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SMALL SATELLITE DEBRIS CATALOG MAINTENANCE ISSUES

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ABSTRACT

The United States Space Command (USSPACECOM) is a Unified Command of the Department of Defense with headquarters at Peterson Air Force Base, Colorado Springs, CO. One of the tasks of USSPACECOM is to detect, track, identify, and maintain a catalog of all man-made objects in Earth orbit. This task we call space surveillance. The most important tool for space surveillance is the satellite catalog. The purpose of this paper is threefold. First, to identify why the command does the job of satellite catalog maintenance. Second, to describe what a satellite catalog is. Third, and finally, to identify small satellite debris catalog maintenance issues. This paper's underlying rationale is to describe our catalog maintenance services so that the members of the community can use them with assurance.

USSPACECOM OVERVIEW

USSPACECOM is a warfighting command. It is authorized to employ forces in support of its missions. USSPACECOM exercises combatant command of its assigned space forces by assigning tasks, designating objectives, and providing direction. A summary of the USSPACECOM mission, taken from the Unified Command Plan, is presented below:

- Space operations to include space control and space support.
- Integrated warning for North American Aerospace Defense Command and other Unified and Specified Commands.
- Planning for eventual operation of the Ballistic Missile Defense system.

Space surveillance is important to all three USPACECOM missions. However, it is actually a subtask of the space operations mission called space control.

Space control is USSPACECOM's warfighting mission. Space control is analogous to sea control. Its goal is to achieve superiority in those areas of space vital to U.S. national interest. Through the space control function, USSPACECOM ensures access to space, tracks objects in space, protects U.S. and allied space-related assets, and when directed, negates hostile space-related forces.

USSPACECOM SURVEILLANCE MISSION

Space surveillance is the fundamental task. It includes detecting objects as they enter space, detecting events caused by objects in space as they occur, and confirming that an object has departed space. Space surveillance is thus essential to control of space. Without accurate surveillance, efforts at assessment and warning, protection, and negation would be futile.

Space surveillance tasking is directed by the USSPACECOM Space Surveillance Center (SSC). The SSC performs space surveillance using both a space-based constellation of geosychronous launch detection sensors and a ground-based network of tracking sensors. The SSC uses this set of sensors to detect and track launches when they enter space. Once the launch is tracked, the SSC can enter information about the launch into the SSC satellite catalog.

To summarize, USSPACECOM maintains the SSC satellite catalog because it is essential to space control operations. Actually, the principle of maintaining it is simple. The SSC tasks the space surveillance network to use the satellite catalog to track satellites. The SSC then takes the observations and updates the satellite catalog. (See Figure 1) However, the actual processes for maintaining the catalog are not so simple. Thus, this paper will next describe what the satellite catalog is and then how things get into it.

WHAT A SATELLITE CATALOG IS.

"Every State launching an object into space is required to maintain a registry" (Convention on Registration of Objects Launched into Outer Space, 1975). Further, every State is required to provide to the Secretary-General of the United Nations the following information, as soon after launch as practicable.

> Name of launching State (or States), designator of the space object, date and location of launch, basic orbital parameters (nodal period, inclination, apogee, and perigee) and general function of the space object.

The SSC Satellite Catalog contains not only this registry information, but other operationally useful information, as well. In general, the SSC catalog is used in two forms. The first form is the registry. The second one is a data base of current orbital parameters on every object for which the SSC can maintain data. A set of orbital paramenters for an object is called an "element set". Thus, this second catalog is called the SSC element set catalog. The discussion that follows will consider the following three questions. First, what kind of information is kept in the registry? Second, what does the element set catalog contain? And, three, how do objects get into the catalog?

SSC REGISTRY CATALOG

The registry catalog maintains the following kinds of information on each object:

The SSC number, satellite common name, international designator, owner source, launch date, launch site, and decay date (when appropriate).

The SSC number is assigned sequentially by the SSC as objects of the launch attain orbit and have a current element set. For example, the oldest object in orbit is satellite number 0005, Vanguard 1, a payload, launched from Air Force Eastern Test Range on March 17, 1958.

