Engine Combustion Network

Towards ECN 6: Topic 1/2/3 overview

Non-Reactive Spray committee

Topic 1:	**Internal flow**	**Mathis Bode** m.bode@itv.rwth-aachen.de
Topic 2:	**Near nozzle flow- break-up**	**Michele Battistoni** michele.battistoni@unipg.it
Topic 3:	**Atomization and mixing**	**Michele Bardi** michele.bardi@ifpen.fr
	Committee coordinator	**R. Payri** rpayri@mot.upv.es

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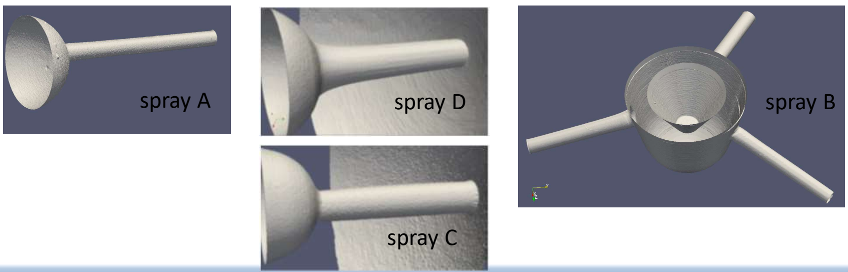
Notes

- More and more simulations consider both nozzle internal flow and near-field flow and how this affects spray characteristics
  - This allows proper boundary conditions
  - Transient effects can be tackled
  - Focusing on either nozzle internal flow or near-field flow only seems questionable (possibly, same simulation for two topics)

- Three different nozzles available: Spray A, C, D, (B from topic 7)
  - With known boundary conditions:
    real geometries, with needle tip motion and wall temperatures



Main Research Objectives

1. Temperature dependence
2. Transient spray angle
3. Spray structure

   (putting together the puzzle from micro to macro)
4. Multiple injections/moving needle

1) Temperature dependence 1/3

- Objective: Impact of temperature effects on the spray formation (fuel and walls)
  - real orifice temperature vs. presumed (nominal cases)
  - different fuel and nozzle wall temperatures
  - cavitation occurrence
- Motivations:
  - Temperature at orifice is uncertain in many experiments
  - Spray C/D showed different behavior with respect to changes in temp.
  - What happens if we introduce lighter fuels or blends (toluene, n-heptane, iso-octane, etc…)?
  - What fuel temp. do we start caring of transcritical/supercritical behavior?
- Hypothesis:
  - Evaporation and mixing changes, atomization might not
  - If cavitation is present, temperature has a huge impact (spray C)
  - If cavitation is not present, temperature has a mild effect (spray D and A)

1) Temperature dependence 2/3

- Quantities for study:
  - For internal flow (topic 1)
    - Integral volume fraction as function of wall temperature
    - Volume fraction as function of nozzle inlet distance and wall temp.
    - Liquid density, exit velocities (velocity profile), …
    - Thermal boundary layer
  - For external flow (topic 2)
    - Cone angle as a function of time
    - Radial, axial profiles of mass distribution
    - Radial, axial profile of droplet size (measured LDM, etc… or simulated)
  - Mixing (topic 3)
    - Cone angle as a function of time
    - Radial, axial profiles of mass distribution
    - Radial and axial profile of velocities
    - Known effect on liquid length

1) Temperature dependence 3/3

- References for temperature effect
  - Published data / experiments:
    - Sandia SAE 2018 paper LDM and Schlieren (Spray C/D)
    - IFPEN new test campaign? (Velocity field?)
    - CMT tests *Payri et al, ATE 2012 /* Spray A - Liquid length
    - Ask for more fuel Temperature tests spray C/D?
  - ECN presentations:
    - ECN5.7: Fuel temperature in spray A (Pedro Marti),
    - ECN5.7: hot Spray C vs. D (Shane Daly),
    - ECN5.7: Asymmetry of Spray C cavitation (Brandon Sforzo)
- Proposed common fuel temperature conditions for ECN6:
  - 300 K (cold condition)
  - 363 K (std)
  - 423 K (high temperature)

2) Transient spray angle (1/3)

- Objective: Understanding of development of spray angle over time
- Motivations:
  - Mixing in the near field, and liquid length and mixture fraction in the far field are affected.
  - Transient measurement show a change of the spray angle over time which is not understood nor generally considered for spray modeling.
- Hypothesis:
  - Fluid mechanics causes:
    - Varying turbulence levels generated by geometry imperfections, flow accelerations, and needle motion.
  - Thermodynamics causes:
    - Varying propensities to cavitate, susceptible to fuel temperature variations from SOI to EOI.

