SHARING SPACE SITUATIONAL AWARENESS DATA

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The Commander, United States Strategic Command (CDRUSSTRATCOM) accepted responsibility for sharing space situational awareness (SSA) information/services with commercial & foreign entities from the US Air Force on 22 Dec 09 (formerly the Commercial & Foreign Entities Pilot Program). The requirement to share SSA services with non-US Government (USG) entities is derived from Title 10, United States Code, Section 2274 (2010) and is consistent with the new National Space Policy. US Strategic Command's (USSTRATCOM's) sharing of SSA services consists of basic services (Two-Line Elements, decay data and satellite catalog details) available on www.space-track.org and advanced services (conjunction assessment, launch support, etc) available with a signed agreement. USSTRATCOM has requested USG permission to enter into international agreements to enable SSA data exchange with our foreign partners. USSTRATCOM recently authorized Joint Functional Component Command for Space (JFCC SPACE) to share Conjunction Summary Messages (CSMs) with satellite owner/operators whose satellites have been identified as closely approaching another space object. CSMs contain vector and covariance data computed using Special Perturbations theory. To facilitate the utility of the CSMs, USSTRATCOM has and is hosting CSM Workshops to ensure satellite operators fully understand the data contained in the CSM in order to provide an informed recommendation to their leadership. As JFCC SPACE matures its ability to accept ephemeris data from a satellite operator, it will be necessary to automatically transfer that data from one security level to another. USSTRATCOM and Air Force Space Command are coordinating the integration of a cross domain solution that will allow JFCC SPACE to do just that. Finally, USSTRATCOM is also working with commercial and governmental organizations to develop an internationally-accepted conjunction assessment message.

The United States Government (USG), specifically the Department of Defense, has been integrating data from diverse sources for decades. In recent years, more and more commercial entities have been integrating our data into their operations, whether to use General Perturbation (GP) Two-Line Elements (TLEs) to perform a rudimentary form of conjunction assessment (CA) or to provide a new app for the iPhone.

For the longest time, the USG was one of the few organizations able to fund and conduct space surveillance using optical telescopes and various types of radar. Unfortunately, despite decades of experience tracking objects in space, we had not matured either our equipment or our processes to the point that we were able to prevent the Iridium-Cosmos collision about 18 months ago. As a result, there are two belts of debris orbiting our planet, today and for years to come. As space has become more congested and budgets have shrunk, the need to integrate data has increased. Fortunately, the number of organizations who have developed or are developing space situational awareness (SSA) capabilities, including analytical tools, has also increased.

FROM COLLISION TO SSA SHARING AGREEMENTS

As a result of the collision, United States Strategic Command (USSTRATCOM) conducted an internal review of our CA processes. We made changes to our internal procedures, acquired additional computational capability and increased the number of analysts. In the latter half of last year, Congress passed legislation allowing USSTRATCOM, in essence, to provide SSA services and information to, and obtain SSA data and information from, non-USG entities, our SSA mission partners. In the legislation, there are two restrictions on sharing SSA information; First, the mission partner must agree in writing to pay an amount that may be charged and secondly, they must agree not to transfer any data or technical information to a third party without prior approval.
We address the first requirement in the agreement by clearly stating that SSA services are available at no charge. It's not right to charge satellite owner/operators (o/o) for data that will enable them to keep their satellite from breaking into hundreds or thousands of pieces; further polluting the final frontier. The second requirement is also stated clearly in the SSA Sharing Agreement. We address requests for third-party sharing on a case-by-case basis, using the Orbital Data Request (ODR).
Once an agreement is signed, Joint Functional Component Command for Space (JFCC SPACE) can start working with our newest mission partner, exchanging data as agreed. We currently have 16 mission partners, who

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
SEP 2010		**00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Sharing Space Situational Awareness Data	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Strategic Command,Offutt Air Force Base,NE,68113**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
2010 Advanced Maui Optical and Space Surveillance Technologies Conference, 14-17 Sep, Maui, HI.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

collectively operate over 230 payloads in various orbits. At a minimum, an agreement enables us to screen routine maneuvers to ensure an o/o doesn't maneuver into a conjunction. Signing an agreement also allows o/o to tailor their CA notifications to fit into their ops tempo and their comfort zone. But space flight safety is in everyone's interest so, in conjunction with the lawyers, we've established emergency CA criteria.

