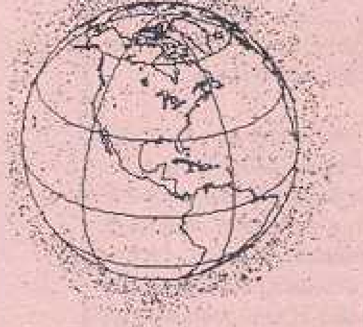
Orbital Debris Quarterly News



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NEWS

First Natural Collision Of Cataloged Earth Satellites

Nicholas Johnson

A French government spacecraft was damaged on 24 July when a fragment from a European Space Agency (ESA) Ariane rocket body collided with the spacecraft's gravity-gradient boom, severing the vital appendage in half. The incident marked the first time that two objects in the U.S. satellite catalog are known to have accidentally run into one another. Fortunately the collision, which occurred with a relative velocity of 14.8 km/s, produced only a single piece of debris, the upper portion of the gravity-gradient boom, large enough to be tracked.

Both objects were in nearly identical retrograde orbits at the time of the event. The CERISE spacecraft (Satellite Number 23606, International Designator 1995-033B) is a microsatellite of British design with a mass of only 50 kg, launched as a secondary payload with the multinational Helios 1A spacecraft on 7 July 1995. The orbit of CERISE prior to the collision was 663 km by 676 km at an inclination of 98.14°. The other participant in the encounter was Satellite Number 18208 (International Designator 1986-019RF) which was generated in November, 1986, when ESA's SPOT 1 rocket body broke up into nearly 500 tracked debris. The orbit of this fragmentation debris at the time of the collision was 660 km by 680 km at an inclination of 98.14°. The similarity of the orbits, whose orbital planes were separated by 167° in right ascension, created a situation of frequent close encounters prior to the impact.

The first observation of the collision debris by the U.S. Space Surveillance Network (SSN) occurred on 27 July when it had separated sufficiently from CERISE to be resolved as an independent object. Subsequent tracking by SSN sensors permitted the establishment of a preliminary orbit description, leading to official cataloging of the debris as Satellite Number 23994 within a few days.

On 6 August the Space Science Branch at NASA Johnson Space Center compared the orbit of the newly cataloged Satellite 23994 with those of the four previously known objects associated with the 1995-033 mission and found a likely relationship with CERISE. Using USAF Space Command's COMBO (Computation of Miss Between Orbits) program, a close approach of less than 1 km between Satellite 23606 and Satellite 18208 was determined to have taken place at 0948 GMT on 24 July over the southern Indian Ocean. NASA/JSC then contacted the Naval Space Operations Center (NAVSPOC) at Dahlgren, Virginia, to obtain confirmation of the analysis and to acquire background tracking data on Satellite 23994. NAVSPOC replicated the NASA findings and, using direct observational data and special perturbation theory, was able to refine the miss distance uncertainty to within 137m. In addition, NAVSPOC identified a minor perturbation in the orbit of Satellite 18208 which occurred about the time of the event.

The manufacturer of the spacecraft bus, Surrey Satellite Technology Ltd at the University of Surrey, United Kingdom, was contacted by NASA on 7 August with an inquiry about possible anomalous spacecraft readings which might indicate a collisional event. The company confirmed that CERISE had suffered a sudden, permanent change at 0948 GMT on 24 July. Their analysis of the attitude and moments of inertia of the spacecraft suggested that the 6m, gravity-gradient boom had been severed at 3.1-3.2

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The Orbital Debris Quarterly News

Inside...

NEWS

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meters from its base. The spacecraft remained operational, and attempts were underway to compensate for the degraded attitude control system.

This occurrence has underscored the advisability of examining in greater detail the circumstances surrounding so-called "anomalous events." Detected a few times a year on average, anomalous events usually are characterized by the separation of one or a few objects from a resident space object at a low velocity. Frequently, these objects exhibit high area-to-mass ratios and decay more rapidly than their parent satellite.

Historically assessed as possible satellite degradation products, some of these debris may originate from collisions between the parent satellite and small - cataloged or uncataloged - orbital debris. For example, the CERISE collision is reminiscent of the sudden loss of a portion of a gravity-gradient boom on an old U.S. DOD satellite several years ago.

Preliminary Post Flight Results - Space Flyer Unit Debris Impact Inspection

Joseph Loftus, Jr.

The Space Flyer Unit was retrieved on January 13, 1996 by STS 72 after having been launched 10 months earlier on the H-II on March 18, 1995. The SFU is Japan's first reusable unmanned platform for space science and technology experiments. Unfortunately the solar arrays were jettisoned because of a failure to latch. The body of the spacecraft was an octagonal structure 4.46 M in diameter and 30. M in height with a total exposed surface of ~146m^2.

The first month of the mission was devoted to infra-red celestial observations, thereafter the spacecraft was inertially oriented to the sun for the balance of the mission. The surfaces to be inspected are the aluminized MLI, silver teflon louvers and radiator, painted aluminum surfaces such as scuff plates and external panels, ~ 25m^2.

Initial inspection of 18m^2 logged 337 impact features greater than ~ 200μm. The three largest craters were: a 2.5 mm crater with delamination of the teflon out to 13.4 mm on the teflon coated aluminum of the IR telescope; a penetration on the edge of the MLI around the shade of the IR telescope with a hole diameter of 4.5 mm and torn parts extending >20 mm, and a 2.5 mm crater on the silver teflon radiator with a depth of 500 m, and a delamination zone of 10.5 mm.

The preliminary results are in good agreement with LDEF, EuReCa and Hubble. There are some unique materials combinations that have not been studied previously. Future plans provide for automated high precision inspection, chemical analyses and maintenance of a data archive consistent with LDEF and others. In the future digital images and spreadsheets of the preliminary data will be made available on the World Wide Web.

Major Satellite Breakup In June

Nicholas Johnson

The recent fragmentation of a small, 2-year-old upper stage has produced a record number of long-lived debris which are being tracked by the U.S. Space Surveillance Network (SSN). The incident occurred at 625 km, but debris is now spread throughout low Earth orbit (LEO), from 250 km to more than 2,500 km.

