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Inter-Agency Space Debris Coordination Committee

IADC Statement on Large Constellations of Satellites in Low Earth Orbit

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Revision History

Issue	Revision	Date	Reason for Revision
1	0	2017-11-10	Initial published version
1	1	2021-07-06	Update based on AI 33.1 "Review of environmental impact of small satellites and large constellations"

List of Abbreviations

Abbreviation	Description
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CSA	Canadian Space Agency
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ESA	European Space Agency
IADC	Inter-Agency Space Debris Coordination Committee
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
PMD	Post Mission Disposal
ROSCOSMOS	Russian State Space Corporation ROSCOSMOS
SSAU	State Space Agency of Ukraine
UKSA	United Kingdom Space Agency

1 Background

The Inter-Agency Debris Coordination Committee (IADC) was established to exchange information on space debris research activities between its member space agencies. The IADC currently comprises the Italian Space Agency (ASI), the Centre National d'Etudes Spatiales (CNES), China National Space Administration (CNSA), Canadian Space Agency (CSA), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), the European Space Agency (ESA), the Indian Space Research Organisation (ISRO), Japan Aerospace Exploration Agency (JAXA), the Korea Aerospace Research Institute (KARI), the National Aeronautics and Space Administration (NASA), the Russian State Space Corporation ROSCOSMOS (ROSCOSMOS), the State Space Agency of the Ukraine (SSAU), and the UK Space Agency (UKSA).

In addition to reviewing all on-going cooperative space debris research activities between its member organizations, the IADC recommends new opportunities for cooperation, serves as the primary means for exchanging information and plans concerning orbital debris research activities, and identifies and evaluates options for debris mitigation.

As appropriate, the IADC communicates the findings of its work to the wider space community such as the IADC Space Debris Mitigation Guidelines first published in 2002, and subsequently updated in 2007, 2020 and 2021. These IADC Guidelines informed, and provided the basis for, the development of the Space Debris Mitigation Guidelines of the United Nations (UN) Committee on the Peaceful Uses of Outer Space, which were endorsed by the UN General Assembly in its resolution 62/217, dated 22 December 2007.

2 Rationale

At its 33rd meeting in Houston in March 2015, the IADC noted the emerging plans for large constellations of spacecraft in Low Earth Orbit (LEO) and recognised the potential for such systems to have an important influence on the evolution of the space debris environment and consequent impact on the population of human-made spacecraft orbiting the Earth. Accordingly, in March 2015, the IADC committed to conduct a series of investigations and analyses to investigate the potential risk posed by such constellation systems and consider potential mitigation actions, which could help inform the design and operation of such distributed architectures to ensure that they are developed in a predictable and sustainable manner. A number of its independent member agencies undertook to perform a series of coordinated computer simulations and conduct a comparative study to evaluate the results and identify key issues/influences, and seek to communicate its findings to the wider space community. Finally, in April 2017, the IADC converged on a study program bundling the expertise of space debris environment modelling experts in order to assess the outcome of such constellation traffic as a function of various technical factors. This was done with the help of independent models, leading to a consolidated view on the influence of key parameters.

Recognising in 2017 that a number of constellation architectures were in the process of development, and that timely guidance could help to inform the design and operation of such systems, the IADC intended to follow a two-track approach to address this issue. First, based on the outcome of initial reflections, it offered a number of preliminary qualitative observations that operators could consider in their conceptual design.

With this revision, as more substantive and comprehensive modelling data became available from the coordinated international studies, more detailed and quantitative guidance is offered to inform the design and operation of such constellation systems.

3 Considerations for large constellations of satellites

The IADC first seeks to reinforce the relevance of its existing space debris mitigation measures to constellation architectures, as reflected in the IADC and UN Space Debris Mitigation Guidelines, the most pertinent aspects of which can be summarised as follows:

- Spacecraft and orbital stages should be designed not to release debris during normal operations.
- The potential for break-ups during mission should be minimised
- All space systems should be designed and operated so as to prevent accidental explosions and ruptures after end-of mission.
- In order to limit the risk to other spacecraft and orbital stages from accidental break-ups after the completion of mission operations, all on-board sources of stored energy of a spacecraft or orbital stage, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels and momentum wheels, should be depleted or made safe when they are no longer required for mission operations or post-mission disposal.
- During the design of spacecraft or orbital stages, each program or project should demonstrate, using failure mode and effects analyses or an equivalent analysis, that there is no probable failure mode leading to accidental break-ups.
- During the operational phases, a spacecraft or orbital stage should be periodically monitored to detect malfunctions that could lead to a break-up or loss of control function. In the case that a malfunction is detected, adequate recovery measures should be planned and conducted; otherwise disposal and passivation measures for the spacecraft or orbital stage should be planned and conducted.
- Intentional destruction of a spacecraft or orbital stage, (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other spacecraft and orbital stages should be avoided.
- Whenever possible spacecraft or orbital stages that are terminating their operational phases in orbits that pass through the Low Earth Orbit (LEO) region, or have the potential to interfere with the LEO region, should be de-orbited (direct re-entry is

preferred) or where appropriate manoeuvred into an orbit with a reduced lifetime. Retrieval is also a disposal option.

