STANDARDIZATION BY ISO TO ENSURE THE SUSTAINABILITY OF SPACE ACTIVITIES

A. Kato(1), B. Lazare(2), D. Oltrogge(3), H. Stokes(4),

(1) JAXA, Tsukuba, Japan, Email: kato.akira@jaxa.jp
(2) CNES, Toulouse, France, Email: Bruno.Lazare@cnes.fr
(3) Analytical Graphics Inc., 7150 Campus Drive Suite 260, Colorado Springs, CO 80919, Oltrogge@agi.com
(4) PHS Space Ltd, Pitlochry, UK, Email:hedley_stokes@msn.com

ABSTRACT

The ISO / Technical Committee 20 / Sub-committee 14 develops debris-related standards and technical reports to mitigate debris and help ensure mission and space sustainability. While UN Guidelines and the IADC Guidelines encourage national governments and agencies to promote debris mitigation design and operation, the ISO standards will help the global space industry promote and sustain its space-related business.

In this paper the scope and status of each ISO standard is discussed within an overall framework. A comparison with international guidelines is also provided to demonstrate the level of consistency. Finally, as a case study, the ISO standards are applied to a CubeSat mission, thus demonstrating their usability on a relatively recent and popular class of satellite.

1 INTRODUCTION

During the past decade or so, a number of internationally-agreed guidelines and recommendations have been published with the aim of mitigating the growth in orbital space debris. In particular, the guidelines of the Inter-Agency Space Debris Co-ordination Committee (IADC) recommend important debris mitigation measures that should be implemented in the design and operation of space systems. Whilst guidelines such as these provide a common understanding for the adoption of mitigation measures, they are not necessarily written in a style that is suitable for application in the commercial world. This can lead to differences in interpretation, with consequences for fair competition and for long-term sustainability of space activities.

Because remediating the space environment is challenging with existing technologies, the most effective way to ensure the long-term sustainability of space activities is currently to standardize the implementation of debris mitigation measures. Standardization will have a major role in the coming years to help regulatory bodies and operators to create and apply, in an efficient manner, appropriate space debris regulations and best practices. Since 2003, ISO – the International Organization for Standardization – has been meeting this challenge by transforming the IADC guidelines into a set of measurable and verifiable requirements to minimise the creation of debris during the launch, operation, and disposal of space systems. The requirements are contained in a series of standards that also capture industry best practice and specify definite actions to be taken by satellite manufacturers and operators to achieve compliance.

It should be noted that the measures contained within the ISO debris mitigation standards can be adopted voluntarily, or be brought into effect through commercial contract, or be incorporated as a condition within national regulations. Thus, for new space-faring nations, who want to establish a regulatory framework, the ISO standards can assist in the creation of binding national regulations.

2 BACKGROUND

2.1 Orbital Debris Environment and Major Contributing Factors

The orbital debris environment has deteriorated to the point that the risk of debris-induced damage cannot be ignored even for unmanned spacecraft.

The major causes of debris generation are:

- Mission-related objects released during operations.
- Break-ups caused by intentional or accidental fragmentation as a result of collisions or explosions.
- Space systems left in useful orbital regions after the end of operations.

In an effort to address these problems the Inter-Agency Space Debris Coordination Committee (IADC) issued a debris mitigation guidelines document in 2002 (updated in 2007). Subsequently, in 2008, the United Nations (via UNCOPUOS) published high-level guidelines designed to be consistent with the IADC. Both documents are very important since they establish a common understanding for the recommended implementation of debris mitigation measures. They have also provided a solid foundation for the construction of a set of debris mitigation standards within ISO. This has been an on-going activity since 2003.

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A key objective of the ISO debris standards is to formulate the recommendations contained in the IADC and UN guidelines in such a way that they can be readily applied in the contractual agreement between a customer and supplier. This helps to avoid differences in interpretation during the procurement of spacecraft or launch services. Thus, within an international context, the widespread adoption of ISO debris standards will help to foster fair competition and promote long-term sustainability of space activities.

