PAPER AAS 05-198

Space Standards, Rules, Innovation, and Inhibition

DAVID FINKLEMAN, CENTER FOR SPACE STANDARDS AND INNOVATION

ANALYTICAL GRAPHICS INC.

AAS/AIAA Space Flight Mechanics Conference

COPPER MOUNTAIN, COLORADO JANUA RY 23-27, 2005

AAS Publications Office, P.O. Box 28130, San Diego, CA 92198

AAS 05-198

Space Standards, Rules, Innovation, and Inhibition

David Finkleman[†]

The purpose of this paper is to introduce the broad astrodynamics and space operations community to the role of international standards, the implications of standardization, and current thrusts in space standards. We review the structure of the international standards community and its entry into the space enterprise. We suggest that characteristics of the physical environment be standardized, but not the physics. We urge that data exchanges include measures of accuracy and precision. In particular, covariances are absolutely essential for effective interaction within the astrodynamics enterprise. We discuss the legal, ethical, and competitive implications of standardization in three venues: orbit determination and estimation, communication with and among satellites, and satellite navigation and precise positioning. Finally, we describe current initiatives within the International Standards Organization (ISO) Orbital Debris Coordination Working Group (ODCQWG) and offer for comment embryonic approaches for orbital data exchange for the purpose of mitigating collisions and resulting space debris.

INTRODUCTION

Millions of cell phone users confidently reenergize their devices in their automobiles, their homes, and airport terminals all over the world. Because there are engineering standards. Unfortunately, they must carry an array of adapters if they travel widely. Because "standards" are not exactly uniform everywhere in the world. If an innovative manufacturer developed a new charger that were much more efficient and less expensive but required a different kind of charging receptacle, his device would probably not sell well. Because it is non-standard.

Standards can enable commerce, but they can inhibit innovation. Standards can assure sufficient levels of performance, interoperability, and performance which may all be insufficient for many applications. Standards may be adopted voluntarily, driven by market forces, or they may be imposed by statute with physical sanctions far beyond loss of market share.

How should standards apply to space enterprises, which require sophisticated technology and which are characterized by engineering at the margin, exceptional weight constraints,

[†] Senior Scientist, Center for Space Standards and Innovation, Analytical Graphics, Inc., 7150 Campus Drive, Colorado Springs, CO 80919. E-Mail: dfinkleman@centerforspace.com. Phone: (719) 510-8282, FAX: (719) 573-9079. Web Site: http://www.centerforspace.com

and extremely expensive activities? What are the legal, diplomatic, and societal impacts of space standards? What should the role of the AIAA, industry, and Government be?

THE STANDARDS COMMUNITY

ISO (International Organization for Standardization) is the world's largest developer of standards. Although ISO's principal activity is the development of technical standards, ISO standards also have important economic and social repercussions. ISO standards make a positive difference, not just to engineers and manufacturers for whom they solve basic problems in production and distribution, but to society as a whole.

The American National Standards Institute (ANSI) has served as administrator and coordinator of the United States private sector voluntary standardization system for more than 80 years. Founded in 1918 by five engineering societies and three government agencies, the Institute remains a private, nonprofit membership organization supported by a diverse constituency of private and public sector organizations.

Throughout its history, ANSI has maintained as its primary goal the enhancement of global competitiveness of U.S. business and the American quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems and promoting their integrity. The Institute represents the interests of its nearly 1,000 company, organization, government agency, institutional and international members through its office in New York City, and its headquarters in Washington, D.C.

ANSI promotes the use of U.S. standards internationally, advocates U.S. policy and technical positions in international and regional standards organizations, and encourages the adoption of international standards as national standards where they meet the needs of the user community.

The Institute is the sole U.S. representative and dues-paying member of the two major non-treaty international standards organizations, the International Organization for Standardization (ISO), and, via the U.S. National Committee (USNC), the International Electrotechnical Commission (IEC). As a founding member of the ISO, ANSI plays a strong leadership role in its governing body while U.S. participation, via the USNC, is equally strong in the IEC.

