T3.4 – Smart models for next-generation aircraft engine design

Status and next steps

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CoE RAISE All-Hands Meeting

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Outline

1. Hydrogen as a future fuel – *Modeling perspectives*
2. Hydrogen as a future fuel – *Design perspectives*
3. Next steps

Hydrogen as a future fuel

Modeling perspectives

3D Direct Numerical Simulation (DNS)

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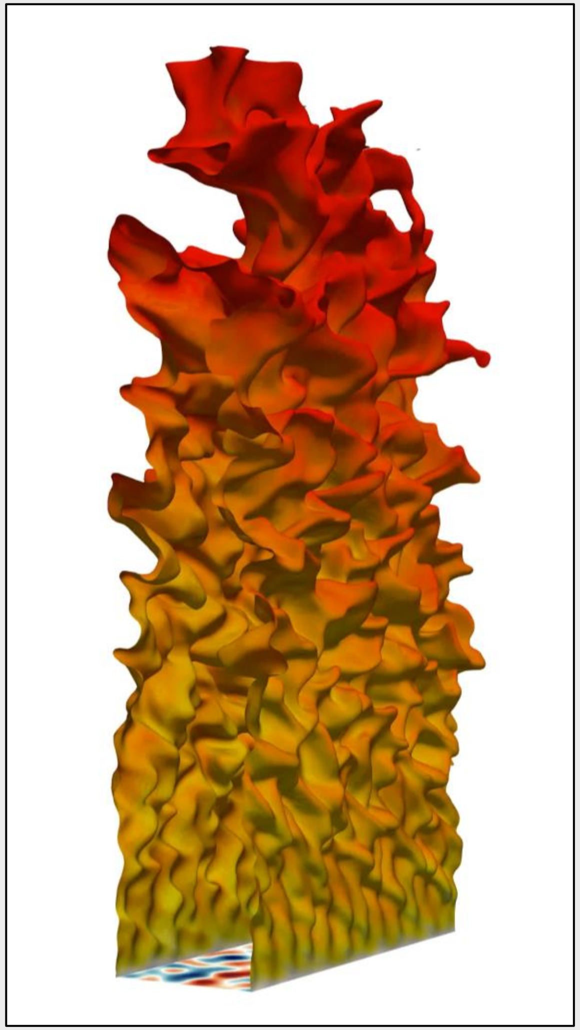
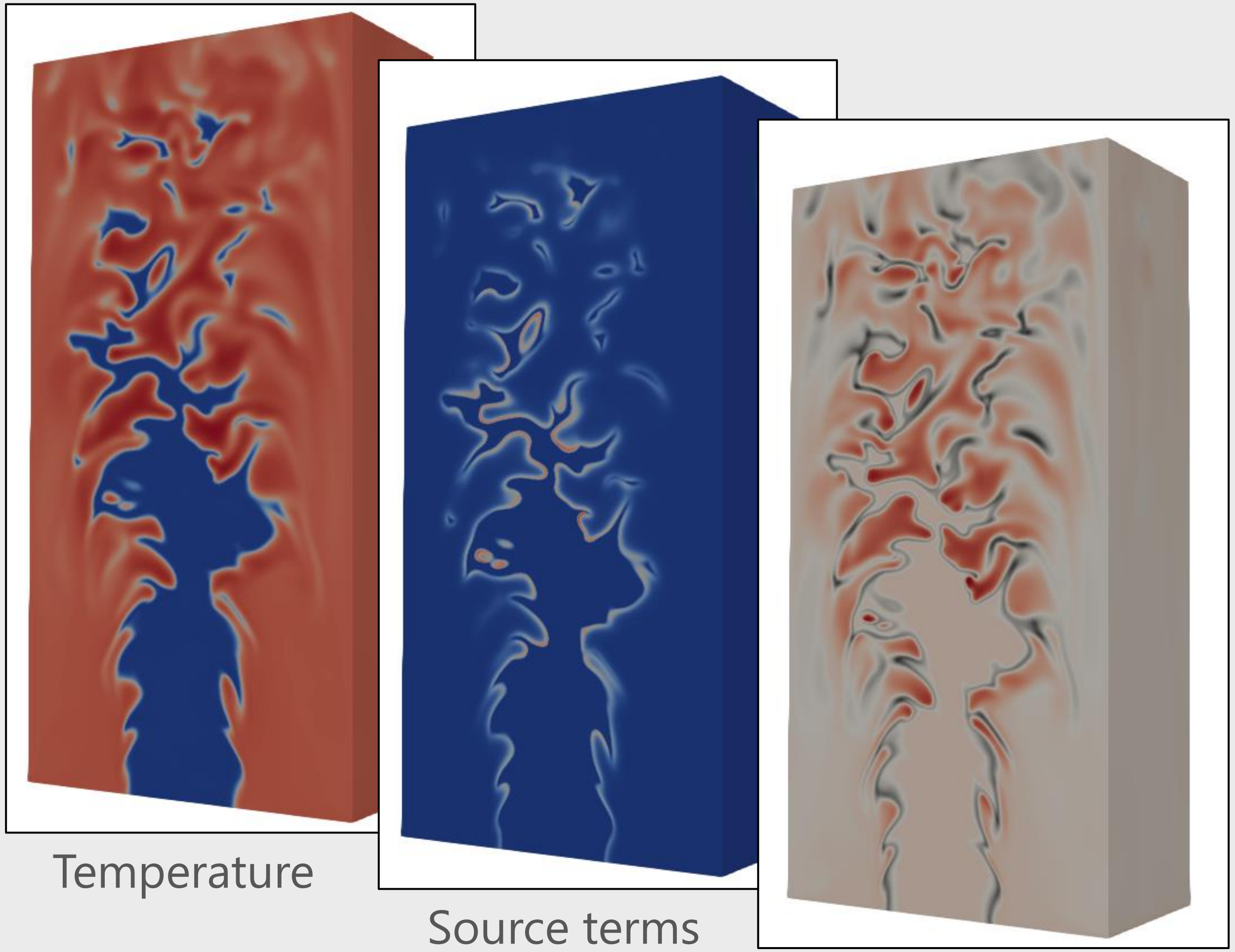