On 3 June 1996 a Pegasus Hydrazine Auxiliary Propulsion System (HAPS; International Designator 1994-029B; Satellite Number 23106), used by the STEP II mission on 19 May 1994, violently brokeup in an orbit of 586 km by 821 km with an inclination of 82.0°. Although the dry mass of the abandoned HAPS was estimated to be only 97 kg, by August the total number of debris identified and tracked by the SSN was approximately 700. This amount represents an order of magnitude more large debris than predicted by current explosion and collision breakup models. The debris were distributed in a highly symmetric manner about the breakup position in altitude, inclination, and apparent size. Two months after the event, only debris with very low perigees had experienced noticeable orbital decay.

The HAPS vehicle, which was employed for only the second time on the STEP II mission, failed to place its payload into the assigned, circular orbit due to a premature shutdown of the main propulsion system. After executing a contact avoidance maneuver, the 93-cm tall, 97-cm wide HAPS contained an estimated 5-8 kg of residual propellant. Since no passivation measures were undertaken, compressed nitrogen and helium for the attitude control and propellant pressurization systems, respectively, were also left on board. No range safety explosive package was carried, and the electrical system is believed to have been completely discharged at the time of the event.

The NASA Johnson Space Center is closely analyzing data from the SSN and the vehicle's manufacturer and vendors with three prime objectives: (1) to determine the cause of the fragmentation for the purpose of developing preventive measures on future vehicles, (2) to understand better the nature of the tracked debris and its implications for satellite breakup models, and (3) to assess the threat of the debris to operating spacecraft in LEO. Special observations of the HAPS orbital plane have been undertaken by HAX and Haystack to define more completely the smaller debris particles, particularly in the 1-10 cm diameter size regime. Attempts to observe the tracked debris with NASA's CCD Debris Telescope (CDT) have met with only limited success, supporting the hypothesis that the debris may be physically small with a high radar reflectivity. Of thirty-nine objects for which observations were attempted, only seven were observed.

This hypothesis might also explain the very large number of debris which are visible to the SSN and which appear to be larger than 10 cm in diameter. The use of composite tanks for the hydrazine, nitrogen, and helium fluids is under investigation as a potential source of such debris. The effects of the natural environment, particularly the flux of

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News on Upcoming Meetings

47th International Astronautical Federation (IAF) Congress

The 47th IAF Congress will be held in Beijing, China on October 7 - 11, 1996. There will be three orbital debris sessions as a part of the 29th Safety and Rescue Symposium (IAA.6). There have also been space debris sessions in the space law colloquia at these meetings in the past. For more information contact: The IAF Secretariat, IAF, 3-5 Rue Mario-Nikis, 75015 Paris, France.

The 2nd European Conference on Space Debris

The Second European Conference on Space Debris, organized by the European Space Agency, will be held in Darmstadt, Germany, March 17-19, 1997. Abstracts are due November 15, 1996. For more information, contact Professor Walter Flury, ESOC, Robert-Bosch-Str. 5, 64293, Darmstadt, Germany.

Meeting Report

ISTS Space Debris Synopsis

Susuma Toda and S. Deshpande (NAL)

The 20th ISTS (International Symposium on Space Technology and Science) was held from 19th May until 25th May in Gifu-shi, Gifu prefecture, Japan. This bi-annual event hosted some 800 attendees, presenting some 400 papers, including a poster session, on a variety of advances in Space Technology and Science.

Six main sessions were held over the 5 days in subjects varying from Propulsion, Materials and Structures, Astrodynamics, Navigation, Fluid Dynamics, Aero-thermodynamics, On-orbit and ground support systems and Space Transportation. On Tuesday 21st May sessions m-3 and m-4 concentrated on space debris, chaired by, C.R. Maag and Y. Suzuki, and W. Flury and V. Chobotov.

The m-3 session opened with a discussion given by W. Flury of ESA/ESOC outlining ESA's Space Debris activities and ESA's role in the Inter Agency Space Debris Co-ordination group. ESA's future plans include updating the current understanding of the debris population via increased modeling of the environment, hydrocode modeling of impact processes and the inclusion of impact data from the analysis of retrieved spacecraft. ESA has planned to observe the current population via radar installations in Germany and optical systems in Tenerife and to correlate with the current tracked population released via USSPACECOM.

Observational limitations on the detection of space debris were presented, including the use of a bistatic radar using satellite tracking stations and VLBI techniques as proposed by Takano et al, of ISAS. With the appropriate VLBI correlator such a system could measure objects down to 0.025 m^2 using the 20m diameter antenna at Kagoshima Space Center and the 64m receiver antenna at Usuda Deep Space Center. The utilization of a on-orbit observational satellite to measure the debris population was discussed by Takano et al from NASDA. A number of orbits were discussed that could allow the detection of all objects down to 1cm within a 2 year observational period. Such a system would utilize current CCD array formats using an optical lens system.

Reynolds and Kato compared the guidelines developed in the NASA Safety Standard 1740.14 and the NASDA Standard (NASDA-STD-18) and the associated assessment procedures required in each case. In general the NASA and NASDA guidelines complement one another, with NASA guidelines being more debris environment oriented and the NASA guidelines being more engineering oriented. The effort to limit orbital debris generation must be an international effort. If one program or country does not cooperate, all programs are put at risk. The cooperative effort between the United States and Japan presented in this paper seems to be a good example of what must be done in the future.

The m-4 session concentrated more on materials and the effects of space debris and impact damage in general. The most up-to-date information on the small particle environment was presented by Maag et al., of T&M Engineering, with the analysis of data from the currently active ICA payload, on the Mir space station. The results have once again opened the eyes of the orbital debris community to the problem of debris clouds intersecting spacecraft orbits. Mir has been bombarded by debris clouds with enhanced fluxes some 40-60 times larger than the background at a periodicity of some 6000 minutes. The consequence of such debris clouds plays an important role when we consider the International Space Station orbit will have a similar orbit to that of Mir. The monitoring of these debris cloud becomes even more pertinent when considering the expected large number of service EVA's required for station maintenance and for general station survivability.

