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HESTIA

HydrogEn combuSTion In Aero engines

www.hestia-project.eu

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HESTIA partners at the project kick-off meeting in Paris

In this issue:

A few words from the Coordination

Stephan Zurbach & Nicholas Treleaven - Safran

It seems like only yesterday that hydrogen fuelled aircraft were a thing of science fiction, and yet here we are, nine months into the HESTIA project. We are very proud of our team and the work they do. We are lucky to count all of the European aircraft engine manufacturers in our ranks and many of the best combustion laboratories on the planet.

We have seen presentations of work being done in Canada, Poland, France, the UK, Italy and Germany. We have simulations and experiments going on at lab scale using tried and trusted technology as well as the cutting edge, and we have people trying to work out how we will integrate all of this research and development into real engines.

In HESTIA, we have started at a fundamental level. We use the TRL (Technology Readiness Level) scale developed by NASA to describe the progression of technology from the moment an idea is sketched on paper (TRL1) right up to the moment a product enters into service (TRL9). The goal of HESTIA is to get from TRL1: the objective of a hydrogen engine, up to TRL3: an experimental proof of concept. At the end of the project we will publish a roadmap of how TRL6: a ground test of a completed engine, can be achieved by 2028, ready for a 7-year development cycle that takes us to a possible 2035 entry into service of the first hydrogen civil aircraft.

It is early days, but we have already learned a lot. With 3.5 years to go, we hope you will stick around to find out how far we go!

Towards multi-regime combustion modelling for future hydrogen engines

Samuel Dillon, **Renaud Mercier** - Safran, Digital Sciences & Technologies Department
Benoît Fiorina - EM2C Laboratory, CNRS, CentraleSupélec, Universite´ Paris-Saclay

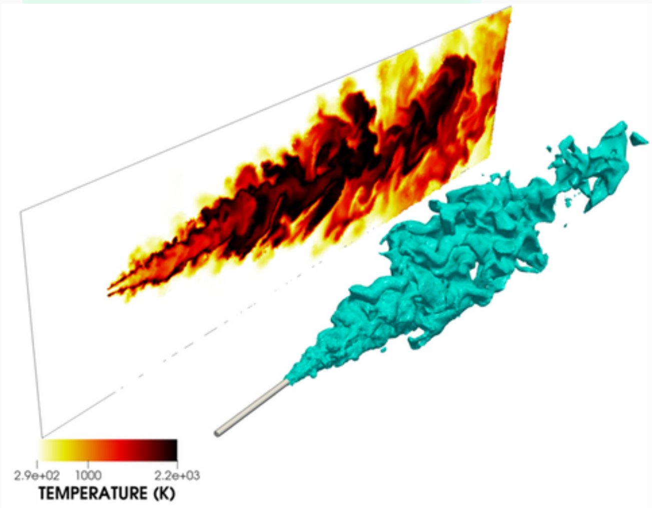
The decarbonisation of the aviation industry yields numerous scientific challenges, among them the design of novel combustion chambers for hydrogen fuel applications. A complete redesign of existing propulsive systems is needed since hydrogen differs greatly from carbon-based fuels from a thermochemical and transport perspective (larger flame speeds, sensitive to thermodiffusive instabilities, etc.). Consequently, the modern-day technologies stemming from traditional carbon-based fuels, such as Safran Aircraft Engine's Multi Staged Fuel Injection (MSFI) system designed for lean kerosene operation, will need a complete overhaul to account for the vastly differing combustion behaviour of hydrogen. In an effort to increase safety measures and reduce emissions, future hydrogen combustion chambers are expected to operate under multi-mode combustion regimes (reduced risk of flashback, lower emissions of harmful nitrogen-oxides NOx).

The design process of new propulsive technology consists of two key elements: 1) high-fidelity experimentation and 2) high-performance computing. It is common practice in industry to incorporate computational modelling techniques throughout the design process in order to verify and optimise new designs. With increasing computational resources comes increasing simulation capabilities. However, high-fidelity combustion simulations remain very computationally expensive. Therefore, models capable of accurately predicting complex combustion phenomena at smaller, unresolved scales are needed to reduce simulation sizes and thus alleviate the immense computational effort otherwise required.

Modelling multi-regime turbulent combustion is challenging from both a chemistry and turbulent flame interaction perspective, which is why recent work has been dedicated to the development of a low-cost multi-regime model capable of incorporating detailed chemistry effects whilst correctly preserving flame structures.

