Small Satellite Standards Development

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ABSTRACT: The Air Force Research Laboratory, in conjunction with numerous government, academic, professional organizations and industry, is initiating the development of a set of small satellite standards. It is envisioned that these standards will encompass standard launch vehicle mechanical and electrical interfaces, as well as inter-satellite mechanical, electrical and software interfaces. The procedure that is being followed in the standards development process is to engage the stakeholders in the small satellite community in a dialogue to determine which, if any, of the above standards can be implemented in the near term. Those standards would then be included in relevant future solicitations from the participating Government agencies through Small Business Innovative Research (SBIR) and other contract vehicles.

The author believes that small satellites represent a potential disruptive technology in the aerospace industry. However, the disruptive nature of small satellites lies in their ability to be simpler, cheaper and more modular than larger spacecraft. In order to achieve modularity, a set of small satellite standards needs to be developed and employed. This paper will assess the critical path to standards development, including past examples, as well as progress to date in the development of a set of small satellite standards.

INTRODUCTION

Overview/ Purpose

As the small satellite community undertakes a standards development effort it is prudent to first take a step back and examine the lessons learned from previous standards development efforts. This study should include specific examples from the previous standards development efforts (including failures and successes), but equally important it should include an examination of the procedure associated with a standards development process. The purpose of this paper is to provide this background study as a reference for future small satellite standards development efforts.

STANDARDS

Definition

The term 'standard' can have many different meanings. It is therefore useful to precisely define what we mean when we say 'standard'. In the context of this paper, a standard is a rule or requirement that is determined by a consensus opinion of users and that prescribes the accepted criteria for a product, process or procedure.[6] The underlying assumption is that the accepted criteria represents the best

technical approach, but this is more of a measure of success of the standards development process than the actual standard. In considering the concept of standards as they relate to satellites, the goal is most often interoperability, and a standard is the means to that end. The benefits of interoperability are the same for small satellites as in other applications, most notably a reduction in total product cost and ability for companies to specialize. Industry has an interest in standards specifically because it allows for competitive specialization. This is especially applicable to the small satellite community, where the vast majority of the suppliers are specialized, with very few small companies maintaining a broad core competency. Standardization would allow these small specialized companies to be more profitable.

In examining standards, the best ones are transparent to the end user – they are accepted. This implies utility and cost effectiveness. For completeness, standards can also serve the purpose of safety, quality or consistency, although these are typically not the reasons for using standards in the satellite industry.

History

Standards have been in existence for nearly as long as civilization. Very early examples include the use of stones for weight standards, and various standards for currency. In the U.S., some of the notable early standards were the railroad standard gage, the standard brick size and, more recently, the adoption of standard electrical appliance specifications. Currently in the U.S., there are in excess of 30,000 voluntary standards, which have been developed by more than 400 organizations.[6] This represents a conservatively low number compared to the total number of standards in use in the U.S. today.

The formal standards development process in the United States dates back 100 years with the formation of what is now the American National Standards Institute (ANSI) in 1918. In fact, standards development in the US preceded this by a few decades with work at the various professional engineering organizations (IEEE, ASME, ASCE, etc.).

Today, other organizations also exist in the US and worldwide that serve the same function (NIST, ISO, etc.). Regardless, it is apparent that there is a significant history and lessons learned database from which one can draw.

Standards Process

As one begins to undertake a standards development effort, two things quickly become apparent: 1. While the concept of a standard is easy to intellectually grasp (in fact the better the standard, the easier it appears) the implementation of a standard technically is often very difficult. When one attempts to develop a standard, one is moving a significant amount of the technical work to the front of the process. This is beneficial in the long run because it can greatly reduce the recurring engineering costs for a product. 2. In spite of the fact that the technical side of developing a standard is difficult, the process of obtaining the standard is even more difficult. The mechanics of a standards development effort is estimated to consume approximately double the resources (financial, manpower, schedule) as compared to defining the technical standard.

