Abstract - Orion Spacecraft MMOD Protection Design and Assessment

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The Orion spacecraft will replace the Space Shuttle Orbiter for American and international partner access to the International Space Station by 2015 and, afterwards, for access to the moon for initial sorties and later for extend outpost visits as part of the Constellation Exploration Initiative. This work describes some of the efforts being undertaken to ensure that Orion design will meet or exceed the stringent MicroMeteoroid and Orbital Debris (MMOD) requirements set out by NASA when exposed to the environments encountered with these missions. This paper will provide a brief overview of the approaches being used to provide MMOD protection to the Orion vehicle and to assess the spacecraft for compliance to the Constellation Program's MMOD requirements.

Orion Background

The Orion vehicle is being assessed for 210 day missions to the International Space Station (ISS), short duration missions to the moon (Lunar Sortie) and long duration (210 day) missions to the moon (Lunar Outpost). The assessed vehicle consists of a Crew Module (CM) and a Service Module (SM) in a configuration that is similar to the architecture of the Apollo spacecraft. The SM provides propulsion capabilities as well as other support utilities such as, water, compressed gases, active thermal control and power to the CM. The CM houses the crew and provides the Thermal Protection System (TPS) that is necessary for Earth entry. The CM separates from the SM prior to Earth reentry.

Orion Bumper-II Assessment

NASA's standard MMOD assessment software, BUMPER-II, is used to assess the Orion spacecraft for MMOD Loss Of Crew (LOC) and Loss Of Mission (LOM) risk levels. BUMPER-II has a long track record of use on various NASA manned programs, such as on mission analysis for the Space Shuttle and ISS. NASA's latest anisotropic meteoroid and orbital debris environments are currently being used with the BUMPER-II software. Finite element models are pre- and post-processed I-DEAS CAD version 12. Input and output data are pre- and post-processed using EXCEL spreadsheets and macros.

Orion MMOD Requirements

Loss Of Crew (LOC) MMOD Systems Requirement Document (SRD) requirements are defined for each of the Orion mission types. The LOC requirement is 1 in 800 for ISS missions, 1 in 1000 for lunar sortie missions and 1 in 500 for lunar outpost missions. In addition, Loss Of Mission (LOM) and LOC flow down requirement allocations for overall vehicle LOC and LOM reliability are expected to be defined very soon. The delay in receiving the flow down allocations proved the importance of having separately defined MMOD SRD requirements for a program such as this.

MMOD Environments

Current analyses use the ORDEM2000 as the orbital debris environment generator and MEMCxP/LunarMEM as the meteoroid environment generator. The ORDEM2000 environment as implemented by the NASA/JSC code KX orbital debris program office in BUMPER-II v1.48_m is used for all analyses. The MEMCxP v2.0 meteoroid environment for Earth orbital spacecraft as developed by the NASA/MSFC meteoroid environment office is used for all meteoroid analyses up to the lunar sphere of influence (66,000 km to the moon). The LunarMEM v2.0 as developed by the NASA/MSFC meteoroid environment office is used for lunar orbital spacecraft within the lunar sphere of influence.

MMOD Vehicle Model

MicroMeteoroid and Orbital Debris (MMOD) Analysis, using the BUMPER-II analysis code, uses detailed Finite Element Models (FEM) for the spacecraft that are produced using the I-DEAS® CAD System. The FEM is created starting from CAD 3D models that are translated into I-DEAS from Pro-Engineer® Wildfire 2® vehicle models.

The BUMPER-II analysis code can only process surface models, thus all critical components inside the vehicle are projected onto the Outer Mold Line (OML) of the vehicle. These outer surfaces are broken up into separate Property Identifier (PID) regions enabling assignment of specific wall or shield properties to the PID regions in accordance with their corresponding vehicle design properties. Then the regions are meshed using 2D surface elements. Figure 1 shows the most recent Orion MMOD analysis FEM. It is made up of approximately 86000 elements and 480 unique PID regions.

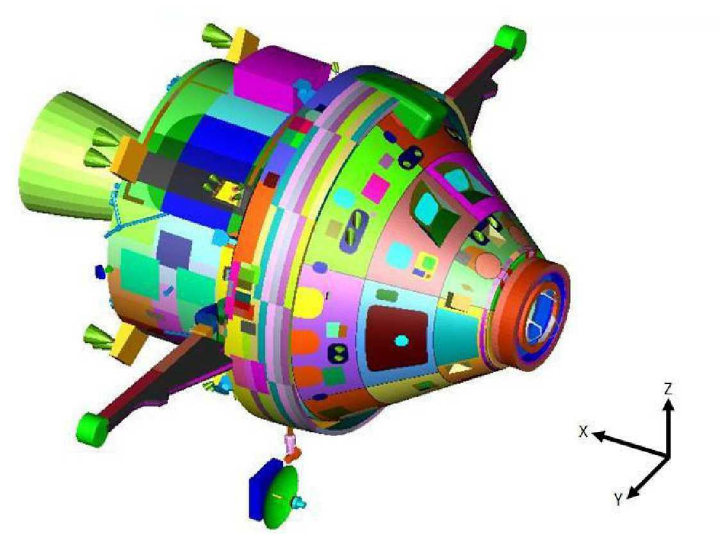

Figure 1, Orion MMOD Vehicle Model

Failure Criteria

A failure criterion is established for each component that is modeled as part of the vehicle analysis. This criterion defines the degree of damage that when exceeded counts as a failure. With the Orion spacecraft, the CM backshell TPS is the largest risk driver and the vehicle's overall risk levels are quite sensitive to the backshell failure criterion. Failure of the backshell TPS is counted when the depth of penetration into the TPS exceeds the limit determined by entry thermal analyses. This is an area getting a lot of attention for further MMOD and thermal (arc jet) testing. Other areas where the failure criteria are receiving a lot of attention include the propulsion fuel tanks, high pressure gas tanks and propulsion lines.

