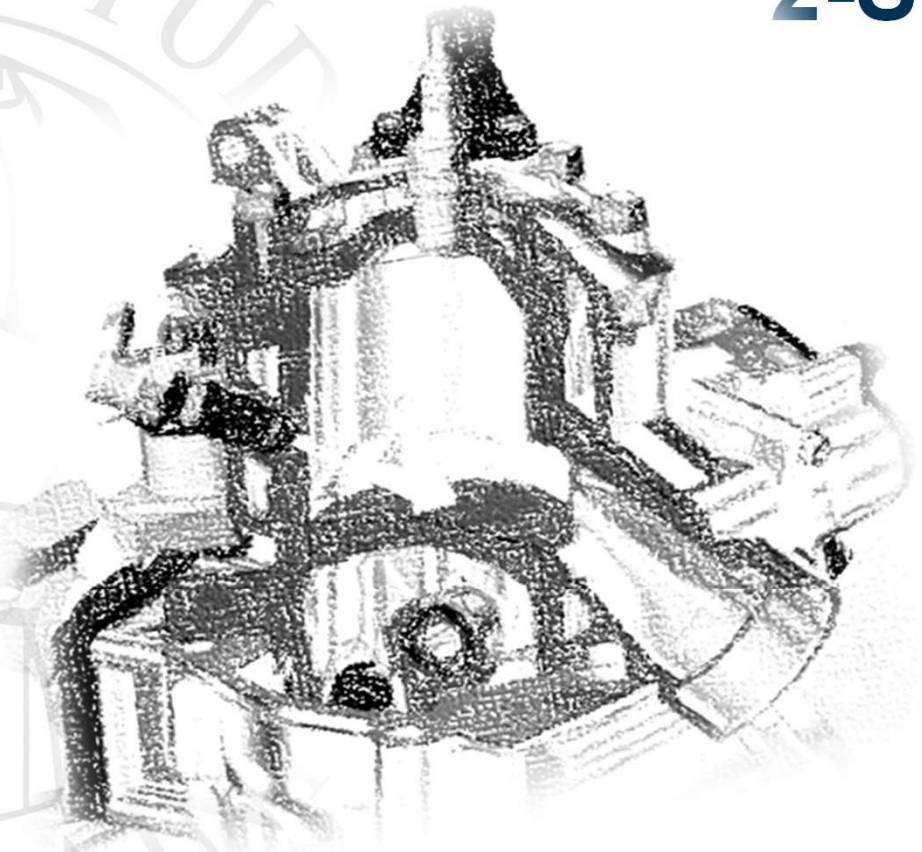
2-Stroke LPDI



Prof. Giovanni Ferrara
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Background

- Small two stroke SI engine application
  - Motorbikes
  - Scooters
  - Snowmobiles
  - Outboards
  - Gardening machineries
    - Grass trimmers
    - Chainsaws
    - Brush-cutters
    - …

Background

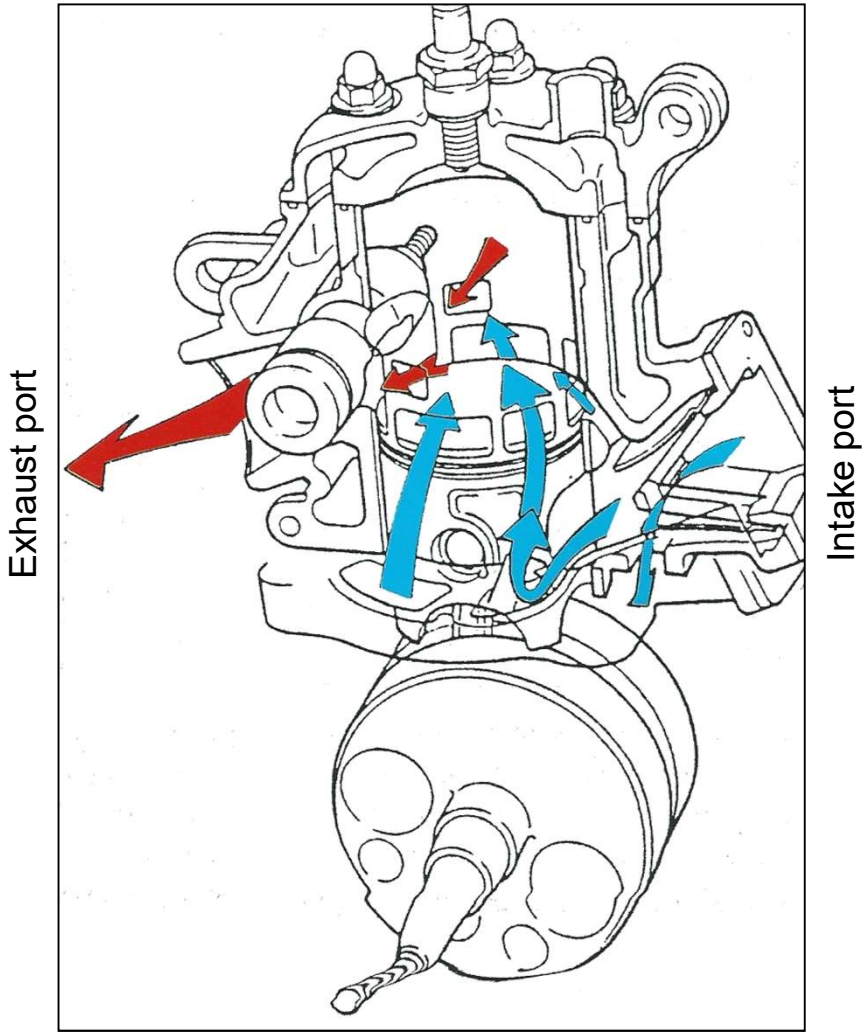
- Advantages
  - Simplicity & Low cost production & Reliability
    - Less mechanical parts respect to 4S engine
  - Low mechanical friction
    - No valve-timing system
  - High power density
    - Lightweight / Compactness
- Drawbacks
  - High fuel consumption
  - Oil consumption
  - High raw emissions
    - Emission regulations
    - HC emission

2S Engine Head

4S Engine Head

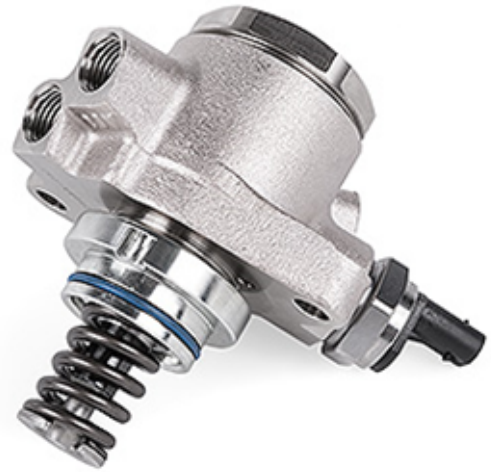
Background

- Short circuit issue
  - Carbureted & PFI engine
    - Fuel and air mixture short circuit
      - Air and fuel premix before entering into the engine
      - Intake and exhaust ports contemporary opened
    - Unburned fuel at exhaust port
    - High fuel consumption
    - High raw HC emission
    - Oil consumption
      - Oil is premixed with air and fuel
      - Oil short circuits trough the exhaust port



HPDI Engine

- Fuel Short circuit reduction
  - Fuel consumption reduction
  - HC emission reduction
- High Pressure Direct Injection
  - No fuel short-circuit
    - Injection phase at closed ports
  - High costs components
    - High pressure fuel pump
    - High pressure injector
  - Increase in mass and layout issues
    - Motorbike
    - Scooter
    - Snowmobile
    - Small 2S engine for gardening machineries
  - Engine complexity grows



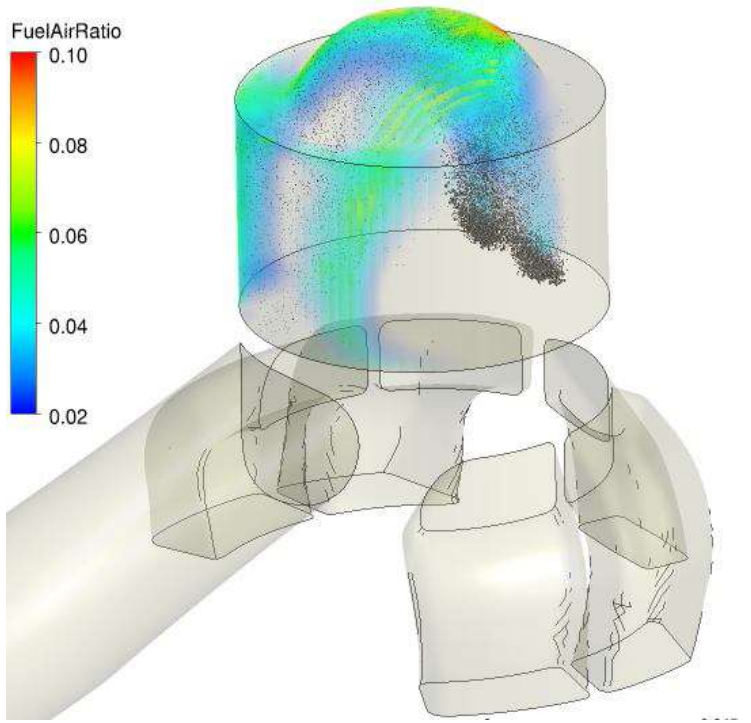
High pressure fuel pump

High pressure injector

LPDI Engine

- Fuel Short circuit reduction
  - Fuel consumption reduction
  - HC emission reduction