1. Anchored turbulent flame similar to an engine injector configuration
2. Relevant topology with a progressive flame folding
3. No sub-grid scale model used (turbulence-chemistry interaction well captured)

Mesh: 262 million of cells in a rectangular domain of 17 cm^3

Cost: 500 000 CPUh (8 ms physical time)

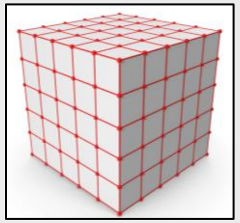
Hydrogen database description



Temperature

Source terms

Fuel/Air ratio

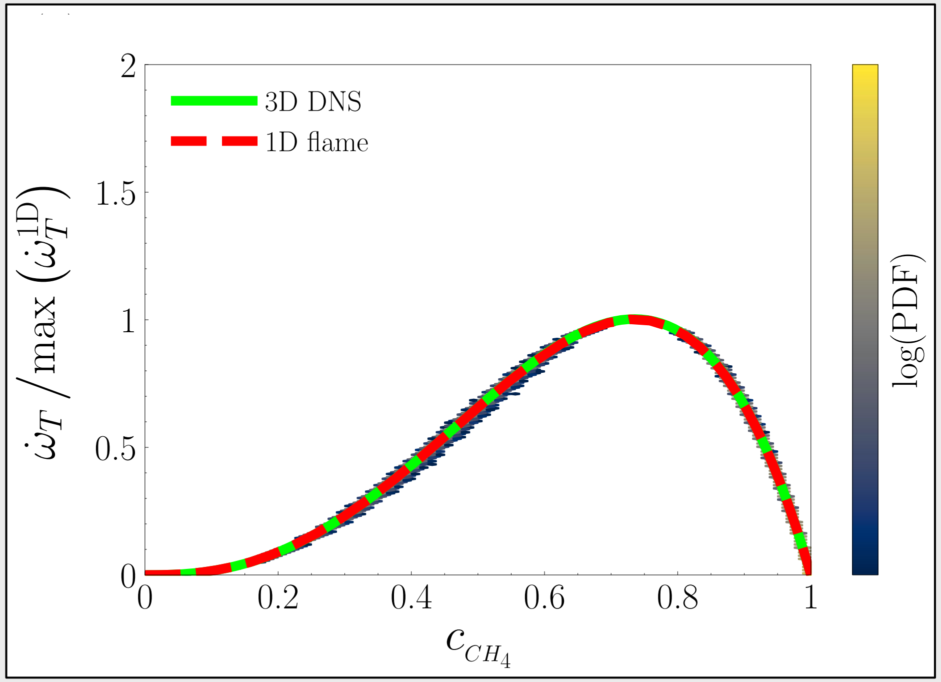


- Regular 3D Cartesian mesh
- +90 snapshots of 1280x640x320 cells
- Hexahedral cells of size $\Delta = 40\ \mu m$
- 9 species and 21 reactions to describe chemistry
- HDF5 file format

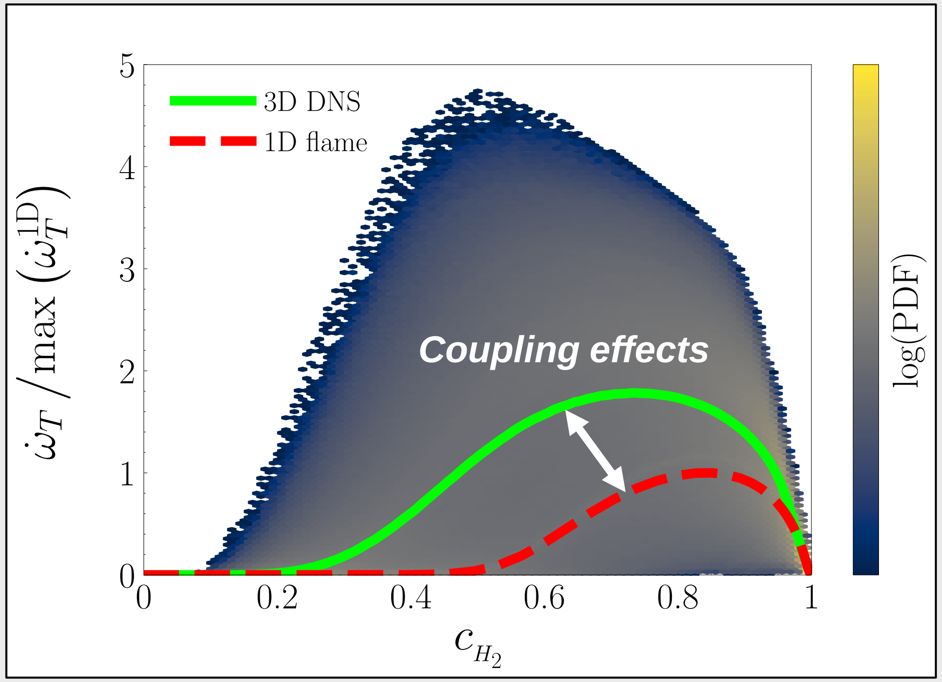
Learning database of **~15 TB**

Physical analysis on highly resolved data

Methane flame



Hydrogen flame



- **3D effects** of turbulence (*curvature, strain*) strongly affect the hydrogen flame
- Thermo-diffusive instabilities/turbulence coupling occurs at ***diffusive spatial scales***

