In Search of Standards for the Operation of Small Satellites

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This paper considers the need for standards for the operations of small spacecraft. First, it considers a definition for what a small spacecraft is and discusses the elusiveness of this definition. Then, the paper turns to the ‘large space’ community and it examines their fears about small spacecraft as well as the operating paradigms that they are used to and how these drive their expectations for the operations of small spacecraft. Next, a prospective composition for a preliminary set of operating standards is discussed. Finally, a discussion of the benefits of standardization and what the different communities could expect to enjoy from the standardization process is presented.

I. Introduction

THIS paper considers the need for standards for the operations of small spacecraft. It begins with a discussion of what constitutes a small spacecraft. Several notions, to this end, that have been previously articulated are considered. Is a spacecraft classified as small by physical mass and dimensions? Is it based on risk tolerance? Is it based on an operating paradigm? Are what Swartwout termed ‘University Class’ spacecraft [1] ‘small in spirit’, no matter what their physical dimensions and mass are? After a discussion of the definition of small spacecraft completed, the paper next considers the need for standards from multiple perspectives. The benefits of operations standardization from the perspective of the small satellite community are first considered. The success of the CubeSat standard (both in terms of size and operating paradigm) is presented as a case study. From this, the paper extrapolates what the effect of ‘game changers’ such as the addition of propulsion and the expansion of the use of the standard for higher-impact missions could be. Benefits from having well defined operating standards to developers in the CubeSat and larger small spacecraft community are presented and evaluated.

Next, the paper turns to the ‘large space’ community and it examines their fears about small spacecraft as well as the operating paradigms that they are used to and how these drive their expectations for the operations of small spacecraft. Several short case studies highlight scenarios where small spacecraft can have a large and negative effect on the operations of an operator of larger craft. For each, several prospective approaches to mitigate the problem are presented and evaluated. Finally, this section concludes with the presentation of a prospective ‘wish list’ of operating standards that large spacecraft operators may suggest for the small spacecraft community.

Third, the composition of a set of prospective operating standards is proposed with a goal of meeting the needs of multiple constituencies. The areas covered by such a set of standards are discussed. Prospective evaluation criteria for such standards are also discussed. These evaluation criteria include their technical feasibility and the impact that the implementation of the standard would have on the small spacecraft community, on the large space community and on other stakeholders.

The paper continues with a discussion of a pathway to the implementation of such a set of standards. Several different approaches (ranging from voluntary adoption to launch provider mandated to national law to international regulation) for standard implementation are discussed and a brief discussion of the pros and cons of each is presented.

Finally, the paper concludes with a discussion of the benefits of standardization and what the different communities could expect to enjoy from the standardization process. A vision of a future with greater (indirect, via remote control) access to space by a larger number of individuals on a more frequent is presented and the benefits of this are discussed.

II. What is a Small Spacecraft

At the formation meeting of the AIAA Small Satellite Technical Committee, the question of what is a small satellite was extensively discussed. Proposed definitions ranged significantly and both this and the question of what this definition should be based on (size, budget, operating paradigm or something else) was left unresolved. A panel at the same (AIAA Space 2013) conference presented an equally unspecific definition, ranging from spacecraft that
could be handiwork to those that are dishwasher-size or larger. That what a small satellite is cannot be easily defined is somewhat ironic given that mankind’s first spacecraft (Sputnik [2]) and the United States’ first (Explorer I [2]) likely fit the many definitions of a small satellite; small spacecraft are thus as old as space exploration itself.

Departing from proofs-of-concept and so-called ‘beepsats’, small spacecraft are now commonly used for student training [3] and research platforms [1]. They also support commercial purposes [4] and military [5] objectives. However, due to their size and cost, their risk profile is dissimilar to conventional (large) spacecraft: when a $5,000 satellite [6] can prospectively impair (or require expensive fuel consumption from) a $50 million one, risk parity doesn’t exist.

