



1. Form 4: 2. New Work Item Proposal (NP)

Circulation date 2020-04-27	Reference number: Enter Number (to be given by ISO Central Secretariat)
Closing date for voting Click here to enter a date.	ISO/TC 20 /SC 14
Proposer <input checked="" type="checkbox"/> ISO member body: Click here to enter text. <input type="checkbox"/> Committee, liaison or other ¹ : Click here to enter text.	<input type="checkbox"/> Proposal for a new PC N Click here to enter text.
Secretariat Click here to enter text.	

A proposal for a new work item within the scope of an existing committee shall be submitted to the secretariat of that committee.

¹The proposer of a new work item may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General. See ISO/IEC Directives Part 1, [Clause 2.3.2](#).

The proposer(s) of the new work item proposal shall:

- make every effort to provide a first working draft for discussion, or at least an outline of a working draft;
- nominate a project leader;
- discuss the proposal with the committee leadership prior to submitting the appropriate form, to decide on an appropriate development track (based on market needs) and draft a project plan including key milestones and the proposed date of the first meeting.

The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information.

IMPORTANT NOTE

Proposals without adequate justification risk rejection or referral to originator.

Guidelines for proposing and justifying a new work item are contained [in Annex C of the ISO/IEC Directives, Part 1](#).

- The proposer has considered the guidance given in the Annex C during the preparation of the NP.

Resource availability:

- There are resources available to allow the development of the project to start immediately after project approval* (i.e. project leader, related WG or committee work programme).

* if not, it is recommended that the project is first registered as a preliminary work item (a Form 4 is not required for this) and when the development can start, Form 4 should be completed to initiate the NP ballot.

Proposal (to be completed by the proposer, following discussion with the committee leadership)

Title of the proposed deliverable

English title

Space Systems – Design, Testing and Operation of a Spacecraft Large Constellation

French title (if available)

Systèmes spatiaux - Les exigences particulières de la conception, le test, le fonctionnement, et l'élimination des grandes constellations

(In the case of an amendment, revision or a new part of an existing document, include the reference number and current title)

Scope of the proposed deliverable

This standard will address aspects that are unique or especially important to large constellations of spacecraft, including mission design, spacecraft design, operation and disposal, to promote safe spacecraft operations and the preservation of the orbital environment to ensure the long-term sustainability of space activities. It will include the selection of the large constellation's operational orbit, quality assurance required to successfully complete the mission, methodologies to assure safe operations for all the space users and on-ground residents, mitigation of space debris generation, and the proper disposal of large constellation spacecraft.

Existing ISO standards provide basic requirements to address some of these aspects. But large constellations, which could conceivably lead to a tenfold increase in the number of spacecraft flown within the next decade, may require that unique, more stringent requirements are imposed beyond the current traditional space utilization-based requirements. The goal of this proposed standard is to codify existing large constellation best practices and expected norms of behaviour proactively to meet this burgeoning space utilization use case.

Purpose and justification of the proposal

Globally, the commercial space industry has filed applications for nearly 60,000 new large constellation spacecraft within the next ten years. While only a portion of these applications will give rise to operational spacecraft, we anticipate the active spacecraft population to be four to ten times larger within the next decade. This year alone, it is on track to double.

This “system of systems” set of large constellation spacecraft will introduce many new spacecraft manufacturers and operators to the complexities of mission and spacecraft design, testing, launch, deployment and on-orbit operations, data exchange, and disposal. This standard is needed to codify requirements and expected norms of behaviour for large constellations to ensure that this burgeoning one to three trillion-dollar space economy is on a stable and sustainable path.

Consider the following:

Is there a verified market need for the proposal?

What problem does this document solve?

What value will the document bring to end-users?

See [Annex C](#) of the ISO/IEC Directives part 1 for more information.

See the following guidance on justification statements in the brochure ‘Guidance on New work’: <https://www.iso.org/publication/PUB100438.html>

Please select any UN Sustainable Development Goals (SDGs) that this document will support. For more information on SDGs, please visit our website at www.iso.org/SDGs.

- GOAL 1:** No Poverty
- GOAL 2:** Zero Hunger
- GOAL 3:** Good Health and Well-being
- GOAL 4:** Quality Education
- GOAL 5:** Gender Equality
- GOAL 6:** Clean Water and Sanitation
- GOAL 7:** Affordable and Clean Energy
- GOAL 8:** Decent Work and Economic Growth
- GOAL 9:** Industry, Innovation and Infrastructure
- GOAL 10:** Reduced Inequality
- GOAL 11:** Sustainable Cities and Communities
- GOAL 12:** Responsible Consumption and Production
- GOAL 13:** Climate Action
- GOAL 14:** Life Below Water
- GOAL 15:** Life on Land
- GOAL 16:** Peace and Justice Strong Institutions
- N/A **GOAL 17:** Partnerships to achieve the Goal

Preparatory work

(An outline should be included with the proposal)

- A draft is attached
- An outline is attached
- An existing document will serve as the initial basis

The proposer or the proposer's organization is prepared to undertake the preparatory work required: Yes No

If a draft is attached to this proposal

Please select from one of the following options (note that if no option is selected, the default will be the first option):

- Draft document can be registered at Working Draft stage (WD – stage 20.00)
- Draft document can be registered at Committee Draft stage (CD – stage 30.00)
- Draft document can be registered at Draft International Standard stage (DIS – stage 40.00)
- If the attached document is copyrighted or includes copyrighted content, the proposer confirms that copyright permission has been granted for ISO to use this content in compliance with [clause 2.13](#) of the ISO/IEC Directives, Part 1 (see also the [Declaration on copyright](#)).

Is this a Management Systems Standard (MSS)?

- Yes No

NOTE: if Yes, the NP along with the Justification study (see Annex SL of the Consolidated ISO Supplement) must be sent to the MSS Task Force secretariat (tmb@iso.org) for approval before the NP ballot can be launched.

Indication of the preferred type or types of deliverable to be developed

- International Standard
- Technical Specification
- Publicly Available Specification

Proposed Standard Development Track (SDT)

To be discussed between proposer and Secretary considering, for example, when does the market (the users) need the document to be available, the maturity of the subject etc.

- 18 months* 24 months 36 months 48 months

* Projects using SDT 18 are eligible for the 'Direct publication process' offered by ISO /CS which reduces publication processing time by approximately 1 month.

Draft project plan (as discussed with committee leadership)

Proposed date for first meeting: 2020-06-15

Proposed dates for key milestones:

1st Working Draft (if any) circulated to experts: 2020-07-15

Committee Draft ballot (if any): 2020-10-15

DIS submission*: 2021-02-15

Publication*: 2021-06-15

* Target Dates on DIS submission and Publication should preferably be set a few weeks ahead of the limit dates (automatically given by the selected SDT).

For guidance and support on project management; descriptions of the key milestones; and to help you define your project plan and select the appropriate development track, see: go.iso.org/projectmanagement

NOTE: The draft project plan is later used to create a detailed project plan, when the project is approved.

Known patented items (see ISO/IEC Directives, Part 1, [clause 2.14](#) for important guidance)

Yes No

If "Yes", provide full information as annex

Co-ordination of work

To the best of your knowledge, has this or a similar proposal been submitted to another standards development organization?

