Orion Handling Qualities During ISS Rendezvous and Docking

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The Orion spacecraft was designed to rendezvous with multiple vehicles in low earth orbit (LEO) and beyond. To perform the required rendezvous and docking task, Orion must provide enough control authority to perform coarse translational maneuvers while maintaining precision to perform the delicate docking corrections. While Orion has autonomous docking capabilities, it is expected that final approach and docking operations with the International Space Station (ISS) will initially be performed in a manual mode. A series of evaluations was conducted by NASA and Lockheed Martin at the Johnson Space Center to determine the handling qualities (HQ) of the Orion spacecraft during different docking and rendezvous conditions using the Cooper-Harper scale. This paper will address the specifics of the handling qualities methodology, vehicle configuration, scenarios flown, data collection tools, and subject ratings and comments.

The initial Orion HQ assessment examined Orion docking to the ISS. This scenario demonstrates the Translational Hand Controller (THC) handling qualities of Orion. During this initial assessment, two different scenarios were evaluated. The first was a nominal docking approach to a stable ISS, with Orion initializing with relative position dispersions and a closing rate of approximately 0.1 ft/sec. The second docking scenario was identical to the first, except the attitude motion of the ISS was modeled to simulate a stress case (± 1 degree deadband per axis and ± 0.01 deg/sec rate deadband per axis). For both scenarios, subjects started each run on final approach at a docking port-to-port range of 20 ft. Subjects used the THC in pulse mode with cues from the docking camera image, window views, and range and range rate data displayed on the Orion display units. As in the actual design, the attitude of the Orion vehicle was held by the automated flight control system at ± 0.5 degree deadband per axis. Several error sources were modeled including Reaction Control System (RCS) jet angular and position misalignment, RCS thrust magnitude uncertainty, RCS jet force direction uncertainty due to self plume impingement, and Orion center of mass uncertainty.

The second assessment evaluated the HQ of Orion while acquiring the docking axis. This scenario demonstrates the coarse translational control authority by arresting the lateral motion during the Acquisition of Docking Axis (ADA) maneuver on the docking axis (see Figure 1). Subjects used the THC in a pulse mode to acquire the docking axis and then station-keep. As with the initial assessment, the attitude was automatically controlled by Orion's flight control system. The target, the ISS, was commanded in a Torque Equilibrium Attitude of zero degrees of yaw and roll and negative seven degrees of pitch with respect to the Local Vertical Local Horizontal frame. The ADA evaluation modeled several error sources including RCS jet angular misalignment, RCS jet position, RCS thrust uncertainty, RCS jet force direction uncertainty due to self plume impingement, Orion center of mass uncertainty, initial relative state dispersions (Orion with respect to ISS position, velocity, and attitude), and ISS attitude control deadbanding.

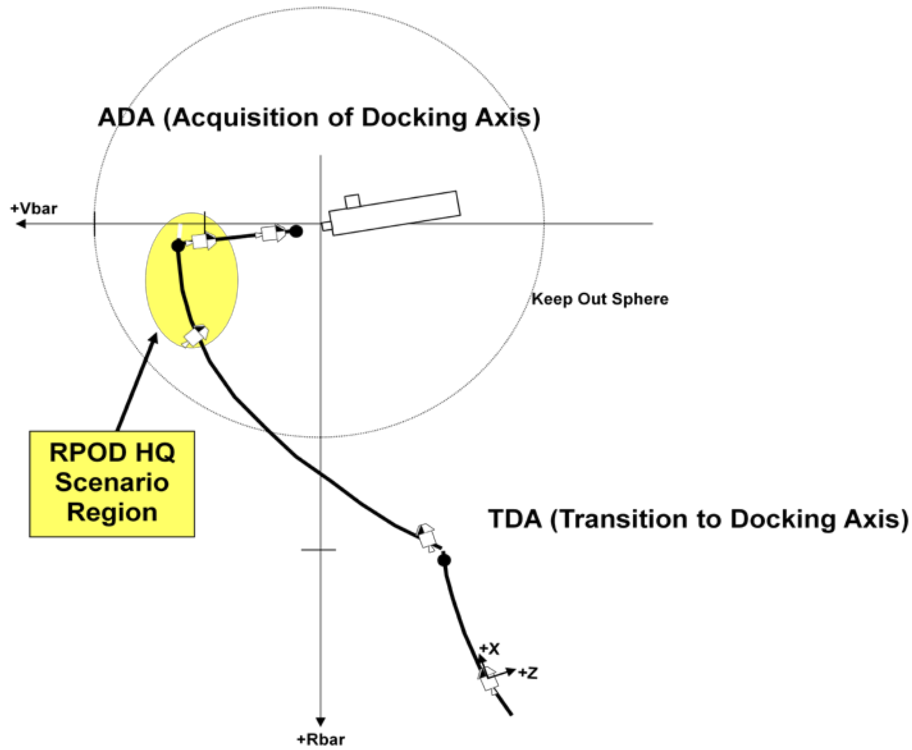

Figure 1. The ADA scenario flight profile.

The docking assessment used ten astronauts as test subjects for each scenario and the ADA scenario used five astronauts to rate the HQ using the Cooper-Harper Rating Scale (Cooper and Harper, 1969).

