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INSIDE...

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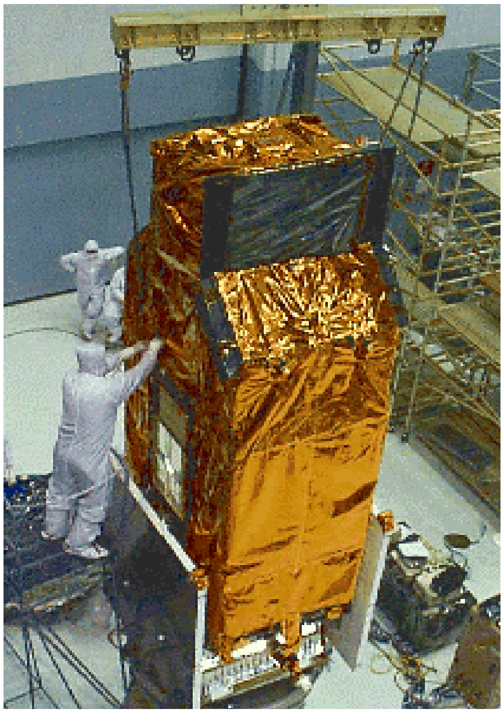
FUSE Satellite Releases Unexpected Debris

In early June 2004 NASA's Far Ultra-violet Spectroscopic Explorer (FUSE) spacecraft (International Designator 1999-035A, US Satellite Number 25791) was the source of nine debris large enough to be detected and tracked by the US Space Surveillance Network (SSN). The 1360-kg spacecraft was launched into a nearly circular orbit near 750 km on 24 June 1999 and continues to perform well. Early on 6 June 2004 FUSE temporarily entered a safe mode which resulted in the closure and re-opening of its four main sensor doors. Analyses by SSN personnel indicate that the new debris separated from FUSE at very low velocities about the time of the door closures.

A preliminary assessment suggests that the nine objects might be fragments of the multi-layer insulation which covers the majority of the spacecraft. The effects of long-term exposure to the space environment can lead to such insulation becoming brittle and susceptible to spacecraft movements or small particle impacts. If the new debris are pieces of insulation, then their orbital lifetimes might be considerably shorter than typical spacecraft, rocket bodies, and other debris at that altitude. Tracking data through the end of June supports this hypothesis. The investigation into this anomalous event is continuing. ♦



FUSE spacecraft being prepared for launch.

Publication of the 13th Edition of *History of On-Orbit Satellite Fragmentations*

The 13th edition of *History of On-Orbit Satellite Fragmentations*, JSC-62530, has recently been published. This document details the 173 known breakups and 43 anomalous events of on-orbit objects from the first known breakup in June 1961 through 31 December 2003. This edition of the document discusses low Earth orbit and geosynchronous orbit spatial density, in-orbit and decayed object analysis by country of origin, and a comprehensive categorization of breakups and debris by assessed cause, year, and parent object type. Several color graphs and tables are included to illustrate information related to these topics.

A significant update from the 12th edition was the re-categorization of events due to aerodynamic effects at or near the time of reentry. Because these "aerodynamic" events had no effect on the environment past the very near term, they are listed separately from events of other environmentally impacting causes.

Each fragmentation event is outlined in a two page format. The first page consists of information such as the physical characteristics and orbital parameters of the parent object prior to the breakup, breakup event epoch, altitude and location, and assessed cause. A general summary of the event can be found under the Comments heading. Reference documents on the subject breakup or on breakups of satellites of same type are listed for some events. The second page consists of a Gabbard diagram for the debris cloud (if sufficient orbit element data were available). Each anomalous event is described on one page, with basic information about the object and event. Gabbard diagrams are not included for anomalous events because of the typically low debris count.

The 13th edition is available for download in Adobe PDF format on the NASA Orbital Debris Program Office website, www.orbitaldebris.jsc.nasa.gov. The *History of On-Orbit Satellite Fragmentations* has been published regularly since 1984. ♦

NEWS

FCC Issues New Orbital Debris Mitigation Regulations

The Federal Communications Commission (FCC) adopted on 9 June 2004 an extensive new set of rules concerning the mitigation of orbital debris. The FCC issued a notice of Proposed Rulemaking in 2002 and subsequently received comments from industry on the proposed rules which covered the design, operation, and disposal of spacecraft subject to licensing from the FCC. The new rules closely follow the US Government Orbital Debris Mitigation Standard Practices, which were developed in 1997 and adopted in 2001. Applicants are encouraged, but not required, to use the NASA safety standard on orbital debris mitigation (NSS 1740.14) when assessing their debris mitigation plans and preparing those plans for submission to the FCC. The full FCC Report and Order can be found at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-130A1.doc.

In an effort to solicit more specific reentry risk information from license applicants, the Federal Communications Commission on 16 June 2004 issued a Public Notice (DA 04-1724, Report No. SPB-208) clarifying existing FCC regulations in this area. Applicants must first state whether the reentry will be controlled or uncontrolled. For the former case, applicants must identify the geographic region in which surviving components are expected to strike the Earth and measures to be taken to warn people who are likely to be in the geographic region during the time of reentry. For cases in which the reentry will be uncontrolled, the applicant must estimate the number, size, and mass of components which are expected to reach the Earth's surface and estimate the probability of human casualty from the surviving debris.

The FCC Public Notice suggests that applicants might find useful reentry risk assessment tools developed by the NASA Orbital Debris Program Office. Debris Assessment Software (DAS) permits a simple, conservative evaluation of reentry risk, is easy to use, and is available to the public via the NASA orbital debris website (www.orbitaldebris.jsc.nasa.gov). For a more detailed, high fidelity risk assessment, the Object Reentry Survival Assessment Tool (ORSAT) is available, although the complexity of this model requires operation by trained technical personnel. ♦

Annual Meeting of the IADC

The Inter-Agency Space Debris Coordination Committee (IADC) held its annual meeting at Abano Terme, Italy, during 19-22 April 2004. Delegations from 10 of the 11 IADC members were in attendance, representing the national space agencies of the United States, the Russian Federation, China, Japan, India, France, Germany, Italy, and the United Kingdom, as well as the European Space Agency. The IADC was established in 1993 to promote the exchange of technical information on orbital debris and to encourage its mitigation in the design and operation of space systems.

During the four-day meeting, dozens of presentations were given in the four permanent working groups to address issues concerning the measurement, modeling, and mitigation, through both technical and policy means, of orbital debris. One of the accomplishments of the meeting was the approval of the IADC Protection Manual which is devoted to the effects of hypervelocity impacts of small particles and which will soon be available on the IADC public website (www.iadc-online.org).