Yes No

If "Yes", please specify which one(s):

[Click here to enter text.](#)

A statement from the proposer as to how the proposed work may relate to or impact on existing work, especially existing ISO and IEC deliverables. The proposer should explain how the work differs from apparently similar work, or explain how duplication and conflict will be minimized

As stated above ("Scope"), this standard will focus on the unique aspects associated with Large Constellations. For any/all aspects deemed to not be legitimately unique to large constellations, this standard will incorporate by reference compliance with the existing ISO standards for these disciplines, such as the subset of ISO standards included in the referenced documents below:

A listing of relevant existing documents at the international, regional and national levels

10784: Space systems — Early operations
 14302: Space systems — Electromagnetic compatibility requirements
 14620: Space systems — Safety requirements
 14622: Space systems — Structural design
 14623: Space systems — Pressure vessels and pressurized structures - Design and operation
 14950: Space systems — Unmanned spacecraft operability
 15864: Space systems — General test methods for spacecraft, subsystems, and units
 16126: Space systems — Space systems - Survivability of unmanned S/C against impacts
 16127: Space systems — Prevention of break-up of unmanned spacecraft
 16158: Space systems — Avoiding collisions with orbiting objects
 16164: Space systems — Disposal of satellites operating in or crossing Low Earth Orbit
 16679: Space systems — Relative motion analysis elements after LV/SC separation
 17666: Space systems — Risk management
 18146: Space systems — Space debris mitigation design, operation guidelines for spacecraft
 20188: Space systems — Product assurance requirements for commercial satellites
 23041: Space systems — Unmanned spacecraft operational procedures — Documentation
 23339: Space systems — Unmanned S/C residual propellant mass estimation for disposal DV
 24113: Space systems — Space debris mitigation requirements
 26872: Space systems — Disposal of satellites operating at geosynchronous altitude
 26900: Space systems — Space data and information transfer— Orbit data messages
 27852: Space systems — Estimation of orbit lifetime
 27875: Space systems — Re-entry risk management for unmanned S/C and LV stages
 IADC Space Debris Guidelines
 IADC Statement on Large Constellations
 U.S. Space Policy Directive 3:
 U.S. Orbital Debris Mitigation Standard Practices 2019
 Space Safety Coalition’s Best Practices for the Sustainability of Space Operations
 (and many other national and international guidelines and regulations)

Please fill out the relevant parts of the table below to identify relevant affected stakeholder categories and how they will each benefit from or be impacted by the proposed deliverable(s)

	Benefits/impacts	Examples of organizations/companies to be contacted
Industry and commerce – large industry	This standard will provide guidance and normative mandates to Large Constellation spacecraft manufacturers, mission designers, and operators to promote the responsible and sustainable use of outer space.	Large constellation owners, operators, satellite designers and builders, industry associations.
Industry and commerce – SMEs	This standard will provide guidance and normative mandates to SMEs to promote the responsible and sustainable use of outer space.	Large constellation owners, operators, satellite designers and builders, industry associations.

Government	This standard will provide guidance and normative mandates for potential interpretation and adoption by government entities when assembling government regulations related to the responsible and sustainable use of outer space.	Space State Actors
Consumers	Click here to enter text.	Click here to enter text.
Labour	Click here to enter text.	Click here to enter text.
Academic and research bodies	This standard can provide research institutions and universities with relevant areas where research would best benefit space sustainability and large constellation operator efficiency and commercial feasibility.	Universities, research institutions.
Standards application businesses	Click here to enter text.	Click here to enter text.
Non-governmental organizations	This standard can offer guidance and insight into ways that NGOs can propose and adopt best practices for Large Constellations in their aspirational and educational content.	Space Safety Coalition
Other (please specify)	Click here to enter text.	Click here to enter text.
<p>Liaisons</p> <p>A listing of relevant external international organizations or internal parties (other ISO and/or IEC committees) to be engaged as liaisons in the development of the deliverable(s).</p> <p>Click here to enter text.</p>	<p>Joint/parallel work</p> <p>Possible joint/parallel work with</p> <p><input type="checkbox"/> IEC (please specify committee ID) Click here to enter text.</p> <p><input type="checkbox"/> CEN (please specify committee ID) Click here to enter text.</p> <p><input type="checkbox"/> Other (please specify) Click here to enter text.</p>	
<p>A listing of relevant countries which are not already P-members of the committee</p> <p>Click here to enter text.</p> <p>NOTE: The committee manager shall distribute this NP to the ISO members of the countries listed above to ask if they wish to participate in this work</p>		

<p>Proposed Project Leader (name and e-mail address)</p>	<p>Name of the Proposer (include contact information)</p>
<p>WG1: Akira Kato, zr824774@tc5.so-net.ne.jp WG3: Dan Oltrogge, oltrogge@agi.com</p>	<p>Akira Kato, zr824774@tc5.so-net.ne.jp Dan Oltrogge, oltrogge@agi.com</p>
<p>This proposal will be developed by</p>	
<p><input checked="" type="checkbox"/> An existing Working Group (please specify which one: SC14 WG1 and 3) <input type="checkbox"/> A new Working Group (title: Click here to enter text.) (Note: establishment of a new WG must be approved by committee resolution) <input type="checkbox"/> The TC/SC directly <input type="checkbox"/> To be determined</p>	
<p>Supplementary information relating to the proposal</p>	
<p><input checked="" type="checkbox"/> This proposal relates to a new ISO document; <input type="checkbox"/> This proposal relates to the adoption as an active project of an item currently registered as a Preliminary Work Item; <input type="checkbox"/> This proposal relates to the re-establishment of a cancelled project as an active project. <input type="checkbox"/> Other: Click here to enter text.</p>	
<p>Maintenance agencies (MA) and registration authorities (RA)</p>	
<p><input type="checkbox"/> This proposal requires the service of a maintenance agency. If yes, please identify the potential candidate: Click here to enter text.</p> <p><input type="checkbox"/> This proposal requires the service of a registration authority. If yes, please identify the potential candidate: Click here to enter text.</p>	
<p>NOTE: Selection and appointment of the MA or RA is subject to the procedure outlined in the ISO/IEC Directives, Annex G and Annex H, and the RA policy in the ISO Supplement, Annex SN.</p>	
<p><input checked="" type="checkbox"/> Annex(es) are included with this proposal (give details)</p>	
<p>(1) Outline of Large Constellation standard (2) Draft standard</p>	
<p>Additional information/questions</p>	
<p>This item will be developed and reviewed mainly in WG1 and WG3 with support of WG7.</p>	

Outline of “Space Systems – Design, Testing and Operation of a Spacecraft Large Constellation”

1. Scope

This standard will address aspects that are unique or especially important to large constellations of spacecraft, including mission design, spacecraft design (including debris mitigation design, verification, etc.), testing (including acceptance testing, on-orbital check-out, etc.), operation (including launch and on-orbit collision avoidance, space data exchange, etc.) integration of demanding launch schedules into civil and commercial airspace, optical brightness disruption to astronomy and naked eye observing, Radio Frequency Interference (RFI) and disposal. For those aspects deemed to not be unique to large constellations, this standard will incorporate by reference compliance with the existing ISO standards for these disciplines.

3. Definition of a Large Constellation

- a. *NOTE: A commonly accepted definition of a “large constellation” is 100 spacecraft or more, but hinging the definition upon a rather arbitrary spacecraft quantity will face the same difficulties that arose when arbitrarily defining a small satellite. Recall that it was the consensus of many Working Groups that standards are not necessarily driven by the size (or quantity) of spacecraft... To be discussed.*

4. Requirements unique or particularly important to large constellations

The sheer quantity of spacecraft underscores the need to standardize the design, testing and operations of Large Constellation spacecraft. Broad considerations for such constellations include:

- Mission design
- Design of spacecraft and launch vehicle
 - Debris mitigation design
- Testing
 - Qualification testing
 - Acceptance testing
 - On-orbital check-out
- Safe operation
 - Data exchange
 - Collision avoidance
 - Space situational awareness and operational control
- Disposal
 - Disposal reliability and timing

- a. **Specific unique and/or particularly important requirements for Large Constellations are contained in the table below.**

Form 4: New work item proposal (NP)