The standards community is often affected by a wide variety of federal, state and local legislative and regulatory proposals, many of which are not front-page news. Legislators and their staff often need a neutral source of information regarding standards and how to gain access to the appropriate developers. Additionally, government agencies use standards both directly and indirectly in their work: in regulations and laws, in procurement, and in internal operations.

ANSI's role is as an information provider, bridging the gap between standards developers and the governmental agencies that create legislation affecting the standards community. In addition, since the passage of The National Technology Transfer and Advancement Act of 1995 (P.L. 104-113) (NTTAA) as well as the issuance of The Office of Management and Budget Circular A-119, ANSI has worked to facilitate the growing trend of government agencies using voluntary consensus standards created by the private sector as an alternative to agency-developed standards. Since the passage of the NTTAA, this trend has accelerated, as the law makes clear that this is not just a good idea, but a requirement where use of such standards is consistent with agency policy, and appropriate for agency purposes.

The NTTAA is very significant. It virtually mandates that the Government employ industry consensus standards and that Government agencies not create independent standards where consensus standards exist. OMB Circular A-119 implements PL 104-113 in the Executive Branch. It states that: "The use of [voluntary consensus] standards, whenever practicable and appropriate, is intended to achieve the following goals:

- Eliminate the cost to the Government of developing its own standards and decrease the cost of goods procured and the burden of complying with agency regulation.
- Provide incentives and opportunities to establish standards that serve national needs.
- Encourage long-term growth for U.S. enterprises and promote efficiency and economic competition through harmonization of standards.
- Further the policy of reliance upon the private sector to supply Government needs for goods and services."

The Act requires that each agency must report by 31 Dec of each year decisions in the previous fiscal year to use governbment-unique standardes in lieu of voluntary consensus standards. The report must ilnclude explantions of reasons by use of a voluntary consensus standard would be inconsistent with applicable law or otherwise impractical. Thus ***any space standard developed with suitable consensus (AIAA, AAS, ANSI, or ISO) should be used within the Government for the reasons noted with bullets above.***

ANSI has delegated the responsibility for space standards to the AIAA. This is not an absolute delegation, but is a *de facto* delegation for all ISO standards development related to the space industry. Does this delegation give the AIAA the right to determine space standard policy for the US? Perhaps or perhaps not. However the responsibility to act in the interests of the US has not been accepted by any US agency. Acting responsibly may require the AIAA to accept a role it has not been chartered to perform.

STANDARDS IN SPACE ENTERPRISE

Many of the 225 ISO Technical Committee areas apply to aerospace. The preponderance of the industry embraces ISO 9000 quality management principles and

ISO 14000 environmental consensus. ISO 9000 principles are derived from the collective experience and knowledge of the international experts who participate in ISO Technical Committees. [1] Each Technical Committee is divided into SubCommittees for major functional areas, and the subcommittees are further parsed into Working Groups with very specific focus. TC 20 deals specifically and exclusively with Aircraft and Space Vehicles. SC 6 develops the Standard Atmosphere, and SC 8 standardizes aerospace terminology, clearly important areas for all in our profession. Two Subcommittees within TC 20 are dedicated to activities in space: SC 13 - Space Data and Information Transfer Systems and SC 14 - Space Systems and Operations. The Jet Propulsion Laboratory, as an agent of NASA leads SC 13, and the AIAA leads SC 14. It is very important that many nations participate voluntarily in TC 20 and its subcommittees. Recognizing the diversity of space and aircraft endeavors, SC's 13 and 14 have begun the lengthy and bureaucratic process of establishing a separate TC for Space.

