To Orbit and Beyond: Present Risks and Liability Issues from the Launching of Small Satellites

Ms. Ntorina Antoni[*] *and Mr. Federico Bergamasco*[**]

Small satellites -designed mainly for scientific or educational purposes at a low cost- have low mass and small size. They are frequently launched as secondary payloads in low Earth orbit for short-term or long-term missions. The growing number of small satellites - especially CubeSats - experienced in the last years, combined with reliability issues in single or multiple expected upcoming launches, raises concerns about the safety and sustainability of space activities, as well as, the liability for damage caused by space objects. The major concerns relating to small satellite missions are the risks of congestion of certain orbital regimes along with the hazard of collision and space debris creation in low Earth orbit. Currently, their small size and mass prevent them to be equipped with a propulsion system or braking device that would allow them to perform collision avoidance manoeuvres or active de-orbiting manoeuvres in order to adhere to the 25-year orbit lifetime limit, as defined by COSPAR and also required by their design specifications. Operations in low Earth orbit are inherently high risk due to the high amount of space debris in some regions, especially after the collision of Cosmos 2251 and Iridium 33 satellites. These factors, combined with the fact that small objects are difficult to track accurately, contribute significantly to increase the probability of on-orbit collision with other space objects by preventing the latter to perform reliable collision avoidance manoeuvres. In order to mitigate such risk, it is highly recommendable for the operators of small satellite missions to comply with the voluntary Space Debris Mitigation Guidelines of the UNCOPUOS. This paper will argue that regardless of their design or mission, small satellites are space objects falling under the scope of application of international space law. As the Outer Space Treaty and the

---

[*] International Institute of Air and Space Law, Leiden University, The Netherlands, dorina_andoni@hotmail.com.

[**] International Institute of Air and Space Law, Leiden University, The Netherlands, feder.bergamasco@gmail.com.

Liability Convention impose obligations on States, and do not bind private entities, the engagement of private actors in the launching of small satellites complicates the question of liability for damage. The liability risk can be managed by imposing mandatory licensing and insurance requirements in domestic laws for on-orbit operation of small satellites. Therefore, there is an enhanced necessity for States to establish a regulatory framework for these activities in a national level, as a means to comply with the obligation of authorization and supervision stated by Article VI of the Outer Space Treaty. In consideration of the above, this paper presents the implications of small satellite missions and makes recommendations to ensure compliance of their launch and operation with the *corpus juris spatialis*, in the interest and benefit of the international space community.

I. Introduction

There is no official definition of a small satellite. Based on their mass, small satellites are classified as mini-satellites (100 -500 kg), micro-satellites (10-100 kg), nano-satellites (1-10 kg), pico-satellites (0.1-1 kg) and femto-satellites less than 100 g.[1] A subset of nano-satellites is the CubeSat, with mass 1-2 kg in a 10x10x10cm cuboid unit, referred to as 1U. The units might be combined to produce larger mass and volume systems such as 3U and up to 6U, according to the current developments.

The very first small satellites launched into Low Earth Orbit (LEO) were Sputnik 1 with 83.6 kg mass, Explorer 1 with 13.9 kg and Vanguard 1 with 1.47 kg.[2] The new turn of the Space Age, especially the last two decades, in the "faster, better, cheaper" design philosophy has been very influential in the development of increasingly sophisticated spacecraft with smaller size and mass. This new fad is reflected in the number of 92 small satellite launches in 2013 and, 122 satellites -with mass between 1 and 50 kg-launched from January 2014 till August 2014. For year 2020, between 410 and 542 launches of small satellites are predicted to take place, most of them based on the CubeSat standard.[3] The CubeSat standard was originally introduced by California Polytechnic State University and by Professor Robert Twiggs at Stanford University in 2000 with the aim of developing very small satellites by universities through the standardization of the launch interface, known as PPOD.[4]

This concept has boosted the number of developed satellites enormously

---

[1] LELE, SINGH, Space Security and Global Cooperation, Academic Foundation, 2009, p.162.

[2] HELVAJAN, JANSON, Small Satellites: Past, Present and Future, AIAA, The Aerospace Press, 2009, p.1.

[3] BUCHEN, Presentation *Spaceworks' 2014Nano/ Microsatellite Market Assessment* in Proceedings of the AIAA/USU Conference on Small Satellites, Technical Session I: Private Endeavors, 2014.

[4] TWIGGS, *Origin of Cubesat* in HELVAJAN, JANSON, *supra note* 2, p. 151-173.

worldwide because of the low manufacturing and launching costs. Although CubeSats were initially developed for educational purposes –used to train students in the design, integration and operation of spacecraft-, they have evolved to a standard platform for communications, technology demonstration and scientific experiments.[5] It has democratized access to space for developing countries and it has expanded to more than 50 space-faring nations with the USA, Europe, Japan, China, and Russia performing CubeSat missions independently or via the ISS. They are used in commercial, military or government programs by large space organizations like NASA and ESA, as well as private companies such as SpaceX, Boeing and Lockheed Martin which are the main actors in launching or planning to develop CubeSats.

