ACTIVITIES ON SPACE DEBRIS IN U.S.

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ABSTRACT

In the U.S. space debris activities are addressed at all government levels, from the Executive Office of the President to the individual federal agencies to specialized centers, laboratories, organizations, and research groups. U.S. Space Policy specifically challenges government agencies to seek to minimize the creation of space debris and to promote debris minimization practices, both domestically and internationally. A set of space debris mitigation standard practices has been developed and adopted by relevant U.S. government agencies, and their application by the commercial aerospace community is highly encouraged. A growing number of U.S. government agencies have issued their own space debris mitigation policies, directives, regulations, and standards.

Space debris research, including the definition and modeling of the current and future near-Earth space environment and the development of debris protection technologies, is principally conducted by NASA and the Department of Defense. The U.S. Space Surveillance Network continues to provide the most complete and timely characterization of the population of space debris larger than 10 cm. During the past several years major advancements have been achieved in extending this environment definition in LEO to include particles as small as only a few millimeters. The inspection of returned spacecraft surfaces continues to shed light on the even smaller debris population. With improvements in computer technology, new and more capable programs have been and are being developed to solve a number of operational and research problems.

Finally, the academic and industrial sectors of the U.S. are also increasing their participation in and contributions to space debris operations and research. The cooperation of spacecraft and launch vehicle developers and operators is essential to the U.S. objective of promoting the preservation of the space environment for future generations.

1. INTRODUCTION

Space debris issues and activities in the U.S. are normally separated into two fundamental categories: natural debris and orbital debris. The former includes asteroids, comets, meteoroids, and cosmic dust, which are natural objects in orbit about the Sun or are transiting the solar system. U.S. research on these bodies and particles has been and continues to be extensive with increased attention paid in recent years to Near-Earth Objects (NEOs), which pose potential collision threats to the Earth. The second category, which is the subject of this paper, consists of the multitude of both small and large artificial, i.e., man-made, debris in orbit about our planet. These orbital debris are the subject of considerable efforts by agencies of the U.S. government, by industry, by academia, and increasingly by the general public.

2. U.S. GOVERNMENT

2.1 <u>Interagency Activities</u>

President Ronald Reagan's update of the U.S. National Space Policy on 5 January 1988 was the first White House declaration to address specifically the topic of orbital debris and to recognize the need for its mitigation to preserve near-Earth space for future generations. This Presidential decree affirmed that

> "All space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness."

Succeeding national space policies by the Bush Administration (16 November 1989) and by the Clinton Administration (14 September 1996) expanded upon this directive. During 1988 under the auspices of the Interagency Group (Space), a working group on orbital debris led by NASA and the Department of Defense (DoD) and including representatives of many other

Proceedings of the 3rd European Conference on Space Debris, ESOC, Darmstadt, Germany, 19 - 21 March 2001
(ESA SP-473, August 2001)

federal agencies prepared the first national assessment on orbital debris. Issued on behalf of the President's National Security Council in February 1989, this document [1] surveyed the nature of the debris environment as well as policies related to it. An orbital debris program process (Fig. 1) was developed.

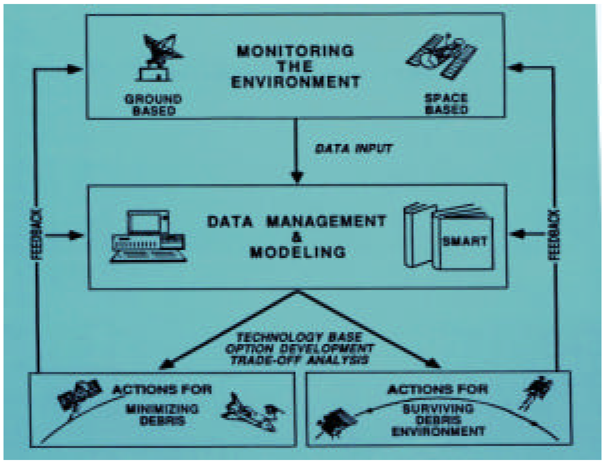

Fig. 1. The Orbital Debris Program Process from the Report on Orbital Debris, 1989.

