National Aeronautics and
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CONSTELLATION PROGRAM DESIGN SPECIFICATION FOR NATURAL ENVIRONMENTS

REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Baseline	-		Baseline (Reference CxCBD C000093/1-1, dated 12/14/06)	12/15/06
		001	Change 001 (Reference CxCBD C000125/1-1, dated 6/28/07) *(C000125 included two new tables [3.3.4-1 and 3.3.4-2]. These tables were not updated to reflect the previously Baselined numbering format at this time.)*	07/18/07

NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

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1 INTRODUCTION

1.1 Purpose

The Design Specification for Natural Environments (DSNE) completes environment-related requirements from architecture, system level, and lower tier documents by specifying the ranges of environmental conditions that must be accounted for by the design of all Constellation Program elements. As such, it forms a part of those specifications. It has been pulled out into a separate document to assure clarity and consistency, and to prevent the requirements documents from becoming cluttered with extensive amounts of technical material. It is based on the Constellation Design Reference Missions and Operational Concepts Document and the models, data, and environment descriptions in the Natural Environments Definition for Design (NEDD). The NEDD provides additional detailed environment data and model descriptions to support analytical studies for Constellation systems.

1.2 Scope

This document defines the environmental parameter limits; i.e. maximum and minimum values, energy spectra, or precise model inputs, assumptions, model options, etc., to be used in the design and development of all Constellation Program elements. Its application is primarily for the design and development of flight hardware. It is not intended as a definition of operational models or operational constraints, nor is it adequate, in and of itself, for ground facilities which may have additional requirements (e.g. building codes and local environmental constraints). Where operational constraints have been accepted by the Program that influence design environments, such cases will be noted in “Limitations.” This document is applicable to all elements of the Constellation Program.

“Natural environments,” as the term is used here, 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 Constellation Program flight vehicles and destination surface systems. Included are terrestrial environments at launch, abort, and normal landing sites (winds, temperatures, pressures, surface roughness, sea state, etc.); space environments (ionizing radiation, orbital debris, meteoroids, thermosphere density, plasma, solar, Earth and lunar emitted thermal radiation, etc.); lunar surface environments; and Mars atmosphere and surface environments. All of these factors are outside the actual control of the Program, so the Program controls the “definition” of these factors, i.e. the models, data sets, and descriptions, in order to maintain a uniform, consistent, and verifiable baseline for hardware development. This definition is contained in the Constellation Program NEDD. This document, the DSNE, pulls from the NEDD the specific parameter limits, profiles, and values that are associated with specific design requirements.

Some environmental specifications in this document are tied specifically to the Design Reference Missions (DRMs). The mission schedules and timelines with respect to the activity and mission phase are documented in both CXP-70000 Constellation Architecture Requirements Document (CARD) and CXP-70007 Constellation Design

Reference Missions and Operational Concepts Documents respectively. Coordination between these environment specifications and the DRMs must be maintained. This document is compatible with the current DRMs, but updates to the mission definitions and variations in interpretation may require adjustments to the environment specifications. The primary landing sites have not been selected as of the date of release of this document, however, the environmental data provided in this document assumes landing at prepared landing sites within the western United States or in water. These boundaries and assumptions should be considered preliminary and subject to change.

Requests for clarification, interpretation, or questions concerning this document should be addressed to the Constellation Program, Systems Engineering and Integration Office: Environments and Constraints SIG. Points of contact are Dr. Jeffrey Anderson (256)544 -1661 or email: b.jeffrey.anderson@nasa.gov and David Cheuvront (281) 244 - 7091 or email:david.cheuvront-1@nasa.gov.

The following table (Table 1) provides the mapping of the Constellation Design Reference Missions and Operational Concepts Document (DRMConOps) and the corresponding sections in the Design Specification for Natural Environments (DSNE).

Table 1 DRM ConOps/DSNE Matrix

DRMConOps		DSNE	
Section No.	Title	Section No.	Title
5	Operations And Capability By Phase	NA	NA
5.1	Pre-Delivery	NA	NA
5.2	Pre-Launch-Ground Processing	3.1	Pre-Launch-Ground Processing Phases
5.3	Launch Operations	3.2	Launch Countdown and Earth Ascent Phases
5.4	Earth Ascent Phase	3.2	Launch Countdown and Earth Ascent Phases
5.5	Low Earth Orbit (LEO) Operations	3.3	In-Space Phases
5.6	ISS On-Orbit Operations	3.3	In-Space Phases
5.7	Cruise Outbound Operations	3.3	In-Space Phases
5.8	Lunar Orbit Operations – Pre-Surface	3.3	In-Space Phases
5.10	Lunar Orbit Operations – Post Surface	3.3	In-Space Phases
5.11	Cruise – Earth Inbound Operations	3.3	In-Space Phases
6.12	LSAM Ascent Underspeed	3.3	In-Space Phases
5.9	Lunar Surface Operations	3.4	Lunar Surface Phases
5.12	Entry Operations	3.5	Entry and Landing Phases
5.13	Landing Operations	3.5	Entry and Landing Phases

Table 1 DRM ConOps/DSNE Matrix (concluded)

5.14	Recovery Operations	3.7	Recovery and Post Flight Processing Phases
5.15	Post-Flight Processing	3.7	Recovery and Post Flight Processing Phases
5.16	Refurbishment	NA	NA
6	Contingency and Off-Nominal Operations	3.6	Contingency and Off-Nominal Landing Phases
6.1	Pad Emergency Egress	3.6	Contingency and Off-Nominal Landing Phases
6.2	Pad Abort	3.6	Contingency and Off-Nominal Landing Phases
6.3	Launch Scrub Turnaround	3.6	Contingency and Off-Nominal Landing Phases
6.4	Extended Scrub Turnaround	3.6	Contingency and Off-Nominal Landing Phases
6.5	Ascent Aborts	3.6	Contingency and Off-Nominal Landing Phases
6.6	Abort From LEO	3.6	Contingency and Off-Nominal Landing Phases
6.7	Abort From Trans-Lunar Orbit	3.6	Contingency and Off-Nominal Landing Phases
6.8	Incomplete LOI Maneuver	3.6	Contingency and Off-Nominal Landing Phases
6.9	Post-LOI Aborts	3.6	Contingency and Off-Nominal Landing Phases
6.10	Lunar Descent Abort	3.6	Contingency and Off-Nominal Landing Phases
6.11	Early Surface Mission Termination	3.6	Contingency and Off-Nominal Landing Phases
6.13	Trans-Earth Coast Contingencies	3.6	Contingency and Off-Nominal Landing Phases
6.12	Off Nominal Entry	3.6	Contingency and Off-Nominal Landing Phases
6.14	Off Nominal Recovery	3.6	Contingency and Off-Nominal Landing Phases
6.15	ISS Contingency Operations	3.6	Contingency and Off-Nominal Landing Phases
6.16	Contingency EVA – Lunar Missions	3.6	Contingency and Off-Nominal Landing Phases

2. APPLICABLE DOCUMENTS

2.1 REQUIREMENT DOCUMENTS

CXP-70000	Constellation Architecture Requirements Document (CARD)
CXP-70072-ANX01	Constellation Program Management Systems Plan, Annex 1, Constellation Glossary, Acronyms, and Nomenclature
CXP-70007	Constellation Design Reference Missions and Operational Concepts Document
CxP 70024	Constellation Program Human-Systems Integration Requirements
CXP-70044	Constellation Program Natural Environment Definition for Design (NEDD)
CXP 70142	Navigation Standards Specification Document
MIL-HDBK-310,	Global Climatic Data for Developing Military Products, Department of Defense Handbook, June 23, 1997
MIL-STD-810F	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, Method 508.
NASA-HDBK 1001	Terrestrial Environment (Climatic) Criteria Handbook for use in Aerospace Vehicle Development Environment
NCRP Report 132	Radiation Protection Guidance for Activities in Low-Earth Orbit
NCRP Report 142	Operational Radiation Safety Programs for Astronauts in Low-Earth Orbit: A Basic Framework
RTCA 160/DO-160D	Environmental Conditions and Test Procedures for Airborne Equipment
SAE ARP5412	Aircraft Lightning Environment and Related Test Waveforms
SAE ARP5414	Aircraft Lightning Zones

2.2 APPLICABLE MODELS/DATASETS

Models

Global Reference Atmosphere Model (GRAM99 Version 3 or Later)

Gravity Recovery And Climate Experiment (GRACE) Gravity Model 02 C (GGM02C)

Lunar Gravity Model: LP150Q

Orbital Debris Engineering Model (ORDEM2000)

Meteoroid Engineering Model (MEM)

Datasets

Jimsphere Wind Profile Datasets

3 NATURAL ENVIRONMENT SPECIFICATION

3.1 PRE-LAUNCH - GROUND PROCESSING PHASES

3.1.1 Transportation Environments to the Launch Site (Kennedy Space Center)

Description

This section is reserved for special environmental requirements for shipping flight hardware to Kennedy Space Center (KSC) not covered by other standard shipping requirement 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.

NEDD Reference Sections

None

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

Specifies ground wind environments (altitude range 0 to 150 m), up to and including the maximum design limits flight hardware will be exposed to 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 discrete and spectral gust environments. “Storage” applies to on-pad or outside storage only.

NEDD Reference Sections

3.1 Ground Winds

3.1.1 Eastern Range

3.1.1.1 Peak Wind Profile

3.1.1.3 Spectral Gust Environment

3.1.1.4 Discrete Gust Model

Design Limits

Table 2 provides the design peak wind profiles for the various operational phases at selected altitudes. The design 10-minute steady-state wind profiles associated with the design peak wind profiles are provided in Table 3. The 10-minute steady state wind profile is that profile that could produce the instantaneous peak winds (gusts) in Table 2 over a 10-minute period. See NEDD Section 3.1.1.1 to determine profile values between those altitudes given in Tables 2 and 3.

Table 2 – Design Peak Wind Speed Profile

Height	Peak Wind Speed Profile		
	Transport to/from Pad	On-Pad (Unfueled)	On-Pad (Intermediate and Fully Fueled)
(m)	(m/sec)	(m/sec)	(m/sec)
10	28.6	36.0	22.1
18.3	30.8	38.3	24.2
30	32.7	40.3	26.0
60	35.6	43.3	28.8
90	37.4	45.2	30.6
120	38.8	46.6	31.8
150	39.8	47.7	32.9

Table 3 – 10-Minute Steady-State Wind Speed Profile Associated with the Design Peak Wind Speed Profile

Height	10-Minute Steady-State Wind Speed Profile		
	Transport to/from Pad	On-Pad (Unfueled)	On-Pad (Intermediate and Fully Fueled)
(m)	(m/sec)	(m/sec)	(m/sec)
10	17.9	22.5	13.8
18.3	20.5	25.4	16.0
30	22.7	28.0	18.0
60	26.1	31.8	21.1
90	28.3	34.2	23.0
120	29.9	35.9	24.5
150	31.1	37.3	25.7

For fatigue load analyses, the design frequency of occurrence of 30-second peak winds at the 18.3 m reference height is provided in Table 4. Any analysis should contain at least one occurrence of the design peak wind of 38.3 m/sec. The number of occurrences of a selected 30-second peak wind range for any time period greater than or equal to 30 seconds can be determined by multiplying the probability of occurrence by the number of 30-second intervals in the chosen time period. For example, there are approximately 1238 occurrences of 30-second peak winds in the range 4.75 to 5.25 m/sec in a 5 day period (number of 30-second intervals in 5 days is 14400, 14400 * 0.08598149 = 1238.13).

Table 4 – Occurrence Probabilities of 30-Second Peak Wind Speed in 0.5 m/sec Intervals (Centered at Value x) at the 18.3 m Reference Height

Peak Wind Speed x (m/sec)	Probability	Peak Wind Speed x (m/sec)	Probability
0.5	0.003246387	20.0	0.00003324119
1.0	0.01116703	20.5	0.00002514178
1.5	0.02681171	21.0	0.00001901570
2.0	0.04885758	21.5	0.00001438224
2.5	0.07209810	22.0	0.00001087772
3.0	0.09057693	22.5	0.000008227152
3.5	0.1006679	23.0	0.000006222421
4.0	0.1019312	23.5	0.000004706180
4.5	0.09616256	24.0	0.000003559402
5.0	0.08598149	24.5	0.000002692063
5.5	0.07381466	25.0	0.000002036071
6.0	0.06144696	25.5	0.000001539928
6.5	0.04997189	26.0	0.000001164683
7.0	0.03992827	26.5	0.0000008808765
7.5	0.03147963	27.0	0.0000006662268
8.0	0.02456889	27.5	0.0000005038823
8.5	0.01902905	28.0	0.0000003810975
9.0	0.01465325	28.5	0.0000002882325
9.5	0.01123435	29.0	0.0000002179967
10.0	0.008584661	29.5	0.0000001648757
10.5	0.006543492	30.0	0.0000001246991
11.0	0.004978202	30.5	0.00000009431272
11.5	0.003781923	31.0	0.00000007133080
12.0	0.002869999	31.5	0.00000005394906
12.5	0.002176178	32.0	0.000000040802862
13.0	0.001649065	32.5	0.00000003086010
13.5	0.001249042	33.0	0.000000023340178
14.0	0.0009457197	33.5	0.00000001765269
14.5	0.0007158649	34.0	0.00000001335112
15.0	0.0005417658	34.5	0.00000001009775
15.5	0.0004099448	35.0	0.000000007637148
16.0	0.0003101621	35.5	0.000000005776143
16.5	0.0002346464	36.0	0.000000004368624
17.0	0.0001775048	36.5	0.000000003304087
17.5	0.0001342717	37.0	0.000000002498954
18.0	0.0001015647	37.5	0.000000001890014
18.5	0.00007682245	38.0	0.000000001429459
19.0	0.00005810643	38.5	0.000000001081131
19.5	0.00004394942		

For thermal assessments involving wind effects, the winds must be assumed to be steady-state over one hour, from any direction, with horizontal speeds in the design range provided in Table 5.

Table 5 – Design High and Low One-Hour Steady-State Wind Speed Profile for Use in Thermal Assessments

Height	1-Hr Steady-State Wind Speed Profile for Thermal Assessments	
(m)	(m/sec)	
	Design Low	Design High
10	0	9.8
18.3	0	11.7
30	0	13.3
60	0	16.0
90	0	17.8
120	0	19.1
150	0	20.2

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, while periods of discrete gusts are varied over the range of critical periods and the gusts are applied individually. Spectral and discrete gust are to be varied to identify the maximum system response. Both gust models are provided in NEDD Sections 3.1.1.3 and 3.1.1.4 and are applied to the steady-state wind profiles given in Table 3.

For the various operational phases, the design wind shear is determined by subtracting the 10-minute steady-state wind (from Table 3) at the altitude corresponding to the base of the vehicle from the peak wind (from Table 2) 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 sec^{-1} (this paragraph TBR-023-001).

Model Inputs

The peak and steady-state wind profile models are provided in NEDD Section 3.1.1.1. The peak wind profile model requires a peak wind value at a reference height of 18.3 meters as input. For transport to and from the pad, use $u_{18.3}$ = 30.8 m/s for construction of the maximum design limit peak wind speed profile up to 150 m. For the on-pad stay (unfueled) phase, use $u_{18.3}$ = 38.3 m/s for construction of the maximum design limit peak wind speed profile up to 150 m. For the on-pad stay (intermediate and fully fueled) phase, use $u_{18.3}$ = 24.2 m/s for construction of the maximum design limit peak wind speed profile up to 150 m. Tables 2 and 3 list the peak and 10-minute steady-state wind speed profiles, respectively, at selected heights for the above phases. The steady-state wind profile for thermal assessments (Table 5) is constructed by first determining the peak wind profile with $u_{18.3}$ = 17.7 m/s. This peak wind profile is then used to determine the steady-state wind profile for thermal assessments.

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

Limitations

All height levels are with respect to height Above Ground Level (AGL). Input into model must be in meters/second (m/s) for wind speed and meters for height.

Technical Notes

Design limit for the transport to/from the pad of 30.8 m/s at the 18.3 m 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). Weather forecast should be utilized to assure that high wind events, such as thunderstorms or tropical weather, will not be present during transport operations.

Design limit for the unfueled case of 38.3 m/s at the 18.3 m 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.

Design limit for the fueled case of 24.2 m/s at the 18.3 m reference level is the 99th percentile peak wind speed for a one day exposure period at KSC.

For thermal assessments, it is desired to have a design value for a steady-state wind averaged over a one hour period. However, surface meteorological data for the Eastern Range provides 10-minute averaged steady-state winds. Therefore, the design limit steady-state wind for thermal assessments was reduced to the 95th percentile value to account for the difference in averaging time.

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.

3.1.4 Radiant (Thermal) Energy Environment for Ground Operations a

Description

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

NEDD Reference Sections

3.2 Solar Radiation

3.2.1 Eastern Range

Design Limits

Table 6 lists the Design High and Design Low Solar Radiation Energies for KSC as a function of the time of day.

Table 7 gives the Design High and Design Low Sky Temperatures for KSC.

Model Inputs

None

Limitations

None

Technical Notes

The design high presents clear day direct incident radiant energy to a horizontal surface. 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 low presents cloudy day diffuse radiant energy which would apply to all surfaces. The actual radiant energy absorbed by these surfaces would also be a function of surface optical properties. These data should be used in conjunction with the sky temperature.

Table 6 Design high and design low radiant energy as a function of time of day

Time of Day	Design High* Solar Radiation	Time of Day	Design Low Solar Radiation
Hour (LST)	W/m^2	Hour (LST)	W/m^2
0500	0	0500	0
0600	795	0600	0
0700	934	0700	0
0800	1108	0800	0
0900	1213	0900	0
1000	1248	1000	0
1100	1283	1100	0
1200	1248	1200	0
1300	1283	1300	0
1400	1248	1400	0
1500	1248	1500	0
1600	1248	1600	0
1700	1178	1700	0
1800	1004	1800	0
1900	830	1900	0
2000	0	2000	0

*to a horizontal surface.

Table 7 Sky temperature design limits for KSC

	Sky Temperature (°C)
Design High	10.0
Design Low	-34.4

3.1.5 Air Temperature Environment for Ground Operations at KSC

Description

Specifies the design maximum and minimum surface air temperature for ground operations at KSC, including transportation to/from the pad and on-pad operations.

NEDD Reference Sections

3.3 Temperature

3.3.1 Eastern Range

Design Limits

Maximum: 38.0°C

Minimum: -6.0°C

Model Inputs

None

Limitations

For thermal assessments involving wind effects, the winds must be assumed to be steady state over one hour, from any direction, with horizontal speeds ranging from zero to values given in Section 3.1.3, Table 5.

Technical Notes

Design limits represent the maximum and minimum air temperature from hourly surface observations at the Eastern Range for the period of record 1957-2002. 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 is affected by chilling from the cold surfaces of the fuel tank and from the main engine drains purges and can be colder than the air temperature.

3.1.6 Air Pressure Environment for Ground Operations at KSC

Description

Specifies the design maximum and minimum sea-level air pressure for ground operations at KSC, including transportation to/from the pad and on-pad operations.

NEDD Reference Sections

3.4 Pressure

3.4.1 Eastern Range

Design Limits

Maximum: 1037.4 hPa at sea level

Minimum: 973.9 hPa 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 hPa and then a return to original pressure can be expected within a 24 hour period. Typically, a maximum pressure change of 6 hPa can be expected within a one hour period. [100 Pa = 1 hPa = 1 millibar (mb) = 0.01450377 pound/in^2 (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 Eastern Range for the period of record 1957-2002. NOTE: Testing for critical systems may involve pressures higher than those listed in this document. Refer to the appropriate test & verification plan for specific systems.

3.1.7 Humidity Environment for Ground Operations at KSC

Description

Specifies the design environment of surface humidity for ground operations at KSC, including transportation to/from the pad and on-pad operations.

NEDD Reference Sections

3.5 Humidity

3.5.1 Eastern Range

Design Limits

Design Limits for Surface Dew Point:

Table 8 contains Psychrometric data for the dew point temperature versus temperature envelope for KSC

Figure 1 contains a graphical depiction of the Psychrometric data for the dew point temperature versus temperature envelope for KSC

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 is based on hourly surface observations for the Eastern Range from 1957 to 2002. Figure 1 shows the limits in Table 8. The range of dew point temperatures, and associated air temperatures, from Table 8 represents the worst case environment to be used in design studies. Values chosen between these limits must be within the envelope in Figure 1.

Table 8 - Psychrometric data, dew point temperature versus temperature envelope for KSC

Temperature (ºC)	Dew Point (ºC)
-4	-14
-4	-4
28	28
36	28
40	15
11	-14

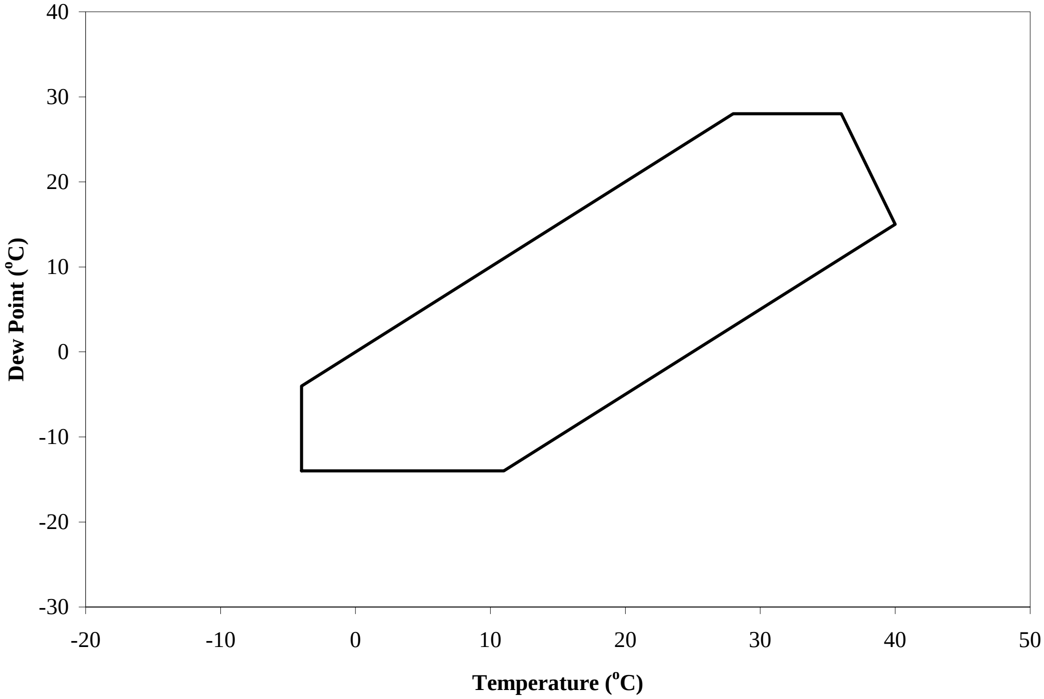

Figure 1 - Psychrometric data, dew point temperature versus temperature envelope for KSC

3.1.8 Aerosol Environment for Ground Operations at KSC

Description

This specifies the aerosol environment for ground operations at KSC, including transportation to/from the pad and on-pad operations.

