TNF target flame: Premixed turbulent $NH_3/H_2/N_2$-air jet flames at atmospheric pressure

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Introduction

Ammonia (NH_3) is a carbon-free hydrogen carrier with significant potential as a fuel for the decarbonization of future power systems, including gas turbines and internal combustion engines. Its combustion poses several challenges, such as high ignition energy, low reactivity, slow flame propagation, and elevated nitrogen oxides (NO_x) emissions. Co-firing ammonia with a more reactive fuel, such as hydrogen H_2, enhances its reactivity and ensures stable combustion [1]. However, burning ammonia fuel blends might also strongly influence the emission formation. Rich-quench-lean (RQL) technologies have been proposed as a strategy to reduce emissions in ammonia combustion [2]. Premixed piloted jet flames, with their well-defined boundary conditions, offer a robust framework for studying the impact of turbulence on the macroscopic and microscopic flame structures of staged-combustion systems at atmospheric conditions.

The macroscopic flame properties encompass information on the local flame topology, as measured by two-dimensional (2D) Rayleigh scattering, accompanied by the microscopic flame properties, including information on thermochemical states (temperature and main species), measured simultaneously by 1D Raman/Rayleigh. The study aims to provide quantitative data to evaluate the complex interactions between NH_3 and H_2 along with effects of turbulence on molecular transport based on local thermochemical states and instantaneous flame structures.

Experimental setup and geometry

Figure 1 shows a schematic of the piloted turbulent jet burner. Based on the McKenna burner design, this configuration includes a concentric jet nozzle (inner diameter D = 4.5 mm), a central porous sintered stainless steel pilot plate (inner diameter 6.3 mm and outer diameter 60.5 mm), and an outer porous sintered bronze coflow annulus. Both the pilot and coflow matrix feature a porosity of approximately 0.4. To ensure temporally constant inflow temperature conditions, the pilot porous block is water-cooled. Additionally, nitrogen is utilized as a shielding coflow to minimize the entrainment of cold air, creating a controlled environment for combustion experiments.

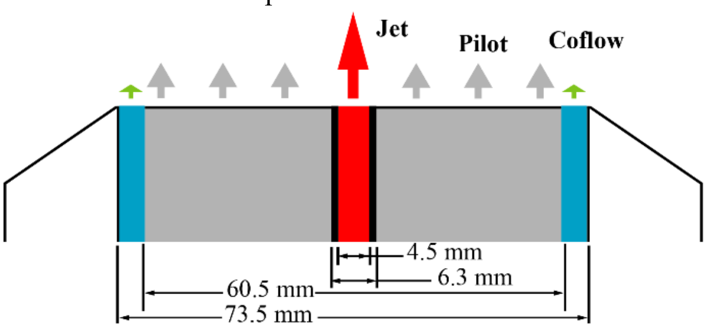

Figure 1: Schematic of the piloted turbulent jet burner

Operation conditions

Premixed jet flames have been investigated for a wide range of operating conditions. For this purpose, the equivalence ratio ϕ_{global}, the jet bulk velocity U_0, as well as the pre-cracking ratio have been varied. The operational conditions include a range of jet Reynolds numbers Re from approximately 6,000 to 18,000. Depending on the equivalence ratio, effective Lewis numbers were between 0.83 and 1.1. Table 1 provides an overview of the operational conditions.

Table 1. Flow configuration and properties of premixed $NH_3/H_2/N_2$/air turbulent flames.

Case	H_2 (%)	ϕ_{global} (-)	U_0 (m/s)	x/D	U_{pilot} (m/s)	ϕ_{pilot} (-)	Le	T_{ad} (K)	S_L (m/s)	Re
H045U025	45	0.8 / 1.0 / 1.2 / 1.6	25	7	2.5	0.57	0.88 / 0.9 / 0.93 / 0.98	1945 / 2150 / 2060 / 1830	0.32 / 0.46 / 0.47 / 0.28	6472 / 6350 / 6242 / 6057
H045U050	45	0.8 / 1.0 / 1.2 / 1.6	50	7	2.5	0.57	0.88 / 0.9 / 0.93 / 0.98	1945 / 2150 / 2060 / 1830	0.32 / 0.46 / 0.47 / 0.28	1300 / 12700 / 12500 / 12100
H045U075	45	0.8 / 1.0 / 1.2 / 1.6	75	7	2.5	0.57	0.88 / 0.9 / 0.93 / 0.98	1945 / 2150 / 2060 / 1830	0.32 / 0.46 / 0.47 / 0.28	19400 / 19050 / 1870 / 18200
H030U050	30	0.8 / 1.0 / 1.2 / 1.6	50	7	2.5	0.57	0.98 / 1.0 / 1.01 / 1.04	1910 / 2120 / 2020 / 1780	0.16 / 0.25 / 0.24 / 0.15	13500 / 13380 / 13240 / 13000
H015U050	15	0.8 / 1.0 / 1.2 / 1.6	50	7	2.5	0.57	1.07 / 1.0 / 1.09 / 1.1	1880 / 2100 / 1983 / 1735	0.09 / 0.13 / 0.14 / 0.08	14000 / 13900 / 13900 / 13800
H045P057U070	45	0.57	70	3.5	2.5	0.57	0.83	1610	0.12	18570
	45	0.57	70	7	2.5	0.57	0.83	1610	0.12	18570
	45	0.57	70	10.5	2.5	0.57	0.83	1610	0.12	18570