Need to model this sub-grid scale synergy in LES

Deep-Learning for turbulent combustion modeling

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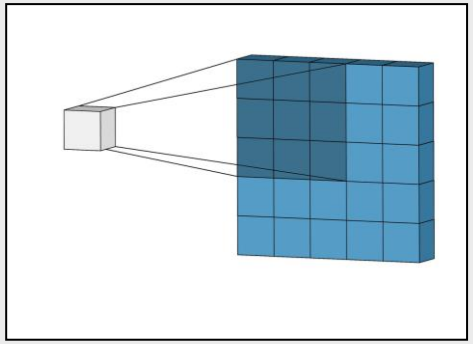
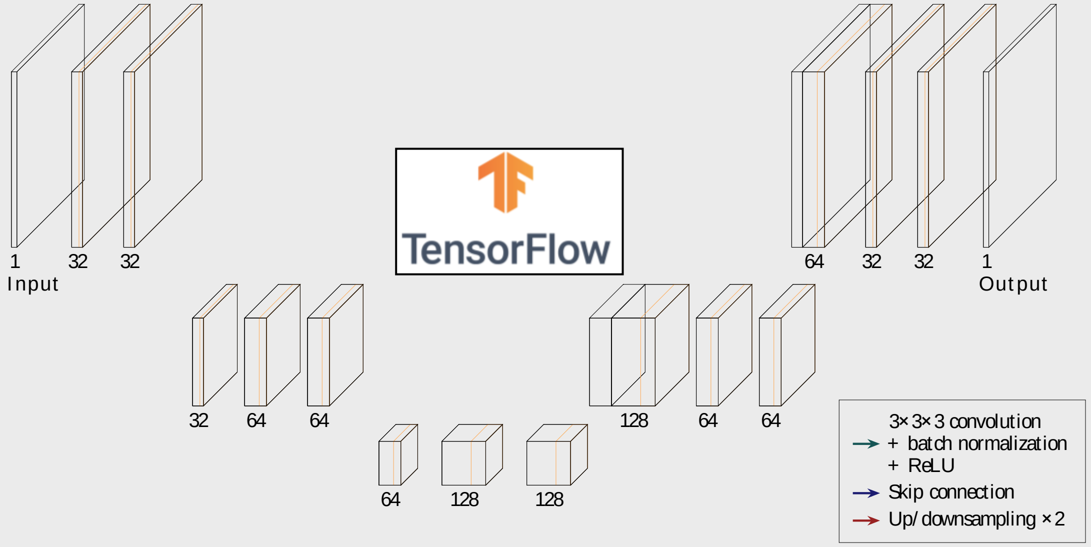
- Convolutional Neural Networks (CNN) for computer vision tasks :
  - Well suited for *structured* data fields (Cartesian mesh)
  - *Locality* and *translation equivariance* inductive biases (good for diffusive scales!)
  - Flame analogous to a highly wrinkled sheet



- U-Net architecture[5] :
  - Field-to-field task (2D-3D image segmentation)
  - Encoder-decoder structure
  - Aggregation of *multi-scale* information (skip connections)



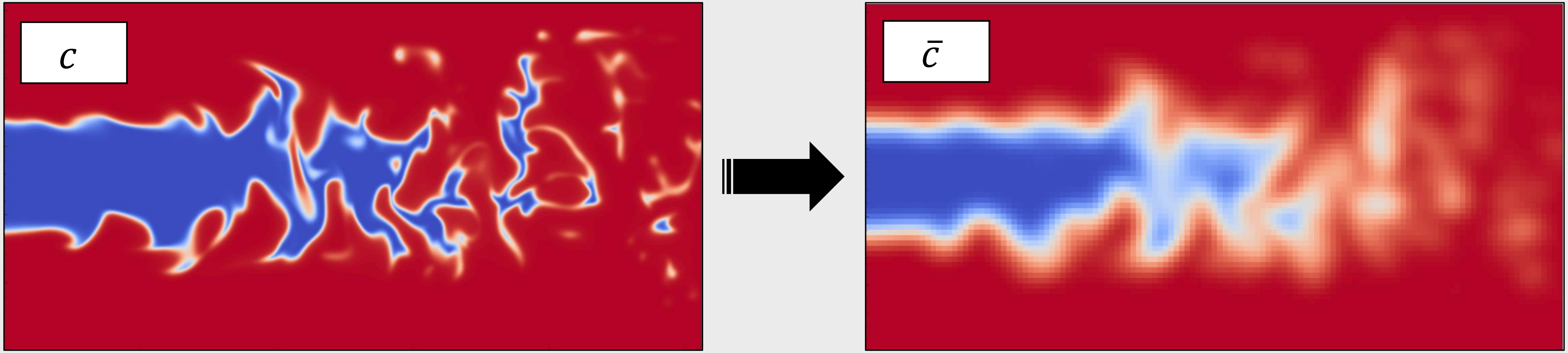
5. Ronneberger, O., et al. (2015, October). U-net: Convolutional networks for biomedical image segmentation. In International Conference on Medical image computing and computer-assisted intervention (pp. 234-241). Springer, Cham.