The effects of secondary impacts generated from spacecraft structures was highlighted by Deshpande et al. of NAL in studying the chemical residues detected on a selection of HST solar array cells. The analysis points to the likelihood that the impactor was thermal control paint and that the HST was itself a generator of space debris, namely, thermal control paint from the Wide Field and Planetary Camera.

Apart from space debris, spacecraft are subjected to impacting particles from the natural micrometeoroid population. Neish, of NAL, discussed the need to better define the impact velocity and direction for such particles as these particles can cause more penetrative damage to spacecraft surfaces with their higher velocity and directionality. It is therefore important to be able to further characterize the meteoroid mass/velocity and direction properties in parallel with defining the space debris population.

Defining the current population is only one side of the problem. The other is the protection of future systems and the remaining papers discussed hypervelocity impact testing. The use and limitations of shaped charge impact testing were high-lighted by Kobayashi et al. of MHI, and the hole size and propagation of crack lengths were discussed by Schonberg et al., of University of Alabama / Huntsville, with respect to penetration of the Space Station module walls.

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Guest Article

U. S. Initiatives in the International Effort to Mitigate the Orbital Debris Environment

George M. Levin
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1988 TO 1992

NASA took the lead in carrying out the recommendations set out in the 1989 "Report on Orbital Debris," by the Interagency Group (Space) for the National Security Council (NSC). Initial activities were focused on achieving two major objectives: a) characterization of the LEO orbital debris environment, and b) raising the awareness of the spacefaring nations to the importance of understanding and mitigating the orbital debris environment.

Starting in 1990, NASA undertook an extensive program to measure and model the orbital debris environment using the Haystack Orbital Debris Radar in order to provide design requirements for the international Space Station. These data characterizing the orbital debris environment were also intended to provide the technical foundation for any future policies, standards and legal norms associated with orbital debris.

In response to direction from the NSC, NASA also took the lead in organizing bilateral meetings with the space agencies of the spacefaring nations to raise the awareness of these nations to the problems posed by orbital debris and to encourage cooperative debris research.

These early activities proved very successful in promoting both the coordination of orbital debris research and the early implementation of voluntary mitigation activities. These bilateral activities also set the stage for later multilateral international initiatives to measure, model, and mitigate the orbital debris environment.

As a result of these early bilateral discussions, the spacefaring nations recognized that the difficulties associated with understanding the orbital debris environment are too complex and too extensive for any one nation to undertake on its own. In addition, the ability to measure the orbital debris environment using different techniques and to model the orbital debris environment using differing assumptions or differing approaches has greatly improved the confidence placed in the results of these analyses. We also believe that these bilateral discussions are the major reason that recent radar measurements of the debris environment continue to show the results of voluntary debris mitigation measures.

1992 TO THE PRESENT

The Inter-Agency Space Debris Coordination Committee

By the end of 1991, it was recognized that the bilateral approach for coordinating orbital debris research had become too time consuming and too expensive. The time had come to initiate multilateral discussions. In October 1992, NASA, ESA and Japan met for the first time at NASA's Johnson Space Center and set the stage for the formation of the Inter-Agency Orbital Debris Coordination Committee (IADC).

In March 1993, ESA hosted a meeting of the IADC at their European Space Operations Center (ESOC) in Darmstadt, Germany. The ESOC meeting was also attended by members of the Russian Space Agency (RSA). In future meetings, the IADC membership grew with the addition of the Chinese National Space Agency (CNSA), the French National Space Agency (ONES), the British National Space Agency (BNSA), and the Indian Space Agency (ISRO).

The IADC was formed to: a) exchange technical information on space debris activities between the member agencies; b) facilitate opportunities for cooperation in space debris research; c) review progress of ongoing cooperative activities; and d) identify debris mitigation options.

The operation of the IADC is controlled by its Terms of Reference, first adopted by the member agencies in October 1993. These Terms of Reference were most recently revised in March 1996. The IADC is structured around a Steering Committee and four specialized Working Groups. The host of each meeting acts as the chair of the meeting.

Each member of the IADC is represented in the Steering Group. Each member must also be represented in Working Group 4 (Mitigation). Representation in the other Working Groups is desirable but not mandatory.

The Working Groups are focused on the following four areas:

1. Measurements

2. Environment and Data Bases

3. Protection

4. Mitigation

The Working Groups are composed of 2-3 experts from each member. Each Working Group has a Chair and Vice-Chair who are elected to serve for a term which includes two meetings. After the second meeting, the Vice-Chair automatically succeeds to the Chair and a new Vice-Chair is elected from the Working Group.

The National Research Council

As noted earlier, the period between 1988 and 1993 led to significant progress in an international understanding of the orbital debris environment as well as the issues associated with the generation of orbital debris. By 1993, NASA recognized that the technical findings in the U.S. Government's 1989 "Report on Orbital Debris" were dated. NASA felt it was time to revisit the issue - this time from an international perspective. NASA contracted with the Aeronautics and Space Engineering Board of the National Research Council (NRC) for an "Orbital Debris Technical Assessment Study." This study formally began in June of 1993. The study was performed by the NRC's Committee on Space Debris. This committee was chaired by Dr. George Gleghorn and consisted of: Dr. James Asay, Mr. Dale Atkinson, Dr. Walter Flury, Mr. Nicholas Johnson, Mr. Donald Kessler, Dr. Stephen Knowles, Prof. Dr. Dietrich Rex, Dr. Susumu

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Guest Article

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Toda, Prof. Dr. Stanislav Veniaminov, and Mr. H. Robert Warren.

The charter of the Committee on Space Debris called for their report to: a) characterize the current debris environment; b) project how this environment might change in the absence of new measures to alleviate debris proliferation; c) examine ongoing alleviation activities pertaining to space debris; d) explore measures to address the problem, including further research on debris monitoring and modeling, and methods to minimize space debris (including spacecraft design, shielding, collision avoidance, and disposal and deorbiting of upper stages and spacecraft); and e) develop a set of recommendations on the technical methods to address the problem of debris proliferation.

The NRC's Committee on Space Debris released their report entitled "Orbital Debris A Technical Assessment" in June 1995.

