

# DIN EN 16603-10-04:2015-05 (E)

## Space engineering - Space environment; English version EN 16603-10-04:2015

---

<b>Foreword</b> .....	<b>12</b>
<b>Introduction</b> .....	<b>13</b>
<b>1 Scope</b> .....	<b>14</b>
<b>2 Normative references</b> .....	<b>15</b>
<b>3 Terms, definitions and abbreviated terms</b> .....	<b>17</b>
3.1 Terms defined in other standards .....	17
3.2 Terms specific to the present standard .....	17
3.3 Abbreviated terms.....	26
<b>4 Gravity</b> .....	<b>29</b>
4.1 Introduction and description .....	29
4.1.1 Introduction .....	29
4.1.2 Gravity model formulation .....	29
4.1.3 Third body gravitation.....	31
4.1.4 Tidal effects.....	31
4.2 Requirements for model selection and application .....	31
4.2.1 General requirements for gravity models.....	31
4.2.2 Selection and application of gravity models.....	32
<b>5 Geomagnetic fields</b> .....	<b>33</b>
5.1 Introduction and description .....	33
5.1.1 The geomagnetic field and its sources .....	33
5.1.2 The internal field .....	33
5.1.3 External field: ionospheric components .....	34
5.1.4 External magnetic field: magnetospheric components.....	34
5.1.5 Models of the internal and external geomagnetic fields .....	34
5.2 Requirements for model selection and application .....	36
5.2.1 The internal field .....	36
5.2.2 The external field .....	36
5.3 Tailoring guidelines.....	37

<b>6</b>	<b>Natural electromagnetic radiation and indices</b>	<b>38</b>
6.1	Introduction and description	38
6.1.1	Introduction	38
6.1.2	Electromagnetic radiation and indices	38
6.2	Requirements	41
6.2.1	Electromagnetic radiation	41
6.2.2	Reference index values	42
6.2.3	Tailoring guidelines	42
6.3	Tables	43
<b>7</b>	<b>Neutral atmospheres</b>	<b>45</b>
7.1	Introduction and description	45
7.1.1	Introduction	45
7.1.2	Structure of the Earth's atmosphere	45
7.1.3	Models of the Earth's atmosphere	45
7.1.4	Wind model of the Earth's homosphere and heterosphere	46
7.2	Requirements for atmosphere and wind model selection	47
7.2.1	Earth atmosphere	47
7.2.2	Earth wind model	48
7.2.3	Models of the atmospheres of the planets and their satellites	48
<b>8</b>	<b>Plasmas</b>	<b>49</b>
8.1	Introduction and description	49
8.1.1	Introduction	49
8.1.2	Ionosphere	49
8.1.3	Plasmasphere	50
8.1.4	Outer magnetosphere	50
8.1.5	Solar wind	51
8.1.6	Magnetosheath	51
8.1.7	Magnetotail	51
8.1.8	Planetary environments	52
8.1.9	Induced environments	52
8.2	Requirements for model selection and application	52
8.2.1	General	52
8.2.2	Ionosphere	53
8.2.3	Auroral charging environment	53
8.2.4	Plasmasphere	54
8.2.5	Outer magnetosphere	54
8.2.6	The solar wind (interplanetary environment)	55

8.2.7	Other plasma environments .....	55
8.2.8	Tables .....	56
<b>9</b>	<b>Energetic particle radiation .....</b>	<b>57</b>
9.1	Introduction and description .....	57
9.1.1	Introduction .....	57
9.1.2	Overview of energetic particle radiation environment and effects .....	57
9.2	Requirements for energetic particle radiation environments.....	60
9.2.1	Trapped radiation belt fluxes .....	60
9.2.2	Solar particle event models .....	62
9.2.3	Cosmic ray models.....	63
9.2.4	Geomagnetic shielding.....	63
9.2.5	Neutrons .....	63
9.2.6	Planetary radiation environments .....	64
9.3	Preparation of a radiation environment specification.....	64
9.4	Tables.....	65
<b>10</b>	<b>Space debris and meteoroids.....</b>	<b>66</b>
10.1	Introduction and description.....	66
10.1.1	The particulate environment in near Earth space .....	66
10.1.2	Space debris .....	66
10.1.3	Meteoroids .....	67
10.2	Requirements for impact risk assessment and model selection .....	67
10.2.1	General requirements for meteoroids and space debris .....	67
10.2.2	Model selection and application .....	68
10.2.3	The MASTER space debris and meteoroid model.....	69
10.2.4	The meteoroid model .....	69
10.2.5	Impact risk assessment.....	70
10.2.6	Margins and worst case fluxes .....	71
<b>11</b>	<b>Contamination .....</b>	<b>72</b>
11.1	Introduction and description.....	72
11.1.1	Introduction .....	72
11.1.2	Description of molecular contamination.....	72
11.1.3	Transport mechanisms.....	73
11.1.4	Description of particulate contamination.....	73
11.1.5	Transport mechanisms.....	74
11.2	Requirements for contamination assessment .....	74
<b>Annex A (normative)</b>	<b>Natural electromagnetic radiation and indices .....</b>	<b>75</b>