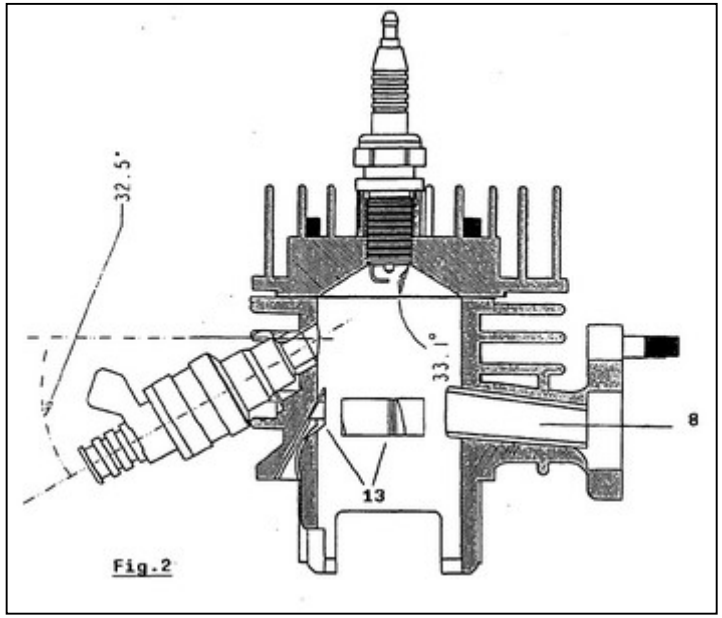
- Low Pressure Direct Injection
  - Strong reduction of fuel short-circuit
    - Interaction between injected fuel and scavenged air
  - Same costs of PFI or carbureted engine
    - Low pressure fuel pump
    - Low pressure injector
  - No increase in mass or layout issues even for small 2 stroke engine
    - Lightweight



LPDI Engine solutions

- Orbital
  - Pre-compressed air chamber
    - Small Reciprocating compressor
  - Fuel and air premixed in the annular chamber
  - Poppet valve allows the mixture to enter in the cylinder

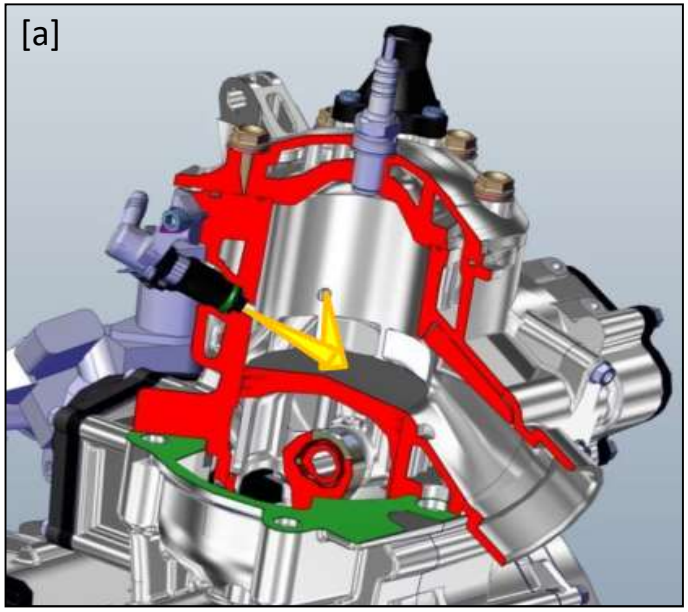
- Athena
  - In-cylinder direct injection
  - Injection direction from the cylinder liner to the cylinder top
  - Stratified charge
  - Injection starts at closed ports



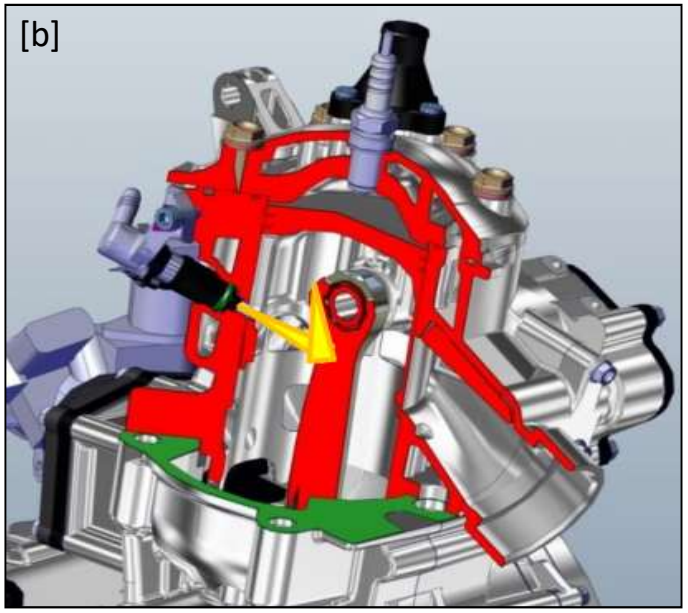
LPDI Engine solutions

- Graz University
  - In-cylinder direct injection
  - Two injectors positioned on the cylinder liner
    - Convergent injectors axis
  - Both direct in-cylinder injection [a] and crankcase injection [b]
    - Direct injection above the piston
    - Scavenge injection under the piston
      - Ports on piston skirt

