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Progress in International Space and Astrodynamics Standards

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This paper will report progress in standardizing important elements of astrodynamics analysis. Via the International Standards Organization (ISO) and its associated processes, international standards will build from fundamental astrodynamic analysis practices to standards for assessing conjunction probabilities, orbit lifetimes, launch collision avoidance and space debris evolution. It has been difficult to achieve international consensus on elements of astrodynamics. We will discuss our experience drafting international standards for sharing orbit data, for describing the manner in which orbits are estimated, for performing conjunction assessment, and for determining orbit lifetimes. We solicit feedback from the astrodynamics community and contributions to the goal of world-wide understanding and collaboration.

INTRODUCTION

Last year we introduced the Astrodynamics community to the role of international standards, the implications of standardization, and emerging thrusts in space standards. (Finkleman, AAS 05-198, Space Standards, Rules, Innovation, and Inhibition, Jan 2005) We argued against standardizing physics and for requiring measures of accuracy and precision. We have proposed several fundamental standards consistent with those principles and within the framework of the International Organization for Standardization (ISO). Some are progressing through the ponderous international process; others encountered obstacles.

One of several key focus areas for international standards in space operations is driven by international recommendations reflected in Inter-Agency Space Debris Coordination Committee (IADC) space debris mitigation guidelines[1] and Federal Communications Commission (FCC) rulings based on those guidelines. The goal is to develop standards for implementing those guidelines, capturing best practices in satellite design, manufacture, and operation. "Space Systems — Orbital Debris — Part 1: Management for Debris Prevention and Mitigation"[2] is the overarching guidance. It cites actions such as launch and on orbit collision avoidance. These actions devolve into supporting standards, including such activities as assessing collision probability, estimating orbital lifetime for satellites and associated debris objects, or disposing of mission-ended

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satellites. These devolve into the manner in which orbits may be described and analyzed, as well as the content and format of data exchange among involved parties. The approach is to build up from the lowest level of fundamental astrodynamic practices.

These standards are imperative (shall), not conditional (should). There will be no alternative content or format, even if those alternatives were functionally sufficient. Standards are doctrine. However, compliance is not binary. There are degrees of compliance. Those to whom these standards might be applied may decline (hopefully for good and sufficient reason) to provide some of the specified elements of information. The omission will be obvious, and the credibility and usefulness of the information set will be diminished. We will give examples of the effects of omitting elements of information.

Process for Orbit Information Exchange

This new work item proposal (NWIP) (ISO/AWI 26885) does not require that anyone exchange anything. National policy, treaties, and other non-technical matters will dictate when such exchanges are necessary.

The objective of this standard is to prescribe the content and format to be used when parties do exchange satellite orbit information. Those affected by another operator's actions must have a complete and well defined data set presented and formatted in a standard manner. This information is essential for predicting the future orbital position and velocity of objects that might interfere with a satellite.

The standard requires each user to transform whatever quantities he/she works with (however they were determined) into a common framework from which others may develop elements of information they use to operate their satellites. Each satellite operation may use a unique set of orbit elements, coordinate systems, and reference frames. These may be determined with proprietary tools or techniques that cannot be revealed. No one need change operational processes he finds most effective. None of this need be revealed to others.

The draft standard delineates four classes of information: descriptive information, satellite state of motion, temporal and spatial information, and estimation state vector and covariance information.

Descriptive Information includes the satellite owner's alphanumeric designation, the internationally accepted name of the satellite, the de facto international designation, Earth gravitation information, and forces assumed to act on the satellite in addition to terrestrial gravitation.

This information is necessary in order to propagate the subject satellite state into the future properly. Propagation under the influence of different offsets of gravitational and non-gravitational forces than were assumed when the provider of the data determined the orbit will be different than the provider's propagation. This is inconsistent with the goal of cooperation and collaboration.

The satellite orbit elements and epoch data item imposes a standard for collaboration independent of the element set that a data provider's individual techniques produce. The standard requires Keplerian elements (right ascension of the ascending node, inclination, semi-major axis, eccentricity, true anomaly and argument of perigee) in an Earth Centered Inertial (ECI) reference frame, expressed in SI units. This unburdens recipients of having to infer complex and potentially unique transformations. Epoch is taken as the time (UTC) of the last observation employed in the orbit determination process. Orbit elements are given at Epoch, whenever that might have been, since propagating them to some more current time introduces uncertainties that might be unique to the propagator.