NEDD Reference Sections

3.6 Aerosols – Surface

3.6.1 Eastern Range

Design Limits

Table 9 contains the Mean sea-salt particle concentration in maritime air masses.

Model Inputs

None

Limitations

Reserved

Technical Notes

None

Table 9 - Mean sea-salt particle concentration in maritime air masses

	Concentration (particles/cm^3)
Sea Level	200 – 300

3.1.9 Precipitation Environment for Ground Operations at KSC

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

NEDD Reference Sections

3.7 Precipitation

3.7.1 Eastern Range

Design Limits

Tables 10 and 11 list design rainfall and hail characteristics at KSC. Steady-state and peak winds given in Section 3.1.3 will be used for studies that require coupling of hail and/or rainfall with wind.

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 rate of fall for raindrops is 6.5 m/sec for all time periods.

Technical Notes

Hail fall at KSC occurs, on average, 0.365 days a year. Therefore, for any given year, there is 36.5% chance of having one day with hail fall. Given that hail has fallen, there is a 5% chance that the diameter of any hailstone will be larger than 2.2 cm. Therefore, the design maximum hailstone size, 2.2 cm, is associated with approximately a 0.9% chance of occurrence over a 180 day exposure period.

Table 10 - Design rainfall, KSC, based on yearly largest rate for stated durations

Time Period	Rainfall Rate	Rainfall Total Accumulation	Raindrop Size	
			Average	Largest
	mm/hr	mm	mm	mm
1 min	*492*	*8*	*2.0*	*6.0*
5 min	*220*	*18*	*2.0*	*5.8*
15 min	*127*	*32*	*2.0*	*5.7*
1 h	*64*	*64*	*2.0*	*5.0*
6 h	*26*	*156*	*1.8*	*5.0*
12 h	*18*	*220*	*1.6*	*4.5*
24 h	*13*	*311*	*1.5*	*4.5*

Table 11 - Design hail characteristics for KSC

Hailstone Diameter Size	2.2 cm
Terminal Velocity	17 m/sec
Number of Hailstones per Hail Fall	260 m^{-2}
Duration of Hail Fall	5 min
Horizontal Velocity	15 m/sec
Density of Hailstone	0.9 g/cm^3

3.1.10 Flora and Fauna Environment for Ground Operations

Description

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

NEDD Reference Sections

None

Design Limits

The natural environment in the launch area is conducive to fungus growth. The specific environment is dependent upon material selection. Methods for testing of materials for fungus growth are given in MIL-STD-810F, Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, Method 508.

Pests in the KSC area include birds (woodpeckers, buzzards), rodents (mice, rats), insects (bees, cockroaches), wild boar and alligators.

Model Inputs

None

Limitations

None

Technical Notes

Currently, design specification only addresses fungus growth and common pests. Additional work needs to be done to address other flora and fauna. Consideration may be given to addressing flora and fauna operationally.

3.1.11 Lightning During On-pad Operations

Description

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.

NEDD Reference Sections

3.8 Lightning

3.8.1 Eastern Range

3.8.5 Lightning Design and Test Criteria

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. Applicable documents are SAE ARP5412, “Aircraft Lightning Environment and Related Test Waveforms,” and RTCA 160/DO-160D, “Environmental Conditions and Test Procedures for Airborne Equipment,” Section 22, “Lightning Induced Transient Susceptibility” and Section 23, “Lightning Direct Effects.”

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 determination of 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 specifies ground wind environments (altitude range 0 to 270 m 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 discrete and spectral gust environment.

NEDD Reference Sections

3.1 Ground Winds

3.1.1 Eastern Range

3.1.1.1 Peak Wind Profile

3.1.1.3 Spectral Gust Environment

3.1.1.4 Discrete Gust Model

Design Limits

Table 12 provides the design peak wind profiles for the vehicle launch phase. The design 10-minute steady-state wind profiles associated with the design peak wind profiles are provided in Table 13. The 10-minute steady state wind profile is that profile that could produce the instantaneous peak winds (gusts) in Table 12 over a 10-minute period. See NEDD Section 3.1.1.1 to determine profile values between those altitudes given in Tables 12 and 13.

Table 12 - Peak Wind Speed Profile for Vehicle Launch

Height	Peak Wind Speed Profile for Vehicle Launch
(m)	(m/sec)
10	15.8
18.3	17.7
30	19.4
60	22.1
90	23.8
120	25.1
150	26.1
180	27.0
210	27.8
240	28.5
270	29.1

Table 13 – 10-Minute Steady-State Wind Speed Profile for Vehicle Launch

Height	10-Minute Steady-State Wind Speed Profile for Vehicle Launch
(m)	(m/sec)
10	9.8
18.3	11.7
30	13.3
60	16.0
90	17.8
120	19.1
150	20.2
180	21.1
210	21.9
240	22.6
270	23.3

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, while periods of discrete gusts are varied over the range of critical periods and the gusts are applied individually. Spectral and discrete gust are to be varied to identify the maximum system response. Both gust models are provided in NEDD Sections 3.1.1.3 and 3.1.1.4 and are applied to the steady-state wind profiles given in Table 13.

The design launch wind shear is determined by subtracting the 10-minute steady-state wind (from Table 13) at the altitude corresponding to the base of the vehicle from the peak wind (from Table 12) 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 sec^{-1}. (entire paragraph TBR-023-002)

Model Inputs

The peak and steady-state wind profile models are provided in NEDD Section 3.1.1.1. The peak wind profile model requires a peak wind value at a reference height of 18.3 meters as input. For vehicle launch, use $u_{18.3}$ = 17.7 m/s for construction of the maximum design limit wind speed profile up to 270 m AGL.

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

Limitations

All height levels are with respect to height above ground level (AGL). Input into model must be in meters/second (m/s) for wind speed and meters for height.

Technical Notes

Design limit for vehicle launch of 17.7 m/s at the 18.3 m reference level is the 99th percentile peak wind speed for the windiest hour of the windiest month based on hourly surface observations for the Eastern Range 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.

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

3.2.2 Surface Air Temperature Environment During Launch

Description

Specifies the design maximum and minimum surface air temperature for vehicle launch at KSC.

NEDD Reference Sections

3.3 Temperature

3.3.1 Eastern Range

Design Limits

Maximum: 37.2°C

Minimum: 0.6°C

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 Section 3.2.1, Table 13.

Technical Notes

Design limits represent the range of temperatures defined in Space Shuttle Flight and Ground System Specification, NSTS 07700, Vol. X, Book 2, Appendix 10.10, Section 11.1.4.2. These limits are also defined in Space Shuttle Launch Commit Criteria and Background, NSTS 16007, Section 4, Weather Rules. The rationale for choosing this design range for launch is that re-design, re-testing, re-certification, etc., of legacy hardware would not be necessary.

3.2.3 Surface Air Pressure Environment During Launch

Description

Specifies the design maximum and minimum sea-level air pressure for vehicle launch at KSC.

NEDD Reference Sections

3.4 Pressure

3.4.1 Eastern Range

Design Limits

Maximum: 1037.4 hPa at sea level

Minimum: 973.9 hPa at sea level

[100 Pa = 1 hPa = 1 millibar (mb) = 0.01450377 pound/in^2 (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 Eastern Range for the period of record 1957-2002. Air pressure can affect tank pressures and vent size selections.

3.2.4 Surface Humidity Environment During Launch

Description

Specifies the design environment of surface humidity for vehicle launch at KSC.

NEDD Reference Sections

3.5 Humidity

3.5.1 Eastern Range

Design Limits

See Section 3.1.7, Design Limits

Model Inputs

None

Limitations

None

Technical Notes

See Section 3.1.7, Technical Notes.

3.2.5 Aloft Wind Environment for Vehicle Ascent

Description

This specifies aloft wind environments and dispersions (altitude range 0 to 90 km) for vehicle ascent at KSC. For Launch Abort System analyses, a design wind profile is provided from the surface to 3050 m.

NEDD Reference Sections

4.1 Winds Aloft

4.1.1 Eastern Range

4.1.1.1 Monthly Vector Wind Profile Model (ER, 0 – 27 km)

4.1.1.2 Ascent Wind Model 28-90 km, Eastern Range

4.2 Discrete Gust Model

4.2.1 NASA 1997 Discrete Gust Model

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

System performance will be evaluated through Monte Carlo analysis of 1000 or more GRAM-99 random profiles per month. Each profile is for a 0 to 90 km altitude range with GRAM-99 inputs per Table 15. Atmospheric wind, temperature, pressure, density should be evaluated simultaneously in each simulation.

Alternatively, system performance can be evaluated with use of the Monthly Vector Wind Profile Model (MVWPM). For the altitude range of 0-27 km, use the 99th percentile monthly and conditional wind vector ellipses from the MVWPM. For the altitude range of 28-90 km, monthly mean vector wind profiles from GRAM 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) to the GRAM monthly mean profile at 35 km. The GRAM monthly mean profile will be used above 35 km. Table 16 lists the GRAM inputs to generate the monthly mean profile to be appended to MVMPM profiles (method for appending profiles is TBR-023-003 at this time). Discrete gusts that produce the desired vehicle response will be individually applied to the wind profiles. The discrete gust model and range of discrete gust magnitudes are provided in NEDD Section 4.2.1.

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

Table 14 provides the design 1% risk on-shore only wind for use in design studies involving the Launch Abort System (LAS). (Design limits for the LAS are TBR-023-004 at this time)

Table 14 – Design 1% Risk On-Shore Wind for Launch Abort System

Altitude (m)	Wind Speed (m/sec)	Wind Direction (degrees)	Altitude (m)	Wind Speed (m/sec)	Wind Direction (degrees)
0	0.00	53	1550	15.00	53
50	13.05	53	1600	14.72	53
100	14.41	53	1650	14.71	53
150	15.27	53	1700	14.27	53
200	15.91	53	1750	14.02	53
250	16.43	53	1800	13.98	53
300	16.44	53	1850	13.85	53
350	16.78	53	1900	14.02	53
400	17.09	53	1950	14.00	53
450	17.00	53	2000	13.91	53
500	17.21	53	2050	13.75	53
550	17.60	53	2100	13.74	53
600	17.40	53	2150	13.61	53
650	17.58	53	2200	13.54	53
700	17.66	53	2250	13.44	53
750	17.53	53	2300	13.48	53
800	17.42	53	2350	13.42	53
850	17.23	53	2400	13.31	53
900	17.04	53	2450	13.16	53
950	16.80	53	2500	13.25	53
1000	16.88	53	2550	13.13	53
1050	16.60	53	2600	13.29	53
1100	16.36	53	2650	13.36	53
1150	16.20	53	2700	13.53	53
1200	15.77	53	2750	13.62	53
1250	15.64	53	2800	13.51	53
1300	15.37	53	2850	13.45	53
1350	15.08	53	2900	13.17	53
1400	15.16	53	2950	13.11	53
1450	15.20	53	3000	13.06	53
1500	14.92	53	3050	13.01	53

Model Inputs

GRAM-99 inputs for Monte Carlo analyses are listed in Table 15 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 of 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 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 to extreme profiles (e.g., 2 or 3 sigma climatological profiles) which GRAM-99 also has the capability to produce.

Table 15 - GRAM-99 input to generate 1000 or more perturbed profiles (0 to 90 km) of wind, temperature, pressure, and density per monthly reference period

Parameter	GRAM-99 variable name	Value
Range reference atmosphere limits – use if near site with a Range Reference Atmosphere (RRA)	sitenear	0.5
	sitelim	2.5
Random output	iopr	1= random
Non-RRA sites	iguayr	1 = period of record
Random perturbations	rpscale	1.0
Small scale perturbations	patchy	0

Table 16- GRAM-99 input to generate monthly mean profiles to be appended to MVWPM profiles

Parameter	GRAM-99 variable name	Value
Range reference atmosphere limits – use if near site with a Range Reference Atmosphere (RRA)	sitenear	0.5
	sitelim	2.5
Random output	iopr	2= none
Non-RRA sites	iguayr	1 = period of record

Limitations

GRAM and MVWPM perturbations in the aloft region are statistically derived. Large-scale perturbations in GRAM follow a cosine wave model, while small-scale perturbations are normally distributed. MVWPM dispersions are developed with the quadravariate normal model, with the assumption that measured wind components are normally distributed at each altitude. Discrete gust may be adjusted (tuned) and applied by the engineer for vehicle response analyses.

Technical Notes

The Monthly Vector Wind Profile Model 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 high-resolution wind profile database for the Eastern Range (NEDD, Section 4.1.1) can be used to evaluate flight simulations to determine the operational capability of the launch vehicle.

The design 1% risk on-shore wind profile is the 1st percentile value at each altitude of the on-shore only wind components at the Eastern Range for the month of October. The month of October was chosen because it contains the largest magnitudes of on-shore wind. The database used for the calculation of the design profile consisted of 1902 high-resolution balloon wind measurements for the period of record 1964-2005, 165 which are from October.

3.2.6 Aloft Air Temperature Environment for Vehicle Ascent

Description

Specifies the aloft air temperature environments (altitude range 0 to 90 km) for vehicle ascent at KSC.

NEDD Reference Sections

4.4 Temperature

4.4.1 Eastern Range

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

System performance will be evaluated through analysis of 1000 or more GRAM-99 random profiles per month. Each profile is for a 0 to 90 km altitude range with GRAM-99 inputs per Table 15. Atmospheric temperature, pressure and density should be evaluated simultaneously in each simulation.

Model Inputs

GRAM-99 input is listed in Table 15 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 of 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 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 to extreme profiles (e.g., 2 or 3 sigma climatological profiles) which GRAM-99 also has the capability to produce.

Limitations

Perturbations in the aloft region are statistically derived and are generated using the input variables in the table 15.

Technical Notes

Thermodynamic parameters during ascent drive vehicle venting rates, aeroheating/aerodynamic loads, and trajectory design. It is suggested that at least 1000 GRAM-99 random profiles be analyzed for vehicle design limit development.

3.2.7 Aloft Air Pressure Environment for Vehicle Ascent

Description

Specifies the aloft air pressure environments (altitude range 0 to 90 km) for vehicle ascent at KSC.

NEDD Reference Sections

4.5 Pressure

4.5.1 Eastern Range

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

See DSNE Section 3.2.6.

Model Inputs

See DSNE Section 3.2.6.

Limitations

See DSNE Section 3.2.6.

Technical Notes

See DSNE Section 3.2.6.

3.2.8 Aloft Air Density Environment for Vehicle Ascent

Description

Specifies the aloft air density environments (altitude range 0 to 90 km) for vehicle ascent at KSC.

NEDD Reference Sections

4.6 Density

4.6.1 Eastern Range

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limit

See DSNE Section 3.2.6.

Model Inputs

See DSNE Section 3.2.6.

Limitations

See DSNE Section 3.2.6.

Technical Notes

See DSNE Section 3.2.6.

3.2.9 Cloud and Fog Environment for Launch

Description

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

NEDD Reference Sections

4.10 Stratospheric and Mesospheric Clouds

Design Limits

The design range for cloud clover is up to and including 100% cloud cover, excluding convective clouds and thunderstorms. The maximum size of any liquid cloud particle is 7 millimeters diameter. The maximum size of any frozen cloud particle is 200 microns. The minimum horizontal ground level visibility is 1000 meters.

Model Inputs

None

Limitations

None

Technical Notes

The maximum size for liquid cloud particles of 7 millimeters 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 microns allows for traverse through mid and high altitude layer clouds (alto and cirrus type).

3.2.10 Rain and Precipitation Environment for Launch

Description

Specifies the precipitation environment for vehicle launch at KSC.

NEDD Reference Sections

3.7 Precipitation

3.7.1 Eastern Range

Design Limits

The maximum design rainfall rate is 7.6 mm/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.

3.2.11 Flora and Fauna Environments During Launch and Ascent

Description

Specifies the flora and fauna environment for vehicle ascent at KSC.

NEDD Reference Sections

None

Design Limits

Avian species with a maximum mass of 2.2 kg may be commonly found up to an altitude of 0.5 km above the top of the mobile launch platform.

Model Inputs

None

Limitations

None

Technical Notes

From a 2005 STS-114 Bird Strike In-flight Anomaly Study, the most common larger species of birds in the KSC area are Osprey (mass 1.4-2.0 kg), Turkey Vultures (mass ~2.0 kg) and Black Vultures (mass 1.6-2.2 kg). Much less common but also present in the KSC area are Bald Eagles (mass 4.5-6.4 kg).

3.2.12 Natural and Triggered Lightning During Launch and Ascent

Description

This 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.

NEDD Reference Sections

3.8 Lightning

3.8.1 Eastern Range

3.8.5 Lightning Design and Test Criteria

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. Applicable documents are SAE ARP5412, "Aircraft Lightning Environment and Related Test Waveforms," and RTCA 160/DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment," Section 22, "Lightning Induced Transient Susceptibility" and Section 23, "Lightning Direct Effects."

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 determination of 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 Phases

Description

Environment parameters identified here are applicable for KSC launch trajectories to target orbit inclinations of 51.6° or less. This specification applies to Constellation vehicles operating at or below latitude 45°N and a peak altitude of 150 km. The magnetic field intensity values applied for geomagnetic shielding calculations were selected based on the 45°N maximum latitude. 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 and displacement damage to flight hardware are negligible for this segment of the environment.

NEDD Reference Sections

3.12 Ionizing Radiation (0-150m)
4.11 Ionizing Radiation (150m – 90km)

Design Limits

Systems that operate at altitudes above 20 km and at or below 150 km altitude will be exposed to the GCR and Design SPE environments of Tables 17 and 18. The low altitude atmospheric neutron environment 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 19 atmospheric neutron environment for the system maximum operating altitude. The 150 km Galactic Cosmic Ray (GCR) and Design Solar Particle Event (Design SPE) environments are not applicable.

Figure 2 and Table 17 present 150 km Linear Energy Transfer (LET) flux for a Design SPE and for solar minimum GCR in stormy magnetic field conditions.

Figure 3 and Table 18 present 150 km differential proton flux for a Design SPE and GCR.

Table 19 presents the flux of >10 MeV neutrons at altitudes to 20 km.

Model Inputs

None

Limitations

Probability that the 150 km proton and Linear Energy Transfer (LET) flux spectra of the Design SPE will not be exceeded is estimated at 97%.

The Galactic Cosmic Ray proton and LET flux 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

Proton and LET flux spectra of the Design SPE can be reproduced in more detail using the CREME96 “Worst Week” flare model. Minimum shielding by earth’s magnetic field is applied by using the “sections of orbits” option in the model’s GTRN module and further selecting bounding McIlwain L values between 2.5 and 3.3. This represents conditions at the approximately 45°N latitude and 150 km altitude where the second stage engine separates from the vehicle. Atomic numbers for Z=1 through Z=92 ions are included for definition of the LET spectrum. All 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 used to simulate a “worst case” SPE exposure at the 97% probability level appropriate for crewed missions included in the Program defined DRM set. The probability is determined by comparison to the Goddard Space Flight Center (GSFC) Emission of Solar Proton (ESP) model.

The GCR proton and LET design specification spectra can be reproduced using CREME96 with the same GTRN module options describe in the previous paragraph and selecting the “Solar Minimum” option for 150 km and the 1-92 atomic number range.

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.

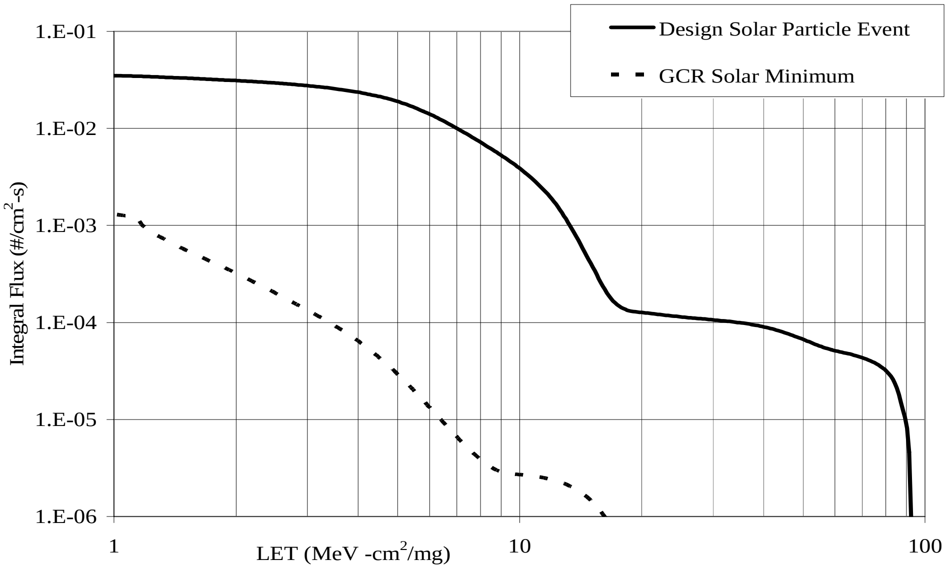

Figure 2 – 150 km LET flux for a Design SPE and Solar Minimum GCR in a Stormy Magnetic Field for 51.6° inclination, 150 km altitude, at 45° North Latitude.