The rapid expansion of small satellite missions has been tempered to a certain extent by mishaps that question the “better” outcome of “faster and cheaper” technology.[6] The first failure occurred in June 2003, when the first multiple CubeSat mission, mainly based on Commercial off-the-shelf (COTS) components and manufactured by educational institutions, was launched on a Eurockot LV launch vehicle into 820 km Sun-Synchronous orbit (SSO). While CUTE-I and XI-IV, launched by Tokyo Institute of Technology in Japan, are still active after 11 years of being launched, three CubeSats either failed to operate after a short time or communication was never established.[7] In the following years a second group of CubeSats and also single ones were launched by various universities into 686 km SSO with similar failure behavior where radio contact was never established or communication was lost after a month of operation.[8] The biggest loss of CubeSats occurred in 2006, where 14 Cubesats from 11 Universities along with other satellites aboard a DNEPR launch vehicle were destroyed after the failure of the rocket. In the year after, even though the launch was successfully conducted by the same rocket, six out of seven -intended to be launched into 700 km SSO- by private companies and also universities failed immediately after injection, never responded, or remained semi-operational.

Although technology for CubeSats has improved the last years and the missions have increased to a great extent, the failure rate has not declined. An average of three missions launched each year fail to reach their goals. The statistics show that 27 out of 34 failures are university led CubeSat missions,

---

[5] THAKKER, Development of a Small University Satellite for Performing a Global Survey of Gravity Waves in Mesosphere, ProQuest 2008, p.118.

[6] FORTESQUE, SWINERD, STARK Spacecraft Systems Engineering, John Wiley and Sons, 2011, preface.

[7] http://lss.mes.titech.ac.jp/ssp/cubesat/index_e.html http://www.space.t.u-tokyo.ac.jp/cubesat/index-e.html
http://www.ne.jp/asahi/hamradio/je9pel/satslist.htm
http://mtech.dk/thomsen/space/cubesat.php

[8] CUTE 1.7 + APD, NCube2 by Norwegian University of Science and Technology, UWE-1 by University of Wurzburg in Germany

with some reservations on the industry led missions for which the data of failed missions are most of the times not disclosed.[9]

The high rate failure of small satellite missions should draw our attention to this issue more closely. Remarkably, 45% of the failed CubeSat missions did not manage to communicate after launch, which brings the identification of causes under close examination. It is assumed that the loss of contact with CubeSats indicate initial problems within the communication hardware, the batteries or the solar panels and the flight processor which are linked to poor functional integration.[10] Apart from the CubeSats lost due to launch failure, there is a high number that after surviving the launch they do not reach the orbit or fail after reaching the orbit to meet their mission objectives. What is the causal link with these CubeSat mission and failure? What does poor functional integration mean, and is it the only cause of these problems? Does the size matter and why does the case of CubeSats differ from the bigger satellites? What are the steps that should be looked at carefully before the development and launching of these charmingly small satellites?

II. Definition of the Problem

(Non-)Reliability of Small Satellites

The problematic around the failure of CubeSats missions brings us to the issue of reliability. Reliability constitutes critical element for space systems in the indication of potential causes of on-orbit failures, and it is to be considered with due regard prior to launching. It can help improve the future missions by adopting risk mitigation plans and insurance coverage.[11] In the case of small satellites missions, and in particular CubeSats, reliability is an important aspect that has not been assessed properly in the past due to the limited data available for statistical analysis. Statistical analysis of the spacecraft is based in different parameters, such as its design lifetime, mass category, launch year, mission type, satellite developer, complexity, its payload size or even the size of the spacecraft itself which can potentially affect the failure of satellites missions.[12]

Aiming at the identification of the root cause failure, various analyses of small satellite missions' reliability have been carried out by Georgia Institute of Technology and by Delft University of Technology. These analyses are based on data derived from SpaceTrack with the aim to construct a Small

---

[9] SWARTWOUT, *The First One Hundred CubeSats: A Statistical Look*, JoSS, 2013, Vol. 2, No.2, p.221.

[10] BOUWMEESTER, GUO, *Survey of Worldwide Pico- and Nansatellite Missions, Distributions and Subsystem Technology*, Acta Astronautica 67, 2010, p.855.

[11] SALEH, CASTET, Reliability and Multi-State Failures, John Wiley and Sons, 2011, Chapter 1.2.

[12] GUO, MONAS, GILL, *Statistical Analysis and Modelling of Small Satellite Reliability*, Acta Astronautica, 2010, p. 97-110.

Satellite Anomalies Database. As a first result, high infant mortality has been demonstrated for small satellites which seem to exhibit very low reliability during the first months following orbit insertion. Infant mortality is less experienced by medium and large satellites, which remain reliable after the first months of the orbit insertion. It is shown in these results that indeed different satellite mass category is correlated with different reliability and failure tendency. In addition to this, infant mortality is highest among satellites with unknown or short design lifetime due to reasons of limited attention to the operational life, low quality components (COTS) and low budgets as it is the case of university missions for educational purposes.[13] The high number failures in university class missions shall be based in some of the above reasons. "Shall" is used to express that the above reasons are based on hypothetical scenarios for differences in failure behaviors.

Apart from the limited budget, also the constraints on the time-frame to build, the testing procedure and the facility allocated to small satellite missions, compared to those of large satellites, are significant factors for their failure.[14] Testing techniques such as parts "burn-in" are critical to "remove latent defects and early failures", if performed at appropriate stress levels and under proper environmental conditions.[15] Therefore, insufficient or total absence of testing performance of CubeSats might lead to infant mortality, contrary to large satellites that are not subject to any limitations during manufacturing and for this reason they are able to reach a higher degree of reliability.

