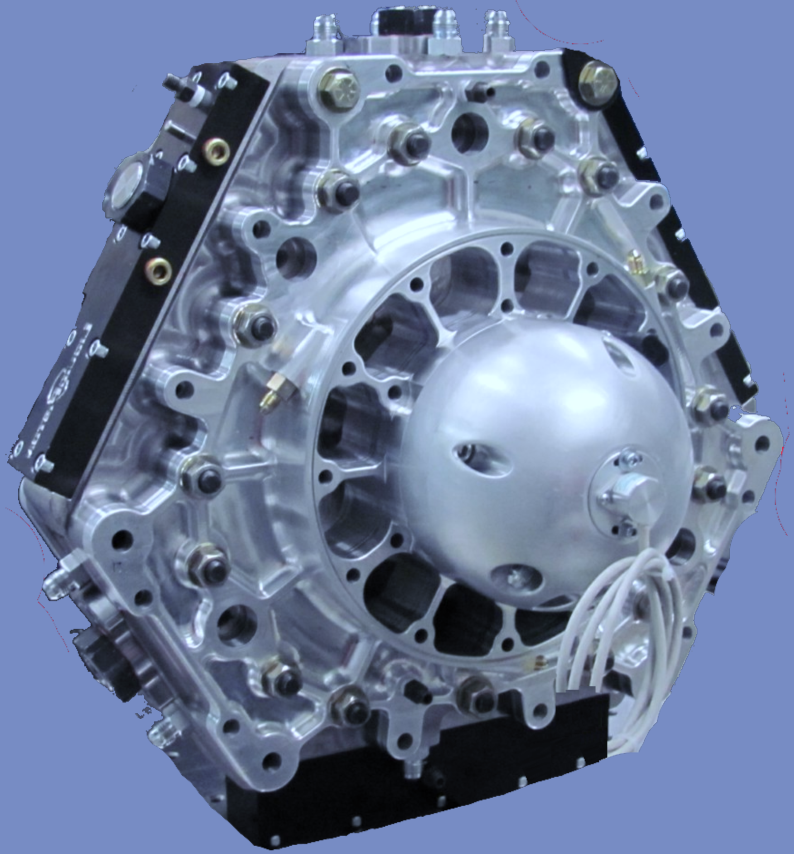
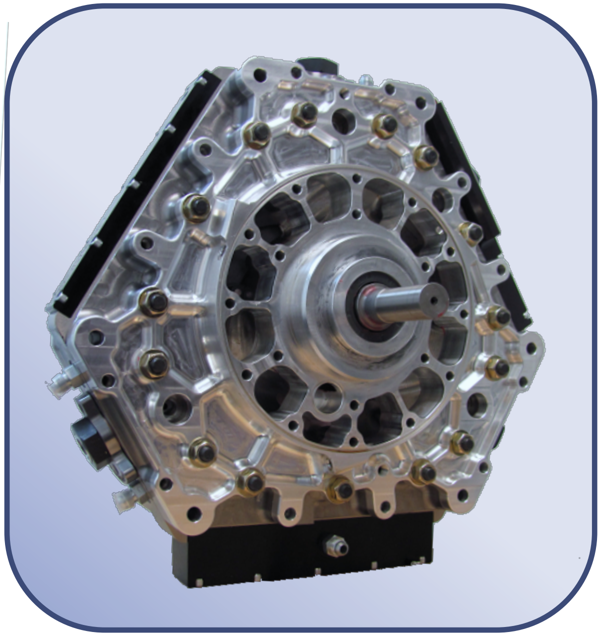


The X-series Rotary Diesel Engine

Alexander Shkolnik, PhD
President, CEO
LiquidPiston
as@liquidpiston.com

Agenda



- Introduction
- Engine Benefits
  - Efficiency / Thermodynamic Cycle
  - Noise
  - Size and Weight
- X1 / X2 Engine Architecture

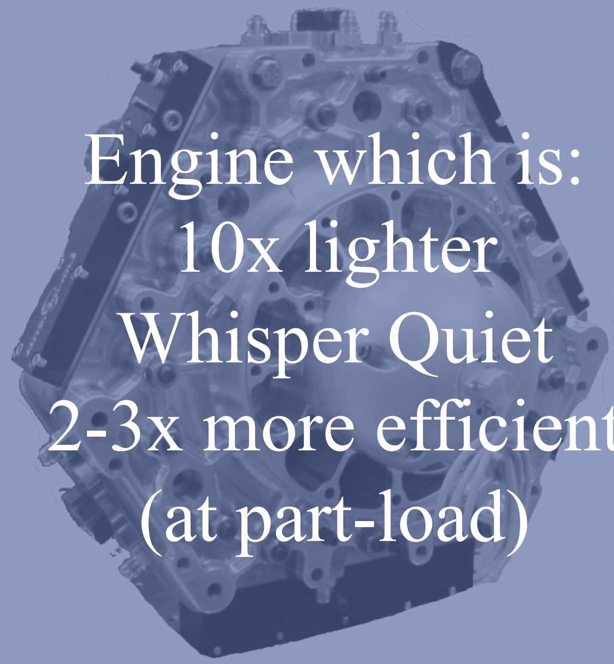
LiquidPiston Objectives

- LiquidPiston is developing an improved thermodynamics cycle, fundamentally changing the operation of the combustion engine.

High Efficiency Hybrid Cycle

+

Rotary Engine Embodiment



LiquidPiston Introduction

- VC-backed startup company incubated at MIT;
- Disruptive technology, poised to commercialize a decade of R&D
- IP / Licensing model.
- Targeting sub-100 HP markets initially
- Prototype engine available Q1 2013 for partner testing

50% Thermal Efficiency engines

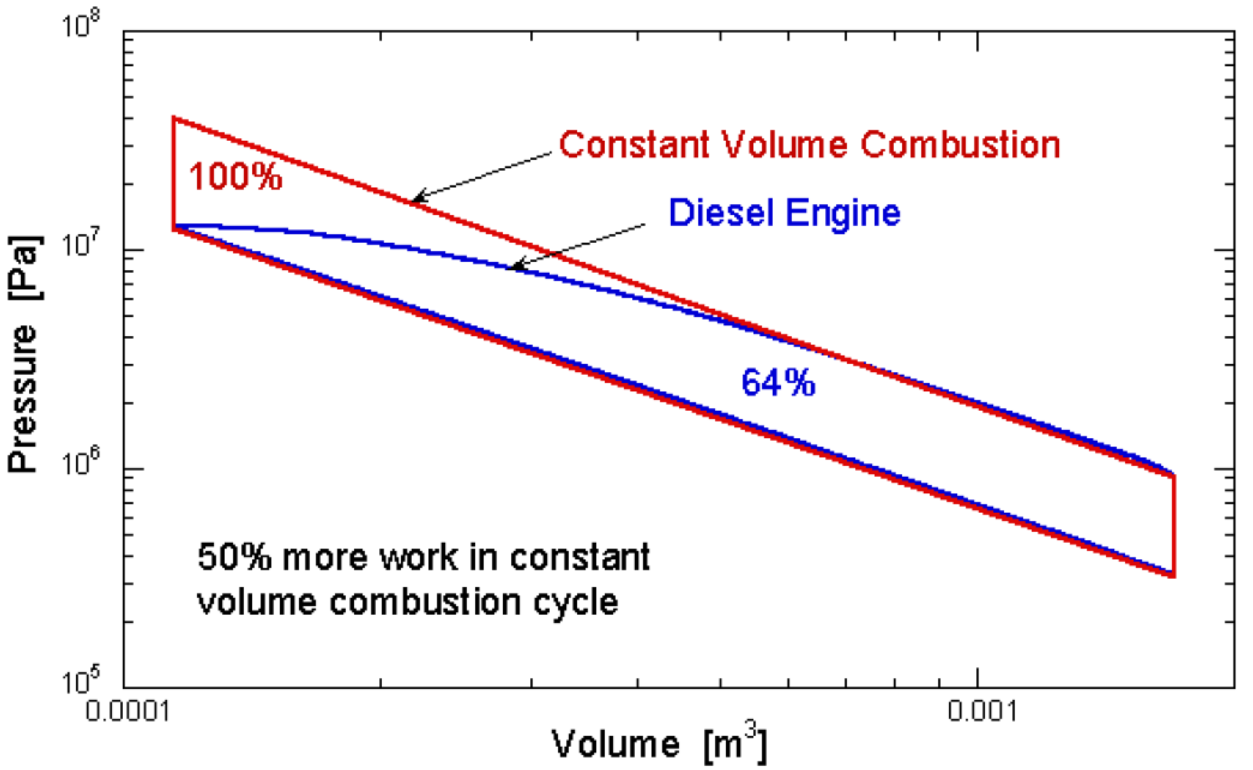
“If technology could be applied to all US Truck and Auto engines, oil consumption could be reduced by 1/3
= oil imports from Persian Gulf “

Wartsila-Sulzer RTA96-C turbocharged two-stroke diesel is the most powerful and efficient prime-mover in the world. Bore 38”, 1820 L, 7780 HP/Cyl at 102 RPM

http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2009/session1/deer09_reitz.pdf , Slide # 28

Benefits of Constant Volume Combustion

Illustration of burn duration penalty

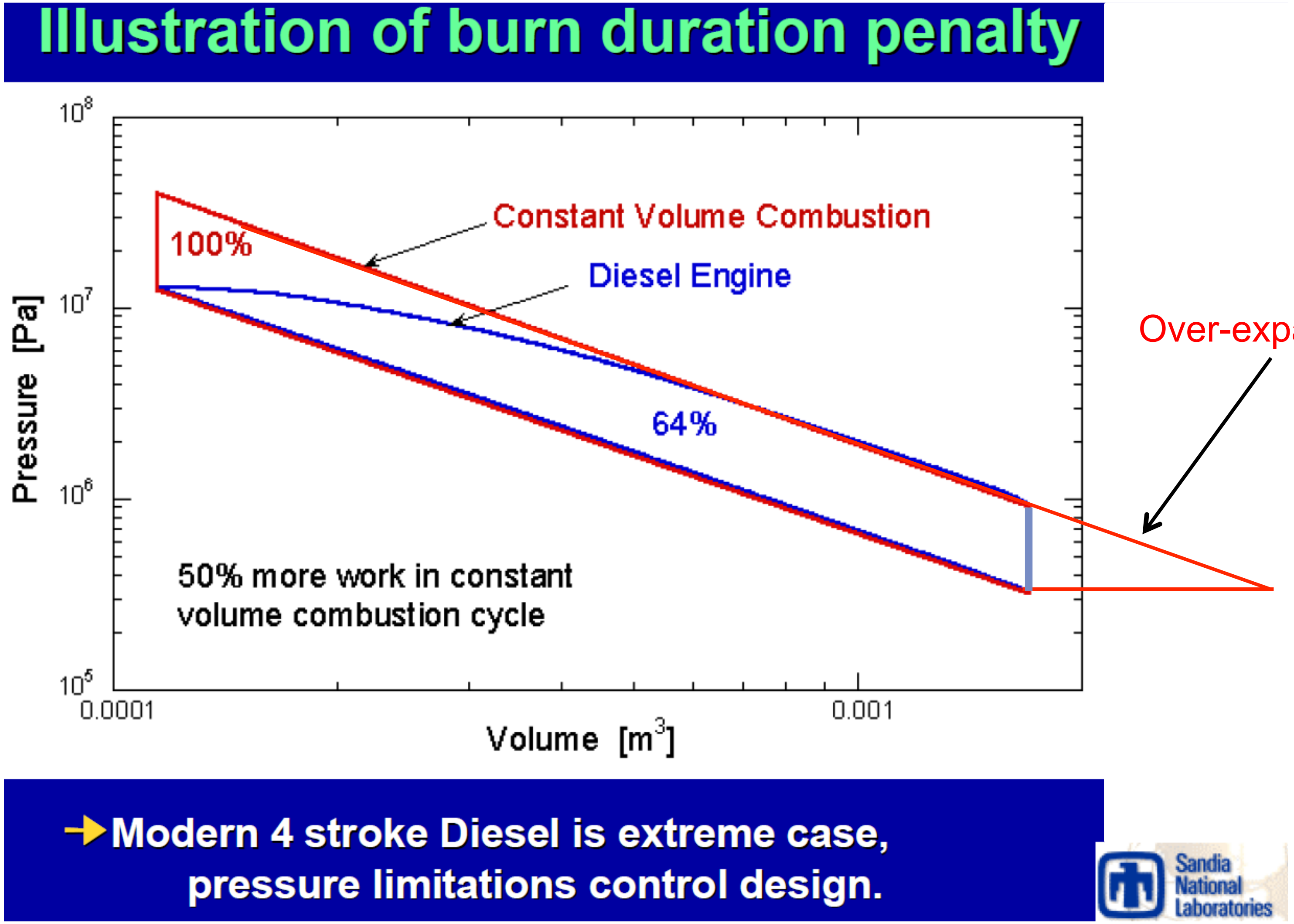


→ **Modern 4 stroke Diesel is extreme case, pressure limitations control design.**

Sandia National Laboratories

"Toward the Development of a Thermodynamic Fuel Cell", Peter Van Blarigan, Scott Goldsborough, Sandia National Laboratories. Hydrogen, Fuel Cells & Infrastructure Technologies Program, Merit Review and Peer Evaluation, May 19 19-22, 2003

