# *Two-Stroke SI Engine with Direct Injection of Air-Saturated Fuel*

***By:***
***Yoav Heichal***
***Aviel Aloni***

***January 2014***

Aeronautics

Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Center for Research in Energy Engineering and Environmental Conservation
Internal Combustion Engine Laboratory

# Introduction

- *Aeronautics Defense Systems Ltd.* is the manufacturer of the *Aerostar* tactical UAV system and the *Orbiter* family of mini-UAV systems
- Aeronautics subsidiary, *Zanzoterra Engines s.r.l.* is producing line of two-strokes UAV engines
- *Aeronautics* is on the verge of production of new line of modern two- strokes engine with high performance.

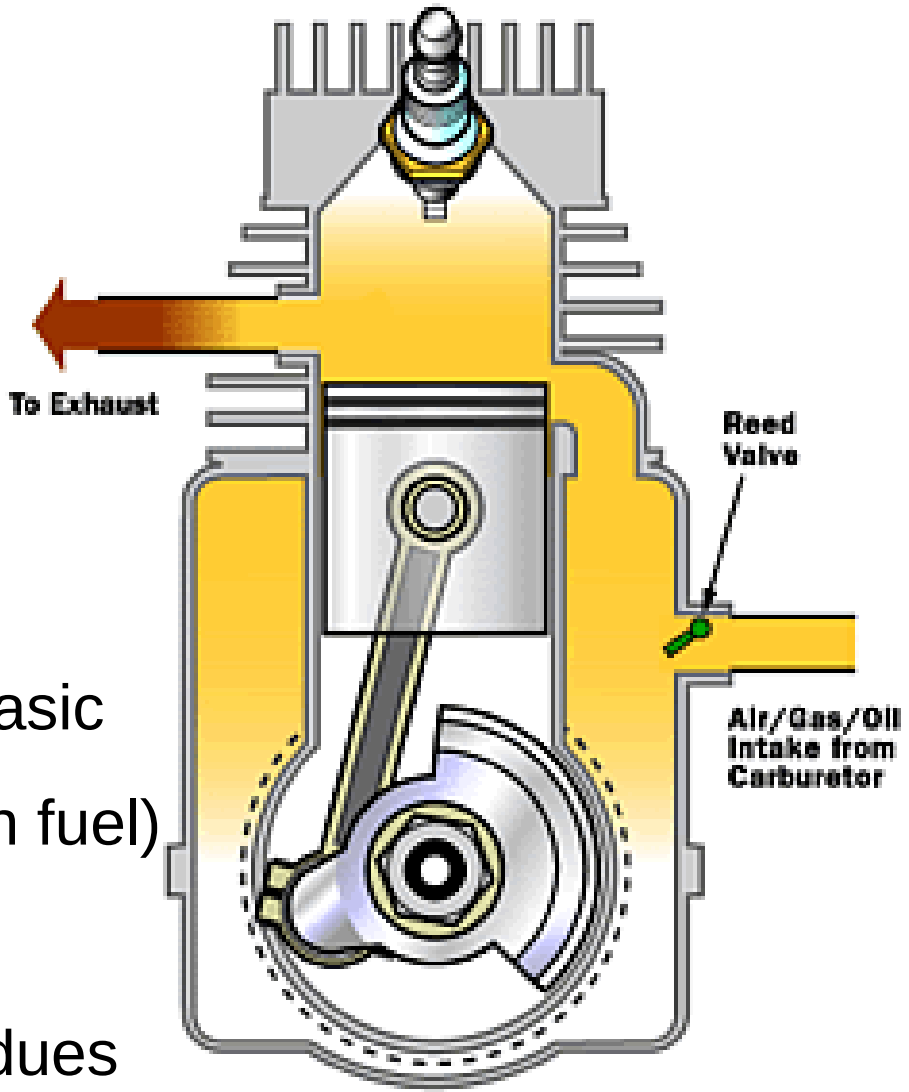
# Two –Stroke Engines

Advantages:

- Simple and light engine
- High-power to weight ratio
- Cost effective engine

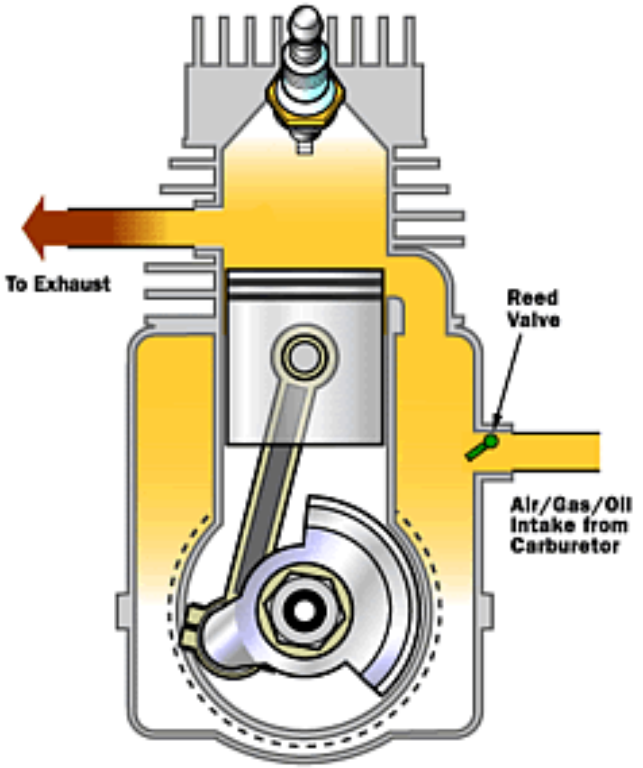
Disadvantages:

- High specific fuel consumption
- Shorter engine life due to very basic lubrication system (oil is mixed in fuel)
- Very high HC emissions
- Oil burns with fuel – carbon residues



# Two –Stroke Engines

- Two-strokes engines will vanish from our world unless new fuel and lubrication systems configurations will be introduced in their design
  - Fuel system must inject the fuel directly into the combustion chamber
  - Lubrication system must be based on separation of oil from fuel