The IADC Steering Group was also very busy during the meeting, spending the majority of its time considering comments on the IADC Space Debris Mitigation Guidelines received from the Scientific and Technical Subcommittee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS). The IADC guidelines were formally presented to the STSC in February 2003 and discussion of the guidelines continued at the STSC meeting in February 2004, where several inquiries and suggestions for the IADC arose.

The next full meeting of the IADC will be held 21-22 April 2005 at the European Space Operations Center in Darmstadt, Germany, immediately after the Fourth European Conference on Space Debris at the same location during 18-20 April. ♦

PROJECT REVIEWS

A Debris Avoidance Feasibility Study for Robotic Satellites

J.L. FOSTER

Collision avoidance maneuvering is a means of mitigating risk from tracked Earth satellites, mainly orbital debris. Maneuvering, however, has associated costs and risks. An holistic approach to debris collision avoidance maneuvering is required for a safe, effective process. A debris collision avoidance feasibility study was recently conducted at Johnson Space Center. The orbital regimes studied included satellites at 400 km altitude with orbital inclinations between 35° and 55°, 550 km altitude near 57° inclination, and Sun synchronous orbits near 700 km altitude. The probability-based approach developed for the International Space Station (ISS) and the Space Shuttle was employed in this study.

Objects in low Earth orbits approximately 10 cm and larger in size are tracked by radar by the US Space Surveillance Network (SSN). From the tracking information, state vector and state vector covariances are determined for all tracked orbiting objects and conjunctions are predicted. Based on the conjunction predictions, debris avoidance maneuvers may be performed for a satellite of interest. From the debris flux experienced by a satellite and the distribution of debris covariances for conjuncting objects, risk reduction, fractional residual risk (FRR), and maneuver rate can be determined as a function of a chosen maneuver threshold collision probability that, in turn, determines a maneuver rate. Higher tasking improves the covariance estimate and lowers maneuver rate.

The flux of tracked objects is small compared with the flux of objects large enough that vehicle shielding is ineffective but too small to be tracked. With annual collision probabilities of between 10^{-4} and 10^{-7} for the relatively small robotic satellites and the risks inherent in any space maneuver, any decision to perform debris avoidance maneuvers for robotic satellites requires careful analysis and thought. Since there is a debris avoidance system in place to support the ISS and the Space Shuttle, the cost of setting up a debris avoidance process is not a major factor. However, there would be operational

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A Debris Avoidance Feasibility Study

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costs associated with increased monitoring of the satellite state vector and its overall situation. A high risk conjunction may require an increase in observations of the conjuncting debris object in order to improve the relative position uncertainty at the time of conjunction. For debris avoidance to be an effective strategy for robotic satellites, the orbit maintenance maneuver fuel budget must take care of most, if not all, debris avoidance maneuvers.

The debris flux for each altitude and inclination was determined using a current 2-line element set debris catalog and a computer code incorporating the Kessler flux model which assumes a uniform precession for every object in argument of perigee and right ascension of ascending node over the time of the flux determination. From measured covariance information on 63 objects near ISS altitude, an empirical expression was developed giving covariance as a function of orbital energy dissipation rate (EDR) or drag and tracks per day for 8- and 24-hour propagations from epoch. The average covariance for each conjuncting object, for an 8-hour and a 24-hour propagation from epoch, was estimated from average tracks per day determined from USAF Space Command's SATRAK program and the orbital drag on the object. Orbital drag is estimated by taking the difference in invariant semi-major axis between 2 element sets of the same object several weeks apart or from the time derivative of the mean motion, if 2 element sets are not available. For a given miss distance, the collision probability is the integral over the projected area of the space vehicle with the probability density function derived from the combined covariances of the target and debris objects for a given miss distance. A contour of constant collision probability is determined for each object for nine collision probabilities between 10^{-3} to 10^{-7} as a function of angle relative to the velocity vector of the target object. Figure 1 shows FRR for objects at 700 km altitude.

Significant risk reduction can be obtained at the expense of a small number of maneuvers. However, with relatively low risk without mitigation, the benefits of performing debris avoidance maneuvers must be carefully weighed. ♦

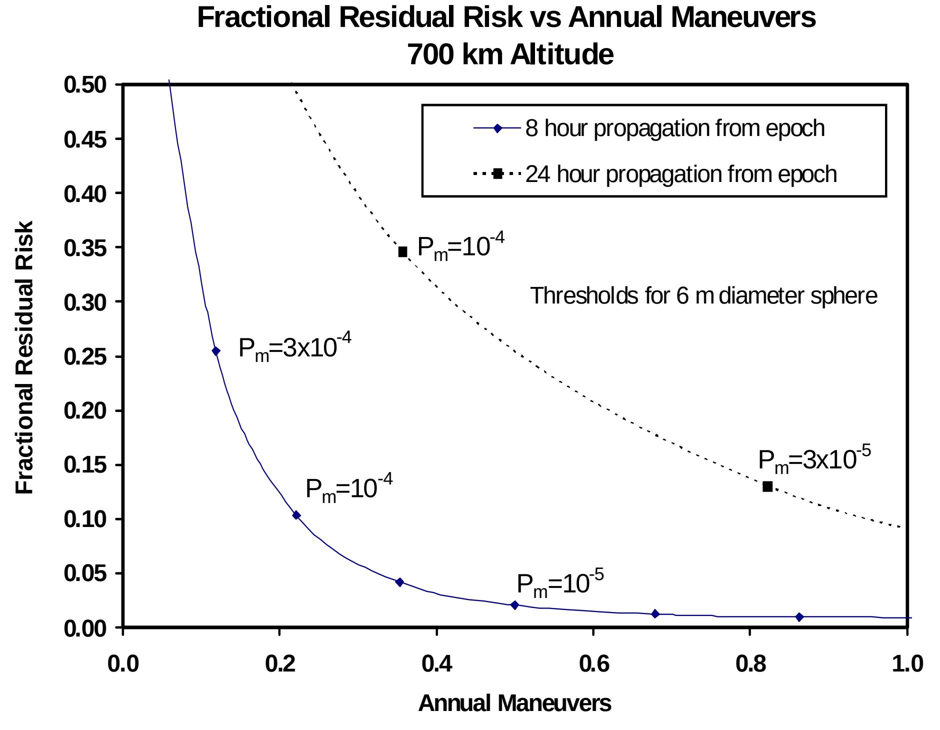

Figure 1. Fractional residual risk at 700 km, orbital inclination 98.2°.

PINDROP – An Acoustic Particle Impact Detector

R. CORSARO, F. GIOVANE, P. TSOU,
J.-C. LIOU, D. BUZASI, & B. GUSTAFSON

The first laboratory tests of a new prototype instrument have recently been successfully completed. This instrument detects a hypervelocity impact by a small particle, and locates the impact site using the propagation characteristics of the acoustic wave generated. The signal amplitude provides a measure of the impact energy. Other signal characteristics are expected to provide structural information about the composition of the impacting particles.

