

# What's Next?

An introduction to the

## Sturman Digital Engine

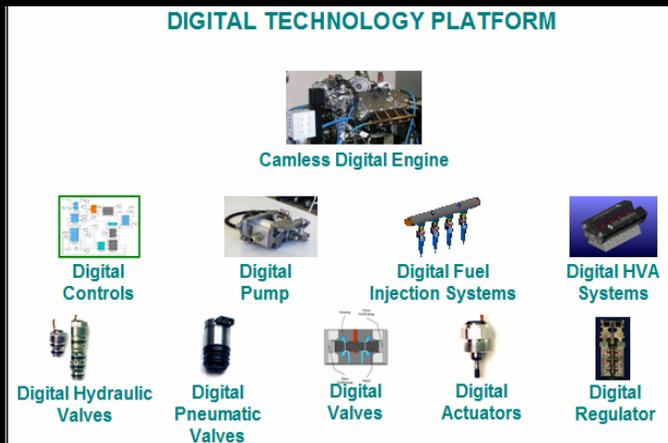
Presented By:  
Eddie Sturman  
Sturman Industries  
Woodland Park, CO



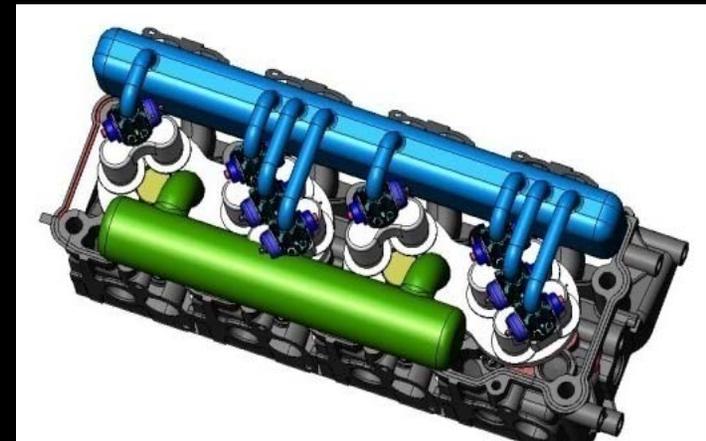
Sturman Industries, Woodland Park, CO

# IN THIS PRESENTATION...

## Digital Technology Platform

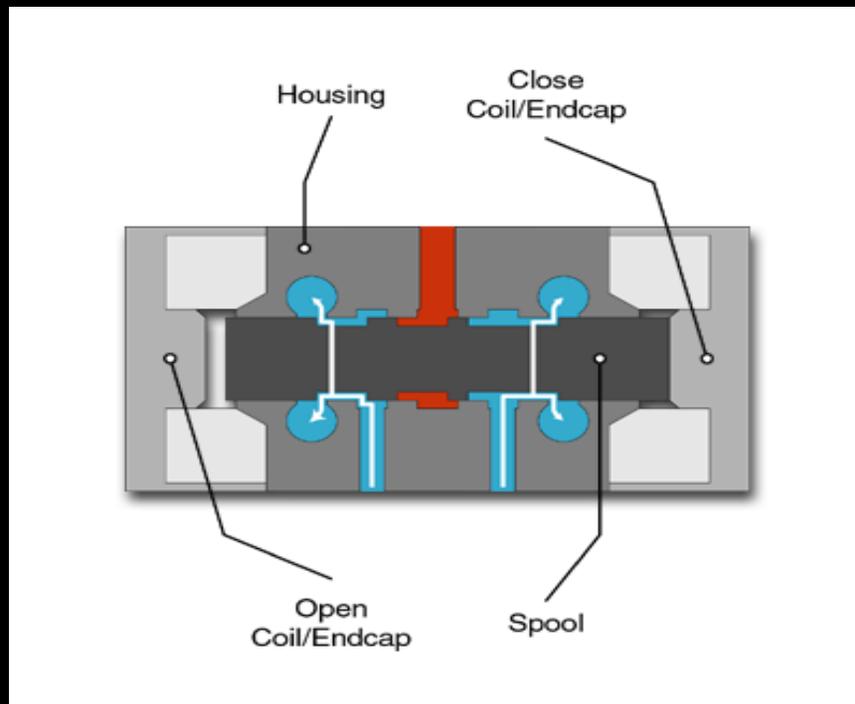


## Digital Engine & Sturman Cycle



## Development Status

# The Core Technology: STURMAN DIGITAL VALVE



*45 Years of Experience*

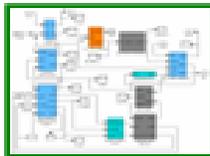
*Space Foundation  
Hall of Fame*

# PERFORMANCE ENABLING Extremely fast, small & intelligent

## DIGITAL TECHNOLOGY PLATFORM



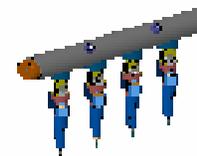
Camless Digital Engine



Digital Controls



Digital Pump



Digital Fuel Injection Systems



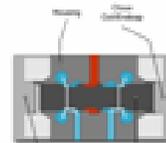
Digital HVA Systems



Digital Hydraulic Valves



Digital Pneumatic Valves



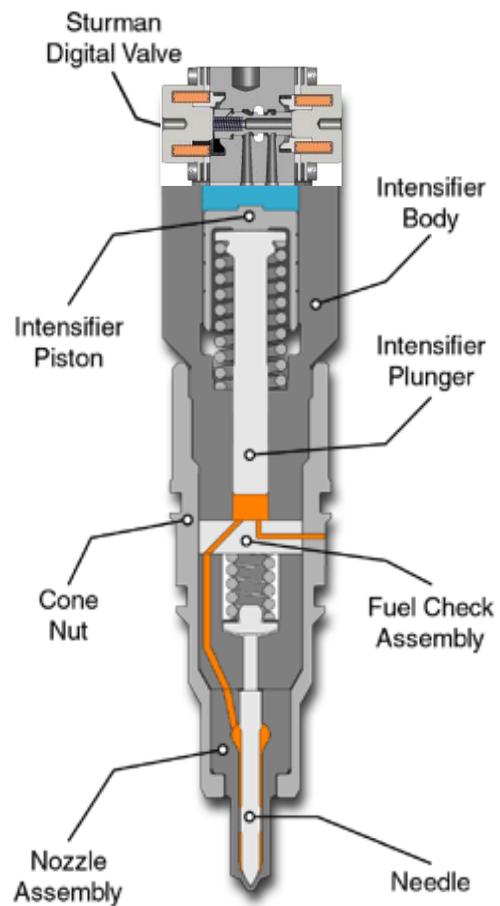
Digital Valves