Direct injection

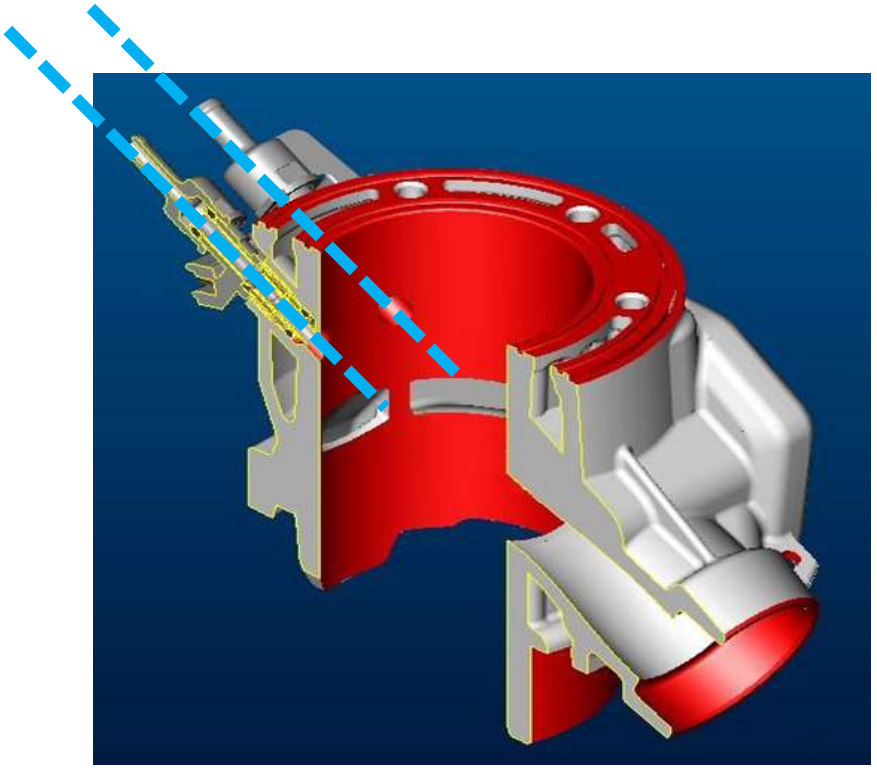


Crankcase injection



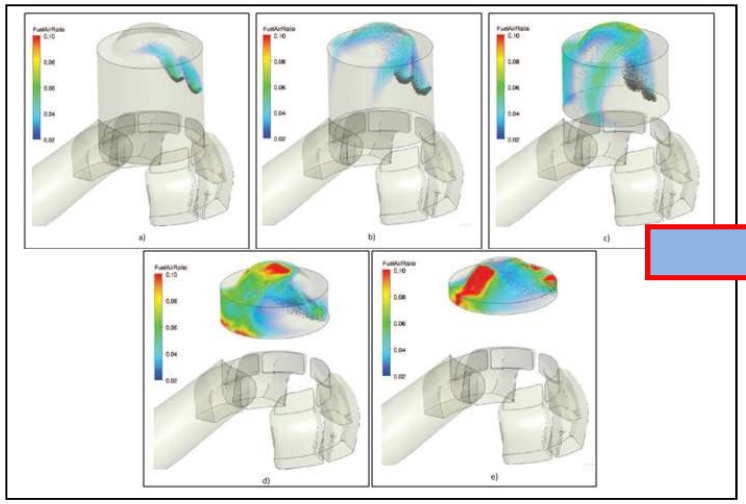
LPDI Engine solutions

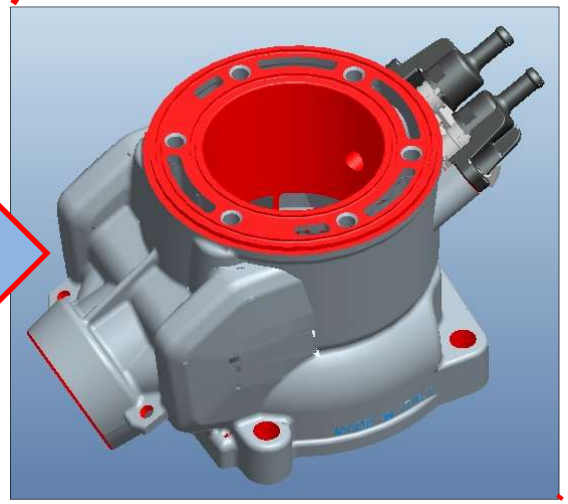
- **Florence University**
  - In-cylinder direct injection
  - Two injectors positioned on the cylinder liner
  - Both direct in-cylinder injection
    - Over the scavenge ports, in exhaust port direction



LPDI Engine - Florence University

1. CFD analysis
2. CAD project
3. New cylinder

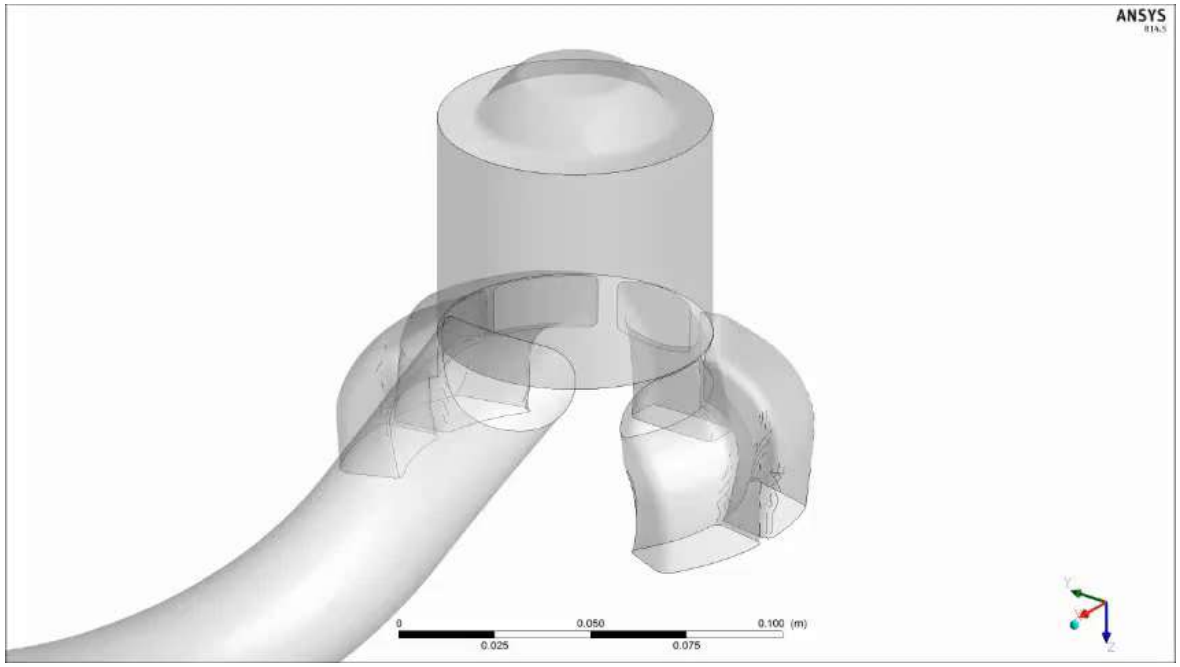


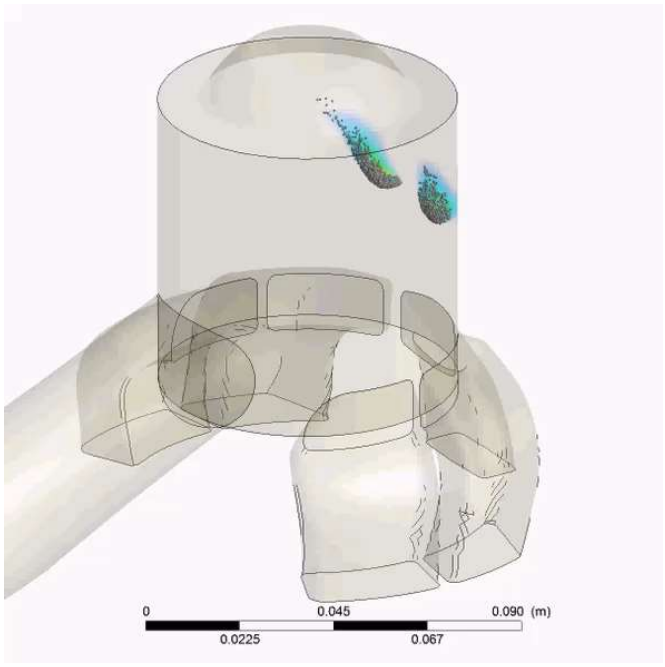


LPDI Engine - Florence University

- CFD analysis

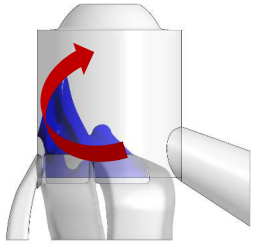
Iso-surface at 80% of air (blue)
Iso-surface at 80% of exhaust gas (red)

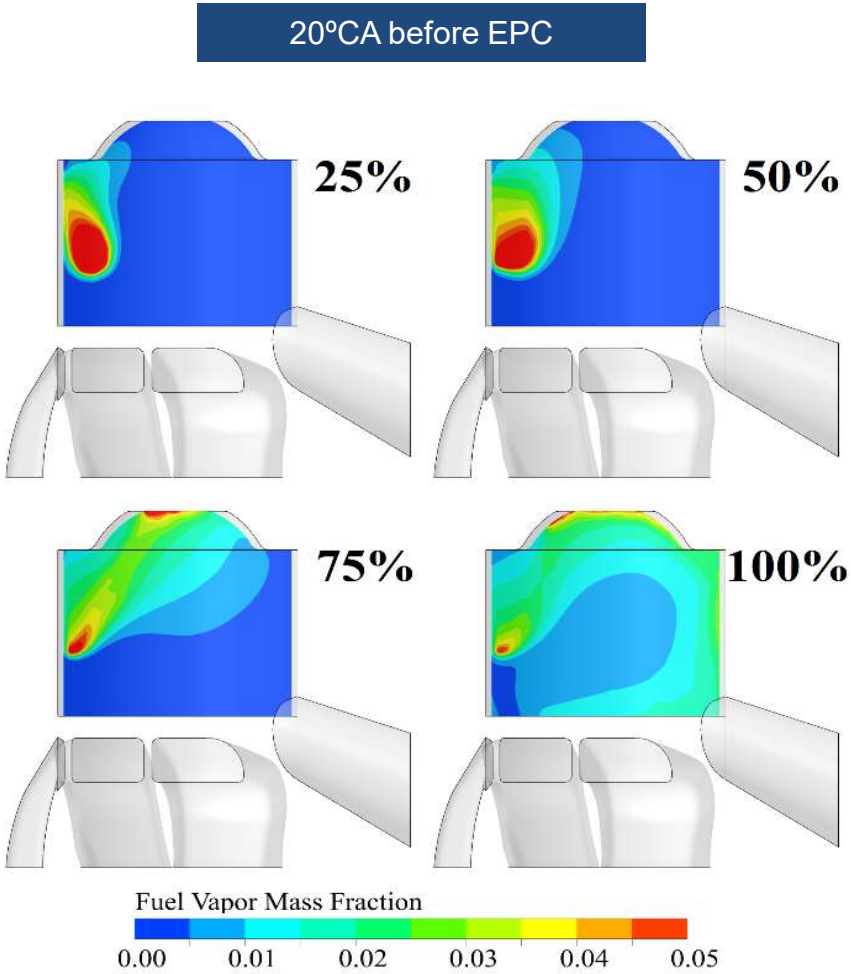




LPDI Engine - Florence University

- Results
  Maximum torque rotating speed
  4 loads (25%, 50%, 75% and 100%)
  - Short-circuit completely absent at partial loads
    - Low injected mass → Late SOI
  - In full load conditions the fuel reaches the exhaust port
    - Early SOI
  - Influence of the rising scavenging current
    - Fuel flow is directed towards the head
    - The low penetration of the fuel jet does not overcome the flow entering from the transfer ports





