System Integration and Engine Test of a 22KN Oxidiser Rich Staged Combustion Rocket Engine

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Abstract

C6 Launch systems (C6) will provide rapid access to orbit for small payloads through a dedicated platform. To do so C6 Launch takes a traditional approach to Aerospace design, opting to be the system integrator by partnering with other companies for major subsystems. The key piece of any rocket system is the powerplant and the systems that are integrated around it. To validate the technologies, systems, and partnerships developed by C6, a 22KN Liquid Oxygen/Jet-A Oxidiser Rich Staged Combustion (ORSC) engine, named the Hadley and produced by Ursa Major Technologies, was integrated onto a vehicle-representative iron-bird system and test-fired. The Hadley engine was hotfired by C6 Launch and its US partner at Spaceport America in April 2021. The design procedure of the Iron-bird Test-stand and supporting structures and systems will be presented. Procedures regarding test setup and details of the engine fire within the limits of ITAR will also be presented.

Introduction

In the *New-Space* industry, it has become customary for launch vehicle developers to vertically integrate the entire vehicle, which typically includes the engines, avionics, etc. Traditionally, this is not the case, as the airframe, the engines, and the avionics are passed to various Subject Matter Experts (SME) or Original Equipment Manufacturers (OEMs) for development. C6 launch Systems follows the traditional approach towards development of aerospace vehicle, where the various OEMS provide systems that undergo final integration by C6. This method reduces the development time of the final vehicle as risk and cost are significantly reduced for the system integrator.

The major component of any launch vehicle, aside from the payload and airframe, are the rocket engines. Through a partnership with Ursa Major Technologies (UMT) (Denver, Colorado), C6 has opted to integrate their *Hadley* engine. The Hadley is an innovative rocket engine, which is a serious gamechanger in the small launch industry. The engine utilises an Oxygen Rich Staged Combustion (ORSC) cycle fueled by Liquid Oxygen (LOX) and Jet-A while maintaining a very low weight.

For C6 to validate operations and development with the engine and the various supporting systems, a Systems Integration & Engine Test (SIET) was performed in partnership with UMT and Spaceport America (SA). The test would constitute the *Iron-Bird* of the C6 launch vehicle which would integrate to the Hadley engine for a test fire. This proceeding will briefly outline many of the component systems and overview the test results.

Test Stand Development

The SIET test-stand was developed over a period of 8 months with the concept of being modular for cost-effective shipping and repairs. This section will overview the various major components of the SIET test-stand beginning with the Avionics, the Ground Station Software (GSS), and finally the Mechanical design.

ITAR Compliance

As the Hadley engine is designed and produced within the United States and is classified as Category 1 under the Missile Technology Control Regime (MTCR), the engine technical data is highly controlled by the International Traffic in Arms Regulations (ITAR). As such, strict export restrictions must be followed at all times. Throughout this project, ITAR compliance was managed and maintained in coordination with a US partner company to C6 launch Systems.

Systems Overview

The iron-bird system was designed to facilitate engine operation and represent the primary vehicle systems. As such, all of the primary vehicle systems were included in a represented form, using commercial components instead of flight-hardware, except for the tracking/navigation, guidance and control, separation, and flight-termination systems. In addition, the objectives of project required the iron-bird system to operate as a single unit and independent of external ground support equipment outside the standard loading/unloading operations. To this end, the iron-bird system contains both tanks, fluids controls, all avionics, battery power, and communications all self-contained within the iron-bird and utilizing a vertical tank structure. In addition, a test structure was installed at Spaceport America's test site in order to facilitate vertical testing of the engine beneath the primary iron-bird system.

Avionics

The avionics system was responsible for monitoring and controlling the test-stand as well as communicating with the ground station during all operations. The avionics system could be powered using on-board batteries or with an external power system. At the start of each test procedure, the team decides which power method to use for the test. The avionics system for the project was divided into 4 main subsystems namely: The Command and Data Handling (CDH) subsystem, Test Frame Communication (TFC) subsystem, Electrical Power Subsystem (EPS) and the Engine Controller Subsystem (ECS).

The Electrical Power Subsystem (EPS) was responsible for managing all electrical power related to the test-stand. It consisted of various fuses, DC-DC converters, AC-DC converters, voltage regulators, and a micro controller to monitor and manage the state of the EPS. The microcontroller also sent the state of the EPS back to the CDH. The EPS further housed numerous high-capacity batteries which could be used to power the test-stand for complete test operations up to 8 hours.

The Test Frame Communication (TFC) was responsible for wirelessly transmitting and receiving data to and from the ground station antenna located approximately 1 km away. The 2.4GHz ISM band was used as the communication channel and power levels were kept below 30dBm to keep the project ITU licence free. Telemetry from the test stand was sent to the ground station, while commands from the ground station could be sent to the test stand, both through the full-duplex wireless link.

The engine Controller subsystem (ECS) was in charge of relaying information from the CDH to the Hadley engine. The ECS was directly interfaced to the engine and managed its low-level state while abstracting the engine operation for the CDH system. This subsystem was required both for ITAR compliance and to facilitate easy support for various different engines if needed in the future (requiring only the ECS to be updated).

The Command and Data Handling (CDH) subsystem acts as the central source for monitoring and controlling between all of the subsystems throughout the test-stand as well as communicating with the ground station throughout all operations; this includes monitoring the EPS, interfacing with the TFC, monitoring and controlling the fluids system via the numerous sensors and actuators, and directing and coordinating engine operation via the ECS. The CDH utilized a primary On-Board Controller (OBC) for the majority of the control and interfaced with the EPS, TFC, and ECS.