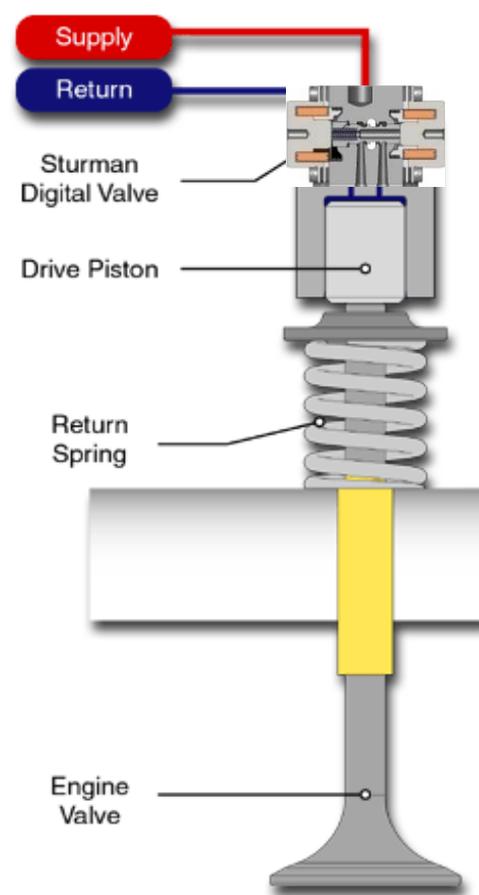
Digital Actuators



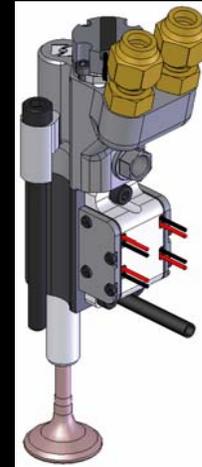
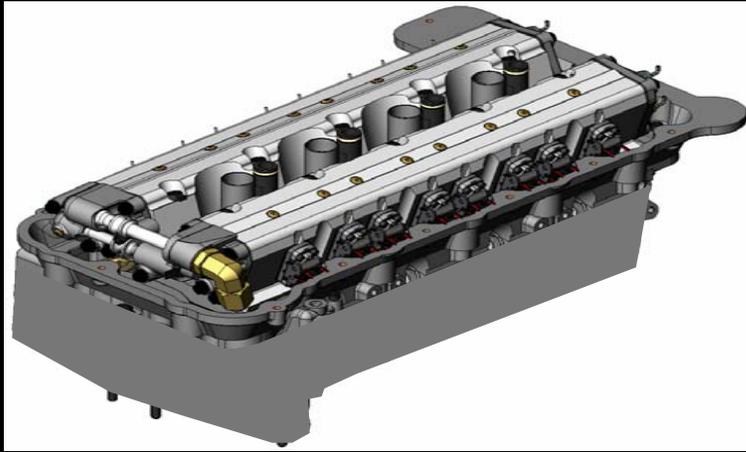
Digital Regulator



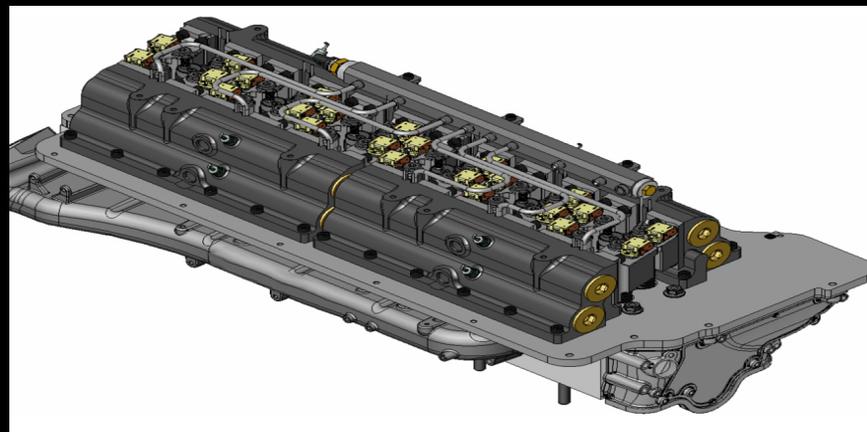
Fuel Injector



HVA



The new Digital Engine  
Builds on past experience  
From Delivery of 17 HVA systems  
To customers around the world



The Digital Engine applies the experience of over 15 years of diesel fuel injector development including a production launch for an OEM in 2002



## NEW DIGITAL INJECTOR

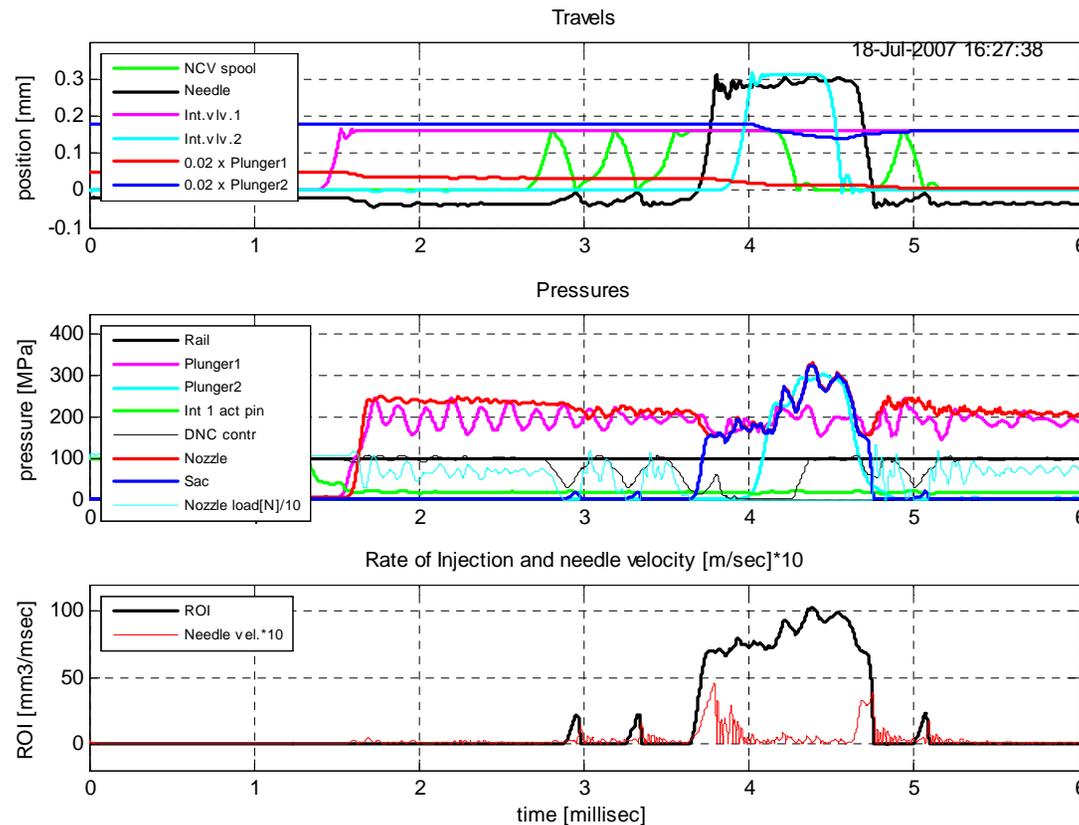
- 3000 bar demonstrate
- 3500 bar target
- Multi-Fuel Capable
- Rate Shaping – multiple events
- High Safety
- Small Quantity Control



# Digital Injector Simulation

Rail pressure 100 MPa

Pilots & start of main and post with IR = 2.0, end of main with IR = 3.3



Quantities:

1.17 / 1.12 / 85.23 / 1.10 mm<sup>3</sup>

Dwells:

280 / 290 / 250 usec

Peak Sac Pressures:

18 / 19 / 326 / 20 MPa

Needle Open Velocities:

0.2 / 0.3 / 1.1 / 0.3 m/s

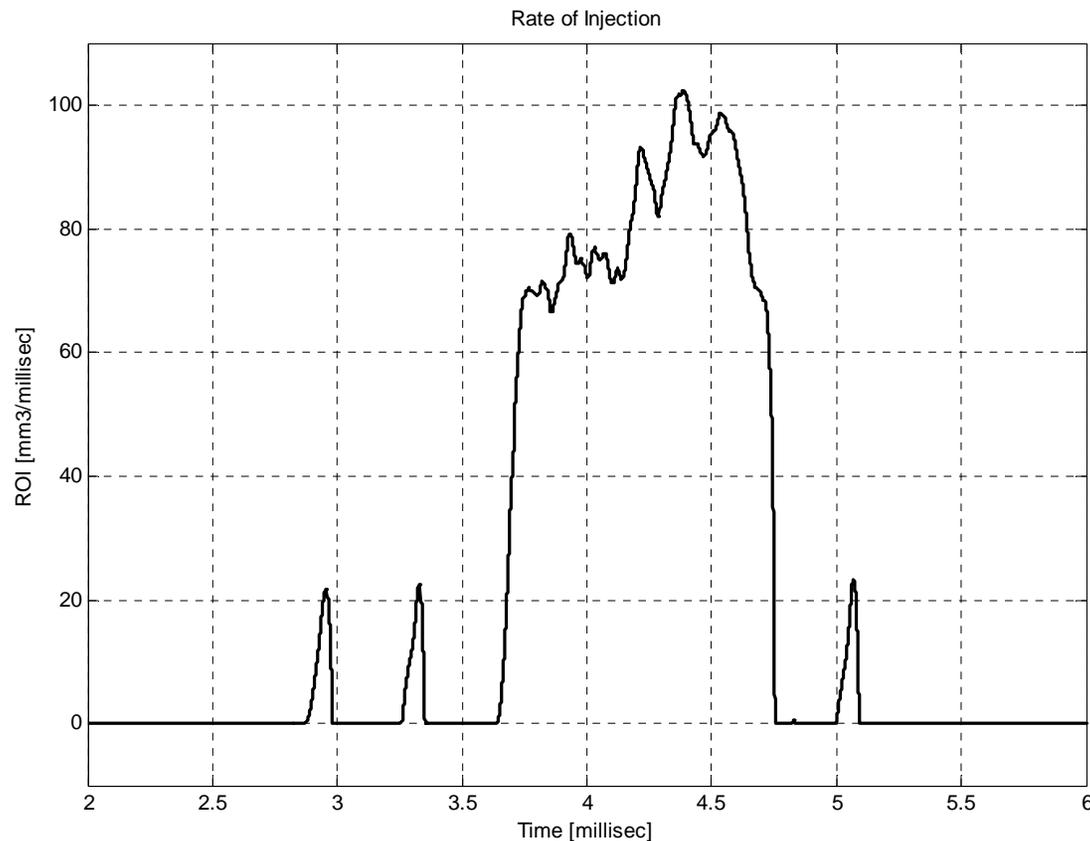
Needle Close Velocities:

0.6 / 0.8 / 3.6 / 0.8 m/s

# Digital Injector Simulation

Rail pressure 100 MPa

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# AIR & HYDRAULIC HYBRID ENGINE

(12) **United States Patent**  
**Sturman et al.**

(10) **Patent No.:** **US 6,415,749 B1**  
**(45) Date of Patent:** **Jul. 9, 2002**

(54) **POWER MODULE AND METHODS OF OPERATION**

(76) **Inventors:** **Oded E. Sturman**, One Innovation Way, Woodland Park, CO (US) 80863;  
**Richard J. Dunn**, 128 Valley Cir., Florissant, CO (US) 80816

(\*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) **Appl. No.:** **09/301,004**

(22) **Filed:** **Apr. 27, 1999**

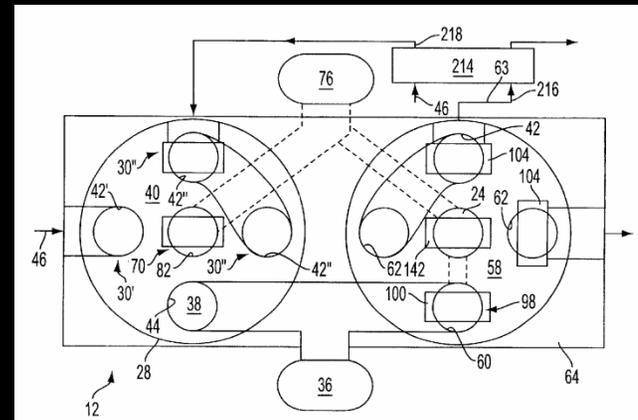
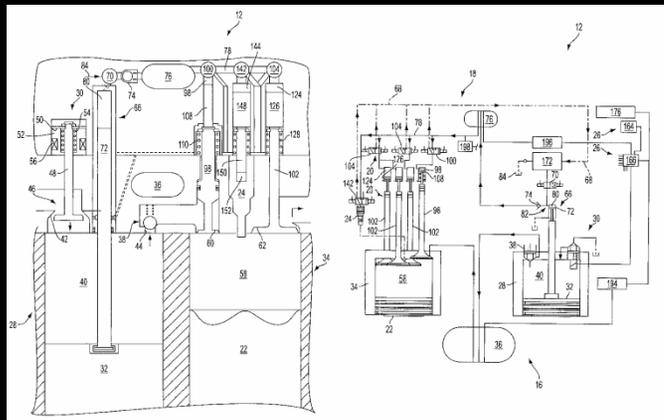
6,005,763 A	12/1999	North .....	361/154
6,012,644 A	1/2000	Sturman et al. ....	239/96
6,105,616 A	8/2000	Sturman et al. ....	137/625.65
6,109,284 A	8/2000	Johnson et al. ....	137/1
6,148,778 A	11/2000	Sturman .....	123/90.12
6,173,685 B1	1/2001	Sturman .....	123/90.12

