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1.0 INTRODUCTION

1.1 Background

This document is derived from the former National Aeronautics and Space Administration (NASA) Constellation Program (CxP) document CxP 70023, titled “The Design Specification for Natural Environments (DSNE), Revision C.” The original document has been modified to represent updated Design Reference Missions (DRMs) for the NASA Exploration Systems Development (ESD) Programs.

1.2 Purpose

The DSNE completes environment-related specifications for architecture, system-level, and lower-tier documents by specifying the ranges of environmental conditions that must be accounted for by NASA ESD Programs. To assure clarity and consistency, and to prevent requirements documents from becoming cluttered with extensive amounts of technical material, natural environment specifications have been compiled into this document. The intent is to keep a unified specification for natural environments that each Program calls out for appropriate application.

1.3 Scope

This document defines the natural environments parameter limits (maximum and minimum values, energy spectra, or precise model inputs, assumptions, model options, etc.), for all ESD Programs. These environments are developed by the NASA Marshall Space Flight Center (MSFC) Natural Environments Branch (MSFC organization code: EV44). Many of the parameter limits are based on experience with previous programs, such as the Space Shuttle Program. The parameter limits contain no margin and are meant to be evaluated individually to ensure they are reasonable (i.e., do not apply unrealistic extreme-on-extreme conditions).

The natural environments specifications in this document should be accounted for by robust design of the flight vehicle and support systems. However, it is understood that in some cases the Programs will find it more effective to account for portions of the environment ranges by operational mitigation or acceptance of risk in accordance with an appropriate program risk management plan and/or hazard analysis process.

The DSNE is not intended as a definition of operational models or operational constraints, nor is it adequate, alone, for ground facilities which may have additional requirements (for example, building codes and local environmental constraints).

“Natural environments,” as the term is used here, refers to the environments that are not the result of intended human activity or intervention. It consists of a variety of external environmental factors (most of natural origin and a few of human origin) which impose restrictions or otherwise impact the development or operation of flight vehicles and destination surface systems. These natural environments include the following types of environments:

a. Terrestrial environments at launch, abort, and normal landing sites (winds, temperatures, pressures, surface roughness, sea conditions, etc.).
b. Space environments (ionizing radiation, orbital debris, meteoroids, thermosphere density, plasma, solar, Earth, and lunar-emitted thermal radiation, etc.).

Destination environments (Lunar surface and orbital, Mars atmosphere and surface, near Earth asteroids, etc.).

Many of the environmental specifications in this document are based on models, data, and environment descriptions contained in the NASA/TM 2016-218229, Natural Environment Definition for Design (NEDD). The NEDD provides additional detailed environment data and model descriptions to support analytical studies for ESD Programs. For background information on specific environments and their effects on spacecraft design and operations, the environment models, and the data used to generate the specifications contained in the DSNE, the reader is referred to the NEDD.

Validation of the models, data, and design limits in this document are provided in Appendix B. The intent is to provide validity of the specified natural environments for use in design assessment, which includes background of the inputs, physics, and methodology used in development of the various models and databases, as well as use in previous NASA programs. Verification of the natural environments is accomplished by confirming the intended specifications are identified in this document. This confirmation is carried out through review by the Natural Environments Integrated Ad Hoc Team, and review, approval, and configuration control by the applicable ESD Programs.

Also, most of the environmental specifications in this document are tied specifically to the ESD DRMs in ESD-10012, Revision E, Exploration Systems Development Concept of Operations (ConOps). Coordination between these environment specifications and the DRMs must be maintained. This document should be compatible with the current ESD DRMs, but updates to the mission definitions and variations in interpretation may require adjustments to the environment specifications.

Table 1.3-1 provides the mapping of the DRMs in ESD-10012, Revision E to the corresponding sections in the DSNE.
<table>
<thead>
<tr>
<th>Exploration Systems ConOps</th>
<th>DSNE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section No.</strong></td>
<td><strong>Title</strong></td>
</tr>
<tr>
<td>7</td>
<td>Operations And Interfaces (Comm. Interfaces not included)</td>
</tr>
<tr>
<td>7.1</td>
<td>Pre-flight Preparation Operations</td>
</tr>
<tr>
<td>7.2</td>
<td>Ground Operations</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Pad and Launch Operations</td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2.6</td>
<td>Launch Scrub</td>
</tr>
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<td>7.3.1</td>
<td>Ascent Operations</td>
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</tr>
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<td>7.5.1</td>
<td>Secondary Payloads</td>
</tr>
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<td>Orion NEA DRM Operations</td>
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<td></td>
</tr>
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<td>7.5.3</td>
<td>Orion Quiescent Mode Docked with Initial Cis-Lunar Habitat (ICH)/Deep Space Habitat (DSH)</td>
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<td></td>
</tr>
<tr>
<td>7.6.1</td>
<td>Entry, Descent, and Landing</td>
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<td>7.7.3</td>
<td>Orion Cis-Lunar Auxiliary Return</td>
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<td></td>
</tr>
<tr>
<td>7.7.4</td>
<td>Off-Nominal Crew Rescue</td>
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<tr>
<td>7.7.5</td>
<td>Ascent Abort</td>
</tr>
</tbody>
</table>

### 1.4 Change Authority/Responsibility
The NASA Office of Primary Responsibility (OPR) for this document is EV44.
Proposed changes to this document will be submitted by a SLS Program Change Request (CR) to the appropriate SLS control board for disposition. The CR process is described in SLS-PLAN-008, SLSP Configuration Management Plan (CMP).

Proposed changes to this document should be vetted through the Cross-Program Natural Environments Integration Ad-Hoc Team (NEIAHT) prior to the submission of an SLS Program CR. Requests for clarification, interpretation, or questions concerning this document should be addressed to the Cross-Program NEIAHT, or the MSFC Natural Environments Branch.

2.0 DOCUMENTS

2.1 Applicable Documents, Models, and Data Sets

2.1.1 Applicable Documents

The following data items include specifications, models, standards, guidelines, handbooks, and other special publications. The data items listed in this paragraph are applicable in the current approved baseline as specified in the SLS Master List of Baslined Data Items to the extent specified herein. Specific revisions of SLS controlled or jointly controlled documents will not be annotated unless required to specify the boundaries of an incorporated agreement or requirement. Data items not controlled by SLS will be annotated by revision.

<table>
<thead>
<tr>
<th>Document Number</th>
<th>Document Revision</th>
<th>Document Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESD 10012</td>
<td>E</td>
<td>Exploration Systems Development Concept of Operations</td>
</tr>
<tr>
<td>MPCV 70024</td>
<td>A</td>
<td>Orion MPCV Program Human-Systems Integration Requirements</td>
</tr>
<tr>
<td>SAE ARP5412</td>
<td>B</td>
<td>Aircraft Lightning Environment and Related Test Waveforms</td>
</tr>
<tr>
<td>SAE ARP5414</td>
<td>A</td>
<td>Aircraft Lightning Zoning</td>
</tr>
</tbody>
</table>

2.1.2 Applicable Models/Data Sets

The following models and data bases are used for specifications. Their application is described in the appropriate sections of this document.

The electronic version is the official approved document. Verify this is the correct version before use.
<table>
<thead>
<tr>
<th>Model/Data Set Identification</th>
<th>Model/Data Set Name/Description</th>
</tr>
</thead>
</table>
| Earth-GRAM                    | Earth Global Reference Atmosphere Model (GRAM)  
As of January 1, 2012 the latest version of this model is Earth-GRAM 2010. Any previous analyses performed using a prior version do not require rework. |
| GGM02C                        | Gravity Recovery and Climate Experiment (GRACE) Gravity Model 02 C |
| GRAIL                         | Gravity Recovery and Interior Laboratory (GRAIL) Lunar Gravity Model |
| MEM R2                        | Meteoroid Engineering Model Revision 2 |
| ORDEM 3.0                     | Orbital Debris Engineering Model 3.0 |
| KSC Jimsphere Wind Profile Database | Kennedy Space Center Jimsphere Wind Profile Database |
| MVWPM                         | Monthly Vector Wind Profile Model |
| KSC Ground Wind Models        | Kennedy Space Center Ground Wind Models |
| KSC Doppler Radar Wind Profiler Database | Kennedy Space Center Doppler Radar Wind Profiler Database |
3.0 NATURAL ENVIRONMENT SPECIFICATION

3.1 Prelaunch – Ground Processing Phases

3.1.1 Transportation Environments to the Launch Site KSC (Reserved)

Description

This section is reserved for special environmental requirements for shipping flight hardware to Kennedy Space Center (KSC) not covered by other standard shipping requirements documents. Examples might include monitoring for lightning discharge or electromagnetic irradiation and monitoring of temperature and pressure extremes. At this time, no special requirements have been identified.

Design Limits

Maximum: Reserved
Minimum: Reserved

Model Inputs

Reserved

Limitations

Reserved

Technical Notes

Reserved

3.1.2 Reserved

3.1.3 Ground Winds for Transport and Launch Pad Environments

Description

This section specifies ground wind environments (altitude range 0 to 150 meters (m) [0 to 492 feet (ft)]), up to and including the maximum design limits for flight hardware that will be exposed during ground operations at KSC, including transportation to and from the pad and on-pad operations. Design specifications include peak wind-speed profile, steady state wind-speed profile, frequency of occurrence of peak winds, and spectral gust environments. “Storage” applies to on-pad or outside storage only.

Design Limits

Table 3.1.3-1 provides the design peak wind profiles, in meters per second (m/s) and feet per second (ft/s), for the various operational phases at selected altitudes. The design steady state wind profiles associated with the design peak wind profiles are provided in Table 3.1.3-2. The steady state wind profile is that profile that could produce the instantaneous peak winds (gusts)
in Table 3.1.3-1, over a 10-minute period. Peak wind profile values between those altitudes given in Tables 3.1.3 are determined by:

\[ u(z) = u_{18.3} \left( \frac{z}{18.3} \right)^{1.6(u_{18.3})^{-3/4}} \]

where \( u(z) \) is the peak wind (m/s) at height \( z \) (m) and \( u_{18.3} \) is the peak wind speed (m/s) at 18.3 m. Steady state profile values between those altitudes given in Table 3.1.3-2 are determined by:

\[ \bar{U}(z) = u(z) \left( 1 + \frac{\left( \frac{18.3}{z} \right)^{0.283 - 0.435e^{-0.2u_{18.3}}} - 0.2}{1.98 - 1.887e^{-0.2u_{18.3}}} \right)^{-1} \]

where \( u(z) \) is the peak wind (m/s) at height \( z \) (m) and \( u_{18.3} \) is the peak wind (m/s) at 18.3 m. Note that metric units (m/s and m) must be used in the above two equations. Once \( u(z) \) and \( \bar{U}(z) \) are determined, they can be converted to English units (ft/s).

**Table 3.1.3-1. Design Peak Wind-Speed Profile**

<table>
<thead>
<tr>
<th>Height</th>
<th>Peak Wind-Speed Profile</th>
<th>On-Pad (Unfueled)</th>
<th>On-Pad (Intermediate and Fully Fueled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>ft</td>
<td>m/s</td>
<td>ft/s</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>28.6</td>
<td>93.8</td>
</tr>
<tr>
<td>18.3</td>
<td>60</td>
<td>30.8</td>
<td>101.1</td>
</tr>
<tr>
<td>30</td>
<td>98</td>
<td>32.7</td>
<td>107.3</td>
</tr>
<tr>
<td>60</td>
<td>197</td>
<td>35.6</td>
<td>116.8</td>
</tr>
<tr>
<td>90</td>
<td>295</td>
<td>37.4</td>
<td>122.7</td>
</tr>
<tr>
<td>120</td>
<td>394</td>
<td>38.8</td>
<td>127.3</td>
</tr>
<tr>
<td>150</td>
<td>492</td>
<td>39.8</td>
<td>130.6</td>
</tr>
</tbody>
</table>
Table 3.1.3-2. Steady State Wind-Speed Profile Associated with the Design Peak Wind-Speed Profile

<table>
<thead>
<tr>
<th>Height</th>
<th>Transport To/From Pad</th>
<th>On-Pad (Unfueled)</th>
<th>On-Pad (Intermediate and Fully Fueled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>ft</td>
<td>m/s</td>
<td>ft/s</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>17.9</td>
<td>58.7</td>
</tr>
<tr>
<td>18.3</td>
<td>60</td>
<td>20.5</td>
<td>67.3</td>
</tr>
<tr>
<td>30</td>
<td>98</td>
<td>22.7</td>
<td>74.5</td>
</tr>
<tr>
<td>60</td>
<td>197</td>
<td>26.1</td>
<td>85.6</td>
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<td>90</td>
<td>295</td>
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<td>92.9</td>
</tr>
<tr>
<td>120</td>
<td>394</td>
<td>29.9</td>
<td>98.1</td>
</tr>
<tr>
<td>150</td>
<td>492</td>
<td>31.1</td>
<td>102.0</td>
</tr>
</tbody>
</table>

For fatigue load analyses, the design frequency of occurrence of 30 s peak winds at the 18.3 m (60 ft) reference height is provided in Table 3.1.3-3. Any analysis should contain at least one occurrence of the design peak wind of 38.3 m/s (125.7 ft/s). The number of occurrences of a selected 30 s peak wind range for any time period ≥30 s can be determined by multiplying the probability of occurrence by the number of 30 s intervals in the chosen time period. For example, there are approximately 1,238 occurrences of 30 s peak winds in the range 4.75 to 5.25 m/s (15.6 to 17.2 ft/s) in a 5-day period (number of 30 s intervals in 5 days is 14,400, 14,400 * 0.08598149 = 1,238.13).

Table 3.1.3-3. Occurrence Probabilities of 30 s Peak Wind Speed in 0.5 m/s Intervals (Centered at Value x) at the 18.3 m Reference Height

<table>
<thead>
<tr>
<th>Peak Wind Speed x</th>
<th>Probability</th>
<th>Peak Wind Speed x</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/s</td>
<td>ft/s</td>
<td>m/s</td>
<td>ft/s</td>
</tr>
<tr>
<td>0.5</td>
<td>1.6</td>
<td>0.003246387</td>
<td>20.0</td>
</tr>
<tr>
<td>1.0</td>
<td>3.2</td>
<td>0.01116703</td>
<td>20.5</td>
</tr>
<tr>
<td>1.5</td>
<td>4.9</td>
<td>0.02681171</td>
<td>21.0</td>
</tr>
<tr>
<td>2.0</td>
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<td>0.04885758</td>
<td>21.5</td>
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<td>2.5</td>
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<td>3.0</td>
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<td>5.0</td>
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</tr>
<tr>
<td>Peak Wind Speed x</td>
<td>Probability</td>
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<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/s</td>
<td>ft/s</td>
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</table>

For thermal assessments involving wind effects, use the following guidelines:

1) For components with time constants less than an hour, or for minimum winds conditions, use the steady-state wind speeds in Table 3.1.3-4.
2) For components with time constants on the order of hours, use the steady-state wind speeds in Table 3.1.3-5.

3) For components with time constants on the order of days, use the diurnal profile of steady-state wind speeds in Table 3.1.3-6. For the design low case, assume the values in Table 3.1.3-6 are constant with altitude from 10 m (32 ft) up to 150 m (492 ft). For the design high case, the wind speed with altitude from 10 m (32 ft) up to 150 m (492 ft) is determined by:

\[ \bar{U}(z) = \bar{U}_{ref} \frac{\ln(z/0.3)}{4.11} \]

where \( \bar{U}(z) \) is the steady-state wind speed (m/s) at height \( z \) (m) and \( \bar{U}_{ref} \) is the design high steady-state wind speed (m/s) from Table 3.1.3-6. Inputs into the above equation must be in metric units (m/s and m).

### Table 3.1.3-4. Design High and Low Steady State Wind-Speed Profiles for use in Thermal Assessments with Time Constants Less Than an Hour

<table>
<thead>
<tr>
<th>Height</th>
<th>Steady State Wind-Speed Profile for Thermal Assessments (Component Time Constants Less Than an Hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Low</td>
</tr>
<tr>
<td>m</td>
<td>ft</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
</tr>
<tr>
<td>18.3</td>
<td>60</td>
</tr>
<tr>
<td>30</td>
<td>98</td>
</tr>
<tr>
<td>60</td>
<td>197</td>
</tr>
<tr>
<td>90</td>
<td>295</td>
</tr>
<tr>
<td>120</td>
<td>394</td>
</tr>
<tr>
<td>150</td>
<td>492</td>
</tr>
</tbody>
</table>
### Table 3.1.3-5. Design High and Low Steady State Wind-Speed Profiles for use in Thermal Assessments with Time Constants on the Order of Hours

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Steady State Wind-Speed Profile for Thermal Assessments (Component Time Constants on the Order of Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Low</td>
</tr>
<tr>
<td></td>
<td>m</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>18.3</td>
<td>0.8</td>
</tr>
<tr>
<td>30</td>
<td>0.8</td>
</tr>
<tr>
<td>60</td>
<td>0.8</td>
</tr>
<tr>
<td>90</td>
<td>0.8</td>
</tr>
<tr>
<td>120</td>
<td>0.8</td>
</tr>
<tr>
<td>150</td>
<td>0.8</td>
</tr>
</tbody>
</table>

### Table 3.1.3-6. Design High and Low Steady State Wind-Speed Profiles for use in Thermal Assessments with Time Constants on the Order of Days

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Steady State Wind-Speed Diurnal Profile for Thermal Assessments (Component Time Constants on the Order of Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Low</td>
</tr>
<tr>
<td></td>
<td>m/s</td>
</tr>
<tr>
<td>00:00</td>
<td>0.6</td>
</tr>
<tr>
<td>01:00</td>
<td>0.7</td>
</tr>
<tr>
<td>02:00</td>
<td>0.7</td>
</tr>
<tr>
<td>03:00</td>
<td>0.6</td>
</tr>
<tr>
<td>04:00</td>
<td>0.5</td>
</tr>
<tr>
<td>05:00</td>
<td>0.5</td>
</tr>
<tr>
<td>06:00</td>
<td>0.5</td>
</tr>
<tr>
<td>07:00</td>
<td>0.6</td>
</tr>
<tr>
<td>08:00</td>
<td>0.8</td>
</tr>
<tr>
<td>09:00</td>
<td>1.1</td>
</tr>
<tr>
<td>10:00</td>
<td>1.4</td>
</tr>
<tr>
<td>11:00</td>
<td>1.9</td>
</tr>
<tr>
<td>12:00</td>
<td>1.8</td>
</tr>
<tr>
<td>13:00</td>
<td>2.0</td>
</tr>
<tr>
<td>14:00</td>
<td>1.8</td>
</tr>
<tr>
<td>15:00</td>
<td>1.8</td>
</tr>
<tr>
<td>16:00</td>
<td>1.5</td>
</tr>
</tbody>
</table>
The design gust environment is characterized by either the spectral gust model or the discrete gust model. The spectral model produces fluctuations from all periods producing significant response of the vehicle. Spectral gusts are to be varied to identify the maximum system response.

The spectral gust environment at height $z$ consists of longitudinal, lateral, and vertical turbulence spectra. The turbulence components are applied to the steady state wind profiles given in Table 3.1.3-2. The longitudinal component of turbulence is parallel to the steady state wind vector with the lateral component in the horizontal plane and perpendicular to the longitudinal and vertical components. These components are given by:

$$S(f) = \left( \frac{1}{1 + c_2 \left( \frac{18.3}{z} \right)^{c_5} \left( \frac{f z}{U_z} \right)^{c_6}} \right)^{c_3}$$

where the values for the various non-dimensional constants $C_1, C_2, C_3, C_4, C_5,$ and $C_6$ given in Table 3.1.3-7 are a function of the turbulent components, $z$ is height in meters, $U_z$ is the steady state wind speed (m/s) at height $z$, and $U_{18.3}$ is the steady state wind speed (m/s) at 18.3 m. The quantity $S(f)$ is a spectral density function of frequency $f$ with units of $m^2 \ \text{sec}^{-2} \ \text{(cycles/sec)}^3$ and the units of $f$ are cycles/sec. The spectral density function is one-sided in the sense that the root mean square value of the corresponding time history is given by the integral of the function from $f = 0$ to $f = \infty$. Note that metric units (m/s and m) must be used in the above equation.

Table 3.1.3-7. Non-dimensional Constants for the Longitudinal, Lateral and Vertical Components of Turbulence

<table>
<thead>
<tr>
<th>Component</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>1.350</td>
<td>29.035</td>
<td>-1.10</td>
<td>1.972</td>
<td>1.00</td>
<td>0.845</td>
</tr>
<tr>
<td>Lateral and Vertical</td>
<td>0.258</td>
<td>9.059</td>
<td>-0.93</td>
<td>2.134</td>
<td>0.580</td>
<td>0.781</td>
</tr>
</tbody>
</table>
Coherence is a non-dimensional term that describes the similarity between two signals. It can vary between 0 (completely dissimilar) and 1 (identical other than a scaling factor and/or lag time). The coherence function associated with the spectral gust model is given by:

$$coh(f, z_1, z_2) = \exp \left[- \frac{0.693f}{k} \left( \frac{z_2}{\bar{u}(z_2)} - \frac{z_1}{\bar{u}(z_1)} \right) \right]$$

where $f$ is frequency (cycles/sec), $\bar{u}$ is the steady-state wind speed (m/sec) at heights $z_1$ and $z_2$, and $k$ is the non-dimensional constant given in Table 3.1.3-8. The coherence function will spatially correlate turbulent time series at heights $z_1$ and $z_2$.

<table>
<thead>
<tr>
<th>Component</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>0.036</td>
</tr>
<tr>
<td>Lateral and Vertical</td>
<td>0.045</td>
</tr>
</tbody>
</table>

The discrete model produces periods of gusts which are varied over the range of critical periods, and the gusts are applied individually. Discrete gusts are to be varied to identify the maximum system response. The discrete gust model has the 1-cosine shape defined by

$$V = \frac{V_m}{2} \left[1 - \cos \frac{2\pi t}{T} \right]$$

where $V$ is the gust magnitude at time $t$, $V_m$ is the maximum gust magnitude, and $T$ is the gust duration. The discrete gusts are applied to the steady state wind profiles given in Table 3.1.3-2. The total wind (steady state plus discrete gust) should not exceed the peak wind given in Table 3.1.3-1. A sufficiently wide range of values of $T$ should be selected to encompass the significant periods of response of the system.

For the various operational phases, the design wind shear is determined by subtracting the steady state wind (from Table 3.1.3-2) at the altitude corresponding to the base of the vehicle from the peak wind (from Table 3.1.3-1) at the altitude corresponding to the top of the vehicle, and then dividing the difference by the vehicle length. If the locations of the top and bottom of the vehicle are not available, use a design wind shear of 0.2 s⁻¹.

**Model Inputs**

The peak wind profile model requires a peak wind value at a reference height of 18.3 m (60.0 ft) as input. The steady state wind profile is determined from the peak wind profile.

For transport to and from the pad, use $u_{18.3} = 30.8$ m/s (101.1 ft/s) for construction of the maximum design limit peak wind-speed profile up to 150 m (492.1 ft).
For the on-pad stay (unfueled) phase, use $u_{18.3} = 38.3 \text{ m/s (125.7 ft/s)}$ for construction of the maximum design limit peak wind-speed profile up to 150 m (492.1 ft).

For the on-pad stay (intermediate and fully fueled) phase, use $u_{18.3} = 24.2 \text{ m/s (79.4 ft/s)}$ for construction of the maximum design limit peak wind-speed profile up to 150 m (492.1 ft).

Tables 3.1.3-1 and 3.1.3-2 list the peak and steady state wind-speed profiles, respectively, at selected heights for the above phases.

The design high steady state wind profiles for thermal assessments (Tables 3.1.3-4 and 3.1.3-5) are constructed by first determining the peak wind profile with $u_{18.3} = 17.7 \text{ m/s (58.1 ft/s)}$. This peak wind profile is then used to determine the steady state wind profile.

The steady state profiles are used as input for the spectral gust models.

**Limitations**

Input into model must be in m/s for wind speed and meters for height. All height levels are with respect to height Above Ground Level (AGL). According to SLS-SPEC-048, vehicle and mobile launcher coordinate system heights are relative to the North American Vertical Datum of 1988 (NAVD 88). The ground level surrounding the launch pad is approximately 4.88 m (16 ft) above the NAVD 88 datum. Engineering assessments requiring ground wind heights relative to the NAVD 88 datum must therefore increase heights by 4.88 m (16 ft). Heights in Tables 3.1.3-1, 3.1.3-2, 3.1.3-4, and 3.1.3-5 would be increased by 4.88 m (16 ft). Input height for all equations must be in height AGL. Once the wind is determined via the equations, the height can be increased by 4.88 m (16 ft).

**Technical Notes**

The modeled peak wind profile is the 3 sigma (99.865th percentile) peak wind-speed profile associated with the reference level peak wind speed. Ground winds during roll-out and on-pad stay can cause fatigue and reduce structural integrity. The peak wind-speed profile can be used to calculate vehicle on-pad base overturning moments and vortex shedding loads.

The steady state wind-speed profile is the 10-minute mean wind-speed profile that could produce the peak wind-speed profile.

The design limit for the transport to and from the pad of 30.8 m/s (101.1 ft/s) at the 18.3 m (60.0 ft) reference level is the limit used for the Space Shuttle Mobile Launch Platform (MLP) during transport operations (Space Shuttle Operations and Maintenance Requirements and Specifications Document, File II, Volume I, Rule S00L00.010, June 6, 2006). The local weather forecast should be utilized to assure that high wind events, such as thunderstorms or tropical weather, will not be present during transport operations.

The design limit for the unfueled case of 38.3 m/s (125.7 ft/s) at the 18.3 m (60.0 ft) reference level is the 99th percentile peak wind speed for a 180-day exposure period at KSC. This limit protects for extreme gusts from thunderstorms that may develop rapidly in the vicinity of the pad.
The design limit for the fueled case of 24.2 m/s (79.4 ft/s) at the 18.3 m (60.0 ft) reference level is the 99th percentile peak wind speed for a 1-day exposure period at KSC.

The design high steady-state wind speed profiles for thermal assessments in Tables 3.1.3-4 and 3.1.3-5 are the 95th percentile steady-state wind speed for a 1-hour exposure period at KSC. The design low steady-state wind speed profile in Table 3.1.3-5 is the 1st percentile steady-state wind speed for a 1-hour exposure period at KSC. The diurnal steady-state wind speed profile in Table 3.1.3-6 is the 1st percentile steady-state wind at each hour of the day at KSC.

### 3.1.4 Radiant (Thermal) Energy Environment for Ground Ops at KSC

**Description**

This section specifies the design radiant (thermal) energy environment and sky temperature limits for ground operations at KSC, including transportation to and from the pad and on-pad operations. “Storage” refers to on-pad or other outside storage only.

**Design Limits**

Tables 3.1.4-1 through 3.1.4-3 are the radiant energy design environments from the previous version of this document. Any previous design assessments based on these environments are still valid and re-assessments are not required. Radiant energy environments include direct incident, diffuse, and sky temperature. Section 3.1.5 provides the air temperature to be used in conjunction with the design environments in Tables 3.1.4-1 through 3.1.4-3.

Table 3.1.4-1 lists the design high radiant energy as a function of time of day.

Table 3.1.4-2 lists the design low radiant energy as a function of time of day.

Table 3.1.4-3 provides the design high and design low sky temperature design limits for KSC.

Tables 3.1.4-4 through 3.1.4-9 are provided for thermal assessments that require more fidelity of the radiant energy environment, specifically for conditions when the sky is clear, partly cloudy, or cloudy. A clear sky is defined as being completely free of clouds, partly cloudy is defined as having 40 to 60% cloud coverage, and cloudy is defined as 100% cloud coverage. Radiant energy environments include direct incident, diffuse, sky temperature, and air temperature. Air temperature is included in this section because the majority of thermal assessments require a coupling of direct incident, diffuse, sky temperature, air temperature, and other environments not provided here (albedo, etc.). The air temperature provided in this section is to be applied only when coupled to the direct incident, diffuse, and sky temperature environments. Design assessments that only require air temperature should use the environments provided in Section 3.1.5.

Table 3.1.4-4 presents design cold radiant energy and sky temperature environment for a cloudy sky.

Table 3.1.4-5 presents design hot radiant energy and sky temperature environment for a cloudy sky.
Table 3.1.4-6 presents design cold radiant energy and sky temperature environment for a partly cloudy sky.

Table 3.1.4-7 presents design hot radiant energy and sky temperature environment for a partly cloudy sky.

Table 3.1.4-8 presents design cold radiant energy and sky temperature environment for a clear sky.

Table 3.1.4-9 presents design hot radiant energy and sky temperature environment for a clear sky.

For thermal assessments requiring wind speed, use Section 3.1.3, Tables 3.1.3-4, 3.1.3-5, and/or 3.1.3-6, for the appropriate application.

**Model Inputs**

None

**Limitations**

None

<table>
<thead>
<tr>
<th>Time of Day (LST)</th>
<th>Direct Incident to a Plane Normal to the Sun</th>
<th>Diffuse to a Horizontal Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour (LST)</td>
<td>W/m²</td>
<td>BTU/hr/ft²</td>
</tr>
<tr>
<td>05:00</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>06:00</td>
<td>56</td>
<td>17.7</td>
</tr>
<tr>
<td>07:00</td>
<td>440</td>
<td>139.5</td>
</tr>
<tr>
<td>08:00</td>
<td>613</td>
<td>194.3</td>
</tr>
<tr>
<td>09:00</td>
<td>701</td>
<td>222.2</td>
</tr>
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<td>833</td>
<td>264.1</td>
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<td>11:00</td>
<td>823</td>
<td>260.9</td>
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<td>259.6</td>
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<td>16:00</td>
<td>766</td>
<td>242.8</td>
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<td>753</td>
<td>238.7</td>
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<td>621</td>
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<td>19:00</td>
<td>376</td>
<td>119.2</td>
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<td>20:00</td>
<td>20</td>
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<tr>
<td>21:00</td>
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</tbody>
</table>
Table 3.1.4-2. Design Low Radiant Energy as a Function of Time of Day

<table>
<thead>
<tr>
<th>Time of Day (LST)</th>
<th>Direct Incident to a Plane Normal to the Sun</th>
<th>Diffuse to a Horizontal Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>09:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>10:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>11:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>12:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>13:00</td>
<td>0 W/m²</td>
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<tr>
<td>14:00</td>
<td>0 W/m²</td>
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<tr>
<td>15:00</td>
<td>0 W/m²</td>
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<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>18:00</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
</tbody>
</table>

Table 3.1.4-3. Sky Temperature Design Limits for KSC

<table>
<thead>
<tr>
<th>Sky Temperature</th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design High</td>
<td>10.0</td>
<td>50</td>
</tr>
<tr>
<td>Design Low</td>
<td>-15.0</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3.1.4-4. Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky

<table>
<thead>
<tr>
<th>Time of Day (LST)</th>
<th>Air Temperature</th>
<th>Sky Temperature</th>
<th>Direct Incident*</th>
<th>Diffuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>12.4</td>
<td>12.4</td>
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<td>0 W/m²</td>
</tr>
<tr>
<td>01:00</td>
<td>12.8</td>
<td>12.8</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>02:00</td>
<td>13.1</td>
<td>13.1</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>03:00</td>
<td>13.3</td>
<td>13.3</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>04:00</td>
<td>13.6</td>
<td>13.6</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>05:00</td>
<td>13.9</td>
<td>13.9</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>06:00</td>
<td>14.2</td>
<td>14.2</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>07:00</td>
<td>14.4</td>
<td>14.4</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
<tr>
<td>08:00</td>
<td>14.9</td>
<td>14.9</td>
<td>0 W/m²</td>
<td>0 W/m²</td>
</tr>
</tbody>
</table>
### Table 3.1.4-5. Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky

<table>
<thead>
<tr>
<th>Time of Day (LST)</th>
<th>Air Temperature °C</th>
<th>°F</th>
<th>Sky Temperature °C</th>
<th>°F</th>
<th>Direct Incident* W/m²</th>
<th>BTU/hr/ft²</th>
<th>Diffuse W/m²</th>
<th>BTU/hr/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>24.1</td>
<td>75.4</td>
<td>24.1</td>
<td>75.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>01:00</td>
<td>24.1</td>
<td>75.5</td>
<td>24.1</td>
<td>75.5</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>23.9</td>
<td>75.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>03:00</td>
<td>24.0</td>
<td>75.2</td>
<td>24.0</td>
<td>75.2</td>
<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
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<td>24.1</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>05:00</td>
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<td>24.0</td>
<td>75.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>06:00</td>
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<td>23.9</td>
<td>74.9</td>
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* Direct Incident is to a plane normal to the sun vector.
### Hot, Cloudy Conditions

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* Direct Incident is to a plane normal to the sun vector.

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### Cold, Partly Cloudy Conditions

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* Direct Incident is to a plane normal to the sun vector.

### Table 3.1.4-7. Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Partly Cloudy Sky

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## Hot, Partly Cloudy Conditions

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* Direct Incident is to a plane normal to the sun vector.


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* Direct Incident is to a plane normal to the sun vector.
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<th>Direct Incident*</th>
<th>Diffuse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°F</td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>10:00</td>
<td>23.9</td>
<td>75.0</td>
<td>7.9</td>
<td>46.3</td>
</tr>
<tr>
<td>11:00</td>
<td>24.5</td>
<td>76.1</td>
<td>8.6</td>
<td>47.5</td>
</tr>
<tr>
<td>12:00</td>
<td>25.0</td>
<td>77.1</td>
<td>8.8</td>
<td>47.8</td>
</tr>
<tr>
<td>13:00</td>
<td>24.5</td>
<td>76.1</td>
<td>8.1</td>
<td>46.6</td>
</tr>
<tr>
<td>14:00</td>
<td>24.1</td>
<td>75.3</td>
<td>7.7</td>
<td>45.9</td>
</tr>
<tr>
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<td>23.4</td>
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<td>7.3</td>
<td>45.2</td>
</tr>
<tr>
<td>16:00</td>
<td>22.5</td>
<td>72.4</td>
<td>6.6</td>
<td>43.8</td>
</tr>
<tr>
<td>17:00</td>
<td>20.6</td>
<td>69.0</td>
<td>5.5</td>
<td>41.9</td>
</tr>
<tr>
<td>18:00</td>
<td>19.2</td>
<td>66.5</td>
<td>3.6</td>
<td>38.5</td>
</tr>
<tr>
<td>19:00</td>
<td>18.7</td>
<td>65.7</td>
<td>3.3</td>
<td>37.9</td>
</tr>
<tr>
<td>20:00</td>
<td>18.3</td>
<td>65.0</td>
<td>2.7</td>
<td>36.9</td>
</tr>
<tr>
<td>21:00</td>
<td>17.9</td>
<td>64.2</td>
<td>2.5</td>
<td>36.4</td>
</tr>
<tr>
<td>22:00</td>
<td>17.5</td>
<td>63.4</td>
<td>2.0</td>
<td>35.6</td>
</tr>
<tr>
<td>23:00</td>
<td>17.4</td>
<td>63.4</td>
<td>1.9</td>
<td>35.5</td>
</tr>
</tbody>
</table>

* Direct Incident is to a plane normal to the sun vector.

**Technical Notes**

Direct incident is the solar radiant energy to a plane normal to the sun vector. The actual radiant energy absorbed by a surface would be a function of the surface optical properties and the surface geometry relative to the Sun vector. Diffuse radiant energy represents the accumulation on a horizontal surface of the scattered solar radiant energy from all directions, not including the direct incident. Sky temperature represents the temperature of the sky assuming it is radiating as a blackbody.

**Tables 3.1.4-1 through 3.1.4-3**

The design high radiant energy presents clear day direct incident radiant energy to a plane normal to the Sun and diffuse radiant energy to a horizontal plane. The actual radiant energy absorbed by a surface would be a function of the surface optical properties and the surface geometry relative to the Sun vector. The design high is based on extreme high values for the month of June. Diffuse values are those associated with the extreme direct incident values. The design low radiant energy presents cloudy day diffuse radiant energy that would apply to all surfaces. The design low is based on extreme low values for the month of December. These data should be used in conjunction with the sky temperature.
Tables 3.1.4-4 through 3.1.4-9

Design limits are developed from the National Solar Radiation Database (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2010/) for the Shuttle Landing Facility, KSC. Cold and hot diurnal profiles are the average of the 10 coldest and warmest days for the given sky conditions (cloudy, partly cloudy, and clear). Since surface air temperature, direct incident radiant energy, diffuse radiant energy, and sky temperature are coupled and depend on sky conditions, it is recommended that each case be used as input into thermal models to determine the worst case.

3.1.5 Air Temperature Environment for Ground Operations at KSC

Description

This section specifies the design maximum and minimum surface air temperature, design hot and cold diurnal profiles, and design hot and cold monthly averaged diurnal profiles for ground operations at KSC, including transportation to and from the pad and on-pad operations.

Design Limits

Maximum: 38.0 °C (100.4 °F)

Minimum: -6.0 °C (21.2 °F)

Table 3.1.5-1 provides the design hot and cold diurnal temperature profiles for KSC.

Table 3.1.5-2 provides the design hot and cold monthly averaged diurnal temperature profiles for KSC.

