Frequency dependence of cryogenic oxygen jet response to transverse acoustic oscillations

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Abstract

Liquid propellant rocket engines face a common problem during their development phases, and sometimes operational lifecycle, known as high frequency (HF) combustion instabilities. These are highly destructive pressure fluctuations in the rocket engine which usually oscillate with the frequency of acoustic resonance modes of the combustion chamber volume. Research efforts are currently underway at DLR Lampoldshausen which aim to understand the mechanisms by which these self-sustaining oscillations in combustion chamber pressure are driven.

Sub-scale rocket combustors with optical access have been used since the 1950s to try and observe and understand the behaviour of flames under conditions simulating those of combustion instabilities. More recently, groups such as CNRS, ONERA and DLR have developed windowed combustors which can also artificially force excitation of acoustic resonance modes by periodically blocking the exhaust nozzle using a toothed-wheel. The DLR combustor designated ‘BKH’ uses this form of acoustic forcing, and is operated at the European Research and Technology Test Facility P8 for cryogenic rocket engines at DLR Lampoldshausen. BKH has a rectangular cross-section in order to fix the excited acoustic resonance frequencies and structures, and optical access windows for application of high-speed imaging of the flame. The injector consists of five shear coaxial elements arranged in a pattern which provides a representative environment for the central element, surrounded on all sides by other elements. The injection parameters are representative of real upper stage liquid rocket engines. The combustor operates with cryogenic oxygen and hydrogen at combustion chamber pressures up to 60 bar. BKH and the experimental setup is illustrated conceptually, and photographed during testing, in Figure 1 with the optical access window clearly visible.

BKH is used to observe flame-acoustic interactions under representative conditions, which may hold the key to discovering which mechanisms are at work in full-scale combustion instabilities. Such interactions have been recorded with high-speed shadowgraph imaging, and are analysed in the proposed paper. Previous studies with BKH have reported measurements of the intact liquid oxygen jet during forced excitation of the first transverse (1T) acoustic mode. High-speed shadowgraph images show significant reduction in the core length during transverse acoustic gas motion. The core length is found to be dependent on the amplitude of the acoustic particle velocity, with a core length reduction of up to 75% for velocities approaching those of naturally occurring HF combustion instabilities. The current paper intends to explore the influence of excitation frequency on this relationship. Core length measurements during 1T mode excitation will be compared to those during excitation of the first combined longitudinal-transverse (1L1T) mode. The 1L1T mode has a similar acoustic field distribution as the 1T mode at the location of the injector, yet has a resonance frequency at least 1000 Hz higher. Knowledge of the influence of acoustic field on the LOx core is important for understanding the driving mechanism of combustion instabilities.

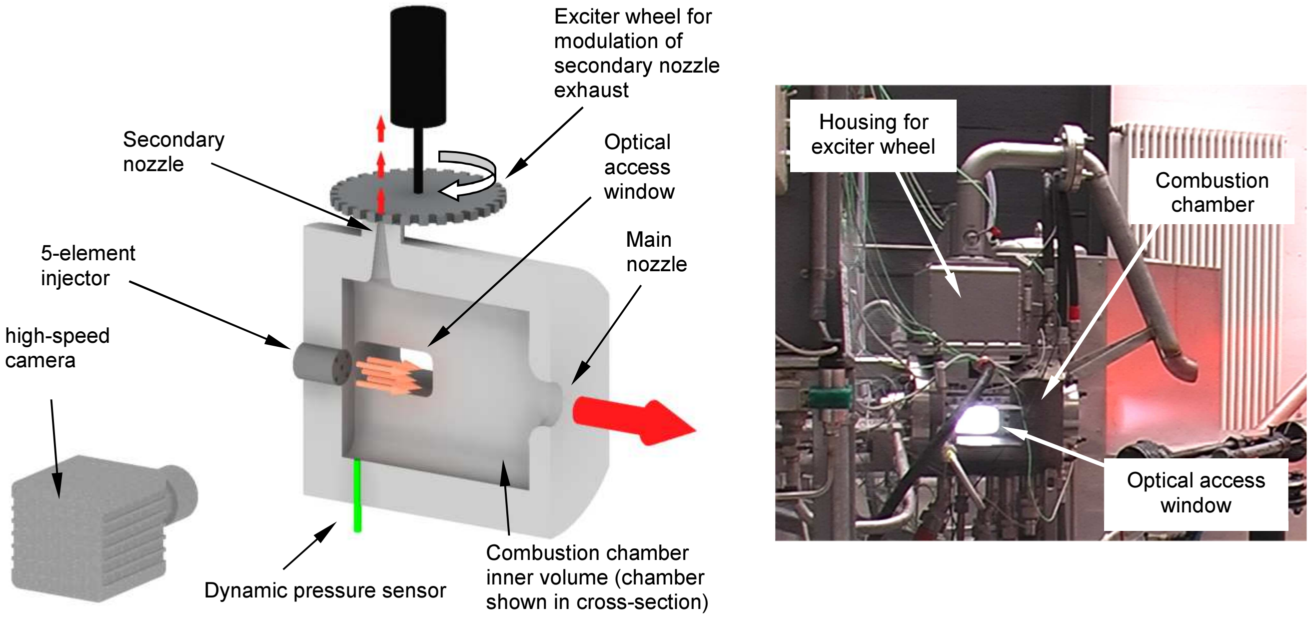

Figure 1 - conceptual illustration of the BKH combustor