The ISO debris standards can also be used as the basis for national regulations on space debris mitigation. For new space-faring nations wanting to establish a regulatory framework this is especially advantageous since it overcomes two significant difficulties:

- Dealing with global issues of safety and debris mitigation on a national scale.
- Not unfairly hampering the competitiveness of national operators.

2.2 Framework in ISO/TC20/SC14

The ISO Space Systems and Operations Committee (TC20/SC14) – a space standards committee comprising representatives from industry, science and institutional organizations – has the skills necessary to succeed in this challenge. Responsibility for the preparation of debris mitigation standards is shared between all seven of SC14's working groups, and is coordinated by WG7 (Orbital Debris Coordination Working Group) – see Figure 1.

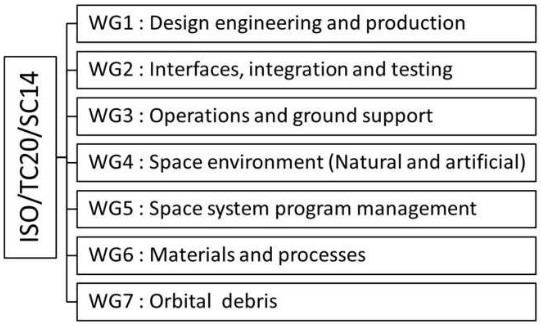

Figure 1 Structure of ISO/TC20/SC14 Committee (Space Systems and Operations)

2.3 Structure of ISO space debris mitigation standards

The overall structure of the ISO standards is presented in Table 1. The set of debris standards consists of a core standard and several lower-level standards which provide detailed practices, procedures and techniques supporting the core standard.

Table 1 Core debris related standards in ISO

	Area	No.	Title
1	**Top**	**IS 24113 ***	**Space Debris Mitigation Requirements**
2	**Prevent break-up**	**DIS 16127**	Prevention of break-up of unmanned spacecraft
3	**Dispose of spacecraft and orbital stages at end-of-life**	**IS 26872 ***	Disposal of satellites operating at GEO altitude
		CD 16164	Disposal of satellites operating in or crossing LEO
		CD 16699	Disposal of orbital launch stages
		IS 27852 *	Estimation of orbit lifetime
		IS 23339 *	Estimating the mass of remaining usable propellant
4	**Safe re-entry**	**IS 27875 ***	Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages
5	**Collision avoidance**	**TR 16158**	Avoiding collisions with orbiting object
		TR 11233	Orbit determination and estimation
6	**Protection from impacts of small debris**	**IS 14200 ***	Guide to process-based implementation of meteoroid and debris environmental models
		DIS 16126	Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts
		IS 11227 *	Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact
7	**Over-all**	**TR 18146**	Design and operation manual for spacecraft operated in the debris environment

Note 1: CD – Committee Draft; DIS – Draft International Standard; IS – International Standard; TR – Technical Report

Note 2: *: Published

3 Introduction to the top-level ISO debris mitigation standard – ISO 24113

The core standard, namely "ISO 24113: Space Debris Mitigation Requirements", contains high-level requirements which aim to mitigate debris by:

- limiting the release of objects during mission operations,
- preventing break-ups,
- disposing of space systems outside the protected orbital regions, and

- ensuring ground safety when objects re-enter.

Thus, the concept is broadly similar to the international guidelines. Although ISO 24113 does not include measures relating to impact protection or collision avoidance, ISO provides other standards or technical reports which address these topics. A technical report on conjunction assessment is currently being prepared. Similarly, to improve protection against small debris impacts, a standard is being developed on the assessment of spacecraft impact survivability. These and other supporting documents will be published in the near future. Table 2 shows a comparison of ISO standards with UN and IADC guidelines.

3.4 Introduction to the main supporting ISO debris mitigation standards

Today the SC14 working groups are in charge of 13 supporting standards and technical reports which describe space debris mitigation good practices. The scope of these standards is as follows:

(1) ISO 26872: Disposal of satellites operating at geosynchronous altitude

This International Standard prescribes requirements for planning and executing manoeuvres and operations to remove an operating satellite from geosynchronous orbit at the end of its mission and place it in an orbit for final disposal where it will not pose a future hazard to satellites operating in the geosynchronous ring.

