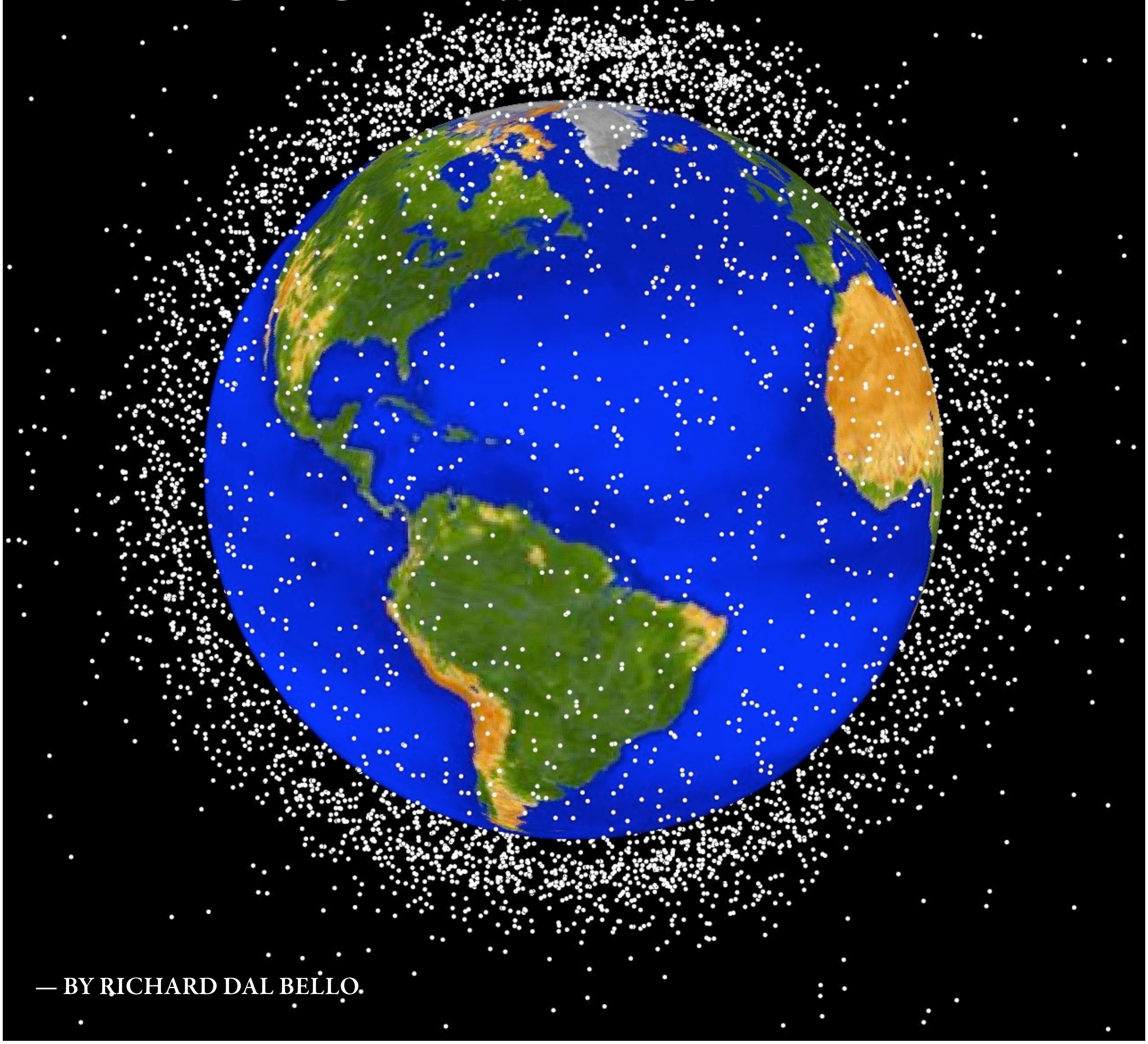
Managing Risk in Space



— BY RICHARD DAL BELLO

Since the launch of Sputnik in 1957, governments and commercial companies have placed thousands of satellites in orbit around the Earth. Most of them have long since burned up reentering the atmosphere or disintegrated into space debris. Today, there are over 16,000 active satellites and debris objects in the public catalog of tracked objects.