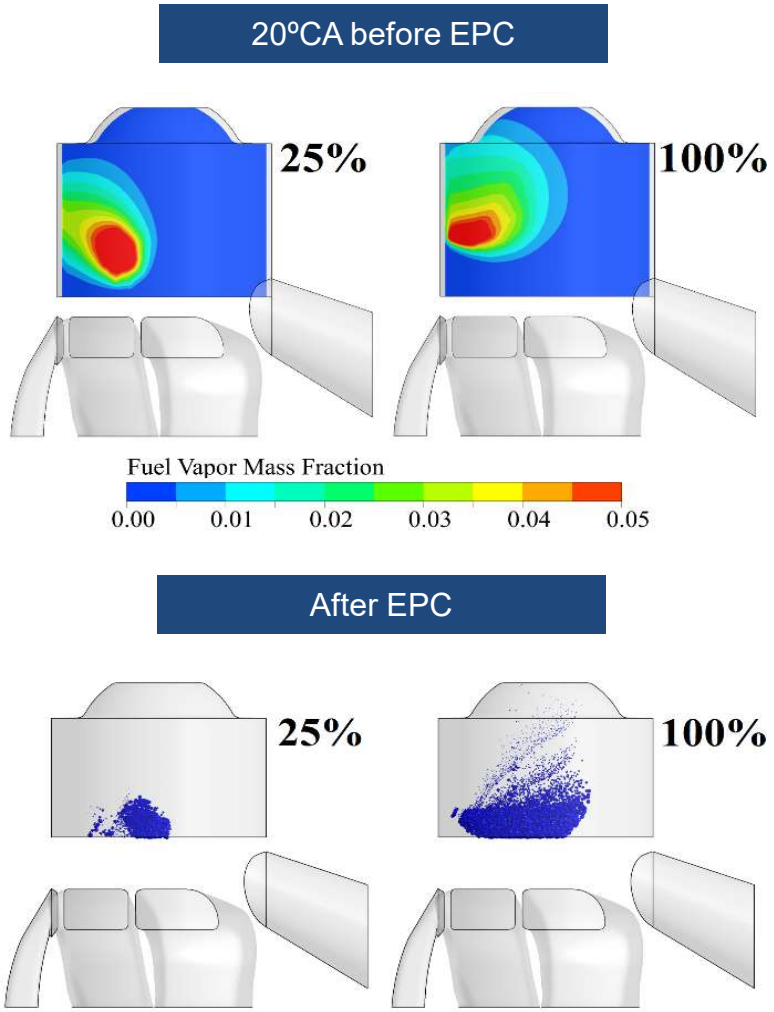
LPDI Engine - Florence University

- Results

  Low rotating speed

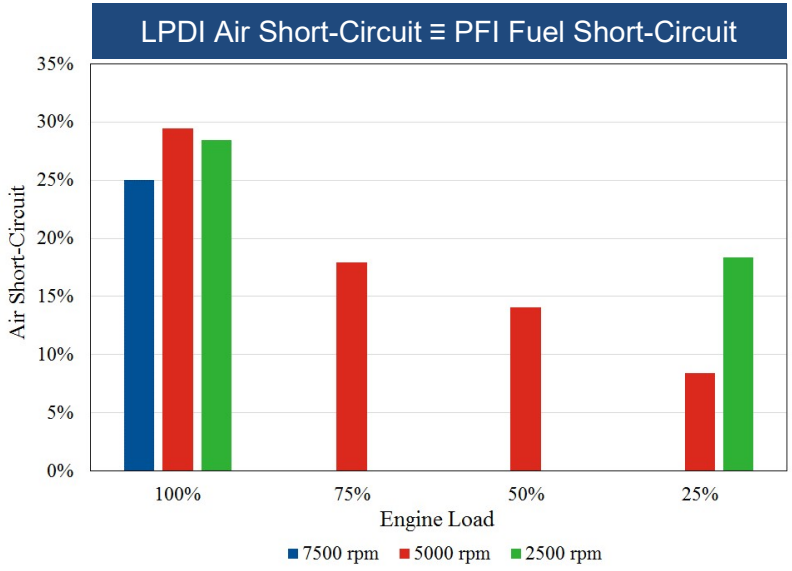
  2 loads (25% and 100%)

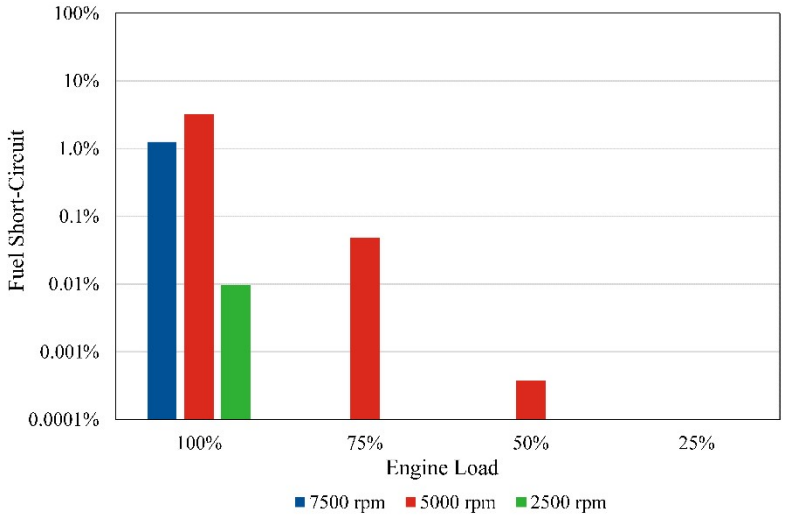
  – The fuel does not reach the exhaust port
    - No short-circuit
    - Low mass fuel injected → Late SOI
  – Different interaction with fresh charge
  – Scavenging flow is not able to direct the spray upwards
    - Almost isotropic vapor distribution
    - The droplets are able to penetrate
    - Collision with the piston crown



LPDI Engine - Florence University

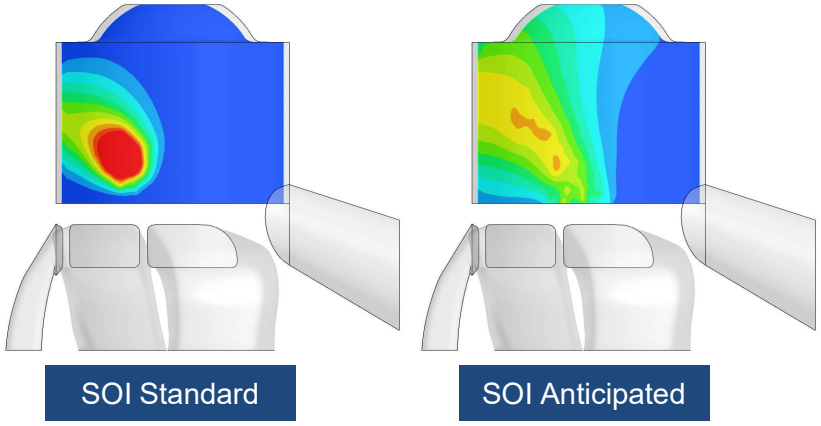
- Results
  - Fuel Evaporation
    - 70-90%
    - Satisfactory in the whole engine operating range
  - Short-Circuit
    - Air: 8-30%
    - Fuel: 0-3%