The Consultative Committee for Space Data Standards (CCSDS) is the most active space related standards body. CCSDS emerged from the worldwide telemetry community. It synthesizes consensus, standardized solutions for common space data handling needs focused on transferring data from satellites to terrestrial receivers. CCSDS is effectively one label of two labels for this standards body; the other is as SC13. CCSDS standards are also ISO standards. More than 250 missions fly voluntarily with CCSDS protocols and use CCSDS approaches to space qualified hardware and software. The Space Assigned Numbers Authority (SANA) a subgroup of TC20/SC13/CCSDS serves the very important function of standardizing spacecraft identification and elements of data streams within data transfer protocols synthesized by the standards community.

What Should Be Standardized?

Most agree that activities that affect health and safety should and must be standardized. We should not all have to suffer the same tragedies, and the world's collective experience can benefit each country, business, and individual. The breadth of world-wide observations and scientific research should also guide developing physical standards for timing, the geopotential, the extended atmosphere, the near-Earth space environment, and similar fundamental determinants of space activity. It is not as clear that other aspects of space systems and operations should be standardized. Some because standards could inhibit success. Some could jeopardize national security by revealing unique practices and technologies.

---

[1] Customer focus, Leadership, Involvement of people, Process approach, System approach to management, Continual improvement , Factual approach to decision making, Mutually beneficial supplier relationships

Independent parameters of the physical environment should be standardized, but physical hypotheses should not. Satellite owners and operators need to be aware of the position and state of motion of objects that could interact with them unintentionally. This means that orbit elements, statements of forces invoked for orbit determination and propagation, and physical parameters such as the shape of the Earth and the gravitational constant should appear in standards. Many such standards exist in independent venues, such as the International Earth Rotation and Reference Systems Service (IERS)[2]. These should be vetted by existing international consensus standards authorities. However, each owner or operator knows best the tolerances and dead bands of his systems, and each may choose approaches best suited to his unique objectives. The standards should be for the purpose of comparison among diverse approaches, as a common ground for discussion and negotiation. Other models and quantitative matters that should be standardized include coordinate reference systems, star catalogs, planetary albedos, and the manner in which orbit elements are expressed for common use. The latter is extremely important, since within the space community different practitioners employ several different approaches: classical orbit elements, state vectors and direction cosines, natural variables, and many hybrid permutations. This diversity introduces additional uncertainty as a result of the transformations required to express one practitioner's personal preferences in those of others.

Determining orbits from diverse observations and estimating future states of satellites is as much art as science. We shouldn't standardize art. However, the description of the manner in which a given practitioner approaches these tasks should be uniformly understandable. Many important orbital regimes exist only because of nonuniform gravitational potentials and non-gravitational forces. The Center for Space Standards and Innovation of Analytical Graphics, Inc., is determining the consequences of using or omitting phenomena such as tides in the Earth's molten core, more specific satellite drag approximations, different coordinate references, and radiation pressure from direct solar radiation and reflection or emission from the Earth. Documents such as this should also be part of a space standards regime.

The number of sources of observations of satellites is growing rapidly. This is important, since only geostationary satellites are continuously visible from the Earth. Satellite owners and operators must rely on uncertain propagation of their satellites' orbits into the future based on generally sparse and localized observations or downlink ranging. Only the United States has a satellite observation network that even approaches world-wide presence, and it is extremely sparse in the Southern Hemisphere. Virtually every satellite owner or operator relies on uncooperative observations of their satellites by sensor systems that belong to others. Each should know the accuracy and precision of those measurements, but most who share observations do not reveal the uncertainties in their sensors.

---

[2] http://www.iers.org/

Legal, Ethical and Competitive Issues

Standards channel development in specific directions. In the space industry today we see a collision of legal issues, which are not well defined, and competitive issues, under tension between short-term and long-term factors. The collision point is described by ethical issues. These can be subdivided to global "good citizen" behavior, US "good citizen" behavior and short-term profits. We will discuss these issues in three example contexts: orbit determination and estimation, communication with and among satellites, and satellite navigation and precise positioning.

