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Space systems — Design, Testing and Operation of a Spacecraft Large Constellation

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Introduction

There are more than dozen spacecraft large constellation programs planned to be launched in the early 2020s. This standard shows a set of standard practices for a large constellation program not to pose excessive collision risk to the other operating spacecraft and other constellations, and to sustain the orbital environment to be stable.

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1   Scope

A large constellation program (defined in 3.1) has fare that its exclusive use of the orbital environment poses the risk to other operating space assets and the orbital environment to be ensured the sustainable space activities in future, if it would not be designed or operated without concerning its risky side.

The contents of this document are taken into considerations in planning, designing, testing, operating and disposal activities for a constellation operated in the LEO protected region.

2   Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

2.1
(Spacecraft) Large constellation
A group of spacecrafts working together as a system.

2.2
TBD

3   Symbols and abbreviated terms

3.1 Symbols

(TBD)

3.2 Abbreviated terms

（TBD）

4   Requirements and recommendations

4.1   Mission design

4.1.1   Selection of operation orbit and collision avoidance

(1) Without reliable collision avoidance functions, the crowded orbital region (defined by the assessment of collision rate in the scheduled on-orbital lifetime) in the LEO protected region shall be avoided.

Another option : Satellite insertion, operational and disposal orbits shall be chosen to minimize collision risk and orbital lifetime, commensurate with mission objectives and constraints.

[Information: Actual application: OneWeb selected the low-density region, 12000 m.]

(2) The radial separation between large constellations shall be kept assuring a margin of safety under both nominal and anomalous operational conditions. *(Ref. SSC 3 a) i)* At least, an operational band in radial direction will be considered to keep the distance from the other constellations.

[Information: Actual application:
  (a) Oneweb takes 125-kilometer separation zone between constellations.
  (b) Kuiper takes 40 km above a Starlink constellation.
  (c) Starlink separates altitude >125 km from other constellations.]

(3) Constellation designers shall control to mitigate collision risk among their own spacecraft in the constellation. *(Ref. SSC 3 a) ii.)*

(4) ~~Constellation designers shall favor constellation designs which increase the time available to detect a failed spacecraft within their constellation and avoid colliding with it.~~ *~~(Ref. SSC 3 a) iii.)~~* (Moved to 4.2.1.2.(4) c))

4.2 Design of spacecraft

4.2.1 Debris mitigation design

Considering the effect of large number of spacecraft involving in the constellation, debris mitigation design required in ISO 24113 shall be fully applied including the limiting of releasing objects, prevention of break-up, successful disposal, etc.

Above all, for the constellations, following design measures are important.

4.2.1.1 Collision avoidance functions

Spacecraft shall have collision avoidance function, and resources for avoidance manoeuvres shall be allocated in design, as required in ISO 24113. Followings are specific requirements to a constellation.

4.2.1.2 Assurance of the successful disposal

The mission terminated spacecraft shall be successfully disposed by removal from the useful orbit region as soon as feasible, 25 years at latest, and by passivation. The probability of successful disposal shall be 0.95, as a target value. However, the probability can't be verified quantitatively during design or operation. It will be proven as a consequence of number of disposal practices. During design and operation, following measures (1) to (4) are required, in addition to the requirements in ISO 24113, to attain the probability would be higher than 0.95.

[NOTE 1: Constellation owners shall have statistical data of the probability as consequent of some numbers of disposal practices, and review the compliance, and will improve the design and operation manners, if the probability is smaller than expected, as required in 4.5.2.]

[NOTE 2: The probability is required to be 0.9 in ISO 24113, but in the case of constellation, it may allow 10 % of number of spacecraft in a constellation, which increases the collision risk largely in the useful orbital region.]

(1) Procedure for Determination of Mission Extension or Termination

For the proper decision to continue, extend or terminate the mission operation complying with the required probability of successful disposal, a "Procedure for Determination of Mission Extension or Termination" (see ISO-TR-18146) shall be developed. The procedure will prevent to extend operation period beyond the limit of the availability of the hardware or the resources, to clear the threshold for mission termination not to cause sudden death during operation, etc.

(2) Assurance of the availability of components that have useful time

a) The components and materials, whose useful time (including "operation life" and "storage time") is limited by degradation, shall be designed or selected to have enough margin to the spacecraft design life.

b) For the critical components, which have the limited operation time or cycles, and whose residual lifetime is worried, the procedure to record the operation log shall be developed to enable life analysis during operation to confirm that the residual life is enough.

c) If the operation period would be extended, the total operation period shall not be exceeded the "useful life" of any components used for disposal.

(3) Reliability of disposal function

The reliability of disposal function shall be calculated based on the world known failure rate database, the reasonable analysis conditions, etc. to demonstrate to be higher than 0.9 as a target value.

