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DESIGN AND EXPERIMENTATION ON A SHAPE-CHANGING DUAL-BELL ROCKET NOZZLE.

Abstract

The environment that a space transport system like a rocket encounters near the Earth is drastically different from the one away from it. Moreover, the external environment changes rapidly as the rocket escapes the atmosphere. The C-D nozzle geometry in use currently operates optimally at only one altitude where the ambient pressure and the exhaust exit pressure are equal. To make the nozzle optimum throughout its burn time, its shape (area ratio) must change accordingly. Advanced nozzles like dual bell nozzles were designed in the 1960s for altitude compensation. However, it had its drawbacks like the loss of specific impulse due to aspiration drag (induced by over-expanded flow) at sea level and transition loss (due to flow transition from bell 1 to bell 2 way before the optimum transition altitude) at low altitudes. The individual baseline nozzles (of bell 1 or bell 2) of the same lengths sometimes pose better overall efficiency than their combined dual bell nozzles. Our present work includes the use of Carbon/Carbon composites in bell 1 and Ti-4.5Al-3V-2Mo-2Fe as the base material for bell 2 (shape-changing) in the dual bell nozzle. The Titanium alloy used for bell 2 is highly flexible with good thermal and mechanical properties showing super-elasticity (at the perfect α/β phase mixture). Shape changing of bell 2 is achieved by the actuation of a bi-stable shape memory alloy (NiTi) which will be laminated into the sheets of the titanium alloy. The SMA poses two stable shapes- one as the extension of bell 1 (primary shape- martensite phase of the SMA) and the other one as bell 2 (on actuation - austenite phase of the SMA). At low altitudes, the nozzle holds the shape of the baseline nozzle 1. At the optimum transition altitude (the point where the flow transition from bell 1 to bell 2 is ideal), the SMA gets actuated and the extended nozzle takes the shape of bell 2, forming the dual bell nozzle. Bell 2 is provided with regenerative cooling to prevent failure due to high temperatures. A miniature model of the nozzle was designed and fabricated. The test results, graphs and the comparison with the conventional dual bell nozzle have been provided in this paper. Acknowledging the fuel efficiency increase that advanced nozzles provide and their probable application in reusable rockets, this demonstration was conducted.