AIAA GNC Conference
8 - 11 Aug 2011
Oregon Convention Center
Portland, Oregon

Orion Entry Handling Qualities Assessments

B. Bihari, M. Tigges, A. Strahan, R. Gonzalez, K. Sullivan, J.P. Stephens, J. Hart, H. Law III, K. Bilimoria, and R. Bailey
NASA Johnson Space Center, Houston TX, 77058

The Orion Command Module (CM) is a capsule designed to bring crew back from the International Space Station (ISS), the moon and beyond. The atmospheric entry portion of the flight is deigned to be flown in autopilot mode for nominal situations. However, there exists the possibility for the crew to take over manual control in off-nominal situations. In these instances, the spacecraft must meet specific handling qualities criteria. To address these criteria two separate assessments of the Orion CM's entry Handling Qualities (HQ) were conducted at NASA's Johnson Space Center (JSC) using the Cooper-Harper scale (Cooper & Harper, 1969). These assessments were conducted in the summers of 2008 and 2010 using the Advanced NASA Technology Architecture for Exploration Studies (ANTARES) six degree of freedom, high fidelity Guidance, Navigation, and Control (GN&C) simulation. This paper will address the specifics of the handling qualities criteria, the vehicle configuration, the scenarios flown, the simulation background and setup, crew interfaces and displays, piloting techniques, ratings and crew comments, pre- and post-fight briefings, lessons learned and changes made to improve the overall system performance. The data collection tools, methods, data reduction and output reports will also be discussed.

The objective of the 2008 entry HQ assessment was to evaluate the handling qualities of the CM during a lunar skip return. A lunar skip entry case was selected because it was considered the most demanding of all bank control scenarios. Even though skip entry is not planned to be flown manually, it was hypothesized that if a pilot could fly the harder skip entry case, then they could also fly a simpler loads managed or ballistic (constant bank rate command) entry scenario. In addition, with the evaluation set-up of multiple tasks within the entry case, handling qualities ratings collected in the evaluation could be used to assess other scenarios such as the constant bank angle maintenance case.

The 2008 entry assessment was divided into two sections (see **Figure 1**). Entry I was the first, high speed portion of a lunar return and Entry II was the second, lower speed portion of a lunar return, which is similar (but not identical) to a typical ISS return.

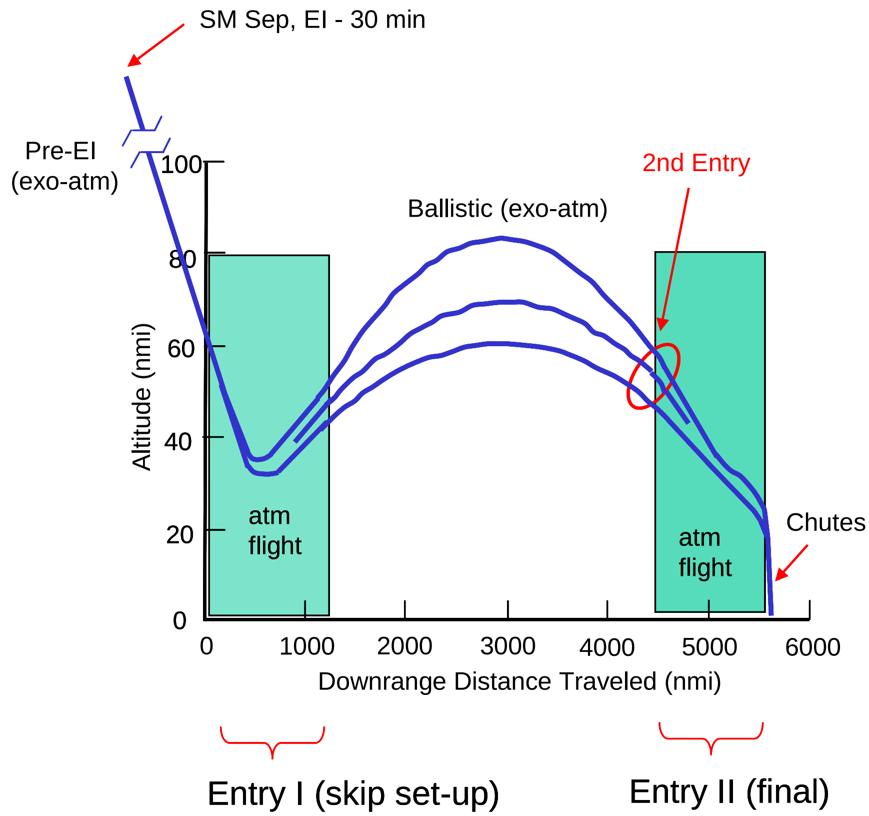

Figure 1: The Lunar skip entry profile used to create the Entry scenario. The green boxes outline the portions of the profile that were flown manually in this evaluation.