Diagnostics

The thermo-chemical states were measured by simultaneous one dimensionally resolved Raman/Rayleigh spectroscopy combined with 2D Rayleigh scattering to resolve the macroscopic flame structures surrounding the 6-mm long 1D Raman/Rayleigh probe volume. Using this combined diagnostic approach, the temperature and species concentrations have been quantitatively measured together with the local flame front curvatures. Detailed information on the experimental setup is provided in refs. [3,4]. Data evaluation is based on the hybrid matrix inversion method [5,6]. Experimental uncertainties are summarized in Table 2.

Table 2. Estimated precision and accuracy in temperature and mole fractions at representative flame conditions.

Scalar	Precision (%)	Accuracy (%)	Temperature (K)
T	1.3	2.0	-
H_2	9.6	8.4	500
H_2O	3.0	2.0	1600
N_2	3.0	1.0	500
NH_3	5.0	2.0	500

Exemplary results

Figure 2 shows time averaged chemiluminescence images of selected operational conditions. Horizontal lines highlight axial positions of the 1D Raman/Rayleigh measurements.

Figure 3 shows the exemplary flame topology by the instantaneous 2D Rayleigh images of turbulent premixed $NH_3/H_2/N_2$/-air flames at different global equivalence ratio ϕ_{global} of 0.8 and 1.6 and increasing bulk velocity U_0 from 25 to 75 m/s.

Figure 4 exemplifies insights into the microscopic flame structure showing the single shot values (blue) and conditional mean values (red) of NH_3 mole fraction (a), H_2 mole fraction (b) with bulk velocities of 25 and 75 m/s.

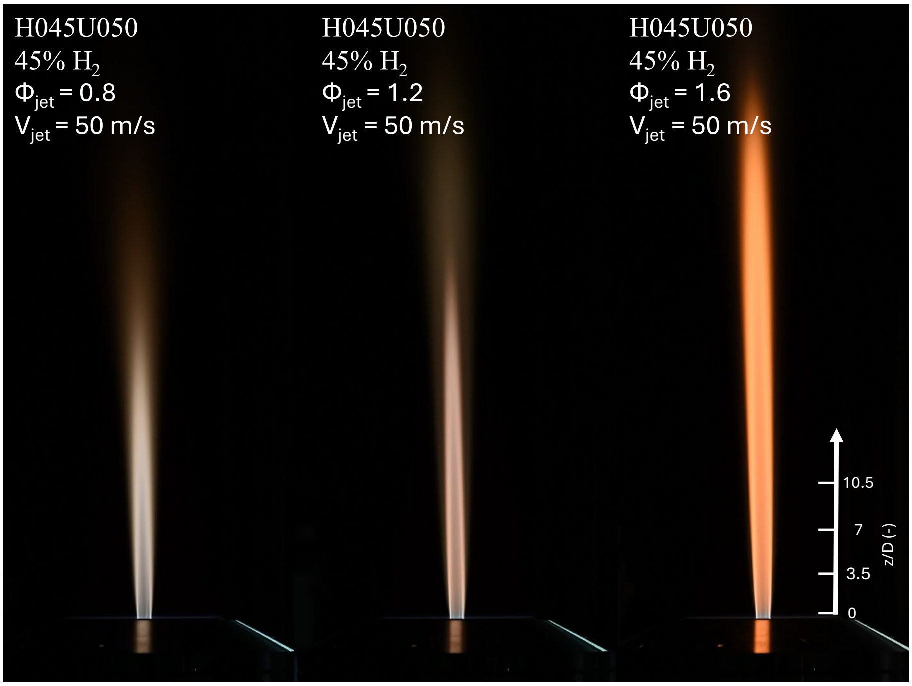

Figure 2: Chemiluminescence images of selected premixed $NH_3/H_2/N_2$/-air flames listed in Table 1