- A spacecraft or orbital stage should be left in an orbit in which, using an accepted nominal projection for solar activity, atmospheric drag will limit the orbital lifetime after completion of operations to maximum of 25 years.
- The probability of success of post mission disposal should be at least 90%.
- If a spacecraft or orbital stage is to be disposed of by re-entry into the atmosphere, debris that survives to reach the surface of the Earth should not pose an undue risk to people or property.
- In developing the design and mission profile of a spacecraft or orbital stage, a program or project should estimate and limit the probability of accidental collision with known objects during the spacecraft or orbital stage's orbital lifetime. If reliable orbital data is available, avoidance manoeuvres for spacecraft and co-ordination of launch windows may be considered if the collision risk is not considered negligible.
- Spacecraft design should limit the consequences of collision with small debris, which could cause a loss of control, thus preventing post-mission disposal.

At this stage (in 2021), it is clear that the significant numbers of spacecraft envisaged in constellation architectures represent a step change in the number of spacecraft operating in the low Earth orbit regime. This change calls into question the validity of the assumptions used to derive the existing space debris mitigation guidelines (e.g. launch traffic models and the numbers of objects in orbit). Significant effort has been put into analysing the robustness of the existing debris mitigation guidelines to manage effectively the new constellations and their impact on the orbital environment in a sustainable manner (e.g. the 25-year lifetime may need to be reduced to limit residence times in orbit).

Another key consideration is the reliability of critical systems and functionality such as end of life disposal, which, amongst other things depends on technological maturity, design choices, and operational concepts and practices. It is clear that significant improvements in the reliability of the disposal function at end of life will be needed for the new constellations compared with that currently demonstrated by space systems on orbit.

With the anticipated number of orbital objects required to establish, maintain and refresh the new architectures, the greatest impact, at least in the short term is on the constellations themselves, in terms of possible close approaches, and the consequent potential burden in terms of conjunction assessment and the possible need for avoidance manoeuvres, which must be accounted for with respect to fuel margins and platform lifetimes. In the long term, the effects of insufficient measures taken by operators of large constellations could spread to other operators. In addition to impacting the long-term space environment in the vicinity of the constellation's mission orbit, there can be impacts on those regions crossed in reaching or disposing from the mission orbit, and these should also be considered and addressed.

4 IADC Considerations in View of Large Constellation Deployment in Low Earth Orbit

4.1 General

Some concepts for large constellations in LEO target at operational altitudes above 1000km. This is far higher than the average space traffic into LEO. It is well known that average natural atmospheric drag induced orbital lifetimes (from end of mission to natural atmospheric re-entry) increase exponentially with altitude. For typical spacecraft, above 1000km these average orbital lifetimes are quasi eternal. Therefore, reliable and effective measures to reduce the post mission orbital lifetime to acceptable limits should be a prime focus for such missions. The IADC has identified the success of such disposal actions as one of the key drivers for the environmental sustainability of these missions.

Also concepts of large constellations in LEO with operational altitudes below 1000km, or even in orbits compliant with the 25-year lifetime limit, have an impact on the space environment. Whether or not a constellation spacecraft or associated launch vehicle orbital state is operational, it increases the burden of administering operational processes used to avoid potential collisions in LEO. Collisions and explosions in lower LEO orbits have the potential to create space debris with long orbital lifetimes in higher orbits and are hence to be avoided.

It is obvious that the negative environmental consequences of failure to implement guidelines are significantly more severe for constellations compared to the common space mission architectures, solely and simply driven by the large numbers of similar spacecraft involved. A design or fabrication flaw has the potential to affect many spacecraft on orbit.

All constellations spacecraft including spares and associated launch vehicle orbital stages should at the very least individually follow the IADC mitigation guidelines. However, the space environmental impact of constellation scales with, among others, the number of spacecraft and associated objects involved, their masses, and orbits used. As such, when planning operational characteristics, e.g. post mission disposal success rate, orbital lifetime of the disposal orbits, or operational orbit height, the constellation should account for its collective impact on the space environment.