The region of space near Earth in which satellites orbit is so large – extending out 22,200 miles for commercial satellites – that one might believe a collision of orbiting spacecraft would be impossible. For example, communications satellites are typically spaced a degree apart - more than 700 km. That would be the same as parking one minibus-sized satellite in Washington, DC and the next in Ottawa. But some satellites are spaced significantly closer, and in fact the International Telecommunications Union (ITU) does not ensure there is any such separation. And as every statistitian knows, there is a big difference between a highly improbable event and an impossible event. Just three years ago, a satellite operated by Iridium Communications for the company's global communication network collided with an uncontrolled Russian spacecraft that had been out of service since 1995. The collision, 490 miles above Siberia, produced over 2,000 pieces of debris larger than 10 centimeters (3.9 inches) in diameter, each one large enough to destroy any orbiting satellite in its path.[1]

To avoid collisions in the increasingly crowded orbital arcs, agencies and companies operating satellites have informally shared position and orbit data for many years. But one problem with informal information sharing is that satellite operators don't use the same standard to represent the position of a satellite in orbit or an object in space. Many different types of software are used to track and maneuver satellites and the data is stored in a variety of formats. So, even operators who wish to share data can't rely on a single, agreed-upon protocol for sharing information. As a result, operators sharing information must maintain redundant file transfer protocols and tools to convert and reformat data so that it is consistent with their own software systems to compute close approaches. While some operators use third-party software for predicting close approaches, others write their own software tools. As the number of satellite operators increases, the problem of maintaining space situational awareness grows more complex. And the smallest operators may not be able to afford, or have the technicians, to participate in the data sharing process.

Recently, the world's leading commercial satellite operators formed the Space Data Association (SDA) to formalize the process of exchanging information and to deal with the overall data compatibility problem. Clearly, the best path to minimize risk in space is for all operators to share what they know about the movement and position of their own satellites in a way that all other companies can use. While this sounds like common sense, governments and commercial companies around the world have each historically acted on their own in launching and monitoring satellites. Agencies and companies coordinate frequency allocation and orbital slots prior to launch, but once a satellite is in orbit, data about the movement of commercial satellites was shared only informally until the establishment of the SDA. Information about the operation and location of many military satellites is still shrouded in secrecy.

The most critical times to share data about satellites are when a new satellite is being placed in orbit or an existing satellite is being shifted from one orbital slot to another. A typical communications satellite is as big and massive as a loaded semi-trailer, and though it appears fixed above the Earth, it is actually traveling thousands of kilometers per hour. Putting a satellite into an orbital slot or moving it to another position above Earth without disturbing any of the other 250+ commercial communications satellites in the GEO[2] plane, as Intelsat routinely does, is a very delicate operation. Yet this process is managed entirely by commercial operators using informal, de facto rules developed through experience and implemented by consensus.

This cooperative process has been used effectively and without incident since the commercial satellite communications era began in the 1960s, primarily because everyone involved realizes that a satellite collision would be catastrophic. Building and launching a satellite costs hundreds of millions of dollars, and this type of investment gives operators a very strong incentive to avoid space collisions at all costs. The increase in the number of satellites and satellite operators has made the need to share data even more acute.

The evolution of how satellite position data is collected has some parallels with the development of air traffic control for commercial aircraft. In the decade following the Wright brothers first controlled, powered flight at Kitty Hawk in 1903, so few airplanes were in the sky at any given time that human flight required little if any monitoring from the ground. However, after the flight experiences during World War I accelerated advances in airplane design, the industry began to flourish, and the first air traffic control systems were put in place.

