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CASE STUDY OF METEOROID FLUENCE ON A MARS SAMPLE RETURN MISSION

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ABSTRACT

Introduction

The Mars Sample Return Campaign must satisfy a Back Planetary Protection requirement that limits the risk of biological contamination of the Earth by Martian microbes. The Earth Return Orbiter (ERO), being developed by the European Space Agency (ESA), will carry a Capture, Containment and Return System (CCRS), which is being developed by NASA to retrieve orbiting samples (OS) from Mars orbit, surround them with two containment layers to create a Contained OS (COS), and transfer the COS to the Earth Entry System (EES), which will be released by ERO to carry the samples through entry, descent and landing at the Utah Test and Training Range. Micrometeoroid impact damage to the Thermal Protection System (TPS) of the EES, which may occur at any time in the ERO mission, is recognized as a potential risk driver for loss of sample containment that needs to be rigorously assessed. A Micrometeoroid Protec-

tion System (MMPS) will be implemented to limit that risk. The MMPS consists of a shield covering the TPS called the Micrometeoroid Garage (MMG) and a system of cameras to inspect the TPS.

An extensive study was performed by the CCRS Project in collaboration with the NASA Engineering and Safety Center (NESC) to assess the probability of damage to the MMG and TPS by meteoroids over the entire ERO mission. This included the computation of the meteoroid fluence on the MMG and directly on the TPS after EES separation, and assessment of damage to the MMG and TPS via hypervelocity impact tests, hydrocode simulations, and empirical damage prediction and ballistic limit equations (BLEs). The focus of this paper is the meteoroid fluence on the MMG.

Scope

The ERO mission consists of several trajectory segments. Each of these segments is accomplished via continuous low-thrust electric propulsion (EP). The segments are: Outbound (Earth to Mars), a downward spiral at Mars, Low Mars Orbit (unthrusted) where the soil sample is retrieved, a spiral up, and Inbound (Mars to Earth).

The NASA Meteoroid Engineering Model (MEM) Version 3 was used to model the meteoroid flux on the MMG over all the trajectory segments. MEM 3 contains meteoroid source populations. For a given trajectory, MEM 3 determines distributions of meteoroid impact velocity and directions relative to the spacecraft. The absolute meteoroid flux levels are determined from the Gruen flux vs. mass model and adjusted using an algorithm in MEM 3 to account for gravitational focusing and shielding by the central body.

During the EP segments of the mission, the spacecraft is continuously changing its attitude. This is necessary to point the thrust vector in a direction to accomplish the orbit transfer and to maintain the solar arrays pointing at the Sun to power the EP. As a result, the MMG orientation does not remain fixed in one of the output coordinate systems available in MEM.

Meteoroid flux files from MEM 3 were provided for two subsequent analyses. In one analysis, the NASA Bumper code used these MEM 3 outputs with BLEs to determine the probability of damage to the TPS. In the second analysis, the Aerospace Meteoroid and Orbital Debris Risk Assessment (MODRA) code was used to determine cumulative meteoroid fluence vs. impact velocity and angle relative to the MMG, which are in turn used to efficiently plan hydrocode simulation runs to assess TPS damage. MODRA is implemented in cluster computing to perform a high-resolution matching of the spacecraft attitude with the trajectory state vector as they both vary along the trajectory segments. Fluences from MODRA can be matched to the hydrocode scenarios with TPS damage exceeding a defined penetration depth to assess damage probability.

Findings

Figure 1 shows two-dimensional histograms of cumulative fluence on the MMG vs. meteoroid impact velocity and angle over the Outbound trajectory segment. MEM 3 produces two separate sets of flux files: one for low density meteoroids (of which ice is the majority constituent) and one for high density meteoroids (chondritic materials, metals, etc.). The figure shows a separate 3D color map for each population to accommodate use with separate hydrocode results or damage prediction equations for different meteoroid materials. For the low-density population, there is a broad velocity distribution from 5 km/s to 65 km/s. For the high-density population, there is a clear mode in the velocity distribution at approximately 20 km/s. For both populations, the angle distribution is broad from 0 to 80 degrees, with a mode at approximately 40 degrees. The broadness of the angle distribution is due to the changing attitude of the spacecraft in the ecliptic plane, and the conical/cylindrical shape of the MMG, both of which spread out the meteoroid radiants relative to the surface of the MMG.

For the low-density population from MEM 3, results show that hydrocode runs at a discrete set of velocities spanning the broad velocity range should be performed. For the high-density population, hydrocode runs at the most likely velocity of 20 km/s can be emphasized. For both populations, hydrocode runs at an angle of 40 degrees with a few cases above and below can be emphasized.

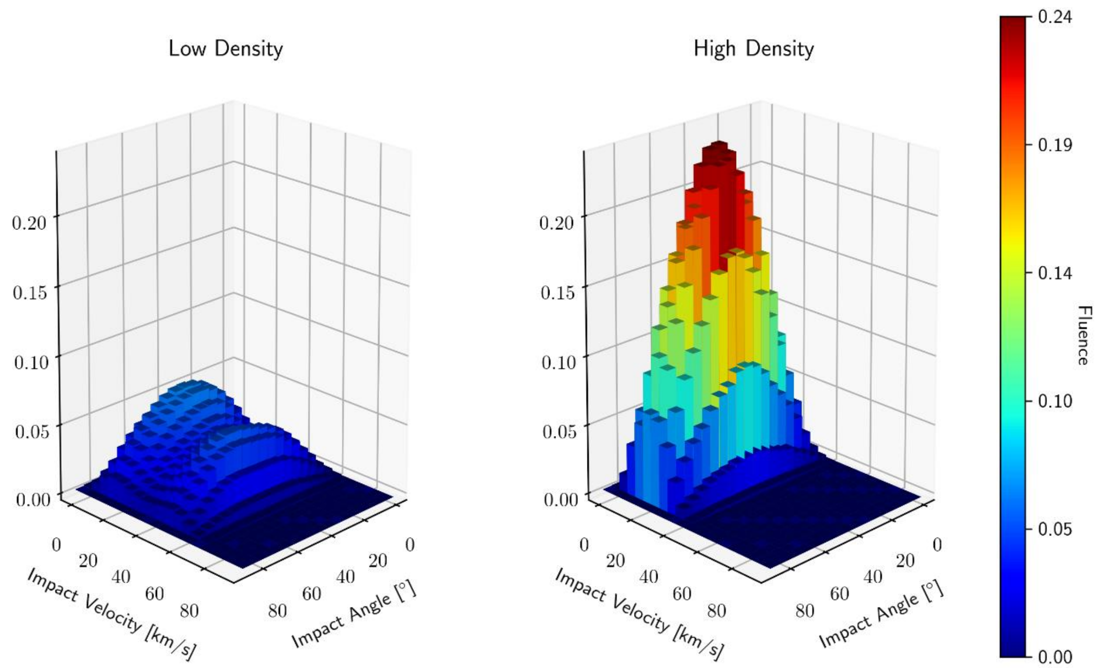

Figure 1. 3D color maps of two-dimensional histograms of cumulative meteoroid fluence on the MMG vs. impact velocity and angle over the Outbound trajectory segment. Fluence is for meteoroid mass ≥ 10^{-6} g. Velocity bin width is 5 km/s. Angle bin width is 5 degrees.

Conclusions and Recommendations

The paper will describe the analysis process in more detail. Fluence distributions over impactor mass, velocity, angle, and kinetic energy will be presented for all the trajectory segments. The paper will serve as a case study and be complementary to other papers that will discuss hydrocode simulations and development of BLEs for the overall study.