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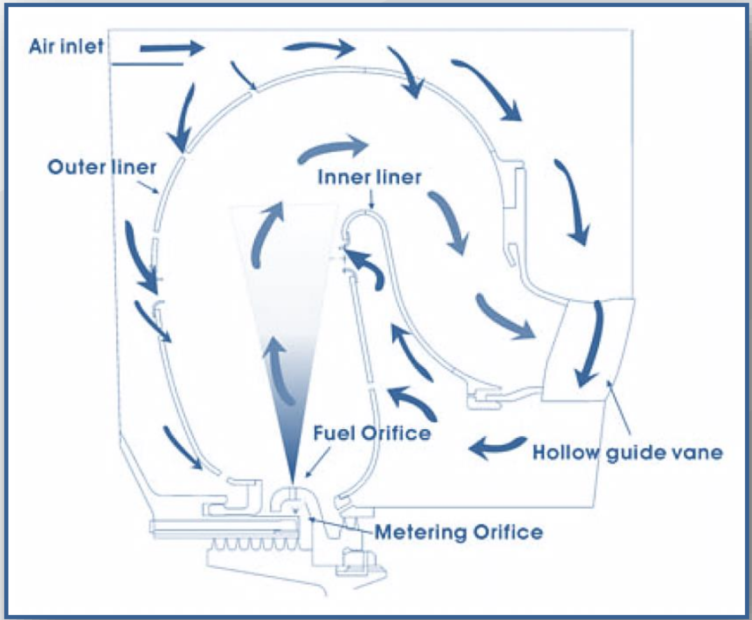
Combustor CFD

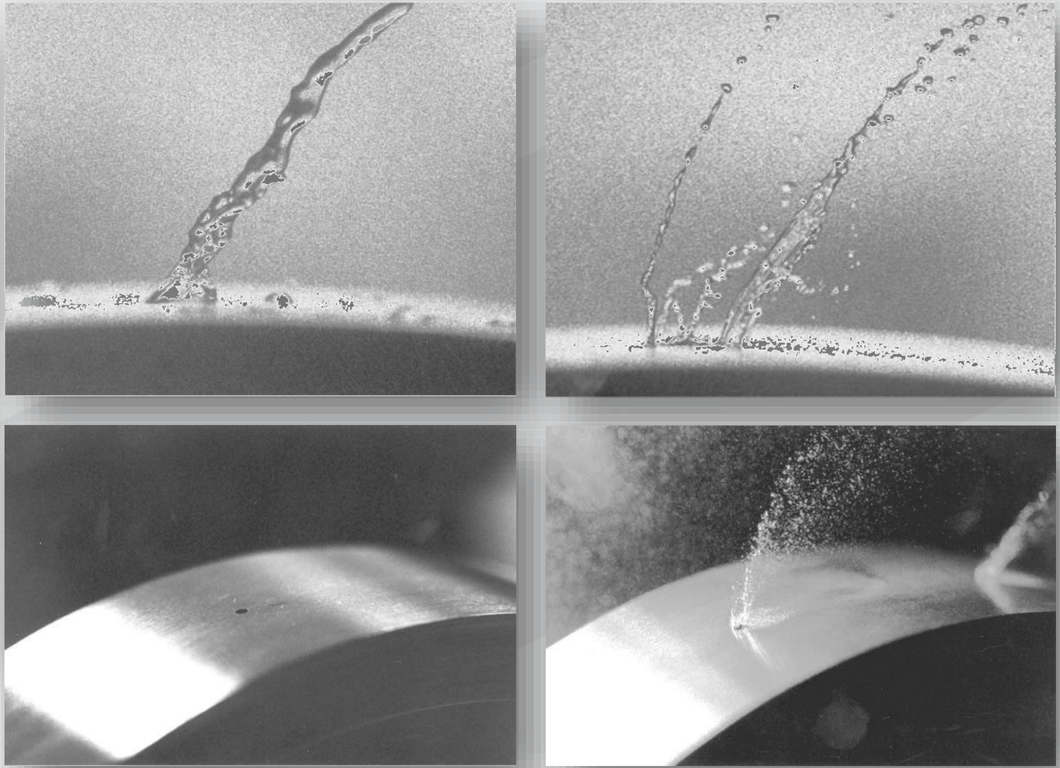
Lagrangian Injection Simulation of a Slinger Combustor

