CONTENT ITEM 1

ITEM 1

Title: *"International Collaboration to Mitigate Space Debris: Issues and Some Answers"*

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International Collaboration to Mitigate Space Debris: Issues and Some Answers

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Introduction: The objective of this paper is to address three critical aspects of the space debris problem. How debris mitigation and management practices might be established, demonstrated, and verified? What technical and administrative authorities might be responsible for implementation and validation? What criteria will be used to judge debris minimization and mitigation sufficiency?

It is not arguable that space debris is an operational risk for all in the world who would benefit from space systems. We need not cite specific references to the nature and growth of the problem. Recent events emphasize the need to mitigate and manage space debris. We do not agree that a dramatic, cascading catastrophe is imminent, but that is certainly possible if the world does not unite to address the problem.

Efforts to Mitigate Space Debris: There are no normative space debris mitigation measures. There are guidelines and recommendations but no binding requirements.

The UN Committee on the Peaceful Uses of Outer Space (COPUOUS) was established by the UN General Assembly in 1959 (Resolution 1472(XIV)) to review the scope of international cooperation in peaceful uses of outer space, devise programmes in this field to be undertaken under United Nations auspices, encourage continued research and the dissemination of information on outer space matters, and study legal problems arising from the exploration of outer space. COPUOUS has been instrumental in scientific research of mutual benefit, such as the CIRA model atmospheres. However, after nearly 50 years, there are no normative outcomes.

The InterAgency Debris Coordination Committee (IADC) is an international governmental forum for worldwide coordination of activities related to the issues of man-made debris in space. Its primary purposes are to exchange information on space debris research among member agencies, to facilitate opportunities for cooperation, to review progress of cooperative activities, and to identify debris mitigation opportunities. It is very important that IADC includes only the designated national space agencies of major spacefaring countries. Beneficial uses of space are civil and commercial, and those aspects are not well represented. National security measures in space could be a significant source of space debris. National security interests are not represented.

We conclude that neither COPUOUS nor the IADC has the authority or the charter to implement any debris mitigation programs or processes. They do not represent those who must develop mitigation techniques nor do they suffer the consequences or compromises of either debris proliferation or measures to restrain debris production.

We examine alternatives to these activities by addressing three important questions.

How will debris mitigation and management practices be established, demonstrated, and verified? Four approaches to establishing such practices are: agency guidelines and practices, provisions of individual space programs, National laws and regulations, and international standards. NASA Technical Standard 8719.14, Process for Limiting Orbital Debris (Aug 2007) applies to NASA programs and programs that NASA sponsors. ESA, ROSCOSMOS, and CNES have similar guidelines. There are no binding or consensus practices across nations or for commercial space systems.

Individual projects implement debris mitigation practices voluntarily but not uniformly. For example, Iridium satellites reserve propellant for end of life disposal maneuvers. Some national laws and regulations implicitly require debris mitigation diligence. In the United States, Federal Communications Commission electromagnetic transmission licensing procedures require a spacecraft debris mitigation plan.

Finally, thrusts among international standards bodies are producing normative documents, but these are voluntary, industrial consensus practices that may be applied only if specified in the acquisition contract..

Each of these alternatives is seriously deficient. Agency rules apply only to those agencies. Individual projects and contracts might consider only measures that are convenient and inexpensive. Coordinating body guidelines and national legislation are conceived by parties that do not have to live with the restrictions or to implement them.

There are numerous examples of laws and regulations, such as many for preserving the natural environment, that are not based on achievable or affordable science or engineering. International standards are voluntary and may converge on consensus practices that are not necessarily the most effective practices. There are competing international standards bodies, and the process for developing and confirming international standards may deny industries with serious intent but meager resources as well as diminishing the influence of predominant industrial partners.

What technical and administrative authorities will be responsible for implementation and validation? Even if there were sufficient authority and cooperation, how would debris mitigation measures be implemented and validated? Ultimately, those responsible for executing and operating space programs are accountable for the consequences of their actions. A customer that accepts a system as suitable for its uses also inherits responsibility. Accountability is not transferable. It only spreads.