The formation of the SDA is a major step toward creating a voluntary "air traffic control" system for space. The SDA is an interactive repository for commercial satellite orbit, maneuver, and payload frequency information.[3] The SDA's principal goal is to promote safe space operations by encouraging coordination and communication among its operator members. Through the SDA's Space Data Center, the satellite operators maintain the most accurate information available on their fleets; augment

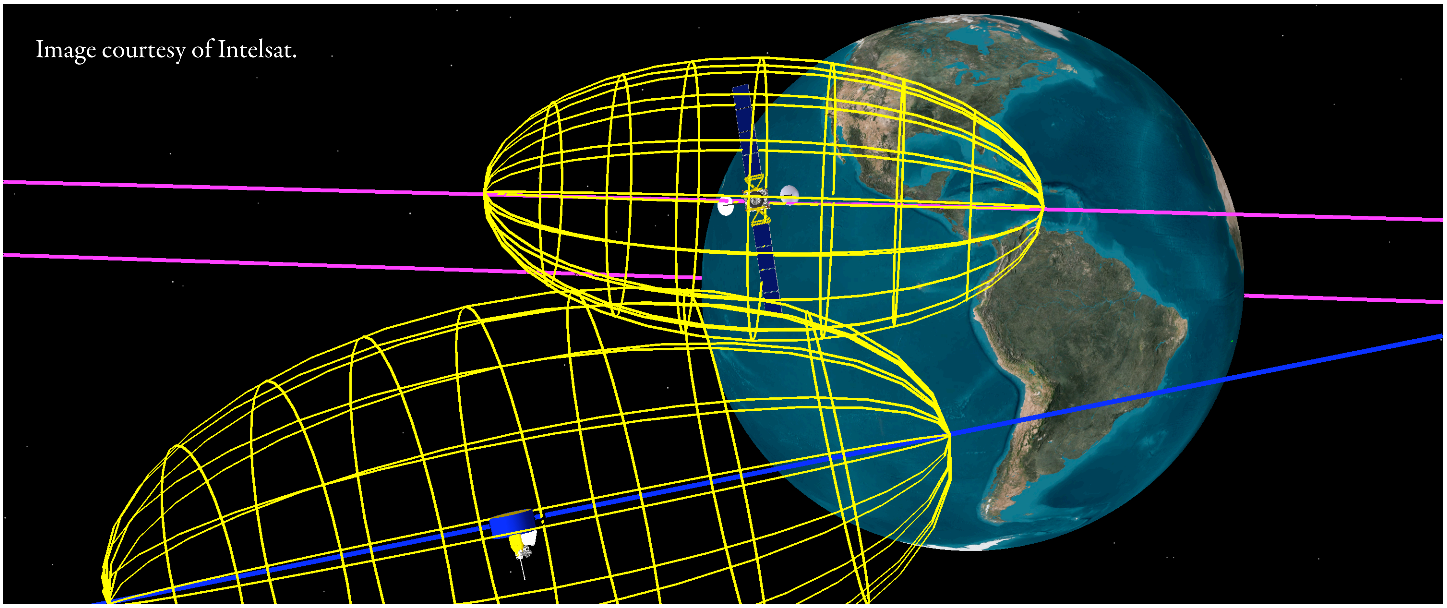


Image courtesy of Intelsat.

augment existing government-supplied data with precise orbit data and maneuver plans; and retrieve information from other member operators when necessary. As a result, the data center:

- Enhances safety of flight.
- Provides efficient, timely, accurate conjunction assessments for members.
- Reduces false alarms, missed events.
- Minimizes member time and resources devoted to conjunction assessment.
- Establishes common format conversions and a common information repository.
- Provides radio frequency interference (RFI) geo-location and resolution support, allowing operators to more rapidly find and address interference sources.
- Encourages the evolution of best practices for members.

Because of the proprietary nature of the operational data, the SDA has been designed to protect information and prevent members from using for commercial purposes the data supplied by competing companies. The members of the SDA contribute operational data through a secure web-based interface on a daily basis and can access data related only to the operation of their own satellites. For example, an operator who only has satellites covering Latin America cannot access data from other parts of the globe. The data center processes information to perform real time identification of "conjunctions" (very close approaches that may lead to a collision) and RFI analysis for SDA members' satellites.

So far, the SDA has actual position information on 237 satellites in geostationary Earth orbit (GEO), and another 110 in low Earth orbit (LEO). The greater the membership of the SDA, the more comprehensive the data and the resulting analysis will be. As new satellite operators continue to join the SDA, the data center will continually improve its reliability in all satellite arcs and develop the system into a truly global and comprehensive database for space situational awareness.

