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Lagrangian Injection Simulation of a Slinger Combustor

יום עיון חישובים נומריים – לשכת המהנדסים

21.01.21

Ariel Cohen



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History of BSEL



Golda Meir, PM of Israel, at BSEL



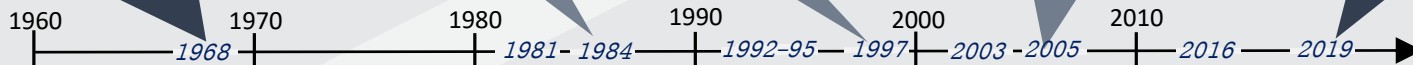
BSEL was founded by Joseph Szydlowski (Turbomeca) and the State of Israel

P&W acquires 40% of BSEL

IPO on Tel-Aviv Stock Exchange

Clal Ind. is the Main shareholder of BSEL

Acquisition of Carmel Forge from PW



Ezer Weizman, President of Israel, at BSEL

State of Israel acquires all of BSEL shares

Ormat acquires 100% of BSEL shares

BSEL acquires LPO, Serbia

FIMI acquires controlling position (45%)



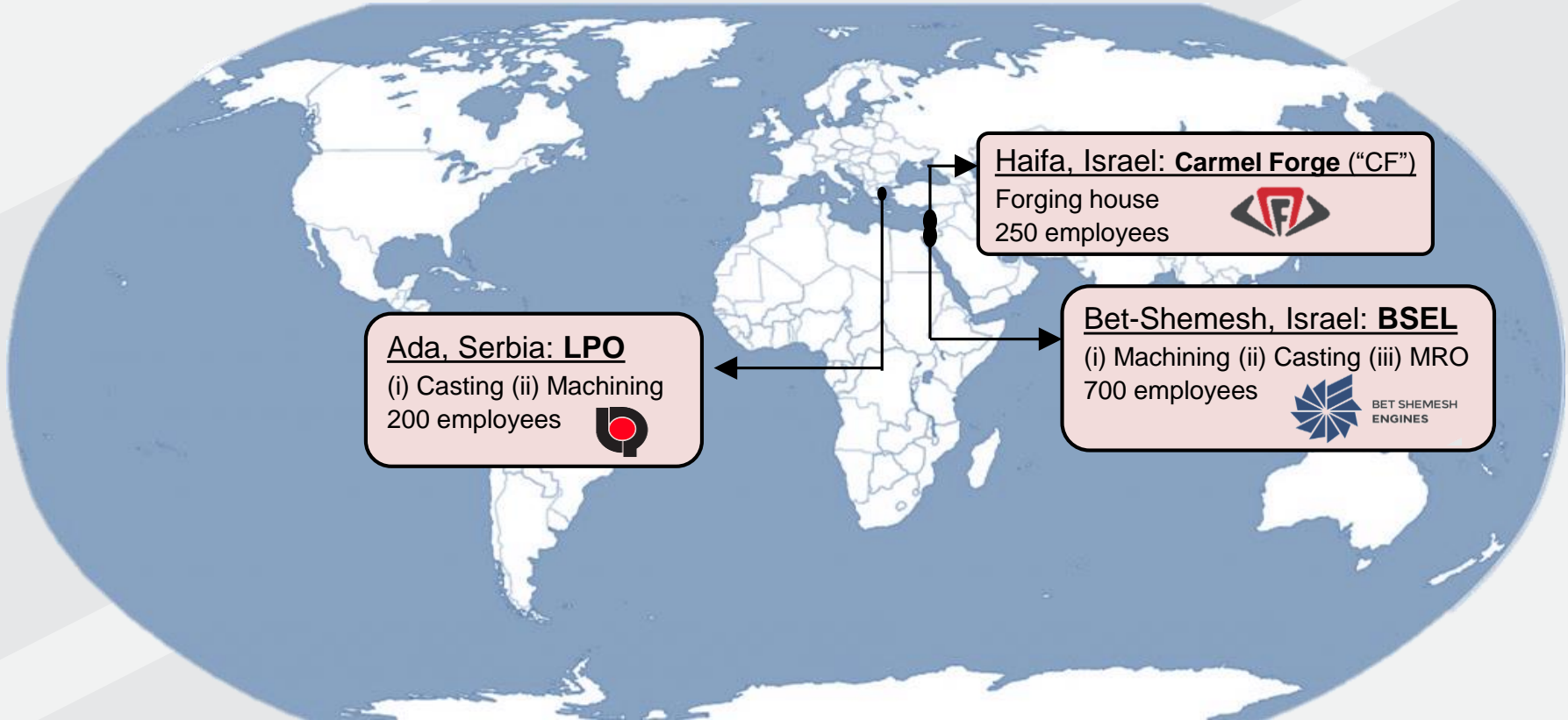


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Bet Shemesh Engines (BSEL) Group

3 Sites; 6 Plants; 1,150 Employees



Ada, Serbia: LPO

(i) Casting (ii) Machining
200 employees



Haifa, Israel: Carmel Forge ("CF")

Forging house
250 employees



Bet-Shemesh, Israel: BSEL

(i) Machining (ii) Casting (iii) MRO
700 employees





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BSEL Group - Main Customers

Parts
(OEM)



Pratt & Whitney Canada

A United Technologies Company



SIEMENS

Avio Aero
A GE Aviation Business



oerlikon



Engines
(MRO and Small
Engines)



RAFAEL
ADVANCED DEFENSE SYSTEMS LTD.



