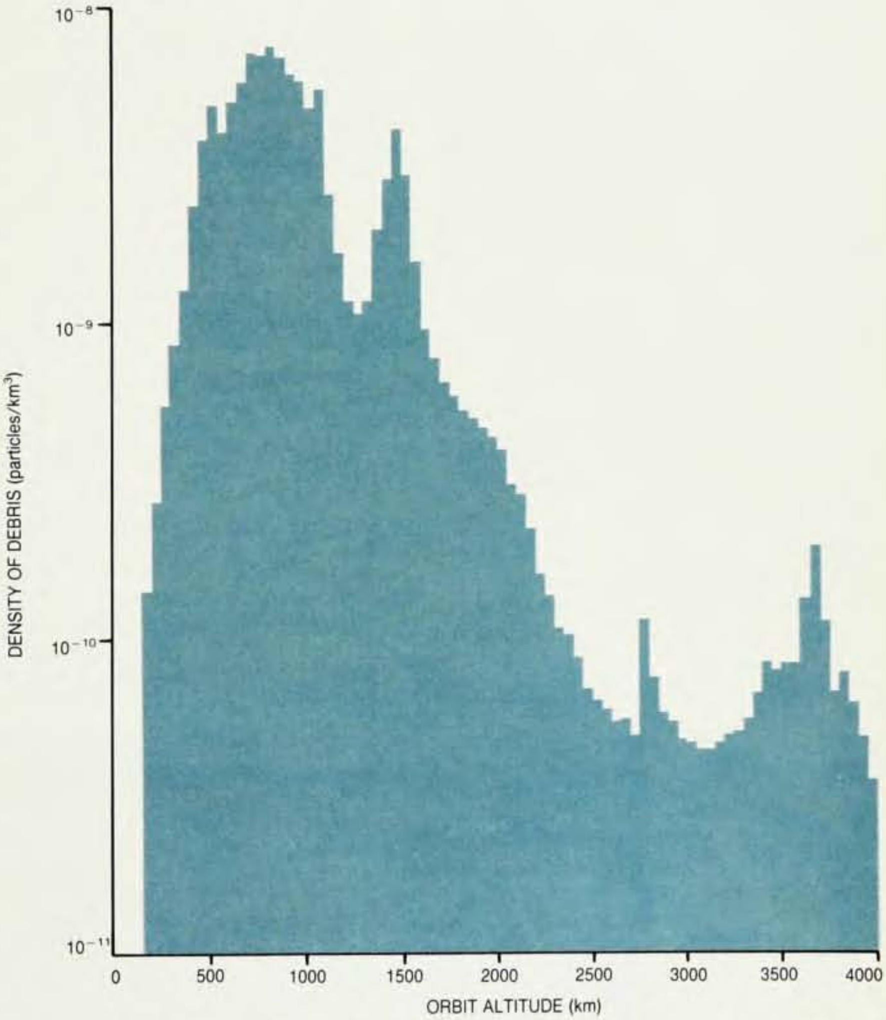
Man-made debris threatens future space operations

Robert C. Reynolds, Eric E. Rice and Donald S. Edgecombe

There is a growing awareness that man-made debris in Earth orbit could, in the near future, begin to have an adverse effect on space operations. Man-made debris in orbit includes spent stages, nonoperating spacecraft, separation components, and explosion fragments. The collision risk for a spacecraft orbiting the Earth depends on the number, mass, and size of debris objects intersecting the spacecraft orbit and on the size of the spacecraft and its operational lifetime in orbit. Battelle's efforts to assess the risk to spacecraft (work performed for NASA Headquarters under Contract NASw-3381) have been directed towards analyzing the collision risk posed by different debris populations to different types of spacecraft and towards predicting how this risk might change with time.[1–4] Staff at NASA's Johnson Space Center and the Aerospace Corporation have made similar analyses.[5–8]

The essential conclusion of previous studies has been that the current practices, which leave debris in orbit, could lead to a state where the risk of collision for operating spacecraft may not just become significant, but might even preclude using certain regions of space in the future due to an uncontrolled growth in the amount of debris.

It is clear that all organizations using the near-Earth space environment should be aware of the potential problem and act to control it before the risk to spacecraft becomes significant. The consequences of depositing objects in orbit must be understood, both for immediate and for future space operations.



Density of tracked man-made debris as a function of orbit altitude. The altitude of the peak (850 km) corresponds to sun-synchronous orbits. (From reference 1).

