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### Design, Integration, Certification and Testing of the Orion Crew Module Propulsion System

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The Orion Multipurpose Crew Vehicle (MPCV) is NASA's next generation spacecraft for human exploration of deep space. Lockheed Martin is the prime contractor for the design, development, qualification and integration of the vehicle. A key component of the Orion Crew Module (CM) is the Propulsion Reaction Control System, a high-flow hydrazine system used during re-entry to orient the vehicle for landing. The system consists of a completely redundant helium (GHe) pressurization system and hydrazine fuel system with monopropellant thrusters. The propulsion system has been designed, integrated, and qualification tested in support of the Orion program's first orbital flight test, Exploration Flight Test One (EFT-1), scheduled for 2014. A subset of the development challenges and lessons learned from this first flight test campaign will be discussed in this paper for consideration when designing future spacecraft propulsion systems.

The CONOPS and human rating requirements of the CM propulsion system are unique when compared with a typical satellite propulsion reaction control system. The system requires a high maximum fuel flow rate. It must operate at both vacuum and sea level atmospheric pressure conditions. In order to meet Orion's human rating requirements, multiple parts of the system must be redundant, and capable of functioning after spacecraft system fault events.

#### System Design

Many challenges were overcome during the design phase of the CM propulsion system for EFT-1. Key driving design requirements included the high flow rate, stressing flight loads and environments, mass limitations, and packaging constraints. These requirements lead to the use of large diameter tubing, tight manufacturing and assembly tolerances, and complex secondary structure. A unique packaging system was utilized



Figure 1: Artist rendering of the Orion MPCV during EFT-1.

[http://www.nasa.gov/pdf/663703main\\_flighttest1\\_fs\\_051812.pdf](http://www.nasa.gov/pdf/663703main_flighttest1_fs_051812.pdf)

to mount the hydrazine and GHe components assemblies, and a complex thruster mounting system was developed to align and attach the engines to the CM primary structure. Several new components were developed and qualified for use in the system, including MR-104G monopropellant engines, and redundant valves.

### Hot Fire Test

In support of the propulsion system qualification effort for EFT-1, a full scale test article was manufactured and hot fire tested. The test article was manufactured using a full scale mock-up of the CM primary structure, and tubing and components nearly identical the flight configuration. Manufacturing and integration of the test article served as a pathfinder for the EFT-1 flight build.

The hot fire test was conducted to validate the propulsion system models and analytical predictions. Test sequences were completed to simulate the full breadth of system flight-operations and worst case fault scenarios. Surprises in the data confirmed the need for test and validated that analytical predictions are indeed difficult to get exactly correct. The testing revealed system water hammer transients much higher than analytically predicted. The testing also revealed that the system is susceptible to gas bubbles in the propellant lines.



Figure 2: Technicians work on an MR-104G thruster, in preparation for the Orion Propulsion System Hot Fire Test.

<http://www.nasa.gov/sites/default/files/orionaprmr2013.pdf>

### Integration and On-Vehicle Installation

The first time installation of the propulsion system on the CM for flight resulted in several lessons learned that can be applied to future integration and installation efforts. The propulsion system was manufactured in stages at multiple locations across the country, presenting unique communication and coordination difficulties. From a design for manufacturability standpoint, lessons were learned in dealing with the tight tolerances required by the design, on-vehicle welding, and design for manufacturability. In order to meet the integration schedule and launch date, the on vehicle installation of the propulsion system was completed in parallel with the installation of multiple other subsystems, presenting a new set of challenges.

## Forward Work

At the time of this abstract, qualification effort for EFT-1 is complete, and the flight propulsion system is fully installed and integrated on the CM. System level check out has yet to be completed for EFT-1.

Lessons learned from the development challenges of this first flight test article are being applied to the next build. Design updates include a CM configuration optimized to make the layout more efficient, and improved design for manufacturability and producibility. Components are being modified to improve performance. System level testing results are being fed into the design. The EFT-1 flight test will be completed in 2014, simulating a deep space re-entry, and providing the ultimate test of the CM propulsion system performance and operation during flight.



Figure 3: Orion EFT-1 Crew Module Midway Through Propulsion Installation.  
<http://www.nasa.gov/sites/default/files/files/OrionMARAugust2013.pdf>