(4) Design of monitoring system and contingency planning

a) The measuring systems shall be designed to monitor the critical parameter to detect symptoms for defect potentially cause a break-up event or loss of disposal function.

b) A contingency plan shall be developed including off-nominal procedures for the case that abnormal data would be detected.

c) Constellation designers shall favour constellation designs which increase the time available to detect a failed spacecraft within their constellation and to take emergent action to prevent break-up, conduct disposal action, or avoid colliding with it. *(Ref. SSC 3 a) iii.)*

Another option: Monitoring system shall be designed to increase the time available to detect a failed spacecraft within their constellation and to take emergent action to prevent break-up, conduct disposal action, or avoid colliding with it.

d) As a contingency plan for the malfunction of disposal function, the spacecraft disposal shall be automatically initiated in the event of loss of power or contact with the spacecraft. *(Ref. FCC)*

[Actual application]
Kuiper;
a) In case the loss of contact beyond a "pre-determined wait period," automatically decommission, deorbit in 5 - 7 years
b) The decommissioning process involves orbit lowering, depleting batteries, emptying fuel lines and tanks, and ensuring charging circuits are "permanently switched off or fused"
c) Disposed within a year by propulsion,
d) use an "unpressurized non-explosive propellant storage" for a chemically inert fuel.]

e) The detail of monitoring system and the contingency plan shall be transferred to the operators.

4.2.1.3 Active removal as a supplemental measure for successful disposal

A contingency plan for the malfunction of disposal function, the active removal can be planed as a redundant measure and prepare the devices to aid the uncooperative capturing, if there are the reliable removal systems qualified.

Alternative option : Large constellation spacecraft can be designed to be maintainable, incorporating grappling mechanisms to support on-orbit servicing and to facilitate capture and deorbit in the event that the spacecraft becomes derelict.

[Actual application: OneWeb designs for removal enable uncooperative capture.]

4.2.1.4   Trackability

The spacecraft shall be designed to be independently trackable and readily identifiable by non-extraordinary means (e.g., beacons, corner reflectors, LED emitters, RCS augmentation), independent of operator intervention.

Another option: Enhance trackability by adding onboard active and/or passive components, if needed. *(Ref. IADC 2017)*

4.2.2   Minimize visual brightness

The spacecraft shall be designed to minimize visual brightness of their spacecraft, both during the checkout and operations phases, to limit disruptions to the astronomy and naked-eye observing communities with taking balance with 4.2.1.4.

*. [Information: Actual application: Starlink was design*ed to have sun visor for naked-e*ye observation.]*

4.2.3   Safe re-entry

(1) Since the difference of the re-entry casualty analysis methodology, there is no clear threshold of the expected number of casualty (Ec) in ISO standard. However, in the case of a large constellation, due to its large number of impacts on the ground, it shall be designed for demise as far as the states of technology allow it.

(2) Ec shall be evaluated on a system-wide, annual basis. *(Ref. SSC 4. d))*

[Actual application: OneWeb is challenging to the design for demise (materials)]

4.3   Testing

Precautions shall be taken to safeguard the environment from dead-on-arrival (DOA) deployments, particularly when launching spacecraft based on a new design*. Such precautions shall include one or more of the following: *(ref. SSC 3 b))*

(1) The design and production procedures of the components, sub-systems and spacecraft shall be verified through testing, analysis, demonstration or similarity without skipping any process even if the classification system would exist in manufacture, and might allow the tailoring of tests or analysis.

(2) As a part of verification, the qualification testing based upon established test standards and procedures to include [1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 in Biography] shall be conducted to all the components, sub-systems and spacecraft proto-flight (or proto-type) model.

(3) All critical components (including those required for maintain spacecraft control and perform active collision avoidance) must have been demonstrated on-orbit. *(Ref. SSC 3. B) ii.)*

(4) Before the delivery of all the components, sub-systems and spacecraft the acceptance testing based upon established acceptance test standards and procedures to include [1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 in Biography] shall be conducted without skipping any process. *(Ref. SSC 3. B) i.)*

(5) Before to injecting spacecraft into the planned operation orbit, they shall be injected into the parking orbit where a natural orbit lifetime of less than 25 years, and served to initial check-out to confirm not to have any defect caused by launch environment, etc. This is particularly critical when spacecraft is manufactured based upon a new design. *(Ref. SSC 3. B) iii.)*

[Actual application: (a) OneWeb launches into a 475 km orbit, test & checkout, and raise to 12000 km. (b) Kuiper conducts system checks below the ISS then raising to their target orbit.]

4.4 Safe operation

4.4.1 Data exchange

(1) Considering the large number of spacecraft in a constellation, and number of them will be deployed in a single launch, and they will travel from the parking orbit to operation orbit after check-out, flight path predictions, maneuver plans and spacecraft attitude and characteristics shall be exchanged with other operators for conjunction management and long-term sustainability purposes.