Ballistic Limit Equations

One or more Ballistic Limit Equations (BLEs) are associated with each PID region (shield/wall type). Bumper-II uses the BLEs to determine the critical diameter that just exceeds the failure criteria for each combination of impact velocity and obliquity. The BLEs, although initially adapted from existing "standard" forms using scaling factors, have largely been updated based on data from hypervelocity impact testing performed by NASA and/or Lockheed Martin. Hydrocode modeling using Autodyn® and CTH® is used to fine tune test plans and to supplement test results. Representative key BLEs will be provided.

Orion Design/Assessment Approach

Feedback is provided to the Orion design organization based on scrutiny of assessment results. By-PID results are sorted by number of failures and failures/exposed area so that it can be determined where additional protection is required and where protection mass can be reduced. Design parameter sensitivities are performed to assess variations enabling evolution to a superior spacecraft configuration.

Orion MMOD Protection

The Orion MMOD protection has evolved to a configuration that meets the program requirements. Figure 2 provides a vehicle layout showing locations of supplemental MMOD protection.

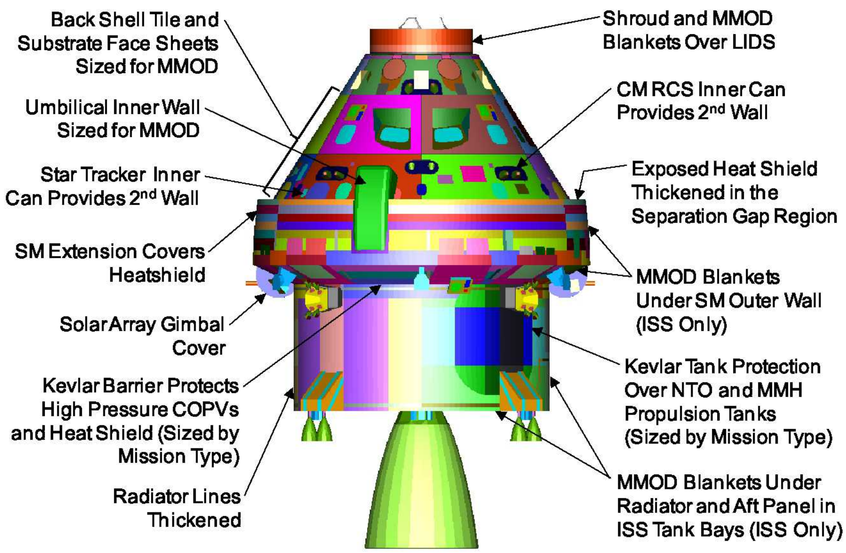

Figure 2, Supplemental MMOD Protection Locations

Supplemental MMOD protection is added to the CM in a number of areas. An outer "bumper" shroud is added around the outside of the LIDS creating a Whipple Shield for protection of its pressure wall. With ISS missions, additional Nextel and Kevlar fabrics are added behind the LIDS bumper providing Stuffed Whipple Shield protection. Inner housings are added around star trackers and Reaction Control System (RCS) pods behind the TPS to provide thermal redundancy after MMOD damage. TPS backshell tile and substrate thicknesses are adjusted to enable meeting overall vehicle requirements. Also, to reduce the risk of the heat shield TPS material receiving damage beyond allowable reentry depth limits, it is thickened in the shoulder region. This is the only area of the heat shield that has some limited direct exposed to MMOD flux.

The SM also has supplemental MMOD protection. The forward segment of the SM is extended over the CM's heat shield to minimize direct exposure of the heat shield to MMOD flux. Nextel and Kevlar "Stuffed Whipple fabrics" are added under this extension as well as under most of the rest of the SM's outer wall to protect the heat shield and other critical components such as tanks and cold plates from MMOD with ISS missions. For lunar missions the blankets are left out since the Whipple Shield configuration is adequate in the less severe lunar MMOD environment. The smaller diameter portion of the SM is covered with Active Thermal Control (ATC) system radiators. The lines and manifolds that are located inside of the radiator panel are thickened towards the outside for MMOD protection. The panel itself helps to protect the radiator lines and manifolds as well as functioning as the “bumper” shield for the main propulsion tanks and various other critical items located within that region of the SM. There is a Kevlar wall protecting components within the forward portion of the SM that have credible shot lines for damage from MMOD angling forward through the radiator panels. There is Whipple shield protection added to the various utilities running within the umbilical and to critical solar array actuators. Also, due to the criticality of protecting the large propulsion fuel tanks there is specialized Kevlar blanket and foam shielding that is used to directly protect critical surfaces from damage from shot lines through the radiators and the SM’s aft closeout panel.