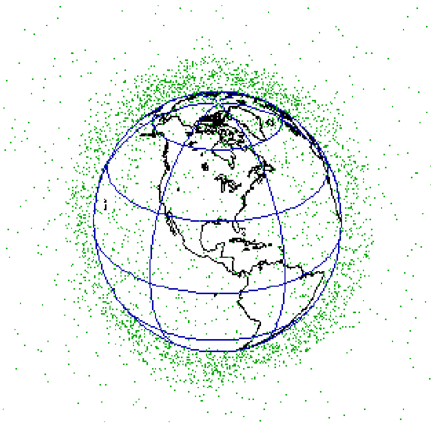
# The Orbital Debris Quarterly News



*A publication of*

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**July - September 1997** **Volume 2, Issue 3**

# NEWS

## Shield Study for Manned Mars Vehicle

JSC is currently evaluating the feasibility of a manned mission to Mars. The Mars Trans Hab (MTH) Design Study Team was formed in March 1997 to develop design concepts for a manned Mars transportation system. The study team proposes that the MTH spacecraft can be initially launched into orbit during an STS mission, following construction of the International Space Station (ISS). The MTH would transfer from low Earth orbit into a high Earth orbit, after which the MTH crew would ferry from the ISS to the MTH via an X-38 vehicle prior to beginning the 200-day trip to a Martian orbit.

The design team's fundamental structural design is based upon a cylindrical Central Structural Core (CSC). An airlock, consisting of a cylindrical structural shell and hatch, is affixed to one end of the CSC. Enveloping the core is an inflatable shell which serves several functions, including shell stiffness and thermal insulation, as well as meteoroid and orbital debris (MOD) protection. The MTH shell features a deployable multi-shock shield consisting of 3 Nextel AF-10 bumpers, each separated by a 10 cm standoff, using low-weight, open-cell foam as the support structure. The rear wall consists of five layers of Kevlar fabric (style 710). The foam is initially compressed for launch into a package approximately 5 cm thick. After achieving orbit, the foam is allowed to expand to its full 30 cm standoff. The pressure bladder is located behind the Kevlar wall. As assessment of the shell's ability to withstand the MOD environment is summarized in the recent report, Mars Trans Hab Meteoroid and Orbital Debris Shield Performance Assessment, Glen Shortliffe and Eric Christiansen, JSC 27892, June, 1997.

A total of seven hypervelocity impact (HVI) experiments were performed to assess the response of the Mars Module Shielding (MMS) concepts. The baseline MMS was capable of withstanding projectile impacts of aluminum spheres measuring up to 6.35 mm in diameter, each traveling about 6.5 km/s and impacting normal to the target.

Further research was performed to investigate the effect of the heavy RTV adhesive used to bond the layers of the MMS together. In two separate experiments, the RTV was omitted from the target configuration. In both cases, it was observed that a 4.76 mm projectile was sufficient to fail the modified MMS shield. Clearly, the RTV layers improved the HVI performance of the shield. Because the RTV is not considered to be part of the overall shield design, further HVI testing is warranted using targets more closely approximating flight hardware, without the RTV coatings.

The cored foam layers used in five of the MMS experiments are believed to have contributed a net shielding benefit by the fact that they fully support the Nextel layers. They also appear to mitigate lateral expansion of the debris cloud which results in smaller entry holes and reduced tearing within the Nextel layers. For this reason, the shielding properties of cored foam "lightening holes", used as a Nextel support mechanism and as a debris cloud mitigation material, should be further investigated.

The probability of no penetration (PNP) for the Mars module was estimated to be ~98% over the entire mission. This PNP does not reflect the MOD threat to the MTH propulsion system or the airlock. The mission parameters and shield ballistic limits must be further refined to assess the integrated PNP for the whole spacecraft.

The Orbital Debris Quarterly News

## Inside...

# NEWS, Continued

## Three Satellite Breakups During May-June

The second quarter of 1997 witnessed three satellite breakups: two in LEO and one in HEO. Two of the events generated more than 70 detectable debris each and were associated with satellite types known for such behavior. The first event occurred about 22 May when an auxiliary motor used by the Ekran 17 mission brokeup in an orbit of approximately 310 km by 22,975 km with an inclination of 46.6 deg. The object (Sat. No. 18719, International Designator 1987-109E) had a reported dry mass of 55 kg and produced at least 72 detectable debris. This was the 15th breakup of a Proton Block DM auxiliary motor since 1984. These motors are separated from the Block DM stage at the start of the final ignition of the stage and are left in the transfer orbit.

A collision between the Mir space station (Sat. No. 16609, 1986-017A) and the Progress M-34 spacecraft (Sat. No. 24757, 1997-014A) on 25 June was widely reported due to the serious damage inflicted and the threat to the safety of the Mir crew. A visual inspection of the Spektr solar array, which was struck, revealed a hole which undoubtedly led to the creation of a limited number of orbital debris. A new debris piece was detected by the US Space Surveillance Network and cataloged as Sat. No. 24845, 1986-017MB. It is unknown whether this fragment came from the Spektr module or the Progress M-34 spacecraft.

The third breakup event of the quarter was the most serious, but the consequences were short-lived. Kosmos 2313 (Sat. No. 23596, International Designator 1995-028A) fragmented on 26 June at an altitude of 285 km in an orbit of approximately 210 km by 325 km with an inclination of 65 deg. The spacecraft had performed an end-of-life maneuver during 22-23 April 1997 and was in a state of natural orbital decay. At least 90 debris were detected in LEO after the event, but few remained by 30 June. Debris from the 3000 kg spacecraft were thrown into orbits with apogees as high as 760 km and were ejected in an asymmetric manner seen after other breakups of this satellite class. Visual observations of Kosmos 2313 by Paul Maley