Another reason that might be connected to the failure of CubeSats is the trend to use low quality and not space rated component, COTS, parts in their design. COTS are inherently hazardous as they constitute state-of-the-art technologies with little or no flight heritage and thus new to the harsh space environment. COTS parts are often initially rated to operate in a narrow range of temperatures that does not always match the thermal requirements associated with the space environment.[16] COTS have shown that are particularly sensitive to the effects of extreme temperatures and high energy particles as they remain less radiation-hardened than electronic parts of traditional suppliers. This vulnerability might affect memories, power devices, or control logic devices, which can result in severe spacecraft failure and increase the degree of infant mortality.[17] Thus, CubeSats relying on COTS are more prone to on-orbit failure behaviors due to restrictive testing

---

[13] DUBOS, CASTET, SALEH, *Statistical Reliability Analysis of Satellites by Mass Category: Does Spacecraft Size Matter?* IAC-09-D1.3.6, p. 5.

[14] SARSFIELD, The Cosmos on a Shoestring, Small Spacecraft for Space and Earth Science, RAND, 1998, p. 67.

[15] GINDFORD, MILES, MURPHY, *Space-Hardware Design for Long Life with high Reliability,*in Proceedings of the Annual Reliability and Maintainability Symposium, 1994, p. 338-341.

[16] FORTESQUE, *supra note* 6, p. 596.

[17] DUBOS, *supra note* 6, p. 10.

of these parts which make them unsuitable for space environment.

Regarding the design of CubeSat, the fact that it is merely based on a “single-string” pattern and not on the redundancy of larger satellite can lead a simple anomaly to the total loss of the spacecraft.[18] Additionally, its small size and low mass offer less shielding by exposing it to the effects of cumulative radiation. Lethal radiation, extreme variations of temperature, storms of micro-meteoroids, swarms of man-made space debris are few of the main elements found in the harsh space environment and pose a huge challenge to the survival of CubeSat.[19]

The elimination of all the aforementioned failure root causes and the enhancement of CubeSat missions’ reliability can be accomplished through the development of risk assessment tools. Specific software tools can provide the developers with information about potential risks and guidance how to avoid unfortunate mishaps that might lead to failure of the mission.[20] It needs to be born in mind that the lower the spacecraft’s reliability, the higher the risk of failure on-orbit.

Small Satellites Constellations Concerns

Another major concern grows currently in the tendency of developers and operators to move from single CubeSat launches to constellations of small satellites. Missions that were only feasible with large satellites can be accomplished by large numbers of small satellites used in formation flying or distributed constellations which coordinate operation of numerous satellites in performing specific function such as remote sensing and navigation.[21] These constellations offer improved performance at a reduced cost and they overcome the restriction of a single small satellite that cannot be equipped with many instruments to perform sophisticated scientific missions as the large satellites. This feature of constellations makes the CubeSat concept very appealing to many actors who plan to send “swarms” of small satellites suitable for a variety of mission tasks.

This is the case for QB50 mission which aims at launching a network of 50 double CubeSats into 320 km for scientific study of the lower thermosphere (90-320 km). Two out of the 50 spacecraft will have thrusters and will

---

[18] CLARK, STRAIN, MAZARIAS, *A High Performance, Very Low Cost Power System for Microspacecraft*, Clydespace Ltd, p. 6.

[19] GALLTON, *The Challenge of Small Satellite Systems to the Space Security Environment*, Thesis, Naval Postgraduate School, California, 2012, p.1; Information about the space weather is be provided by the Space Weather Prediction Center (SWPC) of National Oceanic and Atmospheric Administration (NOAA).

[20] BRUMBAUGH-GAMBLE, LIGHTSEY, *A Software tool for CubeSat Mission Risk Estimating Relationships*, Acta Astronautica, 2014, p. 226-240.

[21] ANDRINGA, HASTINGS, *A Systems Study on How to Dispose of Fleets of Small Satellites*, MIT Space Systems Laboratory, Thesis, 2001, p. 21.

demonstrate the new and innovative formation flying concept which will offer them various relative orbit control options. However, as it is the first time formation flying is used in CubeSats we have to be cautious about how it will be realized regarding the small mass and size and also the coordination with each other.[22]

Although these missions are attractive to the Cubesat community and due to the advantages on cost reduction and flexibility, there are some inherent drawbacks to be taken into account. These drawbacks related to each and single CubeSat increase if multiplied by X number included in constellations. The most recent launch of femto-satellites from a 3U CubeSat, that failed to deploy the 104 Sprites into LEO, is an example which should alarm the ones concerned in developing or operating similar missions. Each Sprite consisted of a 3.5cm square circuit board.

In case the mission had succeeded, it would have prevented Sprites to be tracked by the current Space Situational Network (SSN) of the United States Space Surveillance Network or the Space Situational Awareness (SSA) program by the European Space Agency (ESA), which are able to track objects that are 10 cm in diameter or larger.[23] Thus, the existing space situational awareness capabilities of ground-based networks find it hard to track CubeSats so small in size and low in mass. Small satellites that are untraceable might be much more dangerous than bigger satellites that are traceable.

In addition to this it might be highly likely they will face collision risks between the constellation members or the formation flying objects as potential collisions with them cannot be reliably predicted.[24] This is intrinsically associated with debris mitigation concerns. CubeSats either when operating as single spacecraft or as part of a constellation with little reliability, they might pose a serious hazard to the mission itself, to other spacecraft or to the outer space environment.

