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Direct-Drive Thrust Vector Control System Using a Throttleable H_2O_2/PP Hybrid Rocket Engine

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LONG ABSTRACT

Nowadays, the application of a hybrid rocket propulsion system to space technology has been widely spread and commercialized because of its competitive benefits. As compared with the liquid rocket engines and the solid rocket motor, the hybrid rocket motor has the following advantages: powerful volumetric impulse [1], high safety, low cost, simple system architecture, and the capacity for precise throttling [2]. Polypropylene (PP) is a common industrial product which is easy and cheap to fabricated. It's strong mechanical properties also allows it has a higher melting point than those traditional solid fuel such as paraffin and PMMA. These advantages also make the pp fuel more capable of long time operation for hybrid rockets. For the oxidizer, interest in high-density hydrogen peroxide (H_2O_2) attracts more and more attention these decades. As compared with other oxidizer such as nitrous oxide, hydrogen peroxide could be easily decomposed into hot gaseous oxygen and hot water vapor by a catalytic bed. In addition, it's incompressible and has a better potential in throttling as compared with other supercritical fluids [3]. Finally, the hybrid motor using hydrogen peroxide and plastic fuel has a high ideal specific impulse which could exceed to 250 s at sea level. The ability to control the thrust vector of any rocket propulsion system is the most competitive technology to the launch vehicle. Traditionally, a movable nozzle, a moving vane, or a jet tab was equipped with a gimbal mechanism and an actuator to make the thruster available of vectoring [4]. For hybrid rockets, secondary-injection thrust-vector-control (SITVC) is another approach that was implemented to drive the motor's direction [5]. However, the resulting thrust vector was usually inaccurate due the changing ambient pressure during flying influences the accuracy of thrust vector, further to the flight control performance. Hence, to develop a direct-drive thrust vector control system plays a key role to hybrid rockets.

In this study, a direct-drive thrust-vector-control system using a throttleable 120-kgf class hybrid rocket motor for the development of an advanced two-stage all-hybrid sounding rocket, HTTP-3A, which aims to reach an apogee of exceeding

100 km in 2021. This mentioned hybrid rocket engine based on the requirements using 90% hydrogen peroxide and PP as the oxidizer and fuel respectively. Some details of the design, implementation and tests, focusing on the performance and throttling capability, are described next.

Figure 1 shows the configuration of the 120-kgf hybrid rocket engine. Globular MnO_2 coated with Al_2O_3 was chosen as the catalyst and was compactly packed in the CB to decompose the H_2O_2 into hot water vapor and oxygen. Afterward, the hot gas flowed through a swirling injector, with geometrical swirl number of 3.0, to improve the mixing between gaseous oxidizer and fuel vapor and to increase the combustion efficiency. Then the hybrid motor generates the powerful thrust by a convergent-divergent nozzle.

Figure 2 shows the temporal data for the 16-s and 30-s hot-fire test with $\dot{m}_{ox}$ of 425 g/s. The averaged thrust and chamber pressure both complied with the requirements. Figure 3 shows the measured temporal data during the throttling test. In brief, Table 1 summarizes the corresponding test data in more detail. The nominal thrust during the burn time is ~120 kgf with an impressive sea-level specific impulse is almost 241.8 s (almost 99% engine efficiency). Furthermore, Figure 4 illustrates the snapshots of vertical thrust-vector-control hot-fire test using 4 sets of mentioned throttleable hybrid rocket motors. The vector of propulsion was precisely controlled with the direct-drive TVC system. More details of the test results will be presented in the meeting.

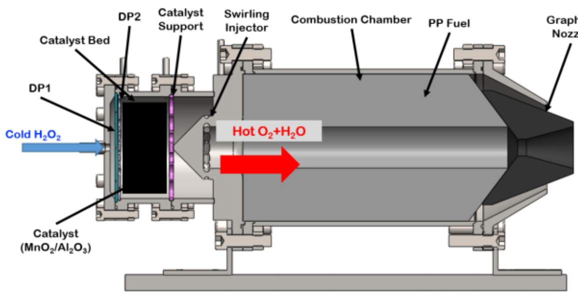
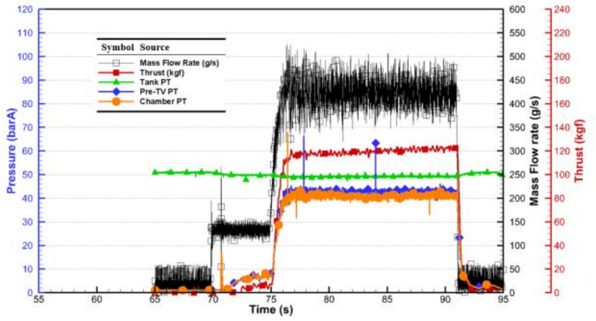
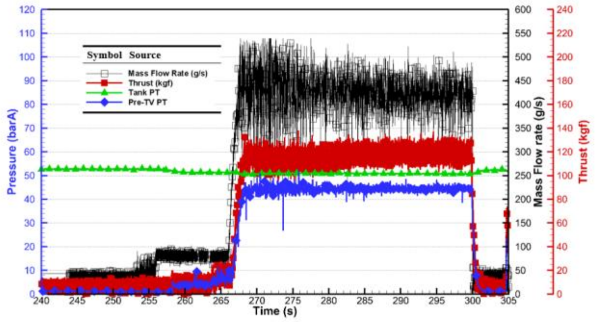


Fig. 1 Configuration of the 120-kgf hybrid rocket engine equipped with a swirling injector



(a)



(b)

Fig. 2 Measured temporal data of the (a) 16 s and (b) 30 s hot-firing test with a fix $\dot{m}_{ox}$ of 425 g/s

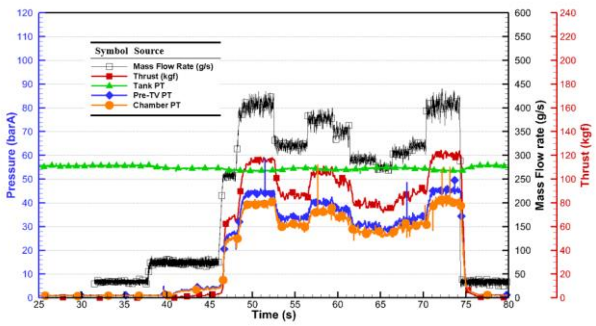


Fig. 3 Measured temporal data for the throttling test

Fig. 4 Snapshot of vertical thrust-vector-control hot-fire test

Table 1 Measured average experimental results for 16 s and 30 s hot-firing test.

	16 s test	30 test
Burn duration (s)	15.67	28.64
Thrust (kgf)	119.40	121.07
Operating $\dot{m}_{ox}$ (g/s)	422.11	425.52
Mean $\dot{m}_{fuel}$ (g/s)	72.92	73.81
O/F ratio	5.79	5.76
Sea level I_{sp} (s)	241.19	242.47
Engine I_{sp} efficiency (%)	97.89	99.14
Uncertainty	< 5 %	< 5 %
Chamber pressure	39.55	39.34

Keywords: *Hybrid Rocket, Throttling, Thrust-Vector-Control, Hydrogen Peroxide, Swirling Injection*

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