*(Continued on page 9)*

### INTERNATIONAL SPACE MISSIONS, APRIL - JUNE 1997

| International Designator | Payloads | Country/ Organization | Perigee (KM) | Apogee (KM) | Inclination (DEG) | Earth Orbital Rocket Bodies | Other Cataloged Debris |
|---|---|---|---|---|---|---|---|
| 1997-12A | DMSP -2-9 (F 14) | USA | 843 | 854 | 98.9 | 0 | 4 |
| 1997-13A | STS-83 | USA | 298 | 303 | 28.4 | 0 | 0 |
| 1997-14A | PROGRESS M-34 | Russia | 377 | 393 | 51.7 | 1 | 0 |
| 1997-15A | KOSMOS 2340 | Russia | 530 | 39807 | 62.9 | 2 | 1 |
| 1997-16A | THIACOM 3 | Thailand | 35726 | 35855 | 0.1 | 1 | 1 |
| | B-SAT 1A | Japan | 35760 | 35815 | 0.2 | | |
| 1997-17A | KOSMOS 2341 | Russia | 978 | 1014 | 82.9 | 1 | 0 |
| 1997-18A | MINISAT | Spain | 562 | 581 | 150.9 | 1 | 0 |
| 1997-19A | GOES 10 | USA | 35778 | 35795 | 0.4 | 1 | 0 |
| 1997-20A | IRIDIUM 8 | USA | 776 | 779 | 86.4 | 1 | 0 |
| | IRIDIUM 7 | USA | 773 | 782 | 86.4 | | |
| | IRIDIUM 6 | USA | 775 | 780 | 86.4 | | |
| | IRIDIUM 5 | USA | 772 | 784 | 86.4 | | |
| | IRIDIUM 4 | USA | 772 | 784 | 86.4 | | |
| 1997-21A | DFH 3-2 | China | 35782 | 35790 | 0.2 | 1 | 0 |
| 1997-22A | KOSMOS 2342 | Russia | 537 | 39822 | 62.8 | 2 | 1 |
| 1997-23A | STS-84 | USA | 388 | 404 | 51.7 | 0 | 0 |
| 1997-24A | KOSMOS 2343 | Russia | 220 | 334 | 65.0 | 1 | 0 |
| 1997-25A | THOR 2A | Norway | 35779 | 35793 | 0.0 | 2 | 0 |
| 1997-26A | TELSTAR 5 | USA | 35771 | 35800 | 0.1 | 2 | 1 |
| 1997-27A | INMARSAT 3 F4 | Inmarsat | 35770 | 35805 | 0.3 | 1 | 1 |
| | INSAT 2D | India | 35755 | 35819 | 0.2 | | |
| 1997-28A | KOSMOS 2344 | Russia | 1509 | 2747 | 63.4 | 2 | 4 |
| 1997-29A | FENGYUN 2-1 | China | 35782 | 35796 | 1.2 | 1 | 0 |
| 1997-30A | IRIDIUM 14 | USA | 774 | 779 | 86.4 | 0 | 0 |
| | IRIDIUM 12 | USA | 773 | 782 | 86.4 | | |
| | IRIDIUM 10 | USA | 774 | 781 | 86.4 | | |
| | IRIDIUM 9 | USA | 775 | 778 | 86.4 | | |
| | IRIDIUM 13 | USA | 774 | 781 | 86.4 | | |
| | IRIDIUM 16 | USA | 775 | 779 | 86.4 | | |
| | IRIDIUM 11 | USA | 776 | 779 | 86.4 | | |
| 1997-031A | INTELSAT 802 | Intelsat | 35720 | 35781 | 0.4 | 1 | 0 |

### ORBITAL BOX SCORE

**(as of 3 JULY 1997, as catalogued by US SPACE COMMAND)**

| Country/ Organization | Payloads | Rocket Bodies and Debris | Total |
|---|---|---|---|
| **CHINA** | 18 | 98 | 116 |
| **CIS** | 1322 | 2514 | 3836 |
| **ESA** | 19 | 190 | 209 |
| **INDIA** | 15 | 3 | 18 |
| **JAPAN** | 57 | 54 | 111 |
| **US** | 663 | 3260 | 3923 |
| **OTHER** | 246 | 23 | 269 |
| **TOTAL** | 2340 | 6142 | 8482 |

# Upcoming Meetings

***SPIE - Optical Science, Engineering and Instrumentation SD97 Symposium***, 27 July - 01 August 1997, San Diego California, U.S.A. This year's theme promotes a comprehensive understanding of the debris environment with an eye toward evaluating the limitations of our knowledge, and to continue to explore the practical implications of operating in an environment with debris. For further information visit the SPIE Web Site at http://www.spie.org/web/meetings/calls/submissions.html or phone 360/676-3290; FAX 360/647-1445; e-mail: sd97@spie.org.

***International Astronautical Congress (IAF)***, 06-10 October 1997, Turin, Italy. The conference theme "Developing Business for Space" will be explored through a series of symposia. Topics to include space technology, inner and outer space missions, economic, legal, management, political and environmental aspects of the world's programs for peaceful utilization of space. For further information, please contact the IAF Secretariat, International Astronautical Federation, 3-5 Rue Mario-Nikis, 75015 Paris - France

***The $32^{nd}$ COSPAR Scientific Assembly*** will be held at the Nagoya Congress Center in Nagoya, Japan, from 12-19 July 1998. The Nagoya Congress Center is located about 10 min. by subway from the centre of the city and it is one of the newest and largest ones in Japan, featuring the Century Hall for 3000 people, a large exhibition hall and International Conference Room and 29 other Meeting Rooms of various sizes. The address of the congress centre is Nagoya Congress Center, 1-1 Atsutanishi-machi, Atsuta-ku, Nagoya-shi 456, Japan, Tel: +81-(0)52-683-7711, Fax: +81-(0)52-683-777 For more information contact Tokai University, Department of Engineering Phone: 81 4 6358 1211 Fax: 81 4 6359 8292

***The Inter-agency Debris Coordination (IADC)*** is scheduled to be held in the USA, 09-12 December 1997.

# Meeting Report

## Leonids Meteor Meeting

An international conference on the Leonids Meteor Storm was held at JSC on 8-9 May 1997. The Leonids meteor shower that occurs annually in late November has been forecasted to storm in 1999. The overall goal of the NASA effort is to determine the hazard to spacecraft that will be posed by the Leonids storm. The last Leonids meteor storm occurred in 1966 when there were few space assets. Now there are a considerable number of satellites that could be adversely affected by the Leonids storm. Spacecraft like the Shuttle can avoid the hazard simply by not launching during the storm which last only for a few hours. However, the already deployed satellites and the International Space Station will be exposed to the storm. It is planned to develop threat mitigation approaches for the storm after the threat is more fully characterized.

This purpose of this meeting was to examine the range of predictions of storm intensity and to develop recommendations for observations and modeling efforts to reduce the uncertainties of the predictions. The meeting was very successful. It brought together many of the scientific experts who are actively engaged in research on the Leonids representing the US, Canada and Taiwan. In general, the experts all agreed that the Leonids will experience enhanced activity in 1999. However, there was no consensus as to the actual intensity of the predicted storm. The numbers of meteors forecasted are more understandable when compared to the normal background meteor rate. The normal background meteor intensity that will be visually seen by an observer under clear sky conditions with a dark sky is about 5 to 10 per hour. The various meteor showers that occur during the year sometimes produce counts as high as 100 per hour. Past observations of Leonids meteor storms have produced estimates as high as 100,000 per hour. It does not appear likely that rates this high will be achieved by the 1999 storm. Nevertheless, rates of tens of thousand per hour will still produce a greatly elevated threat.

An interesting feature of the Leonid's meteors is their very high velocity. Meteor showers are caused by the debris clouds formed by material ejected from comets. This material remains in the cometary orbit. The annual meteor showers occur when the Earth passes through the cometary orbit. The meteor storm occurs when the Earth intersects the major concentration of the cometary debris. The orbit of the debris particles that cause the Leonids has a velocity vector nearly directly opposite to the Earth's velocity around the sun. Thus the Leonid's meteors have a ~72 km/sec velocity relative to the Earth. This very high velocity means that the Leonids have some unusual characteristics. First of all, the high velocity causes them to burn up very high in the atmosphere making them very difficult to observe. Secondly, the high velocity causes considerably more plasma to be generated upon collision. There have been some reports of satellite failures that have been attributed to plasma effects.

Since plasma production is approximately proportional to velocity$^4$, even small Leonid's meteors can generate considerable plasmas. Thus, there may be an additional damage mechanism to the standard penetration that we must consider.