Debris sources. Man-made debris can originate from normal space operations (including the use of pyrotechnic separating devices, spent stages, and space hardware); explosions in orbit, intentional (antisatellite) or accidental, which can contribute hundreds of thousands of pieces of debris; and on-orbit collisions. It is possible to control the rate at which debris accumulates from the first and second sources.

The figure shows the density of man-made debris as a function of altitude for objects being tracked by NORAD in its October 1976 Satellite Situation Report.[9] Some of these 4271 objects were released during normal operation, but a large contribution (around 50%) came from on-orbit explosions. As can be seen from the figure, the maximum potential collision risk occurs near 850 km (460 nautical miles) the altitude favored for Sun-synchronous operations.

Debris control. Preventing the growth of debris is of the utmost importance for the following reasons:

▶ Once debris is deposited in orbit it cannot easily be removed; thus the

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Robert C. Reynolds is research scientist in the Space Systems and Applications Section, Eric E. Rice is associate manager and Donald S. Edgecombe is manager of this section at Battelle Columbus Laboratories, Columbus, Ohio.

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continual deposition of debris continually increases the chance of a collision. An effective debris-removal program would, at this time, appear economically impossible. To capture debris from orbit, the capturing craft must have the same orbit and position as the piece of debris; because the orbital speeds are on the order of 8 km/sec and the orbits are not coplanar, the frequent transitions between orbits can be expected to require a great deal of propulsion energy and a large number of missions.

▶ The only natural mechanism reducing the amount of debris is orbital decay and Earth reentry caused by atmospheric drag. However, this process can take many years, especially for debris deposited at higher altitudes.

▶ Perturbations in the orbital motion of the debris will tend to randomize the distribution of debris throughout the accessible volume, making it extremely difficult to "pre-plan" to avoid debris while operating in that volume.

▶ Because of large relative speeds between colliding objects (of the order of 8 kilometers per second), even small debris pieces can cause extensive damage to spacecraft.

▶ Most important, the collisions between objects in orbit will probably produce a large number of fragments, whose orbits cannot be controlled. Debris generated by collisions can make subsequent collisions more likely and lead to the generation of still more debris. Therefore, once collisions begin to occur, there is a danger that uncontrollable debris growth (cascading) will result in the near-Earth environment becoming too populated with debris to be usable. At the present time, the only effective way to forestall the generation of debris through collisions is to minimize the rate at which debris is deposited.

Collision risk. Spacecraft of many different sizes are being planned, and debris densities at different altitudes vary by several orders of magnitude. These effects combine to yield expected times between collision, ranging from months to millions of years. For small Sun-synchronous spacecraft, collisions with tracked man-made debris are not and are not expected to be a significant problem. But for the large low Earth orbit space structures that are being projected, collisions with tracked debris would probably occur even if the debris population were to be maintained at its present level.

The objects systematically observed by NORAD represents a well-defined population. Unfortunately the minimum size of object that can be tracked using ground-based equipment is much larger than the smallest object capable of causing damage to an operating spacecraft: There are undetected objects that pose an additional collision risk. The number and size distribution of these objects represents the greatest uncertainty in present assessments of collision risk. Donald J. Kessler has discussed this problem and proposed factors to correct for the unobserved objects.[8]

The significance of the growth in debris can best be illustrated by the implications for large space structures. If the debris population increases at 5 percent per year for the next 20 years, large structures launched early in the next century will probably be struck by pieces of debris large enough to cause extensive damage many times during their intended operational lifetimes. Every collision will produce more debris, some of which could later recollide with the structure and produce still more debris. Initial collision velocities with the newly-generated debris will be relatively small (of the order of a few hundred meters per second) but as time passes these velocities will grow to a few kilometers per second. The collision process may eventually produce hundreds of thousands of particles, most of them in the size range of micrograms to milligrams. If the debris problem is not given appropriate importance in formulating policies on the use of near-Earth space, a state might be reached where large vehicles or space stations can not be used in Earth orbit.

Policy considerations. These are several policy or procedural questions for the man-made orbital debris problem that need to be addressed:

First, what current operational practices generate debris and what should be done about them? The USSR, in its recent manned space-station program, reportedly has been dumping garbage and other items overboard.[10] These items have been observed from the ground. The US has experienced explosions of spent stages of several types of launch vehicles. Space operations often generate on-orbit debris (for example, at stage separation). Effective policies and procedures are required to eliminate these debris sources.

