

## The Space Operations Simulation Center (SOSC) and Closed-loop Hardware Testing for Orion Rendezvous System Design

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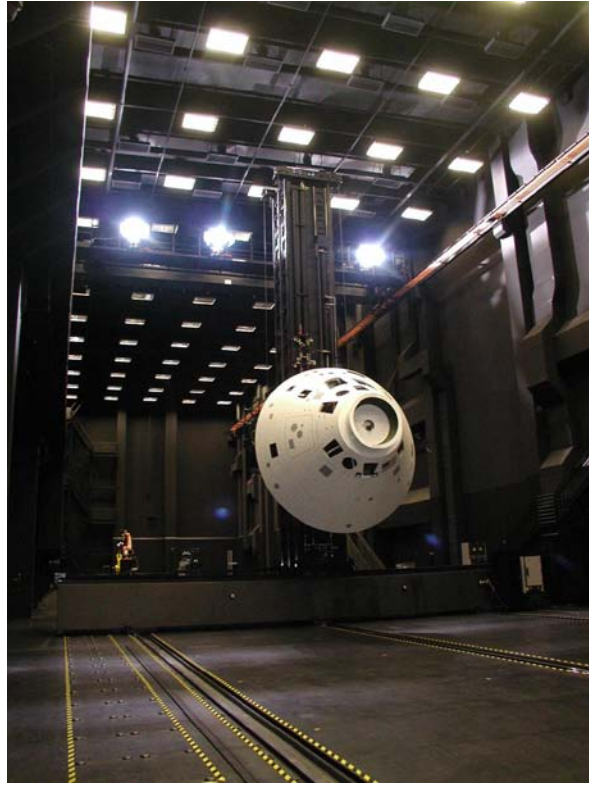
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The Space Operations Simulation Center (SOSC) at the Lockheed Martin (LM) Waterton Campus in Littleton, Colorado is a dynamic test environment focused on Autonomous Rendezvous and Docking (AR&D) development testing and risk reduction activities. The SOSC supports multiple program pursuits and accommodates testing Guidance, Navigation, and Control (GN&C) algorithms for relative navigation, hardware testing and characterization, as well as software and test process development.

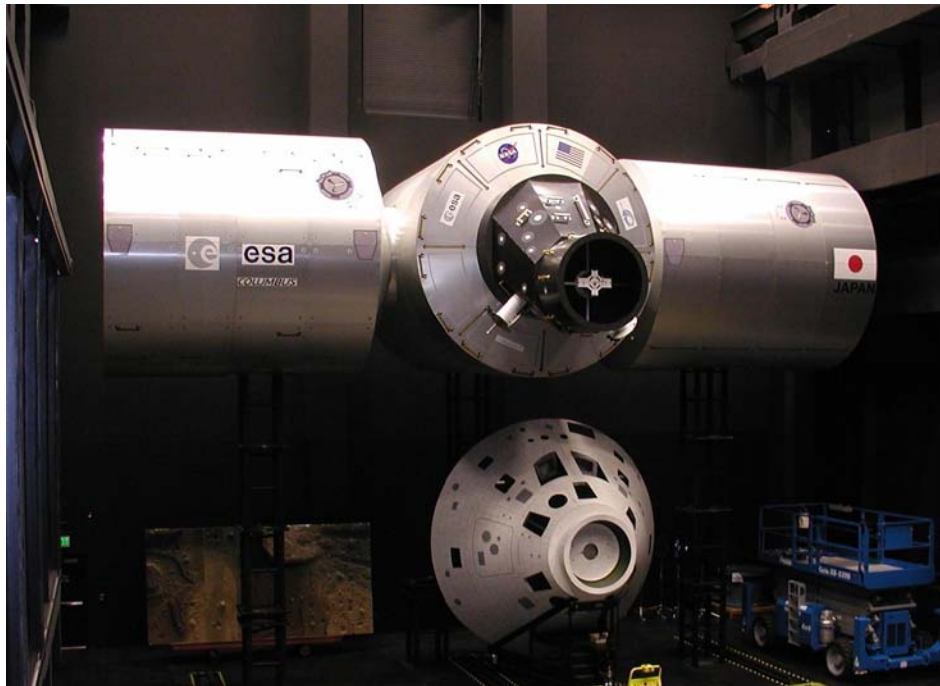
The SOSC consists of a high bay (60 meters long by 15.2 meters wide by 15.2 meters tall) with dual six degree-of-freedom (6DOF) motion simulators and a single fixed base 6DOF robot. The large testing area (maximum sensor-to-target effective range of 60 meters) allows for large-scale, flight-like simulations of proximity maneuvers and docking events. The facility also has two apertures for access to external extended-range outdoor target test operations. In addition, the facility contains four Mission Operations Centers (MOCs) with connectivity to dual high bay control rooms and a data/video interface room. The high bay is rated at Class 300,000 ( $\geq 0.5 \mu\text{m}$  maximum particles/m<sup>3</sup>) cleanliness and includes orbital lighting simulation capabilities.

