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Report to the Chairman, Committee on Science, Space, and Technology, House of Representatives

April 1990

SPACE PROGRAM

Space Debris a Potential Threat to Space Station and Shuttle

GAO/IMTEC-90-18

GAO

United States
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Information Management and
Technology Division

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The Honorable Robert A. Roe
Chairman, Committee on Science, Space,
and Technology
House of Representatives

Dear Mr. Chairman:

As requested by your office on April 14, 1989, this report provides additional and updated information on certain aspects of the space debris issue including (1) the National Aeronautics and Space Administration's (NASA) plans for protecting the space station from space debris, including estimates of costs and risks posed by debris to the space station; (2) the extent and precision of current NASA and Department of Defense debris-tracking capabilities, particularly for debris in the 1- to 10-centimeter range; and (3) the extent to which orbital debris has affected shuttle operations.

As arranged with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the date of this letter. At that time, we will send copies to appropriate congressional committees; the Administrator of NASA; and the Secretary of Defense. We will also make copies available to other interested parties upon request.

This work was performed under the direction of Samuel W. Bowlin, Director for Defense and Security Information Systems, who can be reached at (202) 275-4649. Other major contributors are listed in appendix II.

Sincerely yours,

Ralph V. Carlone
Assistant Comptroller General

Executive Summary

Purpose

Experts estimate that more than 3.5 million man-made objects are orbiting the earth. These objects—space debris—include whole and fragmentary parts of rocket bodies and other discarded equipment from space missions. About 24,500 of these objects (those 1 centimeter or larger) can cause catastrophic damage upon impact, and could pose a threat to future space shuttle missions and the planned space station.

The House Committee on Science, Space, and Technology asked GAO to review certain aspects of the space debris issue: (1) the National Aeronautics and Space Administration's (NASA) plans for protecting the space station from debris, (2) the extent and precision of current NASA and Defense Department debris-tracking capabilities, and (3) the extent to which debris has already affected shuttle operations.

Background

Two of NASA's major efforts are the operational space shuttle and the planned space station. NASA launches the shuttle a number of times each year to perform such versatile missions as transporting payloads and functioning as a research center and repair ship. The shuttle will also be critical to the assembly and operation of the space station. Construction of the station is planned to begin in 1995. It is expected to remain in service for 30 years and cover an area roughly the size of a football field. Cost estimates for the station are approaching $30 billion.

The space environment is expected to become increasingly polluted as worldwide spacecraft launches increase and collisions between debris particles create more debris. This becomes all the more menacing considering that a 1-centimeter aluminum sphere (roughly the diameter of an aspirin tablet) traveling at an average speed of 22,000 miles per hour disperses the same kinetic energy when striking a spacecraft as would a 400-pound safe traveling 60 miles per hour.

The National Security Council calculated, based on the estimated amount of debris in space in 1988, that a spacecraft the size of the space station would be hit by an object larger than 1 centimeter once in 20 years. The Council predicted that this possibility would increase to one hit every 2 years by 2010. NASA and Defense contend these estimates assume that no preventive measures to reduce debris production will take place.

Results in Brief

Any plan to protect the space station from debris must hinge on NASA's estimate of the amount of debris likely to be encountered--and the estimate's accuracy, recency, and reliability. The 1984 model that NASA is now using to design the space station significantly underestimates the amount of debris expected by 2005. As a result, NASA is designing the space station to meet requirements that greatly underestimate the seriousness of the debris environment. NASA officials acknowledge that they have been presented with updated data that reflect a much more severe environment. This updated data, or revised debris model, was rejected by the space station program director partly because of the increased cost to the space station that would result and partly because of a need for further analysis of the risks and hazards posed by space debris. NASA has several efforts underway that are grappling with the space debris environment problem. The critical date for space station design decisions is July 1992.

NASA relies on Defense Department systems to track earth-orbiting objects (on average, 10 centimeters or larger). NASA uses this information to plan launches as well as collision-avoidance maneuvers for the shuttle. Although NASA began discussions with Defense in October 1989 about the requirements for collision avoidance tracking for the station, no such requirement has yet been established.

Shuttle operations to a minor extent have been affected by space debris. Evidence points to one and possibly two shuttles having been struck by debris. Although the damage was not life-threatening, such strikes do underscore the importance of dealing with this potentially catastrophic problem before the station is designed and constructed.

Principal Findings

Protection From Debris

While NASA acknowledges that the space debris environment is much more severe than that reflected in its 1984 model, documents used to guide contractors in designing the station have not been revised to accommodate this severity. As a result, the space station is being designed to meet requirements that underestimate the debris environment. However, NASA appears to be making good progress in revising the 1984 debris model, which will reflect the increased severity in the debris environment. This may increase costs, but NASA does not yet know how much. Once the debris environment is revised, it will provide a basis for debris cost, risk, and hazard assessments which will be used to help decide how NASA should protect the space station. These assessments were planned but had not been initiated when GAO completed its work.

NASA is considering a combination of protective techniques, including (1) shielding the station against small particles, (2) an emergency warning system to alert the crew of potential impact with debris large enough to cause serious damage but too small to track or avoid, and (3) designing the station to move away from large objects. However, NASA cannot conclude which techniques will best protect the space station and its crew until the debris environment is updated and the cost, risk, and hazard analyses are completed. Decisions on the protection techniques must be finalized before completion of critical design reviews in 1992, at which time design requirements for the station are planned to be finalized.

Tracking Limitations

NASA relies on the Defense-operated Space Surveillance Network of 29 radar and optical sensor sites to track space objects. Eleven of the 29 sites can track objects smaller than 10 centimeters but, as a matter of practice, only about 3.5 percent of the objects currently tracked are smaller. Because of uncertainties about the actual number of objects between 1 and 10 centimeters, NASA made an agreement with the U.S. Space Command to use a facility, called Haystack, to count and measure objects in this size range.

Effects of Debris on Shuttle Operations

Original hazard assessments for the shuttle did not factor in the potential damage from space debris, because it was not considered a significant threat to spacecraft when the shuttle was designed. As such, the shuttle could not shield against debris over .4 centimeters. Although debris has never completely penetrated a shuttle surface, two windows and possibly one tile surface have displayed evidence of being hit. After the Challenger accident, flight rules were changed to require the shuttle to avoid collisions with tracked debris provided (1) there is time to plan and execute the maneuver, (2) the debris is predicted to come close to the shuttle, and (3) the maneuver does not compromise the primary payload or mission objectives.

During the first five shuttle missions after the new rules took effect, Defense warned NASA eight times that tracked objects would come close to the shuttle. Only one of these warnings called for an evasive maneuver, but the maneuver was not taken because time was insufficient. No collision occurred. Potential risks to the shuttle are expected to increase in the 1990s as the debris environment becomes worse and shuttle missions are planned to last as much as 4 times longer.

Recommendations

In light of the potential catastrophic risk posed by debris to the space station and the shuttle, GAO recommends that the Administrator, NASA

- initiate and complete the needed risk, hazard, and cost analyses associated with a valid space debris estimate in time for their results to be incorporated into the final design requirements for the space station scheduled for 1992; and
- perform a debris risk and hazard assessment for the shuttle that factors in the anticipated increases in the debris environment and the planned longer duration missions.

Agency Comments

In commenting on a draft of this report, NASA agreed that orbital debris was a growing problem which, if not mitigated, will become an increasing threat to space operations. NASA also highlighted its efforts and those of other space-faring nations to understand the debris environment, its trends, and how best to deal with debris hazards.