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Main Engines Programs



APS 2300
APS 3200
APS 5000
APS 2600
APS 3240



* NGPF (NEO, C-Series, MRJ)
JT8D
PW4000
F100
APS 1000
* F135



* NGPF (NEO, C-Series, MRJ)
V2500
PWC305-6-7/530/545
* GP7000
MTR390
PW812/814
TP400
LM6000



* NGPF (NEO, C-Series, MRJ)
* TRENT
* TXWB
* Sorella
* Stella
TP400
MTR390



CF34 LM6000
M-601 CF6
V2500 * LEAP



FT8
PW210
V2500

SIEMENS

SGT 100
SGT 200
SGT 300/300TS
RT 61/62

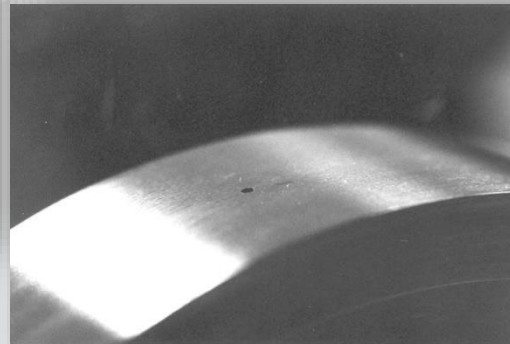
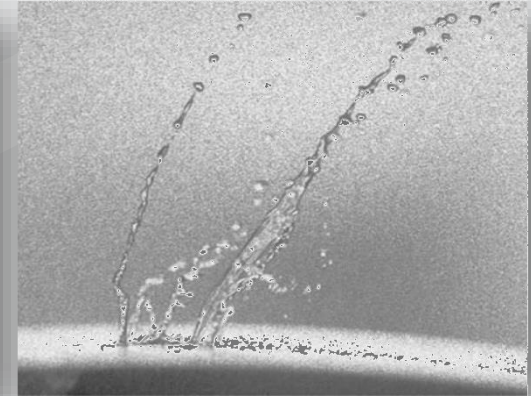
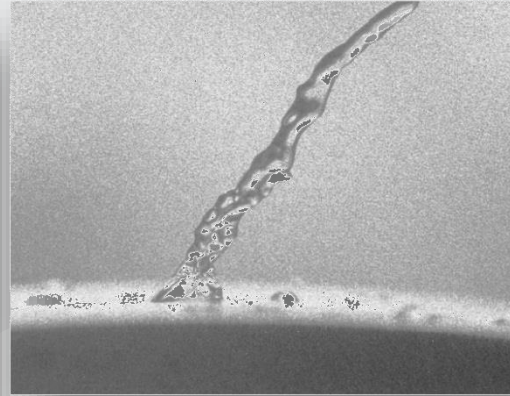
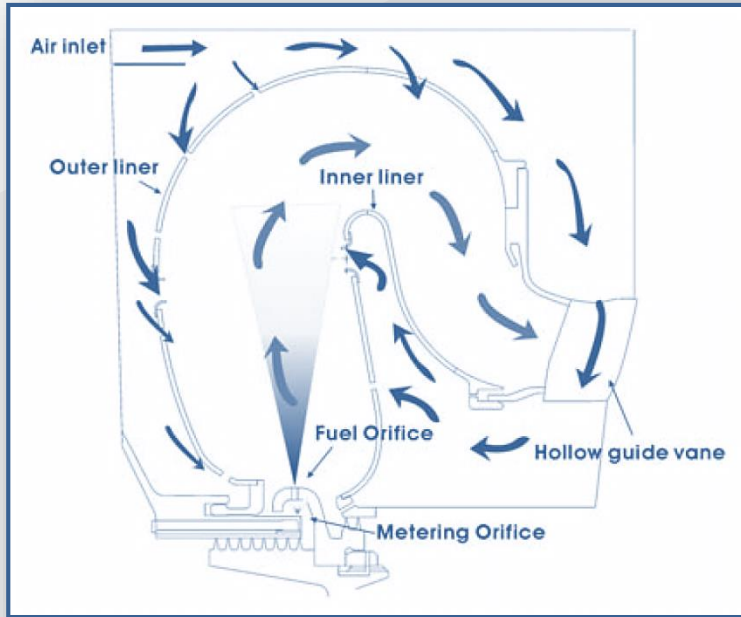
* New Market Programs
Sole Source



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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.

THE POWER OF PROPULSION

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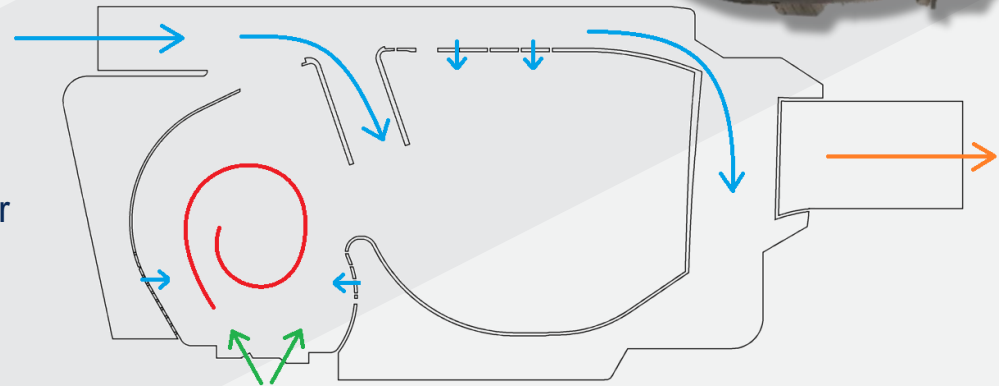
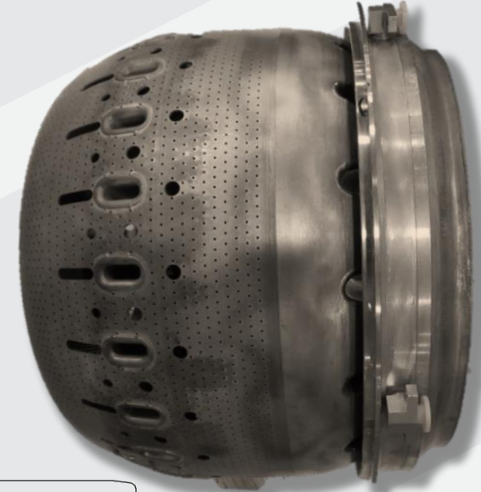


