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9th European Combustion Meeting, Lisbon (Portugal)

Large-Eddy Simulation of Flame Dynamics during Ignition of a Swirling Injector Unit and Comparison with Experiments

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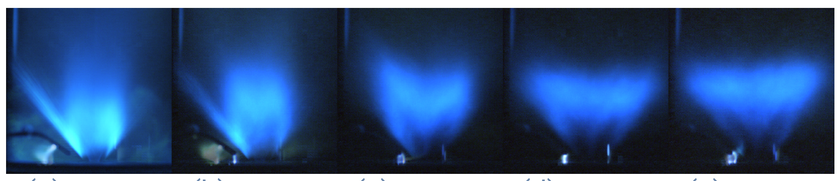
Scope

- A **safe and reliable ignition** of combustion chambers must be ensured for aeronautical applications and gas turbines.
- A **flame flashback** has been observed experimentally [1] during the ignition of spray flames which might have a **damaging effect** on the injection unit.
- Large eddy simulations (LES) can help to investigate and better understand the **dynamic flame behaviour** during ignition.

Experimental Setup

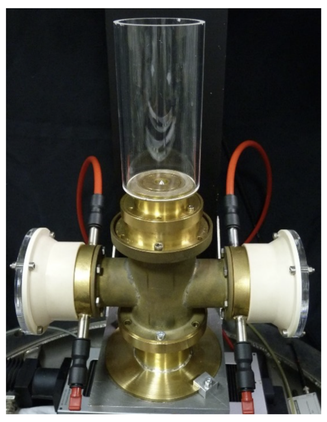
The SICCA combustor is a swirled single-injector spray combustor operated at ambient pressure.

- $\mathcal{P}_{th} \approx 5\,\mathrm{kW}$
- Fuel: liquid n-heptane (C_7H_{16}) at $T = 298\,\mathrm{K}$
- Global equivalence ratio: $\Phi = 0.89$



(a) 4.17 ms (b) 12.5 ms (c) 20.8 ms (d) 29.2 ms (e) 37.5 ms

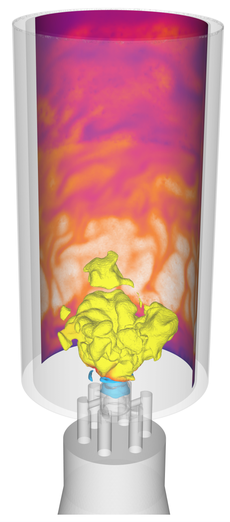
Experimental ignition sequence recorded by a high-speed camera with OH*-filter [1].



Numerical Setup

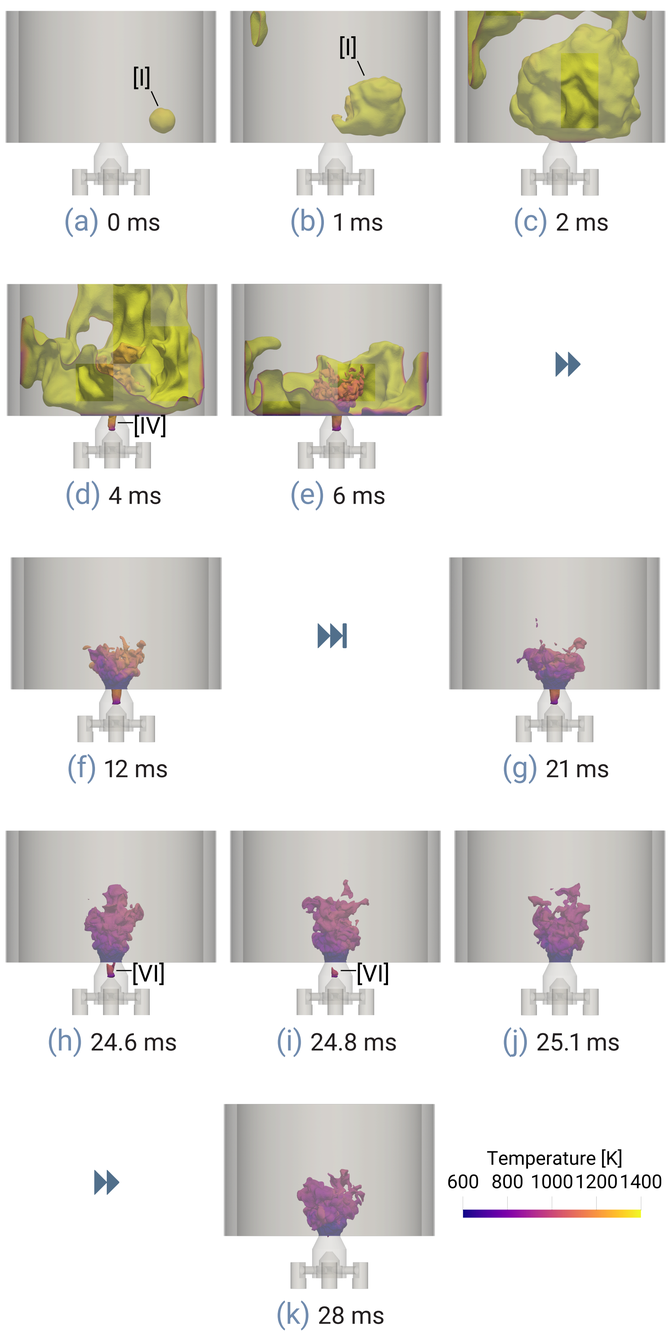
The numerical domain and the sover setup are based on previous work published in [2].