(2) Operators shall publish contact information for their satellite operations centers and maintain response times of less than one hour at all times.

4.4.2 Assurance of resources for disposal manoeuvre

The necessary resource for disposal manoeuvre shall be re-estimated at the mission termination with the latest solar activity, mass of spacecraft, degraded performance of the propulsion system, etc.

4.4.3 radio frequency interference

Large constellation spacecraft and operations shall be conducted in a manner that limits the potential for radio frequency interference (RFI) between themselves and other spacecraft and State Actors. At a minimum, ITU regulations and filings shall be strictly observed.

4.4.4 Monitoring and Contingency plan

(1) Monitoring the critical parameters to detect the symptom of malfunction.

(2) The operation log of the operation life limited items (see 4.2.1.2 (2) b)) shall be recorded, and life analysis shall be done to confirm that the residual life is enough.

(3) Monitoring the critical parameters to detect the symptom of malfunction shall be conducted, and, considering the effect of a failures occurred in a constellation, in case of detecting symptom of failures leading to catastrophic break-up, or loss of disposal functions it shall be notified to public. *(Ref. intention of the draft "International Code of Conduct for space activities".)*

(4) Constellations shall be configured such that constituent failures do not significantly elevate intra-constellation collision risk (e.g. by separating the orbit planes and radial profiles to avoid intersection points).

(5) If satellite failures occur during the deployment of a constellation, root cause(s) should be identified and corrected on the ground before additional satellites are launched.

4.5 Disposal

4.5.1 Disposal timing

A constellation owner and operator shall determine the termination of each spacecraft according to the Procedure for Determination of Mission Extension or Termination (defined in 4.2.1.2.1) to assure the successful disposal.

4.5.2 Disposal probability

The compliance with the probability of disposal to be more than 0.95 shall be proven as a consequence of operation and termination of several spacecraft.

If the symptom of incompliance with the requirement, the design and operation system shall be improved.

Biography

(1) ISO 11227: "Space systems — Test procedures to evaluate spacecraft material ejecta upon hypervelocity impact," available at https://www.iso.org/committee/46614/x/catalogue/ .
(2) ISO 10786: "Space Systems— Structural components and assemblies," available at https://www.iso.org/committee/46614/x/catalogue/ .
(3) ISO 14302: "Space systems — Electromagnetic compatibility requirements," available at https://www.iso.org/committee/46614/x/catalogue/ .
(4) ISO 14622: "Space systems — Structural design — Loads and induced environment," available at https://www.iso.org/committee/46614/x/catalogue/ .
(5) ISO 15864: "Space systems — General test methods for spacecraft, subsystems, and units," available at https://www.iso.org/committee/46614/x/catalogue/ .
(6) ISO 16454: "Space systems — Structural design — Stress analysis requirements," available at https://www.iso.org/committee/46614/x/catalogue/ .
(7) ISO 16781: "Space systems — Simulation requirements for control system," available at https://www.iso.org/committee/46614/x/catalogue/ .
(8) ISO 17566: "Space systems — General test documentation," available at https://www.iso.org/committee/46614/x/catalogue/ .
(9) ISO 19683: "Space systems — Design qualification and acceptance tests of small spacecraft and units," available at https://www.iso.org/committee/46614/x/catalogue/ .
(10) ISO 19924: "Space systems — Acoustic testing," available at https://www.iso.org/committee/46614/x/catalogue/ .
(11) ISO 19933: "Space systems — Format for spacecraft launch environmental test report," available at https://www.iso.org/committee/46614/x/catalogue/ .
(12) ISO 21648: "Space systems — Flywheel module design and test," available at https://www.iso.org/committee/46614/x/catalogue/ .
(13) ISO 23038: "Space systems — Space solar cells— Electron and proton irradiation test methods," available at https://www.iso.org/committee/46614/x/catalogue/ .
(14) ISO 24637: "Space systems — Electromagnetic interference (EMI) test reporting requirements," available at https://www.iso.org/committee/46614/x/catalogue/ .
(15) ISO 24638: "Space systems — Pressure components and pressure system integration," available at https://www.iso.org/committee/46614/x/catalogue/ .
(16) ISO 26871: "Space systems — Explosive systems and devices," available at available at https://www.iso.org/committee/46614/x/catalogue/ .
(17) ISO 14623: "Space systems — Pressure vessels and pressurized structures — Design and operation," available at https://www.iso.org/committee/46614/x/catalogue/ .
(18) ISO TR 18146: "Space systems — Design and operation guidelines for spacecraft operated in the debris environment," available at https://www.iso.org/committee/46614/x/catalogue/ .
(19) NASA General Environmental Verification Standard, available at https://standards.nasa.gov/standard/gsfc/gsfc-std-7000
(20) NASA-STD-7002, "Payload Test Requirements," available at https://standards.nasa.gov/file/2773/download?token=KJiLHl1h