A.1	Solar activity values for complete solar cycle .....	75
A.2	Tables.....	76
<b>Annex B (normative)</b>	<b>Energetic particle radiation .....</b>	<b>80</b>
B.1	Historical dates of solar maximum and minimum .....	80
B.2	GEO model (IGE-2006) .....	80
B.3	ONERA MEOv2 model .....	80
B.4	FLUMIC model .....	81
B.4.1	Overview .....	81
B.4.2	Outer belt ( $L > 2,5 R_e$ ) .....	81
B.4.3	Inner belt ( $L < 2,5 R_e$ ) .....	82
B.5	NASA worst case GEO spectrum .....	83
B.6	ESP solar proton model specification.....	83
B.7	Solar ions model.....	84
B.8	Geomagnetic shielding (Størmer theory) .....	84
B.9	Tables.....	85
<b>Annex C (normative)</b>	<b>Space debris and meteoroids.....</b>	<b>97</b>
C.1	Flux models .....	97
C.1.1	Meteoroid velocity distribution .....	97
C.1.2	Flux enhancement and altitude dependent velocity distribution .....	97
C.1.3	Earth shielding and flux enhancement from spacecraft motion.....	99
C.1.4	Meteoroid streams .....	100
C.2	Tables.....	102
<b>Annex D (informative)</b>	<b>Gravitation .....</b>	<b>105</b>
D.1	Gravity models: background .....	105
D.2	Guidelines for use.....	106
D.3	Availability of models .....	108
D.4	Tables.....	108
D.5	Figures .....	109
<b>Annex E (informative)</b>	<b>Geomagnetic fields.....</b>	<b>110</b>
E.1	Overview of the effects of the geomagnetic field.....	110
E.2	Models of the internal geomagnetic field .....	110
E.3	Models of the external geomagnetic field .....	111
E.4	Magnetopause boundary .....	112
E.5	Geomagnetic coordinate system – $B$ and $L$ .....	112
E.6	Tables.....	115
E.7	Figures .....	117

<b>Annex F (informative) Natural electromagnetic radiation and indices .....</b>	<b>119</b>
F.1 Solar spectrum .....	119
F.2 Solar and geomagnetic indices – additional information .....	119
F.2.1 E10.7 .....	119
F.2.2 F10.7.....	119
F.2.3 S10.7 .....	120
F.2.4 M10.7.....	120
F.3 Additional information on short-term variation .....	120
F.4 Useful internet references for indices.....	121
F.5 Earth electromagnetic radiation .....	121
F.5.1 Earth albedo.....	121
F.5.2 Earth infrared .....	122
F.6 Electromagnetic radiation from other planets .....	123
F.6.1 Planetary albedo .....	123
F.6.2 Planetary infrared.....	123
F.7 Activity indices information.....	123
F.8 Tables.....	123
F.9 Figures .....	124
<b>Annex G (informative) Neutral atmospheres.....</b>	<b>127</b>
G.1 Structure of the Earth’s atmosphere .....	127
G.2 Development of models of the Earth’s atmosphere.....	127
G.3 NRLMSISE-00 and JB-2006 - additional information .....	128
G.4 The GRAM series of atmosphere models. ....	129
G.5 Atmosphere model uncertainties and limitations .....	129
G.6 HWM93 additional information .....	129
G.7 Planetary atmospheres models.....	130
G.7.1 Jupiter .....	130
G.7.2 Venus.....	130
G.7.3 Mars.....	131
G.7.4 Saturn .....	131
G.7.5 Titan.....	131
G.7.6 Neptune .....	131
G.7.7 Mercury.....	131
G.8 Reference data .....	132
G.9 Tables.....	133
G.10 Figures .....	138
<b>Annex H (informative) Plasmas.....</b>	<b>142</b>