One of the many recommendations of this report included the retention of an Interagency Working Group on Orbital Debris "as a coordinating mechanism for issues, policies and activities concerning the orbital debris problem". This working group continues today to be the principal forum for periodic reviews of orbital debris activities and issues. Currently led by the White House Office of Science and Technology Policy, this working group includes representatives from NASA, DoD, the Department of State, the Department of Transportation (DoT), the Department of Commerce, the Federal Communications Commission (FCC), the Department of Justice, and other White House offices.

The Interagency Working Group on Orbital Debris prepared a revised assessment of orbital debris in 1995 [2] with five recommendations primarily directed to NASA, DoD, and the Department of State. These recommendations have guided federal research and policy initiatives on orbital debris up to the present:

(1) continue and enhance debris measurement, modeling and monitoring capabilities,
(2) conduct a focused study on debris and emerging LEO systems,
(3) develop governmental/industry design guidelines on orbital debris,
(4) develop a strategy for international
(5) review and update U.S. Government policy on debris.

In response to Recommendation 1, a NASA-DoD Working Group on Orbital Debris was established in 1997 with an emphasis on debris measurements and modeling. Also in 1997, NASA and DoD developed the first U.S. Government Orbital Debris Mitigation Standard Practices, which were subsequently presented to U.S. industry in January 1998 along with a special assessment of debris issues for LEO constellations. The Interagency Working Group on Orbital Debris also served as a forum for developing national and international strategies on orbital debris, including U.S. participation in the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations' Committee on the Peaceful Uses of Outer Space.

In addition, *ad hoc* interagency working groups have been established to address special interest topics related to orbital debris. For example, in 2000 when plans were being prepared to decommission the commercial Iridium satellite constellation, the Department of Justice led an *ad hoc* interagency working group to evaluate the consequences, including risks to people on Earth, of and alternatives to the disposal of the 74 controllable spacecraft. Some of these meetings also included representatives from pertinent industry. During the past few years another *ad hoc* interagency working group monitored plans for the disposal of the Russian Mir space station and coordinated efforts for U.S. preparations, including the tracking of Mir and potential reentry observations.

2.2 <u>NASA</u>

The NASA orbital debris program, centered at the Lyndon B. Johnson Space Center in Houston, Texas, has led U.S. orbital debris research for a quarter of a century [3]. This multi-faceted program spans the entire spectrum of orbital debris activities from environment characterization (all altitudes and all sizes; past, present, and future) to understanding the effects and consequences of hypervelocity impacts to the improvement of shielding designs to the development of spacecraft and launch vehicle designs and operations for the curtailment of the growth of the orbital debris population.

NASA's orbital debris monitoring research complements that of DoD by concentrating on debris normally not seen by the U.S. Space Surveillance Network (SSN), i.e., objects less than 10-30 cm in LEO and less than 100 cm near GEO. During the past decade, NASA has been able to discern with significant confidence the nature of the

0.5 and 10 cm. These objects, due to their sheer number and relative energy, constitute the greatest threat to operational spacecraft, both manned and robotic. Every year NASA collects more than a thousand hours of near-Earth debris observations using the only can the size of the impactor often be determined, but also its composition can usually be ascertained. Shuttle window inspections first identified the existence of a large population of small paint particles in Earth orbit.