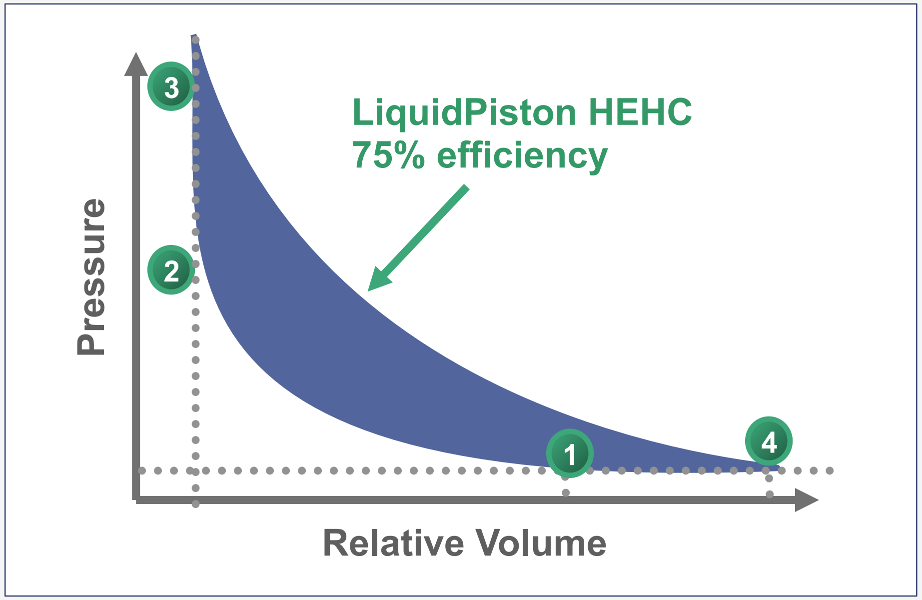
Benefits of Constant Volume Combustion

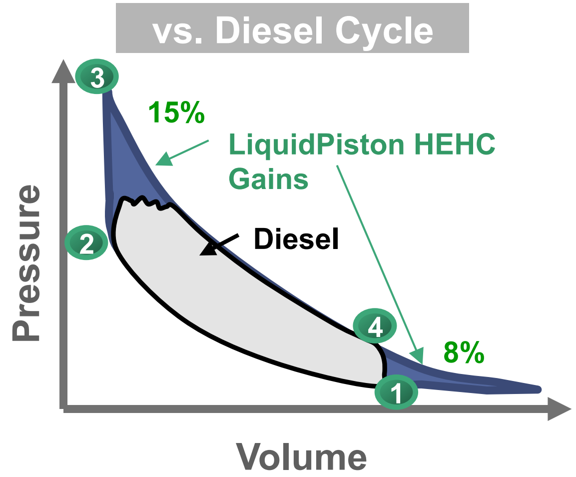


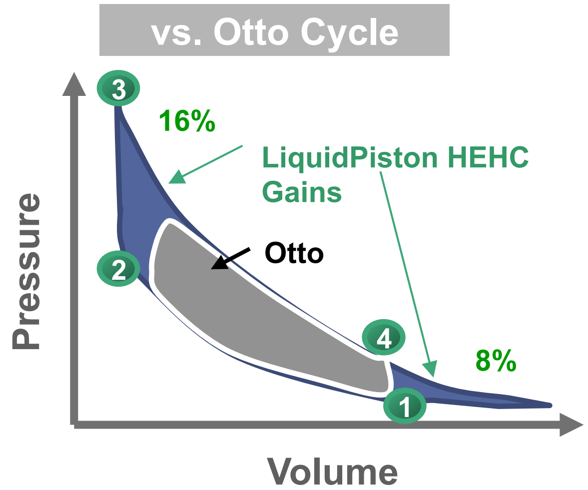
"Toward the Development of a Thermodynamic Fuel Cell", Peter Van Blarigan, Scott Goldsborough, Sandia National Laboratories. Hydrogen, Fuel Cells & Infrastructure Technologies Program, Merit Review and Peer Evaluation, May 19 19-22, 2003

HEHC Thermodynamic Cycle

- Patent-pending "High Efficiency Hybrid Cycle" (HEHC)
- Thermodynamics optimized for fuel efficiency
- Efficiency proportional to area within P-V curve



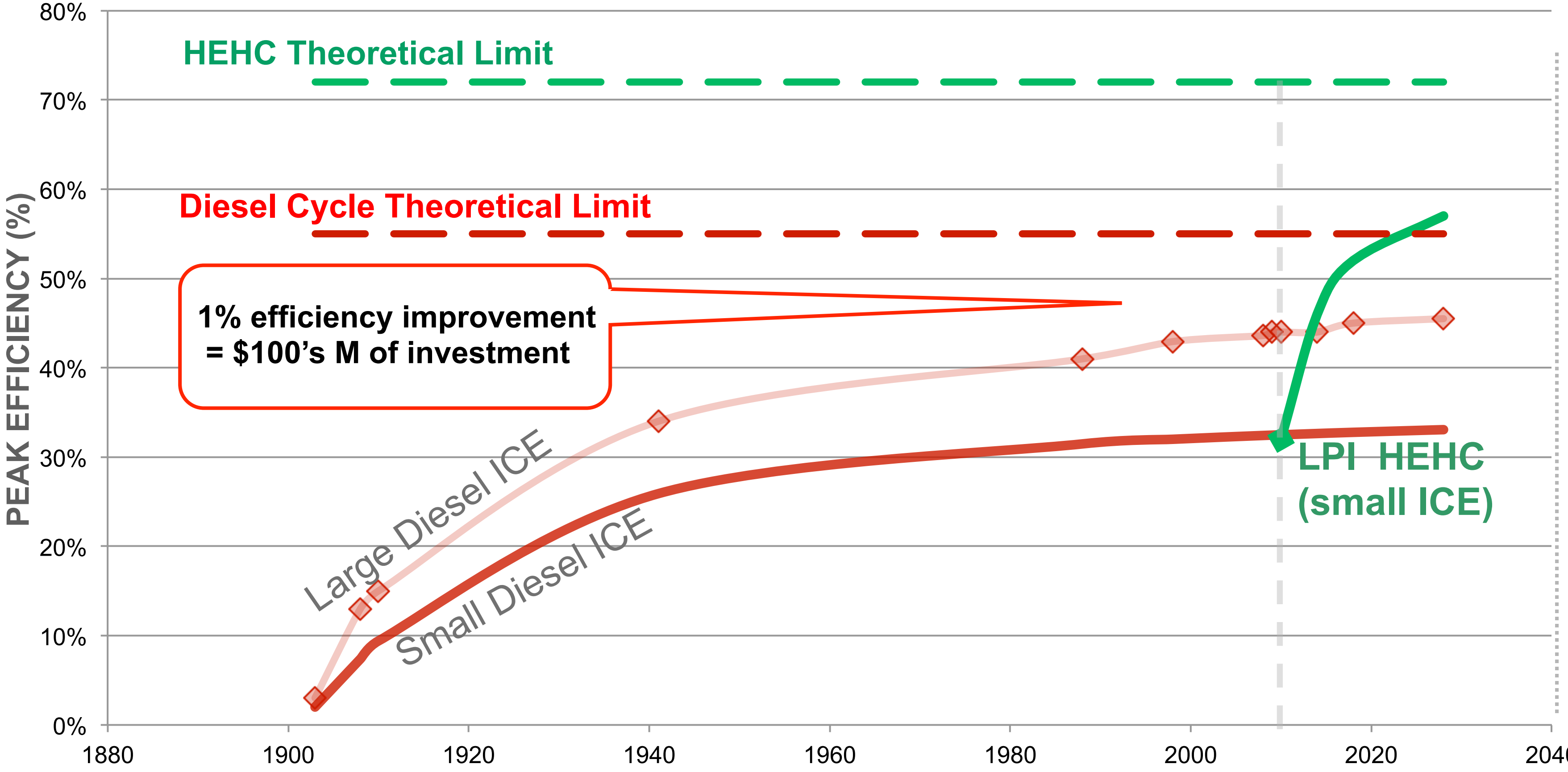




HEHC combines best features of multiple existing cycles:

- High air compression ratio (Diesel)
- Constant volume combustion (Otto)
- Over-expansion to atmospheric pressure (Atkinson)
- Internal cooling with air or water (Rankine)

The Innovation: HEHC™ Engine



HEHC = High Efficiency Hybrid Cycle

Source: J. Heywood; Kubota; Kohler; Wright Experience; Wikipedia; LPI

A new engine architecture on a new learning curve

Ability to achieve dramatic efficiency gains with far less investment

Engine Noise

Sources of noise in Diesel engines:

1. Combustion: rapid pressure change
2. Valves opening and closing
3. High pressure exhaust is turbulent;
   Release to atmosphere is noisy,
   requires muffler
4. Piston slap

Source: Li et. al. “A STUDY OF THE NOISE FROM DIESEL ENGINES USING THE INDEPENDENT COMPONENT ANALYSIS”, Mechanical Systems and Signal Processing (2001) 15(6), 1165}1184 doi:10.1006/mssp. 2000.1366

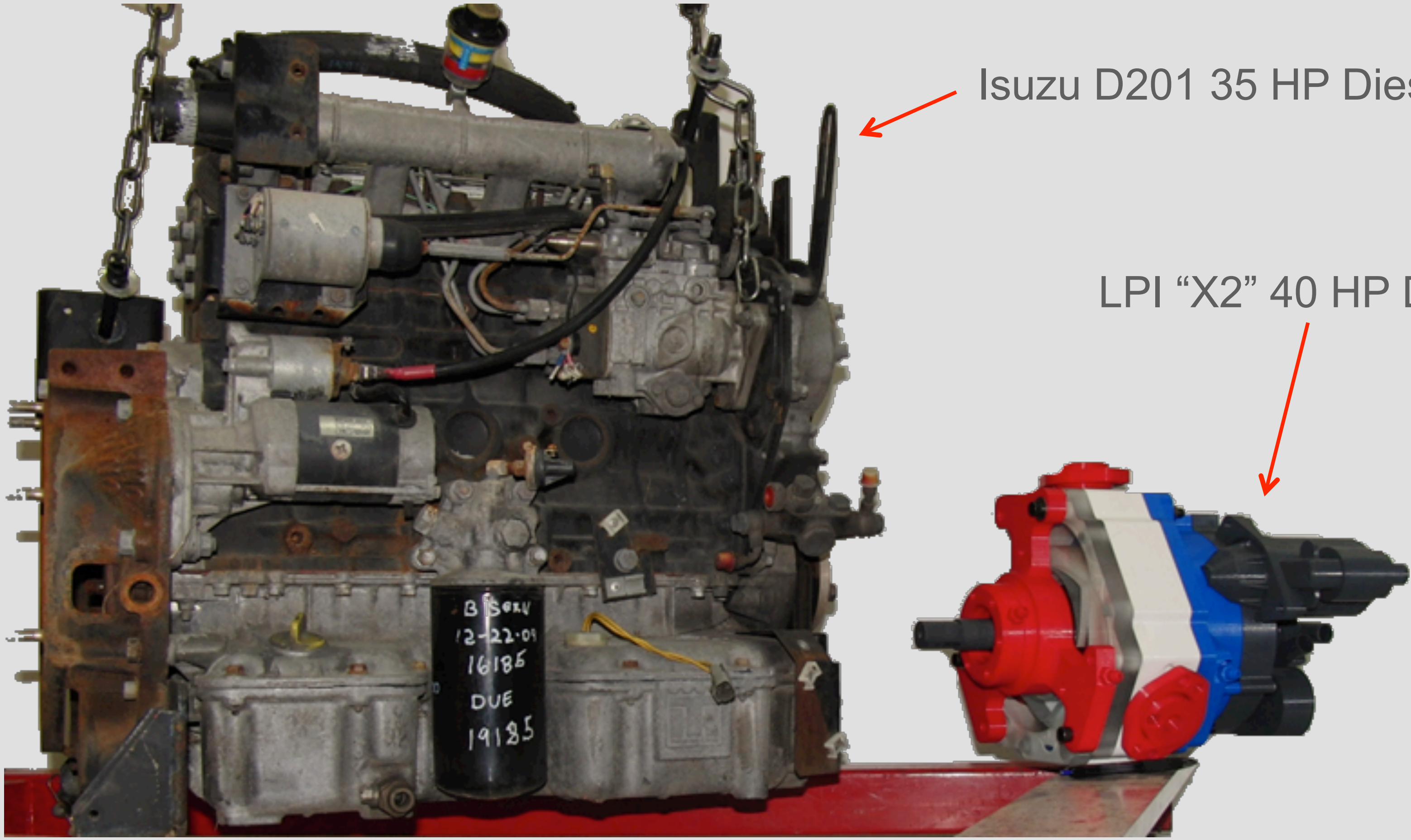
Sources of noise in Diesel engines:

1. ~~Combustion: rapid pressure change~~
2. ~~Valves opening and closing~~
3. ~~High pressure exhaust is turbulent; Release to atmosphere is noisy, requires muffler~~
4. ~~Piston slap~~

NVH: Vibration is minimal – engine is purely balanced

Source: Li et. al. "A STUDY OF THE NOISE FROM DIESEL ENGINES USING THE INDEPENDENT COMPONENT ANALYSIS", Mechanical Systems and Signal Processing (2001) 15(6), 1165}1184 doi:10.1006/mssp. 2000.1366