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Description of the Case

- 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



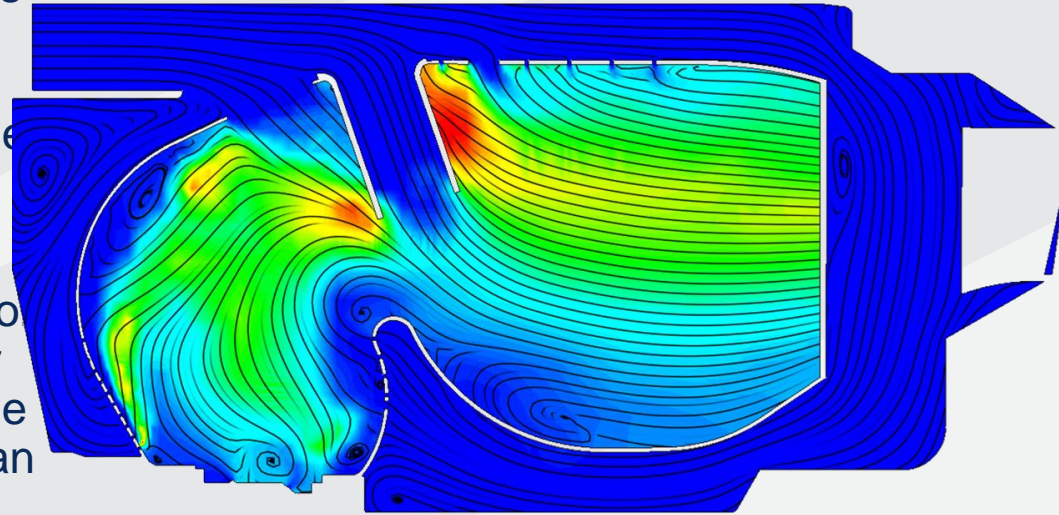


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Reference Simulation

- 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 order to maintain the correct injection velocity
- The prediction of the flame location 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

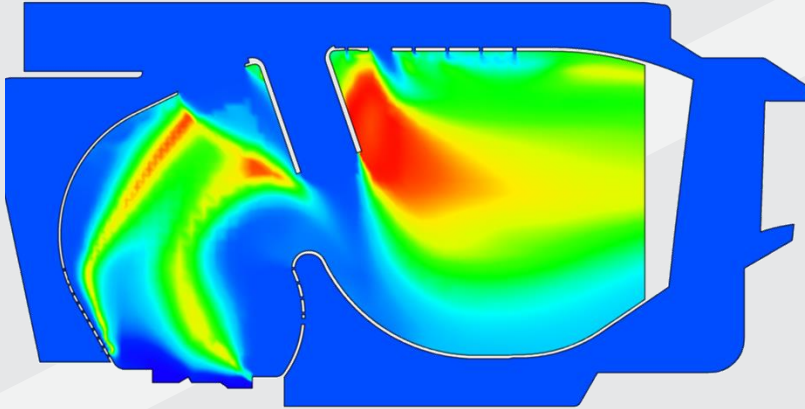


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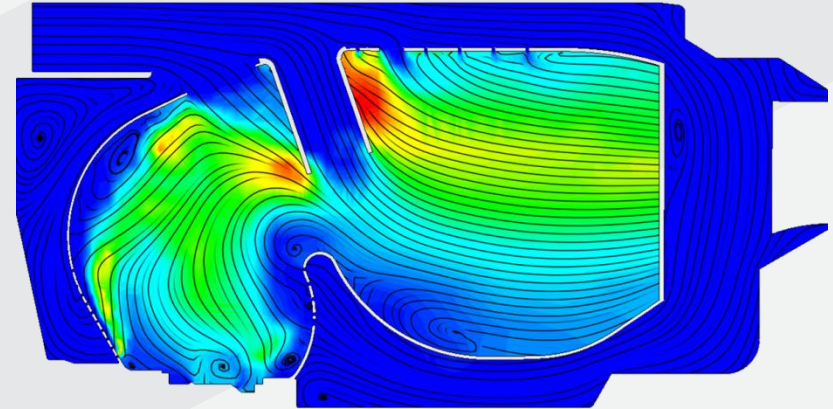


Numeca – Gas Injection

- In Numeca FINE™/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 $k-\epsilon$ turbulence model with extended wall function