Second, should a policy be adopted which regulates what objects may be left in long-life or high-risk orbits? The reduction in collision hazard achieved under a policy regulating the objects that may be left in long-life orbits will have to be weighed against the reduction in mission performance and the increased costs that such measures will likely require. An example of a positive approach already taken is that NASA's Marshall Space Flight Center has imposed requirements that the orbit-transfer vehicles being studied under MSFC contract either be returned to Earth or be placed in an out-of-the-way orbit, above geosynchronous altitude.

Third, what are the implications of antisatellite operations? The intentional destruction of objects on orbit would probably generate a large number of debris objects. In fact, the USSR is believed to have recently conducted several tests of its on-orbit, shrapnel-producing, antisatellite system. Since antisatellite testing by the US may be regarded as essential to our national security, a clear understanding of its consequences to other space operations is needed. An analysis of the on-orbit debris produced will provide information not only on the short-term and long-term effects of such experiments but also on the effectiveness of strategies and procedures for minimizing the long-term effects. Three areas of antisatellite activity that need to be considered in terms of their on-orbit debris hazards are:

▶ devices that employ a fragmentation/shrapnel technique

▶ devices that employ particle or laser beams

▶ the deliberate introduction of debris to deny access to particular orbital regions.

Fourth, if the on-orbit debris hazard becomes significant, will collision-avoidance systems relieve the problem? Collision-avoidance systems are possible for mitigating the collision risk between an active spacecraft and a large detectable piece of debris. However, because the large speed of a spacecraft relative to the debris objects, small objects (which will be most numerous) may cause considerable damage in a collision. The small size and large relative speeds would probably require that sophisticated detection equipment be located on the spacecraft. The added weight for a suitable detection system and propellant needed to perform the evasive maneuvers would reduce the useful payload, perhaps beyond the acceptable limits.

Fifth, if the on-orbit debris hazard becomes significant, will impact protection ("bumpers") relieve the problem? Because of the large collision speeds, bumpers to prevent damage by debris particles will have to be large, sophisticated and perhaps heavy. Although bumpers of any size would reduce the useful payload that can be carried, decisions on the maximum particle size to be protected against and therefore on the amount of bumper material required would have to be guided by a definitive knowledge of the debris population and its kinematic properties. Without a collision warning system it may be impossible to protect certain parts of the spacecraft—solar panels, for example.

Recommendations. In view of the potentially serious hazard to future space operations from man-made orbital debris, we recommend that the US act immediately to develop assessment data, policies, and action plans to control orbital debris from US space program activities; the US should also lead a treaty effort in the international space community.

The development of action plans and policies should involve:

▶ an in-depth assessment of collision risk
▶ a definition of current practice (source definition)
▶ an assessment of alternative debris control policies
▶ the formulation of a national policy covering NASA, DOD, other governmental agencies and commercial organizations to reduce unnecessary debris.

The treaty effort should begin by bringing the problem to the attention of all space users. The United Nations may be the best vehicle for this effort.

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References

1. R. C. Reynolds, N. H. Fischer, Proc. JANNAF Safety and Environmental Protection Specialist Session, March 1980, Monterey, Cal., CPIA Pub. #313 (March 1980).
2. R. C. Reynolds, N. H. Fischer, L. A. Miller, Proc. JANNAF Safety and Environmental Protection Specialist Session, July 1980, Dayton, Ohio, CPIA Pub #325 (July 1980).
3. R. C. Reynolds, D. S. Edgecombe, "Background for On-Orbit Debris Hazard Assessment," Briefing Notes, Battelle Columbus Laboratories, Columbus, Ohio (August 1980).
4. R. C. Reynolds, D. S. Edgecombe, "Status of the On-Orbit Debris Problem for Spacecraft in Low Earth Orbit," Briefing Notes, Battelle Columbus Laboratories, Columbus, Ohio (13 February 1981).
5. V. A. Chobotov, Astronautics and Aeronautics **17** (1980).
6. V. A. Chobotov, "Collision Hazard in Space" USAF/SD: Report No. SD-TR-81-11 (February 1981).
7. D. J. Kessler, B. G. Cour-Palais, J. Geophys. Res., **83**, page 2637–2646 (June 1978).
8. D. J. Kessler, AIAA-80-0855 presented at AIAA International Meeting and Technology Display (May 1980).
9. "Satellite Situation Report," NORAD (October, 1976).
10. "Litter Bugs in Space," Spaceflight **23**, January 1981, page 27 □