Although it may not seem intuitively obvious, the *process* of standards development is more important to the final end product success than the detailed technical inputs to the process. This fact is clearly illustrated by the modus operandi of each of the major standards development organizations, which focus

heavily on procedure vs. technical content. A typical organizational structure is as follows (from ISO) [4]: Membership is open and on an equal basis. Participation is voluntary, but is most often market driven (i.e. participation is often the result of market forces). In other cases (i.e. safety), the organizational force is mandated. For example, in the case of traffic safety standards (e.g. traffic markings and signage). In the end, consensus is the primary end goal of the process with a required mechanism for negative opinions and resolution. This is noteworthy in the aerospace industry, which is not typically noted for its high degree of cooperation.

The standards community generally agrees that the development of standards occurs in a competitive environment, where weaker standards generally do not get adopted or are supplanted by technically superior ones. However, the drawback to this architecture is that some standards can be promulgated by a significant market interest, even if it is not the best technical solution.

SUCCESSFUL (AND UNSUCCESSFUL) STANDARDS

A few select case studies are examined to illustrate 'good' and 'bad' standards. One important conclusion from this analysis is that the technical solution is not the sole driving factor in determining the relative success of a given standard.

Universal Serial Bus (USB)

The Universal Serial Bus (USB) standard, which is probably the most cited example when one discusses the desire for standards in small satellites, is an interesting lesson in successful standards development.

First, the USB Implementers Forum[8] has a very mature standard development process. This can be considered completely separate from the actual technical standard. If one looks at the history of successful standards development, the essential element of a mature standards development process must exist.

Second, the USB standard is being advanced by Intel, Microsoft, Hewlett Packard, NEC and many others. This represents a significant market share in the PC industry. The lesson is that critical mass matters in the successful development and adoption of a standard. In this regard, the small satellite community fails. It is the author's opinion that cooperation in the space community is all but impossible, with the true cooperation required for this level of standards development effort non-existent.

An interesting note on the USB standard: the controlling documentation which defines the technical specification is 650 pages in length. This represents only the original specification, not including any updates, errata, etc. This illustrates the complexity and effort that is involved in accomplishing the end goal of a seamless 'plug-and-play' interoperability. In addition, the USB development effort began in 1995, with a first release of the USB 2.0 standard in 2000. While the USB 1.0 standard existed prior to 2000, one could argue that version 2.0 represents the first non-beta implementation of the standard. This reinforces the timeline advocated by the international standards organizing bodies of 2-6 years for full standard implementation.[4,5]

Ada

The Ada computer programming language was developed by the United States Government, specifically the Department of Defense (DoD), in the time frame from the

late 1970's through the late 1990's, in an effort to standardize and thus reduce the costs of embedded custom software development in DoD systems. The development effort followed a typical systematic Government development approach. The Ada code was even submitted and adopted by both ANSI and ISO in the mid 1990's. This example illustrates that the standard development process is lengthy, in this case spanning decades.

The Ada development effort is frequently quoted within the Government as "what not to do". In examining Ada from a standards perspective, what went wrong? The Ada development team followed the standards development process, including adoption by the appropriate governing bodies. However, one thing that the Ada standards development team failed to capture (possibly deliberately) was the explosion in the personal computer and associated software market. One could probably argue that the Ada standards development process actually worked as originally intended (assuming that the exclusion of the commercial software market was deliberate). In fact, the Ada system is still used in the security dominated Government unique applications for which it was designed (DoD, banking, commercial aviation). The failure, then, is not in the programming language standard, but in the expectations of the onlookers who thought the system would be universally applicable.

However, the Ada example is very useful in illustrating that a great deal of money (hundreds of millions of dollars) is sometimes spent on standards development efforts, with very little return on investment. This is simply a function of the natural market driven standards process. The lesson for small satellite developers is that a standard will find application only among those that have a vested interest in the process. Those that are left out of the process will be very difficult to bring into the fold at a later date. This is not an argument to bring all conceivable stakeholders into the standards process immediately - this would likely lead to group paralysis. Clearly, achieving the correct balance point is not a trivial solution. However, it is possible that the small satellite community is small enough to be able to function towards a standards solution, but large enough to satisfy market forces.