EMERGENCY CA CRITERIA

When this emergency CA criteria is violated, we have legal authorization to contact any o/o regardless whether they have signed an agreement. For an active satellite above low-Earth orbit, we currently notify the o/o if we predict their satellite will approach within 5 kilometers (km) of another orbiting object in the next 72 hours. For an active satellite in low-Earth orbit, we will notify the o/o if we predict it will approach within 1km (overall miss distance) of another orbiting object AND within 200 meters in the radial direction in the next 72 hours. Seventy-two hours is not much time to analyze the data, decide on a maneuver plan and execute that plan, but that's the criteria. We've considered re-engaging the legal team but that idea has been prioritized lower than other issues we're currently working. One of those is to develop a validated list of contact info for 100% of the o/o so the conjunction warning will get to them as close to 72 hours prior to Time of Closest Approach (TCA) as possible. We're only missing contact info for ~70 of the ~1000 active satellites. Unfortunately, our Department of State, at the request of a handful of governments, is serving as a middle-man. Instead of us sending these warnings directly to the o/o, they send it to the US embassy in that country, who then forwards it to the host nation, who then passes it on to the proper agency or organization. So the 72-hour warning time is eaten into by not having direct contact. More on the data we share when a conjunction is identified in a minute, but first, let me explain a little about the two types of data used in the Joint Space Operations Center (JSpOC).

GP vs SP DATA

In January of last year, the JSpOC was screening fewer than 200 of the ~1100 active satellites for conjunction assessment purposes; those 150-200 were considered to be the highest priority for conjunctions by the US Department of Defense (DoD). Today, due to enhancements in the computational capabilities and improved internal processes, the JSpOC screens 100% of the active satellites using its most accurate data, known as Special Perturbation (SP) data. SP numerically integrates the equations of motion including all necessary perturbing accelerations. The SP accelerations available include geopotential, atmospheric drag, lunar-solar gravity, direct solar radiation pressure, constant in-track duration thrust, and solid Earth and ocean tides, thus making SP data much more accurate for CA purposes than the GP data. GP data is computed using the Simplified General Perturbations, Version 4 (SGP4) theory. SGP4 computes the average path of the satellite through space, and is reasonably accurate for long periods of time. However it does not have the inherent physical and mathematical modeling to be considered accurate enough for predicting conjunction assessments.

SCREENING AGAINST THE ENTIRE CATALOG

GP data is that which is available on space-track.org and is further redistributed by popular websites such as Heavens Above, CelesTrak, and some others. GP data has been published to the internet for many years. However, it was never intended to be used to perform conjunction assessment. But it's the only data available so what happens if an o/o were to use it to conduct CA? A couple months ago, an o/o notified us they had just completed a maneuver of their satellite to avoid a piece of debris, based on GP data. Fearing that we may have failed to identify a conjunction or failed to notify an operator, we quickly screened that satellite against the entire SP catalog, including the ~6,000 analyst satellites, those objects that we track but can't catalog because we don't know which launch they came from. The results of that screening did show a close approach but not close enough to warrant an emergency notification to the operator. So from our perspective, the maneuver was unnecessary; valuable fuel expended. That's one bad example but we know other o/o who use a GP screening to alert them to potential close approaches in advance of the 72 hours emergency notification. The JSpOC uses the SP theory to perform all CA screenings and they screen against all man-made objects we're tracking, including those not publicly shared. As I mentioned, there are ~6,000 objects, some of which are classified, others we have not collected enough data to catalog yet, that we screen all the active satellites against.

DATA NOT ACTIONABLE

After identifying a conjunction that meets the emergency CA criteria, the JSpOC notifies the o/o with basic orbital data on the pending conjunction, to include common name, time of closest approach, overall miss distance and the component miss distances. Many o/o claimed that was not enough data to tell whether the close approach was high probability or not. In addition, they had no idea what kind of maneuver (magnitude or direction) would increase the miss distance. In May, we began sharing the error in each of the component directions while we were staffing a better solution. Within the first two weeks, we received feedback from one o/o stating that that additional information prevented them from conducting two maneuvers – saving fuel for another day.
With only this basic data on the conjunction, o/o are forced to submit maneuver plans to be screened one at a time, to see which maneuver would provide a satisfactory miss distance. It's kind of like playing "Marco Polo". For each maneuver plan submitted, the JSpOC provides updated data AND whether the maneuver might cause a subsequent close approach so the o/o could determine which maneuver was most favorable. We knew that wasn't the optimal solution. Meanwhile, we were staffing a permanent fix to the problem.