A result of the meeting was a plan for observations of the November 1997 Leonids shower. The geometry of the 1997 shower causes North America to be a preferred observing site. Radar observations are planned in Houston at JSC, in Ontario, Canada by the University of Western Ontario and on Taiwan. Optical observations are planned for Nova Scotia, Canada; Ontario, Canada; Houston, Texas; Cloudcroft, New Mexico; and California. It appears that the 1997 Leonids will be well observed. The results of the observations will be given to modelers to use in updating their predictions of the intensity of the 1999 storm.

# Guest Article

## Review of International Activities in Orbital Debris Environment Modeling

**Darren S. McKnight**

**Introduction**

There is a wide variety of work being conducted outside the United States in developing orbital debris environment modeling tools. Several recent analyses have examined space debris models, usually using NASA models as a baseline for comparison. [Ref. 1-2] For this review, environment models will be grouped into two general classes: population and flux. Population models provide the number of objects in orbit as a function of time, type, and orbital parameters while flux models provide an impact flux (or impact probability, as appropriate) for a specified satellite. Generally speaking, a flux model has some sort of population model resident within it to allow impact flux calculations to be made.

The population is determined partially from measurements and partially from modeling. Measurements include remote observations such as "the catalog" or Haystack data but also include returned samples such as such as acquired from the Long Duration Exposure Facility (LDEF) data. Modeling includes representations for sources and sinks of debris such as orbital decay, breakups, and solid rocket motor firings. Some modeling must also take place when interpreting impact data and remote observations. In this way the population is developed through a complex meshing of measurements and modeling. For this reason, all models considered in this review and used in any capacity by the orbital debris community can be considered semi-empirical.

An additional dimension of orbital debris environment models is the length of time over which they are applied. Once an initial population is determined the length of time the population is propagated in time is directly associated to its intended use. Several programs look centuries into the future to look at long-term issues such as collisional cascading and debris mitigation measures while others only project several years. Normally the longer in time you go the less accurate and precise the output. For this reason, the flux models usually are not applied too many years into the future because they are nominally applied to a specific satellite and its design so large uncertainty levels limit their usefulness for system analyses.

**Models Being Examined**

Models from seven non-US organizations will be discussed in this article. They follow individually with short descriptions; the article will conclude with a short comparison of these tools.

Japan: No specific Japanese environment model has been well documented in the open literature. However, it is clear that Japanese scientists and engineers have focused on the geosynchronous orbit (GEO) in their analyses. At GEO the orbital debris population is not well known due to the lack of measurements available, the sensitive nature of satellite health in this region, and the perceived low collision risk.

China: The Chinese have begun to publish technical papers in the area of orbital debris environment modeling over the last few years. [Ref. 3-4] However, the current efforts basically constitute the exercising of discrete components of models but they have not been combined in an integrated fashion as a monolithic tool. The efforts thus far are pushing toward a basic population model.

India: The Indian contribution to the orbital debris community has taken a more analytic approach. They have taken this approach due to "inadequacies of orbital [debris] data available in the public domain, even of large trackable debris." [Ref. 5] The current effort produces a population distribution a short time in the future (one year) but the approach is extensible to longer periods of time. The Indians have developed an interesting concept called an Equivalent Breakup Unit (EQBU) which is a normalized function of the effect of breakups on the environment and includes both mass and orbital characteristics of the debris.

Italy: The Italian efforts over the years have focused on long-term population modeling and analyses related to debris mitigation measures, the impact of deploying large LEO satellite constellations, and collisional cascading. [Ref. 6] The two models applied by the Italians are the Semi-Deterministic Model (SDM) and STochastic Analog Tool (STAT). Both are baselined by the CNUCE 1994.0 Orbital Debris Reference Model as reduced from the USSPACECOM catalog obtained via NASA Goddard Space Flight Center. STAT statistically (based on previous growth patterns) evolves the population as bins defined by semimajor axis, eccentricity, and mass. SDM uses the same physical models for breakups and the initial population but evolves the population by propagating the movement of the larger objects individually. A very fast semi-analytical Debris Cloud Propagator is used to efficiently project the population of large objects over time while a user-defined option for including smaller (nontrackable) objects is permitted. Inputs required include launch rate and explosion rate; the collision rate is determined by the calculated collision probability plus an assessment of the effect of the collision based on advanced breakup models.

England: Scientists and engineers at the Defense Evaluation and Research Agency (DERA, formerly Defence Research Agency, DRA) under the leadership of Dr. Richard Crowther have steadily improved their debris modeling capabilities over the last decade. [Ref. 7] Their efforts have focused largely on LEO satellite constellation survivability. Several models are currently being used but only two will be discussed in this article: Integrated Debris Evolution Suite (IDES) and PLATFORM. (These two models plus several others constitute what they call their Space Debris Simulation (SDS) suite.) IDES depicts objects larger than 10 microns in the debris environment and determines the long-term collision hazard. IDES deterministically builds a 1996 population by generating debris from all known breakup events and other deposited objects taken from the USSPACECOM catalog. From 1996 onward a detailed traffic model is used to project the trackable population while orbital decay algorithms are applied to the nontrackable population as perceived in 1996. Key factors for future growth include launch rate, mitigation measures, and explosion rate while collision rate is calculated. IDES provides flux calculations to a selected satellite as a possible output. However, they also developed PLATFORM which "enable[s] a

*(Continued on page 10)*

# Project Reviews

## LEO Constellation Modeling

The project to study orbital debris environmental effects associated with LEO constellations is completing a study of a high altitude constellation patterned on a Soviet navigational satellite constellation that has been active since 1972. This case is being used as a test of the CONSTELL program to compare model predictions of constellation experience with what has been observed for this constellation. The model constellation was run over 20 years and assumed that 10 spacecraft constituted the constellation each having a mission lifetime of 1.25 years. The mission orbit altitude for the constellation was taken to be 1015 x 960 km and it was assumed there was 1 upper stage used per spacecraft delivered to orbit. It was also assumed that the spacecraft and upper stages were abandoned in this mission orbit at the end of their mission life (on delivery of the payload for the upper stages and after 1.25 years for the spacecraft). It was assumed that there were no design failures in the spacecraft, as these were accounted for in the 1.25 year mission life.

Some results of this test case are presented in two figures. Figure 1 is the temporal record of spacecraft and upper stages placed in orbit to maintain the constellation, which was assumed to be deployed at time 0 (January 1, 1975 or 1975.0). As might be expected this figure shows a regular pattern reflecting the constellation replacement every 1.25 years. Figure 2 presents plots of spatial densities of objects 1 cm and larger for the background environment (taken from ORDEM96) and from constellation associated objects for times 1975.0 and 1995.0. The 1975.0 constellation distribution arises from the initial spacecraft and upper stages used to deploy them. The constellation-induced environment for 1995.0 includes all of the spacecraft and upper stages used to maintain the constellation (as shown in Figure 1) and debris generated by constellation breakups (the model predicted 0.40 breakups from collision-rates based on the flux of background objects and constellation debris). This result corresponds to the reasonable conclusion that the probability of such an event occurring historically was small and is consistent with observations. It can be seen from this figure that the expected 1 cm environment from such a constellation would be nearly 2 orders of magnitude below the background after 20 years. That is, if this was a projection for a proposed constellation and future growth of the background environment was neglected it would be expected that the environment from 1 cm and larger constellation debris after 20 years would be roughly an order of magnitude less than from the background environment at the operating altitude of the constellation and would be 1 to 2 orders of magnitude less for space users at most other altitudes.