# Two –Stroke Engines and UAV Systems

- Introduction of direct injection (DI) systems to reduce SFC
- Introduction of separate lubrication systems
- Usage of heavy fuels
  - Military logistics consideration- uniform fuel to all combat vehicles
  - High boiling point allows simple fuel systems for high altitude operation
  - High density fuel, smaller volume of aircraft fuel tanks
  - Less flammable fuel, allows operation of UAS onboard NAVY vessels
- Usage of spark ignition systems (SI) in order to allow engine structure to maintain its light weight construction

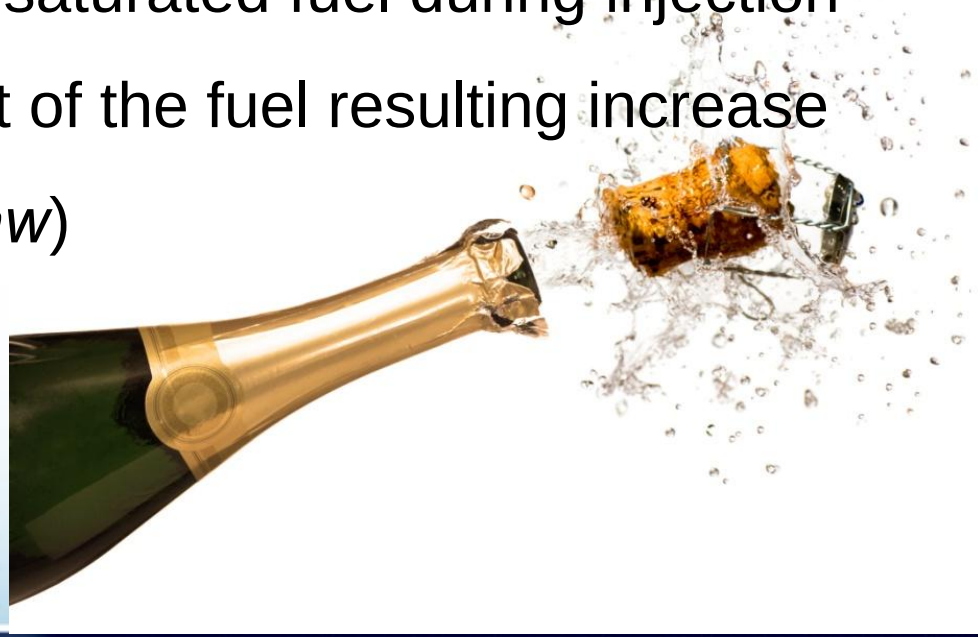
# Challenges in Implementation of DI ignited by Spark

- Pressure in the combustion chamber is high at the time of injection, requiring high pressure pumps (~100 bar)
- Time to achieve homogenous mixture of fuel and air is short
- Air-fuel mixture around the spark source (spark plug tip) has to be close to stoichiometric value
- Cold engine start is difficult due to low rate evaporation of fuel

➢ *The key for successful implementation of DI+SI engine is perfect atomization of the fuel before combustion process starts*

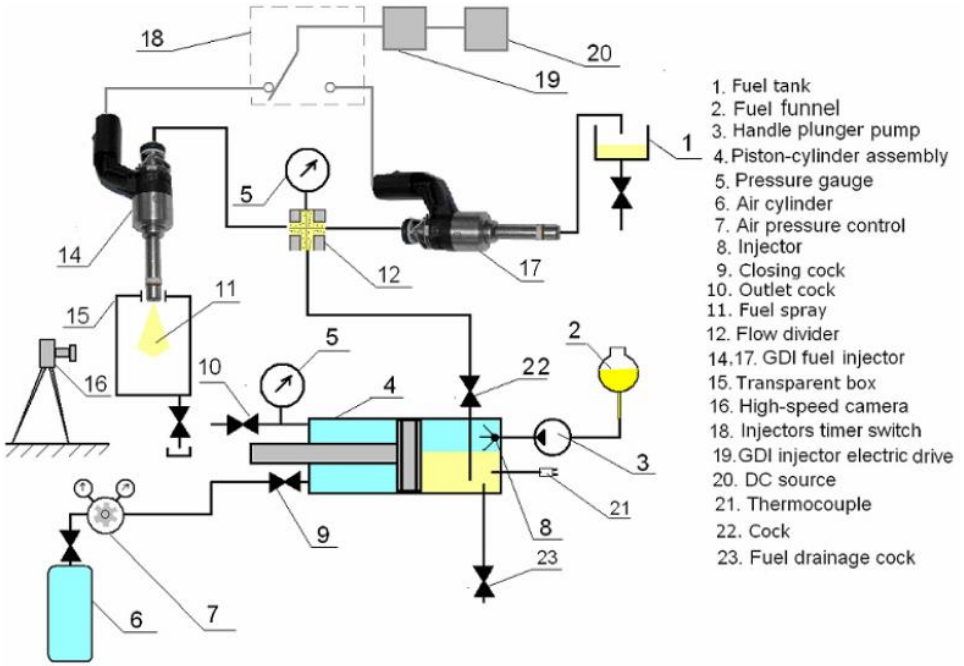
# Novel Solution for DI SI Engine Construction

- The ***Technion*** is the inventor of a air saturated fuel system
- High pressure injection system generates fine fuel spray
- When air is dissolved in fuel, part of the air-fuel mixture is formed before fuel is injected into the combustion chamber
- Drop in the pressure of the air saturated fuel during injection causes air bubbles to burst out of the fuel resulting increase of fuel atomization (*Henry's Law*)