The United Nations Committee on the Peaceful Use of Outer Space

In February 1994, the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) met in Vienna. The issue of space debris was taken up for the first time in this forum. The STSC agreed with the position put forth by the United States and the other members of the IADC which called for a firm technical and scientific basis before any future legal action on the part of the United Nations. Most importantly the STSC agreed to the U.S. position that the United Nations should refrain from legal discussions of orbital debris until a technical consensus is reached.

In February 1995, the STSC adopted a multi-year plan to study orbital debris. The plan called for the first year to focus on measurements, the second year to focus on modeling, and the third year to focus on mitigation. At the end of the third year, the STSC plans to issue its report.

The STSC met most recently in February 1996 and heard reports on the orbital debris measurement programs of some of its member nations.

The International Telecommunication Union

In May 1992, the United States introduced a detailed analysis developed by NASA on the problem of the safing and disposal of geostationary satellites to the International Telecommunication Union. The U.S. proposal was a plan for the interim and long term management of the geostationary environment. This proposal required operators to raise the orbits of obsolete spacecraft 200-300 km above the geostationary arc and to eliminate stored energy sources from spent GEO-transfer stages and obsolete spacecraft. This proposal was accepted by Working Group 4. It is presently under review by Working Groups 7, 8, 10, and 11.

THE FUTURE

A number of international cooperative activities are presently in the formative stages under the auspices of the IADC. Listed below are some of these joint projects presently under consideration.

1. An exploratory international geostationary orbital debris observation campaign.
2. An investigation of space debris in the altitude range 800-1000 km.
3. A coordinated FGAN, Russia, and U.S. radar measurement campaign.
4. The development of joint data bases.
5. The development of a standardized protection data base.
6. The development of a plan for coordinating and sharing data on the reentry of risk objects.

SUMMARY

In the past decade, NASA and the national space agencies of the spacefaring nations have worked diligently to address the problems associated with orbital debris. More than ever, it is clear that close international cooperation is necessary for dealing effectively with orbital debris.

Since the 1989 report was issued, three important international developments related to debris have taken place. First, through NASA's efforts, an International Space Agency-level organization (the Inter-Agency Space Debris Coordination Committee) was formed to facilitate the exchange of technical research and information related to debris. NASA, Japan, ESA, RSA, CNSA, CNES, BNSA, and ISRO currently have agency-level representation on the Committee. Second, the United States introduced a detailed analysis on the problem of the safing and disposal of geostationary satellites to the International Telecommunication Union. Third, the United States joined consensus with other members of the Scientific and Technical Subcommittee of the United Nations Committee on Peaceful Uses of Outer Space to take up the subject of space debris as a formal agenda item.

The United States considers the development of technical cooperation and consensus to be a prerequisite for any potential international agreements, regulatory regimes or other such measures relating to orbital debris.

Spurred by the recognized need to maximize the safety of human space flight and to protect international space assets, NASA will continue to exercise its leadership role in understanding and mitigating the orbital debris environment.

Guest Article Submission Requirements

To submit an article to be considered for publication, please send it in machine readable format on diskette to C. Karpiuk, NASA Johnson Space Center, Mail Code SN3, Houston, Texas 77058 or via e-mail to karpiuk@snmail.jsc.nasa.gov. If possible, please send a hard copy of the paper to the mailing address above to assure that the electronic version was received unchanged.

PROJECT REVIEWS

Synergistic Use of EVOLVE/CHAIN Comparison

Robert Reynolds and Peter Eichler

Debris environment projections are of great importance for assessing the necessity and effectiveness of debris mitigation measures. Two significantly different types of models have been developed to model orbital debris environment evolution.

Evolve Model Background: EVOLVE was developed by Dr. Robert Reynolds at NASA/JSC as an evolution model that defines the environment as a time-varying ensemble of intact space systems and debris fragments each in an orbit and having mass, cross-sectional area, and other associated data. EVOLVE uses as input data the historical record of launch traffic (spacecraft, upper stages, and operational debris) and mission model data for future traffic, and uses breakup models to determine the distribution of debris fragments resulting from collisions or explosions occurring in orbit. The orbit propagator accounts for atmospheric drag and perturbations associated with the oblateness of the Earth (J2) and, for highly elliptical orbits, lunar and solar perturbations.

CHAIN Model Background: Because of the very high consumption of computer time and memory, debris evolution models like EVOLVE are not very well suited for long term (centuries or millennia) projections needed to study long term environment evolution including collisional cascading effects. An alternative approach is the Particle-in-a-Box (PIB) model, typified by the CHAIN model developed by Dr. Peter Eichler at the Technical University Braunschweig, and now used at NASA/JSC. CHAIN, which was developed specifically to study the problem of very long term environment evolution and collision chain reaction effects, reduces the debris environment to random elements in a set of size and altitude bins. Precise traffic models, breakup models, orbit propagation, and non-fragmentation source terms comparable to those used for EVOLVE are only used once in the preprocessing software to define rate coefficient and fit functions for CHAIN. By this the computer time required for environment projections can be reduced by about 3 orders of magnitude compared to a debris evolution model like EVOLVE.

There are advantages and drawbacks to each approach - EVOLVE is slow but can explicitly simulate essentially any conditions affecting debris environment evolution and is very good for calculating debris environment development over time scales of decades to perhaps some centuries. CHAIN is fast and well-suited to analyzing debris environment stability and orbital debris environment evolution over centuries or millennia, but the proper determination of the rate coefficients is essential and very difficult.

Having both types of models available within a single research group has proven to be extremely useful. A comparison of both models down to the module level lead to mutual improvements and validations. A 3-Step approach using both the EVOLVE and CHAIN model in a synergistic way was used to increase the reliability of long term environment projections. In Step 1 EVOLVE historical projections 1957-1995 could be validated by comparison to measurements. In Step 2 the traffic model in CHAIN, i.e. the initial conditions of 1.1.1995 and the yearly growth terms of the population in the different mass/altitude bins, could be adjusted to the results of EVOLVE for the first 100 years projection time. Very long term projections of CHAIN, based on the validated boundary conditions of EVOLVE can now be performed with a reasonable level of reliability in the basic tendencies of the results.

This synergistic interplay between the environment models is still developing. Future plans include more detailed analysis of the sensitivities of the basic tendencies of the results to uncertainties in major modeling parameters.