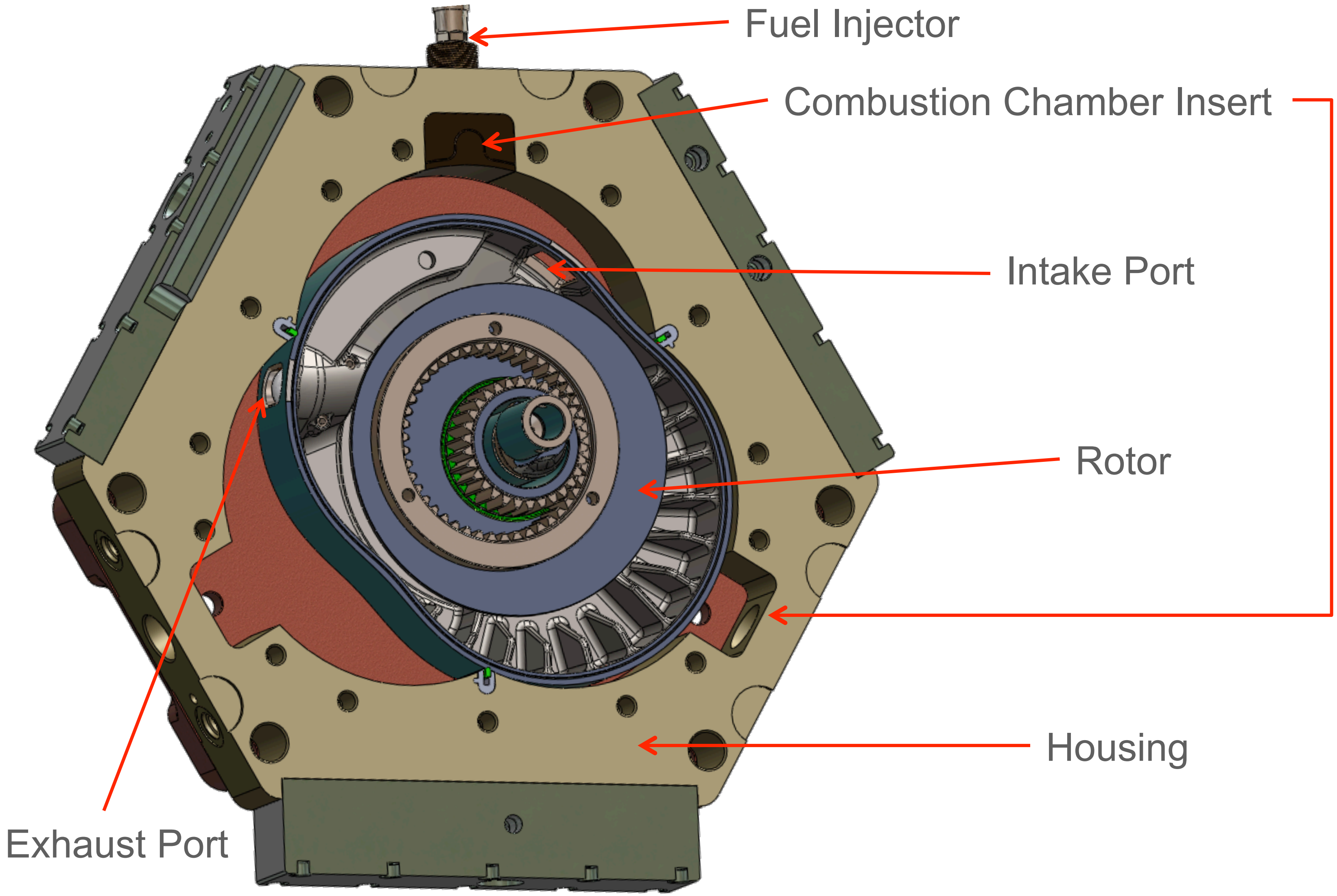
Unparalleled Power Density



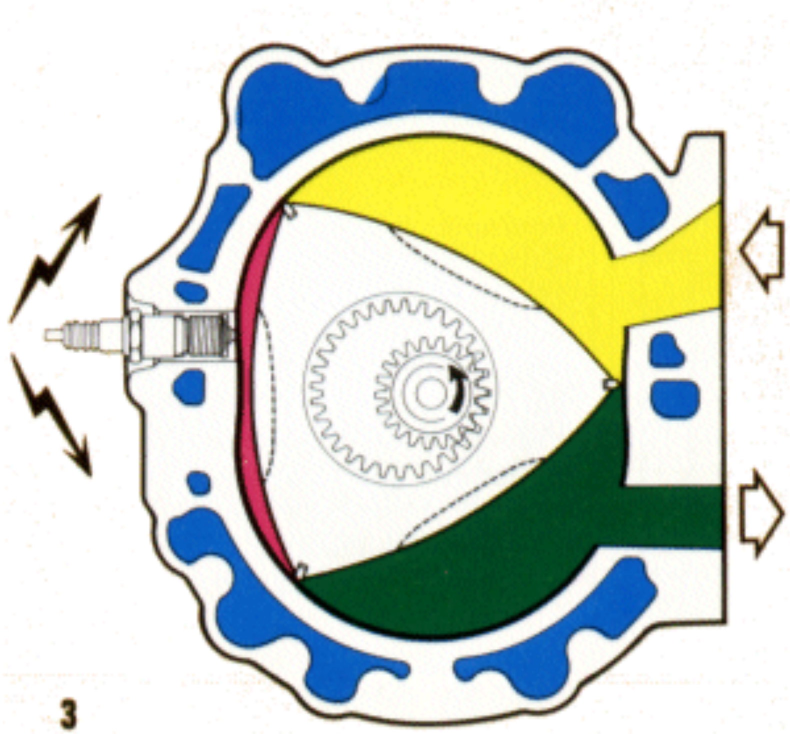
Isuzu D201 35 HP Diesel Engine

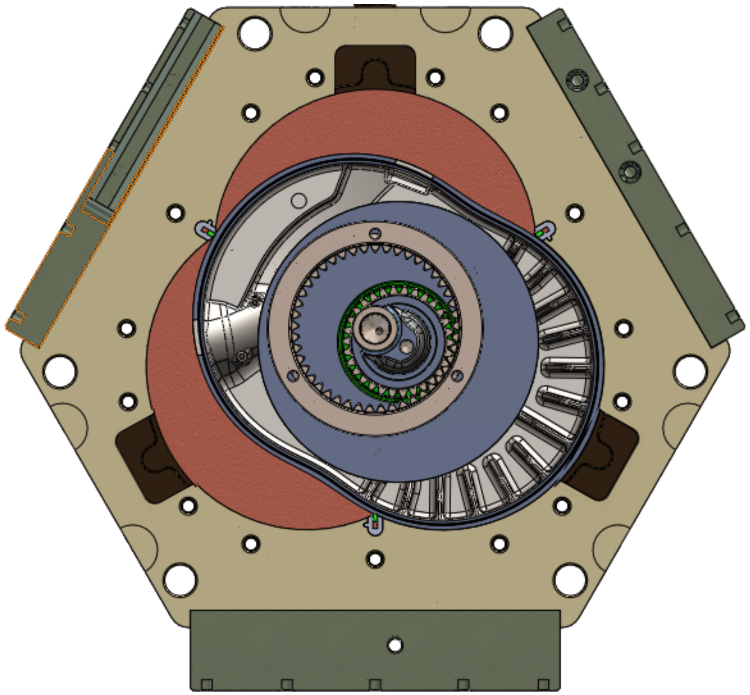
LPI “X2” 40 HP Diesel

X1 primary components



Not a Wankel

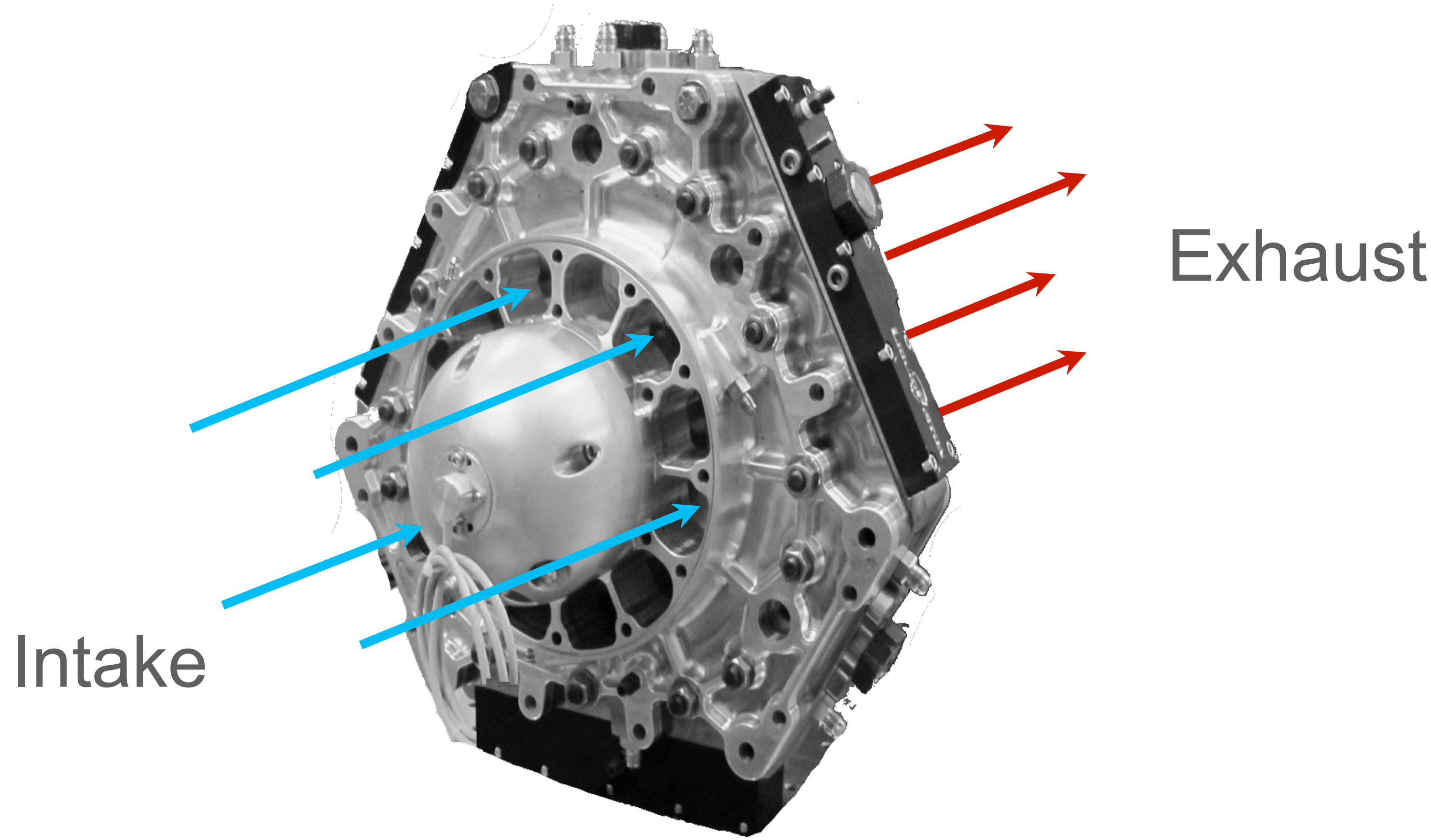




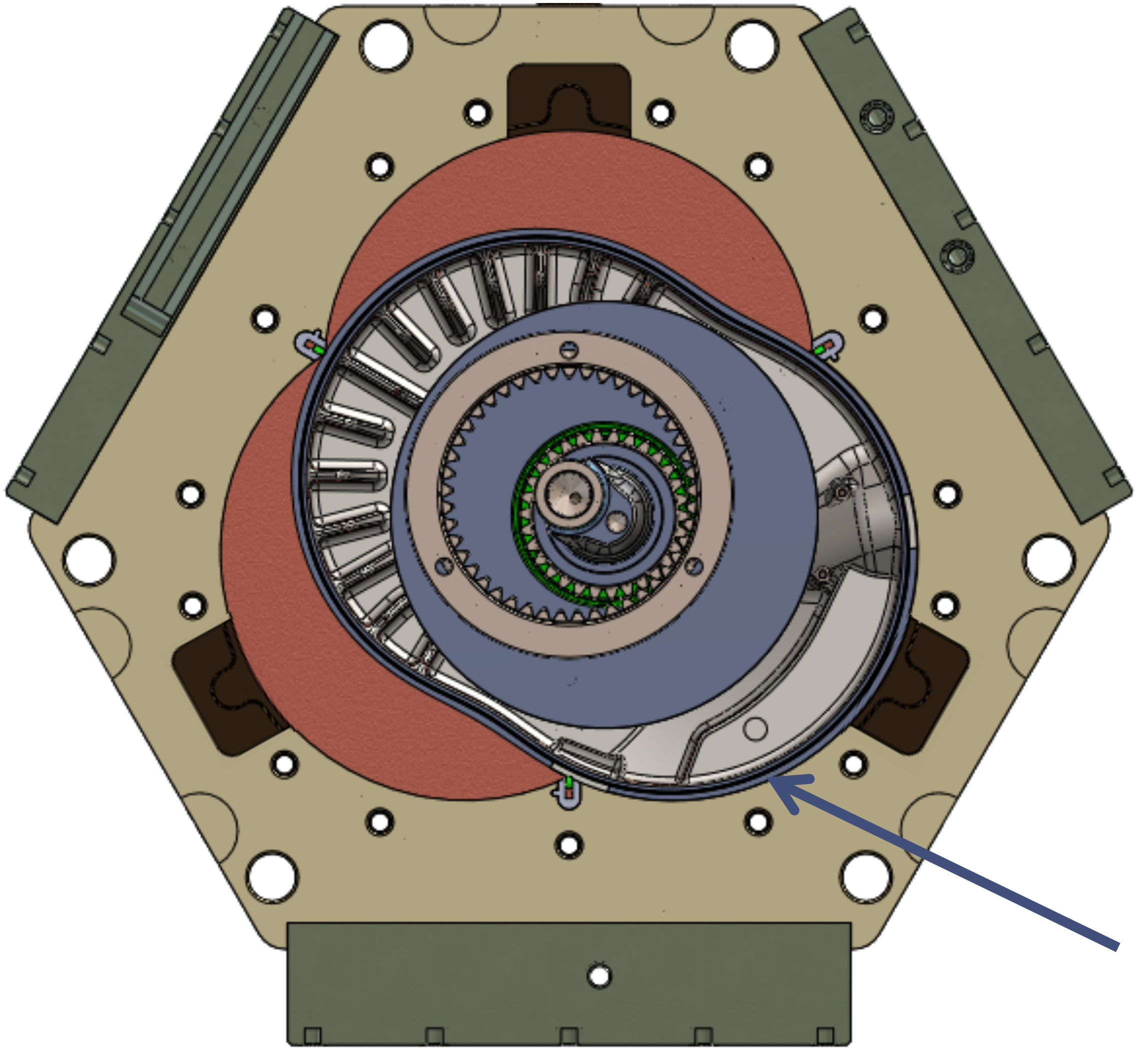
Wankel Engine
- Low Compression ratio
- No constant-volume combustion
- No over-expansion

LPI X1 Engine
- High Compression ratio
- Constant-volume combustion
- Over-expansion