Filtering and coarsening

- **Large Eddy Simulation (LES)** still mandatory for design purposes :
  - Spatial filtering DNS data using Gaussian kernel (avoid aliasing)

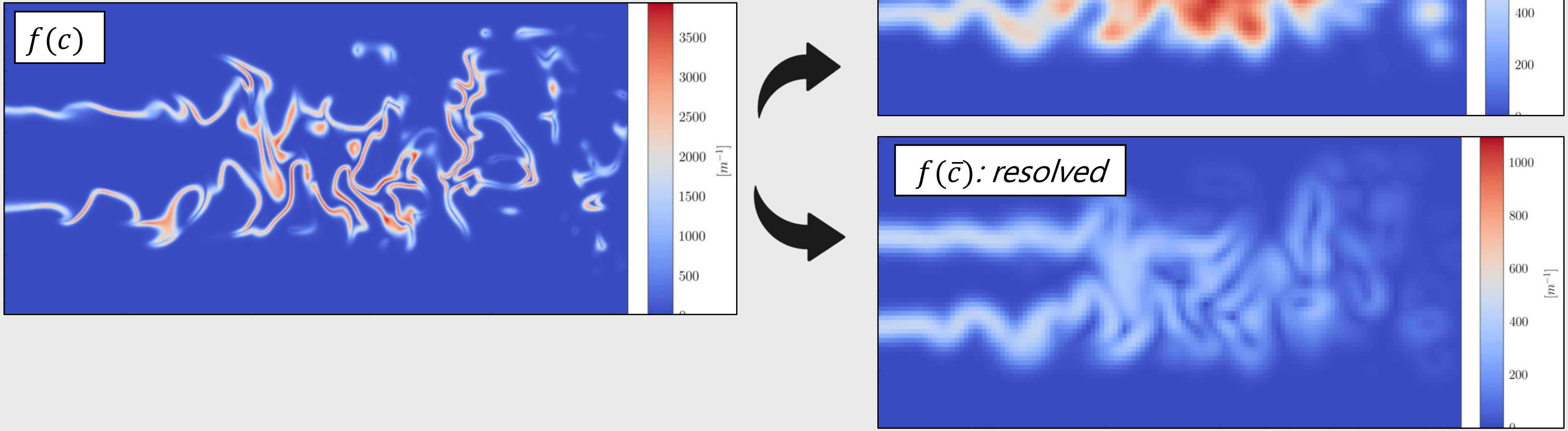
$$\overline{Q(x,t)} = \int_{\mathcal{V}} F_{\Delta}(x - x')Q(x',t)dx'$$

  - Downsampling the data (coarser grid)