SMALL SATELLITE STANDARDS DEVELOPMENT

Desired Framework

As a starting point, it is helpful to lay out what the small satellite community wants from standards. Based on the author's personal experience, the most commonly evoked comparison is between a satellite and a personal computer. The stated goal is to develop a satellite solution that has the desired PC attributes: ease of use, plug-and-play capability, component interoperability, etc.

The similarities between a PC and a typical satellite are numerous, with the degree of similarity significantly outstripping the differences. This degree of similarity lends itself to the PC / satellite analogy, making the comparison a valid one. However, one should be mindful of tracking the important differences between the two, most notably the remote, harsh environment in which a satellite must operate, so that a fair comparison can be made.

History / Reality

Several attempts have been made in the aerospace industry at standardization or interoperability of satellites. In all cases, the result was less than the original intent of a

sweeping industry-wide change. In some cases nominal interoperability was realized for a period of time. In other cases, the 'standard' died with the program. The lesson of history is often overlooked in all fields, and engineering is no exception. However, in this case an important lesson should be taken from history, namely that the standards development process is a process, not a eureka moment. To be successful takes dedicated hard work and significant amounts of time. The previous attempts at standardization in the aerospace industry should not be seen as failures, but instead as incremental steps toward problem solution. If one looks at the PC industry – our closest model – one can see the same pattern. Multiple attempts at standardization have been made over time in the PC industry, with varying degrees of success at each step. In fact, if one looks closely at the PC architecture, it is actually a very complex interweave of standards that have been developed and matured over time. The PC example appears as an integrated simple solution to the user precisely because it is a good standard.

One other important lesson to be learned from the PC industry is the approximate cost of standards development. A quick survey of the literature puts the estimate for an average PC standard (Ethernet or OSI, for example) at anywhere from $10M to $500M. It is unlikely that the R&D side of the satellite industry will be able to garner this level of resources for a standards development effort.

Examples: Universities

Several recent standards development efforts have been undertaken within the university small satellite community. One program of note is the CubeSat effort, which has done very well at defining a standard satellite volume and mass, and maintaining that standard through time. In addition, several recent University class small satellite efforts (PCSat, Sapphire, etc.) have adopted degrees of standardization in their satellites, significantly leveraging personal computer COTS components and associated standards. In these cases, the standard was adopted because of a lack of resources at the universities to develop customized solutions. As is noted later, the true test of these systems will not be if they are fully optimized, but if they provide a market solution (i.e. not are they perfect, but are they good enough).

Examples: Launch Vehicles

Another excellent example of standardization in the aerospace industry is in the launch market. Because there are relatively few providers for space lift, the mechanical interface for satellites (physical interface, volume, mass) is standardized. The trade space for the satellite designer is more or less set by the launch vehicles, and more importantly is widely accepted. In effect, this results in a de-facto set of standards. If the satellite designer cannot live within the mass constraints of a given system, they move to the next most capable vehicle.

Examples: Air Force Research Laboratory

The Air Force Research Laboratory, Space Vehicles Directorate recently began an effort to evaluate the concept of taking terrestrial personal computer and other COTS components and standards and building a functional R&D focused satellite. Early results from the study suggest that a capable system can be developed to meet the R&D satellite market needs. If this system can be realized, several significant advantages result:

1. The process of taking an R&D payload from the lab bench to the satellite is significantly streamlined. Most all lab bench setups for developing

experiments already utilize a PC interface.

2. The system will be highly evolvable over time, directly following the PC industry as it advances.
3. The system interface will be greatly simplified, again following the common PC user interface and system architecture.
4. The system cost will be significantly reduced by utilizing high volume / low cost COTS components. In addition, custom interface development non-recurring engineering (NRE) costs are significantly reduced.

The final results of the study are pending, but initial trade studies suggest that a very capable system can be assembled for very low cost.