Intake / exhaust

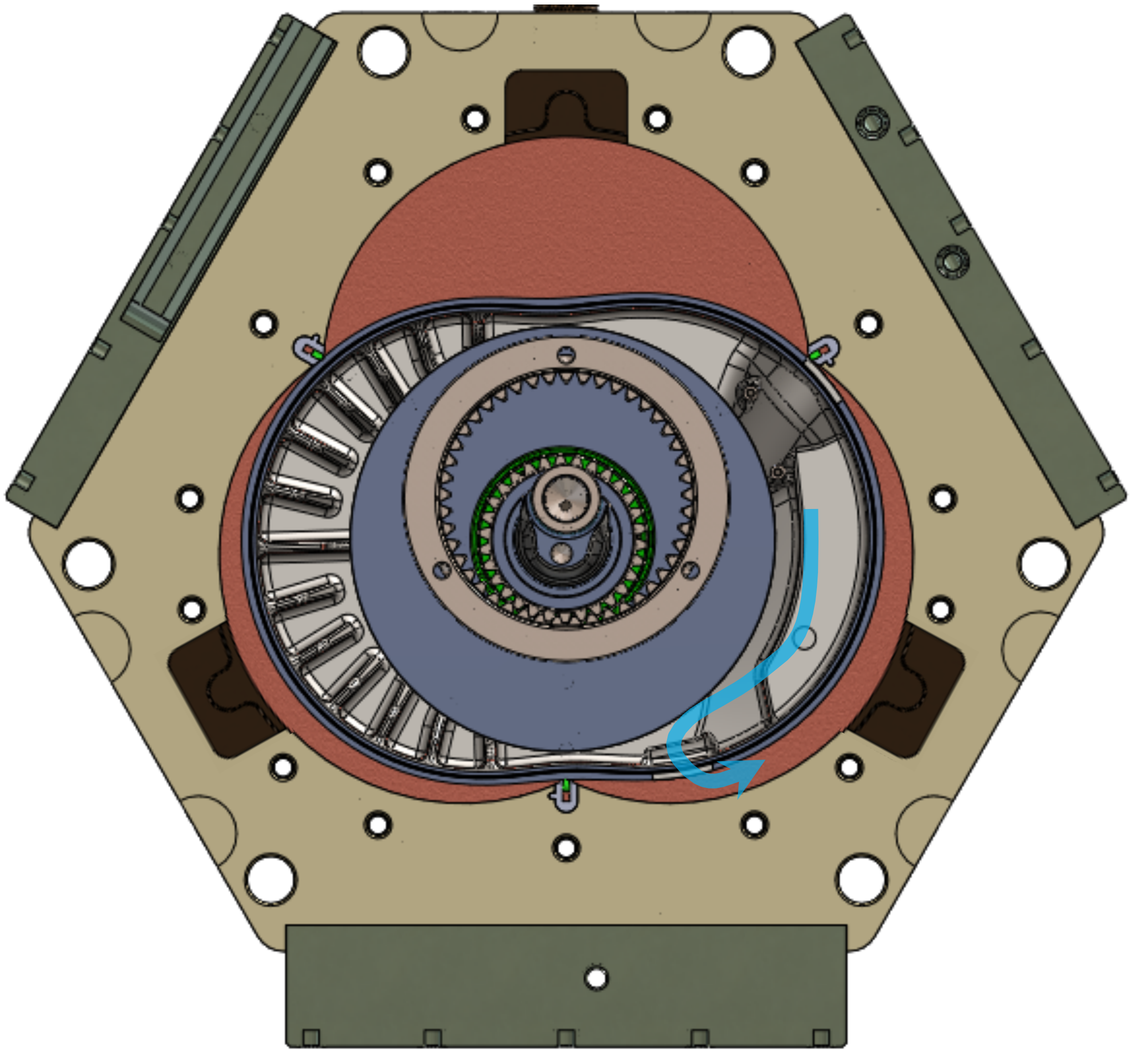


X1 Operation: 0 Degrees (shaft rotation)