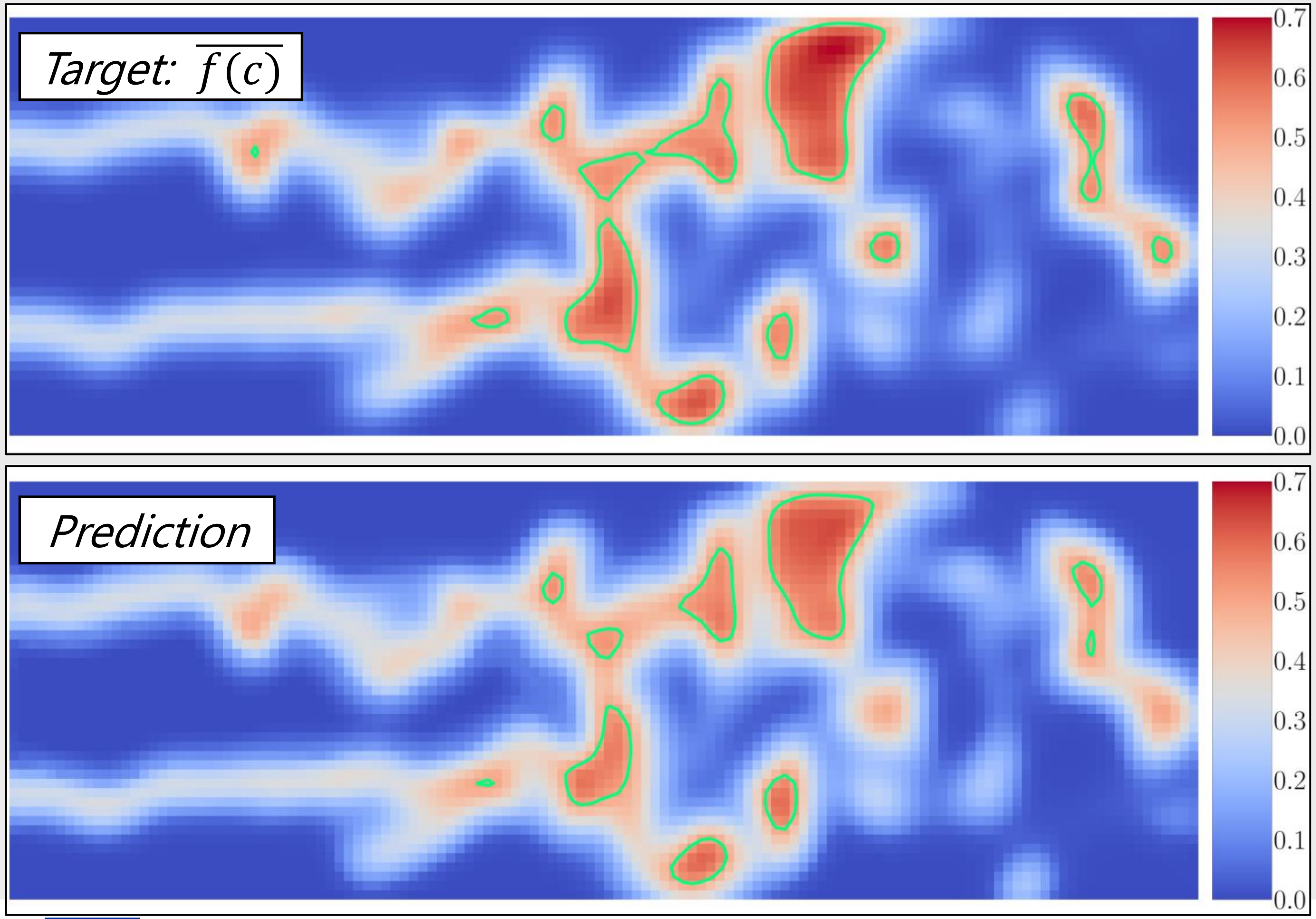
Flame surface density

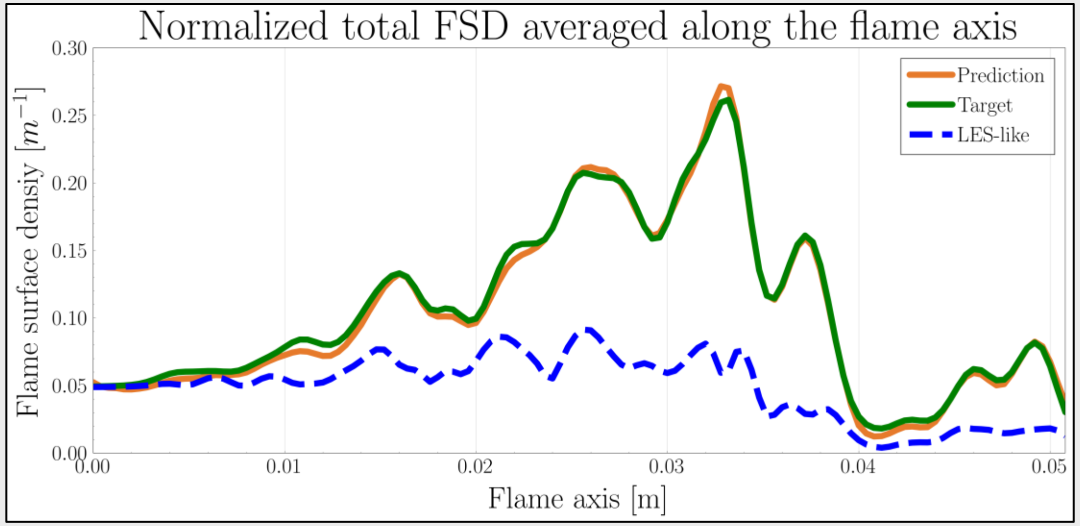
- **Flame surface density** is a key parameter in combustion:
  - Used for species source term modeling
  - Function of variable c



Off-line predictions of the flame surface

- Infering the *total* **flame surface density (FSD)** from a ***resolved quantity*** (here $\bar{c}$)



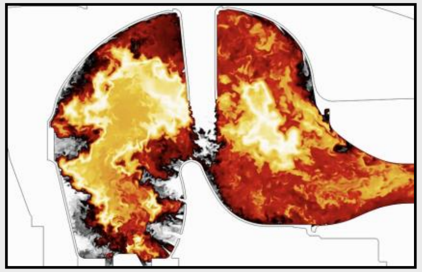


- High accuracy of the *off-line* predictions of total FSD from resolved field
- Outperforms conventional models[6,7]

6. Lapeyre, C. J., et al. (2019). Training convolutional neural networks to estimate turbulent sub-grid scale reaction rates. Combustion and Flame, 203, 255-264.
7. Xing, V., et al. (2021). Generalization capability of convolutional neural networks for progress variable variance and reaction rate subgrid-scale modeling. Energies, 14(16), 5096

Towards *online* predictions

Modeling strategy



CPUs

SAFRAN helicopter engine

Task 3.3 support

AVBP-DL

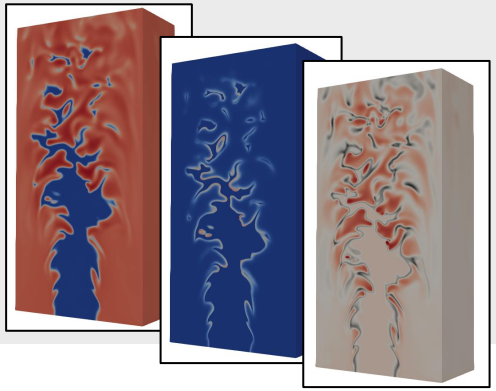
Online predictions

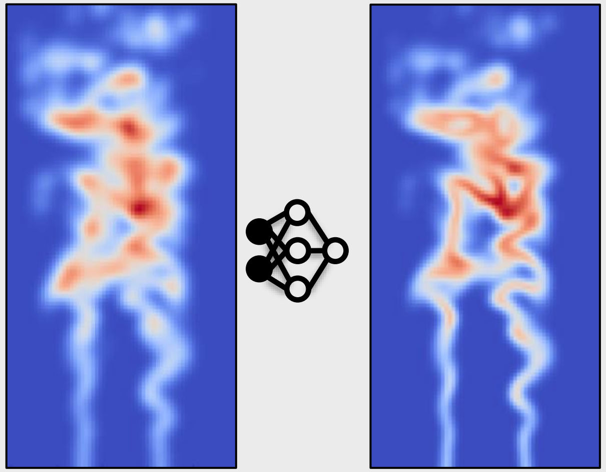
GPUs

Data-driven model (CNN)