Numeca – static temperature



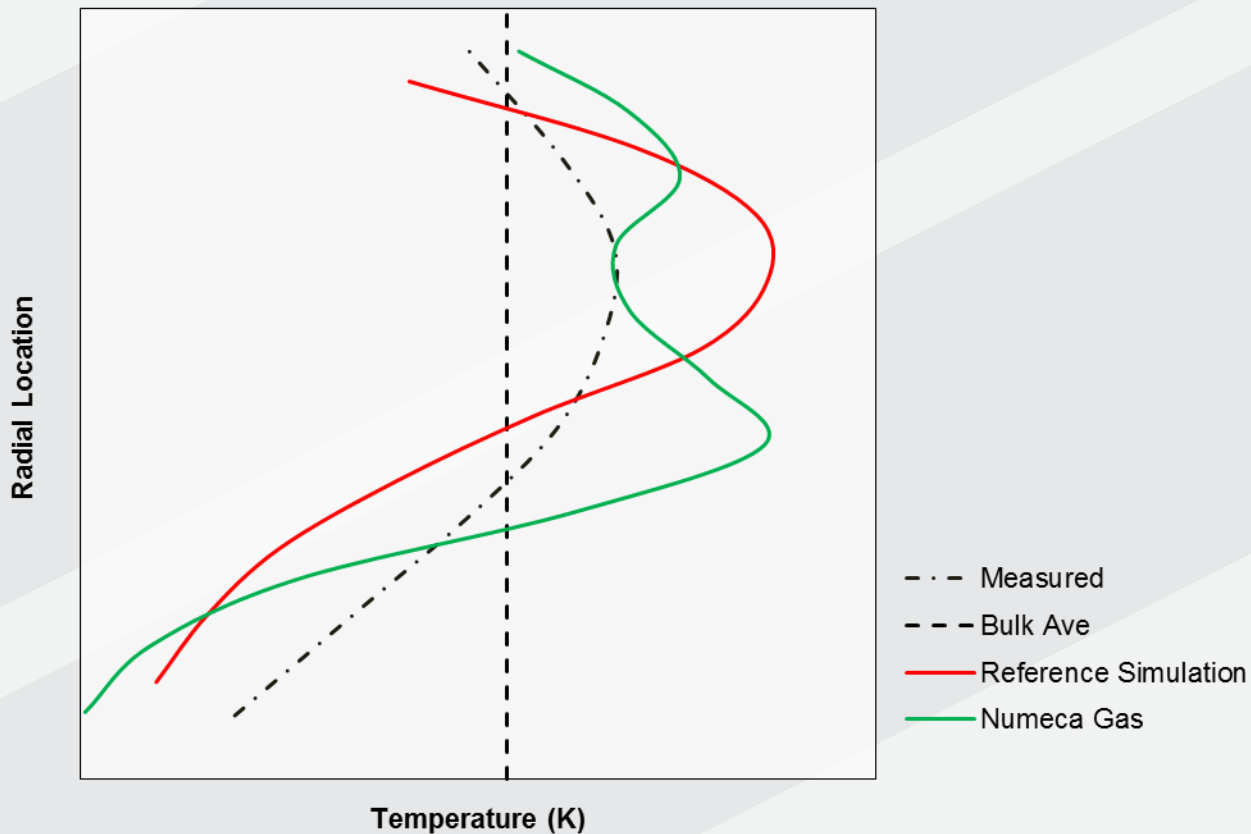
Reference simulation results - temperature and streamlines



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Outlet Temperature Profiles

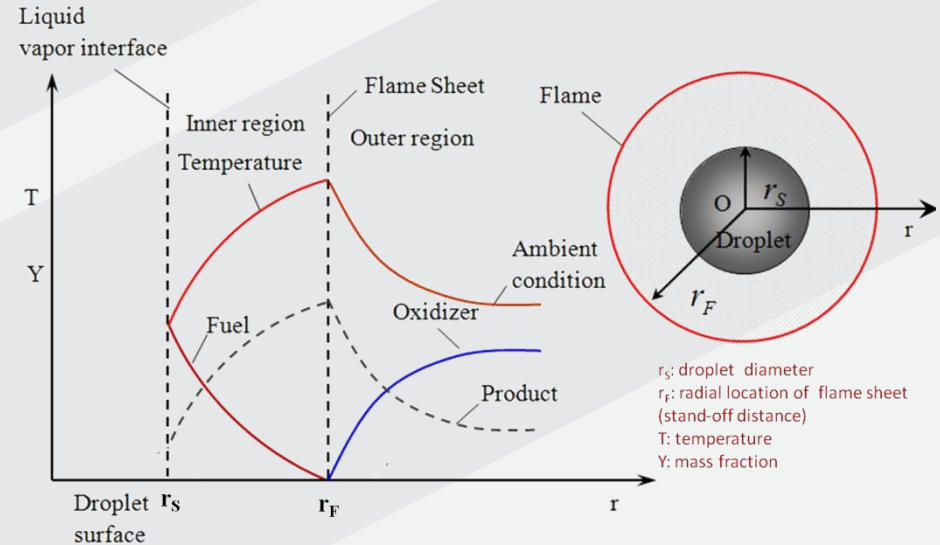
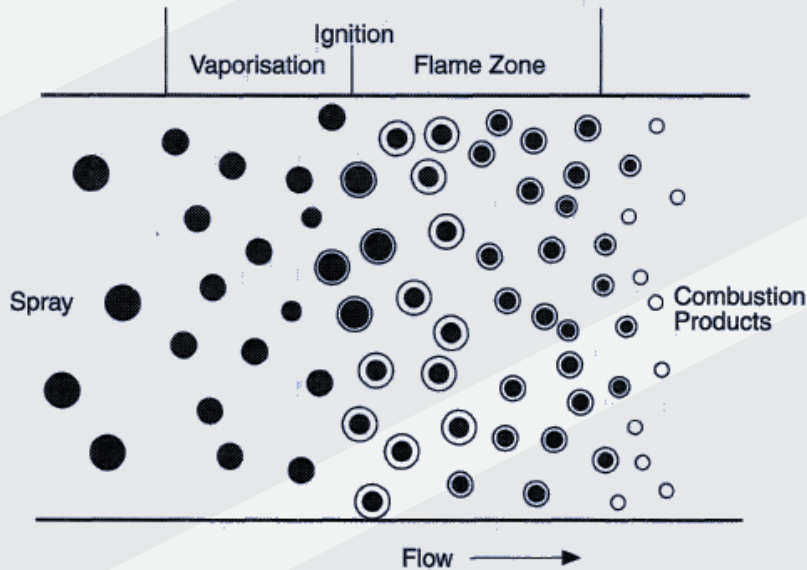