(2) ISO 27852: Estimation of orbit lifetime

This International Standard describes a process for the estimation of orbit lifetime for satellites, launch vehicles, upper stages and associated debris in LEO-crossing orbits. The standard also clarifies the following:

- modelling approaches and resources for solar and geomagnetic activity modelling,
- resources for atmosphere model selection, and
- approaches for satellite ballistic coefficient estimation.

(3) ISO 27875: Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages

This International Standard provides a framework with which to assess, reduce and control the potential risks that spacecraft and launch vehicle orbital stages pose to people and the environment when those space vehicles re-enter the Earth's atmosphere and impact the Earth's surface. The standard is intended to be applied to the planning, design and review of space vehicle missions for which controlled or uncontrolled re-entry is possible.

(4) ISO 23339: Estimating the mass of remaining usable propellant

This International Standard describes requirements for estimating the mass of remaining usable propellant of spacecraft for designing propellant measurement systems. The standard applies to spacecraft with either mono- or bi-propellant propulsion systems using liquid or gaseous chemical propellants.. In order to perform spacecraft disposal manoeuvre as planned, the estimation of available propellant mass becomes essential.

(5) ISO 16127: Prevention of break-up of unmanned vehicle

This International Standard defines the requirements to reduce the risk of on-orbit break-up of unmanned spacecraft, both the possibility of a break-up caused by an unplanned internally-caused event and by depleting to a safe level all the sources of stored energy at the end of a spacecraft’s life. The standard is designed for use in planning, verifying and implementing the prevention of break-up of a spacecraft.

(6) ISO 16164: Disposal of satellites operating in or crossing Low Earth Orbit

This International Standard focuses on the disposal of satellites operating in, or crossing, Low Earth Orbit. Post-mission disposal of an Earth-orbiting satellite broadly means removing the satellite from its operational orbit to a region of space where it is less likely to interfere or collide with other operational satellites or with orbital debris. This standard specifies requirements for:

- planning for disposal of satellites operating in LEO to ensure that final disposal is sufficiently characterised and that adequate propellant will be reserved for any propulsive manoeuvre required,
- selecting a disposal orbit where the satellite will re-enter the Earth’s atmosphere within the next 25-years, or where the satellite will not re-enter the protected region within the next 100-years, and
- estimating, prior to launch, a 90% or better probability of successfully executing the disposal manoeuvre.

(7) ISO 16699: Disposal of orbital launch stages

Post-mission disposal of launch vehicle orbital stages broadly means removing the stages from the protected regions of space (see ISO 24113) so as not to interfere or collide with the other users of those protected regions in the future. Post-mission disposal also means passivating the stage in its current orbit if such an orbit is considered to be a disposal orbit for the specific space program.

(8) ISO 16158: Space systems - Avoiding collisions with orbiting objects

This Technical Report is a guide for establishing essential collaborative enterprises to prevent collisions between orbiting objects. The orbits of satellites must be compared with each other to discern physically feasible approaches that could result in collisions The process begins with the best possible trajectory data, provided by satellite operators or sensor systems developed for this purpose.. The trajectories so revealed must then be examined more closely to estimate the probability of collision. The spectrum of feasible manoeuvres must be fully examined whenever collision risk exceeds the operational collision risk thresholds and/or violates miss distance criteria established by each satellite operator.

(9) ISO 11233: Orbit determination and estimation

This Technical Report prescribes the manner in which orbit determination and estimation techniques are to be described so that parties can plan operations with sufficient margin to accommodate different individual approaches to orbit determination and estimation. The Technical Report prescribes the information that shall accompany such data so that collaborating satellite owners/operators understand the similarities and differences between their independent orbit determination processes. Of course, orbit determination and estimation is key to analysing conjunctions between orbiting objects and assessing the probability of collisions

(10) ISO 14200: Guide to process-based implementation of meteoroid and debris environmental models

This International Standard specifies the common implementation process for meteoroid and debris environment models for risk assessment of spacecraft and launch vehicle orbital stages. The standard gives guidelines for the selection process of models for impact risk assessment and ensures the traceability of using models throughout the design phase of a spacecraft or launch vehicle orbital stage.