Temporal and Spatial Information consists of a coordinate system, a reference frame, and International Earth Rotation and Reference System (IERS) Parameters (and their Epoch). Although the standard requires an Earth Centered triad of axes and an inertial reference frame, those who receive data benefit from knowing the coordinate system and reference frame in which orbit elements were determined.

This information is necessary to orient the satellite and its orbit correctly with respect to the Earth.

State vector and variance/covariance information are essential for collaborative maneuvers. The standard requires that these be provided in Earth Centered coordinates and an inertial reference frame. The state vector is defined as the set of dependent parameters solved for in the over-determined estimation and filtering process. This is a larger vector than just the satellite kinematic state. It may include drag and atmospheric properties, for example. The covariance matrix includes the diagonal variances and off-diagonal influences of each solve-for parameter on the other solve-for parameters (covariances). Covariances are essential to bound uncertainties when propagating from the Epoch in which they determined to some time in the future.

This information is necessary to propagate the satellite into the future with quantified uncertainty. The full estimation state vector is required in order to discriminate among uncertainties in input data and uncertainty introduced by virtue of incomplete modeling of relevant phenomena.

Outcomes:

The proposed standard's requirements are textbook trivial. The elements of information are essential inputs and outputs for orbit determination schemes. There were no serious objections within the SC14 community, and this standard is now a "working draft" in SC14. However SC13 has a more mature standard for Space Data and Information Transfer Systems (DIS 22644). That standard implies the standard TLE format, without covariances, accepts any propagator (which need not be revealed), and is not as diligent about coordinate systems or reference frames. This may be hard to coordinate.

Process for Describing Orbit Estimation and Propagation Techniques

This International Standard new work item proposal (NWIP) prescribes the manner in which orbit determination and estimation techniques are to be described so that parties can plan operations with sufficient margin to accommodate different individual approaches to orbit determination and estimation. This NWIP does not require that information of this nature be exchange. It prescribes how the exchange is accomplished when an exchange is necessary. This information set allows collaborating satellite owners/operators to understand the differences between their independent orbit determination processes and to interpret each others orbit information.

All satellite owners/operators are entitled to a preferred approach to physical approximations, numerical implementation, and computational execution of orbit determination and estimation of future states of their satellites. Mission demands should determine the architecture (speed of execution, required precision, etc.). This International Standard will enable stakeholders to describe their techniques in a manner that is uniformly understood. Implementation details that may have proprietary or competitive advantage should not be revealed.

After several iterations, we settled on the term “Estimation,” which Rudolph Kalman coined in his seminal paper[3]. Estimation encompasses data smoothing among past observations, filtering, which estimates current state using data up to the present moment, and propagation, predicting future phenomena using all data available.

The same data inputs lead to different predictions when they are used in different models. Satellite owners/operators must often accept orbit descriptions developed with physical models that others employ. The differences in orbit propagation as a result of using different physical models and numerical techniques can be significant. Safe and cooperative operations among those who operate satellites demand that each satellite owner/operator understand the differences among their approaches to orbit determination and propagation.

Orbit determination (OD) estimates the orbital characteristics of an object from discrete observations. The set of observations includes external measurements from terrestrial or space-based sensors and measurements from instruments on the satellite itself. Satellite orbit propagation estimates the future state of motion of a satellite whose orbit has been determined from past observations.

Orbit Propagation (OP) predicts the future state of motion of an object in orbit and the uncertainties in the state of motion, both based on orbital characteristics derived from past observations.

A satellite’s motion is described by a set of approximate equations of motion. The degree of approximation depends on the intended use of orbital information. Observations are subject to systematic and random uncertainties; therefore, OD and propagation are probabilistic.

A spacecraft is influenced by a variety of external forces, including terrestrial gravity, atmospheric drag, multi-body gravitation, solar radiation pressure, tides, and spacecraft thrusters. Selection of forces for modeling depends on the accuracy and precision required from the OD process and the amount of available data. The complex modeling of these forces results in a highly non-linear set of dynamical equations.

Many physical and computational uncertainties limit the accuracy and precision of the spacecraft state that may be determined. Similarly, the observational data are inherently non-linear with respect to the state of motion of the spacecraft, and some influences might not have been included in models of the observation of the state of motion.

Satellite OD and OP are stochastic estimation problems because observations are inherently noisy and uncertain and because not all of the phenomena that influence satellite motion are clearly discernable. Estimation is the process of extracting a desired time-varying signal from statistically noisy observations accumulated over time. Estimation encompasses data smoothing, which is statistical inference from past observations; filtering, which infers the signal from past observations and current observations; and prediction or propagation, which employs past and current observations to infer the future of the signal.

