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445 N (100-lbf) LO_2/LCH_4 reaction control engine technology development for future space vehicles

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ABSTRACT

The National Aeronautics and Space Administration (NASA) have identified liquid oxygen (LO2)/liquid methane (LCH4) propulsion systems as promising options for some future space vehicles. NASA issued a contract to Aerojet to develop a 445 N (100-lbf) LO_2/LCH_4 Reaction Control Engine (RCE) aimed at reducing the risk of utilizing a cryogenic reaction control system (RCS) on a space vehicle. Aerojet utilized innovative design solutions to develop an RCE that can ignite reliably over a broad range of inlet temperatures, perform short minimum impulse bits (MIB) at small electrical pulse widths (EPW), and produce excellent specific impulse (Isp) across a range of engine mixture ratios (MR). These design innovations also provide a start transient with a benign mixture ratio (MR), ensuring good thrust chamber compatibility and long life. In addition, this RCE can successfully operate at MRs associated with main engines, enabling the RCE to provide emergency backup propulsion to minimize vehicle propellant load and overall system mass.

1. Introduction

NASA initiated technology development projects for a LO_2/liquid hydrogen (LH_2) auxiliary propulsion system (APS) in 1971 during the Space Shuttle pre-development period [1–4]. Since 1971, Aerojet has been supporting NASA's continuing efforts to develop alternatives to hypergolic propellants for APS applications. Specifically, Aerojet has leveraged projects funded by NASA, the United States Air Force (USAF), and Aerojet Independent Research and Development (IR&D) to expand the non-hypergolic propellant technology database for space vehicle applications. While early work focused on LO_2/LH_2, the majority of these projects over the past 35+ years have focused on extending the technologies for oxygen/hydrocarbon propellant combinations [5]. Aerojet has been involved with the development of a variety of combustion devices and propulsion systems that utilize oxygen and a range of potential hydrocarbon fuels, including RP-1, RP-2, JP-10, propane, ethanol, and methane [6–12]. This background has proven beneficial with respect to NASA's interest in advancing technologies for oxygen/hydrocarbon propellant systems.

The NASA Exploration Systems Architecture Studies (ESAS), along with multiple other study activities, have identified that LO_2/LCH_4 propulsion systems are a promising option for some future space vehicles. Specifically, an integrated main and reaction control propulsion system utilizing LO_2/LCH_4 propellants can provide substantial savings in overall systems mass when compared to conventional hypergolic systems.

This LO_2/LCH_4 propulsion system utilizes a common pressurization system, common propellant tankage, and a sub-cooled liquid feed system with pressure-fed reaction

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control system (RCS) thrusters and a single or multiple pressure-fed main engine(s). Although recent work in LO_2/LCH_4 technology advancement has shown progress, this propellant combination is still considered novel and requires a dedicated risk reduction program prior to proceeding with detailed design, development, and fabrication of an integrated LO_2/LCH_4 propulsion system. To address this necessary risk reduction, the NASA Exploration Technology Development Program (ETDP) has formed a project entitled Propulsion and Cryogenics Advanced Development (PCAD). The PCAD project is jointly managed by the NASA Glenn Research Center (GRC) in Cleveland, Ohio, and the NASA Johnson Space Center (JSC) in Houston, Texas.

The charter of PCAD is to identify and fund programs that develop and expand the maturity of candidate technologies considered to be important for future cryogenic space vehicles. These programs focus on components or subsystems that are deemed lacking in technical maturity but are considered to be essential to successful design, development, and fabrication of an integrated LO_2/LCH_4 propulsion system. Consistent with PCAD's charter, NASA issued a contract to Aerojet to develop a 445 N (100-lbf) LO_2/LCH_4 RCE aimed at reducing the risk of utilizing a cryogenic RCS on a space vehicle.

2. RCE program overview

The NASA-sponsored 445 N (100-lbf) RCE technology development program was divided into four phases: Basic, Option 1, Option 2, and Option 3. The Aerojet program plan for this development effort was structured around these four major phases.