The new model, namely multi-regime F-TACLES (Filtered Tabulated Chemistry for LES), is under testing stages on canonical flame configurations and has been shown to correctly reproduce filtered flame structures. As the push continues towards the use of hydrogen for the decarbonisation of the aviation industry, the previously mentioned low-cost modelling techniques for turbulent combustion will be important for the rapid design/validation of future propulsive technologies.

In HESTIA, the challenge of modelling hydrogen combustion in numerical simulations will be tackled from a number of difference perspectives. In work package one, Task 1.1, highly detailed experiments will be undertaken of relatively simple configurations to better understand flame-turbulence interaction, flame-wall interactions and the production of nitrous oxides. This experimental work will be bolstered through the use of high fidelity DNS (Direct Numerical Simulations) or "model free" simulations in Subtask 1.3.1. Finally an array of new modelling strategies will be developed in Task 1.3, including contributions from PPRIME in Poitiers, the University of Florence, Rolls-Royce, Cambridge University, STFS at the Technical University of Darmstadt and EM2C at CentraleSupélec.



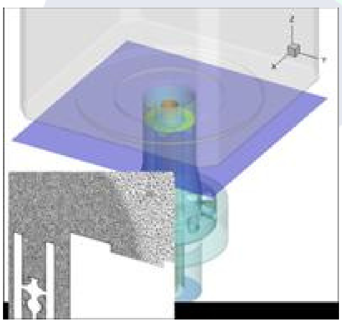
Sandia H2 jet flame simulation

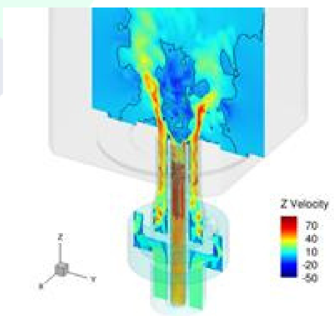
PROJECT PROGRESS
Flame dynamics

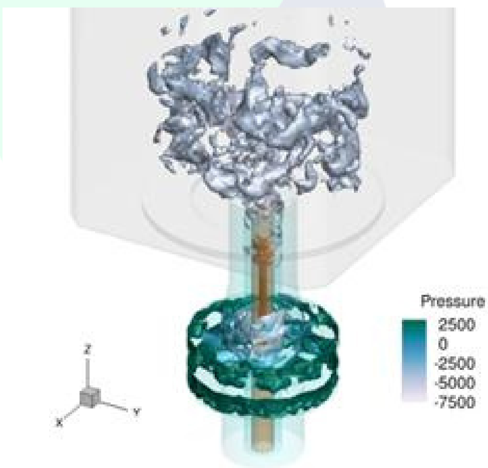
A. Tyliszczak, A. Wawrzak, K. Wawrzak, A. Boguslawski - Czestochowa University of Technology, Department of Thermal Machinery

The main aim of Task 1.2 - Flame dynamics, within Work Package 1 - Mastering key phenomena of H2/air combustion, is to analyse hydrogen flame dynamics in small-scale combustion chambers. The focus is put on thermoacoustic instabilities and behaviour of the flames in rich and lean conditions with oscillating pressure and mass flow. The analysed configurations include injection systems with bluff-bodies, swirlers as well as simple propagating flames in straight channels. The goal of the task is to provide reliable CFD tools, databases and advice for research focussing on practical aero engines.

- The recruitment process of a PhD candidate was initiated at Université d'Aix-Marseille and is on-going (Task 1.2.1). The appointment is expected September/October 2023.
- Preliminary works related to the development of Lattice-Boltzmann methods for the prediction of thermo-acoustic instabilities have been performed.
- Task 1.2.2 (General Electric Deutschland/Università degli Studi di Firenze: Numerical predictions of the thermoacoustic behaviour of low NOx H2 combustor technologies) starts at month 18. ;
- Within Task 1.2.3 (Institut National Polytechnique de Toulouse/Centre européen de recherche et de formation avancée en calcul scientifique: Flame dynamics of a swirled H2/air flame), the identification of stable and unstable modes in MSHI burner powered by hydrogen has been completed. The characterization of the stable and unstable modes as well as the characterization of the combustor acoustic response to external perturbations are in progress.
- Within Task 1.2.4 (Politechnika Częstochowska: Flame dynamics in Rich-Quench-Lean (RQL) combustion regimes), computations of lab-scale burner have been performed (images below).
- Task 1.2.5 (Politechnika Częstochowska: Flame dynamics in Lean-Direct-Injection (LDI) and Multi-Point LDI (MPLDI) started in January 2023 and is in progress. The works focus on the selection of a well-documented test configuration for CFD of MPLDI.