The satellite common name, launch site, and launch date is as stated by the owner when the launch is announced.

The international designator is assigned based on rules in COSPAR Information Bulletin No 9, July 1962.

The international designator contains year of launch and number of the launch that year, on a worldwide basis. The final suffix uniquely and sequentially defines each object put in orbit by that launch.

The SSC uses the following conventions to assign object suffixes. The suffix "A" is always reserved for the primary object of a launch. Then, suffixes are assigned by a combination of availability of element sets and importance of the object, usually payload, rocket body, and then debris. (See Figure 2)

The summary of basic orbital parameters on each object is current as of the date that the catalog was generated. These basic orbital parameters are taken from the SSC satellite element set data base.

SSC ELEMENT SET CATALOG

The most commonly available satellite element set catalog contains "two-card" element sets: This form of satellite element set is described in two 69-character data lines. It is a mean, general perturbations element set using modified Keplerian elements, including; epoch time, drag terms, inclination, right ascension of the ascending node, eccentricity, argument of perigee, mean anomaly, and mean motion in revolutions per day. This mean two-card element set is used with our ephermeris prediction package to generate predictions on the satellite's location. A mean orbit is the mathematically smoothed description of the orbit. An osculating orbit represents the actual orbit of the satellite as it is acted on by natural forces.

Table I provides a summary of objects in the SSC Element Sets Catalog as of 05 June 1990

	PAYLOADS	ROCKET BODIES	DEBRIS
OBJECTS	1666	989	3515

Table I. <u>Summary of Object Types in the SSC Catalog</u>

The structure and content of the SSC satellite catalog is significant to the user. Note that the catalog includes both registry and satellite element set information. We protect the distribution of our catalog because sometimes we have information on a launch that may not be confirmed by the satellite owner. We respect the confidentiality of a satellite owner's decision to not release this information.

HOW THINGS GET INTO THE CATALOG?

The most essential step in space surveillance is to detect man-made objects during launch, before they enter space. This is the most common way that objects are found and entered into the satellite catalog.

Space launches are initially detected before they enter space by the Defense Support Program (DSP), a constellation of satellites in geosynchronous orbit.

With initial launch detection information, the ground-based sensor network is directed by the SSC to locate the new launch and all of its pieces. The sensor tracking data is then used to update the SSC element set data base (Figure 1). When the element sets are associated with the launch event, the launched objects are cataloged. Technically, SSC may have an element set, but no registration information on an object to enter it into the catalog. As of 05 June 1990, there were 370 element sets with no registration information.

Today, twenty-six sensor systems make up the USSPACECOM space surveillance network. Figure 4 depicts the low-altitude coverage provided by our space surveillance sensors at 100nm above the Earth. The dashed line shows a typical Soviet satellite orbit trace for a launch from the Soviet Union.

Another significant way for objects to enter the catalog is when a satellite breaks up into many smaller pieces. When an object breaks up, the cloud of pieces is often found by the large search patterns maintained by certain ground-based sensors. Sensors such as NAVSPASUR, Eglin, and Cavalier keep large search fences up at all times. Administratively, the largest piece of the breakup maintains the satellite catalog name given when the object was initially correlated to a launch. The rest of the pieces are cataloged with new international designator suffixes, beginning from the last cataloged piece of the launch.

Satellites no longer in space are logged in the satellite catalog as "decayed". A decayed satellite is one which reenters the earth's atmosphere; thus, it is no longer in orbit.

Presently, man-made objects reenter from orbit on the average of more than one per day. Of these, over 95% are so small that they break up and burn up in the earth's atmosphere. Those that might survive reentry are monitored in a program called Tracking and Impact Prediction (TIP).

Many factors make it difficult to precisely predict where and when a satellite will decay. There are two important factors to mention. The first one is the fact of atmospheric reentry: the combination of atmospheric drag and unique physical characteristic of the object significantly influences both the speed and course of an object's decay. The second part is that our sensor network, due to sensor coverage limits, cannot maintain continuous track on such objects during their decay phase. Thus, depending on the time of the last track (from just now to three hours ago) the ground area of the reentry prediction could be from 100 to 1000 miles long. Historically, 95 out of 100 objects have decayed within the predicted "confidence window", which has an error of plus or minus 20% of the time from the last observation to the predicted decay time.