- LES solver: AVBP (CERFACS/IFPEN)
- SGS model: Wall Adapting Local Eddy-Viscosity (WALE) model
- Combustion model: Dynamic TFLES with PEA
- Two phase modeling: monodisperse Eulerian-Eulerian model ($d_{inj} = 15.3\,\mu\mathrm{m}$)
- Evaporation model: Abramzon-Sirignano
- Prescribed temperature profile ranging between $T = 773$ and $T = 1173$ K



LES Ignition Sequence

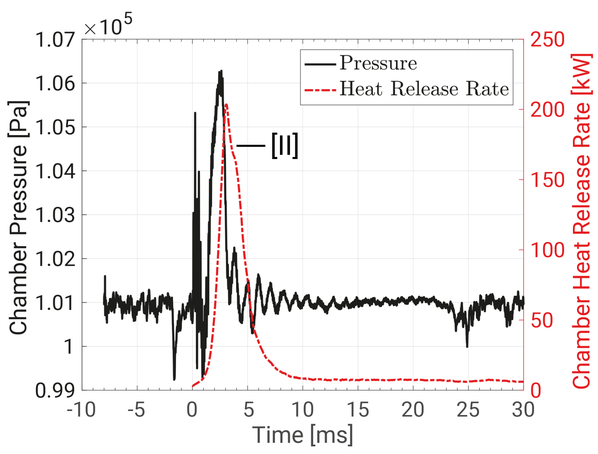
- Ignition with a spherical volume of high temperature burnt gases
- Penetration into the swirler
- Flame edge attached to the swirler
- After a characteristic time: quenching of the lower flame part
- Flame lift-off and stabilization at a distance from the swirler

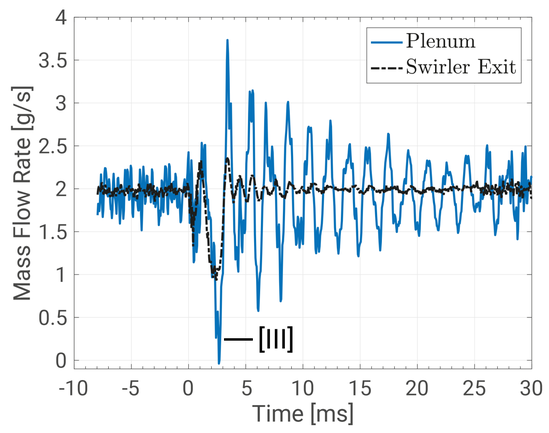


(a) 0 ms (b) 1 ms (c) 2 ms (d) 4 ms (e) 6 ms (f) 12 ms (g) 21 ms (h) 24.6 ms (i) 24.8 ms (j) 25.1 ms (k) 28 ms

Flame shape based on progress variable $c = 0.5$ colored by temperature.