H.1	Identification of plasma regions.....	142
H.2	Plasma effects on spacecraft.....	142
H.3	Reference data .....	143
H.3.1	Introduction .....	143
H.3.2	Ionosphere.....	143
H.3.3	Plasmasphere .....	143
H.3.4	Outer magnetosphere .....	144
H.3.5	Magnetosheath .....	144
H.3.6	Magnetotail and distant magnetosheath.....	144
H.3.7	Planetary environments .....	145
H.3.8	Induced environments.....	145
H.4	Tables.....	146
H.5	Figures .....	149
<b>Annex I (informative) Energetic particle radiation.....</b>		<b>150</b>
I.1	Trapped radiation belts .....	150
I.1.1	Basic data .....	150
I.1.2	Tailoring guidelines: orbital and mission regimes .....	150
I.1.3	Existing trapped radiation models .....	151
I.1.4	The South Atlantic Anomaly .....	153
I.1.5	Dynamics of the outer radiation belt .....	154
I.1.6	Internal charging .....	154
I.2	Solar particle event models.....	154
I.2.1	Overview.....	154
I.2.2	ESP model.....	155
I.2.3	JPL models .....	155
I.2.4	Spectrum of individual events .....	156
I.2.5	Event probabilities.....	157
I.2.6	Other SEP models .....	157
I.3	Cosmic ray environment and effects models.....	158
I.4	Geomagnetic shielding .....	158
I.5	Atmospheric albedo neutron model .....	158
I.6	Planetary environments .....	159
I.6.1	Overview.....	159
I.6.2	Existing models.....	159
I.7	Interplanetary environments .....	160
I.8	Tables.....	160
I.9	Figures .....	162

<b>Annex J (informative) Space debris and meteoroids .....</b>	<b>168</b>
J.1 Reference data .....	168
J.1.1 Trackable space debris .....	168
J.1.2 Reference flux data for space debris and meteoroids.....	168
J.2 Additional information on flux models.....	169
J.2.1 Meteoroids .....	169
J.2.2 Space debris flux models .....	170
J.2.3 Model uncertainties .....	172
J.3 Impact risk assessment .....	172
J.3.1 Impact risk analysis procedure.....	172
J.3.2 Analysis complexity.....	173
J.3.3 Damage assessment .....	173
J.4 Analysis tools.....	174
J.4.1 General .....	174
J.4.2 Deterministic analysis .....	174
J.4.3 Statistical analysis.....	174
J.5 Tables.....	175
J.6 Figures .....	179
<b>Annex K (informative) Contamination modelling and tools.....</b>	<b>182</b>
K.1 Models.....	182
K.1.1 Overview .....	182
K.1.2 Sources.....	182
K.1.3 Transport of molecular contaminants .....	184
K.2 Contamination tools .....	186
K.2.1 Overview .....	186
K.2.2 COMOVA: COntamination MOdelling and Vent Analysis .....	186
K.2.3 ESABASE: OUTGASSING, PLUME-PLUMFLOW and CONTAMINE modules .....	186
K.2.4 TRICONTAM.....	187

## Figures

Figure D-1 : Graphical representation of the EIGEN-GLO4C geoid (note: geoid heights are exaggerated by a factor 10 000).....	109
Figure E-1 : The IGRF-10 field strength (nT, contour level = 4 000nT, at 2005) and secular variation (nT yr <sup>-1</sup> , contour level = 20 nT yr <sup>-1</sup> , valid for 2005), at geodetic altitude 400 km with respect to the WGS-84 reference ellipsoid).....	117
Figure E-2 : The general morphology of model magnetospheric field lines, according to the Tsyganenko 1989 model, showing the seasonal variation, dependent on rotation axis tilt .....	118