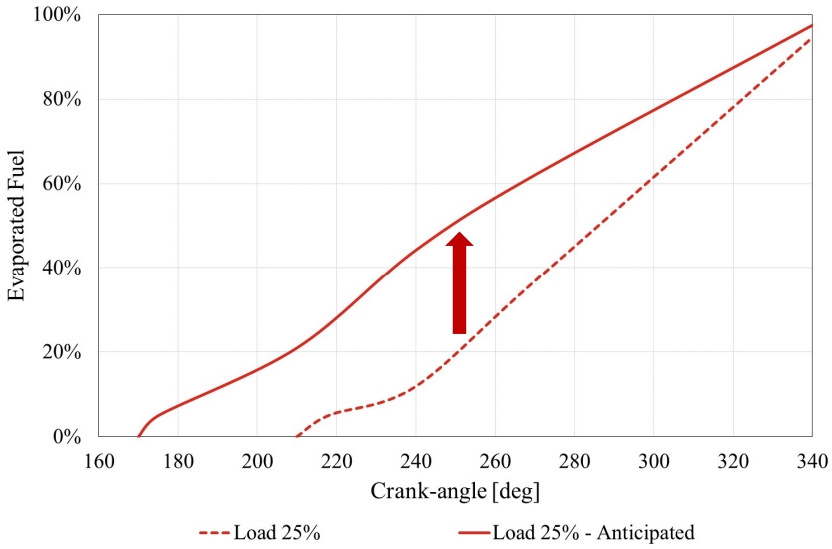




LPDI Engine - Florence University

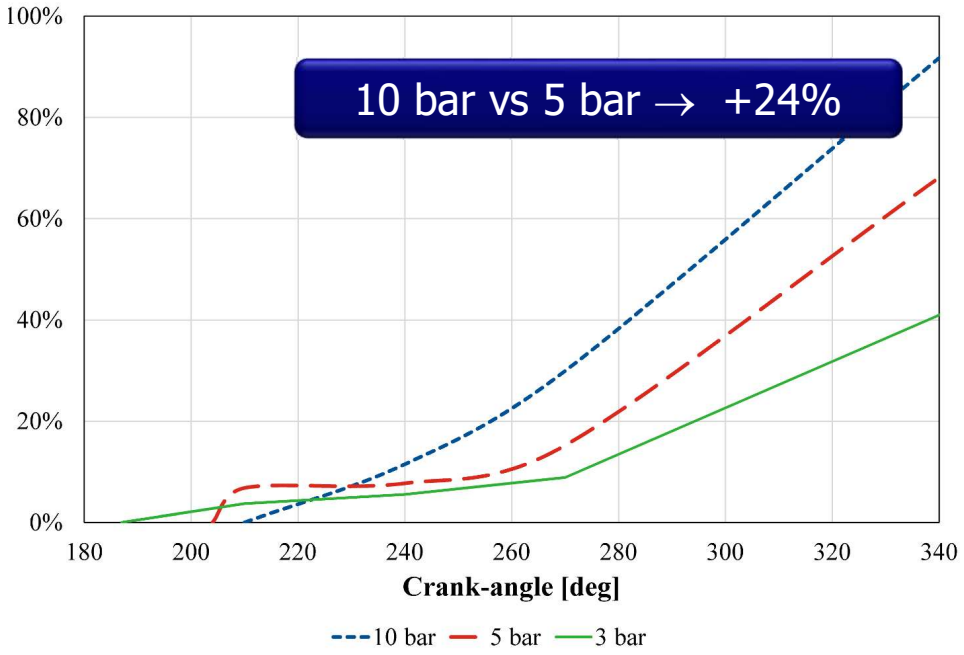
- SOI influence
  - Adjust the SOI
    - Aim: improve the interaction between air and fuel currents
    - Best compromise between fuel evaporation and the reduction of fuel short-circuit
  - SOI strategy has a significant influence
  - Jet is able to interact with the rising scavenge current
    - Improved homogenization & Faster evaporation
  - Slight amount of fuel short-circuit



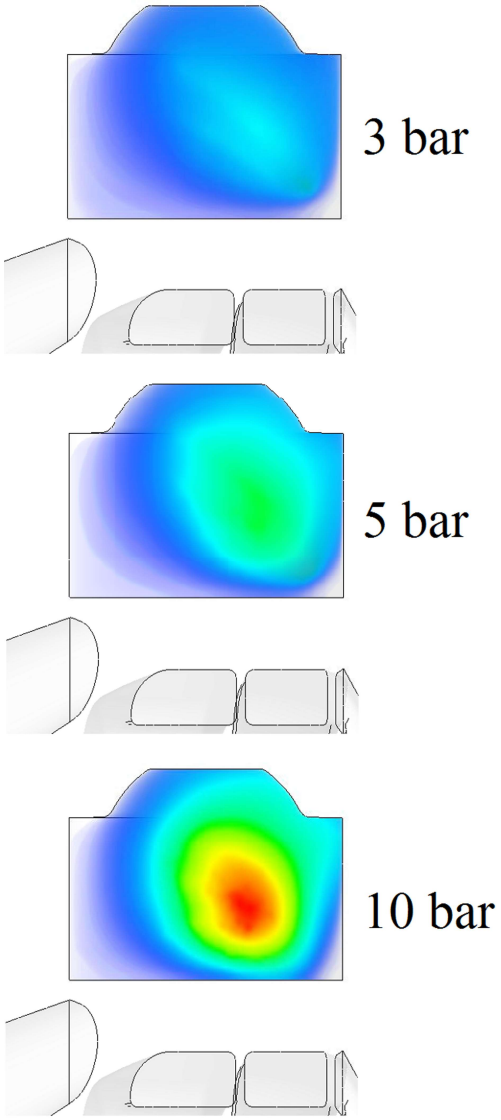


LPDI Engine - Florence University

- Injection Pressure influence (3 bar – 5 bar – 10 bar)
  - High injection pressure (10 bar)
    - Faster evaporation
    - Increased atomization
    - Shorter injection duration



Fuel Vapor Mass Fraction



LPDI Engine - Florence University

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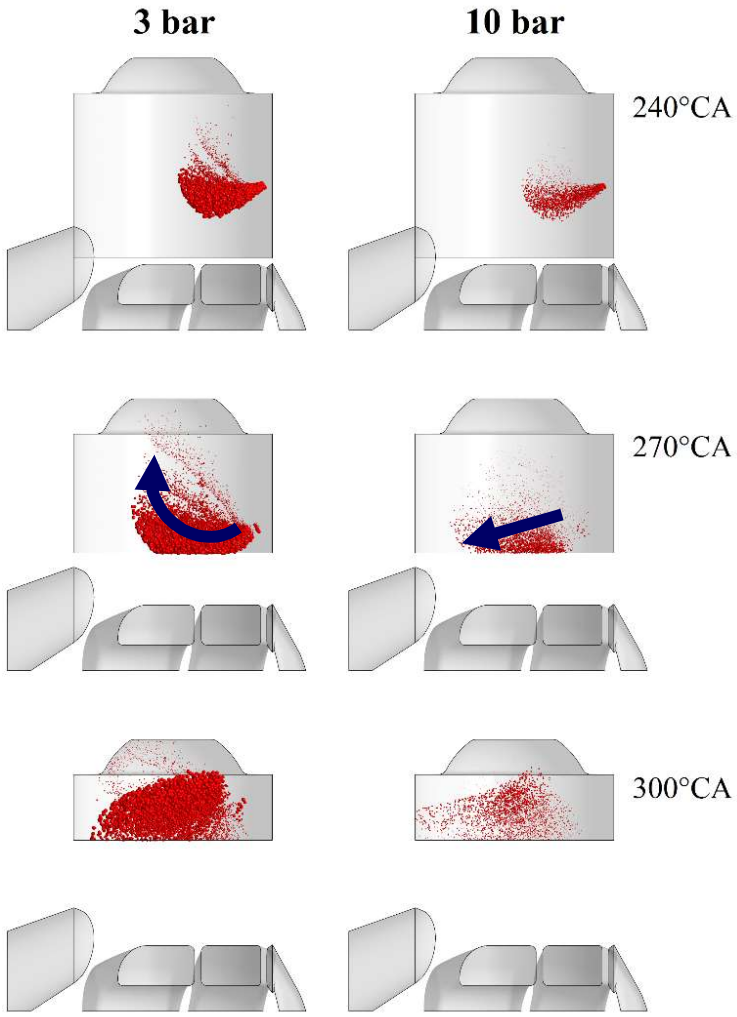
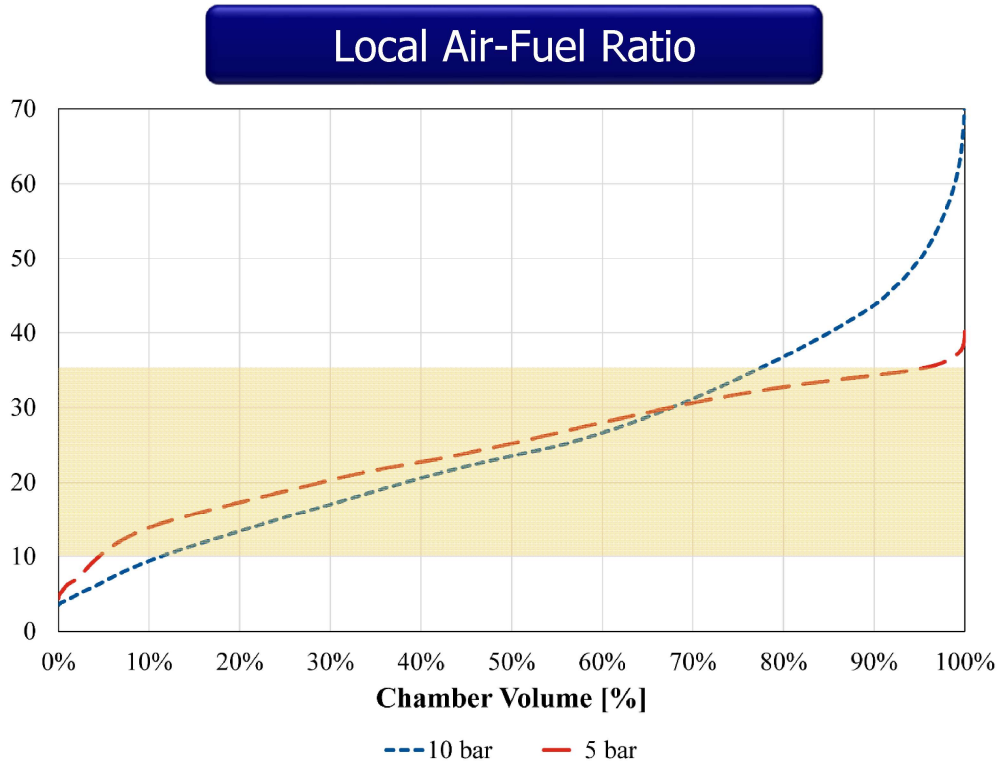