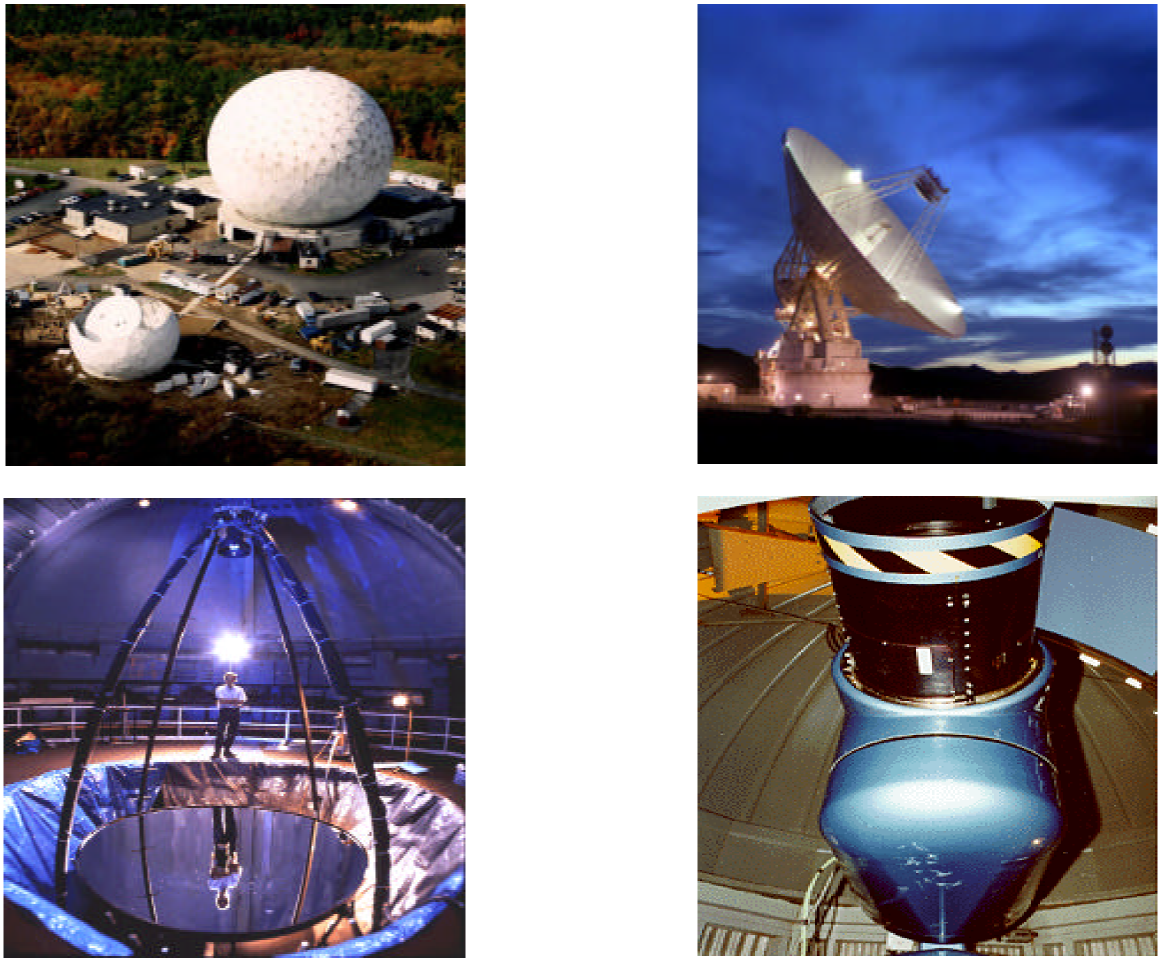

Fig. 2. Principal NASA radars and telescopes used for monitoring the debris environment.

Haystack, Haystack Auxiliary, and Goldstone radars, the Liquid Mirror Telescope (LMT), and the CCD Debris Telescope (CDT) (Fig. 2). These efforts led to the discoveries of a large population of sodium-potassium droplets in LEO as well as a large population of small debris near GEO.