It is desirable to keep each space orbit standard as simple as possible, treating the form and content of orbit data exchange, description of the modeling approach, and other relevant but independent aspects individually. This will develop a sufficient body of standards incrementally, not complicating matters for which there is consensus with matters that might be contentious.

Most in the space community employ only a few major orbit determination architectures. These architectures are cited in Vallado’s text, *Fundamentals of Astrodynamics and Applications*[4]. They are also enumerated in dropdown dialogs within Satellite Toolkit (STK). STK taxonomy shall be adopted uniformly to describe models, approximations, numerical integration, and other important discriminates of an OD approach.

Orbit determination and propagation have several elements in common: force models, coordinate systems, reference frames, and a numerical approach.

Conservative forces (such as gravitation) and non-conservative forces (such as gas-dynamic drag) must be described in a standard manner. The approximation to the Earth’s gravitation must be described in terms of Zonal Harmonic orders and degrees, which capture characteristics of the Earth’s non-spherical shape and non-uniform distribution of mass. The provider of data must also indicate whether multi-body influences were considered, identify other bodies that were included, and describe the manner in which resulting gravitational forces were described. Information must be provided for atmospheric resistance, including aerodynamic coefficients and a description of approximations to the world-wide variation of atmospheric density with altitude. Parameters that govern radiative momentum transfer must also be provided.

The proposed standard requires information on numerical implementation and analytical approximations. Orbit propagation or prediction has evolved synchronously with advances in computational capability. Initially, force models were greatly simplified, and most important non-gravitational forces were approximated analytically. These generally linearized approaches were valid only over short intervals or for small variations from two-body Keplerian motion. Even though more precise numerical integration became feasible, execution times were too long and computation was too expensive to employ numerics regularly. A number of semi-analytical techniques emerged. These reduced numerical complexity (with some compromise to precision) by providing formulae from which significant elements of the propagation work flow could be extracted.

Purely numerical techniques are not yet used frequently. These suffer only the physical approximations made in describing important phenomena and numerical phenomena common to all discrete computations. The standard distinguishes among analytical, numerical, and semi-analytical orbit propagation techniques. Semi-analytical and analytical approaches are considered to be specific “propagators,” not orbit determination tools.

Orbital products depend on the quality and the distribution of inputs, the manner in which conservative and dissipative forces are described, and the manner in which computations are performed. Information on the mutual interaction of data distribution and numerical discretization is also required.

Orbit Determination

This standard requires that the set of orbit elements produced by a data provider’s technique be described. Unlike the orbit data transfer work item, Keplerian elements are not required. There are many different sets of orbit elements. Each is best suited for a particular application, such as aiming antennas, ease of manipulation in various coordinate schemes, or estimating orbits from different types of measurements.
The traditionally used set of orbital elements is called the set of Keplerian elements; Keplerian elements parameters can be encoded as text in a number of formats. The most common of them is the NASA/NORAD "two-line elements" (TLE) format, originally designed for use with 80-column punched cards, but still in use because it is the most common format and works as well as any other. The standard presents several alternative sets of relatively widely used orbit elements. This requirement applies to mean orbits, the sets of parameters that emerge from the smoothing, filtering, or predictive estimation schemes with their secular perturbations removed. There are as many different possible mean orbits as there are permutations of the quantities and functions discussed previously. There are also “osculating orbits,” which are the instantaneous orbital parameters for a satellite path instantaneously tangent to the mean orbit.

The standard also requires that the coordinate system and reference frames in which the orbit determination technique is employed. No standard coordinate system or reference frame is required.

State variables, mean orbits, and variances/covariances are the final requirements. Every orbit estimation process begins with the selection and definition of state variables. State variables are the products of orbit determination. They form a one-dimensional column vector. Classically, the state of an object is just its state of motion, described completely in Newtonian mechanics by its position and velocity. The existence of non-conservative forces and perturbations that cannot be described simply by point mass inverse square Newtonian gravitation expands the number of state variables necessary to estimate an object's motion. Since all sources of uncertainty cannot be explained or even recognized, a fictitious “consider variable” is sometimes augmented to the state vector to capture uncertainties otherwise unaccountable within a tractable set of physically meaningful state variables.

Covariances are measures of the interdependence of uncertainties in orbit state variables relative to their mean values, the degree to which changes in one are related to changes in another. Covariances are, therefore, symmetric matrices. The diagonal elements are called variances, since they involve only a single state variable. The correlation coefficient is the binary covariance of two random variables divided by the product of their individual variances, so that it varies from –1 to +1. If a correlation coefficient is zero, the two variables change independently of each other and are uncorrelated. The sign of a covariance element indicates whether the changes in the two variables are in the same direction or not.