NASA expressed concern with the overall tone of the report which, according to NASA, suggests that it was derelict in its responsibility to protect mission crews and valuable hardware from unnecessary risks. GAO believes the report accurately describes the magnitude of the debris problem and how NASA's efforts to deal with this difficult and complex problem involve cost and safety considerations. NASA also said the report implies that it is ignoring current debris data in designing the space station. GAO believes the report did not imply that NASA was ignoring current space debris data, but, to the contrary, stated that NASA seemed to be making good progress in updating the current model. However, until the contractors are required to use this model, the station continues to be designed to meet a debris environment that NASA admits is understated.

NASA believes it has been fully responsive to the dangers posed by debris and meteoroids, and has performed debris risk and hazard assessments for every manned mission since 1962. GAO disagrees. Although meteoroid dangers have been studied, NASA representatives confirmed that debris risk and hazard analyses have never been performed for the shuttle. Further, at the time GAO completed its work, these analyses, although planned, had not been initiated for the station.

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Abbreviations

GAO	General Accounting Office
IMTEC	Information Management and Technology Division
NASA	National Aeronautics and Space Administration
SSN	Space Surveillance Network
STS	Space Transportation System

Introduction

Millions of objects, both natural and man-made, pass near or orbit the earth at any given time. The natural objects are meteoroids (meteor particles), while the orbiting man-made objects—space debris—include whole and fragmentary parts of rocket bodies and other discarded equipment from space missions. Meteoroids have an average size of about .01 centimeter—about the size of a printed period. About 440 pounds of meteoroid mass are passing near the earth at any time. In contrast, an estimated 6.6 million pounds of man-made objects are in orbit, including about 24,500 pieces believed to be 1 centimeter or larger—about the size of an aspirin tablet.

Spacecraft have historically been designed for protection against meteoroids, which are attracted from space by earth's gravity and briefly pass through the space around the earth before burning up when hitting the atmosphere. Unlike meteoroids, however, space debris remains in earth orbit during its entire lifetime. Although the debris also falls into progressively lower orbits and normally burns up in the atmosphere, the orbital lifetime of a piece of debris can exceed a year or more, depending upon the mass and area of the object. For example, a glass marble in a circular orbit at about 311 miles will stay aloft for about a year, but if it were in orbit at 497 miles, it would stay up for 30 years. Above 559 miles, orbital lifetimes can be 500 years or more. Obviously, then, protection from space debris is an increasingly important factor in spacecraft design.

According to a 1987 publication on space debris,

> "For years the meteoroid environment has driven shielding requirements, but research conducted during the 1970s showed that the artificial debris environment has, for the most part, become the most probable source of spacecraft damage. . . . Due to the orbital nature of artificial space debris, the relative velocity for a collision between an operational satellite and a piece of space debris, both in low Earth orbit, is about 9-11 km/s [kilometers per second]. Consequently, the damage expected from the impact of space debris is likely to be more severe than from meteoroids. A difference in hazards also develops because of different population sizes and because space debris may linger in orbit for years while a given meteoroid passes through the near Earth environment only once."[1]

The estimated mass of the 3.5 million man-made objects in earth orbit is about 15,000 times larger than the mass of natural meteoroids. Man-

[1] Artificial Space Debris, Nicholas L. Johnson and Darren S. McKnight, Orbit Book Company, 1987, p. 68.

made objects in orbit travel at roughly 22,000 miles per hour; a 1-centimeter sphere traveling at that speed disperses the same kinetic energy when striking a spacecraft as would a 400-pound safe traveling at 60 miles per hour. The following table shows the estimated distribution of man-made space debris, by size.

Table 1.1: Estimated Distribution of Man-Made Space Debris

Object size	Number of objects	Percentage	Total mass	Percentage
Over 10 cm	7,000	0.2	6,611,595.4 lbs	99.97
1-10 cm	17,500	0.5	2,204.6 lbs	0.03
Under 1 cm	3,500,000	99.3		
Totals	**3,524,500**	**100.0**	**6,613,800 lbs[a]**	**100.00**

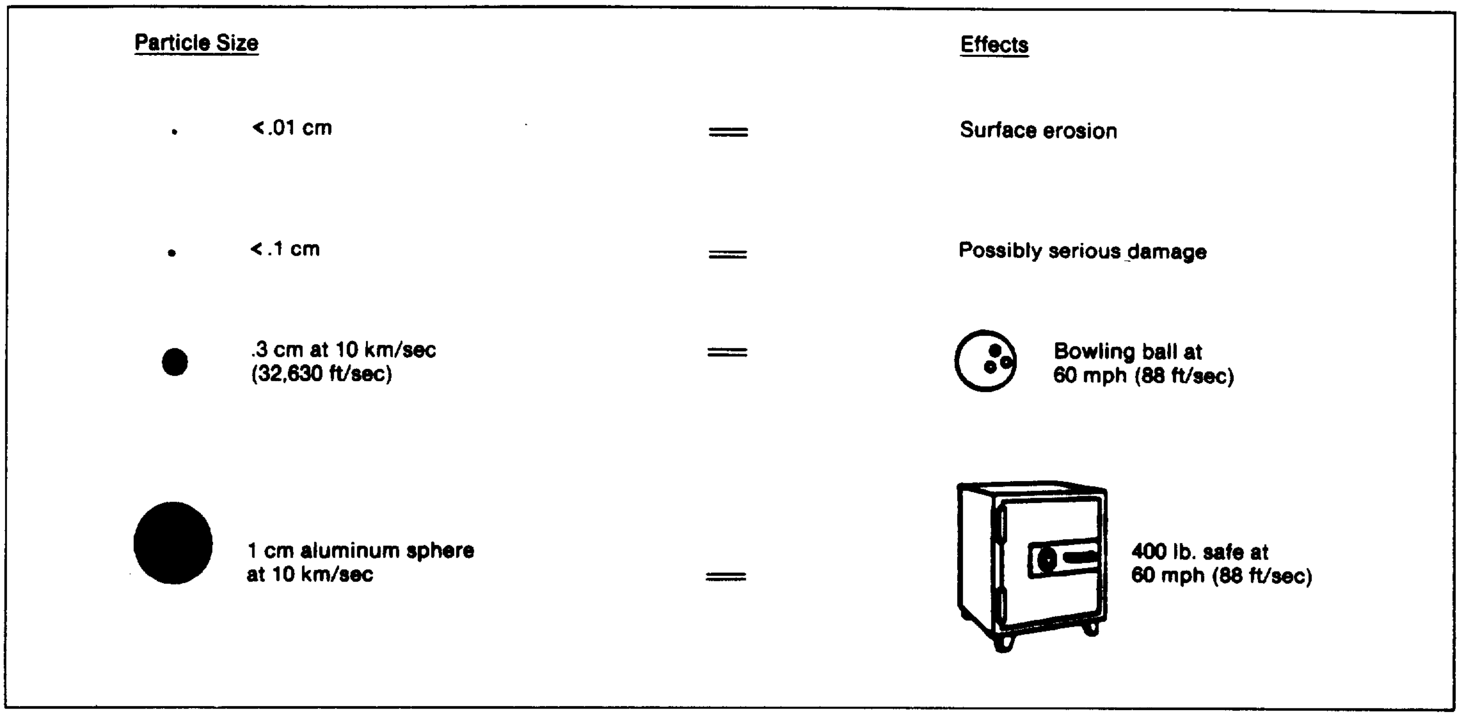
Source: Report on Orbital Debris, by Interagency Group (Space), National Security Council, February 1989.