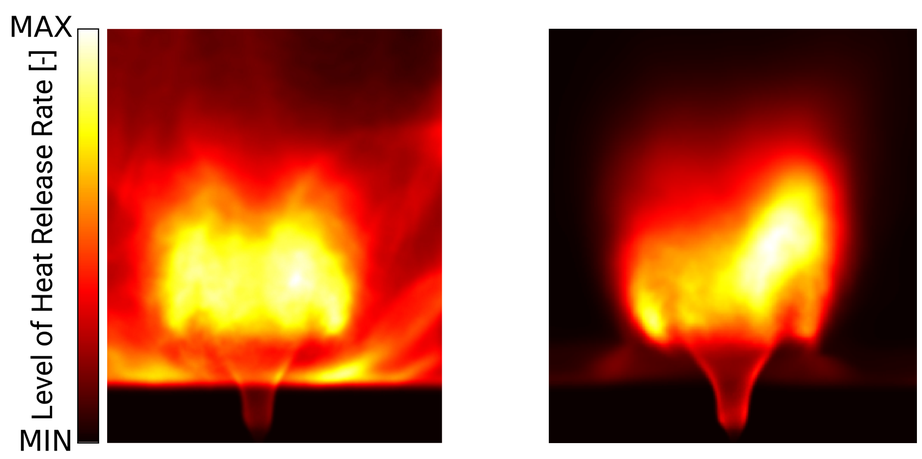
Penetration into the Injector





Phase I: Stabilization and anchoring

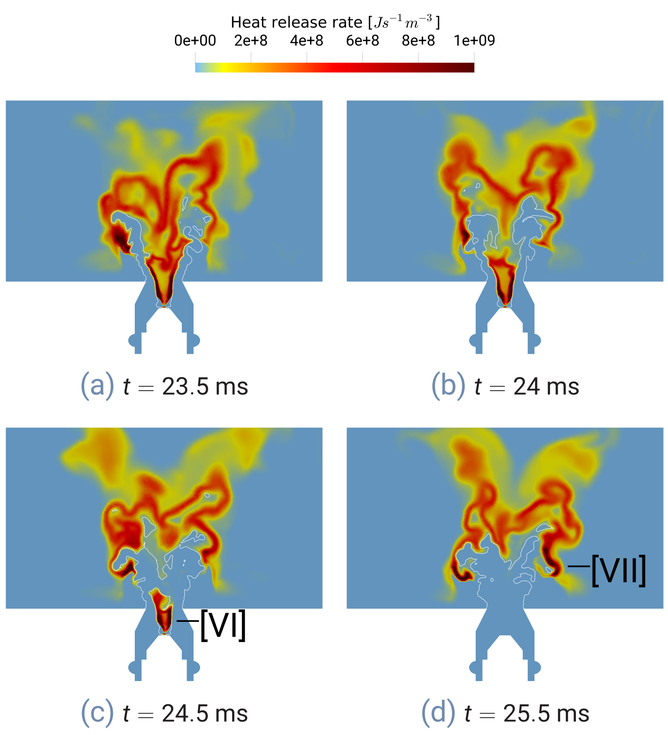
- Growth of the initial flame kernel [I]
- Burnt gas expansion causes acoustic pressure disturbance [II]
- Temporary stagnation of the mass flow rate [III]
- Flame flashback and anchoring attached to the swirler, despite pre-ignition mass flow rates are re-established [IV]
- Transient stabilization in qualitative agreement with experimental data [V]



(a) 4.2 ms (b) 12.5 ms

Line of sight integrated heat release [V].

Flame Lift-Off

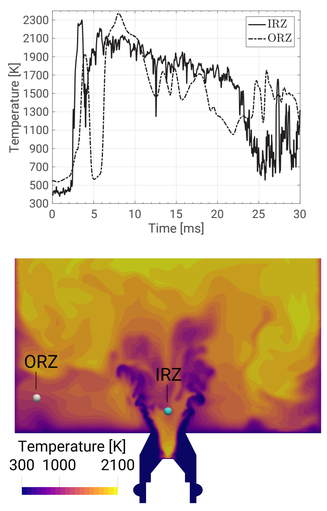


(a) $t = 23.5$ ms (b) $t = 24$ ms (c) $t = 24.5$ ms (d) $t = 25.5$ ms

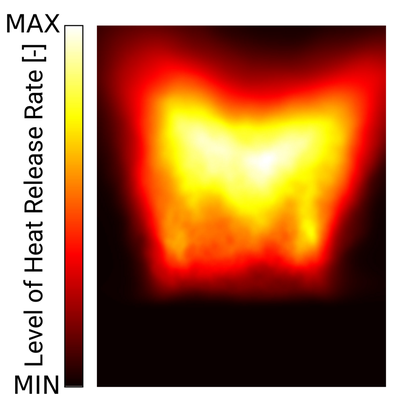
Heat release rate and contour of the progress variable $c = 0.5$ at the combustor mid-plane.

Phase II: Flame lift-off and shape transition

- Lower flame part quenched after a characteristic time related to the cooling of the recirculating burnt gases near the combustor walls [VI]
- Flame lift-off and stabilization detached from the swirler [VII]
- Detached flame shape different with respect to attached flame [VIII]
- Lift-off delay qualitatively retrieves experimental trends [IX]



Cooling of the IRZ and ORZ [VI].



Line of sight integrated heat release at 25.1 ms [IX].

Conclusion

- Capability of LES to properly capture the flame dynamics during ignition including:
  - the stabilization of the flame attached to the swirler
  - the lift-off after a characteristic time
- Good qualitative agreement of the governing mechanisms in each phase with experimental data

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References

[1] K. Prieur, D. Durox, G. Vignat, T. Schuller, S. Candel, Proceedings of ASME Turbo Expo, 4B, (GT2018-76840) (2018).
[2] T. Lancien, K. Prieur, D. Durox, S. Candel, R. Vicquelin, Journal of Engineering for Gas Turbines and Power 140 (2017).

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