Several years ago, the U.S. government began providing commercial operators with satellite position data gathered by the U.S. Strategic Command (USSTRATCOM) using radars and sensors. The position information provided initially for close-approach monitoring, called two-line element (TLE) data, had several drawbacks. First, there was no available and transparent standard for TLE modeling. Second, TLE data did not have the required accuracy for credible collision detection, forcing operators who wanted to avoid collisions to increase the calculated collision margins. This required an increased number of maneuvers, which wasted fuel and could shorten the life of a satellite. TLE data also lacked reliable planned maneuver information, which limited the usefulness of data for longer-term predictions.

The evolution of how satellite position data is collected has some parallels with the development of air traffic control for commercial aircraft.

Recently, USSTRATCOM admitted that the TLE data was imprecise and developed a procedure for providing commercial operators with additional information in the form of conjunction summary messages (CSMs) to operators whose satellites have been identified as closely approaching another space object.[4] These CSMs contain vector and covariance information computed from other data, making it more accurate than TLEs.

However, recent studies funded by Intelsat and SES have concluded that to ensure the highest level of accuracy, it would be beneficial for USSTRATCOM to incorporate data from routine satellite maneuvers. The SDA has offered to augment the global sensor data maintained by USSTRATCOM with more precise operator-generated data to improve the accuracy of conjunction monitoring. The SDA could also provide a standardized method and focal point for operators to share information and facilitate communications between satellite operators and governments interested in making available timely space object catalogues. Hopefully, with the passage of time, the U.S. and other governments will be able to fully capitalize on this industry-sponsored and funded initiative. Solving the problem of government/industry data sharing and the role of the SDA should be a key objective of future international discussions on this topic.

Another major risk to operators is the proliferation of orbital debris from rocket stages, defunct satellites, equipment lost by astronauts and the fragments left from explosions and collisions of satellites. For example, Vanguard 1, launched by the United States in 1958, is expected to remain in orbit at least another 200 years before slowly burning up as it drifts down into the atmosphere.[5] The debris problem is most severe in LEO, where the majority of satellites used for communications and remote sensing operate. Because these satellites are not geostationary and orbit the Earth about every 90 minutes, several satellites are required to provide continuous coverage of any given area. Using observation data produced by radar and optical detectors, operators on Earth maneuver LEO satellites through a debris field of thousands of objects every day.

While GEO is less cluttered with debris than LEO, any objects in GEO pose more of a threat because all of the satellites are in the same orbital plane. In addition, the atmospheric drag that serves to self-cleanse the lower LEO regime of orbital debris is non-existent in the GEO regime, and only the lesser gravity from the sun and moon serve to slowly pull a GEO satellite out of its initial equatorial, circular orbit. In addition, a GEO space object is so distant that any size less than 1 meter (3 feet, 3 inches) in diameter is difficult to see, making the precise nature of the threat unknown.[6]

International efforts are being made to provide better sharing of information about those practices that contribute most to the space debris problem. One is the Inter-Agency Space Debris Coordination Committee (IADC), a coordinating forum for national space agencies that created an important set of voluntary guidelines regarding the mitigation of man-made and natural debris in space.[7] The primary objectives of the IADC are to exchange information on space debris research activities between member national space agencies, to facilitate cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options. Although important, the IADC's work is still only a set of guidelines for national regulators to consider.

Because of the major investment required to design, build and launch a satellite, the commercial industry is rightly concerned that the "tragedy of the commons" not be replicated in Earth orbit.[8] The number of operating satellites and the volume of space debris are both increasing steadily, a fact that does not bode well for a cleaner and safer space environment. As land is on Earth, the orbital planes in space are finite resources that can be depleted or polluted in ways that make continued use impossible.

Today, the valuable LEO environment is in some jeopardy of suffering "the tragedy of the commons" as a result of the significant increase in both space debris and RFI interference. As these threats multiply, satellite operators and their customers are at risk of losing access to a satellite service that benefits both commercial and consumer markets.