AVBP

High-precision database (DNS, Hi-Fi LES)





Resolved on industrial-like mesh

Resolved + sub-grid

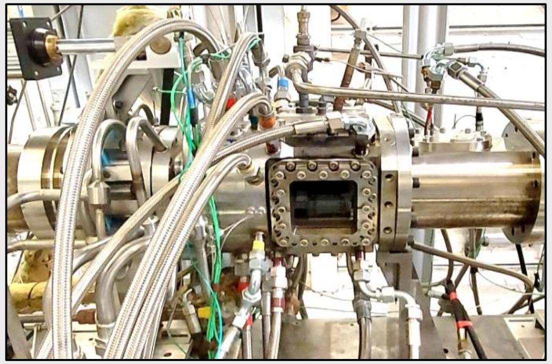
Hydrogen as a future fuel

Design perspectives

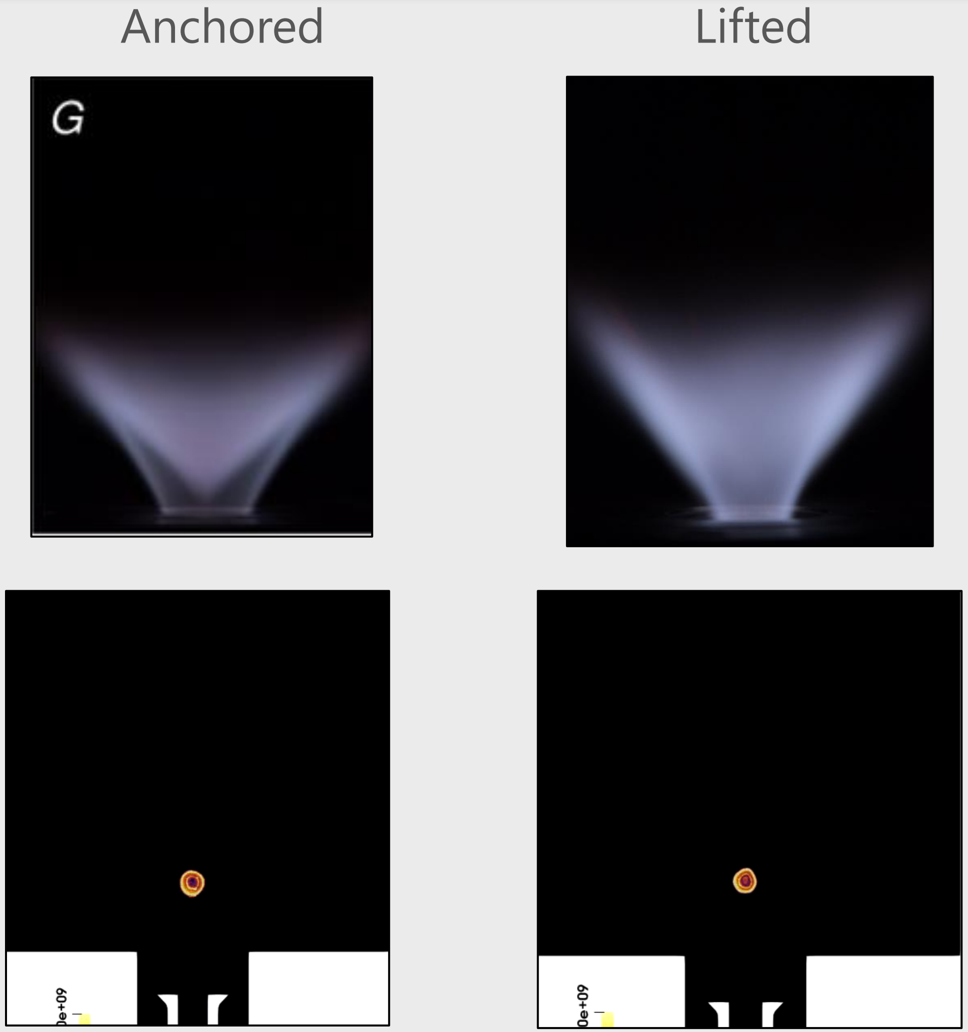
Hydrogen injector for helicopter engine

- Patented Injector Safran HE – IMFT (CNRS)