18th Annual Israeli Jet Engine Symposium November 2019

Ariel Cohen

Slinger Fuel Injection

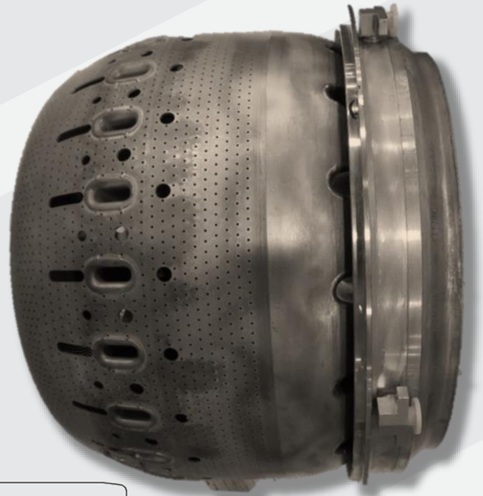


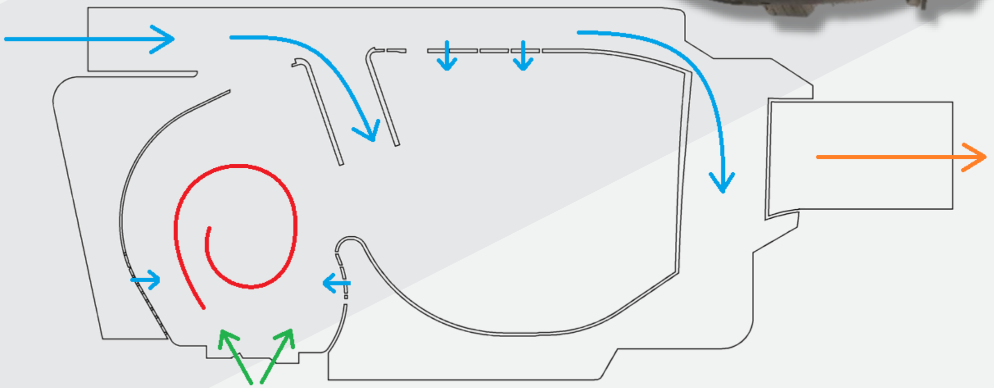


Sources:
Choi, S. et al, Journal of Mechanical Science and Technology 22, 2008.
Dahm, W. J. A. et al, 32nd AIAA Fluid Dynamics Conference, 2002.

Description of the Case

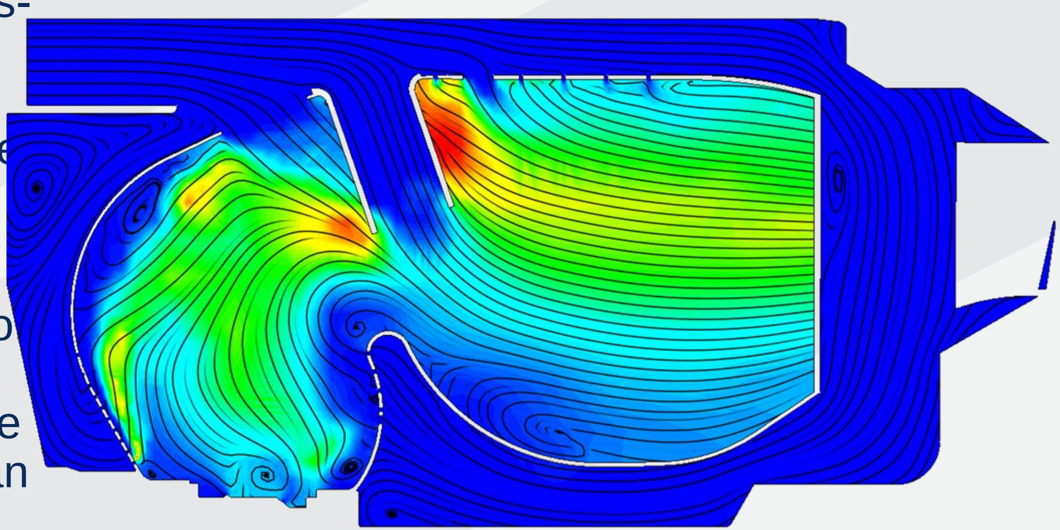
- Slinger combustor – high speed rotary fuel injector incorporating a number of injection orifices results in effective fuel vaporisation
- The combustor is axi-periodic and a single representative segment is used for simulations
- Known combustor performance parameters include:
  - Inlet (compressor exit) air mass flow rate
  - Inlet flow pressure / temperature
  - Fuel inlet mass flow rate
  - Combustor outlet radial temperature profile
- Boundary conditions:
  - Inlet mass flow + velocity vectors (air and fuel)
  - Outlet static pressure





Reference Simulation

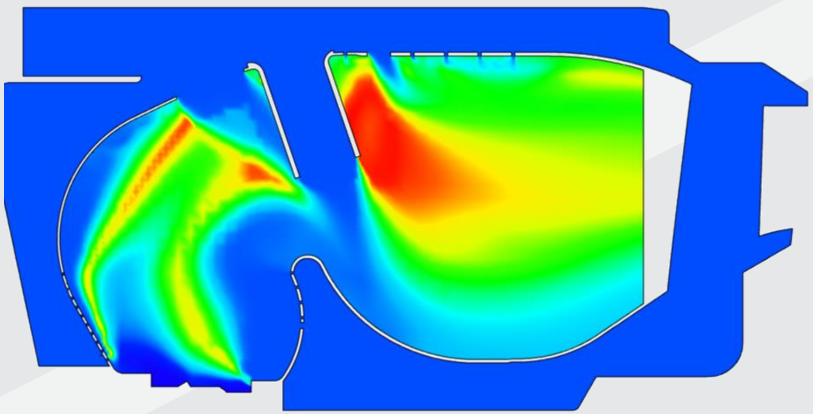
- Reference simulations were performed with a commercial finite volume solver using a Cartesian mesh with immersed boundaries and the k-ε turbulence model
- Fuel injection was based on a gas-phase flow with the surface area of the fuel inlets adjusted to account for the low density in orde to maintain the correct injection velocity
- The prediction of the flame locatio was inaccurate, leading to higher temperatures than expected in the combustor secondary zone and an outlet temperature profile which did not match experimental data



