PACE 2012

Orbital Debris and End of Mission Plans

14 – 18 May, 2012

Orbital Debris Requirements for Missions Passing through LEO, per NASA-STD-8719.14A

(See Background Slides for detailed description of the Requirements)

Major Areas	Spacecraft
Limit the debris released on Earth orbit during deployment or normal operations.	No operational debris identified.
Avoid accidental explosions.	Passivation not necessary in case of controlled reentry.
Limit the risk of collision with large debris (> 10 cm) during orbital time: P ≤ 0.001	* P = 0.00011, assuming deorbit maneuver at End of Mission (EOM) and 3 yrs mission (0.00020 for 5 yrs). Compliant (Non-compliant if uncontrolled reentry is used, with P=0.00179 for 3 yrs and P=0.00202 for 5 yrs)
Limit the risk of collision with small debris during operational life: P ≤ 0.01 total	Components required for deorbit maneuvers should be analyzed for possible damage due to small particle impact.
Dispose properly at end of mission (Orbital lifetime < 25 yrs after mission, not to exceed 30 yrs after launch).	* Orbital lifetime assuming controlled reentry is limited by the mission lifetime (< 25 yrs). Compliant Orbital lifetime without deorbit maneuvers > 30 yrs (Non-compliant).
Reliability of reentry burn	Minimum Probability of Success of reentry burn (Reliability) = 0.90
Limit the risk to human life on ground. The risk of injuring a person on the ground should be 1:10,000 or less.	Uncontrolled: DCA = 11.09 m^2 ; Risk = 1:8,000
	Controlled: The use of controlled reentry mitigates the risk. Reliability of reentry burn is enough for compliance.

Green : compliant or not difficult to achieve. Red: Non-compliant

Atmospheric Reentry Requirements

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

- **The risk to human casualty on ground from surviving components depends on:**
  - The total Debris Casualty Area (DCA) of surviving components.
  - Average population density at the corresponding orbital inclination on the predicted reentry date if left uncontrolled ("*Population density*" for the purpose of this study).
- **In base of the above, the risk to human life is calculated. NASA and international agreements limit the risk to 1:10,000.**

* DCA= Maximum cross-sectional area of surviving part plus a factor to account for the cross-sectional area of a standing person.

Risk to Human Life Exceeds NASA Limits

Mission Design Laboratory

#	Name	Parent	Qty	Material	Thermal Mass (kg)	Diameter /Width (m)	Length (m)	Height (m)	Demise Alt (km)	Total DCA (m2)	Kinetic Energy (J)
1	PACE spacecraft									11.09	
2	Telescope Drum+Shield	1	1	Al	19.63	0.696	0.265		68	0	0
3	Telescope Tube	2	1	Al	6.84	0.215	0.62		60.5	0	0
4	Schmidt Plate +Ring	3	1	Glass	1.623	0.177	0.177	0.025	0	0.54	1488
5	Primary Mirror	3	1	Glass	0.942	0.177	0.177		0	0.6	464
6	Fold Mirror	3	1	Glass	0.29	0.076	0.042		0	0.43	211
7	Momentum Wheel Housing	1	1	Al	7.71	0.362	0.213		69.5	0	0
8	Momentum Wheel	7	1	SS	17.55	0.31	0.31		0	0.83	53458
9	M. Compensation Shaft+Bearings	7	1	SS	1.81	0.125	0.206		59.9	0	0
10	M. Compensation Bearing	7	2	SS	0.04	0.044	0.044		66.1	0	0
11	Scan Drum Motor+Bearings+shaft	7	1	SS	1.19	0.089	0.894		0	0.78	194
12	OCE Structure	1	1	Al	15.011	0.863	0.894	0.543	67.6	0	0
13	Half-Angle Bracket	12	1	Al	1.04	0.28	0.143		0	0.64	210
14	Half-Angle Motor+Bearings+Shaft	12	1	SS	0.9	0.08	0.132		0	0.49	757
15	Cal Housing	1	1	Al	2.29	0.256	0.198		72.8	0	0
16	Cal Shaft+Bearings+Motor	15	1	SS	0.97	0.1	0.19		0	0.54	496
17	Cal Target Bracket+Shutter	15	1	Al	0.38	0.162	0.162	0.1	70.5	0	0
18	Tilt Mech. Stepper Motor	1	2	SS	0.2	0.055	0.138		0	0.94	54
19	Tilt. Mech. Resolver	1	2	SS	0.1	0.02	0.05		69	0	0
20	Triunion	1	2	Ti	1.16	0.12	0.1		0	1.01	992
21	Detector Housing+Optics Tube	1	144	Al	0.094	0.038	0.178	0.038	76.9	0	0
22	Propulsion Tank	1	1	Ti	20.2	0.834			0	1.79	13702
23	RWA Housing	1	4	Al	6.3	0.351	0.132		68.5	0	0
24	RWA Flywheel	23	4	SS	2.7	0.326	0.109		0	2.49	1381
25	Torque Rod	1	3	Al	0.873	0.035	0.77		75.2	0	0
26	Torque Rod Coils	25	3	Cu	0.873	0.026	0.77		72.7	0	0
27	Torque Rod Core	26	3	Iron	1.745	0.023	0.77		61.4	0	0
28	Battery Box	1	1	Al	9.66	0.26	0.28	0.2	63.8	0	0
29	Battery Cell	28	8	Al	3.55	0.13	0.26	0.05	45.8	0	0
30	Structure	1	1	Gr\Ep	64	1.69	3		76.8	0	0