The small (<1 mm) orbital debris environment in LEO is monitored by the examination of spacecraft surfaces which have been returned to Earth. Each Space Shuttle mission affords an opportunity to inspect more than 200 m^2 of surface area for small particle impact sites. Not

Similar examinations of components of the Long Duration Exposure Facility (LDEF), the Hubble Space Telescope, the Mir space station, the Solar Maximum Mission satellite, and others have yielded valuable debris information. NASA photographic surveys of the Hubble Space Telescope (Fig. 3) and the Mir space station have also proved useful. A pioneering experiment, the Orbital Debris Collector (ODC), exposed samples of low-density aerogel to the space environment for many months for the purpose of capturing, relatively intact, small debris particles (Fig. 4).

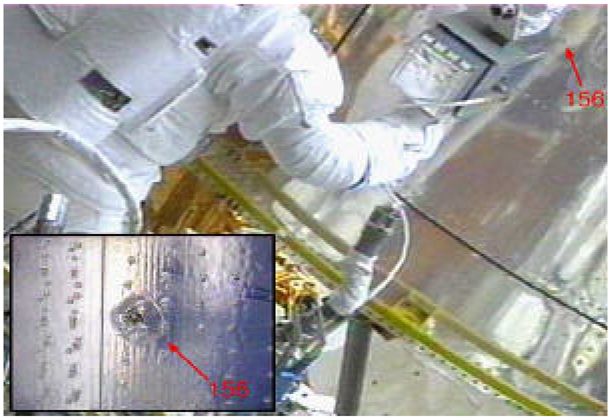

Fig. 3. Debris impacts seen during the second Hubble Space Telescope servicing mission.

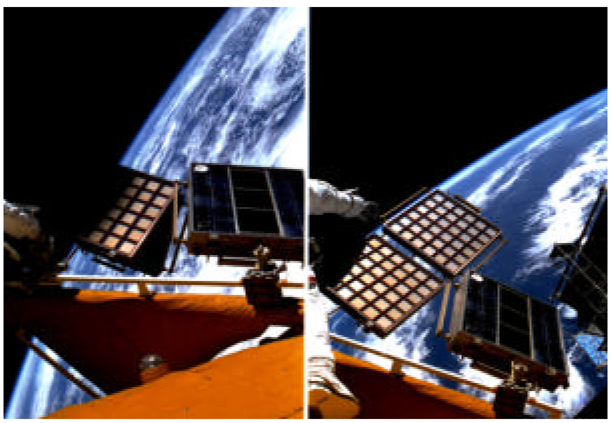

Fig. 4. NASA Orbital Debris Collector and captured sample.

Perhaps the best know of NASA's orbital debris research capabilities are its engineering and evolutionary models [4]. The former is normally used to evaluate the debris threats to spacecraft and orbital stages today and in the near-term, while the latter is beneficial in assessing the effectiveness of various debris mitigation policies and practices through the long-term. From relatively simple relationships developed in the 1980's, NASA's engineering models have grown in complexity and, more importantly, in accuracy as a result of its measurement programs (Fig. 5), culminating in the ORDEM2000 model.

NASA's EVOLVE program, updated to Version 4.0 in 2000, permits studies of possible long-term evolutionary scenarios of the orbital debris population in LEO. A sister model, GEO_EVOLVE, addresses the much higher geosynchronous regime. These Monte Carlo simulations, including subroutines for past and future space traffic, solar activity, orbital perturbations, and satellite breakup debris generation, are valuable in

policies, e.g., satellite passivation and satellite disposal. Quantitative results are usually less important than the identification of evolutionary trends and parameter dependencies (Fig. 6). The EVOLVE and GEO_EVOLVE programs can also aid in cost-benefit analyses for different orbital debris mitigation practices.