Called PINDROP (Particle Impact Noise - Detection and Ranging On Autonomous Platforms), this instrument is being developed under the NASA Planetary Instrument Definition and Development (PIDD) program. Its initial development is directed at instrumenting a conventional aerogel particle-capture array to characterize the near Earth meteoroid and orbital debris environment. The combination of aerogel array and acoustic sensor will potentially allow the composition and physical characteristics measured on captured particles to be represented, for the first time, as a sample of their possible parent body. Additional applications of PINDROP also include the remote assessment of dust fields in distant locations (i.e. comets) where collection and retrieval may not be practical.

The instrumentation under development is an acoustic sensor suite coupled with an autonomous data acquisition system (Figure 1). The sensor suite has been optimized to reject spurious signals and minimize the power requirements of the associated electronics. The acquisition system will record sufficient acoustic travel-time information to identify the impact cell location by sensor-triangulation. It will record the time of each impact occurrence, impact location, environmental data (i.e. temperature), and selected characteristics of the acoustic signal. The latter will be examined to assess the feasibility of additionally determining particle mass, speed, and physical makeup.

For trial design purposes we selected for our initial mission scenario a collection system currently under consideration for deployment in low Earth orbit. This system, the Large Area Dust Collector (LAD-C) is intended to expose 10 m^2 of aerogel for a one-year deployment on the International Space Station (ISS). LAD-C could provide a much needed, updated environment defintion for meteoroids and orbital debris between 100 µm and 1 mm—a size regime that is of interest to risk assessments for STS, EVA, and orbiting satellites. The NASA orbital debris engineering model ORDEM2000 indicates that for a port or starboard facing

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PINDROP

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orientation, about 100 impacts by debris larger than 0.1 mm are expected with a significant fraction of hits having impact speed less than 7 km/s – where impact residuals are better preserved in aerogel and impact physics is better understood.

A sensor was designed to detect impacts with particles having the above impact energy. The model used is an equivalent-network electrical noise model, and PVDF (poly-vanylidene fluoride) was selected as the active material. This is a commercially available piezoelectric polymer film, which generates a charge in response to sudden changes in strain. As designed, this sensor has high sensitivity, very low mass, flexible installation and uses a material that has demonstrated ability to survive orbital flight missions.

Laboratory tests have involved bonding a collection of sensor types on an aerogel-collection frame and impacting the frame in various locations. The frame was fabricated at the University of Florida and for this series of tests it was not populated with aerogel. Ten different PVDF sensors were applied. These included four configuration types (simple single-layer, symmetric, asymmetric, and dual-layer differential), three different film thicknesses (25, 51, and 102 µm) and two different widths (10 and 25 mm).

There were three principal results from this laboratory study. First, the preferred sensor candidate was identified as being the differential configuration fabricated with two layers of 102 µm film, 20 mm in width and length.

Second, the required characteristics of the associated preamplifier were identified. It should have a low noise spectrum from 30-200 kHz to permit adequate sensitivity to low-level signals, a gain of at least 40 dB to provide a robust signal to the subsequent on-board processor, a 30 kHz high-pass filter with at least a 20 dB/octave roll-off to reduce potential false-triggering from low-frequency signal and noise components, and a 150 kHz low-pass filter to reduce extraneous high-frequency noise. The final size should be less than 10 cm^2, to permit mounting it near the sensor to reduce cable capacitance and the possibility of stray electrical pickup. And it should achieve the above objectives with a power consumption no greater than 1.3 mW. This low-electrical power requirement is important since a typical system will be battery powered. Since the preamplifier is the only component that must be "on" at all times, its power requirements are expected to be the principal sink of the power budget. A preamplifier design meeting these unique requirements is being finalized at the US Air Force Academy.

Third, an acoustic propagation model has been developed that accurately predicts the signal arrival time at each sensor. This model can be inverted to locate the impact site using the relative time-of-arrival at three or more sensor locations. From studies of the response of sensors located at various positions on the frame, the leading edge of each signal arrival is typically identified to within 5 microseconds. This temporal resolution is satisfactory for our localization purposes. In the aluminum frame it corresponds to a location uncertainty of 2.5 cm, which is adequate to identify the cell and the region within the cell that is impacted.

Having demonstrated that the approach is technically viable and the sensitivity and resolution are adequate for its intended application, the next stage in the development has been initiated. This involves instrumenting the frame with the optimum sensor and preamplifier array, and additional testing with the cells fully populated with aerogel. These additional tests will use high-velocity impacting particles. The final task in this series is the development of an on-board Data Acquisition and Processing (DAP) module. The development and programming of this processor module has been initiated, and a trial unit will be evaluated during the next round of testing in late 2004. ♦

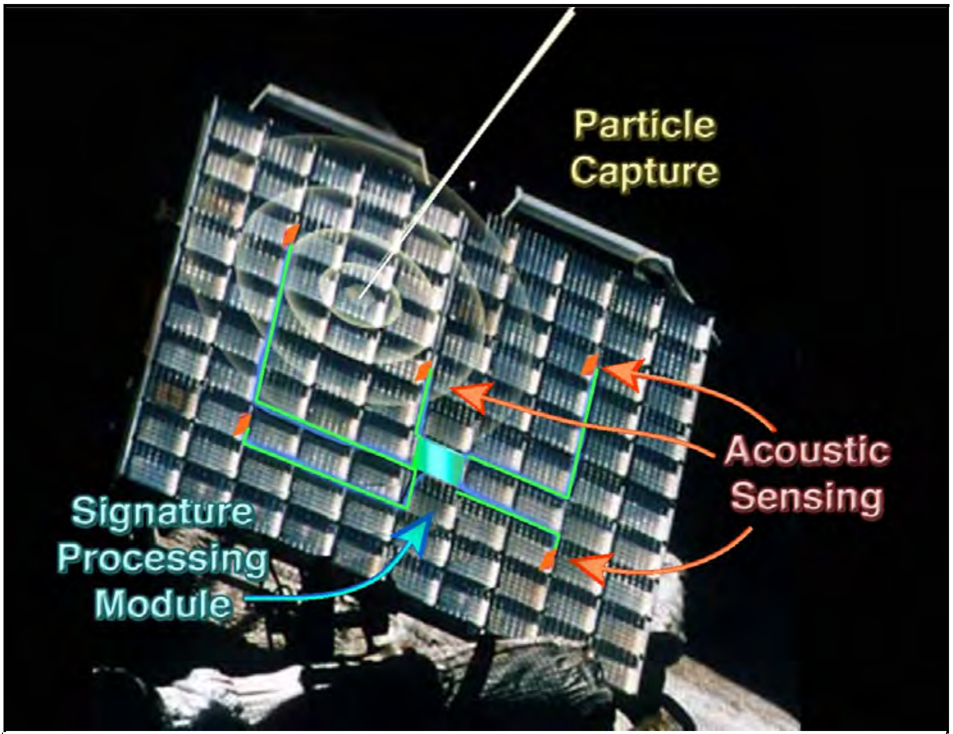

Figure 1. PINDROP system concept shown on conventional aerogel particle-capture array.