As part of its role, the CDH transmits telemetry to, and receives commands from, the ground station both through the TFC subsystem as well as an additional redundant wired communication link. This wired connection was connected directly to the on-board computer through an ethernet connection and is provided for safety-purposes in case of wireless communication loss (all telemetry data is transmitted over both transmission lines).

Due the size/complexity of the fluids system, all of the various fluid actuators and sensors were controlled by an additional microcontroller on the CDH board (separate from, but connected to, the main CDH on-board computer). This fluids microcontroller utilized multiple analog-to-digital channels to monitor the various pressure, temperature, and flow transducers, while various high-side MOSFET circuits control the state of all actuators. This fluids microcontroller operated at a much higher refresh-rate compared to the main OBC and so additionally implemented several automatic fluids control loops such as maintaining propellant tank pressure throughout propellant flow, as well as various fluids safety-features/red-lines such as automatic tank venting above set pressures.

Ground Station Software

The goal for the ground station software is to provide both user and autonomous interaction between the avionics and mechanical components of the test stand. As it would be an initial version of our future ground station, the foundations of allowing the full team to monitor and control system operations was built with scalability in mind. The software systems take full advantage of modern software design principles and takes full advantage of microservice architecture. This enables shortened timelines for both development and integration hours for the rapid changes involved during a test campaign and future development. The current user interfacing web and mobile based app allows for modularity for different subsystems and incorporates our rapid launch mindset with APIs built out for internal Internet of Things (IoT) integrations.

Mechanical Design

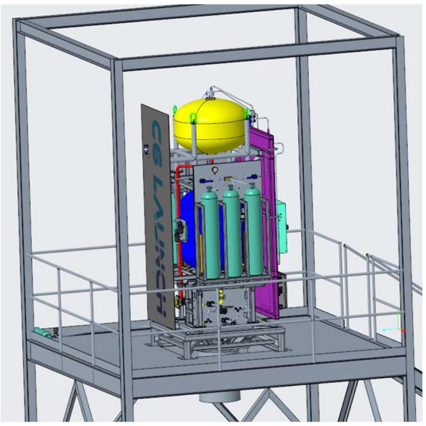

Figure 1 CAD assembly of SIET Teststand

The Test stand consisted of 4 major assemblies, namely the: Vertical Frame Structure (VFS), Engine Frame, and the primary iron-bird system. The engine would integrate directly to the engine frame through an engine plate adapter and interfaced with the iron-bird system via interfacing piping.

The system was designed to be separated into several component pieces for ease of shipping and to be reassembled on site with minimal fitment. As the system was to represent an Iron-Bird, every primary subsystem that would exist on the launch vehicle was present on the stand, with the difference being that industrial grade components were used instead of flight-like hardware. This was done as the intention of the test was to validate systems rather than hardware, the individual hardware can be swapped out for flight-like equivalents in future tests.

The VFS is a simple steel structure which was designed and built as part of this project, but with the capability to support further testing in the future. The stand is raised 9 feet from the ground and includes a 4-foot by 4-foot hole for the engine to mount onto the bottom of the engine frame. Below the engine exhaust is an additional flame deflector plate to protect the concrete below.

The system's pneumatics and fluids controls were developed in several modular sections that controlled key aspects towards maintaining a consistent propellant feed. The major modules were the *Pressurant Supply System (PSS), Pressurant Feed System (PFS), Propellant-Feed Load (PFL) system.*

The pressurant supply system was responsible for combining the pressurant gas supplies into a single supply for the pressurant feed box. It was developed with the capability of shutting off supply to one side of the pressurant supply tanks and with modular capability for connecting to auxiliary systems.

The Pressurant Feed System was developed to take the pressurant gas and distributed it to the various subsystems for use either for valve actuation or supply head pressure for the propellant tanks.

The Propellant Feed Load system was developed for feeding propellant from the tanks to the Hadley engine as well as loading/unloading propellant from the two propellant tanks. The system also contained various sensors and flow meters for data capture.

Overall, the iron-bird system and engine frame enclose approximately a 4-foot by 5-foot footprint with a height of 11 feet.

SIET Test Campaign

The test campaign was conducted at Spaceport America at the Vertical Launch Area (VLA). The VFS was constructed at the VLA and the remaining systems were shipped to the site and integrated.

Figure 2 Full-Flow Cold flow with LARG

Prior to the hot fire of the engine, a number of cold flow tests were required to be completed. The first cold flow was a full flow test of both tanks with simulated pressure drops of the engine to validate the flow rates and control loops in the iron-bird system. The test was conducted with liquid argon (LARG) and water. The use of LARG allowed the simulate the temperatures of LOX without the hazards of LOX and allowed the use of nitrogen gas as a pressurant, there by dropping the cost of multiple cold flows (compared to using helium and liquid nitrogen).

After LOX fills and checkouts, a second series of cold flow tests were conducted with the Hadley attached. These were part of the final system checkout tests before the hot-fire. The hot-fire test consisted of a full burn with both engine throttling and gimballing. The gimballing was restrained in one axis to restrain the flame within the flame bucket.

Figure 3 Hot-fire Test of Hadley

Conclusion and Future Work

The SIET test campaign was a considerable success and the first of its kind in terms of the international partnership between many different organisations from both Canada and the US. As far as is known, this is the first campaign to successfully integrate and hot-fire a US-made engine with an international (in this case Canadian) system while maintaining ITAR-compliance. The test proved that C6 is capable of successfully integrating the Hadley engine and control its operations. In the near future C6 will continue to develop and test the Hadley engine in various configurations with flight-like hardware as well as in multi-engine configurations.