Tripropellant Effervescent Injector Study

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To advance the state-of-the-art with respect to the development of injection elements for the Reusable Launch Vehicle (RLV) engine, Pennsylvania State University (PSU) has designed an effervescent atomizer, as shown in figure 22. This design has a potential application on a tripropellant RP–1/oxygen/hydrogen rocket engine. The injector type is similar to a shear coaxial element. The major difference is that both fuels, RP–1 and gaseous hydrogen, share the center post. The gaseous hydrogen flow enters the liquid RP–1 through three holes located upstream of the center post-exit plane and forms the effervescent fluid. The inside diameter of the center post is 0.15 in, whereas the inner and outer diameters of the gaseous oxygen annulus are 0.18 and 0.5 in. Drop-size measurements and photographic visualizations of the flowfield for cold flow conditions, using gaseous nitrogen and water as simulants, indicate that for high gas-to-liquid volumetric flow ratios, the flow exiting the injector is an extremely dense cloud of small liquid drops.

A hot-fire test series was conducted using a 2- by 2-in square combustor equipped with windows on the chamber walls for the purpose of using a laser-based diagnostic technique. These windows were cooled with a nitrogen purge. To identify the injector performance, the experiments were set up to measure RP–1 drop size and combustion efficiency (C^*) for hydrogen mass flow rate additions from 2 to 10 percent with chamber pressures (Pc) from 230 to 500 psia. This pressure range covers the sub-, trans-, and super-critical regimes of RP–1 propellant. Performance enhancement due to hydrogen addition is also evaluated from this study. An overall optimum mixture ratio of oxidizer to fuel was based upon an established mixture ratio of oxygen/RP–1 of 2.4 (yielding high performance) together with the stoichiometric mixture ratio for oxygen/hydrogen of 8.0 (producing the maximum temperature).

The RP–1 drop sizes in the combusting flowfield were measured using phase Doppler interferometry. Measurements at a location (x = 6 in and r = 0.2 in), as shown in figure 23, are compared for three chamber pressure conditions of 230, 320, and 500 psia. The results show that drop sizes could be measured at both transcritical (320 psia case) and super-critical conditions (500 psia case).

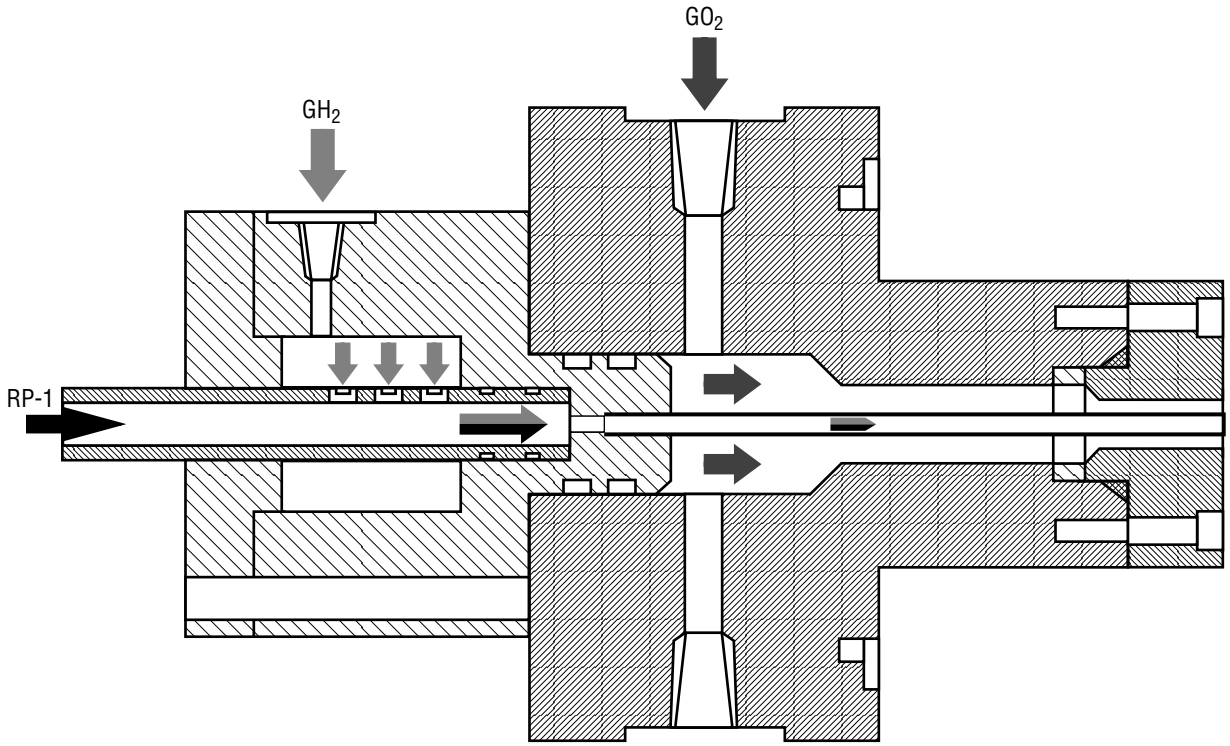

Figure 22.—Schematic of effervescent injector element used for RP–1/GH_2/GO_2 tripropellants.