The information package shall also describe broadly the formalism employed to develop mean elements and covariances: least squares (batch or sequential) or filtering.

Orbit propagators are comprehensive tools that combine physical models, all of the characteristics of orbit determination described above, and data input/output utilities. There are three types of orbit propagators: analytic, semi-analytic, and numerical. Analytic propagators use a closed-form solution of the time-dependent motion of a satellite to produce ephemeris or to provide directly the position and velocity of a satellite at a particular time. Numerical propagators numerically integrate the equations of motion for the satellite. Semi-analytic schemes employ some closed-form approximations and some numerical integration. Orbit propagation models and techniques must be described in the same manner as orbit determination models and techniques; however, they also require complete descriptions of input and output techniques and a mathematically and physically sound description of the growth of uncertainty in orbital parameters from the Epoch of the input data.

When a widely used, consensus-validated, and authoritatively documented propagator is employed, the requirements of this International Standard may be satisfied by citing that documentation and the specific parameter sets that the data provider employed within that propagator, which vary with propagator and version.

Outcomes:

This standard was approved by the United States technical advisory group (TAG) and submitted for international vote. It did not receive sufficient votes at the international working group level. France, the UK, and Russia requested more detail. They also questioned the need for such a standard and asked who would use it and when. The UK clearly misunderstood the intent of the standard. The intent was clarified and a draft of the complete standard provided. The UK will probably withdraw its objections. We believe that France will also endorse the standard as a New Work Item at the next meeting in May 2006. Russia may be harder to convince even though Russian orbit estimation and propagation techniques are already well described in open literature.

Process for Orbit Lifetime Computation

As alluded to above and as described in the IADC Space Debris Mitigation Guidelines[1]"the [IADC] is an international forum of governmental bodies for the coordination of activities related to the issues of man-made and natural debris in space. The primary purpose of the IADC is to exchange information on space debris research activities between member space agencies, to facilitate opportunities for co-operation in space debris research, to review the progress of ongoing co-operative activities and to identify debris mitigation options. One of the IADC's efforts is to recommend debris mitigation guidelines, with an emphasis on cost effectiveness, that can be considered during planning and design of spacecraft and launch vehicles in order to minimize or eliminate generation of debris during operations."

Current IADC guidelines recommend that Low Earth Orbit (LEO)-crossing satellites have a maximum post-mission orbit lifetime of 25 years. This recommendation is based on IADC endorsed long-term predictive modeling of the evolution of the space debris population.

Access to the LEO satellite orbital regime with a relatively low risk of collision with other space objects is a basic prerequisite to the production and trade of satellites and space hardware which will occupy this regime. Accordingly, ISO is collaborating with the IADC to establish standards that will enable space operators to reliably and accurately meet this orbit lifetime recommendation.

Unfortunately, there are numerous methods (Fig. 1) to determine orbit lifetime which may make standardization of this process difficult. These methods can use a wide variety of orbit propagation techniques, atmosphere models, geomagnetic activity predictions and solar predictions (Fig. 2), yielding numerous analysis options.