STS Flight Readiness Reviews

Mark Matney, Eric Christiansen and Albert Jackson, IV

For each Shuttle mission a Flight Readiness Review (FRR) report is prepared by the orbital debris group several weeks before the actual mission. (Preliminary estimate is now done ~1 year before launch) The purpose of the FRR is to provide information on potential encounters with orbital debris or period of unusually large meteoroid activity.

Flight planners want to know the hazard of collision with small orbital debris. This is computed using the debris fluxes from the Engineering Model environment and using the Bumper code to show how such collisions could affect the Shuttle. This danger is distilled into a probability of hazardous collision for each mission. What the Shuttle planners really want to know is if there have been any important changes in the debris collision hazard from other missions. Changes can result from flying the Shuttle at an unusually high altitude or if there has been a recent breakup that temporarily affects the debris flux at the planned orbiter altitude.

Flight planners also want to know the likelihood that they will be given a debris collision avoidance warning from US Space Command. Space Command monitors the environment of satellites larger than 10-20 cm and makes short-term predictions on their orbits. If, during the mission, their calculations show that a tracked object is going to fly through an imaginary box measuring 4km cross-range by 4km radially by 10km downrange centered on the Shuttle, they warn mission control, who then have to decide whether to maneuver the Shuttle to avoid the object. Because the FRRs are prepared several weeks in advance of the mission, it is too early to know which satellites will actually trigger a warning. It is, however, possible to compute statistically what the chances of an encounter will be, and this is the information provided to the planners.

Finally, flight planners want to know if any meteor showers or predicted meteor storms may increase the natural hazard significantly over background levels. Interest in transient meteor activity greatly increased in 1993 when the flight plans for STS-51 were changed on short notice to avoid a possible storm from the annual Perseid meteor shower. While a meteor storm did not occur, it was decided that in the future the Shuttle program should be forewarned of potential storm activity and how it might affect orbiter safety.

Haystack Radar Measurement of the Orbital Debris Environment

Thomas Settecerri, Eugene Stansbery and Mark Matney

The Haystack radar has been observing the orbital debris environment since 1990 using a staring operational mode. Data have been collected at 10° and 20° elevations pointing south and at 90° elevation (vertical). In 1994 two new data collection windows were added: Data were collected at 75° elevation pointing east and at 20° elevation-extended range which collected data at higher altitudes than previously collected at this elevation angle.

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PROJECT REVIEWS

(Continued from page 6)

Four important issues have arisen with the analysis of Haystack data since the last report issued May 20, 1994. First, an error was recently discovered in the software used to select and plot results from the Radar Performance Model in the 1994 report. This error had the effect of exaggerating the difference between Haystack data and the results of NASA's 1991 Engineering Model. The correction of this error does not change any of the qualitative results of that report.

Second, the data reveal a large population of debris between 850-1000 km. altitude in an inclination band between 60° and 70°. The size of most of debris is less than 3 cm diameter and the polarization returns indicate that the shape of this debris is spherical. We believe that these debris may be small droplets of liquid metal coolant leaking out from the thermoelectric nuclear reactors which were separated from the Russian Radar Ocean Reconnaissance Satellites (RORSATs) at the end of their useful lifetime. Environment models show that the number of particles observed by Haystack is consistent with this source using reasonable assumptions of the amount of coolant available.

Third, the fragmentation of COSMOS 1484 (which occurred in October 1993) has increased the small debris population in the 500 km altitude regime to the levels measured in 1990 and 1991. Debris in the orbit plane of this sun synchronous satellite can clearly be seen when data collected from Haystack during December, 1993, is plotted as a function of time of day. However, other analysis concluded that this was a minor fragmentation of an ammonia tank and that the bulk of the satellite apparently remains intact so this investigation continues.

Fourth, the 75° East staring data has been analyzed by looking for debris families that might be associated with individual breakups or groups of breakups. The analysis of the size distributions from these data might provide insight into the causes of the breakups. An additional important result from the analysis is that the count rate or flux of pieces detected by Haystack smoothly merges with the USSPACECOM catalog of tracked objects in the same orbits.

Implications for spacecraft designers:

The increase in the debris environment at 500 km altitude is the result of a minor fragmentation; which may illustrate how easily the environment can degrade. It should also illustrate the need for spacecraft designers to include mitigation efforts in satellite launch vehicle designs to prevent breakups. However, the next solar maximum should cleanse these debris from orbit.

Implications for future measurements:

The Haystack measurements have provided orbital debris researchers with two important new tools for characterizing the debris environment and for developing methods for mitigating the future environment: (1) the ability to detect small debris from previously unknown sources; and (2) the ability to examine size distributions from cataloged objects to objects smaller than 1 cm diameter. Haystack has also shown that the debris environment is dynamic and can change rapidly. Therefore, continued monitoring of the debris environment to sizes below 1 cm should be continued.

Annual copies of the Haystack data analysis report are available as NASA technical reports. For copies, contact Gene Stansbery at NASA Johnson Space Center, Mail Code SN3.

Optical Observations of GEO Debris

David Talent

The large set of debris data on objects resident in GEO currently exists at JSC as a result of a program of observation, reduction, and analysis of 252 hours of data obtained on 42 clear nights during 5 observing runs to Mt. Haleakala on Maui, HI between December, 1992 and April, 1994. During these observing runs, using the portable JSC CCD Debris Telescope (CDT) that has a 1.8 x 1.2 degree field of view, a total of 14375 CCD images were obtained -- including bias, flat fields, and standard star fields. The total number of GEO CCD data images was 13516; since two images were obtained of each field, this means 6758 separate fields were observed. At 442.4 Kby for each image, the total amount of data recorded was 6 Gby.

Orbiting objects were detected in 27.7% of the 6758 fields - 17.2% had a single object in the field, 9.96% had two objects in the field, and 0.005% had three or more. All of the data have been examined in detail during several thousand hours of reduction and analysis effort. Identifications, as complete as possible with the U.S. Space Command unclassified element set catalogs available at JSC have been made, and the preliminary suggestion is that about 20% - 30% of all objects observed are candidates for uncorrelated targets (UCTs). A copy of the complete data set has been sent to Air Force Space Command whose additional input will be used in preparing the final report on this observing campaign.

