NUMERICAL INVESTIGATION OF A NOVEL NON-PREMIXED HYDROGEN BURNER UNDER ATMOSPHERIC PRESSURE CONDITIONS

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Abstract
The non-premixed 100% hydrogen burner conceptualized at University of Florence as part of the project “HydrogEn combuSTion In Aero engines” (HESTIA) is numerically investigated at atmospheric pressure conditions through a reactive Large Eddy Simulation (LES). The lifted V-shaped flame stabilization above the fuel injector is analyzed through flow field considerations. NO_x emissions analysis shows predominantly thermal NO formation. Results support the test rig commissioning.

Introduction

Hydrogen has emerged as a key alternative to conventional aviation fuels for achieving net-zero CO_2 emissions by 2050. Its combustion properties demand rapid, homogeneous mixing and favor lean, non-premixed strategies to mitigate flashback risk. In this context, open-access hydrogen burners become essential to support next-generation combustion system development. Accordingly, a novel non-premixed, swirl-stabilized 100% hydrogen lean burner for aero engine applications was developed within the European project HESTIA [1] and subsequently scaled for testing in the atmospheric facility of the University of Florence.

This work presents a numerical investigation of the scaled burner using reactive LES exploiting a regularized extension [2] of the Dynamic Thickened Flame model for LES (DTFLES) [3] addressing multi-regime flames. NO_x emissions are estimated via the LES-to-RANS (L2R) approach proposed by Amerighi et al. [4].

Test case and numerical methodology

The burner exploits a triple swirler coaxial injector, with the innermost channel supplying hydrogen and hosting a convergent axial swirler, and the two outer channels supplying the primary and secondary air streams and hosting radial swirlers. All swirlers are arranged in a co-rotating configuration, while the effusion cooling system on the dome is arranged in a counter-rotating orientation relative to the swirlers. A sketch of the burner is reported in Fig. 1a.

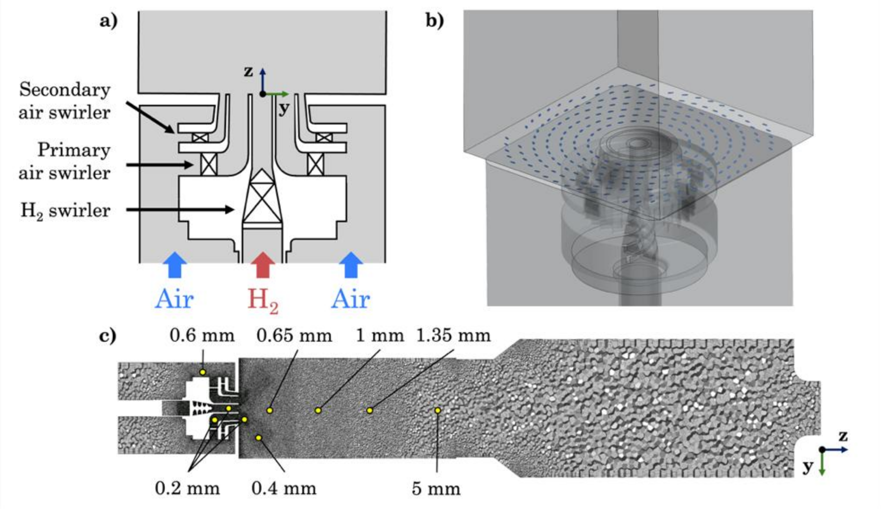

Figure 1. Sketch of the burner (a). Isometric view of the burner with mass flow inlet patches for effusion cooling highlighted in blue (b). Numerical mesh (c).

Table 1. Operating conditions.

$\dot{m}_{Air}^{sw}$	13.793 g s^{-1}	T_{Air}^{sw}	573 K	Φ^{sw}	0.80
$\dot{m}_{Air}^{cool}$	3.245 g s^{-1}	T_{Air}^{cool}	573 K	$\Phi^{sw+cool}$	0.64
$\dot{m}_f$	0.322 g s^{-1}	T_f	300 K	P^{op}	101325 Pa

The computational domain includes the upstream plenum, burner, combustor dome, and flame tube. All walls are assumed adiabatic; effusion cooling holes are not discretized but modeled as oriented mass flow inlets on the dome surface (Fig. 1b). Mass flow rates are imposed at the air plenum and fuel line inlets based on the operating conditions in Table 1, while the outlet is set at a static pressure P^{op}.
The domain is meshed with a static polyhedral grid of 31 million cells (Fig. 1c).
Chemical kinetics relies on the skeletal Boivin 9S12R mechanism [5]. Turbulent combustion is handled through a regularized extension of DTFLES addressing multi-regime flames [2,3], and turbulence-chemistry interaction is recovered via Colin's efficiency formulation [6,7]. NO_x emissions are estimated through the L2R approach [4], accounting for both thermal and N_2O-intermediate pathways.

Results

Figure 2 reports the distributions of axial velocity, temperature, and heat release rate. The pronounced recirculation zone at the injector exit hinders the hydrogen stream and induces a marked radial acceleration of the flow. The high velocity and elevated strain levels, combined with the excess fuel in the early mixing zone, are responsible for the lifted V-shaped flame stabilization above the injector.

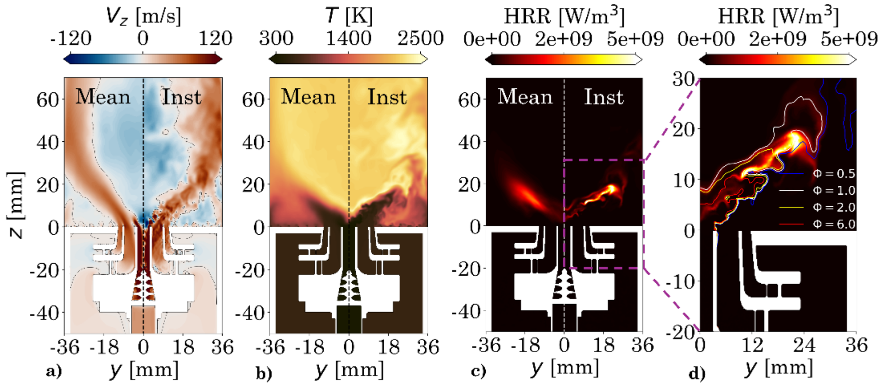

Figure 2. Time-averaged (left) and instantaneous (right) distributions of axial velocity (a), static temperature (b), and heat release rate (c) on the YZ plane. Superposition of instantaneous heat release rate and equivalence ratio isolines (d).

Figure 3 shows that thermal NO is the dominant formation mechanism, with the peak forming in proximity to a weakly stretched diffusive flame front.

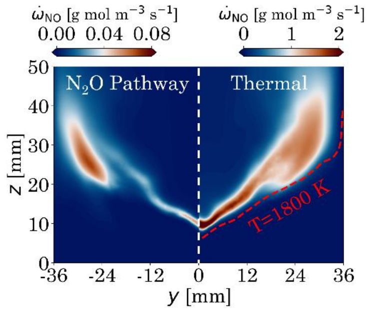

Figure 3. Nitric oxide production rates via N_2O pathway (left) and extended Zeldovich reactions (right) obtained with L2R methodology.

Conclusions

The burner conceptualized at University of Florence as a part of European project HESTIA is investigated at atmospheric pressure conditions via reactive LES.
A lifted V-shaped flame stabilization is observed, and the analysis of NO_x emissions reveals predominant formation of thermal NO.

Acknowledgments

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