Entry I was selected to be flown because it was the most dynamic portion of the lunar skip entry profile and it is the most critical for determining the landing envelope. Entry II was assessed since the handling qualities at a lower velocity could be different from Entry I. The exo-atmospheric segment was not flown manually to shorten the evaluation time, because this period of flight was considered stable, and bank angle changes during this portion of flight have little impact on down range trajectory. During both entry scenarios, the subjects were asked to make bank control inputs with the Rotational Hand Controller (RHC). The objective was to follow the Predictive Guidance (PredGuid) shown on a display page as part of the Attitude Direction Indicator (ADI) data while angles of attack and sideslip were automatically controlled. Ten astronauts were used as subjects for this evaluation.

The objective of the 2010 Orion HQ assessment was to evaluate the handling qualities of the CM during a return from ISS. Again, two different scenarios were evaluated with the difference between the two entry scenarios being the guidance system used. The first scenario used the primary PredGuid system and the second used the Precision Loads Managed backup guidance system (PLM). Ballistic entry is a third method of entry available on Orion, but it was not evaluated during this assessment. As the guidance system downgrades from the nominal PredGuid, to PLM, to ballistic entry, Orion relies less on navigation information due to increasing simplicity, but at a cost of higher acceleration loads on the vehicle and crew as well as increased distance from the desired landing target. PredGuid and PLM (to a limited extent) use roll reversals to improve landing accuracy and reduce g-loads. Ballistic uses only a constant bank rate. The test cases started at entry interface (400,000 ft altitude) and were flown to parachute deployment (approx 40,000 ft altitude). Various dispersions were included to stress both the vehicle systems and the test subjects. Five astronauts were used for this assessment.

The core simulation behind these studies, ANTARES is the NASA high fidelity, six degree of freedom simulation used for Orion GN&C algorithm development and analysis. Although primarily a batch simulation, ANTARES was tailored in this study for real-time pilot-in-the-loop evaluations with a RHC, notional displays for piloting cues and flight control system configuration. ANTARES was used for development of the manual control algorithm prototypes used in the selected scenarios. In addition, ANTARES was used for developing all the scenarios, in the determination of the testing criteria, and specific cases to be used for the evaluations. The ANTARES simulation was integrated into two separate Reconfigurable Operation Cockpit (ROC) mock-ups, where one would be operated in the smaller image surrounding Mini-Dome (see **Figure 2**) and the other in the larger Beta-Dome (see **Figure 3**). Both ROC mock-ups provide a simulated Orion cockpit environment including display units, hand controllers, and out-the-window portals. The three display units in each mock-up are capable of showing Orion displays, overlays, and docking camera views. The simulation domes provide surrounding image projection that could be viewed through the mock-up windows creating an immersive visual environment adding to situational awareness. The first ROC mock-up was utilized in the Mini-Dome for the 2008 assessment where subjects would sit up-right. The second ROC mock-up, utilized for the 2010 study, was installed in the larger Beta-Dome, and while providing the same cockpit design and display capabilities as the first ROC, it also included a medium fidelity seat which allowed the subject to sit recumbent and have the correct gravity vector for the entry.

Figure 2: 2008 Study in ROC Mini-Dome

Figure 3: 2010 Study in ROC Beta-Dome

The first handling qualities study in 2008 generated overall Cooper-Harper scores of 2-5 depending on the task and test subject. The Cooper-Harper rating begins with an assessment of the vehicle's "Adequacy for Selected Tasks or Required Operation" in which the subject decides if the performance achieved was desired, adequate or uncontrollable. Then the subject reviews the aircraft characteristics, the demands on the pilot, and determines the final rating with the lower the number the better. The overall feedback from the test subject was quite positive, indicating the most significant undesirable quality of the human-Orion interface was the “jumpiness” of the guidance command. Between 2008 and 2010 changes were made to both the guidance and control gains driving the manual guidance command, and to the display itself, presenting the command in a different and potentially more intuitive format. Additionally results from the 2010 study captured test subject assessment of manually flying the loads managed contingency scenario. It can be noted that an overall handling qualities improvement was identified from the 2010 study, though still with some noted issues to pursue further. A combined summary of the Copper-Harper ratings given is seen in **Figure 4** for both assessments.