Meanwhile, new observations are planned with the CDT telescope at Cloudcroft, NM. New hardware - an AXIOM AX-7 camera - and software - MIRA PRO S/L - are on order. These changes to the CDT are expected to reduce the limiting magnitude for the CDT by at least 1.5 magnitudes, pushing the system limit to objects as faint as 18.5 magnitude.

EVOLVE Review and Breakup Modeling Update

Anette Bade

The last systematic review of EVOLVE processing and the breakup models it uses was conducted in 1989, prior to the last peak in the solar cycle. Comparisons with the catalog made at that time were favorable. Since that time non-operational objects in orbit should have experienced considerably more interaction with the atmosphere and we would expect that this review should give us a better understanding of the ballistic coefficients of objects in orbit.

To review and improve the breakup models, JSC has been conducting a detailed comparison of catalog data on specific breakups with predictions from the current breakup models. Sixteen significant breakup events, including both low- and high-intensity explosions and collisions, have been simulated in the EVOLVE program and compared to two-line element (TLE) data. The earliest reasonably complete TLE data set for each breakup have been used to compare as closely as possible with initial conditions of the model. To get an insight into the time history of the fragmentation debris and the fidelity of the propagation in EVOLVE, snapshots of the debris were taken at intervals of every few years to compare the distributions in apogee and perigee altitude, inclination, and size. Preliminary indications from the analysis are that the breakup models are predicting too few large objects and that the area to mass ratio, indicated by evidence of greater atmospheric drag effects in the catalog data, for these fragments need to be systematically increased.

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PROJECT REVIEWS

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In addition to the investigation of single breakup events the total EVOLVE population is being compared to the catalog by type of object - payloads, rocket bodies, fragment-ation debris, and operational debris - both for the current environment and for historical environments. We are expecting that rocket bodies, which have relatively simple structure and well known initial decay orbit, should be modeled quite well. Payloads, which have more complex structure and often have stationkeeping, are not expected to be modeled as well, and the results of this investigation might indicate a change in the way EVOLVE treats these objects.

Based on the results of the investigations decisions will be made on updates to the EVOLVE model and the breakup models. When the update is completed the results will be published as a NASA technical report.

New Engineering Model Status

Jing Chang Zhang

The new engineering model (ORDEM96) wasdeveloped at NASA Johnson Space Center and released for review in February of this year. More than 20 international orbital debris experts from ESA, Russia, Japan, China, NASA and other U.S. organizations were invited to participate in the testing and verification phase from March through May. Numerous helpful comments and suggestions were received which are now being incorporated. We wish to thank all the individuals who sent in their comments, especially those who found errors in the document or the software. We will release the model for general use this fall.

Modification of a High Speed Propagator and Their Influence On The LEO And GEO Environment

Karl Siebold and Albert Jackson, IV

The objective of this study was modify the existing high speed orbit propagator developed by Siebold for using in the EVOLVE orbital debris environment evolution model so that is calculated the evolution of Molniya type orbits. Molniya type orbits are defined to have initial inclinations near 63.5°, eccentricities of 0.6 and larger, and apogee altitudes of 30000 km and higher. As is well known, these type of orbits can be highly unstable, experiencing large changes in eccentricity that can cause the objects to move out of the low Earth orbit (LEO) environment or to dive into the lower atmosphere and be lost from orbit.

The interaction of Lunar/Solar perturbations, which change the inclination and eccentricity of these orbits, with the J2 gravitational perturbations of the Earth's oblateness, which causes the argument of perigee to precess, and with the Earth's atmosphere, have been examined. The question whether or not perigee stays in the southern hemisphere have been studied for several objects currently in orbit. Orbital debris issues such as the interference by objects in Molniya type orbits on the LEO and the Geosynchronous (GEO) environment are being considered. In order to perform this study a high speed orbital propagator has been developed that models both eccentricity and inclination changes induced by the Lunar/Solar perturbations.

Results using this propagator are being compared with measurements of cataloged objects and compared with the Everhart integrator, a validated numerical integrator of the equations of motion for an orbiting object. A final report on the first phase of this project, in which the propagator results are compared and compared with catalog data, is planned for September. A report on analysis or breakup in Molniya type orbits is expected in Spring, 1997.

MSX/SBV -- Waiting For Our First Data Of Debris In Situ

David Talent, Faith Vilas, and Phillip Anz-Meador

The basic data analysis software has been completed to analyze image data to be returned from the Midcourse Space Experiment (satellite platform in circular orbit at 888 km altitude and inclination equals 99°) / Space-based Visible Telescope (a six inch diameter f/3 telescope with 6.6° x 1.4° FOV buttable array of CCD chips. (MSX/SBV) sensor. Among the objectives of the activity is the assessment of orbital parameters of observed objects based on circular orbit assumptions and time-tagged angles only data. It is expected that known objects observed will serve as a verification of the technique for determining the orbital parameters. The development of this analysis package was expedited by work that had been done on the Debris Collision Warning Sensor (DCWS) flight experiment, a JSC project currently on hold after going through to detailed design. JSC is looking to the MSX project as a means of getting high quality in situ orbital debris data as well as a partial proof of concept for a DCWS-like sensor.

The NASA/JSC program includes two proposed programs: (1) SU-11: Debris Detection and characterization and (2) SU-12: Ram/Anti-Ram observations.

The Haystack Orbital Debris Analysis System

Thomas Settecerri

Work continues on the Orbital Debris Analysis System (ODAS) which is used to process the Haystack/HAX data.

The ODAS code is a FORTRAN based system with a proC shell that reads and writes from/to an ORACLE database. X-windows is the user interface. The original code was written by Xontech Inc. in 1989-90.

The two Orbital Debris Radar Calibrations Spheres (ODERACS) space flight experi-ments managed by the JSC Space Science branch were designed to verify the Haystack radar calibration and validate the ODAS software. The ODERACS experiments verified that the absolute calibration of the Haystack radar was within 1dB and the orthogonal polarization channels were within 0.5dB of each other.