(11) ISO 16126: Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal

This International Standard defines requirements and a procedure for assessing the survivability of an unmanned spacecraft against space debris and meteoroid impacts to ensure the survival of critical components required to perform post-mission disposal. The standard also describes two impact risk analysis procedures that may be used to satisfy the requirements.

(12) ISO 11227: Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

This International Standard describes an experimental procedure for assessing the behaviour, under orbital debris or meteoroids impacts, of materials that are intended to be used on the external surfaces of all types of low earth orbits. The standard establishes the requirements for the test methods to be satisfied to

		Measures	ISO Standards (or Technical Reports)	UN Guidelines	IADC Guidelines
Limiting Debris Generation	*Released Objects*	Mission related objects	ISO-24113 / §6.1.1	Guideline-1	§ 5.1
		Slag from Solid Motor	ISO-24113 / §6.1.2.2, §6.1.2.3		--
		Products from Pyro.	ISO-24113 / §6.1.2.1 (< 1 mm)		--
	On-orbital Breakups	Intentional Destruction	ISO-24113 / §6.2.1	Guideline-4	§ 5.2.3
		Accidental Break-up	ISO-24113 / §6.2.2 (Probability < 10^{-3})	Guideline-2	§ 5.2.2
		Post-mission Break-up	ISO-24113 / §6.2.2.3 (Detailed in ISO-16127)	Guideline-5	§5.2.1
Disposal at End of Operation	*GEO*	Re-orbit at EOL	ISO-24113 / §6.3.2 (Detailed in ISO-26872) §6.3.2.2: 235 km+ (1,000・Cr・A/m), e < 0.003 §6.3.1: Success Probability > 0.9	Guideline-7	§ 5.3.1
	LEO (MEO)	Reduction of Orbital Lifetime	ISO-24113 / §6.3.3 (Detailed in ISO-16164) §6.3.3.1: EOL Lifetime < 25years §6.3.1: Success Probability >0.9	Guideline-6	§ 5.3.2 (Recommend 25 years)
		Transfer to Graveyard	ISO-24113 / §6.3.3.2 (f)	Guideline-6	§ 5.3.3
		Other manners	ISO-24113 / §6.3.3.2 (a) ~ (e)		§ 5.3.2
Re-entry		Ground Casualty	ISO-24113 / §6.3.4 (Detailed in ISO-27875)	Guideline-6	§ 5.3.2
Collision Avoidance			ISO-16158	Guideline-3	§5.4
Protection from Impact of Debris			ISO-16126		§ 5.4

Table 2 Comparison of ISO standards with UN guidelines and IADC guidelines

characterize the amount of ejecta produced when a surface material is impacted by a hypervelocity projectile. Its purpose is to evaluate the ratio of ejecta total mass to projectile mass, and the size distribution of the fragments. These are the necessary inputs to model the amount of impact ejecta that a surface material might release during its orbital lifetime, thereby helping to assess its suitability for space use, with the mitigation of small space debris in mind.

(13) ISO 18146: Design and Operation Manual for Spacecraft Operated in the Debris Environment

This Technical Report will support engineers and operators in the application of debris mitigation measures during the design and operation of spacecraft. In particular, the document will present what should be done in the design of spacecraft systems, subsystems and components during each of the development phases.

This Technical Report will systematically guide those engineers who are responsible for concept design, system design, subsystem design, component design, or operations in complying with the technical requirements and recommendations.

4 ISO Contribution For Newcomers

The space industry is very evolutionary and dynamic, with many newcomers who are not yet familiar with debris-related issues even though they may have mature quality and reliability management processes. In the past, intentional destruction and post-operation break-ups were responsible for the majority of debris generation, but international guidelines and design improvements have helped to reduce these debris sources.