2) Transient spray angle (2/3)

- Quantities for study:
  - Spray cone angle as function of time
  - Liquid length vs time
  - Mixing field vs time
  - Intact core length
- References for transient spray angle:
  - Published data / experiments
    - Westlye et al. (2016): Penetration and Combustion Characterization of Cavitating and Non-Cavitating Fuel Injectors under Diesel Engine Conditions
    - Matusik et al. (2017): High-resolution X-ray tomography of engine combustion network diesel injectors
  - ECN presentations
    - ECN5.7: Asymmetry of Spray C cavitation (Brandon Sforzo)
    - ECN5.7: hot Spray C vs. D (Shane Daly), and upcoming SAE2018 paper
    - ECN3.4: Liquid and vapor jet penetration with a variable spreading angle
    - ECN4.4: Spray A & B: Spray axis angle fluctuations
    - ECN5: Topic 7 on spray B

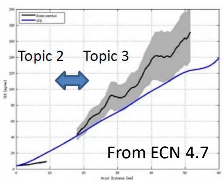
2) Transient spray angle (3/3)

- References for transient spray angle (continuation):
  - Experiments – far field:
    Much data available: collect all the related relevant experimental
    Results (Schlieren/DBI/high-speed data)
    Quantitative interpretation of DBI data ?
    Add the focus on comparison Spray C/D
  - CFD – far field:
    Analysis to be performed on the available simulations
    Specific requirements should be decided in the early instants to be evaluated for the transient spray angle (0.3/0.4/0.5 ms ASOI?)
    New contributions expected for Spray C/D: same instants as for spray A?

3) Spray structure (1/3)

- Objective: Understanding of the spray structure near the nozzle and quantifying atomization (SMD), spatially and temporally

- Motivations:
  - Transition from continuous to dispersed flow is very important for spray modeling
  - Differences between Spray A and Spray D (both non-cavitating) observed
  - Still need to reconcile near-nozzle x-ray radiography (ANL) with down-stream Rayleigh (SANDIA) or LIF (IFPEN)



- Hypotheses:
  - The more cavitation inside the nozzle, the shorter is the continuous liquid core.
  - The shorter the dimensionless nozzle length, the shorter is the continuous liquid core ???
  - Surface instabilities amplified by cavitation and turbulence

3) Spray structure (2/3)

- Quantities for study:
  - Plane averaged volume fraction/SMD as function of distance to orifice
  - Line of sight magnitudes from CFD to be compared with experiments
  - Local statistics -> axial and radial SMD and diameter pdf.
  - Integral amount of cavitation (keeping orifice cross section and cone angle constant!?)
  - USAXS, PDPA, high magnification

- References for SMD/flow structure:
  - Published data:
    - Westlye et al. (2016): Penetration and Combustion Characterization of Cavitating and Non-Cavitating Fuel Injectors under Diesel Engine Conditions
    - Matusik et al. (2017): High-resolution X-ray tomography of engine combustion network diesel injectors

3) Spray structure (3/3)

- References for SMD/flow structure (continuation):
  - Experiments – far field:
    - Quantitative data available:
      - Sandia Rayleigh / IFPEn velocity field (Spray A)
      - IFPEN- LIF (Spray C/D)
      - New IFPEn PIV (Spray A/C/D)
      - Ask for more high resolution data (DBI / LDM etc.) with focus on spray C/D
      - USAXS data for SMD published doi:10.1016/j.ijmultiphaseflow.2017.03.005

  - ECN presentations
    - ECN 5 workshop – topic 2

  - CFD
    - Analysis on the available models.
    - Emphasis on Spray A vs D and C vs D;
    - new contributions

4) Multiple inject./moving needle (1/3)

- Objective: Understanding the interactions between consecutive injections
- Motivations:
  - In real engine injection transients and multiple injections are largely dominating the mixing process
  - The analyses carried out up to now do not enlighten on the models capabilities to correctly reproduce the physics
  - Possibility of extending the analysis with new data available from spray C/D (variation in nozzle shape and internal flow features)
  - At which level we can find injection interaction? on which quantities?
- Hypothesis:
  - The pilot injection affects substantially the initial conditions for the second injection (gas temperature, composition, velocity field)
  - The behavior of the second injection is strongly modified if compared to single event injection