# Novel Solution for DI SI Engine Construction

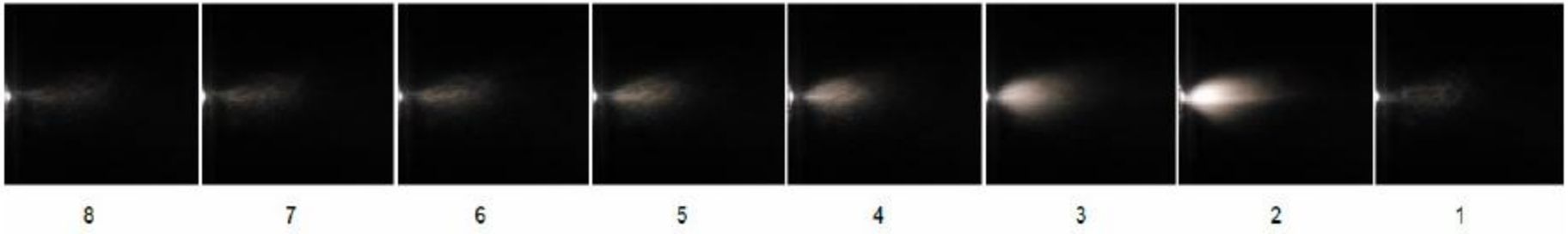
- What is the fuel pressure and temperature effects?
- What is the air pressure (before dissolved in fuel) effects?
- What is the length of time of injection period effects?
- How much air can be saturated in fuel?

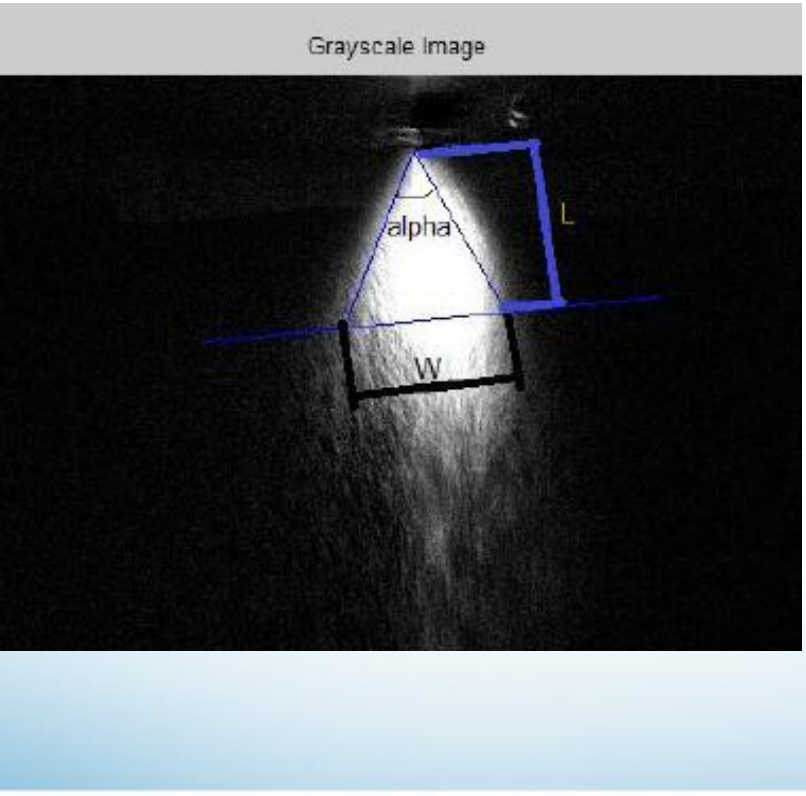



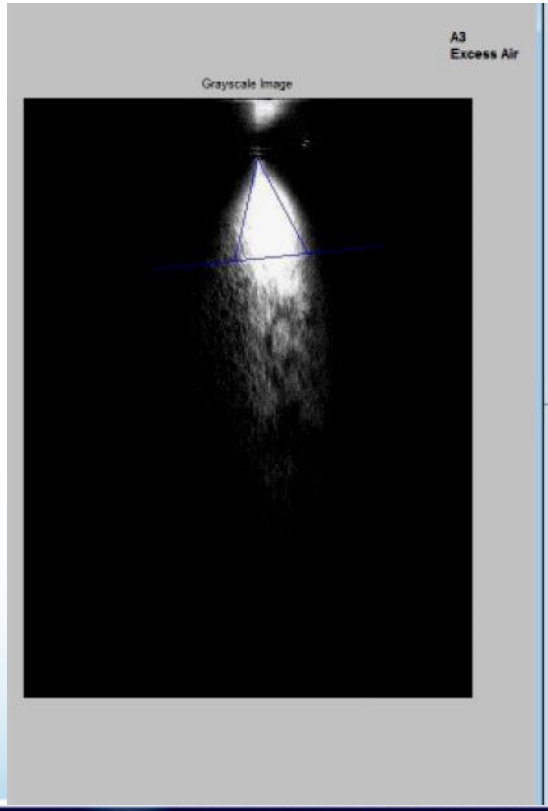


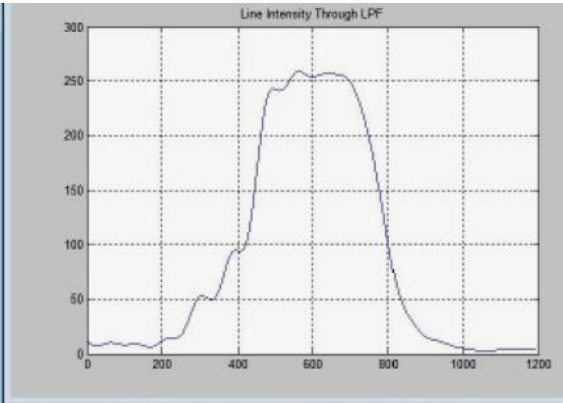

Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Center for Research in Energy Engineering and Environmental Conservation
Internal Combustion Engine Laboratory

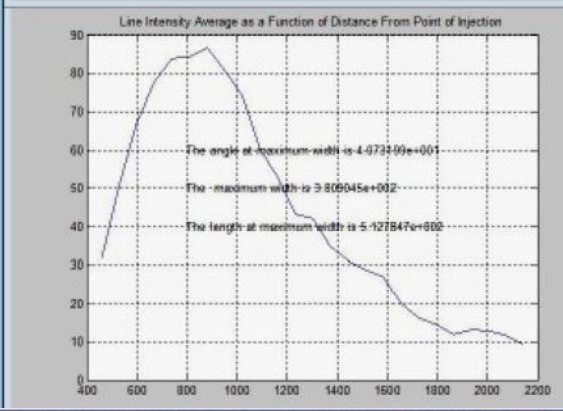
# Optical Methods in Analyzing Test Results






Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Center for Research in Energy Engineering and Environmental Conservation
Internal Combustion Engine Laboratory

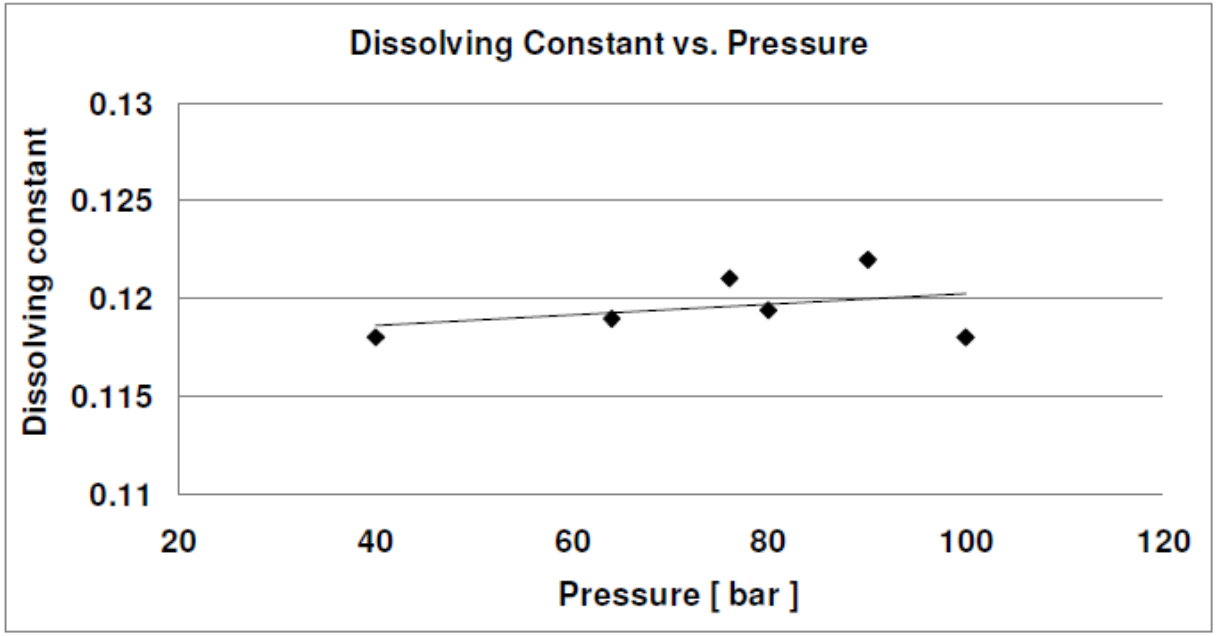
# Empirical Methods in Analyzing Test Results

Test have shown that injecting air saturated fuel with access of air (2-phase flow) decrease spray angle formation

Henry's Law:

$$V_{liquid} = \frac{V_{gas}}{C_t} * \frac{p_{gas}}{p_{liquid}}$$

But what is the value of the dissolving constant $C_t$ ?



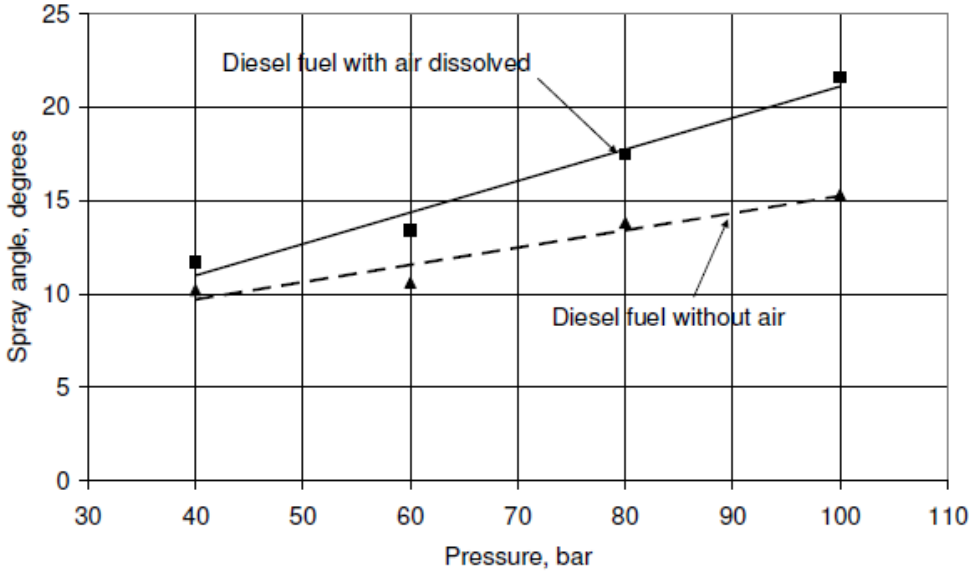
# Test Results- Fuel Spray Formation

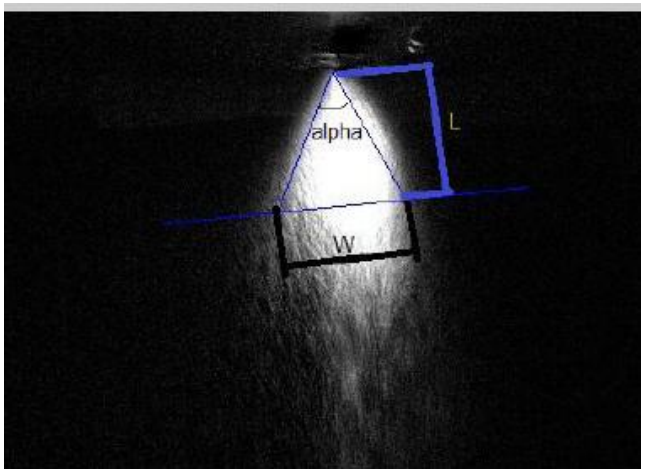
*It was found that dissolving air in heavy fuel results in substantial increase of the spray volume under both low and high pressures. This is an evidence of fuel atomization improvement!*