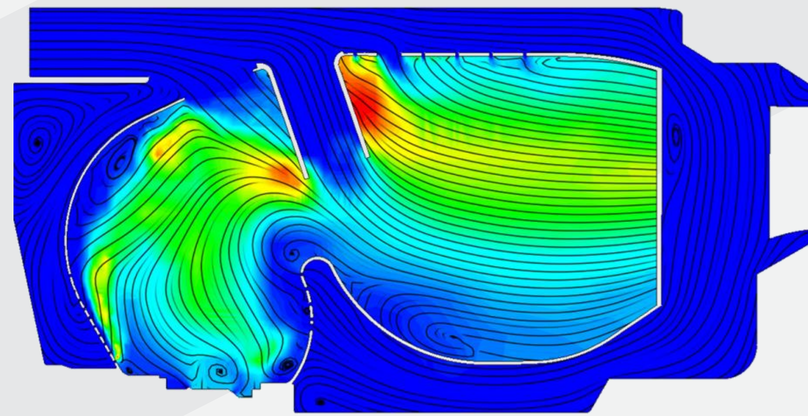
Reference simulation results - temperature and streamlines

Numeca – Gas Injection

- In Numeca FINE^{TM}/Open non-premixed combustion is modeled based on the assumption that the chemical reaction rate is infinitely fast and the mixing rate controls the rate of combustion (see *Lefebvre, A. H., Gas Turbine Combustion, p. 140*)
  - The combustion problem is therefore split into two sub-problems – (a) global mixing and
    (b) local flame structure, with the latter modeled using the flamelet model
- Turbulence is modeled with the k-ε turbulence model with extended wall function