The simulation used the Advance NASA Technology Architecture for Exploration Studies (ANTARES), which is the NASA high fidelity, six degree of freedom simulation used for Orion GNC algorithm development and analyses. Although primarily a batch simulation, ANTARES can be used for real-time pilot-in-the-loop evaluation with a THC, RHC, notional displays for piloting cues and flight control system configuration, and real-time graphics for simulated docking camera views.

NASA's Reconfigurable Operational Cockpit (ROC) Facility was used for both assessments to provide the Orion cockpit environment. The three Orion display units in the ROC are capable of showing Orion displays, overlays, and docking camera views. The ROC (see Figure 2) also provides out-the-window views for situational awareness using image projection.

Figure 2. The ROC facility, where the left photo shows the actual setup (illuminated by the camera flash) and the right photo show an example of out-the-window scene generation.

The results for the two evaluations are presented Figure 3. For the two docking scenarios, nine of ten subjects gave each task a Level 1 rating (rating of 1, 2, or 3) and one subject gave each scenario a Level 2 rating. Subject comments for the stable ISS docking scenario were fairly consistent, with the subjects noting very low cross-coupling of THC command inputs into other vehicle attitude or translation axes. For the ISS in motion case, several pilots noted that the translational pulse size settings were too aggressive and would have preferred a smaller pulse size. Due to the ISS motion and the greater number of inputs required to dock, several pilots noted some attitude dead-banding or mild coupling in this case. Subjects noted this task as more challenging than the stable ISS scenario, but still very achievable.

The ADA scenario results showed a solid Level 1 rating. Subjects commented on the simplicity of performing the ADA task on Orion. No HQ issues were uncovered during the assessment. A couple of comments indicating that a narrower field of view (FOV) would be useful to monitor the motion of the target vehicle and to help determine the direction for nulling Orion's translational rates. Several subjects requested a dynamic overlay showing Orion's relative navigation estimates of the target on the centerline camera view. This would allow the subject to verify that relative navigation system's solutions were valid.

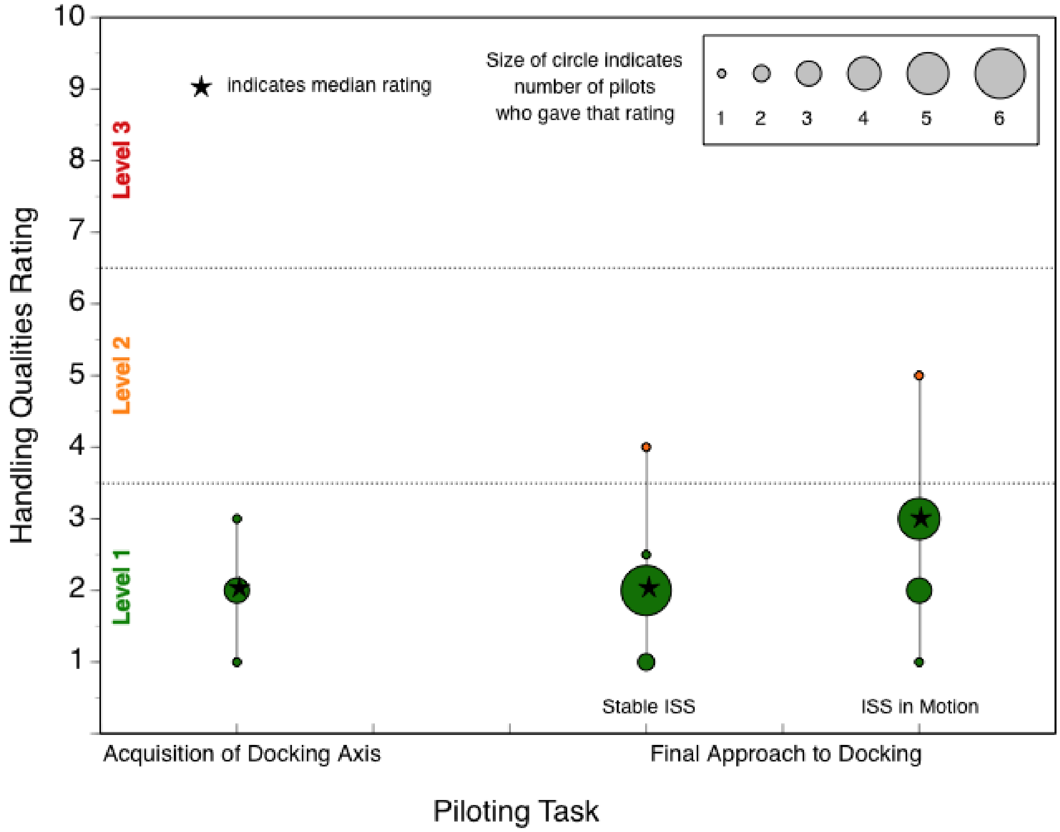

Figure 3. Docking and ADA handling quality rating results.

Overall, the test subjects indicated very minimal cross-coupling between translation and rotation and responses were very predictable, making rendezvous and docking low workload tasks. The tasks evaluated were generally rated as Level 1 indicating that the rendezvous and docking scenarios were readily achievable with the fine and coarse translational authority provided by Orion. Based upon the reported Cooper-Harper Ratings, subject comments, and additional HQ assessments, Orion's vehicle configuration appears to be on the path to achieving the ratings desired for a human rated spacecraft.