Utilizing the Ultra-Sensitive Goldstone Radar for Orbital Debris Measurements

C. STOKELY

Among the limited set of radars available to NASA to assess the small orbital debris environment, the Goldstone facility located in southern California's Mojave Desert is a unique and complementary system to the Haystack and HAX radar systems located in Massachusetts. Two Goldstone antennas comprise an extremely sensitive bistatic radar system capable of efficiently detecting orbital debris as small as 2 mm at 1000 km range. The data that the Goldstone radar can provide is important to the development of more accurate orbital debris models such as ORDEM2000.

Located at 32.24º north latitude, the two antennas comprising the Goldstone bistatic radar system consist of a 70 m transmitter dish separated 497 m from a 35 m receiver dish. Figure 1 shows these two dishes with the transmitter in the foreground and the receiver in the background. The wavelength is 3.5 cm and the average transmitted power is 460 kW. The dishes are setup in a near vertical staring mode to statistically sample the orbital debris environment. The transmitter dish points 1.5º from the zenith and the receiver dish points 1.441º from the zenith. Dish pointing configurations far from the zenith are possible but have not been utilized. Both dishes point in the same direction along their line of centers 154.6º azimuth from north. The system unfortunately does not have a monopulse capability that could be used to determine where the debris passes relative to the center of the beam. This leads to inherent uncertainties of radar cross section (RCS) measurements and does not allow accurate estimations of orbital parameters such as inclination and eccentricity. Nevertheless, the Goldstone radar can provide valuable data for size, radial speed, and altitude that can be incorporated into various orbital debris models.

The presence of two dishes produces a complicated power gain beam pattern that must be characterized in order to accurately interpret radar measurements. The power gain pattern determines the beamwidth, which is directly used for orbital debris flux calculations. The power gain beam pattern is effectively an interference pattern between the transmitter beam and the receiver (reciprocal) beam. For the given pointing direction, the power gain pattern is approximately Gaussian shaped in a horizontal plane above the Earth. The amplitude and width of this Gaussian shape is a sensitive function of height. In previous publications, the 3 dB beamwidth was assumed to be that of the transmitter beam with angular divergence $\Delta\theta = 0.030º$. Based on a detailed analysis of the resultant complicated beam pattern, the actual 3 dB beamwidth is only approximately a quadratic function of the height with an average angular divergence of $\Delta\theta = 0.021º$. However, the peak-to-null beamwidth is more appropriate than the 3 dB beamwidth for flux calculations because there is no monopulse capability with this radar, and hence the object position within the beam cannot be determined. The peak-to-null beamwidth is approximately twice the 3 dB beamwidth. Therefore, the peak-to-null area of the actual beam is larger than the 3 dB transmitter beam despite the smaller angular divergence of the actual beam. Using the peak-to-null area, the flux will be slightly lower than the flux calculated using the 3 dB transmitter beam area.

In 1998, approximately 146 hours of data with 3070 debris measurements were collected from 22 February to 4 October. Approximately 1 detection was measured every 3 minutes. The data is highly processed at the Goldstone complex before being obtained by the Orbital Debris Program Office at the Johnson Space Center. During the data reduction at the Goldstone radar complex, generally 1% to 5% of the data is discarded because these data are believed to be sidelobe events. Some of this discarded data may have been removed from the belief that they were small objects passing through a sidelobe instead of large objects passing through the center of the beam. Additionally, because of hardware limitations in the signal processing, many of the debris greater than 1 cm size are not measurable.

The sizes are derived from the radar cross section measurements using the standard NASA Size Estimation Model[1]. However, since only the principal polarization is measured, the RCS does not incorporate an orthogonal polarization measurement. The measured RCS value is therefore smaller than the true RCS value.

Shown in Figure 2 is the flux versus altitude distribution of debris objects larger than 5 mm. A prominent peak in the flux is located at 900 km. This peak has generally been attributed to NaK droplets leaked from RORSAT satellites[2, 3, 4]. The data is separated into 50 km height bins. The area used in the flux calculation is the surface area of the side of a cone (conic frustrum) defined by the peak-to-null beamwidth with cone height 50 km. Shown in red is the flux calculated using the 3 dB width of the transmitter beam. This flux is larger since a smaller area was used in its calculation.

Radar measurements are crucial for assessing and understanding the orbital debris environment, and are vital for modeling and simulation efforts to better under-

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Figure 1. The Goldstone radar transmitter dish (foreground) and receiver dish (background). In this photo, the antennas are not pointed for orbital debris data taking.

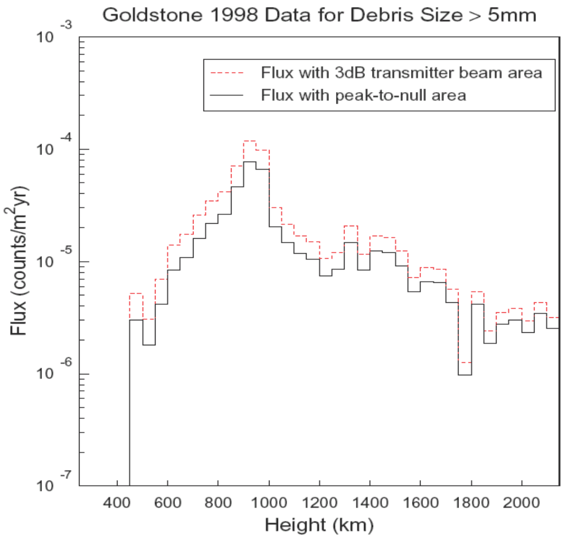

Figure 2. Goldstone radar 1998 data of the annual conical surface area flux versus height. In the black histogram, the flux is calculated using the peak-to-null beamwidth of the overlap of the transmitter beam and the reciprocal receiver beam. In the red histogram, the flux is calculated using the 3 dB beamwidth of the transmitter.

Utilizing the Ultra-Sensitive Goldstone Radar

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stand the long-term and short-term evolution of this environment. The Goldstone radar is an important tool for meeting some of these data needs for orbital debris assessment and mitigation studies.