[a]Defense officials told us they believe that the current total mass of man-made objects in lower earth orbit is 3 to 4 million pounds, based on a study Defense completed after the National Security Council report was published in 1989.

On the basis of concerns about the potential implications for NASA spacecraft from space debris, the Subcommittee on Space Science and Applications, House Committee on Science, Space, and Technology, conducted hearings in July 1988. In February 1989, the Interagency Group (Space) of the National Security Council issued a report on the space debris problem. The Council calculated, on the basis of the estimated amount of debris in space in 1988, that a spacecraft the size of the space station would be hit by an object larger than 1 centimeter once in 20 years. They predicted that this possibility would increase to one hit every 2 years by 2010. Both NASA and Defense pointed out that these collision estimates were based on (1) the assumption that no further preventive measures to reduce the debris production would take place, and (2) the original estimated size of the station (5,000 square meters), as opposed to the current planned size (2,000 square meters). NASA believes the probability of impact will decrease as the world's space agencies initiate debris growth mitigation actions, such as venting unused fuel from orbiting booster stages to help reduce the possibility of explosions in space.

The National Security Council report also explains that the effect of a space debris impact on a spacecraft is related to the object's mass and velocity, and that objects larger than 1 centimeter could cause catastrophic damage. Figure 1.1 shows the relative effects of various size particles.

Figure 1.1: Kinetic Energy and Debris Effects Comparisons for Collisions at 10 Km/Sec (22,369 Miles Per Hour)



Source: Report on Orbital Debris, by Interagency Group (Space), National Security Council, February 1989.

A NASA space debris expert believes that the danger of such collisions is compounded by estimates that the amount of space debris will increase by 5 percent annually for about the next 20 years, as worldwide spacecraft launch rates increase and collisions between debris particles create more debris. Defense officials agree that the debris problem will get worse. Although these officials could not provide a more accurate estimate of the future debris environment, they believed that a 5 percent growth rate is too high. There is concern that the growth of man-made space debris orbiting the earth could substantially threaten the safe and reliable operation of NASA's future space missions. This poses a significant problem in the design of the space station in that the station is expected to be in orbit at a 217- to 311-mile altitude for 30 years, and, when fully deployed, will cover an area roughly the size of a football field.

Experts caution that much uncertainty exists in our knowledge of the exact location, amount, and size of debris, as well as how serious the problem will be in the future. This uncertainty is caused by factors such as (1) our limited ability to measure and actually validate the number and size of particles, and (2) a lack of predictability in the number of future space missions.

Objectives, Scope, and Methodology

On April 14, 1989, the House Committee on Science, Space, and Technology requested that we obtain additional and updated information on certain aspects of the space debris issue, including (1) NASA's plans for protecting the space station from space debris, including estimates of costs to and risks posed by debris to the space station; (2) the extent and precision of current NASA and Department of Defense debris-tracking capabilities, particularly for debris in the 1- to 10-centimeter range; and (3) the extent to which orbital debris has affected shuttle operations.

To obtain information on NASA's current debris-tracking capabilities, we interviewed representatives of NASA's Office of Space Operations in Washington, D.C. They provided information on the coverage and precision of current NASA radars. To obtain insights and information on the technical capabilities and characteristics of radars, we met with representatives of the Wallops Flight Facility at Wallops Island, Virginia.

We also met with representatives of the U.S. Space Command and Air Force Space Command at Peterson Air Force Base in Colorado Springs, Colorado, who provided us with information that identified the extent and precision of Defense capabilities for tracking small debris particles. We obtained documents describing information on radar and optical sensors worldwide, including the capabilities and operation of the Defense Department's Space Surveillance Network and the Space Surveillance Center at Cheyenne Mountain Air Force Base.

To identify NASA's plans for protecting the space station from space debris, obtain estimates of costs or risks that NASA believes debris will have on the space station, and gather information on the effects that space debris has had on shuttle operations, we met with representatives of NASA's Office of Aeronautics and Space Technology, Office of Space Flight, and Office of Space Station, in Washington, D.C.; we also met with representatives of the Jet Propulsion Laboratory in Pasadena, California; the Goddard Space Flight Center in Greenbelt, Maryland; and the Lyndon B. Johnson Space Center in Houston, Texas.

Views of responsible agency officials on the material contained in this report were obtained and were incorporated where appropriate. Our work was performed in accordance with generally accepted government auditing standards, from April 1989 through February 1990.

NASA and Defense Debris-Tracking Capabilities

NASA does not have the capability or operational mission to track space debris. NASA does have nine sensors—all radars, located in Virginia, California, and Bermuda—that track active earth-orbiting satellites and experimental rockets.

To track space debris, NASA must rely on Defense Department systems. The Space Surveillance Network (SSN), operated by the Air Force, Army, and Navy for the U.S. Space Command, is a worldwide network of 29 radar and optical sensor sites, a communications network, and an operations center with a central data processing system. The sensors collect object observation and/or object identification data and transmit them primarily to the Space Surveillance Center at the Cheyenne Mountain Air Force Base in Colorado Springs. Generally speaking, Defense does not track objects less than 10 centimeters in size.

Limitations on Detecting and Tracking Small Objects[1]

While all 29 SSN sensor sites can track objects larger than 10 centimeters, only 11 can track objects smaller than 10, and only 1 of these can track an object as small as 1 centimeter. According to an Air Force Space Command official, most sensors were built to detect and track relatively large objects (e.g., rocket bodies and reentry vehicles) to accomplish the Air Force's space surveillance and ballistic missile warning missions. The radar frequencies and corresponding wavelengths required to accomplish these missions are different from those required to efficiently detect small objects. To detect small objects, certain radars would have to be significantly modified—a time-consuming process that would make the sensors unavailable for their primary missions.

The ability to detect small objects is also dependent on the sensor's beam width and power. A sensor's beam width (area covered by the sensor's signal at a particular altitude), combined with the amount of radar energy the sensor is capable of distributing across the beam coverage area, determines the sensor's ability to detect an object. Since small objects do not return as much energy to the sensor, more energy must be distributed throughout the beam coverage area to assure that the object returns enough energy to be detected by the radar receiver. The larger the beam coverage area, the more power that must be applied to detect small objects.

[1]This report focuses on the limitations of radar sensors. Optical sensors, used primarily for detection and tracking of geosynchronous earth-orbiting objects (above 22,300 miles), also have inherent limitations. For example, weather, the object's reflectivity, and the time of observation each affect the sensor's ability to make accurate sightings.

One radar, known as Haystack, is the most capable of detecting the small objects. Even though Haystack does not use high levels of radar energy, it can detect small objects primarily because it operates at a short wavelength and also because it produces a very narrow beam, and thus a very small beam coverage area. As discussed in chapter 3, NASA is negotiating with the U.S. Space Command for use of this radar to detect and count objects smaller than 10 centimeters.

Tracking Frequency and Data Accuracy

The frequency with which individual space objects are tracked affects the ability to accurately locate the object at some future time. Objects of high interest to the U.S. Space Command (active payloads, for example) are tracked by every sensor each time the object passes through the sensor's field of view. Depending on the object, the sensor, and the type and amount of information required, this may result in numerous observations by individual sensors on each pass. In order to accurately predict the future position of these high-interest objects, SSN must update a mathematical representation of the object's orbit several times a day.