CONJUNCTION SUMMARY MESSAGES

This past July we finally implemented the fix; that is, we were able to start sharing detailed Conjunction Summary Messages for the two conjuncting objects. However, the approved distribution method is not as simple as sending an e-mail to the o/o like we do with the basic data. Because of the sensitivity of this SP data and our desire to share SP data only with the effected o/o, we post the CSMs in a private area of space-track.org. To be able to access these detailed messages, o/o create an account and provide us a list of satellites with which they can execute an avoidance maneuver. We then link the account to that listing of satellites so only the o/o can access CSMs for their satellites. As of 1 Sep, we are sharing CSMs with o/o for ~50% of the active satellites. If you know of a satellite operator not currently receiving these detailed messages, the CSMs, please contact USSTRATCOM/J31 or the JSpOC – it is our intent to share CSMs with ALL o/o. From our perspective, it's the best way to prevent another collision in space. CSMs contain the position and velocity vectors of the conjuncting objects as well as the covariance matrices, or error ellipsoids, for both objects. Having worked with some owner/operators to automate the process of receiving the CSMs, we hope to make them available in XML very soon.

INCORPORATING EPHEMERIS FROM SATELLITE OPERATORS

Although the JSpOC uses its best data to calculate whether two objects are approaching too closely or not, if those particular objects have not been tracked recently, maybe due to weather or maintenance at a sensor, that satellite's predicted position may be off a bit from its actual position. One way to improve the accuracy of the positions of the objects is to collect observations from other sensors. In the case of active satellites, most satellite o/o have highly accurate positional data on their own satellites. In some cases, that data is more accurate than the SP data calculated based on the most recent observation. Some o/o have already made their data available to us. We're currently testing a capability for o/o to simply upload one ephemeris file to the website containing ephemeris for their entire constellation. Our analysts will download the file and upload it to be screened for conjunctions. Although this process will minimize the data transfer time, it is still not as automated as we'd like. Over the past couple years, technology has improved to such a point that it is conceivable for us, even though we're the DoD and not particularly swift at upgrading our capabilities, to automatically ingest o/o ephemeris within the next year. Another unique capability we have is the ability to screen two ephemeris files against each other. Although not frequent, it's not inconceivable for us to identify a potential conjunction between two active satellites. Besides putting the two organizations in touch with one another in that situation, we can screen a proposed maneuver by one entity against a proposed maneuver of another entity. With the data from the CSM, the o/o has all the information they need to avoid the other object. So their only concern is that they don't maneuver into another piece of debris. To ensure that doesn't happen, they send that one maneuver plan to the JSpOC where it is screened against all other potential conjunctors, including the ~6,000 not posted on the website.

CSM WORKSHOP II

Back in July, we hosted a CSM Workshop in the Washington DC area. Our intent was to have our orbital analysts lead a discussion on the CSM and field questions from the flight dynamics personnel from satellite operators. The JSpOC briefer began the workshop with an overview presentation on the JSpOC mission areas, of which CA is only

one, although a very important one. The next briefer provided a line-by-line explanation of the data fields of the CSM. AFSPC then covered how we use o/o ephemeris and how receiving ephemeris from more o/o would improve the accuracy of our conjunction warnings. NASA gave two presentations; the Goddard briefer explained how they have used the JSpOC's data to develop a risk assessment tool for NASA's robotic missions and the NASA Johnson representative provided examples on how they use JSpOC data to decide whether to maneuver the shuttle and/or ISS. The workshop was so successful that we are having another one the week of 18 October at the European Space Agency's (ESA's) Operations Center in Darmstadt, Germany. We're primarily inviting European and Asian satellite operators to the October workshop. However, we are considering hosting a third workshop, probably back in the States in the spring timeframe for those unable to attend the first two. The intent of these workshops is very simple; to educate satellite operators on the contents of the CSM so they can provide a fact-based recommendation to their company or government on whether they should maneuver their satellite or not, weighing the cost and risk as only the o/o can do.

I think we can all agree that it's not in the interest of any nation for another collision to pollute the space environment. An argument could be made that because of how dependent the US is on satellites, that we would suffer the greatest from another collision. So, I guess you could say that we're being selfish by trying to ensure all o/o make educated decisions about close approaches using the best data, while walking that line between transparency and security.