Space is indeed a limited resource. As vast as it appears when looking toward the heavens on a starry night, the portion of space that can be used effectively for communications, weather monitoring, remote sensing and other satellite-based applications is really just a thin shell that extends outward from Earth less than one tenth of the distance to the Moon. Governments and private companies around the planet are investing billions of dollars in next-generation space technology. Every one of those users and potential users of the orbital environment have a stake in its long-term preservation.

While governments were the first to send satellites to near-Earth space, commercial enterprises and consumer services will be the primary users of the orbital arcs in the 21st century and, hopefully, beyond. Consequently, governments and companies operating spacecraft need to take a new approach to enhancing the safety and efficacy of the space environment, an approach that includes more international cooperation among all parties. The Space Data Association is the major step on this path, and that step should be followed by firm actions of governments and all space users to create an international framework that assures the preservation of this valuable resource. ■

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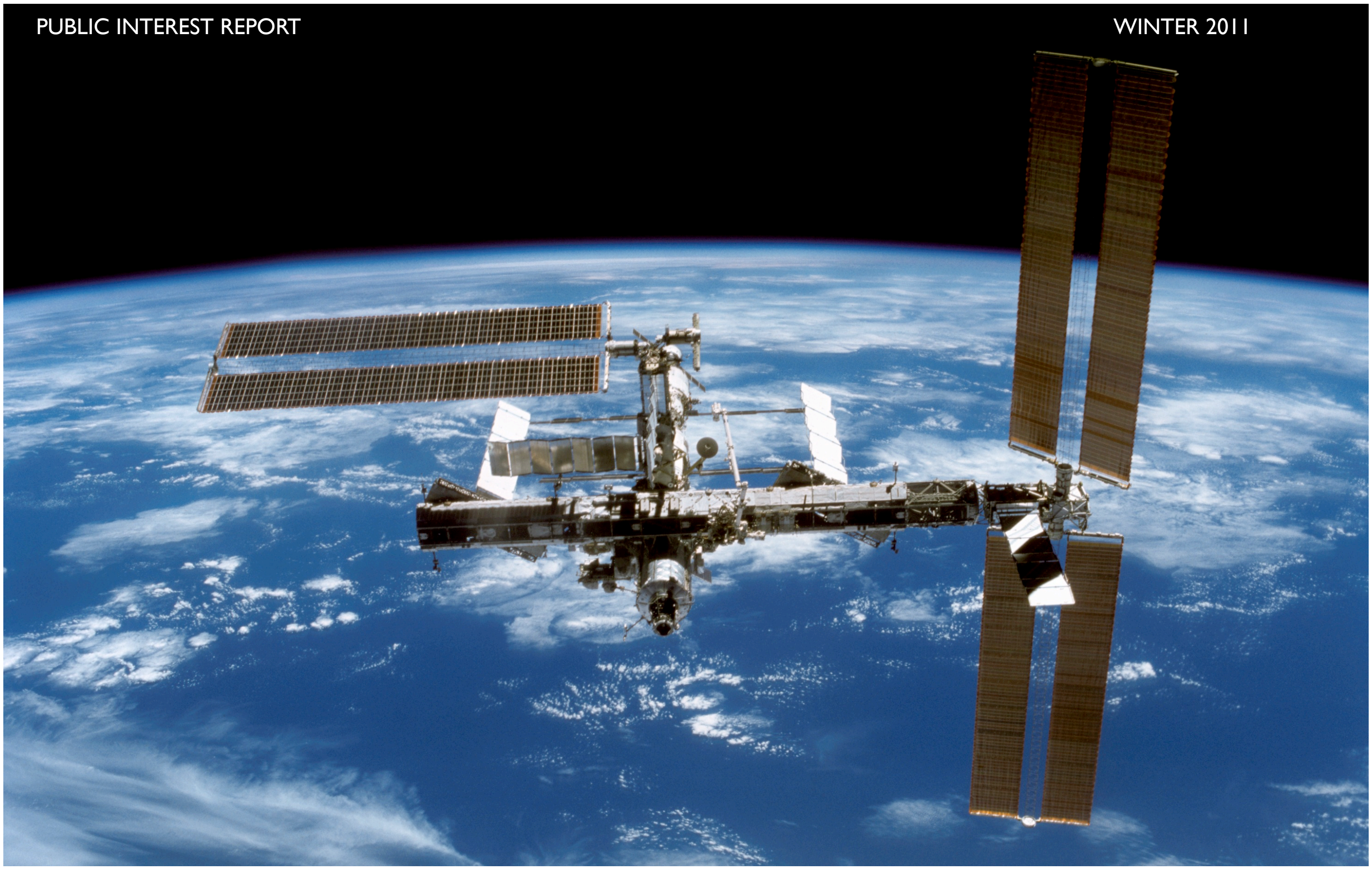