During the Basic Phase, a flight-type detail design was produced that incorporated the features necessary to meet the established operational and design requirements for the engine. The Basic Phase concluded with a critical design review (CDR), and generated a complete design disclosure with supporting analyses to enable fabrication of the engine.

Option 1 then took the completed design disclosure from the Basic Phase and fabricated RCE hardware for hot-fire testing. Two different injector and two different igniter designs were fabricated and tested during Option 1. Option 2 provided the opportunity to perform a design iteration based on the results of the Option 1 testing, and Option 3 fabricated four engines to be delivered to the NASA White Sands Test Facility (WSTF) to be incorporated into a cryogenic APS Test Bed (APSTB). Testing with the cryogenic APSTB provided the opportunity to evaluate an APS with cryogenic fluid management at simulated altitude conditions.

The purpose of this paper is to highlight some of the more important results from the Basic and Option 1 phases of the 445 N (100-lbf) LO_2/LCH_4 RCE program.

3. RCE design description

The Basic Phase of the program established the NASA/Aerojet conceptual flight-type RCE design. This conceptual design enabled the RCE development challenges to be identified along with the corresponding risk reduction activities necessary to address these challenges. The five major technical challenges identified and resolved by the NASA/Aerojet team for the RCE are:

(1) Oxygen-rich (high mixture ratio) start transients and potential chamber burn-through
(2) Reliable and repeatable ignition over a large range of valve inlet temperatures (liquid–liquid to gas–gas conditions)
(3) High engine performance (Isp)
(4) Low MIB (minimum impulse bit) and pulse-to-pulse repeatability
(5) Operation of the RCE at an MR (Mixture ratio) above 3.0 to provide main engine redundancy during flight operations.

The NASA/Aerojet flight-type RCE design consists of the following components: a compact integral exciter/spark plug system, a dual coil direct-acting solenoid valve for oxidizer and fuel, an integral igniter and injector, and a columbium chamber/nozzle with an expansion area ratio of 80:1. The Option 3 engines delivered for WSTF APSTB testing are identical to the flight-type engine with two exceptions: the exciter is not a compact integral design and the nozzle expansion area ratio is 45:1. Fig. 1 shows the Option 3 engine.

The 445 N (100-lbf) LO_2/LCH_4 RCE program has provided risk reduction design/hot-fire data on all five critical challenges and, where permitted by International Traffic in Arms Restrictions (ITAR), this data will be provided.

The exciter used for hot-fire testing is a high-voltage capacitive-discharge-type unit that is used in conjunction with a spark plug to provide an ignition source for the igniter. This exciter, Fig. 2, utilizes a high-voltage lead running from the exciter box to the spark plug, and is similar to previous flight qualified units such as the RL-10 exciter. The high-voltage lead of the current exciter presents a significant reliability risk due to the potential for the corona discharge phenomenon occurring at very low external pressures, that is, high altitude or space. This corona discharge phenomenon bleeds off the high voltage intended for the spark plug through poorly isolated or

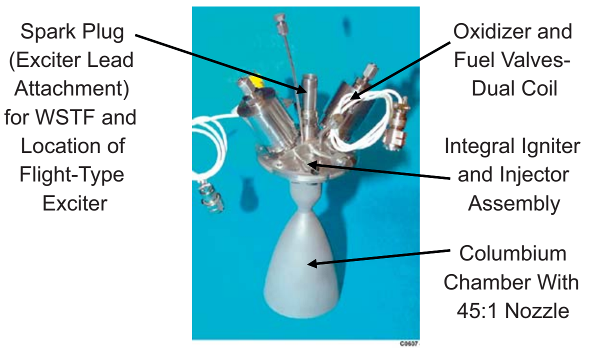

Fig. 1. Deliverable Option 3 White Sands Flight-Type RCE.