Figure F-1 : Solar spectral irradiance (in red, AM0 (Air Mass 0) is the radiation level outside of the Earth's atmosphere (extraterrestrial), in blue, AM1,5 is the radiation level after passing through the atmosphere 1,5 times, which is about the level at solar zenith angle 48,19°s, an average level at the Earth's surface (terrestrial)).	124
Figure F-2 : Daily solar and geomagnetic activity indices over the last two solar cycles	125
Figure F-3 : Monthly mean solar and geomagnetic activity indices over the last two solar cycles	126
Figure G-1 : Temperature profile of the Earth's atmosphere	138
Figure G-2 : Variation of the JB-2006 mean air density with altitude for low, moderate, high long and high short term solar and geomagnetic activities	139
Figure G-3 : Variation of the NRLMSISE-00 mean atomic oxygen with altitude for low, moderate and high long solar and geomagnetic activities	140
Figure G-4 : Variation of the NRLMSISE-00 mean concentration profile of the atmosphere constituents $N_2$ , $O$ , $O_2$ , $He$ , $Ar$ , $H$ , $N$ and anomalous $O$ with altitude for moderate solar and geomagnetic activities ( $F_{10.7} = F_{10.7_{avg}} = 140$ , $A_p = 15$ )	141
Figure H-1 : Profile of electron density for solar magnetic local time = 18hr, solar magnetic latitude=0, $K_p = 0$ and 9 from the GCPM for 1/1/1999	149
Figure I-1 : Contour plots of the proton and electron radiation belts	162
Figure I-2 : Electron (a) and proton (b) omnidirectional fluxes, integral in energy, on the geomagnetic equator for various energy thresholds	163
Figure I-3 : Integral omnidirectional fluxes of protons (>10 MeV) and electrons (>10 MeV) at 400 km altitude showing the inner radiation belt's "South Atlantic anomaly" and, in the case of electrons, the outer radiation belt encountered at high latitudes	164
Figure I-4 : Comparison of POLE with AE8 (flux vs. Energy) for 15 year mission (with worst case and best case included)	165
Figure I-5 : Comparison of ONERA/GNSS model from 0,28 MeV up to 1,12 MeV (best case, mean case and worst case) with AE8 (flux vs. Energy) for 15 yr mission (with worst case & best case)	165
Figure I-6 : Albedo neutron spectra at 100 km altitude at solar maximum	166
Figure I-7 : Albedo neutron spectra at 100 km altitude at solar minimum	166
Figure I-8 : Jupiter environment model (proton & electron versions)	167
Figure J-1 : Time evolution of the number of trackable objects in orbit (as of September 2008)	179
Figure J-2 : Semi-major axis distribution of trackable objects in LEO orbits (as of September 2008)	180
Figure J-3 : Distribution of trackable objects as function of their inclination (as of September 2008)	180
Figure J-4 : The HRMP velocity distribution for different altitudes from the Earth surface.	181