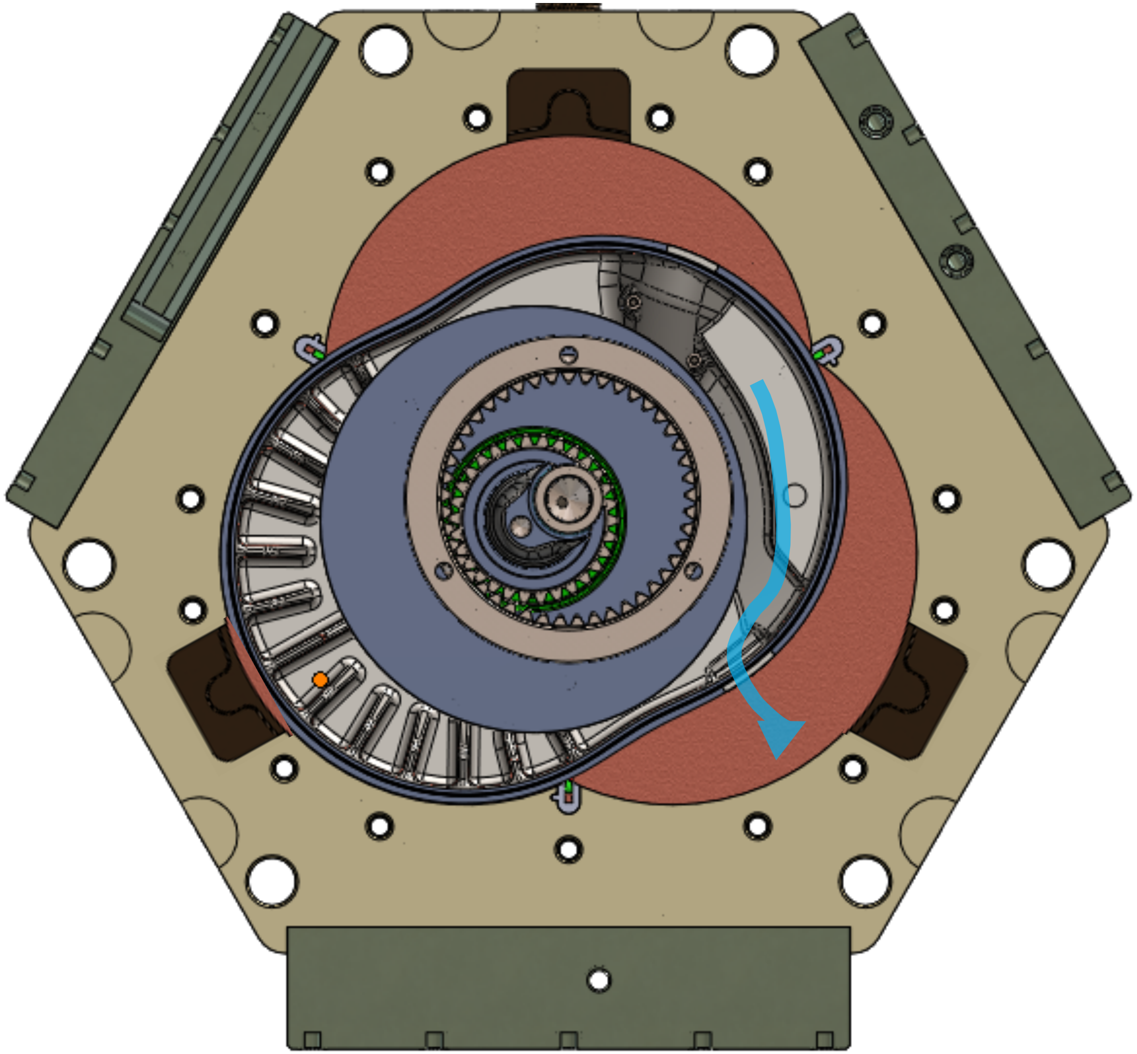
Intake about
to start

65 degrees



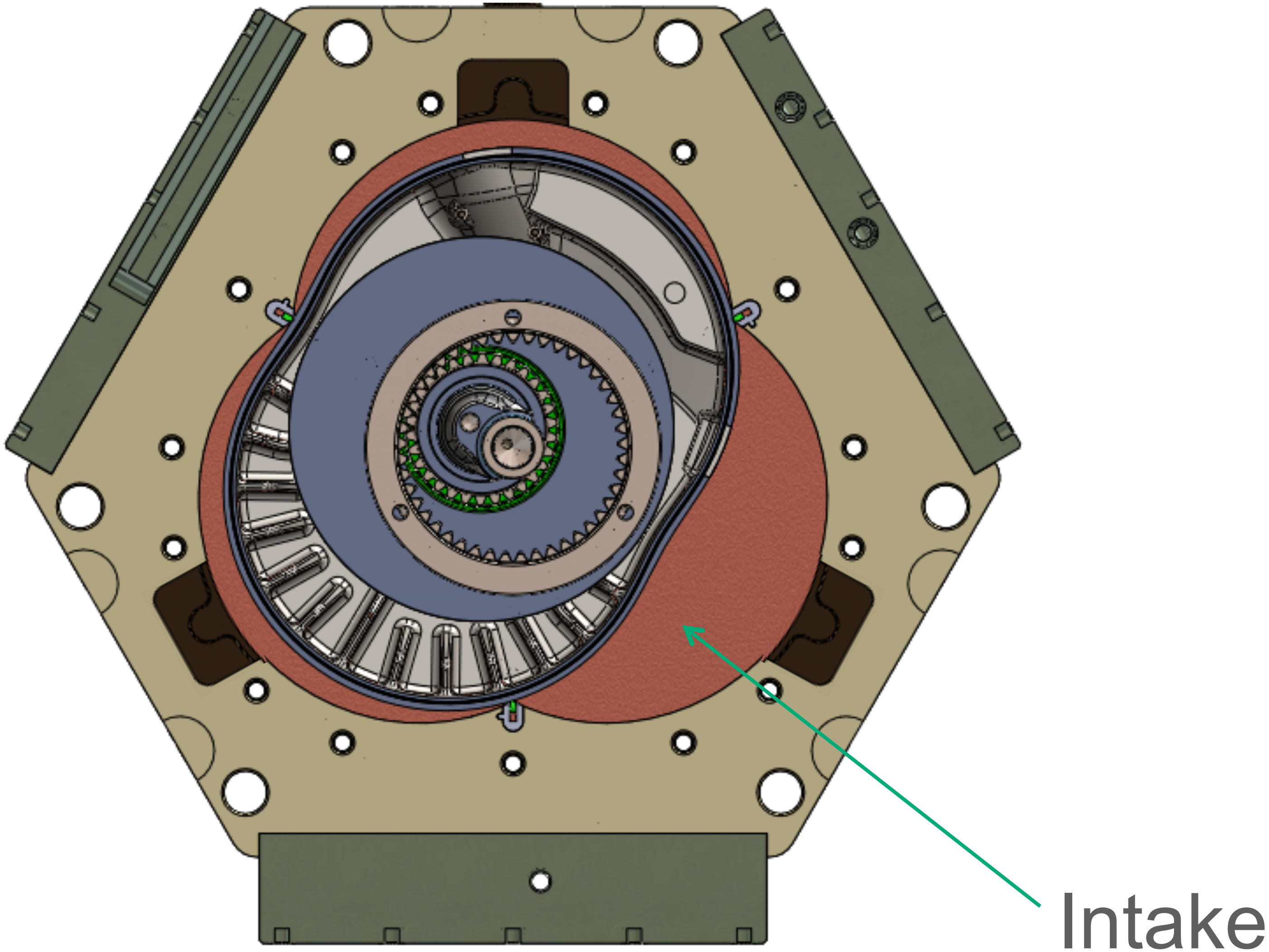
Intake

120 degrees

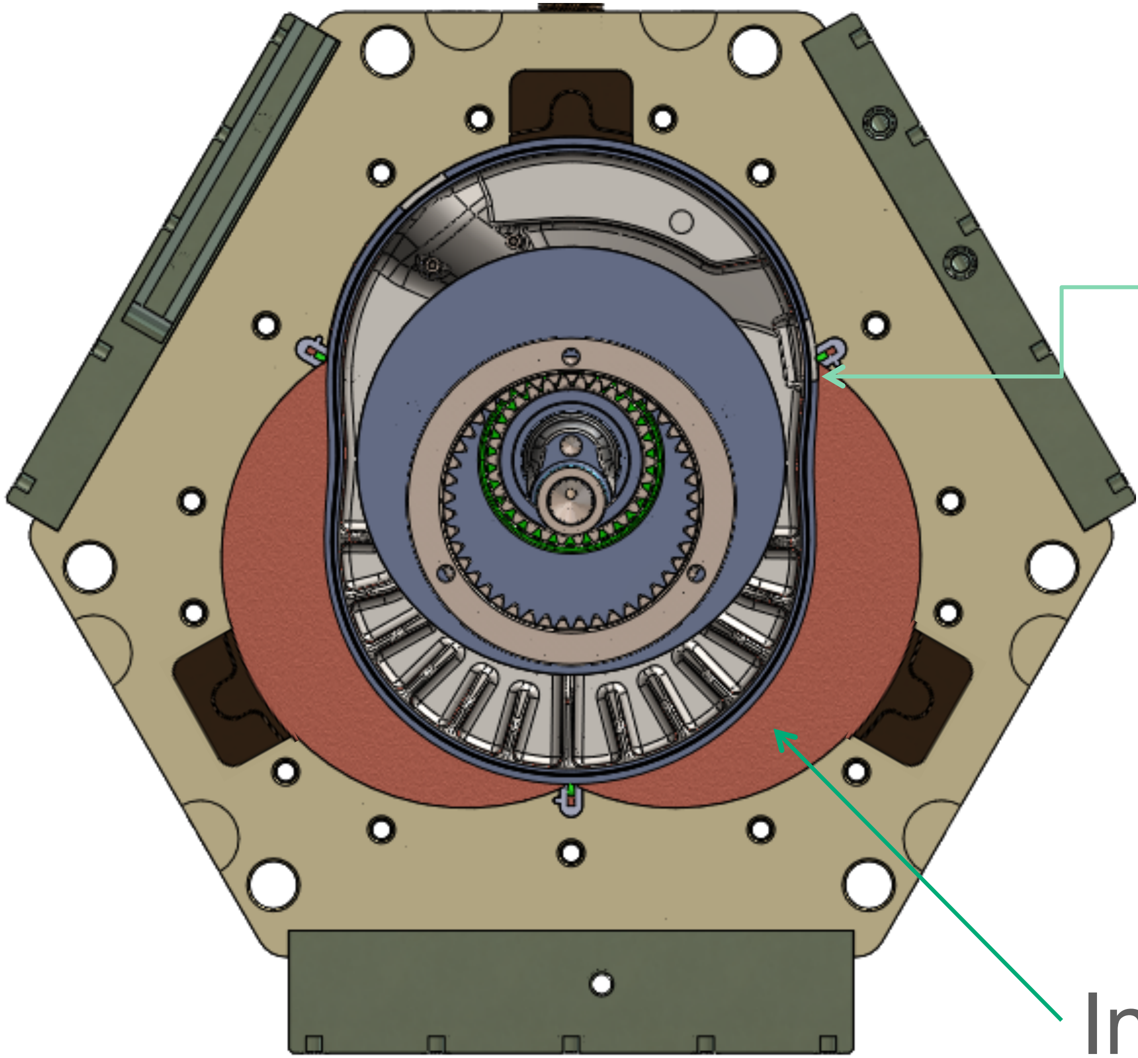


Intake

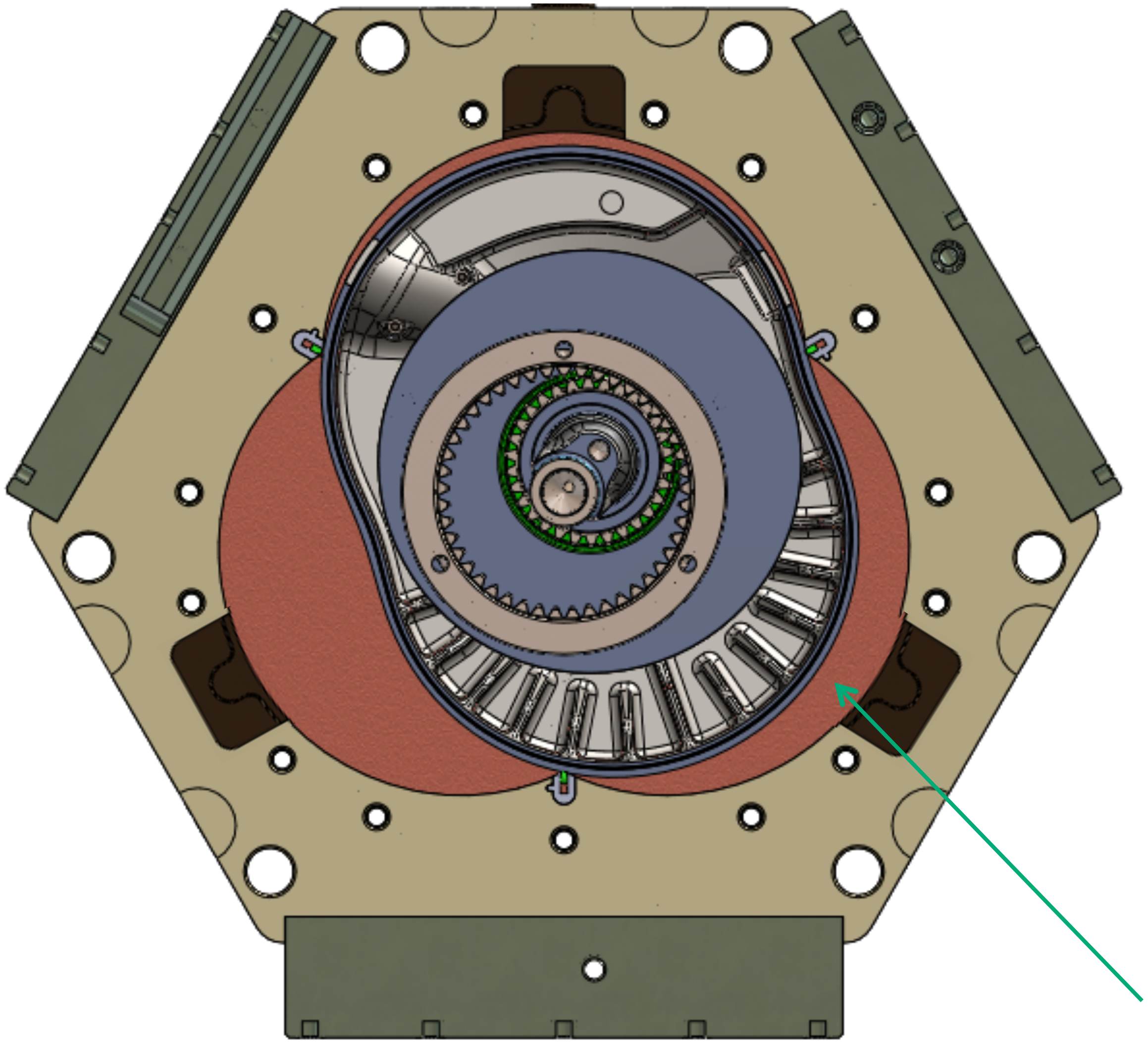
180 degrees



240 degrees

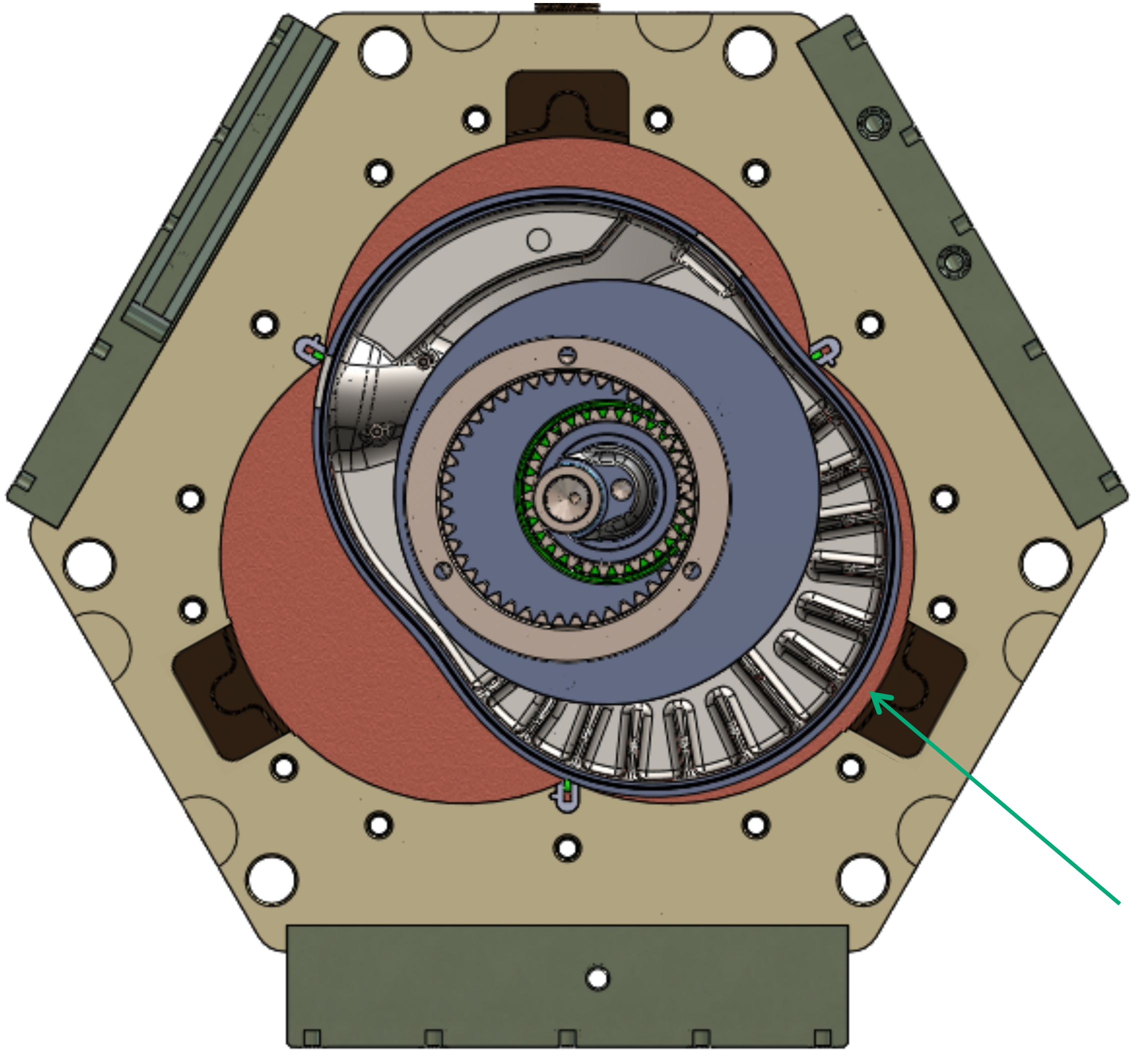


280 degrees



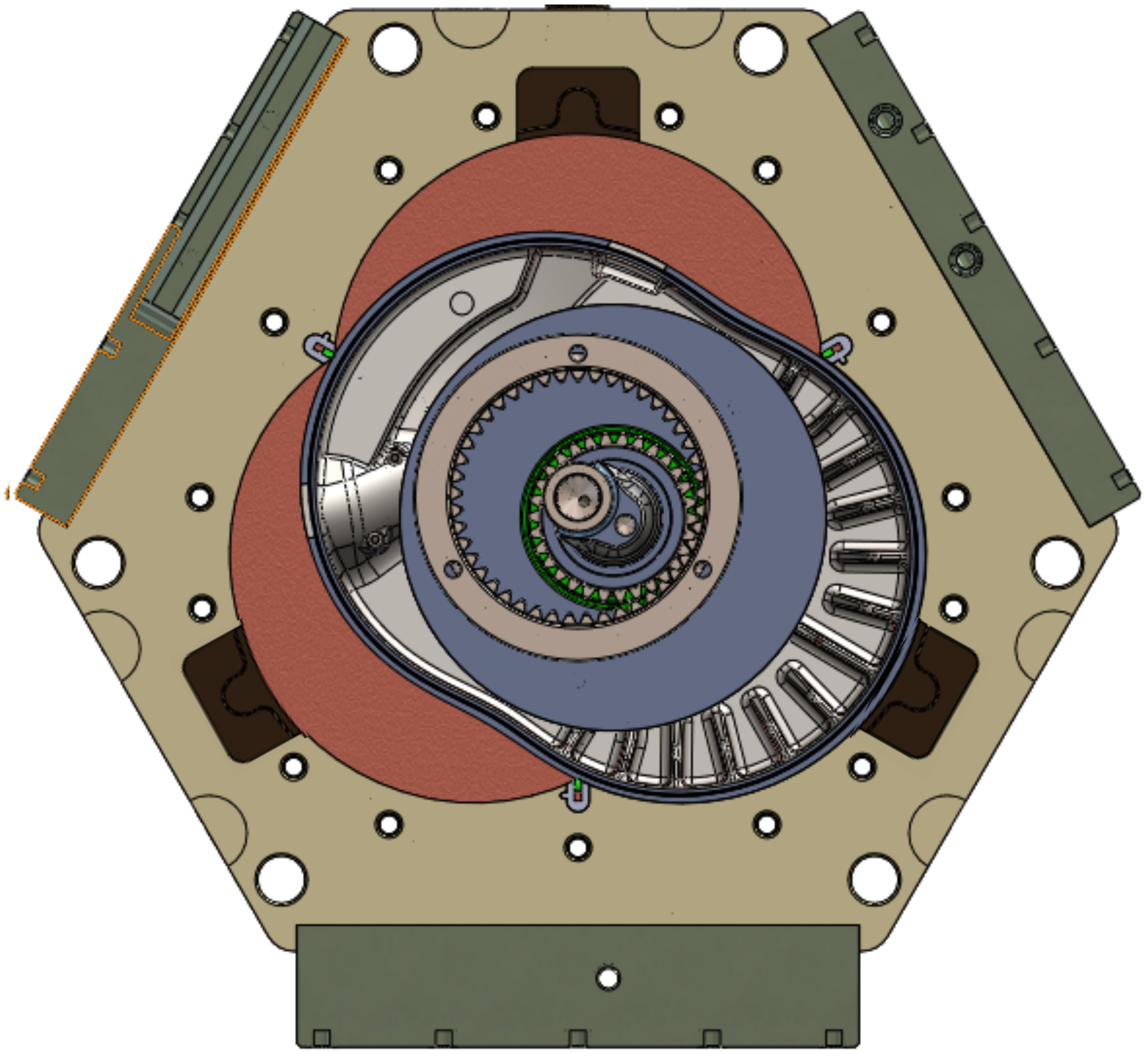
Compression

320 degrees



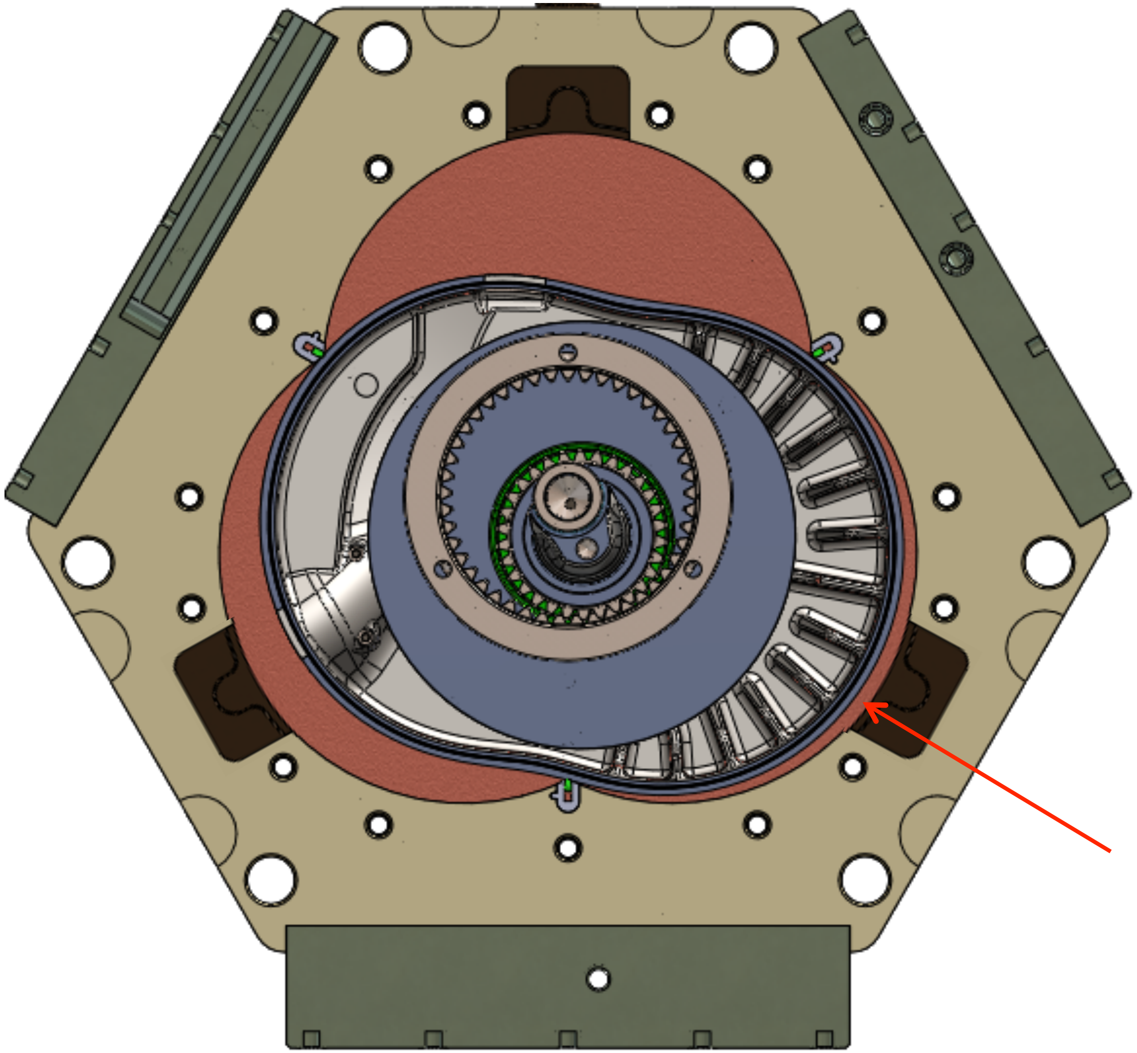
Compression
Almost
Complete

360 degrees



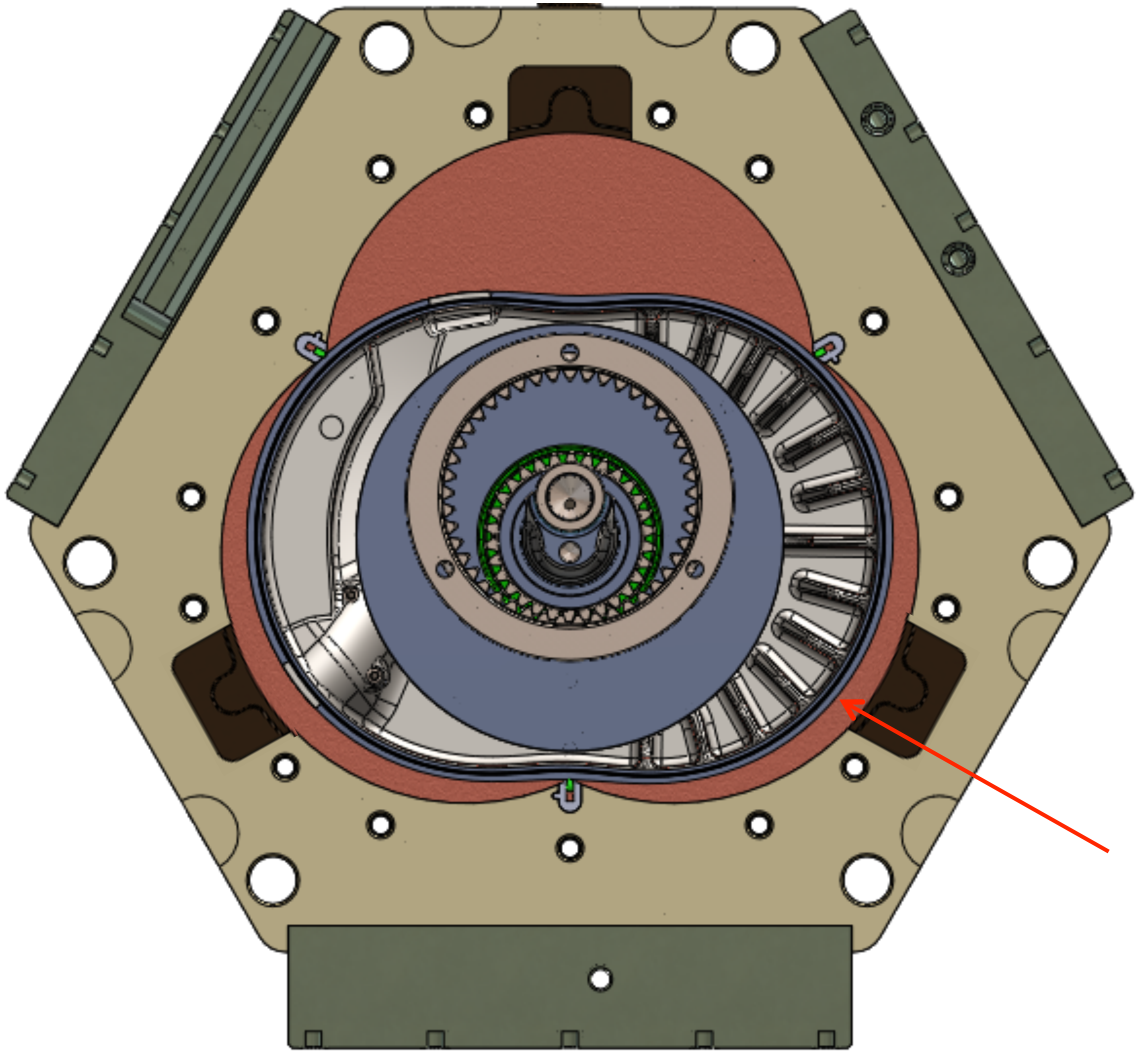
Constant
Volume
Combustion

400 degrees



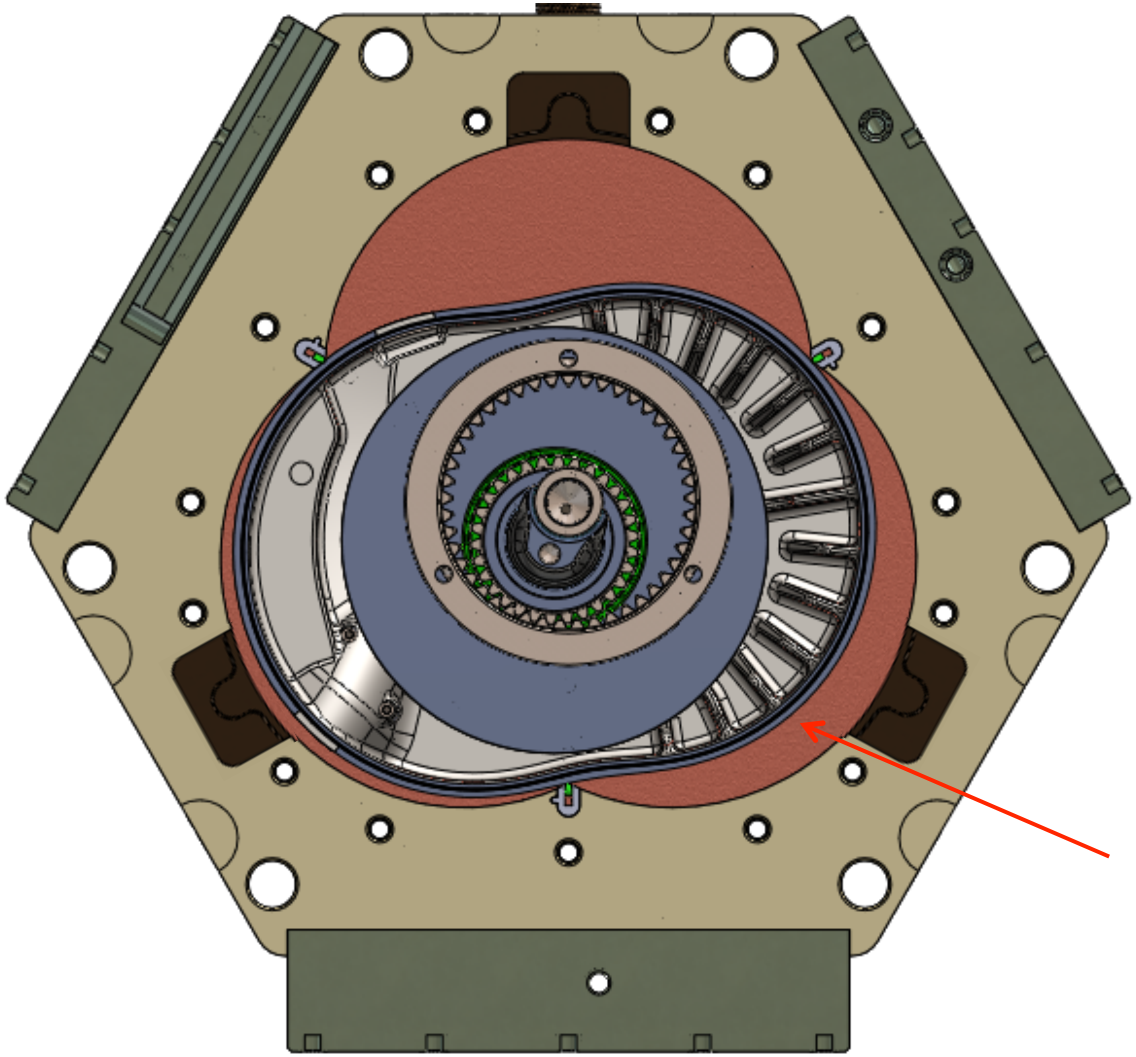
Expansion (power) stroke