One of the most marvelous aspects of space systems is that no single individual could comprehend all of the technical implications. The ability of aerospace industry to produce and operate such systems successfully is a true wonder of the modern world. If the engineers who design, build, and operate such systems are individually incapable of spanning the entire enterprise, how can program authorities or commercial customers assume responsibility for something they could not possibly understand? This phenomenon is endemic to many technologies, but space systems collect all of these mysteries uniquely. Few customers have the skills and experience to guide space system development or validate the outcome.

Space system providers have a serious conflict of interest between offering the most efficient mission solution and mitigating debris. Debris mitigation does not generate revenue.

On the other hand, organizations conceived to guide and validate regulations are vulnerable to self interest. They bear no responsibility for outcomes. If they are diligent, they will diminish mission or revenue producing capability. Eventually, institutional health becomes their mission. They may grow and expand their influence for their own ends rather than the reason for which they were created. For example, ISO does not implement ISO 9000 or monitor its implementation. Hundreds of private organizations now crowd the market with quality control certifications.

What criteria will be used to judge debris minimization and mitigation sufficiency? Sufficiency can be determined in at least three ways: by selecting materials judiciously, by designing structures with predictable failure modes, and by choosing orbit and constellation architectures that minimize risk.

Cracks, voids, and inclusions within materials coalesce under stress which is relieved by fragmentation. This is a scientific fact for all fragmentation processes, not just those in space. Although space qualification for many elements of spacecraft has been relaxed over decades of experience, it may be important to at least balance the costs of extremely diligent material qualification against the benefits of reduced fragmentation risks. For example, the molybdenum used for high quality mirrors is tracked from the miner's pick to the finished article. The forensics of failure in high intensity reflective optics may be a good model for spacecraft raw materials. There are already standards and a body of research in spacecraft coatings and surface treatments that resist erosion or at least erode gracefully.

Fragmentation has two predominant length scales: that of microscopic inclusions noted above and a macroscopic scale of stress concentrations, generally associated with internal structure. One can control fragment size and mass distributions to some extent through structural diligence. Inflatable or pressure rigidized structures may have merit since stresses are more uniformly distributed, materials are less brittle, and non-explosive failure modes are likely.

Finally, we suggest a new regime of orbit and constellation design to minimize both the likelihood of collisions, and the consequences of fragmentation. The field is very immature but very promising. At this writing only John Draim of Rosette Constellation fame, has developed (and patented) orbit classes that avoid concentrations of long term debris, meet many mission requirements, and avoid exposing other satellites to fragmentation risks in the event of catastrophe. We plan research and standards to guide collaborative risk mitigation for future missions.

We cannot judge well the sufficiency of debris mitigation measures. For example, there is no uniformly accepted method of determining orbit lifetime. There is a mature international consensus for the purpose of implementing IADC low Earth orbit removal guidelines, but it is useful only for that purpose. Uncertainties in the properties of the atmosphere, satellite orientation over time, and other independent variables lead to diverse approaches with dramatically different predictions. There is no uniformly trusted approach to conjunction probability estimation. Hypervelocity damage and survivability are immature sciences. There is no terrestrial capability to conduct full scale experiments at full scale relative velocities. Debris mitigation processes and procedures such as end of life passivation interact with mission requirements and capabilities. Reactant purging changes orbits, for example.

Some consensus guidelines have no strong physical basis. IADC guidelines for disposal of satellites from Geostationary Orbit are an example. Research since the guidelines were developed and the rate at which the geostationary belt has been populated cast doubt on recommend supersynchronous orbit raising and the ability to assure that discarded Geostationary satellites do not cross the protected region for 100 years is arguable. Increasing understanding of astrodynamics makes feasible disposal by raising low Earth orbit satellites or lowering geostationary satellites.

These statements lead to the conclusion that consultative body guidelines may not be a sufficient basis for space debris management and mitigation, that there are no authoritative, normative practices, and that the ability to judge sufficiency or assess compliance is arguable. There are also political and national security issues that, as technologists, we cannot broach credibly.

What is the answer?