But what exactly is a small spacecraft? Wertz suggests that “smallsats are broadly defined as satellites weighing less than about 1000 lbs or 500 kg” [7]. The smaller spacecraft have been divided into classifications including mini-, micro-, nano- and pico- satellites with corresponding mass levels ranging from 100-500 kg, 10-100 kg, 1-10 kg and 0.1 -1 kg, respectively. While CubeSat developers may have difficulty seeing a 500 kg spacecraft as small it is less than a tenth of the 5600 kg mass of Intelsat 10 [8] and only about 4.5% of the 11,110 kg launch mass of the Hubble Space Telescope [9]. On the other hand, 500 kg is a hundred-thousand times larger than the 5 gram mass of Cornell’s KickSat [10].

Swartwout’s work [1] suggests another approach to differentiation: he defines so-called “university class” spacecraft by three characteristics and suggests classification by whether “something fundamentally different” exists between categories as opposed to the use of arbitrary mass levels [11]. They are independent devices (but can be connected to another craft), they use “untrained personnel (i.e. students)” and the training these individuals represents a goal “as important as (if not more important)” than the mission tasks. From this definition, a “freedom to fail” is obtained allowing technical risks to be taken that can prospectively encourage discontinuous advancement of technical capabilities and knowledge. Since the initial launch of UoSAT-1 (in 1981) by the University of Surrey [11], over one-hundred of university class spacecraft have been launched [12]. A trend is evident: looking at launches between 2000 and 2008, 51% were less than 10 kg and only 16% were 40 kg or greater. In 2013, however, 10 kg and lighter spacecraft comprised 83% of those launched; only one 10-40 kg (3%) craft was launched and 40 kg and greater spacecraft accounted for only 14% of launches [13] in this class. For the 10 kg and less category of university-class spacecraft, 97% (in 2013) were CubeSats and CubeSats comprised 81% of all university-class spacecraft [13] launched during the year.

As of 2010, the United States accounts for 61% of pico- and nano-satellite developers, according to Bouwmeester and Guo [14], Japan contains 11% and 18% are in Europe. Both the U.S. National Aeronautics and Space Administration [15] and the European Space Agency [16] have been encouraging their growth via providing no-cost-to-developer launch services to qualified institutions.

While many are celebrating what Michael Swartwout has termed as “the long-threatened flood of university-class spacecraft (and CubeSats)” arrival [13], which can be partially (if not largely) attributed to Bob Twiggs and Jordi Puig-Suari’s [17] introduction of the CubeSat standards and self-contained launch mechanism, it is no wonder that large spacecraft operators are voicing concern. This concern likely originates from both legitimate concerns over problematic operations as well as from commercial concerns related to a fear of innovative uses of small spacecraft impairing the ability to sell larger models. The proliferation enabled by smaller form factors (such as the PocketQub [17], boardsats [10] and chipsats [18, 19]) may further exacerbate these concerns.

III. ‘Large Space’ Operator Expectations and Desires

Ten documents largely define international space law [20], guiding and constraining spacecraft operations. Five of these documents are treaties:

- The "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies", known as the "Outer Space Treaty"
- The "Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space" known as the "Rescue Agreement"
- The "Convention on International Liability for Damage Caused by Space Objects", known as the "Liability Convention"
- The "Convention on Registration of Objects Launched into Outer Space", known as the "Registration Convention"
- The "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies", known as the "Moon Agreement"

An additional five are declarations or principles:
• “The Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space”
• “The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting”
• “The Principles Relating to Remote Sensing of the Earth from Outer Space”
• “The Principles Relevant to the Use of Nuclear Power Sources in Outer Space”
• “The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries”

The foregoing restricts states from making sovereign claims (leading to controversy surrounding the recent proposed ASTEROIDS act [21], for example). They also ban certain weapons, requires spatial body use be for peaceful purposes and define a duty to aid astronauts. Perhaps most relevant to small satellites (at present) is the treaties’ establishment of responsibility and liability for citizen/entity activities and objects in space by their states and the requirement that states avoid contaminating outer space [22-26]. While the treaties define procedures for resolving liability disputes [24] and spacecraft registration [25], they provide little guidance as to what it means to be a responsible space operator.