LPDI Engine - Florence University

- Injection Pressure influence (3 bar – 5 bar – 10 bar)
  - High injection pressure (10 bar)
    - Faster evaporation
    - Increased atomization
    - Shorter injection duration

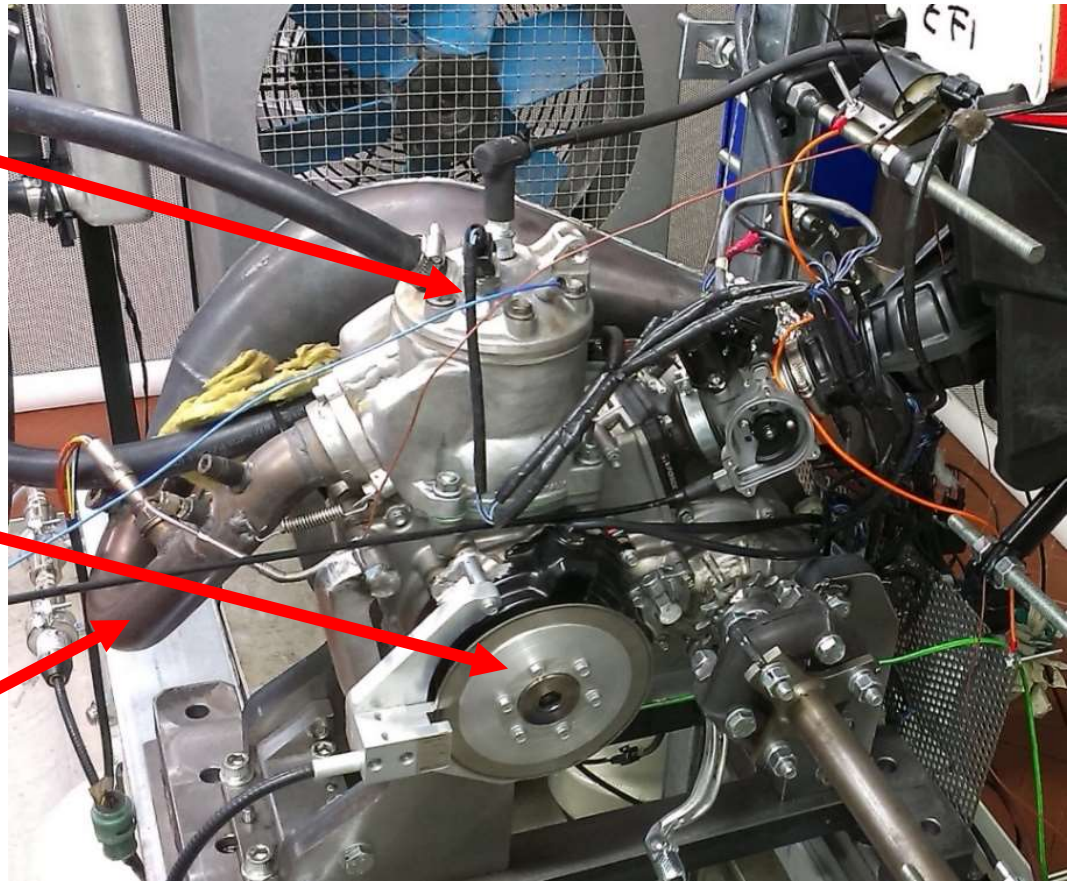
Homogenization
Range 10 < A/F < 35

5 bar → 90% of volume
10 bar → 65% of volume



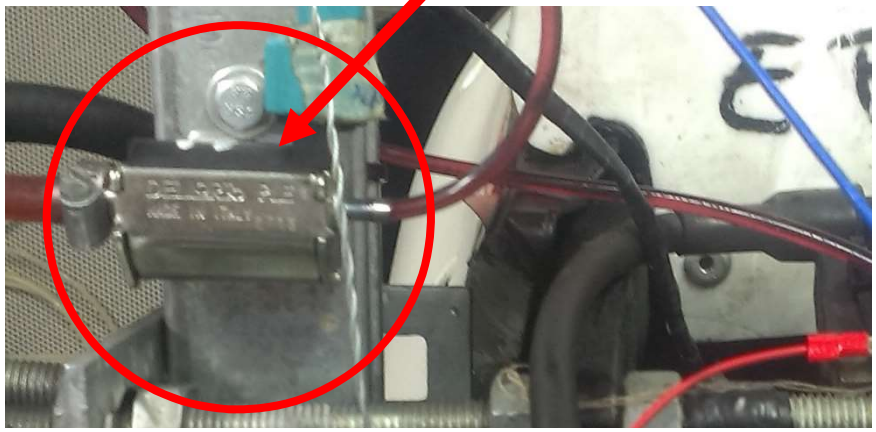
LPDI Engine - Florence University

- Experimental setup