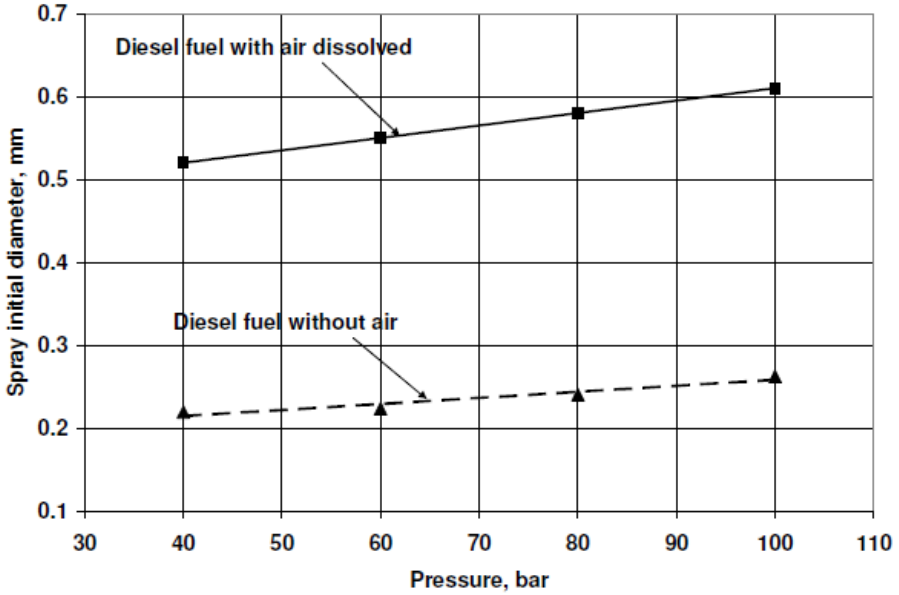
| Pressure | Fuel without air | Fuel with air dissolved |
|---|---|---|
| 40 bar |  |  |
| 60 bar |  |  |

| Pressure | Fuel without air | Fuel with air dissolved |
|---|---|---|
| 80 bar |  |  |
| 100 bar |  |  |