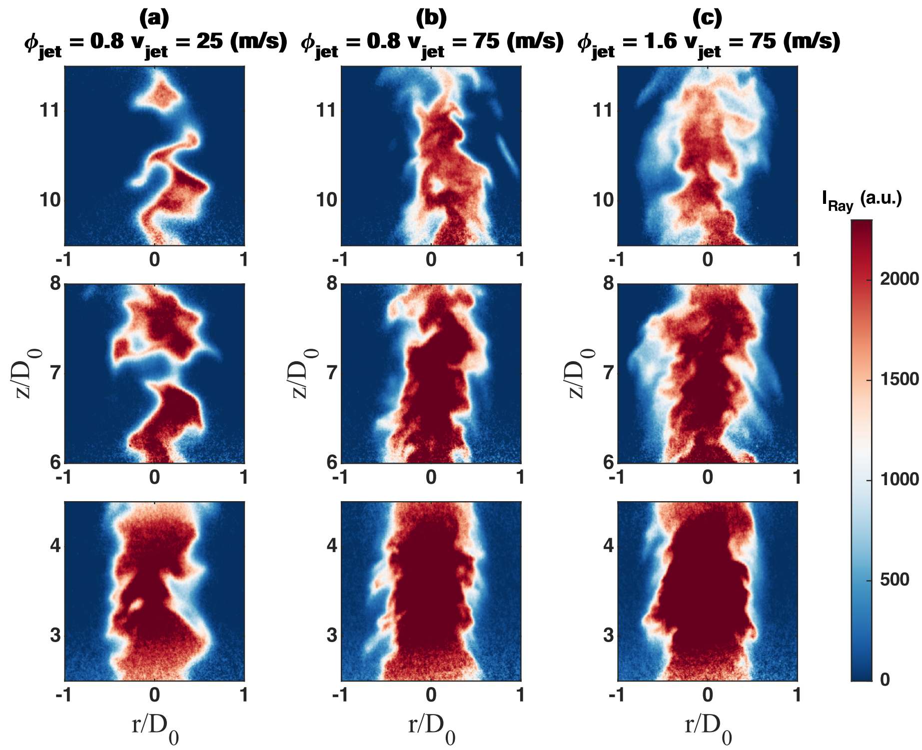

Figure 3: Instantaneous 2D-Rayleigh images of lean to rich premixed $NH_3/H_2/N_2$/-air turbulent flames at different bulk velocities U_0.

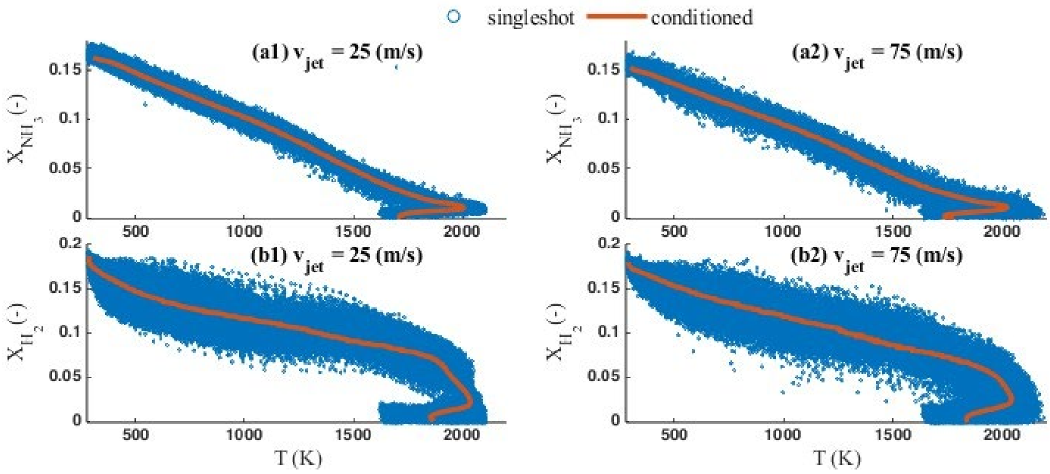

Figure 4: Single shot (blue) and conditional mean values (red) of NH_3 mole fraction (a), H_2 mole fraction (b) in a function of temperature in lean premixed $NH_3/H_2/N_2$-air turbulent flames with bulk velocities of 25 and 75 m/s.

How to get access to the data

Upon request. Contact Dr. Tao Li (tao.li@rsm.tu-darmstadt.de) or Prof. Andreas Dreizler (dreizler@rsm.tu-darmstadt.de).

References

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