1. Bohannon, G.E. *Comparisons of Orbital Debris Size Estimation Methods Based on Radar Data*. XonTech Inc. Contractor Report No. 920123-EB-2048, February, 1992.

2. Kessler, D.J., et al. *The Search for a Previously Unknown Source of Orbital Debris: The Possibility of a Coolant Leak in Radar Ocean Reconnaissance Satellites*. NASA Report, JSC-27737, LMSMSS32426.

3. Matney, M.J., and D.J. Kessler. *Observations of RORSAT Debris Using the Haystack Radar*. Space Forum, 1, pp 109-117 (1996).

4. Stansbery, G., M. Matney, T. Settecerri, and A. Bade. *Debris Families Observed by the Haystack Orbital Debris Radar*. Acta Astronautica, 41, 1, pp 53-56 (1997). ♦

Orbital Evolution of GEO Debris with Very High Area-to-Mass Ratios

J.-C. LIOU & J.K. WEAVER

Recent observations by the European Space Agency's (ESA) 1 m telescope on Tenerife (Canary Islands) have identified a new debris population near the geosynchronous orbit (GEO) region[1]. These faint (18th to 19th magnitude), uncataloged objects have mean motions near 1 rev/day and orbital eccentricities as high as 0.55. The combination of the 24-hour orbital period and high eccentricity is certainly a surprise to the orbital debris community. However, a simple explanation may solve this puzzle. These may be debris with very high area-to-mass (A/M) ratios.

To test this high A/M hypothesis, we performed a series of numerical simulations on debris with A/M's ranging from 0.1 m^2/kg to 35 m^2/kg. The initial mean motions, eccentricities, and inclinations were chosen from 0.998 to 1.01 rev/day, 0.001 to 0.01, and 0.1° to 1°, respectively. Two programs were used to propagate the orbits: SPCM and PROP3D. SPCM is a high fidelity orbit integrator based on Encke's method. Perturbations included in the GEO simulations were solar/lunar gravitational perturbations, geopotential Goddard Earth Model (GEM) 7x7, solar radiation pressure, Earth's shadow effects, and the reflection of solar radiation from the Earth's surface. A time step of 20 minutes was used in the integration. The reflection coefficient was set to 1.25. PROP3D is a fast orbit propagator based on the averaging principle. Perturbations included in the GEO simulations were low order solar/lunar gravitational perturbations, geopotential J_2, J_3, J_4, solar radiation pressure, and Earth's shadow effects. The propagation time step was set to

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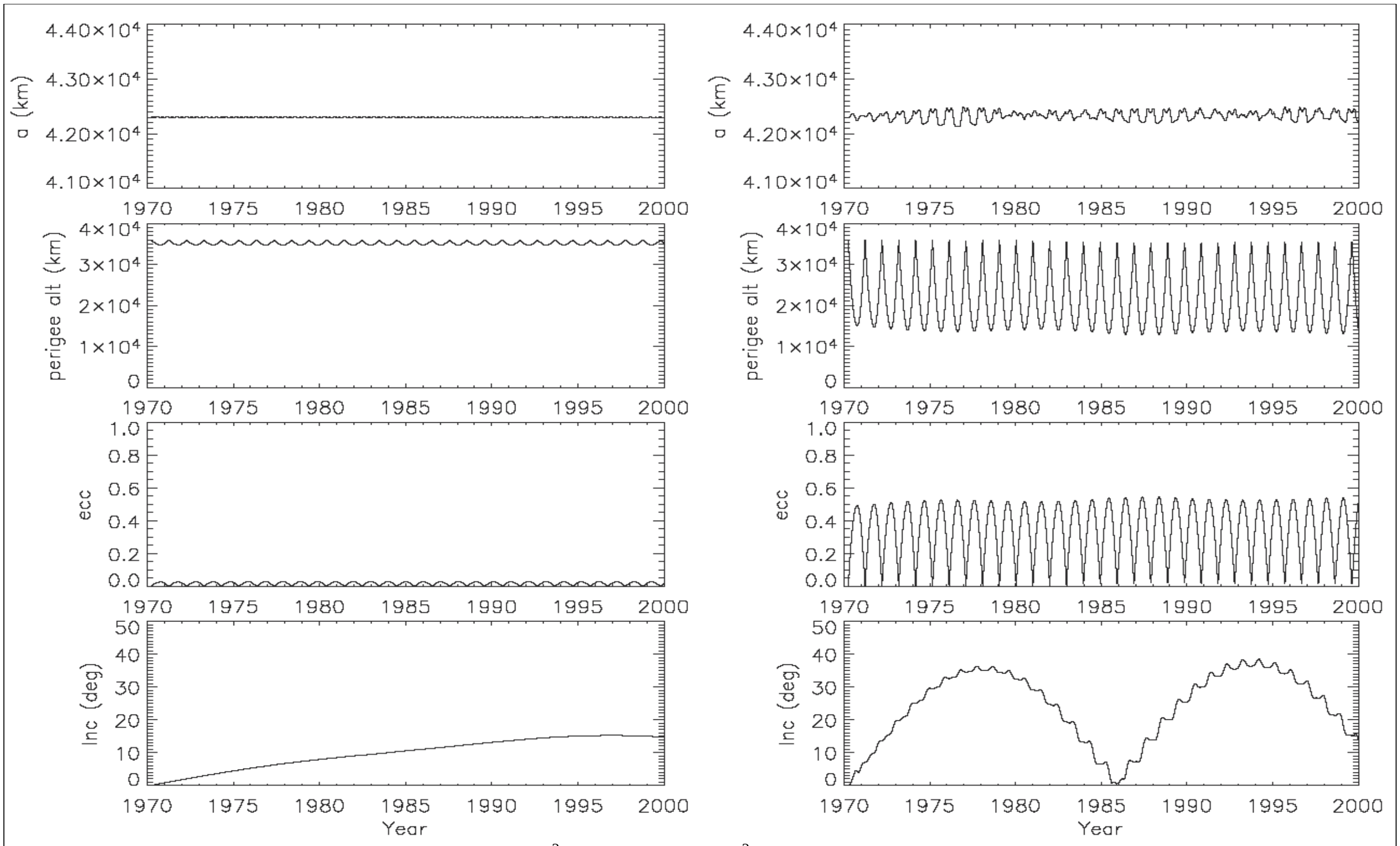

Figure 1. Orbital histories of two GEO objects with 1 m^2/kg (left) and 20 m^2/kg (right), respectively. The dramatic differences between the two were caused by the solar radiation pressure perturbation, which increased with increasing A/M. Note the variations might not be smooth due to the complexity of the object entering and leaving the Earth's shadow.

Orbital Evolution of GEO Debris

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one day.