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[1] NASA Orbital Debris Quarterly News, July 2011.

[2] Most commercial and military satellites operate in one of two orbit planes. The first, low-Earth orbit (LEO), is between 160 and 2,000 meters (100-1,240 miles) above Earth's surface. The other, geostationary Earth orbit (GEO), is a circular orbit 35,786 kilometers (22,236 miles) above the equator.

[3] See: www.space-data.org.

[4] Statement of Major Duane Bird, USAF, US Strategic Command to *AMOS Conference*, September 2010.

[5] NASA's National Space Science Data Center.

[6] David Portree and Joseph Loftus. "Orbital Debris: A Chronology," NASA, 1999.

[7] See: http://www.iadc-online.org. The IADC member agencies include the following: ASI (Agenzia Spaziale Italiana), CNES (Centre National d'Etudes Spatiales), CNSA (China National Space Administration), CSA (Canadian Space Agency), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organisation), JAXA (Japan Aerospace Exploration Agency), NASA (National Aeronautics and Space Administration), NSAU (National Space Agency of Ukraine), ROSCOSMOS (Russian Federal Space Agency), UKSpace (UK Space Agency).

[8] Concept first presented in the seminal article by Garrett Hardin, "The Tragedy of the Commons," *Science*, Vol. 162, No. 3859 (December 13, 1968). The tragedy of the commons posits the situation where rational individuals, acting in their own self-interest, may ultimately render a shared and limited resource unusable, even when it is clearly not in their interest to do so.

Space Data Association

The Case for SSA Collaboration and Data Fusion

— BY RICHARD DAL BELLO

The SDA was formed by leading satellite owners and operators with the goal of increasing the safety and efficiency of their operations in space. To achieve this goal, the operator members need to receive *actionable* Space Situational Awareness (SSA), particularly in the areas of Conjunction Assessment (CA) and Radio Frequency Interference (RFI) mitigation.

The SDA's Space Data Center (SDC) comprises the only SSA analysis system incorporating truly-authoritative maneuver plans and RF data for 70percent of all active satellites in geostationary Earth orbit (GEO). Currently, SDA members share actual position information on 237 satellites in GEO, and another 110 in low Earth orbit (LEO). From the data provided thus far, the SDA has identified significant levels of data incompatibility in the orbit determination and analysis packages used in the space operations community, which includes radar/optical networks, satellite operators, and launch providers. The SDC has systematically addressed this issue by conducting extensive research, operator interchange and astrodynamics development to facilitate the technical "rectification" of operator data into compatible, shared reference frames.

The SDC also uses a combination of quarterly, independent orbit determination (OD) verifications and weekly comparisons against external radar and optical data to ensure the ongoing success of this rectification process. When discrepancies are detected, this diverse-comparison approach allows follow-on investigations to clarify whether operator data or radar and optical data are suspect.

Although computing CA is complex, the concept is actually very simple. Assuming one has precise and reliable data, answering the question, "When will these space objects get too close?" is not technically challenging. There are several reliable COTS software solutions for rapidly detecting such threats. The significant challenge is in making sure that inputs and outputs of the CA and RFI analyses are accurate enough to warrant operator confidence in the results so that managers can select and implement viable risk-mitigation strategies.