Future concerns include break-ups caused by malfunction due to the lack of quality and reliability. Newcomers are expected to learn the entire spectrum of debris mitigation measures and approaches. These include ISO debris mitigation standards addressing program management, design methods, production technology, operation techniques, analysis tools, models, and hardness design.

As part of our ISO outreach, the SC14 Orbital Debris Working Group is producing informative literature on debris mitigation and presenting papers such as this one. These are especially pertinent for newcomer organizations and countries involved in today’s rapid production, launch and deployment of micro-, nano- and CubeSat satellites who are unfamiliar with such standards.

5 ISO Standards Applicable to CubeSat Debris Mitigation

Satellite design, manufacturing, and operations are evolving rapidly due to continual advances in miniaturization, communications, capacity and space sensors. This is especially prevalent in the areas of microsatellites and the standardized “CubeSat” platform, where there are many newcomers to the space business who are not yet familiar with international space operations and debris mitigation guidelines, mandates and best practices.

ISO serves as a key resource in this regard by identifying and codifying space industry best practices to ensure the sustainability of space activities. We are especially working to educate the small satellite community on these applicable space operations and debris mitigation approaches relevant to design, launch, deployment and operations of small satellites.

5.1 The CubeSat Debris Mitigation Quandary

A critical issue with CubeSats currently is the prevalent lack of an orbit disposal plan or proper orbit selection. Examination of all CubeSats launched prior to 2012 revealed that CubeSat operators typically do not adhere to existing IADC guidelines and ISO standards that limit post-mission LEO-crossing orbit lifetime to 25 years. For the 45 deployed CubeSats contained in the red icon clusters depicted in Figure 2, it is estimated that less than half of these CubeSats will have an expected LEO-crossing orbit lifetime of less than 25 years.

The primary cause for this lack of CubeSat compliance is that launch access to space is very difficult for the CubeSat community unless one is able to secure a ride as a secondary payload, in which case the primary satellite(s) select the orbit. Unless the launcher is able to deliver the CubeSats into a separate CubeSat-tailored orbit, CubeSat operators are typically placed into a non-complying orbit. This leads to space debris mitigation issues, since it is still rare that CubeSats have any sort of deorbit module, chemical or electric powered flight, solar sail, electro-dynamic tether, or drag enhancement device to expand their orbital envelop while still complying with the 25-year orbit lifetime limit.

When possible, a better CubeSat launch arrangement is to manifest a single (small) launcher capable of carrying CubeSats to a CubeSat-tailored and compliant orbit, such as has been done on certain DNEPR flights. Advocacy for such “chartered” flights should come from the CubeSat community as well as the launch “brokers” that are supporting them. The CubeSat community can identify a sustainable low-cost opportunity for launching a large number of CubeSats on a single launch vehicle as a primary payload, thereby facilitating sustained access to space for small-scale research missions. This will help foster sustainable use of LEO space.

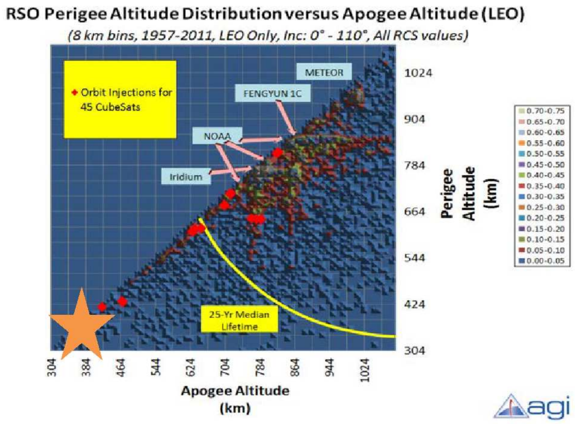

Figure 2 Comparison of all 45 CubeSat deployments versus 25-year orbit lifetime limit