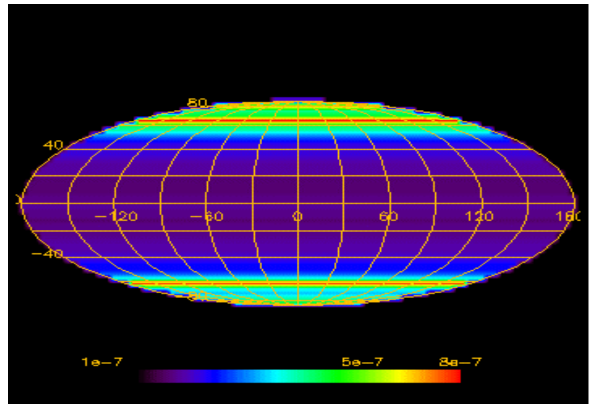

Fig. 5. Orbital debris spatial density for the 800-850 km altitude regime.

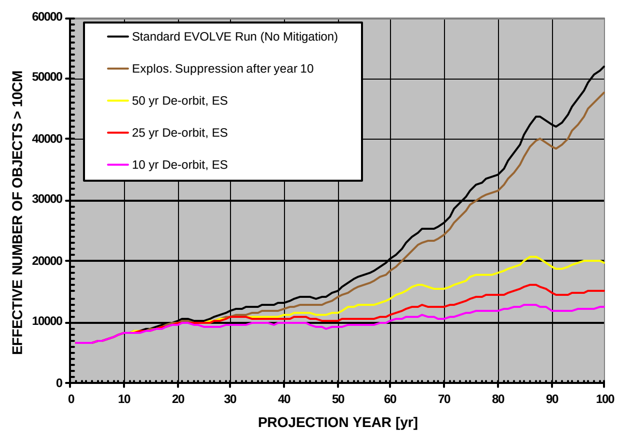

Fig. 6. Sample satellite population growth scenarios produced by EVOLVE 4.0.

The risk posed to people and property on Earth from reentering debris is also an area of research at NASA. To evaluate the number and types of components which might survive reentry to reach the surface of the Earth, NASA, in conjunction with Lockheed Martin, created the Object Reentry Survival Analysis Tool (ORSAT). The model can predict not only which objects might survive, but also where, with respect to the reentry point, they will land. ORSAT results have been used for comparisons with known reentries (e.g., Delta 2 second stages) and to aid in controlled deorbit planning, as in the case of the NASA Compton Gamma Ray Observatory in 2000. In the latter event, NASA, in cooperation with DoD, undertook a reentry observation

Another important aspect of NASA orbital debris research is that of hypervelocity impact phenomenology and the development of more effective debris shields. Working with hypervelocity impact testing facilities at the White Sands Test Facility in New Mexico (Fig. 7), JSC personnel develop test objectives and plans, prepare the necessary projectiles and targets, and evaluate test results. Such tests are essential in determining the vulnerability of critical items on spacecraft, especially the Space Shuttle and the International Space Station. These results, coupled with hydrocode modeling for velocities and particle sizes beyond test capabilities, are incorporated into the NASA BUMPER program to determine component and mission reliabilities. This process has led to Space Shuttle modifications for reducing potential vulnerabilities to orbital debris and to the design of efficient debris shields for the International Space Station. This JSC-led team has also developed innovative shielding designs for large inflatable modules, like Trans Hab.

Fig. 7. Hypervelocity impact facility at the White Sands Test Facility.

In 1995 NASA issued the first detailed set of orbital debris mitigation guidelines in the U.S. government [5]. These guidelines formed the basis for the U.S. Government Orbital Debris Mitigation Standard Practices. To assist NASA program managers in judging their compliance with the NASA guidelines, JSC personnel developed a computer application called Debris Assessment Software (DAS). Each guideline can be evaluated for the specific orbital and vehicle characteristics of the program.

Due to its preeminent role in orbital debris research, NASA often provides technical assistance to other U.S. government agencies. For example, NASA performed the technical evaluation of the proposed Iridium disposal plan for the aforementioned *ad hoc* interagency working group. NASA also supports the FCC and DoT on matters regarding the licensing of commercial communications satellites and launch vehicles, respectively. In 2000, NASA prepared projections of the LEO satellite population in 2015 and 2030 to assist DoD in its evaluations of future space surveillance systems.