SMALL DEBRIS MAINTENANCE ISSUES

Presently, USSPACECOM does not track and maintain orbit predictions on small debris (objects less than 10 cm). However, if USSPACECOM is going to maintain small debris there are three issues that must be addressed. Each of these issues are stated below.

One: All satellite element sets are not alike.

Two: Definition of a Tracking Observation.

Three: Size of Small Debris Tracking Requirement.

ALL SATELLITE ELEMENT SETS AREN'T ALIKE

Actually, the SSC uses several forms of element sets. The first one described was the SSC two-card element set. This form is an analytically derived mean element set. The other common SSC element set is a numerically derived special perturbations vector, or "XYZ" vector. This vector is an osculating representation of an object's orbit. For a visual representation of "mean" versus "osculating" see Figure 3. It is very important to note that these two kinds of element sets cannot directly replace one another.

This issue gets even more complex. Depending on the application, different descriptions of the forces on an orbiting object are included in the element set. For example, near-earth perturbations are different from those experienced in deep space. Near-earth orbits have more atmospheric drag effects than geosynchronous deep-space orbits. Therefore, depending on the requirements of their satellite orbits, other agencies have developed their own element set forms. For example, SSC routinely provides vectors in forms used by Onizuka AFB, CA and NASA Goddard, MD for satellite control. SSC also services six other user coordinate systems in non-real time. Note that this also means that an SSC vector cannot directly replace an Onizuka or NASA vector.

The bottom line to you, as a user, is that any element set is not necessarily equivalent to any other element set. Fortunately, we can provide both element sets and look angle prediction software to authorized agencies.

DEFINITION OF A TRACKING OBSERVATION

There are actually three problems within this issue. The first one is called observation "correlation". The second is definition of how many observation constitute a track. And the third is how many site tracks are needed to define the first SSC element set, called "Element Set 1".

OBSERVATION CORRELATION:

The SSC satellite element set data base provides the location of all trackable objects in orbit around the earth. This data base is used to generate predicted look angle data for comparison to actual track data. If tracking data compares very closely, then the object is identified as a "correlated" object. If the object does not correlate, then it is an "uncorrelated target (UCT)". If all objects in earth orbit have current element sets (and thus are correlated), then a UCT is probably tied to a significant space event. Thus, another good reason for maintaining the satellite catalog is to allow our sensor network to detect new uncorrelated objects rapidly and easily.

Our experience is that failure to use identical correlation procedures both at the SSC and at the sensors can have a measurable impact on the SSC computational process.

DEFINITION OF THE TERM "TRACK".

While a track may contain one observation, it generally contains several observations taken during a length of time. For example, from our historic experience in tracking UCTs, we know that a roughly five minute long track on a near-earth object from a single site will produce an element set good for several revolutions. After that time, new observations are needed. Given that this 5 minute track length on a 90 minute orbit provides a basic element set, our rule of thumb is that the initial track length on a UCT must be at least 5.5% of the orbit period. This rule provides the appropriate track length as a function of period in Table II below.

OBJECT PERIOD (Minutes)	TRACK LENGTH (Minutes)
90	5
100	5.6
250	13.9
300	16.6
500	27.8
800	44.4

TABLE II. Track Length as a Function of Object Period

NUMBERS OF SITE TRACKS IN ELEMENT SET 1.

Once a good track length is obtained, then a certain dispersion of site traking observations is required in order to define the element set parameters. Practically, this is stated in the following rules for SSC Element Set One:

Observations from any three sensors which track the object.

Two sensor's obervations at least one-half revolution apart.

Same sensor's observations on separate revolutions.

Once Element Set 1 is established, the element set can be maintained with a relatively small sample of tracking observations gathered periodically.

In summary, generation of an element set on any object that the SSC will maintain requires not one observation, but several sets of tracking observations. The tracking length will also be a function of the object's orbit period. Note that element set generation is not element set maintenance.