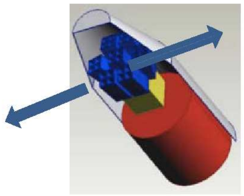

Figure 3: Dedicated CubeSat Launcher

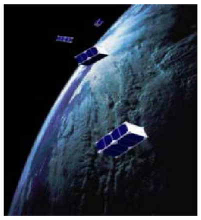

Figure 4 QB50 Mission, 50 CubeSats in LEO

5.2 CubeSat Debris Mitigation Need

One may be skeptical of the utility or need for small satellite developers and operators to be concerned with collision avoidance and damage assessment. But this is needed for several key reasons. The first is simply the rapidity, ease manufacturing and ability to launch numerous small satellites in a very short time.

Second, the existence of upcoming CubeSat thrust capabilities coupled with estimated average collision rates amongst our current space population of approximately once per decade clearly illustrates that even small satellite and CubeSat operators should be interested in learning about and invoking ISO standards and best practices to avoid collisions.

CubeSat teams are actively developing electric propulsion options for small satellites. Such options have the potential to provide substantial maneuvering performance over the life of the vehicle; a simple application of the rocket equation shows that the high Isp performance attainable with electric thrusters yields ΔVs of up to 12 km/s (mass fraction of 2.5) over the life of the vehicle.

Substantial numbers of CubeSats can be deployed, leading to numerous on-orbit conjunctions with other operational satellites. These conjunctions pose not only a real collision risk to other space operators, but perhaps more importantly can cause an operational impact to other operators which may be much higher than the collision risk.

For the more typical CubeSats which have no propulsion capability, it is even more important to "get it right" regarding initial orbit selection, long-term mitigation of collision threat with other operators, and ensuring that a proper deorbit strategy is emplaced.

5.3 CubeSat-Pertinent ISO Standards

The ISO standards that are most pertinent to our hypothetical sample mission include:

24113 – Orbital Debris – Space Debris Mitigation Requirements (avoid object release, breakup; disposal)

16127 – Prevention of Collisions & Breakup

16164 – Disposal of Spacecraft in LEO

16158 – Avoiding Collisions (including use of transparent and well-designed deployment Concept of Operation to facilitate rapid observation association, tracking and ID; benefits CubeSat owner AND other operators)

16699 – Disposal of orbital Launch Stages

Minimizing their post-deploy orbit lifetime + tank passivation

23339 – Residual propellant mass estimation (for deorbit via cold gas or upcoming Electric Propulsion System or EPS)

27852 – Orbit Lifetime Estimation (to ensure a post-mission LEO-crossing orbit lifetime < 25 years).

6 Example of ISO Standards Application to CubeSat Orbit Collision Avoidance

We now examine a hypothetical constellation comprised of 30 CubeSats deployed from an upper stage-mounted PPOD deployment "warehouse." In order to examine some of the debris-related aspects involved, we select an upper stage with a 50 Newton thrust capability at an 365 km circular insertion orbit (averaged orbital elements will be used to define the orbit and examine apogee and perigee altitudes above a spherical Earth to skirt issues associated with large J2 perturbations at this altitude).

The key ISO standards issues for CubeSats are likely to be:

- Is the post-mission lifetime < 25 years?
- Does the deployment approach avoid collisions between deployed CubeSats?
- Does the approach avoid collisions with other operators?
- Do the deployment and Concept of Operations aid the various global space surveillance and

> tracking organizations so that they can readily identify the deployed objects so that other satellite operators can coordinate with them?

Since our notional upper stage has the ability to thrust during deployment (plume impingement issues notwithstanding), we choose to optimize our deployment by incorporating a parametric optimization of thrust vector orientation angles α,δ as shown in

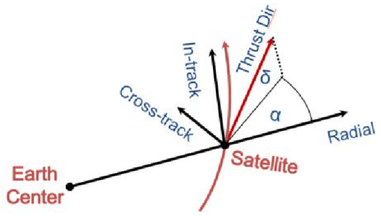

Figure 5 Thrust Vector Orientation Angles (α, δ)

We begin by evaluating ISO 24113 and 15872 CubeSat orbit lifetime criteria. Since the proposed deployment altitude is located at the "star" on Figure 2, we are highly unlikely to exceed a 25-year post-mission lifetime. But we can parametrically evaluate that as shown in Figure 6.

