustion engine.

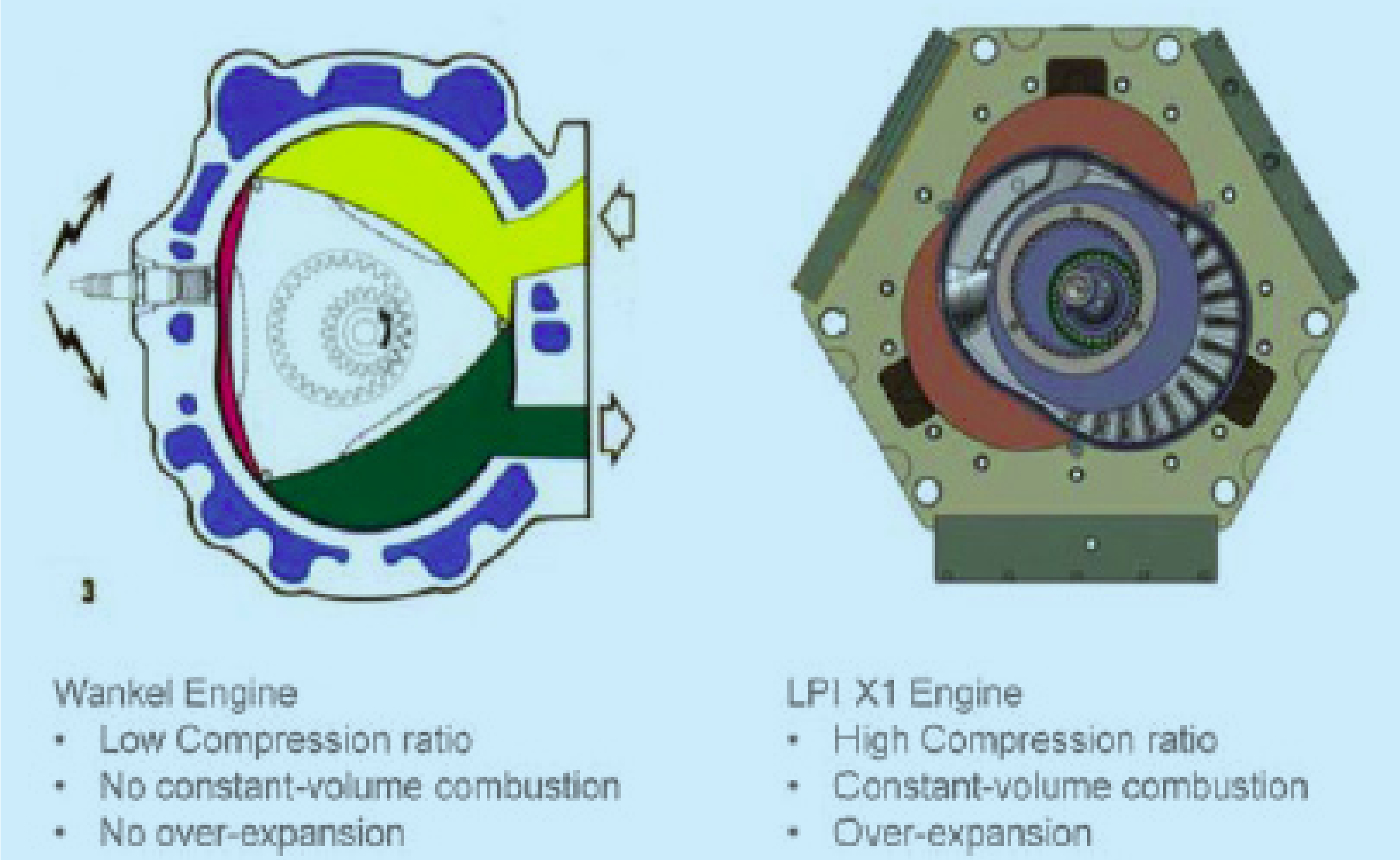


FIG. 8 - COMPARISON OF WANKEL ENGINE TO "INVERTED" X ENGINE FROM LIQUID PISTON [9]

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