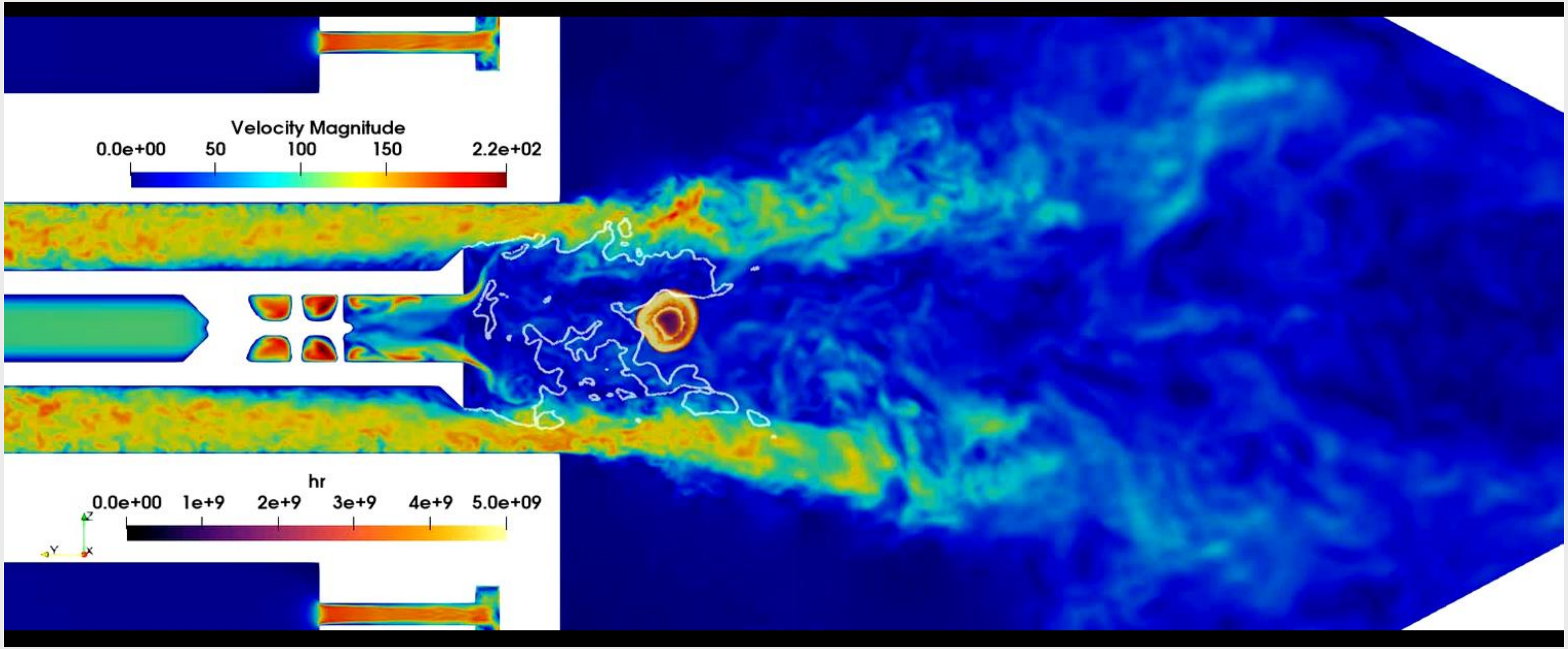
- Experimental campaign at lab scale
  - 2 flame types: *anchored* and *lifted*
  - Exp. led by IMFT
  - Higher pressure-temperature conditions to be tested



- Numerical calculation:
  - Simplified combustion chamber
  - Lab scale operating conditions
  - Simulations led by SAFRAN HE (C. Brunet)
  - BL resolved at injector wall with 100 μm cells



First combustor module ignition



First combustor module ignition

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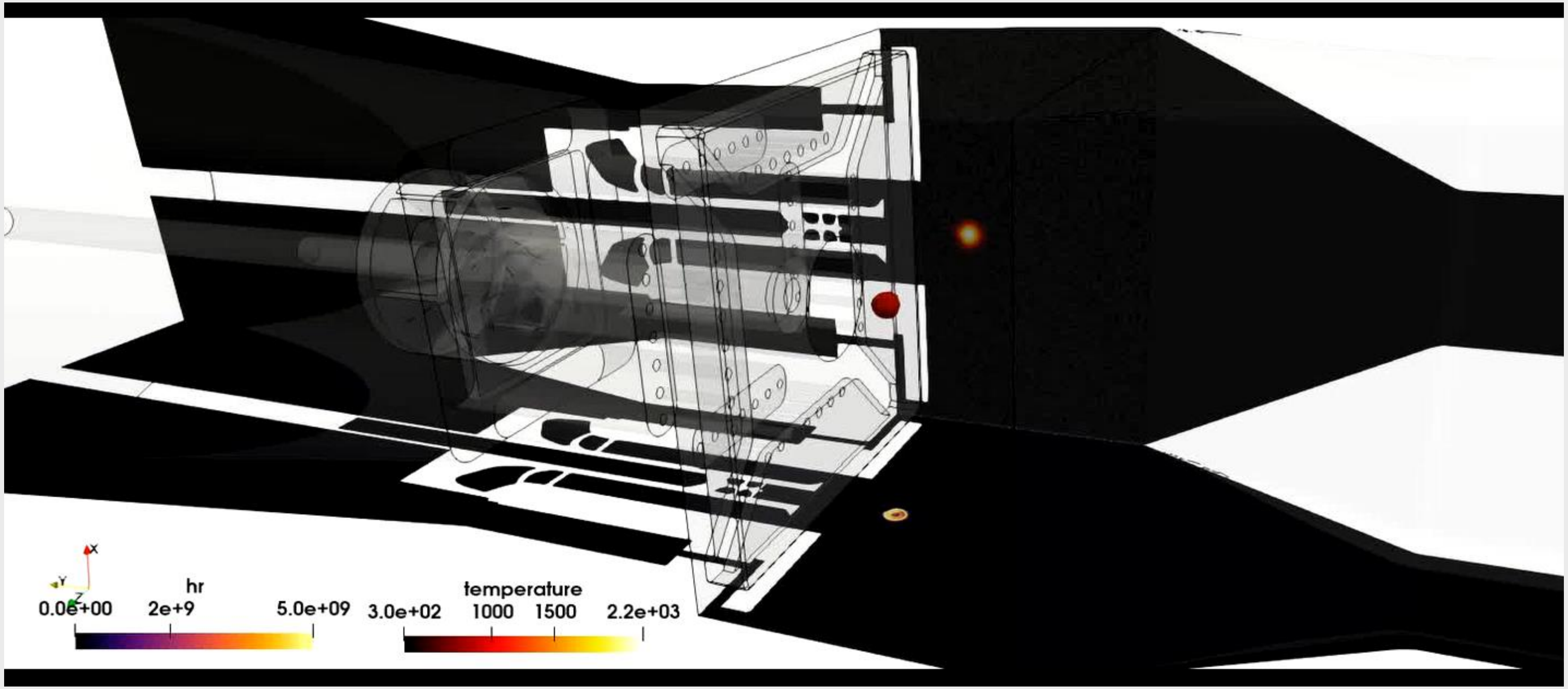