Unique?	Particularly Important?	Broad category	Relevant ISO Standards	
	●	<i>Data Exchange</i>	26900	Flight path predictions, maneuver plans and spacecraft attitude and characteristics shall be exchanged with other operators for conjunction management and long-term sustainability purposes.
	●	<i>Data Exchange</i>	26900	Operators shall publish contact information for their satellite operations centers and maintain response times of less than one hour at all times.
	●	<i>Design of LV & S/C</i>	14622 16126 24113	Satellites and launch vehicles shall be designed to prevent accidental explosions in orbit.
	●	<i>Design of LV & S/C</i>	24113	Objects should not be intentionally destroyed in a manner that generates debris that remains in orbit.
	●	<i>Design of LV & S/C</i>	24113	Power systems shall be designed with robust battery overcharge protections.
●		<i>Design of LV & S/C</i>		Large constellation spacecraft shall be designed to be maintainable, incorporating grapple mechanisms to support on-orbit servicing and to facilitate capture and deorbit in the event that the spacecraft becomes derelict
	●	<i>Design of LV & S/C</i>	14623	Pressure vessels shall be designed to be leak-before-burst.
●		<i>Design of LV & S/C</i>	27875	Large constellation spacecraft shall be designed for demise.
	●	<i>Design of LV & S/C</i>		Autonomous deorbit if not contacted within YYYY months. (???)
	●	<i>Design of LV & S/C</i>	24113	Satellites and launch vehicles shall be designed with the capability to permanently discharge internal sources of energy that could lead to structural fragmentation.
●		<i>Design of Mission</i>		Large LEO satellite constellations shall be designed to maintain adequate radial separation with other large constellations to assure a margin of safety under both nominal and anomalous operational conditions
●		<i>Design of Mission</i>		A large constellation shall be designed to limit the need for active control to mitigate collision risk between its own spacecraft.
●		<i>Design of Mission</i>		A large constellation shall be designed to maximize the time available to detect a failed spacecraft within the constellation and avoid colliding with it.
●		<i>Design of Mission</i>		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).
	●	<i>Design of Mission</i>	24113	No hazardous debris shall be intentionally released into orbit as part of the nominal execution of a space mission.
●		<i>Design of Mission</i>		Satellite insertion, operational and disposal orbits shall be chosen to minimize collision risk and orbital lifetime, commensurate with mission objectives and constraints.

Unique?	Particularly Important?	Broad category	Relevant ISO Standards	
•	•	Qualification & Testing	11227 10786 14302 14622 14623 15864 16454 16781 17566 19683 19924 19933 21648 23038 24637 24638 26871	Large constellation spacecraft and mission designs shall safeguard against deployment of Dead-on-Arrival (DoA), using a combination of a rigorous pre-launch qualification and testing program.
•		Qualification & Testing		Large constellation spacecraft are deployed into altitudes sufficiently low to permit vehicle checkout prior to orbit raising to the operational altitude. This is particularly critical when launching spacecraft based upon a new design.
•		Qualification & Testing		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.
	•	SSA and Operational Control		Operators should employ cybersecurity measures in both their ground and space systems, including encryption and authentication in satellite command links.
	•	SSA and Operational Control	16158	To support collision avoidance activities, operators should maintain knowledge of the flight paths of their assets to within 250 meters (one sigma) in precision and accuracy over a 48-hour prediction.
	•	SSA and Operational Control		Satellites should be independently trackable and readily identifiable by non-extraordinary means (e.g., beacons, corner reflectors, LED emitters, RCS augmentation), independent of operator intervention.
	•	Collision Avoidance	14950 16158 24113	Operators should be capable of performing timely and effective collision avoidance maneuvers to reduce collision probabilities below the governing authority's mandated threshold.
	•	Collision Avoidance	16158 24113	Satellites shall be operated in a manner that minimizes the potential for them to collide with known orbital objects.
	•	Collision Avoidance		Mitigation of conjunctions involving two active satellites should be coordinated between the two operators and resolved with a mutually agreeable course of action or inaction.
	•	Collision Avoidance		(Autonomous collision avoidance process ?)

Form 4: New work item proposal (NP)

Unique?	Particularly Important?	Broad category	Relevant ISO Standards	
	●	<i>Radio Frequency Interference Mitigation</i>		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.
	●	<i>Optical brightness</i>		Large constellation designers and operators shall seek 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.
	●	<i>Disposal Timing</i>	24113	Satellites and LVs should be disposed of upon mission completion promptly, reliably, and safely.
	●	<i>Disposal Timing</i>	24113	Specific criteria for initiating the disposal of large constellation spacecraft shall be developed, included in a disposal plan, evaluated during the mission and, if met, consequent disposal actions shall be executed.
	●	<i>Disposal Timing</i>		Once decommissioned, a LEO satellite should be deorbited within 1x of its operational design life, up to a maximum of five years.
	●	<i>Disposal Probability</i>	24113	The probability for satellite post-mission deorbit operations should be at least 90%.
	●	<i>Disposal Reliability</i>	24113	Operators should monitor the state-of-health of their satellites for anomalous conditions or trends that might lead to fragmentation or loss of deorbit capability.
		<i>Disposal Safety</i>		Launch vehicle stages should be passivated and deorbited upon completion of their missions.
	●	<i>Disposal Safety</i>		After completing disposal maneuvers, satellites should be passivated once collision avoidance maneuvers are no longer practical.
	●	<i>Disposal Safety</i>	24113	Deorbited objects should not pose a significant threat to people, property, or the environment, aggregated over the entire constellation on an annual basis.

5. Relevant existing ISO standards

As noted in the above table, there are numerous published ISO standards which are relevant to these many aspects, and the requirements contained in those standards should serve as integration of demanding launch schedules into civil and commercial airspace, optical brightness disruption to astronomy and naked eye observing, Radio Frequency Interference (RFI), spacecraft testing, operations, space data exchange and disposal.

Informative Annex A: Planned large constellations

Based mainly on the following study.

“LEO Constellation encounter and collision rate estimation: an update”, IAA-ICSSA-20-0021, 2nd IAA Conference on Space Situational Awareness (ICSSA), Washington D.C., USA, Salvatore Alfano, Daniel L. Oltrogge, and Ryan Shepperd], Copyright ©2020 by Analytical Graphics Inc.

Many large constellations of spacecraft have been proposed over the last five years, with many of them involving high-profile owners and operators. While some of these large constellation concepts will fail to materialize, we expect that many new constellations will be realized because the owners and/or sponsors have already obtained substantial funding, backing, momentum, and even regulatory acquiescence.

While not an exhaustive list, key large constellation concepts that may achieve flight status have been aggregated with a number of existing constellations as shown in Table 1. This set of large constellations was gleaned from news media articles, FCC applications, and ITU filings. The reader should bear in mind that the details of many of these constellations are either not known or not publicly disclosed, so this list should be treated as being “notionally representative” of the constellations that we might expect to fly in the next decade.

Table 2. LEO constellations selected for collision likelihood assessment

Operator	# S/C	Altitude (km)	Inclination (deg)	Hard Body Radius (m)
SpaceX, VLEO, next, etc.	36009	328, 482, 498, 1275, etc.	30, 40, 53, 81, etc.	4.79
OneWeb & next	3280	1200	46, 88	1.43
Amazon	3236	630	51.9	0.6
Boeing 1,2 & 3	2956	1000, 1200, 1210	45, 55, 88	1.43
CommSat	800	600	97.8	1.43
AlSTech_Danu	300	591.25	97.8	0.3
EightyLEO	300	279.15	96.6	1.78
Hongyan	300	1100	97.5	3.29
Satellopic	300	486.65	97.4	0.43
Efir	288	870	87.9	1.43
Spire_Global	275	500	3	1.09
Theia	211	750	98.3985	0.3
Planet	200	500	97.4	0.48
Sky_and_Space_Global	200	507.15	97.4	0.3
LaserFleet	192	503.45	97.4	0.18
LuckyStar	156	1000	90	0.18
Xingyun	156	1000	97.7	0.42
Astrome_Technologies	150	1000	97.7	3.26
Swarm	150	442.55	87.3	3.26
Kepler	140	560	90	0.15
Yaliny	140	1000	97.7	0.42
Telesat	117	1000	99.5	0.55
Astro_Digital	100	598.8	97.6	0.21
Canon	100	600	97.4	0.55
Fleet_Space	100	580	97.5	1.88
Orora.Tech	100	650	97.6	0.3
Iridium*	85	781	86.4	0.43
Astrocast	80	586.65	97.8	0.75
ExactView	72	819.05	99.1	0.15
NSLComm	60	279.15	96.6	0.6
Axelspace	50	503.3	97.4	0.85
Hera_Systems	50	500	43	0.23
Hiber	48	600	97.5	0.34
Capella	40	587.8	97.8	0.51