Arthur C. Clarke addresses the implications of “thousands of satellite constellations” by raising his concern about future space travelers that might have to pass through “orbiting minefields” or even worse “orbiting dust storms”. These words portray the inherent risk of this big number of satellites developed with low cost components and design techniques and intended to expand to orbits and beyond.

---

[22] GILL, BOUWMEESTER, ZANDBERGEN, REINHARD, *Formation Flying within a Constellation of Nano-Satellites: The QB50 Mission*, Acta Astronautica, 2013, p.111-112.

[23] KLINKRAD, ESA Presentation, *The Space Debris Environment and Associated Risks*, in World Space Risk Forum 2012, Dubai.

[24] SANDAU, International Study on Cost-Effective Earth Observation Missions, CRC Press, 2006, p. 43.

III. Present Risks Orbital Lifetime and Congestion Risk

CubeSat missions can be considered quite risky based on the aforementioned analysis on the various aspects of reliability and the type of launch as single or not. The risk they pose is mainly on-orbit collision in congested regions, which is associated with their orbital lifetime as determined by certain elements. Students from University of New South Wales analysed the orbital lifetimes of CubeSats in different orbits, which lead us to the following.[25]

Altitude in combination with drag coefficient, solar reflection, spacecraft orientation and atmosphere density can help us to predict to a certain extent the lifetime of a small satellite. The lifetime of a CubeSat located lower than 300 km will be 0-100 days. CubeSats at this altitude cannot be considered hazardous for collision issues. Natural orbital decay can cleanse these very low altitude orbits within one year without the aid of propulsion systems.

CubeSats launched into orbit between 300 and 400 km could last for half a year to 2 years and might pose a hazard of collision *inter alia* with the International Space Station (ISS), which is usually maintained between 355 km perigee and 400 km apogee. ISS has manoeuvered many times the last years in order to avoid collision with any of the hundreds man-made objects falling through its orbit. This risk has been increased in particular after the debris generating event of collision between Cosmos 2251 and Iridium 33 spacecraft in 2009 and, also, the Chinese anti-satellite test of 2007, both of which were located hundreds of kilometers above the ISS altitude.

Therefore, CubeSats located in certain orbital planes or altitude near ISS and affected by the drag coefficient are much more dangerous to collide with the debris created after these two incidents and subsequently with ISS. During its first 15 years of operation, the ISS has managed successfully to carry out 16 avoidance collision manoeuvres with one attempt that failed in 1999 due to insufficient time. In October 2013 the number of catalogued objects that posed potential threats to the ISS was in excess of 800, including objects from less than 1kg to several metric tons.[26] Avoidance manoeuver is considered necessary as long as conjunction assessments of the tracked objects in close approach show a collision risk greater than 1 in 10.000 in the vicinity of ISS.[27]

With the use of SSN the Joint Space Operations Center (JSpOC) of the USSTRATCOM provides conjunction assessments to satellite operators with the aim of performing the necessary avoidance manoeuvres in case of

---

[25] QIAO, RIZOS, DEMPSTER, *Analysis and Comparison of CubeSat lifetime*, Australian Centre for Space Engineering Research, University of New South Wales, Sydney, p. 3.

[26] NASA Orbital Debris Program Office, *Large Space Object Population near the International Space Station*, Orbital Debris Quarterly News, 2014, Vol. 18, Issue 1, p.1-2.

[27] NASA Orbital Debris Program Office, *Increase in ISS Debris Avoidance Manoeuvers*, Orbital Debris Quarterly News, 2004, Vol. 16, Issue 1, p.1-2.

collision risk for identified conjunction events. Similar systems have been adopted by ESA, NASA, JAXA, CNES and DLR. Towards a better quality of these services the database has to be updated continuously by the precise information of the missions provided by the operators to the agencies and then coordinated by all the agencies. Collision in space is not an individual's mission problem but a global problem, as the experience has shown. In particular, CubeSats developers and operators shall apply additional operational procedures to reduce the risk and perform collision avoidance manoeuvres in high congested regions.[28]

When we go to higher orbits above 600 km, natural orbital decay is not effective as CubeSats are not significantly affected by the drag of atmosphere and their lifetime could exceed 25 years. Depending on the area-to -mass ratio, the spacecraft could even stay for hundreds years there.[29] This, however, does not comply with the CubeSat design specification that the orbital decay lifetime shall be less than 25 years after end of mission life and it violates the Debris Mitigation Guidelines on the limit of satellites orbital lifetime. It should also be taken into consideration that the bigger the mass of the CubeSat is the more will increase the expected lifetime especially in higher orbits.[30]

One of the mitigation standards is the reduction of post mission orbital debris lifetime. In this respect, there have been proposals from engineers for tethers, inflatable structures, thin film structures and propulsion systems to be integrated in the CubeSats with the aim to decrease on orbit lifetime or deorbit in the end of the mission.[31] These technical aspects shall be taken seriously into account and the thought that space is "big" should not comfort us. Even in the case the likelihood of collision is very low, this is sufficient to endanger million dollar missions and make operations more difficult. The smaller size of CubeSats equates to smaller collision probability. But the outcome can be a catastrophic collision; bearing in mind the high kinetic energy that might prove to be catastrophic depending on their orbital plane.