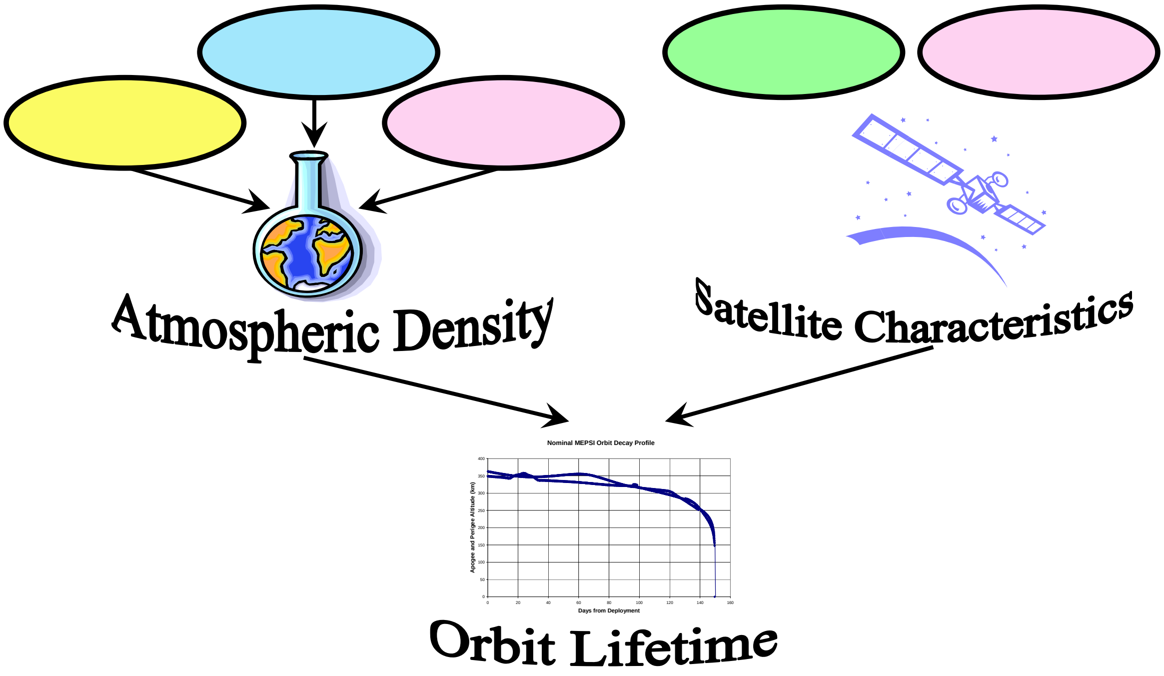


Figure 1 Key Modeling Components in Orbit Lifetime Computation

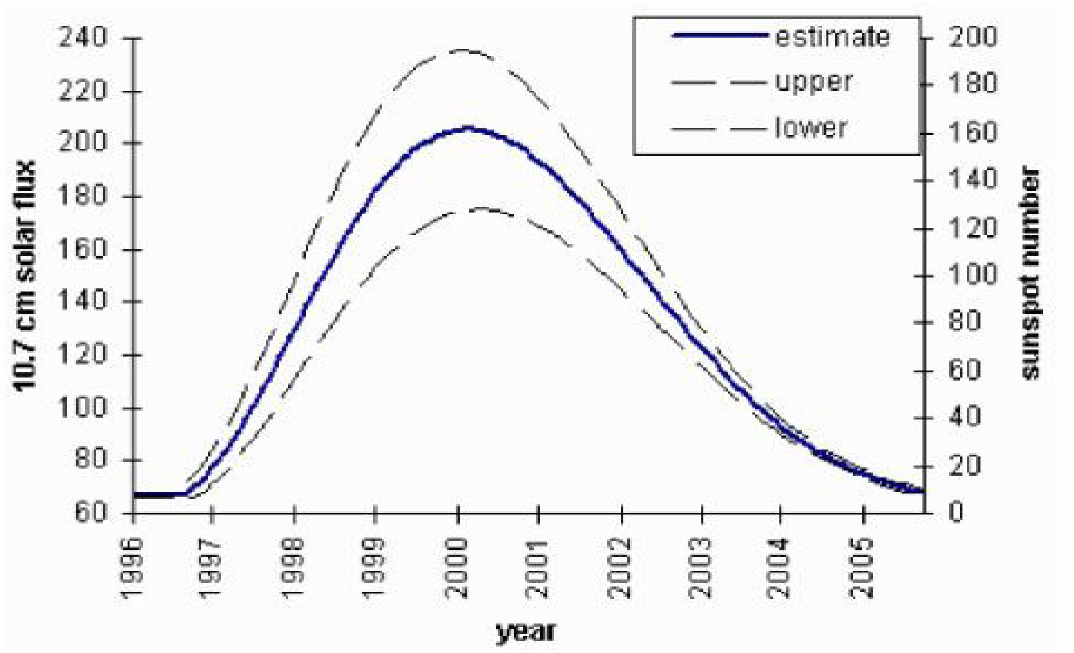


Figure 2 Predicted solar flux & sunspot numbers for solar cycle 23[5].

This international standard (NWIP) should establish a consensus approach for estimating the lifetime of Low-Earth Orbit-crossing orbits. A standard is essential since there must be a common basis for predicting lifetime if a standard maximum lifetime is mandated. Without such a standard, it would be relatively easy to manipulate orbit lifetime predictions by using a variety of atmosphere models[6] and geo/solar activity 'predictions' to achieve the most favorable prediction, thereby effectively circumventing the intent of the guidelines.