LPDI Engine - Florence University

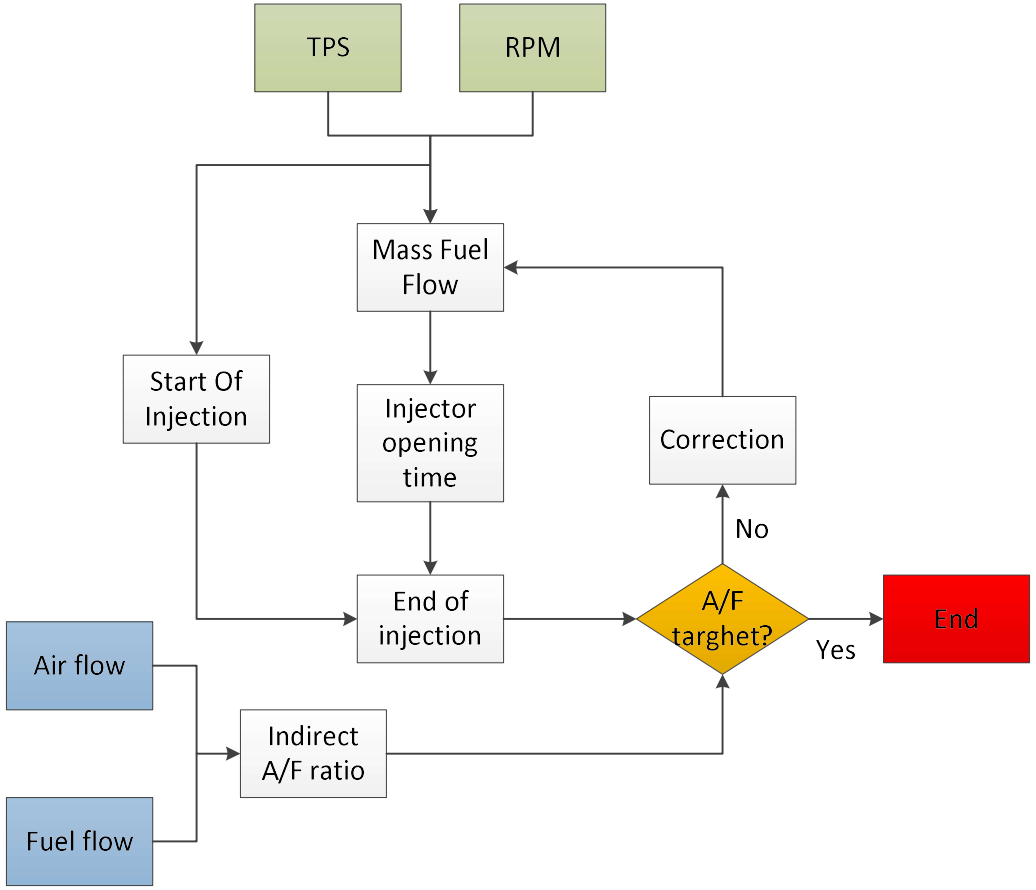
- Lubricant system

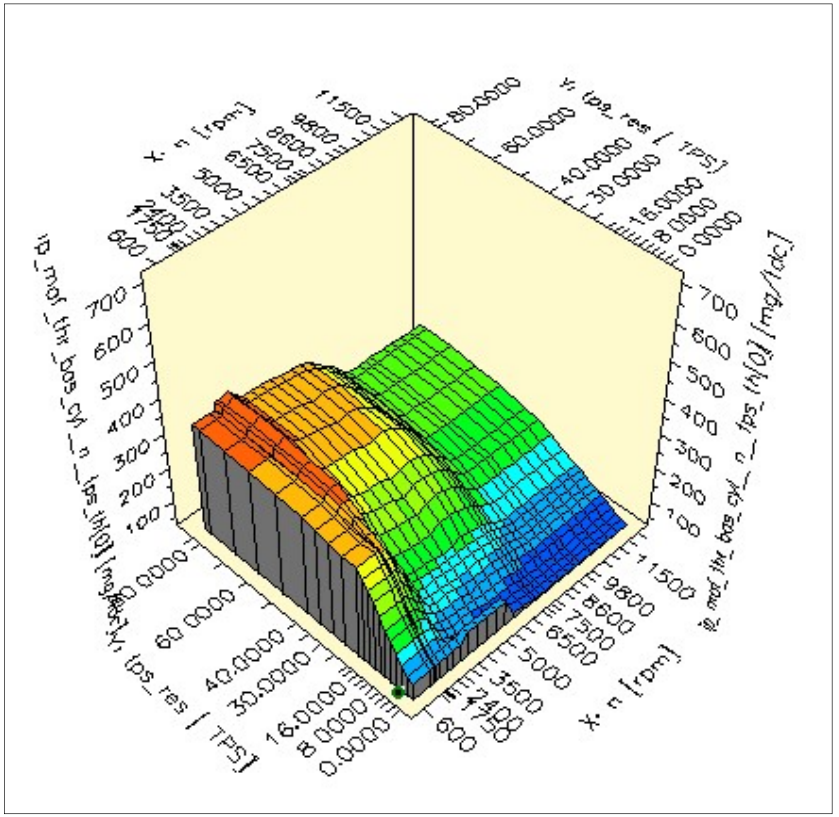


Injection in the intake duct before the reed valve

LPDI Engine - Florence University

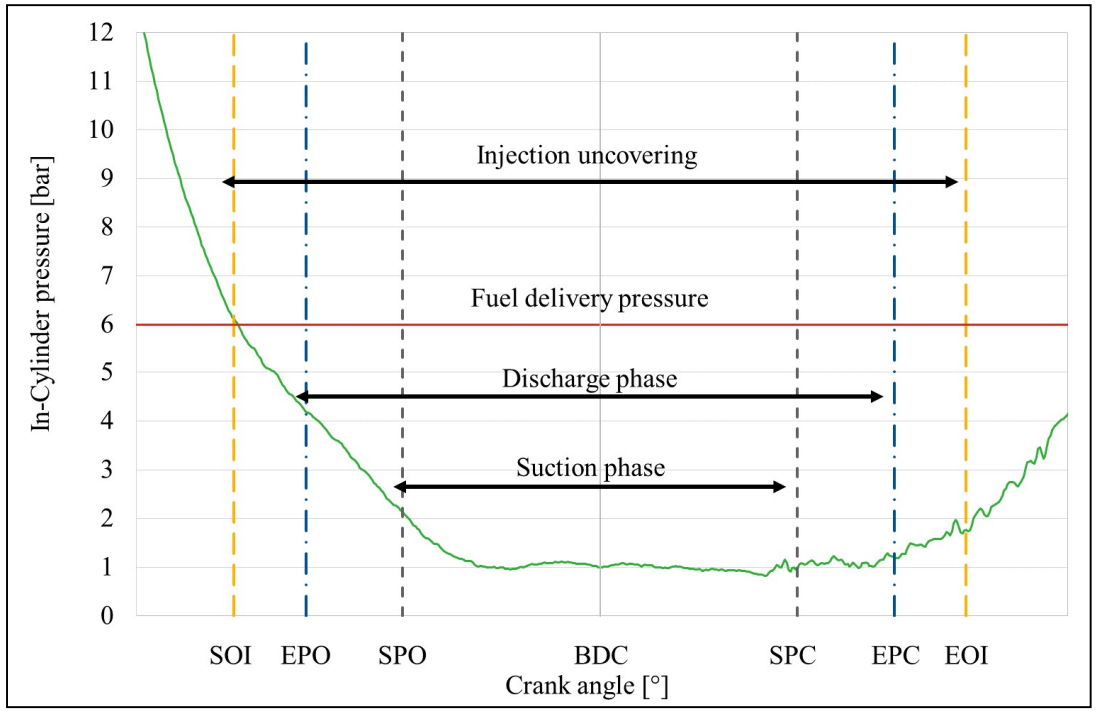
- Engine mapping





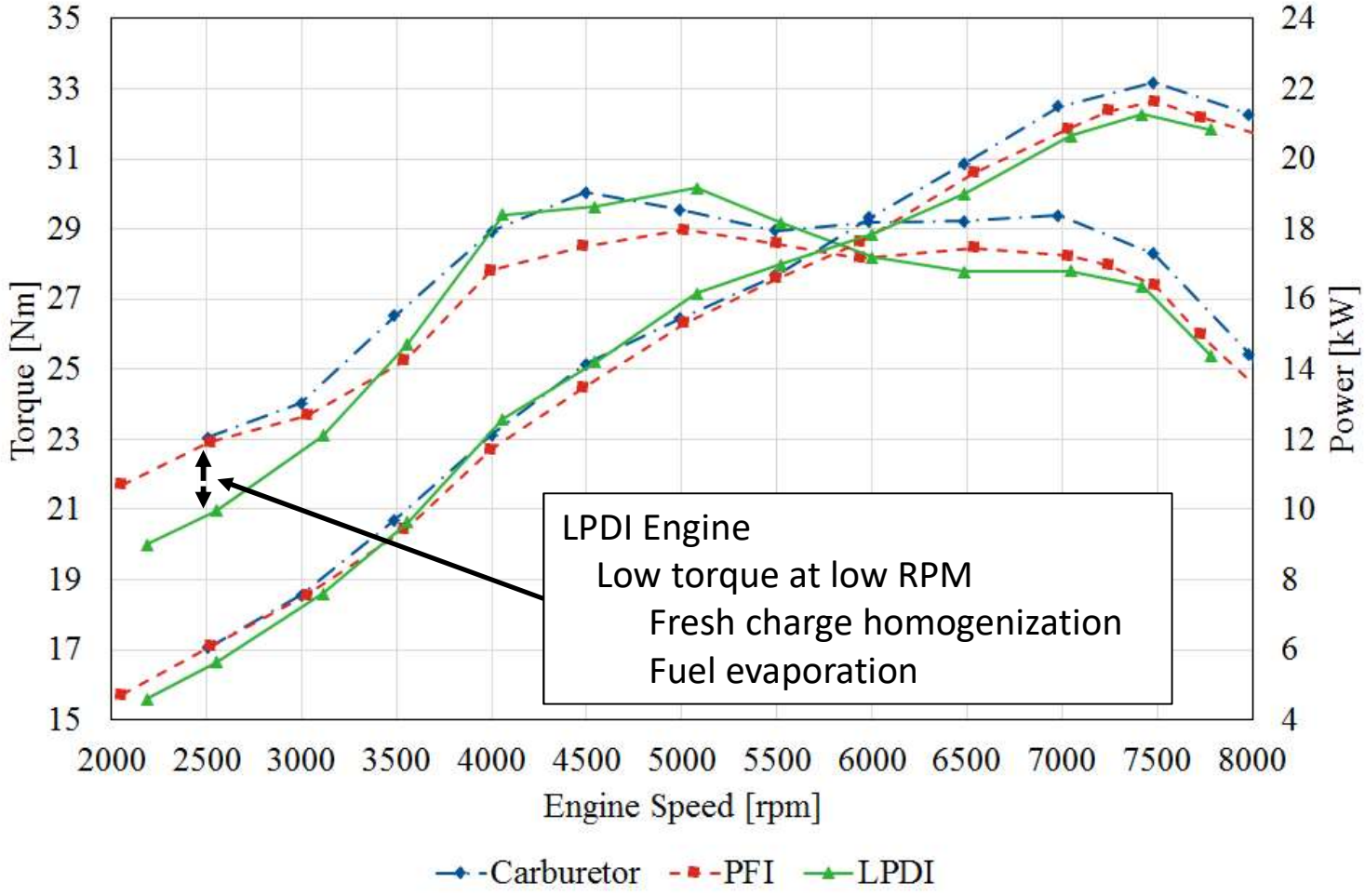
LPDI Engine - Florence University

- Engine mapping
  - Compromise
    - Exhaust gas expulsion
    - Fuel-air mixing
    - Fuel evaporation