**Population Larger than 1 cm for a Historical Constellation in a 1015 x 960 km Elliptical Orbit**

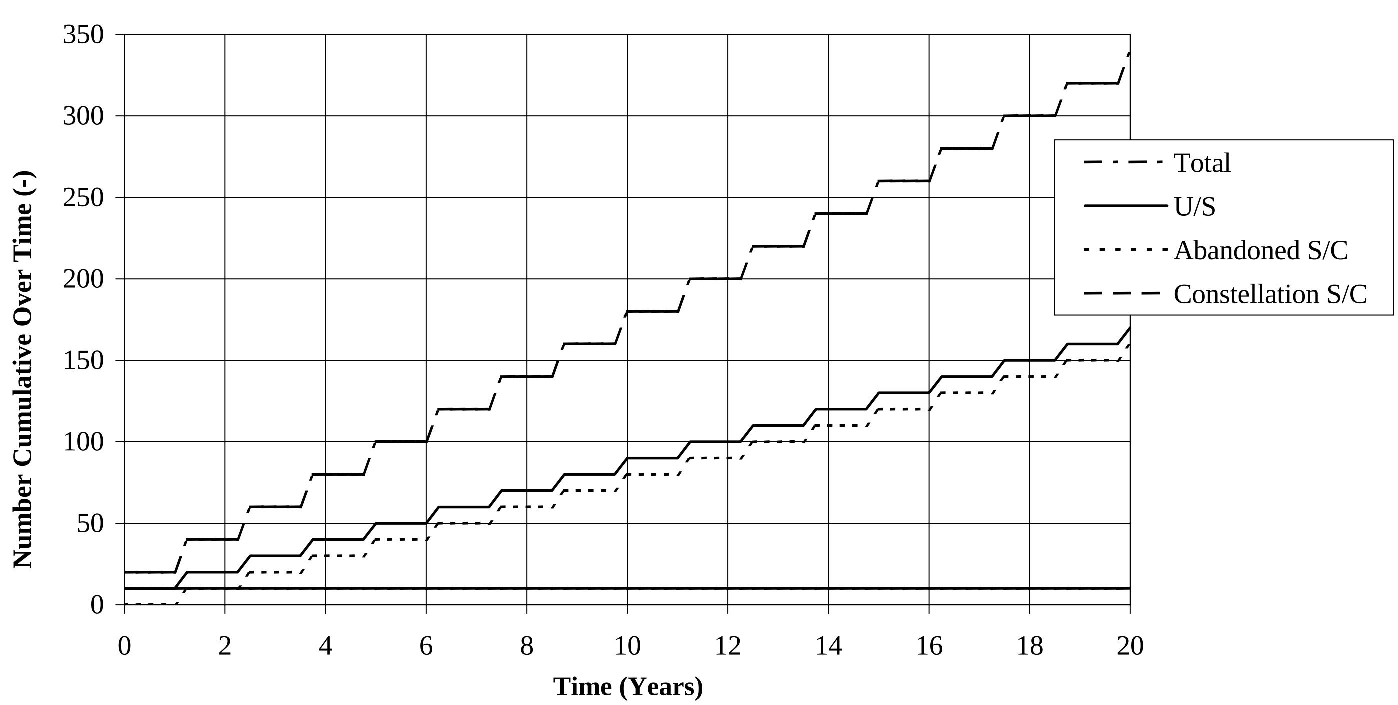


Figure 1. Number of constellation spacecraft and upper stages (U/S) in orbit as a function of time from initial constellation deployment.

# Project Reviews, Continued

**S/C and U/S for an Historical Constellation in a 1015 x 960 km Elliptical Orbit**

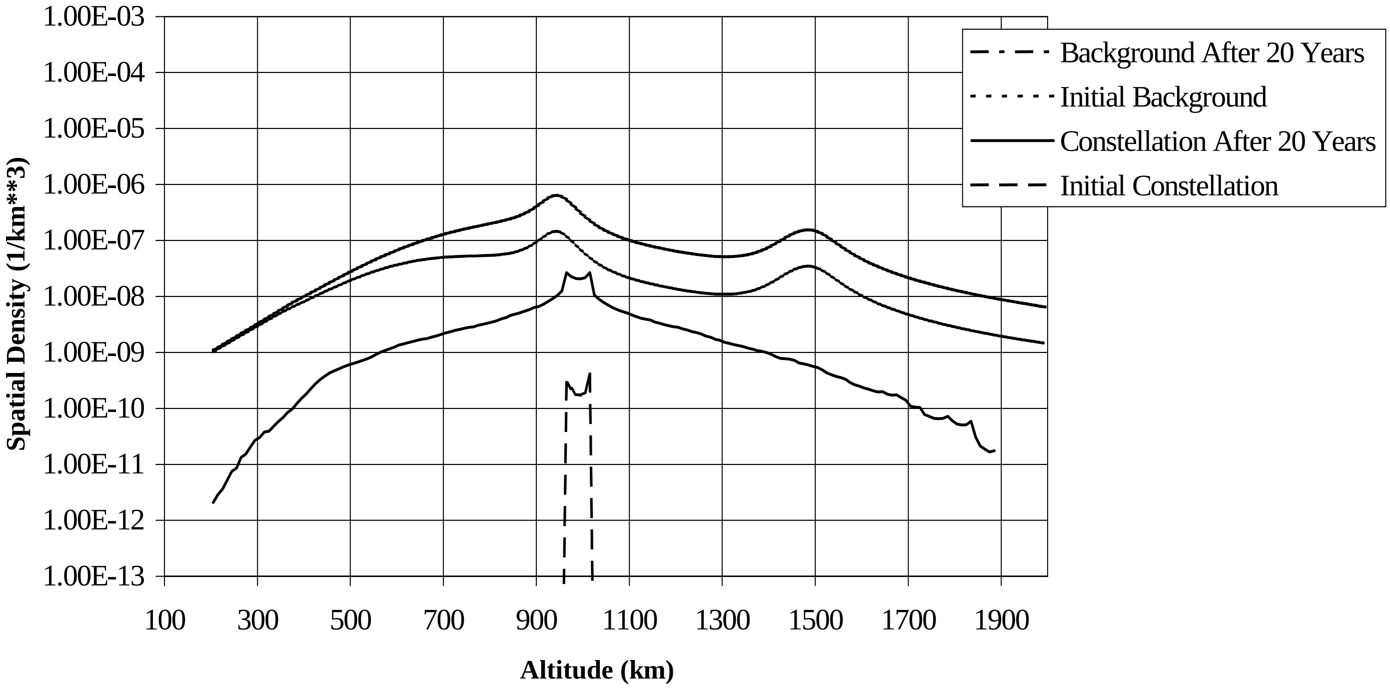


Figure 2. Spatial density of orbital debris 1 cm and larger for the background environment and from the constellation associated environment at the time of initial constellation deployment and after 20 years of constellation operation.