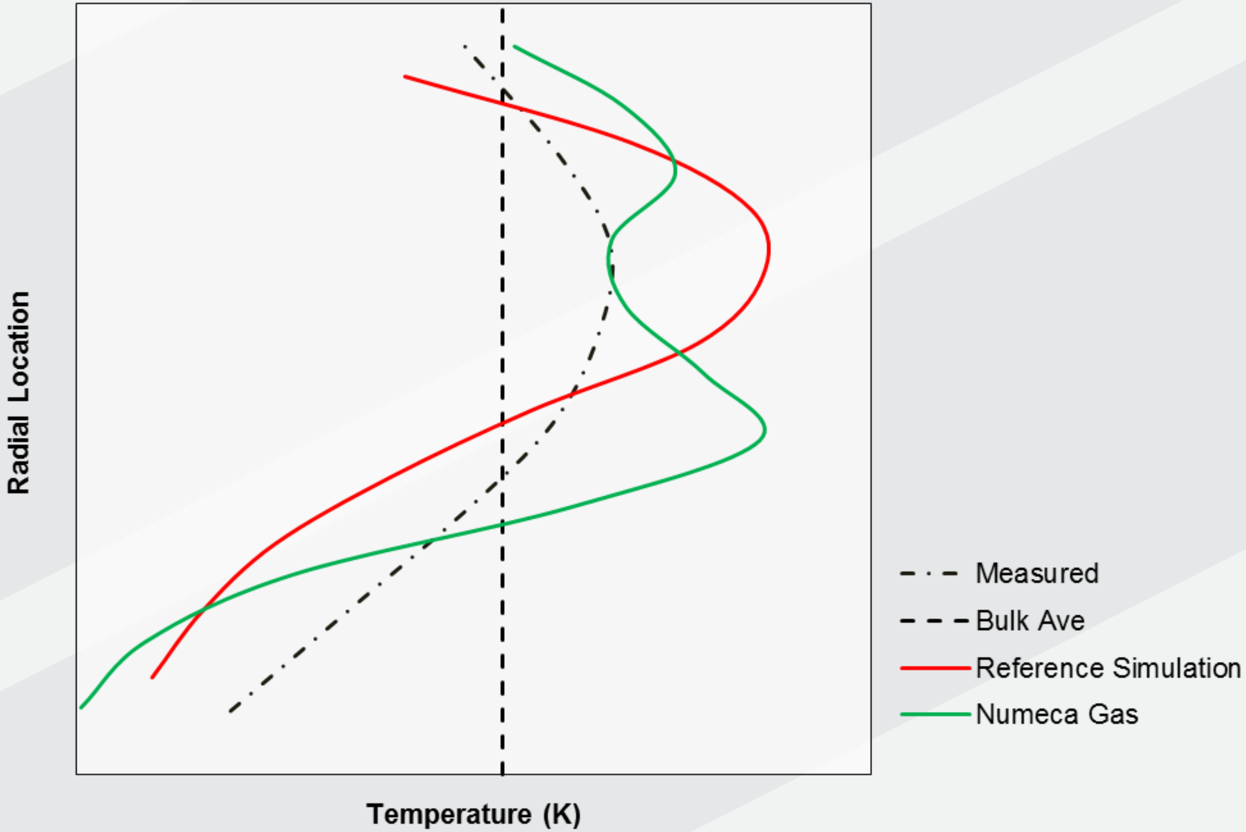


Numeca – static temperature

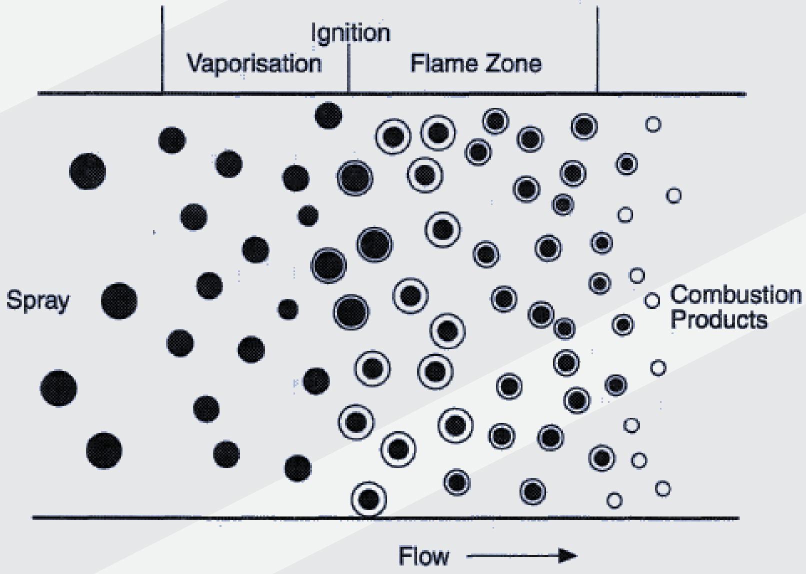


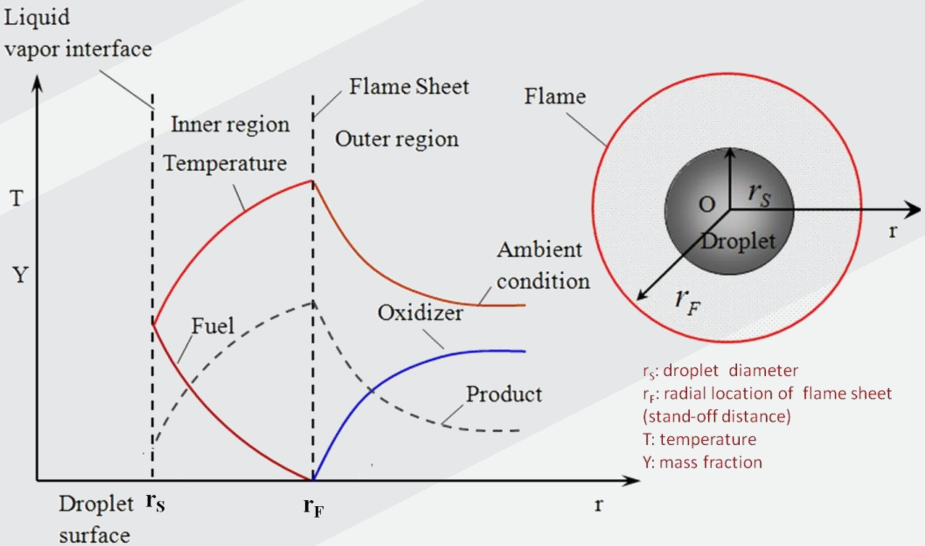
Reference simulation results - temperature and streamlines