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Motivation: Droplet Combustion



Sources:

www.thermopedia.com/content/766/

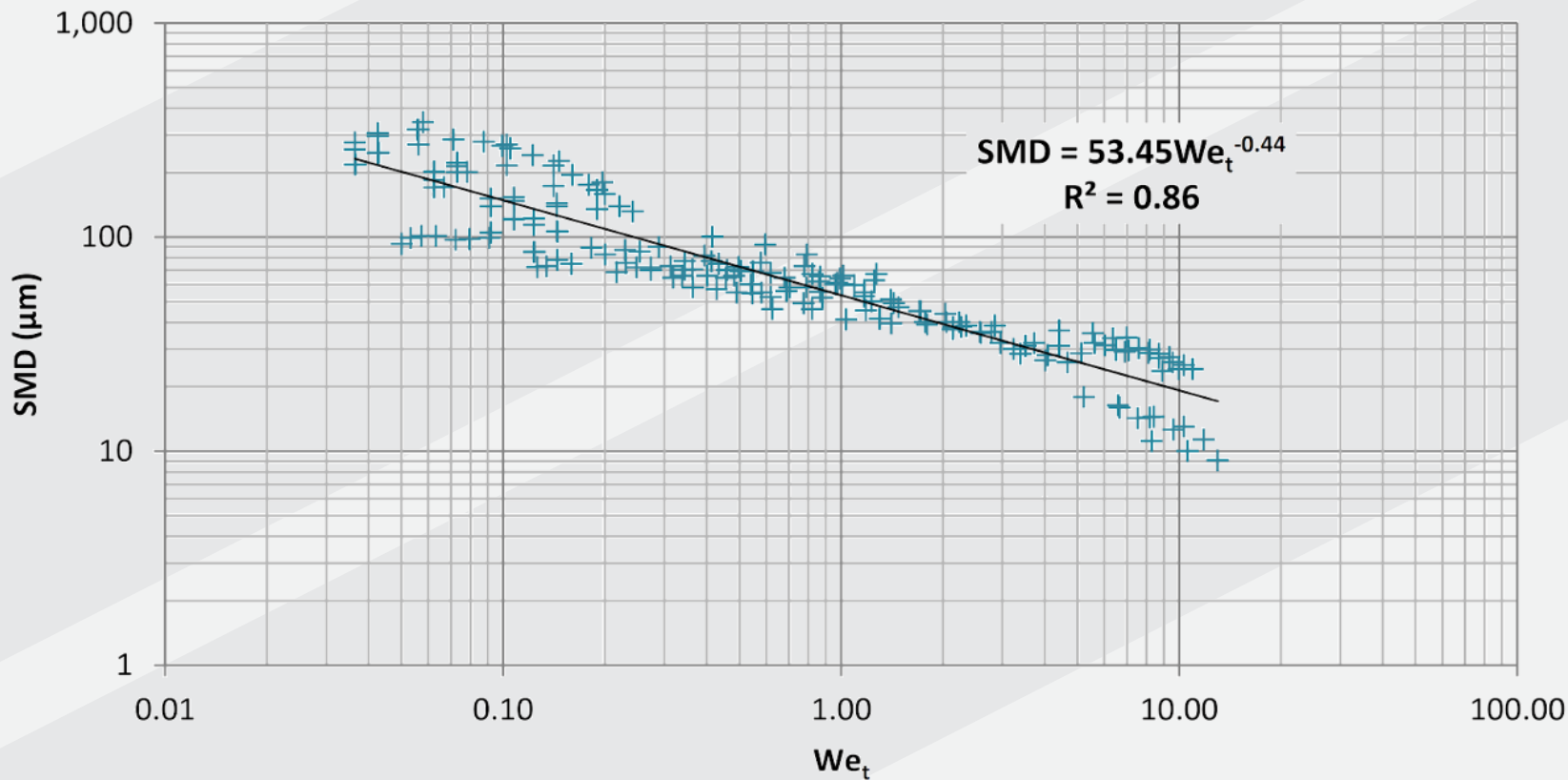
www.home.iitk.ac.in/~mishra/virtual_lab/documentor/theory8.html



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Slinger Performance – Normalised Data from the Literature



