Proceedings of the First European Conference on Space Debris, Darmstadt, Germany, 5-7 April 1993 (ESA SD-01)

UNITED STATES SPACE COMMAND SPACE SURVEILLANCE NETWORK OVERVIEW

LT S.A. Chamberlain, USN and Capt T.A. Slauenwhite, USAF

United States Space Command

ABSTRACT

The United States Space Command operates the Space Surveillance Network (SSN), consisting of 26 radar and optical sensors worldwide and two central processing centers. The primary mission of the SSN is to detect, track, identify and catalog all man-made objects in space. The SSN routinely processes space events which often involve orbital debris, including new satellite launches, breakups, separations and decays. The SSN also assesses collision hazards prior to US launches. The SSN provides a number of products and services to both federal and civilian agencies.

1. INTRODUCTION

The Space Surveillance Network (SSN) System consists of a worldwide sensor network, a communications network, and two central data processing/controlling facilities. The primary facility is the Space Surveillance Center (SSC) located in Cheyenne Mountain, Colorado Springs, Colorado. The backup facility, the Alternate Space Surveillance Center (ASSC), is located in Dahlgren, Virginia, co-located with the Naval Space Surveillance Center. (Ref. 1)

The sensors collect satellite positional and space object identification (SOI) data, and transmit it to the central processing facilities. These centers process and correlate sensor data to develop and maintain an accurate position, intelligence and status database on all man-made, Earth orbiting objects. (Ref. 1)

2. SSN MISSION

The mission of the SSN is to provide data in support of two space surveillance mission areas: space track and space intelligence. (Ref. 1)

The SSN accomplishes space track through data collection efforts on all man-made orbiting space objects. The SSN uses this data to identify and categorize all detected space objects, to maintain an accurate and current catalog of space objects, and to provide reports to military, civilian and scientific agencies. Another aspect of the space track mission is to support space research and development activities through data exchanges and analyst support for experiments and research projects. (Ref. 1)

The space intelligence mission includes space event confirmation, space object discrimination and cataloging, confirmation of domestic satellite configurations, evaluation of satellite malfunctions for domestic and coordinating launch agencies, and technical studies in research and development efforts on future space systems and capabilities. (Ref. 1)

3. SENSOR MISSION CATEGORIES

The 26 sensors which comprise the SSN are capable of tracking both near-Earth and deep space objects, depending on the individual sensor. Deep space satellites are defined as those having orbital periods greater than or equal to 225 minutes. The SSN is divided into three space track mission categories: (Ref. 1)

- Dedicated sensor: fully supports the SSN in its mission of space track operations. (Ref. 1)

- Collateral sensor: has a primary mission of missile attack warning and/or intelligence collection, but still provides support to the SSN. (Ref. 1)

- Contributing sensor: owned and operated by other agencies, but provides SSN support as per contract or special agreement with HQ USSPACECOM. (Ref. 1)

4. SURVEILLANCE FACILITIES

The SSN uses three types of sensors to accomplish the space track mission:

- Radar: includes 9 mechanical tracker sites, 9 phased array sites, and 1 continuous wave radar fence.

- Optical: 6 near real-time sites.

- Passive radio-frequency (PASS): 1 site.

Figure 1 shows the locations of these sensors:

SPACE SURVEILLANCE NETWORK SENSORS

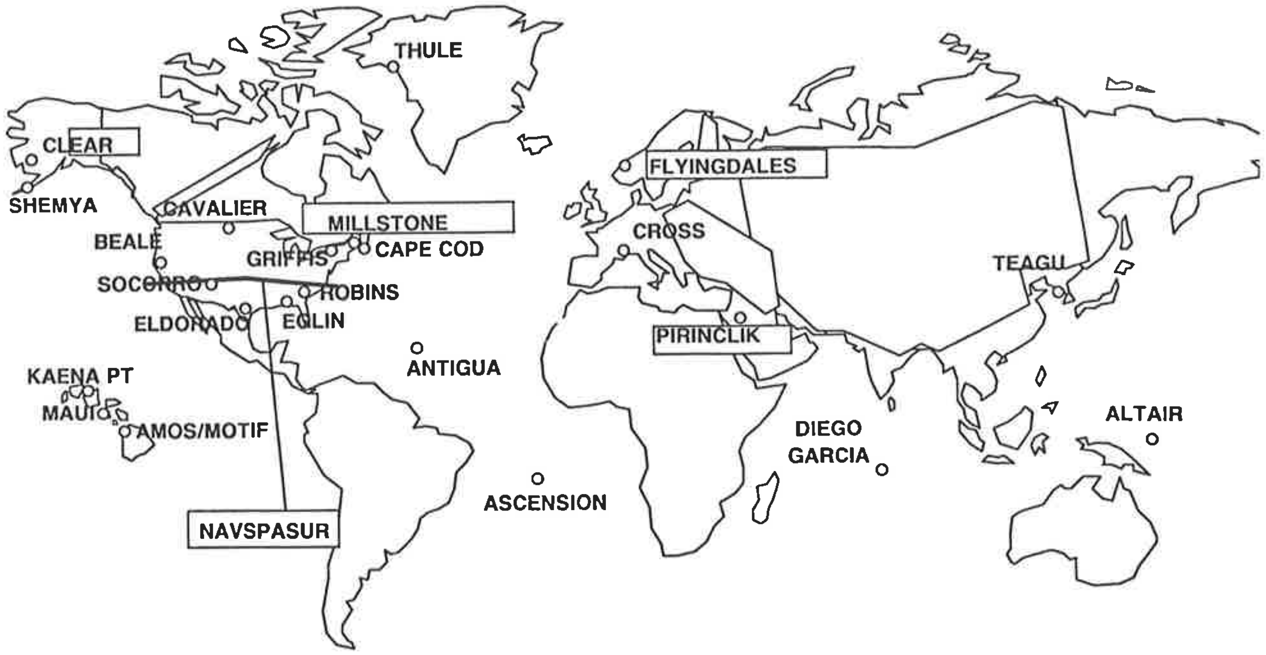

Figure 1. SSN Sensors

5. RADAR SURVEILLANCE FACILITIES

One of the oldest, yet still very capable radar systems in the SSN is the Naval Space Surveillance Fence (NAVSPASUR). This continuous wave radar fence consists of 3 transmit sites (Lake Kickapoo, Texas; Gila River, Arizona; and Jordan Lake, Alabama) which generate a narrow fence several kilometers wide at an altitude of approximately 20,000 km. Return signals from objects which penetrate this fence are collected by six receiver sites (Tattnall, Georgia; Silver Lake, Mississippi; Red River, Arkansas; San Diego, California; Hawkinsville, Georgia; and Elephant Butte, New Mexico). The collected data is sent to NAVSPASUR headquarters, located in Dahlgren, Virginia, for processing. (Refs. 2,3)

Since NAVSPASUR is a stationary beam fence, it cannot accumulate enough data from a single penetration by an object to generate an accurate element set. However, it is sufficient to create a rough element set, with a positional error of 0.7 km and a velocity error of 172 m/sec. The positional error increases to 99 km after 10 minutes, and to over 1900 km after 1 hour. (Ref. 3)

NAVSPASUR acts as the Alternate Space Surveillance Center (ASSC), the operational backup for the SSC. NAVSPASUR provides highly accurate piece count data. Their analysts are extremely capable in associating unknown objects with those objects which have already been cataloged, and in reconstructing the events surrounding satellite breakups.

Mechanically steered dish radars play an important role in the SSN. There are currently 9 dish radars supporting the SSN:

ALTAIR (ARPA Long-Range Tracking and Instrumentation Radar) is part of the Kiernan Reentry Measurements Site (KREMS) complex on Roi-Namur Island in the Kwajalein Atoll. Operated by the US Army, this contributing sensor is the principal SSN deep space radar for the Pacific region. ALTAIR can detect and track objects with a Radar Cross Section (RCS) of 1 m^2 in geosynchronous orbit. It also provides both metric and narrowband Space Object Identification (SOI) data for near-earth objects. With its wide beamwidth, ALTAIR can track up to 14 targets simultaneously. It supports NASA's multi-frequency space debris radar test program, and serves as an acquisition radar for ALCOR. (Refs. 2,3)

ALCOR (ARPA-Lincoln C-Band Observables Radar) is co-located with ALTAIR. This contributing sensor provides high quality wideband coherent imaging data on near-earth satellites. (Ref. 3)

Millstone Hill is a research and development facility of the Massachusetts Institute of Technology's Lincoln Laboratory. This L-band radar can track both near-earth and deep space objects. Millstone is a very sensitive radar, having tracked objects with a RCS of just over 1 m^2 in a geosynchronous orbit. Millstone is also used as an acquisition radar for Haystack. (Refs. 2,3)