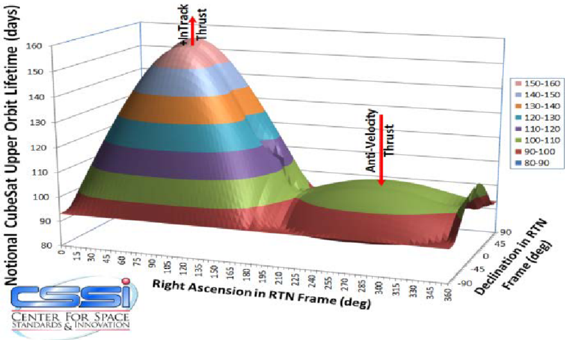

Figure 6 Maximum Orbit Lifetime as f(α, δ)

6.1 CubeSat Collision Risk Mitigation

The Poly-Picosatellite Orbital Deployer (PPOD) used to house and deploy CubeSats during the launch phase uses a combination of inter-CubeSat and PPOD deployment springs to facilitate CubeSat separation. These springs are typically limited in ΔV magnitude to about 1.5 m/s, which for very large CubeSat constellations could produce a "cloud" of very small satellites which would take some time (weeks if not months) to disperse and blend into the background space population.

Modelling of the relative motion between such CubeSats ejected during such a deployment scenario for these 30 CubeSats reveals that the post-deployment close approach distance is highly sensitive to deployment direction. In Figure 7, for example, we see that a deployment which relies solely upon these small deployment ΔVs can lead to near collisions shortly after deployment (all less than 40 meters for any deployment orientation).

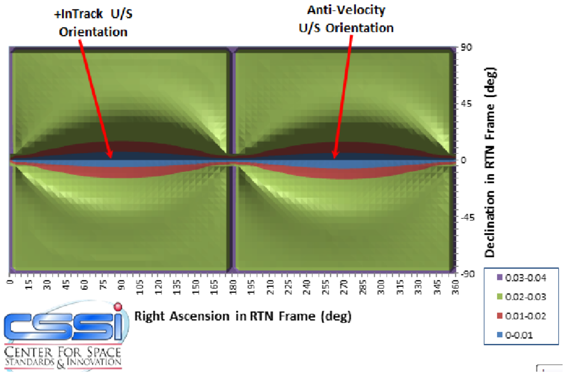

Figure 7 Closest Approach Between CubeSats Vs Deployment Orientation In Absence of Upper Stage Thrust

In Figure 8, we evaluate the effectiveness of adding thrust during deployment. As shown, along- or back-track thrusting is very effective at ensuring that the closest approach between any of the 466 pairings of CubeSat and Upper Stage objects is greater than 1.5 km.

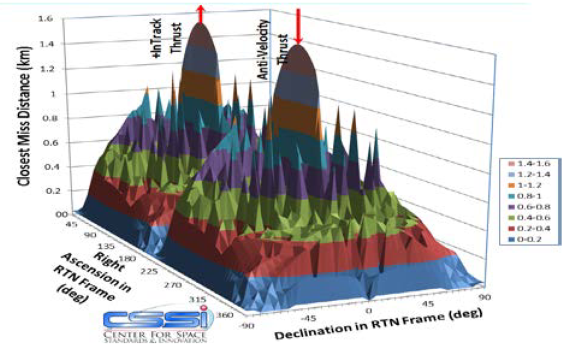

Figure 8 Closest Approach Between CubeSats Vs Deployment Orientation

7 Additional examples of best practices for CubeSats

Although not strictly codified in existing ISO standards, additional space operations best practices are emerging as practical methods to achieve ISO standards goals and objectives. We now briefly discuss a few of these concepts.