Orbit Lifetime prediction is complex, and multiple methods exist to compute it. The applicability of individual methods is a function of orbit class, given the very nonlinear nature of orbital drag (Fig. 3); some simple table lookup methods may be sufficient for very low orbits, whereas higher-fidelity models are required for higher altitude orbits or in cases where resonant orbit perturbations would invalidate low-fidelity models. Further, the selection of solar activity trend(s) and atmosphere models affects orbit lifetime predictions tremendously; variances of as much as 35% can be attributed to atmosphere model selection alone.

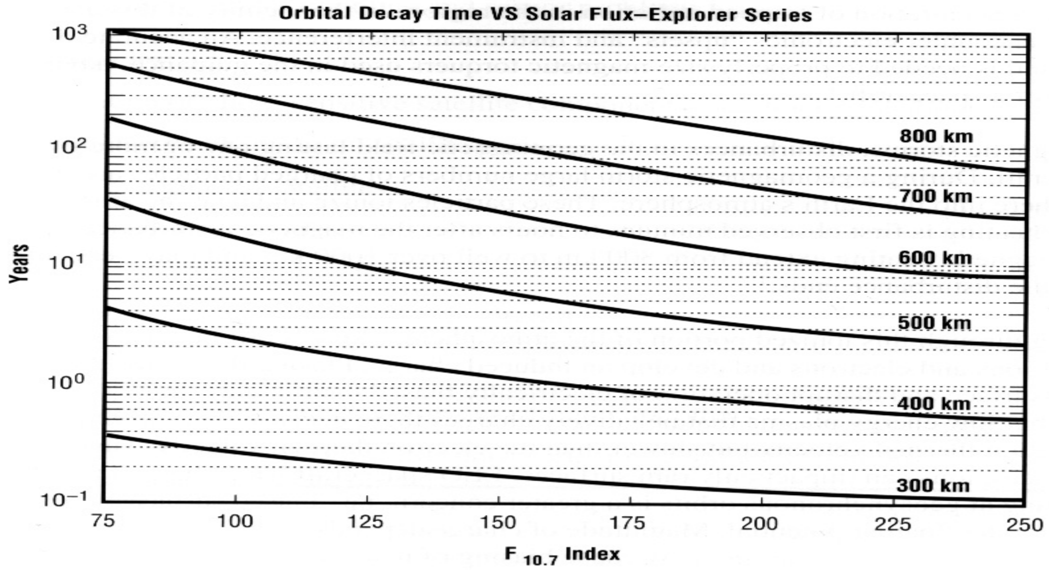


Figure 3 Predicted orbit lifetime versus orbit altitude and solar flux.

An additional goal is to ensure that all space designers and operators that follow the guidelines do so on an equal footing. While national policy, treaties, and other non-technical matters dictate when such entities are to follow IADC guidelines, it would be relatively easy to manipulate orbit lifetime predictions by using a variety of atmosphere models and solar activity inputs to achieve the most favorable prediction, thereby effectively circumventing the intent of the guidelines.

The $F_{10.7}$ Solar Flux Index is a measurable quantity (proxy) that is directly related to atmospheric density. Recent advances in stochastic modeling of solar activity[7] advance orbit lifetime estimation, indicating the possibility of improving our long-term solar activity modeling using a new mean $F_{10.7}$ trend based on orbit energy dissipation rates.

Outcomes:

This NWIP proposal was discussed at the Fall 2005 ISO meeting. The draft NWIP outline was submitted to the ISO member countries in January 2006 for ballot. The ESA representative suggested that a simple set of charts or tabular representation may suffice as a first start for this admittedly complex effort. This tabular representation can then be augmented by higher-fidelity models as the effort proceeds, and when justified by the relative complexity of various orbit perturbation effects. The product would be prepared by recognized international experts and should balance extreme conservatism against excessive optimism. The consensus would then be whether the standard, as a function of satellite parameters (size, mass, physical cross-sections, etc.) and atmospheric parameters, is appropriate. This would make lifetime assessment objective since all would have to use the same charts, data and/or procedures, even though they might not be as scientifically precise or objective as some might desire.

Collision Avoidance

A draft New Work Item Proposal to develop a standard for Launch Collision Avoidance was initiated by the Japanese delegates in 2004. Japan is arguably the space faring nation that is most considerate of intruding on others' activities. Japan wishes to avoid collisions but lacks tools and data sufficient to achieve that goal without almost completely closing all Japanese launch windows.