The United States body of national law does little to help guide in this area as well. The Commercial Space Launch Act of 1984 provides authority to regulate commercial space activities to the Department of Transportation’s Federal Aviation Administration’s Office of Commercial Space Transportation (FAA OCST) [27]. While the FAA OCST does review (per §415.59 of Title 14 of the Code of Federal Regulations) the “orbital parameters for parking, transfer and final orbits” and the “intended payload operations during the life of the payload” [28], it remains unclear as to what defines whether something is an acceptable operations plan or set of orbital parameters. Other laws, like the International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR) impose restrictions, in some cases, on the launch provider that can be used, on participation in spacecraft design and development, and on mission operations (see [29]). However they, also, provide little to define how operators should behave responsibly.

In response to this void, two attempts at developing an international “Code of Conduct for Outer Space Activities” have occurred [30]. First introduced by the European Council in 2008 and reintroduced in 2012, the proposed code [31] of conduct, while not binding on countries adopting it, would be binding on adopters’ citizens and entities. Foust [32] proffers that the code largely contains items that are undisputed. It [31] discusses, in broad principals, how governments and their citizens and entities should interact, suggesting avoiding intentional destruction of other’s spacecraft, consultation, notification, information sharing and technical visits. However, it does little to inform specific decision making.

All of the foregoing have been shaped by the actions, lobbying and considerations of both public and private ‘large space’ operators; however, none really fully captures their wishes. Perhaps these can be best stated as non-interference. Large operators simply want to conduct their business without having to devote time, resources and concern to the activities of small operators.

IV. Towards Operating Standards

Is a set of operating standards for the small spacecraft community necessary? A partial answer to this question can be found by reviewing the consideration of the need for operating standards by the high altitude balloon (HAB) community [33]. Several arguments for their need were advanced including transforming regulatory language and guidelines into specific actionable principles, mitigating the risk of harm to participants and the public, and facilitating the demonstration of conformance, by operators, to a set of best practices (which could mitigate damages in the event that harm befall an individual or property). It was also hoped that they might change the regulatory response to any mishap from banning to investigating deviations from best practices and identifying best practices changes, such as occurred in response to a recent hang gliding mishap in Canada [34].

A. Need for Standards

The consideration of standards in the HAB community can be informative to the small satellite one. Small satellite operations have multiple similarities to HAB operators. University-class spacecraft programs, like university HAB programs, cater to inexperienced developers and operations staffers. Despite their inexperience, these individuals still must make critical decisions. Even if a given program subscribes (and regularly reinforces the importance of following) a general principal, the inexperience staff may lack an understanding of the implications of
a given decision and what decision is suggested by the general principles. An extended discussion of risk factors in small spacecraft development can be found in [35, 36].

Another similarity is the growth of new programs which may be launched (for both) by faculty who are inexperienced with HAB/CubeSat development and/or operations (despite having significant technical or science discipline background). Specific guidelines can, thus, provide a starting point for making informed decisions. The adoption of a set of guidelines may produce several benefits such as reducing the likelihood and/or frequency of mishaps, demonstrating operator responsibility and, thus, effectively disambiguating responsible operators from those acting in an irresponsible manner (limiting the ‘tainting’ effect of irresponsible operators on the community at large).

A recent Kickstarter campaign for “WREN: The First Satellite YOU Can Fly” [37] serves as a case study to illustrate the importance of operating standards. The cancellation of the campaign (due to failing to reach its financial targets) removed this particular concern; however, the proposed mission is still illustrative. The types of safeguards that would be used in the WREN mission to secure the control of its “pulsed plasma thrusters” and ensure trajectory safety are unclear. Given the stated direct nature of control possible and current technological (born of mass and volume constraint) limitations of onboard small spacecraft computational capabilities, it seems unlikely that the spacecraft could have detected and prevented all relevant collision scenarios.