## FOREIGN PATENT DOCUMENTS

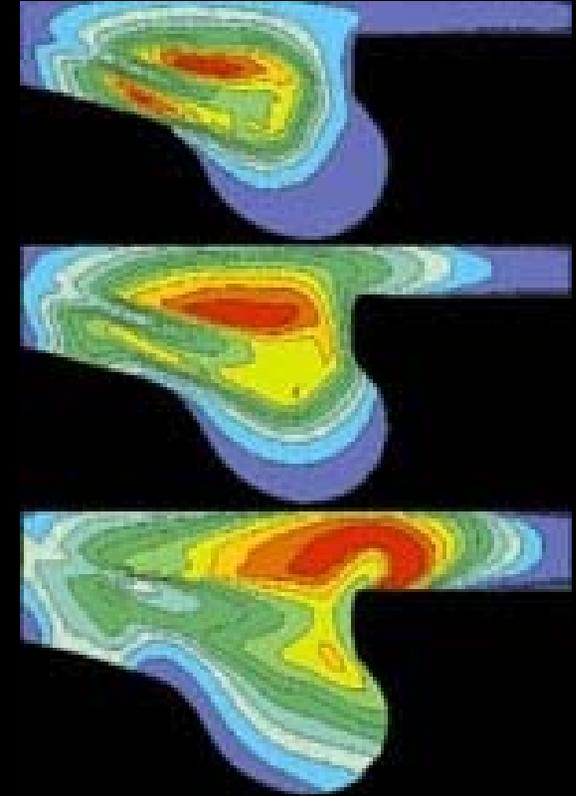
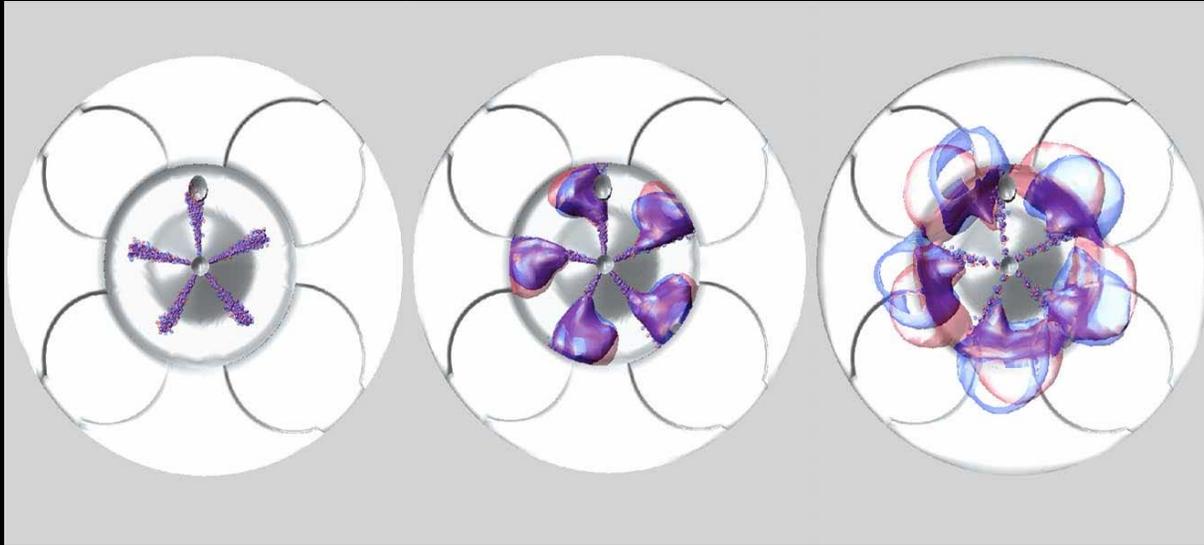
DE	37 27 335 A1	2/1988	..... F02B/71/00
GB	941453	11/1963	
WO	WO 98/11334 A	3/1998	

\* cited by examiner

*Primary Examiner*—Willis R. Wolfe  
*Assistant Examiner*—Hai Huynh



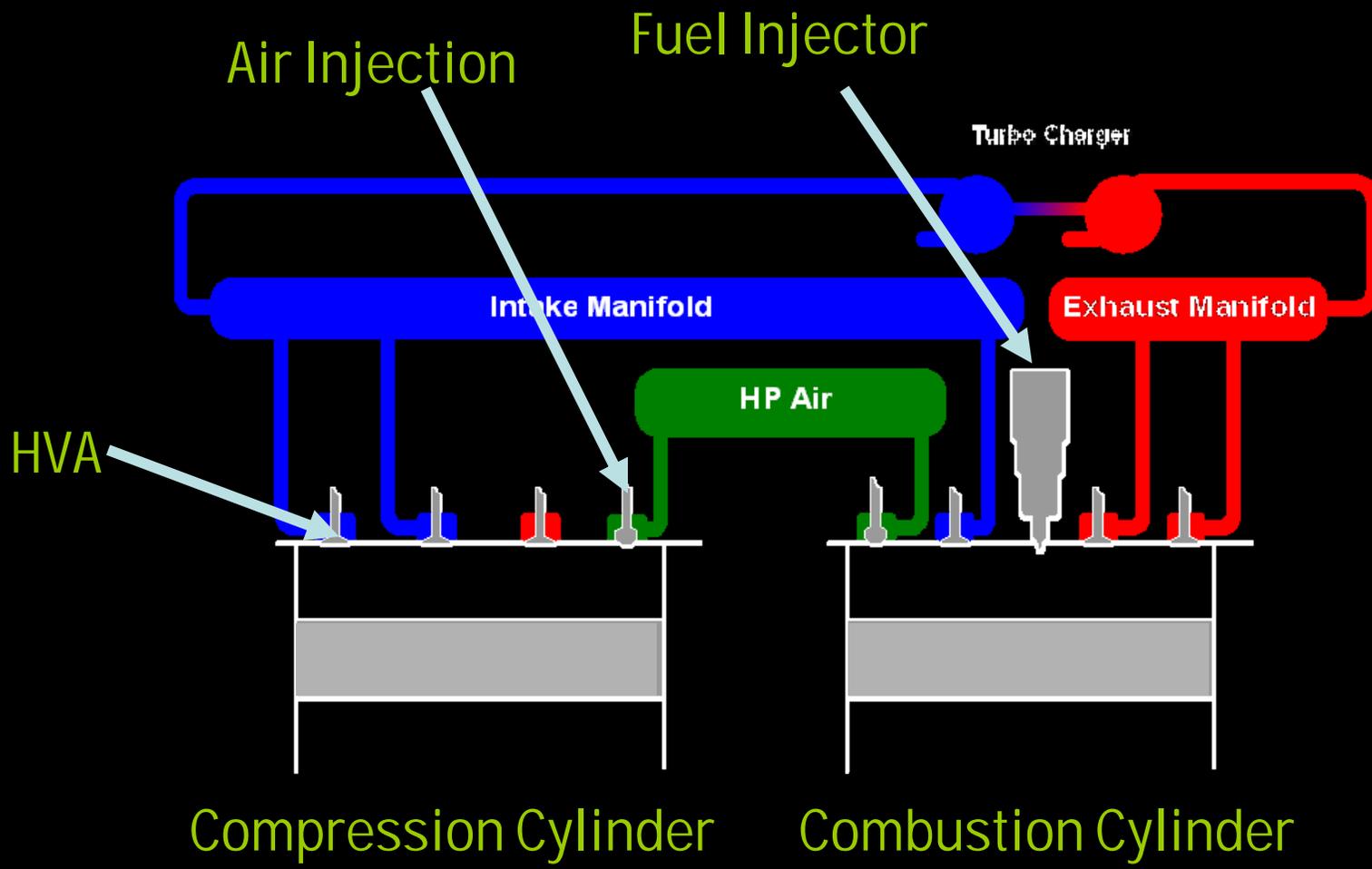
The Digital Engine  
enables complete control  
of fuel and air  
throughout  
ANY combustion cycle