# Test Results Obtained from Test Rig



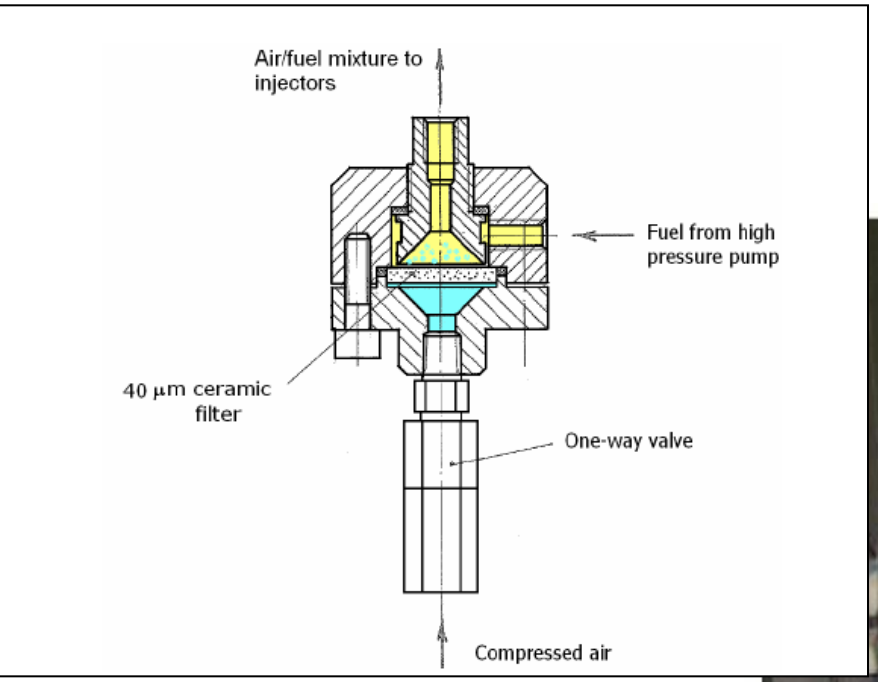



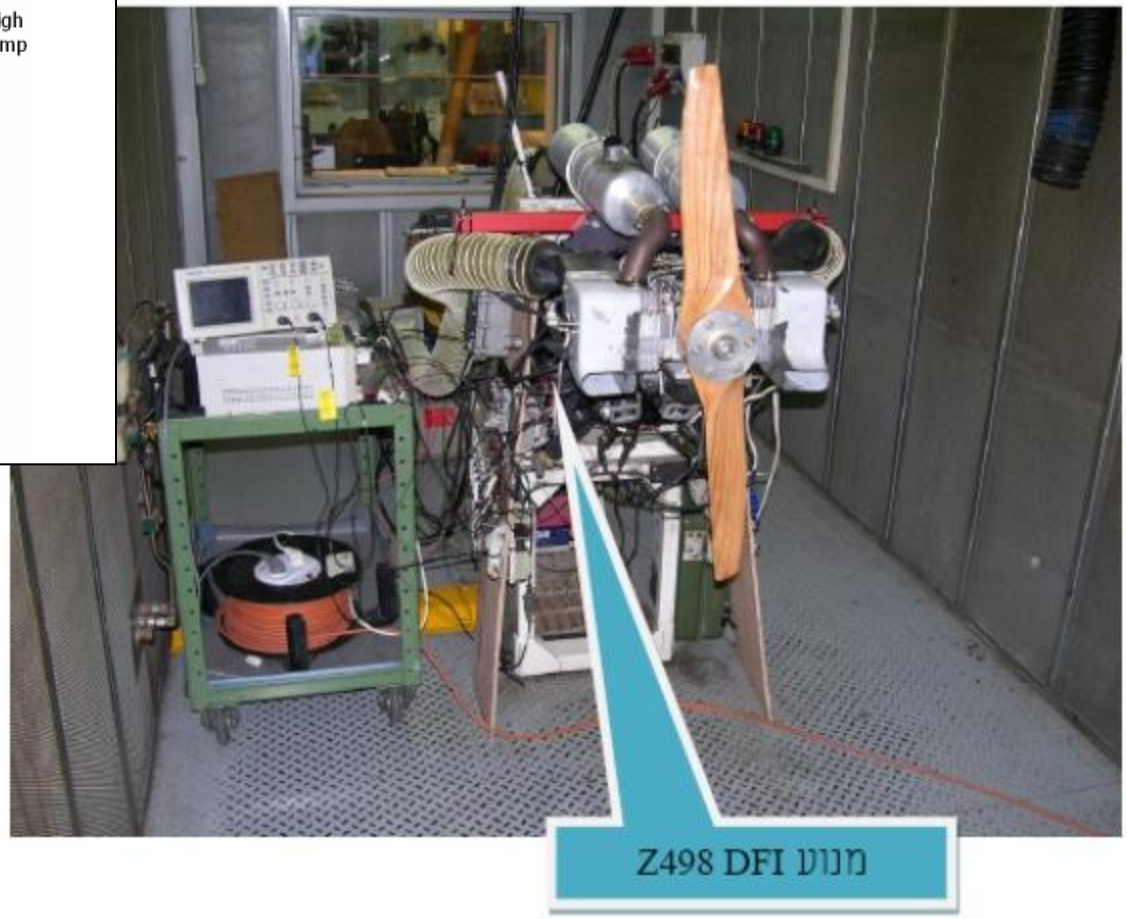






Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Center for Research in Energy Engineering and Environmental Conservation
Internal Combustion Engine Laboratory

# Implementation of Research in Real Engines



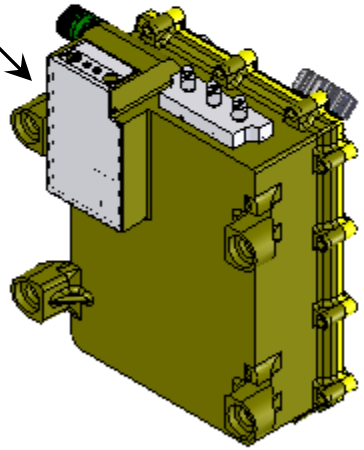



Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Center for Research in Energy Engineering and Environmental Conservation
Internal Combustion Engine Laboratory

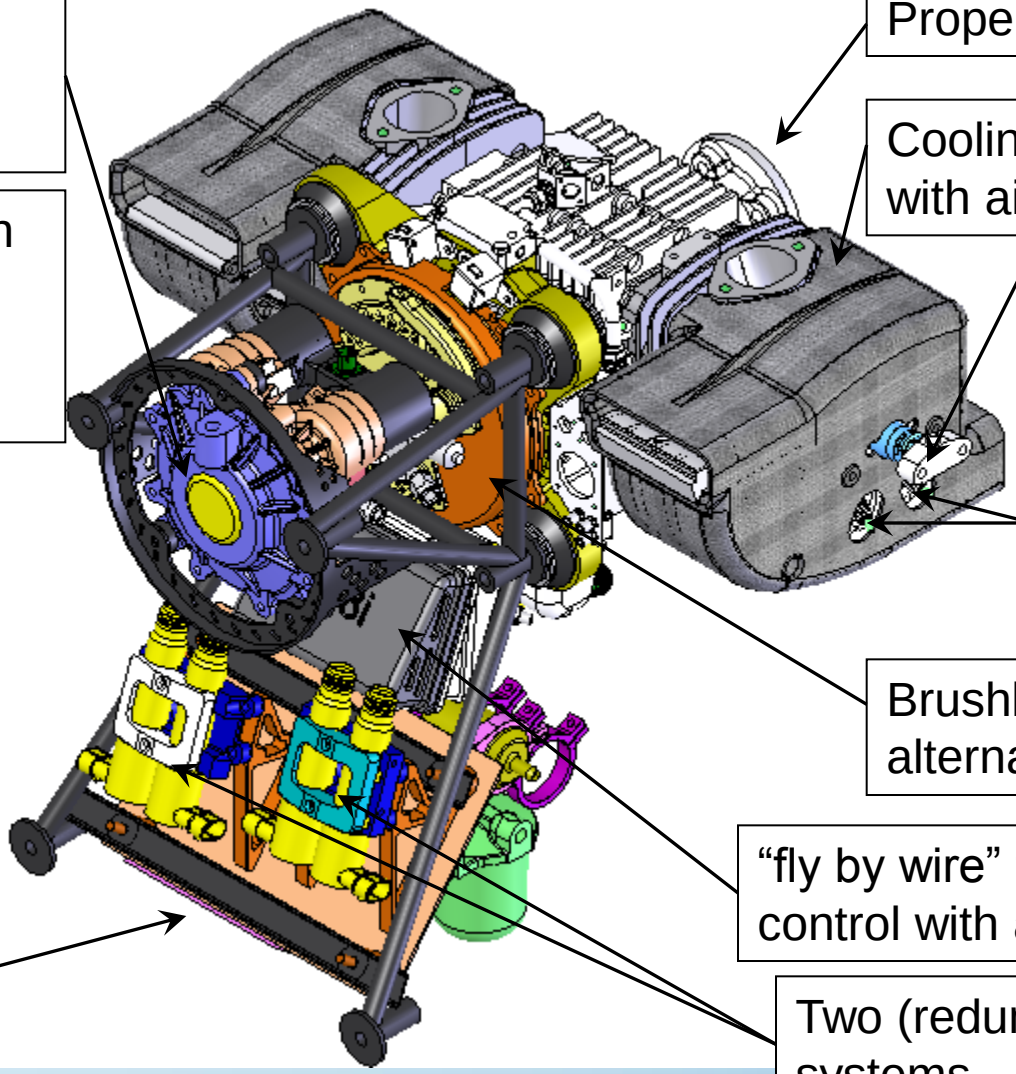
# Implementation of the Research in Real Engines