# Haystack Orbital Debris Data Review Panel

The Haystack radar has been the most important tool used by NASA to study the distribution of LEO orbital debris in the 1 to 10 cm size range. Haystack is unable to track individual objects, so it is limited to doing statistical studies of the environment. In addition, the radar does not directly measure an object's size. Instead it makes a measurement of the object's ability to reflect the transmitter's electromagnetic radiation known as the radar cross-section (RCS). NASA has invested considerable resources into understanding how to use this radar and those like it to derive useful size and orbit distributions of orbital debris.

Because the techniques used for these orbital debris studies are different from those normally applied to radar systems, NASA called a panel of radar experts in 1991-1992 to assess the data collection techniques, estimate how well the radar's data would serve as an input to the orbital debris flux estimation problem, and to make recommendations aimed at maximizing the usefulness of the collection effort. With the recent development of new models, such as ORDEM96, based on the Haystack data it was decided that it was time to revisit the Haystack data analysis project, this time with an emphasis on the adequacy of the collection statistics and the accuracy of the RCS-to-size conversion techniques.

The Haystack Orbital Debris Review Panel was established in December 1996 to consider the adequacy of the data on orbital debris gathered over the past several years with the Haystack radar, and the accuracy of the methods used to estimate the flux vs. size relationship for this debris. It is composed of experts in the field of radar and experts in the field of statistics. The panel was asked to address four specific issues:

1) The number of observations relative to the estimated population of interest.
2) The inherent ambiguity between the measured RCS and the inferred physical size of the object.
3) The inherent aspect angle limitation in viewing each object and its relationship to object geometry.
4) The adequacy of the sample data set to characterize the debris population's potential geometry.

The panel has completed most of its work and is in the process of producing a report documenting the work they have done. As a result of their work, they have helped NASA develop improved methods for removing biases and estimating uncertainties in the size distribution estimates. A summary of their conclusions will appear in a future issue of the Orbital Debris Quarterly News.

# Project Reviews, Continued

## The Total Population in Orbit

The Satellite Catalogs can be used to get information on the total population in orbit as a function of time. The Satellite Catalog contains all objects tracked and cataloged by the US SSN since 1957. Along with other data (e.g., international designator) the Satellite Catalog gives the launch and, if applicable, decay date for each of those objects. Based on this information the number of objects in orbit and the fragments belonging to specific breakups can be identified. These parameters are a function of time, and they are often compared to modeling results.

The tracked objects are entered into the Satellite Catalog only after their source is identified and when they can be tracked on a regular basis. Until they fulfill these criteria they remain in the two-line element set (TLE) data base section with catalog numbers ≥ 80000. In large measure the objects with catalog numbers in the 87xxx and 88xxx series can be considered as fragmentation debris. There are also some fragments scattered in other 8xxxx series.

When it comes to "real-time" comparisons, the objects in the 87xxx and 88xxx catalog number series should be added to the official Satellite Catalog in order to get a more realistic picture of the current environment. The number of objects in these two series varies from a couple of hundreds up to a thousand. At the beginning of 1997, there were 918 objects in orbit with catalog numbers in the 87xxx and 88xxx series (see also Fig. 3).

Fig. 3 shows the history of the total number of cataloged objects in orbit each month and the corresponding number in four different categories (spacecraft (S/C), rocket bodies (R/B), operational debris, fragmentation debris), based on the Satellite Catalog of January 1997.

In order to be as realistic as possible, breakup fragments are added to the environment on the date of breakup event, not the launch date of the fragmentation parent which is given in the Satellite Catalog. Operational debris related to a launch are added at the date of launch. In the Satellite Catalog there is no distinction between operational and fragmentation debris; both are labeled as 'DEB'. To differentiate between fragmentation debris and operational debris belonging to a fragmentation, the list of satellites not associated with fragmentation [Ref.1] was used. Fragmentation parents (S/C or R/B) remain in their corresponding category until the date of event beginning with the event date they are counted in the fragmentation debris category. Operational debris generated by the Salyut 4, 5, 6 and 7 missions and by Mir are not added on the date of launch of the parent, which is given

