Optical Spectroscopy on the Hypergolic MMH/NTO Combustion in Spacecraft Propulsion

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1. Introduction

Within the framework of the joint FOLAN project between DLR and EADS Astrium® investigations on the hypergolic combustion of MMH = monomethylhydrazine and NTO = (di)nitrogen tetroxide N_2O_4 were conducted in order to visualize the flame of recently developed injectors, to further comprehend the hypergolic reaction, and, regarding the usage of a LIDAR system for distance and velocity measurements during approximation and landing on the moon's surface, to examine the scattering behaviour of a laser beam traversing hot exhausting gas. The hypergolic combustion process described here is specifically more complex than conventional (i.e. cryogenic) reactions since the conversion of MMH and NTO takes place via highly energetic, condensable, and potentially durable intermediates [1][2][3][4] that may accumulate in the combustion chamber followed by pressure peaks when spontaneously reacting into the finite state. On the other hand, their ability to autoignite at low temperatures as well as their space storability qualifies both MMH and NTO for remote and long term operations. Handling and storage on the ground, however, prove to be very delicate, and therefore only few published experiments on the MMH/NTO flame have been carried out. Thus, access to the EADS operated test benches P1 and P2 on the DLR site Lampoldshausen enables a variety of investigations on this field.

2. Materials and methods

Using three different EADS Astrium® developed swirl injectors, the fuel MMH and the oxidizer NTO were fed into a transparent borosilicate glass combustion chamber at test bench P2. High speed movie recording of three different spectral windows was realized using a Photron® FASTCAM-ultima APX-i2 camera and optical filters. Flame emission and absorption spectroscopy was carried out by an Andor® Shamrock SR-163 and a Princeton® Acton SP2750 spectrometer.

At test bench P1 spectroscopic experiments on the plume emission of three different engines and thrusters were conducted taking advantage of the Andor® spectrometer for the visible regime, and a Polytec® PSS device for the near infrared region of the optical spectrum.

In order to examine the deflection behaviour of a LIDAR laser beam travelling through hot exhaust gas inside an evacuated vacuum chamber, the backscattered laser signal was recorded using the Andor® spectrometer and a λ=632.8 nm HeNe laser. Both the spectrometer and the laser were placed outside the vacuum chamber with the former focussing into the exhaust plume.

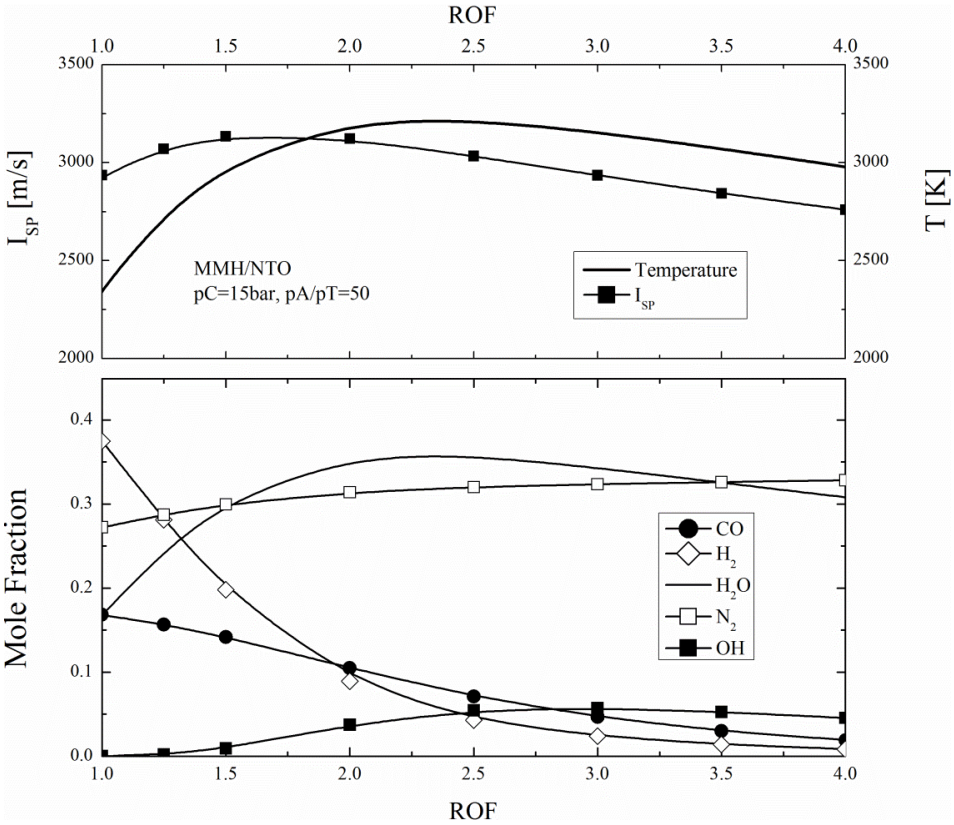

Fig. 1 Hypergolic MMH/NTO combustion: Thermodynamic calculations [5] for typical ROF regimes displaying relevant impellent parameters such as temperature and specific impulse (upper chart) as well as mole fractions of expected constituents generated during the complex combustion process (lower chart).