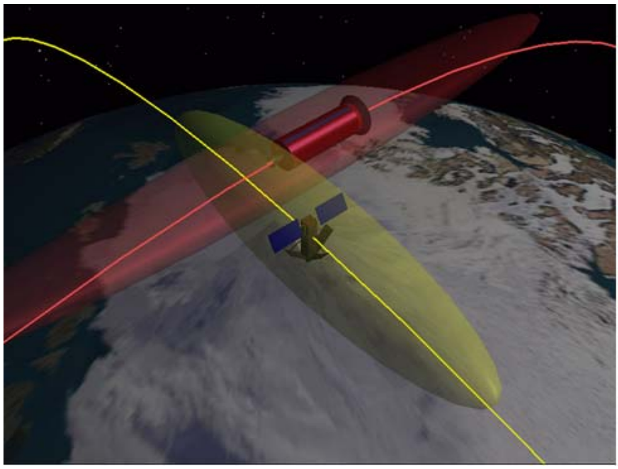
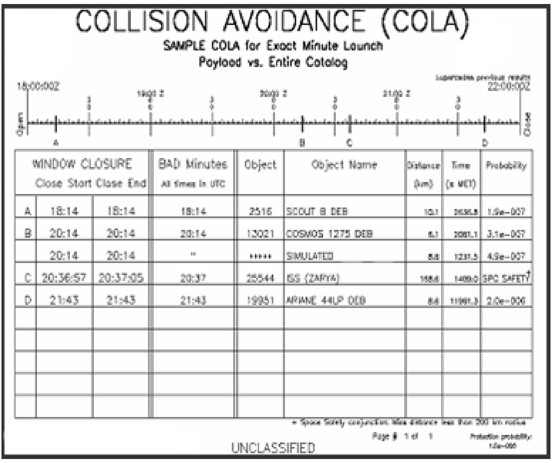


Figure r Conjunction depiction with error volumes[8]



COLLISION AVOIDANCE (COLA)

SAMPLE COLA for Exact Minute Launch
Payload vs. Entire Catalog

	WINDOW CLOSURE Close Start	Close End	BAD Minutes All times in UTC	Object	Object Name	Distance (km)	Time (s MET)	Probability
A	18:14	18:14	18:14	2516	SCOUT B DEB	10.1	2636.8	1.9e-007
B	20:14	20:14	20:14	13021	COSMOS 1275 DEB	6.1	2081.1	3.1e-007
	20:14	20:14	"	*****	SIMULATED	8.8	1231.5	4.9e-007
C	20:36:57	20:37:05	20:37	25544	ISS (ZARYA)	188.6	1409.0	SPC SAFETY†
D	21:43	21:43	21:43	19951	ARIANE 44LP DEB	8.6	11981.3	2.0e-006

* Space Safety conjunction. Miss distance less than 200 km radius

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Protection probability: 1.0e-006

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Figure 5 Sample mission assurance launch COLA analysis product[8]

The initial Japanese draft was based on maintaining a minimum keepout distance between the launching vehicle and all resident space objects. Over the past ten years, US representatives have shown[8] that using this method was not an appropriate measure of the risk of collision; further, a careful comparison of the minimal keepout distance (or spherical keepout volume) approach with a collision probability-based approach (Fig. 4 and Fig. 5) indicates that the spherical keepout volume approach flags far to many low-probability conjunctions, effectively closing launch windows and overly restricting access to space. Lacking quantified uncertainty data for launching vehicles, on-orbit satellites, or both, keepout distances must be very conservative, and many extremely low probability interferences needlessly close launch windows. We have developed a draft NWIP which proposes a standardized process utilizing powered flight trajectories, quantified error data for both the launching and on-orbit objects and the computation of collision probability and its associated mission risk. If the actual covariances are not available, well-validated schemes for synthesizing covariances were described.

Outcomes:

This proposal failed to pass the ballot process to become a New Work Item Proposal. The underlying concern was whether launch collision threat is of sufficient risk to merit an ISO standard governing its practice at this time.

Collision Assessment in General: The first issue is whether there need be separate standards for different kinds of collisions: launch collision avoidance, collision avoidance by orbital regime (low, medium, and high Earth orbits), or collision avoidance standards for some orbital regimes but not others. However, the standard only prescribes how to conduct collision avoidance if parties agree on the necessity. It does not require anyone to avoid collisions. It is a dilemma.

On-Orbit Collision Avoidance: It was strongly felt by the ESA and U.S. representatives that an on-orbit collision avoidance standard should be created at a minimum. Time integration of an on-orbit object’s collision probabilities for multiple conjunctions causes the long-duration collision risk to become significant, particularly for specific orbit regimes. The ISO members agreed to draft up a proposed standard which includes on-orbit collision avoidance.