Space Surveillance

Congress recently enabled providing Air Force Space Surveillance Network data to Non-US Government Entities[3]. Sharing uncooperative observations of satellites leads to legal, ethical, competitive, and diplomatic issues that the Standards community must resolve. If a private or national organization provides satellite observations to others and an expensive anomaly can be attributed to the quality of those observations, who is liable? If a satellite owner/operator has more precise information about another owner/operator's satellite, should he withhold that information for competitive advantage. If a precise knowledge of a satellite's state of motion could enable hostile acts against that satellite, should observations be intentionally corrupted or shared at all? How do standards provide resolution to these questions? By allowing the space industry to state acceptable norms without resorting to the imposition of legal definitions from external bodies.

Intra-Satellite Communications

Communication with and among satellites demands a degree of standardization. The arcane world of communication protocols is dominated by the Internet Engineering Task Force (IETF), a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. The IETF operates within the ISO framework. It is the governing body for terrestrial internet communication and for the interaction of space missions with the terrestrial internet.

The generic Internet Protocol encompasses both the Transfer Control Protocol (TCP) and the Internet Protocol (IP). TCP is an end to end protocol, negotiating feedback between sender and recipient. IP is responsible for carrying data across the network hop-by-hop. TCP is encapsulated within IP datagrams. Individual routers need only examine the IP header of each datagram and are not involved in or burdened by the TCP connection. TCP is a "reliable" protocol, one whose exchanges assure that each data packet is received completely accurately. IP is an "unreliable" protocol, since there is no assurance that a packet was received accurately after it is released. There is an unreliable

[3] PL 108-36, Section 913, Nov 2003

analog of TCP, User Datagram Protocol (UDP), which is encapsulated within TCP for broadcasts that require no feedback. The original, compact and limited access ARPANET used only TCP. The TCP/IP split, or layering, was to enable ARPANET to interact with other kinds of networks. The growth of the Internet has made TCP/IP the de facto standard for all networking. Unfortunately, it is not well suited for long delay, high bit error rate, asymmetric bandwidth conditions that characterize communication with distant nodes, such as high altitude aircraft or satellites.[4]

All information dissemination and retrieval suffers latency. The Internet data transfer process introduces more than 100 msec delays even for the highest bandwidth transactions in the most quiescent and cooperative media. This is an artifact of the evolving protocol schemas. Routers must assemble and continuously update routing tables that represent available connections and the number of hops required to access each. "Reliable" protocols must wait for distant end feedback before routers can remove copies of recently transmitted packets from buffers. This feedback often includes TCP-like flow control exchanges which can slow data transmission to a rate that the recipient is currently capable of accepting. To reduce latency, most protocols transmit several packets in succession, the payload of each buffered. Buffered data is purged when the recipient of any packet within the sliding many-packet windows acknowledges correct receipt. The minimum window size to fully use a link is the bandwidth of the link (bits/sec) multiplied by the round trip delay time (sec), called the bandwidth-delay product. Window size is generally preconfigured by the computational operating system. For example, Windows XP window size is 64 Kbytes. The maximum throughput is the window size divided by the round trip delay time. Even for a 100 msec delay, maximum throughput is only about 4.8 Mbit/sec – independent of bandwidth.

Many innovative procedures can increase throughput on long latency links, but they are all band-aids on a communications architecture that is ill suited. These limitations constrain the kinds of information that can be transmitted successfully. For example, voice communication deals with this through extensive, often lossy compression, and unreliable protocols. Although more sensitive to dropout, streaming video manipulated with these schemes is acceptable in these environments. Data transfer is not.

ISO/TC20/SC13 is addressing efficient intra-satellite and satellite-ground data transfer within the IETF internet protocol schema in order to interface satellites with existing, Internet compatible entry points. Emerging data transfer demands among satellites require a new paradigm.