Haystack Long-Range Imaging Radar (LRIR) is co-located with Millstone. This contributing X-Band radar is normally used by the SSN for wideband imaging. It is capable of detecting orbital debris as small as 1 cm in diameter at an altitude of 1,000 km. (Refs. 2,3)

Antigua is one of the three C-Band dish radars in the SSN. A collateral sensor, its primary mission is Eastern Space and Missile Center (ESMC) support. (Refs. 2,3)

Ascension, the second C-Band dish radar, is also used to support ESMC. It is a vital sensor in determining initial orbital parameters for manned, geosynchronous and interplanetary missions launched from international launch agencies. (Refs. 2,3)

Kaena Point, the third C-Band sensor, supports the Western Space and Missile Center (WSMC). One of its primary roles is determining initial orbital parameters for higher inclination launches from international launch agencies. (Refs. 2,3)

Clear is the only dish radar in the Ballistic Missile Early Warning System (BMEWS). Its geographic location allows it to track objects in near-polar orbits. It is one of the first sensors to track new launches from international launch agencies. Clear is also a good sensor for satellite breakup analysis, since it provides good piece count data. In addition, Clear often provides narrowband SOI data. (Refs. 2,3)

Pirinclik is the last dish radar in the SSN. It has both near-earth and deep space track capability. Together, Pirinclik, Millstone and ALTAIR provide complete radar coverage of the geostationary ring without the solar illumination and weather requirements associated with optical sensors. (Refs. 2,3)

Phased array technology was mainly developed in the US during the 1960's, allowing the capability to track hundreds of objects simultaneously. Phased array radars contain thousands of transmitting elements. The beam is steered by controlling the relative phases and amplitudes between these elements. When the controls are properly designed and computer driven, the beam can be steered in milliseconds, allowing the radar to scan large volumes of space or illuminate many targets in a very short period of time. There are nine phased array radars in the SSN. (Refs. 2,3)

Eglin is one of the most capable sensors in the SSN, with both near-earth and deep space track capabilities. With its separate transmit and receive faces, it can track objects with an RCS as small as 0.04 m^2 in geostationary transfer orbits (Ref. 2), and 0.0001 m^2 in low earth orbit (Ref. 3). It is essential for maintaining the deep space portion of the satellite catalog, and currently spends 70% of its time fulfilling its deep space mission. Eglin is a primary source of RCS data, and also possesses special software to handle dense debris clouds created by satellite breakups. To further accomodate breakup processing, unknown objects detected by NAVSPASUR, which also pass through Eglin's coverage, are automatically handed off to Eglin to permit track data collection (Refs. 2,3)

The Perimeter Acquisition Radar Attack Characterization System (PARCS), also known as Cavalier, is a collateral sensor with a primary mission of missile warning. It is the second most valuable sensor for near-earth catalog maintenance. It is also regarded as the best sensor for the early determination of a satellite breakup, as well as for space debris characterization. These are vital components of collision avoidance support. PARCS also collects narrowband SOI on near-earth objects. (Ref. 3)

Cobra Dane, also known as Shemya, is a single-face, phased array radar, located in the Aleutian Islands off of Alaska. It is a very important sensor in determining initial orbit parameters for high inclination, low earth orbit launches. (Refs. 2,3)

Cape Cod, Beale, Robins and Eldorado are the four radars which comprise the PAVE PAWS system. These two-face, phased array radars have a primary mission of missile warning, but each can track 100 objects simultaneously in support of their space track mission. Combined, these sites provide approximately 10% of the observations which the SSC processes. (Ref. 3)

Thule and Fylingdales are two of the three BMEWS sites. Thule's phased array radar replaced a mechanical tracker and four detection fans in 1987, while Fylingdales' three-faced phased array radar replaced its three dish radars in 1992. Both of these collateral sensors track near-earth objects in moderate to highly inclined orbits. (Ref. 3)

6. OPTICAL SURVEILLANCE FACILITIES

The second type of sensor used in the SSN is the optical sensor. Optical sensors use light gathering and measuring devices, such as telescopes and camaras, to perform data collection functions analogous to those performed by radar systems. The primary data collection functions include tracking data, SOI signatures, and imaging. The main difference is that optical sensors are totally passive. Target illumination is usually supplied by sunlight. Despite their high accuracy, optical sensors have numerous disadvantages. Weather in the vicinity of the sensor must be favorable, lighting conditions correct, and atmospheric conditions must be good. (Ref. 3)