Table 17 – 150 km Integral LET Flux shown in Figure 2.

	Design SPE (3.3≥ L≥2.5)	GCR (3.3≥L≥2.5)
LET (MeV-cm^2/mg)	Integral Flux (Particles/cm^2-s)	Integral Flux (Particles/cm^2-s)
1.00	**3.4932E-02**	**1.2075E-03**
1.27	**3.3859E-02**	**7.2137E-04**
1.60	**3.2489E-02**	**4.1978E-04**
2.01	**3.0976E-02**	**2.5587E-04**
2.54	**2.9217E-02**	**1.4902E-04**
3.20	**2.6791E-02**	**8.6559E-05**
4.04	**2.3427E-02**	**4.7251E-05**
5.09	**1.8468E-02**	**1.9917E-05**
6.42	**1.2197E-02**	**6.6105E-06**
8.09	**7.0166E-03**	**2.8572E-06**
10.21	**3.6284E-03**	**2.6330E-06**
16.42	**2.0165E-04**	**8.9169E-07**
20.47	**1.2534E-04**	**2.0171E-10**
25.81	**1.1255E-04**	**4.8204E-11**
32.55	**1.0290E-04**	**1.7687E-12**
41.05	**8.7942E-05**	**1.6354E-17**
51.76	**6.3141E-05**	**negligible**
65.28	**4.7239E-05**	**negligible**
82.32	**2.7943E-05**	**negligible**
100.25	**2.8893E-07**	**negligible**

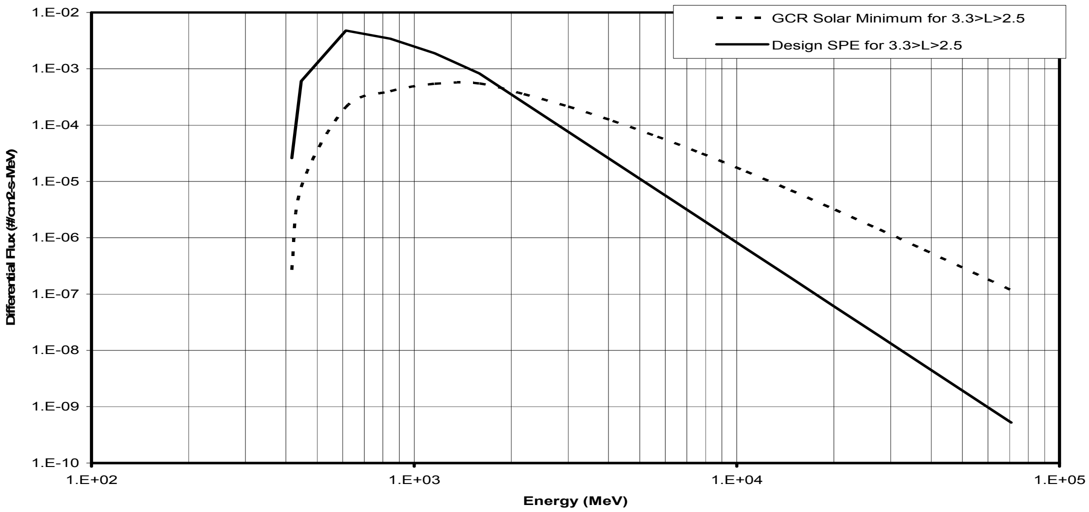

Figure 3 – 150 km Differential Proton Flux of Design SPE and GCR

Table 18 – 150 km Differential Proton Flux shown in Figure 3

	Design SPE (3.3≥L≥2.5)	GCR (3.3≥L≥2.5)
Energy (MeV)	protons/cm^2-s-MeV	protons/cm^2-s-MeV
4.17E+02	2.59E-05	2.68E-07
4.47E+02	6.04E-04	7.93E-06
6.14E+02	4.77E-03	2.08E-04
8.43E+02	3.42E-03	3.98E-04
1.16E+03	1.88E-03	5.43E-04
1.59E+03	8.26E-04	5.48E-04
2.19E+03	2.50E-04	3.54E-04
3.00E+03	7.59E-05	2.12E-04
4.12E+03	2.30E-05	1.19E-04
5.67E+03	6.97E-06	6.25E-05
7.78E+03	2.11E-06	3.13E-05
1.07E+04	6.40E-07	1.50E-05
1.47E+04	1.94E-07	6.96E-06
2.02E+04	5.88E-08	3.15E-06
2.77E+04	1.78E-08	1.40E-06
3.81E+04	5.40E-09	6.09E-07
6.00E+04	9.73E-10	1.82E-07
7.08E+04	5.22E-10	1.17E-07

Table 19 - Flux of > 10 MeV Neutrons at Altitudes to 20 km

Altitude (km)	Integral Flux (n/cm^2-s)
0.02	6.85E-03
0.05	7.05E-03
0.10	7.38E-03
0.30	8.87E-03
0.50	1.06E-02
1.00	1.64E-02
2.00	3.67E-02
3.00	7.62E-02
4.00	1.47E-01
5.00	2.66E-01
6.00	4.53E-01
7.00	7.28E-01
9.00	1.62E+00
10.00	2.27E+00
12.00	3.94E+00
15.00	6.95E+00
17.00	8.96E+00
18.00	9.91E+00
19.00	1.08E+01
20.00	1.15E+01

3.3 IN-SPACE PHASES

3.3.1 Total Ionizing Dose (TID)

Description

This section specifies cumulative TID exposure in units of rads (silicon) for parts and materials exposed to Design Reference Mission (DRM) phases at altitudes greater that 150 km. Almost all the Luna DRM dose to shielded electronic parts is generated by GCR and SPE exposure outside the earth's magnetic field. Unshielded or thinly shielded materials receive most of their DRM dose from low energy solar wind electrons and protons outside the magnetosphere. Trapped radiation belt particles in Low Earth Orbit (LEO) contribute dose to unshielded and shielded parts and materials during Earth Escape, Descent and Earth Return, and Earth Departure Stage (EDS) mission phases. Magnitude of the dose for each LEO mission phase depends on parameters (exposure duration, orbit inclination, etc.) that are not currently defined.

NEDD Reference Sections

7.5 Ionizing Radiation (90-2000km)

8.5 Ionizing Radiation (2000km-10R_e)

11.5 Radiation Environment (10-60R_e)

12.3 Ionizing Radiation (Lunar Space)

Design Limits

Dose contributions for mission phases conducted within Earth's magnetosphere (rendezvous, Earth escape, and Earth return operations) must be added to dose from In-Space sources (Solar Wind, GCR and the Design SPE). For any specified shield thickness, the specified TID exposure applies for items present during all phases of a Lunar Outpost DRM. Maximum mission cumulative TID specifications for the ISS and Lunar DRMs as currently defined do not exceed the Lunar Outpost DRM (Mars DRM is excluded). Items utilized during more than one mission are subject to cumulative exposure from all phases of each DRM in which they are used except that a single In-Space Design SPE should be assumed to occur during the item life.

Figure 4 and Table 20 specify TID inside selected thicknesses of spherical aluminum (Al) shielding from a Design SPE and annual TID rates for solar minimum GCR during phases of lunar DRMs occurring outside earth's magnetosphere. Daily GCR dose is included in the table.

Figure 5 and Table 21 specify TID rates at selected depths inside thin shielding from solar wind exposure (outside the magnetosphere), a selected Earth Escape trajectory, and the selected EDS rendezvous orbit. A semi-infinite plane shield model is applied for defining dose from solar wind. A more conservative spherical shield model is used to define contributions from the other sources represented.

Model Inputs

None

Limitations

Probability that the Design SPE dose will not be exceeded during a single lunar DRM is estimated at 97%. That probability is reduced for multi-mission items because they accumulate exposure to the variable, low level solar particle background during each DRM. The probability reduction is less than 5% for a second Lunar Outpost DRM.

Solar wind dose to thinly shielded items should be examined considering details of mission parameters not currently available. A physics based transport model is required.

Exposure to trapped radiation may add significant dose for thin to moderately shielded items if a vehicle spends more than 8-9 hours inside the magnetosphere.

Technical Notes

The Design SPE and GCR TID specification can be reproduced using CREME96 and selecting the “near earth/interplanetary” option of the FLUX module. Assume Solar Minimum for defining GCR dose. The solar wind dose model is a MSFC/EV13 product developed based on 12 years of Ulysses satellite data collected outside Earth’s magnetosphere. AP8MAX plus AE8MAX or AP8MIN plus AE8MIN model dose, whichever is more for the selected shield thickness, is used to define trapped dose contributions for the Earth Escape trajectory and EDS operations. Dose during Descent and Earth Return (LEO phase) is assumed equal to Earth Escape dose. Twice the “Worst Week” flare model dose is used to represent the Design SPE. The x2 multiplier of the 1989 event is used to simulate a “worst case” SPE exposure at the 97% probability level appropriate for long duration crewed missions included in the Program defined DRM set. The probability is determined by comparison to the GSFC ESP model. Actual SPE exposure may occur as a single SPE or a series of smaller events.

Satellite Tool Kit (STK) is recommended for use in defining Earth Escape trajectory parameters.

Use a semi-infinite plane model to define dose-depth parameters for shielding of solar wind radiation. Use a spherical shield model to define depth-dose from other sources unless a more realistic (less conservative) model of the actual shield geometry is available.

Table 20 - Design SPE and GCR Total Ionizing Dose Inside Shielding

Aluminum Shield Depth	Design SPE In-Space (180 hr event)	GCR Solar Minimum (In Interplanetary Space)	
Cm (inch)	Rads(Si)/event	Rads(Si)/year	Rads (Si)/day
0.0254 (0.01)	5.386E4	13.72	3.756E-2
0.10 cm	2.000E4	12.98	3.553E-2
0.254 (0.10)	6.070E3	12.53	3.430E-2
0.508 (0.20)	2.146E3	11.99	3.283E-2
1.00 cm	8.358E2	11.34	3.103E-2
5.08 (2.00)	6.522E1	8.51	2.329E-2
10.16 (4.00)	1.772E1	6.52	1.784E-2

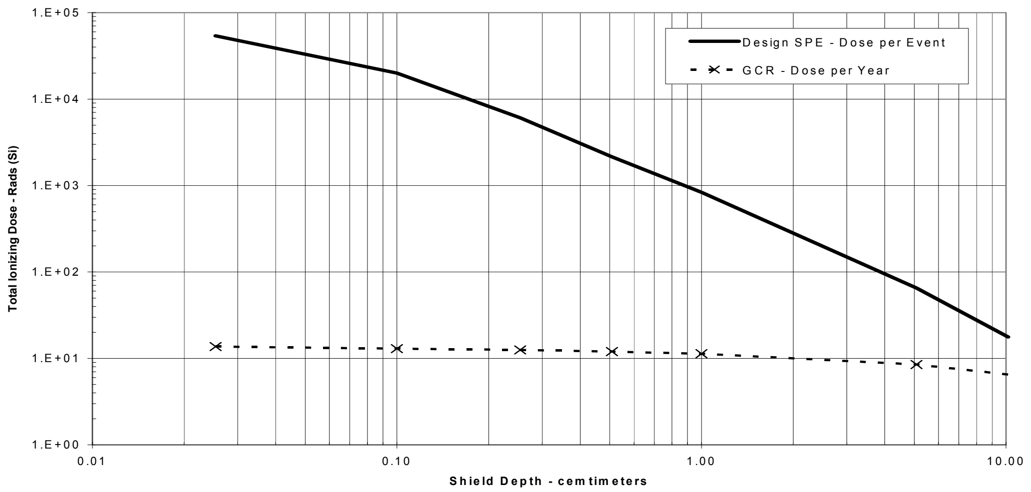

Figure 4 - Design SPE and GCR Total Ionizing Dose Inside Shielding

Table 21 – Solar Wind, Earth Escape, and EDS TID Inside Shielding

Solar Wind (1) Dose/day		Earth Escape Trajectory (2) Dose/Escape		EDS Rendezvous Orbit Dose/day (3)	
Depth (mm Al)	Dose Rads(Si)	Depth (mm Al)	Dose Rads(Si)	Depth (mm Al)	Dose Rads(Si)
1.00E-05	2.16E+06	0.1	2.90E+04	0.1	6.96E-01
2.50E-05	4.35E+05	0.15	1.86E+04	0.15	4.60E-01
5.00E-05	1.29E+05	0.3	7.35E+03	0.3	1.26E-01
7.90E-05	5.81E+04	1	9.60E+02	1	2.03E-02
1.00E-04	3.85E+04	1.5	5.05E+02	1.5	1.82E-02
2.51E-04	7.69E+03	5	2.40E+01	5	1.35E-02
5.01E-04	2.29E+03	7	6.05E+00	7	1.26E-02
7.94E-04	1.02E+03	9	3.21E+00	9	1.18E-02
1.00E-03	6.84E+02	10	2.79E+00	10	1.15E-02
2.51E-03	1.37E+02	15	1.95E+00	15	9.80E-03
5.01E-03	4.08E+01	20	1.58E+00	20	8.57E-03
7.94E-03	1.82E+01	40	9.10E-01	40	5.89E-03
1.00E-02	1.22E+01	60	6.20E-01	60	4.38E-03
2.51E-02	2.43E+00	80	4.50E-01	80	3.39E-03
5.01E-02	7.25E-01	100	3.38E-01	100	2.62E-03
7.94E-02	3.24E-01	150	1.69E-01		
1.00E-01	2.16E-01	300	2.88E-02		
2.51E-01	4.32E-02	500	5.10E-03		

Note: Table values are based on long term averages. Short-term exposure rates are highly variable.

(1) Solar wind dose applies when spacecraft is at altitudes greater than 60,000 km. Dose transport calculated with Integrate Tiger Series (ITS 3.0) and Stopping Range in Materials (SRIM 2006) software.

(2) AE8MAX+AP8MAX dose in spherical shield for one 4.3 hour transit at 28.5° inclination from 365 km, ~latitude -24.5°, ~longitude 22.9° to 60,000 km per STK 6.1 trajectory analysis. Dose transport calculated with Shieldose – II software.

(3) Maximum daily dose inside spherical shield from AE8MAX+A8MAX or AE8MIN+AP8MIN as implemented in SpaceRad software.

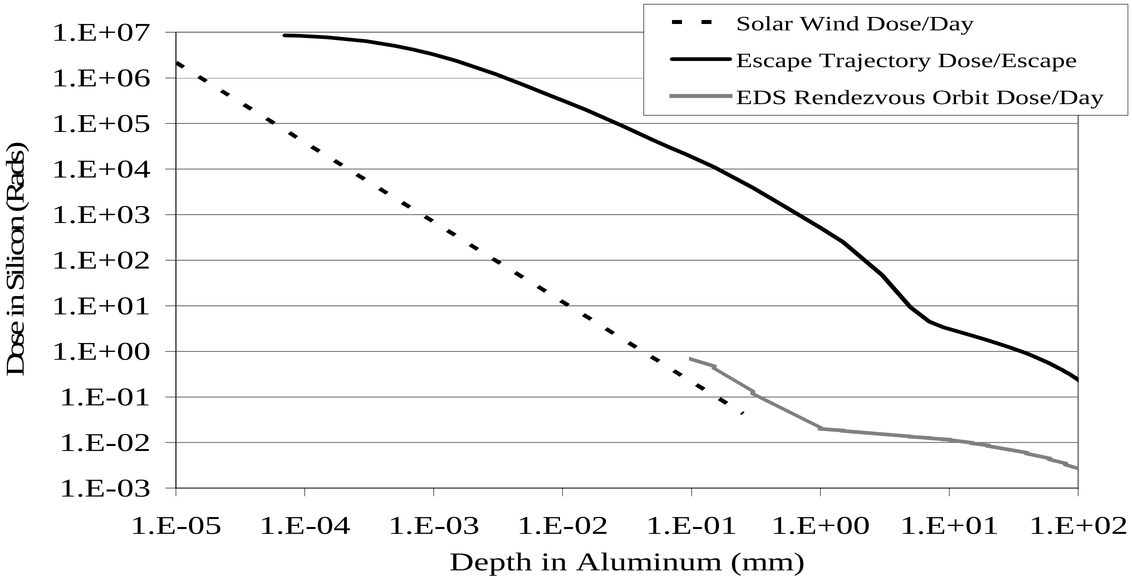

Figure 5 - Solar Wind, Earth Escape, and EDS TID Inside Shielding

3.3.2 Peak Flux for SEE Rate Determinations

Description

Peak GCR and SPE fluxes are encountered outside earth's magnetic field. LET flux values inside spherical aluminum shielding during exposure to Design SPE peak flux are provided to support evaluation of SEE rate concerns for shielded electronics. GCR and SPE proton fluxes are provided to support evaluation of proton effects on unshielded surface materials.

NEDD Reference Sections

7.5 Ionizing Radiation (90-2000km)

8.5 Ionizing Radiation (2000km-10R_e)

11.5 Radiation Environment (10-60R_e)

12.3 Ionizing Radiation (Lunar Space)

Design Limits

Figure 6 and Table 22 present the Design SPE-Peak Rate LET Flux inside selected aluminum shield thicknesses. Each thickness value is identical to the radius of the assumed spherical shielding.

Figure 7 and Table 23 present Integral Proton Flux of a Design SPE and of GCR.

Figure 8 and Table 24 present Differential Proton Flux for the Design SPE and Solar Minimum GCR.

Model Inputs

None

Limitations

Probability that the Design SPE Peak Flux and “Worst Week” Flux will not be exceeded are estimated at 97%.

Technical Notes

The Design SPE LET and proton differential flux specifications can be reproduced in more detail using CREME96 and selecting the “near earth/interplanetary” option of the FLUX module. Use twice the “Peak 5-Minute Average” flare model to define the Design SPE peak LET and differential proton fluxes. Consider ions with Z=1 through 92 for LET flux. Consider only Z=1 ions for proton flux. Assume Solar Minimum for defining GCR flux. Twice the “Worst Week” flare model and Z=1 ions is used to define the Design SPE differential proton flux. The x2 multiplier of the 1989 event is needed to simulate a “worst case” SPE exposure at the 97% probability level appropriate for long duration crewed missions included in the Program defined DRM set. The probability is determined by comparison to the GSFC ESP model. Actual SPE exposure may occur as a single SPE or a series of smaller events. Integral proton flux values were calculated from differential spectra of the CREME96 model by multiplying each spectral point by its energy bin width and summing with all higher energy bins.

A spherical shield model with radius set equal to the minimum shield thickness provides very conservative results. CREME96 can also model flux inside other 3-dimensional 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.