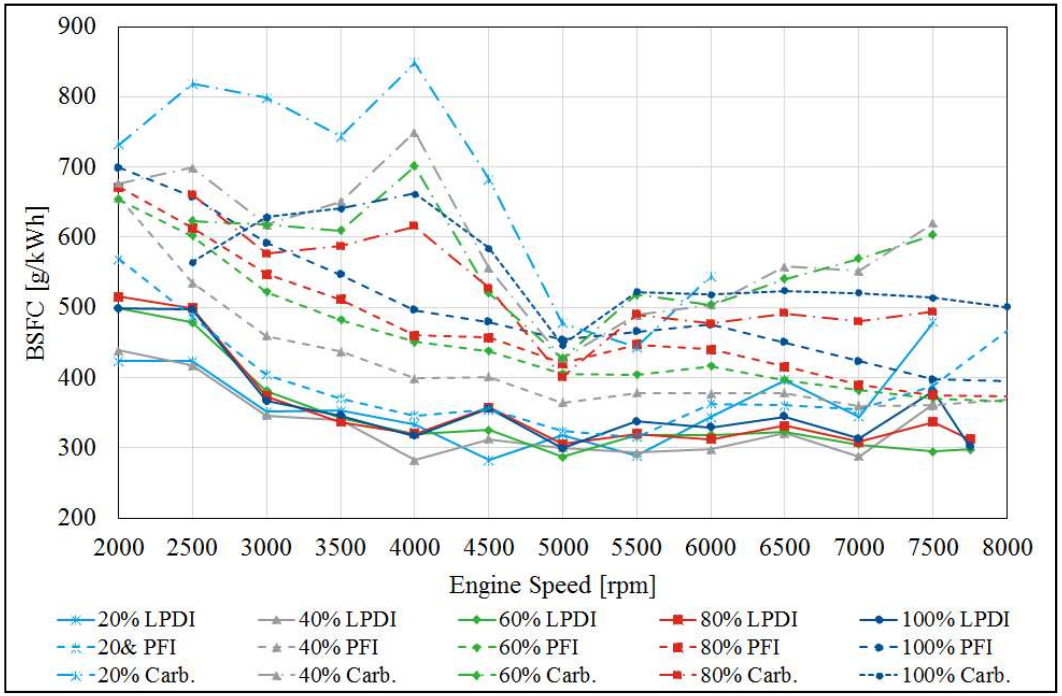
LPDI Engine - Florence University

- Performance



LPDI Engine - Florence University

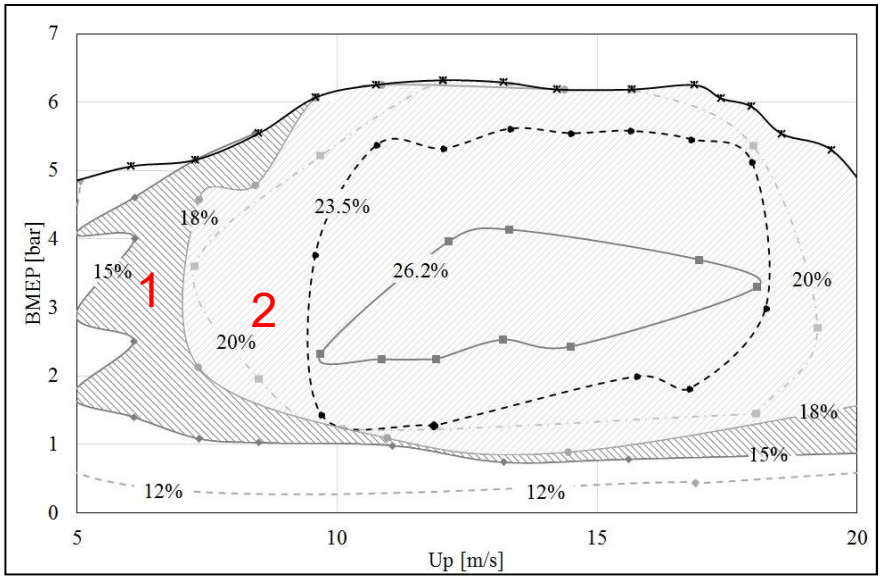
- Brake specific fuel consumption Comparison
  - Carburetor vs PFI vs LPDI
    - LPDI BSFC considerably reduced respect to PFI and Carbureted versions
      - Min BSFC 270 g/kWh
        - » 4000rpm 40% load
    - LPDI High BSFC at low rpm
      - Air-fuel mixing & Low engine efficiency



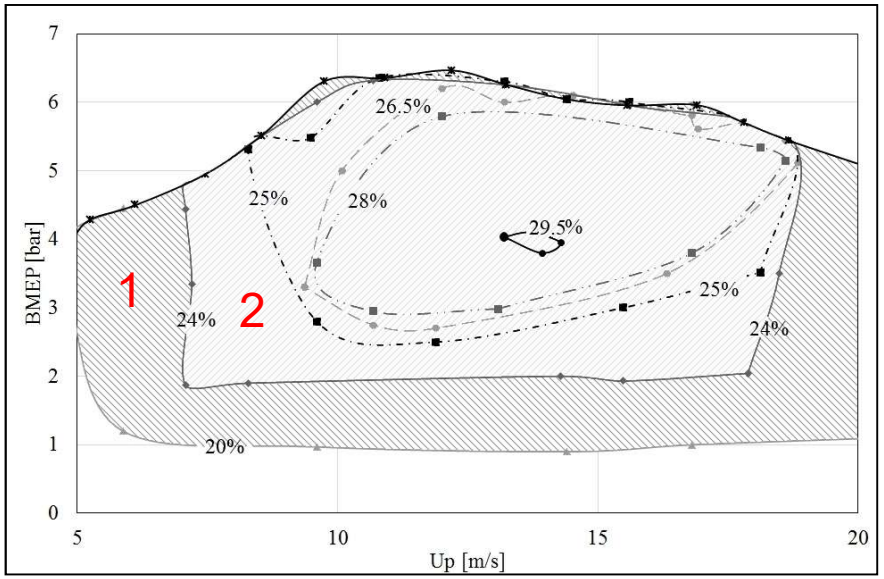
LPDI Engine - Florence University

- Brake specific fuel consumption comparison

PFI

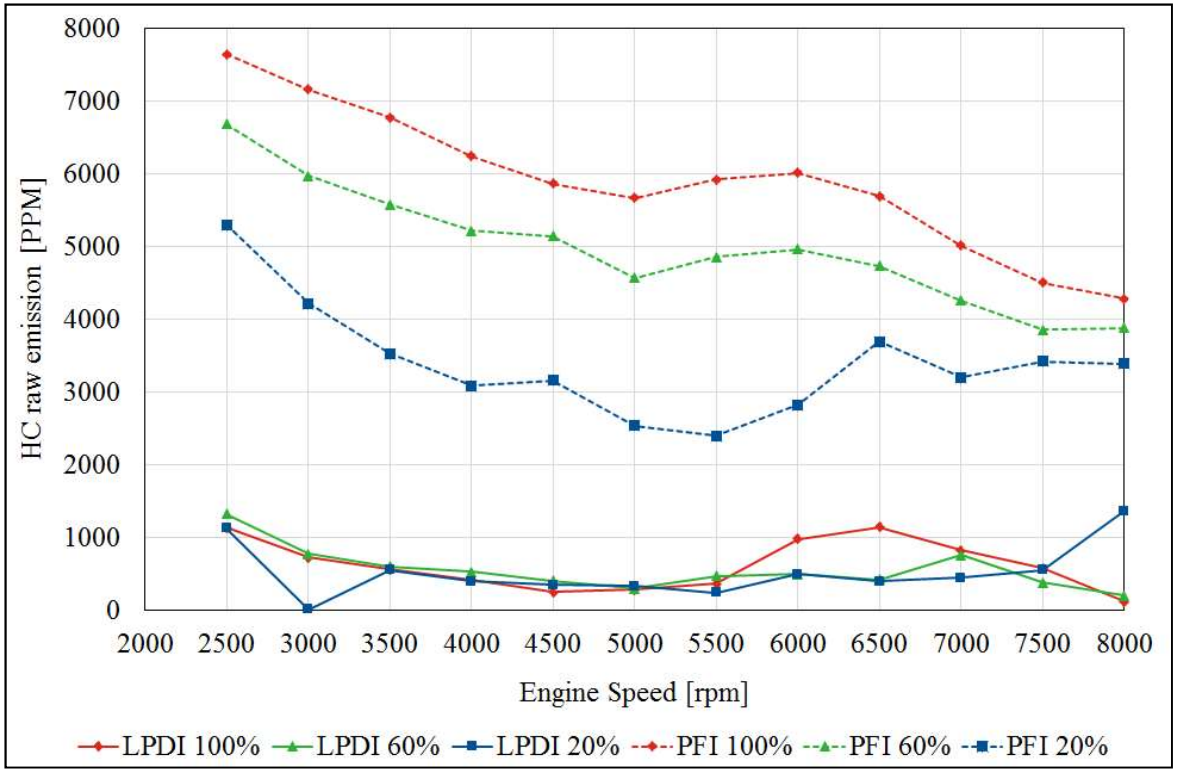


LPDI



LPDI Engine - Florence University

- Exhaust gas emission (HC raw emission)
  - PFI vs LPDI
    - LPDI HC raw emission considerably reduced respect to PFI
    - LPDI HC emission comparable to 4S SI engine



LPDI 2S engine

- Engine performance
  - No significant difference between Carbureted, PFI and LPDI engine
- Specific fuel Consumption
  - Strong consumption reduction for LPDI engine, on average 35% less respect to PFI engine
  - Fuel short circuit reduction
- HC raw emission
  - LPDI engine allows emissions comparable with 4S engine, almost one order less than PFI engine