DCA = 11.09 m^2

Equivalent risk = 1:8,000

Non-Compliant for uncontrolled reentry.

Survives with > 15 J

- Maximum DCA for compliance < 8 m^2

"Total DCA" represent the sum of the DCA's of similar components in the row; the Kinetic Energy is given for an individual component in the row.

Other Disposal Requirements to Consider

Updated requirement, per NASA-STD-8719.14 Revision A:

> 4.6.2.4 *Requirement 4.6-4. Reliability of postmission disposal operations in Earth orbit*: NASA space programs and projects shall ensure that all post mission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows: (Requirement 56567)
>
> a. Be no less than 0.90 at EOM.
>
> b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.

- **If risk to human life > 0.0001 (1:10,000), then controlled reentry must be performed and the probability of failure of the reentry burn must be included in the risk calculation:**

  Risk of human casualty = DCA x Population density x Probability of failure of reentry burn

- **The Probability of failure (P_f) of reentry burn can not exceed 0.10 per Requirement 4.6-4.a.**

Debris Casualty Area (m2)	Probability of failure of reentry bu	Reliability
8	0.946305	0.053695
9	0.841160	0.158840
10	0.757044	0.242956
11	0.688222	0.311778
12	0.630870	0.369130
13	0.582342	0.417658
14	0.540746	0.459254
15	0.504696	0.495304
16	0.473153	0.526847
17	0.445320	0.554680
18	0.420580	0.579420
19	0.398444	0.601556
20	0.378522	0.621478

- Per Req. 4.6-4.b, for a DCA = 11 m^2, the maximum Probability of Success (Reliability) is 0.3118, which is less than 0.90. For this reason, the limit imposed by Req. 4.6-4.b takes precedence, and the minimum Probability of Success = 0.90.

Conclusions

- **Spacecraft is noncompliant for uncontrolled reentry.**
  - Orbital lifetime > 25 yrs.
  - Risk to human life > 1:10,000 of significant injury to humans on ground.
- **The use of controlled reentry to 50 x 700 km allows compliance with the requirements to limit the spacecraft orbital lifetime (Req. 4.6-1.a) and to limit the risk to humans on ground (Req. 4.7-1.a and .c).**
  - The worst-case scenario shows a risk to human life on ground due to objects surviving reentry of 1:8,000 (limit 1:10,000), with a DCA = 11.09 m^2.
    - 39% of the DCA is from the bus, 61% is from the OCE2 instrument.
    - The Polarimeter has not been included in the analysis because of lack of data. Final DCA may be higher once this instrument is analyzed.
  - Any DCA ≥ 8 m^2 results in non-compliance with the 1:10,000 limit.
    - The use of demisable tanks and RWA may reduce the DCA to 6.81 m^2.
- **An alternative EOM disposal strategy can be used to significantly reduce propellant and allow use of a demisable Al tank: controlled deorbit to 510 x 700 km, followed by uncontrolled reentry (see "Propulsion" charts 13 - 15) for a 1100 kg (dry mass) S/C, DCA will be reduced to 9.3 m^2, and risk to human injury reduced to 1 in 9,400, getting close to meet the < 1 in 10,000 requirement**
- **To confirm the reentry analysis results, it is recommended to request an ORSAT (Object Reentry Survival Analysis Tool) analysis from the Orbital Debris Program Office at JSC.**

Acronyms

- DCA – Debris Casualty Area
- EOM – End of Mission
- JSC – Johnson Space Center
- ORSAT – Object Reentry Survival Analysis Tool
- RWA – Reaction Wheel Assembly

BACKGROUND SLIDES

NASA TECHNICAL STANDARD

NASA-STD-8719.14A

National Aeronautics and Space Administration
Washington, DC 20546

Approved: 2011-12-08

Process for Limiting Orbital Debris

Requirements List

4.3 Assessment of Debris Released During Normal Operations

4.3.2 Requirements for the Control of Debris Released During Normal Operations

NASA programs and projects shall assess and limit the amount of debris released (Requirement 56396).