Presumably, the German government (as it was a project in Germany by German nationals) would be held (at least partially, depending on launch provider selection and other factors) liable for damage (under the Outer Space Treaty or the Liability Convention, see Section 2.2) prospectively caused to another spacecraft. It is also possible that, if the controller at the time was a non-German, the controller’s government could be responsible (instead of or in conjunction with the German government, pursuant to somewhat vague wording in Article 6 of the Outer Space Treaty) for damages caused by the craft – a liability that would undoubtedly be unexpected. If a government was forced to pay out damages (without the capability to recover significantly from an operator of limited means), this could have a chilling effect on acceptance of small spacecraft development in that country and worldwide. This type of delegation (and the requirements for doing so safely) could, thus, be a topic of standards coverage. Other operators could use the defined standards and their adherence to them to demonstrate to their national government how they are acting responsibly and thus should not be impeded in response to these concerns.

B. Standards Coverage

This section considers the areas that should and could, prospectively, be covered by a set of CubeSat / small spacecraft operating standards. The development of specific standards is left to discussion within the small spacecraft community and future work.

**Operator Training** – What should operators know before engaging in a small spacecraft mission? How should this knowledge be assessed? How frequently should ‘refresher’ training or testing be undertaken?

**Material Composition** – What materials should be used on CubeSats and other small spacecraft? Should some materials trigger reduced regulation requirements (perhaps in conjunction with other factors)? Should some materials be suggested as not-to-be-used? Should there be different pathways for materials that represent particular safety concerns?

**Structural Integrity** – What should be expected of the structure of a CubeSat? How should this be defined? Are current launch provider / CubeSat / etc. standards representative of minimums or best practices? Are current standards needlessly high?

**Control** – What types of control capabilities should a small spacecraft have? Are there minimum control requirements for all CubeSats? How does the incorporation of propulsion and/or other subsystems impact control requirements?

**Mitigation of Risk to Manned and Unmanned Spacecraft** – What responsibilities should small spacecraft developers take to manned and other unmanned spacecraft? How are these responsibilities split between the operator and the launch provider (particularly for spacecraft without propulsion)?

**Operating Security** – What are minimum and best practices-levels of security standards for small spacecraft?

How should compliance with these standards be validated? Does the existence (or robustness) of certain subsystems (e.g., propulsion) change what level of security is needed?

**Proximity** – How close should a small spacecraft get to another spacecraft? Should standards be different for spacing between affiliated and non-affiliated craft? What is a target level of minimum spacing versus a level at which avoidance action is needed? How do proximity standards impact non-propulsion spacecraft?

**Avoiding Disruption** – How can small spacecraft operators avoid the disruption of other spacecraft (particularly large spacecraft) operators? What types of activities are most disruptive? How should the benefit of the
activity to the operator be considered relative to the impediment / disruption caused to others? Are certain activities ‘rights’ that can be performed irrespective of their impact on others?

**Privacy of Individuals & Other Spacecraft** – What types of sensing should be performed by small spacecraft? Does the type of operator (academic, government, commercial, private, etc.) impact what types of sensing is acceptable? How does/should national privacy / sensing law impact the orbital environment?

**Responsible Science** – What types of safeguards should be in place to protect others from small spacecraft science and engineering activities? Should some activities require review beyond the investigators / participants? Should some activities require extra-institutional review?

**Information Accuracy** – Do / should operators have a requirement to provide only accurate information relating to the location and capabilities of their small spacecraft? What level of accuracy is acceptable? Does operator type or activity type change the need for or level of accuracy required?

**Warning of Proximity** – Should small spacecraft operators have a requirement to actively warn others (particularly those that may lack the capability to track a small spacecraft size object) of their proximity? What format should this warning take?

**Warning of Danger** – Do / should small spacecraft operators have a requirement to actively warn others of danger detected? What types of danger should fall under this requirement? Is active scanning for danger (or particular types of danger) required? Is prompt analysis of data to detect prospective danger required? How should a danger warning be conveyed and to whom?

**Registration and Coordination** – What are / should be best practices for registration and coordination of small spacecraft? Can current processes be streamlined to facilitate workload reduction for both operators / developers and registering / coordinating agencies? Should streamlined processes be only applicable to certain types of missions or missions with certain characteristics?

**Debris Prevention** – What responsibility to prevent debris in orbit do / should small spacecraft operators have? What are best practices to ensure that this responsibility is met?