The fact that CubeSats are not equipped with propellant means that they cannot manoeuver but only orientate in the orbit they are located. As in most of the cases CubeSats are not launched in a separate launcher, but as a secondary payload in a launcher that delivers the payloads in the orbit determined by the primary one. The lack of deorbit capabilities means that small satellites are concentrated in the orbits where large satellites are located and they cannot change. This does not leave much room for these missions to

---

[28] IMRE, TESMER, SCHEPER, *Mission Operations to Improve Space Mission Protection*, p. 1-3.

[29] SHENYAN, ZHIWEI, WANG, WEEDEN, *Analysis of Close Approaches between Small Satellites and Catalog Objects*, IAC-11.A6.2.2, p. 2.

[30] FORTESQUE, *supra note 16*, p. 478-9; ISO Standard 27852, Space systems-estimation of orbit lifetime, See figure 24 at p.11.

[31] OLTROGGE, *An Evaluation of CubeSat Orbital Decay*, in 25th Annual AIAA/USU Conference on Small Satellites, SSC11-VII-2, p. 1.

abide by the 25 year orbital lifetime limit and creates a potential source of collision in high preferable orbits. QB50 mission which uses a single launcher and selects a specific altitude should be an example for future CubeSats missions in compliance with the IADC/ UNCOPUOS guidelines and the ISO Standards. Spacecraft disposal at the end of life shall be accomplished by atmospheric reentry, direct retrieval or manoeuver to a storage orbit.

Risk of on-Orbit Collision in SSO

The increasing number of satellites and space debris in near -Earth space is causing growing concern about the risk of collision between orbiting objects. On 24 July 1996, the first credited collision between two registered space objects was marked. Cerise, a microsatellite launched at an altitude of 700 km collided with a fragment of debris from an exploded third stage of an Ariane launcher at a closing speed of 14 km per second. Although its base was completely severed, the microsatellite remained under ground control but it lost the Earth-pointing orientation.

The risk of collision is eminent in SSO (600 -900 km) where most of the spacecraft are launched and more are planned to be launched thereto.[32] Spatial density is an indicating factor for collision probability among space objects. Even though spatial density is bigger in GEO than in LEO, the collision probability is higher in LEO where space objects orbit the Earth fifteen times in a day while in GEO only once per day. The spatial density is very critical in LEO where the rate of fragment production from collisions is extremely high. In case of collision with space debris, the damage to the space objects can be huge due to the hypervelocity impact, and it can result in the creation of new fragments.[33] The additional particles can lead to increased collision probability and cause an ever-increasing number of new collisions referring to as a “cascading” effect or as “chain reaction”, known as Kessler Syndrome. The collisional hazard in that orbital region may be too high for space operations for centuries to come. The most recent example of collision is that of BLITS nano-satellite with a fragment from the Chinese Anti-Satellite test, which led to BLITS changing orbit and spin rate by getting uncontrollable.[34]

How do we calculate the collisional hazard? Reliable collision probabilities can be estimated only when reliable information exists. Conjunction

---

[32] WEEDEN, *Development of an Architecture of Sun-Synchronous Orbital Slots*, Secure World Foundation, American Institute of Aeronautics and Astronautics p. 1; A few of the CubeSats that failed and remained in SSO, from the many launches taking place thereto: DUBAISAT, SNAP1, UOAST-12, DMC, RAPIDEYE, DEIMOS

[33] Committee on Space Debris, Commission on Engineering and Technical Systems, Division on Engineering and Physical Sciences, National Research Council, Orbital Debris: A Technical Assessment, National Academies Press, 1995, p. 166.

[34] https://directory.eoportal.org/web/eoportal/satellite- missions/b/blits

assessment is based in specific calculations and it has been used to estimate conjunctions of spacecraft with space debris. The past assessments have shown more than 99.9% of the conjunctions occurring in LEO, which seems to be the most problematic area. The number of 24.000 objects in LEO out of 29.000[35] in orbit shows the great degree of concentration. In the case of small satellites the situation has not changed a lot the last years with regard to conjunction probability but, the concern is much higher if we take into account the future growth of CubeSats and constellations. The scenarios are not very optimistic if the CubeSats continue to use the range of 600-900 km in the SSO region without any restriction as to where they are placed, as a vast majority of them does currently. The increased number of conjunctions leads to a high collision probability in SSO much more than GSO where satellites are moving in the same direction.[36] In SSO satellites are moving in different orbital planes and although we do not have any collisions yet, the number of conjunctions is increasing with spacecraft approaching intersection points. This situation will have significant impact in relation to the sustainability of other space objects located therein. These scenarios are created on the absence of future major launches or break-ups. Future developers are strongly recommended to avoid this orbital band and suppress this way the collision probability.

Avoiding a collision in space is a contribution to space debris mitigation. This situation should make CubeSat developers examine carefully the orbit that the spacecraft will be launched into and avoid orbits that with high spatial densities of objects. The Space community, including CubeSat developers, has the obligation to ensure the safe access to space for all mankind and they should not endanger the sustainability of existing or future outer space activities. CubeSats could pose real orbital debris threats to other state or private ventures in outer space, by carelessly deploying "swarms of picosatellites" or other CubeSat constellations. To prevent this from happening, careful assessment of the CubeSat's orbital lifetime and the potential implications from any failure occurring after the separation from the launcher and during the operation is recommended.