SIZE OF A SMALL DEBRIS TRACKING REQUIREMENT

The size of this requirement; that is, how many additional objects need to be tracked is important. For example, if the catalog doubles, we have problems that can be resolved by upgrading equipment. If however, the catalog increases ten-fold, we probably need a great deal more computer and communication capacity and more sensors. In other words, there is a significant cost factor.

SSC SPACE SURVEILLANCE NETWORK

The network used by the SSC uses several types of sensors including mechanical tracking radars, phased array radars, and tracking telescopes. (Table II lists our ground-based sensor capabilities.) The capability of sensors to track is a fixed function of their total sensor tracking opportunities.

For example, mechanical tracking radars generally have only one tracking beam. Also, they generally do not have the inherent capability to track objects smaller than 10 cm. The exception is Haystack. In addition, these sensors have no extra time to track other objects such as small debris. They are primarily used to track high priority objects as payloads and rocket bodies. Thus, these sensors have limited tracking opportunities to track small space debris.

The phased arrays functionally have more than one tracking beam and thus inherently could be used to track more objects. However, only a few have the inherent capability to support tracking objects less than 10 cm. The sensors that could support include the radars at Cavalier and Eglin.

The tracking telescopes also functionally have a single object tracking capability. Depending on refelectivity of the object and site weather, telescopes can track small debris. However, in reality, they have little time to track other objects such as small debris. They are primarily used to track deep space objects and perform periodic deep space searches. Indeed, the command has further requirements for two more deep space tracking sensors.

The bottom line is this. If the catalog doubles, there are few sensors that will have available tracking opportunities to handle this. One would expect that the phased arrays of the existing SSC network should be able to handle it. However, if the catalog increases on the order of tenfold, then new tracking sensors will probably be required.

SPACE SURVEILLANCE COMPUTATIONAL CAPACITY

Now, the computational capacity concern. The current SSC satellite element set data base includes nearly 7,000 objects in earth orbit. The present SSC system (427M) processes approximately 40,000 observations per day. The new SPADOC 4B, due in summer 1991, will not be able to provide significant support to 427M for catalog maintenance. SPADOC 4C, due in mid 1995, is intended to greatly improve catalog maintenance capabilities. It is planned currently to process about 150,000 observations per day.

Satellite element sets are maintained by a process called "differential correction". Fundamentally, this process starts with a site observation and a predicted observation from the current SSC element set. These two positions are compared and the error, or residual, is used to generate a correction to the current element set. Practically, this process "iterates" until the corrected element set fits the site observations on the object. The daily network differential correction process requires a fast scientific computer, not a data base configured computer.

As the numbers of objects increase in the data base, then the need for more speed and/or distributed scientific computer power rises in the SSC.

The loads on the communications system connecting the SSC and the sensors is routinely quite high. Double the size of the catalog and the communications system may not be able to pass the amount of observations required to maintain that doubled satellite catalog. The communications pipes may not be large enough to handle that flow.

The bottom line for computers and communications lines is that we may be able to handle a doubling of the satellite catalog. If larger numbers of objects must be maintained, more scientific computer power and larger communications pipes most probably must be obtained.

CONCLUSION

USSPACECOM has the mission to detect, track, identify, and maintain a catalog of all man-made objects in earth orbit. However, there is currently no military requirement to track small debris, and we do not have, nor are we developing the capability to do so. Most of our sensors are not capable of tracking small debris. Our computational resources and communications lines may functionally handle the problem, but more capacity is probably required. Based on national needs and other important factors, if it is decided to require USSPACECOM to track small debris, then funds must be applied to improve USSPACECOM resources.