Several problems were discovered in ODAS - software bugs and processing procedures - were discovery by the ODERACS experi-ment. Since that time, a new algorithm was developed to better estimate the range, range rate, and amplitude for each pulse, software bugs were corrected, and new processing procedures were implemented.

During this same time period the data processing hardware and system software were also upgraded. The new hardware and operating system were not completely compatible with FORTRAN, ProC, X-

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ABSTRACTS FROM PAPERS

The NASA Engineering Model: A New Approach

Jing Chang Zhang, Donald Kessler, Mark Matney, Peter Eichler, Robert Reynolds, Phillip Anz-Meador and Eugene Stansbery

A computer-based semi-empirical orbital debris model has been developed which combines direct measurements of the environment with the output and theory of more complex orbital debris models. It approximates the environment with 6 different inclination bands. Each band has a unique distribution of semi-major axis, for near circular orbits, and a unique perigee distribution, for highly elliptical orbits. In addition, each inclination band has unique size distributions which depend on the source of debris. Collision probability equations are used to relate the distributions of orbital elements to flux on a spacecraft or through the field of view of a ground sensor. The distributions of semi-major axis, perigee, and inclination are consistent with the U.S. Space Command catalogue for sizes larger than about 10 cm, taking the limitations of the sensors into account. For smaller sizes, these distributions are adjusted to be consistent with the flux measured by ground telescopes, the Haystack radar, and the Goldstone radar as well as the flux measured by the Long Duration Exposure Facility (LDEF) and the Space Shuttle. The computer program requires less than 1 second to calculate the flux and velocity distribution for a given size debris relative to an orbiting spacecraft.

Presented at the31st COSPAR Scientific Assembly, Birmingham, United Kingdom, 14-21 July 1996, Paper No.: B0.7-0015

Lessons Learned from the Comparison of EVOLVE and CHAIN

Robert Reynolds and Peter Eichler

EVOLVE and CHAIN are two models for the projection of the orbital debris environment. They were developed independently using very different conceptual approaches. Consequently, their comparison has proven to be valuable for validating the debris environment projections for both programs. The project to use EVOLVE and CHAIN to validate one another and to develop a complementary use of the two codes has been documented in a series of papers. The early papers in this series were focused on a comparison of results for environment projections over the next 100 years. These comparison produced relatively minor changes (and improvements) in both programs that could be explained by conceptual differences designed into the original codes. Later papers in the series focused on using EVOLVE to establish rate coefficients to be used by CHAIN for longer term environment projections.

In this paper we will review the new understandings that have resulted from these efforts. We will also extend the work on establishing an improved method for using EVOLVE to set conditions for long-term CHAIN environment projections and use this new work to begin investigating the sensitivity of the environment projections to aspects of collisional breakup models that currently are, and in the foreseeable future will continue to be, severely short of data.

Presented at the 31st COSPAR Scientific Assembly, Birmingham, United Kingdom, 14-21 July 1996, Paper No.: B0.7-0029

Issues Arising from the NASA Safety Standard to Control Orbital Debris

Robert Reynolds, Joseph Loftus, Jr. and Donald Kessler

In 1992 NASA adopted a policy to limit the generation of orbital debris. This policy is stated in NASA Management Instruction (NMI) 1700.8, and provides a general statement of policy to take action to limit orbital debris generation if this action is cost effective and consistent with achieving mission objectives. The only specific requirement in the policy is to perform debris assessments during development of NASA programs. To implement this policy, the NASA Office of Safety and Mission Assurance, the sponsor of NMI 1700.8, tasked NASA Johnson Space Center (JSC) with developing guidelines to implement the policy. This tasking resulted in the development of NASA Safety Standard 1740.14: Guidelines and Assessment Procedures for Limiting Orbital Debris.

The Safety Standard has been reviewed and approved by all NASA organizations and NASA programs are now required to perform two debris evaluations, one at Preliminary Design Review (PDR) and a second 45 days prior to Critical Design Review, once the final space system design has been approved. The purpose of the first report is to identify potential problems that a program may encounter in meeting the guidelines, and the second report is to document efforts by the program to resolve those problems.

At this point in time, a primary concern by NASA managers has been the issue of postmission disposal of low Earth orbit systems and upper stages left in high eccentricity orbits. These systems in general wish to deorbit using atmospheric drag to limit the remaining orbit lifetime to 25 years, as stated by the guidelines. To address this issue, JSC has started a series of studies to investigate the most efficient options for reducing orbit lifetime.

In this paper we will review issues raised by the NASA community and the responses that have been made to resolve concerns. Two studies that were designed to minimize costs for postmission disposal will also be discussed in this paper. The first investigates options for disposal maneuvers of upper stages that minimize the cost

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ABSTRACTS FROM PAPERS

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impact on upper stage development. The second investigates options for high altitude low Earth orbit satellites (e.g. Sun-synchronous spacecraft) that have no significant on-board propulsion.

Presented at the 31st COSPAR Scientific Assembly, Birmingham, United Kingdom, 14-21 July 1996, Paper No.: B0.7-0027

Economic Analysis Requirements in Support of Orbital Debris Regulation Policy

Joel Greenberg, Princeton Synergetics, Inc.

As the number of Earth orbiting objects increases so does the potential for generating orbital debris with the consequent increase in the likelihood of impacting and damaging operating satellites. Various debris remediation approaches are being considered that encompass both in-orbit and return-to-Earth schema and have varying degrees of operations, cost, international competitiveness, and safety implications. Because of the diversity of issues, concerns, and long-term impacts, there is a clear need for the setting of government policies that will lead to an orderly abatement of he potential orbital debris hazards. These policies may require the establishment of a supportive regulatory regime.

The Department of Transportation has regulatory responsibilities stemming from its charge to protect the public health and safety, safety of property, and national security interests and foreign policy interests of the United States. This paper will discuss DOT's potential regulatory role relating to orbital debris remediation, the myriad of issues concerning the need for establishing government policies relating to orbital debris supportive regulatory regime.