The purpose of this chapter is to provide additional considerations on how adherence to the IADC mitigation guidelines (see previous chapter) can be achieved by such missions. It should be noted that these do not mean additional or expansion of IADC guidelines, but technical guidance on how to best comply with them. In practice, large constellations will likely require a combination of several of these technical parameters for purposes of mitigating space debris.

4.2 Constellation Design

4.2.1 Altitude Separation

A large amount of spacecraft operating in each other's vicinity increases the probability of collisions in case of contingency and the risk coming from feedback effects in case of explosive or collisional break-up. Strategies can be adopted by design to minimise these risks, e.g. through phasing and control of individual eccentricity vectors (i.e. eccentricity and perigee location) for each orbit plane, thus leading to altitude separations at orbit plane crossings.

- It is recommended to consider sufficient altitude separation between all parts of the constellation in order to minimise the potential collision risk among constellation members.
- Altitude separations at intersections between orbital planes of a constellation have shown to provide positive environmental effects if significant enough to avoid inter-plane conjunctions.
- It is recommended to consider sufficient altitude separation with respect to other large constellations, highly utilised orbits, and other space debris dense orbits in order to minimise the potential collision risk.

4.2.2 Operational orbits

There is a strong relationship between the number of spacecraft failures on orbit and the associated impact on the space environment. This also has direct consequences for the workload connected with conjunction assessment and potential collision avoidance. High values of post mission disposal (PMD) success rates can be achieved by selecting appropriate orbits with naturally limited orbital lifetimes.

- Consider a constellation design and operations that will minimise the likelihood of on orbit collision during all operational phases and after disposal of the constellation spacecraft and associated launch vehicles stages.

4.2.3 Number of spacecraft and configuration

The IADC mitigation guidelines include a target for post mission disposal success rate of no less than 90% for a single spacecraft, but for even a single constellation with a large number of spacecraft, and associated launch vehicle upper stages, amounting to several hundreds to thousands or more objects, this target is insufficient to avoid detrimental evolution of the debris environment, particularly for higher altitude orbits. The minimum disposal success rate should be set accordingly. Each spacecraft in a large constellation should have a probability of successful post mission disposal at a level greater than 90% with a goal of 99% or better. In determining the successful post mission disposal threshold, factors such as mass, collision probability, orbital location, the total number of spacecraft to be deployed taking into account spare spacecraft and spacecraft replenishment rates, and other relevant parameters should be considered. As such, trade-offs between the space environmental impact of a constellation and its design, e.g. at low altitude with short orbital lifetimes but more active operations versus at higher altitude with currently fewer operational hazards but longer orbital lifetimes in case of failure, should be considered.

- Consider a constellation design and configuration, in terms of masses, collision probability, orbital location, the total number of spacecraft to be deployed taking into account spare spacecraft and spacecraft replenishment rates, and other relevant parameters of spacecraft and launch vehicle orbital stages, such that the probability of successful disposal is significantly above 90% and remaining orbital lifetimes after disposal well below 25 years.

4.3 Spacecraft Design

4.3.1 Reliability of the Post Mission Disposal Function

The probability of post mission disposal across all objects in orbit is a driving factor for the stability of the space debris environment, and achieving at least 90% success is already needed in a scenario without large constellations to minimise the risk of instability. The reliability of the post mission disposal function will thus have a major impact on the orbital environment, in particular for constellations that consist of a large number of spacecraft operating at high altitudes within LEO. The following measures are therefore recommended:

- Design for sufficient on-board redundancies of all functions involved in the post mission disposal.
- Design of a monitoring function for the post mission disposal capability.
- The spacecraft design and operations should maximise the reliability to contribute to a probability of success of the disposal significantly above 90%.

4.3.2 Design measures to minimize consequences of break-ups

- Consider a spacecraft design that will minimise the likelihood of break-up during the mission as well as after the disposal. This includes explosive break-ups as well as those caused by impacts due to space debris and micrometeoroid particles.
- Consider in the design a capability for collision avoidance during the mission and disposal phase, and any residual orbital lifetime.

4.3.3 On-ground Risk

During the operation of one or more large constellations, several hundred uncontrolled re-entries can be expected per year. Even if the on-ground risk is moderate on a per spacecraft basis, it will accumulate. To reduce the on-ground risk, it is recommended that the operator consider at least one of the following:

- Consider performing a controlled re-entry.
- Consider spacecraft design options that eliminate entirely or reduce the number and size of harmful fragments impacting ground.

4.3.4 Structural Integrity

Today, accidental explosions are responsible for a significant number of fragments in LEO. Sound implementation of passivation measures according to the IADC guidelines and the associated support documents are, thus, essential.