In addition, the Air Force Research Laboratory, Space Vehicles Directorate, under the University Nanosatellite Program, has undertaken the development of a series of small satellite standardized structural busses. The latest revision of the structural design is designed to interface with the 15" diameter ESPA secondary position and accommodate the best design principles from the previous designs (modularity, scalability, ease of fabrication, etc.). The satellite bus structure is considered 'low hanging fruit' on the potential standards tree, and was therefore the first step taken at AFRL in the standards process. Interestingly, this was not the result of a conscious effort on the part of the AFRL team, but rather a function of the constraints (money, personnel, etc.) and their availability – the structure was done first because it was the easiest, but not with malice of forethought.

CONCLUSIONS

The purpose of this paper has been to provide a background and perspective for those in the small satellite industry who intend to undertake standards development efforts. A few critical statements can be made about the standards development process and should be internalized prior to undertaking a development effort:

1. Standards development is expensive, costing at minimum $1 million, and easily ranging into the $100's of millions for large efforts.
2. Standards development involves both a technical solution and a process to reach community consensus.
3. Standards committee size and time to standards development are inversely related. This is due to organizational complexity and the fact that standards organizations have traditionally been hampered by political (non-technical) issues. Regardless, standards development has historically taken a minimum of 2-6 years, depending on the scale of the effort.
4. Standards development is market driven.

These factors should be considered as the small satellite community undertakes any standards development efforts. In the author's opinion, the small satellite community does not have the inherent market in the near term to sustain a stand alone (i.e. customized) standards development effort. The only path is to take developed standards from the PC and other industries and adapt them to small satellite use. In this regard, small satellites have a distinct advantage over the more traditional large satellite aerospace industry in their flexibility to adapt to new design paradigms.

The fundamental question in this trade is if it makes more sense to adopt PC standards and adjust small satellites to fit (thus leveraging the significant capital investment of the PC

industry – literally billions of dollars for the more common standards), or to develop custom small satellite standards solutions. It is the author's opinion that the latter path is not viable for a multitude of reasons, including the lack of market forces, time to product maturation, and lack of true cooperation in the aerospace industry.

The path that the author is proposing is a complete departure from the traditional satellite design methodology of requirements flow-down from a mission statement. The current requirements flow-down process is a logical one for a mature industry. However, Christensen[2] suggests that disruptive technologies should not, by there very nature, follow the traditional methodology, but should instead strive to create an initial small market solution with the capability to satisfy traditional market needs through an inherently advanced rate of product improvement. If small satellites were to adopt this PC standards paradigm, they could truly realize their potential as a disruptive technology to larger satellites. By hitching a ride on the coattails of the PC industry (to which a satellite already has significant similarities) and adopting their standards, small satellites can realize the significantly accelerated performance growth that disruptive technologies must possess.

As one example, the PC industry has seen significant advancement in processing power (obeying Moore's law), while satellite processing capability has lagged significantly. The logical reason for this is that the traditional satellite processors must be radiation hardened for the space environment. In approaching the systems engineering problem from a different perspective, what if a different system could be developed, say a dual processor watchdog system in a relatively benign LEO environment. A 3GHz PC chip costs $250, while a 250MHz space rated chip costs $10,000. In the systems engineering trade space the space rated chip is roughly 100,000 times as expensive for computing power. In addition, if a paradigm could be adopted to take advantage of the COTS PC chip market, the R&D costs moving into the future would be essentially covered, and the satellite system would grow in capability very rapidly relative to the traditional satellite industry.

References

1. American National Standards Institute (ANSI) Website, http://www.ansi.org/.
2. Clayton M. Christensen, "The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail", Harvard University Press, 1997.
3. Cubesat Official Web Site - CubeSat Design Specification, http://cubesat.calpoly.edu/.
4. International Organization for Standardization (ISO) Website, http://www.iso.ch/iso/en/ISOOnline.frontpage.
5. National Institute of Standards and Technology (NIST) Website, http://www.nist.gov/.
6. NBSIR 87-3576, "The ABC's of Standards Related Activities in the United States", National Institute of Standards and Technology, May 1987.
7. Michael Spring, "The Structure of IT Standardization", http://www.sis.pitt.edu/~spring/new_views/new_views.html, 1995.
8. Universal Serial Bus Implementers Forum, http://www.usb.org.