Natural Environment Definition for Exploration Missions

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I. Introduction

A comprehensive set of environment definitions is necessary from the beginning of the development of a spacecraft. The Cross-Program Design Specification for Natural Environments (DSNE, SLS-SPEC-159) was originally developed during the Constellation Program and then modified and matured for the Exploration Programs (Space Launch System and Orion). The DSNE includes launch, low-earth orbit (LEO), trans-lunar, cis-lunar, interplanetary, and entry/descent/landing environments developed from standard and custom databases and models. The space environments section will be discussed in detail.

II. Background

A. History

Environment definition documents have been used for the design of spacecraft since the earliest days of the space program. SSP 30425 (Space Station Program Natural Environment Definition for Design) and SSP 30512 (Space Station Ionizing Radiation Design Environment) were baselined for the International Space Station (ISS) Program in the early 1990's and this stable, complete set of environments was important to utilize from preliminary design into operations. Our understanding of the space environment and many of the models used to describe it have changed since then but the need for environment definitions during the design process has not.

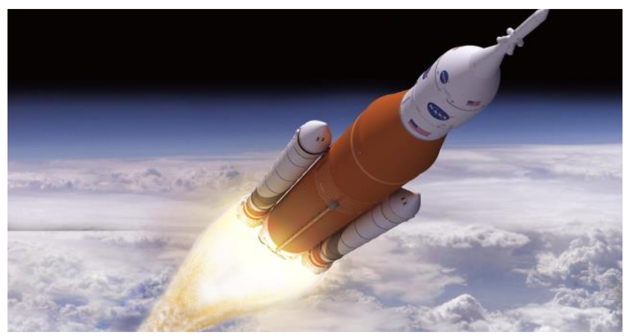
Since the Constellation Program (circa 2005) had elements which would ferry crews to ISS as well as to the surface of the Moon, it was clear that a "buffet approach" was needed to provide environment definitions relevant to those specific elements for their mission profiles. For instance, an ISS taxi would not need to be designed for geosynchronous or lunar wake plasma environments. The DSNE, then baselined as CxP 70023, was structured to allow the various elements of the architecture to specify only the environments to which they would be exposed.

A sister document was developed to provide additional background on the environment definitions in the DSNE. It was CxP 70044 Natural Environment Definition for Design (NEDD). The NEDD has recently been updated and published as a NASA Technical Memorandum, NASA/TM-2016-218229. In addition to the deeper discussion of each environment it contains a description of lunar surface geotechnical properties which was fairly up-to-date a few years ago.

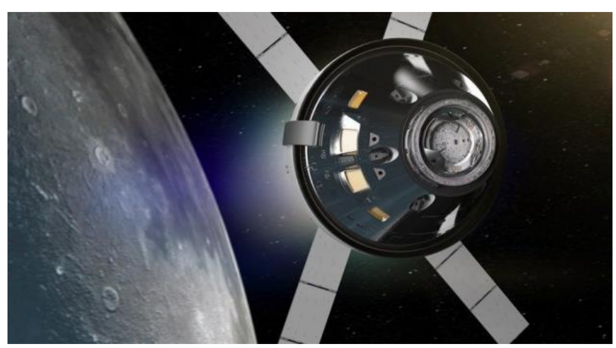
After cancellation of the Constellation Program and the transition to the Exploration Program which consists of the Space Launch System (SLS) and the Orion Multi-Purpose Crew Vehicle, this DSNE structure was easily ported to the new program. As the various Design Reference Missions (DRMs) were developed for the new program, sections were added to the DSNE to ensure that design environments for those DRMs were included. For example, total ionizing radiation dose (TID) was calculated for various highly elliptical orbits being considered and that material has its own section of the document. This is so that designers can add it to the dose for LEO trapped radiation and for a solar energetic particle environment un-shielded by the geomagnetic field in order to specify the TID for the mission. Similarly, the linear energy transfer (LET) for the various phases of the mission can be examined and the worst case can be selected as the design requirement.

SLS-SPEC-159 (initial baseline 2012) Cross-Program Design Specification for Natural Environments grew from the Constellation DSNE. It continues to be revised as new environment data and models become available or as elements of the Program require more detailed information. Revision D is the current baseline but Revision E is in the change review process at the time of this writing.

SLS-SPEC-044-07 SLS Program Vehicle Design Environments, Vol. 7 Natural Environments contains a matrix which assigns the appropriate paragraphs of the DSNE to the Orion and various elements of SLS based on the environments they will encounter in the various DRMs. This aids in requirements flowdown and verification traceability.