NorthStar	40	600	85	0.15
Reaktor	36	494.1	97.5	0.11
Helios	30	687.95	98.1	0.34
GeoOptics	24	514.85	85	0.24
UrTheCast	24	450	45	8.68
GHGSAT	20	505.9	97.4	0.28
ICEYE	18	505.55	97.5	0.64
PlanetIQ	18	775	72	0.4
BlackSky	16	550	55	0.5
OrbComm	16	750	51.6	1.78
Earth-i	15	505	97.7	0.59
AprizeSat	12	677.85	97.8	0.14
Harris	12	495.15	97.5	0.3
Umbral	12	587.8	97.8	3
Zhuhai	10	544.95	43	0.42
Dauria	8	632.55	98.4	0.14
GlobalStar	7	1414	52	3.57
SkySat	6	500	97.41	0.48
HawkEye_360	3	575	97.5	0.24

[Modify to tie up in a bundle if operator is same, by A. Kato]

A summation of spacecraft listed in Table 2 indicates that the number of spacecraft to potentially be launched and operated in the next ten years alone could exceed 57,000. Even if only half of these spacecraft actually get built and launched, we could easily experience a tenfold increase in the number of operating spacecraft.

The orbit regimes to potentially be occupied by these proposed constellations is shown in Fig. 1. These are again based upon the flurry of FCC and ITU licensing applications of the last several years. The Iridium Next constellation is indicated by a box as a reference point. The color-coding (as well as dot size) indicate the quantity of spacecraft in each proposed large constellation listed in Table 1. To prevent obscuration, smaller constellations are superimposed on top of larger constellations if both propose to occupy the same (or similar) orbit regimes.

Potential new spacecraft aggregated 2029 – 2029 as function of year is described in Fig.-2. Quantity of spacecraft introduced by altitude and year are described in Fig.-2.

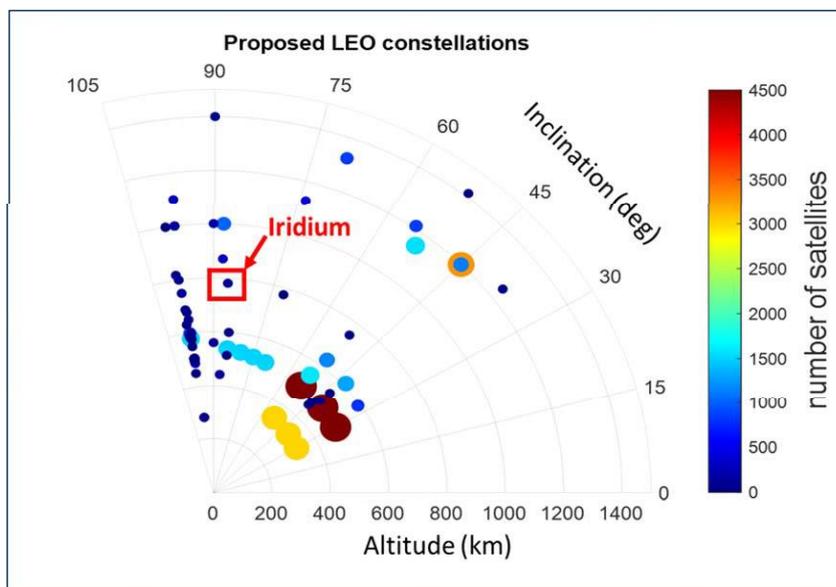


Fig. 1 Proposed LEO constellations IAA-ICSSA-20-0021 ©2020 by Analytical Graphics Inc.

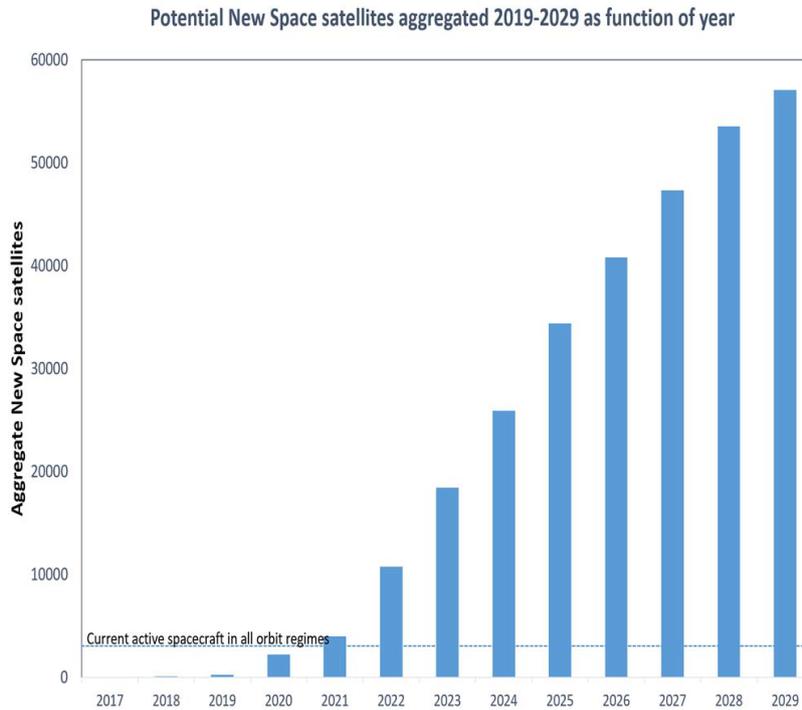


Fig.-2 Potential new spacecraft aggregated 2019 – 2029 as function of year
IAA-ICSSA-20-0021 ©2020 by Analytical Graphics Inc.

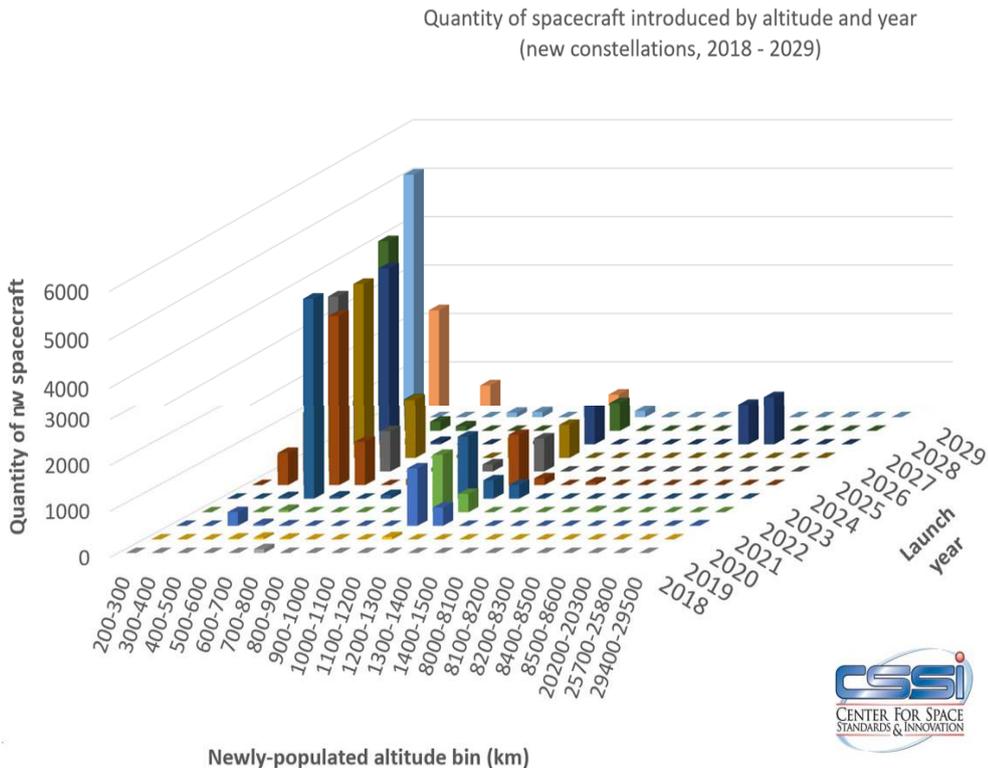


Fig.-3 Quantity of spacecraft introduced by altitude and year are described
(New constellation, 2018 – 2029) IAA-ICSSA-20-0021 ©2020 by Analytical Graphics Inc.