Objects of less interest, however—including debris—are generally tracked once each day. Many objects in this category are hard to track because they are small and require more radar energy to get a return signal, take more time to locate even when they are where they are supposed to be, and are affected more by atmospheric drag and variations in atmospheric density, which alter their orbits. As a result, some objects are not observed at their projected location and, in effect, become lost. Orbital data for these objects may not, then, be updated for several days.

According to Air Force Space Command officials, the accuracy or precision of an object's position at the time an observation is made is usually within a 3,281-foot sphere. The future position of the object is then predicted on the basis of its orbital characteristics, including inclination, altitude, and velocity. Assuming no additional observations are made, the accuracy of the object's predicted position at the altitude of the space station after 24 hours is usually within about a 7.5-mile sphere of its actual position. This is because of changes in the object's orbit caused by atmospheric drag and orbital drift.

Capability to Provide Data for Collision Avoidance

The Air Force is not required to detect and identify all debris, nor does it have or plan to soon acquire the capability to do so. According to Air Force Space Command officials, the Air Force has not studied or approached the space debris issue from a collision-avoidance perspective. As a result, Air Force officials could not estimate the cost or resources necessary to acquire such a capability.

The U.S. Space Command currently provides NASA with data on orbital debris for planning launches and for collision-avoidance maneuvering for the shuttle. The Air Force Space Command performed a study for NASA and determined that certain elements of object location, including altitude and orbital inclination, were accurately predicted, but that the predictions of object velocity were much less accurate. The study noted that velocity could not be accurately predicted because atmospheric density and the object's orientation were constantly changing during each orbit. Without accurate predictions of an object's location (which requires accurately predicting its velocity), potential collisions cannot be reliably forecast.

A U.S. Space Command official acknowledged that the existing SSN cannot provide the detailed information needed for space station collision-avoidance maneuvers. The SSN makes and processes between 40,000 and 50,000 space object observations a day and maintains orbital data on about 7,000[2] objects. According to this official, to constantly monitor all objects in space would require the capability to make and process hundreds of thousands of observations a day. Although the maximum tracking capacity of the sensors has never been determined, the U.S. Space Command plans to stress the SSN (for Defense mission purposes) to determine if it could make and process up to 100,000 observations per day.

A planned replacement for the existing Space Surveillance Center would enable it to process 100,000 observations per day and maintain orbital data on at least 10,000 objects. This system is projected to be operational in fiscal year 1994; however, even this new system will not have the processing ability needed to provide the data required for collision-avoidance maneuvers for the station.

[2] A Defense official told us that 6,698 objects were being tracked as of January 1990. He estimated that 220, or 3.3 percent, of these objects are smaller than 10 centimeters.

NASA's Plans for Protecting the Space Station From Orbital Debris

The increasing hazard of the space debris environment could have a serious impact on the development and cost of the space station. Increased shielding, better tracking accuracy, collision-avoidance maneuvering, or other advanced technologies may be necessary for the safety of the station and its crew. These additional measures would increase costs, although NASA does not know by how much. Critical to all of these activities, however, is an up-to-date, reliable estimate of the debris environment that can be expected over the next 20 years: knowing the extent of the threat is an essential linchpin for planning measures to cope with it.

NASA has several efforts underway that it believes will lead to a more effective and economical strategy for protecting the station. For example, in October 1989, NASA and U.S. Space Command representatives met to discuss the operational support requirements for the space station, possibly including the need for tracking objects smaller than 10 centimeters. NASA is also negotiating an agreement with the Space Command to obtain critically needed data to better define the debris environment, including the size and amount of debris in the 1-10-centimeter range. NASA has several efforts underway that address various aspects of debris protection, including an on-board instrument that may some day serve as a collision-warning sensor, and alternative shielding designs and materials that could result in significant reductions in shielding weight.

NASA is also considering alternative design strategies for protecting the space station from orbital debris, and it appears that the final design may include a combination of techniques, including (1) shielding the station to protect against some debris particles, (2) developing some type of emergency warning system to alert the crew of debris that is large enough to cause serious damage but too small to accurately track and avoid, and (3) building in the capacity to move the station out of the way of larger trackable objects. According to the director for internal environment management for the space station, decisions on these techniques will need to be made before the critical design reviews are completed in 1992.

NASA's Planned Space Station

The Space Station Freedom is a 30-year multipurpose facility. Planned uses of the station encompass a broad spectrum of research disciplines including life sciences, material sciences, astrophysics, earth sciences, planetary sciences, and commercial applications. The station will weigh about one-half million pounds, and will be too large and heavy to be placed into orbit by one launch vehicle. Current planning calls for approximately 20 shuttle flights to get all of the elements, systems, and support equipment to low earth orbit. The total assembly process in space will take about 4 years. Current program milestones call for the first station element to be launched in early 1995, and for the station to have a permanently manned capability by late 1996. Although there are differences of opinion on space station costs, some believe station costs will approximate $30 billion.[1]

Defining the Environment

A NASA expert on space debris at the Johnson Space Center developed a model of the debris environment that used actual data on very large and very small objects and estimates the environment for debris roughly between 1 and 10 centimeters[2] in size. Because the model's accuracy is important for assessing potential damage and reflects directly on shielding needs and protection techniques, NASA plans to obtain actual data on the size and number of objects smaller than 10 centimeters before the space station's critical design review, now set for August 1991 to July 1992. To obtain these data, NASA plans to use a ground-based radar capable of measuring debris in the 1-10-centimeter range. NASA will also learn much about the affects of debris on spacecraft surfaces and the debris environment after analyzing the Long Duration Exposure Facility, which was successfully recovered from space in January 1990.

NASA considered two options for obtaining data on objects smaller than 10 centimeters. The first was to purchase its own radar system, with an estimated cost of $24 million through fiscal year 1997. Data from this radar would be available by October 1991. The second option was to acquire the needed data from an existing radar facility, called Haystack, under an agreement with the U.S. Space Command. This option is estimated to cost about $25 million. Data would reportedly be available in fiscal year 1990. NASA officials believe that performance and long-term requirements could be satisfied by either option. On September 29, 1989, NASA decided to use the Haystack facility. The decision was based primarily on the speed of data availability.

[1] Transition Series: NASA Issues (GAO/OCG-89-15TR).

[2] Data for objects in this range have not been validated by physical evidence of debris impact on spacecraft.

Proposed Revisions to NASA's Definition of the Debris Environment Still Pending

Significant changes in the debris environment have been noted since the original model was approved in 1984. However, the official documents that guide contractors in developing the appropriate shielding for the station have not yet been revised to reflect these changes. As such, several NASA engineers feel that the space station is being designed to meet requirements that greatly underestimate the seriousness of the debris environment.

One NASA document, entitled Program Natural Environment Definition for Design, defines the natural environment requirements for the design of the space station. The natural environment includes meteoroids and space debris, neutral atmosphere, and magnetic fields. On December 14, 1988, the director for internal environment management for the space station submitted a formal request to the space station program director suggesting technical changes to the document. One major technical change called for updating the orbital debris model upon which design requirements are based. This revised model would increase, approximately tenfold, the amount of debris expected by the year 2005. This change would affect the performance, safety, reliability, maintainability, flight operations, mass properties, payloads, weight, and test and verification of the space station.

