Design of the feed system of a Hybrid Rocket Engine

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Over the last decade, space industry has experienced a radical change with the apparition of private companies providing low-cost solutions for nanosatellites launch and civil suborbital flights. In this context, Hybrid Rocket Engine (HRE) technology seems to meet safety and cost-efficiency requirements compared to widely used solid and liquid propulsion systems. From a general point of view, the design of such engine is not straightforward because of its intrinsic transient behavior, i.e., combustion chamber geometry continuously varies with the operating time [1]. In addition, combustion process can be highly unstable because of the potential coupling of turbulent multiphase reacting flow and acoustic modes of the chamber [2]. In practice, such interactions may result in low-frequency instabilities, damage the payload and lead to a partial destruction of the HRE.

Control of oxidizer injection, optimization of atomization process and chamber aerodynamics are then compulsory to ensure a stable behavior of the diffusion flame and improve combustion efficiency [3]. Hence, HRE reliability and performance are closely linked to injection and feed systems. This contribution first proposes a concrete and operational solution to limit oxidizer sloshing and then ensure a continuous feeding of the combustion chamber during a flight. Design, realization and experimental characterization of the anti-sloshing system are detailed. In a second part, a new injector geometry adapted to both single and multi-port fuel grains is presented and experimentally characterized.

Conception of the present anti-sloshing system is based on the identification of the sloshing modes [4] during a typical rocket flight. A combination of several simple anti-sloshing systems [5] has been designed to prevent the identified modes to appear. A test campaign has been conducted to assess the efficiency of the proposed detachable anti-sloshing system. For that purpose, a test bench has been designed to reproduce a relevant range of uniaxial low-frequency solicitations. The cylindrical tank has been chosen transparent in order to follow liquid free surface motion amplitude. For the given tank geometry and operating conditions, measurements have been performed with and without the detachable anti-sloshing system. Waves amplitude drop was found to go up to 68% for the explored frequency range. Spectral analysis has also been conducted to analyse the impact of anti-sloshing system on forced and natural sloshing modes. The probability of a feeding interruption due to high sloshing modes significantly decreased and further work on injection process can now be performed.

As mentioned before, combustion stability and efficiency strongly depend on the ability of the injector to induce strong aerodynamics and create homogeneous oxidizer atomization within the combustion chamber. For that purpose, a new injector has been designed based on both qualitative considerations and literature review [6, 7, 8, 9]. It is composed of an axial orifice surrounded by a swirl vortex chamber. A basic numerical simulation has first been performed to ensure balanced mass flow rates through each injection channel. A cold flow test on a first prototype confirmed the numerical approach and allowed the design of a second prototype for experimental reacting characterization. Reacting tests were performed on a dedicated HRE test bench to compare the specific impulse (ISP) gain of this new injector over a simple axial injector. Results showed an overall ISP improvement of 9 seconds for the experimented combustion chamber geometry. Further investigations and improved measurements are being developed to allow transient analysis of HRE test bench performance focusing on the limitation of pressure oscillations.

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