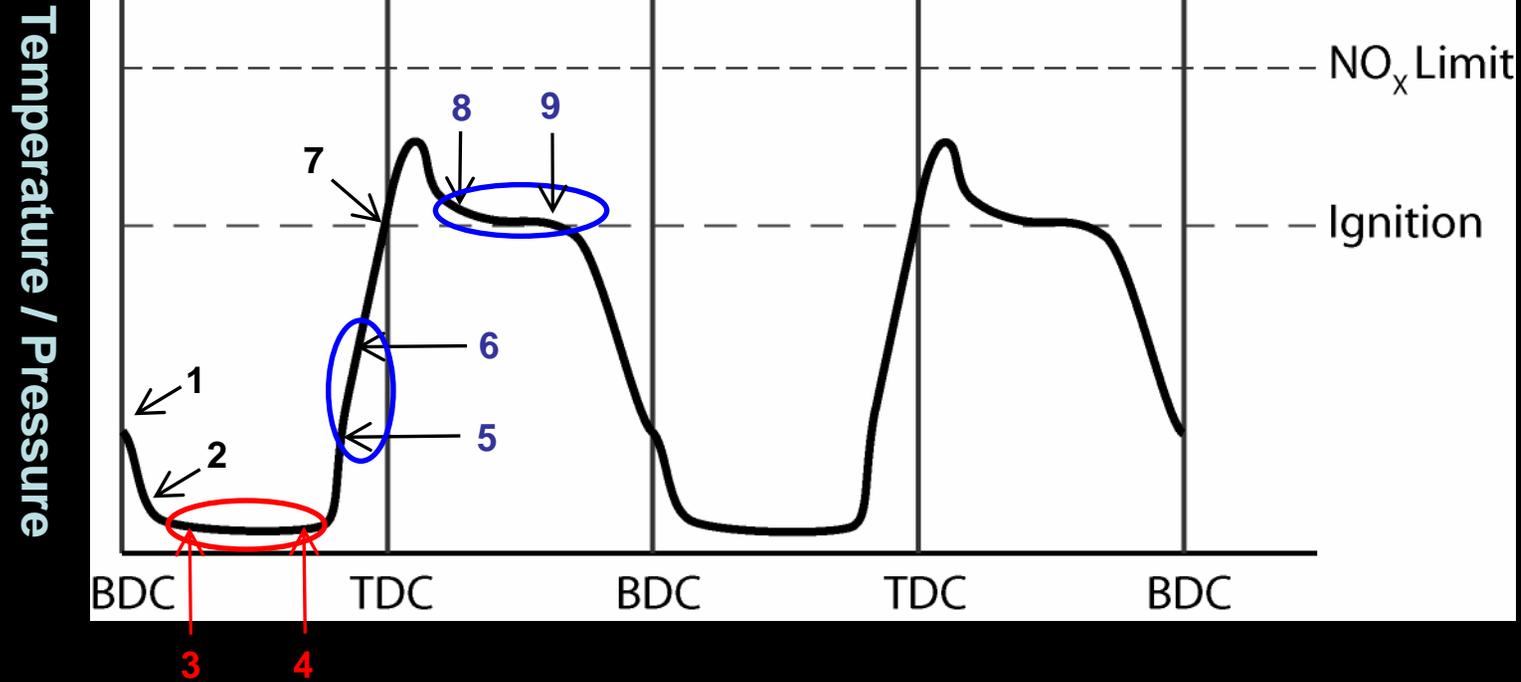
## COMPLETE CONTROL OF THE COMBUSTION PROCESS

- Economical
- Powerful
- Efficient
- Clean

Photos from <http://www.avl.com>



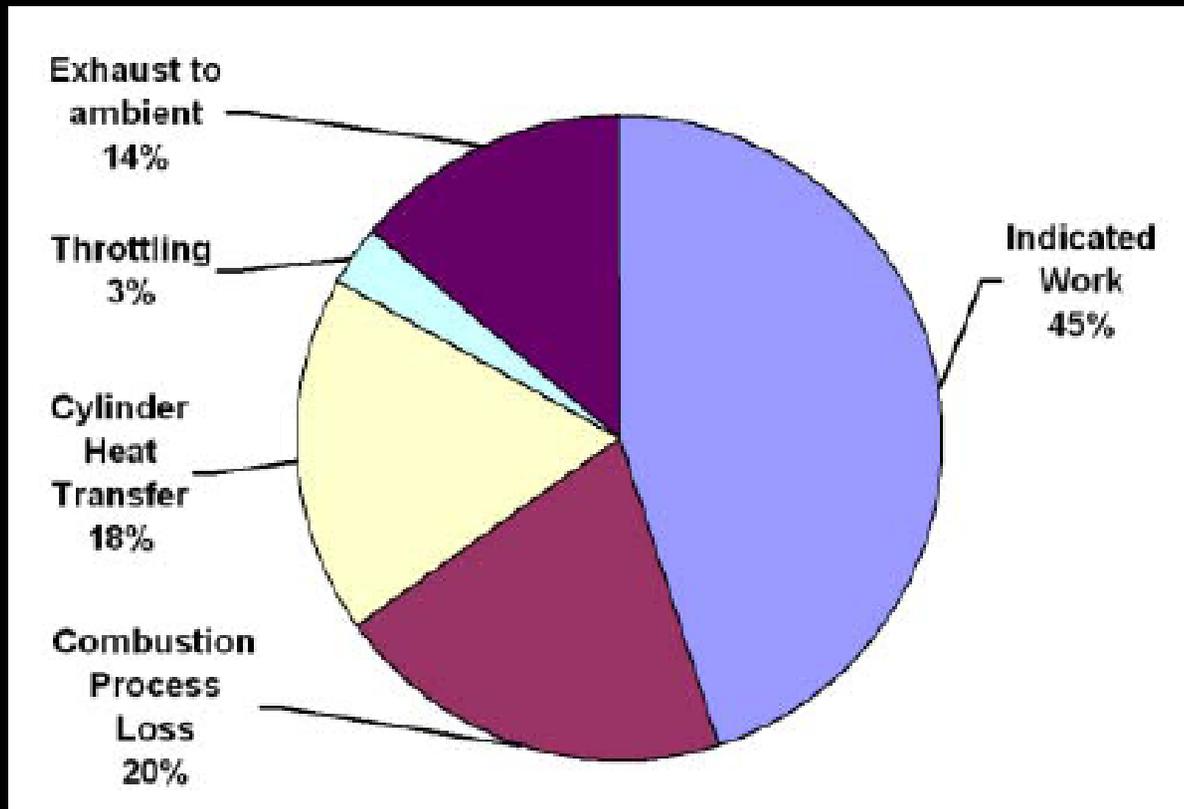
Digital Engine Schematic



1. Exhaust Valve Open (E.V.O)
2. E.V.C.
3. Fuel Injection Starts
4. Fuel Injection ends
5. Air Injection Opens
6. Air Injection Closes
7. Ignition
8. Air Injection Opens
9. Air Injection Closes

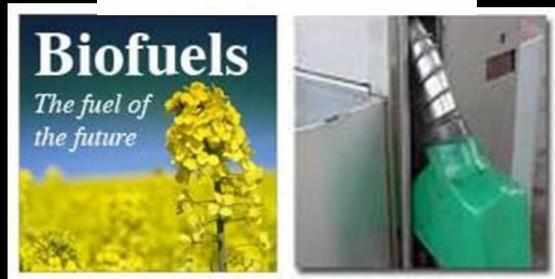
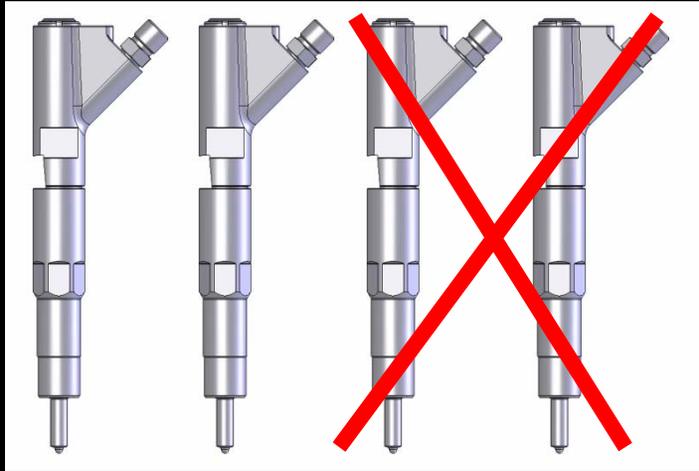


Because the Sturman Cycle atomizes fuel thermally rather than mechanically, it is compatible with almost any fuel type.



