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

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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?
Optical Methods in Analyzing Test Results
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:

\[ V_{liquid} = \frac{V_{gas}}{C_t} \cdot \frac{P_{gas}}{P_{liquid}} \]

But what is the value of the dissolving constant \( C_t \)?
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!
Test Results Obtained from Test Rig

- **Spray angle, degrees**
  - Diesel fuel with air dissolved
  - Diesel fuel without air

- **Spray initial diameter, mm**
  - Diesel fuel with air dissolved
  - Diesel fuel without air

- **Pressure, bar**
  - 30, 40, 50, 60, 70, 80, 90, 100, 110

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

Air/fuel mixture to injectors

Fuel from high pressure pump

40 μm ceramic filter

One-way valve

Compressed air

Z498 DFI

Aeronautics

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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
- 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
- Digital (redundant) engine control unit
- Two (redundant) ignition systems
Implementation of the Research in Real Engines
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Piston with swirl chamber

Forced lubrication orifice

DI injector
The DFI Z498 engine power under operation with different fuels.
Engine Testing Results

![Graph showing Engine speed vs. BSFC for different fuel types: Gasoline, Jet A1, and Jet A1+air dissolved]