The SSN GEODSS (Ground-based Electro-Optical Deep Space Surveillance) network currently consists of four GEODSS sites. These are located in Socorro, New Mexico; Taegu, South Korea; Maui, Hawaii; and Diego Garcia in the Indian Ocean. With only four sites, a portion of the geostationary ring is not covered by the GEODSS network. However, this area is covered by the deep space radars at Pirinclik, Millstone and Eglin. (Ref. 3)

As dedicated sensors, they perform the following tasks: initial deep space object detection and tracking; deep space satellite maneuver detection and tracking; and routine tracking and SOI support for deep space catalog maintenance. They have also been used in "staring modes" to approximate the amount of debris at altitudes below 2,000 km. (Ref. 3)

The standard complement of equipment at each of the GEODSS facilities consists of two 1 meter diameter telescopes with a 2 degree field of view, and two auxiliary telescopes (35 cm and 38 cm), each with a 6 degree field of view, used for general search. The Diego Garcia site is an exception, with three 1 meter telescopes and no auxiliary telescopes. (Ref. 3)

The SSN has two other optical facilities co-located with the Maui GEODSS site: the Air Force Maui Optical Station (AMOS) and the Maui Optical Tracking and Identification Facility (MOTIF).

AMOS is a national asset for DoD electro-optical research and development, and is a contributing SSN sensor. AMOS has a variety of optical equipment, including a laser beam director that provides space object illumination, a star sensor that measures the atmospheric turbulence and a 1.6 meter telescope with a Compensated Imaging System (CIS) which can produce very high resolution images of space objects. (Ref. 3)

MOTIF's optical equipment consists of dual 1.2 meter telescopes on a common mount. An Advanced Multicolor Tracker for AMOS (ATMA) is mounted on one telescope, and a Low Light Level Television (LLLTV) package is on the other telescope. MOTIF can produce classical images (photographs), measurements of long wavelength infrared (LWIR) intensities and photometry (measurements of variations in reflected visible light) of space objects. (Ref. 3)

Position vectors of near-earth space objects detected by the mechanical radar at Kaena Point are handed off to AMOS and MOTIF to assist these optical sensors in acquiring the objects. (Ref. 3)

A Joint Operating Agreement allows the sharing of equipment to accomplish all test/operational objectives of both AMOS and MOTIF. (Ref. 3)

7. COMBINED RF/OPTICAL SPACE SURVEILLANCE SYSTEM (CROSS)

The final category of sensor in the SSN uses a hybrid technology, combining both radio frequency and optical technologies. CROSS, located in San Vito, Italy, is a relatively new SSN sensor. Its passive radio frequency feature provides rough search capability, while the optical feature produces metric tracking data. CROSS fills the optical sensor gap in the Eastern hemisphere to maintain deep space objects. (Ref. 4)

8. ROUTINE SSN OPERATIONS

The primary task of the SSN is to maintain accurate orbital parameters on all objects that are currently in space, as well as develop new element sets for objects which have just been launched or recently discovered.

To accomplish this mission, the SSN forwards over 63,000 observations daily to the SSC, where observation conversion programs and filters estimate a trajectory which closely describes the object's orbit. If this correlates to the particular object, the new element set is published. This orbital data is transmitted to the sensor sites, allowing them to continue tracking the object. It is also made available to authorized satellite operators and space system users.

The accuracy of the resulting orbital parameters depends upon several factors:

- Pass geometry of the observations
- State of the atmosphere
- Ballistic coefficient of the object
- Sensor which provided the observations

- Time elapsed from the element set epoch to the last observation
- Sophistication of the propagation theory used

A typical element set accuracy for an object at an altitude of 1000 km after 10 days may be several kilometers. (Ref. 2)

The number of objects in space has dramatically increased since the launch of Sputnik I in 1957 (see Figure 2 below).

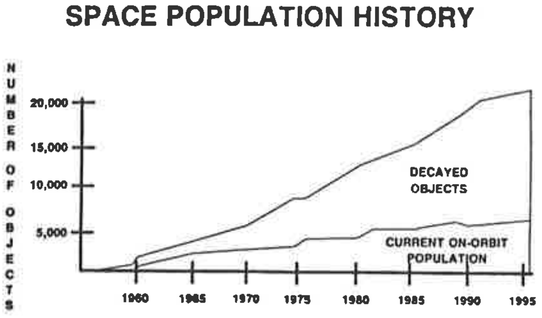

Figure 2. Space Population History

As of 15 March 1993, 22,557 objects have been cataloged. Out of these, over 7,285 objects are still in orbit. Table 1 shows an accounting of objects by country.