This can be achieved, first, by adhering to current Guidelines for effective debris mitigation that will limit debris population growth. More accurately, debris mitigation measures concern the orbital stages disposal of the launch vehicle, the limitation of debris during normal operation, the elimination of the potential for on-orbit break ups, the post mission disposal and the prevention of on-orbit collisions. The IADC Space Debris Mitigation Guidelines have served as the foundation for the development of the UNCOPUOS space debris mitigation guidelines. Despite the non-binding nature of the standards but their function as recommended practices they

---

[35] *Supra note* 24.

[36] *Supra note* 32.

should be followed to the greatest degree possible. They have been enhanced by UNCOPUOS and ISO TC20/SC14/Working Group 3, as well as the Orbital Debris Coordination Group. Also, the establishment of space traffic management could be a solution to preserve the near-Earth space environment. This is based on conjunction assessments and collision warnings. Active debris removal is another solution being considered currently in Switzerland, but is not yet in force. Such a mechanism could be very efficient if it could be used for many CubeSats. Moreover, there are proposals for passive debris removal that can contribute in the sustainability of the space environment.

IV. Liability

Liability for Cubesats Under Corpus Juris Spatialis

The presentation of the risks posed by CubeSat missions brings us to the issue of liabilities in case of damage. Before proceeding to the analysis of the legal implications, it is appropriate to clarify the legal framework provided by the *corpus juris spatialis*, and to what extent it shall be considered relevant to their operation. It cannot be questioned that small satellites are space objects in the same way that large satellites are. Subsequently CubeSats are considered to be space objects and fall under the scope of application of the Space Law Treaties.

The fundamental principles are laid down in Article VI of the Outer Space Treaty (OST), where it states the duty for the appropriate State to authorize and continuously supervise the space activities of non-governmental entities, in order to guarantee the respect of the principles and obligations affirmed by the Treaty. Such obligation is strictly connected with the first sentence of the same Article, according to which States shall bear international responsibility for the activities in outer space carried on by their non-governmental entities. This is implemented at a national level basically through the way of licensing.

A second, essential provision is Art. II of the Registration Convention (REG), where it affirms that States shall establish and maintain an appropriate registry for the launched space objects. The registration gives, according to Article VIII OST, the right-duty to retain jurisdiction and control over the space object,[37] and is one of the main criteria identified by the doctrine to attach the international responsibility according to Article VI OST.[38] The formulation of

---

[37] SCHMIDT-TEDD, MICK, Art. VIII OST, in Hobe, Schmidt-Tedd & Schrogl, Cologne Commentary on Space Law, Vol. I, 2009, at 41.

[38] The other two criteria pointed by the majority of the doctrine are the territorial jurisdiction and the personal jurisdiction. VON DER DUNK, *The Origins of Authorisation: Article VI of the Outer Space Treaty and International Space Law*, in National Space Legislation in Europe: Issues of Authorisation of Private Space Activities in the Light of Developments in European Space Cooperation, Nijhoff, 2011, p. 15-16.

the Article, moreover, clearly implies that any State that proceeds to record the space object in its national register accepts the status of launching State in respect to such space object, and thus the attached liability for damage.

Last but not least, Art. VII OST provide for the liability of the launching States for damage caused by space objects, whether privately or governmentally launched, owned and operated.[39] The combined interpretation of Art. VI and Art. VII of the Outer Space Treaty, establish a State guarantee for damage caused by space activities carried on by private entities.[40]

Importantly, all the above-mentioned provisions involve two main concepts: space activities and space objects. The *corpus juris spatialis*, however, does not provide a definition of the former, and provides a relatively not-satisfactory definition of the latter. According to Art. I d) LIAB, the term “space object” includes component parts of a space object as well as its launch vehicle and parts thereof. That formulation only specifies some of the items that fall within the category, without providing any of the intrinsic qualities that would qualify a space object as such.

Although there is no legal definition on small satellites, including CubeSats, they fit very well under this term and are subject to the relevant provisions. The fact that they lack manoeuvrability, and thus complete control by the operator, does not prevent them by being considered space objects, as it is argued by some scholars. The definition requires the space object to be “launched” into “outer space”, which applies in this case, without further mentioning of size, control and guidance of such object.

The liability for damage is regulated in detail by the Liability Convention (LIAB), which, in its role of *lex specialis*, specifies the principle set by Article VII OST. A dual system is established. Article II LIAB establishes an absolute liability for damage caused by space objects “on the surface of the Earth or to aircraft in flight”, while Article III of the Convention creates fault-based liability for damage caused in outer space “to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State”.

In the former case, the government is internationally obliged to pay compensation irrespective of the proof of negligence or wilful misconduct. The latter case, on the contrary, is more problematic, and it is the one that most likely would apply in the case of CubeSats, as it is highly unlikely that they will be able to survive re-entry. The only damage they might cause -due to the reasons that have been already exposed in the “risks” section- is on-

---

[39] Ibid, p. 20.

[40] It is not the case to discuss here in detail the complex interaction between Art. VI, VII and VIII OST, LIAB and REG, and the relation between international responsibility and State liability. For a comprehensive analysis of the issue, see VON DER DUNK, *Liability Versus Responsibility in Space Law: Misconception or Misconstruction?*, Space and Telecommunications Law Program Faculty Publication, 1991.

orbit damage, meaning damage in outer space to another space object.