2.3 DoD

By far the most important orbital debris activity performed by DoD is the maintenance of the U.S. Satellite Catalog. The dozens of Air Force, Navy, and Army radar and electro-optical space surveillance sensors around the world making-up the SSN send many tens of thousands of observations each day to special processing centers within Cheyenne Mountain, overlooking Colorado Springs, Colorado. There the observations are used to update and refine satellite orbital data and to identify previously unknown objects. The resultant orbital information, in the form of two-line element sets (TLEs), are then forwarded to the individual SSN sensors to coordinate and correlate future observations and to the NASA Goddard Space Flight Center for public dissemination. Today, more than 8700 cataloged and ~1000 uncataloged objects, mainly larger than 10 cm in diameter, are being tracked in Earth orbit by the SSN.

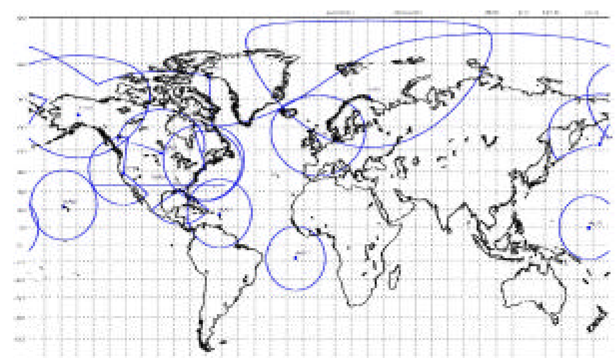

Fig. 8. Low altitude radar coverage regions of the U.S. Space Surveillance Network.

These orbital data are of great interest to the operational aerospace community as well as to orbital debris researchers. Data from the SSN are vital to collision avoidance procedures of the Space Shuttle and the International Space Station. Similarly, SSN data are used by launch vehicle service providers to avoid potential collisions with debris or operational spacecraft during orbital insertion and payload delivery operations. In addition, the SSN provides information on satellite breakups, including identification of the parent object, the approximate time of the breakup, and the number and orbits of the related debris. Another important SSN product is the issuance of satellite reentry predictions

In recent years, interest has been renewed in improving the capabilities of the SSN, particularly lowering the detection and tracking thresholds of the SSN. Whereas the lower size limit of objects tracked in LEO by the SSN today is approximately 10-30 cm, means to lower that threshold to 5 cm or even 1 cm have been and are under investigation. Since 1997 the Air Force Space Command/NASA/National Reconnaissance Office Partnership Council has shown special interest in this issue. During 1997-1998, at the direction of the U.S. Congress, a DoD-led group studied the requirements and potential solutions for an improved space surveillance capability.

Special debris studies and non-routine analyses for DoD are often conducted by Air Force Space Command's Space Warfare Center at Shriever Air Force Base near Colorado Springs. Historically, the Air Force Research Laboratory at Kirkland Air Force Base in Albuquerque, New Mexico, has performed a variety of orbital debris studies, including space surveillance capabilities, hypervelocity impact phenomenology, and debris mitigation policies. The last is also of increasing interest to U. Space Command in Colorado Springs and to U.S. Air Force's Space and Missile Center in Los Angeles, California.

During 1995-1999 DoD, including U.S. Space Command, Air Force Space Command, and the National Reconnaissance Office, issued a number of revised or new directives and instructions on orbital debris [6].

2.4 Other Agencies

Three U.S. government agencies have regulatory responsibilities which may involve orbital debris issues. DoT, through its Office of Commercial Space Transportation in the Federal Aviation Administration, is concerned about the safety of commercial launch vehicles, including their operation in orbit and after mission termination, and the reentry of commercial recoverable vehicles. This office sponsors limited studies related to orbital debris, as well as seeking support from NASA on some topics.