Outlet Temperature Profiles



Motivation: Droplet Combustion

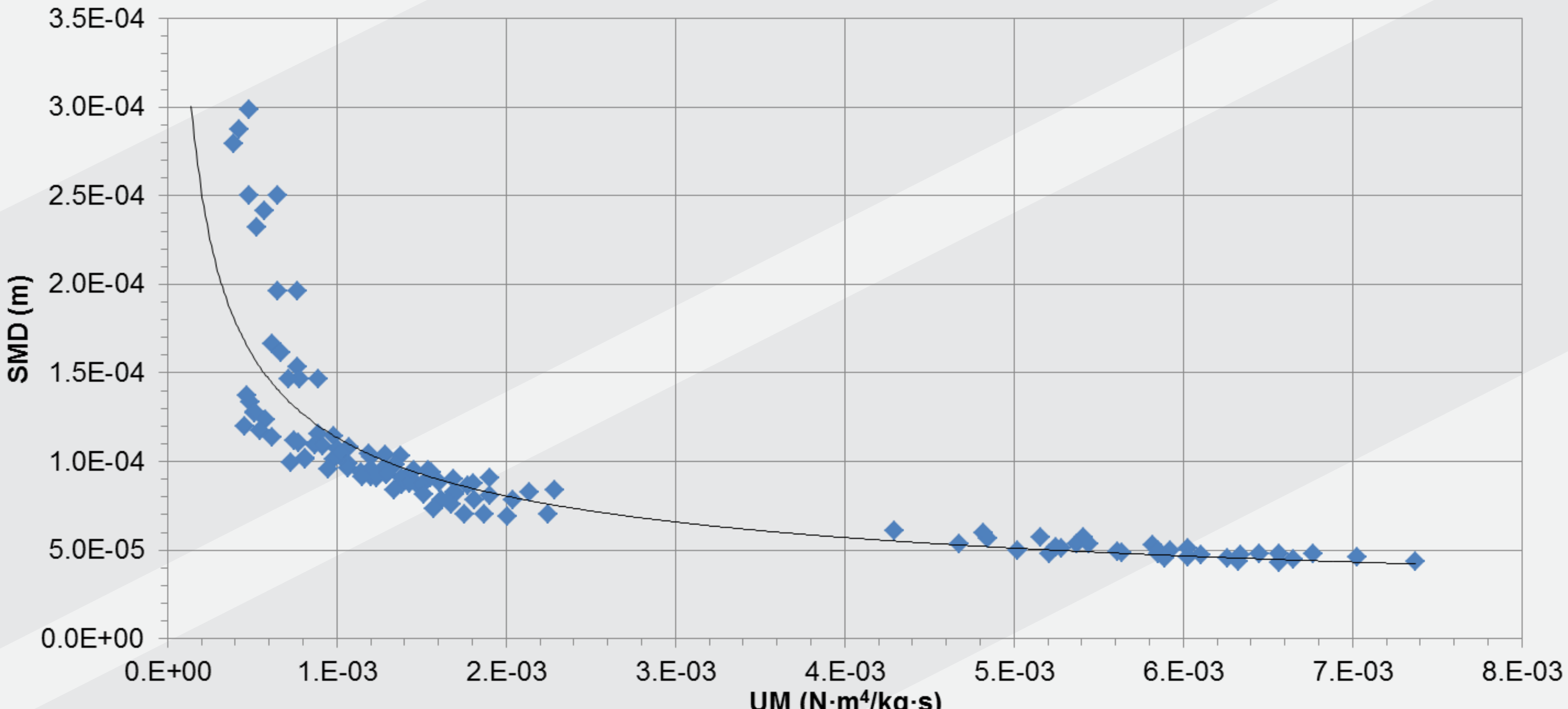




r_S: droplet diameter
r_F: radial location of flame sheet (stand-off distance)
T: temperature
Y: mass fraction

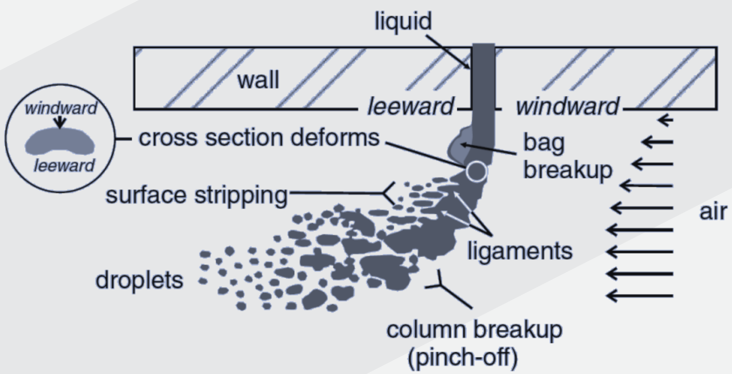
Sources:
www.thermopedia.com/content/766/
www.home.iitk.ac.in/~mishra/virtual_lab/documentor/theory8.html

Slinger Performance – Normalised Data from the Literature



Lagrangian Injection Modelling in Numeca FINE™/Open

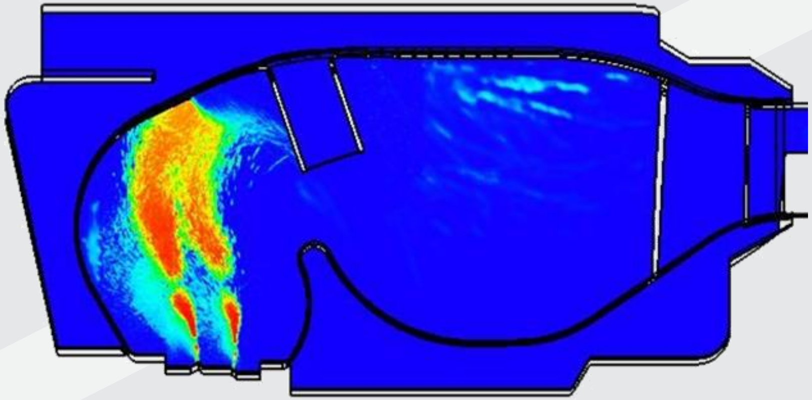
- In the Lagrangian approach parcels, each representing a given number of actual particles, are tracked, their paths through the flow-field determined by Newton's 2nd Law
- Parcels are subject to drag, pressure forces and turbulent dispersion
- Involves more physical models in simulation:
  - Primary atomization
  - Secondary break-up
  - Droplet evaporation
- 3 possibilities to simulate injection:
  - LIZA model for pressure-swirl atomizers,
  - Blob model for plain orifice atomizer
  - Injection points file for arbitrary injection system
- Optional "Momentum Two-Way Coupling" enables the consideration, iteratively, of the mutual interaction between the particle parcels and the surrounding flow