C. Evaluation of Standards

Consideration of the best way to evaluate proposed standards must also be undertaken. Evaluation criteria should include the technical feasibility of the standard as well as the impact that the implementation of the standard would have on the small spacecraft community, the large space community and other stakeholders. Prospectively, these standards, in addition to encouraging beneficent, ethical and non-impactful-to-others operations should have several beneficial characteristics and prospective standards can be assessed based on the extent to which they provide or facilitate these characteristics.

First, any proposed standards should be designed to minimize their compliance costs. For example, many standards (of a type that require validation or, particularly, third-party compliance validation) could be designed so that they could be incorporated into launch provider review procedures. Particularly where a standard is similar to an existing one (e.g., a best practice that says that a greater level of durability is required as compared to the minimum for launch vehicle integration), launch provider verification of the higher standard may have little or no incremental cost.

Second, standards should be designed for streamlining. When possible, review by exception instead of requiring a complete review of every submitted spacecraft, plan or other document should be used. For example, a developer using materials that don’t represent a re-entry hazard (based on all mission parameters) could be spared the need to perform an assessment (and saving regulators the time of reviewing anything beyond a certification of compliance). This would facilitate regulators focusing attention on critical areas (instead of performing reviews to ensure compliance of differently worded plans).

Third, standards should be reviewed to ensure that they do not obfuscate prospective problems. Standards presented as absolutes should be defined in a way that ensures that their (particularly without mission-specific consideration being properly performed) implementation cannot result in a problem in particular mission characteristics. Standards should be designed with a worst-case-scenario in mind and then, when implemented by responsible and well-informed operators, support lowering the proverbial bar based upon mission particulars and the absence of certain types of risk factors or mission characteristics.

D. Pathway to Standards

Several prospective pathways to the implementation of a set of standards with the characteristics discussed herein exist. Standards could be self-applied unilaterally by operators, they could be dictated by national (or institutional) policy, they could be imposed by launch providers (or providers’ / developers’ insurers) or incorporated into a new international treaty. Pragmatically, however, what seems to be the most likely approach is a
combination of the foregoing. Some may adopt best practices (or a subset of a collection of best practices) on their own. Others may require external pressure. Over time, perhaps, the existence of such a set of standards may become an ingrained culture of the small spacecraft community.

V. Conclusion

It is hoped that the development and availability of a set of standards and best practices code will provide new entrants, particularly academic developers with a way to ensure that important safety and other considerations are attended to. Students, in particular, may benefit from the experience of utilizing a robust set of operational specifications which will have similarities to those that they may later encounter in careers in government or industry.

It is important to keep in mind that some elements of any proposed standard set may represent a significant technical challenge or be impractical or impossible for certain missions. The standards should inform, but not dictate, mission decision making. To the extent that an (otherwise demonstrably safe) mission cannot meet a particular standard or a standard exceeds technical capabilities, the standard should serve (with consideration and appropriate approvals) as guideline and an identification of an area of prospective concern, not as a mission-stopper. In some other cases, the implementation cost of a standard may exceed its utility or developer resources and a similar approach should be taken.

It is critical to remember that the peril potentially caused by any spacecraft (large or small) prospectively affects all (nearby) spacefarers, not just others of the same design class. Thus, larger operators will likely hold claims of impracticality of safe operations unpersuasive. If demonstrable safe operation cannot be reached, they may push to limit access to space to small spacecraft that are unable to or fail to demonstrate safe operation capabilities commensurate to the risk posed by the craft. Alternately, to protect innovation, care must be taken to create a pathway gain exception for deviations which is not overly burdensome, while incorporating suitable assessment of whether a given deviation creates unacceptable risk levels.

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References

11. Swartwout, M. Twenty (plus) years of university-class spacecraft: a review of what was, an understanding of what is, and a look at what should be next. 2006.

American Institute of Aeronautics and Astronautics


29. Straub, J.; Vacek, J. In *Do we have an ITAR Problem: A Review of the Implications of ITAR and Title VII on Small Satellite Programs*; Spring 2013 CubeSat Workshop; 2013; .