- Consider high overall spacecraft reliability design to minimise the probability of accidental explosions during operation and improve the likelihood of successful post mission disposal.

Often, critical components/designs leading to accidental explosions are only identified years after launch/operation in orbit, if at all. For example, battery designs which have resulted in explosions during or after operations have only become apparent after a few years in space, after a certain number of duty cycles, or as soon as certain temperatures are reached in non-nominal attitude or non-nominal orbits (often years) after operations.

For large constellations, systemic problems may be manifested due to the large numbers of the same spacecraft series and the associated short production times involved. It is possible that the first of such unanticipated failures occurs once the whole of the series is launched so that design retrofit is not a viable option. New technology has the potential to allow automatic passivation of spacecraft after loss of contact in a safe manner (e.g. electromagnetic cable cutters / valves that react upon loss of voltage) and could be triggered after certain criteria are met (e.g. given time estimates for recovery operations or linked with an on-board assessment of the severity of the anomaly).

- Prior to large scale deployment, it is recommended to test and demonstrate the robustness of spacecraft design, and in particular robustness of systems needed for debris mitigation activities, in a representative environment.

4.3.5 Trackability

The load on space surveillance systems will grow dramatically with the deployment of large constellations. Likewise, the number of conjunction events in these altitudes will grow. Enhancing trackability, e.g. by adding on-board active and/or passive components can improve the orbit determination and prediction. This would have positive impact on conjunction analysis.

- It is recommended to enhance trackability by adding on-board active and/or passive components.

- It is recommended to provide information on planned trajectories prior to performing orbit transfer manoeuvres (e.g. during deployment to the operational orbit and disposal) and to regularly update this information as such manoeuvres proceed.

4.4 Launch Vehicle Orbital Stage Design

Upper stages may operate near the constellation altitude, which raises the same mitigation issues as for the spacecraft they deliver to orbit. The uncontrolled re-entry of upper stages might also raise on-ground safety issues. Strict adherence to the same mitigation guidelines as laid out in ◎ is therefore essential.

4.5 Operations

4.5.1 Collision Avoidance

Active collision avoidance brings benefit, both to the integrity of the constellation and the wider space environment. The overall number of conjunction alerts raised for the constellation spacecraft may have a strong impact on operations of the constellation and other operators. Efficient processes are required to manage this conjunction analysis and collision avoidance. The many avoidance manoeuvres could come on top of routine manoeuvres for constellation management, including during the ascent and descent phase. This means that efficient and open communication with surveillance networks and/or other concerned operators is required for the timely sharing of relevant data.

- Operational collision avoidance should be performed.
- Manoeuvre plans should be communicated to the relevant actors in a timely manner.
- Collision avoidances capabilities should be maintained during the disposal phase.

4.5.2 Disposal Strategy

IADC simulations have clearly shown that a post mission disposal towards sufficiently low altitude is preferred over orbit raising to above 2000km. In view of the large constellations, the latter could ultimately lead to the onset of collisional cascading in altitudes above 2000km, with consequent negative effects to lower altitudes. Depending on the constellation design and operations, the remaining orbital lifetime of constellation after post mission disposal can have a significant effect on the space environment and the operational collision avoidance of other operators.

- Following the post mission disposal 25-year orbital lifetime limit has fewer negative long-term effects to the environment, but shorter lifetimes should be considered.
- To further limit the potential negative effects to the environment, operators are encouraged to consider additional measures beyond the existing guidelines, such as shortening post mission disposal lifetime and maintaining the collision avoidance capability during the post mission disposal phase.
- Monitor on a regular basis the availability of the post mission disposal function and initiate disposal actions as soon as the probability of successful post mission disposal drops to a critical level, even if design lifetime is not reached.

- ➢ For circular disposal orbits, an altitude variability should be applied to avoid creating highly utilised orbits.
- ➢ For eccentric disposal orbit, the apogee should clear the operational altitude at the epoch of disposal and the perigee should be selected to avoid creating highly utilised orbits.

4.5.3 Launch and Early Operations

Interaction with the environment can be reduced by using an intermediate (lower) injection altitude for deployment and early operations. Using sufficiently low intermediate injection altitudes also provides the opportunity to check-out the system in an environment that is naturally compliant w.r.t. the 25-year post mission disposal orbital lifetime.

In light of the reliability issues discussed prior, strict operational procedures aimed at discovering issues with the associated series manufacturing for constellations should be implemented. This can include performing the early operations in a region without direct consequence for the space environment or other operators before reaching the operational altitude.

- ➢ For early operations and/or testing, consider injecting spacecraft in orbital regions with low space object density, and ensured short orbital lifetimes.