7.1 Transparency and coordination with the international space community

To facilitate collaborative efforts to identify collision risks and mitigate threats, it is useful and important to share anticipated post-deployment orbits, deployment sequences and nominal state vectors for large CubeSat deployments. Such collaboration can greatly reduce the time required for independent tracking entities, such as the Space Surveillance Network, to rapidly acquire, track and correctly identify CubeSats soon after deployment. The large uncertainties involved in the launch and early orbit phase can then be greatly reduced. This permits other space operators who are relying on such information to accurately avoid collision threats and to identify the correct CubeSat operator to jointly mitigate threats with.

7.2 Avoidance of collision threat with manned space objects

Guided by the principles espoused in ISO 24113, space operators should seek to minimize risk of collision with other active and debris objects. This is especially true when considering flight safety for manned and man-rated spacecraft. Avoiding the ISS operational orbit regime is highly recommended where possible. The ISS operational altitude band was raised shortly after the Space Shuttle was retired. In the case of the ISS, the Operations Team avoids possible collisions by (1) Constant monitoring to identify potential “watch” collision threats; (2) Reporting of sufficiently threatening “watch” close approaches; (3) Generation of avoidance maneuvers; (4) Management review of the threat with “go”/”no go” avoidance decision; (5) Implementation of the avoidance maneuver and/or possible evacuation of ISS into an escape module for the period of the close approach.

This involved process points out a key issue: Satellite operators should consider more than just collision probability in selecting their orbits, deployment concepts-of-operation and station-keeping strategies. They should also consider the probability that their presence will unduly impinge on another operator’s operations (i.e. Probability of Operations Impingement) in any of the five collision avoidance phases listed above.

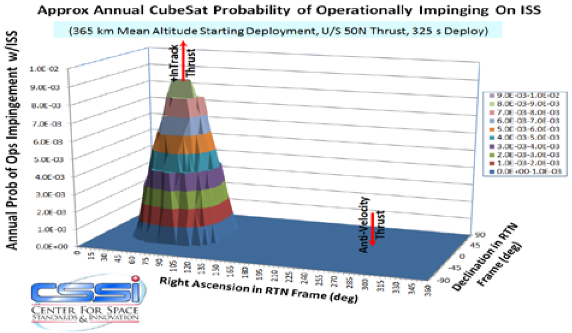

Figure 9 Operational Impingement Probability to ISS

In Figure 9, the probability of operational impingement to ISS is about one in a hundred based upon rough spatial density calculations as shown for the thrusting deployment of the same 30 CubeSats postulated above. While the collision probability is estimated to peak at 1.e-5, it is clear that the probability of operations impingement can be quite high when the thrust during deployment is performed such that some of the CubeSats enter into the ISS (or any other operational satellite) altitude band.

8 Conclusions

Currently, the most effective way to ensure the long-term sustainability of the space environment is to standardize the adoption of space debris mitigation measures. Since 2003 the ISO “Space Systems and Operations” committee, ISO TC20/SC14, has been developing a set of spacecraft engineering standards aimed specifically at mitigating space debris. This set comprises a top-level standard supported by a collection of lower level implementation standards. The top-level standard, ISO 24113 “Space Systems – Space Debris Mitigation Requirements”, prescribes high-level debris mitigation measures which have been derived largely from internationally-agreed guidelines such as those established by the IADC. Their purpose is to avoid the intentional release of debris into Earth orbit during normal operations, avoid break-ups in Earth orbit, and remove spacecraft and launch vehicle orbital stages from high-value orbital regions after end of mission. To help achieve compliance with these high-level measures, the lower level implementation standards provide detailed methods and procedures that specify definite actions to be taken by satellite manufacturers and operators. In general, the implementation standards capture the best practices of industry, thus maximizing their potential for adoption. This point is underlined by applying the standards to the relatively recent CubeSat class of spacecraft.

9 Acknowledgements

The authors are very grateful for the positive contributions made by members of ISO TC20/SC14 towards the development of the ISO space debris mitigation standards.

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