On April 5, 1989, the space station control board met to discuss the proposed changes. According to the minutes of this meeting, the space station program director reviewed the proposed changes and rejected them. Why? On the basis that they mixed environment specifications with space station design requirements, which in effect increased program costs, even though a thorough cost/risk tradeoff analysis had not been performed. In addition, the director stated that the space station program could not fund the proposed redefinition of the space debris environment. Two engineers who attended the meeting told us that they interpreted the director's comments to mean that "the changed debris environment would result in design modifications that NASA could not afford."

According to a NASA space station program representative, the individual NASA centers that reviewed the proposed changes supported the new environment definition, which reflected an increased severity in the space debris problem. A senior NASA engineer voiced his opinion that NASA is wasting time, money, and resources by developing the station to meet understated design requirements. Further, in commenting on proposed changes to the debris protection requirements, experts at one NASA facility commented:

"the driving function for the reliability/safety for the Space Station is currently an externally imposed number for the likelihood of failure. This process is flawed at the outset and will not achieve the desired results—namely a valid protection scheme for the Space Station and its crew and a realistic assessment of the risks involved."

These experts also believe that a bottom-up assessment of the risks involved is necessary, including a realistic evaluation of failure scenarios and individual component failure rates. Recognizing that it was too early to perform such analyses in great detail, the experts nevertheless stated that sufficient information existed to establish rudimentary estimates for reliability and failure in the debris environment. These debris risk and hazard assessments have not been initiated although experts believe they need to be completed well in advance of final design decisions scheduled for 1992. They caution that these analyses need to be carefully planned and will take time. A JPL representative explained that the risk analyses should be based on objective estimates of the threat and bottom-up hazard analyses, not on the current predetermined overall risk goal.

As a result of the April 1989 meeting, action was planned to modify the proposed environment definition, separating requirements from definitions. In February 1990 a NASA official told us that the agency was moving ahead to revise the 1984 model, which will reflect the increased severity in the space debris environment. As a result, costs will increase, but this official did not yet know by how much. Also agreed on at the April 1989 meeting was the need for a plan to detail the contents of and assign responsibility for debris risk analyses. Such a plan has been prepared but as of February 1990 had not been approved by the space station program deputy director.

Shielding

The structures of pressurized elements in space typically incorporate an outer bumper to protect the inner hull from high-velocity particles. The purpose of the outer bumper, or shield, is to fragment, melt, or vaporize the incoming particle and spread its impact over a wider area of the second wall. The thickness, types of materials used for the walls, and the distance between them, as well as the angle at which the debris strikes the walls, are key factors in determining the shield's ability to withstand impact by objects of various sizes.

The current design requirement for the station's critical core equipment is to have a 99.55-percent probability of experiencing no failure due to meteoroid or debris impact that would endanger the crew or space station survivability for 10 years. The original and still official definition of the debris environment calls for shielding to protect against particles as large as .87 centimeter. However, a NASA space debris expert at Johnson now estimates that station designers will need to shield some components against debris as large as 1.6 centimeters, on the basis of the pending but not yet approved redefinition of the debris environment. This particle-size estimate may increase or decrease again as the small (1-10-centimeter) debris environment becomes better understood.

A NASA representative told us that one design assumption that needs to be reevaluated is that no penetration by debris of any size will occur to any pressurized component of the station. For example, this assumption is driving a station design that will not protect the station's occupants should penetration actually occur. They further explained that if the assumption of no penetration changes, major design modifications may be needed such as (1) the development of sensors that can pinpoint the exact location and severity of penetration, and (2) the incorporation of automated systems that would assess damage and help the crew minimize losses.

Research is underway to test the effects of high-speed impact of 3-4-centimeter debris particles on different surfaces and on different shielding designs. One new type of shield being tested is an erectable, deployable shield that would be sent out to absorb debris hits. Another type of shielding material and technique has been tested that shows promise for increasing protection while lowering the weight and cost associated with shielding. One of the inventors of this concept told us that further research and development of this alternative would be needed before NASA could consider it for use on the station.

On-Board Warning System Could Provide Advance Warning for Collisions With Certain Debris Particles

Some debris particles may be too small to track by current systems but big enough to cause serious or catastrophic damage to the station. As stated earlier, current design guidelines require the station to be shielded to withstand the impact of debris particles up to about .87 centimeter. (This requirement may increase to 1.6 centimeters for certain station components if proposed revisions to the debris environment definition are approved.) The Space Command ground-based system generally tracks objects of 10 centimeters or larger, with plans to use these data to provide timely and adequate warning. This leaves a size gap, however, of 9.13 centimeters between the particle size the station is currently required to be shielded against and the particle size that is currently tracked from the ground. Given the expectation that the amount of debris will increase, and thus increase the chances of impact, an on-orbit detection capability for the station has been proposed by several NASA representatives.

NASA representatives see this on-orbit detection capability as having a potential application on the space station. Under this scenario, the sensor would provide advance warning that a debris particle is about to hit the station, thus permitting the crew to take appropriate action to minimize damage or loss of life. For example, advance warning of where a particle will hit could allow time for the crew to seal off the endangered module and move away from the probable point of impact. At the time we completed our work, the program manager for the Debris Collision Warning System estimated that the cost of an experiment to test the feasibility of this concept was about $35-45 million, with plans to fly the experiment on a late 1994 or early 1995 shuttle mission.

Collision-Avoidance Maneuvers

In cases where shielding is not feasible, NASA may have to develop alternate protection measures, such as tracking the debris and maneuvering the station away from potential collisions. It is currently believed that this would be done for objects 10 centimeters and larger. Tracking of these large objects, currently done for the shuttle by the U.S. Space Command, would likely continue for the station. A current design requirement for the station is the ability to maneuver to avoid debris collisions by increasing its speed by 5 feet per second, with 2 hours' warning. However, maneuvering to avoid collisions will only be possible for the station if an accurate and timely orbit determination is made for the approaching object.

As discussed in chapter 2, U.S. Space Command representatives believe that the SSN cannot continually track all space objects and precisely predict each orbit accurately enough to be used as a basis for planning collision-avoidance maneuvers for the station. Additionally, existing sensors and supporting systems have not demonstrated the capability to make or process the number of observations that might be required to provide the precise data required for collision avoidance. NASA and U.S. Space Command representatives are aware of this and met in October 1989 to discuss the need for tracking and advance warning requirements for the station. Depending on these requirements, the U.S. Space Command may need to initiate major system enhancements, which could affect station costs. However, Defense officials told us that decisions about requirements were not resolved at the meeting. Further, Defense commented that one major NASA concern was recognition of the exceptionally high number of maneuvers that would be required of the station, considering only the currently tracked objects, 10 centimeters and larger.

According to a NASA space debris expert at Johnson, the collision-avoidance solution has drawbacks. He estimated that the station could be required to move 24-36 times a year at a 186-mile altitude, and 64 times a year at 311 miles, to avoid collisions with currently known and tracked debris larger than 10 centimeters. This could have a substantial impact on planned microgravity experiments, which may require a 30-day inactive period between maneuvers.

Decisions on Debris Will Affect Station Costs

Detailed information on costs or risks that a more severe debris environment will cause for the space station were not available when we completed our work in January 1990. Decisions on design, cost, and safety tradeoffs for the space station and its ground support systems depend, in part, upon validating the amount, location, and size of debris in space today, as well as the results of debris risk and hazard assessments.