Table 3.1.5-1. Design Hot and Cold Diurnal Temperature Profile

<table>
<thead>
<tr>
<th>Time of Day Hour</th>
<th>Design Hot Diurnal Profile</th>
<th>Design Cold Diurnal Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LST</td>
<td>°C</td>
</tr>
<tr>
<td>00:00</td>
<td>00:00</td>
<td>28.0</td>
</tr>
<tr>
<td>01:00</td>
<td>01:00</td>
<td>27.0</td>
</tr>
<tr>
<td>02:00</td>
<td>02:00</td>
<td>27.0</td>
</tr>
<tr>
<td>03:00</td>
<td>03:00</td>
<td>27.0</td>
</tr>
<tr>
<td>04:00</td>
<td>04:00</td>
<td>27.0</td>
</tr>
<tr>
<td>05:00</td>
<td>05:00</td>
<td>26.0</td>
</tr>
<tr>
<td>06:00</td>
<td>06:00</td>
<td>27.0</td>
</tr>
<tr>
<td>07:00</td>
<td>07:00</td>
<td>28.0</td>
</tr>
<tr>
<td>08:00</td>
<td>08:00</td>
<td>30.0</td>
</tr>
<tr>
<td>09:00</td>
<td>09:00</td>
<td>32.0</td>
</tr>
<tr>
<td>10:00</td>
<td>10:00</td>
<td>33.0</td>
</tr>
<tr>
<td>11:00</td>
<td>11:00</td>
<td>34.0</td>
</tr>
</tbody>
</table>
### Table 3.1.5-2. Design Hot and Cold Monthly Averaged Diurnal Temperature Profile

<table>
<thead>
<tr>
<th>Time of Day Hour</th>
<th>Design Hot Monthly Averaged Diurnal Profile</th>
<th>Design Cold Monthly Averaged Diurnal Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>LST</td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>00:00</td>
<td>26.2</td>
<td>79.2</td>
</tr>
<tr>
<td>01:00</td>
<td>26.0</td>
<td>78.8</td>
</tr>
<tr>
<td>02:00</td>
<td>25.9</td>
<td>78.6</td>
</tr>
<tr>
<td>03:00</td>
<td>25.6</td>
<td>78.1</td>
</tr>
<tr>
<td>04:00</td>
<td>25.3</td>
<td>77.5</td>
</tr>
<tr>
<td>05:00</td>
<td>25.2</td>
<td>77.4</td>
</tr>
<tr>
<td>06:00</td>
<td>25.1</td>
<td>77.2</td>
</tr>
<tr>
<td>07:00</td>
<td>26.0</td>
<td>80.4</td>
</tr>
<tr>
<td>08:00</td>
<td>26.9</td>
<td>80.4</td>
</tr>
<tr>
<td>09:00</td>
<td>28.8</td>
<td>83.8</td>
</tr>
<tr>
<td>10:00</td>
<td>30.0</td>
<td>86.0</td>
</tr>
<tr>
<td>11:00</td>
<td>31.3</td>
<td>88.3</td>
</tr>
<tr>
<td>12:00</td>
<td>32.2</td>
<td>90.0</td>
</tr>
<tr>
<td>13:00</td>
<td>32.6</td>
<td>90.7</td>
</tr>
<tr>
<td>14:00</td>
<td>32.8</td>
<td>91.0</td>
</tr>
<tr>
<td>15:00</td>
<td>32.1</td>
<td>89.8</td>
</tr>
</tbody>
</table>
### Time of Day

<table>
<thead>
<tr>
<th>LST</th>
<th>Design Hot Monthly Averaged Diurnal Profile</th>
<th>Design Cold Monthly Averaged Diurnal Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:00</td>
<td>31.5 °C, 88.3 °F</td>
<td>14.2 °C, 57.6 °F</td>
</tr>
<tr>
<td>17:00</td>
<td>30.6 °C, 87.1 °F</td>
<td>13.5 °C, 56.3 °F</td>
</tr>
<tr>
<td>18:00</td>
<td>29.8 °C, 85.6 °F</td>
<td>11.9 °C, 53.4 °F</td>
</tr>
<tr>
<td>19:00</td>
<td>28.6 °C, 83.5 °F</td>
<td>10.7 °C, 51.3 °F</td>
</tr>
<tr>
<td>20:00</td>
<td>27.5 °C, 81.5 °F</td>
<td>9.9 °C, 49.8 °F</td>
</tr>
<tr>
<td>21:00</td>
<td>27.0 °C, 80.6 °F</td>
<td>9.5 °C, 49.1 °F</td>
</tr>
<tr>
<td>22:00</td>
<td>26.7 °C, 80.1 °F</td>
<td>8.9 °C, 48.0 °F</td>
</tr>
<tr>
<td>23:00</td>
<td>26.5 °C, 79.7 °F</td>
<td>8.7 °C, 47.7 °F</td>
</tr>
</tbody>
</table>

#### Model Inputs

None

#### Limitations

The design maximum and minimum limits are appropriate for thermal assessments with short durations (no more than 3 hours). The design hot and cold diurnal profiles are appropriate for assessments with a duration on the order of days (Table 3.1.5-1). The design hot and cold monthly averaged diurnal profiles are appropriate for thermal assessments on the order of a month, for example, determination of Propellant Mean Bulk Temperature (PMBT).

#### Technical Notes

Temperature data for KSC were obtained from hourly surface observations for the period of record (POR) 1957-2001. Design limits represent the maximum and minimum air temperature over the POR. Design hot and cold diurnal profiles are the 99<sup>th</sup> percentile temperatures for each hour in the hot month (July) and cold month (January), respectively. Design hot and cold monthly averaged diurnal profiles are the 99<sup>th</sup> and 1<sup>st</sup> percentile monthly averaged temperatures for each hour in the hot month (July) and cold month (January), respectively.

Atmospheric temperature is used for defining the thermal conditions acting on the vehicle. Icing on fueled cryogenic tanks can occur due to exposure to ambient air temperatures. Once fuel tank loading has been initiated, the temperature of the air surrounding the other vehicle elements may be affected by chilling from the cold surfaces of the fuel tank and from the main engine drain purges and can be colder than the air temperature.
3.1.6 Air Pressure Environment for Ground Operations at KSC

Description
This section specifies the design maximum and minimum sea-level air pressure for ground operations at KSC, including transportation to and from the pad and on-pad operations.

Design Limits
Maximum: 1,037.4 hectoPascals (hPa) (15.1 pounds per square inch (psi)) at sea level
Minimum: 973.9 hPa (14.1 psi) at sea level

Altitude correction may be necessary for sensitive applications. The total variation of pressure from day to day is relatively small. A gradual rise or fall in pressure of 3.0 hPa (0.04 psi) and then a return to original pressure can be expected within a 24-hour period. Typically, a maximum pressure change of 6.0 hPa (0.09 psi) can be expected within a 1-hour period. [100 Pascals = 1 hPa = 1 millibar (mbar) = 0.01450377 psi]

Model Inputs
None

Limitations
Design limits represent the air pressure at a reference level specified by sea level. The design limit, along with temperature and humidity information, can be used to derive air pressure at other desired altitudes.

Technical Notes
Design limits represent the maximum and minimum sea-level air pressure from hourly surface observations at the ER for the POR 1957-2002.

Testing for critical systems may involve pressures higher than those listed in this document. Refer to the appropriate test and verification plan for specific systems.

3.1.7 Humidity Environment for Ground Operations at KSC

Description
This section specifies the design environment of surface humidity for ground operations at KSC, including transportation to and from the pad and on-pad operations.

Design Limits
Design Limits for Surface Dew Point:

Figure 3.1.7-1 contains a graphical depiction of the psychrometric data for the dew point temperature versus temperature envelope for KSC.
Psychrometric data for the dew point temperature versus temperature envelope for KSC are contained in Table 3.1.7-1.

Figure 3.1.7-1. Psychrometric Data, Dew Point Temperature Versus Temperature Envelope for KSC

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Dew Point (°C)</th>
<th>Temperature (°F)</th>
<th>Dew Point (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.0</td>
<td>24.8</td>
<td>-14.0</td>
<td>6.8</td>
</tr>
<tr>
<td>-4.0</td>
<td>24.8</td>
<td>-4.0</td>
<td>24.8</td>
</tr>
<tr>
<td>28.0</td>
<td>82.4</td>
<td>28.0</td>
<td>82.4</td>
</tr>
<tr>
<td>36.0</td>
<td>96.8</td>
<td>28.0</td>
<td>82.4</td>
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<tr>
<td>40.0</td>
<td>104.0</td>
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<td>59.0</td>
</tr>
<tr>
<td>11.0</td>
<td>51.8</td>
<td>-14.0</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Model Inputs
None

Limitations
None
Technical Notes

Atmospheric humidity is used for defining the thermal and dry/moist conditions acting on the vehicle. The surface psychrometric data are based on hourly surface observations for the ER from 1957 to 2002. Figure 3.1.7-1 shows the limits in Table 3.1.7-1. The range of dew point temperatures and associated air temperatures from Table 3.1.7-1 represents the worst case environment to be used in design studies. Values chosen between these limits must be within the envelope in Figure 3.1.7-1.

3.1.8 Aerosol Environment for Ground Operations at KSC

Description

This section specifies the aerosol environment for ground operations at KSC, including transportation to and from the pad and on-pad operations. The natural environment in the launch area is conducive to sea salt, sand, and dust.

Design Limits

Methods for testing of materials for salt fog and sand/dust are given in MIL-STD-810G, Test Method Standard for Environmental Engineering Considerations and Laboratory Tests. The testing of materials for effects of salt fog exposure is described in Method 509.6. The testing of materials for effects of sand/dust exposure is described in Method 510.6, Procedure 1, for particle sizes less than or equal to 150 microns. The particle concentration to be used with Method 510.6, Procedure 1, is 0.177 g/m$^3$ as specified in Part 3, Section 5.7 of MIL-STD-810G.

Limitations

The aerosol environment for the launch site is poorly defined. The test methods in MIL-STD-810G do not attempt to duplicate the complex environment. They provide generally stressful situations that may reveal potential problem areas in material. Testing in the natural environment, whenever practical, may provide more valuable results.

Technical Notes

Due to the launch site being in a coastal region, systems and material will be exposed to salt fog and suspended sand/dust. The detrimental effects of these aerosols include material corrosion and clogging/binding of moving parts of mechanical components.
3.1.9 Precipitation Environment for Ground Operations at KSC

This section specifies the precipitation environment (rain and hail) for ground operations at KSC, including transportation to and from the pad, on-pad operations, and on-pad or outside storage.

Design Limits

Tables 3.1.9-1 and 3.1.9-2 list the design rainfall and hail characteristics at KSC. Steady state and peak winds given in Section 3.1.3, Ground Winds for Transport and Launch Pad Environments, will be used for studies that require coupling of hail and/or rainfall with wind.

Table 3.1.9-1. Design Rainfall, KSC, Based on Yearly Largest Rate for Stated Durations

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Rainfall Rate</th>
<th>Rainfall Total Accumulation</th>
<th>Raindrop Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm/hr</td>
<td>in/hr</td>
<td>mm</td>
</tr>
<tr>
<td>1 min</td>
<td>492</td>
<td>19.4</td>
<td>8.0</td>
</tr>
<tr>
<td>5 min</td>
<td>220</td>
<td>8.7</td>
<td>18</td>
</tr>
<tr>
<td>15 min</td>
<td>127</td>
<td>5.0</td>
<td>32</td>
</tr>
<tr>
<td>1 hr</td>
<td>64</td>
<td>2.5</td>
<td>64</td>
</tr>
<tr>
<td>6 hr</td>
<td>26</td>
<td>1.0</td>
<td>156</td>
</tr>
<tr>
<td>12 hr</td>
<td>18</td>
<td>0.7</td>
<td>220</td>
</tr>
<tr>
<td>24 hr</td>
<td>13</td>
<td>0.5</td>
<td>311</td>
</tr>
</tbody>
</table>

Table 3.1.9-2. Design Hail Characteristics for KSC

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hailstone Diameter Size</td>
<td>2.2 cm (0.87 in)</td>
</tr>
<tr>
<td>Terminal Velocity</td>
<td>17.0 m/s (55.8 ft/s)</td>
</tr>
<tr>
<td>Number of Hailstones per Hail Fall</td>
<td>260 m² (24 ft²)</td>
</tr>
<tr>
<td>Duration of Hail Fall</td>
<td>5 min</td>
</tr>
<tr>
<td>Horizontal Velocity</td>
<td>15.0 m/s (49.2 ft/s)</td>
</tr>
<tr>
<td>Density of Hailstone</td>
<td>0.9 g/cm³ (0.03 lb/in³)</td>
</tr>
</tbody>
</table>

Model Inputs

None

Limitations

The rainfall amounts should not be interpreted to mean that the rain fell uniformly for the entire referenced time periods. The average terminal velocity for raindrops is 6.5 m/s for all time periods.
Technical Notes

Hailstone diameter size and horizontal velocity in Table 3.1.9-2 are the 5% risk values based on hail fall studies conducted in Illinois (Changnon, 1977).

### 3.1.10 Flora and Fauna Environment for Ground Operations

**Description**

This section specifies the flora and fauna environment for ground operations at KSC, including transportation to and from the launch pad and on-pad operations.

**Design Limits**

The natural environment in the launch area is conducive to fungus growth. The specific environment is dependent upon material selection. Wildlife and insects in the KSC area include, but are not limited to birds (woodpeckers, buzzards), rodents (mice, rats), insects (bees, cockroaches), wild boar, and alligators.

**Model Inputs**

None

**Limitations**

None

**Technical Notes**

Currently, design specification addresses only fungus growth and common pests. Additional work is required to address other flora and fauna. Consideration may be given to addressing flora and fauna, operationally. Methods for testing of materials for fungus growth are given in MIL-STD-810G, Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, Method 508.

### 3.1.11 Lightning Environment for Ground Operations at KSC

**Description**

This section specifies the lightning environment for ground operations at KSC, including transportation to and from the launch pad and stationary storage of the vehicle on the launch pad. Design specifications include standardized voltage and current waveforms derived or characterized to represent the lightning environment at specific zones established on the vehicle.

**Design Limits**

The environment in the launch area is such that systems will be exposed to the direct and indirect effects of lightning. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, Aircraft Lightning Zones, and must be defined and
evaluated for each applicable vehicle configuration. SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms is an applicable document.

**Model Inputs**

Vehicle lightning strike zones are defined for each configuration of the vehicle and ground support equipment.

**Limitations**

Waveforms used for analysis are selected based on vehicle attachment profile and electromagnetic regions.

The most important characteristics of the standard lightning waveforms used for analysis and test are the peak current, continuing current, peak rate of rise, and the action integral, or coulomb content, of the waveform. Secondary characteristics of significance are the time to peak, and the time to fall to 50% of the peak. Peak current and continuing current levels are important for direct attachment assessment. The action integral is the amount of energy contained in the flash event and is most important for determining damage related to direct attachment effects. Rise and fall times are important for indirect effects assessment and analysis.

**Technical Notes**

None

3.2 Launch Countdown and Earth Ascent Phases

3.2.1 Ground Winds Environments During Launch

**Description**

This section specifies ground wind environments (altitude range 0 to 270 m (886 ft) AGL), up to and including the maximum design limits, for vehicle launch at KSC. Design specifications include peak wind-speed profile, steady state wind-speed profile, and spectral gust environment.

**Design Limits**

Table 3.2.1-1 provides the design peak wind profiles for the vehicle launch phase. The design steady state wind profiles associated with the design peak wind profiles are provided in Table 3.2.1-2. The steady state wind profile is that profile that could produce the instantaneous peak winds (gusts) in Table 3.2.1-1. Peak wind profile values between those altitudes given in Tables 3.2.1-1 are determined by:

\[ u(z) = u_{18.3} \left( \frac{z}{18.3} \right)^{1.6} \left( u_{18.3} \right)^{-3/4} \]

where \( u(z) \) is the peak wind (m/s) at height \( z \) (m) and \( u_{18.3} \) is the peak wind speed (m/s) at 18.3 m. Steady state profile values between those altitudes given in Table 3.2.1-2 are determined by:
\[
\bar{U}(z) = u(z) \left( 1 + \left( \frac{18.3}{z} \left( \frac{0.283 - 0.435e^{-0.2u_{18.3}}}{1.98 - 1.887e^{-0.2u_{18.3}}} \right) \right)^{-1} \right)
\]

where \( u(z) \) is the peak wind (m/s) at height \( z \) (m) and \( u_{18.3} \) is the peak wind (m/s) at 18.3 m. Note that metric units (m/s and m) must be used in the above two equations. Once \( u(z) \) and \( \bar{U}(z) \) are determined, they can be converted to English units (ft/s).

**Table 3.2.1-1. Peak Wind Speed Profile for Vehicle Launch**

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Peak Wind-Speed Profile for Vehicle Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/s</td>
</tr>
<tr>
<td>10</td>
<td>15.8</td>
</tr>
<tr>
<td>18.3</td>
<td>17.7</td>
</tr>
<tr>
<td>30</td>
<td>19.4</td>
</tr>
<tr>
<td>60</td>
<td>22.1</td>
</tr>
<tr>
<td>90</td>
<td>23.8</td>
</tr>
<tr>
<td>120</td>
<td>25.1</td>
</tr>
<tr>
<td>150</td>
<td>26.1</td>
</tr>
<tr>
<td>180</td>
<td>27.0</td>
</tr>
<tr>
<td>210</td>
<td>27.8</td>
</tr>
<tr>
<td>240</td>
<td>28.5</td>
</tr>
<tr>
<td>270</td>
<td>29.1</td>
</tr>
</tbody>
</table>

**Table 3.2.1-2. Steady State Wind Speed Profile for Vehicle Launch**

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Steady State Wind-Speed Profile for Vehicle Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/s</td>
</tr>
<tr>
<td>10</td>
<td>9.8</td>
</tr>
<tr>
<td>18.3</td>
<td>11.7</td>
</tr>
<tr>
<td>30</td>
<td>13.3</td>
</tr>
<tr>
<td>60</td>
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<tr>
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<td>150</td>
<td>20.2</td>
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<tr>
<td>180</td>
<td>21.1</td>
</tr>
</tbody>
</table>
The design gust environment is characterized by either the spectral gust model or the discrete gust model. The spectral model produces fluctuations from all periods producing significant response of the vehicle. Spectral gusts are to be varied to identify the maximum system response. The spectral gust environment at height \( z \) consists of longitudinal, lateral, and vertical turbulence spectra. The turbulence components are applied to the steady state wind profiles given in Table 3.2.1-2. The longitudinal component of turbulence is parallel to the steady state wind vector with the lateral component in the horizontal plane and perpendicular to the longitudinal and vertical components. These components are given by:

\[
S(f) = \frac{C_1 \left( \frac{z}{18.3} \right)^{C_3} z \left( \frac{U_{18.3}^2}{U_z} \right)}{1 + C_2 \left( \frac{18.3}{z} \right)^{C_5} \left( \frac{f z}{U_z} \right)^{C_6}}^{C_4}
\]

where the values for the various non-dimensional constants \( C_1, C_2, C_3, C_4, C_5, \) and \( C_6 \) given in Table 3.2.1-3 are a function of the turbulent components, \( z \) is height in meters, \( U_z \) is the steady state wind speed (m/s) at height \( z \), and \( U_{18.3} \) is the steady state wind speed (m/s) at 18.3 m. The quantity \( S(f) \) is a spectral density function of frequency \( f \) with units of m\(^2\) sec\(^{-2}\) (cycles/sec)\(^{-1}\) and the units of \( f \) are cycles/sec. The spectral density function is one-sided in the sense that the root mean square value of the corresponding time history is given by the integral of the function from \( f = 0 \) to \( f = \infty \). Note that metric units (m/s and m) must be used in the above equation.

### Table 3.2.1-3. Non-dimensional Constants for the Longitudinal, Lateral and Vertical Components of Turbulence

<table>
<thead>
<tr>
<th>Component</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>( C_4 )</th>
<th>( C_5 )</th>
<th>( C_6 )</th>
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</thead>
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<td>Longitudinal</td>
<td>1.350</td>
<td>29.035</td>
<td>-1.10</td>
<td>1.972</td>
<td>1.00</td>
<td>0.845</td>
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<tr>
<td>Lateral and Vertical</td>
<td>0.258</td>
<td>9.059</td>
<td>-0.93</td>
<td>2.134</td>
<td>0.580</td>
<td>0.781</td>
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</table>

Coherence is a non-dimensional term that describes the similarity between two signals. It can vary between 0 (completely dissimilar) and 1 (identical other than a scaling factor and/or lag time). The coherence function associated with the spectral gust model is given by:
The coherence function will spatially correlate turbulent time series at heights \( z_1 \) and \( z_2 \).

### Table 3.2.1-4. Non-dimensional Constant for the Coherence Function

<table>
<thead>
<tr>
<th>Component</th>
<th>( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
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<tr>
<td>Lateral and Vertical</td>
<td>0.045</td>
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</tbody>
</table>

The discrete model produces periods of gusts which are varied over the range of critical periods, and the gusts are applied individually. Discrete gusts are to be varied to identify the maximum system response. The discrete gust model has the 1-cosine shape defined by

\[
V = \frac{V_m}{2} \left[ 1 - \cos \frac{2\pi t}{T} \right]
\]

where \( V \) is the gust magnitude at time \( t \), \( V_m \) is the maximum gust magnitude, and \( T \) is the gust duration. The discrete gusts are applied to the steady state wind profiles given in Table 3.2.1-2. The total wind (steady state plus discrete gust) should not exceed the peak wind given in Table 3.2.1-1. A sufficiently wide range of values of \( T \) should be selected to encompass the significant periods of response of the system.

The design launch wind shear is determined by subtracting the steady state wind (from Table 3.2.1-2) at the altitude corresponding to the base of the vehicle from the peak wind (from Table 3.2.1-1) at the altitude corresponding to the top of the vehicle, and then dividing the difference by the vehicle length. If the locations of the top and bottom of the vehicle are not available, use a design wind shear of 0.2 s\(^{-1}\).

### Model Inputs

The peak wind profile model requires a peak wind value at a reference height of 18.3 m (60 ft) as input. For vehicle launch, use \( u_{18.3} = 17.7 \) m/s (58.1 ft/s) for construction of the maximum design limit wind-speed profile up to 270 m (886 ft) AGL.

The steady state wind profile is determined from the peak wind profile, and is used as input for the spectral gust model.

### Limitations

Input into model must be in m/s for wind speed and meters for height. All height levels are with respect to height Above Ground Level (AGL). According to SLS-SPEC-048, vehicle and mobile
launcher coordinate system heights are relative to the North American Vertical Datum of 1988 (NAVD 88). The ground level surrounding the launch pad is approximately 4.88 m (16 ft) above the NAVD 88 datum. Engineering assessments requiring ground wind heights relative to the NAVD 88 datum must therefore increase heights by 4.88 m (16 ft). Heights in Tables 3.2.1-1 and 3.2.1-2 would be increased by 4.88 m (16 ft). Input height for all equations must be in height AGL. Once the wind is determined via the equations, the height can be increased by 4.88 m (16 ft).

Technical Notes

The design limit for vehicle launch of 17.7 m/s (58.1 ft/s) at the 18.3 m (60 ft) reference level is the 99th percentile peak wind speed for the windiest hour of the windiest month based on hourly surface observations for the ER from 1957 to 2001. The modeled profile is the 3 sigma (99.865th percentile) peak wind-speed profile associated with the reference level peak wind speed. Ground winds during launch must be considered to assure tower clearance on lift-off. The peak wind-speed profile can be used to calculate vehicle on-pad base overturning moments and vortex shedding loads.

3.2.2 Surface Air Temperature Environment During Launch

Description

This section specifies the design maximum and minimum surface air temperature for vehicle launch at KSC.

Design Limits

Maximum: 37.2 °C (99.0 °F)

Minimum: 0.6 °C (33.1 °F)

Model Inputs

None

Limitations

For thermal assessments involving wind effects, winds must be assumed to be steady state from any direction, with horizontal speeds in the design range given in Table 3.2.1-2.

Technical Notes

Design limits represent the range of temperatures as described in NSTS 07700, Vol. X, Book 2, Space Shuttle Flight and Ground System Specification-Environment Design, Weight and Performance, and Avionics Events, Appendix 10.10, Section 11.1.4.2. These limits are also defined in NSTS 16007, Space Shuttle Launch Commit Criteria (LCC) and Background, Section 4, Weather Rules. The rationale for choosing this design range for launch is that redesign, retesting, recertification, etc., of legacy hardware would not be necessary.
3.2.3 Surface Air Pressure Environment During Launch

Description
This section specifies the design maximum and minimum sea-level air pressure for vehicle launch at KSC.

Design Limits

Maximum: 1,037.4 hPa (15.1 psi) at sea level

Minimum: 973.9 hPa (14.1 psi) at sea level

[100 Pa = 1 hPa = 1 millibar (mb) = 0.01450377 pound/in² (psi)]

Model Inputs
None

Limitations
Design limits represent the air pressure at a reference level specified by sea level. The design limit, along with temperature and humidity information, can be used to derive air pressure at other desired altitudes.

Technical Notes
Design limits represent the maximum and minimum sea-level air pressure from hourly surface observations at the ER for the POR 1957-2002. Air pressure can affect tank pressures and vent size selections.

3.2.4 Surface Humidity Environment During Launch

Description
This section specifies the design environment of surface humidity for vehicle launch at KSC.

Design Limits
See Design Limits for Section 3.1.7, Humidity Environment for Ground Operations at KSC.

Model Inputs
None

Limitations
None

Technical Notes
See technical notes for Section 3.1.7.
3.2.5 Aloft Wind Environment for Vehicle Ascent

Description

This section specifies aloft wind environments and dispersions (altitude range 0 to 90 kilometers (km) (295,276 ft)) for vehicle ascent at KSC.

Design Limits

System performance will be evaluated through the use of the following wind databases, which can be used individually or by combination of any of the three. The following models/databases can be obtained by contacting the MSFC Natural Environments Branch (MSFC organization code: EV44).

1) Earth-GRAM 2010: Monte Carlo analysis of 1,000 or more Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) random profiles per month. Each profile is for a 0 to 90 km (295,276 ft) altitude range with Earth-GRAM 2010 inputs per Table 3.2.5-1. Atmospheric wind, temperature, pressure, and density should be evaluated simultaneously in each simulation. Earth-GRAM 2010 can be used up to the desired altitude.

2) Monthly Vector Wind Profile Model (MVWPM): For the altitude range of 0 to 27 km (88,583 ft), use the 99th percentile monthly and conditional wind vector ellipses from the MVWPM. For the altitude range of 28 to 90 km (91,864 to 295,276 ft), monthly mean wind profiles from Earth-GRAM 2010 will be appended to the MVWPM profiles. Appending of profiles will be accomplished by linear interpolation from the top of the MVWPM (at 27 km (88,583 ft)) to the Earth-GRAM 2010 monthly mean profile at 35 km. The Earth-GRAM 2010 monthly mean profile will be used above 35 km (114,829 ft). Table 3.2.5-2 lists the Earth-GRAM 2010 inputs to generate the monthly mean profile which will be appended to MVWPM profiles.

3) Measured Wind Databases (KSC Jimsphere Wind Profile Database and KSC Doppler Radar Wind Profiler Database): The KSC measured wind databases provide wind dispersions for a 200 m to 18 km (656 to 59,055 ft) altitude range. If wind data are needed below 200 m (656 ft), the higher fidelity option is to use KSC 150-m Wind Tower data. If higher fidelity is not needed, then it is recommended the wind be linearly ramped from zero at the surface to the value of the first measured wind. If ramping is done, the wind direction in the surface to 200 m (656 ft) altitude range should be held constant and equal to the value of the first measured wind direction. For the altitude range of 19 to 90 km (62,336 to 295,276 ft), monthly mean wind profiles from Earth-GRAM 2010 will be appended to the measured wind profiles. Appending of profiles will be accomplished by linear interpolation from the top of the measured wind (at 18 km (59,055 ft)) to the Earth-GRAM 2010 monthly mean profile at 26 km (85,302 ft). The Earth-GRAM 2010 monthly mean profile will be used above 26 km (85,302 ft). Table 3.2.5-2 lists the Earth-GRAM 2010 inputs to generate the monthly mean profile that will be appended to measured wind profiles.

This design limit also applies to any Launch Abort System (LAS) analyses.
The design gust environment for aloft winds is characterized by either the continuous gust model or the discrete gust model. The continuous gust model is developed from the KSC Jimsphere Wind Profile Database and consists of profiles of high-passed filtered U (east/west) and V (north/south) wind components. The profiles contain wind features ranging from the Nyquist wavelength (2 times the Jimsphere sampling interval) to the filter cutoff wavelength, which is determined based on engineering needs (for example, assessing non-persistent wind features on day of launch). The continuous gust profiles can be obtained by contacting the MSFC Natural Environments Branch (MSFC organization code: EV44).

Discrete gusts that produce the desired vehicle response will be individually applied to the wind profiles. The discrete gust model has the 1-cosine shape defined by

\[ V = \frac{V_m}{2} \left( 1 - \cos \left( \frac{\pi d}{d_m} \right) \right), \quad 0 \leq d \leq 2d_m \]

\[ V = 0, \quad d < 0 \text{ or } d > 2d_m \]

where \( V \) is the gust magnitude at distance \( d \) and \( V_m \) is the gust magnitude at the gust half-width \( d_m \). Discrete gust magnitudes \( (V_m) \) as a function of altitude and gust half-width \( (d_m) \) are provided in Tables 3.2.5-1 (m/s) and 3.2.5-2 (ft/s) for moderate turbulence and in Tables 3.2.5-3 (m/s) and 3.2.5-4 (ft/s) for severe turbulence. It is recommended to use the severe turbulence values (Tables 3.2.5-3 and 3.2.5-4) for all engineering assessments. The moderate turbulence values (Tables 3.2.5-1 and 3.2.5-2) can be used when load relief is needed, given the affected program understands the risk and has provided approval.

### Table 3.2.5-1. Discrete Longitudinal Gust Magnitude (m/s) as a Function of Altitude (km) and Gust Half-width \( d_m \) (m) Based on Moderate Turbulence

<table>
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<th>150.0</th>
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### Table 3.2.5-2. Discrete Longitudinal Gust Magnitude (ft/s) as a Function of Altitude (kft) and Gust Half-width $d_m$ (ft) Based on Moderate Turbulence

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The electronic version is the official approved document. Verify this is the correct version before use.
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Table 3.2.5-3. Discrete Longitudinal Gust Magnitude (m/s) as a Function of Altitude (km) and Gust Half-width $d_m$ (m) Based on Severe Turbulence

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</table>

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Space Launch System (SLS) Program

The design should be developed against the above models to maximum vehicle responses.

**Model Inputs**

Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) inputs for Monte Carlo analyses are listed in Table 3.2.5-3 for each monthly reference period. The spatial and temporal increments are chosen to optimize vehicle response for performance analyses. A large increment may not capture the frequencies (and/or wavelengths) necessary to excite appropriate vehicle responses, while too small an increment can produce very large relative derivatives along the

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Verify this is the correct version before use.
flight path. It is suggested to choose increments that result in spatial steps no smaller than the length of the vehicle.

The inputs given below provide random profiles with random perturbations that can be used to determine envelopes for trajectory and load variables for ascent analyses. An “rpscale” setting of 1.0 represents perturbation scaling equivalent to the climatological environment. If additional analyses to study the effects of more severe perturbations/turbulence are desired, the “rpscale” can be set to a higher value, which should not exceed 2.0. For thermal and aeroheating studies, it may be desirable to design extreme profiles (for example, 2 or 3 sigma climatological profiles) which Earth-GRAM 2010 also has the capability to produce.

**Table 3.2.5-3. Earth-GRAM 2010 Input to Generate 1,000 or More Perturbed Profiles (0 to 90 km) of Wind, Temperature, Pressure, and Density Per Monthly Reference Period**

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<tr>
<th>Parameter</th>
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<th>Value</th>
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<td>iyrrra</td>
<td>3 = 2013 RRA</td>
</tr>
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<td>RRA limits – use if near site with an RRA</td>
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<td>0.5</td>
</tr>
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<td></td>
<td>sitelim</td>
<td>2.5</td>
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<tr>
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<td>Non-RRA sites</td>
<td>NCEPyr</td>
<td>9008 = period of record</td>
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<tr>
<td>Random perturbations</td>
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<tr>
<td>Small scale perturbations</td>
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**Table 3.2.5-4. Earth-GRAM 2010 Input to Generate Monthly Mean Profiles to be Appended to MVWPM Profiles**

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<td>RRA limits – use if near site with an RRA</td>
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<td>sitelim</td>
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<td>Non-RRA sites</td>
<td>NCEPyr</td>
<td>9008 = period of record</td>
</tr>
</tbody>
</table>

**Limitations**

Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) and MVWPM perturbations in the aloft region are statistically derived. Large-scale perturbations in Earth-GRAM 2010 follow a cosine wave model, while small-scale perturbations are normally distributed. MVWPM dispersions are developed with the quadrivariate normal model, with the assumption that measured wind components are normally distributed at each altitude. The MVWPM, KSC Jimsphere Wind Profiles, and KSC Doppler Radar Wind Profiler databases only contain wind data. Profiles of temperature, pressure, and density dispersions for use with these models/databases will need to be acquired from other measured databases, or from Earth-GRAM.
2010. Discrete gusts may be adjusted (tuned) and applied by the engineer for vehicle response analyses.

Technical Notes

The MVWPM approximates the dispersion in the vector wind, relative to the monthly mean, at a reference altitude. It is suggested that the vehicle ascent guidance steering commands be designed to the monthly mean wind profile, which will produce the baseline aerodynamic load indicators at each altitude for a selected month. The aerodynamic load indicators derived from trajectory simulations using the modeled vector wind profiles for a selected reference altitude represent the dispersion from the baseline at that altitude. The KSC Jimsphere Wind Profiles and KSC Doppler Radar Wind Profiler databases can be used to evaluate flight simulations to determine the operational capability of the launch vehicle.

3.2.6 Aloft Air Temperature Environment for Vehicle Ascent

Description

This section specifies the aloft air temperature environments (altitude range 0 to 90 km (295,276 ft)) for vehicle ascent at KSC.

Design Limits

System performance will be evaluated through the use of the following database. The model/database can be obtained by contacting the MSFC Natural Environments Branch (MSFC organization code: EV44).

1) Earth-GRAM 2010: Monte Carlo analysis of 1,000 or more Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) random profiles per month. Each profile is for a 0 to 90 km altitude range with Earth-GRAM 2010 inputs per Table 3.2.5-1. Atmospheric temperature, pressure, and density should be evaluated simultaneously in each simulation.

Model Inputs

Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) input is listed in Table 3.2.5-1 for each monthly reference period. The spatial and temporal increments are chosen to optimize vehicle response for performance analyses. A large increment may not capture the frequencies (and/or wavelengths) necessary to excite appropriate vehicle responses, while too small an increment can produce very large relative derivatives along the flight path. It is suggested to choose increments that result in spatial steps no smaller than the length of the vehicle.

The inputs given in Table 3.2.5-1 provide random profiles with random perturbations that can be used to determine envelopes for trajectory and load variables for ascent analyses. An “rpscale” setting of 1.0 represents perturbation scaling equivalent to the climatological environment. If additional analyses to study the effects of more severe perturbations/turbulence are desired, the “rpscale” can be set to a higher value, which should not exceed 2.0. For thermal and aeroheating studies, it may be desirable to design to extreme profiles (for example, 2 or 3 sigma climatological profiles), which Earth-GRAM 2010 also has the capability to produce.
Limitations

Perturbations in the aloft region are statistically derived and are generated using the input variables in Table 3.2.5-1.

Technical Notes

Thermodynamic parameters during ascent drive vehicle venting rates, aeroheating/aerodynamic loads, and trajectory design. It is suggested that at least 1,000 Earth-GRAM 2010 random profiles be analyzed for vehicle design limit development.

3.2.7 Aloft Air Pressure Environment for Vehicle Ascent

Description

This section specifies the aloft air pressure environments (altitude range 0 to 90 km (295,276 ft)) for vehicle ascent at KSC.

Design Limits

See Section 3.2.6, Aloft Air Temperature Environment for Vehicle Ascent.

Model Inputs

See Section 3.2.6.

Limitations

See Section 3.2.6.

Technical Notes

See Section 3.2.6.

3.2.8 Aloft Air Density Environment for Vehicle Ascent

Description

This section specifies the aloft air density environments (altitude range 0 to 90 km (295,276 ft)) for vehicle ascent at KSC.

Design Limit

See Section 3.2.6, Aloft Air Temperature Environment for Vehicle Ascent.

Model Inputs

See Section 3.2.6.

Limitations

See Section 3.2.6.
Technical Notes

See Section 3.2.6.

3.2.9 Cloud Environment for Launch

Description

This section defines the cloud environments within which the vehicle must be capable of launching.

Design Limits

The design range for cloud cover is up to and including 100% cloud cover, excluding convective clouds and thunderstorms. The size distribution of liquid cloud particles is given by:

\[ N = \frac{N_o}{\Gamma(\nu)} \left( \frac{D}{D_n} \right)^{\nu-1} \exp \left( -\frac{D}{D_n} \right) \]

where \( N \) is the cloud droplet size spectra (m\(^{-3}\) μm\(^{-1}\)), defined as the number of cloud droplets in a cubic meter, within a droplet size interval, \( \Delta D \) (μm), \( N_o, \nu, \) and \( D_n \) are the gamma distribution parameters, \( D \) is the droplet diameter (μm), and \( \Gamma \) is the gamma function. This equation is applicable for a cloud thickness of 3 km (9,843 ft) in the altitude range of 0.5 to 4.5 km (1,640 to 14,764 ft).

The size distribution of frozen cloud particles is given by:

\[ N = 100N_o \left( \frac{D}{10000} \right)^{\mu} \exp \left( -\frac{\lambda D}{10000} \right) \]

where \( N \) is the ice particle size spectra (m\(^{-3}\) · μm\(^{-1}\)), defined as the number of ice particles in a cubic meter, within a particle size interval, \( \Delta D \) (μm), \( N_o, \mu, \) and \( \lambda \) are the gamma distribution parameters, and \( D \) is the particle diameter (μm). This equation is applicable for a cloud thickness of 2 km (6,562 ft) in the altitude range of 6 to 15 km (19,685 to 49,213 ft).

Model Inputs

For liquid cloud droplet diameters \( \leq 19.3 \) μm (0.000760 in), use:

\[ N_o = 2.88 \times 10^8 \text{ m}^{-3} \]
\[ \nu = 8.7 \]
\[ D_n = 1.3 \mu m \]

For liquid cloud droplet diameters > 19.3 μm (0.000760 in), use:

\[ N_o = 7.4 \times 10^7 \text{ m}^{-3} \]
\[ \nu = 8.6 \]
\[ D_n = 2.7 \, \mu m \]

For frozen cloud particles, the parameter \( \lambda \) is a function of temperature given by:
\[
\lambda = 5.80 \exp(-0.114T) \quad \text{for } T > -18^\circ C (-0.4^\circ F) \\
\lambda = 20.25 \exp(-0.042T) \quad \text{for } T < -18^\circ C (-0.4^\circ F)
\]

Temperature \( T \), in °C, is related to altitude \( Z \), in km, with:
\[
T = 0.0506Z^3 - 1.4202Z^2 + 5.7035Z - 4.5349
\]

Once \( \lambda \) is determined, the other parameters are given by:
\[
\mu = 0.076\lambda^{0.8} - 2 \\
N_o = 0.0586\exp(0.077\lambda)
\]

**Limitations**

None

**Technical Notes**

The size distribution for liquid cloud particles is obtained from Miles, et al (2000). The reference gives size distributions for clouds originating in both marine and continental environments. The design limits given here envelop both of these distributions, with a crossover between the two environments at 19.3 \( \mu m \) (0.000760 in) (continental environment at diameters <19.3 \( \mu m \) (0.000760 in), and marine environment at diameters >19.3 \( \mu m \) (0.000760 in)). The size distribution for liquid cloud particles allows the vehicle to traverse stratiform clouds and rain in non-convective situations.

Traversing convective type clouds, such as thunderstorms, could expose the vehicle to ice particles (hail or graupel) with diameters of several centimeters (cm) or larger. Flight path avoidance of thunderstorms is assumed to protect the vehicle from extreme environments such as lightning, hail, and extreme turbulence.

The size distribution for frozen cloud particles (obtained from Heymsfield (2003)) allows for traverse through mid- and high-altitude layer clouds (alto and cirrus type). Temperature as a function of altitude is determined by applying a 3rd order polynomial fit to the yearly average temperature profile from the KSC Range Reference Atmosphere (RRA) between 6 and 15 km.

**3.2.10 Rain and Precipitation Environment for Launch**

**Description**

This section specifies the precipitation environment for vehicle launch at KSC.
Design Limits

The maximum design rainfall rate is 7.6 mm/hr (0.30 in/hr) from non-convective clouds.

The raindrop size distribution is given by:

\[ N = 1 \times 10^5 N_o \left( \frac{D}{10} \right) \alpha \exp \left( \frac{-\Lambda D}{10} \right) \]

where \( N \) is the raindrop size spectra (m\(^3\) mm\(^{-1}\)), defined as the number of raindrops in a cubic meter, within a raindrop size interval, \( \Delta D \) (mm), \( N_o \), \( \alpha \), and \( \Lambda \) are the gamma distribution parameters, and \( D \) is the raindrop diameter (mm). This equation is applicable from raindrops from the surface to 4.5 km (14,764 ft).

