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Design and test firing of a dual bidirectional double vortex bipropellant rocket engine

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Abstract. It is widely recognised that there is a global need for cheaper launchers for small satellites, and there is considerable global effort led primarily by private enterprise to develop these. One way to achieve these lower costs is to use cheaper materials, usually by sacrificing some of the performance benefit. A dual birectional double vortex bipropellant engine has been designed that confines combustion to the core of the rocket engine, thereby maintaining much cooler wall temperatures, enabling the employment of cheaper materials with lower melting temperatures. This paper reports on the design and successful test firing of such an engine with a nominal thrust of 20N, the first time that such an engine has been developed in an educational setting.

1. Introduction

The small satellite market is currently growing rapidly, with over 800 small satellites launched since 2006, a figure that is predicted to rise to over 4500 by 2026 [1]. The market value for small satellite launches stands at around 1.82 billion GBP, with an anticipated growth to 4.37 billion GBP by 2021 [2]. Much of the current research is in the nano-micro satellite sector, between 1-50kg, where an economic expansion is taking place driven by applications such as earth observation, which are of commercial interest.

Such growth in the demand for small satellites drives a requirement for dedicated small satellite launchers [3,4]. At the moment, typical costs for a small satellite launch run between 50-60 million GBP [5,6]. This issue has been recognised by the UK government, which has listed the development of a small satellite launcher as a requirement for future market growth [7]. Although costs of satellites decrease dramatically with size, similar trends are not observed for the launchers themselves, and new approaches are required to achieve such cost savings.

2. Dual bidirectional double-vortex bipropellant rocket engine – design and development

One such approach involves the creation of a double vortex in the rocket combustion chamber. The purpose of this is to confine the combustion to the core of the engine, preventing contact of the hot gases with the walls of the chamber in normal operation, permitting the use of much cheaper materials. This is achieved by the use of specially designed oxidiser injectors, and Figures 1a and 1b show the design and construction of these injectors.

The injector was used with gaseous oxygen (Gox) as oxidiser, with a Perspex design (for inspection purposes) for the combustion chamber. A test firing is shown in Figure 2.

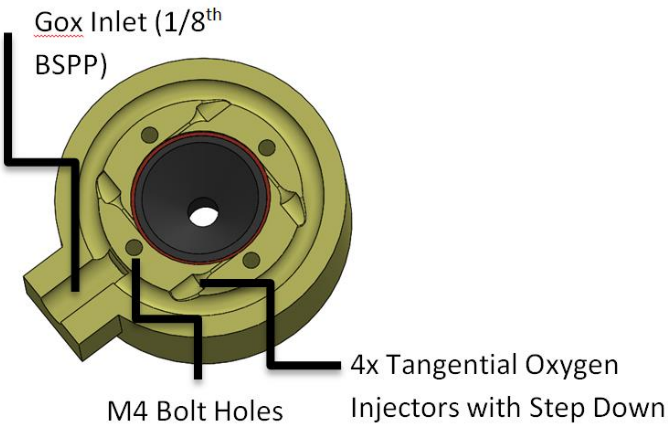

Figure 1a. CAD image cross section of ABS injector

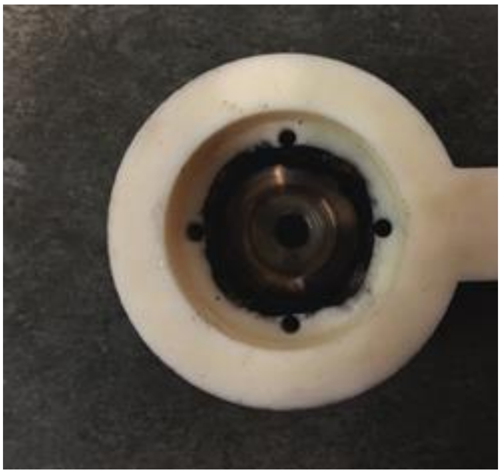

Figure 1b. ABS injector construction

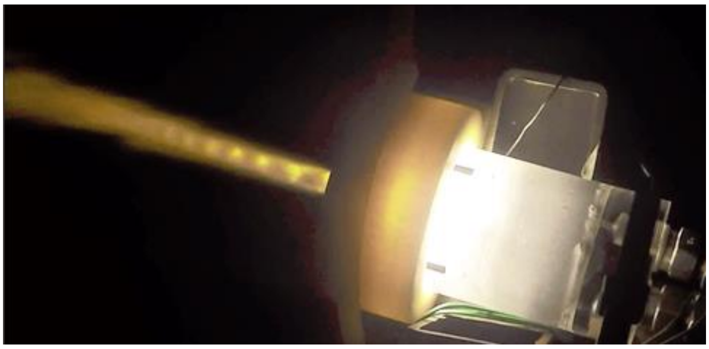

Figure 2. Test firing showing characteristic shockwave diamonds

CFD modelling was also carried out to investigate the flow behaviour within the combustion chamber, and the results of this are presented in Figures 3a and 3b. The streamlines show clear evidence of the formation of a bidirectional double vortex, flowing in one direction along the outer wall and then in the opposite direction around the central axis.