In short span, the constellations deployed in orbit from 2016 to 2023, limiting to those endorsed by Order of spacecraft, Letter of Intent (LOI), Memorandum of Understanding (MOU) or Announcement, constellations, and constituted of more than 50 spacecraft, are shown in Table-2.

Table-2 Number of LEO Spacecraft of large constellation (> 50 S/Cs)
 [Deployed in orbit from 2016 to 2023, *Endorsed by Order of spacecraft, LOI, MOU or Announcement,*]
 (Data source: *Seradata Space Trak 3*) @2020.4.26)

Name of constellation Program	No. of spacecraft	Mass category	Nationality
Starlink (SpaceX)	4483	100 - 500 kg - Minisatellite	United States
Kuiper (Amazon)	3236	500 - 1000kg – Small satellite	United States
Oneweb	600	100 - 500 kg - Minisatellite	United Kingdom
EarthNow	500	100 - 500 kg - Minisatellite	United States
Flock	330	1 - 10 kg - Nanosatellite	United States
Aleph-1 (Nusat)	300	10 - 100 kg - Microsatellite	Argentina
Hongyan	300	10 - 100 kg - Microsatellite	China
Telesat Ka	292	10 - 100 kg - Microsatellite	Canada
Sky & Space Global Pearl	206	1 - 10 kg - Nanosatellite	Australia
Kepler Constellation	142	10 - 100 kg - Microsatellite	Canada
Fleet IOT	102	1 - 10 kg - Nanosatellite	Australia
Danu	101	1 - 10 kg - Nanosatellite	Spain
Kepler GEN-2	90	10 - 100 kg - Microsatellite	Canada
Aerial & Maritime	80	1 - 10 kg - Nanosatellite	Mauritius
Astrocast	66	1 - 10 kg - Nanosatellite	Switzerland
BlackSky Global	60	10 - 100 kg - Microsatellite	United States
Total Number	10,888		

By A.Kato

Even in such short span, we can see the sudden increase of number of spacecraft since 2020 in Fig.-5.

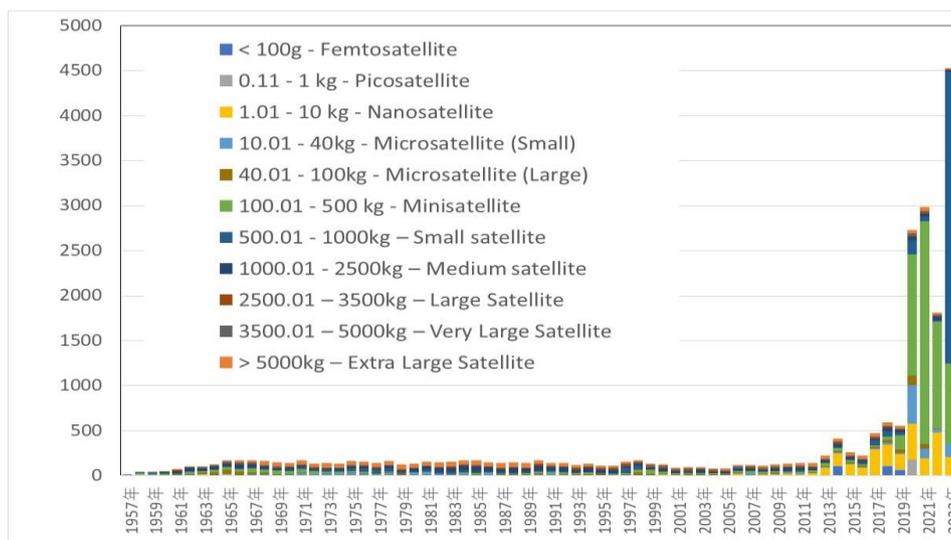


Fig.-5 Number of Spacecraft Launched in the World categorized by Mass Category
 [Ref: Data source: *Seradata Space Trak 3* @20200426] [By A.Kato]

Fig.-6 shows the distribution of constellations along apogee altitude with the total number of catalogued objects in LEO (including fragments, spacecraft, orbital stages larger than

10 cm) as of April 2020. (NOTE: OneWeb, went bankrupt last March, has launched 74 spacecraft. Rest of 3200 spacecraft to be launched into 1,200 km altitude will be cancelled.)

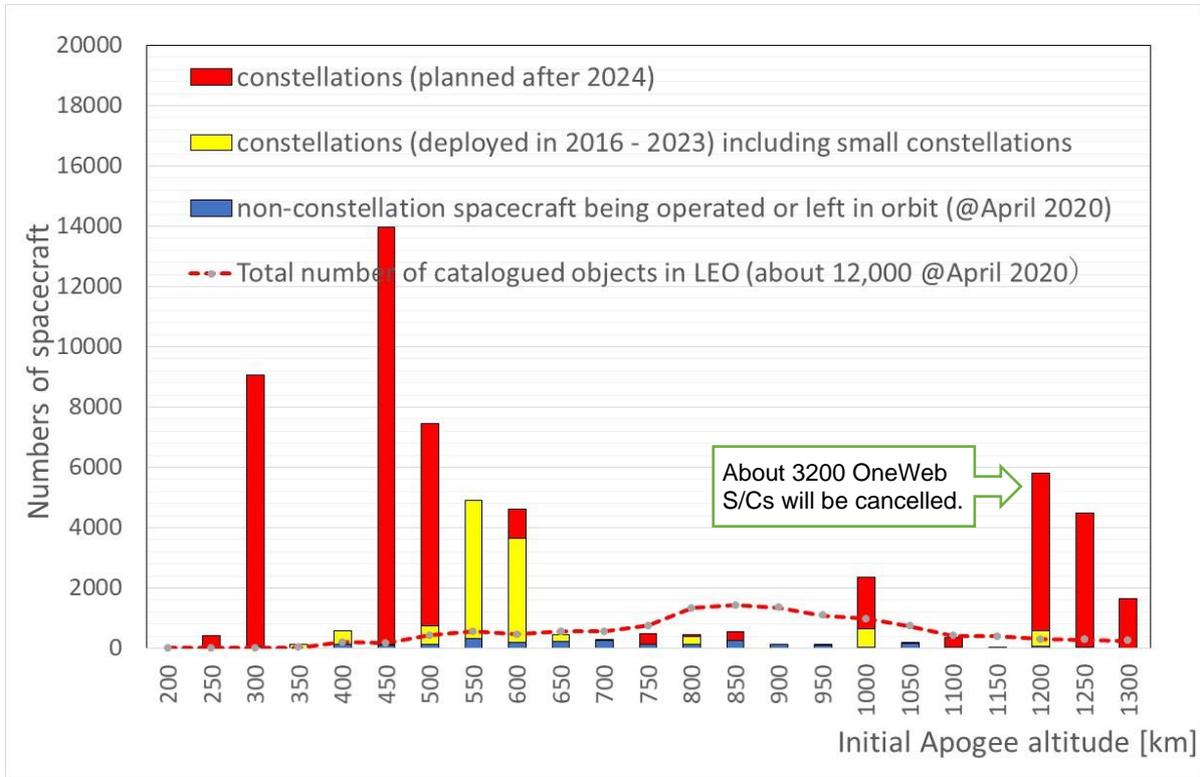


Fig.-6 Apogee altitude of the injection orbit of spacecraft of constellation programs and current total number of all LEO orbital objects including fragments larger than 10 cm [By A.Kato]

Considering the potential orbital objects stemming from the operation of large constellations such as the orbital stages, fragments potentially generated by their break-ups, and failed spacecraft that may lose their disposal function, they must be added to Fig.-6 to estimate the risk of large constellations.