Fully redundant high pressure fuel injection pump

Dry sump lubrication with external fuel tank and triple-redundant fuel pumps



Digital (redundant) engine control unit



Propeller hub

Cooling shrouds with air flow control

Injector (DI)

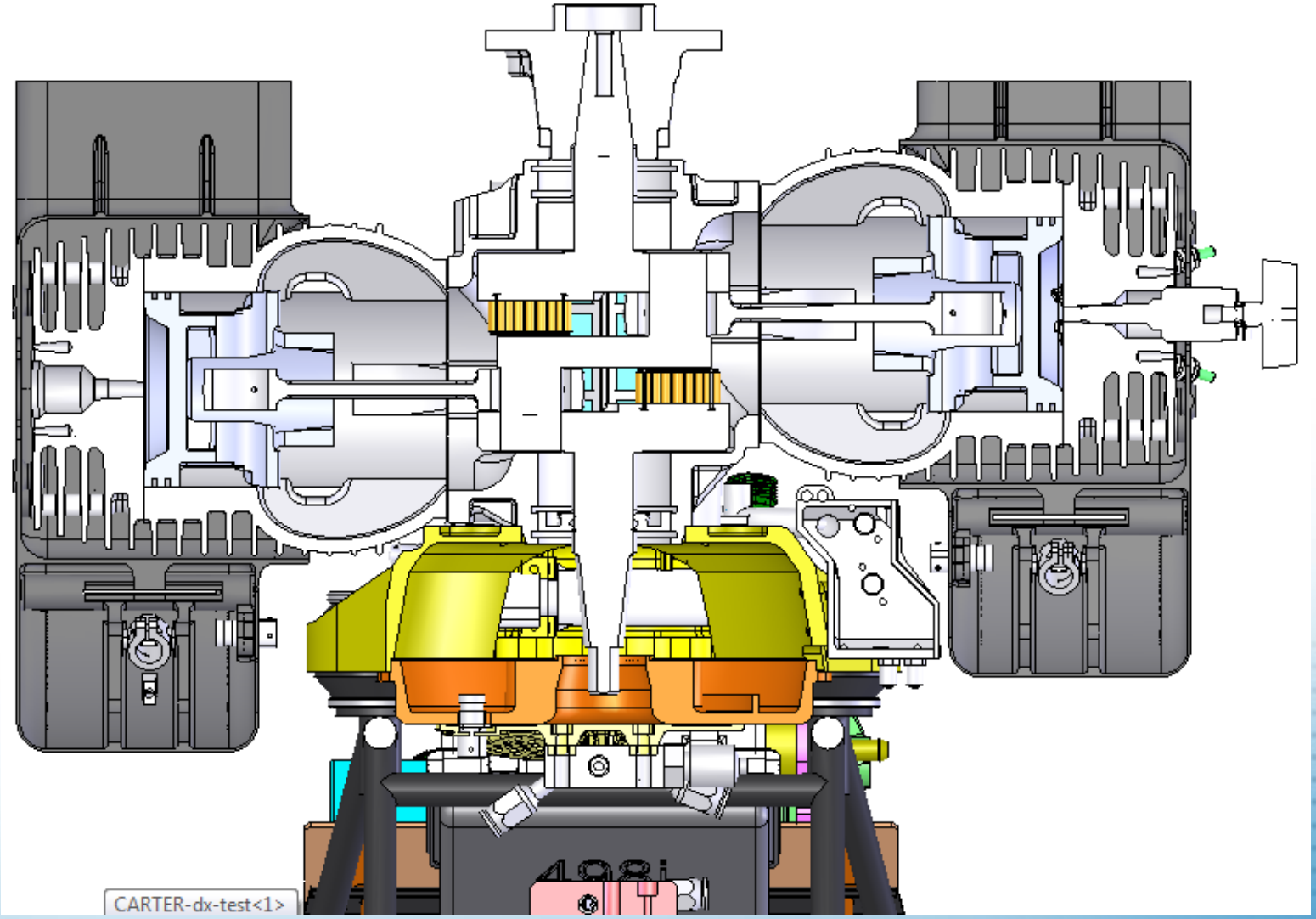
Two spark plugs per cylinder

Brushless starter-alternator

“fly by wire” throttle body control with air-filter

Two (redundant) ignition systems

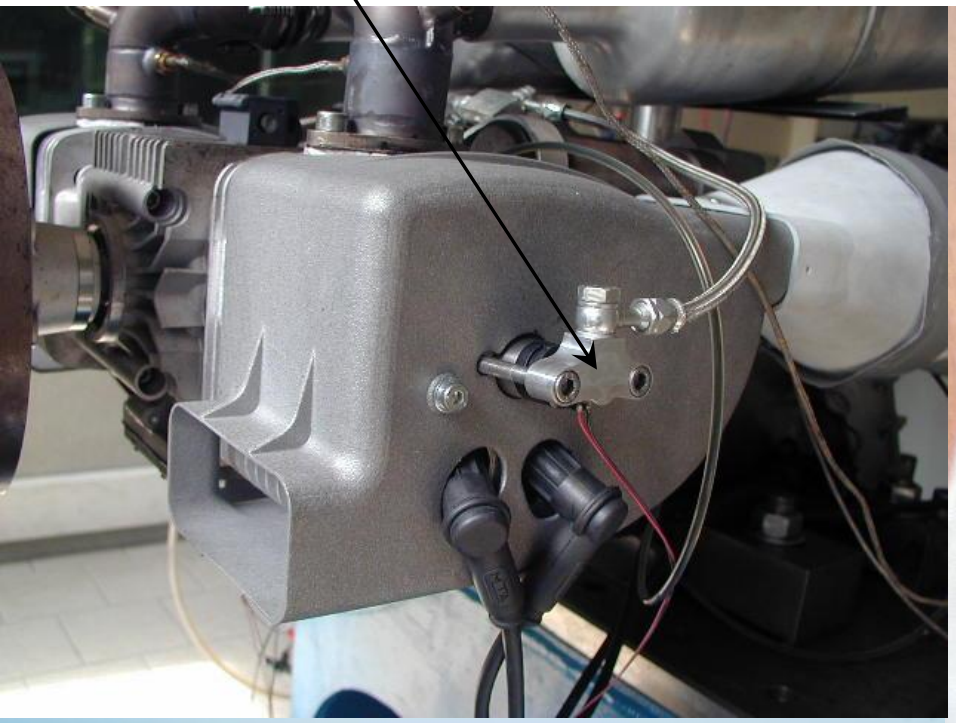
# Implementation of the Research in Real Engines