The National Oceanic and Atmospheric Administration (NOAA) has authority for licensing commercial remote sensing spacecraft. To date its principal concern related to orbital debris has been focused on spacecraft disposition, which may include prevention of breakups (passivation), limiting orbital lifetime, and constraining reentry risks. The FCC is also interested in planned disposal procedures, including risks to other spacecraft and reentry risks, and potential interference, including physical interference, with other satellites.

A summary of the latest orbital debris regulations for these three agencies can be found in [6].

3. U.S. INDUSTRY

Orbital debris interests of the U.S. aerospace industry range from operational concerns to pure research. The designers, manufacturers, owners, and operators of launch vehicles and spacecraft are becoming increasingly aware and knowledgeable of orbital debris issues through their support of U.S. government space missions and by the U.S. government's encouragement that industry voluntary adopt the U.S. Government Orbital Debris Mitigation Standard Practices. Following the U.S. Government Orbital Debris Workshop for Industry in January 1998, a team of NASA and DoD representatives met with senior management of several aerospace industries and with the Space Council of the Aerospace Industries Association of America to discuss further the application of these standard practices.

Industry has been responsive to modifying vehicle designs which might contribute to debris generation, either mission-related debris or fragmentation debris [7]. McDonnell-Douglas (later Boeing) was particularly helpful in resolving breakup problems with Delta launch vehicle second stages, as was Orbital Sciences Corporation with the Pegasus Hydrazine Auxiliary Propulsion System. Motorola gave orbital debris mitigation a high priority in both the design and operation of Iridium spacecraft and in the disposal of launch vehicle orbital stages. Furthermore, U.S. industry has cooperated in the design and operation of GEO spacecraft to permit their transfer to a disposal orbit at the end of mission.

Industry, of course, is a partner with the U.S. government in many areas of orbital debris research. Noteworthy contributions to the field have been made by Teledyne Brown Engineering, Kaman Sciences Corporation, ITT Industries, Lockheed Martin, Boeing North American, Aerospace Corporation, Battelle, and Southwest Research Institute. Several of these firms have contributed their own independent research and development (IR&D) funds to various orbital debris research topics.

4. ACADEMIA

The support of U.S. institutions of higher learning to orbital debris research is also important, and these activities have made very positive contributions to the orbital debris community. The subject of orbital debris is appearing more frequently in curriculums across the country, in aerospace, political science, and legal

Boulder, Colorado, has awarded PhD's to nine students specializing in orbital debris research and many of these individuals are now active in aerospace, supporting the design and operations of launch vehicles and spacecraft. The school has also provided direct support to NASA orbital debris projects, e.g., determining the optical signatures of the Orbital Debris Calibration Spheres (ODERACS).

The University of Chicago's Space Dust (SPADUS) detector is providing data on the small particle environment in LEO fom DoD's ARGOS spacecraft. One Air Force officer who received a Masters degree from the Air Force Institute of Technology, based on his orbital debris thesis, was instrumental in the subsequent adoption of orbital debris mitigation measures by the Iridium enterprise. Research at Rice University in Houston may lead to lighter-weight and more effective debris shields for spacecraft.

Two institutes are helping to make unique contributions to the characterization of the debris environment. The Lincoln Laboratory of the Massachusetts Institute of Technology operates the Haystack and Haystack Auxiliary radars for NASA and DoD research in orbital debris. The laboratory has also assisted in the identification of the sodium-potassium debris family, in the characterization of solid-rocket motor effluents, and in the investigation of other debris characterization techniques. Meanwhile, the Jet Propulsion Laboratory of the California Institute of Technology utilizes the Goldstone radar facilities to detect debris in LEO as small as only a few millimeters.

5. SUMMARY

This paper has demonstrated the considerable level of activity involving orbital debris in the U.S. from the Executive Office of the President to the individual federal agencies to industry and academia. The U.S. is proud of its leadership role in orbital debris research and remains committed to this endeavor. Only with concerted national and international efforts can continued progress be made in the mitigation of orbital debris growth and the preservation of near-Earth space for future generations.

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