*(Continued on page 8)*

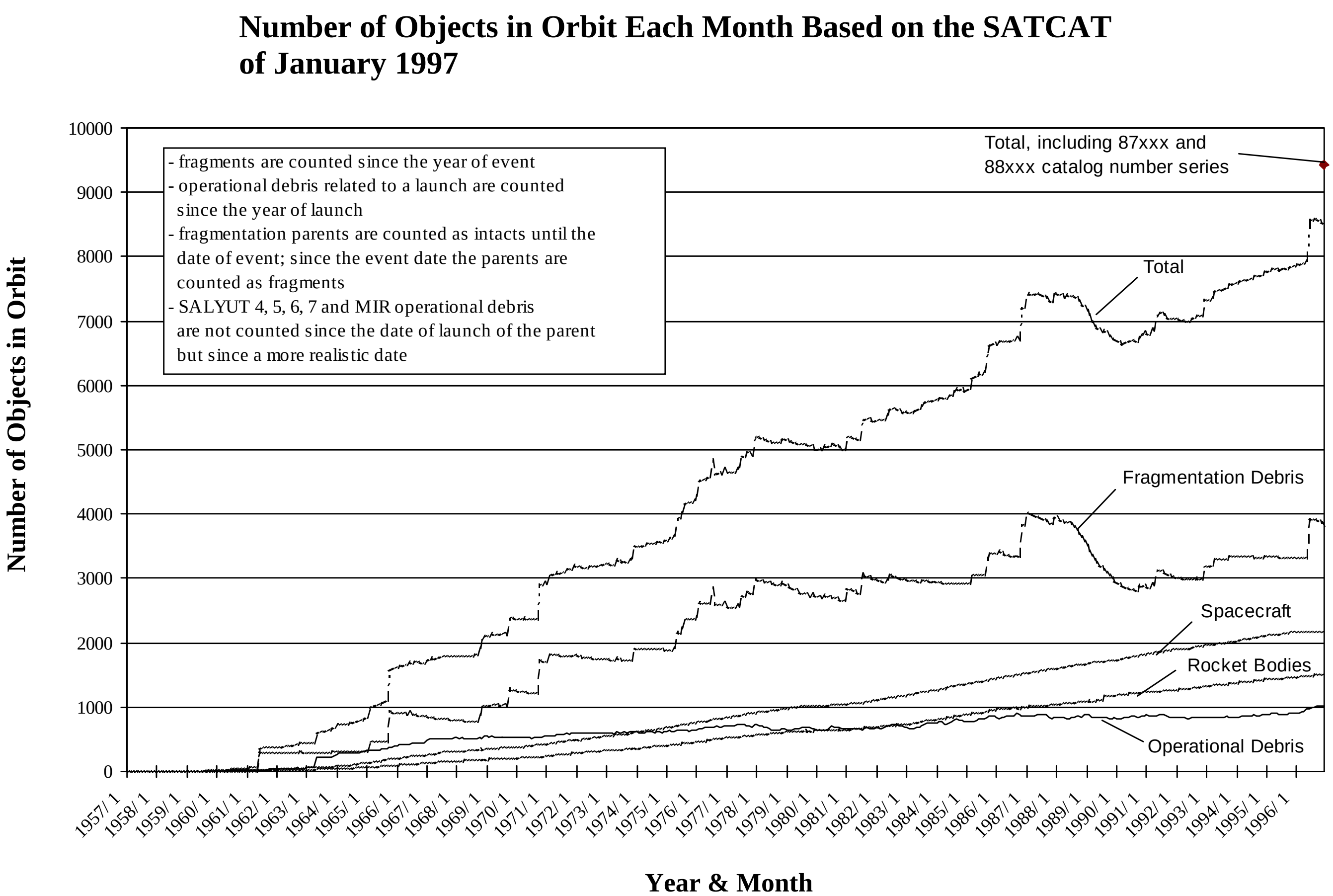


Figure 3. Analysis of the number of objects in orbit based on the Satellite Catalog of January 1997 (total number and differentiated by category)

# Abstracts from Papers

The following abstracts will be presented at the SPIE - Optical Science, Engineering and Instrumentation SD97 Symposium, 27 July - 01 August 1997, San Diego California, U.S.A.

## Comparisons Between Orbital Debris Measurement Data and Modeling Results

Anette Bade, Robert Reynolds, Mark Matney, Peter Eichler, Nicholas Johnson

For orbital debris a variety of measurement data is available: impact analysis results from space returned hardware (LDEF, Shuttle etc.), optical measurements of Earth-based sensors, radar measurements of Earth-based sensors, space-based measurements, and laboratory fragmentation test results. All these data together do not mirror the orbital debris and meteoroid environment in a way that allows the direct estimation of potential hazards for active and planned space missions - this can only be done by modeling. The measurement data are used for the judgment of modeling results and for the calibration of the models themselves.

Important data sources continuously updated and used at NASA / JSC for this comparison with models of the debris environment were the two-line orbital elements sets (TLE), the associated Space Surveillance Catalog, and radar cross-section (RCS) data from the US Space Surveillance Network. The RCS data give a rough approximation of size.

In this paper it is shown how the TLE, the RCS data, and the Catalog are compared to breakup model results. RCS data from December, 1996, for fragmentation clouds from significant breakup events in the Catalog were converted into sizes and compared to corresponding model profiles. It is shown that neither the assumption of a fixed lower trackability size threshold nor the supposition of completeness of the Catalog above a certain size are adequate for comparison purposes. A solution for this problem, i.e., ways for a better data handling, is presented.

A presentation of the number of objects in the Catalog and the number of objects tracked but not yet entered into the catalog show how a realistic picture of the growth and evolution of the total population in orbit can be obtained.

Presented at the SPIE 29 July - 01 August 1997, Session on Characteristics and Consequences of Orbital Debris and Natural Space Impactors II, Paper 3116-25

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## Photographic surveys of the Mir Space Station and the Detection of Orbital Debris and Meteoroid Impacts

Mike Gaunce, Robert Scharf,
Nicholas Johnson, Eric Christiansen

During the period February 1995-May 1997, the US Space Shuttle visited the Russian Mir space station on one close rendezvous and six docking missions. A Detailed Test Objective (DTO-1118) called for extensive photographic and video imagery of the Mir complex for several purposes, including to assess the overall condition of the station and to study the effects of the space environment on a long-duration orbiting platform. Thousands of photographs of Mir from 35 mm Nikon and 70 mm Hasselblad cameras were taken, and more than one hundred hours of video from several cameras located in the Space Shuttle cargo bay were collected. A review of these photographic data has revealed evidence of numerous small particle impacts.

This paper describes the photographic analysis effort at the NASA Johnson Space Center with an emphasis on Mir particulate damage assessment. Sample photographs depicting impact effects are provided. A preliminary attempt is made to compare the observed impacts with predictions base on environment models. A comprehensive comparison between data and the models is hampered by the lack of a complete historical record of the attitude of the Mir space station and by and inability to distinguish between orbital debris and meteoroid impacts from only remote photographic evidence.

## Project Reviews, continued

(Continued from page 7)
in the Satellite Catalog, but from their initial catalog date?

Fig. 3 shows that there is a significant difference for the end of 1996 between the official Satellite Catalog and the Satellite Catalog including the tracked, but not yet cataloged objects. With time a significant number of objects in the 8xxxx series will be identified and added to the official catalog. That means that if this same analysis is performed in the future it will show a Satellite Catalog curve which will be above the current curve at the current time. If the 87xxx and 88xxx catalog series is omitted, the growth of the trackable population and the associated risk will be underestimated, and the growth and the evolution of the total population in orbit will be less realistic.

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# NEWS, Continued

## ESA's ERS 1 Spacecraft Performs Collision Avoidance Maneuver

At the second European Conference on Space Debris held in Darmstadt, Germany in March of this year, Heiner Klinkrad described ESOC's continuing analyses of the close approaches of space objects to ESA's ERS 1 and ERS 2 spacecraft. Two-line element sets from the US Space Surveillance Network are used to predict the positions of known space objects and to calculate daily conjunctions with the ERS spacecraft. In late June, this effort identified a forthcoming close approach between ERS 1 (Sat. No. 21574, 1991-050A) and the derelict Cosmos 614 spacecraft (Sat. No. 6965, 1973-098A). According to ESA calculations, a miss distance of only 130 m was projected at 1325 UTC on 25 June. The associated probability of collision was determined to be 1 in 10,000. As a precaution, ERS 1 performed a 1 m/s evasive maneuver at 1134 UTC, raising the vehicle 4 km above the potential collision location. A maneuver to restore ERS 1's groundtrack was executed the following day. Subsequent orbital data cast doubt on the validity of the original prediction, highlighting the need for additional data and analysis on a timely basis.

## Orbiter Modifications Make It More Robust Against Meteoroids and Debris

The shuttle program looking toward the requirements of the International Space Station assembly has decided to revise its requirements and configuration to protect against mission termination and critical penetrations. The large exposed area of the radiators is one of the most vulnerable parts of the shuttle. Only 10% of the area is the fluid loops through which the ethylene glycol flows but penetration of the loop could cause loss of all of the fluid on that side of the vehicle. To protect against penetration the portion of the radiator will be covered with a strip of aluminum 0.002 thick and an isolation valve will be added. These measures substantially reduce the probability of penetration and also provide protection for the cooling capability of the flash evaporators for normal entry operations.

The reinforced carbon-carbon used at the nose cap and the leading edge of the wing accepts the highest temperatures during entry. To make the system more tolerant of debris damage the insulation that protects the main spar from the radiant heating will be modified so that it can tolerate the increased temperatures that would occur with the inflow of plasma through a penetration.

These two modifications substantially improve the probability of successful ISS assembly flights.

## NRC Reviews Shuttle Meteoroid and Debris Protection

A National Research Council (NRC) panel of orbital debris and battle damage experts chaired by former astronaut Rick Hauck, is conducting a review of the shuttle meteoroid and orbital debris (MOD) protection. The committee has met in Washington in April 27-28 and in Houston June 16-18, 1997. Its Terms of Reference are to examine both the design provisions and the operational procedures used for protection to assure that the risks are minimized but that productivity is not unduly compromised. The committee report is scheduled for release in October 1997.