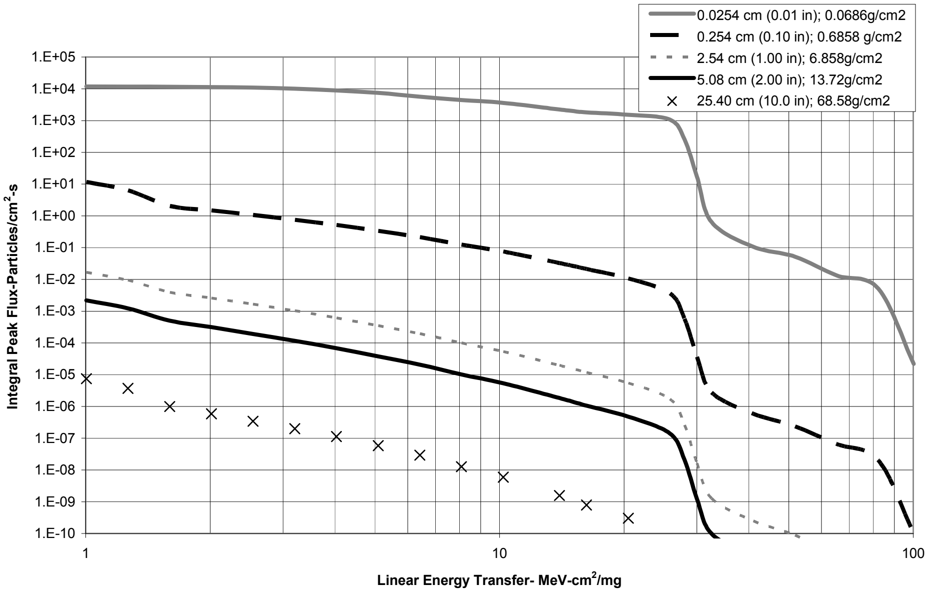

Figure 6 - Design SPE Peak LET Flux for Selected Al Shielding Thicknesses

Table 22 – Design SPE Peak LET Flux

LET	Shield Thickness 0.0254 cm (0.0686 g/cm^2)	Shield Thickness 0.254 cm (0.6858 g/cm^2)	Shield Thickness 2.54 cm (6.858 g/cm^2)	Shield Thickness 5.08 cm (13.72 g/cm^2)	Shield Thickness 25.40 cm (68.58 g/cm^2)
(MeV-cm^2/mg)	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s	Particles/cm^2-s
1.00	1.19E+04	1.18E+01	1.68E-02	2.19E-03	7.49E-06
1.27	1.18E+04	6.33E+00	9.45E-03	1.22E-03	3.73E-06
1.60	1.17E+04	2.06E+00	3.95E-03	5.03E-04	9.99E-07
2.01	1.14E+04	1.50E+00	2.60E-03	3.15E-04	5.86E-07
2.54	1.09E+04	1.07E+00	1.66E-03	1.93E-04	3.44E-07
3.20	1.01E+04	7.51E-01	1.03E-03	1.16E-04	2.00E-07
4.04	8.91E+03	5.18E-01	6.20E-04	6.79E-05	1.13E-07
5.09	7.44E+03	3.38E-01	3.52E-04	3.78E-05	5.82E-08
6.42	5.67E+03	2.15E-01	1.96E-04	2.07E-05	2.93E-08
8.09	4.47E+03	1.25E-01	9.98E-05	1.02E-05	1.26E-08
10.21	3.63E+03	7.51E-02	5.36E-05	5.35E-06	5.92E-09
13.96	2.24E+03	3.27E-02	1.96E-05	1.84E-06	1.57E-09
16.23	1.83E+03	2.12E-02	1.17E-05	1.06E-06	7.91E-10
20.47	1.54E+03	1.06E-02	5.46E-06	4.78E-07	3.03E-10
25.81	1.07E+03	3.62E-03	1.71E-06	1.41E-07	6.58E-11
28.00	2.55E+02	5.73E-04	2.61E-07	2.08E-08	8.02E-12
30.01	1.72E+01	3.67E-05	1.63E-08	1.25E-09	4.24E-13
32.55	6.41E-01	2.77E-06	1.28E-09	9.87E-11	4.20E-14
41.05	1.06E-01	5.84E-07	2.48E-10	1.83E-11	6.70E-15
51.76	5.23E-02	2.37E-07	8.88E-11	6.31E-12	1.82E-15
65.28	1.33E-02	6.56E-08	1.95E-11	1.32E-12	3.05E-16
82.32	5.10E-03	2.01E-08	4.83E-12	3.03E-13	5.57E-17
100.25	2.18E-05	1.00E-10	2.24E-14	1.91E-15	4.18E-18

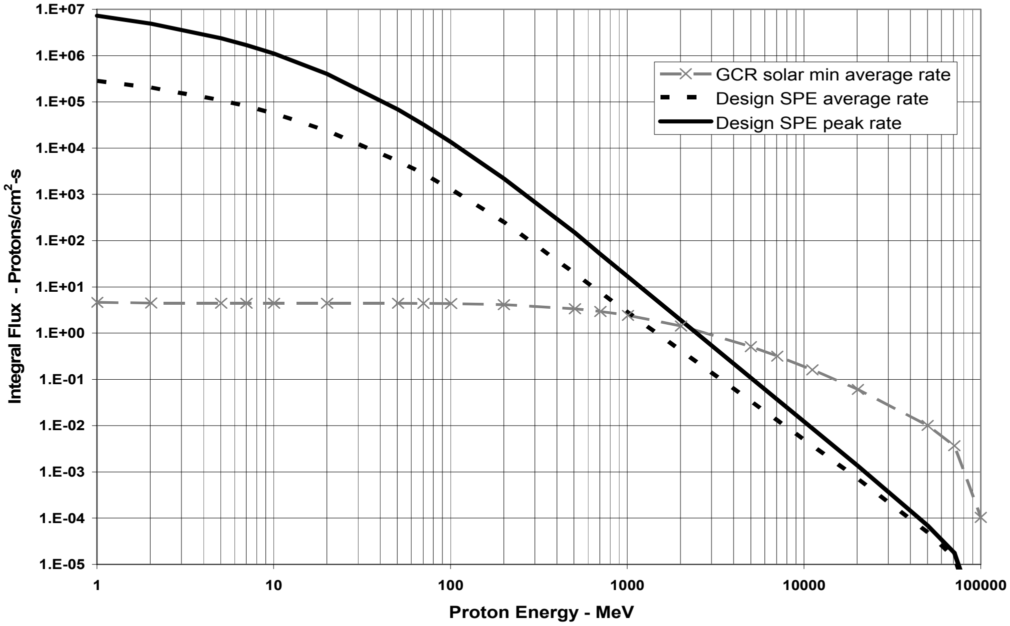

Figure 7 - Integral Proton Flux of a Design SPE and GCR

Table 23 - Integral Proton Flux of a Design SPE and GCR

Proton Energy	GCR In-space (solar min)	Design SPE	Design SPE peak rate
MeV	p+/cm2-s	p+/cm2-s	p+/cm2-s
1.00	4.638E+00	2.839E+05	7.239E+06
2.03	4.491E+00	2.023E+05	4.903E+06
5.04	4.452E+00	1.081E+05	2.373E+06
7.02	4.449E+00	8.055E+04	1.684E+06
10.05	4.447E+00	5.589E+04	1.098E+06
20.03	4.442E+00	2.373E+04	4.011E+05
50.50	4.420E+00	5.272E+03	6.812E+04
70.33	4.396E+00	2.769E+03	3.210E+04
100.69	4.347E+00	1.295E+03	1.339E+04
200.77	4.125E+00	2.527E+02	2.200E+03
506.17	3.358E+00	1.941E+01	1.480E+02
704.94	2.934E+00	7.528E+00	5.094E+01
1009.20	2.418E+00	2.795E+00	1.650E+01
2012.30	1.422E+00	4.159E-01	1.890E+00
5003.80	5.092E-01	3.362E-02	1.081E-01
7065.60	3.175E-01	1.296E-02	3.657E-02
11142.00	1.609E-01	3.680E-03	8.743E-03
20170.00	6.084E-02	7.081E-04	1.349E-03
50153.00	1.007E-02	4.963E-05	6.914E-05
70819.00	3.679E-03	1.405E-05	1.776E-05
100000.00	1.040E-04	3.223E-07	3.772E-07

Table 24 - Differential Proton Flux for a Design SPE and GCR

Proton Energy	GCR Solar Minimum Interplanetary Space	Design SPE Rate (average-180hr event)	Design SPE Peak Rate (Peak 5-minute average)
MeV	protons/cm^2-s-MeV	protons/cm^2-s-MeV	protons/cm^2-s-MeV
1.00	2.542E-01	1.165E+05	3.406E+06
3.02	1.329E-02	3.518E+04	9.489E+05
5.04	2.475E-03	1.787E+04	4.556E+05
7.02	9.831E-04	1.092E+04	2.663E+05
10.05	5.037E-04	6.081E+03	1.399E+05
20.03	4.359E-04	1.657E+03	3.297E+04
30.31	6.237E-04	6.726E+02	1.198E+04
50.50	1.064E-03	1.934E+02	2.925E+03
70.33	1.436E-03	7.942E+01	1.067E+03
100.69	1.857E-03	2.818E+01	3.310E+02
299.59	2.636E-03	7.968E-01	6.818E+00
499.23	2.360E-03	1.213E-01	1.012E+00
704.94	1.963E-03	2.913E-02	2.236E-01
1009.20	1.481E-03	7.555E-03	5.061E-02
3002.80	3.498E-04	1.251E-04	5.540E-04
5003.80	1.333E-04	1.833E-05	6.687E-05
7065.60	6.394E-05	5.007E-06	1.602E-05
10116.00	2.818E-05	1.299E-06	3.626E-06
20170.00	5.191E-06	9.689E-08	2.082E-07
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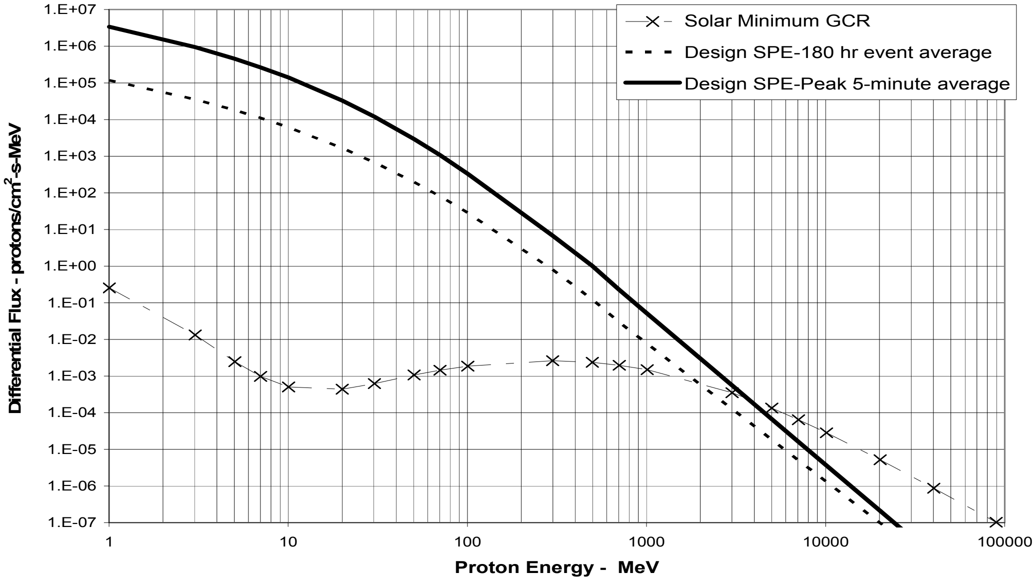


Figure 8 - Differential Proton Flux for Design SPE and Solar Minimum GCR

3.3.3 Cumulative Single Event Effects and Displacement Damage

Description

Integral linear energy transfer (LET) fluence in the In-Space environment outside Earth's magnetic field for selected thickness of spherical aluminum shielding are provided for use in evaluating cumulative single event effect risks for active electronics. Integral proton fluence incident on external surfaces (unshielded) in the same In-Space environment is provided to support evaluation of cumulative displacement damage risk for susceptible parts and materials. One Design SPE is assumed to occur during a DRM, regardless of mission duration; units are particles/event for indicated LET values and number of proton/event for indicated energies. GCR is continuously present; units are particles/day for specified LET values and number of protons/day for specified energies. Daily values **MUST** be multiplied by the assigned number of days of exposure to the In-space environment for the DRM of interest.

NEDD Reference Sections

7.5 Ionizing Radiation (90-2000km)

8.5 Ionizing Radiation (2000km-10R_e)

11.5 Radiation Environment (10-60R_e)

12.3 Ionizing Radiation (Lunar Space)

Design Limits

Figure 9 and Table 25 present GCR LET per day for a Luna DRM at 5 Shielding Depths in spherical Al shielding.

Figure 10 and Table 26 present LET fluence for a Design SPE for a Luna DRM at 5 Shielding Depths in spherical Al shielding.

Figure 11 and Table 27 present integral proton fluence per day for In-Space GCR and integral proton fluence per event for a Design SPE.

Model Inputs

None

Limitations

Probabilities that the Design SPE cumulative LET and proton fluences will not be exceeded are estimated at 97%.

Technical Notes

DRM cumulative In-Space LET and proton fluence specifications are determined by the product of the GCR fluence per day multiplied by the number of exposure days in the maximum duration DRM plus the Design SPE fluence for the same particular shield thickness of interest:

DRM fluence = (GCR fluence/day **x** # of DRM In-Space days) + Design SPE fluence/Event

Where: fluence units (LET/particle or proton energy)

summed values are for the same shield thickness

The radius of spherical shielding is referred to as shielding depth or thickness.

The Design SPE and GCR specifications can be reproduced in more detail using the “near earth/interplanetary” option of the CREME96 FLUX module. Assume Solar Minimum for defining GCR. Use twice the “Worst Week” flare for the Design SPE. The x2 multiplier of the 1989 event is used to simulate a “worst case” SPE exposure at the 97% probability level appropriate for long duration crewed missions included in the Program defined DRM set. The probability is determined by comparison to the GSFC ESP model. Actual SPE exposure may occur as a single SPE or a series of smaller events.

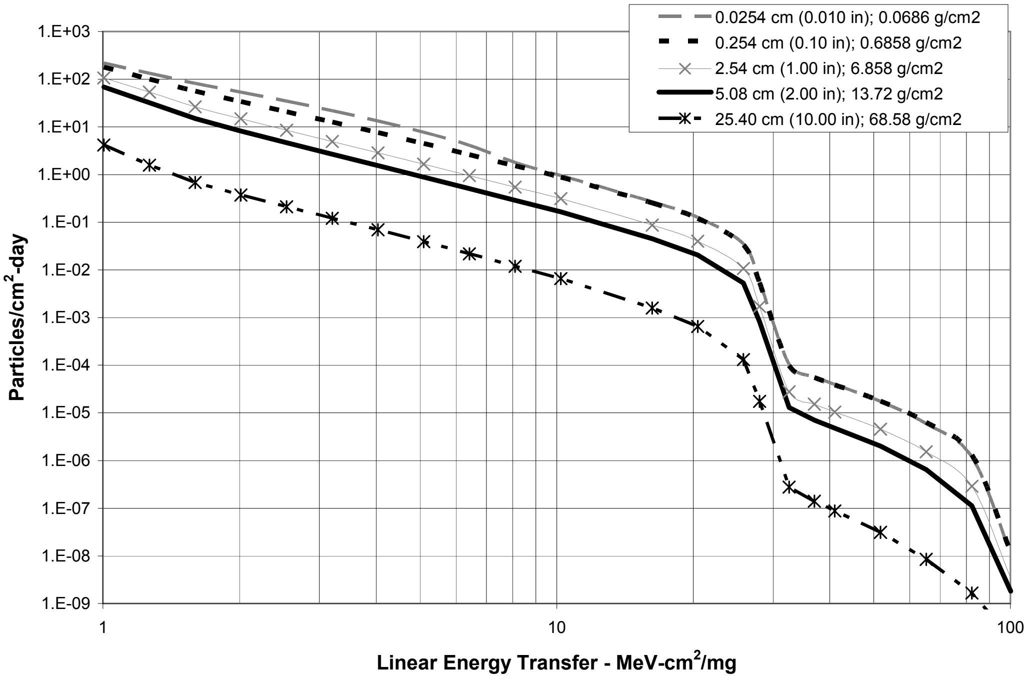


Figure 9 - GCR LET for 1 Day of In-Space Exposure Inside Al Shielding

Table 25 - GCR LET for 1 Day of In-Space Exposure Inside Al Shielding

Particle Linear Energy Transfer (LET)	Al Thickness 0.0254 cm (0.0686 g/cm^2)	Al Thickness 0.254 cm (0.6858 g/cm^2)	Al Thickness 2.54 cm (6.858 g/cm^2)	Al Thickness 5.08 cm (13.72 g/cm^2)	Al Thickness 25.40 cm (68.58 g/cm^2)
MeV-cm^2/mg	particles/cm^2	particles/cm^2	particles/cm^2	particles/cm^2	particles/cm^2
1.00	2.19E+02	1.79E+02	1.07E+02	6.85E+01	4.19E+00
1.27	1.33E+02	1.01E+02	5.35E+01	3.21E+01	1.58E+00
1.60	8.14E+01	5.58E+01	2.64E+01	1.50E+01	6.83E-01
2.01	5.35E+01	3.39E+01	1.48E+01	8.20E+00	3.72E-01
2.54	3.47E+01	2.07E+01	8.47E+00	4.64E+00	2.11E-01
3.20	2.19E+01	1.26E+01	4.91E+00	2.67E+00	1.21E-01
4.04	1.33E+01	7.55E+00	2.86E+00	1.54E+00	6.95E-02
5.09	7.71E+00	4.46E+00	1.65E+00	8.86E-01	3.90E-02
6.42	4.10E+00	2.61E+00	9.50E-01	5.09E-01	2.19E-02
8.09	1.79E+00	1.51E+00	5.43E-01	2.89E-01	1.19E-02
10.21	9.45E-01	8.76E-01	3.11E-01	1.65E-01	6.54E-03
16.23	2.67E-01	2.53E-01	8.70E-02	4.53E-02	1.58E-03
20.47	1.26E-01	1.20E-01	4.00E-02	2.05E-02	6.49E-04
25.81	3.49E-02	3.31E-02	1.07E-02	5.28E-03	1.31E-04
28.00	5.48E-03	5.33E-03	1.71E-03	8.26E-04	1.76E-05
32.55	1.04E-04	9.79E-05	2.78E-05	1.30E-05	2.78E-07
36.98	5.74E-05	5.54E-05	1.53E-05	7.08E-06	1.40E-07
41.05	3.94E-05	3.87E-05	1.04E-05	4.77E-06	8.74E-08
51.76	1.72E-05	1.76E-05	4.53E-06	2.01E-06	3.11E-08
65.28	5.92E-06	6.33E-06	1.53E-06	6.47E-07	8.49E-09
82.32	1.17E-06	1.30E-06	2.89E-07	1.13E-07	1.67E-09
100.25	1.11E-08	1.19E-08	3.43E-09	1.81E-09	1.91E-10

Table 26 – Design SPE LET Fluence Inside Al Shielding for a Luna DRM

Particle Linear Energy Transfer (LET)	Al Thickness 0.0254 cm (0.0686 g/cm^2)	Al Thickness 0.254 cm (0.6858 g/cm^2)	Al Thickness 2.54 cm (6.858 g/cm^2)	Al Thickness 5.08 cm (13.72 g/cm^2)	Al Thickness 25.40 cm (68.58 g/cm^2)
MeV-cm^2/mg	Particles/cm^2	Particles/cm^2	Particles/cm^2	Particles/cm^2	Particles/cm^2
1.00	2.93E+07	4.02E+05	1.73E+03	4.03E+02	4.96E+00
1.27	1.85E+07	2.37E+05	1.20E+03	2.78E+02	2.26E+00
1.60	9.50E+06	1.05E+05	7.30E+02	1.62E+02	1.01E+00
2.01	8.03E+06	7.76E+04	4.92E+02	9.99E+01	5.46E-01
2.54	6.50E+06	5.59E+04	3.16E+02	6.01E+01	3.06E-01
3.20	5.06E+06	3.94E+04	1.96E+02	3.57E+01	1.75E-01
4.04	3.79E+06	2.72E+04	1.19E+02	2.11E+01	1.01E-01
5.09	2.64E+06	1.79E+04	6.98E+01	1.22E+01	5.79E-02
6.42	1.82E+06	1.14E+04	4.05E+01	7.04E+00	3.33E-02
8.09	1.13E+06	6.66E+03	2.29E+01	4.02E+00	1.92E-02
10.21	7.74E+05	3.98E+03	1.33E+01	2.34E+00	1.11E-02
16.23	2.94E+05	1.11E+03	3.85E+00	6.93E-01	3.16E-03
20.47	1.74E+05	5.55E+02	1.89E+00	3.37E-01	1.40E-03
25.81	6.72E+04	1.88E+02	6.10E-01	1.04E-01	3.27E-04
32.55	5.07E+01	1.69E-01	6.78E-04	1.15E-04	3.68E-07
41.05	1.10E+01	4.01E-02	1.72E-04	2.87E-05	8.47E-08
51.76	5.17E+00	1.68E-02	6.81E-05	1.11E-05	2.71E-08
65.28	1.45E+00	4.86E-03	1.82E-05	2.86E-06	6.05E-09
82.32	5.68E-01	1.47E-03	4.72E-06	6.90E-07	1.26E-09
100.25	2.94E-03	7.34E-06	2.54E-08	5.14E-09	1.05E-10