By implementing a more reversible combustion cycle, the Digital Engine can potentially gain back some of the efficiency losses inherent to a flame-front combustion process.

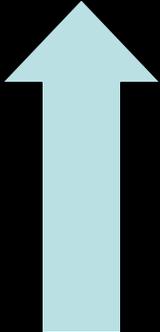
# Inherent benefits of the Digital Engine:



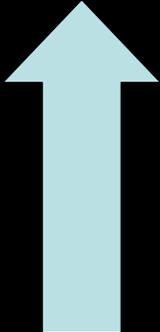
Stroke = 2, 4, 6, 8 ...

# Potential benefits of the Digital Engine running the Sturman Cycle include:

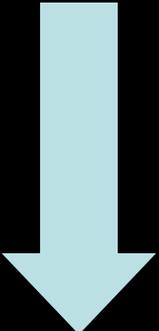
Power



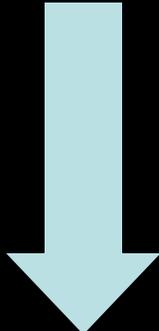
Efficiency



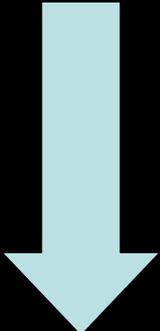
NO<sub>x</sub>, PM, CO<sub>2</sub>



Cost



Engine Size



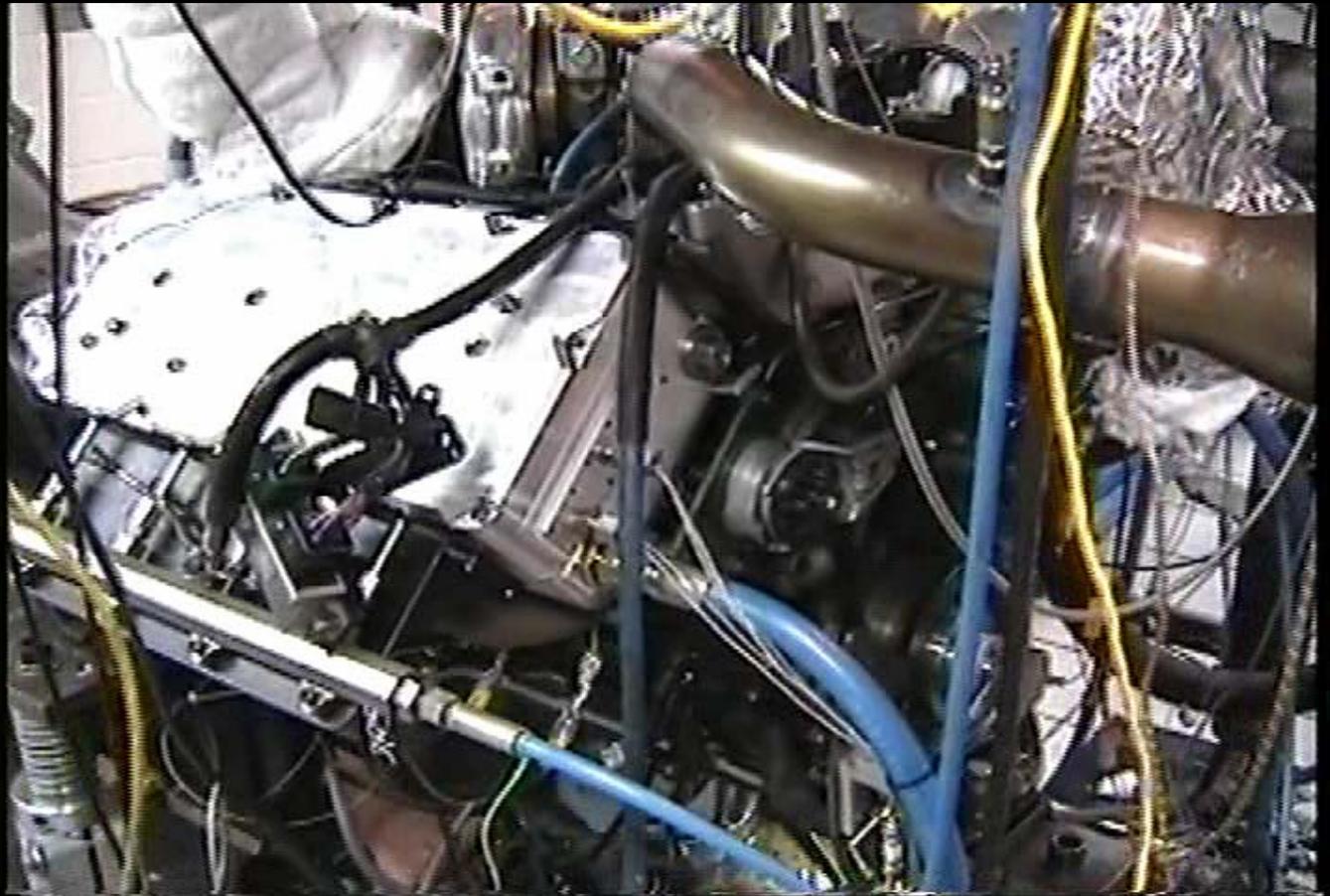
Development

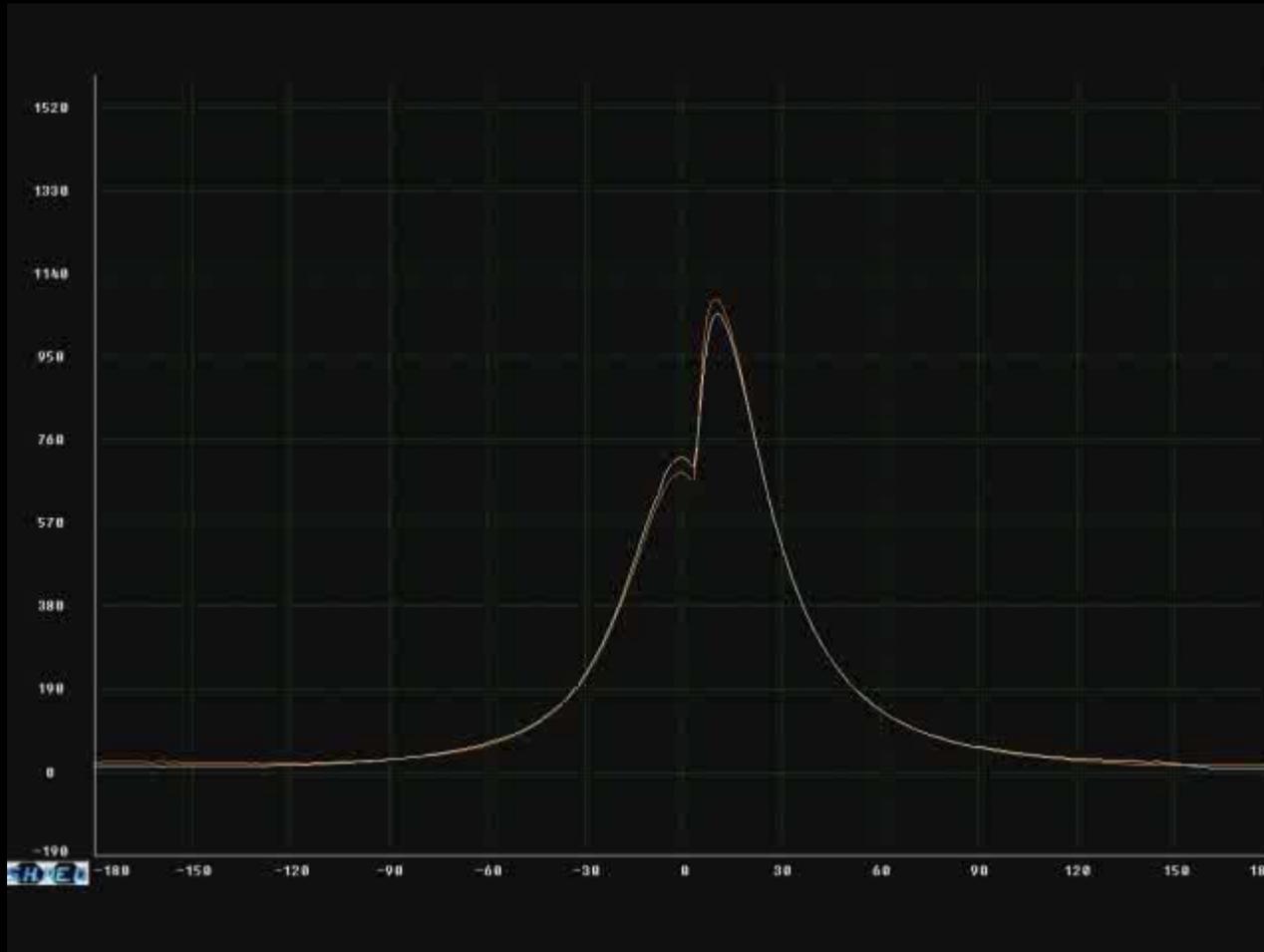


Progress