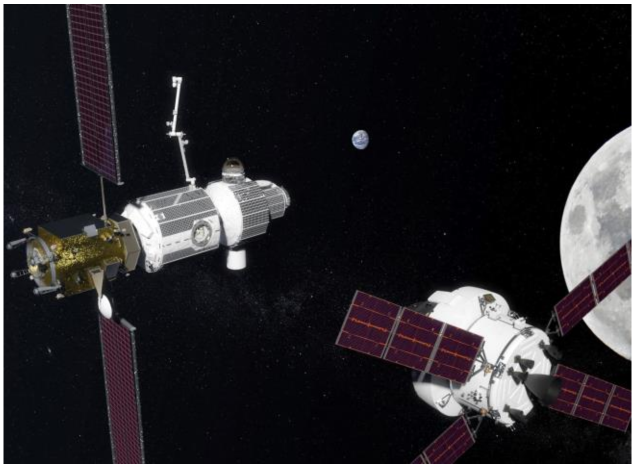


Space Launch System



Orion

The DSNE is also being used for the Deep Space Gateway study, which will use SLS and Orion to construct and utilize an outpost in cis-lunar space. The plans for this effort were recently outlined in NASA's report to the NASA Advisory Council. https://www.nasa.gov/sites/default/files/atoms/files/heo_update_tagged.pdf



Deep Space Gateway

III. Structure of the Document

The DSNE is organized by mission phase starting with launch and ending with entry/descent/landing. There are Reserved (unpopulated TBD) sections for future destinations such as the lunar surface, Mars, and near-earth asteroids. These are not currently required for the hardware development and our knowledge of those environments will likely improve before we need to populate those sections. The current plans call for operation out to cis-lunar space so those relevant sections are mature.

The In-Space paragraphs cover the gamut of environments disciplines with the exception of the Reserved section on Geomagnetic Fields. Since no Exploration hardware is planning to use magnetorquers and will not spend much time in LEO, that section is Reserved for future use if needed. Below is the table of contents with more detail shown for the In-Space paragraphs. Note that the interplanetary mission phases are addressed in the 3.3 environments applicable to geomagnetic unshielded exposure to the solar and cosmic ray environments as well as solar wind plasma environments.

3.1 Prelaunch
3.2 Launch Countdown and Earth Ascent
3.3 In-Space
- 3.3.1 Total Dose
- 3.3.2 Single Event Effects
- 3.3.3 Plasma Charging
- 3.3.4 Ionizing Radiation for Crew Exposure – provided by JSC/Space Radiation Analysis Group
- 3.3.6 Meteoroids and Orbital Debris
- 3.3.7 Earth Gravitational Field
- 3.3.8 Lunar Gravitational Field
- 3.3.9 Thermal Environment for In-Space Hardware – similar to ISS spec for LEO, includes lunar albedo and infrared emission
- 3.3.10 Solar Illumination Environment for In-Space Hardware – solar spectrum, including lunar eclipses
- 3.3.11 In-Space Neutral Atmosphere (Thermosphere) density
- 3.3.12 Geomagnetic Fields (Reserved)

3.4 Lunar Surface (Reserved)
3.5 Entry and Landing
3.6 Contingency and Off-Nominal Landing
3.7 Recovery and Post-Flight Processing Phases
3.8 Interplanetary Space (Reserved but covered by relevant paragraphs in 3.3
3.9 Mars Orbit (Reserved)
3.10 Atmosphere and Surface Phase (Reserved)
3.11 Mars Moons (Reserved)
3.12 Near Earth Asteroid (Reserved)

IV. Structure of Each Section

Each major paragraph of the document contains the following material. This amount of descriptive information is useful to help the spacecraft designers understand and properly account for the applicable environments.

Design Limits
- General discussion followed by figures and tables where appropriate

Model Inputs
- Orbits, size/energy thresholds, etc.
- Limitations
- Caveats and uncertainties on the model outputs

Technical Notes
- Models used and their inputs when Design Limits are tabular

In many cases it is appropriate to simply specify a model and in other cases it is more appropriate to specify the output of the models and the tabular output. For example, design of spacecraft shielding levels for meteoroids is typically performed with a 3 dimensional model of the spacecraft and directional fluxes from the meteoroid environment for the particular trajectory and spacecraft attitude. Publishing tables for this kind of information would be unwieldy so the Meteoroid Engineering Model R2 is specified. However for ionizing radiation environments it is necessary to run the models to prescribe appropriate design environments for the given trajectories and to specify the tabular output of the models as the specification.

V. Examples

A. Figures and tables

Below are examples of some of the ionizing radiation design environments. They show a portion of the Galactic Cosmic Ray (GCR) Linear Energy Transfer (LET) spectra used to assess the single event effects performance of avionics systems. The tabular data is the same as that in the figure.