Some of those decisions, according to NASA representatives, could result in

- increasing the shielding, and hence the cost and weight of the space station, to withstand impact from larger debris objects;
- increasing the technical capability and data processing capacity of defense systems, and hence costs, to track debris smaller than 10 centimeters; and/or
- accepting a higher risk of debris penetration (current specifications call for a 99.55-percent assurance that no penetration will occur).

Effects of Debris on Shuttle Operations

The Space Shuttle

The space shuttle, the heart of America's Space Transportation System (STS), made its first orbital flight in April 1981. The number of yearly shuttle missions steadily rose from two missions in 1981 to nine missions in 1985, just prior to the Challenger accident in January 1986. Now back to flight, the shuttle performs versatile missions such as transporting payloads, as well as functioning as a scientific platform, research center, and repair ship. The shuttle will be essential to the delivery into space, assembly, and operation of the space station.

Orbital debris has affected shuttle operations and may pose increased risks for the shuttle and crew during the 1990s. Shuttle flights have experienced suspected hits from orbital debris on tile and window surfaces, but no pressurized surfaces of the shuttle have ever been penetrated. Subsequent to the Challenger accident, flight rules were changed to provide for emergency maneuvers to avoid potential collisions with space objects tracked by the U.S. Space Command under certain conditions.

NASA engineers at Johnson Space Center explained that the shuttle was designed to protect its occupants and critical systems from hits by small meteoroids, but not space debris. When the shuttle was designed in the late 1960s and early 1970s, space debris was not considered a significant space hazard. Accordingly, the original risk/hazards assessment did not factor in orbital debris. A NASA space debris expert estimated that the orbiter shielding, on the average, would likely prevent penetration by debris particles of about .4 centimeters or smaller. In contrast, window surfaces are reportedly able to safely withstand hits by particles of 1.5 centimeters before loss of cabin pressure occurs. However, windows are normally replaced if struck by objects as small as .01 centimeter.

Safety Margins May Decrease During the 1990s

NASA's original safety requirement for the shuttle was a 95-percent probability that there would be no loss of critical systems due to meteoroid impact over an estimated program life of 500 missions. A NASA space debris expert estimated that if the 1989 space debris environment were factored in, the total program life would drop to 185 missions at 95-percent probability. Put another way, if the original mission life remained constant at 500 missions, the probability would drop from 95 percent to 87 percent. This expert's understanding, however, is that even this lower probability represents an acceptable level of risk for the shuttle and crew.

However, with additional debris being placed in orbit, combined with decreases in periodic solar activity, the safety margins may decrease. For example, solar activity affects the amount of debris orbiting the earth. Every 11 years, high solar activity heats the earth's upper atmosphere, which then expands and moves to higher altitudes. With this heating, the upper atmosphere density increases, causing the orbits of space objects to decay more rapidly. As a result, the debris population decreases. However, in the time between solar peaks, solar activity decreases. This causes the natural process of "cleansing" the environment of space debris to decline dramatically.

A NASA space debris expert added that if one factored in the expected decreases in solar activity and the resulting changes in the density of the earth's atmosphere, the orbital debris environment is anticipated to be much worse by 1997, about the time the space station is planned to become permanently manned. He estimated that to maintain the 95-percent probability, total mission life would drop from 500 to only 49 missions. In contrast, if mission life remained at 500, the probability would drop from 95 percent to about 58 percent that there would be no loss of critical systems due to space-debris impact.

Flight Rules Changed to Require Avoidance Maneuvers

Before the Challenger accident, NASA did not have a policy specifying that evasive actions be taken to avoid space objects, even though it received data from the U.S. Space Command on potential collisions. NASA's rationale was that given the inaccuracies in the position of orbital debris, and slight inaccuracies in the position of the shuttle, a collision-avoidance maneuver was just as likely to move the shuttle toward the tracked debris particle as away from it.

After the Challenger accident, all operating procedures were reassessed, including collision avoidance. NASA performed a study of the validity of its debris-tracking rationale and developed a procedure that takes into consideration any potential errors in the U.S. Space Command data. Currently, the U.S. Space Command performs an analysis for the first 4 to 5 hours of a mission prior to launch and supplies the results to the NASA flight dynamics officer in the mission control center. This prediction basically clears the shuttle for launch. Once the shuttle is in orbit, updated position information is sent to the U.S. Space Command for further analysis.

If a potential collision is detected, the U.S. Space Command notifies NASA about any object whose predicted miss distance is less than 5 kilometers above or below, 5 kilometers to either side, or 25 kilometers ahead or behind the shuttle. If further analysis reveals that this distance has lessened to 2 kilometers above or below, 2 kilometers to either side, or 5 kilometers ahead or behind, a collision-avoidance maneuver is performed, but only if the maneuver does not compromise either primary payload or mission objectives.

As of September 1989, no collision-avoidance maneuvers had been performed. For STS missions 26 through 30, U.S. Space Command warned NASA of eight potential collisions between the shuttle and tracked space objects. After further analysis, only one of the eight warnings required an avoidance maneuver. However, for this case, time was inadequate before the predicted near miss to perform the maneuver. NASA had only about a 15 minute warning, whereas it needs at least 45 minutes to plan and perform the maneuver. The debris did not strike the shuttle.

NASA representatives are not overly concerned about the requirement for the shuttle to perform unscheduled maneuvers, but admitted that emergency maneuvers added some additional risk, if only because such maneuvers deviate from the approved and tested flight plans and can potentially affect mission or payload objectives. Using today's orbital debris environment, they estimated that about 1 flight in 12 would require avoidance maneuvers. They estimated that by the mid-1990s, about one flight in eight would require such maneuvers. Their calculations were based on normal missions lasting about 1 week, and did not take into consideration the extended 16- and 28-day shuttle missions being considered for the future.

Suspected Damage to Shuttle Tile Area

A NASA representative pointed out that damage to shuttle windows and tiles can occur during launch, while in orbit, or during landing—thus making it more difficult to pinpoint the exact time or cause of the damage. A member of the NASA inspection team that first examined STS-29 when it landed said that tile damage was noticed on the shuttle, namely, a small 1/4-inch-wide hole, approximately 2 1/2 inches long. A NASA expert stated that this damage did not appear similar to damage experienced during launch or landing, and thus suspected an orbital debris impact. A core sample of the tile was analyzed and showed the presence of silver. According to a NASA expert, the element silver is not a common material used in constructing the orbiter, solid rocket boosters, or external fuel tank.

A NASA space debris expert explained that it was difficult to absolutely confirm a debris strike in this instance for two reasons. First, he said, it would have been better to remove the entire tile instead of taking a small core sample or scraping. This would have permitted more thorough analysis of the impact area surrounding the hole. Second, the instrument that removed the sample may have contaminated the sample and affected the laboratory analysis.

Damage to Orbiter Windows

Windows also can be damaged during all flight phases. A NASA report covering the first 30 missions showed that there had been damage to 27 windows on 18 shuttle flights. This damage appears as small pits, bruises, or hazing. NASA has replaced 13 of these windows. Except for damage to one overhead window, all damage was either to front, middle, or side windows.