The claimant State, indeed, must prove not only that the damage has been caused by a space object (or its component parts) launched by another State, but also that the damage was due to the latter State's fault or the fault of persons for whom that State was responsible. The concept of fault in space law has been heavily criticised, due to its difficult application in practice. It is not defined, and it would also be very difficult to prove in outer space.[41] Due to limited space monitoring capability, indeed, especially on the part of a claimant State that is not a well -developed space-power, it would be very hard to clearly and convincingly establish fault on the part of the State whose CubeSat (including an untracked small piece of space debris or CubeSat itself) is be believed to have caused the damage[42] The challenge is big for every space object, but becomes bigger for small satellites due to the very small size and mass and for constellations that will perplex the identification of the fault in projects that many States participate, as it is the QB50 project.

The liability for damage, according to Art. VII OST and Art. II LIAB, is borne by the launching State. This term is sub -divided in further categories: a State which launches a space object; a State which procures the launching of a space object; a State from whose territory or facility a space object is launched.

A number of criteria suggest that the notion of "launch procurement" has to be interpreted in a comprehensive way, in order to bring the space operations carried on by private entities under its scope of application.[43] First, the general rationale of the LIAB, as stated in the Preamble, is ensuring the maximum protection to potential victims. In the light of privatisation of space activities, a restrictive interpretation of the term would be inconsistent with such principle, leaving an increasing number of cases potentially outside the absolute-liability umbrella of the Art. II LIAB.

A further tool of interpretation is Art. VI OST, where it bears States with the direct responsibility for space activities carried on by non-governmental entities. As liability for damage is strictly connected with responsibility, it would be inconsistent to accept the principle of State responsibility for private space activities and reject the State liability for private-launched space objects.[44]

The Liability Convention, on the whole, is an important but rather problematic way to seek compensation, even there is no limit to it. However,

---

[41] SMITH, KERREST, Art. III LIAB, In Hobe, Schmidt-Tedd, Schrogl, Cologne Commentary on Space Law, Vol. II, 2009, at 134.

[42] JAKHU, Regulation of Small & Micro Satellites, Institute of Air and Space Law, McGill University, Montreal, Canada.

[43] JAKHU, *Iridium-Cosmos Collision and its Implications for Space Operations,* Yearbook on Space Policy 2008/2009: Setting New Trends, ed. By the European Space Policy Institute, Springer-Verlag Wien, (2010), p. 255.

[44] CHENG, *Article VI of the 1967 Outer Space Treaty Revisited: 'International Responsibility' 'National Activities' and 'The Appropriate State'*, J. SP. L. 26, 9, (1998).

it does not constitute the exclusive instrument at disposal of a potential victim that aims at recovering the damage. Art. XI LIAB allows private claims to be pursued regardless on any action under the Convention. In other words, an injured party has the option to sue directly the responsible private entity before the domestic courts of the launching State, in the case it considers this way more convenient.[45]

Liability and Insurance

As derived from the aforementioned, it is out of question that CubeSats are subject to the liability provisions of the Space Treaties. The combined interpretation of Art. VI and Art. VII of the Outer Space Treaty makes States liable for damage caused by space activities carried on by private entities. In other terms, a State guarantee is established, and governs might find themselves in the unpleasant position to pay potentially massive compensations to victims of accidents caused by private space activities, including CubeSat missions.

It is a common feature of national space legislations therefore to include legal tools for the redistribution of the liability, as nothing in the Treaties obliges States to carry the final burden of such compensations.[46]

The major kinds of provisions adopted by States to regulate third-party liability are constituted by the right of redress of the government against the responsible private entity, and the caps on liability borne by the latter, above which State assumes the guarantee.

Right of recourse and liability ceilings are usually related to a third element, which is the requirement of an insurance coverage against the third-party risk. This provision, usually a condition to obtain the authorization, has the dual function to grant a full and immediate compensation to the victims, and to guarantee the restoration of State in the case it has been held liable under the Space Treaties. The minimum insurance coverage required is commonly related to a fixed amount or to the ceilings on liability.

Although it can be considered a further common feature of NSLs, State practice is as usual greatly heterogeneous in its regulation.

Just a few, aged legislations ignore to provide a minimum set of rules, leaving full room to contractual freedom of the parties.[47] The classic scheme can be figured out as a normative triangle, whose corners are constituted by the right of recourse, the caps on the liability and the insurance requirement. In

---

[45] KERREST, *Liability for Damage Caused by Space Activities*, in Space Law: Current Problems and Perspective for Future Regulation, Eleven International Publishing, 2005, p. 109.

[46] GEHRARD, MOLL, *The Gradual Change from "Building Blocks" to a Common Shape of National Space Legislation in Europe – Summary of Findings and Conclusions*, in Project 2001 Plus, p. 31.

[47] Sweden Act of Space Activities, 1982; Norwegian Act on Launching Space Objects from Norwegian Territory into Outer Space, 1969.

most of the cases, the two latter elements are related: in this way, below the threshold the private operator is in principle liable, but its solvency is granted by an insurance policy of an equivalent amount.[48] Above the threshold, the insurance is no more required, as the State assumes the final responsibility in order to keep insurance premiums at acceptable levels.