Single  
cylinder

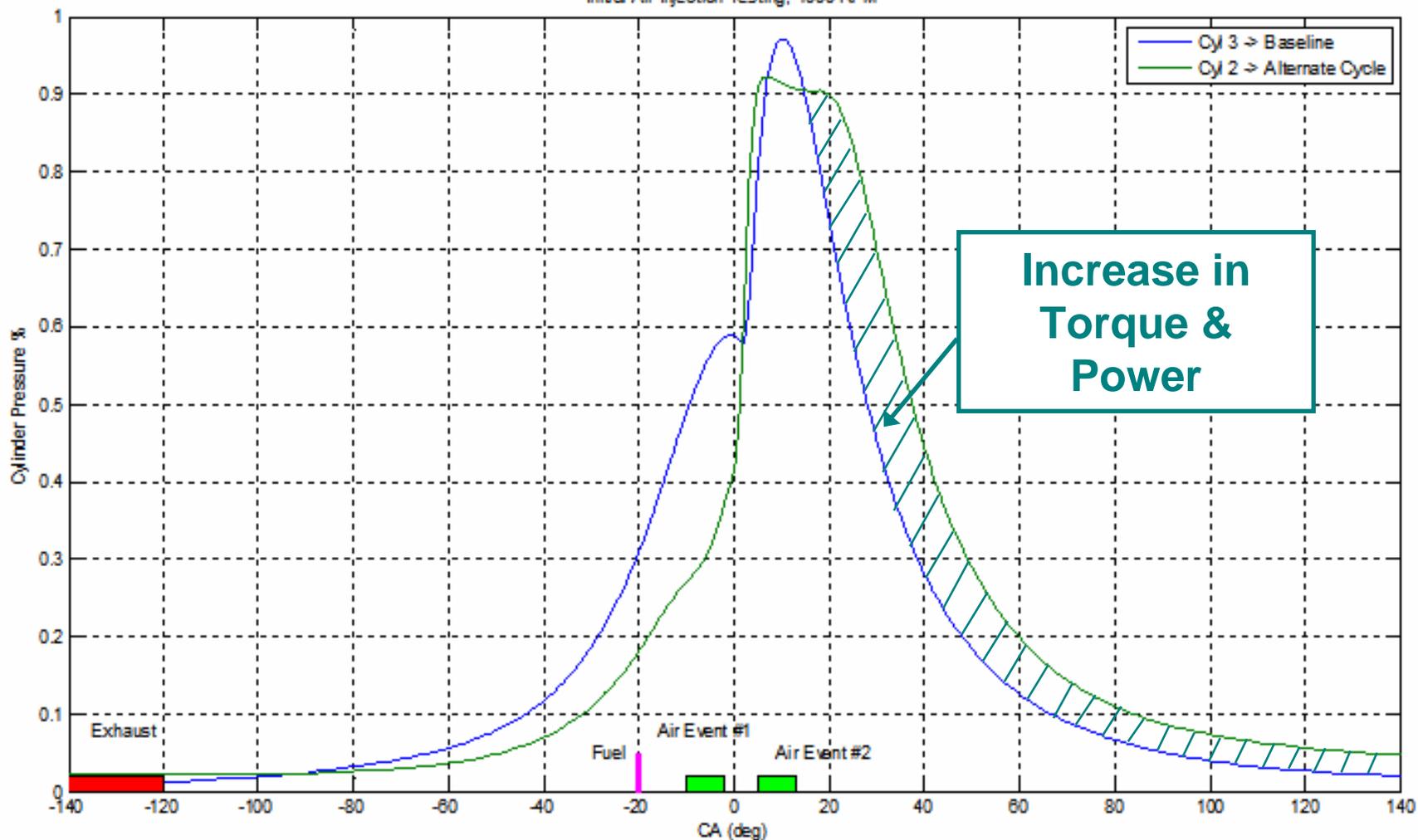
External air  
source



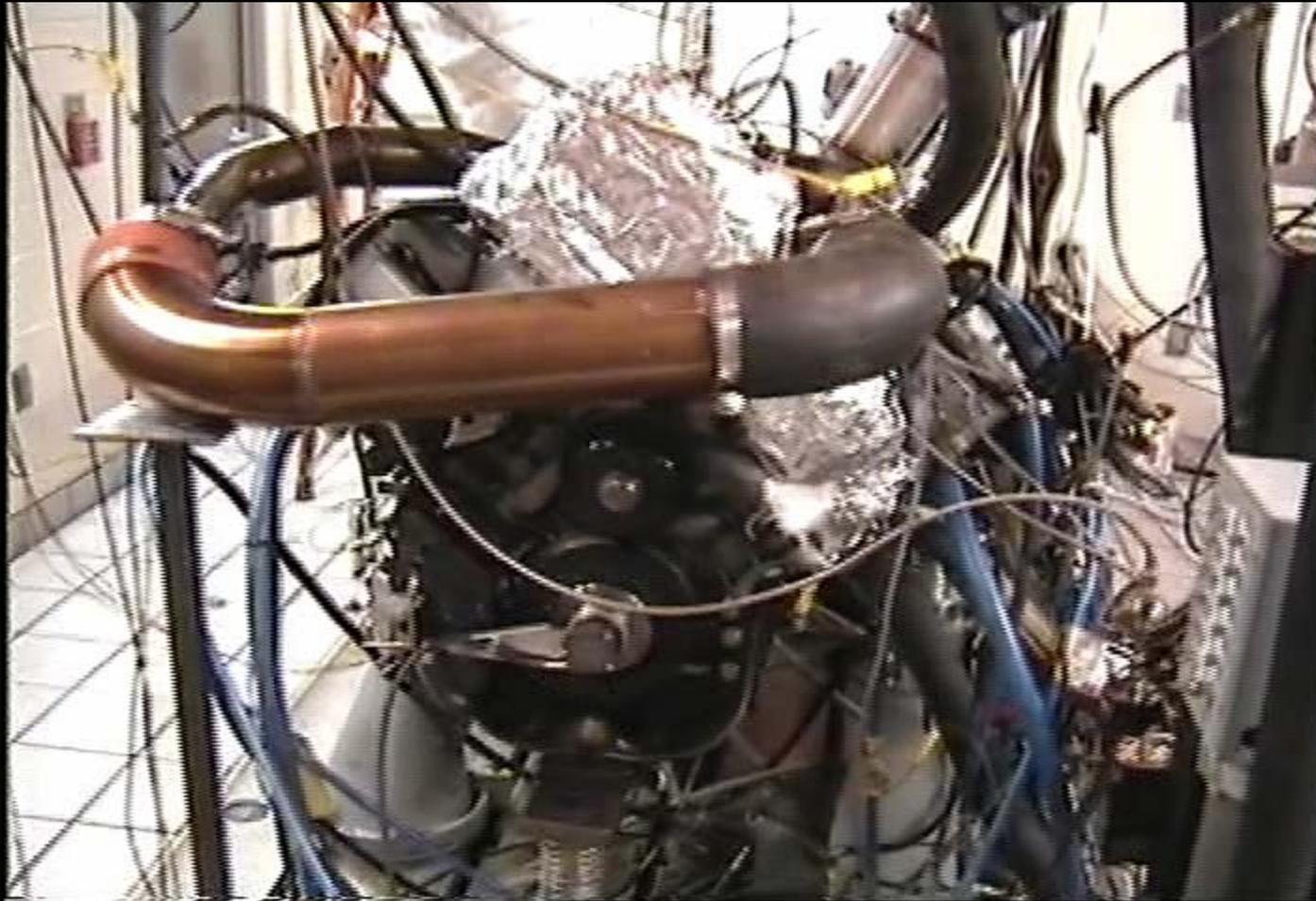


This is a video of cylinder pressure traces in real-time during dyno testing of the Digital Engine.

Initial Air Injection Testing; 1000 RPM



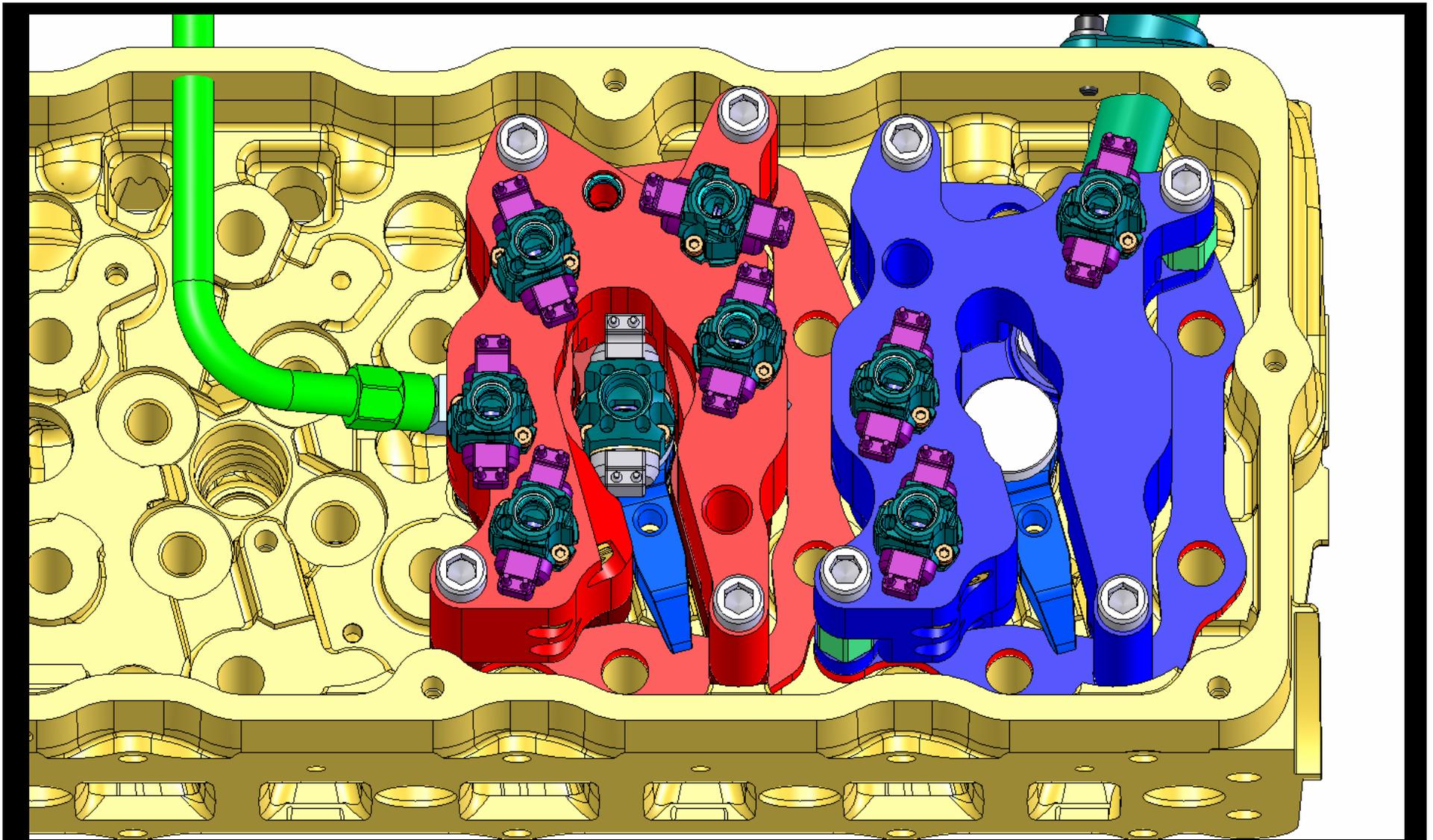
Single cylinder testing has been successful!



The next step is a dual cylinder design.

The dual cylinder design adds a compressor cylinder to the system to replace the external air source.





The goal of the dual cylinder testing is to collect data showing improved emissions, efficiency, and performance.

# Next Steps:



JSAE 20077207  
SAE 2007-01-1930

# US 2010 Emissions Capable Camless Heavy-Duty On-Highway Natural Gas Engine

"The NO<sub>x</sub> emissions on the 13-mode test are 0.005 g/kW-hr., which are well below the target of 0.27 g/kW-hr."

James P. Chiu  
Southwest Research Institute

Joshua D. Taylor  
National Renewable Energy Laboratory

"The Sturman HVA system enables full use of high compression ratio pistons, where full compression ratio can be used at light loads and a reduced effective compression ratio can be used at high loads to avoid knock."

Chun Tai  
Todd Reppert  
Volvo Powertrain North America

Lane Christensen  
Sturman Industries, Inc.

"The Sturman system enables throttleless operation, using early intake valve closing to control load."

Production Scheduled  
Summer 2013