The Department of Transportation has regulatory responsibilities stemming from its charge to protect the public health and safety, safety of property, and national security interests and foreign policy interests of the United States. This paper will discuss DOT's potential regulatory role relating to orbital debris remediation, the myriad of issues concerning the need for establishing government policies relating to orbital debris remediation and their regulatory implicatio ns, the proposed technological solutions and their economic and safety implications. This paper will also address cost-effectiveness and economic analyses as they relate to economic impact analysis (EIA) in support of regulatory impact analysis.

Presented at the 1996 SPIE Conference in Denver, Colorado

Meeting Report

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The ISTS sessions have reiterated the need for agreement between data sources and mitigation standards that all space faring nations can agree and adhere to, and in particular to minimize the production of space debris. It is also clear that in the age of the ISS there is an increased need for a global monitoring system that incorporates not only ground based observational systems but also in orbit monitoring of the small particles, as detected on the Mir Space Station.

The proceedings of selected papers will be published in September, 1996. The 21st ISTS will be held in Ohmiya, Japan, in 1998.

The International Free Flyer Workshop and the DCWS Project

D. Talent and F. Vilas

JSC attended the International Free Flyer Workshop held May 13 - 15 at the University of Maryland Conference Center in College Park, Maryland. The purpose of the conference, sponsored by NASA, was to explore the scientific and technical merit of the free-flyer program that might be associated with the International Space Station. Platforms of this type would use the ISS as a service station from which they could conduct repeated operations in the LEO environment following servicing or upgrades. A presentation was made suggesting that an upgraded version of the Debris Collision Warning Sensor (DCWS) experiment might be a suitable candidate to fly on the Free Flyer platform which would originate at, and return to the International Space Station. A number of attendees showed interest following the presentation and plans for further investigation of this option are planned.

Editor's Note

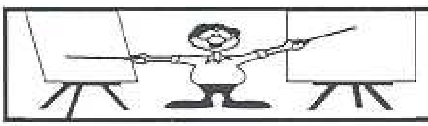
We have gotten off to a good start with the newsletter. After the first issue went out we received a number of requests for additional "subscriptions" and many address changes. We also received several contributions from our readers. Please keep us informed of address changes and let us know if you have news you'd like to share with the other readers.

This last quarter has been very busy for those of us interested in orbital debris. Perhaps most important has been the confirmed collision between 2 cataloged objects - an event predicted by Don Kessler 15 years ago to happen about now. This is our lead story. The breakup of the Pegasus hydrazine auxiliary propulsion system (HAPS) unit has surprised us all with the number of cataloged fragments for the small amount of mass that must be involved. The first debris measurements have been taken from the MSX satellite, and we are looking forward to reporting results from that project in the next newsletter. There are plans to use the Haystack radar in new ways during the next year, looking in the plane where solid rocket motor firings or breakups have occurred to get better data on specific debris sources.

We would like to thank two guest contributors for this issue. George Levin, the Program Manager for Orbital Debris at NASA Headquarters (Code M) has provided a report on results of the interagency conference held in Houston in May to act on the recommendations from the Interagency Report on orbital debris released by OSTP last Spring. Dr. Susumu Toda and S. Deshpaude of the National Aerospace Laboratory have provided an excellent review of the two orbital debris sessions in the 20th International Symposium on Space Technology and Science (ISTS) held in May in Gifu, Japan. Dr. Toda is the head of the Japanese delegation to the Inter-Agency Space Debris Coordination Committee and an organizer of that conference. We would also like to thank Dr. Joel Greenberg of Princeton Synergetics for his abstract for a paper on economic issues for orbital debris mitigation.

DEADLINE!!

The deadline for submitting articles to be considered for inclusion in the next issue is November 1, 1996. Please send the document in machine readable format on diskette to Cindi A. Karpiuk, NASA Johnson Space Center, Mail Code SN3, Houston, Texas 77058 or via e-mail to karpiuk@snmail.jsc.nasa.gov.



PROJECT REVIEWS

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windows, or our peripheral devices, and we continue implementing software interface fixes and testing to return to normalcy. We expect to begin processing in September.

Our analyses have determined that a random phase bias exists in the radar difference channels. This has added an extra analysis and processing step to our procedures to first determine if a phase bias exists and if necessary correct it. This step occurs before determining the orbital debris' path through the beam.

Our current plan is to re-process 1995 Haystack and 1994 HAX data first, and then process the 1995 and 1996 HAX and 1996 Haystack data. Once this is completed we will examine the 1992 - 94 Haystack data to determine if reprocessing is necessary.

NEWS

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micrometeoroids, on the HAPS is being evaluated as a possible cause for the breakup, while other man-induced scenarios, e.g., collision with a small piece of orbital debris or HAPS equipment failure, are also being examined.

Since 1961 at least 135 satellites (about 3.5 % of all space missions) have been involved in on-orbit fragmentations. Approximately 40% of the official US satellite catalog are fragments from these breakups. One of the major sources of breakup debris are the more than 55 rocket bodies which have disintegrated, 90% after successfully fulfilling their payload delivery missions. To date, rocket bodies developed in the US, ESA, Russia, Ukraine, Japan, and China have experienced on-orbit fragmentations.

Acquisition of New CCD Camera at JSC

David Talent

A frame-transfer video rate CCD camera that provides either RS-170 or digital output has been received at NASA-JSC. This system is suitable for use with the LMT; it also may be employed for meteor observations -- perhaps in a co-sensor mode with radar system.

Check the desired box, complete form and mail to C. Karpiuk, NASA Johnson Space Center, Mail Code SN3, Houston, Texas 77058 email - karpiuk@snmail.jsc.nasa.gov

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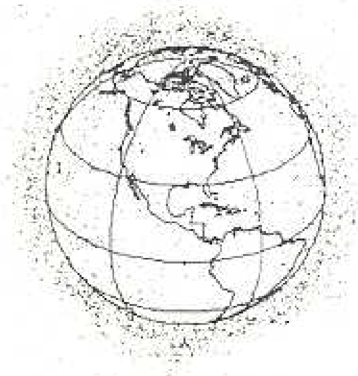

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NEXT ISSUE

- **Report on COSPAR/IAF Activities**
- **First Report on the MSX Data**
- **Report on HAX Radar**
- **Implementation of the NASA Policy to Limit Orbital Debris Generation**
- **Report on the Liquid Metal Telescope (LMT)**

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