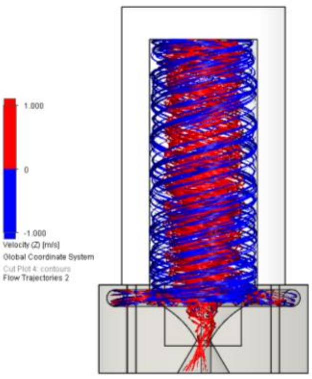

Figure 3a. Axial velocity trajectory plot

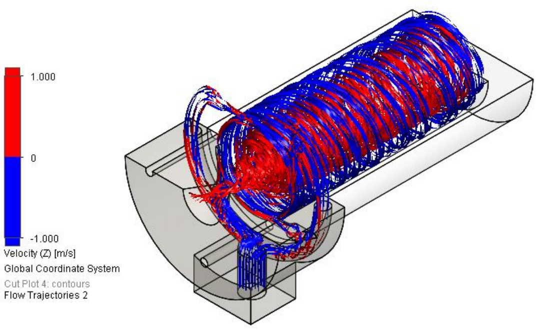

Figure 3b. Isometric axial velocity trajectory plot

3. Testing

A prototype version of the system was constructed, designed for firing for longer durations (up to 25s) than the Perspex-chambered engine. Figures 4a and 4b show the engine at times of T+15 and T+25 respectively, where T represents the ignition time.

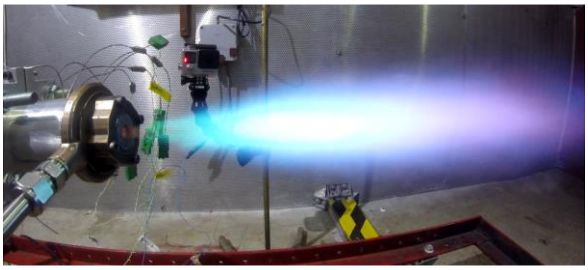

Figure 4a. Hot fire Test 1 at T+15s

Figure 4b. Hot fire Test 1 at T+25 s

Figures 5a and 5b show the interior of the combustion chamber and the injector, indicating that no hear damage has occurred, although the core temperatures are higher than the melting point of the aluminum chamber forming the combustion chamber.

Figure 5a. Test 1 post firing aluminium combustion chamber (no damage)

Figure 5b. Test 1 post firing nozzle and tangential injector

During firing a range of important measurements were recorded, including both pressure (in a range of locations, such as in the combustion chamber) and, importantly, wall temperature. These are displayed in Figures 6 and 7 respectively. Crucially, it can be seen that wall temperatures remained very low (compared to a theoretical burn temperature of around 2700^{o}C) during the test firings. A thrust of 90% of the nominal thrust was achieved during testing.

4. Conclusion

The first DBDV rocket engine in an educational system has been designed, modelled, constructed and tested. It has demonstrated that the dual vortex approach is effective at reducing wall temperatures sufficiently that much cheaper materials can be used. The thrust achieved is close to the nominal design, which provides ground for future development of higher thrust engines dedicated for cheaper small satellite launchers.

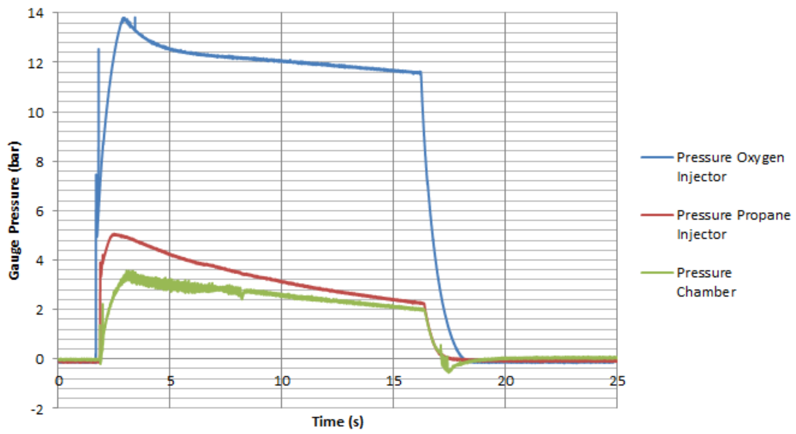

Figure 6. 15s burn Pressure vs Time

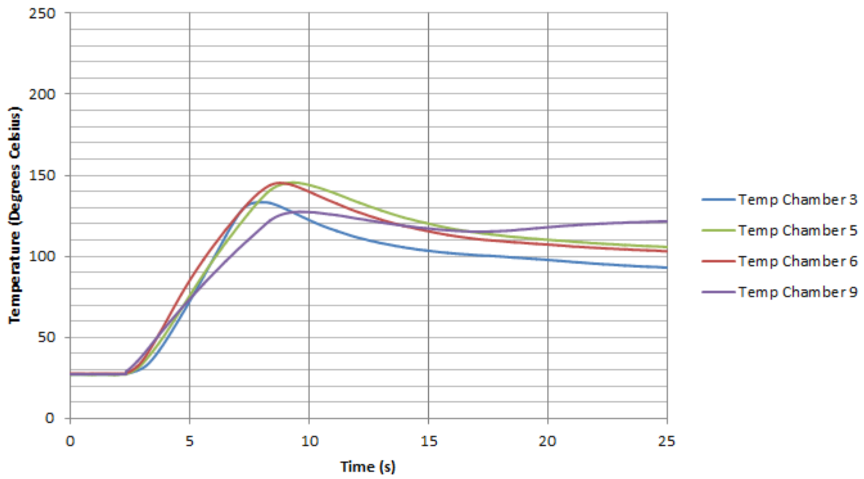

Figure 7. 15s burn Temperature vs Time

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