Table 3.3.2.10.2-5. GCR Integral LET at Solar Minimum for Selected Al Shielding Thickness as a Function of LET

LET	Shield Thickness 0.0254 cm (0.0686 g/cm^2)	Shield Thickness 0.254 cm (0.6858 g/cm^2)	Shield Thickness 2.54 cm (6.858 g/cm^2)	Shield Thickness 5.08 cm (13.72 g/cm^2)	Shield Thickness 25.40 cm (68.58 g/cm^2)
MeV-cm^2/mg	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s
1.01	2.47E-03	2.32E-03	1.30E-03	7.76E-04	2.85E-05
1.27	1.32E-03	1.22E-03	6.01E-04	3.33E-04	1.03E-05
1.61	7.92E-04	7.22E-04	3.21E-04	1.70E-04	4.98E-06
2.10	4.59E-04	4.13E-04	1.69E-04	8.75E-05	2.55E-06
3.20	1.96E-04	1.74E-04	6.51E-05	3.29E-05	9.51E-07
4.05	1.19E-04	1.06E-04	3.84E-05	1.93E-05	5.43E-07
5.06	7.31E-05	6.59E-05	2.31E-05	1.15E-05	3.09E-07
6.46	4.16E-05	3.83E-05	1.31E-05	6.43E-06	1.61E-07
8.07	2.49E-05	2.35E-05	7.83E-06	3.81E-06	8.86E-08

Excerpt of Table 3.3.2.10.2-5

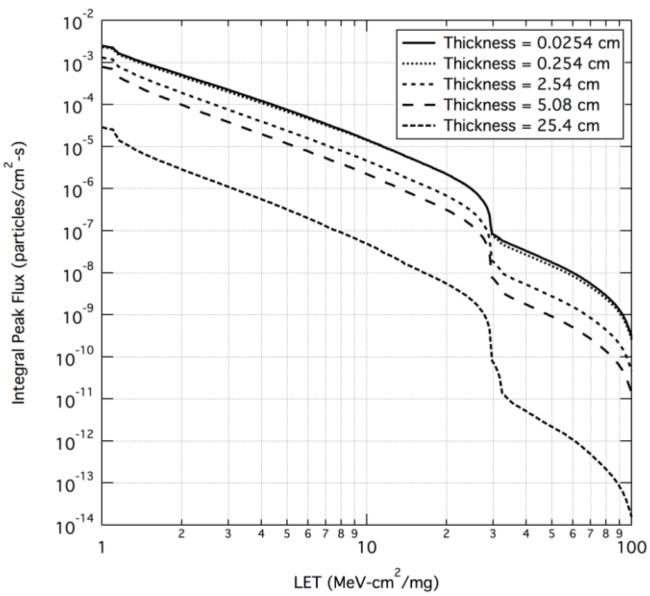


Figure 3.3.2.10.2-5. GCR Integral LET at Solar Minimum for Selected Al Shielding Thickness as a Function of LET

B. Spacecraft charging environments

The following spacecraft charging environments are described in the DSNE. These environments are suitable for use in spacecraft charging models.

Ambient Plasma for less than 1000 km
Geosynchronous orbit – based on SCATHA data
Interplanetary (magnetosheath/magnetotail and solar wind)
Radiation Belt Transit – Fennell et al. 2000
Lunar Wake – Haleakas et al. 2005, Minow, et al., 2008
Polar Orbit – Nascap 2K defaults

VI. Environment Models Specified or Utilized

The following space environment models were utilized either in generating the tables and figures or have been specified for use in design and verification analyses.

GGM02C Earth Gravity
GRAIL Lunar Gravity
Meteoroid Engineering Model (MEM) R2 Meteoroids
ORDEM 3.0 Orbital Debris
Earth-GRAM 2010 includes thermosphere models
- NRL-MSIS
- Marshall Engineering Thermosphere

Ionizing radiation
- AE8/AP8 Trapped Particles
- ESP/Psychic Solar Energetic Particles
- CREME-96 Galactic Cosmic Rays
- Shieldose2 total integrated dose
- O’Neill-Badhwar GCR for crew dose
- King Solar Proton Fluences for crew dose

All of these models are easily accessible. There are newer models available for some of the environments but these were available when the DSNE was initially baselined for the Exploration Program and multiplicative factors have been applied to some to make sure they provide a reasonable but conservative environment definition. These factors are described in the appropriate Technical Notes sections.

VII. Summary

The DSNE provides environment definitions for all phases of manned exploration missions from launch to landing. It represents many man-years of effort by a large team of environments specialists. The in-space portions of the DSNE describe design environments from low-earth orbit, through the radiation belts and geosynchronous region, into cis-lunar and interplanetary space. The DSNE is baselined for use by the SLS and Orion programs and is currently providing reference environments for other projects such as the Deep Space Gateway.

VIII. Acknowledgements

A large number of people were involved in the development of the DSNE. Most worked for Marshall Space Flight Center’s Natural Environments Branch (EV44) but there were contributors from across NASA, academia and industry.

References

References for the various models and datasets mentioned here may be found in DSNE section 5.0

SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE)
https://ntrs.nasa.gov/search.jsp?R=20160004378