Model Inputs

\[ R = 7.6 \text{ mm/hr} \]
\[ \Lambda = \frac{5.588}{0.0984 R^{0.1535}} \]
\[ \alpha = 2.16 \]

\[ N_o = \frac{5.1285 \times 10^{-4} \left( 0.062 R^{0.913} \right) \left( \frac{1}{0.0984 R^{0.1535}} \right)^\alpha}{\left( 0.0984 R^{0.1535} \right)^4} \]

Limitations

None

Technical Notes

The design rainfall rate is the National Oceanic and Atmospheric Administration (NOAA) maximum observational reporting value for moderate rainfall NOAA (2005). This rate was chosen to exclude operations during heavy rainfall produced by convective clouds (thunderstorms). The raindrop size distribution function is obtained from Tattelman and Willis (1985) Tattelman, P. and Willis, P., Model Vertical Profiles of Extreme Rainfall Rate, Liquid Water Content, and Drop-Size Distribution, AFGL-TR-85-0200, September 6, 1985. Flight path avoidance of thunderstorms is desired to protect the vehicle from extreme environments such as lightning, hail, and extreme turbulence.

3.2.11 Flora and Fauna Environments during Launch and Ascent

Description

This section specifies the flora and fauna environment for vehicle ascent at KSC.
Design Limits

In the KSC area, the most common larger species of birds, with a maximum mass of 2.2 kg (4.9 pounds (lbs)) may be found with decreasing number density up to 7.6 km (25,000 ft). Table 3.2.11-1 presents the avian number density with respect to height AGL.

Table 3.2.11-1. Avian Number Density up to 7.62 km (25,000 ft).

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Model Inputs
None

Limitations
None

Technical Notes

Studies over the past twenty years in the KSC area have been consistent with respect to bird populations, however they only provide coarse detail about bird number densities with respect to height and migratory patterns. The most common larger species of birds in the KSC area are black vultures (mass 1.6 to 2.2 kg (3.5 to 4.9 lbs)), turkey vultures (mass ~2.0 kg (4.4 lbs)) and osprey (mass 1.4 to 2.0 kg) (3.1 to 4.4 lbs). Much less common, but also present in the KSC area.
are bald eagles (mass 4.5 to 6.4 kg) (9.9 to 14.1 lbs). Data used to derive Table 3.2.11-1 can be found in NASA MSFC Memo EV44 (15-007), titled ‘KSC Avian Environment Report’.

### 3.2.12 Natural and Triggered Lightning during Launch and Ascent

**Description**

This section specifies the lightning environment for launch and ascent from KSC. Design specifications include standardized voltage and current waveforms derived or characterized to represent the lightning environment at specific zones established on the vehicle.

**Design Limits**

The environment in the launch area is such that systems will be exposed to the direct and indirect effects of lightning. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, Aircraft Lightning Zones, and must be defined and evaluated for each applicable vehicle configuration. SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms is an applicable document.

**Model Inputs**

Vehicle lightning strike zones must be defined for each integrated vehicle configuration.

**Limitations**

Waveforms used for analysis are selected based on vehicle attachment profile and electromagnetic regions.

The most important characteristics of the standard lightning waveforms used for analysis and test are the peak current, continuing current, peak rate of rise, and the action integral, or coulomb content, of the waveform. Secondary characteristics of significance are the time to peak, and the time to fall to 50% of the peak. Peak current and continuing current levels are important for direct attachment assessment. The action integral is the amount of energy contained in the flash event, and is most important for determining damage related to direct attachment effects. Rise and fall times are important for indirect effects assessment and analysis.

**Technical Notes**

None.

### 3.2.13 Ionizing Radiation Environment for Launch, Ascent and Re-entry

**Description**

Environment parameters identified here are applicable for KSC launch trajectories to target orbit inclinations of 51.6° or less. This specification applies to SLS vehicles operating at or below latitude 40°N and a peak altitude of 200 km. The magnetic field intensity values used for geomagnetic shielding calculations were selected based on the 40°N maximum latitude and 200 km altitude at longitudes appropriate for a KSC launch. These parameters are derived from representative ascent trajectories, and provide a reasonable representation of anticipated radiation
environment risk to the launch vehicle systems. The same conditions apply during any phases of re-entry conducted within the same altitude and latitude limits.

The environment at and below an altitude of 20 km consists almost entirely of secondary radiation products, primarily atmospheric neutrons.

Total Ionizing Dose (TID) and displacement damage (DD) to flight hardware are negligible for this segment of the environment.

**Design Limits**

Systems that operate at altitudes above 20 km and at or below 200 km altitude will be exposed to the Galactic Cosmic Ray (GCR) and Design Solar Particle Event (Design SPE) environments of Tables 3.2.13-1, -2, and -3. The low altitude atmospheric neutron environment (Table 3.2.13-4) is not a concern for these systems.

The design limit for systems that operate only at or below 20 km is provided in the Table 3.2.13-4 atmospheric neutron environment for the system maximum operating altitude. The 200 km GCR and Design SPE environments are not applicable.

Figure 3.2.13-1 and Table 3.2.13-1 present 200 km particle flux for a Design SPE, as a function of Linear Energy Transfer (LET), and for solar minimum GCR in stormy magnetic field conditions.

Figures 3.2.13-2 and 3.2.13-3 and Tables 3.2.13-2 and 3.2.13-3 present 200 km differential and integral proton fluxes for a Design SPE and GCR.

Table 3.2.13-4 presents the flux of >10 MeV neutrons at altitudes to 20 km.

**Limitations**

Probability that the 200 km proton energy and particle flux LET spectra of the Design SPE will not be exceeded is estimated at 97%.

The GCR proton energy and particle flux LET spectra represent a worst case (solar minimum) background environment.

The >10 MeV neutron flux is derived from empirical data. No probability has been determined and specified flux could be exceeded during an anomalously large SPE.

**Technical Notes**

Particle flux and LET values are obtained using the Cosmic Ray Effects on Microelectronics 96 (CREME96) model. Minimum shielding by earth’s magnetic field is applied by using the “sections of orbits” option in the model’s Geomagnetic Transmission (GTRN) module, choosing the “stormy” magnetic weather conditions, and further selecting bounding McIlwain L values between 2.4 and 2.55. This represents conditions at the approximately 40°N latitude, 200 km altitude, and appropriate longitudes for the core stage operations.
Proton energy and particle flux spectra are acquired using the FLUX model in CREME96. The Design SPE spectra can be reproduced in more detail using the CREME96 “Worst Week” flare model. Atomic numbers for Z=1 through Z=92 ions are included for definition of the LET spectrum, while the proton fluxes, of course, use only Z = 1. All SPE based flux values are then multiplied by 2 to derive the Design SPE which has twice the flux of the October 1989 solar particle event as represented by the CREME96 model. The x2 multiplier of the 1989 event is needed to simulate a “worst case” SPE exposure at the high 97% probability level appropriate for crewed missions included in the Program defined DRM set. The probability is determined by comparison to the Goddard Spaceflight Center (GSFC) Emission of Solar Proton (ESP) model.

The GCR proton energy and particle flux spectra can be reproduced using the CREME96 FLUX module with the same GTRN module output describe in the previous paragraph and selecting the “Solar Minimum” option for 200 km and the Z=1 or Z=1-92 atomic number range, depending on whether the proton only or full GCR spectrum is desired.

For LET analysis, the particle spectra from the FLUX module are converted using the LETSPEC module, which converts particle flux to LET flux.

For all spectra, appropriate unit conversions must be applied whenever applicable.

The incident spectra will be modified during transport through shielding materials between the environment and equipment inside the vehicle. Modified spectra should be defined using the radiation transport model provided in CREME96 or an alternate approved transport model.
Figure 3.2.13-1. 200 km Integral Flux for a Design SPE and Solar Minimum GCR in a Stormy Magnetic Field for 51.6° Inclination, 200 km Altitude, at 40° North Latitude, as a Function of LET
## Table 3.2.13-1. 200 km Integral LET Flux as Shown in Figure 3.2.13-1

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### Figure 3.2.13-2

**200 km Differential Design SPE and GCR Proton Flux as a Function of Energy**
Table 3.2.13-2. 200 km Differential Proton Flux as Shown in Figure 3.2.13-2.

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### Table: Design SPE (2.55 ≤ L ≤ 2.4) vs GCR (2.55 ≤ L ≤ 2.4)

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Figure 3.2.13-3. 200 km Integral Proton Flux of Design SPE and Integral GCR Flux as a Function of Energy

Table 3.2.13-3. 200 km Integral Proton Flux as Shown in Figure 3.2.13-3

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Table 3.2.13-4. Flux of > 10 MeV Neutrons at Altitudes to 20 km

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3.3 In-Space Phases

Within this section the ionizing radiation environments that lead to Total Dose and Single Event Effect are defined. Within each of these subsections the definition is split into all the phases of the Design Reference Missions (DRMs), as defined in Exploration Systems Development (ESD) Concept of Operations (ESD 10012). As each DRM preliminary design is started, the MSFC Natural Environments Branch/EV44, through the NEIAHT, will generate a memo that details the Ionizing Radiation and Plasma environments for that specific DRM. The memo will use the data provided here and delineate the environments for each DRM mission segment (launch/ascent, staging & injections, mission transit and operations, and return and reentry). Those programs, elements, systems, subsystems and components that will operate during one or more of the DRM mission segments will be responsible for meeting their requirements during and after exposure to the environments as defined in the generated memo.
3.3.1 Total Dose

This section specifies cumulative Total Dose environments. Total Dose consists of two components, Total Ionizing Dose (TID) and Displacement Damage Dose (DDD). To calculate these, the ionizing radiation environments must be defined. TID is determined by transporting these environments through equivalent aluminum thicknesses and determining the deposited energy or dose. TID is given in Systems International derived units of centiGrays [cGy (Si)] for parts and materials exposed to DRM phases at altitudes greater than 150 km. One cGy (Si) equals one rad (silicon). For all regions of space and staging orbits, the TID is calculated using the Space Environment Information System (SPENVIS) version of Shieldose2, which calculates the dose at the center of an aluminum sphere. This does represent a conservative estimate of the TID but a more realistic TID can be calculated by performing three dimensional radiation transport calculations through the structure of the system under consideration.

DDD is determined by transporting the environment fluences and coupling with a damage function to determine the DDD. Since this damage function is material dependent, only the environment fluences are given. Methods for determining the DDD and the material damage functions for Silicon and Gallium Arsenide can be found in Srour, et al., 2003, Johnston, et al., 2013 and Messenger, et al., 2001.

Table 3.3.1-1 gives the applicability matrix for each of the DRMs (down the right hand column) for each of the regions of space defined in this document (across the top of the table) for Total Dose Effects. An “X” is placed in each box where the region of space is applicable to that DRM. For the “Staging and Transit Orbits” column, subsections of 3.3.1.2 are called out as applicable, since not all may be applicable for each DRM. A pseudo region of space is added in Section 3.3.1.10 Solar Particle Events (SPE). Since the number of SPE is a function of total mission time, placing SPE events in each region of space section would place multiple events in a DRM when only one may be appropriate. Therefore, the SPE environment, for both geomagnetic shielded and unshielded, is placed in its own subsection and the appropriate number of events will be incorporated into the DRM memo.

All sections and subsections under Total Dose will give the environments as per day environments. To determine the total dose environments for a specific DRM, the environments for all application sections and subsections must be multiplied by the appropriate number of days spent in that environment, then the appropriate number of SPE accounted for, and then all of these summed for the final dose.

Note: Tables may contain abbreviated data as compared to the plotted data. Complete data sets are available in electronic form.
Table 3.3.1-1. Total Dose Applicability Matrix for the Design Reference Mission by Regions of Space

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<th>Region of Space</th>
<th>LEO (3.3.1.1)</th>
<th>Staging and Transit Orbits (3.3.1.2)</th>
<th>GEO (3.3.1.3)</th>
<th>Interplanetary (3.3.1.4)</th>
<th>Lunar Orbit (3.3.1.5)</th>
<th>Lunar Surface (3.3.1.6)</th>
<th>NEA (3.3.1.7)</th>
<th>Mars Orbit (3.3.1.8)</th>
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3.3.1.1 Low Earth Orbit (LEO)-International Space Station (ISS) Orbit

Design Limits

Total dose contributions for ISS missions (conducted within Earth’s magnetosphere) primarily originate from the Earth’s trapped radiation environments. It is assumed that a single Solar Particle Event (SPE) will occur during the mission and it will add to the total dose.
The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.1-1 and Table 3.3.1.1-1 specify the daily trapped proton, integral and differential, spectra as a function of energy. Figure 3.3.1.1-2 and Table 3.3.1.1-2 specify the daily trapped electron, integral and differential, spectra as a function of energy. Figure 3.3.1.1-3 and Table 3.3.1.1-3 specify the total SPE proton integral and differential spectra as a function of energy.

![Daily Trapped Proton Fluences](image)

**Figure 3.3.1.1-1. Daily Trapped Proton Fluences**

**Table 3.3.1.1-1. Daily Trapped Proton Fluences**

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<th>Daily Differential Trapped Proton Fluence</th>
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<td>Proton Energy</td>
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Figure 3.3.1.1-2. Daily Trapped Electron Fluences

Table 3.3.1.1-2. Daily Trapped Electron Fluences

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Figure 3.3.1.1-3. Proton Fluences of an ISS SPE

Table 3.3.1.1-3. Proton Fluences of an ISS SPE

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Figure 3.3.1.1-4 and Table 3.3.1.1-4 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons. Figure 3.3.1.1-5 and Table 3.3.1.1-5 specify total TID associated with the worst–case as defined in the Emission of Solar Protons (ESP)/ Prediction of Solar particle Yields for Characterizing Integrated Circuits (PSYCHIC) model.

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Figure 3.3.1.1-4. Daily Trapped Belts TID Inside Shielding

Table 3.3.1.1-4. Daily Trapped Belts TID Inside Shielding

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<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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Figure 3.3.1.1-5. Total SPE TID Inside Shielding
Table 3.3.1.1-5. Total SPE TID Inside Shielding

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</table>

The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.1-4. To calculate the final TID specification level for the ISS mission (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.1-4 by the number of days in the mission and add that number to the total SPE TID in Table 3.3.1.1-5. When performing the 3-D shielding calculations, the external trapped ionizing radiation environments (given as daily fluences in the above tables) are multiplied by the number of mission days. Those trapped...
electron and proton mission fluences and the SPE proton fluence are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

Model Inputs
None.

Limitations
None.

Technical Notes
All environment models were run for the assumed ISS orbit of 500 km circular orbit at 51.6° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled by a factor of two to account for the model uncertainty. The SPE TID specification was defined by using the ESP/PSYCHIC model for a one year period during solar maximum conditions with a stormy magnetosphere and a 95% probability of the fluences not being exceeded. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.2 Staging and Transit Orbits
3.3.1.2.1 LEO 185 x 1806 km

Design Limits
Total dose contributions for this staging orbit primarily originate from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, the ESP/PSYCHIC model was used and it was determined that no solar particles penetrate the Earth’s magnetic field in this orbit. Therefore, even for segments that end in this orbit, no SPE will be observed.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.2.1-1 and Table 3.3.1.2.1-1 specify the daily trapped proton, integral and differential, spectra as a function of energy. Figure 3.3.1.2.1-2 and Table 3.3.1.2.1-2 specify the daily trapped electron, integral and differential, spectra as a function of energy.
Figure 3.3.1.2.1-1. Daily Trapped Proton Fluences

Table 3.3.1.2.1-1. Daily Trapped Proton Fluences

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<th>Proton Energy (MeV)</th>
<th>Daily Integral Trapped Proton Fluence (protons/cm²)</th>
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### Table 3.3.1.2.1-2.

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**Figure 3.3.1.2.1-2.** Daily Trapped Electron Fluences
### Table 3.3.1.2.1-2. Daily Trapped Electron Fluences

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Figure 3.3.1.2.1-3 and Table 3.3.1.2.1-3 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons. Since no solar protons penetrate the Earth’s magnetic field for this orbit, no TID from solar protons is generated.
Table 3.3.1.2.1-3. Daily Trapped Belts TID Inside Shielding

<table>
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<th>Aluminum Shield Depth</th>
<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Trapped Proton Daily TID</th>
<th>Total Daily TID</th>
</tr>
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<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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<td>1.39E+05</td>
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### Aluminum Shield Depth

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<th>Aluminum Shield Depth</th>
<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Trapped Proton Daily TID</th>
<th>Total Daily TID</th>
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</thead>
<tbody>
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<td>mm</td>
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<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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<td>1.17E+01</td>
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</table>

The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.2.1-3. To calculate the final TID specification level for this segment (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.2.1-3 by the number of days in the segment. When performing the 3-D shielding calculations, the external trapped ionizing radiation environments (given as daily fluences in the above tables) are multiplied by the number of mission days. Those trapped electron and proton segment fluences are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

### Model Inputs

None.

### Limitations

None.

### Technical Notes

All environment models were run for the assumed an orbit of 185 km x 1860 km at a 28.5° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using...
the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled by a factor of two to account for the model uncertainty. The SPE TID specification was defined by using the ESP/PSYCHIC model for a one year period during solar maximum conditions with a stormy magnetosphere and a 95% probability of the fluences not being exceeded. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.2.2 Radiation Belt Transit

Design Limits

Total dose contributions for this staging orbit primarily originate from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, it is assumed that a single Solar Particle Event (SPE) will occur during this stage and it will add to the total dose. That SPE environment is presented in Section 3.3.1.10.2 Geomagnetic Unshielded since this staging orbit ends outside the Earth’s magnetic field.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.2.2-1 and Table 3.3.1.2.2-1 specify the trapped proton fluence, integral and differential, spectra as a function of energy. Figure 3.3.1.2.2-2 and Table 3.3.1.2.2-2 specify the trapped electron fluence, integral and differential, spectra as a function of energy.
Figure 3.3.1.2.2-1. Trapped Proton Fluences

Table 3.3.1.2.2-1. Trapped Proton Fluences

<table>
<thead>
<tr>
<th>Proton Energy</th>
<th>Integral Trapped Proton Fluence</th>
<th>Differential Trapped Proton Fluence</th>
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<td>protons/MeV·cm²</td>
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The electronic version is the official approved document.
Verify this is the correct version before use.
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Figure 3.3.1.2.2-2. Trapped Electron Fluences

Table 3.3.1.2.2-2. Trapped Electron Fluences

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<td>2.84E+08</td>
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<td>1.65E+08</td>
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<td>3.56E+07</td>
<td>9.64E+07</td>
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<td>5.29E+07</td>
</tr>
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<td>2.87E+07</td>
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<td>7</td>
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</tbody>
</table>

Figure 3.3.1.2.2-3 and Table 3.3.1.2.2-3 specify the Translunar Injection (TLI) TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons.
Figure 3.3.1.2.2-3. Trapped Belts TID inside Shielding

Table 3.3.1.2.2-3. Trapped Belts TID inside Shielding

<table>
<thead>
<tr>
<th>Aluminum Shield Depth</th>
<th>Trapped Electron TID</th>
<th>Bremsstrahlung TID</th>
<th>Trapped Proton TID</th>
<th>Total TID</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>cGy(Si)/TLI</td>
<td>cGy(Si)/TLI</td>
<td>cGy(Si)/TLI</td>
<td>cGy(Si)/TLI</td>
</tr>
<tr>
<td>0.05</td>
<td>6.14E+04</td>
<td>1.18E+02</td>
<td>1.55E+04</td>
<td>7.70E+04</td>
</tr>
<tr>
<td>0.1</td>
<td>3.39E+04</td>
<td>7.25E+01</td>
<td>3.26E+03</td>
<td>3.72E+04</td>
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<td>1.64E+04</td>
<td>4.08E+01</td>
<td>7.65E+02</td>
<td>1.72E+04</td>
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<td>9.80E+03</td>
<td>2.74E+01</td>
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<td>1.02E+04</td>
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<tr>
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<td>6.87E+03</td>
</tr>
<tr>
<td>0.5</td>
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<td>1.57E+01</td>
<td>1.59E+02</td>
<td>4.96E+03</td>
</tr>
<tr>
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<td>1.29E+01</td>
<td>1.16E+02</td>
<td>3.75E+03</td>
</tr>
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<td>6.69E+01</td>
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</tr>
<tr>
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<td>4.16E+01</td>
<td>1.66E+03</td>
</tr>
<tr>
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<td>8.18E+02</td>
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<td>1.74E+01</td>
<td>8.40E+02</td>
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<tr>
<td>2</td>
<td>4.69E+02</td>
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<td>9.89E+00</td>
<td>4.82E+02</td>
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<td>2.80E+02</td>
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<td>6.58E+00</td>
<td>2.89E+02</td>
</tr>
<tr>
<td>3</td>
<td>1.71E+02</td>
<td>2.16E+00</td>
<td>4.83E+00</td>
<td>1.78E+02</td>
</tr>
<tr>
<td>4</td>
<td>6.70E+01</td>
<td>1.59E+00</td>
<td>3.06E+00</td>
<td>7.16E+01</td>
</tr>
</tbody>
</table>
The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.2.2-4.

**Model Inputs**

None.

**Limitations**

None.

**Technical Notes**

All environment models were run for the assumed a trajectory from the SLS Design Analysis Cycle (DAC-2) for the Distant Retrograde Orbit Design Reference Mission. Only the first 6 hours of the trajectory are used as this places the spacecraft in excess of 60,000 km, which is beyond the trapped radiation belts. Additionally, the first 90 minutes of the trajectory are also removed. This removes the Low Earth Orbit section so only the radiation belt transit is considered in these calculations. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled by a factor of two to account for the model uncertainty. TID shielding calculations were performed using the SPENVIS version of Shieldose2 code, solid Aluminum sphere option.
3.3.1.2.3 LEO 241 km Circular

Design Limits

Total dose contributions for this staging orbit primarily originate from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, the ESP/PSYCHIC model was used and it was determined that no solar particles penetrate the Earth’s magnetic field in this orbit. Therefore, even for segments that end in this orbit, no SPE will be observed.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.2.3-1 and Table 3.3.1.2.3-1 specify the daily trapped proton, integral and differential, spectra as a function of energy. Figure 3.3.1.2.3-2 and Table 3.3.1.2.3-2 specify the daily trapped electron, integral and differential, spectra as a function of energy.

![Daily Trapped Proton Fluences](image-url)
### Table 3.3.1.2.3-1. Daily Trapped Proton Fluences

<table>
<thead>
<tr>
<th>Proton Energy (MeV)</th>
<th>Daily Integral Trapped Proton Fluence (protons/cm²)</th>
<th>Daily Differential Trapped Proton Fluence (protons/MeV-cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-01</td>
<td>5.29E+04</td>
<td>1.76E+04</td>
</tr>
<tr>
<td>5.00E-01</td>
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<td>3.69E+04</td>
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</table>
Figure 3.3.1.2.3-2. Daily Trapped Electron Fluences

### Table 3.3.1.2.3-2. Daily Trapped Electron Fluences

<table>
<thead>
<tr>
<th>Electron Energy</th>
<th>Daily Integral Trapped Electron Fluence</th>
<th>Daily Differential Trapped Electron Fluence</th>
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</thead>
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<td>electrons/MeV-cm²</td>
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<td>1.78E+06</td>
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<tr>
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<td>3.40E+05</td>
<td>1.57E+06</td>
</tr>
<tr>
<td>2.00E-01</td>
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<tr>
<td>3.00E-01</td>
<td>9.01E+04</td>
<td>8.53E+05</td>
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<tr>
<td>4.00E-01</td>
<td>3.08E+04</td>
<td>3.96E+05</td>
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<td>9.50E+03</td>
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The electronic version is the official approved document. Verify this is the correct version before use.
Figure 3.3.1.2.3-3 and Table 3.3.1.2.3-3 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons.

<table>
<thead>
<tr>
<th>Electron Energy (MeV)</th>
<th>Daily Integral Trapped Electron Fluence (electrons/cm²)</th>
<th>Daily Differential Trapped Electron Fluence (electrons/MeV·cm²)</th>
</tr>
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<tbody>
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<td>1.10E+02</td>
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<td>4.09E+02</td>
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<td>0.00E+00</td>
</tr>
<tr>
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<td>0.00E+00</td>
<td>0.00E+00</td>
</tr>
<tr>
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<td>0.00E+00</td>
<td>0.00E+00</td>
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<td>0.00E+00</td>
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<tr>
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</table>
### Figure 3.3.1.2.3-3. Daily Trapped Belts TID Inside Shielding

#### Table 3.3.1.2.3-3. Daily Trapped Belts TID Inside Shielding

<table>
<thead>
<tr>
<th>Aluminum Shield Depth</th>
<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Trapped Proton Daily TID</th>
<th>Total Daily TID</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
</tr>
<tr>
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<td>5.55E-02</td>
<td>8.06E-02</td>
</tr>
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<td>6.39E-02</td>
</tr>
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<td>2.73E-02</td>
<td>5.45E-02</td>
</tr>
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<td>2.48E-02</td>
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<td>1.68E-02</td>
<td>4.16E-02</td>
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<td>2.64E-02</td>
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<td>1.36E-02</td>
</tr>
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<td>6.85E-06</td>
<td>8.27E-03</td>
<td>1.05E-02</td>
</tr>
<tr>
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<td>1.13E-03</td>
<td>4.66E-06</td>
<td>7.62E-03</td>
<td>8.75E-03</td>
</tr>
<tr>
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<td>5.96E-04</td>
<td>3.36E-06</td>
<td>7.15E-03</td>
<td>7.75E-03</td>
</tr>
<tr>
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<td>2.24E-04</td>
<td>2.04E-06</td>
<td>6.53E-03</td>
<td>6.76E-03</td>
</tr>
<tr>
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<td>1.15E-04</td>
<td>1.43E-06</td>
<td>6.13E-03</td>
<td>6.24E-03</td>
</tr>
</tbody>
</table>

The electronic version is the official approved document. Verify this is the correct version before use.
The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.2.3-3. To calculate the final TID specification level for this segment (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.2.3-3 by the number of days in the segment. When performing the 3-D shielding calculations, the external trapped ionizing radiation environments (given as daily fluences in the above tables) are multiplied by the number of mission days. Those trapped electron and proton segment fluences are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

### Model Inputs
None.

### Limitations
None.

### Technical Notes
All environment models were run for the assumed orbit of 241 km circular at a 28.5° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled.

<table>
<thead>
<tr>
<th>Aluminum Shield Depth</th>
<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Trapped Proton Daily TID</th>
<th>Total Daily TID</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
</tr>
<tr>
<td>2.50E+00</td>
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<td>3.13E-07</td>
<td>3.91E-03</td>
<td>3.92E-03</td>
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<td>1.71E-07</td>
<td>3.51E-03</td>
<td>3.51E-03</td>
</tr>
<tr>
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<td>3.36E-03</td>
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</tr>
</tbody>
</table>

The electronic version is the official approved document. Verify this is the correct version before use.
by a factor of two to account for the model uncertainty. The SPE TID specification was defined by using the ESP/PSYCHIC model for a one year period during solar maximum conditions with a stormy magnetosphere and a 95% probability of the fluences not being exceeded. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

### 3.3.1.2.4 High Earth Orbit (HEO) 407 x 233,860 km

#### Design Limits

Total dose contributions for this staging orbit primarily originate from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, it is assumed that a single Solar Particle Event (SPE) will occur during this stage and it will add to the total dose. That SPE environment is presented in Section 3.3.1.10.2 Geomagnetic Unshielded since this staging orbit spends the majority of its time outside the Earth’s magnetic field.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.2.4-1 and Table 3.3.1.2.4-1 specify the daily trapped proton, integral and differential, spectra as a function of energy. Figure 3.3.1.2.4-2 and Table 3.3.1.2.4-2 specify the daily trapped electron, integral and differential, spectra as a function of energy.
Table 3.3.1.2.4-1. Daily Trapped Proton Fluences

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<th>Daily Differential Trapped Proton Fluence</th>
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<td>protons/MeV-cm²</td>
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Figure 3.3.1.2.4-1. Daily Trapped Proton Fluences
## Table 3.3.1.2.4-2. Proton Energy and Daily Integral Trapped Proton Fluence

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<td>protons/cm²</td>
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**Figure 3.3.1.2.4-2. Daily Trapped Electron Fluences**
Table 3.3.1.2.4-2. Daily Trapped Electron Fluences

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<th>Daily Differential Trapped Electron Fluence</th>
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Figure 3.3.1.2.4-3 and Table 3.3.1.2.4-3 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons.
### Aluminum Shield Depth

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<th>Bremsstrahlung Daily TID</th>
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<th>Total Daily TID</th>
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<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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<td>5.86E-01</td>
<td>8.27E-01</td>
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<td>7.29E-01</td>
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<td>4.04E-01</td>
<td>5.71E-01</td>
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<td>4.20E-01</td>
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<td>7.81E-02</td>
<td>1.90E-01</td>
<td>2.68E-01</td>
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<td>1.68E-01</td>
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<td>0.00E+00</td>
<td>2.98E-02</td>
<td>8.41E-02</td>
<td>1.14E-01</td>
</tr>
</tbody>
</table>

The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.2.4-3. To calculate the final TID specification level for this segment (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.2.4-3 by the number of days in the segment and add that number to the total SPE TID given in Section 3.3.1.10.2. When performing the 3-D shielding calculations, the external trapped ionizing radiation environments (given as daily fluences in the above tables) are multiplied by the number of mission days. Those trapped electron and proton segment fluences and the SPE proton fluence (found in Section 3.3.1.10.2) are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

**Model Inputs**

None.

**Limitations**

None.
Technical Notes

All environment models were run for the assumed an orbit of 407 km x 233,860 km at a 28.5° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled by a factor of two to account for the model uncertainty. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.2.5 HEO to NEA transit

It is assumed that for this stage the transit will start at the apogee of the HEO orbit. Therefore, the total dose contributions for this staging orbit will not have contribution from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, it is assumed that a single Solar Particle Event (SPE) will occur during this stage and it will add to the total dose. Since this transit is outside the Earth’s magnetic field, the details of this SPE environment for this stage are given in Section 3.3.1.10.2.

3.3.1.2.6 LEO 407 km Circular

The total dose environment model parameters for LEO 407 km circular are bounded by those used for the LEO-ISS. For LEO 407 km circular total dose environments use those presented in Section 3.3.1.1 LEO-ISS Orbit.

3.3.1.2.7 Low Perigee (LP)-HEO 407 x 400,000 km

Design Limits

Total dose contributions for this staging orbit primarily originate from the Earth’s trapped radiation environments. Since this orbit is part of larger DRM, no SPE environment is needed specific to this orbit except for any segment whose mission ends with this orbit. For those segments only, it is assumed that a single Solar Particle Event (SPE) will occur during this stage and it will add to the total dose. That SPE environment is presented in Section 3.3.1.10.2 Geomagnetic Unshielded since this staging orbit spends the majority of its time outside the Earth’s magnetic field.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.2.7-1 and Table 3.3.1.2.7-1 specify the daily trapped proton, integral and differential, spectra as a function of energy. Figure 3.3.1.2.7-2 and Table 3.3.1.2.7-2 specify the daily trapped electron, integral and differential, spectra as a function of energy.
Figure 3.3.1.2.7-1. Daily Trapped Proton Fluences

Table 3.3.1.2.7-1. Daily Trapped Proton Fluences

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<tr>
<th>Proton Energy</th>
<th>Daily Integral Trapped Proton Fluence</th>
<th>Daily Differential Trapped Proton Fluence</th>
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</thead>
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<td>MeV</td>
<td>protons/cm²</td>
<td>protons/MeV·cm²</td>
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*Figure 3.3.1.2.7-2. Daily Trapped Electron Fluences*
### Table 3.3.1.2.7-2. Daily Trapped Electron Fluences

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<th>Daily Differential Trapped Electron Fluence</th>
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Figure 3.3.1.2.7-3 and Table 3.3.1.2.7-3 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons.

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<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Trapped Proton Daily TID</th>
<th>Total Daily TID</th>
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<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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<td>9.71E+02</td>
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<td>5.47E+02</td>
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<td>1.20E-01</td>
<td>4.48E-01</td>
<td>3.52E+01</td>
</tr>
<tr>
<td>Aluminum Shield Depth</td>
<td>Trapped Electron Daily TID</td>
<td>Bremsstrahlung Daily TID</td>
<td>Trapped Proton Daily TID</td>
<td>Total Daily TID</td>
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<td>-----------------------</td>
<td>---------------------------</td>
<td>-------------------------</td>
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</tr>
<tr>
<td>mm</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
<td>cGy(Si)/day</td>
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<td>2.48E-02</td>
<td>3.57E-02</td>
<td>2.78E+00</td>
</tr>
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<td>1.38E-02</td>
<td>2.77E-01</td>
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<td>6.41E-03</td>
<td>7.38E-03</td>
<td>1.49E-02</td>
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<td>6.38E-03</td>
<td>1.21E-02</td>
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<td>5.07E-03</td>
<td>5.64E-03</td>
<td>1.07E-02</td>
</tr>
<tr>
<td>1.60E+01</td>
<td>1.78E-08</td>
<td>4.65E-03</td>
<td>5.14E-03</td>
<td>9.79E-03</td>
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<td>4.77E-03</td>
<td>9.06E-03</td>
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<td>4.42E-03</td>
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<td>9.22E-04</td>
<td>1.66E-03</td>
</tr>
</tbody>
</table>

The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.2.7-3. To calculate the final TID specification level for this segment (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.2.7-3 by the number of days in the segment and add that number to the total SPE TID given in Section 3.3.1.10.2. When performing the 3-D shielding calculations, the external trapped ionizing radiation environments (given as daily fluences in the above tables) are multiplied by the number of mission days. Those trapped electron and proton segment fluences and the SPE proton fluence (found in Section 3.3.1.10.2) are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

**Model Inputs**
None.

**Limitations**
None.
Technical Notes

All environment models were run for the assumed an orbit of 407 km x 400,000 km at a 28.5° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The trapped proton environment was defined using the AP8MIN model, as it represents the worst-case proton environment. The model is then scaled by a factor of two to account for the model uncertainty. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.2.8 High Perigee (HP)-HEO Spiral to 60,000 x 400,000 km

Reserved.

3.3.1.3 Geosynchronous Earth Orbit (GEO)

Design Limits

Total dose contributions for GEO DRM primarily originate from the Earth’s trapped electron environment. It is assumed that a single unshielded Solar Particle Event (SPE) will occur during the mission and it will add to the total dose. The details of the SPE environment for this region of space are given in Section 3.3.1.10.2.

The following tables and graphs provide the ionizing radiation environment data, external to the spacecraft, that can be used as input for 3-dimensional shielding calculations of total ionizing dose or for the calculation of displacement damage dose: Figure 3.3.1.3-1 and Table 3.3.1.3-1 specify the daily trapped electron, integral and differential, spectra as a function of energy.
Figure 3.3.1.3-1. Daily Trapped Electron Fluences

Table 3.3.1.3-1. Daily Trapped Electron Fluences

<table>
<thead>
<tr>
<th>Electron Energy</th>
<th>Daily Integral Trapped Electron Fluence</th>
<th>Daily Differential Trapped Electron Fluence</th>
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<td>electrons/cm²</td>
<td>electrons/MeV-cm²</td>
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<td>Electron Energy</td>
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<td>Daily Differential Trapped Electron Fluence</td>
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<td>----------------------------------------</td>
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</tr>
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<td>MeV</td>
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<td>electrons/MeV·cm²</td>
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<tr>
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</table>

Figure 3.3.1.3-2 and Table 3.3.1.3-2 specify the daily TID inside selected thicknesses of spherical aluminum (Al) shielding from the trapped radiation belt protons and electrons.
### Figure 3.3.1.3-2. Daily Trapped Belts TID Inside Shielding

#### Table 3.3.1.3-2. Daily Trapped Belts TID Inside Shielding

<table>
<thead>
<tr>
<th>Aluminum Shield Depth</th>
<th>Trapped Electron Daily TID</th>
<th>Bremsstrahlung Daily TID</th>
<th>Total Daily TID</th>
</tr>
</thead>
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<td>5.59E+02</td>
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<td>4.92E+03</td>
<td>2.71E+01</td>
<td>4.95E+03</td>
</tr>
</tbody>
</table>
The final TID specification can either be derived by generating a dose versus depth curve by 3-dimensional shielding transport calculations, using the external environments presented at the beginning of this section, or by using the data given in Figure and Table 3.3.1.3-2. To calculate the final TID specification level for the GEO region (when no 3-dimensional shielding calculations are done), multiply the daily Total TID in Table 3.3.1.3-2 by the number of days in the mission segment and add that number to the total SPE TID as given in Section 3.3.1.10.2. When performing the 3-D shielding calculations, the external trapped electron environment (given as a daily fluence in the above table) is multiplied by the number of mission segment days. That trapped electron fluence and the SPE proton fluence (found in Section 3.3.1.10.2) are then used as inputs to code that will perform the 3-D transport calculations. The output of this code will be the TID specification.

**Model Inputs**

None.

**Limitations**

None.

**Technical Notes**

All environment models were run for the GEO of 35600 km at 0° inclination. The trapped electron environment was defined using the AE8MAX model, as it represents the worst-case electron environment. The mean (50%) model is then scaled by a factor of two to account for the model uncertainty. The GEO is outside the trapped proton belt, so no trapped proton
environment exists. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.4 Interplanetary

While operating at or near in Interplanetary space, the only total dose that will be seen is from a geomagnetic unshielded SPE. That environment is given in Section 3.3.1.10.2.

3.3.1.5 Lunar Orbit

While operating at or near the moon, the only total dose that will be seen is from a geomagnetic unshielded SPE. That environment is given in Section 3.3.1.10.2. While, depending on the orbit altitude, the moon may supply some level of shielding, the unshielded SPE gives a conservative bound. Since other minor radiation sources are not included (e.g., albedo neutrons), it is appropriate to use the conservative bound environment for this region.

3.3.1.6 Lunar Surface

While operating on the lunar surface, the only total dose that will be seen is from a geomagnetic unshielded SPE. That environment is given in Section 3.3.1.10.2. While, depending on the orbit altitude, the moon may supply some level of shielding, the unshielded SPE gives a conservative bound. Since other minor radiation sources are not included (e.g., albedo neutrons), it is appropriate to use the conservative bound environment for this region.

3.3.1.7 Near Earth Asteroid

While operating at or near an NEA, the only total dose that will be seen is from a geomagnetic unshielded SPE. That environment is given in Section 3.3.1.10.2.

3.3.1.8 Mars Orbit

Reserved.

3.3.1.9 Mars Surface

Reserved.

3.3.1.10 Solar Particle Events

3.3.1.10.1 Geomagnetic Shielded

Design Limits

The Earth’s geomagnetic field provides a shield for some of the particles from an SPE. In general, for low inclination orbits (28.5° or less), the geomagnetic field completely screens out the particles. For polar orbits, the conservative approach would be to assume the event happens in the unshielded polar regions and using Section 3.3.1.10.2 would be more appropriate. For all other shielded orbits, the calculations done for the ISS orbit provide good bounding data. Therefore, the total dose contributions for a geomagnetic shielded single Solar Particle Event (SPE) is given below, based on the standard ISS orbit.
Figure 3.3.1.10.1-1 and Table 3.3.1.10.1-1 specify the total SPE proton integral and differential spectra as a function of energy.