The situation doesn't allow the optimistic prediction, but we **still have time to prepare for potential large constellations!**

Informative Annex B: risk of collision

Based on the following study.

"LEO Constellation encounter and collision rate estimation: an update", IAA-ICSSA-20-0021, 2nd IAA Conference on Space Situational Awareness (ICSSA), Washington D.C., USA, Salvatore Alfano, Daniel L. Oltrogge, and Ryan Shepperd], Copyright ©2020 by Analytical Graphics Inc.

Knowing the collision risk of satellites operating in LEO is of great importance and interest to the global space community and operators of LEO spacecraft. This is especially true in LEO due to the relatively high "density" of Resident Space Objects (RSOs) which exist in, or cross, the LEO altitude range, the importance of maintaining the safety and commercial viability of the LEO orbit regime for new "large constellation" operators and the increasingly-popular low thrust LEO ascent profile to get to MEO and GEO regimes.

Here we present a wide-ranging assessment of LEO collision risk. We employ a volumetric approach to estimate the frequency of orbital encounters. LEO collision risk is estimated for both current and planned constellations assuming that no (or no effective) remediation or attempt at avoidance is conducted. In addition to the public catalog, we use a representative catalogue consisting of over 700,000 objects down to 1 cm in size.

On the condition that RSO catalog contains 2,268 active satellites and 15,538 inactive objects. The bar chart shown in Fig. 2 characterizes the estimated annual collision rate as a function of altitude for three object pairing types. In Fig. 1,

- a. the blue bars represent the estimated annual collision rate of active spacecraft colliding with each other (active-on-active) ,
- b. the orange bars represent the estimated rate of active spacecraft colliding with inactive resident space objects (active-on-inactive),
- c. The gray bars represent the estimated collision rate of debris colliding with debris (inactive-on-inactive).

As seen in Fig.1, the estimated rate of catalogued debris colliding with itself typically dominates the risk of an active LEO spacecraft colliding with debris, which in turn is typically much higher than the risk of active spacecraft colliding with themselves.

When taking the proposed large constellations into consideration, as seen in Fig. 2, the dramatic increase in active-on-active estimated collision rates indicates that operators must cooperate with each other to a much greater degree to ensure that these conjunctions can be mitigated in a timely and orderly fashion. (As seen in Fig.-6 in Annex-A, the current number of catalogued debris is insignificant in New Space Era. Naturally, fragments and other debris may increase according to the increase of number of spacecrafts, but it is not counted in this analysis.)

The public satellite catalog does not contain all debris objects, as it includes few objects smaller than 10 cm. Yet it is commonly understood that objects that are 1 cm or larger in size can be lethal to a spacecraft if the two collide. These objects are commonly referred to as Lethal Non-Trackable (LNT) debris objects. The estimated annual collision rate of the current RSO active satellites with only the anticipated debris not currently tracked is shown in Fig. 3.

While, the total estimated collision rates for proposed large constellations against other active spacecraft and debris accounting for both the currently-tracked space population as well as the estimated LNT population is shown in Fig. 4.

The reference manuscript reveals more detailed risk of the encounter rate and kinetic energy, to be seen to understand the consequence of a collision will generate larger number of smaller sized debris.

Care and best practice must be incorporated into the design, operations, and disposal phases to minimize collision risk associated with these large constellations.

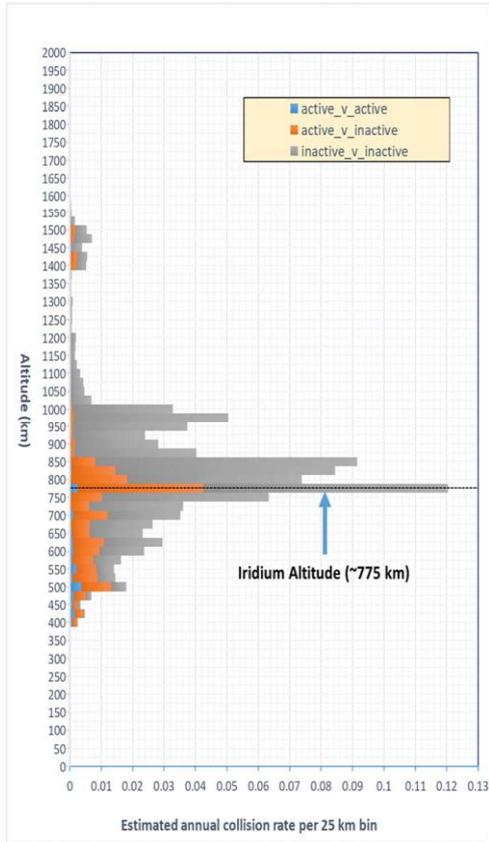


Fig.-1 Annual collision rates for October 29, 2019, 18 SPCS RSO catalogue

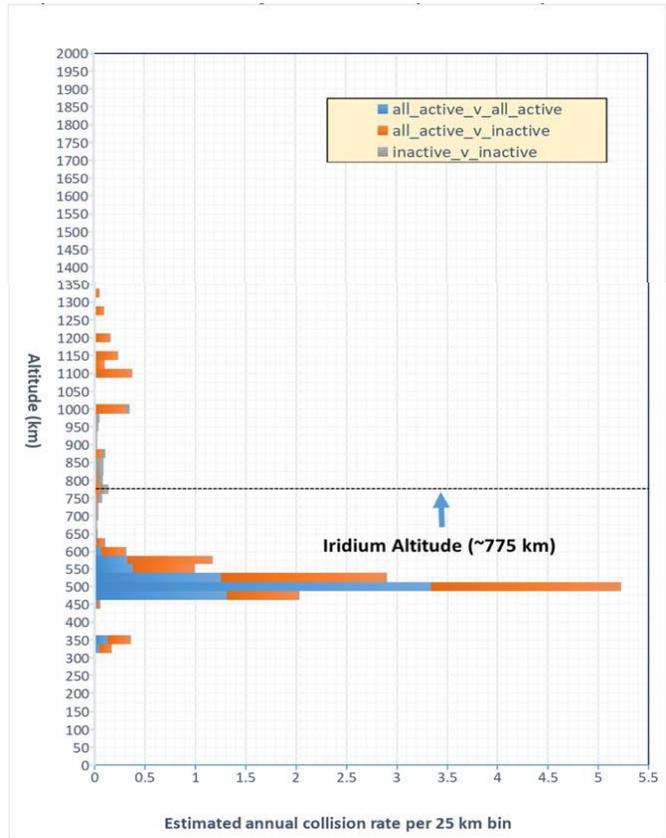


Fig.-2 Annual collision rates (includes October 29, 2019 catalogue and proposed constellations)

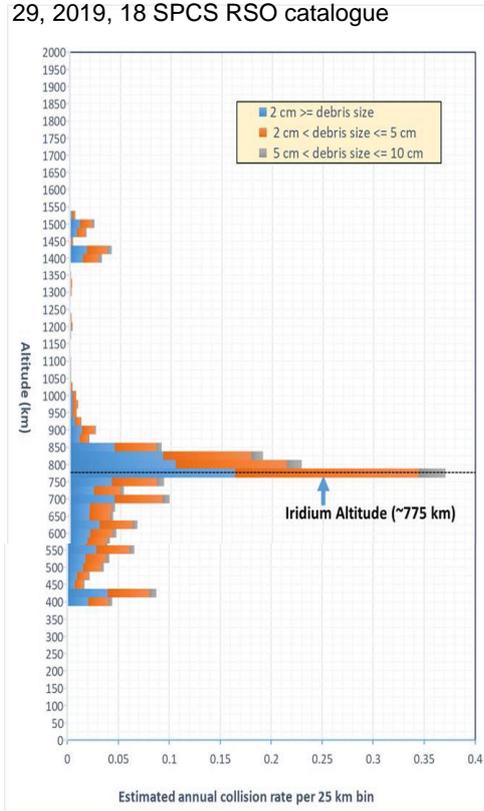


Fig.-3 Annual collision rates (includes October 29, 2019 active catalogue and anticipated untracked debris)