Creating the Environment for Debris Management and Mitigation: We cannot begin to develop, implement, or verify mitigation measures without a sound technical environment for those tasks. We are trying to establish that environment collaboratively, within needs of nations' security and sovereignty, and with a firm, international technical basis. We do this by developing individual national standards that are brought forth for international consensus and modification and which are driven by the needs of industry and the imperative for safe and assured access to space.

There are many national and international standards bodies. Some are government entities, some are purely civil or commercial, and some embody both interests and needs. No single standards body has the authority, credibility, or capability to prevail over all others in common areas. The author speaks as a member of these bodies but not as their representative or as their spokesperson for any national interests. The author also participates in the development of normative standards that are applied voluntarily and tailored to the circumstance, not necessarily adopted in every exhaustive detail. The intent is to establish a common basis within which the intersection of industrial and national goals enables whatever common ground our industries and governments wish.

Voluntary international industrial standards are an excellent foundation for implementing and verifying debris mitigation. Such standards are developed and applied voluntarily. The standards set forth essential elements of process implementation, verification, and documentation. They are driven by user and consumer needs; hence they are self-prioritizing. They must not constrain innovation or deny existing approaches. They are developed ecumenically by working groups chosen for technical expertise and experience, not industrial or national affiliation. They create the environment for collaboration, interoperability, and progress. They are the technical and industrial foundation for policies and regulation.

Spurred by the concerns of member bodies, ISO has evolved a hierarchy and framework for implementing and verifying mitigation measures. ISO has developed several detailed standards for critical debris issues. It is very important that every provision of every standard need not be applied. The standards are intended to be tailored or even modified with sufficient justification and documentation.

Several important standards have already achieved international consensus. The most important requires that each spacecraft development or acquisition program explicitly include requirements for space debris mitigation (ISO 24113). It prescribes documentation and validation of such measures and a Space Debris Management Plan (SDMP) in normative format that describes the organization of debris activities, technical approaches, procedures, and resource requirements. It is important at least at the outset of this process to document and track resource expenditures in order to build value propositions for future work.

Another important standard codifies the IADC guideline for disposing of satellites in geostationary orbit (26872). Most important, it describes the process for selecting and achieving disposal orbits. For example, it is unwise to move directly from active to disposal orbit in a single maneuver. To avoid unrecoverable anomalies and retain positive control, there should be several burns with orbit verification after each.

To assure that each satellite can execute disposal maneuvers and account for stored energy that might be released if there were a collision or explosion, another standard (23339) normalizes processes for determining remaining usable propellants. It describes measurement techniques best at each stage of mission life and mandates propellant allowance for end of life maneuvers as well as revealing measurement uncertainties.

Reentry should not endanger people or cause serious damage. A new standard covers reentry safety and management (27875). At the international level, the most important element is a requirement for a reentry management plan from the outset of a spacecraft development program.

This work includes standards for orbit data transfer with sufficient information for collision avoidance, for end of life passivation, for models of the atmosphere essential to determine satellite drag, for orbit lifetime, and for choosing statistical descriptions of the long term debris population. The field is open to suggestions and consensus from any country or space industry.

Voluntary, consensus derived international standards can provide guidance for implementing debris mitigation, guidance for judging sufficiency, and practices for verifying implementation, because a broad expert technical community develops them, which includes participation of national and industrial policies in the approval process.

Conclusion: There are no authorities or normative rules for mitigating space debris internationally. UN COPUOUS and the IADC coordinate research and formulate guidelines, but they have no jurisdiction. Beyond this jurisdictional issue, it will be difficult to implement such rules or validate the implementation. How much debris mitigation diligence is sufficient is also arguable. Customers and satellite operators generally do not have the skills or resources to judge sufficiency. The best we can do is to create the environment within which nations, satellite service customers, and satellite service providers can try to overcome these difficulties. Standards and best practices establish that environment. International standards define the intersection of national policies, economic considerations, and technical feasibility. There are several international standards organizations. They should collaborate so that development resources are balanced, and they should allocate functional responsibilities among them to minimize duplication.