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Information provided to the SDA by satellite operators is augmented by data from the U.S. Joint Space Operations Center (JSpOC), which operates one of only a handful of global radar and optical sensor networks collecting satellite positioning data. In addition to tracking operational satellites, such networks are the only source for orbital debris information. The JSpOC data is comprised of analytic or "general perturbations" (GP) data (such as the ubiquitous two-line element set or TLE) and higher-fidelity "special perturbations" (SP) data. Using radar and optical sensor networks to track objects in space presents a host of unique technical and programmatic challenges. These include not accounting for routine maneuvers by satellite operators; limited sensor observations; difficulties acquiring satellites; "lost satellites"; conflicting mission priorities; track mis-association problems; lack of sensor scheduling; and sensor lighting constraints. These challenges are chiefly a reflection of the non-cooperative tracking (NCT) technology and not a reflection of NCT staff or tool capabilities.

Satellite operators feel uniquely qualified to generate authoritative satellite data for their space assets because they typically perform hourly transponder ranging sessions with their satellites; have well-calibrated maneuver times, magnitudes and directions; and often have dedicated assets for tracking their spacecraft. Independent analysis of the orbit solutions from satellite operator data has typically revealed very good performance. However, satellite operators face unique challenges as well, including initial difficulties sharing their data with other operators in a mutually-compatible and understandable format and a lack of data for space debris objects.

For an operator to take action based on SSA products, the analyses must be *predictive*, *timely, precise* (i.e., reproducible and convergent) and *accurate*.

It is fairly easy to assess whether a process is *predictive* and *timely*. For CA, space operators typically need a final and definitive assessment of collision risk approximately two days prior to the event. This lead time is sufficient for analyzing the conjunction; planning an avoidance maneuver; briefing the company's decision authority; getting the go-ahead to perform the avoidance maneuver; and executing the maneuver early enough to avoid wasting fuel (because the magnitude of the maneuver required to avoid a conjunction increases as the objects get closer together). Warnings that come with less than two days' notice are problematic because more drastic measures are required to avoid a threat.

To characterize *precision* and *accuracy* in the real world, SSA analysts have a responsibility to apply statistically-relevant, transparent and on-going evaluations of convergence, reproducibility and comparison with complementary data are required. A CA process which predicts satellite conjunction events well in advance and for which predictions of the conjunction vary little from the original prediction or from one another can be said to be *precise* (i.e., reproducible and convergent). Comparisons of SSA predictions with truth models and post-event, best-estimate trajectories can be used to assess SSA whether the prediction is *accurate*.

The SDA members have conducted many systematic studies of CA and RFI analysis convergence. SDA member orbits have been regularly and independently verified for consistency and accuracy. From these studies, the SDA has determined that SSA products are highly sensitive to input errors and process deficiencies.

Consider:

1. For optical sensors, up to 15percent of a satellite's observations are confused or "cross-tagged" with data from another satellite within the sensor's field-of-view, most commonly during the greatest collision threat intervals.[2]
2. By evaluating CA results for a variety of simulated collisions, analysts have determined that SSA based on radar and optical data that neglects satellite maneuvers can drastically underestimate collision risk – to the point of predicting a probability of collision of 1 chance in 10^{300} *(that's 300 zeroes)* for two objects that are in fact on a collision course. [3]
3. Government-led time-difference-of-arrival tests indicate a ten-fold improvement in positional accuracy when operator data is used instead of public data.[4]
4. Because telescopes perform best at night, GEO orbits derived from optical telescopes can experience accuracy degradations of up to 35 km in the daytime.[5]
5. The absence of a radar and optical sensor scheduling algorithm in JSpOC's Space Surveillance Network (SSN)[6] leads to undersampling, cross-tagging, and an inability to improve orbit accuracy.
6. For active satellites being maneuvered, the SDA has found that optical-sensor-derived orbits are usually a week late and can be more than 1,000 km behind operator data in reflecting maneuvers.

The failure of governments and commercial satellite operators to generate a collaborative and accurate SSA picture could result in a geosynchronous satellite collision with potentially dire consequences.[7] Yet there is a clear path for managing this risk, and that path is active collaboration and data fusion. Radar/optical networks and space operators both offer truly unique and complementary capabilities that, when fused together, offer substantially improved SSA. ■

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