Although there were minor discrepancies between the SPCM and PROP3D results, PROP3D was able to capture the major orbital characteristics predicted by SPCM. The similarity between the two model predictions indicates the orbital evolution of a high A/M object in GEO is dominated by major perturbations, not the high-order perturbations ignored by the algorithm in PROP3D. Figure 1 shows the orbital elements as functions of time, based on SPCM integration, for two objects with A/M values of 1 m^2/kg (left) and 20 m^2/kg (right), respectively. The former behaved just like a typical GEO object where its eccentricity remained small and its inclination varied slowly up to 15°. On the other hand, the orbital eccentricity of the latter went through a periodic variation with a peak value of about 0.55 and with a variation period of one year. Its inclination went up to about 40° with a period of more than 15 years. The peak eccentricity value an object could achieve increased with its A/M ratio. For example, the maximum eccentricities for 1 m^2/kg, 10 m^2/kg, 20 m^2/kg, and 30 m^2/kg objects were approximately 0.03, 0.3, 0.55, and 0.7, respectively.

The cause of the dramatic eccentricity variation is the solar radiation pressure perturbation. It is well known that such a perturbation causes yearly periodic variations to an object's semimajor axis and eccentricity; and the effects increase with increasing A/M value[2]. These are well illustrated by the direct numerical integration results shown in Figure 1. To verify the high A/M hypothesis for the GEO objects discovered by ESA, one could track the same object over time, from several months up to a year, to see whether or not its eccentricity follows a yearly variation. In addition, light curve observations may also shed some light on the nature/shape of these objects.

Is it possible to have a population of debris with A/M as high as 20 m^2/kg that would match the maximum eccentricity of 0.55? The surfaces of many satellites are covered with thermal blankets, or Multi-Layer Insulation (MLI, see also the picture and article on FUSE, page 1). MLI often consists of layers of thin aluminized Mylar®, Kapton®, or Nomex®. Typical areal density will give the corresponding A/M's of the layers varying from below 10 m^2/kg to more than 20 m^2/kg. Therefore, it is conceivable that surface degradation, impacts by small meteoroids, or explosions of GEO satellites have led to a population of MLI pieces in GEO. This might be the population that was discovered by ESA.

The existence of a highly eccentric GEO population may have important implications for the environment. Although they spend less time in the GEO traffic zone (35,586 to 35,986 km altitude), their encounter speed with a GEO operational satellite should be higher than that between two typical GEO objects. Whether or not this population poses significant collision risks to operational satellites in GEO needs to be analyzed carefully.

A high A/M (and hence highly eccentric) GEO population also leads to other observable characteristics. For example, the angular motions (hour angle rate versus declination rate) of this population will be scattered, rather than concentrated near the zero hour angle rate, as those recently observed by the NASA Michigan Orbital Debris Survey Telescope (MODEST)[3].

1. Schildknecht, T. *et al. The ESA Survey for Space Debris in GEO and Highly Elliptical Orbits*. 22nd IADC WG1 presentation, 2004.

2. Vallado, D.A. *Fundamentals of Astrodynamics and Applications*, 2nd Ed, Kluwer Academic Pub., 2001.

3. Seitzer, P. *et al. Results from the GEO Debris Survey with MODEST*, ODQN Vol. 8, Issue 1, 2004. ◆

UPCOMING MEETINGS

18-25 July 2004: 35th Scientific Assembly COSPAR 2004, Paris, France.

Space Debris Sessions are planned for the Assembly. These will address the following issues: advanced techniques to measure debris populations, latest modeling results, hypervelocity impact tests, debris shielding, mitigation guidelines, and other related topics. More information on the conference can be found at: http://www.copernicus.org/COSPAR/COSPAR.html.

16-21 August 2004: Meteoroids 2004, Ontario, Canada.

A broad range of meteoroid research topics, including observations, dynamics, chemistry, sources, and distribution of meteoroids in the near Earth environment and in interplanetary space will be discussed during the 5-day conference. More information can be found at: http://aquarid.physics.uwo.ca/meteoroids2004.

13-18 September 2004: Air Force Maui Optical and Supercomputing (AMOS) Technical meeting, Wailea, Maui, Hawaii, USA.

This meeting is recognized internationally as a major annual meeting for the optical, computing, and space surveillance communities. It is intended for scientists, engineers, and technical managers from academia, industry, government, and military programs. Topics include: Adaptive Optics, Astronomy, Atmospherics, High Performance Computing Applications in Astronomy, Imaging, Theory, Algorithms, and Performance Prediction, Laser Propagation and Laser Radar, Non-Resolved, Object Characterization, Orbital Debris, Orbital Prediction, Satellite Modeling, Small or Autonomous Telescope Systems, and Space Situational Awareness. For more information, visit http://www.maui.afmc.af.mil/conferences.html

4-8 October 2004: The 55th International Astronautical Congress, Vancouver, Canada.

A "Space Debris and Space Traffic Management Symposium" is planned for the congress. The Symposium will include five sessions covering space surveillance, debris measurements, modeling, risk analysis, hypervelocity tests, mitigation practices, and traffic management. More information can be found at: http://www.iac2004.ca/intro_no.html.

MITIGATION COLUMN

Mitigating Orbital Debris via Space Vehicle Disposals

Several US space missions have recently demonstrated their commitment to curtailing the growth of the orbital debris environment by following vehicle disposal recommendations set forth in NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris*, and in the US Government Orbital Debris Mitigation Standard Practices. The principal goals are to prevent debris generation by explosions and collisions. The former can be achieved by passivating the vehicle, i.e., depleting sources of stored energy, while the latter can be satisfied by removing the vehicle from highly congested regions of space.

NASA's Gravity Probe B mission began on 20 April 2004 with the launch of the spacecraft into an operational orbit near 640 km altitude. Following release of the spacecraft, the second stage of the Delta 2 launch vehicle (International Designator 2004-014B, US Satellite Number 28231) performed a maneuver to eliminate residual propellants and pressurants and to reduce dramatically the orbital lifetime of the stage. By lowering the stage's perigee to approximately 185 km, operators were able to limit the stay of the stage in Earth orbit from decades to only five weeks. Reentry of the Delta 2 second stage occurred uneventfully over a broad ocean area on 27 May 2004.

The NOAA 11 meteorological spacecraft (International Designator 1988-089A, US Satellite Number 19531), orbiting the Earth at an altitude of approximately 840 km, completed nearly 16 years of service on 16 June 2004. Decommissioning procedures included disconnecting the battery charge and discharge paths to prevent an accidental battery overcharge and subsequent explosion. Since NOAA 11 was designed and launched in the 1980's, prior to the establishment of formal orbital debris mitigation guidelines, the spacecraft was unable to maneuver into a shorter-lived disposal orbit. The next generation of polar-orbiting environmental spacecraft (POES) will have the capability for end-of-mission maneuvers which will significantly reduce their time in Earth orbit and the chances of actual collisions with other resident space objects.