![Graph showing SPE proton integral and differential fluences](image)

**Figure 3.3.1.10.1-1. Integral and Differential Proton Fluences of a Shielded SPE**

**Table 3.3.1.10.1-1. Integral and Differential Proton Fluences of a Shielded SPE**

<table>
<thead>
<tr>
<th>Proton Energy</th>
<th>ISS SPE Integral Fluence per event</th>
<th>ISS SPE Differential Fluence per event</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeV</td>
<td>protons/cm²</td>
<td>protons/MeV·cm²</td>
</tr>
<tr>
<td>1.00E-01</td>
<td>7.11E+09</td>
<td>4.02E+10</td>
</tr>
<tr>
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<tr>
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<td>2.80E+09</td>
<td>3.21E+09</td>
</tr>
<tr>
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The electronic version is the official approved document. Verify this is the correct version before use.
<table>
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<tr>
<th>Proton Energy</th>
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<th>ISS SPE Differential Fluence per event</th>
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Figure 3.3.1.10.1-2 and Table 3.3.1.10.1-2 specify total TID inside selected thicknesses of spherical aluminum (Al) shielding from the ISS SPE. 3.3.1.10.1-2 and Table 3.3.1.10.1-2 specify total TID associated with the worst-case as defined in the ESP/PSYCHIC model.
Figure 3.3.1.10.1-2. Total Shielded SPE TID Inside Al Shielding
Table 3.3.1.10.1-2. Total Shielded SPE TID Inside Al Shielding

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<th>Aluminum Shield Depth</th>
<th>Total ISS SPE TID</th>
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<td>cGy(Si)/event</td>
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Model Inputs
None.

Limitations
Probability that the shielded SPE dose will not be exceeded during a single SPE event is estimated at 95%.
Technical Notes

All environment models were run for the assumed ISS orbit of 500 km circular orbit at 51.6° inclination. The shielded SPE TID specification was defined by using the ESP/PSYCHIC model for a one year period during solar maximum conditions with a stormy magnetosphere and a 95% probability of the fluences not being exceeded. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

3.3.1.10.2 Geomagnetic Unshielded

Design Limits

Total dose contributions for a geomagnetic unshielded single Solar Particle Event (SPE) are given below.

Figure 3.3.1.10.2-1 and Table 3.3.1.10.2-1 specify the total unshielded SPE proton integral and differential spectra as a function of energy. Figure 3.3.1.10.2-2 and Table 3.3.1.10.2-2 specify the total unshielded daily GCR proton integral spectra as a function of energy.

Figure 3.3.1.10.2-1. Integral and Differential Proton Fluence of an Unshielded SPE
## Table 3.3.1.10.2-1. Integral and Differential Proton Fluence of an Unshielded SPE

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<th>Unshielded SPE Differential Fluence per event</th>
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<tbody>
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<td>MeV</td>
<td>protons/cm²</td>
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Figure 3.3.1.10.2-2. Daily Unshielded GCR Integral Proton Fluence

Table 3.3.1.10.2-2. Daily Unshielded GCR Integral Proton Fluence

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Figure 3.3.1.10.2-3 and Table 3.3.1.10.2-3 specify total TID associated with the unshielded SPE environment and Table 3.3.1.10.2-4 specify total TID associated with the daily GCR fluence.

Figure 3.3.1.10.2-3. Total Unshielded SPE TID Inside Al Shielding
### Table 3.3.1.10.2-3. Total Unshielded SPE TID Inside Al Shielding

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<th>Total SPE TID cGy(Si)/event</th>
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### Table 3.3.1.10.2-4. Total Unshielded Daily GCR TID Inside Al Shielding

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<th>Aluminum Shield Depth</th>
<th>Daily GCR TID cGy(Si)/day</th>
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<tr>
<td>5.08e+00</td>
<td>2.33E-02</td>
</tr>
</tbody>
</table>

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Verify this is the correct version before use.
### Model Inputs

None.

### Limitations

Probability that the unshielded SPE dose will not be exceeded during a single SPE event is estimated at 95%.

### Technical Notes

All environment models were run for the assumed an orbit external to Earth’s magnetic field. The unshielded SPE TID specification was defined by using the ESP/PSYCHIC model for a one year period during solar maximum conditions with a stormy magnetosphere and a 95% probability of the fluences not being exceeded. The unshielded GCR daily fluence specification was defined by using CREME96 and selecting the “near earth/interplanetary” option. The TID shielding calculations were performed using the SPENVIS Shieldose2 code, solid Aluminum sphere option.

### 3.3.2 Single Event Effects

This section defines the ionizing radiation environments that may produce single event effects in electrical or electronic systems. Peak Galactic Cosmic Radiation (GCR) and Solar Particle Event (SPE) fluxes are encountered inside and outside Earth's magnetic field. In addition to these, inside the Earth's magnetic field, the peak trapped proton flux has to be included. Flux values inside spherical aluminum shielding during exposure to the SPE peak 5-minute average and worst day average fluxes are provided to support evaluation of Single Event Effects (SEE) rate concerns for shielded electronics. GCR and SPE proton fluxes are provided to support evaluation of proton effects on unshielded surface materials external to the Earth's magnetic field. Trapped and SPE proton fluxes are provided to support evaluation of proton effects on unshielded surface materials internal to the Earth's magnetic field.

A *pseudo* region of space is added in Section 3.3.1.10 Solar Particle Events (SPE). Since all the DRM can be considered “near-Earth”, once outside the geomagnetic field, all regions of space will have the same SPE environment definition. So the unshielded subsection is a convenient place to locate this definition, once, and reference it for all the appropriate regions. The shielded SPE environment still remains with and region of space subsection that is inside the Earth’s magnetic field, as the shielding levels are dependent on the location within the magnetic field. The appropriate SPE environment will be determined for each DRM mission segment and incorporated into the DRM IR and Plasma memo.
Table 3.3.2-1 gives the applicability matrix for each of the DRMs (down the right hand column) for each of the regions of space defined in this document (across the top of the table) for Single Event Effects. An “X” is placed in each box where the region of space is applicable to that DRM. For the “Staging and Transit Orbits” column, subsections of 3.3.2.2 are called out as applicable, since not all may be applicable for each DRM.

Unlike the total dose area, for SEE the environments are not summed. For each DRM mission segment, the worst-case environment from that segment will be the design environment incorporated into the DRM memo for that segment. Systems that are required to operate in multiple segments will have to account for all mission segment worst-case environments in their designs.

Note: Tables may contain abbreviated data as compared to the plotted data. Complete data sets are available in electronic form.
### Table 3.3.2-1. Single Event Effects Applicability Matrix for the Design Reference Mission by Regions of Space

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<th>Region</th>
<th>LEO (3.3.2.1)</th>
<th>Staging and Transit Orbits (3.3.2.2)</th>
<th>GEO (3.3.2.3)</th>
<th>Interplanetary (3.3.2.4)</th>
<th>Lunar Orbit (3.3.2.5)</th>
<th>Lunar Surface (3.3.2.6)</th>
<th>NEA (3.3.2.7)</th>
<th>Mars Orbit (3.3.2.8)</th>
<th>Mars Surface (3.3.2.9)</th>
<th>GCR &amp; Solar Particle Event (3.3.2.10)</th>
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#### 3.3.2.1 LEO-ISS Orbit

**Design Limits**

Figure 3.3.2.1-1 and Table 3.3.2.1-1 present the ISS SPE peak rate LET flux inside selected aluminum shield thicknesses as a function of LET. Each thickness value is identical to the radius of the assumed spherical shielding.
Figure 3.3.2.1-2 and Table 3.3.2.1-2 provide the ISS SPE worst day average fluxes for the same shield geometry and thicknesses.

Figure 3.3.2.1-3 and Table 3.3.2.1-3 present integral proton fluxes of an ISS SPE and of the nominal and peak trapped protons.

Figure 3.3.2.1-4 and Table 3.3.2.1-4 present differential proton fluxes of an ISS SPE and of the nominal and peak trapped protons.

![Graph showing ISS SPE integral peak LET flux for selected Al shielding thickness as a function of LET.]

**Figure 3.3.2.1-1. ISS SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET**

**Table 3.3.2.1-1. ISS SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET**

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## Cross-Program Design Specification for Natural Environments (DSNE)

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Figure 3.3.2.1-2. ISS SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET
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## Let and Incident Proton Flux of an ISS SPE and GCR

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*Figure 3.3.2.1-3. Integral Proton Flux of an ISS SPE and GCR*
Table 3.3.2.1-3. Integral Proton Flux for an ISS SPE, Solar Minimum GCR, Average Trapped Protons and Peak Trapped Protons

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**Figure 3.3.2.1-4.** Differential Proton Flux for ISS SPE and Solar Minimum GCR
### Table 3.3.2.1-4. Differential Proton Flux for an ISS SPE, Solar Minimum GCR, Average Trapped Protons and Peak Trapped Protons

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The electronic version is the official approved document. Verify this is the correct version before use.
Model Inputs

None

Limitations

Probability that the ISS SPE Peak Flux will not be exceeded is estimated at 97%.

Technical Notes

All environment models were run for the assumed ISS orbit of 500 km circular orbit at 51.6° inclination. The ISS SPE LET, and trapped proton integral and differential flux specifications were developed using CREME96 assuming a stormy magnetosphere. All SPE fluxes were multiplied by 2 for model uncertainty. CREME96 generates trapped proton fluxes using the AP8MIN model. All trapped proton fluxes are multiplied by 2 for AP8MIN model uncertainty, and by another factor of 2 for the known AP8MIN model underestimation of fluxes at the altitude of the ISS orbit.

A spherical shield model with radius set equal to the minimum shield thickness provides very conservative results. CREME96 can also model flux inside other 3D shield geometries if the distribution of shielding thicknesses is known.

An industry accepted radiation transport code that provides a semi-infinite slab model should be used to define flux at selected depths within surface coatings and materials.

Not all passes through the SAA will constitute a worst-case pass. The worst-case pass is one that traverses the center of the SAA where the proton flux is at a maximum. The duration of one of these passes is nominally 10 minutes but may be as long as 20 minutes. These worst-case passes constitute approximately 3.6% of the LEO Mission time.

3.3.2.2 Staging and Transit Orbits

3.3.2.2.1 Low Earth Orbit 185 x 1806 km

The orbit does stay inside the Earth’s geomagnetic field during the orbit and the environment contains exposure to the trapped protons. Therefore, the SEE environment model parameters for LEO 185 x 1806 km orbit are the trapped protons, geomagnetic shielded GCR and shielded Solar Particle Event.
Figure 3.3.2.2.1-1 and Table 3.3.2.2.1-1 present the SPE peak rate LET flux inside selected aluminum shield thicknesses as a function of LET. Each thickness value is identical to the radius of the assumed spherical shielding.

Figure 3.3.2.2.1-2 and Table 3.3.2.2.1-2 provide the SPE worst day average fluxes for the same shield geometry and thicknesses.

Figure 3.3.2.2.1-3 and Table 3.3.2.2.1-3 present integral proton flux of the peak trapped protons.

![Figure 3.3.2.2.1-1. SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET](image)

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Figure 3.3.2.1-2. SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET
Table 3.3.2.2.1-2. SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET

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<td>Particles/cm^2-</td>
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**Figure 3.3.2.2.1-3. Integral Peak Trapped Proton Flux**
Table 3.3.2.1-3. Integral Proton Flux for the Peak Trapped Protons

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3.3.2.2 Radiation Belt Transit

The SEE environment model parameters for Radiation Belt Transit trajectory are the geomagnetic unshielded GCR and Solar Particle Event. While the orbit does traverse inside the
Earth’s geomagnetic field, a SPE while outside constitutes the worst-case environment. Also, during the orbit the environment contains exposure to the trapped protons. However, very little time is spent in the trapped proton belt and those fluxes would be dominated by the levels of a SPE. Therefore, for Radiation Belt Transit trajectory, SEE environments use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.2.3 Low Earth Orbit 241 km Circular

The SEE environment model parameters for LEO 241 km circular are bounded by those used for the LEO-ISS. For LEO 241 km circular SEE environments use those presented in Section 3.3.2.1 LEO-ISS Orbit.

3.3.2.2.4 High Earth Orbit 407 x 233,860 km

The SEE environment model parameters for HEO orbit are the geomagnetic unshielded GCR and Solar Particle Event. While the orbit does go back inside the Earth’s geomagnetic field, a SPE while outside constitutes the worst-case environment. Also, during the orbit the environment contains exposure to the trapped protons. However, due the highly elliptical nature of the orbit, very little time is spent in the trapped proton belt and those fluxes would be dominated by the levels of a SPE. Therefore, for HEO orbit SEE environments use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.2.5 High Earth Orbit to Near Earth Asteroid Transit

The SEE environment model parameters for HEO to NEA transit are bounded by those used for the GEO. For HEO to NEA transit SEE environments use those presented in Section 3.3.2.3 Geosynchronous Earth Orbit (GEO).

3.3.2.2.6 Low Earth Orbit 407 km Circular

The SEE environment model parameters for LEO 407 km circular are the same as those used for the LEO-ISS. For LEO 407 km circular SEE environments use those presented in Section 3.3.2.1 LEO-ISS Orbit.

3.3.2.2.7 Low Perigee-High Earth Orbit 407 x 400,000 km

The SEE environment model parameters for LP-HEO orbit are the geomagnetic unshielded GCR and Solar Particle Event. While the orbit does go back inside the Earth’s geomagnetic field, a SPE while outside constitutes the worst case environment. Also, during the orbit the environment contains exposure to the trapped protons. However, due the highly elliptical nature of the orbit, very little time is spent in the trapped proton belt and those levels would be dominated by the levels of a SPE. Therefore, for LP-HEO orbit SEE environments use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.
3.3.2.2.8 High Perigee-High Earth Orbit Spiral to 60,000 x 400,000 km

The SEE environment model parameters for HP-HEO spiral are the geomagnetic unshielded GCR and Solar Particle Event. For HP-HEO spiral SEE environments use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.3 Geosynchronous Earth Orbit (GEO)

The SEE environment model parameters for geosynchronous earth orbit are the geomagnetic unshielded GCR and Solar Particle Event. For GEO SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.4 Interplanetary

The SEE environment model parameters for interplanetary space are the geomagnetic unshielded GCR and Solar Particle Event. For interplanetary space SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.5 Lunar Orbit

The SEE environment model parameters for lunar orbit are the geomagnetic unshielded GCR and Solar Particle Event. For lunar orbit SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.6 Lunar Surface

The SEE environment model parameters for the lunar surface are the geomagnetic unshielded GCR and Solar Particle Event. For lunar surface SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.7 Near Earth Asteroid

The SEE environment model parameters for Near Earth Asteroid (NEA) are the geomagnetic unshielded GCR and Solar Particle Event. For NEA SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.8 Mars Orbit

The SEE environment model parameters for Mars orbit are the geomagnetic unshielded GCR and Solar Particle Event. For Mars orbit SEE environments, use those presented in Section 3.3.2.10.2 Geomagnetic Unshielded.

3.3.2.9 Mars Surface

Reserved.

3.3.2.10 GCR and Solar Particle Event

3.3.2.10.1 Geomagnetic Shielded

The geomagnetic shielded environments are defined in the above sections, as required, since the shielding levels are orbit specific.
3.3.2.10.2 Geomagnetic Unshielded

Figure 3.3.2.10.2-1 and Table 3.3.2.10.2-1 present the SPE peak rate LET flux inside selected aluminum shield thicknesses as a function of LET. Each thickness value is identical to the radius of the assumed spherical shielding.

Figure 3.3.2.10.2-2 and Table 3.3.2.10.2-2 provide the SPE worst day average fluxes for the same shield geometry and thicknesses.

Figure 3.3.2.10.2-3 and Table 3.3.2.10.2-3 present integral proton flux of a SPE and of GCR.

Figure 3.3.2.10.2-4 and Table 3.3.2.10.2-4 present differential proton flux for the SPE and solar minimum GCR.

Figure 3.3.2.10.2-5 and Table 3.3.2.10.2-5 present the GCR LET flux (at solar minimum) inside selected aluminum shield thicknesses as a function of LET. Each thickness value is identical to the radius of the assumed spherical shielding.

Figure 3.3.2.10.2-1. SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET
### Table 3.3.2.10.2-1. SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET

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<th>Shield Thickness 0.254 cm (0.6858 g/cm²)</th>
<th>Shield Thickness 2.54 cm (6.858 g/cm²)</th>
<th>Shield Thickness 5.08 cm (13.72 g/cm²)</th>
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The electronic version is the official approved document. Verify this is the correct version before use.
Figure 3.3.2.10.2-2. SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET
Table 3.3.2.10.2-2. SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET

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Figure 3.3.2.10.2-3. Integral Proton Flux of a SPE and GCR
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<th>GCR In-Space (solar min)</th>
<th>SPE Average p+/cm²-s</th>
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<th>SPE Peak Rate p+/cm²-s</th>
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Figure 3.3.2.10.2-4. Differential Proton Flux for SPE and Solar Minimum GCR
### Table 3.3.2.10.2-4. Differential Proton Flux for a SPE and Solar Minimum GCR

<table>
<thead>
<tr>
<th>Proton Energy (MeV)</th>
<th>GCR Solar Minimum Interplanetary Space</th>
<th>SPE Rate (average/180-hr event)</th>
<th>SPE Worst Day (average-worst 18 hrs)</th>
<th>SPE Peak Rate (Peak 5-minute average)</th>
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Figure 3.3.2.10.2-5. GCR Integral LET at Solar Minimum for Selected Al Shielding Thickness as a Function of LET

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

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<th>Shield Thickness 0.0254 cm (0.0686 g/cm²)</th>
<th>Shield Thickness 0.254 cm (0.6858 g/cm²)</th>
<th>Shield Thickness 2.54 cm (6.858 g/cm²)</th>
<th>Shield Thickness 5.08 cm (13.72 g/cm²)</th>
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### Model Inputs

None

### Limitations

Probability that the SPE Peak Flux will not be exceeded is estimated at 97%.

### Technical Notes

All SPE fluxes - peak (5 minutes), worst day, average (worst week) are generated using the CREME96 model, selecting the near Earth interplanetary orbit option of the FLUX module. All model-generated SPE fluxes are multiplied by 2 for model uncertainty. The GCR peak integral

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</table>
flux vs. LET is also generated using CREME96, again for the near Earth interplanetary orbit option, at solar minimum conditions. $Z=1$-$92$ for all LET plots, and $Z=1$ for all proton plots.

A spherical shield model with radius set equal to the minimum shield thickness provides very conservative results. CREME96 can also model flux inside other 3D shield geometries if the distribution of shielding thicknesses is known.

An industry accepted radiation transport code that provides a semi-infinite slab model should be used to define flux at selected depths within surface coatings and materials.

### 3.3.3 Plasma Charging

Plasma interactions with the spacecraft are complex, vary significantly between the different regions of space, and are highly dependent on the spacecraft design and mission timeline. Interactions within each region also vary hourly, daily, and seasonally due to changes in geomagnetic and solar activity. Plasma charging effects include solar array/power system degradation, contamination, ionospheric scintillation, and spacecraft charging, both surface charging and deep dielectric charging (also known as bulk or internal charging). The following sections specify the charging effects, analysis models, and mitigation techniques that should be employed for each region of space. Table 3.3.3-1 identifies the regions of space that are applicable for each Design Reference Mission. For the “Staging and Transit Orbits” column, subsections of 3.3.3.2 are called out as applicable, since not all may be applicable for each DRM.

In general, spacecraft charging is more serious in GEO than in LEO and in Cis-lunar. Plasma interactions can be quite complicated, and there are significant differences between a space vehicle’s interactions with the relatively low energy plasma in the ionosphere and at very high orbits, and in the auroral regions where the higher energy plasma characteristic of higher altitudes penetrates to LEO. Examples of plasma interaction effects with space vehicle are solar array/power system degradation, contamination, ionospheric scintillation, and spacecraft charging.

### Table 3.3.3-1. Plasma Charging Applicability Matrix for the Design Reference Missions by Regions of Space

<table>
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<th>Region of Space</th>
<th>LEO (3.3.3.1)</th>
<th>Staging and Transit Orbits (3.3.3.2)</th>
<th>GEO (3.3.3.3)</th>
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<th>Lunar Orbit (3.3.3.5)</th>
<th>Interplanetary (3.3.3.5)</th>
<th>Lunar Surface (3.3.3.6)</th>
<th>NEA (3.3.3.7)</th>
<th>Mars Orbit (3.3.3.8)</th>
<th>Mars Surface (3.3.3.9)</th>
<th>Polar Orbit (3.3.3.10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distant Retrograde Orbit</td>
<td>X</td>
<td>3.3.3.2.1 3.3.3.2.2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
### LEOSISS Orbit

#### Design Limits

Table 3.3.3.1-1 provides electron densities (Ne, #/m³) and electron temperatures (Te, eV) of the ionospheric plasma in low Earth orbit for use in evaluating current collection on vehicle conducting surface areas such as solar arrays. Surfaces that are not biased with a net potential relative to the plasma environment will only charge a few volts negative at night and a few tens
of volts positive in daylight. Biased solar arrays operating in the relatively dense plasmas in LEO will experience a current drain on the power system, as a result of losses through coupling to the plasma. High voltage solar arrays (with operating voltages exceeding approximately 55 volts) can result in significant charging and require special attention to design to avoid destructive arcing or current collection that exceeds design requirements. The design environments shown in Table 3.3.3.1 represent extreme high and low values for both density and temperatures which bound the conditions spacecraft will encounter in LEO environments for both day and night.

Table 3.3.3.1-1. Ambient Plasma Environment for less than 1000 km Altitude

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne (m$^{-3}$)</td>
<td>1.0e+8</td>
<td>1.0e+13</td>
</tr>
<tr>
<td>Te (eV)</td>
<td>0.03</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Model Inputs
None

Limitations
This environment applies for low Earth orbits less than 1000 km.

Technical Notes
These environments are derived from Minow, 2004. Surface charging is relatively benign in LEO low inclination orbits unless high voltage solar arrays or other exposed high voltage systems are used.

3.3.3.2 Staging and Transit Orbits
3.3.3.2.1 Low Earth Orbit 185 x 1806 km
For surface charging, low inclination, refer to Section 3.3.3.1 for environment parameters.
For surface charging, high inclination, refer to Section 3.3.3.10 for environment parameters.
For internal charging, refer to Section 3.3.3.2.2 for environment parameters.

3.3.3.2.2 Radiation Belt Transit Environment
Figure 3.3.3.2.2-1 and Table 3.3.3.2.2-1 specify the electron integral flux environment for use in analyses of bulk (internal) charging of insulating materials and isolated conductors.
Analysis of discharge events on spacecraft in geostationary or geostationary transfer orbits has shown that in order to generate electric fields exceeding the dielectric strength of materials, the electron flux must typically be sufficient to provide a fluence of approximately $10^{10}$ electrons/cm$^2$ in 10 hours. However, it must be noted that the temperature of the dielectric is important since time constants for charging and discharging are much longer at low temperatures, and evaluation of charging must include the operational temperatures of the materials.

![Figure 3.3.3.2.2-1. Radiation Belt Transit Average Integral Electron Flux](image)

**Figure 3.3.3.2.2-1. Radiation Belt Transit Average Integral Electron Flux**

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Integral Flux (electrons/cm$^2$-sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>3.27E+07</td>
</tr>
<tr>
<td>0.2</td>
<td>2.67E+07</td>
</tr>
<tr>
<td>0.4</td>
<td>1.78E+07</td>
</tr>
<tr>
<td>0.6</td>
<td>1.18E+07</td>
</tr>
</tbody>
</table>

The electronic version is the official approved document. Verify this is the correct version before use.
<table>
<thead>
<tr>
<th>Energy MeV</th>
<th>Integral Flux electrons/cm²·sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>7.88E+06</td>
</tr>
<tr>
<td>1</td>
<td>5.25E+06</td>
</tr>
<tr>
<td>1.2</td>
<td>3.50E+06</td>
</tr>
<tr>
<td>1.4</td>
<td>2.33E+06</td>
</tr>
<tr>
<td>1.6</td>
<td>1.55E+06</td>
</tr>
<tr>
<td>1.8</td>
<td>1.04E+06</td>
</tr>
<tr>
<td>2</td>
<td>6.90E+05</td>
</tr>
<tr>
<td>2.2</td>
<td>4.60E+05</td>
</tr>
<tr>
<td>2.4</td>
<td>3.06E+05</td>
</tr>
<tr>
<td>2.6</td>
<td>2.04E+05</td>
</tr>
<tr>
<td>2.8</td>
<td>1.36E+05</td>
</tr>
<tr>
<td>3</td>
<td>9.06E+04</td>
</tr>
<tr>
<td>3.2</td>
<td>6.04E+04</td>
</tr>
<tr>
<td>3.4</td>
<td>4.02E+04</td>
</tr>
<tr>
<td>3.6</td>
<td>2.68E+04</td>
</tr>
<tr>
<td>3.8</td>
<td>1.79E+04</td>
</tr>
<tr>
<td>4</td>
<td>1.19E+04</td>
</tr>
<tr>
<td>4.2</td>
<td>7.93E+03</td>
</tr>
<tr>
<td>4.4</td>
<td>5.28E+03</td>
</tr>
<tr>
<td>4.6</td>
<td>3.52E+03</td>
</tr>
<tr>
<td>4.8</td>
<td>2.35E+03</td>
</tr>
<tr>
<td>5</td>
<td>1.56E+03</td>
</tr>
<tr>
<td>5.2</td>
<td>1.04E+03</td>
</tr>
<tr>
<td>5.4</td>
<td>6.94E+02</td>
</tr>
<tr>
<td>5.6</td>
<td>4.62E+02</td>
</tr>
<tr>
<td>5.8</td>
<td>3.08E+02</td>
</tr>
<tr>
<td>6</td>
<td>2.05E+02</td>
</tr>
</tbody>
</table>

Refer to Section 3.3.3.3 Geosynchronous Earth Orbit for surface charging environment parameters.

**Model Inputs**

The orbit averaged flux is to be multiplied by the exposure period determined by the time required to transit the radiation belts (but not less than 4 hours) to determine the appropriate total electron fluence to be used in bulk charging analyses.

Surface charging analyses for radiation belt transits should be run with the correct solar illumination.
Limitations

None

Technical Notes

Radiation belt transit environment was derived from Fennell et al. 2000.

3.3.3.2.3  Low Earth Orbit 241 km Circular

Refer to Section 3.3.3.1 for environment parameters.

3.3.3.2.4  High Earth Orbit 407 x 233,860 km

Refer to Section 3.3.3.2.2 for environment parameters.

3.3.3.2.5  High Earth Orbit to Near Earth Asteroid Transit

Refer to Section 3.3.3.2.2 for environment parameters.

3.3.3.2.6  Low Earth Orbit 407 km Circular

Refer to Section 3.3.3.1 for environment parameters.

3.3.3.2.7  Low Perigee-High Earth Orbit 407 x 400,000 km

Refer to Section 3.3.3.2.2 for environment parameters.

3.3.3.2.8  High Perigee-High Earth Orbit Spiral to 60,000 x 400,000 km

Reserved.

3.3.3.3  Geosynchronous Earth Orbit

Table 3.3.3.3-1 provides worst case surface charging in Geosynchronous Earth Orbit (GEO). Given in the table are parameters for a single Maxwellian or bi-Maxwellian plasma population. This allows for a quick analysis using the single Maxwellian or the added fidelity of modeling the plasma environment as a bi-Maxwellian distribution, which is more representative of the actual GEO plasma environment. Either distribution is acceptable to use. The data are from the Spacecraft Charging at High Altitudes (SCATHA) spacecraft.
Table 3.3.3.3-1. Geosynchronous Orbit (GEO) Plasma Environment Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SCATHA “Worst Case” Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrons</td>
</tr>
<tr>
<td>Single Maxwellian</td>
<td></td>
</tr>
<tr>
<td>Number density (#/cm$^3$)</td>
<td>3.00</td>
</tr>
<tr>
<td>Temperature (eV)</td>
<td>12,000</td>
</tr>
<tr>
<td>Current density (nA/cm$^2$)</td>
<td>0.501</td>
</tr>
<tr>
<td>Double Maxwellian</td>
<td></td>
</tr>
<tr>
<td>Number density, population 1 (#/cm$^3$)</td>
<td>0.87</td>
</tr>
<tr>
<td>Temperature, population 1 (eV)</td>
<td>600</td>
</tr>
<tr>
<td>Number density, population 2 (#/cm$^3$)</td>
<td>1.73</td>
</tr>
<tr>
<td>Temperature, population 2 (eV)</td>
<td>25,800</td>
</tr>
</tbody>
</table>

Model Inputs

Charging analyses should be run until surface potentials have obtained equilibrium.

Limitations

None

Technical Notes

Environment parameters were adapted from Purvis et al., 1984 and Gussenhoven and Mullen, 1982.

3.3.3.4 Interplanetary Orbit

Table 3.3.3.4-1 provides space plasma environment parameters for regions in an interplanetary orbit that one might encounter, such as: magnetosheath, plasma mantle, plasma sheet, and solar wind environments. A range of values is provided where applicable to show the variability in the plasma environment in the regime indicated. The magnetosheath environments are solar wind that has been heated when traversing the bow shock and accelerated back to solar wind speeds.
### Table 3.3.3.4-1. Interplanetary Environment Plasma Parameters

<table>
<thead>
<tr>
<th></th>
<th>Electron Density</th>
<th>Electron Temperature</th>
<th>Ion Velocity</th>
<th>Ion Density</th>
<th>Ion Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m⁻³</td>
<td>eV</td>
<td>km/s</td>
<td>m⁻³</td>
<td>eV</td>
</tr>
<tr>
<td>Magnetosheath / magnetotail</td>
<td>10⁶ - 10⁸</td>
<td>10-2000</td>
<td>400-1000</td>
<td>10⁶ - 10⁸</td>
<td>10-10,000</td>
</tr>
<tr>
<td>Solar Wind</td>
<td>10⁵ - 10⁸</td>
<td>12</td>
<td>400-1000</td>
<td>10⁵ - 10⁸</td>
<td>50</td>
</tr>
</tbody>
</table>

**Model Inputs**

None

**Limitations**

These plasma environments are relevant for interplanetary space outside the Earth’s radiation belts.

**Technical Notes**

Interplanetary and terrestrial magnetotail environments are derived from Paterson and Frank, 1994 and Minow et al., 2008. In addition, the solar wind environments are based on statistical analyses of Interplanetary Monitoring Platform (IMP)-6 and IMP-7 (Feldman et al., 1977).

### 3.3.3.5 Lunar Orbit (High and Low)

For free field lunar plasma environments refer to Section 3.3.3.4.

Table 3.3.3.5-1 provides scaling factors for adjusting free field space plasma environment parameters for the low density and high temperatures found in the lunar wake regions (150° and 180°).

#### Table 3.3.3.5-1. Lunar Wake Plasma Parameters

<table>
<thead>
<tr>
<th></th>
<th>Nₑ/Nₑ₀</th>
<th>Tₑ/Tₑ₀</th>
<th>Nᵢ/Nₑ</th>
<th>Tᵢ/Tₑ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake 150°</td>
<td>0.005</td>
<td>7.6</td>
<td>0.1-1</td>
<td>0.01-1</td>
</tr>
<tr>
<td>Wake 180°</td>
<td>0.003</td>
<td>4.5</td>
<td>0.1-1</td>
<td>0.01-1</td>
</tr>
</tbody>
</table>

**Model Inputs**

Nₑ/Nₑ₀ (Tₑ/Tₑ₀) in Table 3.3.3.5-1 refers to the wake density (temperature) divided by the free field density (temperature).
Limitations

This environment does not apply to the lunar surface.

Technical Notes

Scaling of plasma density and temperature in the lunar wake are based on results published by Halekas et al. 2005 and used by Minow, et al., 2008 for characterizing extreme charging environments in the lunar wake.

3.3.3.6 Lunar Surface

Reserved.

3.3.3.7 Near Earth Asteroid

Refer to Section 3.3.3.4 for environment parameters.

3.3.3.8 Mars Orbit

Reserved.

3.3.3.9 Mars Surface

Reserved.

3.3.3.10 POLAR ORBIT

The auroral charging environment is a combination of the ambient background plasma environment typical of low Earth orbit with an accelerated beam of energetic electrons originating in the distant magnetospheric plasma. Nascap-2k uses a Maxwellian distribution to characterize the cold ambient plasma environment for auroral charging and a Fontheim distribution to describe the energetic auroral particle population. The components of the Fontheim distribution are a power law describing the backscattered and secondary electron fluxes, a Maxwellian modeling the energetic part of the spectrum, and a Gaussian representing the monoenergetic high energy electron beam. The plasma charging environment, both the ambient and energetic populations, are shown in Table 3.3.3.10-1.

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Table 3.3.3.10-1. Polar Plasma Parameters

<table>
<thead>
<tr>
<th></th>
<th>n (m⁻³)</th>
<th>kT (eV)</th>
<th>e⁻ current (A/m²)</th>
<th>Width (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>4.70E+05</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power law</td>
<td>50</td>
<td>1.60E+06</td>
<td>5.00E-08</td>
<td></td>
</tr>
<tr>
<td>Maxwellian</td>
<td>2.50E+04</td>
<td>5.00E-07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gaussian</td>
<td>2.50E+04</td>
<td>2.20E-06</td>
<td>5.00E+03</td>
<td></td>
</tr>
</tbody>
</table>

Model Inputs

None

Limitations

None

Technical Notes

Auroral charging analyses are performed in eclipse conditions because darkness is required to obtain the depletions in the ambient plasma environments. Formation of the accelerated electron beams (Gaussian component) is only possible when the ionosphere is in darkness.

3.3.4 Ionizing Radiation Environment for Crew Exposure

Description

This specification describes the ionizing radiation environment to be used to analyze risk to astronauts for design analyses. The radiation environments of concern to ensure crew health and safety are significantly different in scope and content than are those of concern for ensuring reliability and sustainability of flight hardware and materials. Inclusion of these environments, therefore, is not a duplication or supersedence of the environments specified in Sections 3.3.1 and 3.3.2. SPE, trapped proton, trapped electron, and GCR descriptions are established here to be used as design environments for evaluating crew exposures for all design analyses.

Design Limits

Crew radiation exposure design limits and verification requirements are defined in MPCV 70024, Orion Multi-Purpose Crew Vehicle Program Human-Systems Integration Requirements, Section 3.2.7. Exposures attributed to both SPE and GCR will be calculated for free space. Free-space quantities for LEO scenario analyses may be divided by two (2) to account for effects of the Earth’s magnetic field.

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Solar minimum conditions have been specified for trapped and GCR sources as a conservative basis for crew dose analysis. Solar maximum fluences will not be used.

Trapped radiation will not be considered for purposes of evaluating design analyses beyond a maximum McIlwain L value of 12.

**Model Inputs**

**SPE Source:**

The design reference SPE environment is given by the parameterization of the event total proton integral spectrum of J. H. King’s “Solar Proton Fluences for 1977-1983 Space Missions.” This omnidirectional proton spectrum is given in the inclusive energy range [0.01, 1,000] MeV by the following expressions:

Integral: \[ J(>E) = J_0 \exp\left(\frac{30-E}{E_0}\right) \]

Differential: \[ J(E) = \left(\frac{J_0}{E_0}\right) \exp\left(\frac{30-E}{E_0}\right) \]

With \( J_0 = 7.9 \times 10^9 \) particles/cm\(^2\), and \( E_0 = 26.5 \) MeV

Analysis fluences and resultant exposure values will be reported as totals per event for the analysis profile. Event total differential spectrum is listed in Table 3.3.4-1. These model spectra are available to all contractors, if they so choose, as Government Furnished Equipment (GFE).

### Table 3.3.4-1. SPE Design Event Differential Spectra

<table>
<thead>
<tr>
<th>Energy (MeV/n)</th>
<th>Free Space Differential Spectrum (particles/(MeV-cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>9.244E+08</td>
</tr>
<tr>
<td>0.03</td>
<td>9.237E+08</td>
</tr>
<tr>
<td>0.06</td>
<td>9.227E+08</td>
</tr>
<tr>
<td>0.10</td>
<td>9.213E+08</td>
</tr>
<tr>
<td>0.30</td>
<td>9.144E+08</td>
</tr>
<tr>
<td>0.60</td>
<td>9.041E+08</td>
</tr>
<tr>
<td>1.00</td>
<td>8.905E+08</td>
</tr>
<tr>
<td>1.50</td>
<td>8.739E+08</td>
</tr>
<tr>
<td>2.00</td>
<td>8.575E+08</td>
</tr>
<tr>
<td>3.00</td>
<td>8.258E+08</td>
</tr>
<tr>
<td>4.00</td>
<td>7.952E+08</td>
</tr>
<tr>
<td>6.00</td>
<td>7.374E+08</td>
</tr>
<tr>
<td>8.00</td>
<td>6.838E+08</td>
</tr>
<tr>
<td>10.00</td>
<td>6.341E+08</td>
</tr>
<tr>
<td>14.00</td>
<td>5.453E+08</td>
</tr>
</tbody>
</table>
GCR Source:

The design reference GCR environment is given by the O’Neill-Badhwar model by P. M. O’Neill (2006). Species in the inclusive range $Z = [1,26]$ will be included for the inclusive energy range $[0.01, 50,000]$ MeV/n. Fluences are assumed omnidirectional in units of particles/(cm$^2$-MeV-day). Solar modulation for solar minimum (1977) is required, as given by a solar deceleration potential scalar parameter of $\Phi=748$ MV (Megavolts). Analysis fluences and resultant exposure values will be reported as average per day over the duration of the analysis profile.
Differential spectra for P, C, N, O, and Fe are tabulated for reference in Table 3.3.4-2. This model is available to all contractors, if they so choose, as GFE.

Table 3.3.4-2. GCR Design Differential Spectra (Solar Minimum)

<table>
<thead>
<tr>
<th>Energy (MeV/n)</th>
<th>P</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.168</td>
<td>1.89E-03</td>
<td>2.26E-05</td>
<td>1.74E-03</td>
<td>1.02E-04</td>
</tr>
<tr>
<td>0.03</td>
<td>0.168</td>
<td>1.89E-03</td>
<td>2.26E-05</td>
<td>1.74E-03</td>
<td>1.02E-04</td>
</tr>
<tr>
<td>0.06</td>
<td>0.168</td>
<td>1.89E-03</td>
<td>2.26E-05</td>
<td>1.74E-03</td>
<td>1.02E-04</td>
</tr>
<tr>
<td>0.13</td>
<td>0.212</td>
<td>2.40E-03</td>
<td>4.20E-05</td>
<td>2.21E-03</td>
<td>1.32E-04</td>
</tr>
<tr>
<td>0.23</td>
<td>0.354</td>
<td>3.94E-03</td>
<td>1.38E-04</td>
<td>3.64E-03</td>
<td>2.26E-04</td>
</tr>
<tr>
<td>0.37</td>
<td>0.549</td>
<td>5.99E-03</td>
<td>3.44E-04</td>
<td>5.52E-03</td>
<td>3.47E-04</td>
</tr>
<tr>
<td>0.55</td>
<td>0.817</td>
<td>8.71E-03</td>
<td>7.32E-04</td>
<td>8.01E-03</td>
<td>5.08E-04</td>
</tr>
<tr>
<td>0.81</td>
<td>1.189</td>
<td>0.013</td>
<td>1.42E-03</td>
<td>1.15E-02</td>
<td>7.26E-04</td>
</tr>
<tr>
<td>1.16</td>
<td>1.708</td>
<td>0.018</td>
<td>2.57E-03</td>
<td>1.63E-02</td>
<td>1.03E-03</td>
</tr>
<tr>
<td>1.64</td>
<td>2.426</td>
<td>0.025</td>
<td>4.40E-03</td>
<td>2.30E-02</td>
<td>1.45E-03</td>
</tr>
<tr>
<td>2.30</td>
<td>3.420</td>
<td>0.035</td>
<td>7.18E-03</td>
<td>3.22E-02</td>
<td>2.02E-03</td>
</tr>
<tr>
<td>3.22</td>
<td>4.801</td>
<td>0.049</td>
<td>1.12E-02</td>
<td>4.50E-02</td>
<td>2.82E-03</td>
</tr>
<tr>
<td>4.48</td>
<td>6.706</td>
<td>0.069</td>
<td>1.69E-02</td>
<td>6.27E-02</td>
<td>3.93E-03</td>
</tr>
<tr>
<td>6.22</td>
<td>9.338</td>
<td>0.096</td>
<td>2.46E-02</td>
<td>8.72E-02</td>
<td>5.45E-03</td>
</tr>
<tr>
<td>8.61</td>
<td>12.951</td>
<td>0.133</td>
<td>3.46E-02</td>
<td>0.120601</td>
<td>7.53E-03</td>
</tr>
<tr>
<td>11.91</td>
<td>17.956</td>
<td>0.183</td>
<td>4.76E-02</td>
<td>0.166589</td>
<td>1.04E-02</td>
</tr>
<tr>
<td>13.03</td>
<td>19.660</td>
<td>0.200</td>
<td>5.18E-02</td>
<td>0.182143</td>
<td>1.14E-02</td>
</tr>
<tr>
<td>14.26</td>
<td>21.517</td>
<td>0.219</td>
<td>5.62E-02</td>
<td>0.199043</td>
<td>1.24E-02</td>
</tr>
<tr>
<td>15.59</td>
<td>23.543</td>
<td>0.239</td>
<td>6.09E-02</td>
<td>0.217392</td>
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### Free Space Differential Spectrum (#/(MeV·cm²·day))

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The electronic version is the official approved document.
Verify this is the correct version before use.
Trapped Radiation Sources:

The design reference for trapped particle environments for protons and electrons is given by the AP-8 and AE-8 minimum (Sawyer and Vette, 1976, and Vette, 1991 respectively) using the International Geomagnetic Reference Field (IGRF) magnetic field (epoch 1965) for calculations of magnetic field magnitude $|B|$ and the MacIlwain L parameter as input.