Because of the difficulty in determining the exact time that damage occurred, plus the fact that the chemical and physical analysis of any suspected damage requires the window to be removed and destroyed—an expensive and time-consuming process—NASA does not know precisely how many of the windows were damaged by orbital debris strikes as opposed to ascent or landing strikes. However, a pit was noted on an STS-7 window that experts have concluded was caused by orbital debris. This conclusion was reached on the basis of detailed chemical and physical analyses. The damage was believed to have been caused by a paint chip. On a more recent flight, STS-30, a pit was noted to a right side window that, absent a chemical analysis, experts concluded was caused by a high-velocity impact, which could have been a natural meteoroid or man-made space debris.

Conclusions and Recommendations

The growth of man-made space debris orbiting the earth could substantially threaten the safe and reliable operations of NASA's space missions. Even collisions with debris of 1 centimeter in size could have disastrous effects upon spacecraft and crew. The space station would be at particular risk from debris impact because of its size and the duration of its mission. Additionally, the risk to the shuttle is compounded by the length of missions necessary to construct the station in space.

Significant changes in the amount of debris have been noted since NASA first approved a model of the debris environment in 1984. Although NASA representatives agree that the environment is much more severe than depicted in 1984, the documents that guide contractors in developing the appropriate shielding for the station are outdated and have not been revised to reflect this severity. As such, the space station is being designed to meet requirements that greatly underestimate the seriousness of the debris environment. However, NASA appears to be making good progress in revising the 1984 debris model to reflect the increased severity in the environment.

Further, although NASA is considering various protection techniques to safeguard the station and its crew from debris, it has not yet initiated the necessary risk, hazard, and cost analyses that will be needed to support design decisions on these techniques. NASA cannot conclude which techniques will best protect the space station and its crew until these analyses are completed. These analyses will take time and may involve additional research and development of technologies including shielding and debris detection and tracking. Moreover, time is running out. If the results of these analyses are to have an impact on design decisions scheduled to be made final by July 1992, they must be initiated soon. Waiting too long could ultimately delay the scheduled final design decisions, limit the options for dealing with the debris hazard, or require expensive design changes.

When the shuttle was designed, space debris was not considered a significant space hazard. Accordingly, the original risk/hazards assessment did not factor in orbital debris. Although NASA experts feel that the shuttle currently faces an acceptable level of risk, this may not be true in the future, when the shuttle undergoes longer missions to construct the space station. If these risks are to be understood and anticipated, a risk/hazards assessment for the shuttle that factors in the new debris environment should be performed.

Recommendations

We recommend that the Administrator, NASA,

- initiate and complete the needed risk, hazard, and cost analyses associated with a valid space debris estimate in time for their results to be incorporated into the final design requirements for the space station scheduled for 1992; and
- perform a risk/hazards assessment for the shuttle that factors in the anticipated debris environment and longer duration missions.

Agency Comments and Our Evaluation

Commenting on a draft of our report, NASA agreed that orbital debris is a growing problem which, if not mitigated, will become an increasing threat to space operations. NASA also summarized and highlighted its considerable efforts along with those of other major space-faring nations to understand the debris environment, its trends, and how best to deal with the hazards posed by debris. The information NASA provided in this regard can be found in its written comments on our report in appendix I.

NASA expressed concern with the overall tone of the report which, according to NASA, suggests that it was derelict in its responsibility to protect mission crews and valuable hardware from unnecessary risks arising from space debris. We did not imply that NASA has ignored the risk posed by space debris. We believe our report fairly and accurately describes the magnitude of the debris problem and how NASA's efforts to deal with this difficult and complex problem involve cost and safety considerations.

NASA believes that our report implied that it is ignoring the current debris data in designing the space station. Our report notes that NASA is in fact currently designing the station to meet requirements that significantly underestimate—by NASA's admission—the debris environment that the station will encounter. However, we also clearly point out that NASA is not ignoring the current debris data, but, to the contrary, that NASA seems to be making good progress in updating the 1984 debris model so that it can feed into design decisions for the station.

Regarding the shuttle, NASA feels our report implies that it might take unjustified risks in future shuttle flights. We disagree. Although we believe NASA needs to reevaluate the future risks to the shuttle and crew considering the projected growth of space debris, we believe our report does not suggest neglect, but accurately describes NASA's development of the shuttle in a time when debris was not considered a serious threat, to the mid-1990s, when debris may pose increased risks during extended missions or while building and servicing the space station.

NASA also believes that it is fully responsive to the dangers posed by debris and meteoroids and has performed debris risk and hazard assessments for every manned mission since 1962. To support this assertion for the shuttle, a NASA official gave us a 1988 structural analysis[1] for the orbiter. We disagree with NASA's contentions for the shuttle. On the basis of repeated discussions with knowledgeable senior NASA engineers, space debris was not factored into the risk and hazard analyses that were performed for the shuttle. Further, the 1988 analysis NASA gave us only discussed meteoroid risks and hazards—not space debris. The study concluded that on a "per mission basis" the meteoroid hazard to the orbiter was small. However, the study also concluded that given the number of orbiters in the fleet, combined with the number of missions for each orbiter, the meteoroid hazard to the orbiters is significant. In addition, as of February 1990, although NASA told us that a debris risk analysis plan had been prepared for the station, it had not been approved by the space station program deputy director.

NASA said its efforts have been intensified during the past few years for the Space Station Freedom because it is a large structure with a long mission, and because of the increasing debris population. NASA feels that the space station program is, and has been, paying serious attention to how best to deal with the future hazards posed by space debris. NASA specifically stated that the program is not designing to an incorrect requirement that will result in endangering the mission. We believe our report gives NASA ample credit for paying attention to how to best deal with the debris environment, and discusses NASA's ongoing efforts to protect the station and its crew from debris. However, our work did show that certain requirements may need to be reevaluated. For instance, the design assumption that "no penetration by debris of any size will occur to any pressurized component of the station" may need to be reevaluated because, according to NASA engineers, it is driving a station design that will not protect the station's occupants should penetration actually occur. Detailed comments made by NASA about this report are included in appendix I.

[1]OV-103 Structural Analysis for 6.0 Loads, Volume 18-Miscellaneous Structure, April 1988.

Comments From the National Aeronautics and Space Administration

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

FEB [illegible]

Mr. Ralph V. Carlone
Assistant Comptroller General
of the United States
General Accounting Office
Washington, DC 20548

Dear Mr. Carlone:

Thank you for your January 22, 1990, letter soliciting NASA's comments on the draft GAO report entitled SPACE PROGRAM: Space Debris a Potential Threat to Space Station and Shuttle. We agree that orbital debris is a growing problem which, if not mitigated, will become an increasing threat to our operations in space. NASA and other agencies of the U.S. Government are devoting increasing effort and resources to improve understanding of the debris environment, the risks it poses to safe operations in space, and the appropriate technical responses to mitigate those risks. We are actively working with the other major space-faring nations to ensure their involvement and support in this effort.

We are concerned with the overall tone of the GAO report, which suggests that NASA is derelict in its responsibility to protect mission crews and valuable hardware from unnecessary risks arising as a result of space debris. The implication that NASA is ignoring current debris data in designing Space Station Freedom, and might take unjustified risks in future Space Shuttle flights, indicates a misunderstanding of NASA's design and operation analyses and procedures. Fully responsive to the dangers posed by man-made space debris and meteoroids, debris hazard and risk assessments have been accomplished for every manned mission since 1962, when they were done for the Gemini program. Spacecraft design and mission operations have appropriately reflected these assessments in establishing high probabilities of mission success.