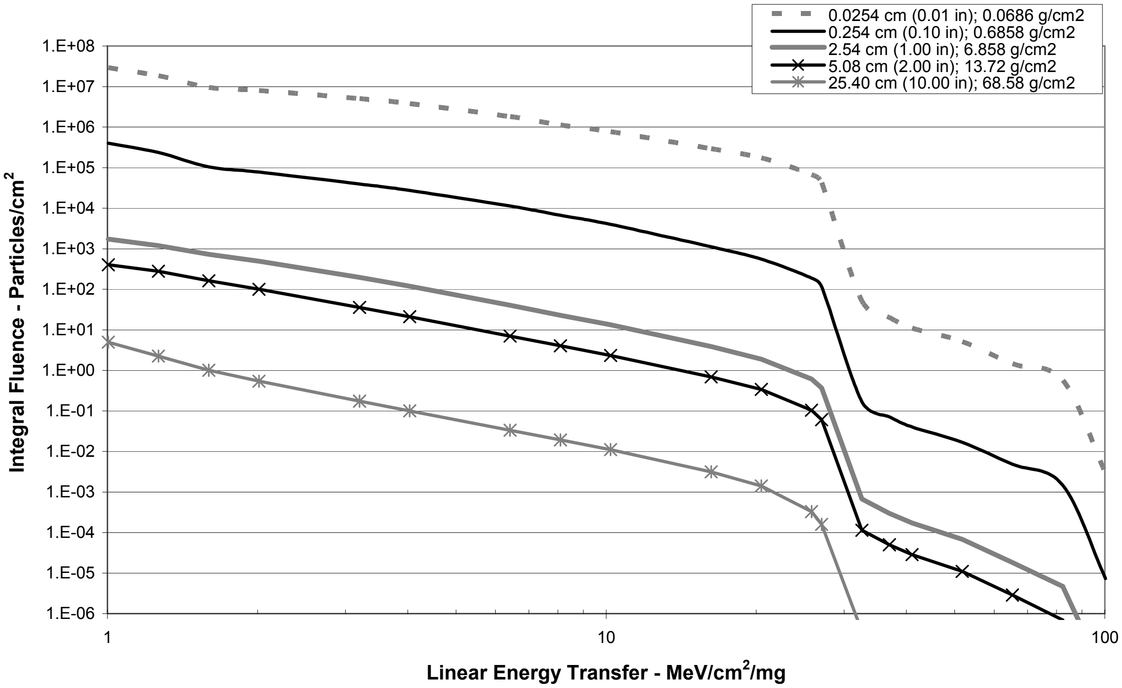


Figure 10 – Design Solar Particle Event Fluence as shown in Table 26

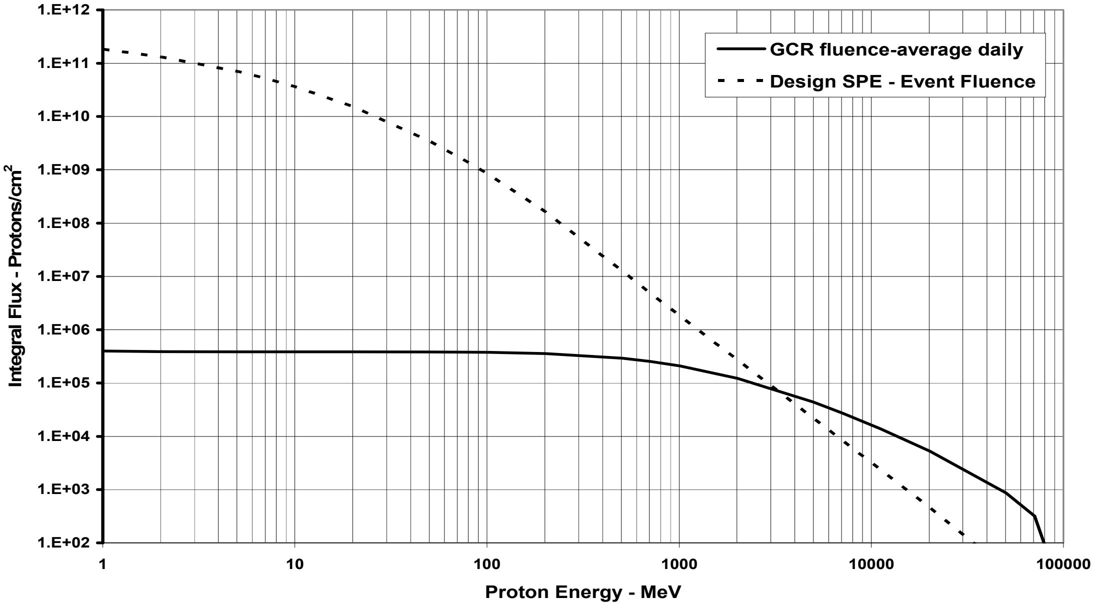


Figure 11- Proton Integral Fluence for a Design SPE and GCR In-Space

Table 27 –Proton Fluence of a Design SPE and 1-Day of In-Space GCR

	GCR - Solar Minimum	Design SPE
Proton Energy	Daily Integral Fluence (protons/cm^2)	Integral Fluence per event (protons/cm^2)
1.00	4.007E+05	1.840E+11
2.03	3.880E+05	1.311E+11
5.04	3.846E+05	7.005E+10
7.02	3.844E+05	5.220E+10
10.05	3.842E+05	3.622E+10
20.03	3.838E+05	1.538E+10
50.50	3.819E+05	3.416E+09
70.33	3.798E+05	1.794E+09
100.69	3.755E+05	8.389E+08
200.77	3.564E+05	1.637E+08
506.17	2.901E+05	1.258E+07
704.94	2.535E+05	4.878E+06
1009.20	2.090E+05	1.811E+06
2012.30	1.229E+05	2.695E+05
5003.80	4.399E+04	2.178E+04
7065.60	2.743E+04	8.399E+03
11142.00	1.390E+04	2.385E+03
20170.00	5.256E+03	4.589E+02
50153.00	8.700E+02	3.216E+01
70819.00	3.179E+02	9.103E+00
100000.00	8.986E+00	2.089E-01

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 Constellation 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 supercedence of the environments specified in Sections 3.3.1 through 3.3.3. Solar Particle Event (SPE), trapped proton, trapped electron, and Galactic Cosmic Ray (GCR) descriptions are established here to be used as design environments for evaluating crew exposures for all Constellation program design analyses.

NEDD Reference Sections

None

Design Limits

Crew radiation exposure design limits and verification requirements are given in Human Systems Integration Requirements (HSIR), CxP 70024, 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 2 to account for effects of the Earth's magnetic field.

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 Constellation program design analyses beyond a maximum McIlwain L value of 12.

Model Inputs

Solar Particle Event Source:

The design reference Solar Particle Event 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 omni-directional proton spectrum is given in the inclusive energy range [0.01, 1000] MeV by the following expressions:

Integral: $J(>E) = J_0 \exp[(30-E)/E_0]$

Differential: $J(E) = (J_0/ E_0) \exp[(30-E)/E_0]$

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 Constellation contractors, if they so choose, as Government Furnished Equipment (GFE).

Galactic Cosmic Rays (GCR) Source:

The design reference GCR (Galactic Cosmic Ray) environment is given by the Badhwar-O'Neill 2004 model by P.M.O'Neill. 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 omni-directional 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 Constellation contractors, if they so choose, as GFE.

Trapped Radiation Sources:

The design reference for trapped particle environments for protons and electrons are given by the AP-8 and AE-8 minimum (Sawyer and Vette, 1976, and Vette, 1991 respectively) using the 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 degrees 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. Trans-lunar 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 Constellation 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.

A technical description of the Low Earth Orbit (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 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 2 less than that in free space.

Table 3.3.4-1 SPE DESIGN EVENT DIFFERENTIAL SPECTRA

Energy (MeV/n)	Free Space Differential Spectrum (particles/(MeV-cm^2)
0.01	9.244E+08
0.03	9.237E+08
0.06	9.227E+08
0.10	9.213E+08
0.30	9.144E+08
0.60	9.041E+08
1.00	8.905E+08
1.50	8.739E+08
2.00	8.575E+08
3.00	8.258E+08
4.00	7.952E+08
6.00	7.374E+08
8.00	6.838E+08
10.00	6.341E+08
14.00	5.453E+08
17.00	4.869E+08
20.00	4.348E+08
25.00	3.600E+08
30.00	2.981E+08
35.00	2.469E+08
40.00	2.044E+08
50.00	1.402E+08
60.00	9.610E+07
70.00	6.589E+07
80.00	4.518E+07
90.00	3.098E+07
100.00	2.124E+07
150.00	3.219E+06
200.00	4.879E+05
250.00	7.395E+04
300.00	1.121E+04
350.00	1.699E+03
400.00	2.574E+02
500.00	5.913E+00
600.00	1.358E-01
700.00	3.120E-03
800.00	7.166E-05
900.00	1.646E-06
1000.00	3.781E-08

Table 3.3.4-2 GCR DESIGN DIFFERENTIAL SPECTRA (SOLAR MINIMUM)

	Free Space Differential Spectrum (#/(MeV-cm^2-day)				
Energy (MeV/n)	P	C	N	O	Fe
0.01	0.168	1.89E-03	2.26E-05	1.74E-03	1.02E-04
0.03	0.168	1.89E-03	2.26E-05	1.74E-03	1.02E-04
0.06	0.168	1.89E-03	2.26E-05	1.74E-03	1.02E-04
0.13	0.212	2.40E-03	4.20E-05	2.21E-03	1.32E-04
0.23	0.354	3.94E-03	1.38E-04	3.64E-03	2.26E-04
0.37	0.549	5.99E-03	3.44E-04	5.52E-03	3.47E-04
0.55	0.817	8.71E-03	7.32E-04	8.01E-03	5.08E-04
0.81	1.189	0.013	1.42E-03	1.15E-02	7.26E-04
1.16	1.708	0.018	2.57E-03	1.63E-02	1.03E-03
1.64	2.426	0.025	4.40E-03	2.30E-02	1.45E-03
2.30	3.420	0.035	7.18E-03	3.22E-02	2.02E-03
3.22	4.801	0.049	1.12E-02	4.50E-02	2.82E-03
4.48	6.706	0.069	1.69E-02	6.27E-02	3.93E-03
6.22	9.338	0.096	2.46E-02	8.72E-02	5.45E-03
8.61	12.951	0.133	3.46E-02	0.120601	7.53E-03
11.91	17.956	0.183	4.76E-02	0.166589	1.04E-02
13.03	19.660	0.200	5.18E-02	0.182143	1.14E-02
14.26	21.517	0.219	5.62E-02	0.199043	1.24E-02
15.59	23.543	0.239	6.09E-02	0.217392	1.36E-02
17.03	25.718	0.261	6.59E-02	0.236987	1.48E-02
18.62	28.134	0.285	7.12E-02	0.258632	1.62E-02
20.36	30.769	0.310	7.69E-02	0.282072	1.76E-02
22.25	33.636	0.338	8.28E-02	0.307379	1.92E-02
24.33	36.765	0.368	8.92E-02	0.334734	2.09E-02
26.59	40.178	0.401	9.59E-02	0.364246	2.28E-02
29.07	43.897	0.436	0.103065	0.396016	2.48E-02
31.78	47.951	0.474	0.110625	0.430143	2.70E-02
34.75	52.363	0.514	0.118615	0.466664	2.93E-02
37.99	57.158	0.557	0.127045	0.505601	3.18E-02
41.53	62.364	0.602	0.135923	0.546956	3.45E-02
45.40	68.005	0.651	0.145247	0.590662	3.73E-02
49.62	74.105	0.701	0.155012	0.636618	4.03E-02
54.24	80.677	0.754	0.165186	0.684581	4.35E-02
59.29	87.769	0.809	0.175791	0.734536	4.68E-02
64.83	95.398	0.866	0.186781	0.786167	5.02E-02
70.91	103.606	0.925	0.198142	0.83928	5.38E-02
77.62	112.424	0.985	0.209833	0.893525	5.76E-02
84.93	121.769	1.045	0.221652	0.94784	6.14E-02
92.93	131.636	1.104	0.233496	1.001645	6.52E-02
101.67	142.006	1.162	0.245243	1.05426	6.91E-02

Table 3.3.4-2 GCR DESIGN DIFFERENTIAL SPECTRA (SOLAR MINIMUM) (Concluded)

	Free Space Differential Spectrum (#/(MeV-cm^2-day)				
Energy (MeV/n)	P	C	N	O	Fe
111.30	152.908	1.218	0.257	1.105	7.29E-02
121.91	164.260	1.271	0.268	1.153	7.66E-02
133.59	175.964	1.321	0.279	1.198	8.02E-02
146.46	187.901	1.364	0.288	1.237	8.35E-02
160.61	199.872	1.401	0.297	1.271	8.64E-02
176.14	211.664	1.431	0.304	1.297	8.89E-02
193.35	223.188	1.451	0.310	1.315	9.08E-02
212.40	234.153	1.461	0.314	1.324	9.22E-02
233.50	244.267	1.459	0.316	1.323	9.27E-02
256.79	253.180	1.444	0.315	1.309	9.25E-02
282.74	260.628	1.416	0.312	1.283	9.14E-02
311.58	266.282	1.373	0.306	1.244	8.94E-02
343.46	269.895	1.317	0.298	1.193	8.67E-02
379.24	271.317	1.247	0.287	1.130	8.32E-02
419.35	270.361	1.166	0.273	1.057	7.90E-02
464.39	266.941	1.077	0.257	0.976	7.43E-02
514.90	261.065	0.984	0.240	0.891	6.92E-02
571.55	252.814	0.891	0.221	0.805	6.39E-02
635.50	242.252	0.798	0.202	0.720	5.84E-02
707.95	229.516	0.705	0.182	0.637	5.27E-02
790.30	214.806	0.614	0.162	0.558	4.71E-02
883.74	198.443	0.529	0.143	0.483	4.15E-02
991.34	180.534	0.451	0.124	0.414	3.62E-02
1114.78	161.600	0.382	0.107	0.349	3.11E-02
1256.49	142.228	0.320	9.04E-02	0.292	2.65E-02
1418.86	123.069	0.265	7.57E-02	0.241	2.23E-02
1608.53	104.400	0.215	6.23E-02	0.196	1.85E-02
1829.20	86.986	0.171	5.05E-02	0.157	1.52E-02
2086.76	71.267	0.134	4.02E-02	0.124	1.22E-02
2388.20	57.399	0.104	3.14E-02	9.64E-02	9.58E-03
2741.57	45.380	7.94E-02	2.41E-02	7.38E-02	7.37E-03
7575.78	5.939	8.12E-03	2.44E-03	7.85E-03	8.90E-04
12554.78	1.835	2.18E-03	6.42E-04	2.24E-03	2.76E-04
17687.42	0.787	8.85E-04	2.46E-04	9.23E-04	1.19E-04
22870.16	0.412	4.43E-04	1.16E-04	4.63E-04	6.22E-05
28131.87	0.243	2.52E-04	6.23E-05	2.63E-04	3.63E-05
33480.56	0.155	1.57E-04	3.66E-05	1.63E-04	2.31E-05
38911.09	0.104	1.05E-04	2.30E-05	1.10E-04	1.58E-05
44418.88	0.074	7.47E-05	1.52E-05	7.80E-05	1.14E-05
50000.00	0.054	5.53E-05	1.04E-05	5.77E-05	8.52E-06

3.3.5 Plasma and Spacecraft Charging Environments

Description

Specifies the space plasma environment that can cause spacecraft charging which, in turn, can lead to a variety of failure mechanisms. Spacecraft charging can impact power system and avionic system design and material selection.

NEDD Reference Sections

7.4	Plasma Environment (90-2000km)
8.4	Plasma Environment (2000km-10R_e)
11.4	Solar Wind (Plasma Environment) (10-60R_e)
12.2	Plasma (Lunar Space)

Design Limits

Table 28 and 29 provide ambient plasmas in Low Earth Orbit (LEO) space at day and night respectively at 350-600 km altitude in 3 latitude zones (10-30, 30-50, and 50-70 degree inclination) for current collection through vehicle conducting surface area such as solar arrays. Solar arrays operating in the relatively dense plasmas in low Earth orbit will experience a current drain on the power system, as a result of losses through coupling to the plasma. Density (Ne,#/m^3), and temperature (Te,eV) values are placed in latitude bins based on the absolute value of the spacecraft latitude (i.e., southern and northern hemisphere data from equivalent latitudes are grouped into a single latitude range). Within each latitude range the percentile Ne, Te values are computed by sorting the data into monotonically increasing order and identifying the data value that corresponds to 1% up to 99% of the Ne, Te values. The 1% and 99% are the design limits.

Table 30 provides worst case spacecraft surface charging environment with high energetic plasma extremes impinging into the isolated (dielectric) materials for the spacecraft charging design consideration in Geosynchronous Orbit (GEO)

Figure 12 and Table 31 specifies the electron integral flux environment for use in analyses of bulk (internal) charging of insulating materials and isolated conductors. 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. Analysis of discharge events on spacecraft in geostationary or geostationary transfer orbits have 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 the temperature of the dielectric is importance 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.

Model Inputs

None

Limitations

In general spacecraft charging is more serious in GEO space than in LEO and in cis-lunar space.

For plasma emissions, ionospheric scintillation effects assessment, plasma variations including plasma depletion in space, the plasma turbulence and solar activities must be included in the spacecraft design. Additional limitations and environmental sensitivities may arise from special hardware selections.

Technical Notes

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 Low Earth Orbit (LEO). Examples of plasma interaction effects with space vehicle are solar array/power system degradation, contamination, ionospheric scintillation, and spacecraft charging. Details of the plasma effects are provided in the NEDD.

Table 28 - Day Time Ambient Plasma At 350 - 600 Km Altitude In Three Latitude Zones (10-30, 30-50, and 50 -70 degree)

(A) Plasma Environment – Day			
Lat. Range		1%	99%
10 to 30	Ne (m^{-3})	1.62E+10	2.57E+12
	Te (eV)	0.082	0.537
30 to 50	Ne	2.10E+10	2.71E+12
	Te	0.086	0.574
50 to 70	Ne	9.20E+09	2.65E+12
	Te	0.074	0.558

Table 29 - Night Time Ambient Plasma At 350 - 600 Km Altitude In Three Latitude Zones (10-30, 30-50, and 50 -70 degree)

(B) Plasma Environment – Night			
Lat. Range		1%	99%
10 to 30	Ne	3.40E+09	1.70E+12
	Te	0.057	0.416
30 to 50	Ne	9.69E+09	3.05E+12
	Te	0.065	0.533
50 to 70	Ne	5.18E+09	2.77E+12
	Te	0.06	0.516

Table 30 - Geosynchronous Orbit Plasma Parameters

	SCATHA "Worst Case" Environment [b]	
Parameter	**Electrons**	**Ions**
Number density (#/cm^3)	3.00	3.00
Current density (nA/cm^2)	0.501	0.016
Number density, population 1 (#/cm^3)		
Parallel	1	1.1
Perpendicular	0.8	0.9
Temperature, population 1 (eV)		
Parallel	600	400
Perpendicular	600	300
Number density, population 2 (#/cm^{-3})		
Parallel	1.40	1.70
Perpendicular	1.90	1.60
Temperature, population 2 (eV)		
Parallel	25100	24700
Perpendicular	26100	25600

[a] Adapted from Purvis et al., 1984.
[b] SCATHA "worst case" from Purvis et al., 1984.

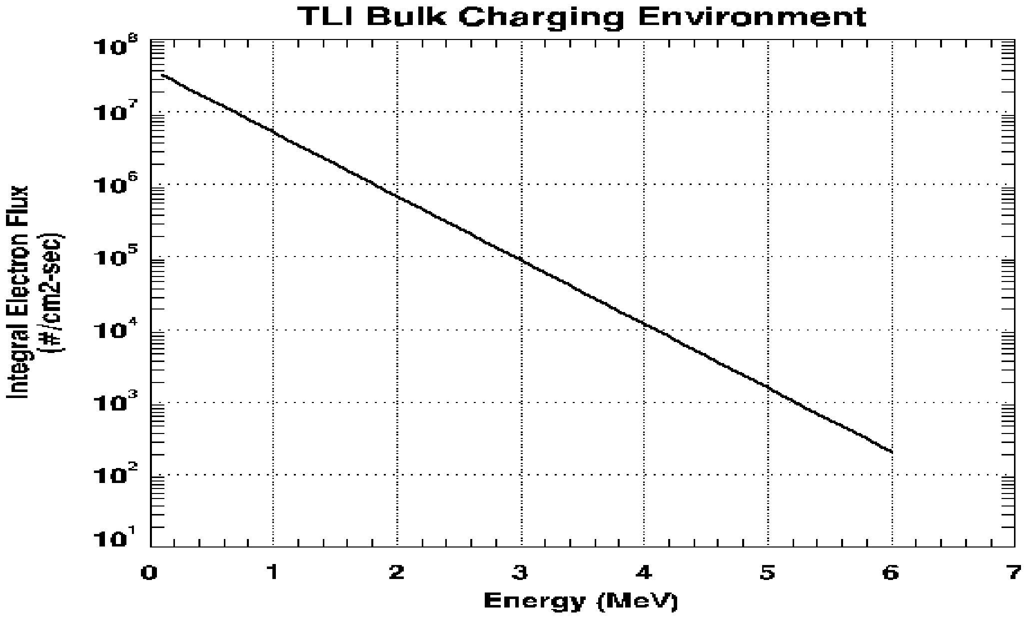


Figure 12 – Trans-lunar Injection (TLI) Trajectory Average Integral Electron Flux.

Table 31. Trans-lunar Injection Bulk Charging Environment

Energy (MeV)	Integral Flux (electrons/cm2-sec)
0.1	3.27E+07
0.2	2.67E+07
0.4	1.78E+07
0.6	1.18E+07
0.8	7.88E+06
1	5.25E+06
1.2	3.50E+06
1.4	2.33E+06
1.6	1.55E+06
1.8	1.04E+06
2	6.90E+05
2.2	4.60E+05
2.4	3.06E+05
2.6	2.04E+05
2.8	1.36E+05
3	9.06E+04
3.2	6.04E+04
3.4	4.02E+04
3.6	2.68E+04
3.8	1.79E+04
4	1.19E+04
4.2	7.93E+03
4.4	5.28E+03
4.6	3.52E+03
4.8	2.35E+03
5	1.56E+03
5.2	1.04E+03
5.4	6.94E+02
5.6	4.62E+02
5.8	3.08E+02
6	2.05E+02

3.3.6 Meteoroid and Orbital Debris Environment

Description

This section specifies the orbital debris and meteoroid environments which pose an impact threat during in-space operations. Orbital debris is only of concern in Earth orbit and especially for a mission docked to Space Station. Meteoroids must be considered a threat during both Earth orbit and lunar 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. Mass, size, velocity, and density are used to compute penetrations and effectiveness of shielding.

NEDD Reference Sections

7.6 Meteoroid and Orbital Debris Environments (90-2000km)

8.6 Meteoroid and Orbital Debris Environments (2000km-10R_e)

11.6 Meteoroid Environment (10-60R_e)

12.4 Meteoroid Environment (Lunar Space)

Design Limits

<u>Low Earth Orbit Mission Phase:</u>

Detailed flux, speed, and directionality limits in the orbital debris and meteoroid environments are to be derived using precise inputs for the environment models, specifically the design reference mission parameters. For the orbital debris environment ORDEM 2000 will be used. The meteoroid environment is defined by the Meteoroid Engineering Model (MEM).

Figure 13 illustrates possible extremes, with respect to direction, for each surface of a cubical spacecraft in the meteoroid environment over one low Earth orbit of a mission.

The current reference mission parameters lack specific information i.e., specific state vectors or two line element sets (TLEs), required by MEM to give one exact environment definition. Therefore, the variety of orbit plane orientations likely to occur during the design reference mission durations, i.e., a 6 month mission, must be evaluated to cover the extremes in the directionality. The meteoroid environment is especially sensitive to the orbit plane's orientation relative to the Sun. The highest flux rates occur when the orbit plane is closest to the ecliptic plane. The extremes for surface orientation displayed are, for example, orbits with a right ascension of ascending node (RAAN) of 180° and 0° during the summer solstice and the vernal equinox of 2020 (an example year). For each surface, the figure displays the cumulative total flux over one orbit calculated in one minute time steps. Please see MEM's documentation for a detailed description of the cube attitude.

Lunar Mission Phase:

Use the design reference mission parameters and mission durations to determine the flux on various surfaces for a spacecraft orbiting the Earth with the Moon's state vectors input into MEM.