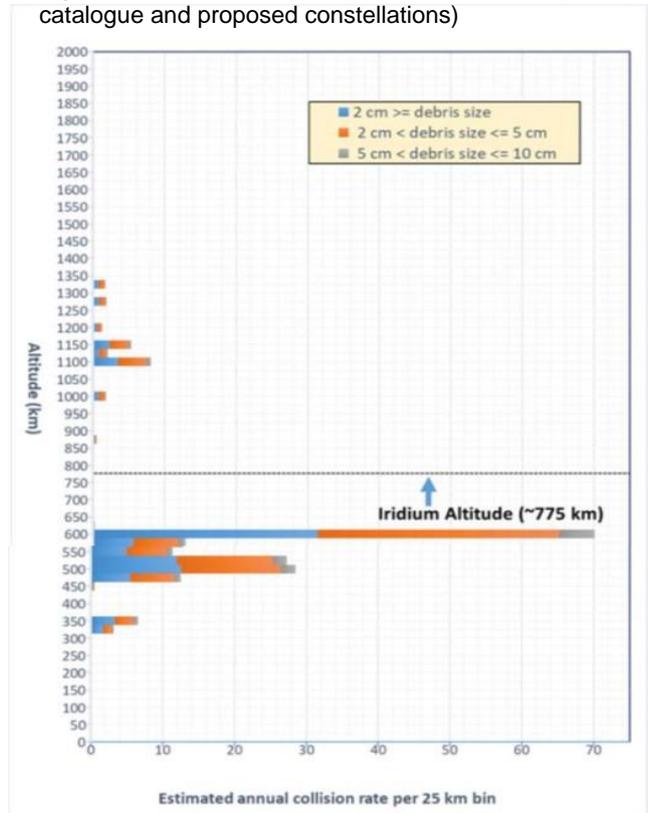


Fig.-4 Annual collision rates (includes October 29, 2019 active catalogue, proposed large constellations, and anticipated untracked debris)

Informative Annex C: Introduction of measures taken by major constellations

The basic concept of this NWIP is to find feasible, practical and effective measures. To adapt the measures **actually taken by current owners of constellation** is effective to suggest to the future constellation owners.

Major owners took measures such as;

- a. Select the operating zone to be less risky for collision.
- b. Avoid the collision within the constellations.
- c. Avoid the collision with the other constellations
- d. Conduct the proper V&V procedure to assure the best quality. And avoid that failed spacecraft would be staying in the operating zone of its constellation.
- e. Controlling the total Ec, and asses the total Ec of all the member spacecraft of a constellation

Actions for;	Oneweb	Starlink (SpaceX)	Kuiper (Amazon)
Contingency for the serious failure	Launched into a 475 km orbit, test & checkout, and raise to 12000 km.		Conduct system checks below the ISS then raising to their target orbit.
Collision avoidance with operating S/C, or other constellations	(1) Operating in the low-density region, 12000 m. (2) 125-kilometer separation zone between constellations	(1) Probability of collision < 0.001 (2) Take separate altitude >125 km from other constellations	40 kilometers above a SpaceX's Starlink constellation
(1) Assurance of fine disposal measures. (2) Contingency for the malfunction of disposal function (3) Avoiding electromagnetic interference	(1) Lifetime < 5 years disposal orbit (2) Deorbit reliability > 0.9 (3) Designed for removal enable uncooperative capture.	(1) Lifetime < 5 years (2) Various measures to avoid RF interference	(1) In case the loss of contact beyond a "pre-determined wait period," automatically decommission, deorbit in 5 - 7 years (2) The decommissioning process involves orbit lowering, depleting batteries, emptying fuel lines and tanks, and ensuring charging circuits are "permanently switched off or fused" (3) Disposed within a year by propulsion, (4) use an "unpressurized non-explosive propellant storage" for a chemically inert fuel.
Controlling the total Ec of the elements of a constellation	Design for demise (materials)		

Informative Annex D: SSC's Guidelines

It is effective to learn from : Space Safety Coalition's Best Practices for the Sustainability of Space Operations.

The Space Safety Coalition (SSC, SpaceSafety.org) is an *ad hoc* coalition of companies and other space relate organizations , that actively promotes responsible space safety through the adoption of relevant international standards and practices, and the development of more effective space safety guidelines, etc.

The SSC publishes a "[Best Practices for the Sustainability of Space Operations](#)" document to address gaps in current space governance and promote better spacecraft design, operations and disposal practices aligned with long term space operations sustainability. This document is a living set of best practices assembled and "owned" by the coalition of like-minded space organizations which have endorsed it. (This best practice has been eendorsed by major space industry stakeholders in 2019.) In the section 3 of above document, focusing on constellation designers and operators, and putting priority on space safety, it provides best practices for designing architectures and operations concepts for individual spacecraft, constellations and/or fleets of spacecraft.

Endorsed by major space industry stakeholders in 2019



Space Safety Coalition's Best Practices for the Sustainability of Space Operations

Date: 16 September 2019

3. Mission and constellation designers and spacecraft operators should make space safety a priority when designing architectures and operations concepts for individual spacecraft, constellations and/or fleets of spacecraft.
 - a. Constellation architectures should include a safety-by-design approach:
 - i. **Adequate radial separation between large constellations** should be maintained to assure a margin of safety under both nominal and anomalous operational conditions.
 - ii. Constellation designers should limit the need for **active control to mitigate collision risk between their own spacecraft**.
 - iii. Constellation designers should favour constellation designs which **increase the time available to detect a failed** spacecraft within their constellation and avoid colliding with it.
 - b. Precautions should be taken to safeguard the environment from dead-on-arrival (DOA) deployments, particularly when launching spacecraft based on a new design*. Such precautions should include one or more of the following:
 - i. Rigorous **ground-based environmental acceptance testing based upon established acceptance test standards and procedures** to include .
 - ii. **Qualification-level testing of all proto-flight spacecraft**, until all critical systems (including those required for maintain spacecraft control and perform active collision avoidance) have been demonstrated on-orbit.
 - iii. Launch into and **initial operation in orbits that comply with a natural orbit lifetime of less than 25 years**.
 - iv. Launch into and **initial operation in orbits at seldom-used altitudes** (see definition of "seldom-used altitude").
4. Spacecraft designers and operators should design spacecraft that meet the following best practices:
 - d. Designers of spacecraft disposed of through atmospheric re-entry should strive to reduce residual **casualty risk to less than 1:10,000 per spacecraft** and additionally should **evaluate casualty risk on a system-wide, annual basis**.

Informative Annex E: Supplemental information for important proposed measures

1. Selection of operation orbit and collision avoidance (sub-clause 4.1.1)

As seen Annex-A and B, constellation spacecraft is concentrated on 450 - 500 km altitude, and the collision between spacecraft, not spacecraft vs fragment, will be the major collision type in future. So, the orbit must be selected to avoid the crowded orbital region. Also, collision among constellations and intra-constellation must be prevented.

Such measures have been taken as followings:

- (a) OneWeb selected the low-density region, 12000 m.
- (b) Oneweb takes 125-kilometer separation zone between constellations.
- (c) Kuiper takes 40 km above a Starlink constellation.
- (d) Starlink separates altitude >125 km from other constellations.]

2. Assurance of the successful disposal (sub-clause 4.2.1.2)

(1) Probability of successful disposal

The number of constellation spacecrafts is so large, up to 57,000. If the Probability of Successful Disposal (PSD) would not reach to 0.9 as defined in ISO 24113, more than 5,700 spacecraft would be left as uncontrollable large debris, it is far from acceptable situation. This STD says 0.95 as a target value. It will be a highest value to be accepted by constellation owners so far.