4) Multiple inject./moving needle (2/3)

- Quantities for study – far field:
  - Spray global parameters: Vapor-Liquid penetration
    Cone angle (Transient)
  - Velocity and mixing field
- References for multiple injections:
  - Published data:
    - Skeen et al. (2015): Visualization of ignition processes in high-pressure sprays with multiple injections of n-dodecane Cavitating and Non-Cavitating Fuel Injectors under Diesel Engine Conditions (double injection spray A)
    - Moiz et al 2017: Simultaneous Schlieren–PLIF Studies for Ignition and Soot Luminosity Visualization With Close-Coupled High-Pressure Double injections of n-Dodecane (Double injection - Spray A)

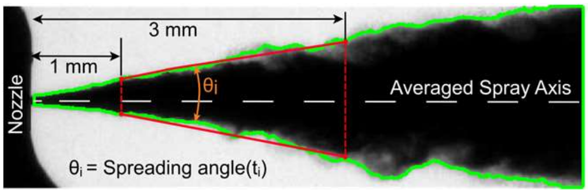
4) Multiple inject./moving needle (3/3)

- References for multiple injections (continuation)
  - Experimental data:
    - Available experimental data (Sandia / TU/e ??)
    - IFPEn new database for spray A with pilot duration / dwell variations
    - IFPEn reference case for Spray C/D
  - CFD:
    - Propose a set of parametric variations on Spray A
    - DT: 0.3 – 0.5 – 0.7 ms
    - Pilot: 0.3 – 0.5 – 0.7 ms
    - Emphasis on reference Split for Spray C/D Split

Info on requested output data (1/2)

Definition of near-exit cone angle:

- average on the range 1-3 mm from exit for Spray A and Spray B
- Average on the range 2-6 mm from exit for Spray C and Spray D
- threshold level = mass based



Iso-contour of fuel concentration 0.001 for both liquid and vapor is a good definition

Info on requested output data (2/2)

For all injectors:

- Mass flow rate and momentum flow rate at the nozzle exit
- Fuel spray tip penetration and near nozzle cone angle vs. time
- Contour plots of projected liquid density at 0.1, 0.5 and 1.0 ms after SOI
  Projection plane is 0° plane (injector in the theta = 0 position)
- Transverse integrated mass (TIM) vs. axial distance at 0.1, 0.5 and 1.0 ms after SOI
- 2D contours of liquid volume fraction (LVF) across cross-section at 0.1, 0.5 and 1.0 ms after SOI at x = 0.1, 0.6, 2.0, 6.0, and 10.0 mm
- Axial and radial profiles of projected density, density and LVF, time-averaged between 0.5-1.0 ms, at x = 0.1, 0.6, 2.0, 6.0, and 10.0 mm (locations for radial profiles)

SMD

- Mean droplet size (SMD) at x = 1, 4, 6, 8, 12, 20 mm time-averaged around 1.0 ms
- SMD at the above axial positions (spatially averaged on the cross section)
- Radial profiles of SMD vs. radial position at the above axial positions (spatially averaged on the smallest possible sampling region – method dependent)
- PDF of droplet diameters at above axial positions

…… to expand ……

Contributors

MODELLING:	EXPERIMENTS:
Argonne : S. Som, G. Magnottl	Argonne : C. Powell, K. Matusik
Aalto University: Armin Wehfritz (now at UNSW)	Brighton: C. Crua
CMT: Pedro Marti, Jose Manuel Pastor	CMT: R. Payri, A. Viera
Sandia: Shane Daly, M. Arienti	CAT: R. Fitzgerald
IFPEN: C. Habchi	Georgia Tech: C. Genzale, B. Knox
Perugia: M. Battistoni	IFPEN : M. Bardi, LM Malbec
Aachen: M. Bode	Orleans : Hairouche, Hespel
U. Tasmania: Hongjiang Yu	Poitiers : J. Sotton, M. Houidi
Umass: D. Schmidt, Peetak Mitra, Sampath Rachakonda	Sandia: S. Skeen, L. Pickett
Georgia Tech: C. Genzale	Tu/e: N. Maes
Wisconsin: M. Trujillo, Arpit Agarwal	
PoliMi: T. Lucchini	
Bochum: Martin Blume	
Zagreb: Zvonimir Petranovic	
Lyon: O. Kaundinya	