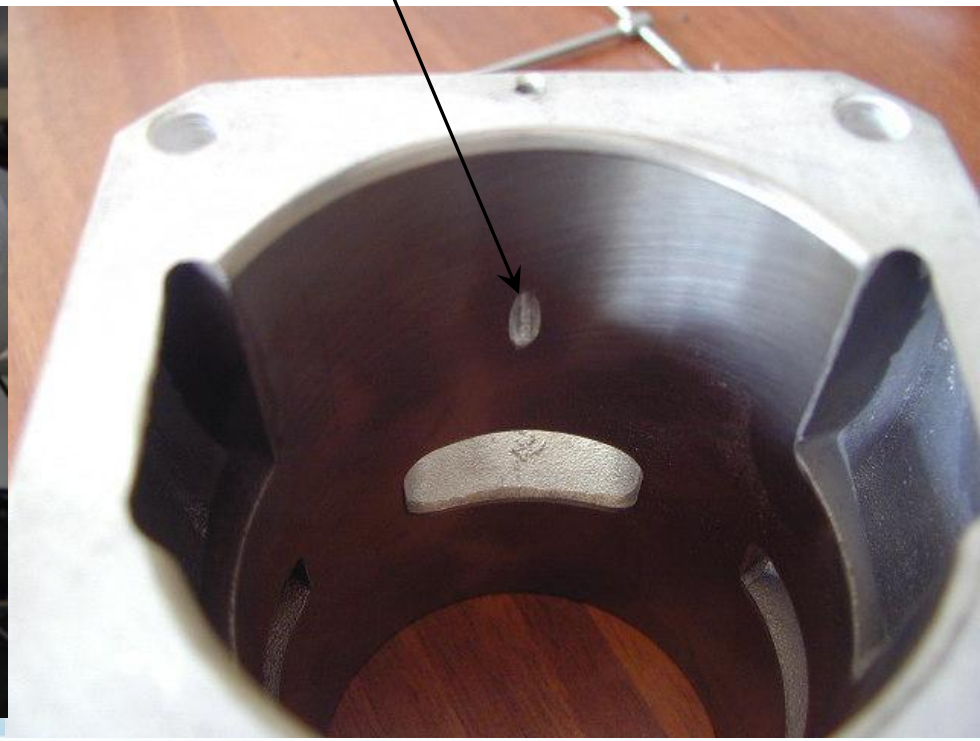
# Implementation of the Research in Real Engines

Piston with swirl chamber

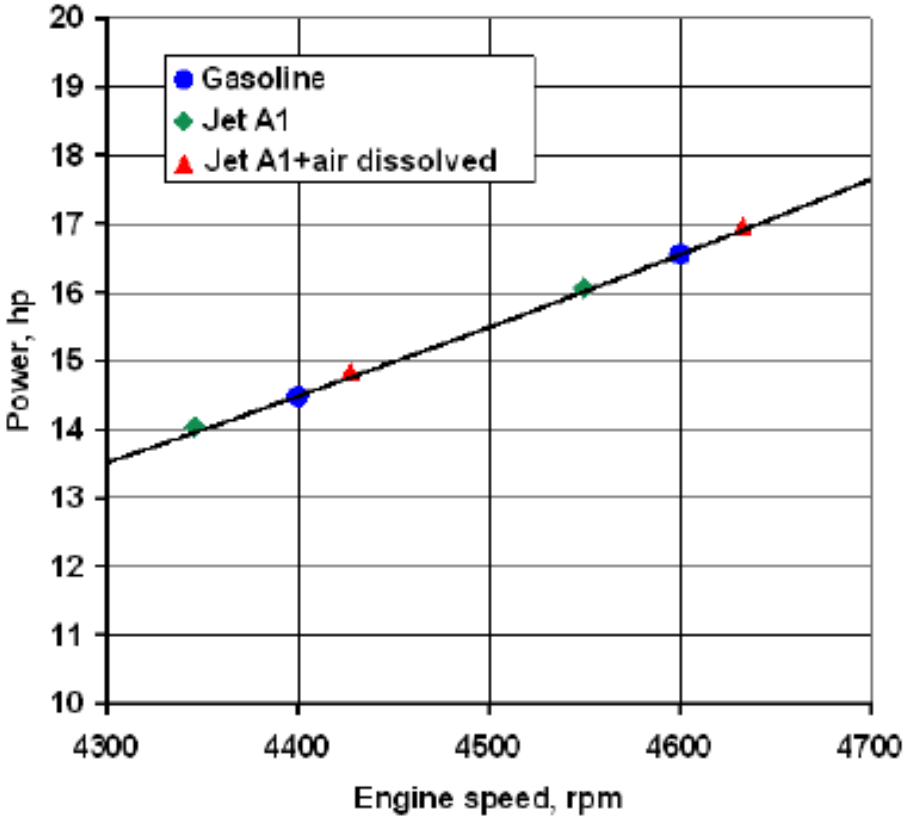
DI injector



Forced lubrication orifice



# Engine Testing Results




. The DFI Z498 engine power under operation with different fuels.

# Engine Testing Results