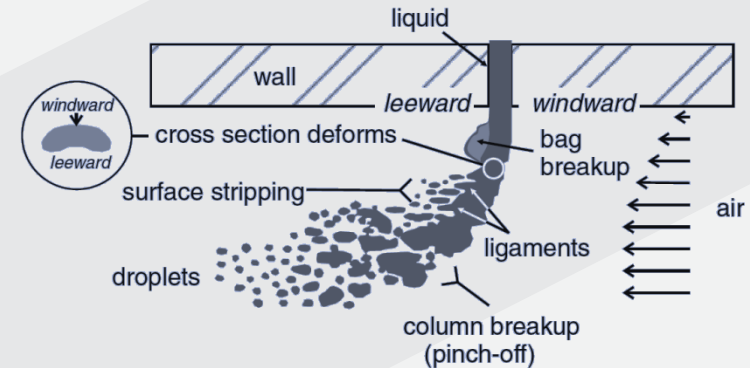


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Lagrangian Injection Modelling in Numeca ~~FINE™/Open~~

- 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

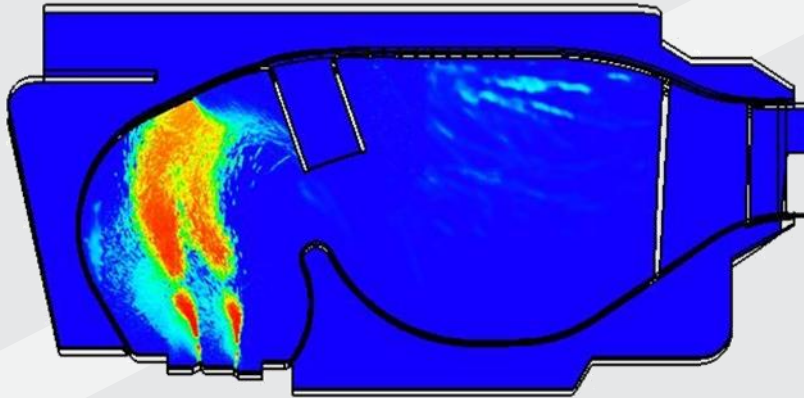


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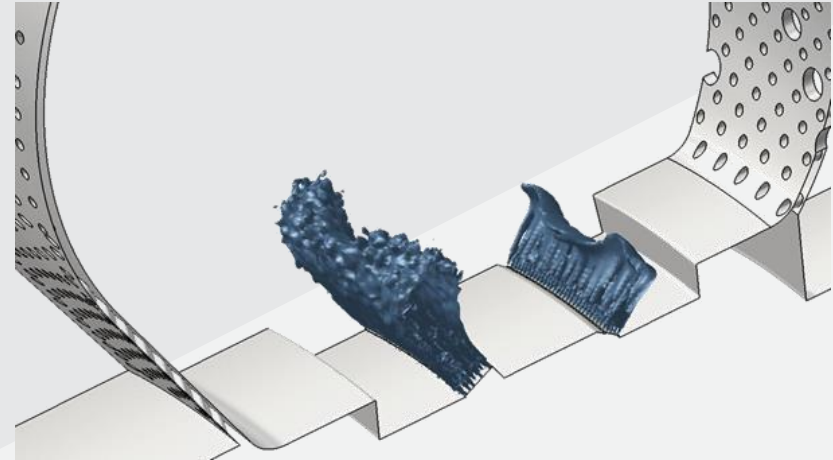


Lagrangian Injection

- 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

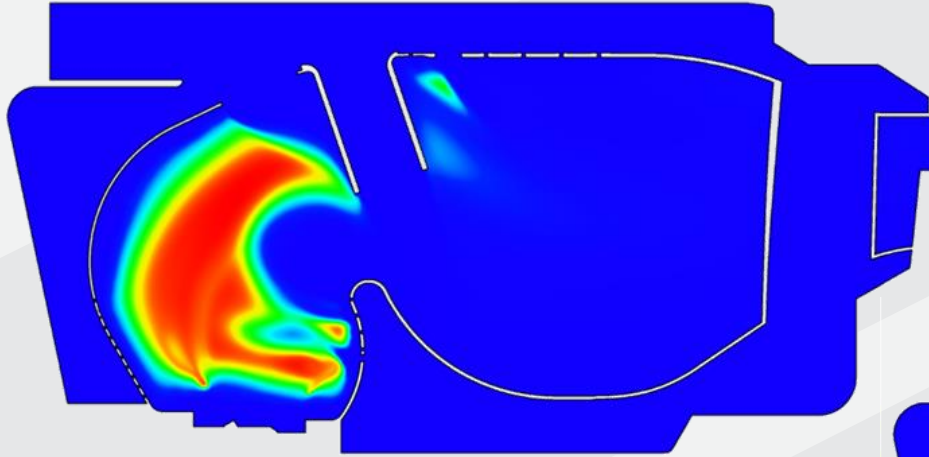




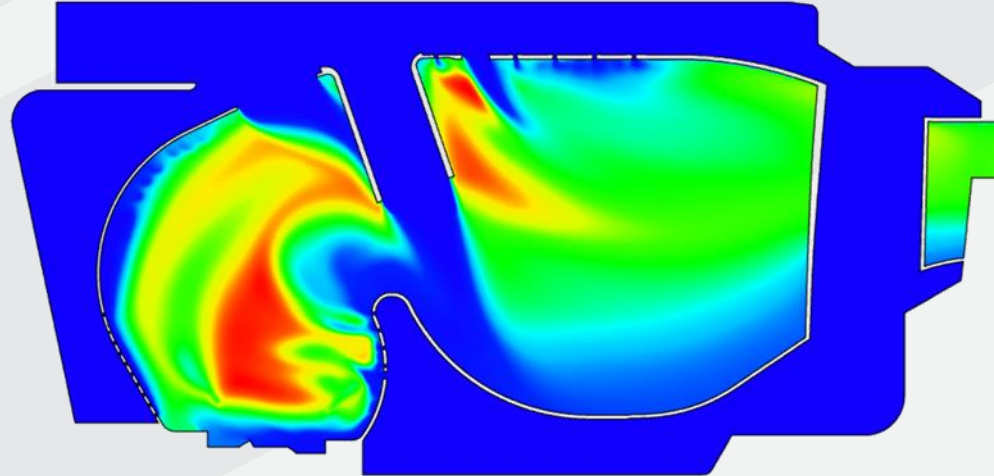
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Lagrangian Injection – Initial Results