Model Inputs

Low Earth Orbit (LEO) Mission Phase:

Use the design reference mission parameters and mission durations as inputs into ORDEM2000 to calculate the debris flux, speed, and directionality. Orbital debris calculations for the LEO phase will be done for the years 2014 to 2020. Additional information is required for input into MEM since the model requires a series of state vectors along an orbit or a Two Line Element set (TLE) to generate an orbit in order to define the meteoroid environment. Orbital altitude and inclination are defined by the CEV to ISS IRD. The orbit orientation angles (Right Ascension of Ascending Node or RAAN, argument of perigee and true or mean anomaly), are required to define a TLE or state vector. In the case of a simple circular orbit, the argument of perigee may be set to zero and the mean anomalies may be chosen at some regular angular interval, leaving RAAN as the deciding factor in the flux variations. Mission durations and time of year should be chosen to cover the extremes of the directional meteoroid flux, and varying the RAANs, or orbit planes.

Lunar Mission Phase:

Use state vectors of the Moon as seen from Earth as inputs into MEM to determine the meteoroid flux at the Moon where Earth focusing is negligible. The Moon's shielding can be approximated by the following equation:

$$\text{Shielding factor} = sf = (1+\cos\eta)/2$$

Where

$$\eta = \text{asin}\,[R_M / (R_M+H)]$$

where R_M is the radius of the moon and H is the height above the Moon's surface.

Limitations

Low Earth Orbit Mission Phase:

There are no uncertainty values, maximums or minimums associated with the orbital debris or meteoroid environments; the models give only expected values. In addition, the orbital debris model ORDEM2000 only models the environment up to 2000 km altitude. MEM only models mass ranges from 10^{-6} grams to 10 grams: those particles considered a threat to spacecraft.

Lunar Mission Phase:

MEM cannot yet model Moon-orbiting spacecraft. TLEs cannot be used to describe the Moon's orbital elements.

Technical Notes

For all Phases:

As a side note, meteor showers are included in an average sense in the overall flux values from MEM. See the NEDD for specific details.

Tentative Transition Plan:

Since it will take several months (estimated delivery date of April 2007, depending on availability of requested resources) to mesh the new meteoroid environment (MEM) into the MMOD risk analysis tool BUMPER, an average meteroid environment for the International Space Station (ISS) orbit (altitude of 400 km, inclination of 51.6 degrees) has been generated to permit realistic assessments for CEV space station missions. This environment, consisting of fluxes, the 1 sigma variabilities in these fluxes, and the average velocities as function of direction from the spacecraft velocity vector, must be read into BUMPER in order for the assessments to be performed. This environment is being distributed by the Hypervelocity Impact Test Facility group at JSC-KX along with the risk assessment tool, BUMPER. Please note that this environment is suitable for the ISS orbit only; environments for other orbits, such as lunar, will have to wait until the meshing of MEM with BUMPER is complete. Also note that this also has an unfortunate consequence in that MMOD assessments will have to be repeated because the myriad of ballistic limit equations and design variables preclude applying simple environment scaling factors to the BUMPER PNPs.

Low Earth Mission Phase:

The debris environment is directional. The meteoroid environment is also directional, but unlike the debris environment, which is fixed with regard to a vehicle reference frame, the meteoroid environment is fixed relative to the Sun. This means that the 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 design reference mission parameters and mission durations.

Lunar Mission Phase:

The Moon has an inclination of 5º relative to the ecliptic plane and the orbit's orientation relative to the Sun changes slowly so the variation in the meteoroid flux is small over a 6 month timescale. To first order, lunar gravitational focusing can be ignored since the Moon's mass is 1/81th that of Earth's, implying an enhancement of a couple of percent over the interplanetary meteoroid flux.

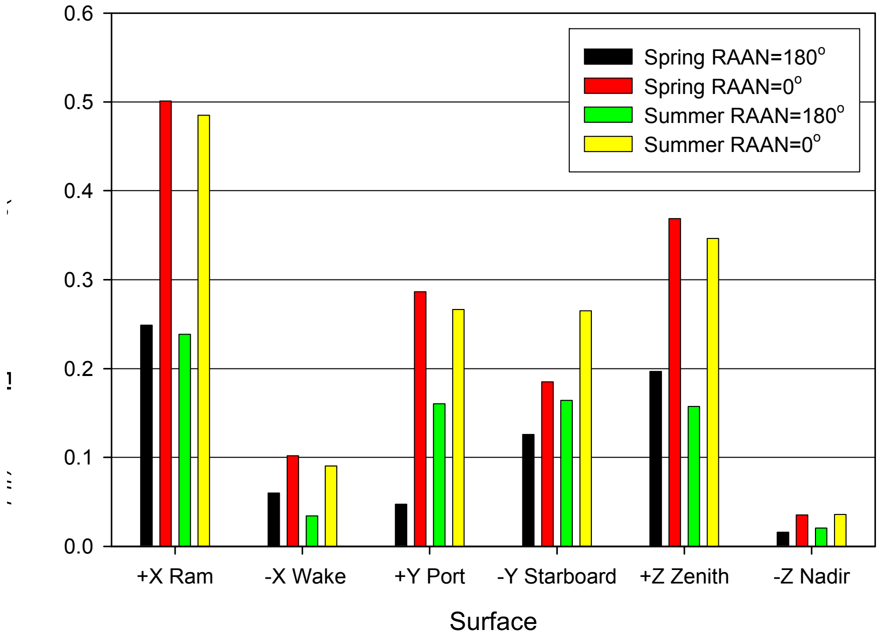


Figure 13 - Cumulative Surface Fluence for a limiting mass of 10-6 g over one orbit at 51.6º inclination, 450 km altitude, year 2020 with different RAANs. This figure is for illustration only.

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 (e.g. propulsion, telecom, and GN&C hardware) to truncate an Earth gravity field to approximately degree and order 8. In fact, assuming a simple central body, inverse square force field is often adequate. 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 and the Navigation Standards Specification Document for model-specific information.

NEDD Reference Sections

7.7 Gravitational Field

8.7 Gravitational Field

Design Limits

Earth Gravity model, GRACE (Gravity Recovery and Climate Experiment) 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. Trajectory and navigation-related model information to be used in the design of reference trajectories and in the development of baseline operational navigation strategies is specified in CxP 70142, Navigation Standards Specification Document.

Model Inputs

See Navigation Standards Specification Document (CxP 70142).

(The Navigation Standards Specification Document will generated and baselined prior to the SDR).

The gravity field is available on-line at the following website: 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 Recovery and Climate Experiment) gravity model GGM02C is a 200th spherical harmonic degree and order model that combines approximately a 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

Detailed gravity models are derived from collecting tracking data from orbiting spacecraft. For the Earth there are, of course, many satellites and extensive data sets. For the Moon, however, this is not the case. Suitable data are currently only available from the Lunar Orbiter missions (I-V), the Apollo 15 and 16 sub-satellites, Clementine, and Lunar Prospector.

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. The use of truncated lower models, even for design, is not appropriate without extensive error and sensitivity analysis. The reader is referred to the NEDD for general gravity field formulation information and the Navigation Standards Specification Document for model-specific information.

NEDD Reference Sections

12.5 Lunar Gravitational Field

Design Limits

Lunar Gravity Model LP150Q Is needed for precise orbit determination. Trajectory and navigation-related model information to be used in the design of reference trajectories and in the development of baseline operational navigation strategies is specified in CxP 70142, Navigation Standards Specification Document. Adequate sensitivity analysis is needed to assure the design will cover the range of Design References Mission's (DRM) as specified in CXP 70142.

Model Inputs

It is important that lunar models not be simply truncated to fewer terms for applications requiring lower fidelity. A lower order model must be generated by fitting a complete dataset with fewer terms.

The Navigation Standards Specification Document, CxP70142, will be generated and baselined prior to the SDR.

The gravity field is available on-line at the following website: *http://pds-geosciences.wustl.edu/geodata/lp-l-rss-5-gravity-v1/lp_1001/sha/* .

Limitations

The data obtained from the above mentioned spacecraft are limited in two important aspects: 1) orbit inclinations are limited to low inclination (less than 30 degrees) and polar inclinations, and 2) no direct tracking data are available from the lunar far-side passages. As a result expected errors in the geoid reach 30 meters on the far-side and orbit propagation errors will be greatest for the 40 to 70 and 130 to 160 degree inclination ranges. The situation cannot be improved until additional data from new missions becomes available.

Technical Notes

The LP150Q gravity model is a 150th spherical harmonic degree and order model that was developed using all available data from past U.S. missions to the Moon including the Lunar Orbiter missions, the Apollo 15 and Apollo 16 sub-satellites, Clementine, and all of the Lunar Prospector Doppler and range data. The model was released in February 2005.

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 (e.g. 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.

Errors intrinsic in the gravity model are predominately due to data limitations. Thus, resulting errors in orbit propagation are very dependent on the orbit being considered.

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 longwave radiation. In addition to the environmental parameters, spacecraft temperatures are dependent on internal sources of thermal energy and the spacecraft geometric configuration.

NEDD Reference Sections

7.2 Thermal Environment (90-2000km)

8.2 Thermal Environment (2000km-10R_e)

11.2 Thermal Environment (10-60R_e)

12.1 Thermal Environment (Lunar Space)

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.

Space sink temperature: 3 K

Orbital beta angle: 0 to 90 degrees

Orbital altitude: 90km to 400km (circular)

<u>Maximum:</u> Solar constant: Earth-Sun: 1422 W/m^2

Lunar-Sun: 1426 W/m^2

Albedo per the NEDD Section 12.1.2

Lunar longwave radiance per the NEDD Section 12.1.3

<u>Minimum:</u> Solar constant: Earth-Sun: 1315 W/m^2

Lunar-Sun: 1310 W/m^2

Albedo per the NEDD Section 12.1.2

Lunar longwave radiance per the NEDD Section 12.1.3

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 degrees (lunar missions)
0 to 75 degrees (ISS missions)
Orbital altitude: 296 ± 10 km (lunar rendezvous)
350 km to 460 km (ISS mission, low case)

Maximum: Solar constant: 1414 W/m^2

Albedo, longwave radiance pairs per the hot cases, Table 32 (lunar missions) or Table 33 (ISS missions)

Minimum: Solar constant: 1322 W/m^2

Albedo, longwave radiance pairs per the cold cases, Table 32 (lunar missions) or Table 33 (ISS missions)

Model Inputs

Solar zenith angle corrections must be applied to the albedo values from Tables 32 and 33 per NEDD Section 7.2. Note also that the table values are referenced to the top of the atmosphere.

Limitations

None

Technical Notes

None

Table 32 - Albedo, OLR Pairs for Critical Systems in Low Inclination Orbits. Albedo and OLR values are referenced to the "top of the atmosphere," RE + 30 km

	COLD CASES		
Averaging Time	Minimum Albedo Alb ⇔ OLR (W/m^2)	Combined Minimum Alb ⇔ OLR (W/m^2)	Minimum OLRAlb ⇔ OLR (W/m^2)
16 second	0.06 ⇔ 273	0.13 ⇔ 225	0.40 ⇔ 150
128 second	0.06 ⇔ 273	0.13 ⇔ 226	0.38 ⇔ 154
896 second	0.07 ⇔ 265	0.14 ⇔ 227	0.33 ⇔ 173
30 minute	0.08 ⇔ 261	0.14 ⇔ 228	0.30 ⇔ 188
90 minute	0.11 ⇔ 258	0.14 ⇔ 228	0.25 ⇔ 206
6 hour	0.14 ⇔ 245	0.16 ⇔ 232	0.19 ⇔ 224
24 hour	0.16 ⇔ 240	0.16 ⇔ 235	0.18 ⇔ 230
	HOT CASES		
Averaging Time	Maximum Albedo Alb ⇔ OLR (W/m^2)	Combined Maximum Alb ⇔ OLR (W/m^2)	Maximum OLR Alb ⇔ OLR (W/m^2)
16 second	0.43 ⇔ 182	0.30 ⇔ 298	0.22 ⇔ 331
128 second	0.42 ⇔ 181	0.29 ⇔ 295	0.22 ⇔ 326
896 second	0.37 ⇔ 219	0.28 ⇔ 291	0.22 ⇔ 318
30 minute	0.33 ⇔ 219	0.26 ⇔ 284	0.17 ⇔ 297
90 minute	0.28 ⇔ 237	0.24 ⇔ 275	0.20 ⇔ 285
6 hour	0.23 ⇔ 248	0.21 ⇔ 264	0.19 ⇔ 269
24 hour	0.22 ⇔ 251	0.20 ⇔ 260	0.19 ⇔ 262
Mean Albedo: 0.18		Mean OLR: 246	

Table 33 - Albedo, OLR Pairs for Critical Systems in Medium Inclination Orbits. Albedo and OLR values are referenced to the "top of the atmosphere," RE + 30 km

	COLD CASES		
Averaging Time	Minimum Albedo Alb ⇔ OLR (W/m^2)	Combined Minimum Alb ⇔ OLR (W/m^2)	Minimum OLR Alb ⇔ OLR (W/m^2)
16 second	0.06 ⇔ 273	0.15 ⇔ 213	0.40 ⇔ 151
128 second	0.06 ⇔ 273	0.15 ⇔ 213	0.38 ⇔ 155
896 second	0.08 ⇔ 262	0.17 ⇔ 217	0.34 ⇔ 163
30 minute	0.12 ⇔ 246	0.18 ⇔ 217	0.27 ⇔ 176
90 minute	0.16 ⇔ 239	0.19 ⇔ 218	0.30 ⇔ 200
6 hour	0.18 ⇔ 238	0.19 ⇔ 221	0.31 ⇔ 207
24 hour	0.19 ⇔ 233	0.20 ⇔ 223	0.25 ⇔ 210
	HOT CASES		
Averaging Time	Maximum Albedo Alb ⇔ OLR (W/m^2)	Combined Maximum Alb ⇔ OLR (W/m^2)	Maximum OLR Alb ⇔ OLR (W/m^2)
16 second	0.48 ⇔ 180	0.31 ⇔ 267	0.21 ⇔ 332
128 second	0.47 ⇔ 180	0.30 ⇔ 265	0.22 ⇔ 331
896 second	0.36 ⇔ 192	0.28 ⇔ 258	0.22 ⇔ 297
30 minute	0.34 ⇔ 205	0.28 ⇔ 261	0.21 ⇔ 282
90 minute	0.31 ⇔ 204	0.26 ⇔ 257	0.22 ⇔ 274
6 hour	0.31 ⇔ 212	0.24 ⇔ 248	0.21 ⇔ 249
24 hour	0.28 ⇔ 224	0.24 ⇔ 247	0.21 ⇔ 245
Mean Albedo: 0.22		Mean OLR: 234	

3.3.10 Solar Illumination Environment for In-space Hardware

Description

Describes the solar spectrum including ultraviolet radiation which can cause deterioration of materials.

NEDD Reference Sections

Section 7.2.1.2 Solar Irradiance

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 34.

Model Inputs

None

Limitations

None

Technical Notes

None.

Table 34 - Solar Spectral Irradiance – Standard Curve, Abridged version

λ = wavelength, μm;
E_λ = solar spectral irradiance averaged over small bandwidth centered at λ, $W \cdot m^{-2} m^{-1}$; and
$D_{0\lambda}$ = percentage of the solar constant (1366.1 $W \cdot m^{-2}$) associated with wavelengths shorter than λ

Note 1 – Double lines indicate change in wavelength interval of integration. Each column continues to next page.

λ	E_λ	$D_{0\lambda}$	λ	E_λ	$D_{0\lambda}$
0.14	9.833×10^{-2}	0.0	0.57	1797	31.39
0.16	0.3195	3.1×10^{-4}	0.58	1801	32.71
0.18	2.042	2.0×10^{-3}	0.59	1758	34.01
0.20	10.83	1.1×10^{-2}	0.60	1745	35.29
0.22	44.93	5.2×10^{-2}	0.62	1663	37.78
0.23	49.64	8.7×10^{-2}	0.64	1610	40.18
0.24	51.83	0.12	0.66	1527	42.48
0.25	59.81	0.16	0.68	1485	44.68
0.26	129.1	0.23	0.70	1438	46.82
0.27	222.1	0.36	0.72	1360	48.87
0.28	212.9	0.52	0.75	1272	51.76
0.29	441.0	0.76	0.8	1132	56.16
0.30	526.0	1.12	0.9	882.6	63.53
0.31	634.5	1.54	1.0	719.7	69.40
0.32	746.5	2.05	1.2	487.1	78.23
0.33	948.7	2.67	1.4	342.5	84.30
0.34	947.3	3.36	1.6	243.5	88.59
0.35	969.5	4.06	1.8	167.1	91.60
0.36	985.2	4.78	2.0	115.0	93.66
0.37	1129	5.55	2.2	81.73	95.10
0.38	1091	6.36	2.4	58.78	96.13
0.39	1093	7.16	2.6	43.86	96.88
0.40	1518	8.12	2.8	33.43	97.45
0.41	1712	9.30	3.0	25.93	97.88
0.42	1740	10.56	3.2	20.45	98.22
0.43	1625	11.79	3.4	16.36	98.49
0.44	1826	13.06	3.6	13.26	98.71
0.45	2030	14.47	3.8	10.87	98.89
0.46	2077	15.97	4.0	8.977	99.03
0.47	2049	17.48	4.5	5.674	99.30
0.48	2057	18.98	5	3.691	99.47
0.49	1955	20.45	6	1.879	99.68
0.50	1948	21.88	7	1.022	99.78
0.51	1911	23.29	8	0.6041	99.84
0.52	1806	24.65	10	0.2663	99.90
0.53	1861	26.00	15	6.106×10^{-2}	99.96
0.54	1861	27.36	20	1.755×10^{-2}	99.98
0.55	1867	28.72	50	1.769×10^{-3}	100.00
0.56	1808	30.07			

3.3.11 In-Space Neutral Atmosphere (Thermosphere) Density

Description

The in-space atmosphere begins at about 90 km altitude and extends to approximately 2000 km. Atomic oxygen in the thermosphere drives selection of external materials. Atmospheric density and its variations are critical to the design of the entry thermal protection systems and entry guidance systems. Ascent environments are assumed to be considered as part of the integrated launch system analysis and are not included here.

NEDD Reference Sections

7.1 Thermosphere (90 km – 2000 km)
7.1.4 Solar and Geomagnetic Indices.

Design Limits

Atomic Oxygen:

Nominal: 5.0 x 10^{21} oxygen atoms/cm^2 – year to exposed ram surfaces for ISS missions.

Maximum short term: 4.4 x 10^{19} oxygen atoms/cm^2 – day

Model Inputs

System performance will be evaluated through analysis of 1000 or more GRAM-99 (includes Marshall Engineering Thermosphere) random profiles for each of the 3 cases in Table 35

Limitations

Although uncertainties are not specifically determined for the GRAM-99 model it is generally accepted that the thermospheric density is modeled to within no better than 15% accuracy (1 standard deviation) by the Marshall Engineering Thermosphere and similar models (e.g. the Mass Spectrometer Incoherent Scatter model). Perturbations on the aloft region are statistically derived and are generated using the input variables in Table 35

Technical Notes

Hardware configuration, orientation relative to ram (velocity vector) direction, and exposure time must be considered. The annual atomic oxygen fluence was adopted from the International Space Station U.S. Laboratory End-Item Specification. It was calculated using nominal ISS trajectory and the Mass Spectrometer Incoherent Scatter

(MSIS-86) model baselined for the ISS Program for atmospheric constituent calculations. A description of the calculations is available in Boeder (1995).

The F10.7 and Ap values were taken from 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 Hickey and Smith, 1992.

Table 35 - GRAM-99 Inputs for Thermosphere Parameter Calculations

Parameter	GRAM-99 variable name	Minimum	Nominal	Maximum
Solar flux F10.7	f10 f10b	67 67	148 148	245 245
Geomagnetic index Ap	ap	7.2	16	55
Date	mn, ida, iyr	July 15	June 1	Jan 10 for systems most sensitive to heights below 90 km Oct 27 for systems most sensitive to heights above 90 km
Local time (does not affect results below 90 km)	ihro, mino, seco	03:00:00	08:00:00	14:00:00
Random perturbations	rpscale	1.0	1.0	2.0
Small scale perturbations	patchy	0	0	1

3.3.12 Geomagnetic Fields

TBA

3.4 LUNAR SURFACE PHASES

Reserved

3.5 ENTRY AND LANDING PHASES

The following environments are applicable to the CEV descent phase and also to descending CLV elements after separation from the vehicle stack during the ascent phase.

3.5.1 Re-entry Neutral Atmosphere

Description

Defines the neutral atmosphere density, composition, and variability for various design applications. All altitude regimes and geographic locations are incorporated into the GRAM-99 model, from the Earth surface to 2000 km.

NEDD Reference Sections

4.0 Aloft (150 m – 90 km)

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

7.1 Thermosphere (90 km – 2000 km)

Design Limits

The neutral atmosphere above 90 km is specified by DSNE Section 3.3.11. 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, 1000 or more Monte Carlo simulations are needed per month for minimum, nominal, and maximum perturbation scale per Table 35. Below 90km GRAM-99 flight profiles with perturbations per Table 15 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 Operations

Description

This specifies the lightning environment for descent and landing operations in the normal landing zones in the western United States. 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.

NEDD Reference Sections

3.8 Lightning

3.8.5 Lightning Design and Test Criteria

Design Limits

See Section 3.1.11, Design Limits.

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 Section 3.1.11, Limitations.

Technical Notes

None

3.5.4 Aloft Winds for Normal Descent and Landing Operations

Description

This specifies aloft wind environments and dispersions (orbit to 300 m AGL) for normal vehicle descent and landing operations. This environment is also applicable to descending launch vehicle elements after separation from the vehicle stack during the ascent phase.