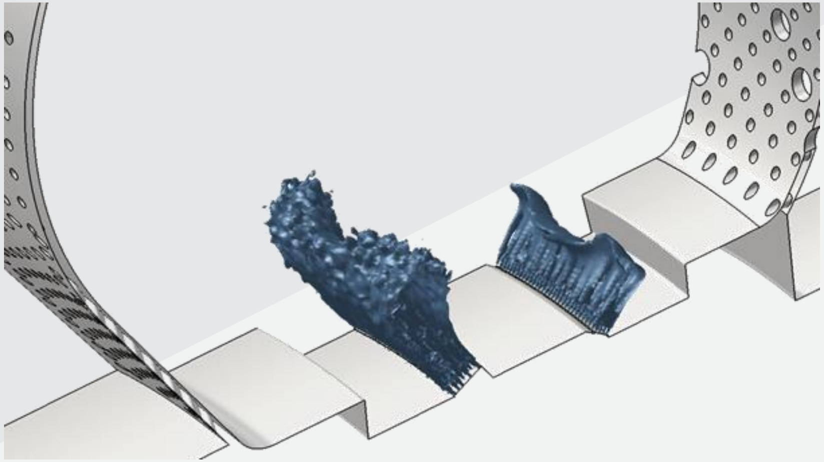
Source:
Sedarsky, D. et al, Exp. Fluids, 2010

Lagrangian Injection

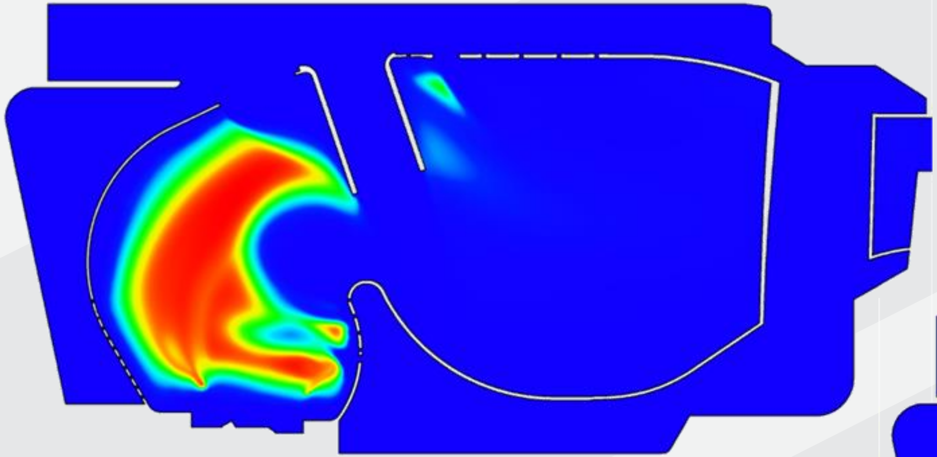
- The fuel injection was modeled using the injection points method
- The droplet size at the fuel inlets is calibrated to match the expected droplet size at a given distance from the injection plane
- In the future, further calibration work will be performed on non-reactive flows, to match the experimental data from the literature
- 70 hours on 120 cores with 15,000 iterations on the fine grid level



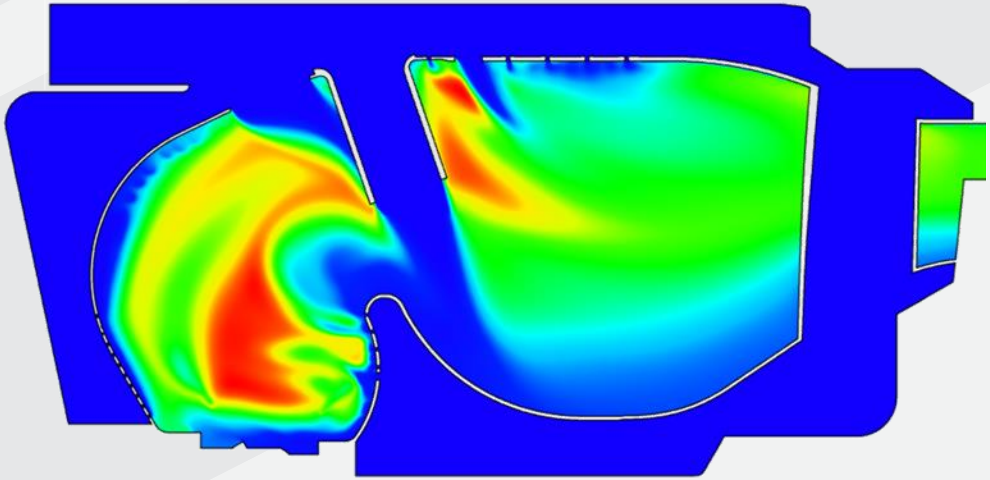
Fuel Spray SMD



Lagrangian Injection – Initial Results

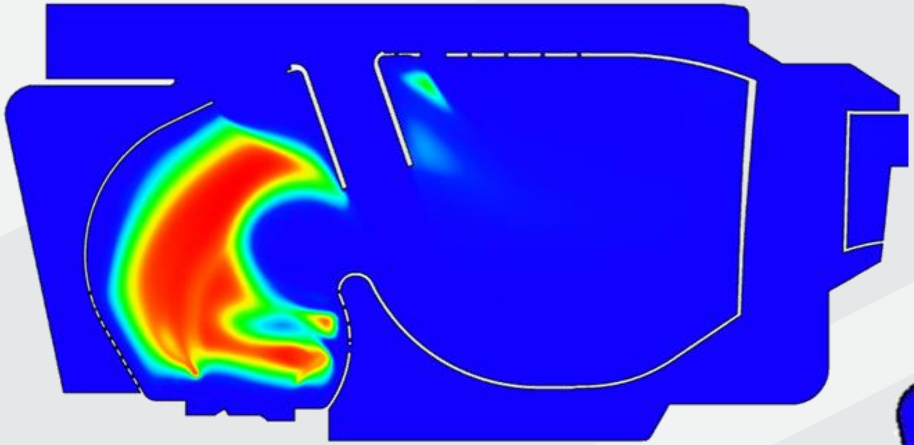


Flame Location (CO Concentration)