Flame Location (CO Concentration)



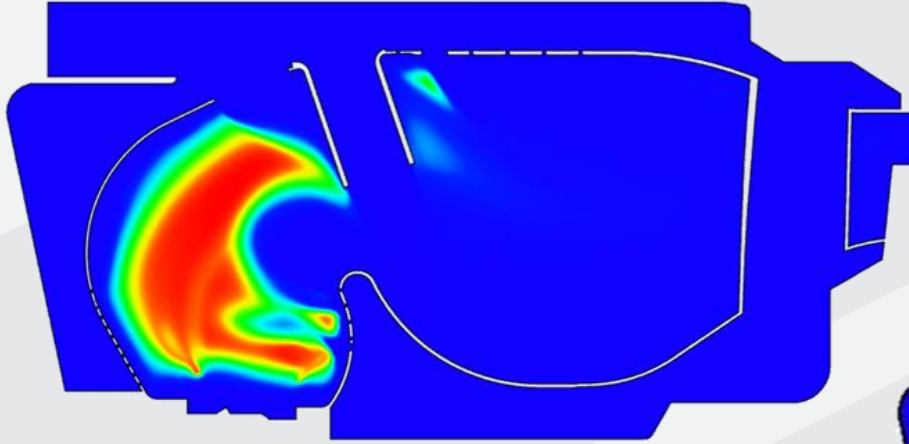
Static Temperature



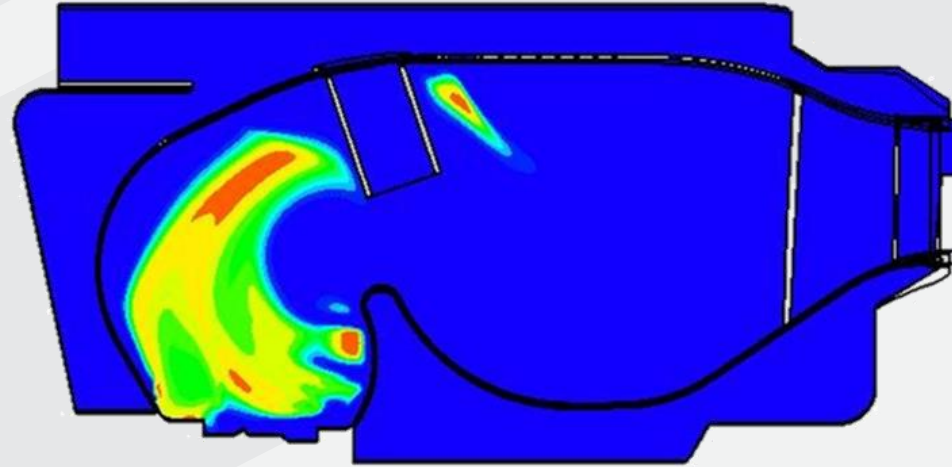
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Lagrangian Injection - The Influence of Momentum Coupling



Flame Location (CO Concentration)
With Momentum Coupling



Flame Location (CO Concentration)
Without Momentum Coupling

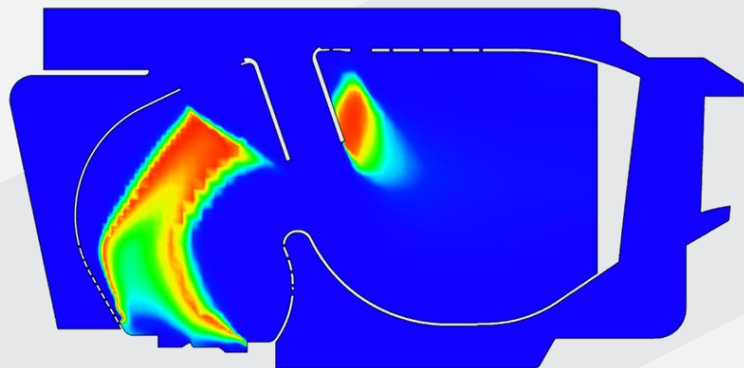


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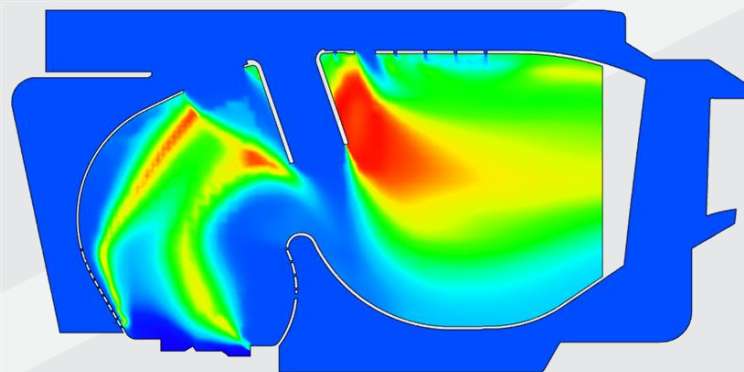