RADAR SENSORS

SYSTEM	LOCATION	SENSOR TYPE	RANGE (KM)	SMALL DEBRIS CAPABILITY
ALCOR	Kwajalein Atoll	C Band	5555 KM	
ALTAIR	Kwajalein Atoll	UHF/VHF	40000 KM	
FPQ-14	Antiqua lls	C Band	2300 KM	
FPQ-15	Ascension lls	C Band	1600 KM	
FPS-92	Clear, AK	UFH	5555 KM	
HAYSTACK	Millstone Hill, MA	X Band	35000 KM	X
COBRA DANE	Shemya lls	L Band	5555 KM	
FPS-85	Eglin, FL	UHF	5555 KM	X
FPS-49	Fylingdales, England	UHF	5555 KM	
NAVSPASUR	Dahlgren, VA	Continuous Wave	8100 KM	
FPQ-14	Kaena Point, HI	C Band	1800 KM	
MILLSTONE	Millstone Hill, MA	L Band	35000 KM	
FPS-79	Pirinclik, Turkey	UHF	4300 KM	
PAVE PAWS	Cape Cod, MA Beale, CA Robins, GA Eldorado, TX	UHF	5555 KM	
PARCS	Cavalier, ND	UHF	3200 KM	X
SAIPAN	Saipan lls	C Band	2500 KM	
SPAR	Thule AFB, Greenland	UHF	5555 KM	

ELECTRO-OPTICAL SENSORS

SYSTEM	LOCATION	SENSOR TYPE	RANGE (KM)	SMALL DEBRIS CAPABILITY
AMOS	Maũi, HI	Visible, LWIR	35000 KM	
GEODSS	Socorro, NM Taegu, Korea Maui, HI Diego Garcia	Visible	35000 KM	X
MOTIF	Maui, HI	Visible, LWIR	35000 KM	
SITU	St Margarets Canada	Visible	35000 KM	

TABLE III. Space Surveillance Sensor Capabilities

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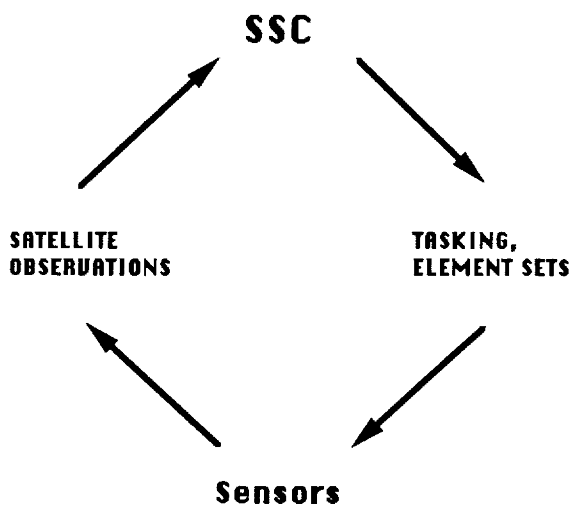