3. Results

Numerical calculations using the "Computer Program for Calculating and Fitting Thermodynamic Functions" [5] yield an optimal I_{SP} for a ROF of 1.6 and 15 bar chamber pressure, which implicates H_2O and H_2 as the main constituents of the combustion (Fig. 1). However, though spectral investigations clearly revealed OH* as the most intense contribution of all emitters inside the combustion chamber, plume measurements lacked almost entirely of the OH* signal suggesting a nearly complete reaction of the OH* radical when leaving the combustion chamber. In addition to the OH* emission, the MMH production remnant sodium brightly emits the prominent D-line at 589 nm. Both OH* and Na emission were used for flame visualizations revealing the structure of the flame induced by the different injector types.

Experiments on the scattering behavior of the λ=632.8 nm laser beam in differently pulsed exhaust plumes of a 10 N thruster were explicitly showing influences of the pulse duration and thus also on the pulse mode (frequency). Fig. 2 depicts the normalized signal of the backscattered laser signal and compares its function of the pulse mode with those of the CN emission band intensity. Though from 10 msec pulse mode to 20 msec pulse mode the scattered laser signal intensity increases and remains up to a pulse mode of 30 msec the intensity clearly decreases for lower pulse frequencies and disappears almost entirely when firing constantly in steady state mode. It is suggested that Mie scattering causes the deflection of the photons on unburnt propellant droplets

which appear the more prevalently the shorter the pulse duration is. This effect is in agreement with the monotonically increasing CN emission intensity as a function of the pulse duration.

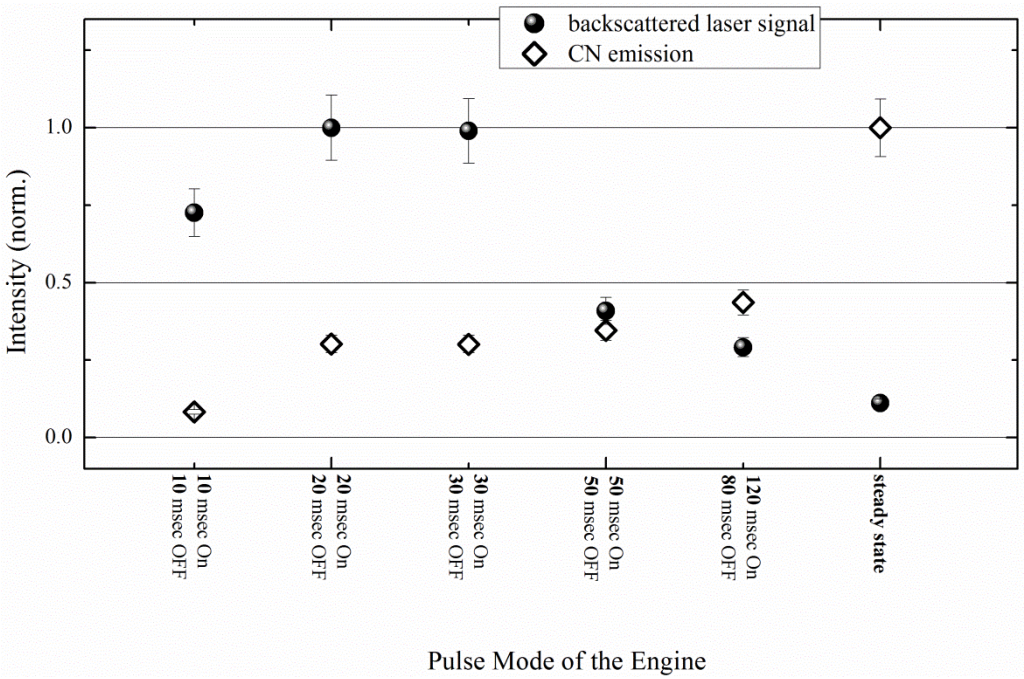

Fig. 2 LIDAR feasibility study: Normalized integral intensities of the backscattered laser signal (round symbols) at λ=632.8 nm, and the emission band of the CN radiation (diamond) at λ=384 nm [6]. Each data point results from a detector exposure time of 10 s. Short pulse durations (high frequency) implicate relatively low CN emission intensities but more intense signals of the laser beam backscattered in the plume of the 10 N LunarLander thruster.

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