SAFRAN

CERFACS

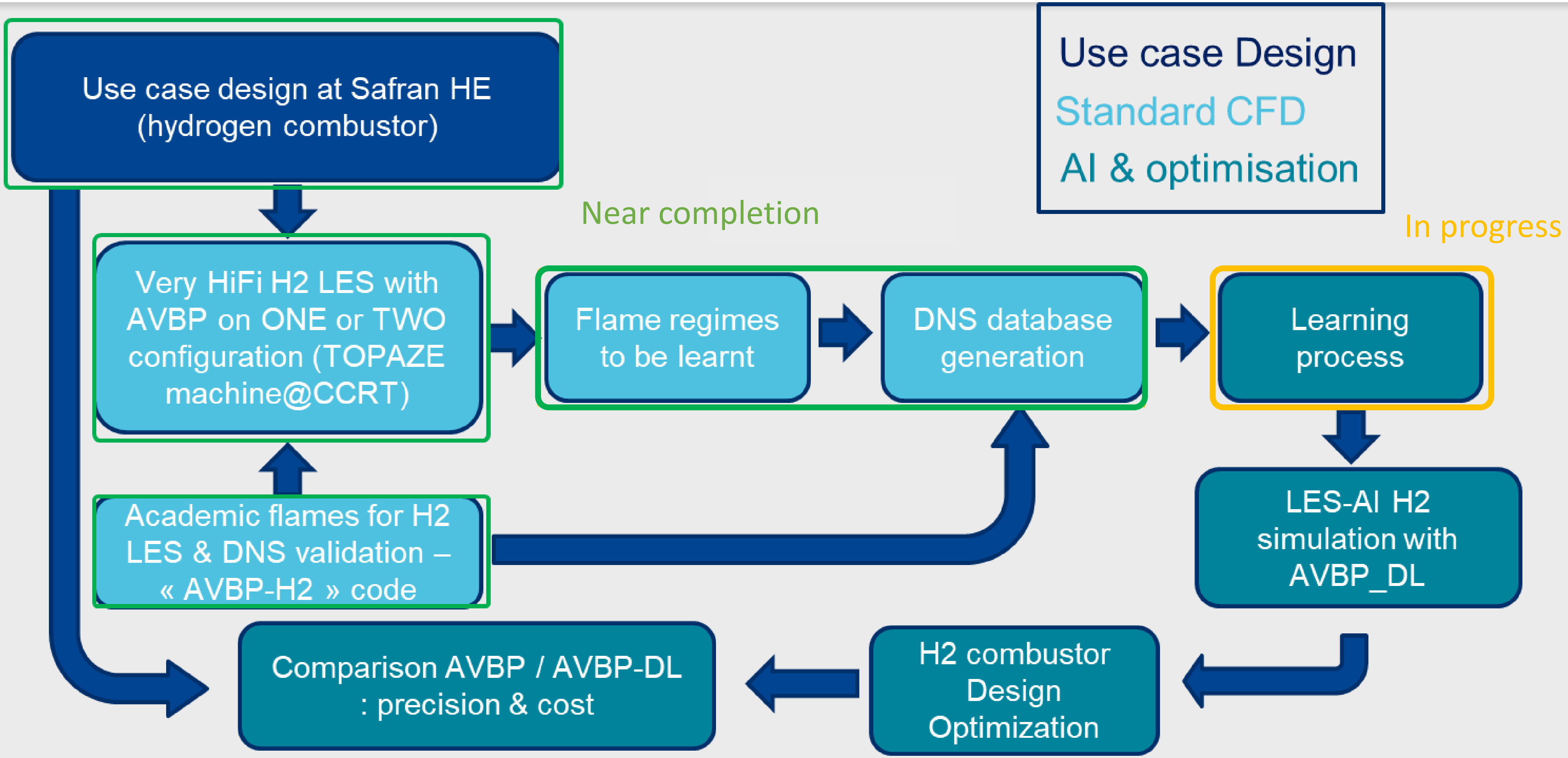
A unique database for AVBP-DL

- Database at lab-scale
  - ✓ Flame topology prediction validated by experiments ✅
  - ✓ Two flame topology depending on the flow regime ✅
- Engine representative conditions
  - New experimental campaign early 2023 at high T and P (ONERA) ✅
  - Simulations of the test rig at real operating conditions ✅
- Combustion chamber & Optimized injector
  - To be done after the injector's optimisation is done
  - Numerical setup to be validated with the two exp. campaigns

Numerical database validated by experiments with realistic geometries and operating points for AVBP-DL validation

Next steps

Future work in T3.4



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