For spacecraft in high altitude geosynchronous orbits (GEO), the recommended disposal strategy is to maneuver the satellite into a storage orbit above GEO where it cannot interfere with operational spacecraft. NASA and other US Government agencies currently recommend placing retired spacecraft into an orbit at least 300 km above GEO, in accordance with a 1993 recommendation of the International Telecommunication Union (ITU). In 1997 the Inter-Agency Space Debris Coordination Committee (IADC) proposed a formula for determining the minimum initial perigee for the storage orbit, based upon spacecraft characteristics, to prevent future gravitational and solar radiation pressure perturbations causing the spacecraft later to come within 200 km of GEO. The ITU, NASA, and other US Government agencies are considering or in the process of adopting the IADC GEO disposal recommendation.

During 5-6 May 2004 the 10-year-old GEOS 8 spacecraft (International Designator 1994-022A, US Satellite Number 23051) reached the end of its useful life and was maneuvered into a disposal orbit of approximately 375 km by 400 km above GEO, satisfying all current US and international recommendations. The three maneuvers employed also consumed all remaining propellant in the spacecraft to prevent a later accidental explosion.

Two US commercial GEO communications spacecraft were retired during the first six months of 2004, and both were maneuvered into storage orbits more than 300 km above GEO. The first was the GSTAR 4 spacecraft (International Designator 1990-100B, US Satellite Number 20946). During the period 29 January – 2 February, the spacecraft conducted a series of maneuvers to place it in a nearly circular orbit about 315 km above GEO. In March the PAS 6 spacecraft (International Designator 1997-040A, US Satellite Number 24891) was decommissioned prematurely due to power system difficulties. Since the spacecraft still contained a significant amount of propellant, the vehicle was placed into a moderately elliptical orbit with a perigee of about 450 km above GEO.

Finally, NASA's Advanced Communications Technology Satellite (ACTS) (International Designator 1993-058B, US Satellite Number 22796) was decommissioned on 28 April after more than 10 years of service. Unfortunately, a 1998 reassessment of propellant reserves revealed a much lower amount than expected, rendering the spacecraft incapable of performing a planned disposal maneuver. In August 2000 ACTS was moved to the stable point near 105^{o} West to ensure that it would not drift around the GEO ring after termination and become a collision hazard.

The events cited above clearly indicate the commitment of the US Government and a growing number of commercial operators to prevent the generation of unnecessary orbital debris by properly disposing of spacecraft and launch vehicle orbital stages at the end of their useful lives. Many other countries and international organizations are following similar procedures to preserve the near-Earth environment for future generations. ♦

Publication of the NASA Orbital Debris Informational CD

An informational CD, *Orbital Debris at NASA Johnson Space Center 2004*, has recently been produced for distribution within NASA, other US Government agencies, industry, and to the international community. The CD contains data from the NASA Orbital Debris Program Office website plus additional information. The major topics on the CD are Orbital Debris Graphics and Animations, Frequently Asked Questions about Orbital Debris, Reference Documents, Modeling, which includes the NASA engineering and evolutionary models, Measurements, Mitigation, Reentry, all issues of the *Orbital Debris Quarterly News*, Research Papers and Photo Gallery. Special features include automatic startup when the CD is inserted into the CD-ROM drive, downloadable software, photographs and graphics that provide a visual insight into the depth of orbital debris research, and orbital debris animations from the 1998 videotape *Orbital Debris Animation*. ♦

INTERNATIONAL SPACE MISSIONS

April—June 2004

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2004-011A	SUPERBIRD 6	JAPAN	35784	35791	0.0	1	0
2004-012A	TANSUO 1	CHINA	597	617	97.7	1	7
2004-012B	NAXING 1	CHINA	598	617	97.7		
2004-013A	SOYUZ-TMA 4	RUSSIA	357	364	51.6	1	0
2004-014A	GP-B	USA	642	645	90.0	1	0
2004-015A	EXPRESS AM-11	RUSSIA	35783	35790	0.0	2	3
2004-016A	DIRECTV 7S	USA	35786	35788	0.0	1	0
2004-017A	AMC-11 (GE-11)	USA	35782	35791	0.0	1	0
2004-018A	ROCSAT 2	TAIWAN	890	892	99.1	1	0
2004-019A	PROGRESS-M 49	RUSSIA	357	364	51.6	1	0
2004-020A	COSMOS 2405	RUSSIA	404	418	65.0	1	0
2004-021A	COSMOS 2406	RUSSIA	847	865	71.0	1	4
2004-022A	INTELSAT 10-02	INTELSAT	EN ROUTE TO GEO			1	1
2004-023A	NAVSTAR 55 (USA 178)	USA	20108	20360	55.0	2	0
2004-024A	APSTAR 5 (TELSTAR 18)	USA	EN ROUTE TO GEO			1	0
2004-025A	LATINSAT D	ARGENTINA	685	712	98.3	2	1
2004-025C	DEMETER	FRANCE	697	722	98.3		
2004-025D	SAUDICOMSAT 1	SAUDI ARABIA	699	750	98.3		
2004-025E	SAUDICOMSAT 2	SAUDI ARABIA	699	782	98.3		
2004-025F	SAUDISAT 2	SAUDI ARABIA	699	735	98.3		
2004-025G	LATINSAT C	ARGENTINA	699	766	98.3		
2004-025H	UNISAT 3	ITALY	696	797	98.3		
2004-025K	AMSAT-ECHO	USA	697	817	98.3		

ORBITAL BOX SCORE

(as of 30 JUNE 2004, as catalogued by US SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	39	285	324
CIS	1357	2632	3989
ESA	35	26	61
FRANCE	34	289	323
INDIA	27	102	129
JAPAN	83	51	134
US	995	2859	3854
OTHER	327	7	334
TOTAL	2897	6251	9148