The insurance requirement can be compulsory by law, or foreseen as a discretionary power of the authority. Some legislations adopt a combination of these two principles, according to which the *an* is required by law and the *quantum* is left to a case-by-case assessment. State is often a mandatory beneficiary of the policy, in case it has paid under Liability Convention, therefore it can obtain the indemnification directly from the insurer and avoid a long and costly legal claim against the operator.[49]

The insurance requirement can be sometimes waived by a demonstration of equivalent financial responsibility, or exempted on a temporary basis for specific reasons.[50]

It is worthy to briefly analyze here the US Commercial Space Launch Act, which can be considered the most comprehensive and efficient national space legislation currently in force.[51] Contrary to the legislations of smaller space-faring nations, its main purpose is to foster the private space industry by relieving it from any possible financial risk related to third party liability.

It does not provide the State with any proper right of recourse, and is based on a three-layers liability system focused on the insurance requirement. The first, fundamental threshold is the lowest among three possible amounts: the "Maximum Probable Loss",[52] the maximum insurance coverage available in the market at a reasonable price, and the fix amount of US$ 500.000.000, corrected for inflation. Up to this level the operator must be covered by an insurance policy, and the US Government shall be nominated as additional beneficiary in case of a claim under LIAB.

To the extent the compensation exceeds the cap, the US government would carry the burden of such excess, up to an express limit of US$ 1.500.000.000,

---

[48] Exceptions to this principle are Belgian Law and UK Law, in which the minimum insurance coverage is established by the competent authority and not necessarily related to liability thresholds. Belgian Law, Art. 5.2; UK Law, Art. 5.2. Revision of the UK Law is currently on going in order to fix this inconsistency.

[49] For instance: French Space Operations Act, Art.- 6.

[50] For instance: French Law, Art. 17, Decree 2009 643.

[51] Contrary to most of the NSLs, however, it applies only to the launch and re-entry phase, and leaves uncovered the on-orbit operations.

[52] The probable damage is that ordinary damage which may occur in most of the accidents related to space launches. The maximum probable damage refers to the ordinary accidents which may originate maximum losses. HERMIDA, Legal Basis for a National Space Legislation, 2004, note 491 at 88. Since 2004, its assessment is made case-by case by the Office of the Associate Administrator for Commercial Space Transportation, instituted by the Federal Aviation Authority.

corrected for inflation. These provisions apply in principle both in case of a State-to-State compensation procedure under the Liability Convention, and in case of direct domestic lawsuit against the operator. In the unlikely case the amount of the damage exceeds the second threshold, the situation changes according to the way the victim has opted to seek compensation. In the latter case, the US$ 1.500.000.000 ceiling is absolute, and the victim has no right of compensation above it. In the former case, however, the US would bear unlimited liability under international treaties, and would be a matter of US internal law whether and to what extent the US government can call upon the licensee to reimburse him for that part too.[53] Until now we have dealt with the re-allocation of third party liability, which is the only one regulated by the Space Treaties. The US legislation, together with a few others, as anticipated above, aims to provide a more penetrating discipline of liability, taking in consideration other involved risks.

The first further risk to be dealt with is the one carried by the Government in the case of damage to its property, through a two -layered system.[54] The CSLA obliges operators to obtain an additional liability insurance, whose beneficiaries are the United States, its agencies, contractors and subcontractors, personnel and the customer of the launch licensees, and its personnel, with no cost to the United States, to cover the possible damage sustained by those entities, up to the lowest of these three amounts: the "Maximum Probable Loss", the maximum liability insurance available on the world market at reasonable cost, and the fixed amount of US$ 100.000.000, corrected for inflation. Above that limit, the United States, its agencies, contractors and subcontractors involved in launch services are obliged to enter in reciprocal waivers of claim with the commercial launch provider, its contractors, subcontractors and customers, as well as the contractors and the subcontractors of such customer. In this way the US government absorbs the risks to the extent the claim exceeds the amount of the insurance.

What is rather unclear in the US CSLA and also other national space legislations is whether these regulations on the liability caps in insurance apply to small satellites. The high prices might prevent developers to seek for it, while at the same time States would be exposed to bear their obligations as they derive from the Treaties in case of damage.

---

[53] KERREST, VON DER DUNK, *Liability and Insurance in the Context of National Authorisation*, in National Legislation in Europe: Issues of Authorisation of Private Space Activities in the Light of Developments in European Space Cooperation, Nijhoff, 2011, p. 144.

[54] In practical terms, it is to cover the case in which a launch provider enters in arrangement with the US government to use its launch facility, and the latter sustains a damage following an accident during the launch operation. See HERMIDA, Legal Basis for a National Space Legislation, 2004.

IV. Conclusions

In conclusion, the aim of this paper was to stress out the risks associated to the new disruptive technology of small satellites, with a particular emphasis on CubeSats. The presentation of reliability and small satellite constellations as a part of the problems the CubeSat community is facing, did not intend to degrade this new concept which is so much appealing to researchers, students, scientists and industry. On the contrary, the analysis emphasizes the elements that shall be taken into consideration so that we prevent the risks from being realised. Although this is a legal paper, also focusing on liability concerns, it seeks to draw everyone's attention to the root of the problem and encourages the space community to be proactive by abiding to the Space Debris Mitigation Guidelines instead of having another "unexpected" catastrophic collision. Nothing is unexpected with this high congestion in SSO. Collision will bring damage and then someone will have to pay compensation according to the international space law. In this case, insurance can protect the State from being obliged to cover the damage caused by its private entity pursuant to the liability caps. How many new developers insure CubeSats? Shouldn't this ring the alarm clock to national authorities and be encouraged to adopt regulations that apply also to small satellites? Small or big, each space activity, each space object added into the vast outer space shall be in the interest of all mankind.