PROJECT PROGRESS
Development of hydrogen strut injection systems

V. Gope, A. Vandel, B. Quevreux, P. Xavier, G. Cabot, F. Grisch - INSA Rouen Normandie - CORIA

The geometry of the injection systems developed by INSA Rouen Normandie within the framework of the HESTIA program consists of an array of micro-injectors with alternating geometric shapes and hydrogen injection orifices uniformly distributed along the length of the injector body.

The selected geometries are designed to produce intense vortex structures at the injector outlet in order to rapidly promote air/fuel mixing and consequently the flame stabilization as well as the reduction of pollutant emissions. More precisely, the fuel injector must be able to produce vortex motions leading to a rapid increase in the interface surface between the fuel and air and thus improving the micro-mixing. Hydrogen is injected along the flow axis in the core of each vortex structure and along the spanwise direction through a series of orifices whose diameters are adapted to the dimensions of the vortices. Several geometries will be examined in the future to study the mechanisms of interaction between the vortices and mixing and combustion efficiencies.

To this end, initial experiments were conducted at room temperature and atmospheric pressure to visualize the effect of vortices on mixing downstream of an alternative-wedge fuel injector. Figure 1 shows instantaneous images of the mixing zone recorded by illuminating thin particles seeded into the flow by a pulsed laser sheet. Instantaneous evolution of mixing is then collected at different distances downstream of the injector. The flow visualization shows a strong undulation of the distribution of particles resulting from the vortex induced velocity, which destabilizes the airflow while significantly improving the mixing. In parallel, the formation of vortices was studied numerically by performing 3D calculations with the LES YALES2 code. As an example, figure 2 depicts the local pressure variations at the outlet of the injector, and confirms the development of counter-rotating vortices along the outlet surface of the injector, as already observed experimentally.

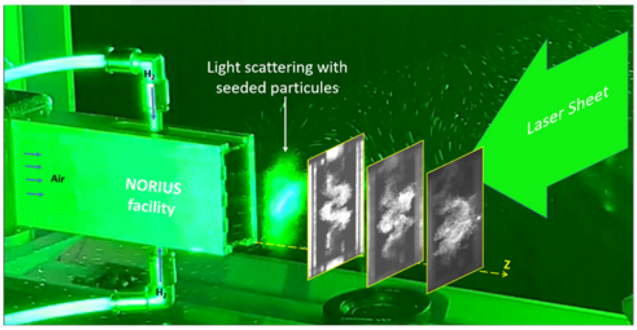


Figure 1: Experimental visualization of the flow pattern at various distances downstream from the alternative-wedge fuel injector