Launch Collision Avoidance: Apart from Japan, there are only a select few countries that perform launch collision avoidance. The CNES representatives have looked at launch collision risk and concluded that the risk is very low. Based upon this finding, the ESA representatives feel that it is infeasible or impossible to get orbit and launch trajectory data of sufficient quality to conduct a meaningful probabilistic assessment and that the probabilities are objectively so low that launch collision avoidance isn’t even necessary. The data quality issue has merit. Unless the orbit of a potential collision partner is determined nearly at the time of the launch, the actual location of the object may be very much in doubt. The necessity or desirability of launch collision avoidance depends strongly on a satellite’s targeted orbit characteristics, inclination, and the neighboring space population; objects having inclinations at the latitude of heavily used launch sites or crowded orbit regimes (e.g., Geosynchronous Earth Orbit) are at higher risk than for other launching vehicles.

General Observations:

The astrodynamics community is new in the International Standards enterprise. A few standards conceived for other purposes, such as planning scientific data transfer among satellites, require orbit data. All such existing citations employ only two line element sets. A key word search on the web sites of collaborating organizations, such as the European Cooperation for Space Standardization (ECSS), revealed no instances of the word “orbit” in any of their documents.

Deliberations on a number of these proposed or draft NWIPs sensitized us to the fact that the purpose of international standards is to foster market development and collaboration, not to advance science. Production, operations, and management are the most important elements of international space standards. Models and techniques must be well understood and widely accepted before the international community will incorporate them in standards. Specific techniques that facilitate complying with standards may be published as Technical Reports, but they should not be incorporated in the standards. Aspects of many of these astrodynamics-related standards have led some to conclude that the standards should be Technical Reports, but this is often offset by the direct and indirect impact these standards can have on production, operations, and management.

Many in the space community fear that they will have to comply with any new standard. Even though standards are voluntary and compliance can be incrementally accomplished not binary, and though only a small set of standards applies to any particular activity, many worry that addressing a new standard will consume time and resources unnecessarily.

Some participants are unwilling to provide the scope of information that standards development activities may require either for competitive or fiscal reasons. They feel that having no standard at all is better than having a standard which they could be criticized for ignoring.

Language is a significant barrier. ISO is not a government organization. It is a private, non-profit, collaboration of international spacecraft designers and space operators. It lives from membership fees and sales of standards. It does not support translators. English and French are the official languages, but few participants speak both in addition to their native language. China, Japan, Russia, and Ukraine appear to have great difficulty with English.

The ISO process is ponderous. It allows four years for a concept to move from a New Work Item Proposal (NWIP) to an International Standard (IS). The stages are: NWIP, Working Draft (WD), Committee Draft (CD), Draft International Standard (DIS), and International Standard. The interval between stages is a year, although it could be shortened by soliciting votes between regularly scheduled meetings, which are semi-annually for working groups, and annually for Subcommittees.

Few participants are astrodynamics experts. (Although some from ESA, such as Dr. Heiner Klinkrad, are highly regarded astrodynamicists.) Most such are reluctant to agree to anything until they can check with their experts, who are not present at the meetings.

Conclusion and Charge to the Astrodynamics Community

Last year we revealed the framework within which the United States would develop consensus commercial astrodynamics standards. We described a philosophy for standardizing some processes and practices without inhibiting creativity or challenging sound, but different, approaches. We have developed a strategy within which we have proposed several fundamental standards. At least two are now official ISO work items. We have cemented international relationships and learned the political and technical environment. We need the entire community to participate, since we already claim to be representing all United States interests. We need most of all "use cases" for the standards we have already proposed and developed. We are often asked what circumstances would require that any of our standards be employed. For example, "What operations or circumstances would require that stakeholders describe each other's orbit determination or propagation schemes?" The answer seems obvious to those in the profession, but it is evidently not as clear to those who practice in other venues of space operations. We ask all who are exposed to this paper to review the draft standards, which are available from us or the AIAA, and conceive practical use cases that we can use to reinforce the need for these standards. The next SC14 Plenary is in Colorado Springs in May. We invite your participation.

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[2] ISO TC 20, SC 14, Orbital Debris Coordination Working Group, Working Draft WE 24113, Nov 2005 (available only to designated representatives to ISO activities).

[3] Kalman, R.E., A New Approach to Linear Filtering and Prediction Problems, Transactions of the ASME, Journal of Basic Engineering 82 (Series D): 35-45, 1960

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