420 degrees



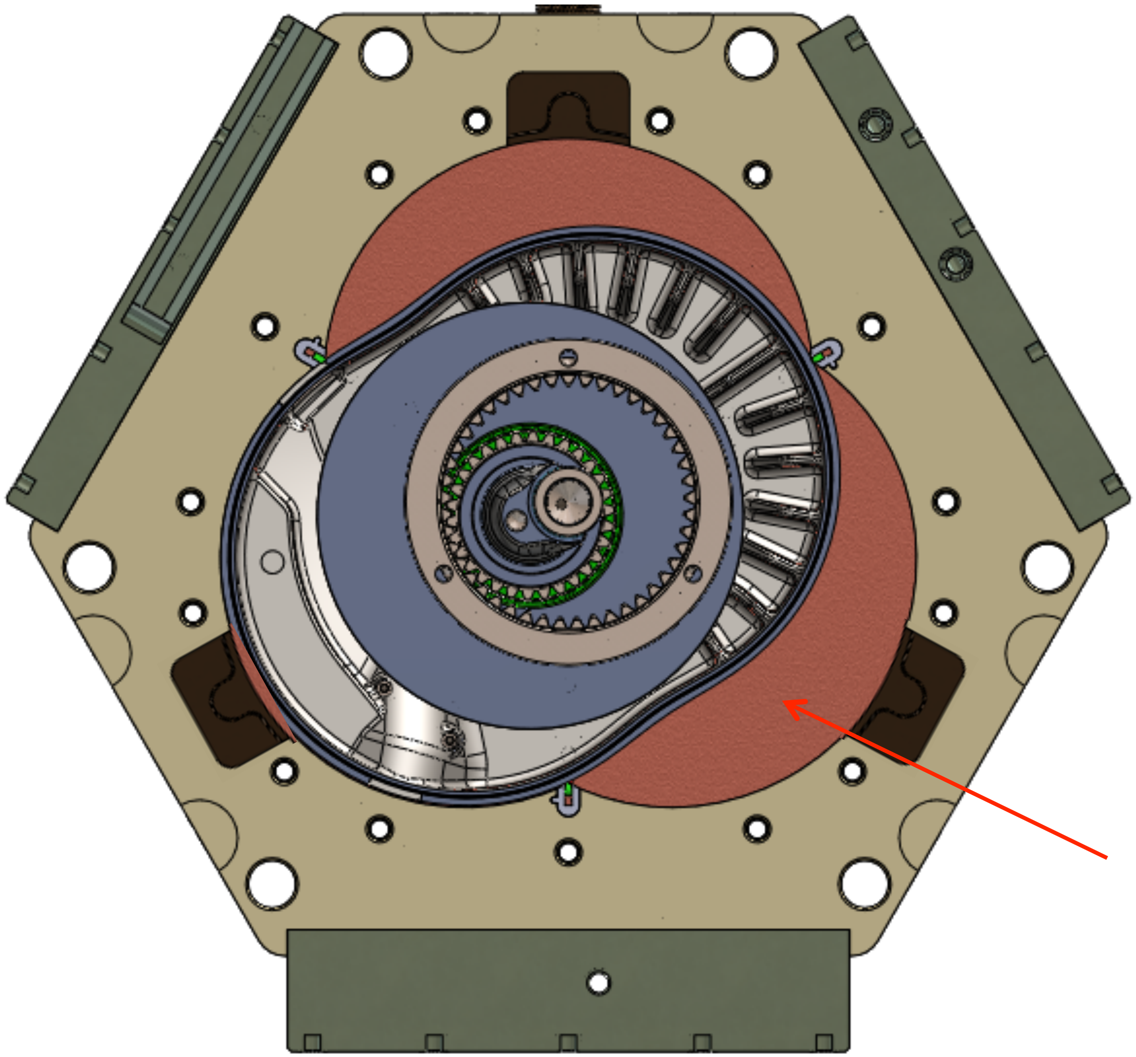
Expansion (power) stroke

440 degrees



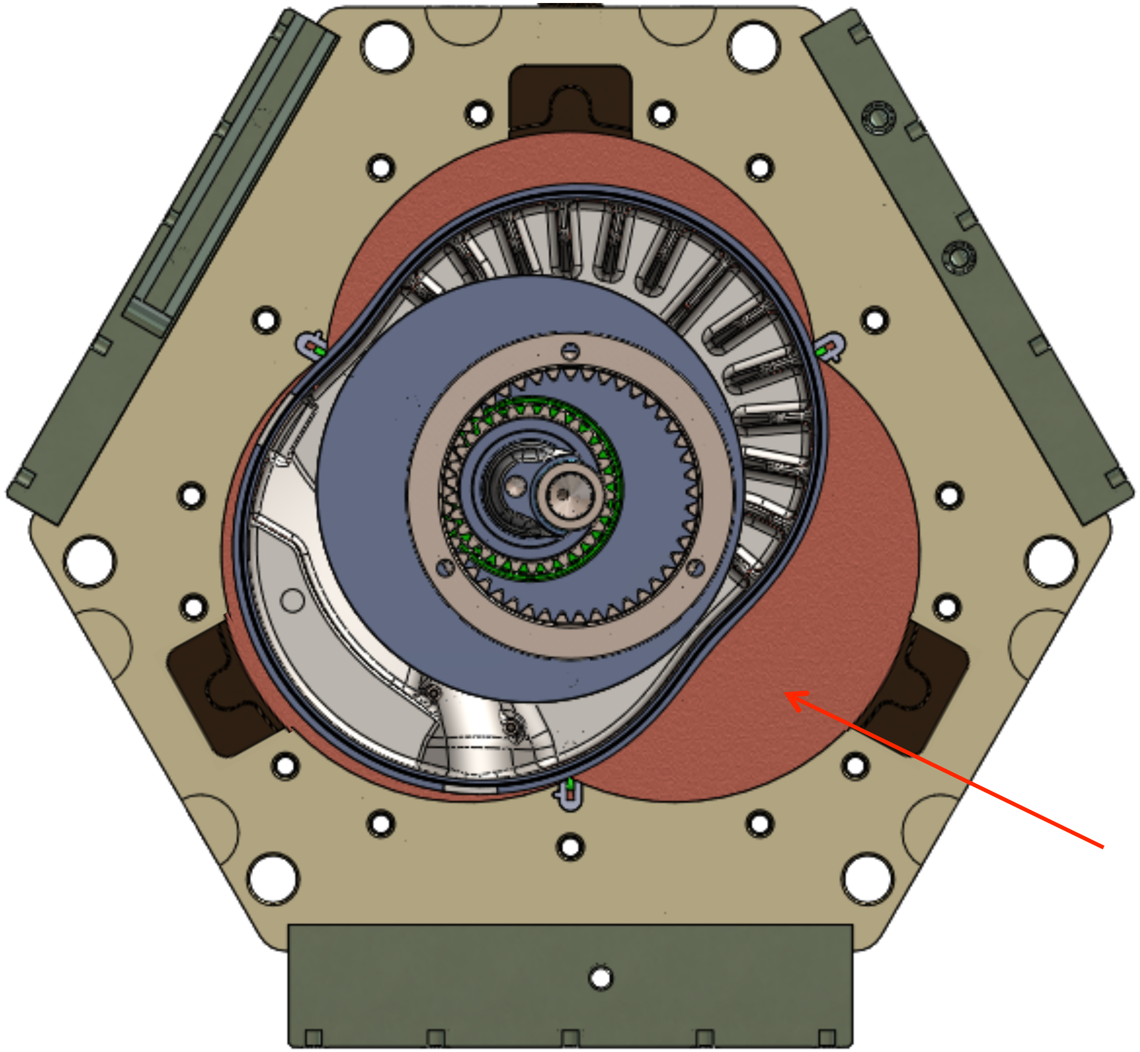
Expansion
(power) stroke

480 degrees



Expansion (power) stroke

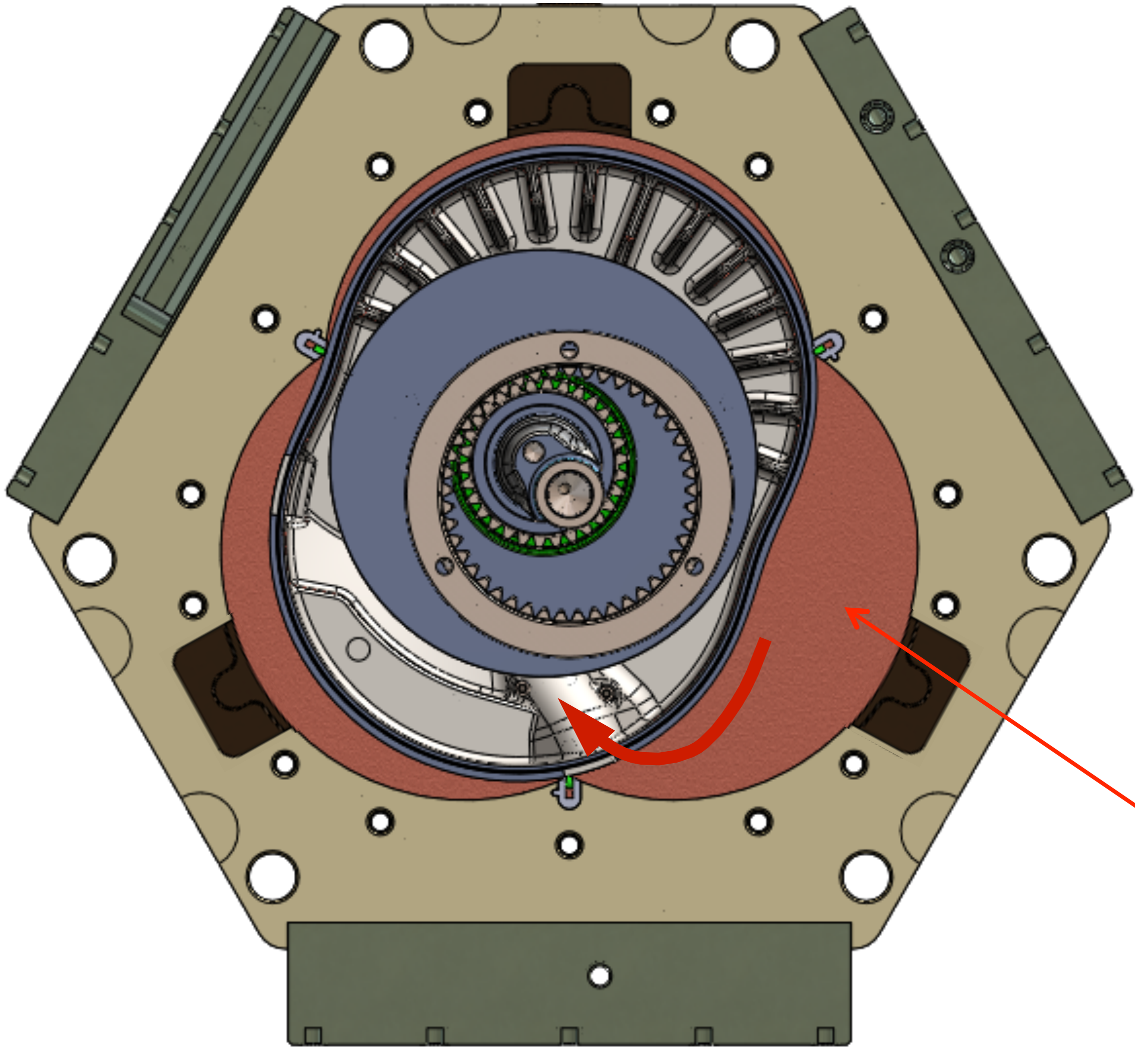
520 degrees



Expansion (power) stroke

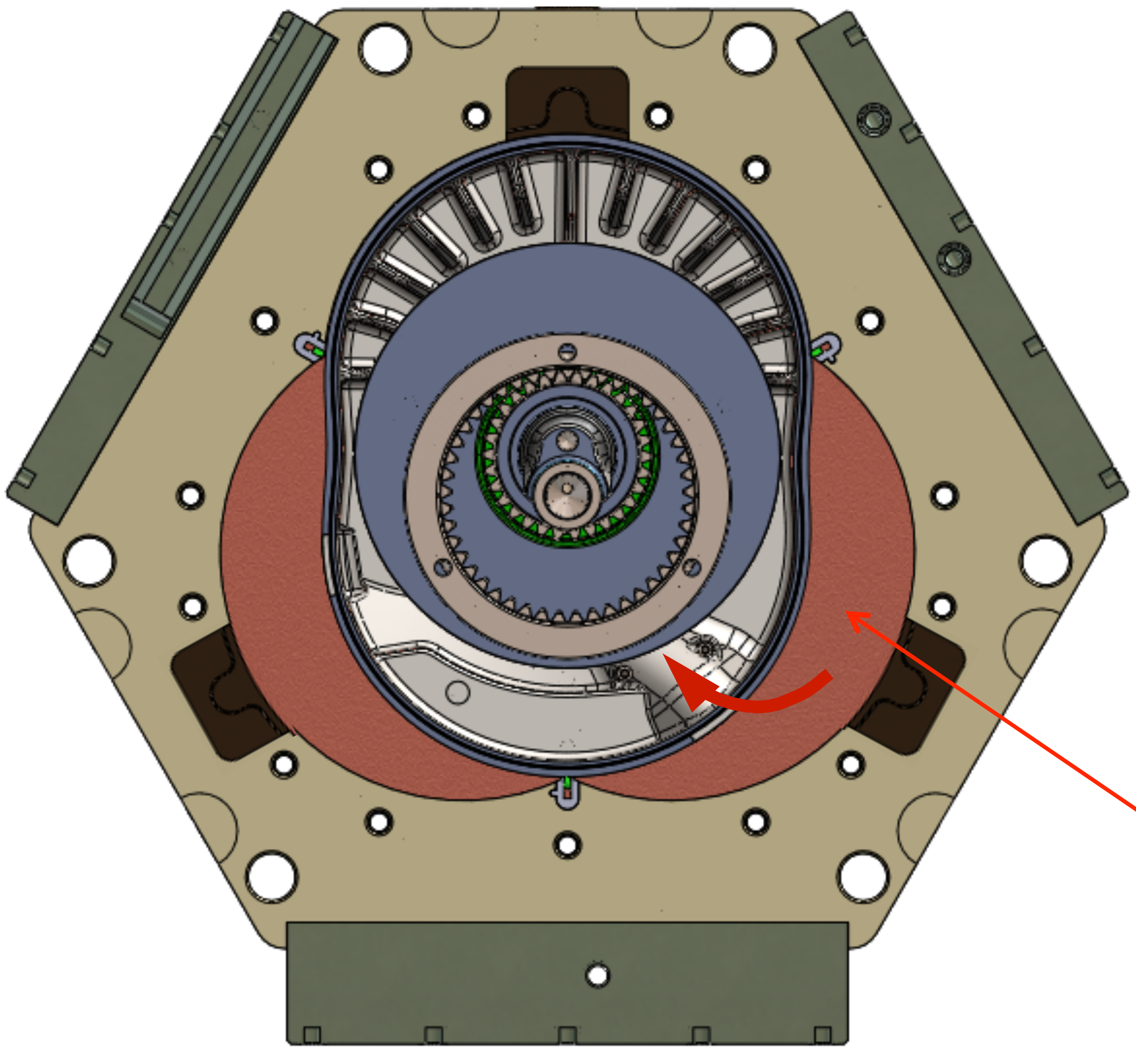
560 degrees

LiquidPiston



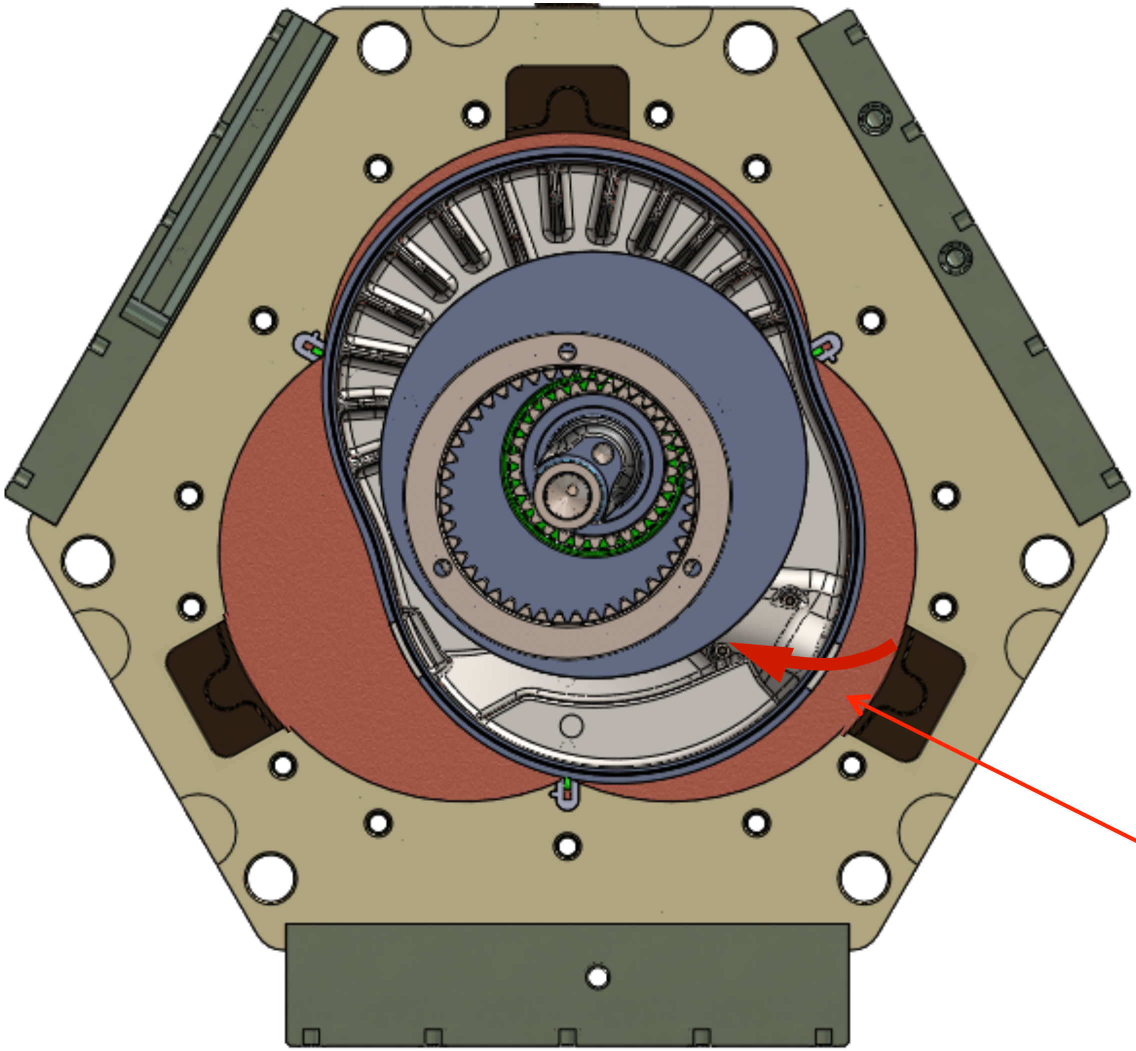
Exhaust Stroke

600 degrees



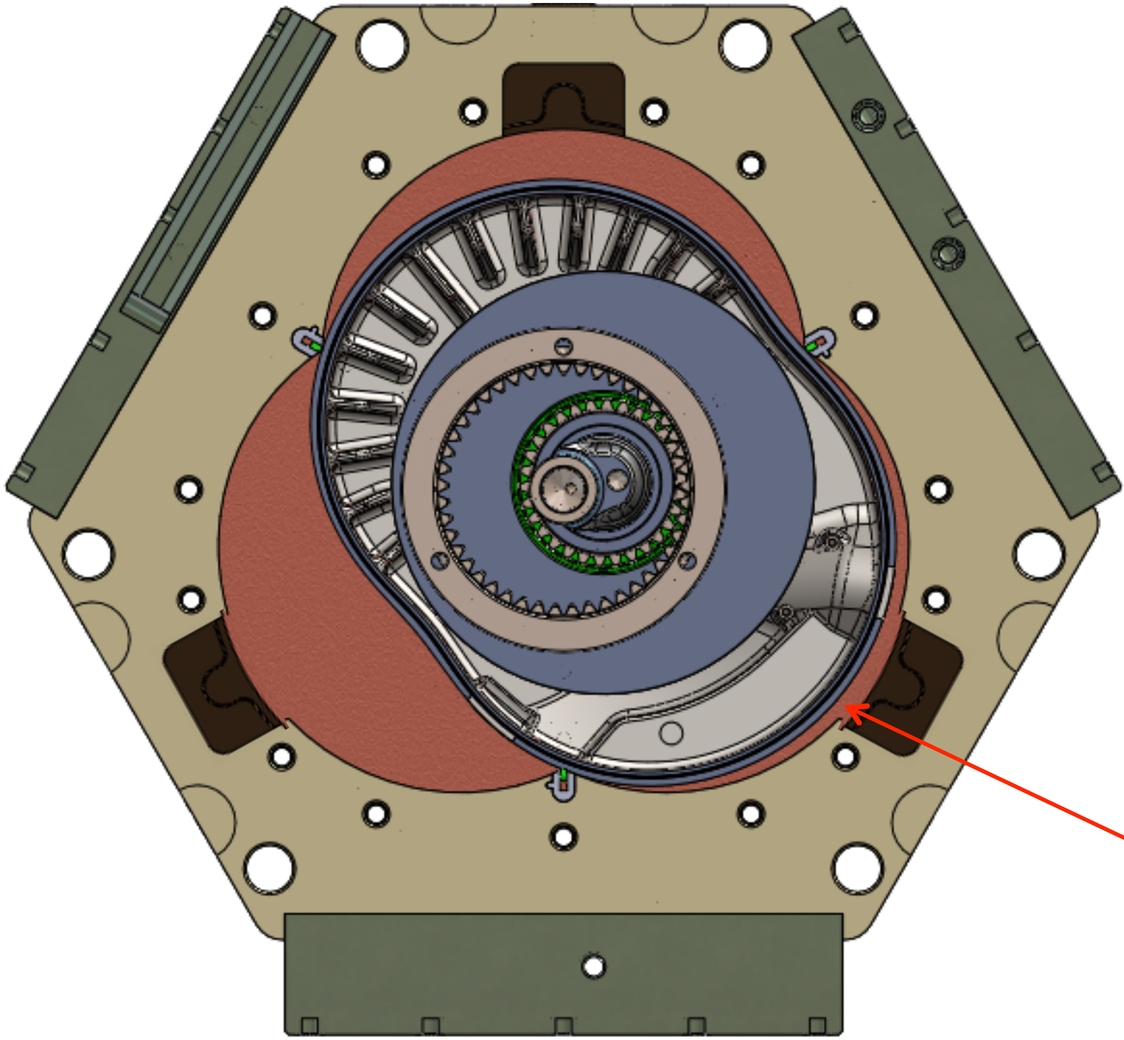
Exhaust
Stroke

640 degrees



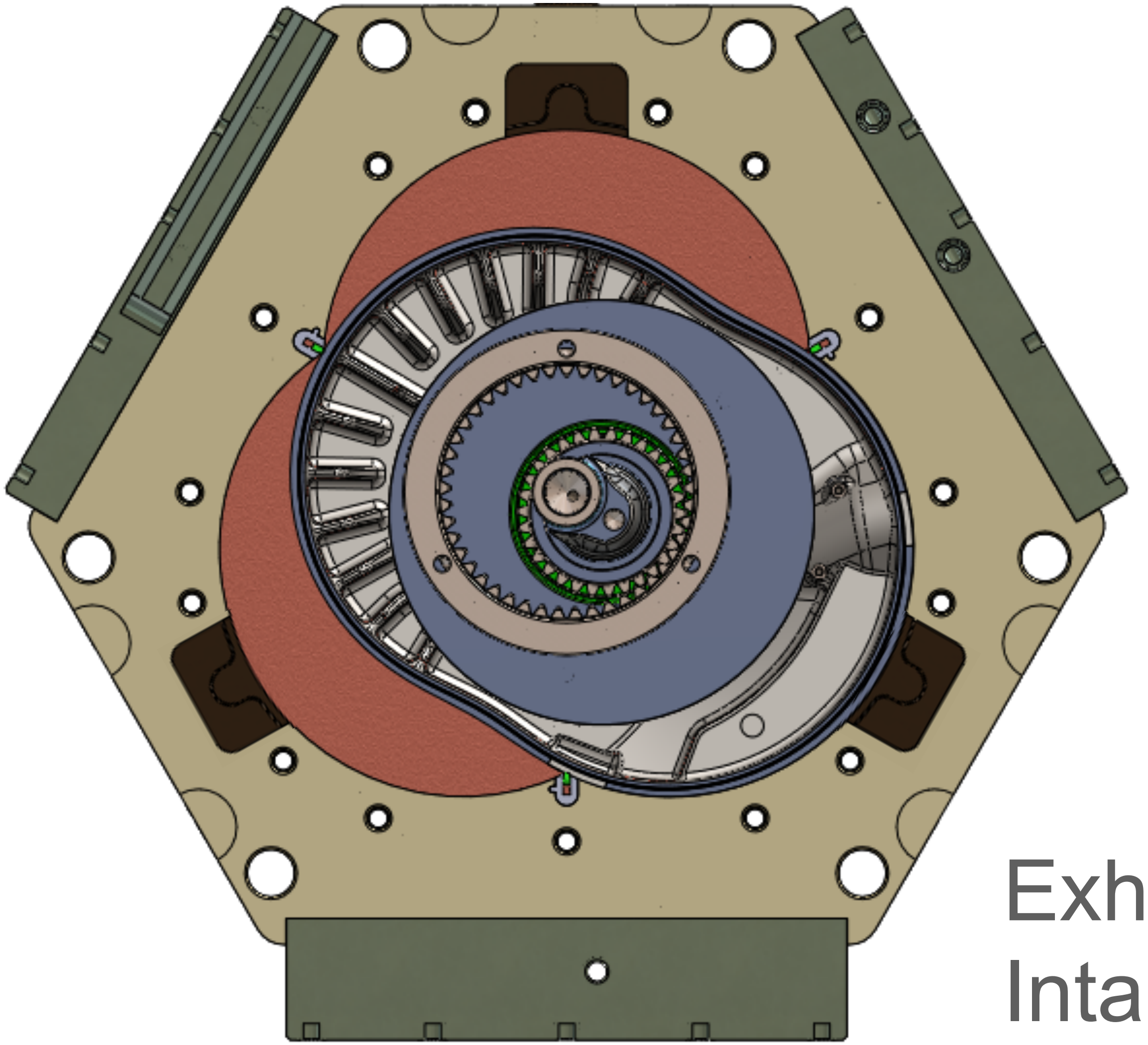
Exhaust Stroke

680 degrees



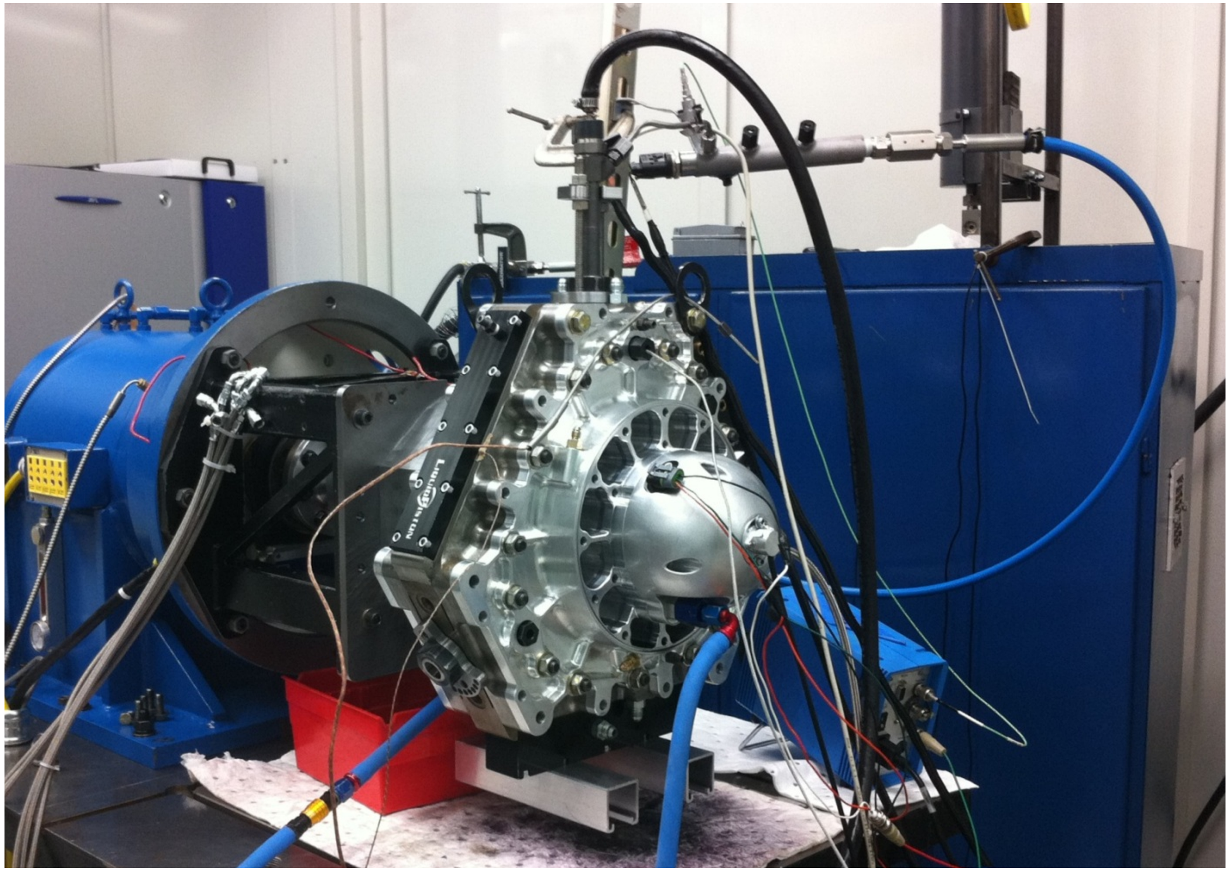