LEO analysis will be determined using circular orbits at 51.6° inclination and 500 km altitude. LEO analysis fluences and resultant exposure values will be reported as average per day over the duration of the analysis profile.

Translunar insertion trajectory analysis fluences and resultant exposure values will be reported as totals per transit for the analysis profile. These model trapped spectra are available to all contractors, if they so choose, as GFE.

Limitations

None

Technical Notes

Crew exposure will be managed As Low As Reasonably Achievable (ALARA) per CxP 70024, Section 3.2.7.1.1, Cradle ID-HS3085.
A technical description of the LEO environment and free-space GCR environment applicable to crew health concerns may be found in the National Council on Radiation Protection and Measurements (NCRP) Report Number 132, Radiation Protection Guidance for Activities in Low-Earth Orbit, Chapter 3, and in NCRP Report Number 142, Operational Radiation Safety Programs for Astronauts in Low-Earth Orbit: A Basic Framework, Chapter 4.

GCR and trapped proton dose contributions are greatest during the solar minimum portion of the solar cycle, roughly a factor of two (2) more than during solar maximum. Therefore, solar minimum conditions are appropriate for prediction of design requirements for crew protection.

Earth’s magnetic field deflects part of the SPE and GCR radiation so that exposure in LEO is roughly a factor of two (2) less than that in free space.

Technical information on the current and historical versions of the IGRF model is available at http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html.

3.3.5 Reserved

3.3.6 Meteoroid and Orbital Debris Environment

Description

This section specifies the meteoroid and orbital debris (M/OD) environments that pose an impact threat during in-space operations. Orbital debris is only of concern in Earth orbit. Meteoroids must be considered a threat during Earth orbit, lunar and interplanetary missions. Meteoroid storms are not included in this section, as they are mitigated operationally and not during the design phase. Meteoroids and orbital debris should be considered in combination, as their risk is cumulative. Mass, size, velocity, and density are used to compute penetrations and effectiveness of shielding.

Design Limits

For All Phases:

The meteoroid models for the Earth, lunar and interplanetary phases can be found in the Meteoroid Engineering Model, Release 2 (MEM R2) software package. The orbital debris environment in Earth orbit is described by the Orbital Debris Engineering Model 3.0 (ORDEM 3.0).

LEO Mission Phase:

Detailed flux, speed, and directionality limits in the M/OD environments are to be derived using precise inputs for the environment models, specifically the DRM parameters as specified in ESD 10012. Orbital Debris Engineering Model 3.0 (ORDEM 3.0) will be used for the orbital debris environment. The meteoroid environment is defined by the MEM R2.

Lunar Mission Phase:
The meteoroid environment for spacecraft orbiting the Moon is defined by MEM R2. Orbital debris is not a threat in lunar orbit.

**Model Inputs**

**LEO Mission Phase:**

Use the DRM orbital parameters and mission durations as inputs into ORDEM 3.0 to calculate the debris flux, speed, and directionality. Additional information is required for input into MEM R2 since the model requires a series of state vectors along an orbit in order to define the meteoroid environment. Use the given orbital altitude and inclination as defined by the DRM parameters with various orbit orientation angles (Right Ascension of Ascending Node or RAAN, argument of perigee, and true or mean anomaly), to construct a series of state vectors in Earth-centered inertial (ECI) coordinate frame for input into MEM R2. Mission durations should be chosen based on the DRM parameters.

**Lunar Mission Phase:**

Use state vectors in the Moon-centered inertial (MCI) coordinate frame, constructed from the orbital parameters and mission durations specified in ESD 10012 as inputs into MEM R2. As mentioned above, state vectors can be generated (given orbital altitude and inclination) with a variety of orbit orientation angles. State vectors representing the distant retrograde orbits can also be used in MEM R2.

**Limitations**

**For All Phases:**

ORDEM provides expectation values and uncertainties for the orbital debris environment parameters. MEM only models the mass ranges from $10^{-6}$ grams to 10 grams (those particles considered a threat to spacecraft) and does not provide uncertainties. A future release of MEM will address uncertainties.

The meteoroid environment is especially sensitive to the orbital plane’s orientation relative to the Sun. The highest flux rates occur when the orbital plane is closest to the ecliptic plane. The current DRM parameters lack specific information, making it difficult to define the design limits for the meteoroid environment. Consult the models’ help files for instructions on how many random draws are necessary to adequately sample the range of orbit Right Ascension of Ascending Nodes (RAAN).

Meteor showers are included in an average sense in the overall flux values from MEM R2. See the NEDD for specific details.

**LEO Mission Phase:**

The orbital debris model, ORDEM 3.0, models the environment up to geosynchronous orbit altitude (36,000 km altitude). MEM R2 contains models for Earth orbit, lunar orbit and interplanetary space.
Figure 3.3.6-1 illustrates possible extremes, with respect to direction, for each surface of a cubical spacecraft in the meteoroid environment over one LEO of a mission. The extremes for surface orientation displayed are, for example, orbits with a RAAN of 180° and 0° during the summer solstice and the vernal equinox of 2020 (an example year). Beta angles are also included to demonstrate the variability in meteoroid directionality. For each surface, the figure displays the cumulative total fluence over one orbit calculated in 1-minute time steps. Please see the MEM R2 documentation for a detailed description of the cube attitude.

**Lunar Mission Phase:**

The meteoroid model, MEM R2, lunar orbit option is valid for spacecraft orbiting the Moon for altitudes no greater than the Moon’s sphere of influence. Beyond this altitude, the interplanetary option should be used.

This figure is for illustration only.

*Figure 3.3.6-1. Cumulative Surface Fluence for a Limiting Mass of $10^{-6}$ g Over One Orbit At 51.6° Inclination, 450 Km Altitude, Year 2020 with Different RAANs*

**All Mission Phases:**
The debris environment is directional, and in LEO is generally fixed with regard to a vehicle’s orbital motion reference frame, whereas the meteoroid environment is fixed relative to the Sun. This means that the perceived meteoroid environment will vary with time, as the orbit (and vehicle) changes orientation relative to the solar direction. This will require the evaluation of the meteoroid fluxes throughout the course of the mission, as described by the DRM parameters and mission durations. The meteoroid model will evaluate the meteoroid flux throughout the course of the mission if the user defined state vectors adequately describe the vehicle’s position and velocity along the orbit whether it is in Earth orbit, lunar orbit, or heliocentric orbit.

3.3.7 Earth Gravitational Field

Description

Accurate gravity models are required for precision navigation, operational planning, and long-term orbit propagations; however, the use of high degree and order models are generally not needed for flight system design. It is usually sufficient for the design and development of flight hardware (for example, propulsion, telecom, and GN&C hardware) to truncate an Earth gravity field to approximately degree and order 8. As a result, in keeping with the overall objective of the DSNE, a complete description of the recommended Earth gravity model will not be provided in this document. The reader is referred to the NEDD for general gravity field formulation information.

Design Limits

Earth Gravity model, GRACE model GGM02C, is used to evaluate the gravitational field strength for use in hardware applications. The truncation to degree and order 8 is acceptable for hardware design.

Model Inputs

The gravity field is available online at the following web site:
http://www.csr.utexas.edu/grace/gravity/.

Limitations

As stated above, a truncated gravity field may be utilized for the design and development of flight hardware. For design applications, truncation to degree and order less than 8 require supporting error analysis.

Technical Notes

The GRACE gravity model GGM02C is a 200th spherical harmonic degree and order model that combines approximately 1 year of GRACE K-band range-rate, attitude, and accelerometer data with surface gravity and mean sea surface information. The model was released in October 2004.
3.3.8 Lunar Gravitational Field

Description

To a much greater extent than for Earth, the use of accurate gravity models is required at the Moon for precision navigation, operational planning, and long-term orbit propagations due to the complex nature of the lunar gravity field and the lower altitudes at which lunar spacecraft are typically flown. The reader is referred to the NEDD for general gravity field formulation information.

The Gravity Recovery and Interior Laboratory (GRAIL) lunar gravity model will be used for Exploration missions. The GRAIL mission placed two spacecraft into the same orbit around the Moon. As they flew over areas of greater and lesser gravity, caused both by visible features such as mountains and craters and by masses hidden beneath the lunar surface, they moved slightly toward and away from each other. An instrument aboard each spacecraft measured the changes in their relative velocity very precisely, and this information was translated into a high-resolution map of the Moon's gravitational field. This gravity-measuring technique is essentially the same as that of the Gravity Recovery And Climate Experiment (GRACE), which began mapping Earth's gravity in 2002.

Design Limits

The GRAIL Lunar Gravity Model is needed for precise orbit determination. Adequate sensitivity analyses are needed to assure that the design will cover the range of Design Reference Missions.

Model Inputs

The GRAIL model may be truncated to fewer terms for use in different applications. It is recommended that sensitivity analyses be performed to determine if the lower fidelity field is adequate for the particular application.

The gravity field is available online at the following Planetary Data System (PDS) web site:

http://pds-geosciences.wustl.edu/grail/grail-l-lgrs-5-rdr-v1/grail_1001/shadr/

Note that there are 3 models available at this site; one from Goddard Space Flight Center (gggrx_0660pm_sha) and two developed by the Jet Propulsion Laboratory (jggrx_0420a_sha and jjgrx_0660b_sha). Except for small data weighting and calibration differences the two models are nearly identical for the low degree and order generally used for mission planning and operations. The GSFC model gggrx_0660pm_sha should be used for consistency across the Exploration Programs. The binary files in the following location

http://pds-geosciences.wustl.edu/grail/grail-l-lgrs-5-rdr-v1/grail_1001/shbdr/

also contain the covariance matrices useful for error analyses.

The models on the PDS site are tide-free and do not contain the corrections for permanent Earth tide needed by some orbit propagators. If the design team using this model determines that the
added accuracy from tidal corrections is necessary, then the corrected coefficients should be calculated using

\[
C_{20}\text{ perm tide} = C_{20}\text{ tide-free} - 1.6541\times10^{-6} \times k_2
\]

\[
C_{22}\text{ perm tide} = C_{22}\text{ tide-free} + 2.8676\times10^{-6} \times k_2
\]

Where the \( k_2 \) tidal Love number is found in the .LBL file and \( C_{20\text{ tide-free}} \) and \( C_{22\text{ tide-free}} \) coefficients are in the .TAB file. The proper planetary ephemeris to use with the model is also found in the .LBL file. The values of lunar radius and GM are found in the .TAB file. Refer to the .LBL file for locations of those values and description of the model format.

**Limitations**

The GRAIL model is a vast improvement over the previous models which had no direct measurements of the field of the lunar farside. While the SHA (ASCII) version .TAB file contains estimates of the errors for each individual model coefficients, the SHB (binary) .DAT files contain the covariance matrix for use in Monte Carlo analyses if desired. Although truncation of the model is acceptable sensitivity analyses should be performed to allow trades between computational efficiency and orbit propagation accuracy.

A different correction for the permanent tide can be computed including the Earth and the Sun but the inclusion of the Sun only adds another 0.5\% to the permanent tide correction.

The GRAIL models have not been evaluated for orbit prediction and navigation performance for low-degree or truncated fields.

**Technical Notes**

The GRAIL mission is described at this web site:


For operational considerations, the accuracy of the lunar gravity field is very important. Since there is essentially no atmosphere on the Moon, spacecraft may use very low-altitude orbits (for example, 100 km or lower). At low altitudes, the variations in the lunar gravity field have a large effect on long-term orbit stability. For example, without some type of orbit maintenance or station keeping a satellite placed in a circular polar lunar orbit at 100 km altitude will impact the surface in about 160 days.

**3.3.9 Thermal Environment for In-Space Hardware**

**Description**

This section specifies the external thermal parameters that determine the spacecraft heat balance, solar irradiance, Earth and lunar albedo radiation and emitted long-wave radiation. In addition to the environmental parameters, spacecraft temperatures are dependent on internal sources of thermal energy and the spacecraft geometric configuration.
3.3.9.1 Thermal Environment for Lunar Phases

Design Limits

From the perspective of external environmental conditions, the hot extreme will occur in lunar orbit. The short-term (<1 hour) cold extreme will occur in lunar orbit during eclipse; otherwise, it will occur in the Earth-Moon transit phase. See the NEDD, Section 12.6 Lunar Eclipse, for detail.

The solar constant, as defined in Section 3.3.9.2, applies to lunar orbit. However, there is an enhanced range of variation due to changes in Moon-Sun distance caused by the Moon orbiting the Earth. This motion adds or subtracts up to 405,504 km to the variations in the Earth-Sun distance considered in Section 3.3.9.2, so the effective solar constant range is as follows (does not include a ±5 W/m² measurement uncertainty):

- Maximum solar flux: 1,421 W/m²
- Mean solar flux: 1,367 W/m² (Solar Constant)
- Minimum solar flux: 1,315 W/m²

For the near side of the Moon, average values of the normal albedo are provided by Dollfus and Bowell, 1971 for wavelengths from 0.327 µ to 1.050 µ. To convert this data to an average bolometric value, the data was averaged weighted by the solar spectrum as approximated by a blackbody curve for 5,780 K. The resulting value is:

Average bolometric normal albedo = 0.12 (lunar near side)

Local surface variations will cause an orbiting spacecraft to experience short-term variations about this value. These could range from a low of 0.07 to a high of 0.20. The average reflectivity is 164 W/m² with a maximum of 285 W/m² and minimum of 91 W/m² for the near side.

The surface of the far side of the Moon is dominated by "lunar highlands" terrain that tends to be somewhat brighter than the near side, which has numerous darker maria. For the far side, local normal albedo data is available for the waveband at 750-nm from UV/Vis instrument (camera) from the Clementine mission. Noting that the curve fit of albedo against wavelength for the near side data crossed 750-nm essentially right at the average value, 0.12, it can be assumed that the 750-nm normal albedo will be a close approximation to the normal bolometric albedo. Thus, the following (Lawson et al., 2000):

Average bolometric normal albedo = 0.15 (lunar far side)

Temporal variation about this value will be ±0.05. The average reflectivity is 154 W/m² with a maximum of 285 W/m² and minimum of 131 W/m² for the far side.

The ranges of variation quoted here should bound the values seen by low orbiting spacecraft. In higher orbits, some spatial averaging will occur and the range of variation will diminish somewhat.
Lunar Long-Wave Radiance

Analysis of the Long-Wave Infrared Camera (LWIR) data from the Clementine mission (Lawson et al., 2000) indicates that the radiance from the Moon, as viewed by a nadir-looking spacecraft, can be well represented by a simple Lambertian thermal balance model. The term Lambertian implies equal scattering in all directions. Given the slow rotation rate of the Moon, effects of thermal inertia on the surface can be neglected for this application. On this basis, the thermal balance at the lunar sub-solar point can be expressed by the Stefan-Boltzmann law:

$$\varepsilon \sigma T_s^4 \approx (1 - \bar{\alpha}) S_o/R_L^2$$

where:
- $\varepsilon$ is the long-wave emissivity of the surface, assumed to equal 1
- $\sigma$ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ W m}^{-2} \text{K}^{-4}$)
- $T_s$ is the lunar surface temperature at the sub-solar point
- $\bar{\alpha}$ is the average lunar normal bolometric albedo = 0.15
- $S_o$ is the average solar constant at 1 AU from Section 7.2.1.1

On the sunlit side, the solar irradiance varies as $\cos(i)$, where $i$ is the solar incidence angle (the angle between the Moon-Sun vector and the Moon-satellite vector). A good approximation for the gross lunar surface temperature variation is therefore:

$$T \approx T_s \cos^{1/4}(i)$$

As a result the lunar long-wave radiance on the sunlit side is:

$$I_{LW} \approx \varepsilon \sigma T^4 \approx (1 - \bar{\alpha}) S_o \cos(i)$$

The uncertainty and range of variation due to local albedo effects is approximately 270 W/m² at the sub-solar point. This corresponds to a ±20 K surface temperature variation. As the solar incidence angle increases to ~ 80°, the range of surface temperature variation increases to ~ 60 K, but the irradiance variation is much less than at the sub-solar point because of the power law.

On the dark side, the first part of this expression still applies:

$$I_{LW} \approx \varepsilon \sigma T^4$$

with the dark side temperature equal to 100, ±20 K. (The analyst may wish to add an interpolation over the small discontinuity at $i = 90^\circ$.)

Space sink temperature: 3 K
Orbital beta angle: 0 to 90°

Lunar Eclipse
A lunar eclipse occurs when the Earth is between the Sun and the Moon, and the Earth's shadow falls on the Moon. The Moon's orbit is 5° inclined with respect to the Earth's orbit around the Sun. This results in a lunar eclipse occurring only when the ascending or descending nodes fall in the ecliptic during a full moon. Lunar eclipse tables can be found at http://sunearth.gsfc.nasa.gov/eclipse/lunar.html for the years 1901 through 2100. There may be up to five lunar or solar eclipses in a year but the combined total of both will never exceed seven.

There are three types of lunar eclipses: penumbral, partial, or total. During a penumbral eclipse, the Moon only encounters the penumbral shadow. A partial eclipse will have only part of the Moon going through the penumbral and umbral shadows. However, during a total eclipse, the Moon experiences all three types of events during the eclipse: penumbral, partial, and total. Light is refracted in the Earth's atmosphere and will give the Moon an orange, red, blue green, or purple hue while totally immersed in the umbra. The color is dependent on atmospheric conditions on Earth while the Moon is experiencing totality.

The stellar apparent magnitude is a numerical value of the observed brightness of a celestial object as seen from Earth. A full moon has an apparent magnitude of -12.6 (the brighter an object the lower the numerical value), while the Moon during totality ranges from -3.5 to 1.5. These numbers are derived using an eclipse model during mid-eclipse. Using these computed values, the solar flux can be calculated during an eclipse from the following equations:

\[ \Delta m = m_{\text{eclipse}} - m_{\text{full moon}} = m_1 - m_0 \]  
Calculates the decrease in apparent magnitude during an eclipse.

\[ I_0 = 10^{\Delta m/2.5} \]  
Calculates the ratio of brightness of a full moon to the eclipsed Moon \( I_1 \)

\[ \text{Eclipse flux} = 1367 \text{ W/m}^2 \]  
Calculates the solar flux during a lunar eclipse using the average \( I_0/I_1 \) solar flux at the Moon of 1,367 W/m²

This corresponds to 0.03% to 0% of solar flux reaching this region. This is of concern to a spacecraft orbiting the Moon if the spacecraft is dependent on solar energy.

During the years 2018-2035, the worst case lunar eclipse occurs on June 26, 2029. Using the data from this eclipse as an example, a spacecraft in a circular orbit would experience totality for the following altitudes vs. times around the Moon and would experience worst case minimum solar flux for times indicated in Table 12.6-1.

### Table 3.3.9.1-1. Projected Worst Case Minimum Solar Flux during Lunar Eclipse, Dated June 26, 2029

<table>
<thead>
<tr>
<th>Orbit Altitude</th>
<th>Totality</th>
<th>No Solar Flux (Worst Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 km</td>
<td>188 minutes</td>
<td>233 minutes</td>
</tr>
<tr>
<td>500 km</td>
<td>197 minutes</td>
<td>242 minutes</td>
</tr>
<tr>
<td>1,000 km</td>
<td>177 minutes</td>
<td>234 minutes</td>
</tr>
</tbody>
</table>

#### 3.3.9.2 Thermal Parameters for Near-Earth Phases
Limits for Earth orbit cases where spacecraft configuration, power usage, or operations differ from the lunar orbit cases such that thermal performance needs to be evaluated are given below:

Space sink temperature: 3 K

Orbital beta angle: 0 to 56° (lunar missions)

0 to 75° (ISS missions)

Maximum: Solar constant: 1,414 W/m²

Albedo, long-wave radiance pairs per the hot cases in Table 3.3.9.2-1 for lunar missions or Table 3.3.9.2-2 for ISS missions.

Minimum: Solar constant: 1,322 W/m²

Albedo, long-wave radiance pairs per the cold cases in Table 3.3.9.2-1 for lunar missions or Table 3.3.9.2-2 for ISS missions.
### Table 3.3.9.2-1. Albedo, Outgoing Longwave Radiation (OLR) Pairs for Critical Systems in Low-Inclination Orbits

<table>
<thead>
<tr>
<th>Averaging Time</th>
<th>Minimum Albedo Alb ↔ OLR (W/m²)</th>
<th>Combined Minimum Alb ↔ OLR (W/m²)</th>
<th>Minimum OLR Alb ↔ OLR (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 second</td>
<td>0.06 ↔ 273</td>
<td>0.13 ↔ 225</td>
<td>0.40 ↔ 150</td>
</tr>
<tr>
<td>128 second</td>
<td>0.06 ↔ 273</td>
<td>0.13 ↔ 226</td>
<td>0.38 ↔ 154</td>
</tr>
<tr>
<td>896 second</td>
<td>0.07 ↔ 265</td>
<td>0.14 ↔ 227</td>
<td>0.33 ↔ 173</td>
</tr>
<tr>
<td>30 minute</td>
<td>0.08 ↔ 261</td>
<td>0.14 ↔ 228</td>
<td>0.30 ↔ 188</td>
</tr>
<tr>
<td>90 minute</td>
<td>0.11 ↔ 258</td>
<td>0.14 ↔ 228</td>
<td>0.25 ↔ 206</td>
</tr>
<tr>
<td>6 hr</td>
<td>0.16 ↔ 245</td>
<td>0.16 ↔ 232</td>
<td>0.19 ↔ 224</td>
</tr>
<tr>
<td>24 hr</td>
<td>0.16 ↔ 240</td>
<td>0.16 ↔ 235</td>
<td>0.18 ↔ 230</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Averaging Time</th>
<th>Maximum Albedo Alb ↔ OLR (W/m²)</th>
<th>Combined Maximum Alb ↔ OLR (W/m²)</th>
<th>Maximum OLR Alb ↔ OLR (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 second</td>
<td>0.43 ↔ 182</td>
<td>0.30 ↔ 298</td>
<td>0.22 ↔ 331</td>
</tr>
<tr>
<td>128 second</td>
<td>0.42 ↔ 181</td>
<td>0.29 ↔ 295</td>
<td>0.22 ↔ 326</td>
</tr>
<tr>
<td>896 second</td>
<td>0.37 ↔ 219</td>
<td>0.28 ↔ 291</td>
<td>0.22 ↔ 318</td>
</tr>
<tr>
<td>30 minute</td>
<td>0.33 ↔ 219</td>
<td>0.26 ↔ 284</td>
<td>0.17 ↔ 297</td>
</tr>
<tr>
<td>90 minute</td>
<td>0.28 ↔ 237</td>
<td>0.24 ↔ 275</td>
<td>0.20 ↔ 285</td>
</tr>
<tr>
<td>6 hr</td>
<td>0.23 ↔ 248</td>
<td>0.21 ↔ 264</td>
<td>0.19 ↔ 269</td>
</tr>
<tr>
<td>24 hr</td>
<td>0.22 ↔ 251</td>
<td>0.20 ↔ 260</td>
<td>0.19 ↔ 262</td>
</tr>
</tbody>
</table>

Mean Albedo: 0.18  
Mean OLR: 246

Albedo and OLR values are referenced to the “top of the atmosphere,” $R_e + 30$ km.
### Table 3.3.9.2-2. Albedo, OLR Pairs for Critical Systems in Medium-Inclination Orbits

<table>
<thead>
<tr>
<th>Averaging Time</th>
<th>Minimum Albedo Alb ⇔ OLR (W/m²)</th>
<th>Combined Minimum Alb ⇔ OLR (W/m²)</th>
<th>Minimum OLR Alb ⇔ OLR (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 second</td>
<td>0.06 ⇔ 273</td>
<td>0.15 ⇔ 213</td>
<td>0.40 ⇔ 151</td>
</tr>
<tr>
<td>128 second</td>
<td>0.06 ⇔ 273</td>
<td>0.15 ⇔ 213</td>
<td>0.38 ⇔ 155</td>
</tr>
<tr>
<td>896 second</td>
<td>0.08 ⇔ 262</td>
<td>0.17 ⇔ 217</td>
<td>0.34 ⇔ 163</td>
</tr>
<tr>
<td>30 minute</td>
<td>0.12 ⇔ 246</td>
<td>0.18 ⇔ 217</td>
<td>0.27 ⇔ 176</td>
</tr>
<tr>
<td>90 minute</td>
<td>0.16 ⇔ 239</td>
<td>0.19 ⇔ 218</td>
<td>0.30 ⇔ 200</td>
</tr>
<tr>
<td>6 hr</td>
<td>0.18 ⇔ 238</td>
<td>0.19 ⇔ 221</td>
<td>0.31 ⇔ 207</td>
</tr>
<tr>
<td>24 hr</td>
<td>0.19 ⇔ 233</td>
<td>0.20 ⇔ 223</td>
<td>0.25 ⇔ 210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Averaging Time</th>
<th>Maximum Albedo Alb ⇔ OLR (W/m²)</th>
<th>Combined Maximum Alb ⇔ OLR (W/m²)</th>
<th>Maximum OLR Alb ⇔ OLR (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 second</td>
<td>0.48 ⇔ 180</td>
<td>0.31 ⇔ 267</td>
<td>0.21 ⇔ 332</td>
</tr>
<tr>
<td>128 second</td>
<td>0.47 ⇔ 180</td>
<td>0.30 ⇔ 265</td>
<td>0.22 ⇔ 331</td>
</tr>
<tr>
<td>896 second</td>
<td>0.36 ⇔ 192</td>
<td>0.28 ⇔ 258</td>
<td>0.22 ⇔ 297</td>
</tr>
<tr>
<td>30 minute</td>
<td>0.34 ⇔ 205</td>
<td>0.28 ⇔ 261</td>
<td>0.21 ⇔ 282</td>
</tr>
<tr>
<td>90 minute</td>
<td>0.31 ⇔ 204</td>
<td>0.26 ⇔ 257</td>
<td>0.22 ⇔ 274</td>
</tr>
<tr>
<td>6 hr</td>
<td>0.31 ⇔ 212</td>
<td>0.24 ⇔ 248</td>
<td>0.21 ⇔ 249</td>
</tr>
<tr>
<td>24 hr</td>
<td>0.28 ⇔ 224</td>
<td>0.24 ⇔ 247</td>
<td>0.21 ⇔ 245</td>
</tr>
</tbody>
</table>

Mean Albedo: 0.22  
Mean OLR: 234

Albedo and OLR values are referenced to the “top of the atmosphere,” \( R_e + 30 \) km.

**Model Inputs**

For the near-Earth phases, the design verification to thermal environments specified in this requirement shall account for variations in inclination, altitude, and SZA as described below. Note, in particular, that the table values are referenced to the top of the atmosphere and that the Albedo values must be corrected for SZA.

**Orbital Altitude and "Top of Atmosphere"**

The OLR and albedo radiation received on a satellite surface diminishes as its altitude increases, i.e., as the satellite moves away from the source. This effect is accounted for as part of the "view factor" in thermal calculations. Derived OLR and albedo data measurements from satellites at several altitudes (610, 815, and 849 km) were corrected to the apparent source surface (30 km above Earth surface) or "top of atmosphere." Thus, in applying this data the analyst should...
assume a source at \( R_e + 30 \) km, where \( R_e \) is the Earth's radius, 6378.140 km equatorial. Failure to do so leads to a slight underestimate of the OLR and albedo radiation by a factor of:

\[
F_a = \frac{(R_e + A)^2}{(R_e + 30 \text{ km} + A)^2}
\]

(7.1)

where \( A \) is the orbital altitude. The error is quite small (\( F_a = 0.9911 \) at \( A = 300 \) km) and decreases (\( F_a \) approaches one) with increased altitude.

Orbital Inclination, Beta Angle, and Solar Zenith Angle

Orbital "inclination" refers to the angle between the Earth's polar vector and the vector normal to the satellite's orbit plane. Thus, an equatorial orbit has an inclination of zero; a perfect polar orbit has an inclination of 90°. The orbital "beta" angle is the minimum angle between the satellite's orbit plane (the closest to a Sun-pointing vector possible in the plane) and the Sun-Earth vector. The beta angle can be thought of as the solar elevation angle with respect to the orbit plane. The angle between the Sun-Earth vector and the Earth-satellite vector is termed the "Solar Zenith" Angle (SZA). The SZA is zero when the Sun is directly above the satellite (Earth-satellite-Sun in a straight line) and 90° when a satellite is directly over the terminator. Except for special Sun synchronous cases, the SZA varies rapidly over an orbit; the minimum SZA is equal to the absolute value of the beta angle.

Limitations

None

Technical Notes

None

3.3.10 Solar Illumination Environment for In-Space Hardware

Description

This section describes the solar spectrum, including ultraviolet radiation, which can cause deterioration of materials.

Design Limits

Hardware configuration, orientation relative to the Sun, and exposure time must be considered for solar irradiation for the Space Vehicle Segment. Intensity is specified in Table 3.3.10-1.

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>( E_{\lambda} )</th>
<th>( D_{0\lambda} )</th>
<th>( \lambda )</th>
<th>( E_{\lambda} )</th>
<th>( D_{0\lambda} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14</td>
<td>( 9.833 \times 10^{-2} )</td>
<td>0.0</td>
<td>0.57</td>
<td>1,797</td>
<td>31.39</td>
</tr>
</tbody>
</table>

Note 1 – Double lines indicate change in wavelength interval of integration. Each column continues to next page.
The electronic version is the official approved document. Verify this is the correct version before use.
The electronic version is the official approved document. Verify this is the correct version before use.
Table 3.3.11-1. Earth-GRAM 2010 Inputs for Thermosphere Parameter Calculations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Earth-GRAM 2010 Variable Name</th>
<th>Minimum</th>
<th>Nominal</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar flux $F_{10.7}$</td>
<td>$f_{10}$ $f_{10b}$</td>
<td>67</td>
<td>148</td>
<td>245</td>
</tr>
<tr>
<td>Geomagnetic index Ap</td>
<td>$ap$</td>
<td>7.2</td>
<td>16</td>
<td>55</td>
</tr>
<tr>
<td>Date</td>
<td>$mn$, $ida$, $iyr$</td>
<td>July 15</td>
<td>June 1</td>
<td>Jan 10 for systems most sensitive to heights below 90 km Oct 27 for systems most sensitive to heights above 90 km</td>
</tr>
<tr>
<td>Local time (does not affect results below 90 km)</td>
<td>$ihro$, $mino$, $seco$</td>
<td>03:00:00</td>
<td>08:00:00</td>
<td>14:00:00</td>
</tr>
<tr>
<td>Random perturbations</td>
<td>$rpscale$, $ruscale$, $rwscale$</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Small scale perturbations</td>
<td>$patchy$</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Limitations

Although uncertainties are not specifically determined for the Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) model, it is generally accepted that the thermospheric density is modeled to within no better than 15% accuracy (1 standard deviation) by the MET and similar models (for example, the Mass Spectrometer Incoherent Scatter model). Perturbations on the aloft region are statistically derived and are generated using the input variables in Table 3.3.11-1.

Technical Notes

Hardware configuration, orientation relative to ram (velocity vector) direction, and exposure time must be considered. The $F_{10.7}$ and Ap values were taken from the NEDD, 7.1.4, Solar and Geomagnetic Indices. The minimum values are the minima of the minimum profiles. Nominal solar flux and geomagnetic index values are the maxima of the mean solar cycle profile. Maximum solar flux and geomagnetic index values were selected to produce a 95 percentile global maximum exospheric temperature and corresponding neutral density for a maximum solar cycle profile “Bin 5” conditions per “Ninety-day Solar and Geomagnetic Activity Input Files for Thermospheric Variation Simulation: Simulation Data Files Release 2,” (Hickey and Smith, 1992).

3.3.12 Geomagnetic Fields (Reserved)

3.4 Lunar Surface Operational Phases

Most lunar surface environments are identified in this section. However, the design specifications for each environment are undefined and reserved for further studies. Future studies/analyses are needed to complete the section.
3.4.1 Lunar Surface Geological Environment (Reserved)

Rationale: Statistical distributions of lunar craters, rock size, and slopes are required to conduct design studies for ESD architecture used in landing on and moving over the lunar surface.

a. Crater size distributions
b. Rock size distributions
c. Slope distributions

3.4.2 Lunar Regolith Properties (Reserved)

Rationale: Mechanical properties of lunar regolith are required for design and evaluation of ESD hardware capabilities for operating on the lunar surface.

a. Mechanics properties
b. Regolith composition
c. Particle size and shape

3.4.3 Lunar Dust (Reserved)

Rationale: Properties of lunar dust are required for engineering systems to operate in dusty lunar environments and for defining system requirements for removing dust from human habitats.

3.4.4 Lunar Regolith Electrical and Photoelectric Properties (Reserved)

Rationale: Dielectric, photoelectric, and electron emission properties of the lunar regolith are required for evaluation of charging hazards on the lunar surface due to interactions of the space plasma and radiation environment with the lunar regolith.

a. Bulk conductivity (lunar noon to cryogenic temperatures)
b. Dielectric constant
c. Photoelectric emission of lunar fines
d. Secondary electron emission—bulk material

3.4.5 Optical Properties (Reserved)

Rationale: Properties of photon absorption and reflection on the lunar surface and in dusty lunar environments at optical and radio wavelengths are required for design of optical and radar landing sensor systems.

a. Optical properties of dust at visible and radio wavelengths
3.4.6 **Lunar Thermal Environment (Reserved)**

*Rationale:* Thermal properties of the lunar regolith are required for design of ESD lunar architecture and evaluation of thermal behavior of systems operating on the lunar surface.

a. Specific heat (bulk material)
b. Thermal conductivity (bulk material)
c. Surface temperature
d. Subsurface temperature

3.4.7 **Lunar Radiation Environment (Reserved)**

*Rationale:* Systems operating on the lunar system must be designed to withstand the space radiation environment as well as the radiation environment due to neutrons generated by interactions of energetic solar particles and GCR.

a. Lunar surface ionizing radiation
b. Lunar neutron environment

3.4.8 **Lunar Surface Plasma Environment (Reserved)**

*Rationale:* Plasma environments on the lunar surface are required for evaluating ESD risk for electrostatic discharge risk from excess charge collected from the plasma environments. Specific risk regions include the lunar wake and shadowed regions on the lunar surface, although environments will be provided to evaluate charging in all lunar environments.

3.4.9 **Lunar Ejecta Environment (Reserved)**

*Rationale:* ESD hardware operating on the lunar surface or in low lunar orbit will be exposed to a secondary ejecta environment produced during impacts of primary meteors on the lunar surface.

3.5 **Entry and Landing Phases**

The following environments are applicable to the MPCV descent phase and also to descending Space Launch System (SLS) vehicle elements after separation from the vehicle stack during the ascent phase.

3.5.1 **Re-entry Neutral Atmosphere**

*Description*

This section defines the neutral atmosphere density, composition, and variability for various design applications. All altitude regimes and geographic locations are incorporated into the
Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) model, from the Earth surface to 2,000 km (6,561,680 ft).

**Design Limits**

The neutral atmosphere above 90 km (295,276 ft) is specified in Section 3.3.11, In-Space Neutral Atmosphere (Thermosphere) Density. Section 3.3.11 is also compatible with the further breakout of the specification in the various 3.5 Sections.

**Model Inputs**

Above 90 km (295,276 ft), 1,000 or more Monte Carlo simulations are needed per month for minimum, nominal, and maximum perturbation scale per Table 3.3.11-1. Below 90 km (295,276 ft) Earth-GRAM 2010 flight profiles with perturbations per Table 3.5.4-1 will be used. Atmospheric temperature, pressure, and density should be evaluated simultaneously in each simulation.

**Limitations**

None

**Technical Notes**

None

3.5.2 **Reserved**

3.5.3 **Lightning During Normal Landing**

**Description**

This section specifies the lightning environment for descent and landing operations in the normal landing zones offshore or in the western U.S. This environment is also applicable to descending launch vehicle elements after separation from the vehicle stack during the ascent phase. Design specifications include standardized voltage and current waveforms derived or characterized to represent the lightning environment at specific zones established on the vehicle.

**Design Limits**

See the Design Limits in Section 3.1.11, Lightning During On-pad Operations.

**Model Inputs**

Vehicle lightning strike zones are defined for the integrated vehicle in re-entry and landing configurations, including with and without parachutes deployed, while descending through the atmosphere or residing on land or water after landing.

**Limitations**

See the Limitations in Section 3.1.11, Lightning During On-pad Operations.
Technical Notes

None

3.5.4 Aloft Winds for Normal Descent and Landing

Description

This section specifies aloft wind environments and dispersions (orbit to 300 m (984 ft) AGL) for normal vehicle descent and landing operations. This environment also applies to re-entering and descending launch vehicle elements after separation from the vehicle stack following the ascent phase.

Design Limits

System performance will be evaluated through analysis of 1,000 or more Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) random profiles per month. Each profile is for an orbit to 300 m (984 ft) AGL flight profile into the landing site of interest with Earth-GRAM 2010 inputs per Table 3.5.4-1. Atmospheric wind, temperature, pressure, and density should be evaluated simultaneously in each simulation.

Table 3.5.4-1. Earth-GRAM 2010 Input to Generate 1,000 or More Perturbed Profiles (0 to 90 km) of Temperature, Pressure, and Density Per Monthly Reference Period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Earth-GRAM 2010 variable name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRA data set</td>
<td>iyrrra</td>
<td>3 = 2013 RRA</td>
</tr>
<tr>
<td>RRA limits – use if near site with an RRA</td>
<td>sitenear</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>sitelim</td>
<td>2.5</td>
</tr>
<tr>
<td>Random output</td>
<td>iopr</td>
<td>1= random</td>
</tr>
<tr>
<td>Non-RRA sites</td>
<td>NCEPyr</td>
<td>9008 = period of record</td>
</tr>
<tr>
<td>Random perturbations</td>
<td>rpscale, ruscale, rwscale</td>
<td>1.0</td>
</tr>
<tr>
<td>Small scale perturbations</td>
<td>patchy</td>
<td>0</td>
</tr>
</tbody>
</table>

Model Inputs

Earth-GRAM 2010 (see note in 2.1.2 Applicable Models/Data Sets) input is listed in Table 3.5.4-1 for each monthly reference period. The model automatically sets surface roughness for a given location input, but the location resolution is relatively course (1 degree by 1 degree). The surface roughness input should be checked when the model is being used for applications in a region where two or more significantly different surface types exist, such as near a coastline.