INTERNATIONAL STANDARD FOR CONJUNCTION MESSAGES

But there's more to avoiding a collision than merely identifying the close approach in enough time to conduct a maneuver. We've got to communicate the message from the JSpOC to the o/o. Part of that is having valid contact info for each o/o, but an equally important part is the o/o understanding the data in a timely fashion. In recent years, the benefits of developing international standards for space data have become more prevalent. Recently, we began working with the Consultative Committee on Space Data Standards and, next month, I'll be presenting a concept paper at their semi-annual meeting, proposing that we develop an international standard for conjunction messages. As I mentioned earlier, Orbit Data Messages, such as the Orbital Ephemeris Message, the Orbital Parameters Message and the Orbital Mean-Elements Message, have already been accepted as international standards. Don't be surprised if you see OMMs posted on space-track.org alongside the TLE data. Over the next couple months, we will be working with commercial and governmental organizations also interested in a standardized conjunction message. Within the next couple years, we hope to see a Conjunction Assessment Message (CAM), added to the list of orbit data messages already accepted as international standards. In addition, there is some talk about collaborating on a Launch Conjunction Message in the future as well.

A WORK IN PROGRESS

Despite periodic upgrades to the space surveillance network, using the most accurate data, and screening those objects not shared publicly, occasionally our data is not as accurate as we would like. For example, for several days after launch, we reported a satellite was still in its geosynchronous transfer orbit when in actuality, it had already proceeded into geosynchronous orbit. In this case, the JSpOC did not request data from the o/o, which could have prevented us from posting inaccurate positional data. Internally, we had been tracking the satellite in geosynchronous orbit as an analyst sat (one of the 6,000 not posted) and were able to correct the error after several days of reliable tracking. As I mentioned, this situation could have been prevented had an operator at the JSpOC contacted the o/o and requested ephemeris. As a result of this situation, we have modified our procedures to ensure JSpOC operators understand they can contact the o/o in the future. Any time a launch takes place, it takes several days of observations from a variety of sensors for our analysts to properly catalog the pieces. To facilitate that process, we encourage all o/o to let us know some basic information about the upcoming launch, like how many pieces they expect to be in orbit, when the stages are scheduled to separate, what trajectory they plan to use, etc. By working with us, we can catalog the objects correctly sooner and, in the event something goes wrong, provide essential data to assist in anomaly resolution.

WAY AHEAD

The US Air Force recently reaffirmed its commitment to replace the hardware known as the Space Defense Operations Center (SPADOC) computer and the Astrodynamics Support Workstation (ASW) currently in use at the JSpOC with the acquisition of the JSpOC Mission System (JMS). With the incremental delivery schedule, we hope

to start seeing infrastructure improvements in the next year. Over the next five years, we expect to make orbital information available to others net-centrically by implementing a service-oriented architecture at the JSpOC. In addition, we have high hopes for new sensors such as the Space-Based Space Surveillance satellite, whose launch date is less than two weeks away. Other new sensors include the Space Surveillance Telescope, located in the desert southwest of the United States, the Space Fence, a major acquisition program for two or three S-band radars that should increase our ability to track small objects and decrease the time it takes to catalog an object, particularly those in the manned spaceflight orbit. We also hope to increase our international ties as other countries bring new telescopes, radars and satellites to bear and to incorporate data from existing sensors already operating, even though they are not part of the space surveillance network. Despite having integrated diverse data for years, we have our work cut out for us.

But please don't think that procuring new hardware is the only way to succeed. We're also looking at ways to work smarter with the existing resources we have. For example, we're looking to determine if the way we're tasking the sensor network is as optimally as possible. We're also interested to see just how accurate our conjunction assessment predictions are and how we can accurately inform an o/o how accurate our data is. In fact, we've recently conducted an informal study with some friends from ESA and are looking into some interesting research other analysts are conducting. By sharing data, we hope to learn ways to tackle this problem from a different perspective. We're also looking at smarter ways to identify on-orbit conjunctions – maybe our screening volumes should be larger or based on something other than a pure miss distance.

Finally, now that USSTRATCOM has the authority to sign SSA Sharing Agreements with commercial organizations, expect our J5 directorate to be contacting commercial satellite operators. The services we can provide include conjunction assessment and launch support, both tracking and launch CA, but also anomaly resolution, re-entry or de-orbit support, disposal/end-of-life support and electromagnetic interference resolution. We hope to be given the authority to sign agreements and start sharing data with other governments as well, but the process to get that authority from our government has not been completed yet.

CLOSING

In summary, the last 18 months have brought on vast changes in the way we conduct and share SSA. Many decades-old policies have been changed as a result of rationally questioning why the policy was originated. In some cases, we have re-looked at security issues and decided the risk of not sharing the data out-weighed the risk of sharing it. Just like I could not have predicted a year ago that we'd be sharing CSMs, developing an international standard and accepting o/o ephemeris from commercial operators, I don't know what we'll be doing this time next year, but if we continue working with o/o, both foreign and domestic, space will continue to be a safe frontier for all, into the next generations.