Gas vs Lagrangian Injection

Gas-Phase Fuel Injection

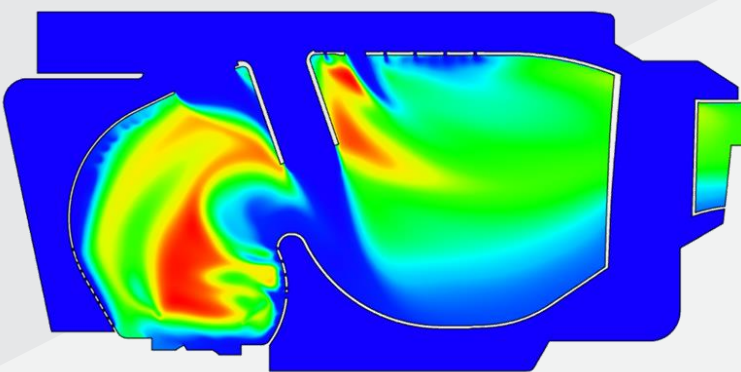
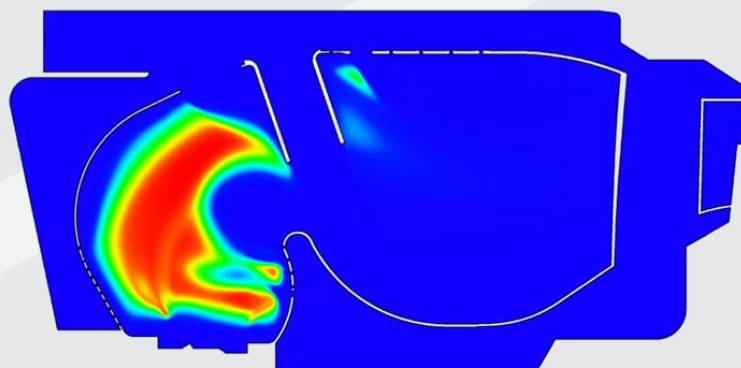


Flame
Location
(CO
Concentratio
n)



Static
Temperature

Liquid-Phase (Lagrangian) Fuel Injection

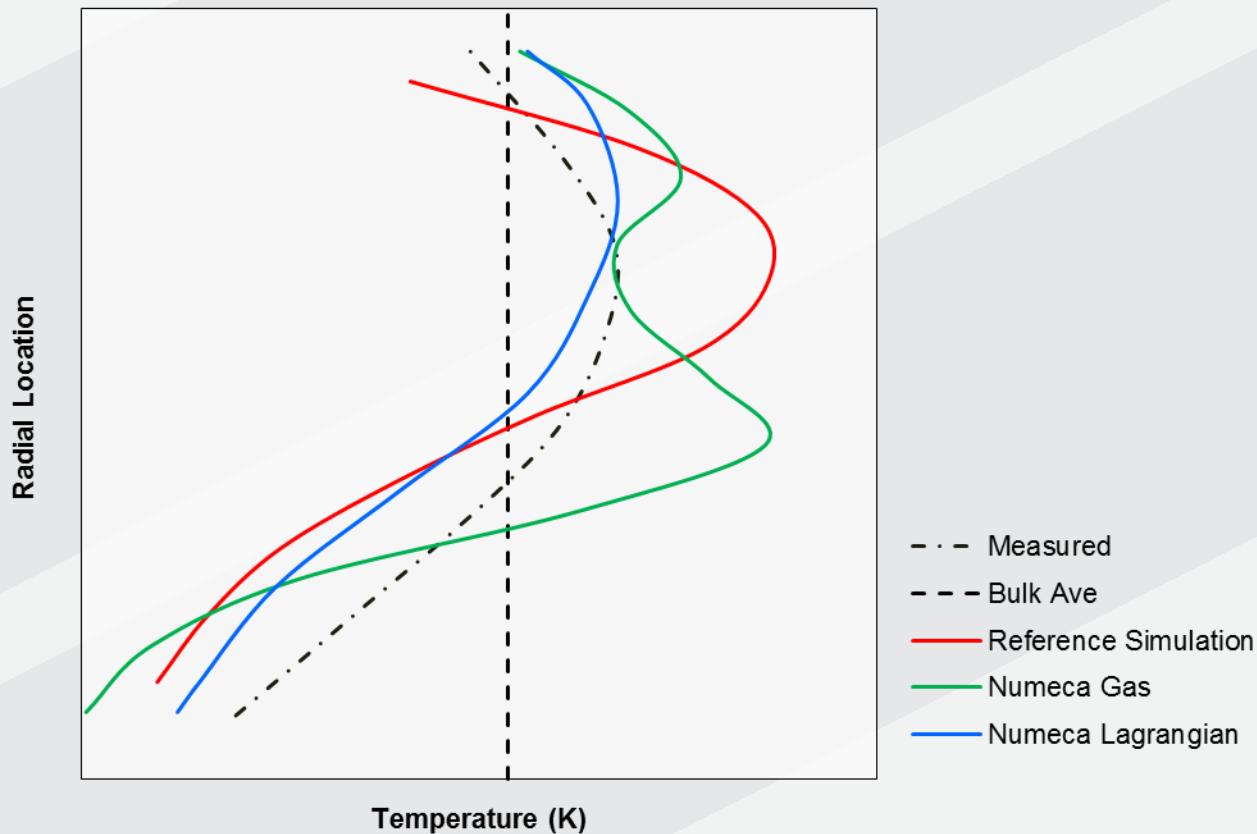




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Summary – Outlet Temperature Profiles





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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 $k\epsilon$)
- ❑ 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