The spatial and temporal increments are chosen to optimize vehicle response for performance analyses. A large increment may not capture the frequencies (and/or wavelengths) necessary to excite appropriate vehicle responses, while too small an increment can produce very large relative derivatives along the flight path. Choose increments that result in spatial steps no smaller than the length of the vehicle.
The inputs given provide random profiles with random perturbations that can be used to
determine envelopes for trajectory and load variables for descent analyses. An “rpscale” setting
of 1.0 represents perturbation scaling equivalent to the climatological environment. If additional
analyses to study the effects of more severe perturbations/turbulence are desired, the “rpscale”
can be set to a higher value, which should not exceed 2.0. For thermal and aeroheating studies, it
may be desirable to design to extreme profiles (for example, 2 or 3 sigma climatological profiles)
which Earth-GRAM 2010 also has the capability to produce.

Limitations

Perturbations in the aloft region are statistically derived and are generated using the input
variables in Table 3.5.4-1. Earth-GRAM 2010 does not define the turbulent boundary layer in the
lowest 300 m (984 ft) AGL, so separate analysis is required for winds in this region. (See Section
3.5.8, Surface Winds for Normal Landing.)

Technical Notes

None

3.5.5 Aloft Air Temperature for Normal Descent and Landing

Description

This section specifies air temperature environments and dispersions (orbit to 300 m (984 ft)
AGL) for normal vehicle descent and landing operations. This environment also applies to re-
entering and descending launch vehicle elements after separation from the vehicle stack
following the ascent phase.

Design Limits

See Section 3.5.4, Aloft Winds for Normal Descent and Landing.

Model Inputs

See Section 3.5.4.

Limitations

Perturbations in the aloft region are statistically derived and are generated using the input
variables in Table 3.5.4-1.

Technical Notes

None

3.5.6 Aloft Air Pressure for Normal Descent and Landing

Description

This section specifies air pressure environments and dispersions (orbit to 300 m (984 ft) AGL)
for normal vehicle descent and landing operations. This environment also applies to re-entering
and descending launch vehicle elements after separation from the vehicle stack following the ascent phase.

**Design Limits**

See Section 3.5.4.

**Model Inputs**

See Section 3.5.4.

**Limitations**

See Section 3.5.5, Aloft Air Temperature for Normal Descent and Landing.

**Technical Notes**

See Section 3.5.5.

### 3.5.7 Aloft Air Density for Normal Descent and Landing

**Description**

This section specifies air density environments and dispersions (orbit to 300 m (984 ft) AGL) for normal vehicle descent and landing operations. This environment also applies to re-entering and descending launch vehicle elements after separation from the vehicle stack following the ascent phase.

**Design Limits**

See Section 3.5.4.

**Model Inputs**

See Section 3.5.4.

**Limitations**

See Section 3.5.5.

**Technical Notes**

See Section 3.5.5.

### 3.5.8 Surface Winds for Normal Landing

**Description**

This section specifies surface wind environments (altitude range 0 to 300 m (984 ft) AGL), up to and including the maximum design limits, for normal vehicle land and water landing operations. Design specifications include peak wind-speed profile, steady state wind-speed profile, and spectral gust environment.
Design Limits

Maximum: Peak wind-speed profile (0 to 300 m (984 ft) AGL) derived from the 10 m (32.8 ft) reference level peak wind speed from any azimuth is given by:

\[ u(z) = u_{10} \left( \frac{z}{10} \right)^k \]

where \( u(z) \) is the peak wind speed (m/s) at height \( z \) meters above natural grade (0 to 300 m (984 ft) AGL), \( u_{10} \) is the design peak wind speed (m/s) at 10 m (32.8 ft), and \( k \) is a dimensionless exponent, where \( k = 1/7 \) for land landings and \( k = 0.11 \) for water landings.

The steady state wind-speed profile is obtained from the above peak wind-speed profile by dividing the peak wind speed by a gust factor of 1.4:

\[ \overline{U}(z) = \frac{u(z)}{1.4} \]

where \( \overline{U}(z) \) is the steady state wind speed (m/s) at height \( z \) meters above natural grade and \( u(z) \) is the peak wind speed (m/s) at height \( z \) meters above natural grade (determined above). Spectral gust is obtained by using the steady state wind speed at 10 m (32.8 ft) determined above with:

\[ \Phi_u(\omega, z) = \frac{2}{\pi V(z)} \left[ L_{10} \left( \frac{z}{10} \right)^q \left[ \sigma_{10} \left( \frac{z}{10} \right)^p \right]^2 \right] \frac{1}{1 + \left[ L_{10} \left( \frac{z}{10} \right)^q \left( \frac{\omega}{V(z)} \right) \right]^2} \]

\[ \Phi_w(\omega, z) = \frac{1}{\pi V(z)} \left[ L_{10} \left( \frac{z}{10} \right)^q \left[ \sigma_{10} \left( \frac{z}{10} \right)^p \right]^2 \right] \frac{1 + 3 \left[ L_{10} \left( \frac{z}{10} \right)^q \left( \frac{\omega}{V(z)} \right) \right]^2}{1 + \left[ L_{10} \left( \frac{z}{10} \right)^q \left( \frac{\omega}{V(z)} \right) \right]^2} \]

where \( \Phi_u \) and \( \Phi_w \) are the gust spectra for the longitudinal (\( u \)) and lateral, vertical (\( w \)) components at height \( z \) above natural grade, \( V(z) \) is the magnitude of the steady state wind vector relative to the vehicle at height \( z \), and \( \omega \) is the frequency in units radians per second (rad/s). The gust spectra parameters (\( L_{10}, \sigma_{10}, p, \) and \( q \)) are for altitudes below 300 m (984 ft) and are provided in Table 3.5.8-1.

Minimum: No wind, calm for both land and water landing sites.
Table 3.5.8-1. Dryden Gust Spectra Parameters for the Longitudinal, Lateral, and Vertical Components for the Landing Phase

<table>
<thead>
<tr>
<th>Component</th>
<th>$\sigma_0$ (m/s)</th>
<th>$p$</th>
<th>$L_{10}$ (m)</th>
<th>$q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
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<td>0.16</td>
<td>21</td>
<td>0.65</td>
</tr>
<tr>
<td>Lateral</td>
<td>1.67</td>
<td>0.25</td>
<td>11</td>
<td>0.83</td>
</tr>
<tr>
<td>Vertical</td>
<td>1.15</td>
<td>0.36</td>
<td>5</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Model Inputs

For vehicle descent and landing onto land, use $u_{10} = 19.5$ m/s (metric units must be used in the equation) for construction of the maximum design limit wind-speed profile up to 300 m (984 ft) AGL. This value of $u_{10}$ is applicable to normal land landings. A value for off-nominal land landing has not been defined.

For normal descent and landing operations into water, the steady state design wind speed at 10.0 m (32.8 ft) height above the surface is 8.2 m/s (26.9 ft/s), which implies a peak wind $u_{10} = 11.48$ m/s (37.7 ft/s). This value is associated with the sea state conditions defined in section 3.5.18, Sea State for Normal Water Landing.

Technical Notes

Design limit for vehicle land landing of 19.5 m/s (64 ft/s) at the 10.0 m (32.8 ft) reference level is the 95th percentile peak wind speed for a 1-hr exposure period at Edwards Air Force Base (EAFB). The steady state wind-speed profile is the 10-minute mean wind-speed profile that could produce the peak wind-speed profile determined above.

Design steady state wind speed limit of 8.2 m/s (26.9 ft/s) at the 10.0 m (32.8 ft) reference height for vehicle water landing is associated with the sea conditions defined in section 3.5.18 Sea State for Normal Water Landing.

Longitudinal and lateral components of turbulence fluctuate with height. The longitudinal component of turbulence is parallel to the steady state wind vector with the lateral component in the horizontal plane and perpendicular to the longitudinal and vertical components.

3.5.9 Surface Air Temperature for Normal Landing

Description

This section specifies the design maximum and minimum surface air temperature for normal vehicle land and water landing environments. Zones for normal land landings are assumed to be contained in a geographical region in the western U.S., and the zone for water landing is assumed to be contained by oceanic regions within a 685 km (370.0 nmi) radius of San Diego, California.
**Design Limits**

Maximum air temperature over land: 46.0 °C (114.8 °F)

Minimum air temperature over land: -38.0 °C (-36.4 °F)

Maximum air temperature over water: 26.7 °C (80.1 °F)

Minimum air temperature over water: 3.8 °C (38.9 °F)

**Model Inputs**

None

**Limitations**

For any required thermal assessment involving wind effects over land, the winds must be assumed to be steady state at 10.0 m (32.8 ft) height, with horizontal speeds ranging from 0.0 to 13.9 m/s (45.6 ft/s). This wind was determined by using the steady state wind equation and peak wind of 19.5 m/s (64.0 ft/s) for land landings given in Section 3.5.8, Surface Winds for Normal Landing.

For any required thermal assessment involving wind effects over water, the winds must be assumed to be steady state at 10.0 m (32.8 ft) height with horizontal speeds ranging from 0.0 to 8.2 m/s (26.9 ft/s). This value is associated with the sea state conditions defined in Section 3.5.18, Sea State for Normal Water Landing. The peak wind value of 11.5 m/s (37.7 ft/s) was determined by multiplying the maximum steady state wind by the 1.4 gust factor given in Section 3.5.8, Surface Winds for Normal Landing.

**Technical Notes**

Design limits for normal land landings represent the maximum and minimum extreme temperatures from hourly surface observations recorded at selected locations in the normal land landing area.

Design limits for normal water landings were determined using six-hourly air temperature output within the normal water landing area from a global climatology. Air temperatures were obtained from the European Centre for Medium-range Weather Forecasts (ECMWF) Re-Analysis (ERA-40), which contains air temperature records on a 2.5° x 2.5° grid every six hours for the 1979-2002 period of record. The global dataset was subsetted to only contain temperatures within the normal landing area. Design limits were determined by comparing the minimum and maximum recorded air temperatures to the 0.5th and 99.5th percentile temperatures with 95.0% confidence intervals applied for each month (Barbré, 2012). Design limits are the empirical minimum and maximum air temperatures during December and September, respectively.
3.5.10 Surface Air Pressure for Normal Landing

Description
This section specifies the design maximum and minimum sea level air pressure for normal vehicle landing operations.

Design Limits
Maximum: 1,051.9 hPa
Minimum: 989.4 hPa

[100 Pa = 1 hPa = 1 millibar (mbar) = 0.01450377 pound/in² (psi)]

Model Inputs
Design limits specify the air pressure referenced to standard sea level conditions. For applications related to on-land landings or operations, the sea level pressure must be corrected to the applicable pressure at landing site elevation. The design limits, along with temperature and humidity information, can be used to derive design limits for air pressure at other desired altitudes.

Limitations
None

Technical Notes
Design limits represent the monthly mean sea level air pressure ±3 standard deviations (maximum value of standard deviation for each month) from hourly surface observations at selected locations in the normal landing area.

3.5.11 Surface Air Humidity for Normal Landing

Description
This section specifies the design limits for surface air humidity for normal vehicle landing operations.

Design Limits
Maximum: 100% Relative Humidity
Minimum: 5% Relative Humidity

Model Inputs
None

Limitations
None
Technical Notes
None

3.5.12 Aerosols for Normal Descent and Landing

Description
This section specifies the aerosol environment for normal (on land) vehicle descent and landing operations. Aerosol environments for in water-landings are specified in Section 3.5.21, Aerosols for Water Landing.

Design Limits
Reserved (see Technical Notes)

Model Inputs
None

Limitations
None

Technical Notes
This specification will be provided if land landing for normal operations is returned to the programs.

3.5.13 Precipitation for Normal Descent and Landing

Description
This section specifies the precipitation environment for normal vehicle descent and landing operations both on land or water.

Design Limits
The maximum design rainfall rate is 7.6 mm/hr (0.30 in/hr) from non-convective clouds.

Model Inputs
None

Limitations
None

Technical Notes
The design rainfall rate is the National Oceanic and Atmospheric Administration (NOAA) maximum observational reporting value for moderate rainfall. This rate was chosen to exclude operations during heavy rainfall produced by convective clouds (thunderstorms). Flight path
avoidance of thunderstorms is desired to protect the vehicle from extreme environments such as lightning, hail, and extreme turbulence.

### 3.5.14 Flora and Fauna for Descent and Landing

**Description**

This section specifies the flora and fauna environment for all descent and landing operations, including landing operations conducted on land or sea. Normal land landings should occur at prepared sites where exposure to flora and fauna hazards has been mitigated to acceptable levels.

**Design Limits**

During descent and land landing operations, the design limit for an avian species is a maximum mass of 2.2 kg (4.9 lbs) up to an altitude of 0.5 km (1,640.4 ft) above ground level.

During land landing operations, the design limit includes ground brush up to 0.6 m (2.0 ft) height.

During land landing operations, the design limit includes mammals with mass up to 10 kg (22 lbs).

No flora or fauna environments are specified for water landings.

**Model Inputs**

None

**Limitations**

None

**Technical Notes**

Although large mammals such as deer, cattle, and wild horses are not uncommon in open range areas in the western U.S., it is impractical to protect against collision with one of significant mass. The bird mass collision criteria for descent and landing operations were selected to maintain commonality with the ascent phase criteria.

### 3.5.15 Surface Characteristics and Topography for Normal Land Landing

(Soil conditions at the land landing site will be provided if this option is exercised.)

**Description**

This section specifies the design surface characteristics for normal landing operations. Normal landings should occur at prepared sites that fall within the design limits specified below.
Design Limits

The design limit for maximum surface slope of the land landing site will be 5°. The site will be clear of solid objects projecting more than 0.3 m (1.0 ft) above the surface. The site will be clear of ditches deeper than 0.3 m (1.0 ft).

Model Inputs

None

Limitations

None

Technical Notes

The selection of surface was made based on preliminary surveys of potential land landing sites. It is anticipated that any designated site will be prepared to meet this specification.

3.5.16 Cloud Environment for Normal Descent and Landing

Description

This section defines the cloud and visibility environments for normal descent and landing operations.

Design Limits

The design range for cloud cover is up to and including 100% cloud cover, excluding convective clouds and thunderstorms. The maximum size of any liquid cloud particle is 7 mm (0.3 in) diameter. The maximum size of any frozen cloud particle is 200 μm (0.008 in).

Model Inputs

None

Limitations

None

Technical Notes

The maximum size for liquid cloud particles of 7 mm (0.3 in) allows the vehicle to traverse stratiform clouds and rain in non-convective situations. Traversing convective type clouds, such as thunderstorms, could expose the vehicle to ice particles (hail or graupel) with diameters of several centimeters or larger. Flight path avoidance of thunderstorms is assumed to protect the vehicle from extreme environments such as lightning, hail, and extreme turbulence. The maximum size for frozen cloud particles of 200 μm (0.008 in) allows for traverse through mid and high altitude layer clouds (alto and cirrus type).
3.5.17 Radiant (Thermal) Energy Environment for Normal Landing

Description
This section specifies the design radiant (thermal) energy environment and sky temperature limits for normal landing operations.

Design Limits
Table 3.5.17-1 presents design cold radiant energy and sky temperature environment for a cloudy sky.
Table 3.5.17-2 presents design hot radiant energy and sky temperature environment for a cloudy sky.
Table 3.5.17-3 presents design cold radiant energy and sky temperature environment for a partly cloudy sky.
Table 3.5.17-4 presents design hot radiant energy and sky temperature environment for a partly cloudy sky.
Table 3.5.17-5 presents design cold radiant energy and sky temperature environment for a clear sky.
Table 3.5.17-6 presents design hot radiant energy and sky temperature environment for a clear sky.

Model Inputs
None

Limitations
None
Table 3.5.17-1. Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky

<table>
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<th>Time of Day Hour (LST)</th>
<th>Air Temperature °C</th>
<th>°F</th>
<th>Sky Temperature °C</th>
<th>°F</th>
<th>Direct Incident* W/m² BTU/hr/ft²</th>
<th>Diffuse W/m²</th>
<th>BTU/hr/ft²</th>
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</table>

* Direct Incident is to a plane normal to the sun vector.
### Table 3.5.17-2. Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky

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<th>°F</th>
<th>Sky Temperature °C</th>
<th>°F</th>
<th>Direct Incident* W/m² BTU/hr/ft²</th>
<th>Diffuse W/m² BTU/hr/ft²</th>
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* Direct incident is to a plane normal to the sun vector.
Table 3.5.17-3. Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Partly Cloudy Sky

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* Direct Incident is to a plane normal to the sun vector.
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* Direct Incident is to a plane normal to the sun vector.
### Table 3.5.17-5. Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Clear Sky

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* Direct Incident is to a plane normal to the sun vector.
### Table 3.5.17-6. Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Clear Sky

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* Direct Incident is to a plane normal to the sun vector.

### Technical Notes

Design limits are developed from the National Solar Radiation Database (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2010/) for San Diego, CA (Lindbergh Field). Cold and hot diurnal profiles are the average of the 10 coldest and warmest days for the given sky conditions (cloudy, partly cloudy, and clear). Since surface air temperature, direct incident radiant energy, diffuse radiant energy, and sky temperature are coupled and depend on sky conditions.
conditions, it is recommended that each case be used as input into thermal models to determine the worst case.

Direct incident is the solar radiant energy to a plane normal to the sun vector. The actual radiant energy absorbed by a surface would be a function of the surface optical properties and the surface geometry relative to the Sun vector. Diffuse radiant energy represents the accumulation on a horizontal surface of the scattered solar radiant energy from all directions, not including the direct incident. Sky temperature represents the temperature of the sky assuming it is radiating as a blackbody.

### 3.5.18 Sea State for Normal Water Landing

**Description**

This section specifies the design maximum and minimum wave conditions for nominal water landings. Wave height and wind speed limits were determined through examining conditions near the coast of Southern California. Wave period limits, which are conditional to wave height, were determined by examining data across the globe.

**Design Limits**

**Minimum**: Significant Wave Height (SWH): No waves.

**Maximum**: SWH: 2.0 m (6.6 ft)

Minimum average wave periods associated with the design maximum SWH are displayed in Table 3.5.18-1. The energy spectrum associated with the design maximum SWH is provided in Table 3.5.18-2. The energy spectrum may be truncated on the high frequency end to limit the calculated water surface slope to the dimensions of interest to the engineering application. The limit of the high frequency end of the energy spectrum can be determined using the following equation:

\[
 f_{\text{max}} = \frac{g}{\sqrt{2 \cdot \pi \cdot (L/2)}}
\]

where \( f_{\text{max}} \) is the maximum frequency (Hz), \( g \) is gravity (m/s\(^2\)), and \( L \) is the smallest wavelength (m) of interest for the engineering application. The energy spectrum is used to derive water surface slope distributions using the following equations:

\[
 I' = \sum_{i=1}^{n} \left( \frac{\mu_{i}^2}{g} \right) \cdot \left[ A_{i}(\mu_{i}) \right]^2 \cdot \Delta \mu_{i}
\]
where $I^*$ is the omnidirectional slope variance, $g$ is gravity, $n$ represents the total number of frequency bins, and $[A(\mu_i)]^2$ and $\Delta \mu_i$ are the energy spectrum (m$^2$/Hz) and bandwidth (Hz), respectively, associated with the $i^{th}$ frequency bin.

The directional components of slope variance are determined by multiplying slope variance by the constants $f(\theta) = 0.625$ and $g(\theta) = 0.375$ (Cote et al., 1960), which are representative values of how the slope variance is divided into its directional components:

$$
\sigma_{ud}^2 = I^* \cdot f(\theta)
$$
$$
\sigma_c^2 = I^* \cdot g(\theta)
$$

where $\sigma_{ud}^2$ is the upwind-downwind slope variance component and $\sigma_c^2$ is the crosswind slope variance component. Each directional slope standard deviation component is used to run a 10,000 case (typical) Monte Carlo Simulation assuming a Gaussian distribution where $r_{ud}$ and $r_c$ are zero-mean, unit variance Gaussian random variables. The directional water surface slope components are determined using the following equations:

$$
\mu_{ud} = \arctan(\sigma_{ud} \cdot r_{ud})
$$
$$
\mu_c = \arctan(\sigma_c \cdot r_c)
$$

where $\mu_{ud}$ is the upwind-downwind water surface slope component (rad), and $\mu_c$ is the crosswind water surface slope component (rad). Each pair of directional water surface slope component values is applied to the following equation to create a water surface slope distribution:

$$
\mu = \arctan\left(\sqrt{\tan^2\mu_{ud} + \tan^2\mu_c}\right) \cdot \frac{180}{\pi}
$$

where $\mu$ is the total water surface slope (degrees).

Minimum Winds: Calm, no winds.

Maximum Winds: 8.2 m/s (26.9 ft/s) steady-state wind speed at 10.0 m (32.8 ft) height above surface as referenced in Section 3.5.8, Surface Winds for Normal Landing.

Sea state characteristics and probability of occurrence: Defined by the Corrected-European Centre for Medium Range Weather Forecasts Re-Analysis (C-ERA40) database (Caires and Sterl, 2005).
Model Inputs

Table 3.5.18-1. Minimum Average Wave Period Corresponding to Given SWH

<table>
<thead>
<tr>
<th>Significant Wave Height (m)</th>
<th>Minimum Average Wave Period(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>2</td>
</tr>
<tr>
<td>0.5-1.0</td>
<td>2</td>
</tr>
<tr>
<td>1.0-1.5</td>
<td>3</td>
</tr>
<tr>
<td>1.5-2.0</td>
<td>4</td>
</tr>
<tr>
<td>2.0-2.5</td>
<td>4</td>
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<tr>
<td>2.5-3.0</td>
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</tr>
<tr>
<td>3.0-3.5</td>
<td>5</td>
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<td>5.5-6.0</td>
<td>7</td>
</tr>
<tr>
<td>6.0-6.5</td>
<td>7</td>
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<tr>
<td>6.5-7.0</td>
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<tr>
<td>≥ 7.0</td>
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</tbody>
</table>

The energy spectrum is listed in Table 3.5.18-2 and is used to derive water surface slope.

Table 3.5.18-2. Energy Spectrum for 2 m SWH

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Energy (m²/Hz)</th>
<th>Bandwidth (Hz)</th>
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<tr>
<td>0.025</td>
<td>0.00330</td>
<td>0.005</td>
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<tr>
<td>0.030</td>
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<td>0.040</td>
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<td>0.005</td>
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<td>0.045</td>
<td>0.02890</td>
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<td>0.050</td>
<td>0.09460</td>
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<td>0.20230</td>
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<tr>
<td>0.070</td>
<td>0.38370</td>
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<td>Frequency (Hz)</td>
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<td>Bandwidth (Hz)</td>
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<tr>
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</tbody>
</table>
Figure 3.5.18-1. Cumulative Distributions of Water Surface Slope for 2 m SWH

Limitations
None

Technical Notes
Wave observations follow a Rayleigh distribution (Demirbilek and Vincent, 2002). An estimation of various wave heights may be determined from this distribution, where SWH corresponds to the average of the highest one-third of waves, and maximum wave height depends on the number of observed waves and the SWH.

The average wave period is defined as the average of the wave periods over the last 20 minutes of the 6-hour observation reported by the C-ERA-40 database. The minimum average wave period is the lowest average wave period associated with the specified SWH range. The C-ERA-40 database is used to determine the number of SWH observations that fall within the given SWH ranges in Table 3.5.18-1, where the first height is included in the SWH range but the second height is not included. The minimum average wave periods in Table 3.5.18-1 are identified by determining which 1-second wave period range contains the 1st percentile of wave periods observed for the given SWH range. If the 1st percentile falls between two values within the wave period range, the lower of the two wave period values is used to be conservative.
The C-ERA40 database is developed from the ECMWF atmospheric re-analysis for the POR (1957-2002) with emphasis on the POR (1971-2000). Data reported in the C-ERA-40 database is provided every 6 hours on a 1.5° latitude x 1.5° longitude grid. Note that, although the term “C-ERA-40” refers to the SWH, wind speed, and wave period databases in this document, SWH is the only variable that was corrected.

A water surface slope distribution derived from the full energy spectrum is illustrated in Figure 3.5.18-1 with and without the energy extrapolated from 0.58 to 0.8 Hz. Both distributions represent the extreme case of 5,422 energy spectra. The x-axis represents water surface slopes that are less than the value of the x-tick.

The energy spectrum in Table 3.5.18-2 is developed using 5.0 m (16.4 ft) wind speed data from buoys 46047 and 46069, near San Nicolas Island, CA, in the NDBC network and spectral data from buoy 067, near San Nicolas Island, CA, in the Coastal Data Information Program (CDIP) buoy network. The spectral data ranges from 0.025 to 0.58 Hz and is reported every half hour, along with the corresponding SWH. This archived buoy data, when compared with the National Data Buoy Center (NDBC) spectral data, provides spectral data at higher frequencies in the area of interest. The spectral data is used from August over a 9-year POR (1999-2007) and is limited to SWH ≤ 2.0 m (6.6 ft) and wind speed ≤ 8.2 m/s (26.9 ft/s). The energy spectrum in Table 3.5.18-2 represents a single spectrum from August 23, 2001, at 03:49 Universal Time Coordinated (UTC) and is created using: (1) the energy in each frequency bin from 0.025 to 0.58 Hz, and (2) energy that is extrapolated from 0.58 to 0.80 Hz with an exponential curve (y = 3.9708·exp-9.1189x) that is fit to the energy found in each frequency bin from 0.30 to 0.58 Hz. Here x is the desired frequency (Hz) and y is the resulting energy (m²/Hz).

The spectrum was selected based on the distributions seen in Figure 3.5.18-1 where the spectrum not only covers the higher probabilities of steeper water surface slopes, but it also covers the water surface slopes seen at higher frequencies when the energy spectrum is extrapolated.

3.5.19  Reserved

3.5.20  Sea Surface Temperature for Water Landing

Description

This section specifies the design maximum and minimum sea surface temperatures for normal water landings. The zone for water landing is assumed to be contained by oceanic regions within a 685.0 km (370.0 nmi) radius of San Diego, California.

Design Limits

Maximum: 25.4 °C (77.7 °F)
Minimum: 10.3 °C (50.5 °F)

Model Inputs

None
Limitations

None

Technical Notes

Design limits for normal water landings were determined using weekly mean sea surface temperature output within the normal landing area from a global climatology. Sea surface temperatures were obtained from the National Centers for Environmental Prediction Optimal Interpolation (NCEP-OI) dataset, which contains weekly mean sea surface temperature records on a 1.0° latitude x 1.0° longitude grid for the 1981-2012 period of record. The global dataset was subsetted to only contain temperatures within the normal water landing area. Design limits were determined by comparing the minimum and maximum recorded temperatures to the 0.5th and 99.5th percentile temperatures with 95.0% confidence intervals applied for each month (Barbré, 2012). Minimum and maximum design limits are the 0.5th and 99.5th percentile temperatures with 95.0% confidence during March and September, respectively.

3.5.21 Aerosols for Water Landing

Description

This section specifies the aerosol environment for both normal and off-nominal water vehicle descent and water landing operations.

Design Limits

The vehicle will encounter sea salt spray if landing is in the sea.

Model Inputs

None

Limitations

The vehicle may encounter volcanic dust, but this is not considered a design case.

Technical Notes


3.6 Contingency and Off-Nominal Landing Phases

This section describes the design environments for contingency (including aborts) and other off-nominal landing conditions. Typically these are along the ascent or landing trajectories where such events are most likely to occur. Where possible the same models and specifications as for normal landing operations have been applied, and the specification is simply a reference to the corresponding normal landing section.
3.6.1 Re-entry Neutral Atmosphere for Off-Nominal Descent and Landing

Same as Section 3.5.1. Apply the model to the location of interest.

3.6.2 Reserved

3.6.3 Lightning During Off-Nominal Landing

Same as Section 3.5.3.

3.6.4 Aloft Winds for Off-Nominal Descent and Landing

Same as Section 3.5.4. Apply the model to the location of interest. In the event of on-pad or near pad abort scenarios, the KSC Measured Wind Database or Earth-GRAM 2010 can be used to evaluate abort performance. All other off-nominal descent and landing scenarios should use Earth-GRAM 2010.

3.6.5 Aloft Air Temperature for Off-Nominal Descent and Landing

Same as Section 3.5.5. Apply Earth-GRAM 2010 to the location of interest.

3.6.6 Aloft Air Pressure for Off-Nominal Descent and Landing

Same as Section 3.5.6. Apply Earth-GRAM 2010 to the location of interest.

3.6.7 Aloft Air Density for Off-Nominal Descent and Landing

Same as Section 3.5.7. Apply Earth-GRAM 2010 to the location of interest.

3.6.8 Surface Winds for Off-Nominal Landing

Design Limits

Same as Section 3.5.8 with the model inputs as specified here.

Model Input:

Minimum surface wind for all off-nominal cases is calm conditions, i.e. no wind.

Maximum off–nominal land landing surface winds are not defined.

For off-nominal water landings, the maximum 10.0 m (32.8 ft) height steady state design wind is 13.9 m/s (45.6 ft/s). This value is associated with the sea state conditions defined in Section 3.6.18, Sea State for Off-Nominal Water Landing. The peak wind value of 19.5 m/s (63.8 ft/s) was determined by multiplying the maximum steady state wind by the 1.4 gust factor given in Section 3.5.8, Surface Winds for Normal Landing.

3.6.9 Surface Air Temperature for Off-Nominal Landing

Description

This section specifies the design maximum and minimum surface air temperature for off-nominal vehicle water landing environments. Currently, no off-nominal land landing zones have been
defined by the Program. Zones for off-nominal water landings include the normal water landing zone described in 3.5.9, Surface Air Temperature for Normal Landing, as well as different skip entry trajectories covering the eastern Pacific Ocean and a 29° inclination orbit from KSC to the western coast of Australia.

**Design Limits**

Maximum: 32.2 °C (90.0 °F)

Minimum: 3.0 °C (37.4 °F)

**Model Inputs**

None

**Limitations**

For any required thermal assessment involving wind effects over water, the winds must be assumed to be steady state at 10.0 m (32.8 ft) height with horizontal speeds ranging from 0.0 to 13.9 m/s (45.6 ft/s). This value is associated with the sea state conditions defined in Section 3.6.18, Sea State for Off-Nominal Water Landing. The peak wind value of 19.5 m/s (63.8 ft/s) was determined by multiplying the maximum steady state wind by the 1.4 gust factor given in Section 3.5.8, Surface Winds for Normal Landing.

**Technical Notes**

Design limits for off-nominal water landings were determined using six-hourly air temperature output within the water landing areas corresponding to 23 different skip entry trajectories provided by the Orion Program, as well as the area immediately surrounding a 29.0° inclination orbit extending over water regions from KSC to the western coast of Australia. Air temperatures were obtained from the ERA-40 dataset, which contains air temperature records on a 2.5° x 2.5° grid every six hours for the 1979-2002 period of record. The global dataset was subsetted to only contain temperatures within the off-nominal landing area. Design limits were determined by comparing the minimum and maximum recorded air temperatures to the 0.5th and 99.5th percentile temperatures with 95.0% confidence intervals applied for each month (Barbré, 2012). Design limits are the empirical minimum and maximum air temperatures during March and April, respectively.

### 3.6.10 Surface Air Pressure for Off-Nominal Landing

Reserved.

### 3.6.11 Surface Air Humidity for Off-Nominal Landing

Same as Section 3.5.11.

### 3.6.12 Aerosols for Off-Nominal Descent and Landing

Same as Section 3.5.12.
3.6.13 Precipitation for Off-Nominal Descent and Landing

Same as Section 3.5.13.

3.6.14 Flora and Fauna for Off-Nominal Descent and Landing

Reserved.

3.6.15 Surface Characteristics and Topography for Off-Nominal Descent and Landing

Reserved.

3.6.16 Cloud Environment for Off-Nominal Descent and Landing

Same as Section 3.5.16.

3.6.17 Radiant (Thermal) Energy Environment for Off-Nominal Descent and Landing

Reserved.

3.6.18 Sea State for Off-Nominal Water Landing

Description

This section specifies the design maximum and minimum wave conditions for off-nominal water landings. Wave height and wind speed limits were determined through examining conditions near the coast of Southern California and in the Atlantic Ocean. Wave period limits, which are conditional to wave height, were determined by examining data across the globe.

For pad and near-pad aborts, a capsule could land in water shallow enough such that the capsule contacts the ocean floor, which could enhance the likelihood of increased damage to the vehicle and injury to any crew onboard. Therefore, engineering assessments of capsule landings within coastal water regions must characterize the probability of the capsule contacting the ocean floor, which is partially a function of the ocean floor’s depth. The area of ocean from the shoreline out to approximately 10-m water depth is the area most influenced by natural and man-made phenomena. Along the KSC coast, tides, breaking waves, and influences from storms such as hurricanes and Nor’ Easters induce natural erosion. Additionally, man-made influences such as shoreline restoration efforts and near-coast construction impact the ocean’s bathymetry. These influences cause the water depth at a given location to change over time. Tidal variations of roughly 1 m apply throughout the KSC/CCAFS near-shore environment. Sandbars can cause variations of roughly 1-2 m, and can change location. Shoals, which are associated with capes and other shallow areas, can also cause changes of near 2-6 m over longer time periods.

Design Limits

Minimum: Significant Wave Height (SWH): No waves.
Maximum: SWH: 4.0 m (13.1 ft)

Minimum average wave periods associated with the design maximum SWH are displayed in Table 3.5.18-1 in Section 3.5.18, Sea State for Nominal Water Landing.

The energy spectrum associated with the design maximum SWH is provided in Table 3.6.18-1. The energy spectrum may be truncated on the high frequency end to limit the calculated water surface slope to the dimensions of interest to the engineering application. The limit of the high frequency end of the energy spectrum can be determined using the following equation:

\[
f_{\text{max}} = \sqrt{\frac{g}{2 \cdot \pi \cdot \left(\frac{L}{2}\right)}}
\]

where \(f_{\text{max}}\) is the maximum frequency (Hz), \(g\) is gravity (m/s\(^2\)), and \(L\) is the smallest wavelength (m) of interest for the engineering application. The energy spectrum is used to derive water surface slope distributions using the following equations:

\[
I^* = \sum_{i=1}^{n} \left(\frac{\mu_i^2}{g}\right)^2 \cdot [A_i(\mu_i)]^2 \cdot \Delta \mu_i
\]

where \(I^*\) is the omnidirectional slope variance, \(g\) is gravity, \(n\) represents the total number of frequency bins, and \([A_i(\mu_i)]^2\) and \(\Delta \mu_i\) are the energy spectrum (m\(^2\)/Hz) and bandwidth (Hz), respectively, associated with the \(i^{th}\) frequency bin.

The directional components of slope variance are determined by multiplying slope variance by the constants \(f(\theta) = 0.625\) and \(g(\theta) = 0.375\) (Cote et al., 1960), which are representative values of how the slope variance is divided into its directional components:

\[
\sigma_{ud}^2 = I^* \cdot f(\theta)
\]
\[
\sigma_c^2 = I^* \cdot g(\theta)
\]

where \(\sigma_{ud}^2\) is the upwind-downwind slope variance component and \(\sigma_c^2\) is the crosswind slope variance component. Each directional slope standard deviation component is used to run a 10,000 case (typical) Monte Carlo Simulation assuming a Gaussian distribution where \(r_{ud}\) and \(r_c\) are zero-mean, unit variance Gaussian random variables. The directional water surface slope components are determined using the following equations:

\[
\mu_{ud} = \arctan(\sigma_{ud} \cdot r_{ud})
\]
\[
\mu_c = \arctan(\sigma_c \cdot r_c)
\]
where $\mu_{ud}$ is the upwind-downwind water surface slope component (rad), $\mu_c$ is the crosswind water surface slope component (rad). Each pair of directional water surface slope component values is applied to the following equation to create a water surface slope distribution:

$$\mu = \arctan \left( \sqrt{\tan^2 \mu_{ud} + \tan^2 \mu_c} \right) \cdot \frac{180}{\pi}$$

where $\mu$ is the total water surface slope (degrees).

**Minimum Winds:** Calm, no winds.

**Maximum Winds:** 13.9 m/s (45.6 ft/s) steady state wind speed at 10.0 m (32.8 ft) height above surface as referenced in Section 3.6.8, Surface Winds for Off-Nominal Landing.

**Sea state characteristics and probability of occurrence:** Defined by the C-ERA-40 database (Caires and Sterl, 2005).

**Water depth for pad and near-pad abort landings off the KSC coast:** Defined by a model to be assimilated into abort analyses. See Technical Notes.

**Model Inputs**

The energy spectrum is listed in Table 3.6.18-1 and is used to derive water surface slope.

### Table 3.6.18-1. Energy Spectrum for 4 m SWH

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Figure 3.6.18-1. Cumulative Distributions of Water Surface Slope for 4 m SWH

Limitations
None

Technical Notes
See Section 3.5.18 on Sea State for Nominal Water Landing for Technical Notes on the definition of SWH and maximum wave height, the process for determining the minimum average wave period associated with the SWH, and the C-ERA-40 database, which is used to define sea state characteristics and probability of occurrence. Data reported in the C-ERA-40 database is provided every 6 hours on a 1.5º latitude x 1.5º longitude grid. Note that, although the term “C-ERA-40” refers to the SWH, wind speed, and wave period databases in this document, SWH is the only variable that was corrected.

A water surface slope distribution derived from the full energy spectrum is illustrated in Figure 3.6.18-1 with and without the energy extrapolated from 0.58 to 0.8 Hz. Both distributions represent the extreme case of 5,934 energy spectra. The x-axis represents water surface slopes that are less than the value of the x-tick.

The energy spectrum in Table 3.6.18-1 is developed using 5-meter wind speed data from buoys 46047 and 46069, near San Nicolas Island, CA, in the NDBC network and spectral data from buoy 067, near San Nicolas Island, CA, in the CDIP buoy network. The spectral data ranges from 0.025 to 0.58 Hz and is reported every half hour, along with the corresponding SWH. This archived buoy data, when compared with the NDBC spectral data, provides spectral data at
higher frequencies in the area of interest. The spectral data is used from March over a 6-yr POR (2000-2005) and is limited to SWH ≤ 4.0 m (13.1 ft) and wind speed ≤ 13.9 m/s (45.6 ft/s).

The energy spectrum in Table 3.6.18-1 represents a single spectrum from March 29, 2001, at 00:13 UTC and is created using: (1) the energy in each frequency bin from 0.025 to 0.58 Hz and (2) energy that is extrapolated from 0.58 to 0.80 Hz with an exponential curve \( y = 3.9773 \cdot \exp^{-9.052x} \) that is fit to the energy found in each frequency bin from 0.30 to 0.58 Hz. Here \( x \) is the desired frequency (Hz) and \( y \) is the resulting energy (m²/Hz).

The spectrum was selected based on the distributions seen in Figure 3.6.18-1, where the selected spectrum not only covers the higher probabilities of steeper water surface slopes, but it also covers the water surface slopes seen at higher frequencies when the energy spectrum is extrapolated.