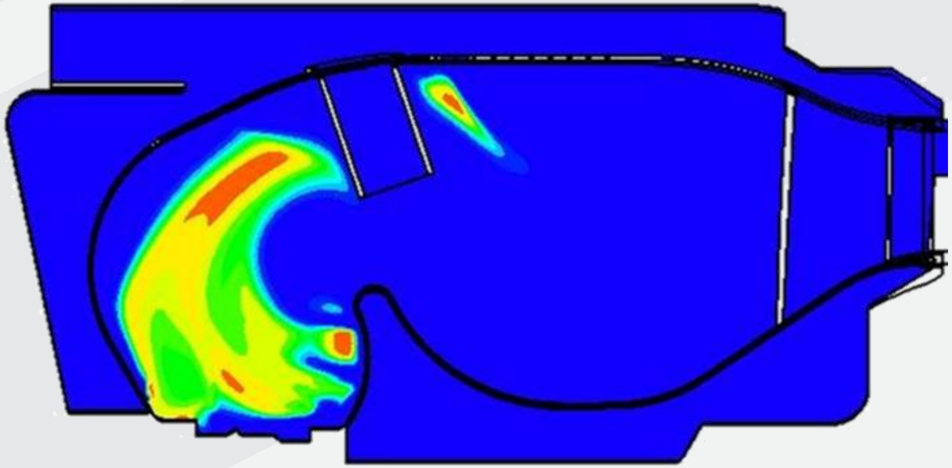


Static Temperature

Lagrangian Injection - The Influence of Momentum Coupling



Flame Location (CO Concentration)
With Momentum Coupling

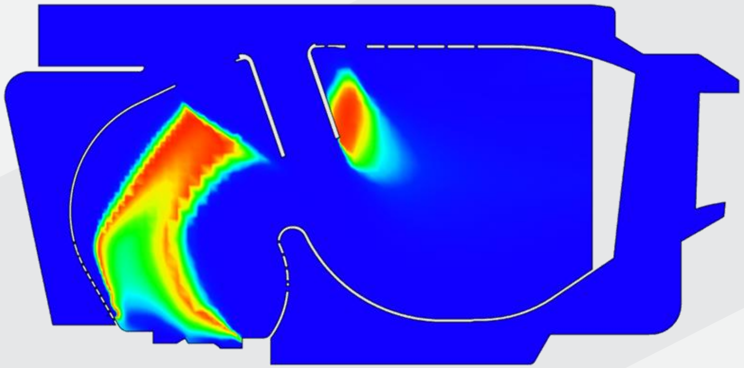


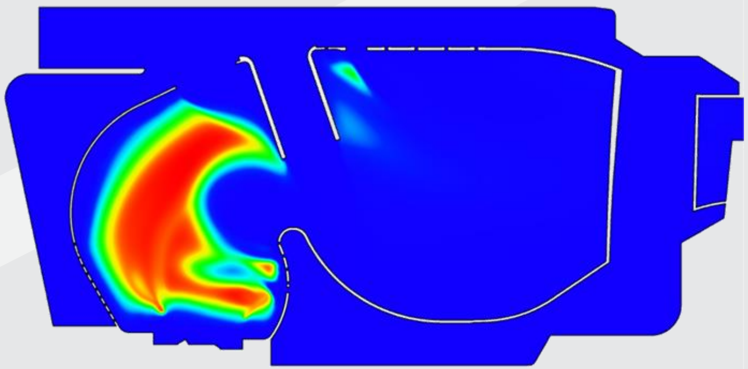
Flame Location (CO Concentration)
Without Momentum Coupling