## Tables

Table 6-1: Conversion from $K_p$ to $a_p$ .....	43
Table 6-2: Electromagnetic radiation values .....	43
Table 6-3: Reference fixed index values .....	43
Table 6-4: Reference index values for variations of $a_p$ .....	43
Table 8-1: Worst-case bi-Maxwellian environment .....	56
Table 8-2: Solar wind parameters .....	56
Table 9-1: Standard field models to be used with AE8 and AP8 .....	65
Table A-1 : Solar cycle 23 solar activity indices averaged over 30-day (1 month) intervals .....	76
Table B-1 : Minima and maxima of sunspot number cycles .....	85
Table B-2 : IGE 2006 GEO average model – electron flux ( $\text{keV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ ) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year. ....	86
Table B-3 IGE 2006 GEO upper case model - maximum electron flux ( $\text{keV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ ) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year. ....	87
Table B-4 : MEOv2 average case model - average electron flux ( $\text{MeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ ) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year. ....	89
Table B-5 : MEOv2 upper case model - maximum electron flux ( $\text{MeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ ) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year. ....	89
Table B-6 : Worst case spectrum for geostationary orbits .....	90
Table B-7 : Values of the parameters for the ESP model .....	90
Table B-8 : Values to scale fluence from >100 MeV to >300 MeV .....	91
Table B-9 : CREME-96 solar ion worst 5-minute fluxes in an interplanetary environment .....	91
Table B-10 : CREME-96 solar ion worst day fluxes in an interplanetary environment .....	93
Table B-11 : CREME-96 solar ion worst week fluxes in an interplanetary environment .....	95
Table C-1 : Normalized meteoroid velocity distribution .....	102
Table C-2 : The annual meteor streams .....	103
Table D-1 : Degree power attenuation for an orbit at 25 000 km altitude .....	108
Table D-2 : Coefficients of the EIGEN-GL04C model up to degree and order $8 \times 8$ .....	109
Table E-1 : IGRF-10 data for epoch 1960-2010 .....	115
Table E-2 : Sibeck et al. Magnetopause model .....	116
Table F-1 : Reference values for average planetary albedo and infra-red radiation .....	123
Table G-1 : Altitude profiles of the atmosphere constituents $\text{N}_2$ , O, $\text{O}_2$ , He, Ar, H, N and anomalous O for low solar and geomagnetic activities (NRLMSISE-00 model - $F_{10.7} = F_{10.7_{avg}} = 65$ , $A_p = 0$ ) .....	133

Table G-2 : Altitude profiles of the atmosphere constituents N <sub>2</sub> , O, O <sub>2</sub> , He, Ar, H, N and anomalous O for mean solar and geomagnetic activities (NRLMSISE-00 model - $F10.7 = F10.7_{avg} = 140$ , $A_p = 15$ ).....	134
Table G-3 : Altitude profiles of the atmosphere constituents N <sub>2</sub> , O, O <sub>2</sub> , He, Ar, H, N and anomalous O for high long term solar and geomagnetic activities (NRLMSISE-00 model - $F10.7 = F10.7_{avg} = 250$ , $A_p = 45$ ) .....	135
Table G-4 : Altitude profiles of total density $\rho$ [kg m <sup>-3</sup> ] for low, moderate, high long and high short term solar and geomagnetic activities (JB-2006 model).....	136
Table H-1 : Regions encountered by different mission types .....	146
Table H-2 : Main engineering concerns due to space plasmas.....	147
Table H-3 : Ionospheric electron density profiles derived from IRI-2007 for date 01/01/2000, lat=0, long=0.....	147
Table H-4 : Profile of densities for solar magnetic local time = 18hr, solar magnetic latitude=0, Kp = 5,0 from the GCPM for 1/1/1999.....	148
Table H-5 : Typical plasma parameters at geostationary orbit .....	148
Table H-6 : Typical magnetosheath plasma parameters.....	148
Table H-7 : Typical plasma parameters around L2 .....	148
Table H-8 : Worst-case environments for eclipse charging near Jupiter and Saturn .....	149
Table H-9 : Photoelectron sheath parameters .....	149
Table H-10 : Some solar UV photoionization rates at 1 AU .....	149
Table I-1 : Characteristics of typical radiation belt particles .....	160
Table I-2 : Recommended updated values of the parameters of the JPL model .....	160
Table I-3 : Proton fluence levels for energy, mission duration and confidence levels from the ESP model with the NASA parameters from Table B-7. ....	161
Table I-4 : Parameters for the fit to the peak fluxes from the October 1989 events.....	161
Table J-1 : Approximate flux ratios for meteoroids for 400 km and 800 km altitudes.....	175
Table J-2 : Cumulative number of impacts, $N$ , to a randomly oriented plate for a range of minimum particle sizes using the MASTER-2005 model.....	175
Table J-3 : Cumulative number of impacts, $N$ , to a randomly oriented plate for a range of minimum particle sizes using the MASTER-2005 model.....	176
Table J-4 : Cumulative number of impacts, $N$ , to a randomly oriented plate for a range of minimum particle sizes using the MASTER-2005 model.....	177
Table J-5 : Cumulative number of impacts, $N$ , to a randomly oriented plate for a range of minimum particle masses .....	178
Table J-6 : Parameters (appearing in Eq. (C-15) to account for modified meteoroid fluxes encountered by spacecraft in circular Earth orbits at various altitudes ...	179