Exhaust
Stroke

720 degrees



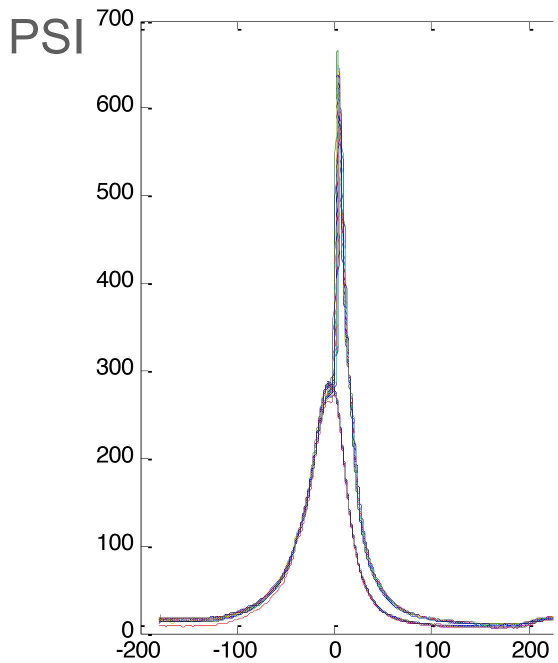
Exhaust Completes
Intake Starts

Status: X1 Engine on Dyno, firing



70 HP X1 engine prototype on Dyno

Firing and motoring data



Status

- Alpha (X1) prototype is undergoing testing in-house
- Beta (X2) prototype engine available Q1 2013
  - 40 HP
  - 35% efficiency (better than today's 40-HP Diesel's)
  - Sufficient durability for testing
  - Clear path to competitive advantage: 10x reduction in size and weight, low noise, low vibration, simple to assemble, etc.
- Seeking strategic partners to test the engine in their applications
- LPI expects to raise additional financing in Q1 2013
  - Measure and address concerns with emissions and durability
  - Pre-production prototype for EPA certification by Q4 2014

Long-Term Potential Benefits

- 50% part-load efficiency (3x higher efficiency)
  - 1/3 fuel, or 3x range
- 2 HP / Lbs (10x higher than Diesel)
  - Additional fuel savings and payload increases for mobile applications
- Multi-fuel capability
- NVH – quiet and vibration free
- Simple assembly – few parts to maintain
- Cooling with internal air charge; no external cooling systems, no muffler

Visit us at booth E204