NEDD Reference Sections

4.1 Winds Aloft

4.9 Global Reference Atmosphere Model 1999 (GRAM-99)

Design Limits

System performance will be evaluated through analysis of 1000 or more GRAM-99 random profiles per month. Each profile is for an orbit to 300 m AGL flight profile into the landing site of interest with GRAM-99 inputs per Table 36. Atmospheric wind, temperature, pressure and density should be evaluated simultaneously in each simulation.

Model Inputs

GRAM-99 input is listed in Table 36 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 of 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 below 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 (e.g., 2 or 3 sigma climatological profiles) which GRAM-99 also has the capability to produce.

Limitations

Perturbations in the aloft region are statistically derived and are generated using the input variables in the table 36. GRAM does not define the turbulent boundary layer in the lowest 300 m AGL so separate analysis is required for winds in this region. (See Section 3.5.8.)

Technical Notes

None

Table 36 - GRAM-99 input to generate 1000 or more perturbed profiles (0 to 90 km) of temperature, pressure, and density per monthly reference period

Parameter	GRAM-99 variable name	Value
Range reference atmosphere limits – use if near site with a Range Reference Atmosphere (RRA)	sitenear	0.5
	sitelim	2.5
Random output	iopr	1= random
Non-RRA sites	iguayr	1 = period of record
Random perturbations	rpscale	1.0
Small scale perturbations	patchy	0

3.5.5 Aloft Air Temperature for Normal Descent and Landing Operati

Description

This section specifies air temperature environments and dispersions (orbit to 300 m AGL) for normal vehicle descent and landing operations. This environment is also applicable to descending launch vehicle elements after separation from the vehicle stack during the ascent phase.

NEDD Reference Sections

4.4 Temperature

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

See Section 3.5.4.

Model Inputs

See Section 3.5.4.

Limitations

Perturbations in the aloft region are statistically derived and are generated using the input variables in the table 36.

Technical Notes

None

3.5.6 Aloft Air Pressure for Normal Descent and Landing Operations

Description

This section specifies air pressure environments and dispersions (orbit to 300 m AGL) for normal vehicle descent and landing operations. This environment is also applicable to descending launch vehicle elements after separation from the vehicle stack during the ascent phase.

NEDD Reference Sections

4.5 Pressure

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

See DSNE Section 3.5.4.

Model Inputs

See DSNE Section 3.5.4.

Limitations

See DSNE Section 3.5.5.

Technical Notes

See DSNE Section 3.5.5.

3.5.7 Aloft Air Density for Normal Descent and Landing Operations

Description

This section specifies air density environments and dispersions (orbit to 300 m AGL) for normal vehicle descent and landing operations. This environment is also applicable to descending launch vehicle elements after separation from the vehicle stack during the ascent phase.

NEDD Reference Sections

4.6 Density

4.9 Global Reference Atmospheric Model 1999 (GRAM-99)

Design Limits

See DSNE Section 3.5.4.

Model Inputs

See DSNE Section 3.5.4.

Limitations

See DSNE Section 3.5.5.

Technical Notes

See DSNE Section 3.5.5.

3.5.8 Ground Winds at Landing Site

Description

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

NEDD Reference Sections

3.1 Ground Winds

4.2 Discrete Gust Model

4.2.1 NASA 1997 Discrete Gust Model

Design Limits

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

$$u(z) = u_{10}\left(\frac{z}{10}\right)^{1/7}$$

where *u(z)* is the peak wind speed at height *z* meters above natural grade (0 to 300 m AGL), and u_{10} is the design peak wind speed at 10 meters.

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/sec) at height *z* meters above natural grade and *u(z)* is the peak wind speed (m/sec) at height *z* meters above natural grade (determined above). Spectral gust is obtained by using the steady-state wind speed at 10m determined above with:

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

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

where Φ_u and Φ_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 ω is the frequency in units radians per second. The gust spectra parameters (L_{10}, σ_{10}, *p*, and *q*) are for altitudes below 300 m are provided in Table 37.

Minimum: None

Model Inputs

For vehicle descent and landing, use u_{10} = 19.5 m/s for construction of the maximum design limit wind speed profile up to 300 m AGL.

Technical Notes

Design limit for vehicle landing of 19.5 m/s at the 10 m reference level is the 95th percentile peak wind speed for a one hour exposure period at 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.

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.

Table 37 - Dryden gust spectra parameters for the longitudinal, lateral and vertical components for the landing phase

Component	σ_{10}	p	L_{10}	q
	(m/sec)	(non-dimensional	(meters)	(non-dimensional)
Longitudnial	2.31	0.16	21	0.65
Lateral	1.67	0.25	11	0.83
Vertical	1.15	0.36	5	1.05

3.5.9 Surface Air Temperature for Normal Landing Operations

Description

This section specifies the design maximum and minimum surface air temperature for normal vehicle landing environments. Zones for normal landings are contained in a geographical region in the western United States.

NEDD Reference Sections

3.3 Temperature

Design Limits

Maximum: 46°C

Minimum: -38°C

Model Inputs

None

Limitations

For any required thermal assessment involving wind effects, the winds must be assumed to be steady state with horizontal speeds ranging from 0 to 13.9 m/sec. This wind was determined by using the steady-state wind equation and peak wind (19.5 m/sec) given in Section 3.5.8.

Technical Notes

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

3.5.10 Surface Air Pressure for Normal Landing Operations

Description

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

NEDD Reference Sections

3.4 Pressure

Design Limits

Maximum: 1051.9 hPa

Minimum: 989.4 hPa

[100 Pa = 1 hPa = 1 millibar (mb) = 0.01450377 pound/in^2 (psi)]

Model Inputs

Design limits specify the air pressure referenced to standard sea level conditions. For design activities, 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 Operations

Description

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

NEDD Reference Sections

3.5 Humidity

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 Operations

Description

This section specifies the aerosol environment for normal (on land) vehicle descent and landing operations. Aerosol environments for on water landings are specified in section 3.5.21.

NEDD Reference Section

None

Design Limits

The vehicle will encounter blowing sand and alkali dust in the landing area. Additional details and sources are TBD (TBD-023-004).

Model Inputs

None

Limitations

None

Technical Notes

Additional information is available in NASA Handbook 1001, Section 10.

3.5.13 Precipitation for Normal Descent and Landing Operations

Description

This section specifies the precipitation environment for normal vehicle descent and landing operations.

NEDD Reference Sections

3.7 Precipitation

Design Limits

The maximum design rainfall rate is 7.6 mm/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 Operations

Description

This section specifies the flora and fauna environment for all descent and landing operations, including landing operations conducted on land or sea. Per program decision, normal landings will only occur at prepared sites where exposure to flora and fauna hazards have been mitigated to acceptable levels.

NEDD Reference Sections

None

Design Limits

During descent and landing operations, the design limit for an avian species is a maximum mass of 2.2 kg up to an altitude of 0.5 km above ground level.

During landing operations, the design limit includes ground brush up to 0.6 m height.

During landing operations, the design limit includes mammals with mass up to 10 kg.

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 United States, 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 Landing Operations

(Soil conditions at the landing site to be provided by SDR.)

Description

This section specifies the design surface characteristics for normal landing operations. Per program decision, normal landings will only occur at prepared sites that fall within the design limits specified below.

NEDD Reference Sections

None

Design Limits

The design limit for maximum surface slope of the landing site will be 5 degrees. The site will be clear of solid objects projecting more than 0.3 meter (1 ft.) above the surface. The site will be clear of ditches deeper than 0.3 meter (1 ft.).

Model Inputs

None

Limitations

None

Technical Notes

The selection of surface slope was made based on preliminary surveys of potential landing sites. It is anticipated the sites finally designated will be prepared to meet this specification.

3.5.16 Cloud and Fog Environment for Normal Descent and Landing Operations

Description

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

NEDD Reference Sections

4.10 Stratospheric and Mesospheric Clouds

Design Limits

The design range for cloud clover is up to and including 100% cloud cover, excluding convective clouds and thunderstorms. The maximum size of any liquid cloud particle is 7 millimeters diameter. The maximum size of any frozen cloud particle is 200 microns. The minimum horizontal ground level visibility is 1000 meters.

Model Inputs

None

Limitations

None

Technical Notes

The maximum size for liquid cloud particles of 7 millimeters 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 microns 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 defines the radiant thermal environments for normal landing operations.

NEDD Reference Sections

3.2 Solar Radiation

3.2.2 Edwards Air Force Base

Design Limits

Table 38 Design high and design low radiant energy as a function of time of day

Table 39 Sky temperature design limits

Model Inputs

None

Limitations

None

Technical Notes

The design high presents clear day direct incident radiant energy to a horizontal surface. 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 low presents cloudy day diffuse radiant energy which would apply to all surfaces. The actual radiant energy absorbed by these surfaces would also be a function of surface optical properties. These data should be used in conjunction with the sky temperature.

Table 38 - Design high and design low radiant energy as a function of time of day

Time of Day	Design High* Solar Radiation	Time of Day	Design Low Solar Radiation
Hour (LST)	W/m^2	Hour (LST)	W/m^2
0500	0	0500	0
0600	795	0600	0
0700	934	0700	0
0800	1108	0800	0
0900	1213	0900	0
1000	1248	1000	0
1100	1283	1100	0
1200	1248	1200	0
1300	1283	1300	0
1400	1248	1400	0
1500	1248	1500	0
1600	1248	1600	0
1700	1178	1700	0
1800	1004	1800	0
1900	830	1900	0
2000	0	2000	0

*to a horizontal surface.

Table 39 - Sky temperature design limits

	Sky Temperature (°C)
Design High	10.0
Design Low	-34.4

3.5.18 Sea State for Water Landing

Description

This section specifies the design maximum and minimum wave conditions for water landings.

NEDD Reference Sections

3.10 Sea State

Design Limits

Maximum: Significant wave height: 9 meters

Significant wave height is average of highest one-third of waves.

Maximum wave height is twice significant wave height (for large sample >2,000 waves).

Minimum wave period associated with maximum significant wave height (9 m): 12 seconds

Minimum: Significant wave height: no waves.

Maximum: Steady-state wind speed at 10 meter height above surface:
20.6 m/s.

Model Inputs

None

Limitations

Many of the sea state data sets are from ship measurements biased toward lower wave heights since ships purposely try to avoid bad weather.

Technical Notes

For sea state characteristics the primary data base utilized is the Global Wave Climatology Atlas of S. Caires, A. Sterl, et. al., (http://www.knmi.nl/onderzk/oceano/waves/era40).

This data base is developed from the European Centre for Medium Range Weather Forecasts (ECMWF) atmospheric reanalysis for the Period Of Record (1957-2002) with emphasis on the Period Of Record (1971-2000). Much of this data is available at the web site http://www.knmi.nl/onderzk/oceano/waves/era40/ . Significant wave height 90% quantiles are in the range 6 to 8 m (Beaufort Wind No. 8) for large portions of the North Atlantic during the months of January, February, March, November and December. Other consulted data bases include the Period Of Record (1985-1995) data which is on a NASA/MSFC CD ROM and run on commercial MATLAB software per the description in section 3.10 of the NEDD; Period Of Record (1992-2003) data provided by NASA/KSC for Beaufort Wind Number probabilities along the ground track of a 51.6 degree inclination launch northward from Kennedy Space Center (KSC) over the North Atlantic; and Period Of Record (1854-1969) data provided by NASA/JSC from U.S. Navy Marine Climatic Atlas of the World, Version 1.0, March 1992 for plots of North Atlantic mean wave heights by month.

Worst months to launch relative to North Atlantic sea state conditions are: November, December, January, February, and March.

3.5.19 Sea State for Crew Rescue

Description

This section specifies the design maximum and minimum wave conditions for crew rescue.

NEDD Reference Sections

3.10 Sea State

Design Limits

Maximum: Significant wave height: 4 meters (TBR-023-006)

Minimum wave period associated with 4 meter significant wave height:
8 seconds (TBR-023-006).

Minimum: Significant wave height: no waves.

Maximum steady-state wind speed at 10 meter height above surface: 13.9 m/s (TBR-023-006).

Model Inputs

None

Limitations

Many of the sea state data sets are from ship measurements biased toward lower wave heights since ships purposely try to avoid bad weather.

Technical Notes

See 3.6.18 for Technical Notes.

3.5.20 Sea Surface Temperature for Water Landings

Description

This section specifies the design maximum and minimum sea surface temperatures for water landings.

NEDD Reference Sections

3.10 Sea State

Design Limits

Maximum: 36°C (97°F)—Ascent
Maximum: 36°C (97°F)—Descent

Minimum: -2°C (28°F)—Ascent
Minimum: -2°C (28°F)—Descent

Note that sea surface temperature and wave height parameters are independent such that maximum wave height can be concurrent with minimum sea surface temperatures.

Model Inputs

None

Limitations

None

Technical Notes

For sea surface temperature the primary data base utilized is the Period Of Record (1961-1990) NOAA data which can be seen at the web site http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/ . Another consulted data base is the Period Of Record (1854-1969) data provided by NASA/JSC for plots of North Atlantic mean sea surface temperature by month. Department of Defense Handbook, MIL-HDBK-310, Global Climatic Data for Developing Military Products, was also utilized.

3.5.21 Aerosols for On-water Landing Operations

Description

This section specifies the aerosol environment for abort on water vehicle descent and landing operations.

NEDD Reference Section

None

Design Limits

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

Model Inputs

None

Limitations

None

Technical Notes

Additional information is available in NASA Handbook 1001, Section 10.

3.6 CONTINGENCY AND OFF-NOMINAL LANDING PHASES

3.6.1 Reserved

3.6.2 Reserved

3.6.3 Reserved

3.6.4 Reserved

3.6.5 Reserved

3.6.6 Reserved

3.6.7 Reserved

3.6.8 Reserved

3.6.9 Reserved

3.6.10 Reserved

3.6.11 Reserved

3.6.12 Aerosols for Abort Descent and Landing Operations

Description

This section specifies the aerosol environment for abort on water vehicle descent and landing operations.

NEDD Reference Section

None

Design Limits

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

Model Inputs

None

Limitations

None

Technical Notes

Additional information is available in NASA Handbook 1001, Section 10.

3.6.13 Reserved

3.6.14 Reserved

3.6.15 Reserved

3.6.16 Reserved

3.6.17 Reserved

3.6.18 Sea State for Abort In-Water Landing

Description

This section specifies the design maximum and minimum wave conditions for abort in-water landings.

NEDD Reference Sections

3.10 Sea State

Design Limits

Maximum: Significant wave height: 9 meters

Significant wave height is average of highest one-third of waves.

Maximum wave height is twice significant wave height (for large sample >2,000 waves).

Minimum wave period associated with maximum significant wave height (9 m): 12 seconds

Minimum: Significant wave height: no waves.

Maximum: Steady-state wind speed at 10 meter height above surface: 20.6 m/s.

Model Inputs

None

Limitations

Many of the sea state data sets are from ship measurements biased toward lower wave heights since ships purposely try to avoid bad weather.

Technical Notes

Wind speeds in Table 40 are steady state, as compared to peak winds as in DSNE Section 3.6.8.

For sea state characteristics the primary data base utilized is the Global Wave Climatology Atlas of S. Caires, A. Sterl, et. al., (http://www.knmi.nl/onderzk/oceano/waves/era40).

This data base is developed from the European Centre for Medium Range Weather Forecasts (ECMWF) atmospheric reanalysis for the Period Of Record (1957-2002) with emphasis on the Period Of Record (1971-2000). Much of this data is available at the web site http://www.knmi.nl/onderzk/oceano/waves/era40/ . Significant wave height 90% quantiles are in the range 6 to 8 m (Beaufort Wind No. 8) for large portions of the North Atlantic during the months of January, February, March, November and December. Other consulted data bases include the Period Of Record (1985-1995) data which is on a NASA/MSFC CD ROM and run on commercial MATLAB software per the description in section 3.10 of the NEDD; Period Of Record (1992-2003) data provided by NASA/KSC for Beaufort Wind Number probabilities along the ground track of a 51.6 degree inclination launch northward from Kennedy Space Center (KSC) over the North Atlantic; and Period Of Record (1854-1969) data provided by NASA/JSC from U.S. Navy Marine Climatic Atlas of the World, Version 1.0, March 1992 for plots of North Atlantic mean wave heights by month.

Worst months to launch relative to North Atlantic sea state conditions are: November, December, January, February, and March.

Table 40 - State of Sea: International Meteorological Code WMO code 3700; with Beaufort WMO wind code 1100

Sea State Code	**Beaufort Wind No.*	*Assoc.Beaufort Wind Speed **m/sec** (knots)	Sea State Descriptive Terms	$H_{1/3}$ of Waves	
				(m)	(ft)
0	*0-1*	**< 0.5 – 1.5** (<1 – 3)	Calm (Glassy)	0	0
1	*2*	**2.1 – 3.1** (4 – 6)	Calm (Rippled)	0 – 0.1	0 – 0.3
2	*3*	**3.6 – 5.1** (7 – 10)	Smooth (Wavelets)	0.1 – 0.5	0.3 – 1.7
3	*4*	**5.7 – 8.2** (11 – 16)	Slight	0.5 – 1.25	1.7 – 4
4	*5*	**8.7 – 10.8** (17 – 21)	Moderate	1.25 – 2.5	4 - 8
5	*6*	**11.3 – 13.9** (22 – 27)	Rough	2.5 – 4	8 - 13
6	*7*	**14.4 – 17.0** (28 – 33)	Very Rough	4 – 6	13 - 20
7	*8*	**17.5 – 20.6** (34 – 40)	High	6 – 9	20 - 30
8	*9*	**21.1 – 24.2** (41 – 47)	Very High	9 – 14	30 - 45
9	*10-12*	**24.7 - >32.9** (48 - >64)	Phenomenal	Over 14	Over 45

Note: Exact bounding height is assigned to lower code; e.g. a height of 4 m is sea-state coded 5 (Beaufort Wind Number 6).

* The Beaufort wind numbers and their associated wind speeds are included here.

3.6.19 Sea State for Crew Rescue after Abort In-Water Landings

Description

This section specifies the design maximum and minimum wave conditions for crew rescue.

NEDD Reference Sections

3.10 Sea State

Design Limits

<u>Maximum</u>: Significant wave height: 4 meters (TBR-023-006)

Minimum wave period associated with 4 meter significant wave height:
8 seconds (TBR-023-006).

<u>Minimum</u>: Significant wave height: no waves.

Maximum steady-state wind speed at 10 meter height above surface: 13.9 m/s (TBR-023-006).

Model Inputs

None

Limitations

Many of the sea state data sets are from ship measurements biased toward lower wave heights since ships purposely try to avoid bad weather.

Technical Notes

See 3.6.18 for Technical Notes.

3.6.20 Sea Surface Temperature for Abort In-Water Landings

Description

This section specifies the design maximum and minimum sea surface temperatures for abort in-water landings.

NEDD Reference Sections

3.10 Sea State

Design Limits

<u>Maximum:</u> 36°C (97°F)—Ascent aborts

<u>Maximum:</u> 36°C (97°F)—Descent aborts

<u>Minimum:</u> -2°C (28°F)—Ascent aborts

<u>Minimum:</u> -2°C (28°F)—Descent aborts

Note that sea surface temperature and wave height parameters are independent such that maximum wave height can be concurrent with minimum sea surface temperatures.

Model Inputs

None

Limitations

None

Technical Notes

For sea surface temperature the primary data base utilized is the Period Of Record (1961-1990) NOAA data which can be seen at the web site http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/ . Another consulted data base is the Period Of Record (1854-1969) data provided by NASA/JSC for plots of North Atlantic mean sea surface temperature by month. Department of Defense Handbook, MIL-HDBK-310, Global Climatic Data for Developing Military Products, was also utilized.

Worst months to launch relative to North Atlantic sea state and minimum sea surface temperature conditions are: November, December, January, February, and March. Avoid mission abort splash down of CEV in cold sea surface temperature regions near Newfoundland. This means avoiding areas between 63°W and 40°W longitude. In the event of an ascent mission abort it is advantageous to cross-track to the right (South) and/or splash down downrange beyond longitude 40°W to avoid the colder sea surface temperatures.

The design limits for ascent aborts are based on in-water landing along the ground track of an ascent from Kennedy Space Center, Florida to the International Space Station (ISS) with an inclination orbit of 51.6°. Maximum sea surface temperature for ascent aborts is for the Arabian Sea/Persian Gulf. Maximum sea surface temperature for descent aborts is 36°C (96°F) which represents the 1-percent value for the warmest month (August) in the Persian Gulf. Minimum sea surface temperature for all aborts is -2°C (28°F) which represents the 1-percent low sea surface temperature during the worst winter month in the area near Newfoundland. MIL-HDBK-310 states all-time low sea surface temperature worldwide was -6°C off coast of Newfoundland.

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 United States.

3.7.1 Environments for Post-Flight and Recovery Operations at KSC

Except for the sea state specification in section 3.7.2, specifications for Post-Flight and Recovery Operations at KSC are provided in DSNE Section 3.1.

3.7.2 Sea State for KSC Post-Flight and Recovery Operations

Sea state data for vehicle element recovery zones will be included in this section when it becomes available.

3.7.3 Lightning Specification for Post-Flight and Recovery Operation in the Normal Landing Area

Description

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

NEDD Reference Sections

3.8 Lightning

3.8.5 Lightning Design and Test Criteria

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, “Aircraft Lightning Zones,” and must be defined and evaluated for each applicable vehicle configuration. Applicable documents are SAE ARP5412, “Aircraft Lightning Environment and Related Test Waveforms,” and RTCA 160/DO-160D, “Environmental Conditions and Test Procedures for Airborne Equipment,” Section 22, “Lightning Induced Transient Susceptibility” and Section 23, “Lightning Direct Effects.” 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 Ground Winds at Landing Site

The ground wind environment specified in DSNE Section 3.5.8 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 Operation in the Normal Landing Area

The surface air temperature limits specified in DSNE Section 3.5.9 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 Operation in the Normal Landing Area

The surface air pressure limits limits applicable to post-flight and recovery phase operations in the normal landing area are specified in DSNE Section 3.5.10.