Gas vs Lagrangian Injection

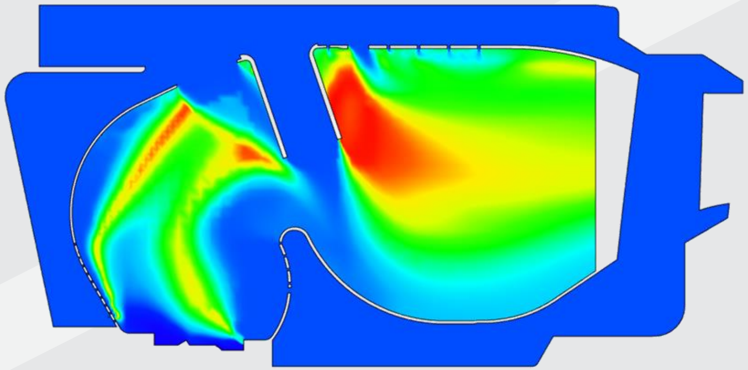
Gas-Phase Fuel Injection

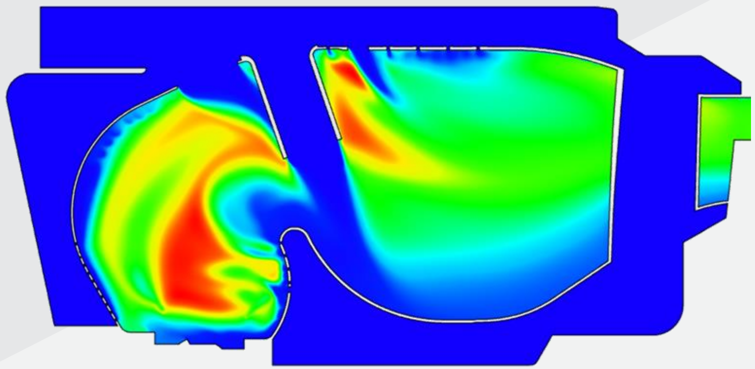
Liquid-Phase (Lagrangian) Fuel Injection





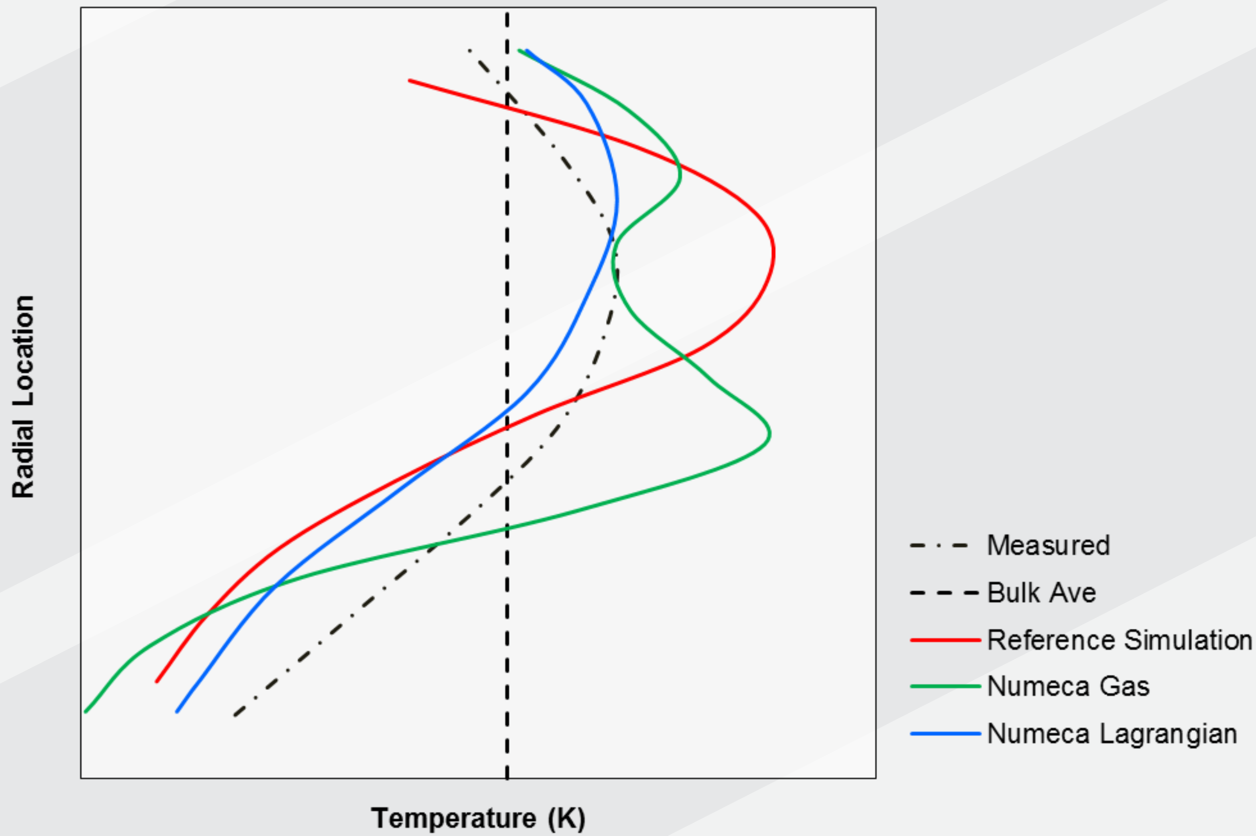
Flame Location (CO Concentration)





Static Temperature

Summary – Outlet Temperature Profiles



Conclusions and Further Work

- In order to properly predict the flame location in a non-premixed combustor with centrifugal fluid-phase fuel injection, the Lagrangian approach is used, with momentum coupling
- Localised stoichiometric fuel-air ratio regions are a characteristic of fuel sprays and this effect is not properly predicted by gas-phase fuel injection, in which the fuel-air ratio is smoothed out over the entire region
- Strong dependency of the outlet temperature profile on fuel injection velocity and direction and on injection droplet size, small dependency on turbulence model (SST vs kε)
- Further calibration of the fuel spray SMD is required in order to properly match the expected droplet size distribution
- CHT simulations will be performed in order to predict the combustor wall temperatures, thus providing an additional calibration tool for the simulation