FIGURE 1. Space Surveillance Satellite Catalog Maintenance

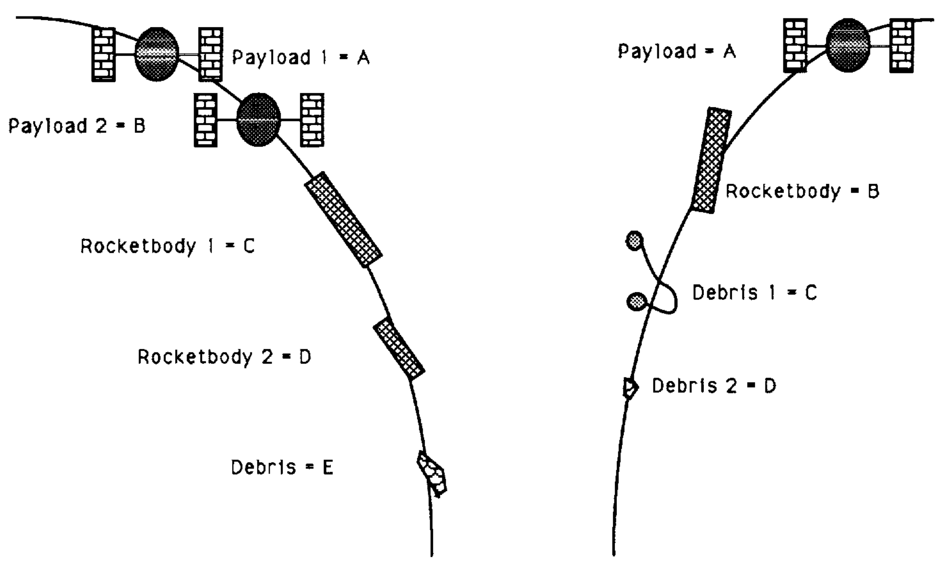

FIGURE 2. Precedence for Assigning International Designators

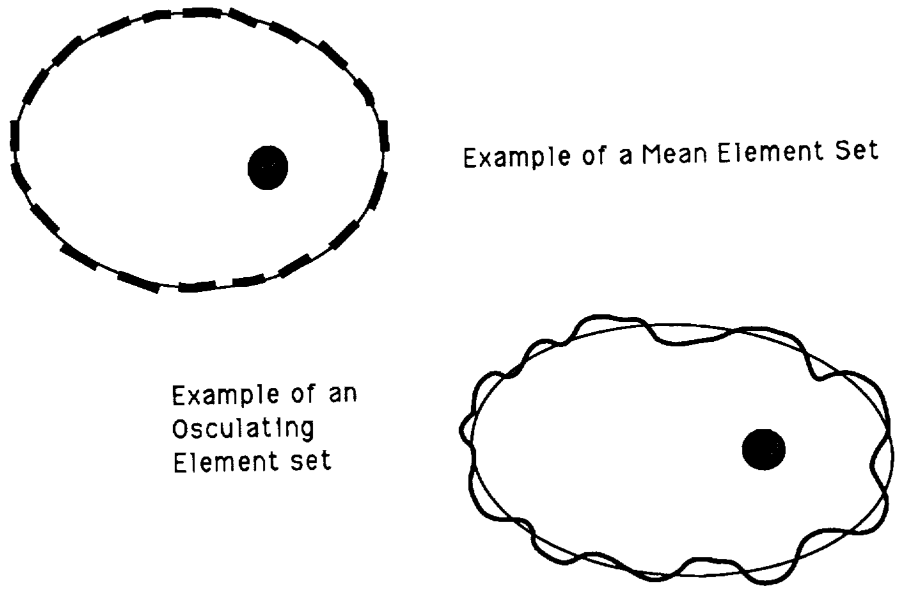

FIGURE 3. Distinction between Mean and Osculating Orbits

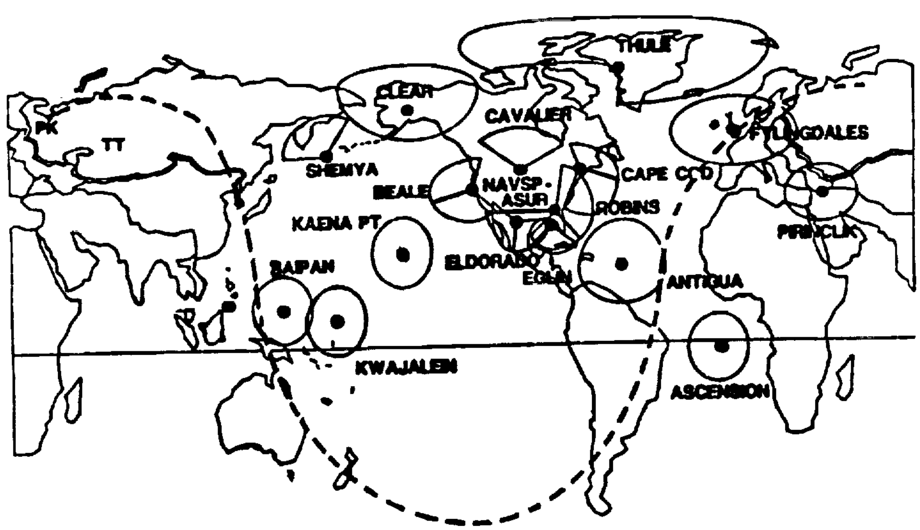

FIGURE 4. Low Altitude Ground-based Space Surveillance