## Three Satellite Breakups During May-June, continued

*(Continued from page 2)*

on 29 and 30 June indicated that the spacecraft was largely intact, another characteristic of this type of breakup.

The SN3 Space Science Branch, notified of the breakup within hours by US Naval Space Command personnel, conducted an immediate and extensive analysis of the debris cloud characteristics due to potential threats to the Mir space station and the imminent launch of STS-94 on 1 July. The latter mission was of special concern due to its planned orbit proximity (300 km) near the heart of the debris cloud. Calculations were made of critical penetration and radiator tube penetration risks posed by the breakup debris. The additional risks were projected to not exceed established Space Shuttle program guidelines and, therefore, the STS-94 mission was not delayed due to the breakup. Assessments were also made of possible close approaches of the known debris with STS-94 which was dedicated to microgravity experiments and for which collision avoidance maneuvers were undesirable.

## Editor's Notes

One of the important events in the orbital debris world was the retirement in July of George Levin as the NASA Program Manager for Orbital Debris. George was a very active and very knowledgeable supporter of our orbital debris research efforts and we will miss him greatly. George has moved from his position with NASA to a new job with the National Research Council. During his tenure as Program Manager, the orbital debris measurements program for NASA was greatly expanded to include both NASA and DoD telescope observations and, most important, the development of the haystack radar project. George was also instrumental in developing interagency cooperation within the Government and in making the Interagency Space Debris Coordination Committee an effective international voice for orbital debris issues.

George, we wish you the best of luck.

# Guest Article, Continued

(Continued from page 4)

user to construct an accurate 3D representation of a space platform, subject the configuration to hypervelocity debris and meteoroid impacts during its proposed mission life, and help identify an appropriate protection solution." PLATFORM gives the user a very user-friendly means to interface with the particulate design environment.

ESA/ESOC: The Technical University of Braunschweig (TUB) has been a critical component of the European debris research community for many years. They have developed a couple of critical models under ESOC funding. TUB originally developed CHAIN (this model was recently updated to CHAINEE) which is used to estimate very long-term debris effects. CHAINEE bins the population down to several centimeters by mass and altitude. Future growth is then directly input as adjustments to these matrices. As with other long-term, evolutionary models some datum state must be set to initiate propagation of the environment - it is 1 Jan 1995 for CHAINEE. Closed form algorithms depicting the removal of mass from orbit and migration of this mass between altitude bins are used vice individual orbit propagation schemes. A more comprehensive environment model also developed by TUB is the Meteoroid and Space Debris Terrestrial Environment Reference (MASTER). [Ref. 8] The 1996 population was created by simulating all known breakup events up to that point and then adjusting the population through examination of returned samples and remote observations. MASTER provides three different tools: the Analyst Application, the Engineering Application, and the Radar Post Processor. The population for all three applications is generated identically by considering launches, explosions, and collisions that each generate debris. The population is then partitioned within spherical control volume bins that are sliced by right ascension and declination plus altitude intervals. This approach is memory intensive but provides the data in a format conducive to a variety of post processing applications.

Russia: Nazarenko has been responsible for the majority of Russian debris environment models presented publicly over the last ten years. His approach to environment evolution applies basic operations research techniques of reducing large amounts of time series information. His population model is very empirical in nature. Largely a multiple regression applied to relevant parameters for trackable objects and scaled up for nontrackable objects. As far as flux modeling, the Russian contributions are not well-documented in the open literature, but their robust application to Mir vulnerability assessments have proven them to be accurate and reliable for flux-like applications. Examination of offerings of a flux model have shown it to be very similar to ORDEM96 in that it portrays impact and velocity distributions for a given spacecraft and orbital scenario and provides comparable results.

**Discussion of Models**

The review of these environment models will focus on application and not on accuracy or consistency between models. There are several major aspects of each of these models that would have to be examined before a complete quantitative comparison could take place: breakup models for collisions and explosions; orbital decay algorithms; launch rate effect on population; explosion rate; explosion model; complete fragmentation threshold; modeling of mitigation measures; reduction of data from returned samples and remote observations; and many more. The models reviewed exhibit the evolution of the understanding of the community and highlights major new issues of concern such as LEO satellite constellations. The comprehensiveness of the MASTER tool and the SDS suite make them the most practical for any new entrant into the orbital debris fray (exclusive of course of NASA's suite of ools that include EVOLVE, ORDEM96, CONSTEL and BUMPER). MASTER and SDS have well-conceived system architectures and well-documented linkages to other relevant research in the community related to breakup modeling, debris measurements, etc. SDM/STAT, the Russian environment model, and CHAINEE provide excellent focused applications for long-term environment evolution with little regard to individual satellite risk assessment. They provide a superb testbed for issues with life cycles on the order of decades and are well-documented in the literature. All in all, this review has found the non-US debris community models to be robust and well-conceived for the most part. On the other hand, all the models reviewed have the general tendency of omission of the generating source of objects below 5mm since breakup events alone cannot justify the exhibited population's effects. This is an issue that is currently being addressed in ORDEM96 and evolve by including source functions for solid rocket motor effluents, paint flakes, etc.

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## Guest Article, Continued

*(Continued from page 10)*


7. Crowther, R., Barrows, S., Marsh, V., Stokes, H., and Walker, R., "Risk Analysis for Satellite Constellations: Studies at the Defence Research Agency", Presented at the 47th International Astronautical Congress, Paper IAA.-96-IAA.6.4.04, Beijing, China, Oct 7-11, 1996.

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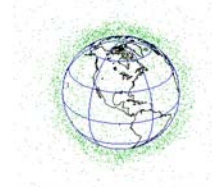