3.7.7 Surface Air Humidity for Post-Flight and Recovery Operation in the Normal Landing Area

The surface air humidity conditions applicable to post-flight and recovery phase operations in the normal landing area are specified in DSNE Section 3.5.11.

3.7.8 Aerosol Environment for Post-Flight and Recovery Operation in the Normal Landing Area

The aerosol environment for the normal landing area is specified in DSNE Section 3.5.12.

3.7.9 Precipitation Environment for Post-Flight and Recovery Operation in the Normal Landing Area

The precipitation environment for the normal landing area is specified in DSNE Section 3.5.13.

3.7.10 Flora and Fauna Environment for Post-Flight and Recovery Operations in the Normal Landing Area

The flora and fauna environment for the normal landing area is specified in DSNE Section 3.5.14.

3.7.11 Surface Characteristics and Topography for Post-Flight and Recovery Operation in the Normal Landing Area

Design specifications for the surface characteristics and topography of the normal landing area are specified in DSNE Section 3.5.15.

3.7.12 Cloud and Fog Environment for Post-Flight and Recovery Operation in the Normal Landing Area

The cloud and fog environment in the normal landing area is TBD (TBD-023-005).

3.7.13 Radiant (Thermal) Energy Environment for Post-Flight and Recovery Operation in the Normal Landing Area

The radiant energy environment in the normal landing area is specified in DSNE Section 3.5.17.

3.8 INTER-PLANETARY SPACE SPECIFICATION

Reserved

3.9 MARS ORBIT SPECIFICATION

Reserved

3.10 MARS ATMOSPHERE AND SURFACE PHASE SPECIFICATION

Reserved

4 VERIFICATION FOR NATURAL ENVIRONMENTS

Verification that a flight system will meet its functional and performance requirements during and after exposure to a range of natural environment factors requires a systematic, integrated approach that addresses, in addition to the direct environmental effects, the following interactions:

1) Many environmental effects are dependent on the configuration of the integrated vehicle(s) or systems. For example, lightning attach points and current paths will be different for separate systems than they are for integrated systems. CEV will be partially shielded from meteoroids and orbital debris when it is attached to ISS, but the ISS will also reflect and radiate heat onto the CEV.
2) Certain environmental effects are dependent on the operating conditions of the system, or some other system. A simple example is system temperature which depends on the amount of heat generated internally by the operating system as well as the energy balance with the external environment. An example involving multiple systems is the ground systems and the integrated vehicle; configuration changes in elements of the ground system could change wind effects on the vehicle (vortex shedding) and shadowing of solar radiation.
3) Cumulative or latent effects such as ionizing radiation dose effects in materials and electronics, in addition to acute effects like single event upset.
4) Some environmental conditions are causally related so that extremes may tend to occur together, or they may be anti-correlated so that they seldom or never occur together.
5) Certain environmental factors can have synergistic effects. For example, meteoroid or orbital debris impacts generate a burst of plasma which can lead to sustained arcs or electromagnetic discharge effects if sufficient electrical potential gradients are present.

Additional information on many of these factors is contained in CxP 70044, Constellation Program Natural Environment Definition for Design (NEDD), but the NEDD information is not all-inclusive.

4.1 INTEGRATED VERIFICATION APPROACH

The approach specified here uses the standard “down the V, up the V” systems engineering process. Adaptations are allowed as necessary to address the specifics of each requirement and system, but all cases require a top-down analysis to identify the applicable environments, effects, and dependencies on hardware configuration, operating condition, and the other factors listed above. This serves to scope the problem and serves as the starting point for the next tier down where, typically, the number of applicable environments will narrow but additional configurations, operating modes, and other factors will be introduced.

The recommended reporting format for this analysis is the development of a series of Natural Environment Requirement Sensitivity and Applicability Matrices (NERSAMs), specific to the functional or performance requirement for a system (then element and subsystem) for each mission phase. See Figures 14 and 15 for an illustration, thermal control of the CEV subsystems. Across the top of the matrix are listed the environmental factors from the DSNE for the mission phase in question. If so desired, a NERSAM for all mission phases may be constructed instead of one for each mission phase. If this is the case, across the top should be listed all of the DSNE Environments Sections. In the example given, note the addition of special factors, e.g. synergistic and modified natural environments, where appropriate. Hardware configurations and/or interfaces and operational modes are listed down the side of the matrix. As in Figure 15, a “zoning” approach may be used to separate “internal” (internal to the system/subsystem to which the requirement applies) and external configurations and operational modes. Subsystems within the same zone are exposed to the same environments, simplifying lower tier analyses and tests. The point of the matrix is to form a structure to aid in thinking through the list of potential effects as defined above in relation to the specific function or performance being verified. Thus, it is very important that the listings of environments across the top and configurations and operating modes down the side be complete with respect to the requirement (function) being verified.

1) Integrated Scope and Planning Analysis: The first step is to look at the subject hardware system and the function or performance requirement to be verified in terms of the possible environmental direct effects and interactions as identified above, filling in the matrix indicating which are applicable and which are not. Next, identify a verification method and any configuration sensitivities and synergies for each applicable block. In our sample matrices these are identified in each block by references to more detailed information in other documents. Empty blocks imply a non-applicable interaction.

2) Verification Planning: Plan the block by block verification process. The interactions (environment correlations, synergistic effects, etc.) will call for special test conditions, analysis scenarios, and data products, so be sure these are clearly identified in the plan.

3) Detailed Block-level Verification: Execute the plan from step 2), obtaining the verification test results, analyses, and supporting data as required.

4) Integrated Roll-up Analysis and Report: In many cases the verification will be fairly simple and this may be just a summary “rack and stack” of the products from the previous step. For other cases, the interactions may be quite complex and substantial analysis and documentation will be required.

In all cases, whether based on NERSAMs or some other systems engineering format, the verification closure reports are to be clearly related to the integrated systems analysis that organizes and guides the verification process.

The tests and analyses that form the basic verification in step 3) above will come from various phases of the program. Many analyses may be performed early during the design phase, for example, in support of the design process or because the appropriate personnel and tools are readily available. Thus, it is very advantageous that the planning, steps 1) and 2), be accomplished early in the program to minimize missing data and erroneous assumptions. It is costly if an analysis report late in the process that is supposed to cover some portion of the lower tier verification, fails to address an important vehicle configuration or operating condition. This can only be avoided by implementing a disciplined and systematic approach.

	Ionizing Radiation Dose	Ionizing Radiation Peak Rate	Ionizing Radiation Integral Fluence for SEE	Ionizing Radiation for Crew Exposure	Plasma and Spacecraft Charging	Meteoroid and Orbital Debris	Earth Gravitational Field	Lunar Gravitational Field	Thermal Natural	Solar Illumination	Natural Neutral Atmosphere	Others ………….
a) Crew Module	X	X	X	X	X	X	X		X	X	X	
b) Service Module	r.A	r.B	r.C		r.E	r.F	r.G		r.H	r.I	r.J	
c) Crew Module Mated to Service Module (Integrated Δ)	X	X	X	X	X	X						
d) Service Module Mated to Crew Module (Integrated Δ)	X	X	X		X	X						
e) Others ………….												

Figure 14 NERSAM Notional Example (CEV Total System/LEO Mission Phase)

Faded-out entries are not applicable to the thermal control system example. r.X is a reference to a document and section wherein the verification method(s) is (are) detailed and/or a verification closure report has been issued.

	Ionizing Radiation Dose	Ionizing Radiation Peak Rate	Ionizing Radiation Integral Fluence for SEE	Plasma and Spacecraft Charging	Meteoroid and Orbital Debris	Thermal Natural	Solar Illumination	Natural Neutral Atmosphere	Others …………
Zone 1 – Interior, Shielded[1], Pressurized									
i. Pressure Vessels						X			
ii. Electronics Boxes						X			
iii. Cabling						X			
iv. APUs						X			
v. EMAs						X			
vi. ……..									
Zone 2 – Interior, Shielded[1], Unpressurized									
i. Electronics Boxes						X		X	
ii. Cabling						X		X	
iii. Plumbing						X		X	
iv. Main Rocket Motor						X		X	
v. ………..									
Zone 3 – Exterior, Shielded[1], Not Exposed									
i. Cables in Trays	X	X	X		X	X	X	X	
ii. Potted Components in Boxes	X	X	X		X	X	X	X	
iii. …									
Zone 4 – Exterior, Not Shielded[1], Exposed									
i. RCU	X	X		X	X	X	X	X	
ii. Antennas	X	X		X	X	X	X	X	
iii. Thermal Control Surface	r.K	r.L		r.M	r.N	r.O	r.P	r.Q	
iv. Cables	X	X		X	X	X	X	X	
v. ……									

[1] Shielded means behind a radiation equivalent of 0.5 cm of Aluminum, Not Shielded has less shielding than this.

Figure 15 NERSAM Notional Example for Thermal Control System Function and Performance

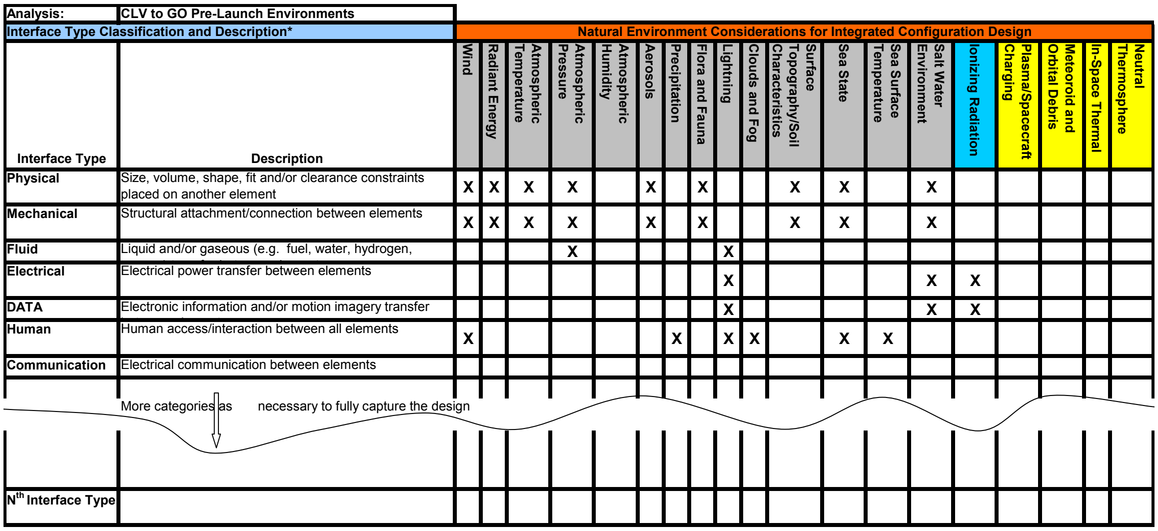
(CEV Service Module/LEO Mission Phase) r.X is a reference to a document and Section wherein the verification method(s) is (are) detailed and/or a verification closure report has been issued.

Figure 16 (DELETED)

4.2. SPECIAL CASES

4.2.1. Interfaces and Protected Subsystems

In some cases, interfaces for example, the requirements and thus the design approach may be oriented toward protection – preventing the environment effects from reaching the system – rather than designing to operate directly exposed to the environment. In these cases verification consists of a) assuring that the protection is sufficient and b) ensuring that the functions for the subsystem, which may reach outside the protective envelop, are not degraded by environmental effects. For analysis of these cases an alternative to the NERSAM based on interface type or functional breakdown may be used to organize the verification process. An example is provided in Figure 17.



Analysis:	CLV to GO Pre-Launch Environments																			
Interface Type Classification and Description*		Natural Environment Considerations for Integrated Configuration Design																		
Interface Type	Description	Wind	Radiant Energy	Atmospheric Temperature	Atmospheric Pressure	Atmospheric Humidity	Aerosols	Precipitation	Flora and Fauna	Lightning	Clouds and Fog	Surface Topography/Soil Characteristics	Sea State	Sea Surface Temperature	Salt Water Environment	Ionizing Radiation	Plasma/Spacecraft Charging	Meteoroid and Orbital Debris	In-Space Thermal	Neutral Thermosphere
Physical	Size, volume, shape, fit and/or clearance constraints placed on another element	X	X	X	X		X		X			X	X		X					
Mechanical	Structural attachment/connection between elements	X	X	X	X		X		X			X	X		X					
Fluid	Liquid and/or gaseous (e.g. fuel, water, hydrogen,				X					X										
Electrical	Electrical power transfer between elements									X					X	X				
DATA	Electronic information and/or motion imagery transfer									X					X	X				
Human	Human access/interaction between all elements	X						X		X	X		X	X						
Communication	Electrical communication between elements																			
	More categories as necessary to fully capture the design																			
Nth Interface Type																				

*Interface type classification and descriptions as described in Table 3-2 Constellation Reference Architecture Document (RAD)

Figure 17 Alternative form of a NERSAM for interface sensitivity assessments

4.2.2 Impact of Atmospheric Variability on Flight Vehicle Systems Verification (Under Review-planned baseline at SDR)

Verification of requirements for systems that are sensitive to atmospheric profiles (winds, wind shears, or thermodynamic properties) along a flight path present a special verification problem for several reasons. First, the atmosphere is highly variable so a very large number of simulations is required to adequately capture the possible range of effects. Second, the responses of vehicle systems to atmosphere variations are complex and may be non-linear so that it is impossible to tell from inspection which atmospheric profiles will cause the engineering parameters to exceed the design limits. Even for profiles that are known to cause exceedances, there is no simple way to tell which features of the profile caused the problem.

The currently favored design approach begins by using the Global Reference Atmosphere Model (GRAM-99) to generate Monte Carlo fashion, a large number of simulated atmosphere profiles. Since the properties of the atmosphere vary with time of the year, simulations are required for each month. These profiles are fed, usually as they are generated, into a GN&C simulation code that generates the flight profiles, steering commands, required motor performance parameters, etc. The results from the GN&C simulation are then fed to loads, aero-heating and other specialty analysis areas for determination of vehicle performance in each area. For each area there must be some level of design margin above the predicted performance profile to assure adequate design.

For verification of the design one naturally turns to Monte Carlo simulation in a case like this. Since the re-entry atmosphere is unmeasured at the time of the mission and the launch atmosphere will have temporal variations which cause changes from the measured profile, verification should be performed to a high level, typically 0.997 percentile, “3 sigma of a normal distribution” or similar value. For the sake of this discussion, we term the value of the engineering parameter corresponding to the percentile value the “verification value.” Direct Monte Carlo verification for high percentile values requires a very large number of trials and does not seem practical for this complex analysis, given the code run times and the branching, multi-discipline nature of the analyses. Therefore the following process has been defined as an acceptable substitute.

When the final design and design parameters have been set, the design will be verified by the following steps:

1) Run 1000 (minimum) simulations per month.
2) For each month generate the probability distribution function for the engineering parameter of interest (not the environment parameters). For each distribution, determine the verification value associated with the desired percentile for the parameter.
3) Find the mean and spread of the verification values for the 12 (minimum) monthly simulations. (See Figure 18) Usually the most extreme of these, the “worst month,” will be the design point (without safety margin added).
4) The design can be considered verified if the design point plus margin is large compared to the mean of the verification values. “Large” for most cases means that the separation between the verification value and the design point plus margin is 5x (default value) the spread in the verification values from the monthly distributions. See the illustration in Figure 18. The exact criteria for each engineering parameter should be set in the appropriate tier requirements; if it is not, the default value applies.
5) Additional verification will also be performed against the Vector Wind Model (for launch) and against measured atmospheres. Several hundred measured atmospheres are available from the Environments and Constraints SIG for KSC.
6) If verification to this standard proves difficult, increasing the number of Monte Carlo trials should narrow the spread in the verification values and thus make it easier to meet the criteria, and with increased confidence. If this does not work the issue may be traced to seasonal variations in the atmospheric profiles. Consult with the Environments and Constraints SIG for help with additional options.

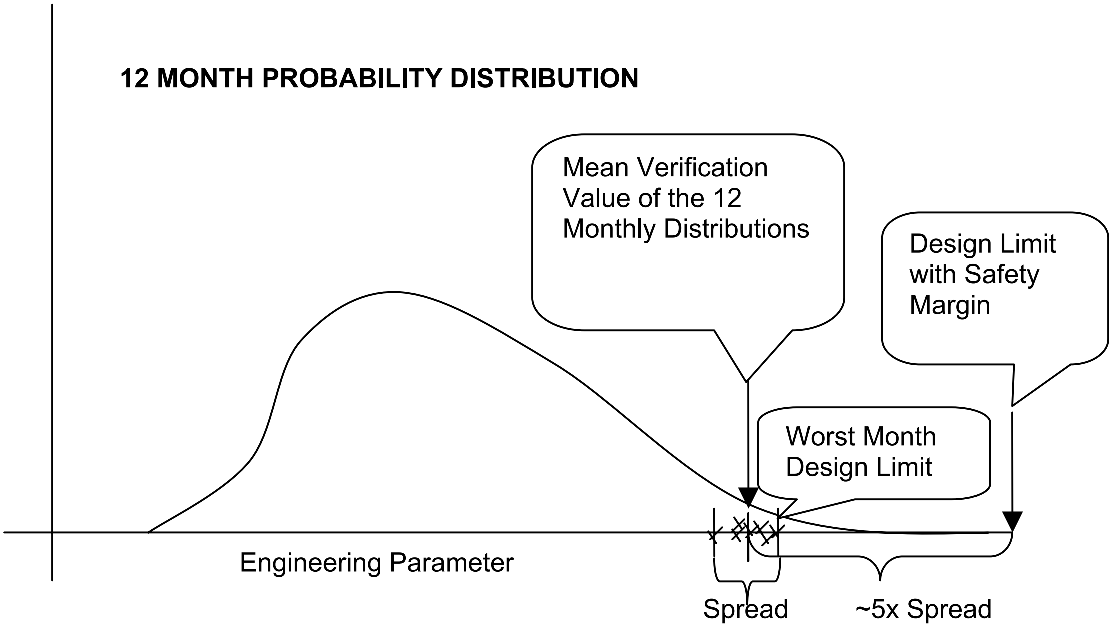


Figure 18 Concept for Verification of Engineering Parameters Dependent on GRAM Atmosphere Variability

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Appendix A Acronyms and Abbreviations

AGL	Above Ground Level
ALARA	As Low As Reasonably Achievable
CaLV	Cargo Launch Vehicle
CDV	Cargo Delivery Vehicle
CEV	Crew Exploration Vehicle
CLV	Crew Launch Vehicle
CONUS	Continental United States
CREME	Cosmic Radiation Effects on Micro Electronics
CSS	Common Support Systems
DRM	Design Reference Mission
DSNE	Design Specification for Natural Environments
EAFB	Edwards Air Force Base
EDS	Earth Departure Stage
ESP	Emission of Solar Proton
ESMD	Exploration Systems Mission Directorate
GCR	Galactic Cosmic Radiation (Rays)
GEO	Geosynchronous Orbit
GFE	Government Furnished Equipment
GRAM	Global Reference Atmosphere Model
GSFC	Goddard Spaceflight Center
GTRN	Geomagnetic Transmission Routine
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEO	Low Earth Orbit
LET	Linear Energy Transfer

LSAM	Lunar Surface Access Module
LST	Local Standard Time
MATLAB	Matrix Laboratory
MEM	Meteoroid Engineering Model
MET	Marshall Engineering Thermosphere model
MIL-STD	Military Standard
MMOD	Micrometeoroids and Orbital Debris
M/OD	Meteoroids and Orbital Debris
MSFC	Marshall Space Flight Center
MSIS	Mass Spectrometer Incoherent Scatter model
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurement
NERSAM	Natural Environment Requirement Sensitivity and Applicability Matrices
NEDD	Natural Environments Definition for Design
OLR	Outgoing Long-wave Radiation
ORDEM	Orbital Debris Engineering Model
PNP	Probability of No Penetration
RRA	Range Reference Atmosphere
SCATHA	Spacecraft Charging at High Altitudes
SEE	Single Event Effects
SPE	Solar Particle Event
SRD	System Requirements Document
TBD	To Be Determined
TBR	To Be Reviewed
TID	Total Ionizing Dose
TLI	Trans Lunar Injection
TPS	Thermal Protection System

WWID	Worst Week Integral Dose

Appendix B TBD/TBR Burn Down Plan

TBD/TBR Number	Planned Closure Date (m/d/y)	Actual Closure Date (m/d/y)	Method Of Resolution (see directions)	TDS # (If Applicable)	Need Milestone = PBS, SDR, CDR or Other?	Comments
TBD-023-001	5/23/07		Model analysis		PBS	IR total dose
TBD-023-002	5/23/07		Model analysis		PBS	IR total dose
TBD-023-003	5/23/07		Coord. W JSC		PBS	Human dose
TBD-023-004	9/28/07		Analysis, Projects coordination	SIG-08-1001		Landing sites soil properties
TBD-023-005	9/28/07		Analysis, Projects coordination			Landing sites fog/cloud environment
TBR-023-001	12/31/07		Analysis, Projects coordination			Relying on future work to coordinate with CEV's capabilities and re-calculate launch capabilities
TBR-023-002	12/31/07		Analysis, Projects coordination			Relying on future work to coordinate with CEV's capabilities and re-calculate launch capabilities
TBR-023-003	12/31/07		Analysis, Projects coordination			Relying on future work to coordinate with CEV's capabilities and re-calculate launch capabilities
TBR-023-004	12/31/07		Analysis, Projects coordination			Relying on future work to coordinate with CEV's capabilities and re-calculate launch capabilities
TBR-023-005	5/23/07		Coord. W CEV/JSC		PBS	Ground brush height
TBR-023-006	9/28/07		Analysis, Projects coordination	SIG-09-1005 (KSC)		Sea State