Another problem is that PSD can't be verified in the design phase nor in the operation phase. Since the PSD depends on many factors such as (1) availability or quality, (2) reliability, (3) collision rate with space objects, (4) endurance for operation life and storage life, (5) sufficiency of resources for disposal, (6) faculty to detect default and emergency response capability, etc., it can't be necessarily defined by measurable factors. So, it is written as a target value in this draft standard. The actual PSD will be proven as a consequence of number of disposal actions.

In the first draft, several measures are written to assure the high probability of disposal. They are (a) high reliability of disposal function, (2) control of Operation Life Limited Items and Storage Life Limited materials, and limit the lifetime extension not to exceed the useful time, (3) monitoring critical components, etc. The probability may be proven after the number of disposal actions, as a consequence.

(2) Procedure for Determination of Mission Extension or Termination (sub-clause 4.2.1.2 (1))

To allow the limitless extension of operation time, while requiring high reliability, is risky. The extension of operation period will be allowed under the condition of enough margin of residual operation life or storage life, no wariness for corrective action for failures, no symptoms of failures in critical components, or sufficient resource for disposal manoeuvres, etc. The decision of extension should be conducted authorized procedures defined with considering those factors.

(3) Reliability (sub-clause 4.2.1.2 (3))

The reliability is required to be 0.9 in ISO 24113. Basically, to require strictly high reliability, a " Reliability Analysis Standard" should be presented from ISO. However, there is no procedure agreed internationally. Without a rule how to calculate it, it can't be required strictly. Actually, Failure Rate Database, analysis condition of the temperature, correction factor for JANS parts, etc. are not agree in the world. Yet, if operation lifetime would be extended, the reliability may be re-calculated from the initiation of operation to the revised EOM. This is the same situation when we analyse Ec for re-entry. European tools calculated

considering time dependent mass change, but NASA and JAXA analyse it with a lumped mass approach. The difference is great. Then, in ISO 24113, there is no clear quantitative requirement for Ec.

Also, there are following problems to calculate reliability.

- a) There are several Failure Rate Databases such as MIL-HDBK-217F, FIDES, Vita, etc. The MIL 217F is most popular database, but it was developed in 1995 and have not revised since then. The recent high reliability parts are not reflected in 217F. Many engineers think that the calculated reliability is relative value to evaluate the adequacy of design architecture or circuit design, etc. FIDES and Vita have been developed recently, and there are great differences with 217F. However, the major industries have not been accustomed to use it.
- b) To keep using 217F, the world organization apply the correction factors defined in each organization. These factors are different among countries or companies.
- c) Also, there are difference in the temperature condition. They may be an average value of estimated design temperatures, estimated highest design temperature, temperature confirmed by thermal test, expected operation temperature, etc. The difference between the average temperature and highest temperature will cause $\Delta R(\text{reliability}) = 0.05$ in system reliability.

If ISO forces too strict reliability, they will change the method to get high reliability. It is no use to require high value. The value of 0.9 would be a moderate one.

(4) Monitoring system and contingency planning (sub-clause 4.2.1.2 (4) c)

Requirement of "*Constellation designers shall favour constellation designs which increase the time available to detect a failed spacecraft within their constellation and avoid colliding with it*" comes from SSC 3 a) iii. In this draft, not only collision avoidance, the break-up prevention and detecting loss of disposal function are added.

If the communication infrastructure for a constellation is limited to ground tracking & control stations which are geographically similar, then passes may be limited to several times per day, delaying the detection of on-orbit failures. By using intra-constellation satellite-to-satellite communications or a global network of ground stations, the time from failure to detection will be reduced to some extent. Use of an external data relay satellite service may be another option. It is also possible to reduce the occurrence of intra-constellation conjunctions by means of orbital design.

(5) Active removal as a supplemental measure for successful disposal (sub-clause 4.2.1.3)

If we can take optimistic standpoint that the reliable active removal systems will be developed, it is preferable to prepare the devices to aid the uncooperative capturing. However, so far there is no reliable removal system developed or qualified, and yet there are several proposals for capturing method (net, harpoon, magnetic connection, etc.). So, this recommendation is available when such reliable removal system has been qualified.

3. Safe re-entry (sub-clause 4.2.3)

The threshold for Ec is widely understood to be less than 0.0001. However, it was designated on the condition that annual number of impacts of system level objects are about 100. Considering the number of spacecrafts contained in the constellations and their replacement for every 5 - 7 years, several hundreds of spacecrafts may impact on the ground. Now, Ec is controlled each spacecraft, but in New Space Era, it should be assessed for all the constellation elements annually.

4. Testing (sub-clause 4.3)

(1) Qualification and acceptance testing (sub-clause 4.3 (1),(2) and (4))

DoD-HDBK-343 “Design, construction and testing requirements for one of a kind space equipment”, ECSS-M-00A “Space Project Management”, and NASA “Engineering guide to the mission design process” or “NMI 9010.1A Classification of NASA Payloads”, etc. define the class (or category) of space system considering its priority and require adequate management, reliability, risk/budget control corresponding to the class. A spacecraft designated as low class, the requirement for test-level, redundancy, etc. can be tailored. However, for a spacecraft belonging to large constellation should be given highest class and complete V&V should be conducted.

(2) Not-flight- proven Items (sub-clause 4.3 (3) and (5))

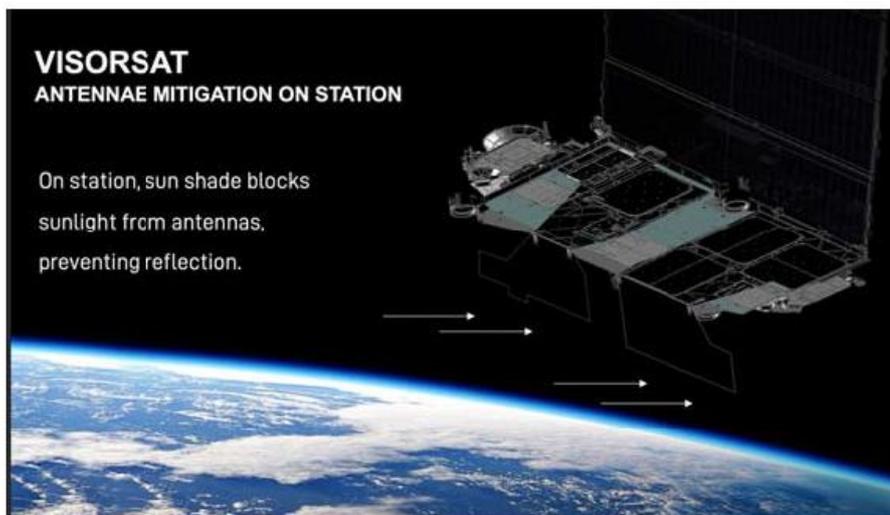
All critical components (including those required for maintain spacecraft control and perform active collision avoidance) must have been demonstrated on-orbit. At least not-flight-proven items should be applied as one side of redundant circuit as secondly devices.

5. Minimize visual brightness (Sub-clause 4.2.2)

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 Trackability.

SpaceX believes in importance of a natural night sky for us to enjoy. They aim followings.

- a) Making the spacecraft generally invisible to the naked eye within a week of launch (during initial check-out conducted with a specific configuration.)
- b) Minimizing Starlink’s impact on astronomy by darkening don’t saturate observatory detectors with applying deployable visor to the spacecraft to block sunlight from hitting the brightest parts of the spacecraft.



Starlink spacecraft has an average apparent magnitude of 5.5 when on-station and brighter during orbit raise. Objects up to about magnitude 6.5 – 7 are visible to the naked eye (naked eye visibility is closer to 4 in most suburbs), and the goal of Starlink is to be magnitude 7 or better.

The necessity of visor will be depend on the altitude of orbit, reflectance of components and their area.