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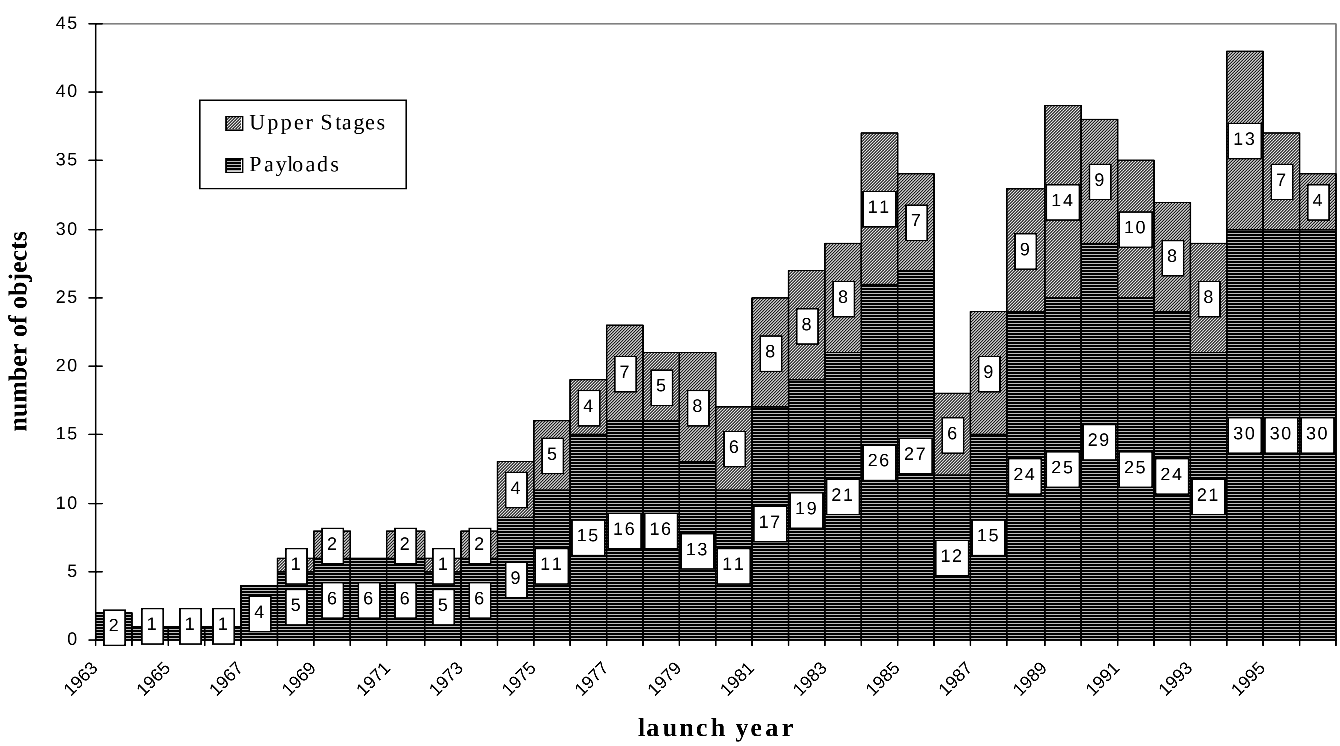
**Payloads and upper stages launched into geosynchronous orbit regime**




The above figure depicts the history of payloads and upper stages launched into the geosynchronous orbit (GEO) regime. The objects included are those that can interact with GEO satellite, but does not include upper stages left in geosynchronous transfer orbits. Satellites of the IDCSP series and related upper stages, residing in orbits about 1000 to 2000 km below GEO, are also not considered.


# Visit the NASA JSC Website!

Visit the NASA Johnson Space Center Space Science Branch's Website at **http://sn-callisto.jsc.nasa.gov**. The Orbital Debris Quarterly News is posted to this site with many other space research items. The webpage divides the Orbital Debris Research Project into the following four broad research efforts: Modeling, Mitigation, Measurement and Protection.

The modeling area includes information on the EVOLVE program, the primary NASA orbital debris environment model for short-term (a few decades to a few centuries) evolution of the orbital debris environment, and ORDEM96, the NASA engineering model. ORDEM96 has been adopted by the International Space Station (ISS) program as the reference model for redesign and by both the ISS and STS programs for risk assessment. This model has been implemented in software available to the space community from the website, and has been implemented in the BUMPER code at JSC.

The measurement area encompasses radar and optical measurements.

Radar Measurements - NASA's main source of data for debris in the size range of 1-30 cm is the Haystack radar. The Haystack radar, operated by MIT Lincoln Laboratory, has been collecting orbital-debris data for NASA since 1990 under an agreement with the U.S. Air Force. The most recent published report is JSC-27436, Haystack Measurements of the Orbital Debris Environment, 1994-1996.

NASA has conducted limited observation campaigns using the radar systems located at Kwajalein Atoll (U.S. Army; USAKA), the FPS-85 phased array radar at Eglin AFB, Florida, the Millstone radar and Firepond Telescope in Massachusetts, and the Perimeter Acquisition Characterization Radar System (PARCS) in North Dakota. NASA has also participated in debris searches organized by the U.S. Air Force Space Command and by the FGAN radar located in Germany.

Optical Measurements - Some debris objects reflect radar well, but sunlight poorly. Others reflect sunlight well, but radar poorly. It follows that radar and optical telescopes see somewhat different debris populations. In addition, optical telescopes perform better than radars for detection of debris at very high altitudes, such as geosynchronous orbit. To get a more complete picture of the orbital-debris environment, both radar and optical measurements are needed. NASA is using two optical telescopes for measuring orbital debris: a 3 m diameter liquid mirror telescope (pictured on the left), which is referred to as the LMT, and a charged coupled device-equipped 0.3 m Schmidt camera, which is commonly referred to as the CCD Debris Telescope or CDT.

The LMT was developed at NASA-JSC and moved to Cloudcroft, New Mexico for the purpose of measuring the population of small orbital debris particles. By "staring" straight-up, the telescope can observe the orbital debris that passes overhead through its 0.40 degree field-of-view. The LMT is "housed" inside a large six story observatory with a 50 ft diameter dome which was originally built by the US Air Force for satellite observations and studies of missile launches from nearby White Sands.

The CDT is a 12.5-inch aperture Schmidt portable telescope with pointing capability that was used in 1990 and 1991 at the Rattlesnake Mountain Observatory in Washington for measuring the optical properties of known particles of orbital debris.

The Midcourse Space Experiment (MSX) observatory is a Ballistic Missile Defense Organization project which offers major benefits for both the defense and civilian sectors. The MSX program sponsored a series of blind searches for orbital debris in the negative ram direction (opposite to the velocity vector). This pointing direction should minimize the angular velocity of debris passing through the field of view of the instruments and provide favorable conditions for detecting small debris. The program is providing JSC with both visible light and IR data from these searches which will be analyzed at JSC.

Orbital Debris Protection - Conducting hypervelocity impact measurements to assess the risk presented by orbital debris to operating spacecraft and developing new materials and new designs to provide better protection from the environment with less weight penalty is a function of the Hypervelocity Impact Technology Facility (HIT-F).

Litter in space, or "orbital debris," predominantly consists of fragments from exploding upper-stage rocket bodies or satellites. Millions of objects the size of a B-B gun pellet are believed to orbit the earth, passing one another at speeds that average about 22,000 miles per hour. Because pieces of orbital debris remain in orbit for a long time, there is concern that high-speed collisions between such objects will eventually produce even more debris in Earth orbit, as well as pose a potential hazard to manned space flights. Orbital debris is a growing international problem that will require more attention as space operations increase. Our scientists are working on the options available to control, limit, and/or reduce the orbital-debris population. This work is described in detail in Orbital Debris: A Technical Assessment available on line through the National Research Council.

Orbital Debris Mitigation - Evaluating alternatives for controlling the risk to operating spacecraft, which includes both spacecraft protection and debris environment control. This activity is the focus of all of the other research areas. NASA has adopted a policy to control the generation of orbital debris in NASA Management Instruction 1700.8 and implemented this policy in NASA Safety Standard 1740.14. All NASA flight projects are now required to provide debris assessments as a normal part of the project development. A copy of the NASA Safety Standard 1740.14 can be downloaded from this site.

Also available on line: The National Science and Technology Council Committee on Transportation Research and Development Interagency Report on Orbital Debris.