Satellites exist in an environment quite different from the terrestrial internet. Even the emerging trend in mobile internetworking (IPv6) focuses on relatively short atmospheric links among thousands of itinerant potential nodes. Satellite locations are very

[4] Satellites and the Internet, Challenges and Solutions, DC Palter, SATNEWS publishers, 800 Siesta Way, Sonoma, CA 95476, 2004(ISBN 0-936361-36-0)

predictable. As Iridium demonstrated, network switching is not a random process. Optical communication among satellites is also more effective than optical communication within the atmosphere. The greater native bandwidth of optical links will not be used very effectively within the scheme of old, internet protocol based data transfer. Arguably, religious backward compatibility with a potentially marginal terrestrial internet scheme inhibits the evolution of space missions. This is an example of standards hindering progress.

How should the community address this need? Establishing new, voluntary standards is only part of the answer. Who will develop these standards in the face of the monstrous installed internet compatible base? Who would adopt those standards without assured payback? What would be the legal and competitive implications of the Government imposing such standards? Is it ethical for a few large space organizations and companies to impose a growth restrictive communications architecture on a global industry? What internal and external competitive risks is the US space industry willing to accept in expanding future markets? Can two communications architectures be created and allowed to and compete in a single standards regime?

Satellite Navigation and Positioning

Emerging space missions require precise and relatively continuous knowledge of the individual states of motion (position and velocity) of collaborating satellites. At present, exquisite schemes using onboard GPS and aided by occasional terrestrial ranging, estimate a satellite's state to within about 2 cm at a bandwidth of a few hertz. Future applications, such as tightly coupled sparse apertures, demand an order of magnitude better precision and bandwidth.

Current and planned GPS and GPS-like constellations will not permit that performance. GPS based satellite position determination is constrained by the following.

- Dilutions of precision are less favorable than on the Earth and are often changing very rapidly.
- GPS reception and onboard temporal resolution are affected by large Doppler shifts.
- GPS transmissions may traverse more of the ionosphere and atmosphere in the limb of the Earth.
- GPS is nearly co-altitude or below many important Earth satellite orbits.

Although the community has been quite innovative, existing GPS standards are not sufficient. The universe of Earth orbiting satellites would benefit greatly from transmissions higher in the electromagnetic spectrum than GPS, smaller antennas for a given received signal level, freedom from multipath, atmospheric refraction, and scattering, and extremely precise stellar references. This would facilitate advances and efficiency in Earth orbit and, potentially, for more distant missions. It would allow more effective use of densely populated orbital bands, such as geostationary and sun synchronous regimes. Precise and nearly continuous satellite state determination would make routine such operations as closed loop, daylight satellite tracking, It would greatly reduce the likelihood and enhance response to potential encounters among objects orbiting the Earth.

Here as well, a legacy standards regime may not be appropriate. New sets of standards should be developed for this exciting application. Such standards would promote exchange and collaboration among farsighted organizations.

Current Space Standards Initiatives: .

The ISO Orbital Debris Coordination Working Group (ODCWG) guides development of a consistent and internationally endorsed set of implementation standards for mitigating orbital debris. ISO New Work Item Proposal (NWIP) 318, Routes to Compliance and Management for Debris Mitigation, entered the ISO process in May 2004. It describes goals and processes for debris mitigation, leading to specific standards in contributing technical areas. This framework encompasses minimizing objects released during normal operations, preventing on-orbit breakups, removing mission ended systems from useful orbital regions (protected areas), minimizing the risk posed by reentries, and avoiding on-orbit collisions. Principles developed by the InterAgency (Space) Debris Coordinating Committee (IADC), a non-governmental group including representatives from all space-faring nations established to coordinate space debris research and develop recommendations for mitigating the space debris hazard, are being incorporated to a significant extent. Guidelines recommended by IADC include: control of debris released during normal operations, control of debris generated by accidental explosions, control of debris generated by intentional breakups, limiting debris generated by on-orbit collisions, post-mission disposal of space structures, limiting risk from debris surviving reentry, and control of collision hazards of tether systems. These guidelines specify what should be done, but not how those actions should be accomplished. For example, objects in low Earth orbit should be removed in less than 25 years. In the U.S., NASA and DoD have adopted these guidelines as mission requirements adding that "the sum of the lifetimes of all objects dispersed below 2000 km from a single mission shall be less than 100 object-years. "