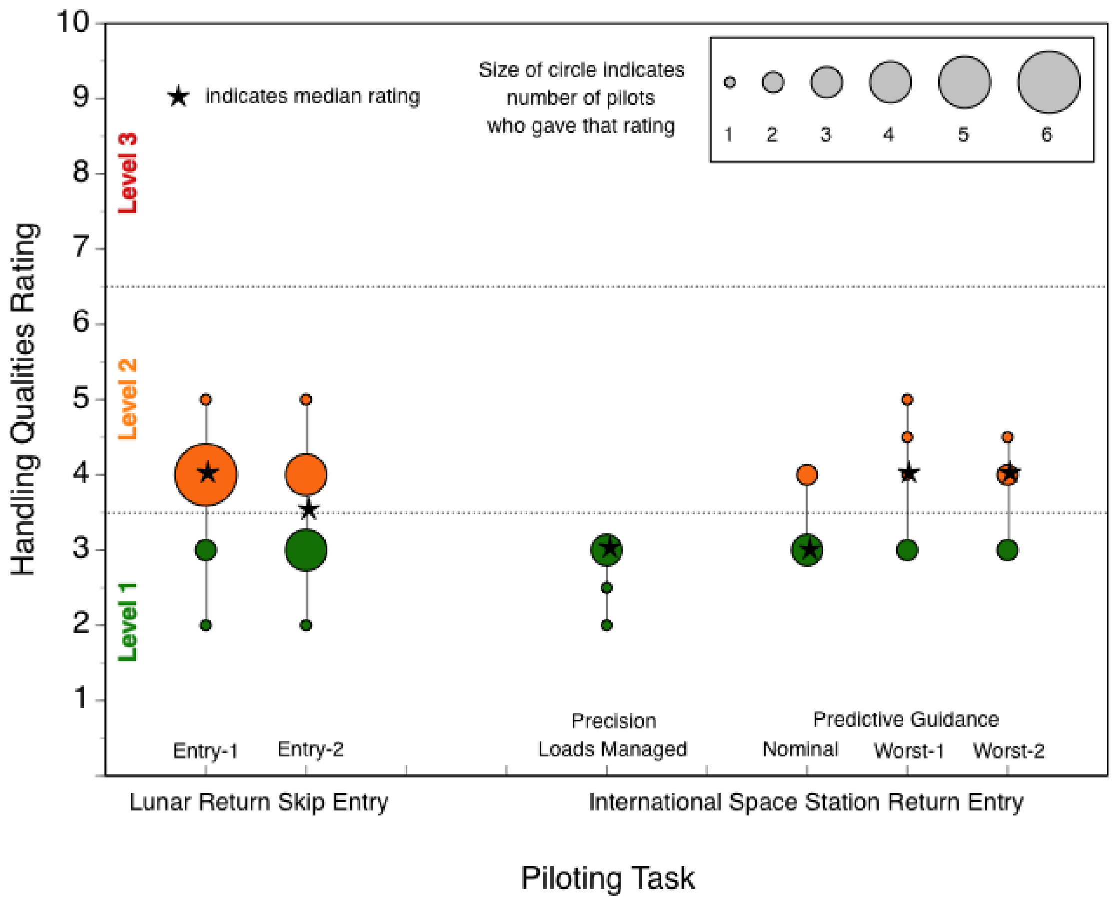

Figure 4: 2008 and 2010 Results - Bubble graph display of the Handling Qualities Evaluation Cooper-Harper Rating results.

Both studies proved to be very worthwhile, providing a substantial amount of information and test subject feedback regarding the human-machine interface for manually commanding a capsule re-entry. This information will continue to inform the guidance, control, display, and overall piloted entry task design for the Orion vehicle as it continues to mature. Additionally, this information will inform NASA on how to incorporate handling qualities into requirements being developed for crewed spacecraft.