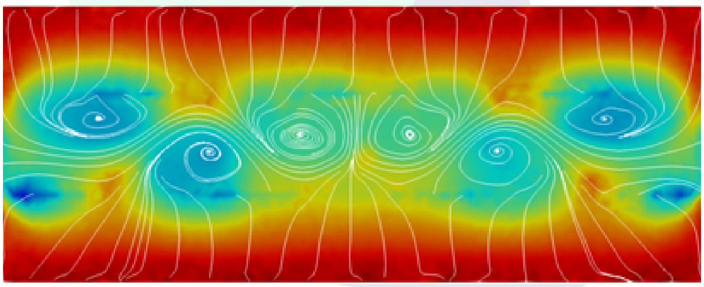


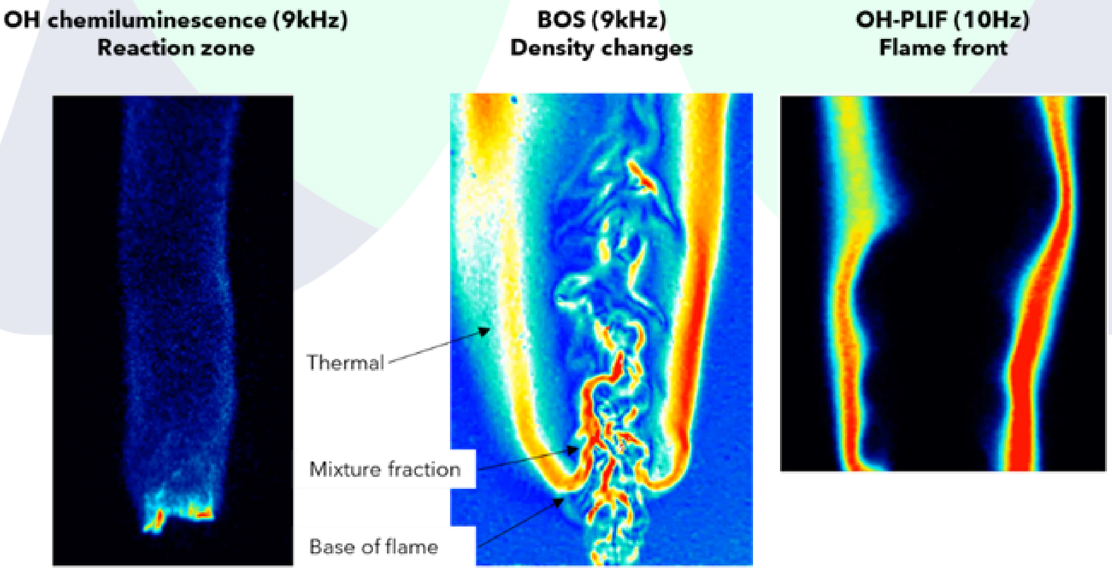
Figure 2: Illustration of the radial distribution of the vortices at the exit of the injector, demonstrating their interactions between themselves and the shear layers

PROJECT PROGRESS
Characterisation and optimisation of H2 injection systems under representative aircraft configurations

Murthy Ravikanti - Rolls-Royce UK

The main aim of Task 3.1 - Characterisation and optimisation of H2 injection systems under representative aircraft configurations, within WP3 - Specifications and operability assessments, is to numerically assess and optimise H2 fuel injector concepts within practical aero engine combustor geometry and operating conditions. The modelling tools required for this work are to be developed and validated via modelling and experimental work planned in Work Packages 1 (Mastering key phenomena of H2/air combustion) and 2 (Injection systems design – incremental & breakthrough technologies), as well as experimental work planned in Work Package 3 itself. Given the dependency of WP3 on the completion of tasks in WP1 and WP2, majority of the sub-tasks (3.1.1 to 3.1.4) are not scheduled to start until M24. However, sub-task 3.1.5 to be delivered by Rolls-Royce UK and Loughborough University collaboration is scheduled to start in M3, and progress update on it is given below.

- A funding contract has been agreed between Loughborough University and Innovate UK in December 2022, thereby allowing Loughborough University to initiate recruitment of a post-doctoral researcher in January 2023. The recruitment process is on-going and the researcher appointment is expected by June/July 2023.
- Rolls-Royce and Loughborough have jointly defined three preliminary multipoint injector concepts for low TRL testing, their mechanical designs have been developed and CFD pre-test assessment is on-going.
- Work has also been progressed in capturing requirements for the low TRL rig and defining high level concepts. It is expected that atmospheric and elevated pressure testing will be carried out on two separate test rig arrangements. Atmospheric testing with optical diagnostics is expected to commence in December 2023 and demonstration experiments to set up the optical kit have already been initiated with butane flames (images below).



Clustering activities

The HESTIA project has formed the ClimAvTech cluster along with five other EU-funded projects working to mitigate the climate impact of aviation:

MINIMAL - Minimum environmental impact ultra-efficient cores for aircraft propulsion

BeCoM - Better Contrails Mitigation

MATISSE - Multifunctional structures with quasi-solid-state Li-ion battery cells and sensors for the next generation climate neutral aircraft

OVERLEAF - nOVel low-prEssure cRyogenic Liquid hydrogEn storAge For aviation

EFACA - Environmentally Friendly Aviation for all Classes of Aircraft

The projects of the ClimAvTech cluster will engage in scientific cooperation and conduct joint dissemination activities.

Executive Board meeting in Berlin

In February, the HESTIA Executive Board met at the Rolls-Royce Deutschland headquarters in Berlin to discuss the progress accomplished during the first six months of the project.

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