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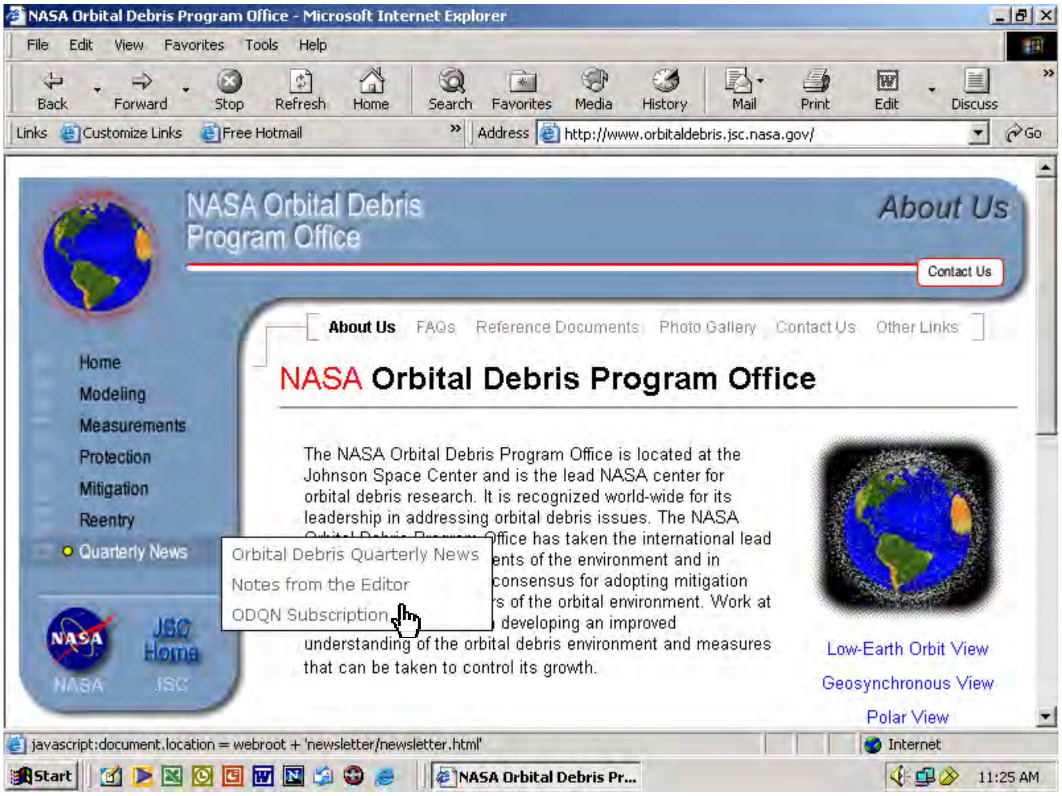

NASA Orbital Debris Program Office

The NASA Orbital Debris Program Office is located at the
Johnson Space Center and is the lead NASA center for
orbital debris research. It is recognized world-wide for its
leadership in addressing orbital debris issues. The NASA
Orbital Debris Program Office has taken the international lead
ents of the environment and in
consensus for adopting mitigation
s of the orbital environment. Work at
developing an improved
understanding of the orbital debris environment and measures
that can be taken to control its growth.

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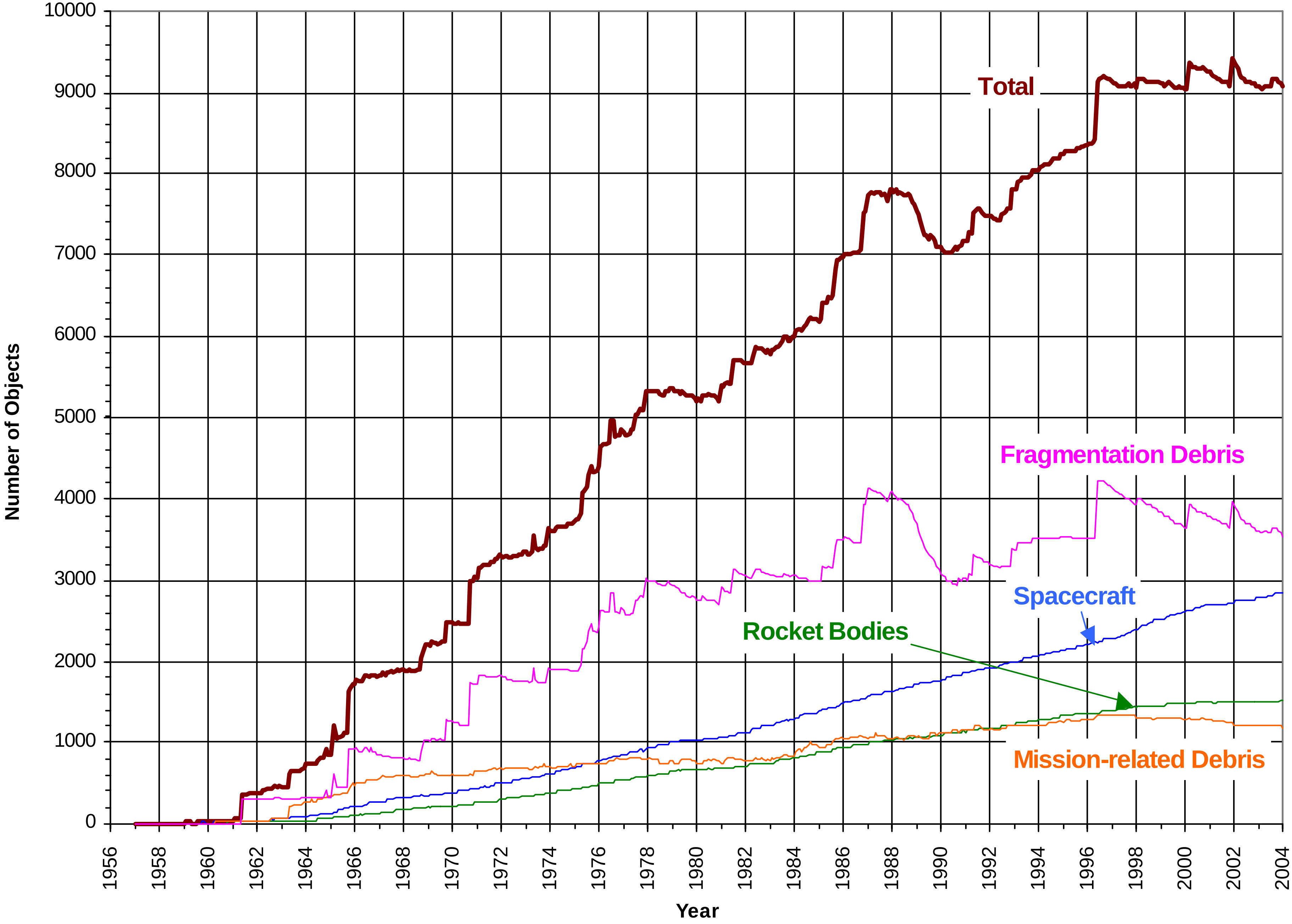

Monthly Number of Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the US Space Surveillance Network. Note that the number of tracked but uncataloged objects 10 cm and larger has risen more than 1300 since 1996 due to changes in the cataloging process. "Fragmentation debris" includes satellite breakup debris and anomalous event debris while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.