A water depth model used for capsule landing analyses off the coast of KSC was developed by the United States Geological Survey (USGS) using an extension of a study performed for the United States Air Force (USAF) (Thomson et al., 2015). First, sonar and lidar-based measurements dating from 1956, 2010, and 2014 were interpolated to a constant grid within a specified domain. The interpolation grid points were spaced nominally 50 m apart in the cross-shore direction and 250 m apart in the alongshore direction using a curvilinear grid that followed the contour of the shoreline. Next, the depth at each gridpoint was computed as a weighted mean between these datasets, with newer datasets being assigned a greater weight. In addition, uncertainties were calculated in Thomson et al. (2015) representing instrument uncertainties, variations over time and the short spatial scales that were filtered by the interpolation. For application to capsule landings, tidal influences on instantaneous water depth were added in a similar fashion and the root-sum-square (RSS) of all of the uncertainties were computed. This RSS parameter is used as the standard deviation of the water depth at a given gridpoint. The resulting model thus contains parameters representing the mean and standard deviation of water depths at each gridpoint within the model’s domain, which specifically applies to launches from the KSC Launch Complexes.

For a given abort simulation, a water depth is randomly selected, assuming depths are Gaussian distributed, from the mean and standard deviation of the depth’s distribution statistics at the closest gridpoint to the abort location.

3.6.19 Reserved

3.6.20 Sea Surface Temperature for Off-Nominal Water Landing

Description

This section specifies the design maximum and minimum sea surface temperatures for off-nominal water landings as defined in Section 3.6.9, Surface Air Temperature for Off-Nominal Landing.
Design Limits

Maximum: 32.0 °C (89.6 °F)
Minimum: 10.4 °C (50.7 °F)

Model Inputs
None

Limitations
None

Technical Notes

Design limits for off-nominal water landings were determined using weekly mean sea surface temperature output within the water landing areas corresponding to 23 different skip entry trajectories provided by the Orion Program, as well as the area immediately surrounding a 29.0° inclination orbit extending over water regions from KSC to the western coast of Australia. Sea surface temperatures were obtained from the NCEP-OI dataset, which contains weekly mean sea surface temperature records on a 1.0° latitude x 1.0° longitude grid for the 1981-2012 period of record. The global dataset was subsetted to only contain temperatures within the off-nominal water landing area. Design limits were determined by comparing the minimum and maximum recorded sea surface temperatures to the 0.5th and 99.5th percentile temperatures with 95.0% confidence intervals applied for each month (Barbré, 2012). Minimum and maximum design limits are the 0.5th and 99.5th percentile temperatures with 95.0% confidence during April and January, respectively.

3.7 Recovery and Post-Flight Processing Phases

This section describes the environments hardware and personnel will be exposed to during post-flight and recovery operations near KSC and in the normal landing sites located in the western U.S.

3.7.1 Environments for Post-Flight and Recovery at KSC

Except for the sea state specification in Section 3.7.2, Sea State for KSC Post-Flight and Recovery, specifications for post-flight and recovery operations at KSC are provided in Section 3.1, Prelaunch-Ground Processing Phases.

3.7.2 Sea State for KSC Post-Flight and Recovery

Reserved.

3.7.3 Lightning Specification for Post-Flight and Recovery

Description

Design specifications include standardized voltage and current waveforms derived or characterized to represent the lightning environment at specific zones established on the vehicle.
Design Limits

The environment in the normal landing area is such that systems will be exposed to the direct and indirect effects of lightning. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, and must be defined and evaluated for each applicable vehicle configuration. SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms is an applicable document. Ground support elements may have less stringent requirements to be specified at a later date.

Model Inputs

Vehicle lightning strike zones are defined for the integrated vehicle in re-entry and landing configurations, including with and without parachutes deployed, while descending through the atmosphere or residing on land or water after landing.

Limitations

Waveforms used for analysis are selected based on vehicle attachment profile and electromagnetic regions.

The most important characteristics of the standard lightning waveforms used for analysis and test are the peak current, continuing current, peak rate of rise, and the action integral, or coulomb content, of the waveform. Secondary characteristics of significance are the time to peak, and the time to fall to 50% of the peak. Peak current and continuing current levels are important for direct attachment assessment. The action integral is the amount of energy contained in the flash event, and is most important for determination of damage related to direct attachment effects. Rise and fall times are important for indirect effects assessment and analysis.

Technical Notes

None

3.7.4 Surface Winds for Post-Flight and Recovery

The ground wind environment specified in Section 3.5.8, Surface Winds for Normal Landing, is applicable to post-flight and recovery phase operations conducted in the normal landing area.

3.7.5 Surface Air Temperature for Post-Flight and Recovery

The surface air temperature limits specified in Section 3.5.9, Surface Air Temperature for Normal Landing, are applicable to post-flight and recovery phase operations in the normal landing area.

3.7.6 Surface Air Pressure for Post-Flight and Recovery

The surface air pressure limits applicable to post-flight and recovery phase operations in the normal landing area are specified in Section 3.5.10, Surface Air Pressure for Normal Landing.
3.7.7 Surface Air Humidity for Post-Flight and Recovery

The surface air humidity conditions applicable to post-flight and recovery phase operations in the normal landing area are specified in Section 3.5.11, Surface Air Humidity for Normal Landing.

3.7.8 Aerosol Environment for Post-Flight and Recovery

The aerosol environment for the normal landing area is specified in Section 3.5.12, Aerosols for Normal Descent and Landing.

3.7.9 Precipitation Environment for Post-Flight and Recovery

The precipitation environment for the normal landing area is specified in Section 3.5.13, Precipitation for Normal Descent and Landing.

3.7.10 Flora and Fauna Environment for Post-Flight and Recovery

The flora and fauna environment for the normal landing area is specified in Section 3.5.14, Flora and Fauna for Descent and Landing.

3.7.11 Surface Characteristics and Topography for Post-Flight and Recovery

Design specifications for the surface characteristics and topography of the normal landing area are specified in Section 3.5.15, Surface Characteristics and Topography for Normal Landing.

3.7.12 Cloud and Environment for Post-Flight and Recovery

The cloud and fog environment in the normal landing area is specified in Section 3.5.16, Cloud and Environment for Normal Descent and Landing.

3.7.13 Radiant (Thermal) Energy Environment for Post-Flight and Recovery

The radiant energy environment in the normal landing area is specified in Section 3.5.17, Radiant (Thermal) Energy Environment for Normal Landing.

3.8 Interplanetary Space Specification

Reserved.

3.9 Mars Orbit Specification

Reserved.

3.10 Mars Atmosphere and Surface Phase Specification

Reserved.

3.11 Mars Moon Specification

Reserved.

3.12 Near Earth Asteroid Specification

Reserved.
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4.0 COMPLIANCE ASSESSMENT OF NATURAL ENVIRONMENTS

It is recommended that compliance assessments be developed by each integrated Program and its elements for the applicable natural environments specifications in this document. Compliance for each applicable natural environment can be met by demonstrating a robust design to the specified environment, utilizing operational mitigation strategies to reduce exposure to the natural environment, or choosing to accept the risk of exposure to all or a portion of the environment. In the latter case, each Program should acknowledge that they accept any adverse situations that may occur from exposure to the full environment.

Programs will coordinate any compliance assessments that affect other programs through the Cross-Program NEIAHT. The program representative will also keep the NEIAHT informed of internal program assessments as a courtesy.
5.0 REFERENCES

The following documents and reference materials contain supplemental information to guide the user in the application of this document.


CxP 70023, Constellation Program Design Specification for Natural Environments (DSNE), Revision C


NASA MSFC Memo EV44 (15-007), KSC Avian Environment, 17 August 2015.


NASA/TM 2016-218229, Natural Environment Definition for Design (NEDD).


NSTS 16007, Space Shuttle Launch Commit Criteria (LCC) and Background, Section 4, Weather Rules.


SLS-PLAN-008, SLSP Configuration Management Plan

SLS-SPEC-048, Cross-Program Integrated Coordinate Systems.


# APPENDIX A
## ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACE</td>
<td>Advanced Composition Explorer</td>
</tr>
<tr>
<td>AGL</td>
<td>Above Ground Level</td>
</tr>
<tr>
<td>Al</td>
<td>aluminum</td>
</tr>
<tr>
<td>ALARA</td>
<td>As Low As Reasonably Achievable</td>
</tr>
<tr>
<td>AO</td>
<td>Atomic Oxygen</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>C-ERA40</td>
<td>Corrected-European Centre for Medium Range Weather Forecasts Re-Analysis</td>
</tr>
<tr>
<td>CDIP</td>
<td>Coastal Data Information Program</td>
</tr>
<tr>
<td>cGy</td>
<td>centiGrays</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeters</td>
</tr>
<tr>
<td>CR</td>
<td>Change Request</td>
</tr>
<tr>
<td>CREAM96</td>
<td>Cosmic Ray Effects on Microelectronics 96</td>
</tr>
<tr>
<td>CxP</td>
<td>Constellation Program</td>
</tr>
<tr>
<td>DD</td>
<td>Displacement damage</td>
</tr>
<tr>
<td>DDD</td>
<td>Displacement damage dosage</td>
</tr>
<tr>
<td>DRM</td>
<td>Design Reference Mission</td>
</tr>
<tr>
<td>DRM ConOps</td>
<td>Design Reference Missions and Operational Concepts</td>
</tr>
<tr>
<td>DSH</td>
<td>Deep Space Habitat</td>
</tr>
<tr>
<td>DSNE</td>
<td>Design Specification for Natural Environments</td>
</tr>
<tr>
<td>EAFB</td>
<td>Edwards Air Force Base</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Centre for Medium Range Weather Forecasts</td>
</tr>
<tr>
<td>ER</td>
<td>Eastern Range</td>
</tr>
<tr>
<td>ESD</td>
<td>Exploration Systems Development</td>
</tr>
<tr>
<td>ESP</td>
<td>Emission of Solar Protons</td>
</tr>
<tr>
<td>ev</td>
<td>Electron Volts</td>
</tr>
<tr>
<td>EVA</td>
<td>Extravehicular Activity</td>
</tr>
<tr>
<td>ft</td>
<td>Feet</td>
</tr>
<tr>
<td>ft/s</td>
<td>Feet per second</td>
</tr>
<tr>
<td>g/cm²</td>
<td>Grams Per Square Centimeter</td>
</tr>
<tr>
<td>g/cm³</td>
<td>Grams Per Cubic Centimeter</td>
</tr>
<tr>
<td>GCR</td>
<td>Galactic Cosmic Radiation (Rays)</td>
</tr>
<tr>
<td>GEO</td>
<td>Geosynchronous Earth Orbit</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>MeV</td>
<td>Megaelectronvolts</td>
</tr>
<tr>
<td>mg</td>
<td>Milligrams</td>
</tr>
<tr>
<td>MIL-STD</td>
<td>Military Standard</td>
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<tr>
<td>MLP</td>
<td>Mobile Launch Platform</td>
</tr>
<tr>
<td>mm/hr</td>
<td>Millimeters Per Hour</td>
</tr>
<tr>
<td>MPCV</td>
<td>Multi-Purpose Crewed Vehicle</td>
</tr>
<tr>
<td>MSFC</td>
<td>Marshall Space Flight Center</td>
</tr>
<tr>
<td>MSIS</td>
<td>Mass Spectrometer Incoherent Scatter</td>
</tr>
<tr>
<td>MV</td>
<td>Megavolts</td>
</tr>
<tr>
<td>MVWPM</td>
<td>Monthly Vector Wind Profile Model</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NASA-HDBK</td>
<td>NASA Handbook</td>
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<tr>
<td>NASA/TM</td>
<td>NASA Technical Memorandum</td>
</tr>
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<td>NAVD 88</td>
<td>North American Vertical Datum 88</td>
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<tr>
<td>NCEP-OI</td>
<td>National Centers for Environmental Prediction-Optimal Interpolation</td>
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<td>NCRP</td>
<td>National Council on Radiation Protection and Measurements</td>
</tr>
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<td>NDBC</td>
<td>National Data Buoy Center</td>
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<tr>
<td>NEA</td>
<td>Near Earth Asteroid</td>
</tr>
<tr>
<td>NEDD</td>
<td>Natural Environment Definition for Design</td>
</tr>
<tr>
<td>NEIAHT</td>
<td>Natural Environments Integration Ad-Hoc Team</td>
</tr>
<tr>
<td>nm</td>
<td>Nanometers</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>nmi</td>
<td>Nautical Mile</td>
</tr>
<tr>
<td>OLR</td>
<td>Outgoing Long-wave Radiation</td>
</tr>
<tr>
<td>ORDEM 3.0</td>
<td>Orbital Debris Engineering Model 3.0</td>
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<tr>
<td>PDS</td>
<td>Planetary Data System</td>
</tr>
<tr>
<td>PMBT</td>
<td>Propellant Mean Bulk Temperature</td>
</tr>
<tr>
<td>POR</td>
<td>Period of Record</td>
</tr>
<tr>
<td>psi</td>
<td>Pounds Per Square Inch</td>
</tr>
<tr>
<td>PSYCHIC</td>
<td>Prediction of Solar particle Yields for Characterizing Integrated Circuits</td>
</tr>
<tr>
<td>Re</td>
<td>Radius of the Earth</td>
</tr>
<tr>
<td>RAAN</td>
<td>Right Ascension of Ascending Node</td>
</tr>
<tr>
<td>RRA</td>
<td>Range Reference Atmosphere</td>
</tr>
<tr>
<td>SAA</td>
<td>South Atlantic Anomaly</td>
</tr>
<tr>
<td>SCATHA</td>
<td>Spacecraft Charging at High Altitudes</td>
</tr>
<tr>
<td>s</td>
<td>Second(s)</td>
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The electronic version is the official approved document.
Verify this is the correct version before use.
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<tr>
<th>Abbreviation</th>
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<td>SEE</td>
<td>Single Event Effects</td>
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<tr>
<td>SIG</td>
<td>Systems Integration Group</td>
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<td>SLS</td>
<td>Space Launch System</td>
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<tr>
<td>SPE</td>
<td>Solar Particle Event</td>
</tr>
<tr>
<td>SPENVIS</td>
<td>Space Environment Information System</td>
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<tr>
<td>SWH</td>
<td>Significant Wave Height</td>
</tr>
<tr>
<td>SZA</td>
<td>Solar Zenith Angle</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>TBR</td>
<td>To Be Reviewed</td>
</tr>
<tr>
<td>TID</td>
<td>Total Ionizing Dose</td>
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<tr>
<td>TLI</td>
<td>Translunar Injection</td>
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<tr>
<td>TPM-1</td>
<td>Trapped Proton Model-1</td>
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<tr>
<td>UTC</td>
<td>Universal Time Coordinated</td>
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<tr>
<td>W/m²</td>
<td>Watts Per Square Meter</td>
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# APPENDIX B

## NATURAL ENVIRONMENT VALIDATION MATRIX

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<td>3.1 Prelaunch - Ground Processing Phase</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>3.1.1 Transportation Environments to Launch Site KSC</td>
<td>N/A</td>
<td>The Peak Wind Profile Model was developed through statistical analysis of KSC 500-ft wind tower data. The model is designed to envelope peak wind variability with height (to a specified sigma level) above an 18.3 m reference level. Details of the databases, processes, and physics used in developing the Peak Wind Profile Model are given in &quot;Characteristics of Atmospheric Turbulence as Related to Wind Loads on Tall Structures,&quot; G. Fichtl et. al., Journal of Spacecraft and Rockets, Dec. 1969, Vol. 6, No. 12, pp. 1396-1403, and in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision. Comparison of the Peak Wind Profile Model to measured data from the KSC 500-ft wind tower has been conducted (see NASA/MSFC/EV44 Memo EV13-05-007). The study showed that the model envelopes measured peak wind profiles to the appropriate probability level (sigma level). Peak Wind Profile Model was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification;</td>
</tr>
<tr>
<td>3.1.2 Reserved</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Peak Wind Profile Model</td>
<td>The Peak Wind Profile Model was developed through statistical analysis of KSC 500-ft wind tower data. The model is designed to envelope peak wind variability with height (to a specified sigma level) above an 18.3 m reference level. Details of the databases, processes, and physics used in developing the Peak Wind Profile Model are given in &quot;Characteristics of Atmospheric Turbulence as Related to Wind Loads on Tall Structures,&quot; G. Fichtl et. al., Journal of Spacecraft and Rockets, Dec. 1969, Vol. 6, No. 12, pp. 1396-1403, and in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision. Comparison of the Peak Wind Profile Model to measured data from the KSC 500-ft wind tower has been conducted (see NASA/MSFC/EV44 Memo EV13-05-007). The study showed that the model envelopes measured peak wind profiles to the appropriate probability level (sigma level). Peak Wind Profile Model was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification;</td>
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</table>
### Section 3.1.3 Ground Winds for Transport and Launch Pad Environments

#### Table 3.1.3-1 Design Peak Wind Speed Profiles

<table>
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<th>Validation Statement</th>
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<tr>
<td>Steady-State Wind Profile Model</td>
<td>The Steady-State Wind Profile Model is constructed by reducing the Peak Wind Profile Model by altitude dependent gust factors. The gust factors were developed through statistical analysis of KSC 500-ft wind tower data. Details of the databases, processes, and physics used in developing the gust factors and Steady-State Wind Profile Model are given in &quot;Characteristics of Atmospheric Turbulence as Related to Wind Loads on Tall Structures,&quot; G. Fichtl et. al., Journal of Spacecraft and Rockets, Dec. 1969, Vol. 6, No. 12, pp. 1396-1403, and in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision. Steady-State Wind Profile Model was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
</tr>
</tbody>
</table>
| Table 3.1.3-1 Design Peak Wind Speed Profiles | The Design Peak Wind Speed Profiles in Table 3.1.3-1 are constructed by inputting the appropriate peak wind speed at the 18.3 m level into the Peak Wind Profile Model. For the transport to/from pad case, the 18.3 m peak wind speed of 30.8 m/s is the heritage value used for Space Shuttle Mobile Launch Platform (MLP) transport operations (Space Shuttle Operations and Maintenance Requirements and Specifications Document, File II, Vol. I, Rule S00L00.010, June 6, 2006). For the on-pad unfueled case, the 18.3 m peak wind speed of 38.3 m/s is the 99th percentile value for a 180-day exposure period at KSC. For the on-pad fueled case, the 18.3 m peak wind speed of 24.2 m/s is the
<table>
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<th>Section</th>
<th>Model/Dataset/Design Limit</th>
<th>Validation Statement</th>
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</thead>
<tbody>
<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Table 3.1.3-2 Steady-State Wind Speed Profiles</td>
<td>99th percentile value for a 1-day exposure period at KSC. The on-pad cases values (38.3 m/s and 24.2 m/s) were used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
</tr>
<tr>
<td>3.2.1 Ground Winds Environments during Launch</td>
<td>Table 3.2.1-2 Steady State Wind Speed Profile for Vehicle Launch</td>
<td>The Steady-State Wind Speed Profiles in Table 3.1.3-2 and Table 3.2.1-2 are constructed by reducing the Peak Wind Speed Profiles in Table 3.1.3-1 and 3.2.1-1, respectively, with an altitude dependent gust factor (Steady-State Wind Profile Model). The applied gust factor is based on a 10-minute averaging period. (The steady-state wind speed profile is the 10-minute mean wind speed profile that could produce the peak wind speed profile.) The steady-state wind speed profiles were used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
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<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Table 3.1.3-3 30-second Peak Wind Speeds for Fatigue Load Assessments</td>
<td>Details of the 30 second peak wind speed distribution in Table 3.1.3-3 is provided in NASA MSFC Memo ES42 (92-67), &quot;Probabilities of Ground Winds for SSP Fatigue Loads.&quot; The 30-second peak wind distribution was developed from the statistics of 170 hours of wind tower 1-second data. To better represent a long term climatology, the 170 hours worth of 30-second statistics were scaled to 1-hour statistics from a 33-year period. The 30-second peak wind distribution was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
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<tr>
<td>Section</td>
<td>Model/Dataset/Design Limit</td>
<td>Validation Statement</td>
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</tr>
<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Table 3.1.3-4 Design Wind Speed Profiles for Thermal Assessments (Time constants less than an hour)</td>
<td>Space Shuttle Flight and Ground System Specification: Environment Design, Weight and Performance, and Avionics Events). Design low wind profile of no wind is the extreme for the cold case. Design high wind profile is the steady-state wind speed profile, developed from the peak wind speed profile with a 17.7 m/s input wind at 18.3 m (17.7 m/s is the 95th percentile peak wind value for a 1-hour period. See section 3.2.1 Steady-State Wind Speed Profile for liftoff.). Design high wind profile was determined through statistical analysis of KSC LC 39B 60-ft database using MATLAB. Data was vetted through the SLS Thermal Environments Task Team on 11/05/2013 and the Natural Environments Integration Ad Hoc Team on 11/07/2013.</td>
</tr>
<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Table 3.1.3-5 Design Wind Speed Profiles for Thermal Assessments (Time constants on the order of hours)</td>
<td>Design low wind profile is the 1st percentile steady-state wind speed at 60-ft for a 1-hour exposure period at KSC. The steady-state value at the 60-ft level is used at all heights up to 500 ft. The 1st percentile level is chosen since it is highly unlikely the wind speed would be completely calm over several hours. Design high wind profile is the steady-state wind speed profile, developed from the peak wind speed profile with a 17.7 m/s input wind at 18.3 m (17.7 m/s is the 95th percentile peak wind value for a 1-hour period. See section 3.2.1 Steady-State Wind Speed Profile for liftoff.). Design low wind profile was determined through statistical analysis of KSC LC 39B 60-ft database using MATLAB. Data was vetted through the SLS Thermal Environments Task Team on 11/05/2013 and the Natural Environments Integration Ad Hoc Team on 11/07/2013.</td>
</tr>
<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Table 3.1.3-6 Design Wind Speed Profiles for Thermal Assessments (Time constants on the order of days)</td>
<td>The diurnal steady-state wind speed profiles are the 1st (design low) and 99th (design high) percentile steady-state wind at each hour of the day at KSC. Percentile values were obtained from KSC Launch Complex</td>
</tr>
</tbody>
</table>
### Section 3.1.3 Ground Winds for Transport and Launch Pad Environments

#### KSC Launch Complex 39B 60-ft Wind Tower Data

- **Validation Statement:**
  - 39B 60-ft database. MATLAB was used to determine percentile values.
  - Data was vetted through the SLS Thermal Environments Task Team on 11/05/2013 and the Natural Environments Integration Ad Hoc Team on 11/07/2013.

#### Design Spectral Gust Model

- **Validation Statement:**
  - The underlining physics of the spectral gust model are given in the Monin-Obukhov Similarity Theory. Monin-Obukhov has been used extensively in the atmospheric science community to represent mean flow and turbulence properties in the atmospheric surface layer. The spectral gust model was developed by adjusting Monin-Obukhov...
<table>
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<th>Section</th>
<th>Model/Dataset/Design Limit</th>
<th>Validation Statement</th>
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<tr>
<td>3.1.3 Ground Winds for Transport and Launch Pad Environments</td>
<td>Coherence Model</td>
<td>Details of the Coherence Model are given in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision. (See Section 2.2.6.3)</td>
</tr>
<tr>
<td>3.2.1 Ground Winds Environments during Launch</td>
<td>Discrete Gust Model</td>
<td>The “1-cosine” gust shape is an industry standard. The Discrete Gust Model was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
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<td></td>
<td></td>
<td>Production of the National Solar Radiation Database (NSRDB)”, Solar Energy, 62 (4).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All data in Section 3.1 are obtained from the Shuttle Landing Facility grid point of the NSRD.</td>
</tr>
<tr>
<td>3.1.4 Radiant (Thermal) Energy Environment for Ground Ops at KSC</td>
<td>Sky Temperature</td>
<td>All sky temperature values in Tables 3.1.4-4 through 3.1.4-9 are determined from air temperature, dew point temperature, and sky cover. Details of the calculation, along with model validation, are given in K. Wang and S. Liang, &quot;Global atmospheric downward longwave radiation over land surface under all-sky conditions from 1973 to 2008&quot;, J. Geophysical Research, Vol. 114, D19101, 2009.</td>
</tr>
<tr>
<td>3.1.4 Radiant (Thermal) Energy Environment for Ground Ops at KSC</td>
<td>Table 3.1.4-1 Design High Radiant Energy as a Function of Time of Day, Table 3.1.4-2 Design Low Radiant Energy as a Function of Time of Day</td>
<td>Design high and low direct incident are the maximum and minimum values at each hour for the months of June and December, determined from the NSRD. Design high (low) diffuse values are those associated with the design high (low) direct incident values. MATLAB was used to determine maximum and minimum values.</td>
</tr>
<tr>
<td>3.1.4 Radiant (Thermal) Energy Environment for Ground Ops at KSC</td>
<td>Table 3.1.4-3 Sky Temperature Design Limits for KSC</td>
<td>Design high and low sky temperature limits are obtain from NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision.</td>
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<tr>
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<tr>
<td>3.1.4 Radiant (Thermal) Energy Environment for Ground Ops at KSC</td>
<td>Table 3.1.4-4 Cold Design Radiant Energy, Cloudy Sky</td>
<td>Values in Tables 3.1.4-4, 3.1.4-6, and 3.1.4-8 were determined by taking the average at each hour for the 10 coldest days with cloudy skies (100% sky cover), partly cloudy skies (40 to 60% sky cover), and clear skies (0% sky cover) from the NSRD (1991-2010). Cold days were determined by calculating the average daily temperature for each day in the period of record, and selecting the 10 coldest days that met the specific sky condition.</td>
</tr>
<tr>
<td></td>
<td>Table 3.1.4-5 Hot Design Radiant Energy, Cloudy Sky</td>
<td></td>
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<tr>
<td></td>
<td>Table 3.1.4-6 Cold Design Radiant Energy, Partly Cloudy Sky</td>
<td>Values in Tables 3.1.4-5, 3.1.4-7, and 3.1.4-9 were determined by taking the average at each hour for the 10 hottest days with cloudy skies (100% sky cover), partly cloudy skies (40 to 60% sky cover), and clear skies (0% sky cover) from the NSRD (1991-2010). Hot days were determined by calculating the average daily temperature for each day in the period of record, and selecting the 10 hottest days that met the specific sky condition.</td>
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<td>Table 3.1.4-7 Hot Design Radiant Energy, Partly Cloudy Sky</td>
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</tr>
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<td></td>
<td>Table 3.1.4-8 Cold Design Radiant Energy, Clear Sky</td>
<td>Data was compared to NSRD data to ensure profile properly represented the specific condition. Methodology was vetted through the SLS Thermal Environments Task Team on 11/05/2013 and the Natural Environments Integration Ad Hoc Team on 11/07/2013.</td>
</tr>
<tr>
<td></td>
<td>Table 3.1.4-9 Hot Design Radiant Energy, Clear Sky</td>
<td></td>
</tr>
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<td>3.1.5 Air Temperature Environment for Ground Ops at KSC</td>
<td>Patrick Air Force Base/Shuttle Landing Facility surface observations</td>
<td>The Patrick Air Force Base (PAFB)/Shuttle Landing Facility (SLF) surface observations contain hourly values of various meteorological data. The period of record is 1957-2001 (1957-1977 from PAFB, and 1978-2001 from SLF). The PAFB/SLF database was quality controlled by the MSFC</td>
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<tr>
<td>3.1.5 Air Temperature Environment for Ground Ops at KSC</td>
<td>Max and min design limits for air temperature</td>
<td>Natural Environments Branch (EV44) and used throughout the Space Shuttle Program.</td>
</tr>
<tr>
<td>3.1.5 Air Temperature Environment for Ground Ops at KSC</td>
<td>Table 3.1.5-1 Design Hot and Cold Diurnal Temperature Profile</td>
<td>The design hot and cold diurnal profiles are the 99th and 1st percentile temperatures for each hour in the hot month (July) and cold month (January), respectively, from the PAFB/SLF database. MATLAB was used to determine percentile values.</td>
</tr>
<tr>
<td>3.1.5 Air Temperature Environment for Ground Ops at KSC</td>
<td>Table 3.1.5-2 Design Hot and Cold Monthly Averaged Diurnal Temperature Profile</td>
<td>The design hot and cold monthly average diurnal profiles are the 99th and 1st percentile monthly averaged temperatures for each hour in the hot month (July) and cold month (January), respectively, from the PAFB/SLF database. MATLAB was used for averaging, and determining percentile values.</td>
</tr>
<tr>
<td>3.1.6 Air Pressure Environment for Ground Ops at KSC</td>
<td>Max and min design limits for air pressure</td>
<td>Max and min design pressure limits of 1037.4 hPa and 973.9 hPa, respectively, are the max and min of the PAFB/SLF meteorological database (1957-2001). MATLAB was used to determine percentile values.</td>
</tr>
<tr>
<td>3.1.7 Humidity Environment for Ground Ops at KSC</td>
<td>Table 3.1.7-1 Psychrometric Data, Dew Point Temperature Versus Temperature Envelope for KSC</td>
<td>Table 3.1.7-1 was determined by plotting temperature vs. dew point temperature for the entire period of record of the PAFB/SLF database, and constructing an envelope around all the data points.</td>
</tr>
<tr>
<td>3.1.8 Aerosol Environment for Salt fog and sand/dust environment</td>
<td>The salt fog and sand/dust environment is given in MIL-STD-810G, Test Method</td>
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<tr>
<td>Ground Ops at KSC</td>
<td></td>
<td>Standard for Environmental Engineering Considerations and Laboratory Tests. Method 509.6 describes the environments/tests for salt fog. Method 510.6, Procedure 1 describes the test procedure for sand/dust with particle sizes less than 150 microns. The sand/dust particle concentration is 0.177 g/m³, per Part 3, Section 5.7 of MIL-STD-810G.</td>
</tr>
</tbody>
</table>
| 3.1.9 Precipitation Environment for Ground Ops at KSC       | Table 3.1.9-1 Design Rainfall, KSC, Based on Yearly Largest Rate for Stated Durations | Design rainfall rates are described in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision.  
Design rainfall rate was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events). |
<p>| 3.1.10 Flora and Fauna Environment for Ground Ops           | Flora and fauna environment | The KSC area contains numerous wildlife, including birds, rodents, insects, wild boar, and alligators. Observations validate the presence of wildlife at KSC. Methods for testing of materials for fungus growth are given in MIL-STD-810G, Method 508. |
| 3.1.11 Lightning Environment for Ground Ops at KSC          | Lightning environment      | The KSC environment is such that systems will be exposed to the direct and indirect effects of lightning. Observations validate the presence of lightning at KSC. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, Aircraft Lightning Zones and SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms. |</p>
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<tbody>
<tr>
<td>3.6.3 Lightning During Off-Nominal Landing</td>
<td></td>
<td>The Design Peak Wind Speed Profiles in Table 3.2.1-1 are constructed by inputting the appropriate peak wind speed at the 18.3 m level. For launch, the 18.3 m peak wind speed of 17.7 m/s is the 99th percentile value for a 1-hour exposure period at KSC. The 17.7 m/s value was used during Space Shuttle design and operations (NSTS 07700, Vol. 10, Book 2, Space Shuttle Flight and Ground System Specification; Environment Design, Weight and Performance, and Avionics Events).</td>
</tr>
<tr>
<td>3.2.1 Ground Winds Environments during Launch</td>
<td>Table 3.2.1-1 Peak Wind Speed Profile for Vehicle Launch</td>
<td>Max and min design limits (99 deg F and 33 deg F) represent the range of temperatures for launch used by the Space Shuttle Program and listed in NSTS 16007, Space Shuttle Launch Commit Criteria and Background, Section 4, Weather Rules. The rationale for choosing this design range for launch is that redesign, retesting, recertification, etc., of legacy hardware would not be necessary.</td>
</tr>
<tr>
<td>3.2.2 Surface Air Temperature Environment During Launch</td>
<td>Max and min design limits for air temperature</td>
<td>Max and min design limits (99 deg F and 33 deg F) represent the range of temperatures for launch used by the Space Shuttle Program and listed in NSTS 16007, Space Shuttle Launch Commit Criteria and Background, Section 4, Weather Rules. The rationale for choosing this design range for launch is that redesign, retesting, recertification, etc., of legacy hardware would not be necessary.</td>
</tr>
<tr>
<td>3.2.5 Aloft Wind Environment for Vehicle Ascent</td>
<td>Earth-GRAM 2010</td>
<td>Details of the model are provided in NASA/TM-2011-216467, The NASA Marshall Space Flight Center Earth Global Reference Atmospheric Model - 2010 Version. Verification and validation details are provided in EV44 (14-002), Verification and Validation Report, Earth GRAM 2010 Version 4.0. Earth-GRAM is a well-established model that has been used for various space programs, including Space Shuttle, Constellation, and SLS/MPCV.</td>
</tr>
<tr>
<td>3.6.4 Aloft Winds for Off-Nominal Descent and Landing</td>
<td>Monthly Vector Wind Profile Model</td>
<td>The Monthly Vector Wind Profile Model (MVWPM) is built with the quadrivariate normal statistics from the serial complete</td>
</tr>
</tbody>
</table>
### Wind Profile Database Validation


The MVWPM has compared favorably with long-term climatological databases (NOAA databases). For the KSC vicinity, statistics from several different measurement systems (wind profilers, balloon systems, etc.) have shown good agreement with the MVWPM dispersions and shears. Comparison of aerodynamic load indicators (ALI) in launch vehicle simulations has shown that the MVWPM sufficiently envelopes ALI determined from 1800 detailed wind profiles (S. I. Adelfang, O. E. Smith, and G. W. Batts, Ascent Wind Model for Launch Vehicle Design, J. Spacecraft and Rockets).

### Aloft Wind Environment for Vehicle Ascent

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</table>
| 3.2.5 Aloft Wind Environment for Vehicle Ascent | Measured Wind Database (KSC DRWP Database) | ED44 (01-015), Automated Meteorological Profiling System High Resolution Flight Element Analysis Results, July 2001."

The KSC Jimsphere Wind Profile database consists of high-resolution (HR) balloon data, and has been quality controlled and validated through statistical comparison to established climatology by the MSFC Natural Environments Branch. The Jimsphere/HR balloon system and database was used in Space Shuttle design and DOL operational assessments.

Details of the KSC DRWP are provided in:

Schumann et. al., Performance Characteristics of the Kennedy Space Center 50-MHz Doppler Radar Wind Profiler Using the Median Filter/First-Guess Data Reduction Algorithm, J. Atmospheric and Oceanic Technology, Vol. 16, May 1999, pages 532-549.


The KSC DRWP database consists of high temporal resolution wind profiles, which have been quality controlled and validated through statistical comparison to established climatology by the MSFC Natural Environments Branch. Details of the quality control process are given in R. E. Barbre, Quality Control Algorithms for the Kennedy Space Center 50-MHz Doppler Radar Wind Profiler Winds Database, J. Atmospheric and Oceanic Technology, Vol. 29, December 2012, pages 1731-1743.
## Section 3.2.5 Aloft Wind Environment for Vehicle Ascent

### Details of the development of the KSC DRWP database

Details of the development of the KSC DRWP database are given in Barbre, Jr. 2015: Development of a Climatology of Vertically Complete Wind Profiles From Doppler Radar Wind Profiler Systems. American Meteorological Society. 17th Conference on Aviation, Range, and Aerospace Meteorology. Paper 8.1. Phoenix, AZ.

The KSC DRWP was used as an independent check of balloon wind profiles during Space Shuttle DOL operations.