4.3.2.1 *Requirement 4.3-1: Debris passing through LEO*: For missions leaving debris in orbits passing through LEO, released debris with diameters of 1 mm or larger shall satisfy both Requirement 4.3-1a and Requirement 4.3-1b (Requirement 56397).

a. Requirement 4.3-1a: All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release (Requirement 56398).

b. Requirement 4.3-1b: The total object-time product shall be no larger than 100 object-years per mission (Requirement 56399). The object-time product is the sum of all debris of the total time spent below 2000 km altitude during the orbital lifetime of each object. (See section 4.3.4.2 for methods to calculate the object-time product.)

4.3.2.2 *Requirement 4.3-2: Debris passing near GEO*: For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees latitude), released debris with diameters of 5 cm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km (Requirement 56400).

4.4 Assessment of Debris Generated by Explosions and Intentional Breakups

4.4.2 Requirements for the Area

4.4.2.1 Accidental Explosions

Orbital debris analyses assess the probability of accidental spacecraft and launch vehicle orbital stage explosion during and after completion of deployment and mission operations.

4.4.2.1.1 Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

4.4.2.1.2 Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

4.4 Assessment of Debris Generated by Explosions and Intentional Breakups, cont.

4.4.2.2 Intentional Breakups

Orbital debris analyses evaluate the effect of intentional breakups of spacecraft and launch vehicle orbital stages on other users of space.

4.4.2.2.1 *Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups:* Planned explosions or intentional collisions shall:

a) Be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years (Requirement 56453). For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup.

b) Not generate debris larger than 1 mm that shall remain in Earth orbit longer than one year (Requirement 56454).

4.4.2.2.2 *Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:* Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10^{-6} (Requirement 56455).

4.5 Assessment of Debris Generated by On-orbit Collisions

4.5.2 Requirements for the Collision-induced Risk to Disposal Area

NASA programs and projects shall assess and limit the probability that the operating space system becomes a source of debris if it collides with orbital debris or meteoroids (Requirement 56505).

4.5.2.1 *Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit:* For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

4.5.2.2 *Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:* For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).

4.6 Postmission Disposal of Space Structures

4.6.2 Requirements for the Area

4.6.2.1 *Requirement 4.6-1. Disposal for space structures passing through LEO:* A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option:

- Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
- Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

4.6 Postmission Disposal of Space Structures, cont.

4.6.2.2 *Requirement 4.6-2. Disposal for space structures near GEO*: A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO with a predicted minimum perigee of GEO +200 km (35,986 km) or below GEO with an apogee of GEO – 200 km (35,586 km) for a period of at least 100 years after disposal (Requirement 56563).

4.6.2.3 *Requirement 4.6-3. Disposal for space structures between LEO and GEO*:

a) A spacecraft or orbital stage shall be left in an orbit with a perigee greater than 2000 km above the Earth's surface and apogee less than 500 km below GEO (Requirement 56565).

b) A spacecraft or orbital stage shall not use nearly circular disposal orbits near regions of high value operational space structures, such as between 19,200 km and 20,700 km (Requirement 56566).

4.6.2.4 *Requirement 4.6-4. Reliability of postmission disposal operations in Earth orbit*: NASA space programs and projects shall ensure that all post mission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows: (Requirement 56567)

a. Be no less than 0.90 at EOM.

b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.

4.7 Survival of Debris From the Postmission Disposal Earth Atmospheric Reentry Option

4.7.2 Requirements for the Area

NASA space programs and projects that use atmospheric reentry as a means of disposal for space structures need to limit the amount of debris that can survive reentry and pose a threat to people on the surface of the Earth. This area applies to full spacecraft as well as jettisoned components.

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

b) For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

4.8 Additional Assessment Requirements for Tether Missions

4.8.2 Requirements for the Area

Requirement 4.8-1. Mitigate the collision hazards of space tethers in Earth or Lunar orbits: Intact tether systems in Earth and lunar orbit shall meet the requirements limiting the generation of orbital debris from on-orbit collisions (Requirements 4.5-1 and 4.5-2) and the requirements governing postmission disposal (Requirements 4.6-1 through 4.6-4) to the limits specified in those paragraphs. Due to the potential of tether systems being severed by orbital debris or meteoroids, all possible remnants of a severed tether system shall be compliant with the requirements for the collision, debris, and disposal of space structures (Requirement 56652).