The dual motion simulators are rail-mounted 6DOF robot mechanisms that are used for simulating docking vehicles. The larger of the mechanisms is supported on three rails, and the second, smaller mechanism is supported on two rails. Also, the facility supports several mock-ups to aid in simulating real-world rendezvous and docking scenarios: the International Space Station (ISS) mock-up including the APAS-To-LIDS Adapter System (ATLAS), the Low-Impact Docking System (LIDS) mock-up, a full-size, lightweight mock-up of the Orion Crew Module (CM), and an asteroid mock-up. The ISS mock-up is a static target that has a fixed location within the SOSC high bay, whereas the Orion CM mock-up is a mobile unit that can be mounted to the large robot mechanism when real-world simulations are desired and the asteroid mock-up can be mounted on the fixed base robot to simulate a moving body. The ATLAS is integrated as part of the ISS mock-up when required and is the adapter that allows the LIDS to be deployed and useful as part of the ISS docking system. The ISS mock-up is composed of three modules representing a portion of the ISS: the National Aeronautics and Space Administration (NASA) Harmony module (Node 2), the European Space Agency (ESA) Columbus module, and the Japan Aerospace Exploration Agency (JAXA) Kibo module. In

addition, the Harmony module has a docking port attachment called the Pressurized Mating Adapter (PMA-2) with a lidar target mounted at its center.



**Figure 1: Large Robotic Mechanism (with existing Orion Crew Module mounted) located in SOSC High Bay**



**Figure 2: Full-sized Mock-ups in SOSC High Bay: Left to Right – ESA Columbus Module, NASA Harmony Module with PMA-2 attached on forward end, JAXA Kibo Module, and CM mounted on cradle below**

The initial objectives for Orion testing in the SOSC were two-fold: first to characterize the facility resources (motion control, target environment, lighting, etc) as providing a space-like environment for future Orion testing, and second to develop a core capability to execute a closed-loop Orion rendezvous and docking simulation in the SOSC. The focus of this paper will be on the latter objective, closed-loop rendezvous capability within the test facility.

The Orion program conducted testing in the SOSC in late 2011 in order to execute a closed-loop rendezvous simulation using GN&C flight software (FSW) algorithms developed by the Orbit MODE Team (OMT). The test included executing the GN&C FSW algorithms closed-loop with the Vision Navigation Sensor (VNS) that was flown on the Space Shuttle (STS-134) Development Test Objective (DTO) earlier in the year in STORRM (Sensor Test for Orion Relative navigation Risk Mitigation). While the DTO tested performance of the Orion Relative Navigation (RelNav) hardware in a space environment, it did not test the overall performance of the Orion RelNav system. The purpose of testing in the SOSC facility was to take the DTO one step further and characterize the performance of the entire Orion RelNav system in various Orion docking profiles. This round of tests was only the beginning of what will be required to develop rendezvous capability for the Orion vehicle, but it gave the team the opportunity to integrate the software and hardware components of the RelNav system for the first time.

The Orion Rendezvous, Proximity Operations and Docking (RPOD) system has been matured greatly over the past five years. The first versions of the flight software has been developed and tested in simulations. Regardless of how much testing the RPOD software is subjected to, these software-only closed-loop tests have limitations. The VNS tested on STORRM is being tested with the image processing software (centroiding, reflector identification, pose estimation) and the RPOD GNC flight software (the controller, the guidance system and the relative navigation filters), along with the delays/latencies associated with the throughput limitations of the systems used to emulate the image processing software. This paper will discuss the testing rationale, the test configuration, the test limitations and the test results. We will show that these tests have greatly increased the confidence in the maturity of the Orion RPOD design, reduced some of the latent risks and in doing so validated the design philosophy of the Orion RPOD system.

The testing to date has demonstrated that the proximity operations and docking phase of the mission, which has been tested in the SOSC, is rapidly maturing. Extensive tests have increased confidence in the design, in the performance, and in the robustness of the design. This will be discussed in the paper.