Only about 10% of the total on-orbit population are active payloads. The remainder consists of dead payloads and debris from expended rocket bodies, objects associated with launches and satellite breakups. The largest breakup in history occurred in 1986: the Spot 1 Rocketbody, from which 488 pieces were cataloged. As of 1 April 1993, 59 of these pieces were still in orbit. (Ref. 5)

SSN analysts spend a good portion of their time performing satellite breakup processing. They associate and correlate numerous observations into individual pieces of debris, and catalog the results. They also determine the parent satellite, and estimate the time and location of the breakup. The orbital debris community may use this information to determine a possible cause of the breakup, as well as suggest the nature of the orbital debris cloud. (Ref. 2) To date, approximately 8,000 pieces from breakups have been cataloged, and processing still continues from the breakups which occurred in the past six months. (Ref. 5)

Another function supported by the SSN deals with collision hazard assessment. Using a computer algorithm, analysts can determine the closest point of approach between one satellite and another satellite or group of satellites during a specified time period. This task is performed prior to new US launches and during Space Shuttle missions, as well as for breakup analysis. Thus, operators can be warned of an impending collision in time to perform appropriate evasive maneuvers. (Ref. 2)

9. SSC PUBLICATIONS

The SSC publishes two major publications: the Satellite Catalog and the RCS Catalog.

The Satellite Catalog is an historical record of all cataloged objects since 1957. For each object, it gives general information such as: international designator, satellite number, common name, country of origin, launch date, launch site and average RCS value. (Refs. 2,5)

For objects currently in orbit around the Earth, it also provides basic orbital parameters (orbital period, inclination, apogee and perigee). For objects which have escaped Earth orbit (such as probes), instead of orbital parameters being listed, a descriptive statement of their status is printed (such as Selenocentric Orbit). (Refs. 2,5)

Acknowledged "lost" satellites are denoted by "No Current Elements," and satellites for which orbital information is restricted have "No Elements Available" in the orbital parameters columns. The elements listed for satellites which have decayed are representative of an earlier part of the satellite's life and are given for general information only. (Refs. 2,5)

The Satellite Catalog is published annually, and is updated on a weekly basis. It has limited distribution (For Official Use Only). However, NASA Goddard Space Flight Center generates an equivalent report (the Satellite Situation Report) for the general public using the SSC database. (Ref. 2)

The other SSC report is the RCS Catalog. It contains data only on in-orbit objects, and lists the satellite number, apogee, perigee, inclination, orbital period and average RCS value. This publication contains information on both cataloged objects, as well as objects which are being tracked by the SSN, but are not yet cataloged (8X,XXX series objects). The RCS Catalog is updated annually, and is available for public use. (Refs. 2,6)

Country	Payloads	Debris	Total
USA	617	2,608	3,225
CIS	1,249	2,278	3,527
United Kingdom	17	1	18
Italy	3	4	7
Canada	16	0	16
France	23	18	41
Australia	6	1	7
Japan	49	55	104
Germany	12	1	13
NATO	6	0	6
PRC	11	81	92
India	8	1	9
Spain	2	0	2
ESA	26	122	148
France/Germany	2	0	2
Czechoslovakia	1	0	1
Indonesia	6	0	6
ITSO	42	0	42
Brazil	4	0	4
Saudi Arabia	3	0	3
Mexico	2	0	2
Sweden	3	0	3
Luxemburg	2	0	2
Argentina	1	0	1
IMSO	3	0	3
Korea	1	0	1
Total	2,115	5,170	7,285

USA = United States of America
CIS = Commonwealth of Independent States
NATO = North American Treaty Organization
PRC = People's Republic of China
ESA = European Space Agency
ITSO = International Telecommunications Satellite Organization
IMSO = International Maritime Satellite Organization

Table 1. Earth Satellite Population

10. REFERENCES

1 USSPACECOM REGULATION 55-12, United States Space Command, 1 June 1992.

2 Johnson, Nicholas L., "U.S. Space Surveillance", Paper B.8-M.1.01, presented at World Space Conference, 1 Sep 1992.

3 Space Surveillance Network Handbook, Air Force Space Command, 30 Sep 1988.

4 Walker, M., Capt, USAF, Passive Space Surveillance (PASS) Brief, Headquarters Air Force Space Command/DOJ, 1 Jan 1992.

5 Satellite Catalog, 1st Command & Control Squadron, Air Force Space Command, 11 March 1993.

6 RCS Catalog, 1st Command & Control Squadron, Air Force Space Command, 1 Oct 1992.