NASA has devoted a considerable effort over the years toward understanding the orbital debris environment and its trends. A comprehensive debris characterization program has embraced a systematic accumulation of debris data from all available sources and generation of mathematical models describing the debris environment. The mathematical models provide population densities as a function of orbital altitude, debris particle size, and future time. Debris data have been obtained from radars, optical telescopes, and material returned from space. Because of detection limitations, observation data inputs from these sources to the models have been limited. Thus, the lack of data on small objects necessitates reliance on modeling of breakup events, which are a major contributor to the small debris population. Therefore, considerable effort has been devoted to the study of breakups (explosions and collisions) in detail, both experimentally and theoretically, in order to be able to develop a model of the small debris environment.

Periodically, as new data have been obtained, the mathematical models have been updated. The current 1984 model, being used for spacecraft design, has been updated as a result of obtaining new data (both radar and optical). This 1988 update is being used for hazard and risk analyses, but not yet for spacecraft design, because it has the same large degree of uncertainty (factor of 2-5 times) as the previous model. The baseline will be changed to include system design also when sufficient data are obtained from LDEF and from operation of the Haystack radar to decrease the uncertainty factor, resulting in a greater confidence in the model and an associated change in the design requirement, if required.

It is an indisputable conclusion that much more data are needed to yield a reasonable certainty with the model. NASA has been aggressively pursuing a program with the U.S. Space Command to obtain the data needed on the debris environment, with reasonable error margin. Then Space Station Freedom can use the data to conduct a sound, well-structured, design process. NASA and the U.S. Space Command have effected an agreement to provide these much needed data by using the Haystack radar and a new Haystack Auxiliary radar in the Boston, Massachusetts, area.

Information about the current debris environment is extremely limited by the inability to effectively track objects smaller than 10 cm in diameter. The current Space Surveillance Network was not designed to track small particles (less than 10 cm) of debris as part of its mission. There is a high degree of uncertainty in our knowledge of the current orbital debris environment and in our projections of the future environment. Factors which contribute significantly to this uncertainty are: (1) limited measurements; (2) a lack of accurate predictability for the level of future space activities; (3) the indeterminate causes of breakup events as major debris sources; and (4) the lack of information on the degree and schedule of activities of all space-faring nations specific to mitigating the growth of debris generation.

The development of improved protection techniques has supplemented the debris characterization effort. The need for protection from space debris has always been a design consideration. Some missions can be planned to avoid debris-threatening regions such as congested orbital inclinations or altitudes, and spacecraft can be designed to minimize damage from a debris impact (redundancy or placement of critical components). However, the most straight-forward approach has been, and will probably continue to be, the use of shielding. Consequently, NASA has a significant program addressing the development of new shielding concepts. Structures and materials research is coupled with hypervelocity testing to provide the necessary data with which satisfactory shielding can be developed.

In response to the growing recognition that a more formal mechanism needs to be established for addressing debris considerations, efforts to define the problems and to identify options for dealing with them have been expanded. In 1988, NASA formed an in-house Orbital Debris Steering Group, which examines and makes recommendations on potential activities, procedures, and policies. This Steering Group has been involved in such efforts as the radar program to obtain data on space debris at Space Station Freedom altitudes to a size as small as 1 cm, the formulation of the NASA portion of the Interagency Report on Orbital Debris, and the component elements of the Research Plan required by the Interagency Report.

Efforts have been intensified during the past few years for the Space Station Freedom because it is a large structure with a long mission life, and because of the increasing population density of the debris, unless measures are taken to mitigate the growth of that density. Contrary to the implications of the draft report, the Space Station Freedom program is, and has been, paying serious technical and managerial attention to how best to deal with the future hazards posed by space debris. Specifically, the program is not designing to an incorrect requirement that will result in endangering the mission.

During the period leading up to Preliminary Design Review, which will be completed in about a year with the first formal critique of the design work, the Space Station program has the following actions underway: The Deputy Director for Program and Operations is creating a specific focus within his office at Reston, Virginia, for all the program activities related to debris. Responsibility for starting this work has been assigned. Formal action on establishing the current best model for projection of the debris environment is in work. Since actual hardware design cannot be based on probabilistic estimates of the environment with large uncertainties, sound engineering practices require that the design teams be given a specific set of physical design parameters. This involves specifying protection against impact of particles of specific size, arriving with a specified range of velocities and directions. This specification is expected by the first of April 1990; actual design can then proceed.

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Prior to the Critical Design Review, which is about two and one-half years from now, NASA will study the physical evidence of the returned LDEF mission and the data being provided by the Haystack radar observation activities. These actual data will allow development of the best model projections of the range of hazards expected. In parallel, the physical test activities and the improvement of test capabilities will be supporting the design activities. To cope with the hazards projected by the modeling efforts, NASA will choose a combination of built-in initial hardware protection, enhancements of flight protection features if future growth in hazard warrants, operational procedures, and supporting operational capabilities. At that time there will be a determination as to whether or not the design features provide acceptable risk without further modification.

NASA recognizes that the United States cannot fully address the debris issue without the cooperation of other nations. To that end, NASA has initiated bilateral dialogues with research and technical institutions in other major space-faring nations, to apprise them of current U.S. research on debris and to learn more about their efforts in this area.

An important step along these lines in the past year has been a series of briefings on the conclusions of the Interagency Group (Space) Report on Orbital Debris. NASA representatives briefed ESA and the space agencies of West Germany, France, Japan, Canada, and the Soviet Union on the report, with particular emphasis on those sections dealing with current U.S. understanding of the debris environment, debris population growth projections, and candidate measures to mitigate debris creation.

Even before the briefings, NASA had pursued a variety of specific international cooperative activities in this field. For example, NASA has shared its experience in redesigning the Delta expendable launch vehicle upper stage to prevent on-orbit breakup due to propellant explosions with ESA and the French space agency CNES, to assist them in avoiding similar debris-producing accidents with Ariane third stages.

Since ESA's establishment of its own Orbital Debris Working Group over two years ago, NASA specialists have met with their ESA counterparts at intervals to exchange information and explore opportunities for active cooperation. NASA currently provides the German Ministry for Research and Technology (BMFT) with U.S. tracking data for inclusion in a comprehensive debris data base, receiving in return a commitment for the provision of observational data from a German radar to support U.S. observations in the event of an on-orbit breakup event. A NASA-ESA agreement is being pursued for increased scientific dialog and exchange of research materials, and NASA is actively exploring possibilities for cooperation with other major space-farers.

The impact rates and probabilities reflected in the GAO report have been derived from interpretation of the Interagency Group (IG) Report on Orbital Debris. However, the impact rates in the IG report were based on the assumption that "no further preventative measures will take place, and that operational practices will not change." As described above, the world's space agencies have recognized the significance of the space debris issue and have already initiated some debris growth mitigation actions. Moreover, it is reasonable to expect that more actions will be implemented as additional attention is focused on the issue. These will very probably modify the future trends significantly. Hence, the probability of impact stated for both 1988 and 2010 should be expected to decrease. The probability of impact for the Space Station Freedom is also less than that shown in the GAO report, because the area of the Space Station will be approximately 2000 square meters versus the 5000 square meters of a large space structure used in calculating the probabilities for the cases cited in the IG report.

NASA appreciates the opportunity to clarify some of the apparent misunderstandings mentioned above. Additionally, if you desire, we would be glad to present a more detailed oral review of the report at your convenience.

Sincerely,

John E. O'Brien
Assistant Deputy Administrator

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