The Federal Communications Commission (FCC) issued in June 2004 a Report and Order (FCC 04-130) which requires all who wish to communicate with the United States from orbit to submit plans for minimizing and mitigating orbital debris that might result. FCC rules are generally consistent with IADC and NASA guidelines. The FCC specifically declined to prescribe approaches.

This is the venue in which the International Organization for Standardization (ISO) operates. Quantitative and specific standards are required to facilitate enterprise and promote commerce within abstract guidelines. Without standards, each developer, operator, and consumer would have to assess the capabilities of their products and services from first principles, independently, and at each occasion. ISO is chipping away at specifics, which if satisfied guarantee widespread acceptability. For example, the total remaining energy content of a satellite is a measure of the consequences of unintended energy release (explosion) and is also critical for maneuvers to dispose of the satellite. This leads to standardized approaches to determining remaining propellant mass. Avoiding collisions requires common, trustworthy approaches for exchanging orbital data so that stakeholders can collaboratively understand the threat and plan mitigations. This leads to the standard we are developing for a common data exchange format for orbital data.

After extensive deliberation, the ODCWG is considering the following for orbital data exchange. If this is agreed as an ISO project, the following may be the basis for review and comment leading to an International Standard.

1. A prescribed rigorous definition of the vector type, reference frame, units, digits-of-precision, and other essential information. If any stakeholders choose to operate in a different manner, they must still exchange data in the prescribed common reference frame. Those developing this standard feel that it would be burdensome for everyone to have to convert everyone else's data.

2. Covariances should be required and the covariances should be captured in the TNW frame (T=tangential to osculating orbit, N='NADIR-like' and W=Orbit Angular momentum vector direction). Sharing error matrices in this frame allows a rapid examination and breakdown of the in-track, cross-track and radial errors by inspection, together with ready access to the cross correlation terms. Generation of covariance matrices in a frame that is orbit-relative is prudent because we do not have to worry about timing definitions, definition of Cartesian frames, or other extraneous details.

3. The rigorous reference frame should be LDBARV or Earth-Fixed Greenwich (Longitude, Declination, Beta=Inertial flight path angle measured with respect to the radius vector, Azimuth=inertial flight azimuth, radius and velocity).

4. In addition to fundamental orbital data, the following information should be exchanged for more complete understanding of predictions from different sources:

   a. Physical models or simulations with which that data was employed to predict the potential collision

   b. Numerical and computational information necessary to reproduce results

   c. Practices and Procedures through which data, models, and numerics were employed to produce the collision estimate.

Any of the above may be provided by reference to standard, widely available sources, such as texts, ISO standards, archive technical literature, or similar sources. Any of the above which are recurring or configuration controlled may be submitted or archived where available to stakeholders and need not be refreshed or resubmitted unless there are changes.

We offer this suggestion for comment and discussion by the United States astrodynamics community.

Observations and Conclusions:

The international standards process is Byzantine and time consuming. It is complicated by conflicting economic, political, and technical matters. Overcoming these barriers is precisely the goal. If we can accomplish this even in small measure, space will be more useful, productive, and rewarding. It is very important that the ISO is a collaborative body that spans technical activity worldwide and not an organ of any National government or any governmental consortia.

The US community has been slow to accept standards for space activity. We have described the framework within which space standards are developed and described examples of progress to date. We have reviewed some of the economic, technical, and legal benefits and issues of space standards. There are many examples of the benefits and inhibitions of standards. The AIAA is a pivotal influence and should reengage the US and international standards community.