### Details of the processes and physics used to develop the Discrete Gust Model


The moderate turbulence standard deviations result in slightly conservative estimates, while severe turbulence deviations result in extremely conservative estimates compared to gust magnitudes determined from measured wind profiles (Barbre presentation to the Cross-Program Joint Loads Task Team on 09/27/2012, "Proposed Modifications to the NASA Discrete Gust Model Atmospheric Turbulence Input"). The Discrete Gust Model has been used extensively in the aerospace field, including both military and NASA developed vehicles.
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<tr>
<td>3.2.5 Aloft Wind Environment for Vehicle Ascent</td>
<td>Tables 3.2.5-1, 3.2.5-2, 3.2.5-3, and 3.2.5-4 Discrete Gust Magnitude</td>
<td>Gust magnitudes in Tables 3.2.5-1, 3.2.5-2, 3.2.5-3, and 3.2.5-4 are constructed by using the 1-Cosine discrete gust model, and the gust standard deviations selected from Table 2-71 of NASA TM-2008-215633. Gust magnitudes are constructed at the 99% probability level. Gust magnitudes based on moderate turbulence compare favorably to measured data, while magnitudes based on severe turbulence are conservative compared to measured data, as shown in Barbre presentation to the Cross-Program Joint Loads Task Team on 09/27/2012, &quot;Proposed Modifications to the NASA Discrete Gust Model Atmospheric Turbulence Input&quot;.</td>
</tr>
<tr>
<td>3.2.5 Aloft Wind Environment for Vehicle Ascent</td>
<td>Continuous Gust Model</td>
<td>The Continuous Gust Model was developed with the same methodology as defined by the Aerospace Corporation. The model was vetted through the Natural Environments Integrated Ad Hoc Team, Joint Loads Task Team, and Ascent Flight Systems Integration Task Team. The Aerospace Corporation also provided independent validation.</td>
</tr>
<tr>
<td>3.2.5 Aloft Wind Environment for Vehicle Ascent</td>
<td>Table 3.2.5-3 Earth-GRAM 2010 Input for Monte Carlo Runs</td>
<td>Table 3.2.5-3 provides input to run Earth-GRAM random profiles for ascent Monte Carlo assessments. It is recommended to use the Range Reference Atmosphere data set (monthly climatology) when available, since it provides a better statistical representation of the available sites. Random perturbations are set to nominal dispersions. Patchy turbulence is turned off (patches of severe turbulence). Suggested Earth-GRAM inputs are standard inputs for typically Monte Carlo assessments.</td>
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<tr>
<td>3.2.6 Aloft Air Temperature Environment for Vehicle Ascent</td>
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<td>3.2.7 Aloft Air Pressure Environment for Vehicle Ascent</td>
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<td>3.2.8 Aloft Air Density Environment for Vehicle Ascent</td>
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<td>3.2.5 Aloft Wind Environment for Vehicle Ascent</td>
<td>Table 3.2.5-4 Earth-GRAM 2010 Input for Monthly Mean Profiles</td>
<td>Table 3.2.5-4 provides input to run Earth-GRAM to generate profiles of monthly means. It is recommended to use the Range Reference Atmosphere data set (monthly climatology) when available, since it provides a better statistical representation of the available sites. Random output is turned off (no random perturbations). Suggested Earth-GRAM inputs are standard inputs for building monthly mean profiles.</td>
</tr>
<tr>
<td>3.2.9 Cloud and Fog Environment for Launch</td>
<td>Size distribution of liquid cloud particles</td>
<td>The size distribution for liquid cloud particles, and comparison of statistical fits to observed data, is provided in Miles, et. al., Cloud Droplet Size Distributions in Low-Level Stratiform Clouds, J. Atmospheric Science, Vol. 57, Jan 2000, pages 295-311.</td>
</tr>
<tr>
<td>3.2.9 Cloud and Fog Environment for Launch</td>
<td>Size distribution of frozen cloud particles</td>
<td>The size distribution for frozen cloud particles, and comparison of stastical fits to observed data, is provided in A. Heymsfield, Properties of Tropical and Midlatitude Ice Cloud Particle Ensembles. Part II: Applications for Mesoscale and Climate Models, J. Atmospheric Science, Vol. 60, Nov 2003, pages 2592-2611.</td>
</tr>
<tr>
<td>3.2.10 Rain and Precipitation Environment for Launch</td>
<td>Design Rainfall rate</td>
<td>The design rainfall rate is the NOAA maximum observational reporting value for moderate rainfall (NOAA, Federal Meteorological Handbook No. 1, Surface Weather Observations and Reports, FCM-H1-2005, Sept 2005). This rate was chosen to exclude operations during heavy rainfall produced by convective clouds (thunderstorms). NOTE: There is currently a Cross-Program Launch Commit Criteria to not launch through precipitation.</td>
</tr>
<tr>
<td>3.2.10 Rain and Precipitation</td>
<td>Raindrop size distribution</td>
<td>The raindrop size distribution function, and comparison of stastical fits to observed data,</td>
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<tr>
<td>Environment for Launch</td>
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<td>is provided in P. Tattleman and P. Willis, Model Vertical Profiles of Extreme Rainfall Rate, Liquid Water Content, and Drop-Size Distribution, AFGL-TR-85-0200, Sept 1985.</td>
</tr>
<tr>
<td>3.2.11 Flora and Fauna Environments</td>
<td>Bird mass</td>
<td>Studies over the past twenty years in the KSC area have been consistent with respect to bird populations, however they only provide coarse detail about bird number densities with respect to height and migratory patterns. The most common larger species of birds in the KSC area are black vultures (mass 1.6 to 2.2 kg (3.5 to 4.9 lbs)), turkey vultures (mass ~2.0 kg (4.4 lbs)) and osprey (mass 1.4 to 2.0 kg) (3.1 to 4.4 lbs).</td>
</tr>
<tr>
<td>Environments during Launch and Ascent</td>
<td>Table 3.2.11-1 Avian Number Density</td>
<td>Data used to derive Table 3.2.11-1 can be found in NASA MSFC Memo EV44 (15-007), KSC Avian Environment Report.</td>
</tr>
<tr>
<td>3.2.12 Natural and Triggered Lightning</td>
<td>Lightning environment</td>
<td>The KSC environment is such that systems will be exposed to the direct and indirect effects of lightning. Observations validate the presence of lightning at KSC. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, Aircraft Lightning Zones and SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms. NOTE: There is currently a Cross-Program Launch Commit Criteria to minimize the risk of triggering lightning during launch.</td>
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<tr>
<td>Launch and Ascent</td>
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<tr>
<td>3.2.13 Ionizing Radiation Environment</td>
<td>CREME96</td>
<td>The CREME 96 model was selected to calculate this environment because it is the industry standard for ionizing radiation environments which affect avionics. The Technical Notes of 3.2.13 describe the model settings used. These were selected to give a conservative but reasonable environment for hardware design. The use of the 51.6 deg inclination orbit and &quot;stormy&quot; geomagnetic conditions ensures some exposure to solar energetic particles and a factor of 2 is applied</td>
</tr>
<tr>
<td>Launch, Ascent, and Re-entry</td>
<td>Table 3.2.13-1 200 km Integral LET Flux</td>
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<td>Table 3.2.13-2 200 km Differential Proton Flux</td>
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<td>Table 3.2.13-3 200 km Integral Proton Flux</td>
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<tr>
<td>3.2.13 Ionizing Radiation Environment for Launch, Ascent, and Re-entry</td>
<td>Table 3.2.13-4 Flux of $&gt;10$ MeV Neutrons at Altitudes to 20 km</td>
<td>Table was derived from empirical data.</td>
</tr>
<tr>
<td>3.3 In-Space Phases</td>
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<td><strong>3.3.1 Total Dose</strong></td>
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| | | The SPENVIS space environments tool was used to generate these environments. SPENVIS includes an orbit generator and industry standard radiation environments (CREME96 for galactic cosmic rays, AE8/AP8 trapped radiation, ESP/PSYCHIC solar energetic particles, and SHIELDOSE2 radiation transport). The Technical notes of each section describe the model inputs which were selected to provide a conservative but reasonable environment for hardware design. The orbits were chosen to cover the range of Design Reference Missions in Table 3.3.1-1. SPENVIS is described at www.spenvis.oma.be. AE8/AP8 are described in Vette, J. I., The AE-8 Trapped Electron Model Environment, NSSDC/WDC-A-R&S 91-24, 1991, Vette, J. I., The NASA/National Space Science Data Center Trapped Radiation Environment Model Program (1964-1991), NSSDC/WDC-A-R&S 91-29, 1991b. ESP is described in Tylka, A. J., Dietrich, W. F. and Boberg, P. R., Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996, IEEE Trans. Nucl. Sci., vol. 44, no. 6, pp.
### Section 3.3.1.1 Low Earth Orbit (LEO)-International Space Station (ISS) Orbit

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<td>Table 3.3.1.1-2 Daily Trapped Electron Fluences</td>
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<td>Table 3.3.1.1-3 Proton Fluences of an ISS SPE</td>
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<td>Table 3.3.1.1-4 Daily Trapped Belts TID Inside Shielding</td>
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<td>Table 3.3.1.1-5 Total SPE TID Inside Shielding</td>
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<td>AE8MAX Model</td>
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<td>AP8MIN Model</td>
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<tr>
<td>ESP/PSYCHIC Model</td>
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The 51.6 deg inclination, 500km orbit was chosen because an ISS docking mission was in the "study DRMs" list. The material was left in the DSNE because it provides a conservative LEO environment including trapped protons, galactic cosmic rays, and solar particle events reduced by geomagnetic shielding. The Technical Notes describe the inputs to the models and probability levels selected. The models are described in the validation entry for 3.3.1.
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<td>3.3.1.2 Staging and Transit Orbits</td>
<td>SPENVIS</td>
<td>The 28.5 deg inclination 185 x 1806 km staging orbit was selected to represent the pre-trans-lunar injection portion of the SLS mission. The more likely orbits are more circular (see 3.3.1.2.3) but exposure to the radiation belts at the 1806 km apogee provides a conservative estimate of the dose. The models are described in the validation entry for 3.3.1 and the Technical notes describe the model input parameters and the factor of 2 applied to account for the uncertainty in the trapped radiation models. The models are described in the validation entry for 3.3.1.</td>
</tr>
<tr>
<td>3.3.1.2.1 LEO 185 x 1806 km</td>
<td>Table 3.3.1.2.1-1 Daily Trapped Proton Fluences</td>
<td>After the TLI burn the SLS upper stage, Orion, and other payloads will transit the high flux regions of the trapped radiation belts. The models are described in the validation entry for 3.3.1.</td>
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<td>Table 3.3.1.2.1-2 Daily Trapped Electron Fluences</td>
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<td>Table 3.3.1.2.1-3 Daily Trapped Belts TID Inside Shielding</td>
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<tr>
<td>3.3.1.2.2 Radiation Belt Transit</td>
<td>Table 3.3.1.2.2-1 Daily Trapped Proton Fluences</td>
<td>This section is representative of the environment for circular pre-TLI orbits. The models are described in the validation entry for 3.3.1.</td>
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<td>Table 3.3.1.2.2-2 Daily Trapped Electron Fluences</td>
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<td>Table 3.3.1.2.2-3 Daily Trapped Belts TID Inside Shielding</td>
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<td>3.3.1.2.3 LEO 241 km Circular</td>
<td>Table 3.3.1.2.3-1 Daily Trapped Proton Fluences</td>
<td>This type of staging orbit is unlikely for current DRMs but is included to cover possible future missions. The models are described in the validation entry for 3.3.1.</td>
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<td>Table 3.3.1.2.3-2 Daily Trapped Electron Fluences</td>
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<td>Table 3.3.1.2.3-3 Daily Trapped Belts TID Inside Shielding</td>
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<tr>
<td>3.3.1.2.4 High Earth Orbit (HEO) 407 x 233,860 km</td>
<td>Table 3.3.1.2.4-1 Daily Trapped Proton Fluences</td>
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| 3.3.1.2.7 Low Perigee (LP)-HEO 407 x 400,000 km | Table 3.3.1.2.7-1 Daily Trapped Proton Fluences  
Table 3.3.1.2.7-2 Daily Trapped Electron Fluences  
Table 3.3.1.2.7-3 Daily Trapped Belts TID Inside Shielding | This type of staging orbit is unlikely for current DRMs but is included to cover possible future missions. The models are described in the validation entry for 3.3.1. |
| 3.3.1.8 High Perigee (HP)-HEO Spiral to 60,000 x 400,000 km | N/A | N/A |
| 3.3.1.3 Geosynchronous Earth Orbit (GEO) | Table 3.3.1.3-1 Daily Trapped Electron Fluences  
Table 3.3.1.3-2 Daily Trapped Belts TID Inside Shielding | All translunar missions will pass through here. The models are described in the validation entry for 3.3.1. |
<p>| 3.3.1.8 Mars Orbit | N/A | N/A |
| 3.3.1.9 Mars Surface | N/A | N/A |
| 3.3.1.10 Solar Particle Events | N/A | N/A |
| 3.3.1.10.1 Geomagnetic Shielded | Table 3.3.1.10.1-1 Integral and Differential Proton Fluences of a Shielded SPE | The solar particle event and geomagnetic shielding models are described in the validation entry for 3.3.1. |</p>
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<td>3.3.2.10.1 Geomagnetic Shielded</td>
<td>Table 3.3.1.10.1.2 Total Shielded SPE TID Inside Al Shielding</td>
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| 3.3.1.10.2 Geomagnetic Unshielded | Table 3.3.1.10.2-1 Integral and Differential Proton Fluence of an Unshielded SPE  
Table 3.3.1.10.2-2 Daily Unshielded GCR Integral Proton Fluence  
Table 3.3.1.10.2-3 Total Shielded SPE TID Inside Al Shielding  
Table 3.3.1.10.2-4 Total Unshielded Daily GCR TID Inside Al Shielding | The solar particle event model is described in the validation entry for 3.3.1 |
| 3.3.1.2.5 HEO to NEA transit | | |
| 3.3.1.4 Interplanetary | | |
| 3.3.1.5 Lunar Orbit | | |
| 3.3.1.6 Lunar Surface | | |
| 3.3.1.7 Near Earth Asteroid | | |
| 3.3.2.10.1 Geomagnetic Shielded | | |
| 3.3.2 Single Event Effects | Table 3.3.1.10.2-1 Integral and Differential Proton Fluence of an Unshielded SPE | The SPENVIS space environments tool was used to generate these environments. SPENVIS includes an orbit generator and industry standard radiation environments (CREME96 for galactic cosmic rays, AE8/AP8 trapped radiation, ESP/PSYCHIC solar energetic particles, and SHIELDOSE2 radiation transport). The Technical notes of each section describe the model inputs which were selected to provide a conservative but reasonable environment for hardware design. The orbits and trajectories were chosen to cover the range of Design Reference Missions in Table 3.3.1-1. SPENVIS is described at www.spenvis.oma.be. AE8/AP8 are described in Vette, J. I., The AE-8 Trapped Electron Model Environment, NSSDC/WDC-
3.3.2.1 LEO-ISS Orbit

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| 3.3.2.2.6 Low Earth Orbit 407 km Circular | Table 3.3.2.1-2 ISS SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET  
Table 3.3.2.1-3 Integral Proton Flux for an ISS SPE, Solar Minimum GCR, Nominal Trapped Protons and Worst SAA Pass  
Table 3.3.2.1-4 Differential Proton Flux for an ISS SPE, Solar Minimum GCR, Nominal Trapped Protons and Worst SAA Pass | shielding. The Technical Notes describe the inputs to the models and probability levels selected where appropriate. The models are described in the validation entry for 3.3.2. |
| 3.3.2.2 Staging and Transit Orbits | | |
| 3.3.2.2.1 Low Earth Orbit 185 x 1806 km | Table 3.3.2.2.1-1 SPE Integral Peak LET Flux for Selected Al Shielding Thickness as a Function of LET  
Table 3.3.2.2.1-2 SPE Worst Day Integral Flux for Selected Al Shielding Thickness as a Function of LET  
Table 3.3.2.2.1-3 Integral Proton Flux for the Peak Trapped Protons | See 3.3.2 for Validation information |
<p>| 3.3.2.9 Mars Surface | N/A | N/A |
| 3.3.2.10 GCR and Solar Particle Event | | |</p>
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<tr>
<td>3.3.2.10.2</td>
<td>Geomagnetic Unshielded</td>
<td>This section is representative of the environment for orbits which are outside of earth's geomagnetic field such as cis-lunar and interplanetary space. There are no trapped protons and electrons but the spacecraft is exposed to the full spectrum of energetic charged particles from Solar Particle Events (SPE) and Galactic Cosmic Rays (GCR).</td>
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<td>3.3.2.2.2</td>
<td>Radiation Belt Transit</td>
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<td>3.3.2.2.4</td>
<td>High Earth Orbit (HEO) 407 x 233,860 km</td>
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<td>3.3.2.2.5</td>
<td>High Earth Orbit to Near Earth Asteroid Transit</td>
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<td>3.3.2.2.7</td>
<td>Low Perigee-High Earth Orbit 407 x 400,000 km</td>
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<td>3.3.2.2.8</td>
<td>High Perigee-High Earth Orbit Spiral to 60,000 x 400,000 km</td>
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<td>3.3.2.3</td>
<td>Geosynchronous Earth Orbit (GEO)</td>
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<td>3.3.2.4</td>
<td>Interplanetary</td>
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<td>3.3.2.5</td>
<td>Lunar Orbit</td>
<td></td>
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<tr>
<td>3.3.2.6</td>
<td>Lunar Surface</td>
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<td>3.3.2.7 Near Earth Asteroid</td>
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<td>3.3.2.8 Mars Orbit</td>
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<tr>
<td>3.3.3 Plasma Charging</td>
<td></td>
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</tr>
<tr>
<td>3.3.3.1 LEO-ISS Orbit</td>
<td>Table 3.3.1-1 Ambient Plasma Environment for less than 1000 km Altitude</td>
<td>Minow, J.I., “Development and implementation of an empirical ionosphere variability model”, Advances in Space Research, 33, 2004, pp. 887-892.</td>
</tr>
<tr>
<td>3.3.3.2.3 Low Earth Orbit 241 km Circular</td>
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<td></td>
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<td>3.3.3.2.6 Low Earth Orbit 407 km Circular</td>
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<tr>
<td>3.3.3.2 Staging and Transit Orbits</td>
<td></td>
<td></td>
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<tr>
<td>3.3.3.2.1 Low Earth Orbit 185 x 1806 km</td>
<td>see Sections 3.3.3.1, 3.3.3.10, and 3.3.3.2.2</td>
<td>see Sections 3.3.3.1, 3.3.3.10, and 3.3.3.2.2</td>
</tr>
<tr>
<td>3.3.3.2.2 Radiation Belt Transit</td>
<td>Table 3.3.2.2-1 Radiation Belt Transit Average Integral Electron Flux</td>
<td>Fennell, J. E., Harry C. Koons, Margaret W. Chen, and J. Bernard Blake, &quot;Internal Charging: A Preliminary Environmental Specification for Satellites&quot;, IEEE Transactions on Plasma Science, Vol. 28, No. 6, December 2000, p. 2029.</td>
</tr>
<tr>
<td>3.3.3.2.4 High Earth Orbit (HEO) 407 x 233,860 km</td>
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<tr>
<td>3.3.3.2.5 High Earth Orbit to Near Earth Asteroid Transit</td>
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<td>3.3.3.2.7 Low Perigee-High Earth Orbit 407 x 400,000 km</td>
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### Section 3.3.3.2.8 High Perigee-High Earth Orbit Spiral to 60,000 x 400,000 km

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### Section 3.3.3 Geosynchronous Earth Orbit

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### Section 3.3.3.4 Interplanetary Orbit

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### Section 3.3.3.5 Lunar Orbit (High and Low)

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### Section 3.3.3.6 Lunar Surface

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<tr>
<td>3.3.3.8 Mars Orbit</td>
<td>N/A</td>
</tr>
<tr>
<td>3.3.3.9 Mars Surface</td>
<td>N/A</td>
</tr>
<tr>
<td>3.3.3.10 Polar Orbit</td>
<td>Table 3.3.10-1 Polar Plasma Parameters</td>
</tr>
<tr>
<td>3.3.5 Reserved</td>
<td>N/A</td>
</tr>
<tr>
<td>3.3.6 Meteoroid and Orbital Debris Environment</td>
<td>MEM R2</td>
</tr>
</tbody>
</table>
### Section | Model/Dataset/Design Limit | Validation Statement
---|---|---
3.3.6 Meteoroid and Orbital Debris Environment | ORDEM 3.0 | Assessment Team, the Independent Review of Constellation (Cx) Orion Vehicle Micrometeoroids and Orbital Debris Risk Analysis (NESC-RP-08-00468), the multinational Inter-Agency Space Debris Coordination Committee (IADC) Comparison of Meteoroid Models (IADC Action Item 24.1, executed by Working Group 2 in 2009), and a 2011 National Research Council (NRC) team “Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs”. Except for the IADC report, which was a comparison of various models and made no determination of relative merit, all of the panels have agreed with the finding published in chapter 4 of the NRC report: "The Meteoroid Environment Model incorporates in its predictions the latest available data on the meteoroid environment, including the directionality and full velocity distribution of the meteoroids. It is currently the NASA model that is most consistent with the known meteoroid environment.

3.3.7 Earth Gravitational Field | GRACE model GGM02C | The GGM02 Earth gravity model is based on the analysis of 363 days of GRACE in-flight data, spread between April 4, 2002 and Dec 31, 2003. GGM02C - complete to degree 200 - is based on satellite measurements and is constrained with terrestrial gravity information. The new GGM02 model builds upon the experience with the older GGM01 model, and is also derived from globally distributed, precise inter-satellite range rate measurements derived by the GRACE
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<tr>
<td>3.3.8 Lunar Gravitational Field</td>
<td>GRAIL</td>
<td>The GRAIL lunar gravity model is based on measurements made by the GRAIL spacecraft. The GRAIL mission placed two spacecraft (GRAIL-A and GRAIL-B), flying in formation, into orbit around the Moon to study its internal structure. By very precisely measuring the distance of one orbiter relative to the other, the orbital perturbations caused by the Moon could be observed. Combining this with the orbiter position as determined from Earth-based observations, the mass distribution on the Moon could be determined. The GRAIL spacecraft entered lunar orbit on December 31, 2011, and January 1, 2012. The mission ended on December 17, 2012, with a controlled impact of both spacecraft on the lunar surface. The model underwent extensive peer review prior to be made available on the NASA Planetary Data Systems - Geosciences repository.</td>
</tr>
<tr>
<td>3.3.9 Thermal Environment for In-Space Hardware</td>
<td>solar flux</td>
<td>These are standard values of the solar flux adjusted for distance from the sun.</td>
</tr>
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</table>
### Section 3.3.9.1 Thermal Environment for Lunar Phases

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<tr>
<td>Lunar Eclipse</td>
<td>Lookup of worst case lunar eclipse length from eclipse prediction tables.</td>
</tr>
<tr>
<td>Table 3.3.9.1-1, Projected Worst Case Minimum Solar Flux during Lunar Eclipse, Dated June 11, 2029</td>
<td>Calculated from eclipse prediction tables.</td>
</tr>
<tr>
<td>Table 3.3.9.2-1, Albedo, Outgoing Longwave Radiation (OLR) Pairs for Critical Systems in Low-Inclination Orbits</td>
<td>From Justus et al., NASA/TM-2001-21122 &quot;Simple Thermal Environment Model (STEM) User's Guide&quot;.</td>
</tr>
<tr>
<td>Table 3.3.9.2-2, Albedo, OLR Pairs for Critical Systems in Medium-Inclination Orbits</td>
<td></td>
</tr>
<tr>
<td>Table 3.3.11-1 Earth-GRAM 2010 Inputs for Thermosphere Parameter Calculations</td>
<td>This set of inputs to the Marshall Engineering Thermosphere module of the Global Reference Atmosphere Model were selected to span the ranges of solar flux, season, and local time so conservative values of thermospheric density could be computed.</td>
</tr>
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<tr>
<td>3.6.1 Re-entry Neutral Atmosphere for Off-Nominal Descent and Landing</td>
<td></td>
<td></td>
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<td>3.3.12 Geomagnetic Fields (Reserved)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3.4 Lunar Surface Operational Phases</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3.5 Entry and Landing Phases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5.4 Aloft Winds for Normal Descent and Landing</td>
<td>Earth-GRAM 2010</td>
<td>Details of the model are provided in NASA/TM-2011-216467, The NASA Marshall Space Flight Center Earth Global Reference Atmospheric Model - 2010 Version. Verification and validation details are provided in EV44 (14-002), Verification and Validation Report, Earth GRAM 2010 Version 4.0. Earth-GRAM is a well established model that has been used for various space programs, including Space Shuttle, Constellation, and SLS/MPCV. Verification and validation details are provided in EV44 (14-002), Verification and Validation Report, Earth GRAM 2010 Version 4.0.</td>
</tr>
<tr>
<td>3.5.4 Aloft Winds for Normal Descent and Landing</td>
<td>Table 3.5.4-1 Earth-GRAM 2010 Input to Generate 1,000 or More Perturbed Profiles (0 to 90 km) of Temperature, Pressure, and Density Per Monthly Reference Period</td>
<td>Table 3.5.4-1 provides input to run Earth-GRAM random profiles for ascent Monte Carlo assessments. It is recommended to use the Range Reference Atmosphere data set (monthly climatology) when available, since it provides a better statistical representation of the available sites. Random perturbations are set to nominal dispersions. Patchy turbulence is turned off (patches of severe turbulence).</td>
</tr>
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<tr>
<td>3.5.6 Aloft Air Pressure for Normal Descent and Landing</td>
<td></td>
<td>Suggested Earth-GRAM inputs are standard inputs for typically Monte Carlo assessments.</td>
</tr>
<tr>
<td>3.5.7 Aloft Air Density for Normal Descent and Landing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6.4 Aloft Winds for Off-Nominal Descent and Landing</td>
<td></td>
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<tr>
<td>3.6.5 Aloft Air Temperature for Off-Nominal Descent and Landing</td>
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<tr>
<td>3.6.6 Aloft Air Pressure for Off-Nominal Descent and Landing</td>
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<tr>
<td>3.6.7 Aloft Air Density for Off-Nominal Descent and Landing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5.8 Surface Winds for Normal Landing</td>
<td>Peak Wind Speed Profile</td>
<td>Rationale for $k = 0.11$ over water is found in Hsu, S.A., E.A. Meindl, and D.B. Cilhouesen: 1994. Determining the Power-Law Wind-Profile Exponent under Near-Neutral Stability Conditions at Sea. Journal of Applied Meteorology. Vol. 33. pp. 757-765. Also, the following concluded that $k=1/7$ is valid if $z_0$ is at least an order of magnitude smaller than the reference level height: Peterson, E. W. and J.P. Hennessey, Jr.: 1978. On the Use of Power Laws for Estimates of Wind Power</td>
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<tr>
<td>3.5.8 Surface Winds for Normal Landing</td>
<td>Table 3.5.8-1 Dryden Gust Spectra Parameters for the Longitudinal, Lateral, and Vertical Components for the Landing Phase</td>
<td>Parameters in Table 3.5.8-1 are obtained from NASP-NEC-NERD #030194, National Aerospace Plane (NASP), X-30 Natural Environment Requirements Document (Rev. 1.0), March 1, 1994.</td>
</tr>
<tr>
<td>3.5.8 Surface Winds for Normal Landing</td>
<td>Reference Level Peak Wind Speed (Water)</td>
<td>Reference level peak wind speed of 8.2 m/s is given in Section 3.5.18</td>
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<tr>
<td>3.7.4 Surface Winds for Post-Flight and Recovery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5.9 Surface Air Temperature for Normal Landing</td>
<td>Max/Min over land</td>
<td>Design limits for normal land landings represent the maximum and minimum extreme temperatures from hourly surface observations recorded at selected locations in the normal landing area.</td>
</tr>
<tr>
<td>3.5.9 Surface Air Temperature for Normal Landing</td>
<td>Max/Min over water</td>
<td>Design limits for normal water landings were determined using six-hourly air temperature output within the normal water landing area from a global climatology. Air temperatures were obtained from the European Centre for Medium-range Weather Forecasts (ECMWF) Re-Analysis (ERA-40), which contains air temperature records on a 2.5° x 2.5° grid every six hours for the 1979-2002 period of record. The global dataset was subsetted to only contain temperatures within the normal landing area. Design limits are the empirical minimum and maximum air temperatures during December and September, respectively (Barbré, 2012: &quot;Analysis of DSNE Air and Sea Surface Temperature Updates&quot;, Jacobs ESSSA Group Report ESSSA-FY13-31).</td>
</tr>
<tr>
<td>3.5.10 Surface Air Pressure for Normal Landing</td>
<td>Max/min design limits</td>
<td>Design limits represent the monthly mean sea level air pressure ±3 standard deviations (maximum value of standard deviation for each month) from hourly surface observations at selected locations in the normal landing area.</td>
</tr>
<tr>
<td>3.7.6 Surface Air Pressure for Post-Flight and Recovery</td>
<td>Max/min design limits</td>
<td></td>
</tr>
<tr>
<td>3.5.11 Surface Air Humidity for Normal Landing</td>
<td>Max/min design limits</td>
<td>100% is the maximum relative humidity observable in the boundary layer. Although relative humidity less than 5% can occur, these events are extremely rare in the boundary layer.</td>
</tr>
<tr>
<td>3.6.11 Surface Air Humidity for</td>
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<td>3.7.7 Surface Air Humidity for Post-Flight and Recovery</td>
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<td>3.5.12 Aerosols for Normal Descent and Landing</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>3.6.12 Aerosols for Off-Nominal Descent and Landing</td>
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<tr>
<td>3.7.8 Aerosol Environment for Post-Flight and Recovery</td>
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</tr>
<tr>
<td>3.5.13 Precipitation for Normal Descent and Landing</td>
<td>Design Rainfall rate</td>
<td>The design rainfall rate is the NOAA maximum observational reporting value for moderate rainfall (NOAA, Federal Meteorological Handbook No. 1, Surface Weather Observations and Reports, FCM-H1-2005, Sept 2005). This rate was chosen to exclude operations during heavy rainfall produced by convective clouds (thunderstorms).</td>
</tr>
<tr>
<td>3.6.13 Precipitation for Off-Nominal Descent and Landing</td>
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<tr>
<td>3.7.9 Precipitation Environment for Post-Flight and Recovery</td>
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<td></td>
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<tr>
<td>3.5.14 Flora and Fauna for Descent and Landing</td>
<td>Avian Species</td>
<td>The bird mass collision criteria for descent and landing operations were selected to maintain commonality with the ascent phase criteria (see section 3.2.11).</td>
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<tr>
<td>3.5.14 Flora and Fauna for Descent and Landing</td>
<td>Ground brush</td>
<td>Ground brush design height of 0.6 m is used to cover typical desert vegetation, such as sagebrush.</td>
</tr>
<tr>
<td>3.5.14 Flora and Fauna for Descent and Landing</td>
<td>Mammals</td>
<td>Although large mammals such as deer, cattle, and wild horses are not uncommon in open range areas in the western U.S., it is impractical to protect against collision with one of significant mass. The design limit of 10 kg is to protect from collisions with smaller mammals.</td>
</tr>
<tr>
<td>3.5.15 Surface Characteristics and Topography for Normal Landing</td>
<td>The design limit for maximum surface slope of the land landing site will be 5°. The site will be clear of solid objects projecting more than 0.3 m (1.0 ft) above the surface. The site will be clear of ditches deeper than 0.3 m (1.0 ft).</td>
<td>The selection of surface was made based on preliminary surveys of potential land landing sites. It is anticipated that any designated site will be prepared to meet this specification. Details can be found in NASA Constellation Program white paper, K. Altino and R. Buehrle, Kennedy Space Center Terrain and Wind Environments for Orion Pad Abort Land Landings (Task Description Statement #SIG-08-1003: Contingency Land Landing Design Criteria Development).</td>
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<tr>
<td>3.5.16 Cloud and Fog Environment for Normal Descent and Landing</td>
<td>Cloud Cover</td>
<td>Up to 100% cloud cover</td>
</tr>
<tr>
<td>3.5.16 Cloud and Fog Environment for Normal Descent and Landing</td>
<td>Liquid Cloud Particle Size</td>
<td>The maximum size for liquid cloud particles of 7 mm (0.3 in) allows the vehicle to traverse stratiform clouds and rain in non-convective situations. Cloud particle size data is provided in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision.</td>
</tr>
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<td>for Post-Flight and Recovery</td>
<td>Frozen Cloud Particle Size</td>
<td>The maximum size for frozen cloud particles of 200 mm (0.008 in) allows for traverse through mid and high altitude layer clouds (alto and cirrus type). Cloud particle size data is provided in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision.</td>
</tr>
<tr>
<td>3.5.16 Cloud and Fog Environment for Normal Descent and Landing</td>
<td>Table 3.5.17-1 Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky</td>
<td>Values in Tables 3.5.17-1, 3.5.17-3, and 3.5.17-5 were determined by taking the average at each hour for the 10 coldest days with cloudy skies (100% sky cover), partly cloudy skies (40 to 60% sky cover), and clear skies (0% sky cover) from the NSRD (1991-2010). Cold days were determined by calculating the average daily temperature for each day in the period of record, and selecting the 10 coldest days that met the specific sky condition.</td>
</tr>
<tr>
<td></td>
<td>Table 3.5.17-2 Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Cloudy Sky</td>
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<td>Table 3.5.17-3 Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Partly Cloudy Sky</td>
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<td>Table 3.5.17-4 Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Partly Cloudy Sky</td>
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<td>Table 3.5.17-5 Cold Design Radiant Energy and Sky Temperature as a Function of Time of Day, Clear Sky</td>
<td>The table values were determined from NSRD data for San Diego, CA (Lindbergh Field).</td>
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<td>Table 3.5.17-6 Hot Design Radiant Energy and Sky Temperature as a Function of Time of Day, Clear Sky</td>
<td></td>
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<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Min Significant Wave Height</td>
<td>The lowest environment physically possible is the no waves case.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Max Significant Wave Height</td>
<td>Availability of &quot;sea state 3&quot; conditions (1.25 m SWH, 8.2 m/s wind speed) were assessed at the CxP Integrated Stack TIM. At the TIM, it was shown that increasing the SWH limit to 2.0 m provided reasonable availability in the regions of interest while still being within recovery limits. Reference presentation Barbre, R.E. 2007. Integrated Stack TIM - Team 0 Land and Water Landing. Environments and Constraints Systems Integration Group. Presentation to CxP. Houston, TX. November 2007.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Max Frequency Equation</td>
<td>This equation is based on the vehicle's size and the physical relationship between frequency and wavelength.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td></td>
<td>Baseline study: Cox, C. S., and W. H. Munk (1956), Slopes of the sea surface deduced from</td>
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<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td>Water Surface Slope Components</td>
<td>Arctangent function is used to back out a slope given a slope for an individual MC run.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Water Surface Slope Distribution</td>
<td>Total slope is computed as the root sum squared of the individual slope components for an individual MC run.</td>
</tr>
<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td>Min Winds</td>
<td>No wind is the lowest environment physically possible.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Max Winds</td>
<td>Availability of &quot;sea state 3&quot; conditions (1.25 m SWH, 8.2 m/s wind speed) were assessed at the CxP Integrated Stack TIM. At the TIM, it was shown that a threshold of 8.2 m/s had acceptable availability while still being within recovery limits. Reference presentation Barbre, R.E.. 2007. Integrated Stack TIM - Team 0 Land and Water Landing.</td>
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<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Table 3.5.18-1 Minimum Average Wave Period Corresponding to Given SWH</td>
<td>The minimum average wave periods in Table 3.5.18-1 are identified by determining which 1-second wave period range contains the 1st percentile of wave periods observed for the given SWH range. If the 1st percentile falls between two values within the wave period range, the lower of the two wave period values is used to be conservative.</td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Table 3.5.18-2 Energy Spectrum for 2 m SWH</td>
<td>The energy spectrum in Table 3.5.18-2 is developed using 5.0 m (16.4 ft) wind speed data from buoys 46047 and 46069, near San Nicolas Island, CA, in the NDBC network and spectral data from buoy 067, near San Nicolas Island, CA, in the Coastal Data Information Program (CDIP) buoy network. The spectral data ranges from 0.025 to 0.58 Hz and is reported every half hour, along with the corresponding SWH. This archived buoy data, when compared with the National Data Buoy Center (NDBC) spectral data, provides spectral data at higher frequencies in the area of interest. The spectral data is used from August over a 9-year POR (1999-2007) and is limited to SWH ≤ 2.0 m (6.6 ft) and wind speed ≤ 8.2 m/s (26.9 ft/s). The energy spectrum in Table 3.5.18-2 represents a single spectrum from August 23, 2001, at 03:49 Universal Time Coordinated (UTC) and is created using: (1) the energy in each frequency bin from 0.025 to 0.58 Hz, and (2) energy that is extrapolated from 0.58 to 0.80 Hz with an exponential curve (y = 3.9708·exp(-9.1189x)) that is fit to the energy found in each frequency bin from 0.30 to 0.58 Hz. Here x is the desired frequency (Hz) and y is the resulting energy (m^2/Hz).</td>
</tr>
<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td>Table 3.6.18-1 Energy Spectrum for 4 m SWH</td>
<td></td>
</tr>
<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>Figure 3.5.18-1 Cumulative Distributions</td>
<td>Figure 3.5.18-1 is a cumulative distribution of water surface slope from the CDIP buoy used to derive the energy spectrum.</td>
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<tr>
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<tr>
<td>3.5.18 Sea State for Normal Water Landing</td>
<td>C-ERA40</td>
<td>The C-ERA40 database is developed from the ECMWF atmospheric re-analysis for the POR (1957-2002) with emphasis on the POR (1971-2000). Data reported in the C-ERA-40 database is provided every 6 hours on a 1.5° latitude x 1.5° longitude grid. Note that, although the term “C-ERA-40” refers to the SWH, wind speed, and wave period databases in this document, SWH is the only variable that was corrected. Reference: Caires, S. and A. Sterl, “A New Nonparametric Method to Correct Model Data: Application to Significant Wave Height From the ERA-40 Re-analysis”, Journal of Atmospheric and Oceanic Technology, Vol. 22, No. 4, 2005, pp.443-459. EV44 selected the 1971-2000 POR to correspond to WMO at the time and from a subjective perception of improved data collection methodologies. Also, note that we're now using ERA-Interim, but the C-ERA-40 was used to derive the numbers in the DSNE.</td>
</tr>
<tr>
<td>3.5.19 Reserved</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3.5.20 Sea Surface Temperature for Water Landing</td>
<td>Max/min design limits</td>
<td>Design limits for normal water landings were determined using weekly mean sea surface temperature output within the normal landing area from a global climatology. Sea surface temperatures were obtained from the National Centers for Environmental Prediction Optimal Interpolation (NCEP-OI) dataset, which contains weekly mean sea surface temperature records on a1.0° latitude x 1.0° longitude grid for the 1981-2012 period of record. The global dataset was subsetted to only contain temperatures within the normal water landing area.</td>
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### Section: Cross-Program Design Specification for Natural Environments (DSNE)

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<tr>
<td>3.5.21 Aerosols for Water Landing</td>
<td>sea salt spray</td>
<td>The landing area is in an environment conducive to sea salt spray. Details of sea salt spray can be found in Cloud particle size data provided in NASA TM-2008-215633, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development, 2008 Revision.</td>
</tr>
<tr>
<td>3.6 Contingency and Off-Nominal Landing Phases</td>
<td></td>
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<tr>
<td>3.6.2 Reserved</td>
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<td>N/A</td>
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<tr>
<td>3.6.8 Surface Winds for Off-Nominal Landing</td>
<td>See Section 3.5.8</td>
<td>&quot;Sea state 5&quot; conditions (4.0 m SWH, 13.9 m/s wind speed) was assessed at the CxP Integrated Stack TIM. At the TIM, it was communicated that a threshold of 13.9 m/s corresponded to the maximum achievable wind by Orion. Reference presentation Barbre, R.E.. 2007. Integrated Stack TIM - Team 0 Land and Water Landing. Environments and Constraints Systems Integration Group. Presentation to CxP. Houston, TX. November 2007.</td>
</tr>
<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6.9 Surface Air Temperature for</td>
<td>Max/min design limits</td>
<td>Design limits for off-nominal water landings were determined using six-hourly air</td>
</tr>
</tbody>
</table>
### Validation Statement

Temperature output within the water landing areas corresponding to 23 different skip entry trajectories provided by the Orion Program, as well as the area immediately surrounding a 29.0° inclination orbit extending over water regions from KSC to the western coast of Australia. Air temperatures were obtained from the ERA-40 dataset, which contains air temperature records on a 2.5° x 2.5° grid every six hours for the 1979-2002 period of record. The global dataset was subsetted to only contain temperatures within the off-nominal landing area. Design limits are the empirical minimum and maximum air temperatures during March and April, respectively (Barbré, 2012).

Analysis documented in:


The report contains the methodology used to select limits.

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<tr>
<td>Off-Nominal Landing</td>
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<tr>
<td>3.6.10 Surface Air Pressure for Off-Nominal Landing</td>
<td>N/A</td>
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<tr>
<td>3.6.14 Flora and Fauna for Off-Nominal Descent and Landing</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>3.6.15 Surface Characteristics and Topography for Off-Nominal Descent and Landing</td>
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<tr>
<td>3.6.17 Radiant (Thermal) Energy Environment for</td>
<td>N/A</td>
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<tr>
<td>Off-Nominal Descent and Landing</td>
<td></td>
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</tr>
<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td>Min Significant Wave Height</td>
<td>The lowest environment physically possible is no waves.</td>
</tr>
<tr>
<td>3.6.18 Sea State for Off-Nominal Water Landing</td>
<td>Max Significant Wave Height</td>
<td>&quot;Sea state 5&quot; conditions (4.0 m SWH, 13.9 m/s wind speed) was assessed at the CxP Integrated Stack TIM. At the TIM, it was recommended that a threshold of 4.0 m SWH be instituted as &quot;a compromise between launch availability, risk, and design feasibility&quot;. Reference presentation Barbre, R.E. 2007. Integrated Stack TIM - Team 0 Land and Water Landing. Environments and Constraints Systems Integration Group. Presentation to CxP. Houston, TX. November 2007.</td>
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<td>3.6.19 Reserved</td>
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<tr>
<td>3.7 Recovery and Post-Flight Processing Phases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7.1 Environments for Post-Flight and Recovery at KSC</td>
<td>See Section 3.1, except for sea states</td>
<td></td>
</tr>
<tr>
<td>3.7.2 Sea State for KSC Post-Flight and Recovery</td>
<td>Reserved</td>
<td>N/A</td>
</tr>
<tr>
<td>3.7.3 Lightning Specification for Post-Flight and Recovery</td>
<td>Lightning environment</td>
<td>The environment in the normal landing area is such that systems will be exposed to the direct and indirect effects of lightning. Descriptions and conditions for the application of lightning environment waveforms are detailed in SAE ARP5414, Aircraft Lightning Zones and SAE ARP5412, Aircraft Lightning Environment and Related Test Waveforms.</td>
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<tr>
<td>3.8 Interplanetary Space Specification</td>
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<td>3.9 Mars Orbit Specification</td>
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<td>3.10 Mars Atmosphere and Surface Phase Specifications</td>
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<td>3.11 Mars Moon Specification</td>
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<td>3.12 Near Earth Asteroid Specification</td>
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