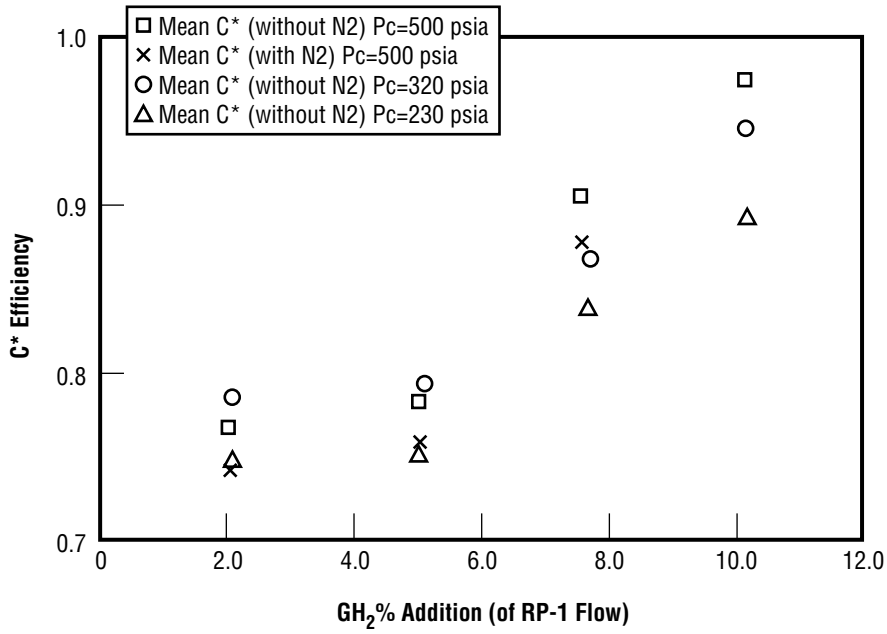

FIGURE 23.—RP–1/GH_2/GO_2 rocket C* efficiency for increasing flow rate of GH_2 (percentage of RP–1 flow).

University/Industry Involvement: Robert J. Santoro and Charles Merkle, The Propulsion Engineering Research Center of the Pennsylvania State University.

Biographical Sketch: Huu P. Trinh has worked in the area of liquid rocket engine combustion at MSFC since 1987. He has used computational and analytical models to analyze rocket engine performances. Currently, he monitors a project of providing technologies for main chamber and preburner injectors. The effort is conducted under a PSU NRA cooperative agreement to support the RLV program. In addition, he evaluates injector performance of the Fastrac engine and analyzes proposed Bantam main and gas generator injectors.

The effects of hydrogen mass addition on C* efficiency for subject injector are presented in figure 24 for three chamber pressure cases. For comparison purposes, the C* efficiencies at a chamber pressure of 500 psia were calcualted both with and without the nitrogen purge. The results clearly show that the combustion efficiency increases with the increase of hydrogen mass flow rate. The measurements are consistent for the tested chamber pressures of 230, 320, and 500 psia. For the effervescent injector, atomization is clearly improved with the addition of hydrogen. The fast reaction rate of hydrogen/oxygen as compared to that of RP–1/oxygen translates to a high-temperature oxidizer-rich environment near the injector face. Consequently, the two aforementioned effects would enhance the combustion efficiency.

Sponsor: Office of Space Access and Technology

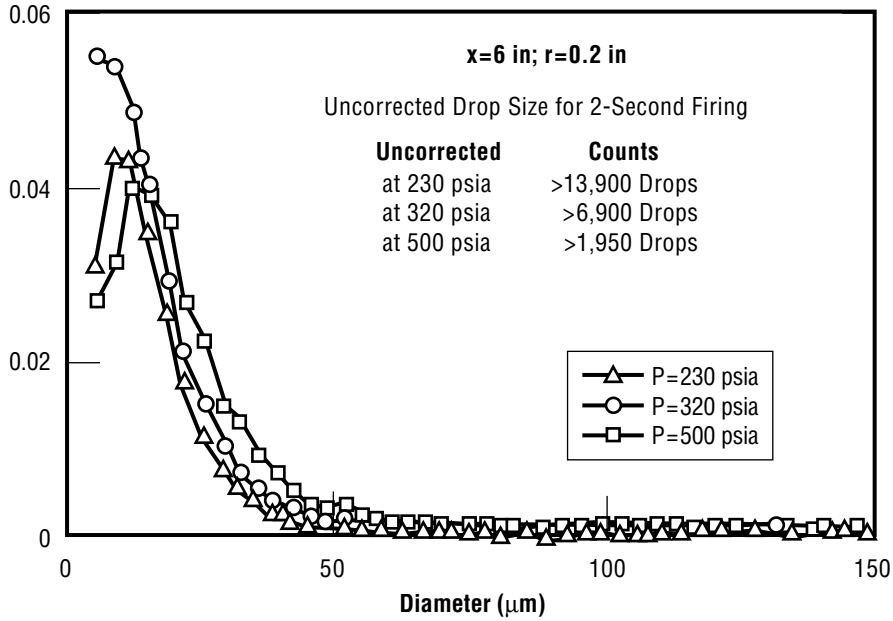

FIGURE 24.—Measured RP–1 drop size probability density functions for three chamber pressure conditions. GH_2 flowrate equal to 10 percent of RP–1 flowrate.